Geovisual Analytics and Crisis Management

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ABSTRACT

Increasing data heterogeneity, fragmentation and volume, coupled with complex connections among specialists in disaster response, mitigation, and recovery situations demand new approaches for information technology to support crisis management. Advances in visual analytics tools show promise to support time-sensitive collaboration, analytical reasoning, problem solving and decision making for crisis management. Furthermore, as all crises have geospatial components, crisis management tools need to include geospatial data representation and support for geographic contextualization of location-specific decision-making throughout the crisis. This paper provides an introduction to and description of Geovisual Analytics applied to crisis management activity. The goal of Geovisual Analytics in this context is to support situational awareness, problem solving, and decision making using highly interactive, visual environments that integrate multiple data sources that include georeferencing. We use an emergency support function example to discuss how recent progress in Geovisual Analytics can address the issues a crisis can present.

Keywords

Geovisual Analytics, Geospatial Information, Visualization

INTRODUCTION

To meet the challenges of complex crisis management situations, new interactive visualization tools are in development to deal with large, complex datasets and similarly large and complicated analytical tasks. These systems must help enable connections between response, mitigation, and recovery specialists in disaster situations. Recent crises have revealed the need for visualization tools to support time-sensitive collaboration, analytical reasoning, problem solving and decision making in analysis, planning and time-sensitive response activities (Thomas and Cook, 2005). As almost all crisis management activity contains a geospatial component, these activities will necessarily include geospatial data.

The purpose of this research-in-progress paper is to provide an introduction and description of Geovisual Analytics and its use in crisis management activity. Geovisual Analytics can be brought to bear to support situation awareness, problem solving, and decision making using highly interactive, visual environments that integrate multiple data sources. We use an emergency support function example to discuss how research in Geovisual Analytics can address the issues a crisis can present. We also highlight Geovisual Analytics tools currently in development at the Penn State GeoVISTA Center that can support crisis management. Our paper concludes with possible avenues for further research in Geovisual Analytics as it relates to crisis management.

WHAT IS GEOVISUAL ANALYTICS?

Geovisual Analytics is an emerging interdisciplinary field that integrates perspectives from Visual Analytics (grounded in Information and Scientific Visualization) and Geographic Information Science (growing particularly on work in geovisualization, geospatial semantics and knowledge management, geocomputation, and spatial analysis). Geovisual Analytics tools help identify relevant geospatial information, data, and knowledge by supporting analytical process that meld innate human abilities of vision and cognition with computer-based visual interfaces that provide flexible connections to relevant data and supporting knowledge, and that are specifically designed to provide support for analytical reasoning. Often the activities that Geovisual Analytics is directed toward involve recognizing relevant information in enormous datasets that make what is relevant difficult to determine using traditional methods. Geovisual Analytics is an increasingly important tool for activities ranging from counter-terrorism and crisis management, through environmental science, to strategic business decision making.

Conceptually, Geovisual Analytics system design efforts for crisis management can build from the following guidelines for visual analytics generally, as outlined in Thomas and Cook (2005):

- Use sense making, cognition, and perception foundations for tools that support reasoning for complex tasks
- Address issues of analytical scale and the interplay between complexity and urgency that dictates and determines the scale
- Synthesize different types of information from different sources into unified representations to find meaning
- Integrate views of large-scale information spaces, coordinated views of information in context, and overviews and details
- Leverage innate human abilities to reason about time and space

Geovisual Analytics investigation requires tools that are highly interactive and support exploration (Allendoerfer et al., 2005), that work with end-users previous experience and mental models, and that allow for evidence to be assessed and hypotheses to be easily evaluated. Thus far, Geovisual Analytics tool development has focused on information analysis relevant to domains such public health threat analysis (Proulx et al., 2006) and historical geography of fragmentary archival documents (Figure 1) (Weaver et al., 2006).

The ultimate end goal of Geovisual Analytics investigation is the dissemination of results to decision makers who

Figure 1: The 'Hotels Viz', a Geovisual Analytics application built in the Improvise interactive visualization construction system (Weaver, 2004). Users can explore spatial and temporal aspects in past travel behavior based on historical registry entries from historic hotels.

need a succinct communication of the interpretations made by an analyst or group of analysts. Geovisual Analytics tools must support visual outputs that can be used as artifacts of persuasion in whatever medium is used to convey the story (Gershon and Page, 2001).

PROBLEM DOMAIN

In all phases of the disaster cycle, crisis management activity and real-world events generate huge volumes of data from heterogeneous sources such as news reports, video feeds, email, text messaging, RSS feeds, and camera-enabled cell phones. Most of these data contain an explicit geospatial component (e.g., derived from GeoRSS feeds), or implicit geospatial references (e.g., place names extracted from a news report) (Figure 2). For example, the Geovisual Analytics application shown in Figure 2 extracts and plots geographic place names and disaster concepts from news stories (shown on the bottom of the figure) to visually reveal potentially unknown geographical and/or conceptual relationships between places in Google Earth™ (shown on the top of the figure).

In emergency response activities, information from trusted sources may be of critical importance in time sensitive situations. For example, the United States Senate Committee On Homeland Security And Governmental Affairs (hereafter "the Committee") investigation into the response to the Hurricane Katrina disaster of 2005 reported that the Department of Homeland Security (DHS) issued incomplete and contradictory situation reports during the event, and in turn DHS, "…failed to recognize, or disregarded as unconfirmed, many of the reports that it did receive" (Committee On Homeland Security And Governmental Affairs, 2006:19-2).

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Figure 2: The Context Discovery Application (Tomaszewski, 2007)

Another important (potential) input to crisis management activity is information about past (or hypothetical) events that can inform present situations. Examples of this include knowledge derived from response training exercises, post-hoc analyses of real responses to disasters, and vulnerability assessments that are used to formulate hazard mitigation strategies. An example of failure to use the first type of information effectively was found in the Committee's investigation of the Hurricane Pam training exercise of 2004 that preceded Hurricane Katrina in 2005. Although some lessons from the Pam exercise were applied in Katrina, "…far too many of the Hurricane Pam

lessons were not applied. Despite this being 'the storm we've always feared', despite our being well aware of the impact of such a storm on New Orleans, and despite the fact that federal, state and local agencies came together in July 2004 to do a 'live rehearsal' of a response in such a circumstance…too little was done to act on the plans resulting from Hurricane Pam" (The Committe 2006:8-9).

Some crisis situations inherently need to be examined from a geographic perspective over time. For example, with a phenomenon like the Avian Flu virus, information about where and when deaths and illnesses are occurring is relevant input to policy decisions for public officials internationally and not only for officials in the locations where the illnesses/deaths are occurring. Actors at multiple scales must be informed about the spread of the disease to prepare accordingly, be kept aware of the effectiveness of preventive strategies in use by others, and understand the interconnected hierarchies of relevant events and information at many levels (Proulx et al., 2006).

GEOVISUAL ANALYTICS AND CRISIS MANAGEMENT

An example of a situation in which a Geovisual Analytics system can benefit crisis management activities can be found in Emergency Support Function (ESF) #5 - Emergency Management Annex from the United States National Response Plan[1] (NRP). The purpose of ESF #5 is listed as:

"Emergency Support Function (ESF) #5 – Emergency Management is responsible for supporting overall activities of the Federal Government for domestic incident management."

The Planning section of ESF #5 indicates that it "…coordinates with the DHS Science and Technology Directorate and agencies with special technical capabilities to request support for geospatial intelligence, modeling, and forecasting." The overall ESF is tasked with providing situation reports across multiple jurisdictional levels before, during, and after a crisis.

Geovisual Analytics systems in particular can be used to support geospatial intelligence, situation awareness, and any other tasks that require analysis and knowledge construction using geospatial information. For example, geovisualization of storm events, vehicle crashes, and vehicle movement can reveal patterns of response activity across multiple spatial and temporal scales. The ability to dynamically express queries through the manipulation of graphical components of a user interface can provide an intuitive means to discover relationships among activities and objects for complex events that might span multiple jurisdictions (Figure 3).

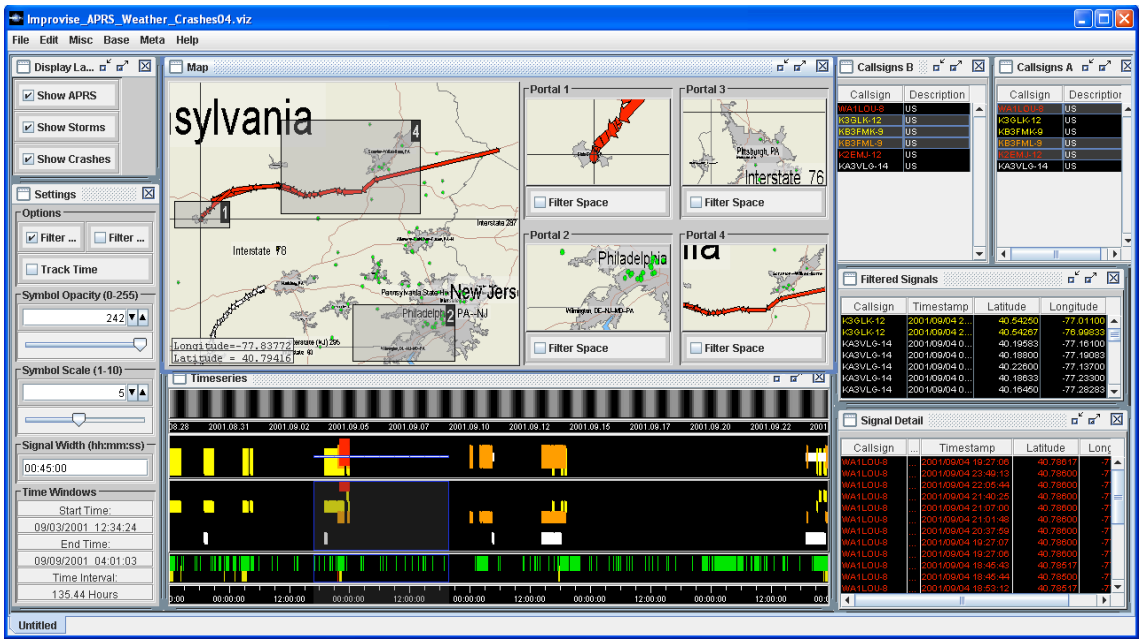

Figure 3: Another Improvise visualization, in which linked displays allow the cross-filtering of vehicle movement, crash events, and storm events in time series and multiple maps (Stryker, 2007).

[1] http://www.dhs.gov/xlibrary/assets/NRP_FullText.pdf

Furthermore, Geovisual Analytics can aid collaboration processes where dynamic, time critical response situations require actors to engage in tasks for which they may not have procedural training or experience or where information is fragmentary or incomplete (MacEachren, 2005). For example, the complexity of the NRP may create difficulties for on-the-ground responders during a crisis. Computational methods can be used to search and extract relevant information from large information spaces such as the NRP, planning reports or operation manuals created by government entities in order to build ontology-based representations (Mitra and Pan, submitted).

Interactive tools can help users navigate these resources to construct meaning and derive alternative courses of action. This approach of distilling essential information and presenting it in an interactive visual format allows actors to take rapid action during a crisis situation by sharing, comparing and discussing ontologies created by individuals or using ontologies created to externalize and share information that would not be readily accessible to the group.

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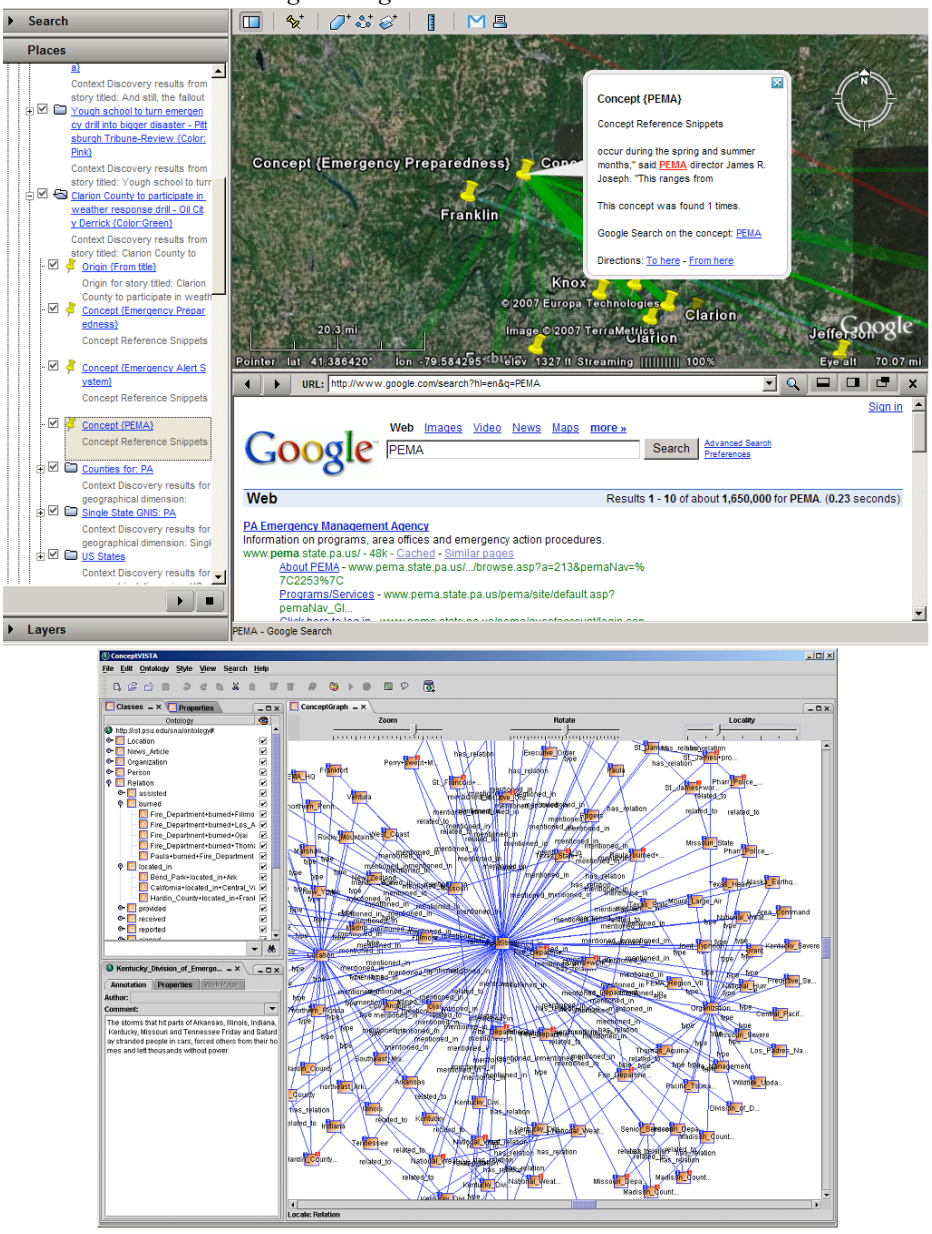

Figure 4: Linked concept map-geographic map applications.

Ontologies created by users in a crisis situation can be visually rendered as concept maps that are linked to geographic maps (Figure 4). In Figure 4, the application shown on the bottom right, ConceptVISTA[2], is used to visually represent graph-based ontologies. Concepts from these graph-based ontologies can also be viewed in the Context Discovery Application (Tomaszewski, 2007) via Google Earth™, shown on the top, which can represent non-spatial concepts that have relationships with geographical entities in a geographical display.

Geovisual Analytics can also be used to evaluate how data and tools are used during the analytical process itself. Tools are now under development to track and visualize how interactions, tool arrangements, and data processing events in an information space facilitate analytical reasoning, sense making, and hypothesis generation (Keel, 2006). Analytical environment states (like window layouts, visual

[2] http://www.geovista.psu.edu/ConceptVISTA/index.jsp

symbology, and mouse interactions) and contextual cues (like annotations and screenshots) can be captured, visualized, recalled and transferred so that analyses can be reused. These data can be used for training purposes to show new analysts how others have successfully (or unsuccessfully) attempted analyses. They can also be stored in an archive for analysts to revisit in order to inform a current analytical task, or to retrace the steps taken in a prior situation to understand how a decision or hypothesis originated (Robinson and Weaver, 2006) (Figure 5).

As seen in Figure 5, ReVise records interactions and allows users to examine these artifacts through an overlay on the visualization. Mouse clicks are symbolized with green diamonds, and mouse drags are symbolized with red dots. Interactions can be revisited and visualized to examine how tools and data were used during analysis. Interactions like key-presses and mouse movements are caught and reprojected into an interactive overlay that allows users to visually explore session activity. For example, during a serious snowstorm, emergency managers' analysis sessions could be recorded to keep track of which maps were used, which spatial analysis tools were brought to bear, and what workflows were common. Supervisors might evaluate these patterns after the fact to evaluate the decisions that were made, as well as the tools and data that were most relevant to the problem.

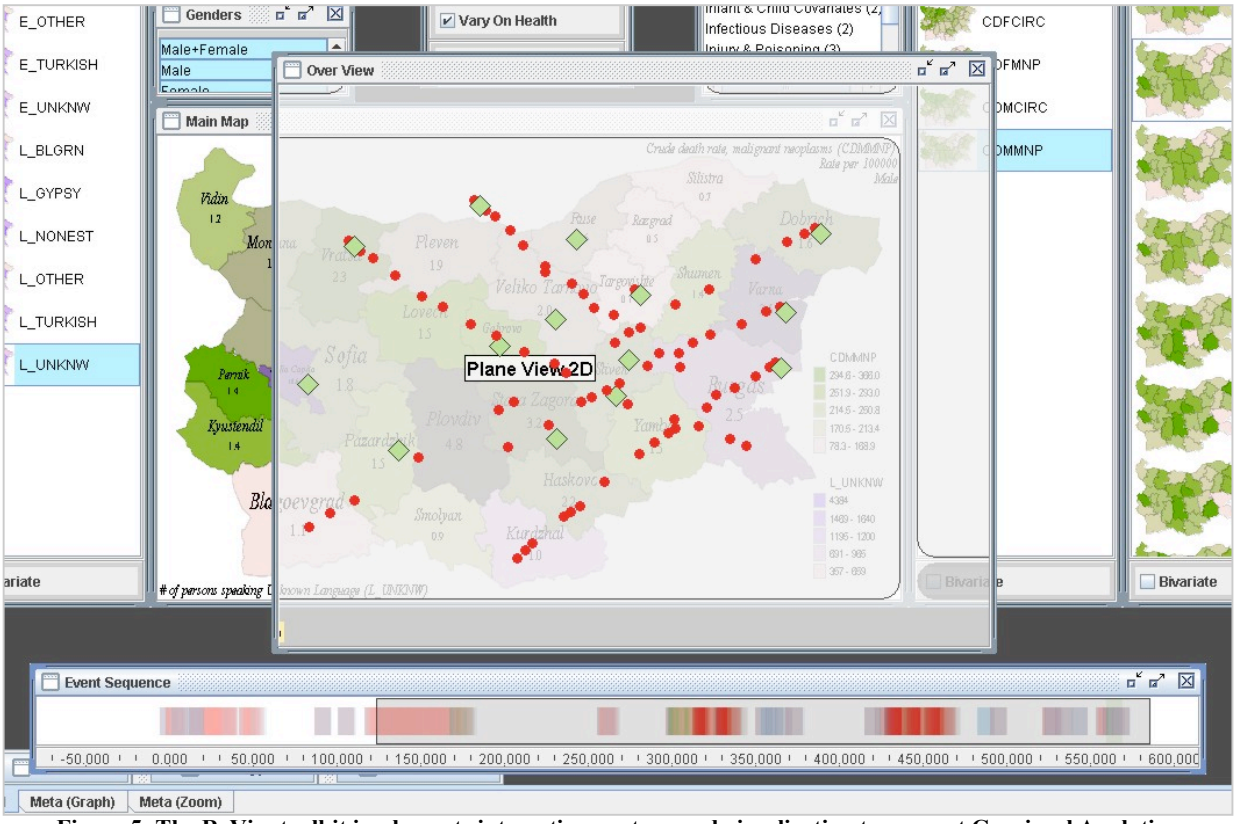

Figure 5: The ReVise toolkit implements interaction capture and visualization to support Geovisual Analytics.

FUTURE RESEARCH

Additional research is needed to explore how Geovisual Analytics can support crisis management activity. Our research group is currently designing a small-world simulation-based experiment using the NeoCities platform (McNeese et al., 2005). NeoCities supports study of coordinated group work with map-based information systems for crisis management.

CONCLUSION

Geovisual Analytics is a new paradigm for how information technologies can be used to process complex geospatial information to facilitate decision making, problem solving, and insight into geographical situations. This paradigm is well suited for a variety of tasks in the crisis management domain. As we have described, Geovisual Analytics can

be used for situation awareness, supporting collaboration, decision making, and evaluating the analytical process itself. Further research in Geovisual Analytics will improve the efficacy of information systems designed for crisis management tasks.

ACKNOWLEDGMENTS

The research reported here has been supported by the National Science Foundation under Grant EIA-0306845. This work is also supported by the National Visualization and Analytics Center, a U.S Department of Homeland Security program operated by the Pacific Northwest National Laboratory (PNNL). PNNL is a U.S. Department of Energy Office of Science laboratory.

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