Highlighting Techniques to Support Geovisualization

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Abstract

One often cited advantage of coordinated geovisualizations is that users are able to quickly view data elements from multiple perspectives. This is typically supported by providing a special visual cue during rollover on a data element. This cue, commonly called highlighting, can be defined as the transient visual effect that is applied on data items across views when a mouse cursor or other input device has moved overhead. Visual highlighting techniques have been largely unexplored in research on coordinating multiple views. Today, virtually all visualization environments rely on simple color-based highlighting styles. This paper offers a typology of five visual highlighting styles, as well as a typology of four interactive highlighting behaviors that are promising for future development.

Keywords---, Highlighting, Linked Brushing, Indication, Geovisualization

Introduction

Defining highlighting is a challenge because there is little agreement across the literature in geovisualization and information visualization. Becker and Cleveland's (1987) work on brushing scatterplots defines a strategy called transient paint in which data chunks across views are painted with a special color whenever a brush is overhead. In geovisualization literature this technique is sometimes called indication (MacEachren et al. 2003) where it has been described as "…transient picking, as in a mouse-over." Contemporary information visualization research suggests the term highlighting for this transient visual link across views (Seo and Shneiderman 2004; Ware and Bobrow 2005). For this research, the term is used to describe the transient visual effect that is applied on data items across views when a mouse cursor or other input device has moved overhead.

This paper presents a typology of five visual styles of highlighting. Each method is described in detail and graphical examples in the form of mockups are provided. These styles are then described in terms of four interactive behaviors through which they may be presented to users.

Motivation

Exploring and extending highlighting methods is worth pursuing because they may prove necessary in order for analysts to take advantage of increasingly complicated geovisual displays. In current practice, highlighting is most-commonly limited to a single colored overlay on the visual display.

The coordinated highlighting inherent in visualizations serves as the visual dynamic gateway to multivariate data, and therefore it is important to ensure that the design of the highlighting itself is well-refined and aesthetically styled to both enable and inspire effective use. This will ensure that we have satisfied the Rule of Self-Evidence for coordinating multiple views as proposed by Baldonado et al. (2000). This rule states that designers should take advantage of, "…perceptual cues to make relationships among views more apparent to the user."

Recent work by Ware and Bobrow (2004; 2005) has focused on the use of motion as an alternative to static highlighting strategies. Their time and accuracy study using both methods with node-link diagrams suggests that motion and static highlighting methods are essentially equal in effectiveness, and that the two used together are significantly more effective – an important finding that is expanded upon in section four. One assumption Ware and Bobrow make is that static highlighting is only done using colored outlines on rollover. This is an assumption worth challenging because there is much that can be done with visual variables besides use colored outlines. This work is focused on what can be done in terms of cartographic design to enhance geovisualization tools that combine maps and other views in highly interactive ways.

Highlighting styles

A number of potential styles exist for visual highlighting. Few of them have been implemented in visualization environments save for color-based highlighting, which has achieved almost universal adoption in contemporary visualization environments.

The styles described in this section are not necessarily exhaustive, as there are sure to be other ways to indicate linkages across views. This research focuses on visual methods that use preattentive visual variables like color, shape, and depth of field (Ware 2004) to help ensure maximum usability to end users. The styles presented also preserve (to an extent) the color, shape, and size of all data elements – a consideration intended to keep highlighting from conflicting with accurate interpretation as much as possible.

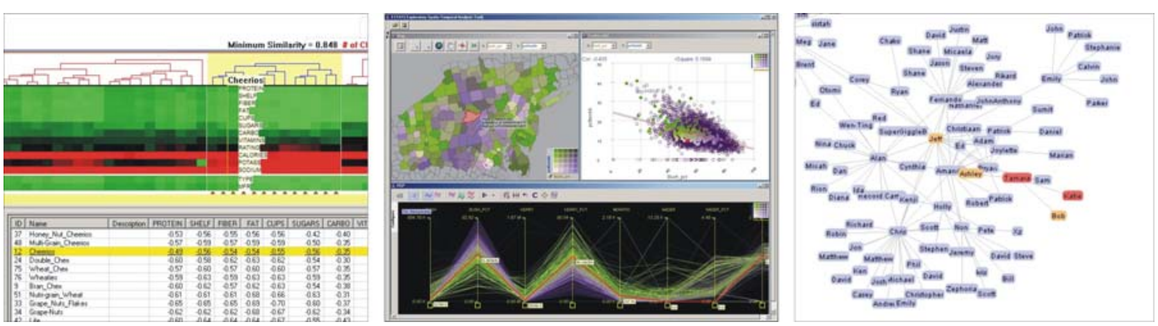

Figure 1: Examples of color-based highlighting in current systems.

Each style is presented in a mock-up display that simulates coordination between a map, scatterplot, and parallel coordinate plot. This choice does not imply that the styles could not also be applied to text or other visual encodings found in visualization environments. The basic mock-up uses points, lines, and polygons, a decision made to ensure broad applicability and to reflect the "building blocks" found in most coordinated geovisualizations.

Color-based highlighting

The most common highlighting style in use today is that of color-based highlighting. Color-based highlighting causes data elements in linked displays to become conspicuously outlined or filled with a designated color. Figure 1 shows examples of current systems and how they apply color-based highlighting (Heer et al. 2005; Robinson et al. 2005; Seo and Shneiderman 2002). Many visualization environments and consumer software packages make use of color-based highlighting, and with the exception of Ware and Bobrow (2005), the literature suggests that the research community concerned with information visualization takes for granted that the term highlighting refers to the color-based style.

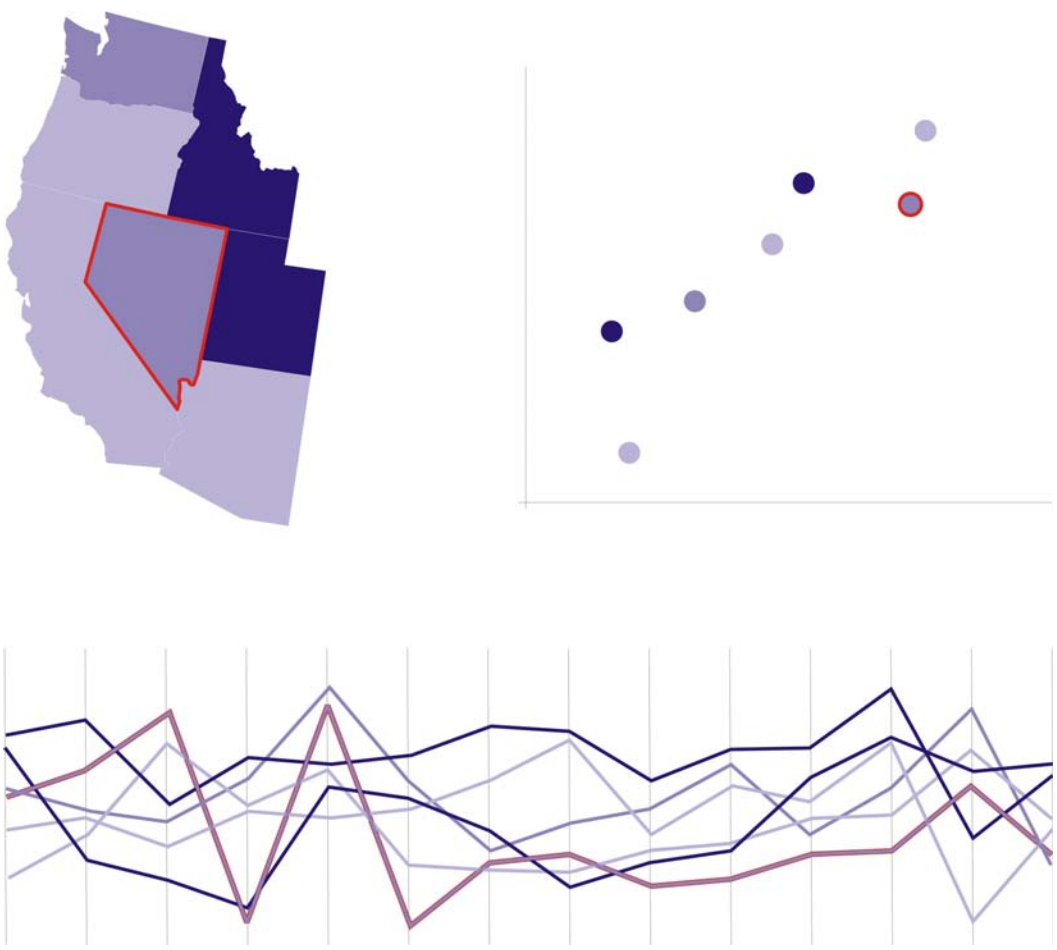

Figure 2: Color-based highlighting.

Color-based highlighting (Figure 2) can be drawn in a number of line-width, color, and stroke style combinations. Color-based highlighting could also be extended to include soft edges and specular effects to simulate realistic backlighting (Figure 3). This may more closely match the real world “highlighting” that one does with a spotlight or flashlight. Softening the edges also appears to have the effect of ‘lifting’ the object of interest above its neighbors.

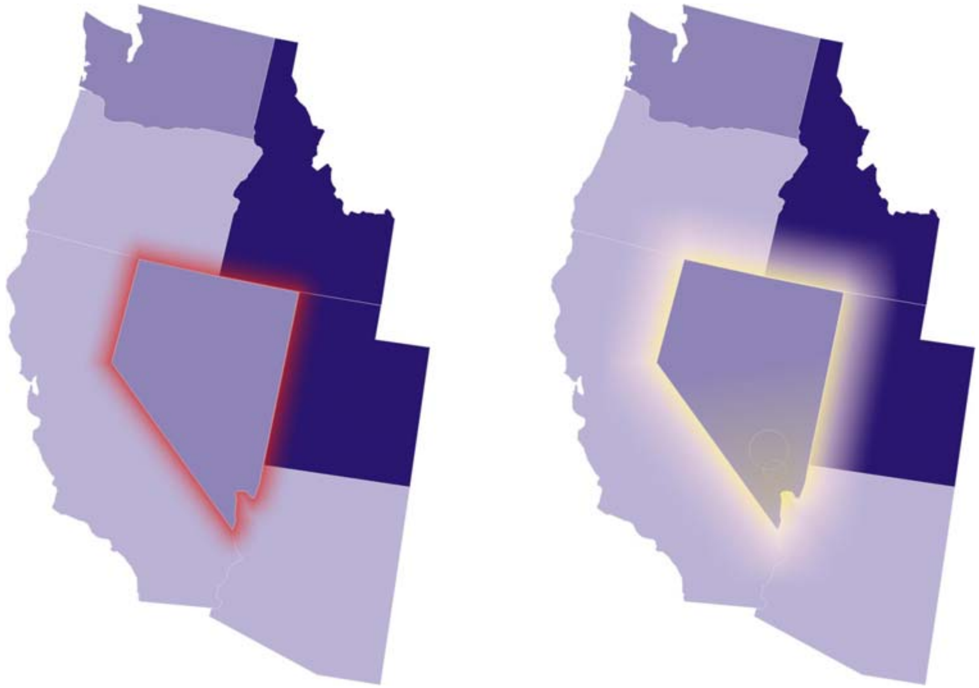

Figure 3: Soft and Specular color-based highlighting styles.

Leader lines

For decades, Cartographers have used lines to connect labels to their respective spaces when geography or other mediating factors prevented close placement (Slocum et al. 2005). Lines can be used to connect data elements in linked visualization environments in much the same way (Figure 4).

Lines have been used in all kinds of computer graphics to visually link data items. Seo and Shneiderman have recently used lines to link items across different clustering views (Seo and Shneiderman 2002). This idea can be extended further to draw lines dynamically based on cursor position. These lines can be drawn radiating from the cursor location over the data element in question. This is a sensible strategy given that we know users are starting at that item given their cursor location.

Leader lines can be drawn and visually manipulated in terms of color, stroke width, and stroke style. As shown in the Figure 4 example, it is clear that one design challenge will involve connecting leader lines to linear data representations as is shown in the parallel coordinate plot. Deciding where the line connects and how it remains visible is a problem that will need to be carefully evaluated.

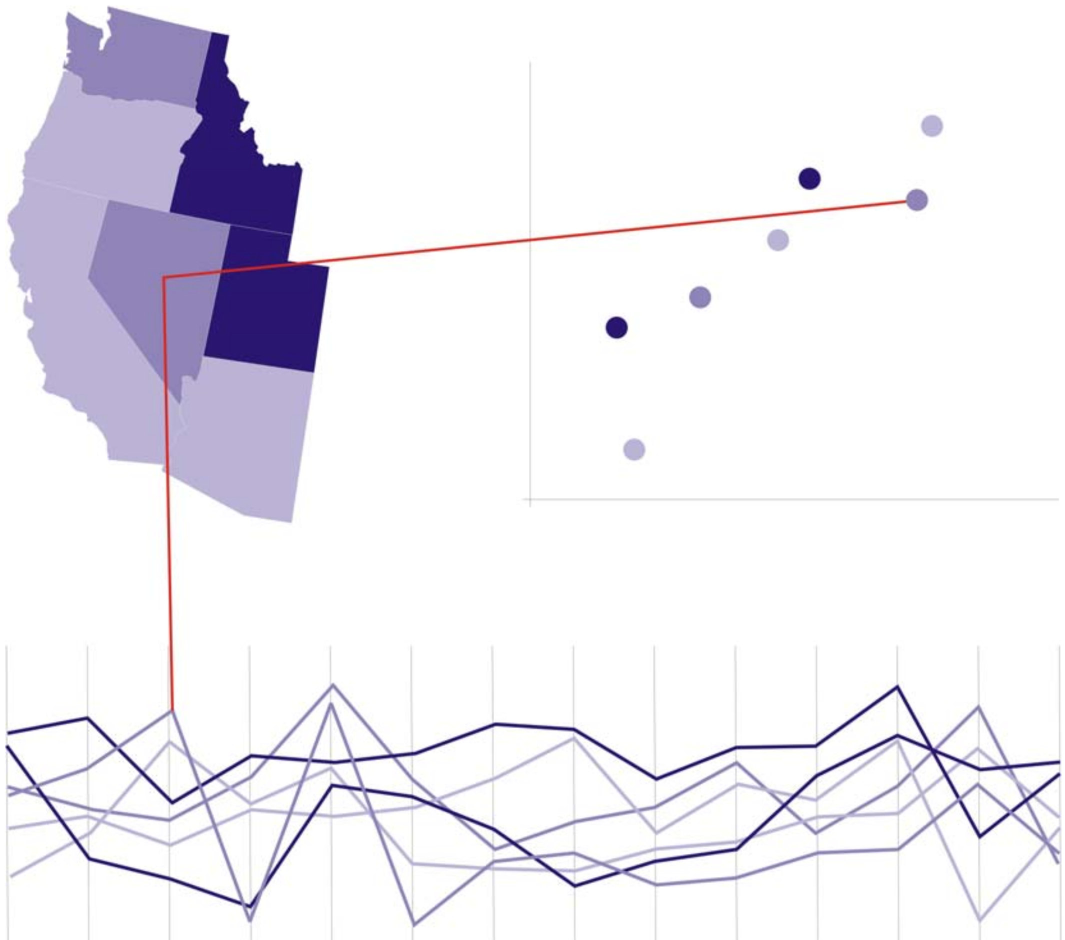

Figure 4: Leader lines.

Depth of field

Depth of field highlighting creates areas of contrasting sharpness to separate a particular data element from its context (Figure 5). The depth of field effect is used often in photography and cinematography to compose a scene. MacEachren (1992; 1995) suggested focusing as an addition to the common set of visual variables described by Jacques Bertin (1983). Kosara et al. have recently implemented this technique in an information visualization context (Kosara et al. 2001, 2002). Their technique is called Semantic Depth of Field (SDOF), so named because blurriness is indicated by relevance, rather that by an arbitrary selection. According to their user studies of SDOF, the depth of field effect processed pre-attentively, making it a promising candidate for a static highlighting method.

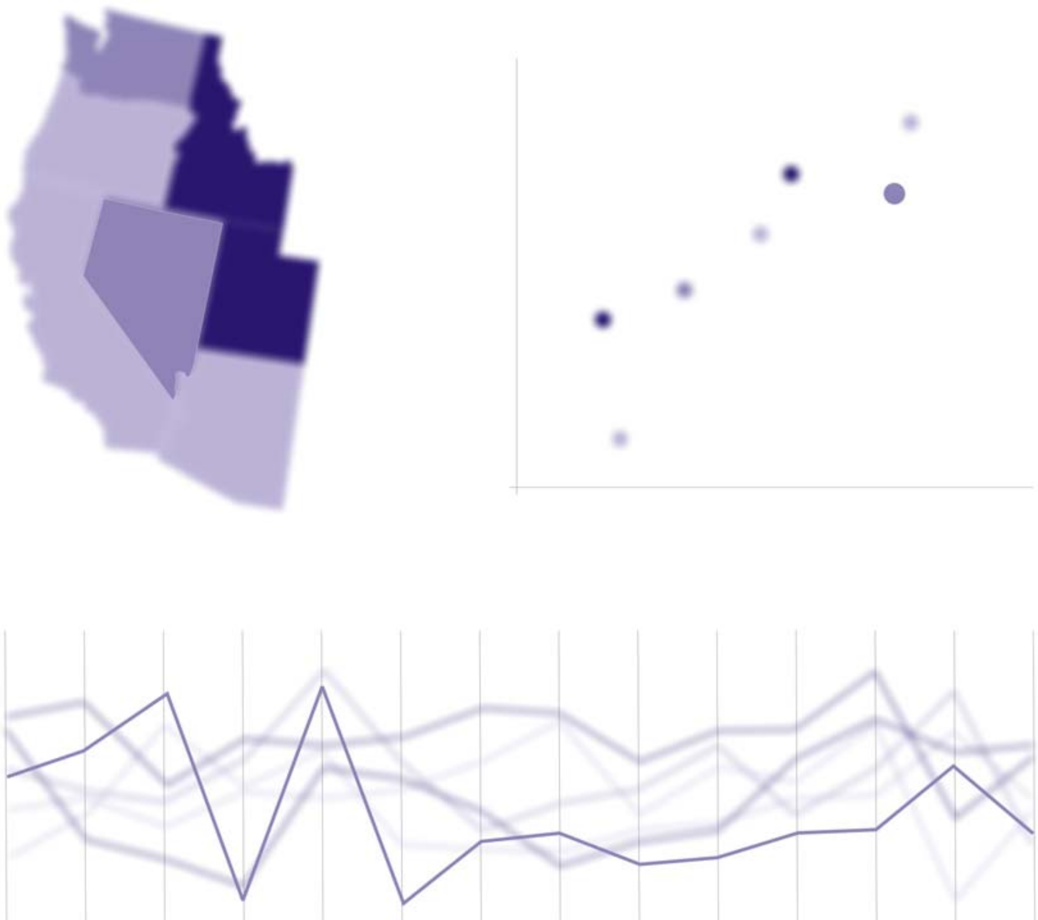

Figure 5: Depth-of-field.

Depth of field can be manipulated by changing the areas in and out of focus. As Kosara et al. suggest, it is possible to incorporate some kind of ranking or measure of similarity to control "how deep" certain items appear, but in the case of simply highlighting one data element across linked displays, the problem is less complex and we need only know how much blur is needed on the background information to make the highlighted elements appear linked.

Transparency

Transparency can be used to dissolve the context around the object of interest. The proposed highlighting style focuses attention on linked items by increasing the transparency of their context (Figure 6). This reduces visual complexity, but preserves (to some extent) the integrity of color and symbol information outside of the focal points in each view. Like depth of field, transparency was also added to the list of cartographic visual variables by MacEachren (1995). Transparency has been proposed to highlight specific items in a menu (Bowes et al. 2003), and by (Nguyen and Huang 2004) as a method of combining overviews with detail in a layered display. It has not yet been evaluated as a transient highlighting technique.

Transparency can be controlled by setting the alpha level of objects as they are rendered in the display. One challenge that the transparency highlighting style presents is to determine the appropriate level of transparency for displays that have been colored according to a classification method. In the example shown in Figure 4, the light color that has been assigned to one category is almost entirely washed out.

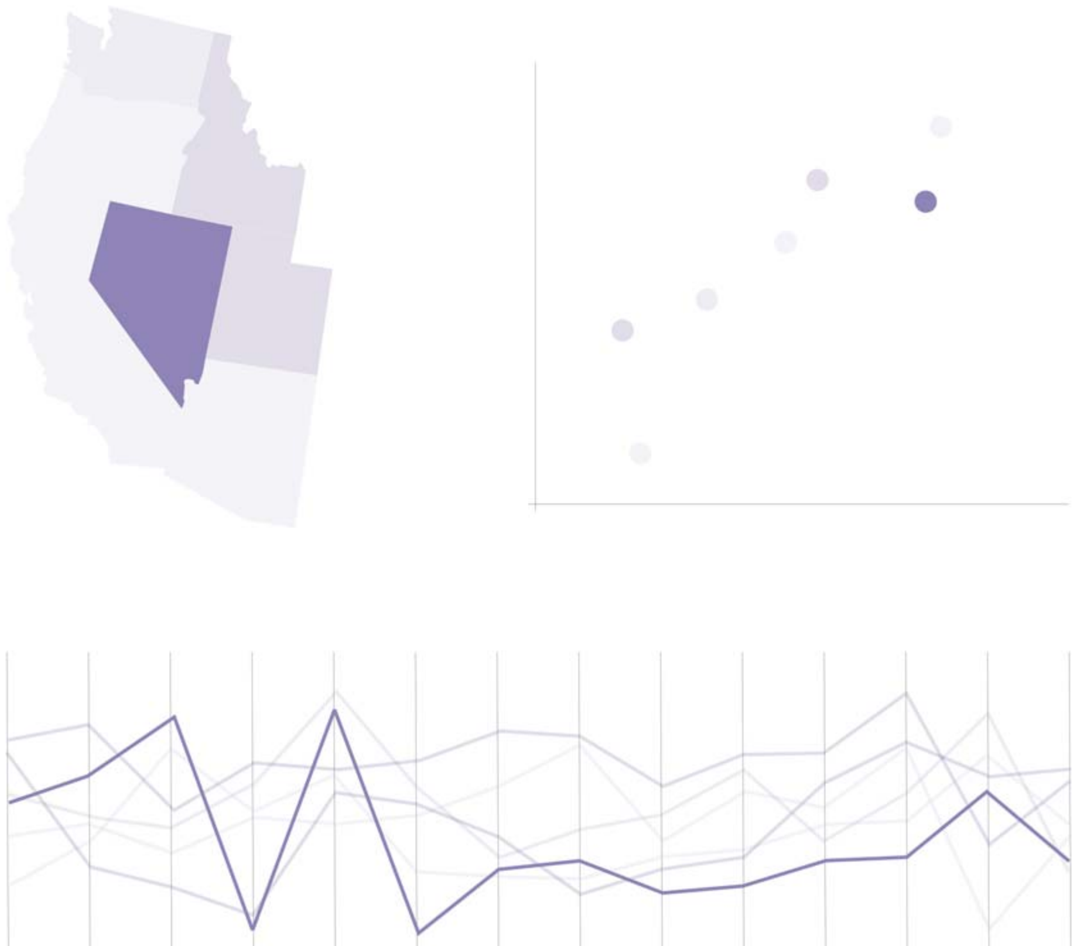

Figure 6: Transparency.

Contour lines

Another technique inspired by map design is the use of contour lines (Figure 7). The assumption for this technique is that users may be able to quickly discern those data items that are contoured because they appear “higher” than those that are not contoured.

Contour lines can be expressed visually by changing the number of contours, their width/color/stroke style, and the distance between contours. The example in Figure 5 shows three steps of contouring using a dark-to-light color gradient from inside to outside. Based on searches through recent literature, there is reason to believe that no prior work in visualization has tried contouring as a highlighting style.

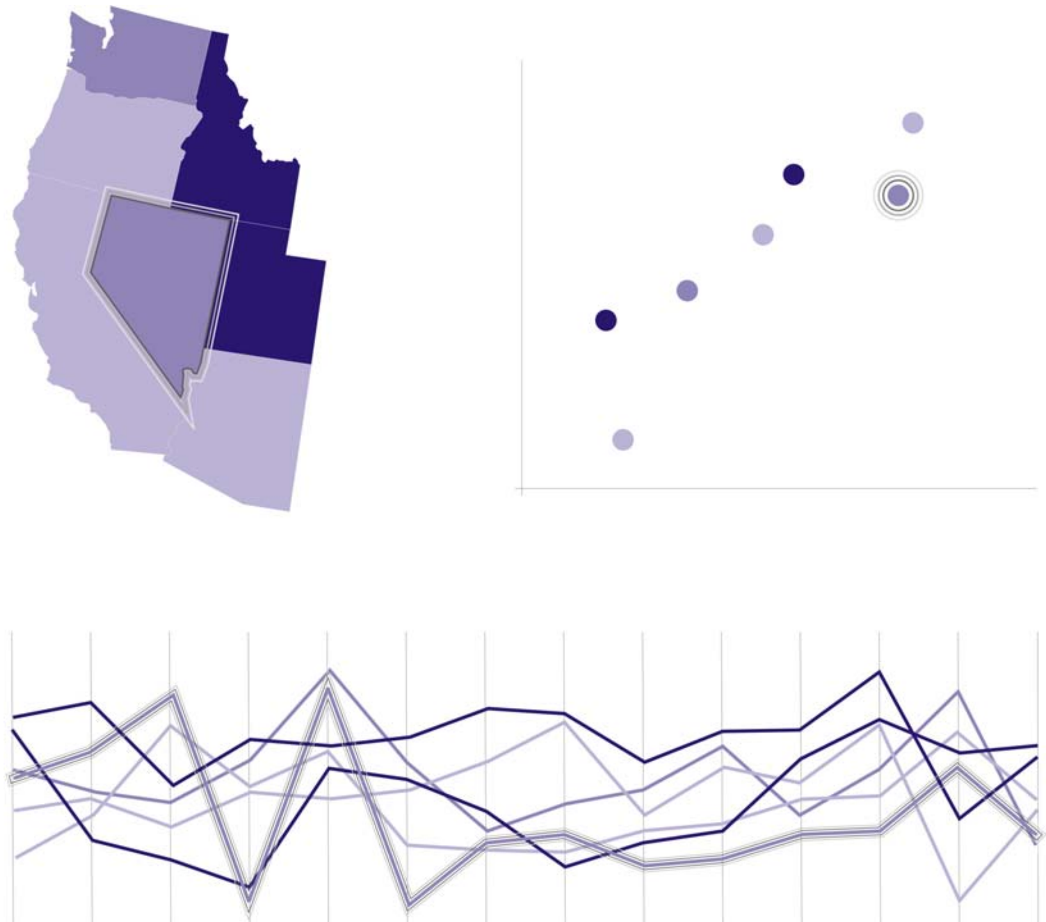

Figure 7: Contour lines.

Other methods

Many modifications of these five simple styles can be created by taking advantage of their respective sets of visual variables. Styles such as color-based highlighting, leader lines, and contour lines may use a variety of line strokes, widths, and color combinations. Various levels of transparency and depth of field could be applied to achieve effective differentiation from background data.

A highlighting style could use color saturation to indicate where a user should direct their attention across views. This method was not included here as a potential candidate for implementation because it would violate a critical principle of design for information visualization; that of the overview (Shneiderman 1996). A user's ability to effectively understand the overview of a dataset would be diminished if only the indicated data chunk was colored.

Style reduction is another potential candidate. This method would only work with visualizations that are designed with many outlines and/or other ancillary visual encodings that can be removed without erasing the data chunk entirely. This method is potentially useful for displays that are especially rich in labels and other adornments, as the example here illustrates (Figure 8).

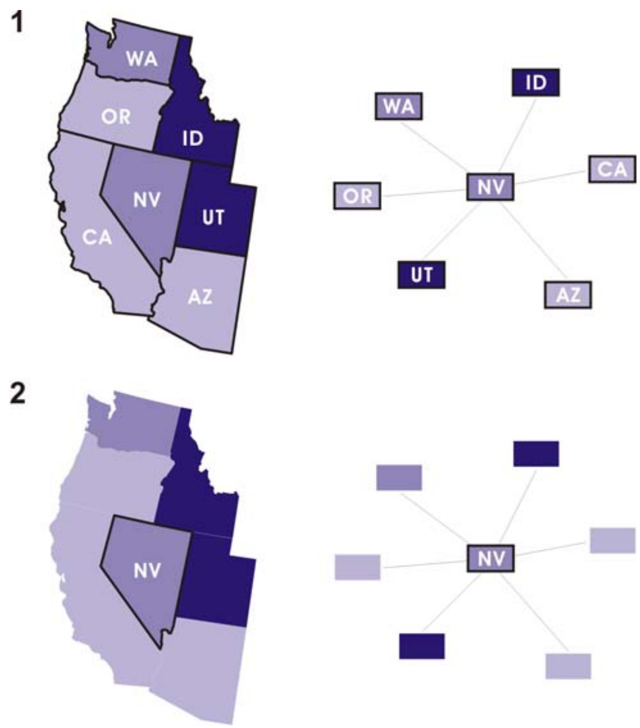

Figure 8: Style reduction.

Highlighting interactions

Highlighting interactions are defined as the mechanisms within which highlighting styles can be applied. This section describes a proposed typology of highlighting interactions that includes single, compound, categorical, and continuous methods.

Single method

As implemented in the vast majority of contemporary visualization environments, single method highlighting is the simple application of one highlighting style upon rollover of a data element. In each corresponding display, this same data element is overlaid with the same highlighting style. The figures shown in section three are all examples of single method highlighting.

Compound method

Compound highlighting is proposed to include more than one highlighting style, layered on or near the data element of interest upon mouseover. Compound highlighting may be useful when a single method alone fails to adequately reduce visual complexity to facilitate quick interpretation. Compound highlighting may be either conjunctive or disjunctive.

An example of conjunctive highlighting is the use of multiple styles in combination on each view. Conjunctive highlighting essentially treats styles as layers that can be stacked on one another (Figure 9). Ware and Bobrow (2005) have presented compelling evidence that a conjunction of static and motion highlighting is a very effective technique. Compounds of multiple static styles have not been evaluated, and this is one area to explore in future work.

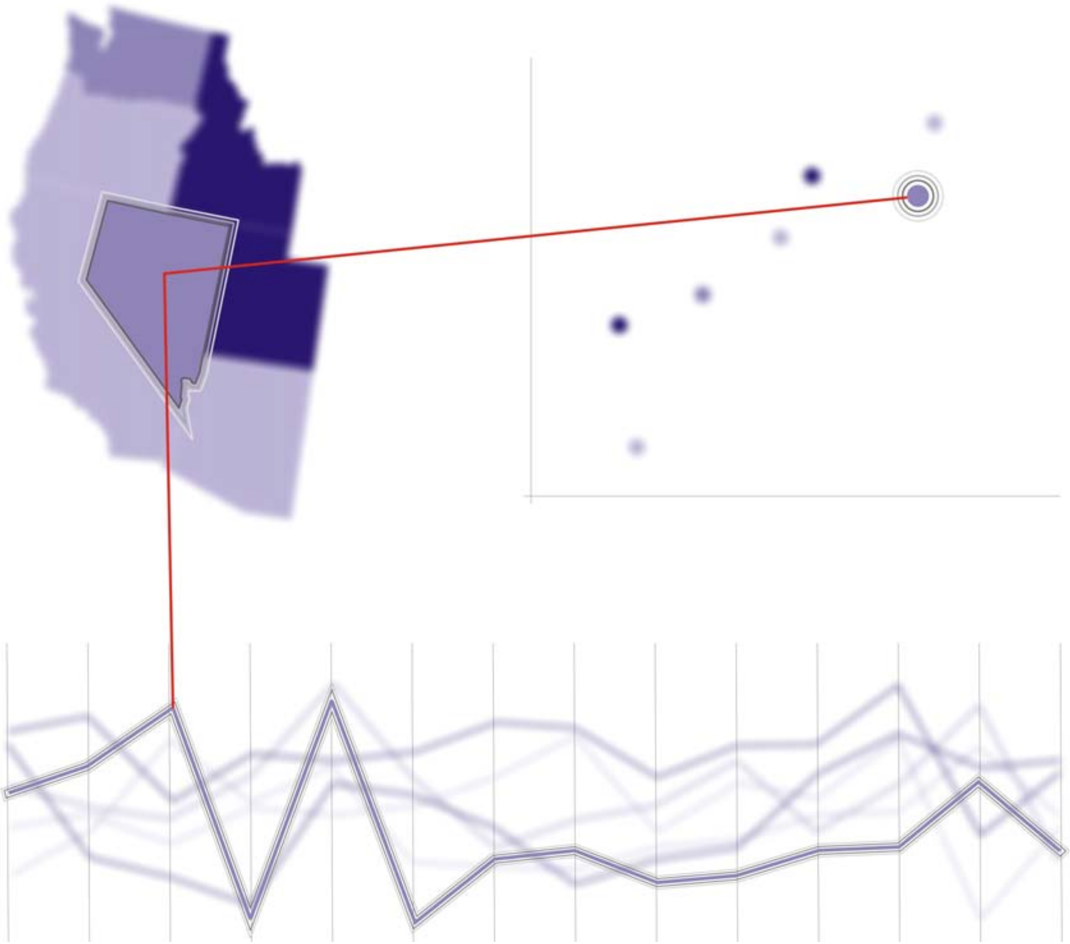

Figure 9: Compound conjunctive highlighting using depth of field, contour lines, and leader lines.

A disjunctive compound highlight may use a single style unique to each type of view. Using the style template as an example, the map may use a color highlight, the scatterplot a contour, and the parallel coordinate plot depth-of-field (Figure 8). While it is certainly possible to implement this kind of disjunctive compound method, it is hard to imagine that it would be easier to interpret than a single, consistent method (compound or not) applied to all displays equally.

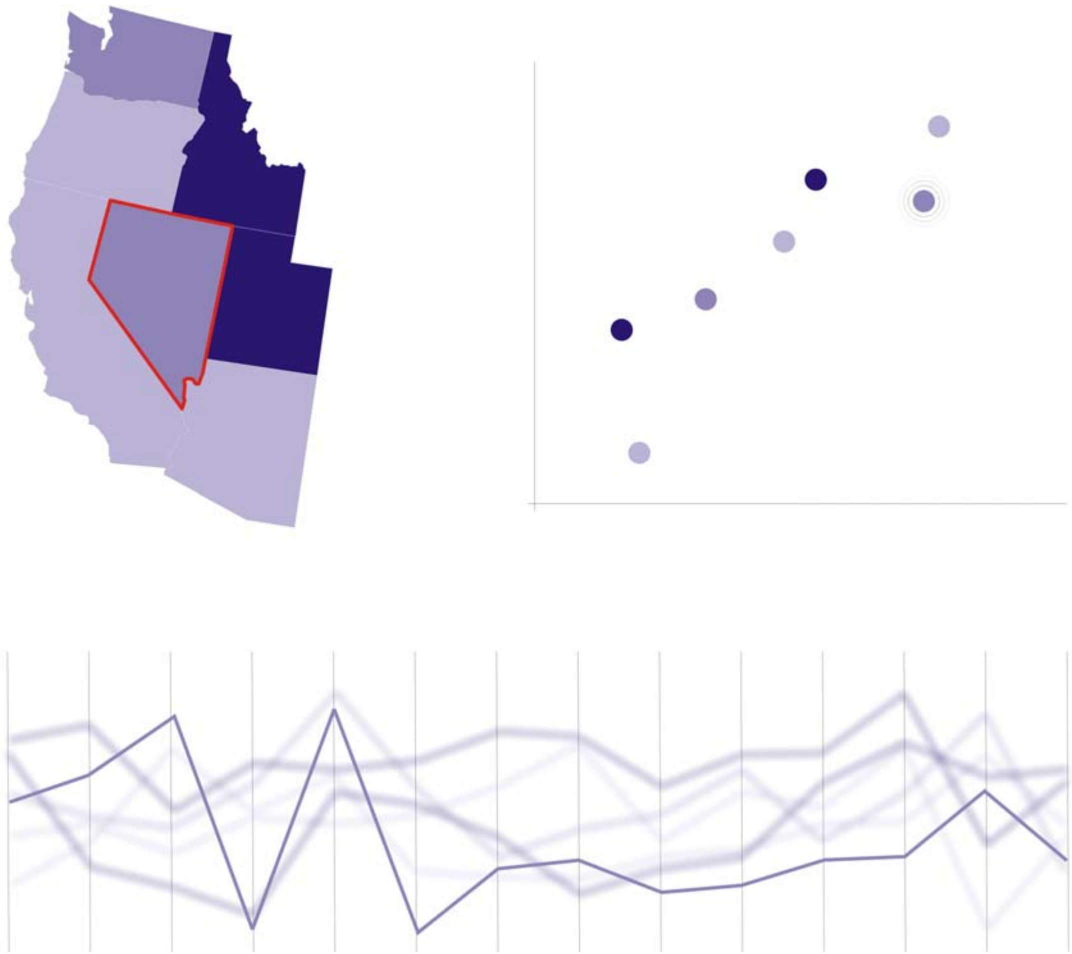

Figure 10: Compound disjunctive highlighting using color (for the map), contour lines (for the scatterplot), and depth of field (for the PCP).

Categorical method

Methods of visual highlighting can be thought of as categorically or continuously applied, rather than simply binary. Categorical highlighting may follow a classification that has occurred on a dataset to adapt the visual highlighting method based on the category within which a data item resides (Figure 11). This type of highlighting may be quite useful for analysts who wish to reveal details such as data uncertainty, statistical significance, or clustering results.

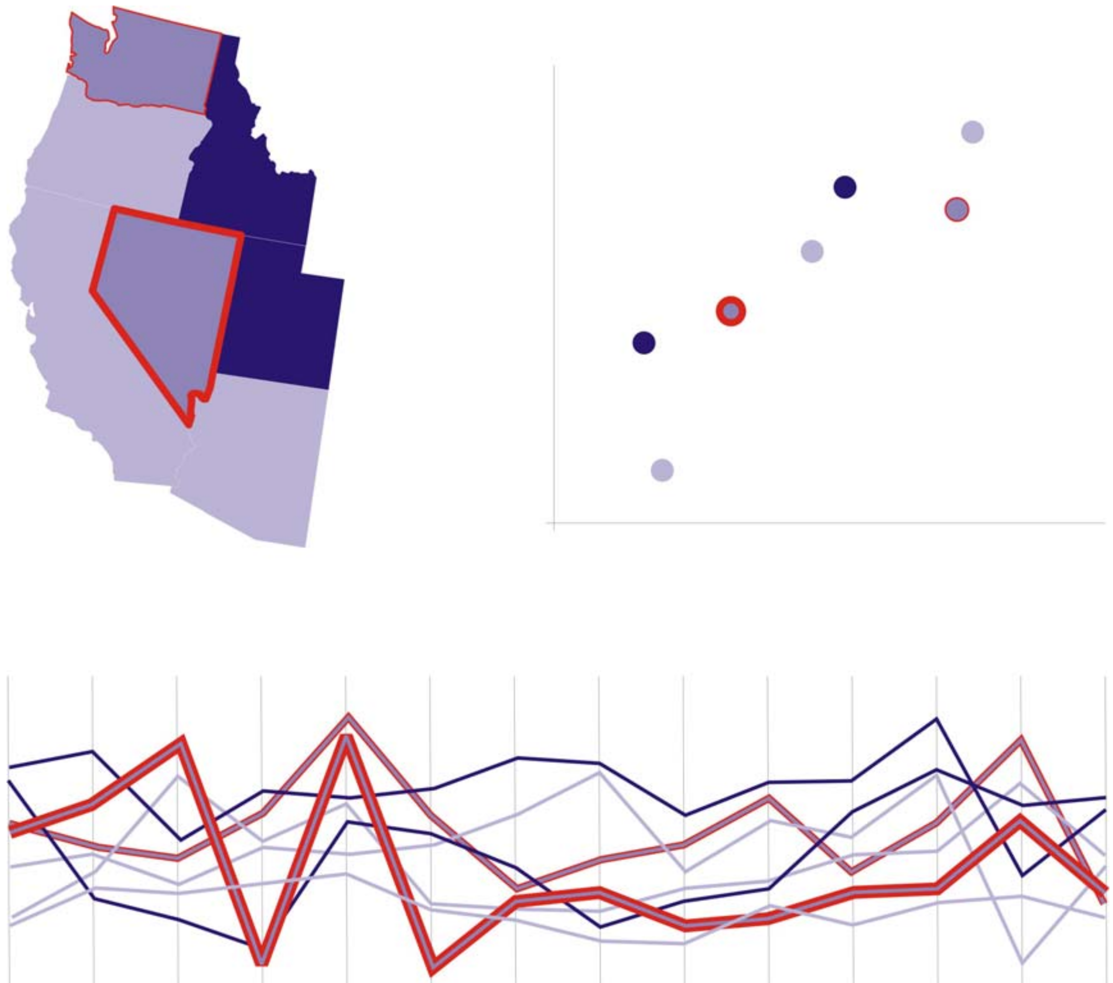

Figure 11: An example of categorical color-based highlighting. The mouse cursor is over Nevada, and its neighbor in the same class is also highlighted with a less intense outline.

As shown in Figure 9, the directly linked item in each view has the strongest line width associated with it, while other members of the same category of classification use lighter widths. This is designed to convey the direct connection first and allow the context to appear as a secondary effect.

It is relatively easy to imagine how this method might be applied to leader lines using the same strategy of differing line widths (Figure 12).

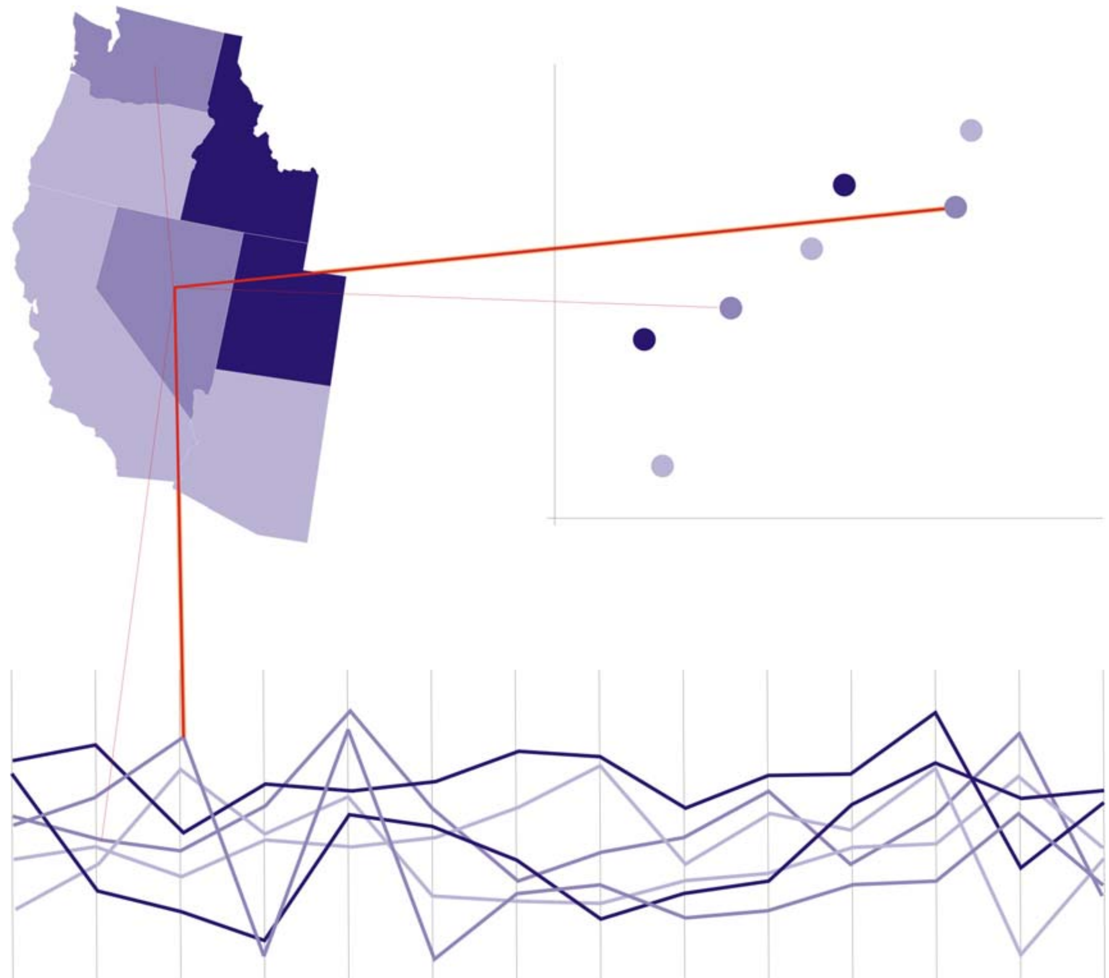

Figure 12: An example of categorical leader lines. The mouse cursor is over Nevada and its neighbor in the same class (Washington) is also indicated by lighter weight lines.

Similarly, contouring might use line widths or the number of contoured steps to indicate the direct linkage as well related items. Transparency and depth-of-field present a greater challenge because their effects are not so obvious if they are applied in a categorical manner. Precisely what steps of transparency and depth of field that people can discriminate easily are as of yet not well understood, and this is an important area for future research. Starting with a high/medium/low strategy makes sense for an initial implementation. Figure 13 describes the highlighting styles presented in terms of how they might logically be applied to categories and which visual variables could be manipulated to achieve those effects.

Highlighting Style	Series Logic	Visual Variables
Color-Based Highlighting	Light / Medium / Heavy	Line Thickness / Color
Contour Lines	Immediate / Local / Regional	Line Thickness / Color / Steps
Transparency	Opaque / Translucent / Clear	Alpha Intensity
Leader Lines	Light / Medium / Heavy	Line Thickness / Color
Depth-of-Field	Shallow / Middle / Deep	Sharpness

Figure 13: Typology of categorical highlighting.

Continuous method

Continuous highlighting is the application of a highlighting style along a gradient from one value to another. This would be potentially beneficial to analysts who want on-demand details that would indicate a raw value or ranking along a continuous scale. For example, a meteorologist examining climate data for multiple countries might rely on the highlighting style to reveal the daily average temperature or mean annual precipitation.

Continuous highlighting can also be done by continuously degrading the highlighting method according to a function of local context – similar items nearby will highlight with an increasingly lower saturation or intensity to emphasize relative associations while leaving the highest levels of attention for the items closest to the area of interest.

Design and implementation challenges

The design and implementation of the highlighting styles and interactions we propose requires attention to issues of usability, performance, and common programming paradigms in a variety of ways.

In terms of usability, well-designed legends are essential to the effective implementation of our highlighting strategies. Legends need to support users' understanding of particular highlighting styles and interactions, and they will also function as the interface through which highlighting parameters are changed. These legends should contain the basic controls for setting highlighting categories and their visual primitives, just as they function today in tools like ESTAT (Robinson et al. 2005) to allow similar changes to map colors and classification.

Each highlighting style will need to be carefully adapted to the specific context of use. The types and overall number of views as well as the display resolution will have an impact on which styles best accomplish the task of transient picking. For example, styles like depth of field and transparency will likely have a narrow usable range to make things "pop" appropriately, especially when implemented in a categorical or continuous manner.

In terms of performance, interactive application of depth-of-field and transparency effects will further tax systems that are already stretched in terms of computational resources. For depth of field effects, Kosara provides an example of a fast algorithm (Kosara et al. 2002) that works for interactive visualizations. For transparency we will need to investigate methods for rendering quick alpha changes.

Successful implementation of the leader lines style will require that we think beyond window frames as absolute containers. This is a very common programming paradigm that will demand a creative solution. Solving this problem for leader lines will open the door to further efforts aimed at 'pushing back' the visual overhead that windows and widgets create in current systems.

Prototype toolkit

A demonstrative toolkit featuring the five proposed highlighting styles has been developed using Macromedia Flash (Figure 14). This toolkit mirrors the static diagrams shown in previous sections and includes a simulated map, scatterplot, and parallel coordinate plot. Highlighting methods can be switched on and off using mode buttons and specific parameters for each method can be adjusted by making changes to the ActionScript code. The purpose of this toolkit is to facilitate formative evaluations of the highlighting styles in order to refine their parameters.

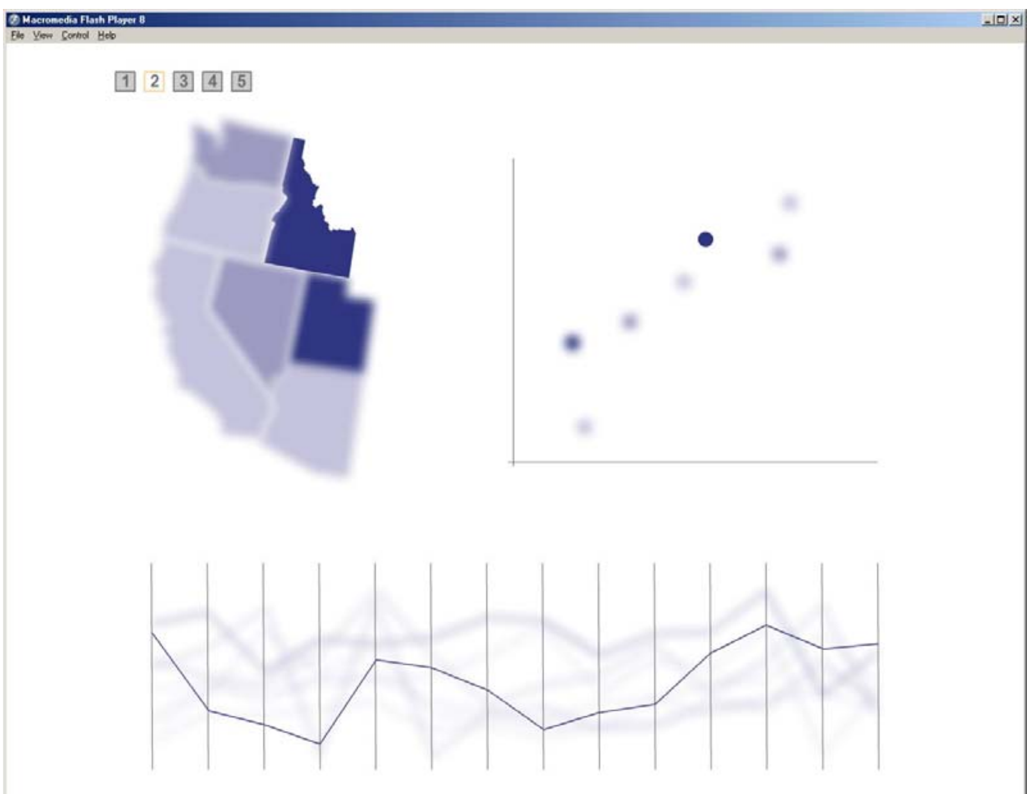

Figure 14: Screen capture of the Flash prototype toolkit, demonstrating the depth of field technique. The toolkit is available at http://www.personal.psu.edu/acr181/h-light_testbed.swf

Future work

A data-driven testbed based on the Improvise (Weaver 2004) visualization toolkit is currently in development. This testbed will feature a set of common visualization tools and provide user controls to select and combine each of the highlighting methods. Building the testbed in Improvise will enable the development of a common highlighting coordination mechanism that can then be used in a wide array of real-world applications that have already been built.

The highlighting styles and interactions described here are part of ongoing efforts at the GeoVISTA Center to design usable and intuitive visualization tools for analysts. When the data-driven testbed has been completed, formative evaluations will take place using focus groups, surveys, and verbal protocol analysis to refine the design and interaction of each highlighting method.

This typology is limited to static, visual techniques, but we do not seek to diminish the potential that motion-based, sonic, and haptic methods hold for future implementation. By starting with the styles and interactions as proposed in this paper, we hope to learn more about how highlighting should be appropriately designed and then move to implement more complicated methods that take advantage of these guidelines.

Finally, the focus on highlighting that we present here is not done without thinking ahead to the problem of indicating *selected* data items across multiple views. Many, if not all of the styles presented in this paper can be envisaged as methods for indicating selected portions of data. We will experiment with highlighting styles for selection once we have implemented them for transient rollovers. For example, one can imagine using one particular highlighting style to support transient picking, while relying on another to indicate where items have been selected.

Conclusion

The highlighting styles and interactions outlined here are poised to play a valuable role in facilitating exploration and analysis using coordinated visualization tools. Current systems rely on but one of many potential static highlighting techniques, and the other styles presented have not yet been thoroughly evaluated. Additionally, providing a deeper level of interaction within highlighting to reveal categorical or other associations may help analysts acquire contextual information on-demand through an intuitive interface.

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