Emergency Data Analysis via Semantic Lensing

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ABSTRACT

Emergency situations often play out over extended geographic regions and can present response personnel with numerous types of data at various level of detail. Such data may be displayed in mapping software tools that organize the data into layers. Sufficiently complex scenarios can result in dense, occluded, and cluttered map displays. We investigated a localized, "detail-on-demand" filtering strategy called semantic lensing that in certain situations provides a more efficient and desirable approach than filtering global layers for mitigating clutter and occlusion.

An initial formal user study with these semantic lenses has shown their value in aiding decision makers during tasks that might occur during detection of and response to emergency situations. Completion times are significantly faster when using lenses, and workloads are significantly lower. Future work will evaluate additional features and task-specific applicability, and may support the distribution of such a lens tool to emergency preparedness and response personnel.

Keywords

Information visualization, analysis, lens interaction.

INTRODUCTION

Geographic information system (GIS) displays typically contain many data layers ranging in type and level of detail (LOD) that often result in dense, occluded, and cluttered map displays. This can lead to cognitive overload, requiring excessive manual interaction to tailor and filter the scene on a global (entire view) level. The result is a loss of context due to changes in the map's LOD, view region, scale, and content, as well as performance degradation due to refresh delays.

We developed a plug-in to ESRI ArcGIS's ArcView, a leading geospatial data viewer and analysis software application. Our plug-in allows the user to view selected map layers in a semantic lens via a "details on-demand" filtering strategy. Our experiment illustrated its efficiency over the current practice of toggling on and off global layers when performing representative geospatial intelligence tasks in a crisis management domain. The lens provides an efficient visual portal to data otherwise typically occluded.

RELATED WORK

Semantic lenses have been a research focus for visualization techniques and data analysis since the early nineties. Traditionally, semantic lenses support one or both of the following functions: decluttering—reducing visual clutter to enhance clarity of a region or feature of interest; and adding semantic information—providing the ability to see additional information in a lens, without losing context or diverting attention.

Early work in the field was done by Xerox PARC with their "magic lens" research. These lenses generally showed additional information that was semantically related to the areas of a display beneath the lens (Stone, Fishkin, and Bier, 1994). This was one example of their more general see-through interface research which included other ideas such as putting tools or functions semantically related to screen objects into a "glass" layer over those objects (Bier, Stone, Pier, Buxton, and DeRose, 1993).

More recently Idelix has developed the ability to render specific map or imagery layers using their Pliable Display Technology which at its core is an implementation of distortion-based magnification lensing (Idelix, 2004). Lenses are also being researched as tools for visualizing temporal-based changes (Silvers, 1995), and enhancing views of 3D data in augmented reality spaces (Looser, Billinghurst, and Cockburn, 2004) and virtual reality (Viega, Conway, Williams, and Pausch, 1996).

We found minimal evidence of human-computer interaction (HCI) investigations into the use of semantic lenses for emergency response; this research is an early step in exploring the roles that lenses can play in geospatial analysis for emergency response. Additionally, there seemed to be little use of geo-referenced layers of data (such as those found in existing GIS products) in lensing or other visualization techniques. Our work is novel in its approach to displaying "semantically-related" data to assist in geospatial analysis.

LENS PROTOTYPE AND USES

To explore the impact of semantic lensing on emergency management we developed a lightweight semantic lens plug-in using ESRI ArcObjects and C#. We are also implementing semantic lens implementations for ESRI MapObjects, ESRI ArcIMS, Google Maps, and OpenMap.

Lens Capabilities

While we have several lensing capabilities in development, this research focuses on a semantic "filter" lens. With the filter lens, any combination of layers may be selected to display in the lens for either rapidly augmenting (adding layers to) or de-cluttering (removing layers from) the scene. Multiple lenses can be used simultaneously with different layers selected in each lens. Lenses may be resized and repositioned as needed. This functionality is in contrast to the built-in capabilities of ArcView (and most other GIS tools) which only allow layers to be shown or hidden for the entire scene.

Using Semantic Lenses

It is our contention that lenses are most useful for obtaining localized details on demand by quickly swiping over or focusing on an area of interest to augment understanding. Because of the temporary nature of this use, lenses can easily be invoked or discarded. When in "lens" mode (activated by a toolbar icon), a user simply selects the layer(s) desired to be seen in the lens, right-clicks on the map, and selects "semantic lens" to invoke. The lens appears in the upper-left corner of the map and can be dragged to anywhere on the map as a lightweight, engaging tool. To discard a lens the user selects it and presses the *zero* key.

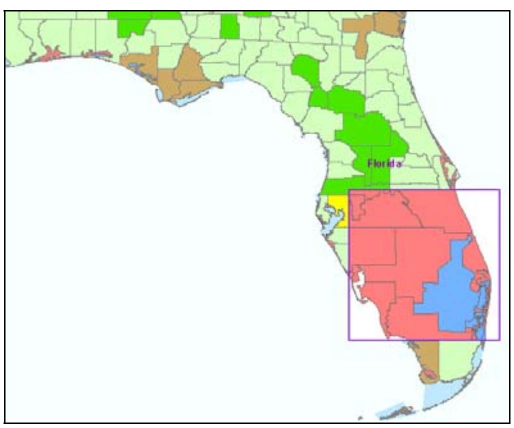

Figure 1. Example of pink and blue data constrained to a Semantic Lens

Lenses are also advantageous for highlighting different data in distinct regions of the screen. For example, a traffic analyst might add a lens to each bridge around a city to simultaneously highlight congestion at each separate location.

In contrast, ArcView's built-in ability to toggle the display of data layers presents a global means of filtering. The user is able to show or hide each layer as desired by simply filling or clearing a checkbox next to the layer name, and may re-order the "stacking" of layers (disallowed for our experiment). However, data for a given layer is either shown for the entire view or hidden completely. If data from one layer obscures that from another, it does so without regard to what portion of the view the user cares about or the nature of the task at hand. Hiding or showing a layer may also involve significant redraw time as the entire screen is updated.

USER STUDY

We designed an experiment with two hypotheses to investigate if and how semantic lenses can be applied to GIS for managing and preparing for crisis-like situations:

- H1: Using semantic lenses instead of the built-in layer manipulation will allow users to perform certain tasks involving multi-layered maps faster and more accurately.
- H2: Users will experience less total workload (a lower amount of effort) when performing tasks with semantic lenses instead of global layer filtering.

To investigate our hypotheses we constructed two layered maps for use during testing. Both maps included 13-14 active (displayed) data layers and exactly seven inactive (not displayed) layers. The inactive layers were never required to complete the tasks, but were included to better emulate complexity common to map data.

Thirty participants were recruited from across The MITRE Corporation's campus in Bedford, MA. They had varying levels of experience with mapping and ArcGIS software.

First, each participant trained using a printed tutorial which explained the relevant features of GIS software and semantic lenses. The user was walked through the processes of identifying data based on symbol or color, correlating data between layers, turning on and off layers, and creating and manipulating lenses, all within the ArcView application using a tutorial map different from those used during the tasks. Completion of the tutorial provided each user with the basic skills and knowledge needed to accomplish the tasks.

Each participant completed two task sets, each comprising three tasks. Task Set A referred only to Map A and Task Set B to Map B. Corresponding tasks for each set were comparable (e.g., Tasks A1 and B1 were similar). Each task required the user to find and count the total number of locations at which all specified criteria across various layers were matched. The criteria for the first task of each set consisted of specific values on two layers, while the criteria for the second and third tasks specified values for three layers. Both sets of tasks had emergency management themes; for example, in one task users looked for values representing areas at high risk for forest fires, while in another they looked for locations in which health funding changes might affect large populations.

Following a within-subject protocol, all participants encountered both conditions, with the independent variable alternating which participants used lenses with Task Set A and which used them for Task Set B. All participants performed Set A first and Set B second. Participants were allowed to use lenses for only one task set and were required to identify each match and note their final answer.

Two quantitative dependent variables were measured for each task: accuracy and time. Time values were considered valid only for tasks in which participants were 100% accurate. For each task set participants rated several aspects of the workload they experienced using six 1-10 rating scales based on NASA's multi-dimensional Task Load Index (TLX) scoring system (NASA, 1987). The six scales used were:

- Mental demand
- Physical demand
- Temporal demand
- Effort
- Performance
- Frustration level

After the second set of workload scales, participants completed a weighting questionnaire which provided a method to rank the participants' subjective workload preferences. In effect, the TLX scores provided relative workload values for lensing vs. global layer filtering across all tasks.

RESULTS

Speed

Nine independent-samples t-tests were performed comparing the mean times to complete the tasks with 100% accuracy between the lens condition. The tests analyzed across all tasks, Task Set A, Task Set B, and each individual task (6 in all). In every task, the lensing mean time was faster than global layer filtering. Lensing was significantly faster across all tasks ($t(104)=3.62$, $p<.001$), for Task Set A ($t(46)= 3.42$, $p=.001$), and for Task A1 ($t(21)=2.61$, $p=.016$).

For tasks with unevenly distributed data points such as Tasks A2 ($t(20)=1.87$, $p=.077$) and B2 ($t(21)=1.72$, $p=.100$), the lens conditions were faster, though not significantly. This suggests a low statistical power (not enough participants were tested) and that perhaps with more participants statistical significance may be observed.

Accuracy

Three independent-samples t-tests were employed to compare the percentage of correct answers between the lens conditions across all tasks, for Task Set A, and for Task Set B. In every case, the lens condition was more accurate than global layers, and across all tasks the difference was nearly significant (t(156)=1.81, p=.072); see Table 1).

	Semantic Lensing	Global Layer Filtering	N
Accuracy (%)	73	60	158

Table 1. Accuracy of Semantic Lensing and Global Filters

Workload Assessment

Total workload scores were compared between lens conditions using the Mann-Whitney significance test across all tasks, for Task Set A, and for Task Set B. In all cases, the lens condition yielded significantly lower total workload scores: $z=-4.0$, $p<.0001$ for all tasks; $z=-1.992$, $p=.046$ for Task Set A; and $z=-3.405$, $p=.001$ for Task Set B.

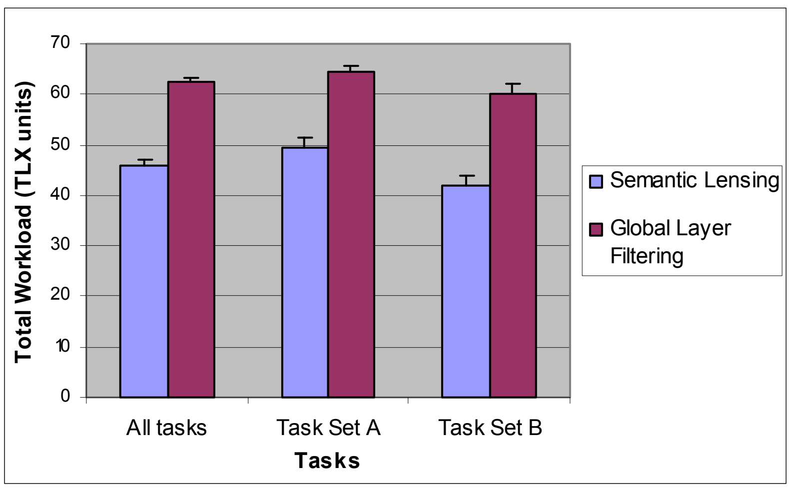

Figure 2. Total Workload Experienced for Semantic Lensing vs. Global Filter

CONCLUSION

Semantic lenses can significantly assist the analysis of layered image data in some circumstances, compared to global filters alone. Statistical analyses show that across six representative tasks, using a lens can be faster (sometimes significantly) than just global filtering. The faster speed (significant) and higher accuracy for semantic lenses across all tasks (in the aggregate) confirms hypothesis H1. Workload scores were significantly lower for lenses across all tasks, confirming hypothesis H2. These results are primarily applicable to the type of analysis tested, which requires high levels of manual manipulation and the repeated acquisition of varying levels of detail while maintaining context—common activities when working with geographic data pertaining to complex situations.

With 30 participants in total, there were not enough data to obtain significance for each individual task aside from Task A1 (as few as nine data points in some cases). However, each individual task was performed faster and more accurately using lenses, suggesting that with more participants one may find statistically significant differences in both speed and accuracy.

Overall, our findings indicate that the semantic lens plug-in should be distributed to certain emergency personnel as an additional tool in their arsenal of techniques for analyzing large amounts of data, particularly for time-critical tasks on multi-layered maps that require high levels of manual manipulation.

LIMITATIONS AND FUTURE WORK

Our findings should be considered in light of three limitations of our experiment:

- Variable participant familiarity with GIS analysis;
- Variability in their GIS software interaction skills;
- Interaction differences between lens invocation and switching global layers.

These factors increase the complexity of such experiments. More investigations are required to determine the general applicability of our findings to other interaction techniques and to other data used during geographical analysis. In these future investigations, we aim to recruit local responders and analysts as participants and rely less upon MITRE personnel.

In addition to the plug-in for ESRI ArcView, we have implemented semantic lenses for ESRI MapObjects and Google Maps. We hope that this variety of implementations allows us to explore semantic lens use in a much wider variety of contexts. Other lens types under development include a label lens, query lens, magnification lens, and compound lens. Each of these provides a dynamic method of viewing and analyzing complex geographical data.

Further studies are in progress to help us more fully understand the applicability, value, and efficacy of lenses in the field of emergency management.

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