Multi-Focused Geospatial Analysis Using Probes

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Abstract—Traditional geospatial information visualizations often present views that restrict the user to a single perspective. When zoomed out, local trends and anomalies become suppressed and lost; when zoomed in for local inspection, spatial awareness and comparison between regions become limited. In our model, coordinated visualizations are integrated within individual probe interfaces, which depict the local data in user-defined regions-of-interest. Our probe concept can be incorporated into a variety of geospatial visualizations to empower users with the ability to observe, coordinate, and compare data across multiple local regions. It is especially useful when dealing with complex simulations or analyses where behavior in various localities differs from other localities and from the system as a whole. We illustrate the effectiveness of our technique over traditional interfaces by incorporating it within three existing geospatial visualization systems: an agent-based social simulation, a census data exploration tool, and an 3D GIS environment for analyzing urban change over time. In each case, the probe-based interaction enhances spatial awareness, improves inspection and comparison capabilities, expands the range of scopes, and facilitates collaboration among multiple users.

Index Terms—Multiple-view techniques, geospatial visualization, geospatial analysis, focus + context, probes.

1 Introduction

A similarity across the majority of GIS applications and geospatial visualizations is the singularity of the viewing perspective. For example, in map-based visualizations, the user is generally restricted to viewing one region of the map at a particular zoom-level. When zoomed out to see the entire extent of the dataset, local trends and anomalies, which are often of interest, become suppressed and ultimately lost in the global picture, especially as the scale of the dataset increases. To discover and inspect these local details, the user must zoom in to a level at which they become visible. However, by doing so, one loses both the global overview and context of the local region. This both limits the user's spatial awareness and prohibits comparison between distant local regions.

In the model presented within this paper, coordinated information visualizations are integrated directly within the main geospatial visualization. User defined regions-of-interest are linked to each coordinated visualization, delineating which data is presented in each visualization. Furthermore, these interfaces, which we call probes, allow the user to interact directly with the geospatial data within the regions-of-interest as well. By using multiple probes, the user can simultaneously observe and interact with many different local regions across the entire range of scales (ranging from global to the smallest individual units) without losing spatial awareness. This is particularly useful when dealing with complex simulations or analyses in which the local values and behaviors differ greatly from each other and/or the system as a whole.

To illustrate the general usefulness of our probe concept for enhancing geospatial visualizations, we incorporate it within three unique existing applications. First we apply probes within a 3D geographic information system (GIS) environment used to visually explore the changes (new buildings, etc) detected (using aerial laser range-finding) to a urban area between years. The second application we augment is designed for visual analysis of census data across large urban areas. Finally, we create a new, entirely probe-based interface for an agent-based social simulation that models the various factions and behaviors of an entire country. In each case one can see benefits including uninterrupted spatial awareness, improved inspection and comparison capabilities, ability to view data at multiple scales simultaneously, and increased potential for collaboration among multiple users. These common benefits are then more elaborately discussed in a more general context within Section 5.

We also perform an informal user evaluation with experts in both GIS and architecture. Each group was presented with the original applications and their probe-enhanced counterparts. It was obvious that these everyday users of geospatial visualization applications had all encountered some of the shortcomings we address in this paper. Their comments confirm that, with the addition of probes, the presented applications become increasingly effective with more intuitive interaction.

2 Previous Work

Donelson's [7] Spatial Data Management System presents a large projected display of a 2D graphical information space. The interface is two-handed, supporting panning and zooming. Two joysticks, a tablet, and two secondary monitors that are touch sensitive are provided. One monitor displays a "world view" of the entire information space along with a 'you-are-here' rectangle which provides visual context for the user as he views a particular 2D region on the large display. The other monitor, "the key maps monitor," shows auxiliary information such as a chapter outline when the main screen displays text files, or a time-line when the main screen displays video.

Furnas [12] describes generalized fisheye views. In the spatial domain, the metaphor is a fisheye camera lens that shows higher detailed, less distorted imagery toward the center of the field-of-view and less detailed, compressed imagery toward the outer field-of-view. In additional to the geospatial example of Steinberg's famous poster "New Yorker's View of the United States", Furnas presents experimental studies showing that people's concepts of complex non-spatial structures also exhibit fisheye character. Furnas presents Degree of Interest functions to describe fisheye display of information for both spatial and non-spatial data. He also acknowledges the significance in geospatial contexts of supporting multiple foci in fisheye views. He gives an example of a person who has lived in multiple states whose mental map of the geography is fisheye in character but with foci at each location in which he has lived. In the context of non-interactive cartography, Kadmon and Shlomi present a mathematical approach for such multi-focal map rendering [15]. Our modification to the UrbanVis [6] tool applies the multiple foci concept but in 3D, driven by a 'urban legibility'

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level-of-detail algorithm. Leung and Apperley [16] give an overview of distortion based techniques circa 1994.

More recently, Furnas [13] focuses not on the variations of geometric distortion, but on the different degree-of-interest (DOI) functions and how these determine what information is and is not included in the display. He discusses how this concept can be carried to non-visual domains as well.

Bier et al. [2][3] present the Toolglass and Magic Lenses, a see-though 2D, two-handed GUI interface. The Toolglass and Magic Lens are see-though windows whose positions are controlled by the user's second hand with a trackball+wheel device. The user's first hand controls a regular mouse and pointer. Graphical filters in a toolglass can be overlaid on other objects to reveal alternate visual representations while the mouse cursor continues to allow direct manipulation of the objects through the Toolglass. Bier et al. cite earlier works with similar concepts of filters for changing information in visualized systems but these earlier works lacked the metaphor of a movable lens. Viega et al. [20] extend the concept of Magic Lens to 3D including both flat, planar lenses and volumetric lenses.

Perlin and Fox [17] introduce the zoomable 2D Pad interface. This interface includes portal filters, which show "non-literal views of cooperating objects." For instance, when a portal filter is position over tabular data, within the portal a bar chart could be displayed.

Our concept of probes relates to this prior work as follows: We start with a View+Close-up [13] implementation of the Focus+Context metaphor. However, the user can define, place and scale multiple regions in the view for which the Close-up windows, or insets, are generated. The interactive manipulation of the regions-of-interest (ROI) boundaries and the fact that the view geometry within the ROI are drawn in an specialized manner borrows from Magic Lens and portal filters. However, while Magic Lens or portal filters just present an alternate rendering of the selected geometry in the main view, with probes an additional inset window displays secondary representations of the selected data. Unlike a standard View+Close-up inset in cartography, this inset is typically an alternate 2D infovis representation of the data in the ROI. Further, the inset window can contain interactive controls that affect the ROI and the inset's infovis graphic supports linked brushing.

Compared to a Toolglass, the probe inset pane with interactive controls decouples the ROI from the location of the controls. Significantly, probes are more than just labeled push-pins found in physical and digital 3D maps such as Google Earth [14]. Push-pins are not areal and labels are not dynamically varying infovis displays with optional 2D GUI controls. Commercial GIS tools such as ArcGIS [10] provide map views, tabular views and various basic graphing capabilities but it is not possible to interactively tie a multiplicity of these latter two view types to a multiplicity of ROIs on the map view.

Linking an information visualization view to a separate map view is an established and effective method of providing spatial context by connecting abstract depictions (e.g. parallel coordinates) with the geospatial origin (e.g. a region on a map) of the data being depicted. Andrienko and Andrienko [1] present an application in which a choropleth map is coupled with a separate window displaying box-and-whiskers plots of group statistics. Each plot is linked to the choropleth map by common shading color. While similar to our probes, in that the plots are linked back to their spatial origins, the basic pair being linked is fundamentally different. As we later define in Section 3, our basic unit, a probe, consists of a user-defined region-of-interest and a linked visualization, whereas the basic unit in Andrienko's work is a class. In the map view each entity or region belongs to one of a specified number of classes. In the linked visualization, there is one plot for each of the same number of classes. Classes do not overlap, are not necessarily connected, and are thus not equivalent to the type of freely user-defined regions-of-interest we utilize.

Edsall [9] presents a similar but more advanced multiple linked views environment with HealthVisPCP, in which he links a parallel coordinate plot with a scatter plot and a choropleth map. The map is colored to indicate each regions classification (into a user-specified number of classes) according to a statistic. Lines in the parallel coordinate plot, and dots in the scatter plot are then likewise colored through the same classification. Brushing the records in either visualizations highlights those records in the map view. Again the user does not define regions-of-interest (e.g. by circling areas), but instead chooses a variable-of-interest and a number of classifications across that variable's range. The intended usage here could be considered the reserve of our system: here the user picks an interesting region of the information visualization to find the spatial areas contributing to it, whereas in our work that user picks an interesting region in the geospatial view to find information about the data associated with or contained within that region.

MANET [18] supports moving, rescaling, tiling, stacking and overlaying multiple plots of various types (scatter plots, box plots, etc.). Sets of arbitrary windows can be designated as siblings which can be manipulated (e.g. open and closed, scaled, resized) as a group. An index window provides a virtual display showing all the windows on the screen, where each window is represented by a grey box. Re-arranging these mini-windows re-arranges the actual windows on the desktop. Up to four virtual screens can be configured and the index window allows rapid switching between these virtual screens. Similar concepts are now ubiquitous in multi-desktop extensions for common operating systems' GUI shells. Plots can be interactively interrogated by mousing over plotted points or groups of plotted points. The particular type of interrogation varies with the plot type. MANET supports 'cues' which are special locations on a plot where the mouse cursor changes shape to indicate some type of manipulation of the plot is possible with further mouse input. Generalized brushing of data is supported. MANET also supports interactive choropleth maps [19] which can be linked via brushing to other plots. For instance, the user could bring up a choropleth map and a set of box plots, brush one or more regions of the map, and the associated data points on in the box plots would be highlighted. However, it does not appear possible to select two separate regions-of-interest of the map and then display two sets of box plots, each of which summarizes only one of the two separate map selections. Therefore, there is no way to generate a third set of box plots to highlight the differences in the statistics between the two regions.

Dykes [8] presents *cdv*, which provides interactive, dynamic 2D cartographic information visualization through a web browser. Dykes demonstrates a number of applications using *cdv*. One application is for exploring the spatial-temporal distribution of tourists in a German park. Selecting a given map location pops-up a 2D line plot showing the number of people visiting that location versus time. A line is drawn connecting the 2D plot to the map location whose data it reflects. Multiple 2D plots can be brought up simultaneously for the selected locations. Dynamic linking and brushing between these plots is supported. This is similar to the probes concept we present. However, our probes are more general. First, in our system, the user can select arbitrary regions-of-interest on the map. Second, our probes' plot windows are capable of displaying one of many types of 2D visualizations as selected by the user. Third, we describe a mechanism that allows two probe windows to be selected and for generating a third window that directly compares the plots in the original two windows.

Dykes strongly advocates cursor driven map interrogation for examining local phenomena. With his "continuity probe" the user selects a zone (country, state, etc.) on a map and the selected zone and the neighboring zones are colored to reflect local tendencies of various statistics. For example, the mean income of the selected zone may be calculated and then the deviation from the mean can be used to color the zones in the selected neighborhood with red hues indicating above local average income and blue indicating below local average incomes. Multiple color-coded co-variance matrices show the co-variance among all the selected zones. This demonstrates the ability to display multiple 2D plots of the same type for a given selected region. Again this is not quite as flexible as the probe interface we describe, as it does not appear to support displaying multiple 2D plots of different types for a given selection region. Furthermore, it is unclear if multiple neighborhoods can be selected and have their individual 2D plots displayed and compared.

Dykes also discusses interactive adjustment of the distance weights applied to a selected zone's neighbors when computing various neighborhood statistics. We do not currently support any explicit weighting within the probe's region-of-interest. In many of our example applications, the user can paint the selected region as a arbitrary shape (e.g. circle, a general blob, or a curve following a road) so there is not always a meaningfully defined center of the selected region from which to measure the distance for computing a cell weight. However, the UrbanVis environment does allow the user to "weight" how much of the visualization to devote to depicting the data from the center of a region versus the outlying portion of the region.

3 Probes

The main building blocks of our design are probes. We define a probe as a pair consisting of a user-defined region-of-interest and a pane containing any variety of information visualizations coordinated to depict and interact with the data within that region-of-interest. The region-of-interest and the visualization pane are linked either directly (e.g. by a line) or indirectly (e.g. the region-of-interest and the pane's background are shaded the same color).

To create a probe, the user selects a region-of-interest (e.g. specifying a central focal point and extent radius, or through manual selection for irregularly shaped regions) and then chooses a location for the visualization pane to be overlaid directly within the main geospatial visualization. Once created, a probe visually presents a focused, local view into the dataset/model along with an intuitive visual linkage back to the overall dataset/model.

4 Applications

We begin by presenting the results of integrating our probe concept into three tested and published applications. In each case, we describe the limitations of the original application, and discuss the benefits gained by applying the probe concept.

It should be noted that inserting our "on-demand" probes within an application will never remove or limit existing capabilities and functionality, but always adds benefits such as extending beyond a single-perspective, adding multi-focus and multi-scale inspection and interaction, and increased potential for collaborative use. This is not to say that probes are perfect, as issues including occlusion and visual scalability can certainly arise. However, their "on-demand" nature ensures that an application's original functionality can be maintained by restricting probe creation. Several caveats to their use are discussed later in Section 6.

4.1 Urban Change in a 3D GIS Environment

The first application we integrate probes within is a 3D GIS visualization. This primary function of this application is to detect changes such as construction, deforestation, etc. in an urban environment between annual aerial LIDAR scans [5] (Figure 1). Aside from the primary 3D GIS view, a heatmap is presented on the side to depict the global distribution of the changes (in height and area) across the entire urban environment. Filtering is allowed on the heatmap, which controls the visibility of changes in the 3D view based on their area and height measurements.

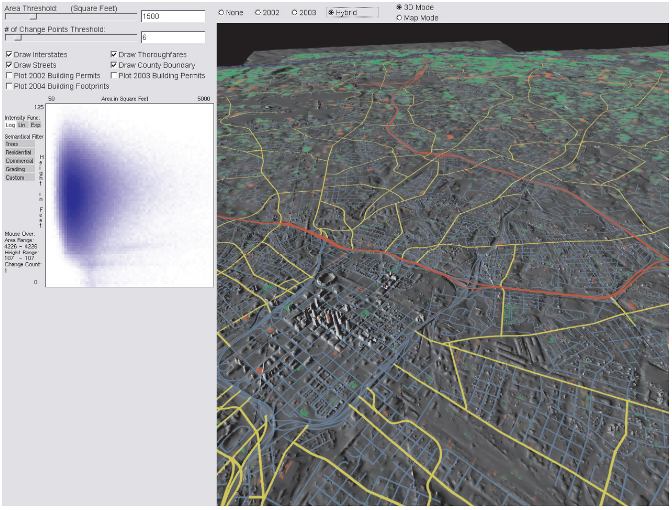

Fig. 1. Shown here is the original interface for the urban LIDAR change application. The main window (right) presents a 3D fly-around view of the county. To the side, a heatmap (upper left) shows the global distribution of all changes across the entire county. It is a density-shaded scatter plot with the vertical axis tied to the heights of change models and the horizontal axis tied to the projected 2D areas of change models. Different types of changes (e.g. newly built houses) generally fall in predictable areas of the heatmap. By selecting regions within the heat map, the user can filter the changes presented in the main window.

Similar to most traditional GIS applications, this visualization allows for a single perspective that is directly tied to the viewable screen area. When the user zooms into a small region, it is difficult to maintain the global overview and context as the single perspective limits the user's spatial awareness. Conversely, as the user zooms out, local details become suppressed and difficult to see. Furthermore, since the heatmap is tied directly to the user's perspective, there is no easy way to compare the trends and patterns of two or more regions without saving the images to file and comparing them offline.

Probes are introduced to this visualization to remedy these issues. A user defines a region-of-interest using a mouse, and a probe interface appears directly within the 3D view. Within the probe interface is the heat map visualization, now showing the distribution of only those changes within the region-of-interest. Also present are the filtering controls, here again their domain switches from global to local filtering. Multiple probes can be added on the same display, and they are differentiated based on the colors of the probes and the highlights of the regions-of-interest (Figure 2).

In the scenario presented in Figure 2, the user selects two regions-of-interest on the terrain. The first region, shown in blue, consists primarily of commercial buildings. The second region, shown in red, is a partially rural area that contains a number of new residential developments under construction at the time. It is clearly visible that the distributions in these two regions are different by examining their corresponding heatmaps. The magenta arrow in Figure 2 shows a concentration of changes found only in the second, residential region. This region can then be used to filter the entire county, revealing all the similar new residential developments.

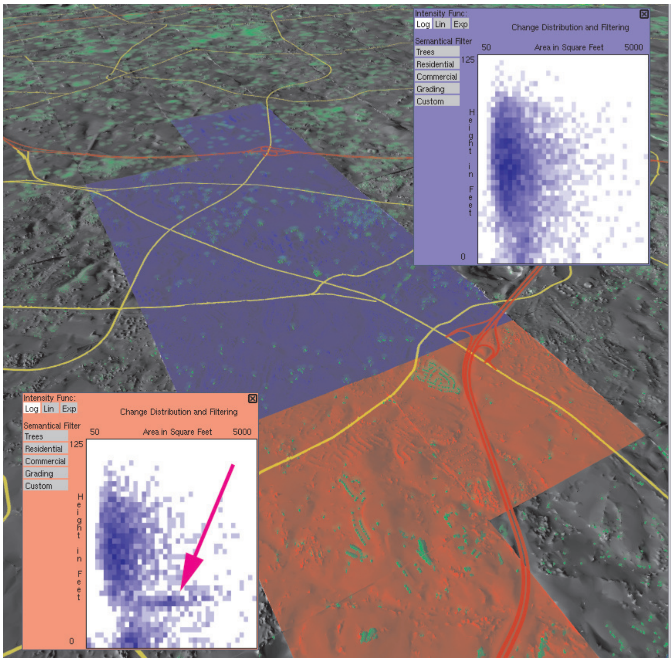

Fig. 2. Shown here, the user has selected two regions-of-interest, the blue is a commercially zoned district, and the red mostly residential. The visualizations for each probe present a heat map showing the distribution (in height and area) of changes detected in the respective regions-of-interest. The magenta arrow points to a concentration of changes found only in the residential region. This region on the heat map can then be used as a global filter, revealing other similar new residential developments elsewhere.

Even in this simple example, the power of the probe interface is apparent. The user can now examine regions from afar so as to maintain spatial awareness in relation to the surrounding regions. With the heatmaps displayed directly in the 3D view, the user can easily relate the abstract information visualizations with their corresponding spatial locations. More importantly, comparison between locations is now trivial as the heatmaps can be juxtaposed for immediate comparisons. This can be done either visually, as shown in Figure 2, or directly, by requesting a comparison pane of the two probes. By selecting two probes, a third pane can be requested, which simply presents a difference image of the two probes' heatmaps. In a previous paper [5], a manually created difference image was created outside the application to illustrate the differences in changes between two regions. The ability to do this type of comparison directly within the application is a powerful improvement. Further discussion of direct comparison abilities follows in Section 4.3.

4.2 Census Data Exploration Tool

UrbanVis [6] is an application designed to explore an urban environment and its corresponding census information by combining a 3D urban model view with an abstract information visualization view (Figure 3). With the use of the yellow sphere as control, the user can interactively navigate an urban environment and explore relationships between spatial and abstract information in a multi-resolution manner.

Unlike the LIDAR system described in the previous section, UrbanVis already separates the region of interest (as denoted by the yellow sphere) from the visible screen area. This view independence allows the user of UrbanVis to explore the urban model while retaining spatial awareness. However, similar to the LIDAR system, UrbanVis allows for only a single perspective and therefore cannot support comparison of different localized regions.

By applying the probe concept to UrbanVis, the user can now interact with multiple regions of interest in the 3D model view. As shown in Figure 4, each region of interest is now accompanied by an information panel exactly like the one shown on the left of Figure 3. The information panels can be moved around directly on the 3D model view but are always connected to the yellow spheres by a (white) line to maintain a clear relationship between the two. When two information panels are placed next to each other, the differences and similarities between the two local regions become apparent.

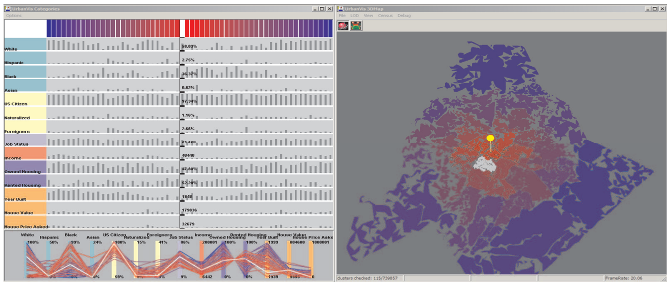

Fig. 3. Shown here is the original interface of the UrbanVis application. It consists of both a 3D map view (right), used to select a region-of-interest, and a coordinated visualization (left).

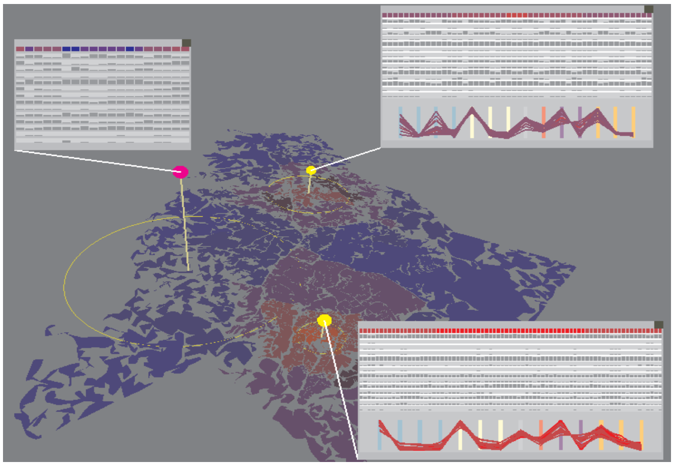

Fig. 4. After modification to utilize probes, the user can now select multiple, variable sized regions-of-interest within the 3D view. Each region-of-interest is then linked to a resizable version of the original coordinated information visualization. By resizing the panels for each probe, the user can control the granularity/abstraction of the depiction of the data from the probe. Resizing is extended further in Figure 5.

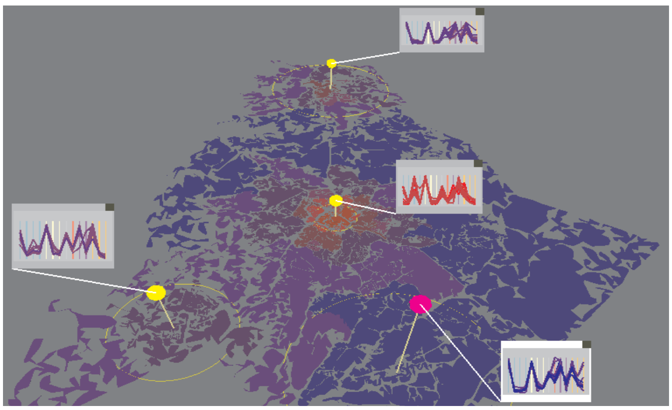

Fig. 5. Shown here, the coordinated visualizations for each probe have been limited to solely the parallel coordinates view and resized to the point where each shows only the most general view of the associated data. Here the probes begin to resemble "flags" stuck in the map, giving a simple representation, allowing for quick visual comparison. (Assuming the user knows how to interpret them.)

It is easy to see the comparison capability gained from using probes in UrbanVis; the user can now compare multiple local regions simultaneously within the application, without a navigational burden. However, another subtle but relevant advantage is that the resizable information panel allows the user to "annotate" regions using small information panels (Figure 5). These small information panels now act like glyphs in that they give an aggregated, high-level overview of the selected regions of interest without taking up much screen real estate.

4.3 Agent-based Social Simulation

Our agent-based simulation and visualization tool is created to visualize the results of a live agent-based simulation that allows a user to experiment with different social theories and scenarios in Afghanistan. Like the two visualizations described in Section 4.1 and Section 4.2, we apply the probe concept to an existing visualization of the agent-based system (Figure 6). However, unlike the previous two visualizations, the introduction of probes transformed the agent-based tool nearly completely.

Like the original LIDAR system, the agent-based tool is also limited to a single perspective that is tied to the viewable map area. Similarly, the additional infovis views in the agent-based tool such as the bar chart and the time-series view are also tied to this single perspective. However, unlike the LIDAR system or UrbanVis, the main purpose of the agent-based tool is for the user to manipulate variables within the simulation and visualize the effects of the changes. Most of these variables are global in that they affect the simulation of the entire country, some are tied to fixed single locations or a specific regions. It is clear that without proper organization, an exponential number of controls are needed to capture all combinations of all the variables. In fact, Figure 6 shows some of the 150+ sliders that were needed to operate a few relatively simple social theories.

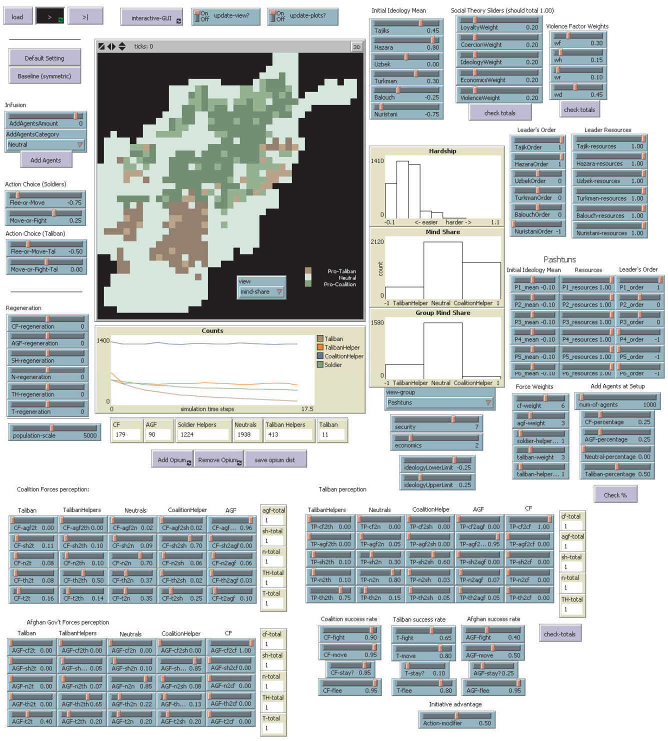

Fig. 6. The agent-based social simulation's original interface. Notice the large portion of screen-space dedicated to sliders and other control elements, which are ambiguous in terms of their scope. The single map view allows for only one variable to be seen at a time. Likewise, the four graphs can only depict global statistics across the entire simulation.

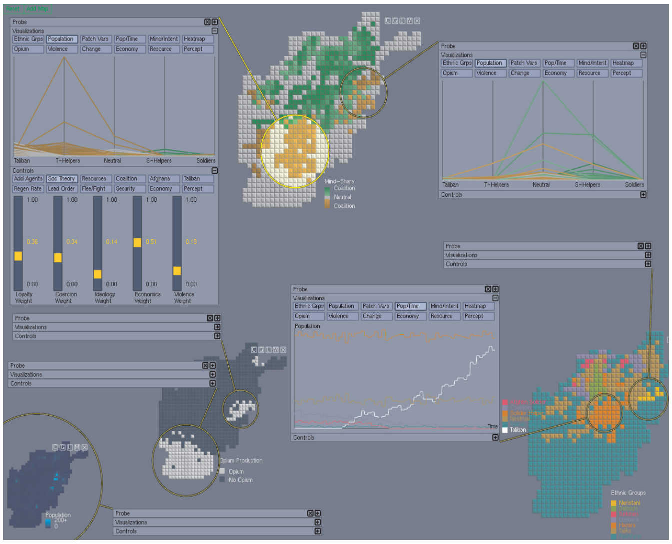

Fig. 7. An example workspace in our new, probe-based interface. Notice that the user can add any number of different overview maps. Probes can then be inserted into these maps, spawning linked coordinated visualization/interaction panes. This extends observation and interaction across all levels, from global to individual cells.

In addition to the issue of over-crowding from excessive sliders shown in Figure 6, the agent-based tool suffers another equally severe interaction issue, in that the sliders offer no spatial context in terms of their relationships to the corresponding geographical regions. Users and observers of this agent-based simulation are often left wondering what slider to operate in order to affect a specific region of interest. This incongruity between the visualization and its controls greatly diminishes the effectiveness of the simulation as an experimental platform for testing social theories.

By applying our probe concept, we can greatly increase the effectiveness of the interface. As can be seen in Figure 7, multiple instances of maps are now allowed, with each map colored based on a particular dimension in the data (e.g., ethnic group, loyalty, etc.). However, most importantly, the 150+ sliders can now be replaced by an "on-demand" tabbed control panel of sliders directly associated with each probe (Figure 8). This combination of sliders with geo-located probes makes the effect of each slider intuitive and obvious, in that interaction with a slider now only (locally) effects the region tied to its corresponding probe (i.e. whatever portion of the simulation the user has circled). It should be noted that the original, global controls can be replicated by simply creating a region-of-interest encompassing the entire simulation, as shown in the bottom-left of Figure 7.

The implication of a visualization that has capabilities for both passive inspection and active manipulation is striking. As shown in Figure 8, the user has selected two nested regions to test the impact of an increased economy in a small selected region and its effect in the surrounding areas. With the probe interfaces, the user can directly modify the economy of the small selected region and observe its effects in the probe associated with the surrounding areas. In this example, it appears that as the residents of the selected small region increase in wealth, the population of Taliban agents diminishes in the surrounding area.

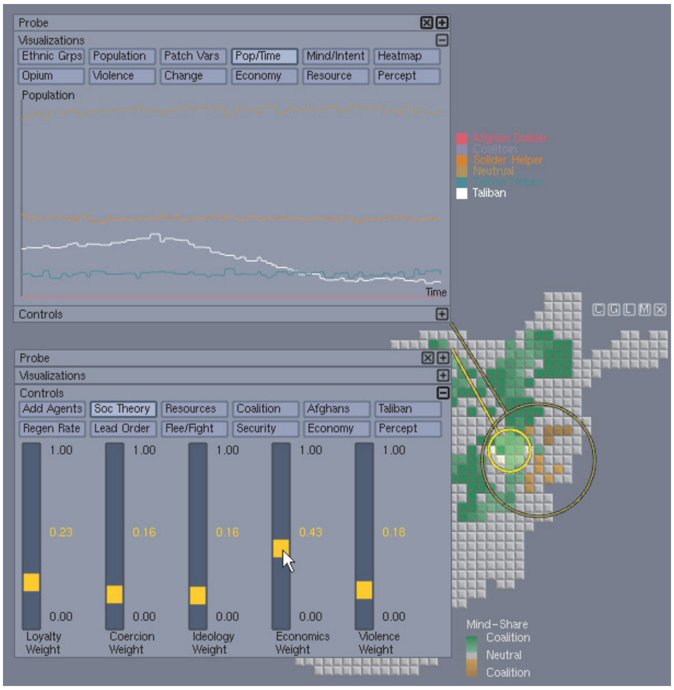

Fig. 8. The use of localized control capabilities is shown in this scenario. Here, the user places a probe (the smaller circle) over the city of Kabul and expands the control section of that probe's interface and manipulates local variables to test out a new social theory within the city limits. A second probe (the larger circle) has been added to encompass the surrounding region, which has some pockets of Taliban loyalists (brown cells). This probe is setup to graph the relative populations of various factions over time. The user can easily see that after the new social theory is enacted within Kabul, the number of Taliban agents (white line) in the surrounding decreases.

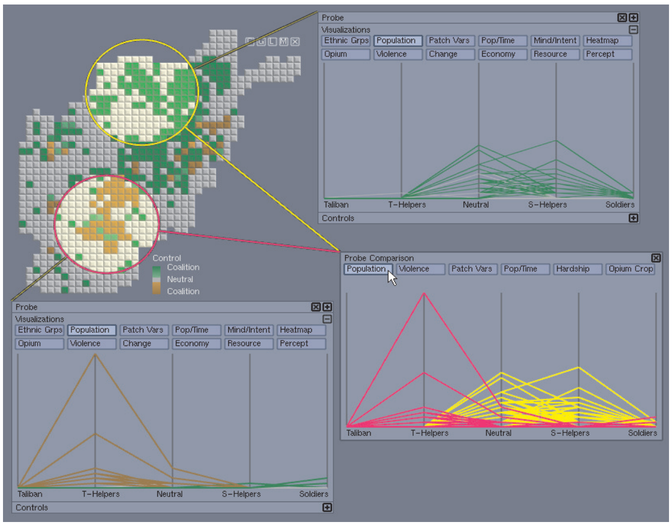

Fig. 9. Shown here, the user has created two probes, one over a Taliban-controlled area (magenta circle/brown cells) and one over a Coalition-controlled area (yellow circle/green cells). Each is set to display the relative populations of each type of agent using parallel coordinates. Then by choosing to create a direct comparison (bottom right pane) of the two probes, the user can see the values from each region-of-interest together in a single visualization.

A common task when testing social theories is to directly compare two regions-of-interest. With the probe interface this task becomes trivial. We are not limited to strictly visual comparison, but instead allow the user to directly compare multiple regions-of-interest through the use of a comparison pane. As shown in Figure 9, a comparison pane can be created between any two existing probes to visualize the relationships between the two regions-of-interest there are tied to. In this example, the user has selected a "union" operation, combining the two selected regions into a single view, immediately revealing the differences in population characteristics, while preserving (using color) the distinction between the two data sources. Numerous possible operations are possible within this framework, including the previously mentioned difference image of two heatmaps and the intersection between overlapping regions-of-interest.

The most obvious benefit gained by adding probes to this application is the ability to inspect multiple local regions at once. Where the original fixed coordinated visualizations once reflected the global model's values, we now have any number of dynamically created visualizations each able to reflect the values in regions-of-interest of every size and shape imaginable. We can now provide superior comparison capabilities by directly presenting regions-of-interest together or against each other in their own visualizations.

The probe interface also allows for geospatial-based manipulation of the simulation and visualization; the user gains the freedom to choose regions-of-interest of any size and shape and interact with their properties directly, allowing for easy experimentation of complex social theories and immediate visualization of their effects. Finally, by replacing the static interface with a unrestrained workspace, enabling and encouraging the user to add and remove "on-demand" interface elements as needed, we not only remove the original clutter and wasted screen space, but also extend the single-user application into one that has potential to support multiple users.

5 Evaluation

We performed informal evaluations of our probe-enhanced applications to solicit feedback regarding the usefulness over the previous interfaces. Each of the three systems were presented first in their original form, and then with probes to two audiences, each with a mixture of both faculty members and graduate students. The first group consisted of thirteen participants from the Center for Applied GIScience at UNC Charlotte, while the second group consisted of eight participants from the College of Architecture at UNC Charlotte. A few participants had previous experience designing and working with the original UrbanVis.

5.1 View Independence

Using probes removes the burden of having to change zoom-levels to inspect local data. By preserving the global view, we ensure that the user always perceives the overall dataset. Visually depicting the selected regions-of-interest directly on the global view ensures that the user always knows the context of the local region. By using multiple probes, distant local regions can now be simultaneously inspected and directly compared onscreen, alongside the global view. This preserves maximum spatial awareness and decreases the navigation required to switch between zoom-levels.

Many participants identified the issue of loss of spatial awareness when constrained to a single perspective as one they have encountered in their work. Even though some of their existing applications have the ability to present multiple camera views (e.g. 3D modelling suites), one participant noted that "when trying to navigate in true 3D space, you often lose track of where something is in [the overall] space," while another elaborated that "where there's a lot of data….its important to be able to drill down" but that "sometimes you dive into detail on something and its not easy to navigate your way back out again." They saw our work as being a solution to this problem, in that "all [the probes] are organized by the overall metaphor of the map, so it really does help a lot [to know that] this window relates, in this way, to the other windows" and that this linkage "allows you to navigate more fluidly between different parts."

5.2 Multi-Focus Inspection

Probes allow the user to dynamically specify regions-of-interest and select from a wide variety of "drop-in" information visualizations. An assortment of methods are appropriate for selecting regions-of-interest: circular regions can be generated from a focal point and an extent, irregular regions can be selected manually unit-by-unit, etc. Extending the target of a coordinated visualization beyond what is merely onscreen at the time to these more flexible and precise regions improves both relevancy and accuracy. By allowing different visualizations to be tied to each probe, we can perform a wider range of inspections at one time than if we were limited to a traditional coordinated visualization interface.

By using multiple probes, the user can select multiple local regions and view their values side-by-side, or directly together in a comparison pane, always along with a global reference for overall context. This removes cognitive memory requirements, avoids change blindness, and speeds up comparison.

All participants appreciated the view independence and multi-focus aspects allowing them to access lower-level information about multiple local regions, while preserving the higher-level overview. The multiplicity of scales available for visualization simultaneously was also well received, with one participant specifically commenting that "having multiple scales is incredibly interesting, because at different scales you may be starting to visualize different processes."

The comparison abilities were also identified as attractive by the participants, one noted that having that capability in her application would make it "a lot easier to compare all my variables [while looking at it] quickly." Being able to investigate multiple regions without "having to go through the steps of selecting them and then opening up attribute tables" was described as "fast and intuitive."

5.3 Location-specific Manipulation

The creation of probes at a multitude of different shapes and sizes not only enhances inspection capabilities, but interaction capabilities as well. The user is no longer limited to applying adjustments and controls specific predetermined scales. This extends once global controls into specific local regions, empowering the user to more precisely interact with the data.

Several participants expressed enthusiasm about our probe concept's potential to enhance their own existing projects with locally-tied interaction. Their projects included a landslide hazard analysis application, an interactive disease outbreak map, and a cellular urban growth simulation. The cellular urban growth simulation was the center of much discussion, as it had many parallels to the agent-based social simulation discussed in Section 4.3. In particular they saw the probes as an attractive method of being able to "change parts of the simulation…and affect the simulation locally," and "a really exciting opportunity to take to the decision makers."

6 Caveats

An obvious but important issue, well know amongst spatial scientists and raised by several participants, that must be discussed in relation to this work is the modifiable areal unit problem (MAUP) [11]. Variations in how local areas are delineated can cause comparisons between the visualizations of their aggregated values to be misleading. A classic example is crime-mapping, where many times crimes are recorded and reported per police beat, can be argued to be an inferior and misleading region choice as opposed to aggregating the reports instead by local neighborhoods, each with equal numbers of homes. Scale also plays a role in the MAUP, as local variation can be lost when aggregated into a larger region (a problem partially solved by our multi-scale probes) as well as misleading comparisons when comparing local regions of significantly different size (e.g. area or population.) In summary, often care must be given to how local regions are selected for aggregation, to ensure that the selections are meaningful, equal, and of similar scale; since we leave region selection to the user, a potential improvement to this work is providing assistance in selecting regions with similar characteristic for more accurate comparison.

There are possible scalability issues that may arise when probes are implemented within applications requiring significant processing to render their information visualizations. What may have been sufficiently fast to draw in a single inset view, may be too slow for deployment across multiple probes. This is especially true if the visualization requires extra calculation to aggregate information to condense itself to a smaller screen size. The UrbanVis application detailed in Section 4.2, for example, ran much slower under the strain of having to calculate multiple levels-of-detail and aggregations for each region-of-interest, something it was not originally designed to do efficiently.

Visual scalability can also quickly become an issue as the number of probes created increases, both in terms of screen real estate and overall cognitive load to the viewer. The two basic methods we used to help alleviate these issues were to make the probe interfaces collapsible (see Figure 7) and to make the probe interfaces resizable (see Figures 4 & 5). Collapsing a probe interface reduces the screen space needed to display a probe interface, maintains visibility of the region-of-interest, and reduces the overall visual complexity of the application. Resizing probe interfaces also achieves these benefits, and has the additional advantage of allowing the user to customize the complexity of the associated visualization. As shown in Figure 5, this can help with a shortage of screen real estate, as it permits the user to fit more, smaller visualizations onscreen at once. However, consideration must of course be made in regards to how the visualizations are resized downward, into a more glyph-like form, in order to ensure that they are able to be correctly interpreted and meaningfully compared.

Another issue arises from overlapping regions of interest denoted by probes. This is particularly problematic and ambiguous if direct data manipulation is allowed on each probe, as is the case in the agent-based system. This overlap creates a one-to-many mapping issue, since there can be multiple controls affecting one area. There are some obvious solutions to alleviate this problem, such as prompting the user when a conflict arises. However, we find this problem to be more application and domain-specific, and effective solutions may be found on a case-by-case basis.

7 Discussion

Although in this paper we demonstrate the effectiveness of applying probe interfaces to geospatial visualizations, we believe that this concept can be applied to more abstract data spaces as well. The most obvious visualizations that can benefit from this are tools that present a spatial layout in which the locations of data items are of importance, such as in an organizational chart or graph layout. However, it is also conceivable that this type of interface can be extended to any information visualization that presents an overview that can be drilled into further. In theory, this probe-based interface should be very generalizable, and we look forward to exploring the possibility of applying this interface to other types of visualizations.

We remove fixed single perspective interfaces, and instead allow the user to dynamically insert interface elements anywhere they are needed. There is an immediate benefit of this style of interaction for collaboration, as there are no theoretical limits to the number of probes or map instances. Multiple users can interact with the same visualization at the same time without interfering with each other's views. An attractive interface device for deploying this kind of probe-based visualization is a multi-touch table, which has been demonstrated to be an effective medium for a multi-user environment. As the popularity of touch surfaces increases, we hope that our interface and its future extensions will be widely used and applied.

Brewer et al [4] developed a prototype collaborative geovisualization environment and used it to perform interviews/informal evaluations with domain experts to ascertain what is expected/required of geospatial visualizations when they are to be used collaboratively. Some of their findings are particularly relevant to our work: the role of maps in a collaborative environment, drawing attention, and joint interface controls. Most of their participants mentioned that in a collaborative environment, the role of the maps were to provide the context in which discussion would take place. The importance of the map for conveying spatial characteristics and locations is vital when attempting to communicate a finding to a collaborator, thus our system succeeds in this aspect; results (in the form of visualizations) always have a direct visual link back to the map that provides spatial context. The need to draw attention to areas on the map (via circling or pointing) was also raised by most of their participants. Again, the way in which we link results back to their contextual locations explicitly draws attention from the results (the discussion topic) to the source on the map. Finally, while most participants saw the need for joint interface controls, they also raised the issue of potential conflicts. Solutions proposed included turn-based control and separate control panels for each user. A solution such as we show in Section 4.3, in which a single, global interface is replaced by on-demand controls, tied to local regions, has the potential to alleviate potential conflicts by allowing each user to manipulate variables for only their own specific regions-of-interest, (perhaps even in only their own map).

8 Conclusion

We have presented a probe-based concept that can be used to replace or supplement the single perspective, fixed interfaces of traditional geospatial visualization applications. Coordinated information visualizations, linked to user defined regions-of-interest, become directly integrated within the main view. Interaction controls are also relocated within dynamic "on-demand" interfaces, reducing clutter and allowing for local control across the entire range of scales. Together, these changes bring many benefits including view independence, multi-focus inspection, location-specific manipulation across the entire range of scales, and increased potential for collaboration.

We demonstrate the usefulness and applicability of our methods by modifying three unique geospatial applications to utilize probes. In each case we can see the benefits gained by moving away from traditional single-viewpoint interfaces. Our informal evaluations with experts in GIS and architecture confirm that with the addition of probes, the three geospatial visualization and analysis tools become more useful and intuitive.

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