INFORMATION CONTEXT SUPPORT IN GEOCOLLABORATIVE INTERFACES

By

Eli R. Hooten

Dissertation
Submitted to the Faculty of the
Graduate School of Vanderbilt University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY
in

Computer Science

May, 2014

Nashville, Tennessee

Approved:
Julie A. Adams, Ph.D.
Robert E. Bodenheimer, Ph.D.
Aniruddah Gokhale, Ph.D.
Alexander Klippel, Ph.D.
Timothy P. McNamara, Ph.D.

Copyright ©2014 by Eli R. Hooten
All Rights Reserved

ACKNOWLEDGMENTS

This work would not have been possible without the financial support of the National Defense Science and Engineering Graduate Research Fellowship. Additionally, the support of a Vanderbilt Discover grant awarded in 2012 did not support this work directly, but did allow me to continue the development and evaluation of Feature Sets while participating in other research endeavors.

I am indebted to my research advisor, Dr. Julie A. Adams, for her support and guidance throughout my graduate school career. I am also grateful to Sean T. Hayes, who provided frequent assistance and expert input in all matters analytical and statistical. Each of the members of my Dissertation Committee has provided me extensive personal and professional guidance and taught me a great deal about the rigors of scientific research.

I am grateful to the unending support of my family during this process; their encouragement was crucial to many of my personal and professional accomplishments during my time at Vanderbilt University. I am particularly thankful to my wife Jessica who, as a scientist herself, was a frequent source of inspiration and commiseration.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

Introduction

I.1 Problem Statement

Information context is used to provide information with additional meaning and place that information within the context of the overall environment (Dourish and Bellotti, 1992). Geocollaborative work domains, such as disaster response and community-based urban planning, frequently use digital maps to provide information context (e.g., Buszko et al. 2001; Convertino et al. 2009; Meyer et al. 2011; Monares et al. 2011; Velde et al. 2005; Wu et al. 2009). These domains hinge on collaboration between multiple individuals to reach successful outcomes; therefore, it is crucial to support effective collaboration, communication, and flexibility in order to support proper decision making (Andrienko et al., 2007).

Collaborators in geocollaborative software applications typically perform tasks that are contingent upon knowledge of the region's geography; therefore, digital maps are frequently used in geocollaborative domains. The current state of the art in geocollaborative software applications is limited in the visualization of and interaction with information on the digital map. For example, single information entities are typically represented using a point of interest (POI) placed on the digital map. These POIs can lead to visual clutter and loss of information saliency, which hinders wayfinding, navigation, and orientation (Klippel et al., 2006).

Mobile Shared Workspaces (MSWs) are geocollaborative applications that support loosely-coupled cooperative work in the mobile context (Rodríguez-Covili et al., 2011). MSWs facilitate collaboration between groups of geospatially distributed users and are typically supported using mobile devices, such as tablets and smartphones, and map-based software applications (Neyem et al., 2006; Rodríguez-Covili et al., 2011). MSWs frequently leverage digital maps and POIs (e.g., Meyer et al. 2011; Monares et al. 2011; Neyem et al. 2006; Rodríguez-Covili et al. 2011).

Previous research has established the following general design requirements for MSW applications based on the results of observational field studies (Herskovic et al., 2011; Rodríguez-Covili et al., 2011):

- *Autonomy.* Users must be able to perform meaningful work, even if they are disconnected from the network and/or physically isolated from others.
- *Ad-hoc Communication.* Collaboration must be supported regardless of physical location.
- *Group Awareness.* Each user must be able to obtain an awareness of other group members and their reachability (e.g., online/offline status).

- *Messaging.* Collaborators must be able to contact each other and communication should be facilitated by the MSW.

- *Information Sharing.* The MSW must integrate information to form a coherent picture of the world state and allow users to control information flow.

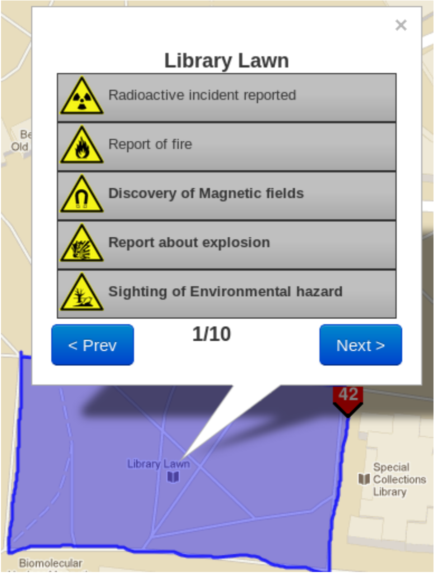
Visualization techniques can support many of the MSW design requirements, particularly *Information Sharing*. Other requirements, such as *Group Awareness*, *Autonomy*, and *Messaging* may be supported through effectively designed visualization techniques. The current state of the art in MSW software applications is limited in the visualization of and interaction with information on a digital map.

Visual clutter can hinder object recognition, negatively impacting a user's ability to search for relevant information (Dobson, 1980; Fredrikson et al., 1999; Humphrey and Adams, 2010; Phillips and Noyez, 1982) and hinder perceptibility and understanding (Delort, 2010; Klippel et al., 2006). Visual clutter can obscure the underlying digital map and increase the difficulty of performing wayfinding and navigation; therefore, important contextual relationships between on-screen information may be lost.

Information context support in the MSW and other geocollaborative application domains is typically fragmented across the interface or is rudimentary; relying on multiple widgets external to the digital map (e.g., Convertino et al. 2005; Wu et al. 2009) or basic visualization techniques (e.g., Buszko et al. 2001; Meyer et al. 2011; Neyem et al. 2006) to communicate context. Multiple widgets can be problematic, particularly on mobile devices, since multiple widget changes may be required in order to accomplish a single task or access required information (Rashid et al., 2012). Research in visual cognition (Auckland et al., 2007; Biederman et al., 1982; Davenport and Potter, 2004), computer vision (Torralba et al., 2006), and cognitive neuroscience (Bar, 2004) shows that providing contextual information to objects can improve recognizability, since objects in the real world are rarely recognized in a vacuum and surrounding information can provide valuable insight into the object itself.

Geocollaborative software applications may be improved by developing novel techniques in two key areas: information visualization and information interaction. This research develops and evaluates Feature Sets, a new method for visualizing and interacting with geospatial information (see Figure I.1). Feature Sets address visual clutter problems inherent to POI-based visualization methods, while leveraging information context to provide additional meaning to displayed information.

POIs present numerous design and interaction issues when placed on a digital map. For example, POIs typically require direct interaction (e.g., clicking or tapping) in order to be selected; therefore, the POI's icon must be large enough to directly select. Ensuring that direct selection is always possible requires thresholding the minimum size of the POI, such that it is always large enough to accurately select. POIs that leverage


Library Lawn

Radioactive incident reported

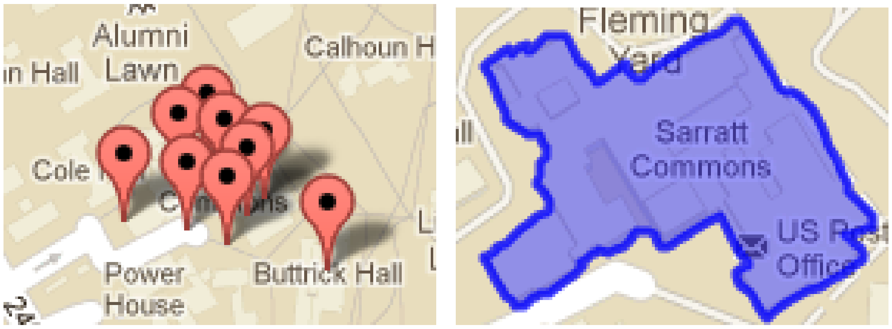
Report of fire

Discovery of Magnetic fields

Report about explosion

Sighting of Environmental hazard

Figure I.1: A Feature Set displaying a subset of the information contained within its blue geospatial area.



(a) POIs

(b) Feature Set

Figure I.2: POIs and Feature Sets representing identical data in the same map region.

iconography must also remain large enough to be clearly visible to the user. At higher zoom levels, POIs that are large enough for selection and/or clear viewing may obstruct significant portions of the digital map on which they appear (see Figure I.2). Methods to overcome the precise selection issue of POIs exist (e.g., Yatani et al. 2008), but these methods rely on an icon that must remain large enough to be salient at any zoom level, potentially causing map occlusion and contributing to visual clutter.

Prior research addresses visual clutter by focusing on three approaches: changing the appearance of data (e.g., Fredrikson et al. 1999; Humphrey and Adams 2010; Wu et al. 2009), spatially distorting the information (e.g., Fuchs and Schumann 2004), and temporally modifying the data by altering size and opacity (Ellis and Dix, 2007; Humphrey and Adams, 2010). These approaches mitigate visual clutter by employing grouping mechanisms that only group information of a single type (e.g., Delort 2010; Fredrikson et al. 1999; Humphrey and Adams 2010; Markerclusterer 2009; Wu et al. 2009). Feature Sets attempt to mitigate visual clutter through domain-specific groupings, such as geospatial location. These groupings are not necessarily contingent upon the type of information being grouped, the information must only possess a shared characteristic inherent to the domain (e.g., geospatial locality).

Prior research has identified the importance of information context in collaborative workspaces (Dourish and Bellotti, 1992). Supporting information context ensures that communicated content possesses the appropriate character to place the information within the context of the overall environment. Feature Sets can be used to provide context for the information they represent. Three different types of information context are supported by Feature Sets: geospatial, temporal, and semantic. Geospatial context is supported by providing geospatial containers for information (i.e., the area of interest), the temporal context is supported through temporal ordering of information contained within a Feature Set, and the semantic context is supported through providing novel methods for filtering and sorting related information within a Feature Set. Through supporting these contexts, Feature Sets provides a usability benefit when compared to POI-based approaches.

Feature Sets provide greater benefits than visual clutter reduction. Feature Sets are geospatial containers that allow for non-type based groupings of information on a digital map that are designed to provide overview information, filtered information, and details on demand. Feature Sets are designed to support information context, which can impart additional meaning to displayed information, improving usability and performance. Additionally, Feature Sets are the first known visualization technique designed specifically to address MSW design guidelines.

The contributions of this work are three-fold. First, types of information context relevant to digital map-based interfaces are defined. Second, the geospatial visualization and interaction technique Feature Sets was developed using these information contexts. Finally, three user evaluations were performed to determine Feature Sets' impact on user performance within a map-based interface. Results obtained from these evaluations are used to discuss the benefits of Feature Sets from a design perspective, and to recommend design guidelines that can be used for the design of future geospatial information visualization and interaction techniques.

CHAPTER II

Background

II.1 Determining Information Context

Geospatial information is difficult to represent, since geographic space is complex, heterogeneous, and vast (Anselin, 1989). Visualized information may be closely coupled to both space and time, rendering it difficult to interpret quickly; therefore, geospatial interfaces must provide analytic-visual support for human reasoning (Andrienko et al., 2011). Information displayed on a map may also be difficult to verbalize, or be described solely by spatio-temporal means (Andrienko et al., 2007); therefore, it is necessary to provide flexible constructs for interpreting data beyond simply a spatial or temporal sense. Geocollaborative systems compound these issues, since these systems must account for multiple actors with potentially varying roles (Andrienko et al., 2007).

Geocollaborative software requires users to obtain knowledge of a geospatial region, the information that is contained therein, and the activities and motivations of other users (e.g, Buszko et al., 2001; Rinner et al., 2005; Rodríguez-Covili et al., 2011). Geocollaborative software applications frequently provide mechanisms to support understanding, typically implemented using multiple widgets (e.g., Monares et al., 2011; Velde et al., 2005; Wu et al., 2009) or novel improvements (e.g., Meyer et al., 2011; Rinner et al., 2005; Wu and Zhang, 2011).

Prior research has determined the importance of information context, which promotes group awareness and shared understanding in collaborative scenarios (Janssen and Bodemer, 2013). Collaborating through shared workspaces can simplify communication of shared information, coordinate activities, and provide group awareness (Gutwin et al., 2008; Nomura et al., 1998). Prior research has shown contextual awareness in shared workspace systems is pivotal to possessing an overall awareness of the collaboration, resulting in improved performance, reduced error, and increased understanding (Carroll et al., 2006; Christiansen and Maglaughlin, 2003). Therefore, ensuring that information context is adequately supported in collaborative systems is critical to performance and task outcomes.

Geocollaborative applications provide a complex domain where problems and information may be distributed among many different sources, but synthesized in one location (i.e., the digital map). Therefore, geocollaborative applications may provide a suitable domain for understanding information context within map-based applications and determining how information context may alleviate common issues with geospatial information visualization.

MSW and geospatial communityware are two active geocollaborative domains. MSWs support loosely-coupled cooperative work in a mobile context (Rodríguez-Covili et al., 2011), while facilitating collaboration between groups of distributed users. Geospatial communityware allows users to reach a consensus regarding community-based tasks and issues (Sidlar and Rinner, 2009). Both domains typically rely on digital maps (e.g, Buszko et al., 2001; Meyer et al., 2011; Monares et al., 2011; Nivala and Sarjakoski, 2003; Sidlar and Rinner, 2009) that assist with wayfinding, navigation, and orientation (Cheverst et al., 2000; Darken and Cevik, 1999; Delort, 2010; Klippel et al., 2006; Nivala and Sarjakoski, 2003; Sarjakoski and Nivala, 2005).

Prior research has produced generalized requirements for the design of MSW applications (see Chapter I.1). Rodríguez-Covili et al. (2011) decomposed MSW application design into a reference architecture through generalizing the results of MSW field studies in construction site management, fire emergency response, and hospital scenarios. The resulting reference architecture was designed to address general MSW software requirements.

Visualization can play a large role in reinforcing all of Rodríguez-Covili et al.'s stated requirements except for *Ad-hoc Communication*, which must be facilitated in order for collaboration to take place. For example, visualization changes can indicate that a user's connectivity to collaborators has been lost. Altering the visualization (see Figure II.1), allows the user to perform autonomous work with the knowledge that a portion of his or her on-screen information is potentially stale or outdated.

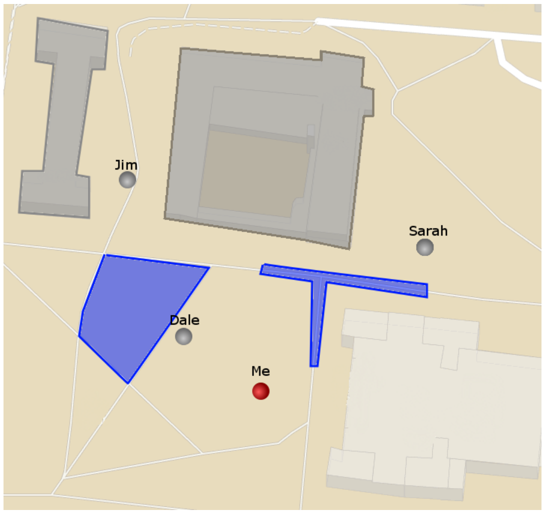
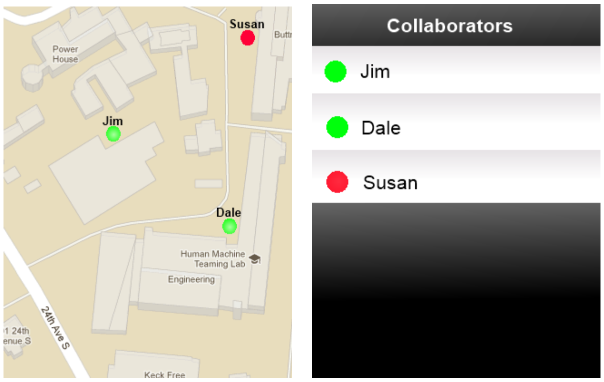


Figure II.1: An MSW visualization indicating a user's connectivity status. Stale information is shown in grayscale. Current information (e.g., information added by the user) is shown in color. The user's location (i.e., the icon labeled "Me" on the map) is shown as a red circle to indicate that he/she is offline.

MSW applications typically rely on standard widgets to fulfill thse MSW design requirements. For example, *Group Awareness* is provided through the use of a contact list (see Figure II.2) that displays each collaborator's connectivity status (i.e., online or offline). The positions of other collaborators, tasks to be



(a) Collaborator Map (b) Collaborator List

Figure II.2: (a) A mobile device visualization using a digital map. The map representation provides connectivity information and the offline user's (i.e., Susan's) last known location. (b) A standard online/offline collaborator list (e.g., Buszko et al., 2001; Meyer et al., 2011; Monares et al., 2011), where green indicates online and red offline.

performed, and points of interest are indicated by a POI placed on a digital map. A text-based chat widget fulfills the *Messaging* requirement. A file browser is used to share certain types of information. Many collaboration applications use a multiple widget approach, both in the MSW (Buszko et al., 2001; Meyer et al., 2011; Monares et al., 2011; Velde et al., 2005) and geospatial communityware (Convertino et al., 2005, 2009; Fredrikson et al., 1999; Kolbe et al., 2003; Wu et al., 2009) domains.

Several widgets may be needed to provide information context in geocollaborative applications (e.g., Buszko et al., 2001; Convertino et al., 2005; Velde et al., 2005). Numerous widgets can be difficult to manage on a mobile device, since multiple widget changes may be required in order to accomplish a single task or access required information (Rashid et al., 2012). Requiring multiple widgets to complete a single task may be problematic on a mobile device, since widgets may need to be displayed full screen in order for the components to be large enough for viewing and selection. Utilizing a single widget that encompasses the needed functionality may be more useful, since attention will not be diverted between multiple widgets and interaction may be simplified. Such a widget can provide information about an on-screen item, its creator, and the means of messaging the creator. Single widgets that aggregate the functionality and information necessary to complete relevant tasks is an approach that is not found with current MSW applications, and may provide a usability benefit. Aggregation can synthesize multiple data sources to reduce the total number of widgets required to support the MSW. For example, a listing of collaborators' connectivity status can be included in the MSW, and the information can be aggregated into a combined visualization (see Figure II.2).

Many software systems have been developed within the geocollaborative software domain, and five particular systems were chosen for analysis. These five systems provide a well-rounded representation of geocollaborative software applications, particularly in terms of information context support. An analysis of the features provided by these five systems resulted in three types of information context these system leverage to mitigate data visualization issues: *geospatial*, *temporal*, and *semantic*. Each of the three types of information context are leveraged by these systems to present geospatial information in unique and convenient ways. The aspects of the five chosen geocollaborative systems that support information context are described below, and the three types of information context are defined as follows:

- *Geospatial.* The meaning imparted by the location of information on the digital map. For example, a POI representing an explosion in an abandoned field may have a very different meaning than an identical POI placed over an occupied building.
- *Temporal.* Time-based information inherent to displayed information (Ellis and Dix, 2007). For example, in an MSW application, if a user adds a POI to the map indicating the presence of smoke, immediately followed by the presence of fire, a collaborator may assume the fire is the cause of the smoke. If the opposite occurs, smoke placed after fire, a collaborator may infer that the fire has been extinguished. The temporal character of each POI provides context necessary for comprehension.
- *Semantic.* The shared characteristics between items that provide greater meaning to each of the related items (Dourish and Chalmers, 1994) or task being performed. These characteristics can be user or scenario defined. For example, a clustering of POIs of the same type (e.g., POIs representing bombs or people) may have more meaning than a single POI of that type, or vice versa.

The ability to provide rudimentary annotations drawn on the map, referred to as "sketching", is a commonly leveraged technique to support information context (e.g., Convertino et al., 2005; Ens et al., 2011; Hopfer and MacEachren, 2007; Meyer et al., 2011; Monares et al., 2011; Ochoa et al., 2011). Sketching is a powerful and flexible mechanism when combined with digital maps. Sketching provides geospatial context by allowing users to leverage underlying geography (e.g., circling a building, sketching a particular route, and emphasizing displayed information elements). Sketching can indicate associations between disparate information items (e.g., drawing an arrow from one item to another, writing free-form text to enhance meaning) and provide semantic context. Sketching also provides the ability to create boundary objects on the map, which help facilitate communication and understanding between collaborators (MacEachren and Brewer, 2004).

The geocollaborative applications developed by Convertino et al. (2005, 2009) and Wu et al. (2009) utilize multiple map viewports to provide semantic and geospatial context. Each collaborator can see a public view of the digital map in one interface panel and a private view in the other (see Figure II.3). A user can create

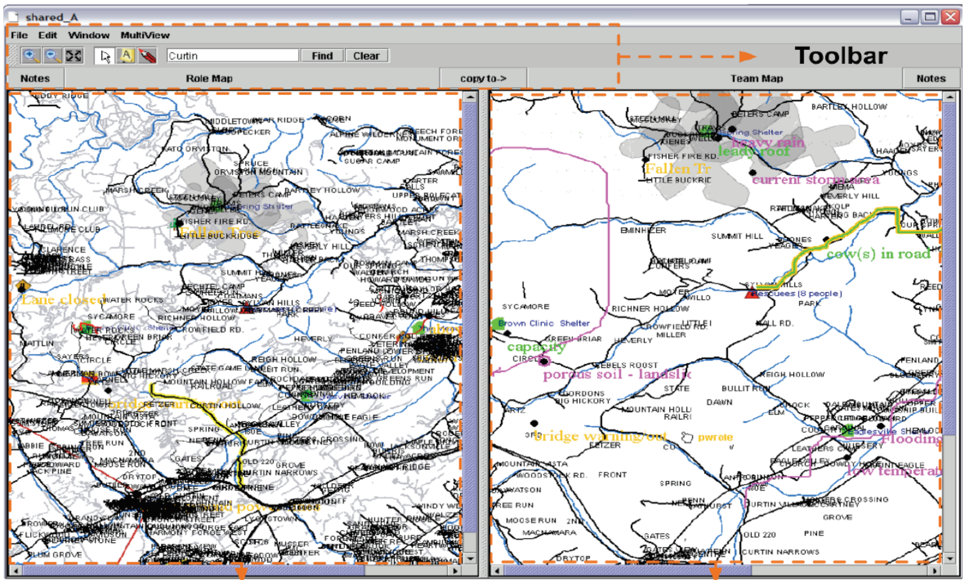


Figure II.3: A multiple viewport application (Convertino et al., 2005), with a public viewport *(left)* and a private viewport *(right)*. The public map is densely cluttered with POIs, whereas the private map has relatively few POIs.

information in the private map that is only viewable by his or herself, while simultaneously viewing and contributing to a public map. Private views can be shared, such that if a user requires that a collaborator view his or her map, the user can invite the collaborator to do so. Multiple viewports provide a clear distinction between public and private data; however, two map views can be space intensive. Due to limited screen real estate on mobile devices, multiple viewports may be inappropriate for the MSW domain. Other issues, such as contention for the control of the shared public viewport (Wu et al., 2009), may also be problematic in MSW scenarios.

Multiple views provide a coarse-grained semantic context by separating public and private information. The public view can also provide *Group Awareness* by displaying information created by other collaborators. Convertino et al.'s (2009) shared viewport approach provides a buddy list and chat tool to support *Group Awareness* and *Messaging*. Wu et al.'s system provides a separate Aggregation Chart widget and an Annotation Browser that aggregates similar information into type-based and chronological groupings; however, their approach does not integrate this information into a single visualization, and multiple widgets will likely be cumbersome on a mobile device.

Wu et al. (2009) developed a geocollaborative application that supported temporal context through an Annotation Browser that aggregates similar information into chronological groupings. An Aggregation Chart that aggregates similarly typed data in a graph, supporting semantic context, was also implemented. Wu et al.'s approach does not integrate information into a single visualization, relying instead on multiple widgets.

	Context		
Design	**Geospatial**	**Temporal**	**Semantic**
Convertino et al. (2005)	POIs, Sketching, Views	*	Sketching
Meyer et al. (2011)	POIs	*	*
Rodríguez-Covili et al. (2011)	POIs, Sketching	Time stamps	Sketching, Relatetd Information
Velde et al. (2005)	POIs, Zooming	Ontology	Ontology
Wu et al. (2009)	POIs, Sketching, Views	Annotation Browser	Sketching, Aggregation Chart

Table II.1: Summary of each discussed method's approach to providing information context. *(∗ Indicates that visualization support was not explicitly stated.)*

An MSW application developed by Rodríguez-Covili et al. (2011) utilizes time stamps associated with each POI. Time stamps are disparate when only associated with single POIs. A user must manually interact with each POI in order to obtain a chronological ordering of events. Velde et al. (2005) developed an MSW that provides temporal context via an ontological database. The database implementation was robust, supporting user-specified queries, but was implemented as a separate widget independent of the digital map.

Zoom levels can be used to facilitate geospatial context through controlling the display based on a user's zoom level (Velde et al., 2005). Zooming assumes that mobile collaborators will work in very specific regions of the map; therefore, each user's visualization is limited to the user's work area. This approach is utilized by the SHARE system (Velde et al., 2005), which ensures privacy, to an extent, by limiting data access and visualization based on the geospatial distribution of the collaborators. Higher-ranking group members can view more of the map and, as such, can access more data than lower-ranking collaborators. Zooming is more space efficient than multiple map views, but may be too limited of an approach. For example, a user may lose context of the overall scenario by being unable to view information that is added to other portions of the map, limiting geospatial context.

Layers overlayed on top of the digital map can implement a type-based approach to information control, and can support semantic context by expressing relationships between displayed information (Chi, 2000; Hooten et al., 2011; Kimelman et al., 1994; Viljoen, 1997). For example, a single layer can represent the information provided by a single group or user, or information of a single type. Through toggling the visibility of multiple layers, users can visualize only the types of data that is relevant to the task being performed. A potential downside is that layers may become difficult to manage if too many layers exist and interaction with each individual layer is required to toggle visibility. Another approach is to provide coarser-grained layering techniques that can quickly alter the visible state of large amounts of information.

Major portions of the five geocollaborative systems discussed in this section incorporate one or more of the three information contexts. Table II.1 summarizes the interface components used in each of the five reviewed geocollaborative applications that support information context.

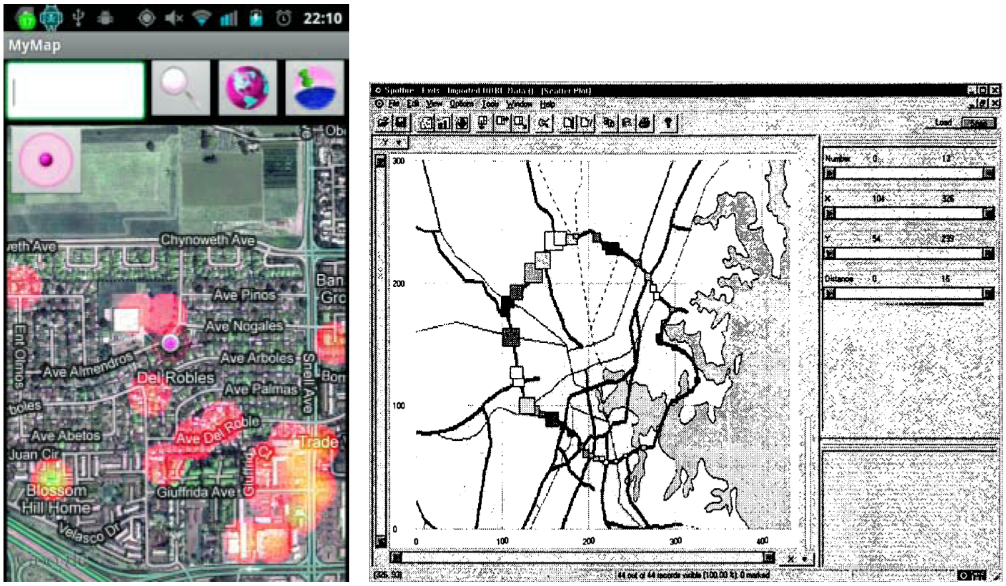
Each of the described systems provides unique methods to create information, disseminate knowledge, and collaborate effectively when using a map-based interface. However, none of the geocollaborative applications discussed in this section integrate the three information context types into a single, unified visualization. Rather, multiple widgets are used, or support is distributed between multiple methods. Each approach uses POIs, which are susceptible to visual clutter, and can negatively impact information context. While these systems provide real-world examples of geocollaborative software applications, they do not necessarily demonstrate truly effective use of information context. Other map based visualization techniques, such as those that are designed to alleviate visual clutter, may provide greater insight into the application of information context for displaying information on a digital map.

II.2 Visual Clutter Reduction Techniques

POIs are the primary means to convey information context on a digital map. POI specification requires placing an icon at a particular location and, in some cases, providing additional information (e.g., text, multimedia). POIs are common in both two-dimensional and three-dimensional digital maps (Löffler et al., 2007; Velde et al., 2005). Domain-specific iconography may provide meaning to the POI (e.g., Humphrey and Adams, 2010; Löffler et al., 2007; Velde et al., 2005; Zhang and Adams, 2011). POIs are nearly ubiquitous information communication tools in geocollaborative applications (Buszko et al., 2001; Convertino et al., 2005; Herskovic et al., 2011; Meyer et al., 2011; Rodríguez-Covili et al., 2011; Velde et al., 2005; Wu et al., 2009), and are the *de facto* standard for visualizing data in many web-based mapping frameworks (Google, 2012; Microsoft, 2012; OpenLayers, 2012).

POIs can cause visual clutter (Fredrikson et al., 1999; Humphrey and Adams, 2010; Rinner et al., 2005; Velde et al., 2005; Wu et al., 2009), which hinders understanding and lowers perceptibility of information (Klippel et al., 2006). General techniques to minimize POI visual clutter fall into three categories: appearance, which alters the look of the data; spatial distortion, which displaces data (Fuchs and Schumann, 2004); and temporal modification (Dragicevic et al., 2011; Ellis and Dix, 2007). Specific visual clutter reduction methods include heat maps (Fisher, 2007; Wu and Zhang, 2011), aggregation (Fredrikson et al., 1999; Markerclusterer, 2009), Markerclusterer (Markerclusterer, 2009), grid and distance based clustering (Google, 2013), and the General Visual Abstraction algorithm (Humphrey and Adams, 2010). Spatial distortion techniques are not applicable to map-based interfaces, since spatial location is typically important in geocollaborative domains; however, appearance altering and temporal modification techniques are applicable.

Appearance altering techniques typically mitigate visual clutter by aggregating on-screen information. The aggregated visualization is usually contingent on a type-based grouping. For example, heat maps reduce visual clutter by exploiting semantic and geospatial context through grouping all collocated items of the same



(a) Heat Map (b) Aggregates

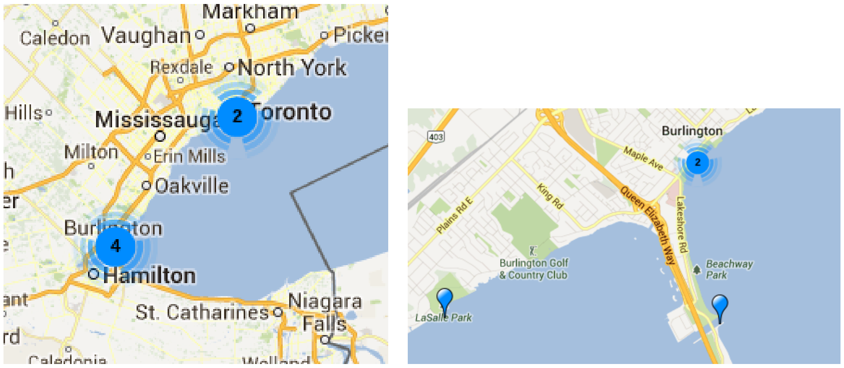
Figure II.4: A visualization of (a) heat maps (Wu and Zhang, 2011) and (b) aggregates (Fredrikson et al., 1999). Both demonstrate a frequency visualization based on item type, where color denotes the frequency of the item's occurrence in a particular geographic region.

type. Heat map visualizations (Wu and Zhang, 2011) have been used to display check-in information from Foursquare (Foursquare, 2011) to show a location's popularity (see Figure II.4a), while aggregates (Fredrikson et al., 1999) were used to display the frequency of motor vehicle accidents on high-traffic roadways (see Figure II.4b).

Heat maps and aggregates reduce visual clutter caused by large groups of close-proximity, similarly-typed POIs. Neither approach accounts for densely-packed arrangements of differently typed items. For example, if heat maps were used to overlay check-ins from Foursquare and Yelp (Yelp!, 2011), the overlapping heat maps can cause visual clutter. Toggle functionality can allow a user to enable/disable specific heat maps (or aggregates), but this approach restricts the user to viewing single item distributions, which limits geospatial context to items of a single type.

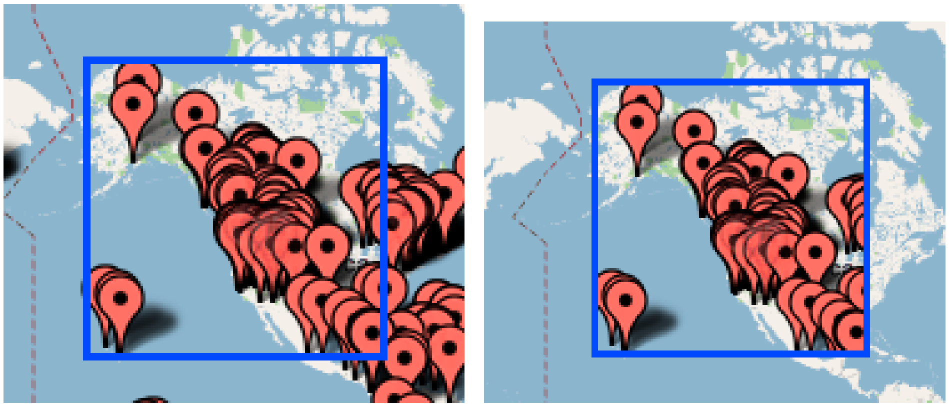
Clustering techniques include grid-based clustering, distance clustering, and MarkerClusterer (Markerclusterer, 2009). Grid-based clustering sections a map into equal sized grids and aggregates all POIs contained within a grid space into a single POI with a number displaying the count of aggregated POIs. The aggregated POI is placed at the center of the grid, an approach that may not accurately describe the data being aggregated, but reduces visual clutter and ensures that overlap of POIs will not occur. Hexagonal-binning dissects the map into hexagons (Field, 2012), and suffers the same limitation as grid-based clustering. Distance-based clustering aggregates POIs based on their distance from a cluster centroid, which is specified algorithmically through iteration of existing POI locations. Clustering is a data grouping mechanism based on geospatial location only.

MarkerClusterer aggregates collocated POIs into a single circular marker visualization, referred to as a cluster, with a count of aggregated POIs displayed. Zooming in on a single cluster separates it into individual clusters, each comprised of portions of the collocated POIs represented by the higher level cluster. MarkerClusterer differs from previously presented clutter reduction methods because it aggregates information based solely on geospatial location. This aggregation technique ensures that visual clutter will never occur, since it is impossible for areas, at any zoom level, to become crowded (see Figures II.5a and II.5b). MarkerClusterer does not visually define the area encompassed by a single cluster; therefore, when zooming in on more than one marker, it can be difficult to determine which POIs belong to which cluster.



(a) MarkerClusterer

(b) MarkerClusterer Zoomed

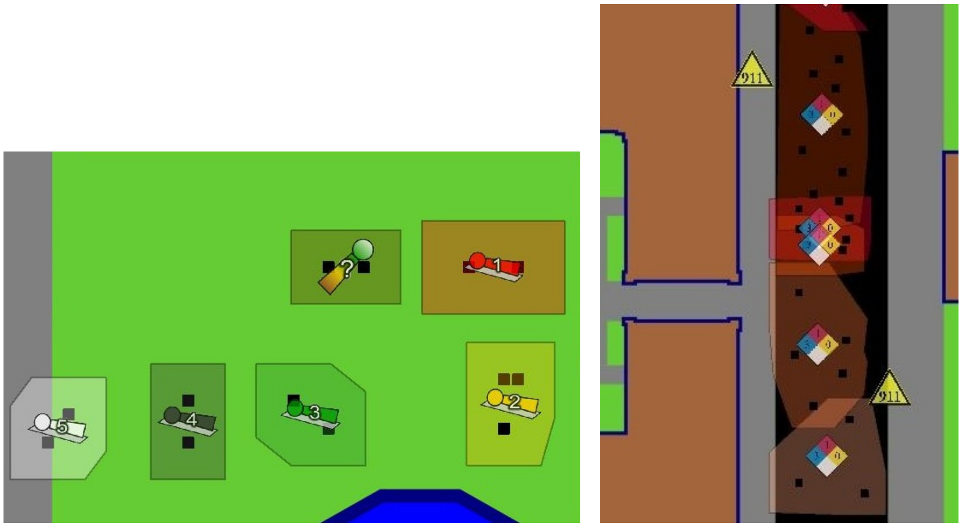


(c) Default View

(d) Viewport Modified

Figure II.5: A Markerclusterer (2009) visualization for Burlington shown in a default view *(a)* and a zoomed in view *(b)*. Zooming in breaks contained POIs into smaller clusters or individual POIs. Zooming also effects visualized information in viewport management techniques *(c)* and *(d)*.

Viewport management limits the display of POIs based on the user's current viewport. As the user zooms out from the current view, new POIs that fall outside of the original viewing area are not displayed (see Figures II.5c and II.5d). This approach prevents additional visual clutter that results from manipulating the



(a) GVA (uncluttered) (b) GVA (cluttered)

Figure II.6: The GVA's type-based grouping showing an uncluttered and cluttered use case (Humphrey and Adams, 2010). The black squares indicate the locations of individual POIs within the group.

map; however, the displayed POIs may still be cluttered. Additionally, if POIs remain a fixed size on screen, greater portions of the map will be obscured as the user zooms out.

The General Visual Abstraction (GVA) algorithm (Humphrey and Adams, 2010) utilizes temporal modification to mitigate visual clutter. The GVA calculates a POI's visual score to form type-based groupings (see Figure II.6a) and uses animation to alter the size and transparency values of on-screen information (Humphrey and Adams, 2010). Several factors affect the visual score, with the most influential being whether or not the user has recently interacted with the POI. Interaction occurs when the mouse cursor hovers over a POI. Grouping occurs when many identically-typed POIs are collocated and have sufficiently low visual scores (see Figure II.6). The GVA augments type-based grouping by exploiting the temporal context, but it does not place items into a chronological ordering.

Each presented visual clutter reduction method leverages at least one type of information context. Heat Maps and Aggregates leverage the geospatial and semantic contexts; however, if many differently-typed POIs are located in the region, these methods may not adequately reduce visual clutter. Markerclusterer leverages only the geospatial context; however, it may still occlude underlying geography, and zooming in on a particular marker in order to reveal the contained POIs is the only means of identifying the specific location of individual POIs. The GVA supports type-based groupings only and does not present a chronological ordering of information, providing temporal context only in terms of item interaction history. Grid based clustering techniques place representative POIs at the center of single grid spaces, removing geospatial context. Distance based clustering only visualizes information at a cluster's centroid, limiting geospatial context.

Viewport techniques limit the on screen display of information, but occlusion can still occur. Clustering and viewport management techniques do not provide temporal or semantic context. While all of the presented methods reduce visual clutter, they only support information context in a limited fashion.

II.3 Map-Based Interfaces and Wayfinding

MSW scenarios are typically undertaken in real-world environments, where collaborators may have a need to determine routes between various locations within the environment by wayfinding. Wayfinding is defined as the process of determining and following a path or route between an origin and a destination (Golledge, 1999). Wayfinding is the purposeful navigation between geospatial locations and is a prominent application of spatial cognition.

Wayfinding is subdivided into two categories: unaided wayfinding, which is navigation without the use of a map or other assistive device; and aided wayfinding, which comprises the use of maps, signs, and navigation assistants (Wiener et al., 2009). Maps are intended to provide survey knowledge and facilitate the creation of mental representations of an environment (Montello and Freundschuh, 1995). Survey knowledge provides the spatial awareness necessary to plan new routes, shortcuts, and detours (Klippel et al., 2010). The ability to bolster survey knowledge is crucial to MSW scenarios, especially those occurring in highly dynamic environments, where external factors may cause survey information to change over time.

Prior wayfinding research has determined that it is beneficial to make users aware of their location through a mobile interface (e.g., Klippel et al., 2006, 2010; Nivala and Sarjakoski, 2003). This awareness can be facilitated via an icon on the interface's map that updates to reflect the changing position of the user (Darken and Cevik, 1999). A user's location can be determined easily through the use of a global positioning system, WIFI networks (Sammarco et al., 2008), accelerometers (Bylemans et al., 2009), and radio frequency identification tags (Hekimian-Williams et al., 2010).

Digital maps that reflect the user's current location are generally referred to as You-Are-Here (YAH) maps (Levine, 1982). YAH maps are intended to provide assistance with route planning, navigation, and orientation by allowing a user to instantly determine his or her location with respect to the environment (see Figure II.7). YAH maps can also be used to indicate the position of other agents in virtual and real worlds. For example, in robot control scenarios, it is common to display a YAH map that indicates the current position of the robot in relation to the mapped area (e.g., Drury et al., 2007; Hayes et al., 2010; Nielsen and Goodrich, 2006). While not explicitly stated in the literature, numerous MSW applications utilize the YAH map to provide survey knowledge to mobile, distributed users (e.g., Buszko et al., 2001; Löffler et al., 2007; Monares et al., 2011; Rodríguez-Covili et al., 2011).

Previous work has developed the following design criteria for effective YAH map design (Klippel et al.,

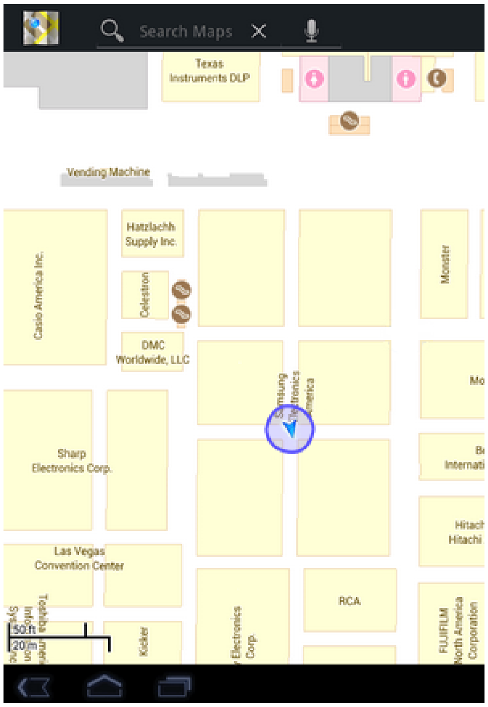


Figure II.7: A digital YAH map (Klippel et al., 2006) showing the user's position and orientation as an arrow. The circle around the arrow indicates uncertainty in the location measurement.

2006):

- *Completeness*: All information that is necessary to complete the given task must be presented on the map.
- *Perceptibility, syntactic clarity, visual clutter*: All task-relevant items on the map must be easily perceptible and identifiable, with visual clutter being the biggest threat to perceptibility.
- *Semantic clarity*: All symbols must be imbued with meaning, and be self-explanatory.
- *Pragmatics*: A good design must take into account how, when, and where information is used.

These criteria can, at times, conflict with one another and result in usability problems. For example, completeness and perceptibility may not be possible if a large quantity of information must be displayed to ensure completeness, since a large amount of displayed information may result in visual clutter. Achieving full semantic clarity can also be a hindrance, since providing unique symbols for a multitude of information types may result in information overload.

The link between visual clutter and wayfinding is important, and previous research has shown that map readers may be unable to ignore unwanted or irrelevant graphic information (Dobson, 1980). Therefore, MSW applications that display large amounts of information on the digital map may hinder a user's ability to wayfind. It is important to provide methods to reduce visual clutter, such that wayfinding can be improved in dynamic scenarios (e.g., disaster response and construction management).

Designing YAH maps for mobile devices can result in even greater design challenges. Early YAH maps were typically large stationary maps that displayed relevant information from the perspective of the particular map's location in the environment (Levine, 1982). Static YAH maps may only need to provide for a small subset of possible tasks that are achievable with respect to the user's current location. YAH maps utilized on mobile devices are carried with the user and are subject to the changing goals of users and environmental conditions; therefore, mobile YAH maps must account for a larger possibility of use cases.

Prior research has classified the wayfinding challenges that occur when performing assisted navigation (Owens and Brewster, 2011). Owens and Brewster's wayfinding classification categorizes errors into three broad sources: the map being used, the navigator, and the environment. Map errors are typically related to misrepresentations of information on the map (e.g., a path being omitted, obscured, or misrepresented). Navigation errors are typically related to miscues in judgment, hesitation, or disorientation. Environmental errors arise when the environment has changed and the map no longer reflects the current environmental state.

A mobile YAH map can remedy environmental errors by providing updated information concerning the environment (e.g., indicating closed roads and blocked paths); however, care must be taken to prevent map errors when using a digital YAH map on a mobile device. For example, information items placed on the screen may obscure relevant paths. Information relevant to a path (e.g., indication that a path is blocked or inaccessible) may also be obscured by other information. If added information is not salient enough, navigation errors may lead to reduced wayfinding performance. Therefore, methods that reduce visual clutter on a digital map may also improve wayfinding ability by reducing navigation errors.

Many MSW applications and frameworks implement YAH maps to provide localization information to the user and to other collaborators (e.g., Buszko et al., 2001; Löffler et al., 2007; Monares et al., 2011; Rodríguez-Covili et al., 2011). Previous research in the design of mobile guides also emphasizes the importance of location awareness in mobile map-based applications (Nivala and Sarjakoski, 2003); however, conflicting opinions exist as to whether or not localization information is beneficial in mobile collaboration scenarios. Nova et al. (2006) utilized location awareness in a collaborative game and determined that when sharing location information between users, task performance did not improve. The authors also stated that users became much more passive when localization information was provided. Ultimately, the authors concluded that by not broadcasting location information, participants were forced to communicate more often, leading to greater communication of relevant information.

Prior research has determined that the use of a mobile device for navigation can discourage engagement and degrade spatial knowledge acquisition, thus hindering the development of survey knowledge necessary for wayfinding (Parush et al., 2007). Mobile navigation systems can excel at providing route knowledge between distinct locations, but may fail at effectively developing survey knowledge (Parush et al., 2007). Mobile navigation systems may remove humans from the loop, providing an automated means of route discovery that requires little cognitive effort. Map-based MSW applications often attempt to develop a user's survey knowledge and spatial awareness; therefore, a higher level of user engagement may be necessary than that which is typically utilized in mobile navigation systems.

Despite the findings of Nova et al. (2006) and Parush et al. (2007), the pervasive use of YAH maps in other MSW applications supports the notion that YAH maps are generally beneficial for mobile collaboration, but the benefits of utilizing location awareness and the YAH map may be domain dependent. For example, the task devised by Nova et al. was a relatively straightforward search-based task that may not have required location awareness to be carried out successfully. As task difficulty increases; however, the need for location awareness may increase, lending validity of the use of the YAH map in more dynamic domains. A highly dynamic scenario may also increase user engagement, mitigating one of the key issues in developing survey knowledge (Parush et al., 2007).

II.4 Evaluation Techniques

II.4.1 Tasks for Map-Based Application Evaluations

Prior research has developed navigation tasks that can be used to quantitatively evaluate a user's level of survey knowledge, both when using a map and when navigating an environment unassisted. These tasks fall into two distinct categories: searching and exploration. Example tasks include (Darken and Cevik, 1999):

- *Targeted Search*: A search task where the desired target is indicated on a map.
- *Primed Search*: A search task where the target's location is given, but the target is not shown on the map. The search is presumed to be non-exhaustive.
- *Naive Search*: A search task where no knowledge of the target's location is provided, implying an exhaustive search.
- *Exploration*: A general wayfinding task in which there is no specific target. A user may be asked to explore an area and report any interesting items that were found.

These task types provide an adequate starting point for defining domain-specific search and wayfinding tasks when using digital maps. Darken and Cevik (1999) implemented each of the four task types in order to compare forward-up and north-up virtual map displays. These task types were also used effectively to study wayfinding in large virtual worlds (Darken and Cevik, 1999; Darken and Sibert, 1996) and can be modified for MSW scenarios. For example, a primed search can be accomplished by tasking the user with finding an item on the map within an indicated region (e.g., a city block, a large structure). Naive search can be accomplished by tasking a user with finding a particular named target on a map (e.g., a particular building or a POI representing a particular event). An exploration task can ask the user to scan a certain area and report any items of interest that may be indicated by POIs on the map. Targeted search is unnecessary, since all other tasks require finding a target on the map. Wayfinding can augment these tasks by requiring users to navigate to particular items of interest in the real world or guide simulated agents to destinations via the mobile interface.

Prior research has developed general strategies for testing map reading comprehension under the effects of visual clutter. Phillips and Noyez (1982) conducted one of the first map-based visual clutter evaluations using geological survey maps, and developed several questions to evaluate the effect of visual clutter. These questions can be categorized into two basic types: pointed questions and general questions. Pointed questions related to satisfying specific queries, such as determining the location of rivers and roads on the map. General questions were phrased as timed true/false questions that required a general survey of the map. For example, a general question asked participants to determine whether or not limestone rock formations ever occurred at greater than 305 meters on the presented map. General questions require a more exhaustive search of the map in order to determine general environmental characteristics. Pointed questions typically involve finding a number of a particular type of item. Many of Phillips and Noyez's questions were timed; however, the authors did not provide a justification of the time intervals used, indicating that the intervals were perhaps chosen by experimentation and were task specific.

General and pointed questions can be adapted to a mobile YAH map used in an MSW scenario. Pointed questions can ask about items of importance on the map. General questions can task the user with developing a higher-level understanding of the scenario by making connections between items present on the map. For example, in a first response scenario, a general question may ask if a building is likely to catch fire in the future. The participant must determine if items representing fire reports are in close proximity to the building in order to determine if a fire may spread to the particular building. Such a question may require more cognitive effort than simply finding a particular piece of information on the map.

II.4.2 Situation Awareness Measurement for Map-Based Application Evaluations

Situation awareness (SA) measurements provide another means to evaluate the effectiveness of digital map-based software applications. Many formal definitions of SA exist (e.g., Dominguez 1994; Fracker 1988; Sarter and Woods 1991); however, all definitions typically pertain to one's ability to understand an environment and its actors in order to carry out the appropriate actions within it. The most commonly accepted definition, provided by Endsley (1988), defines SA as the perception of environmental elements, the comprehension of their meaning, and the projection of the elements' status in the near future.

The theoretical model of SA is a framework comprised of three levels. These three levels comprise the perception of information, comprehension, and projection (Endsley, 1995). SA is thought to be a product of the process of acquiring external information and intergrating that information with working and long-term memory to form a mental model of the environment (Endsley, 2000). The three levels of SA conceptualize this process and are defined as follows:

- *Level I: Perception.* Perceiving the status, attributes, and dynamics of relevant elements in the environment. Level I SA is comprised primarily of monitoring and recognition.
- *Level II: Comprehension.* Synthesizing disjoint elements of Level I SA into a coherent state of the environment. Achieving Level II SA typically requires pattern recognition, interpretation, and evaluation of the environment.
- *Level III: Projection.* Projecting future actions of the elements in the environment. Level III SA is achieved through obtaining knowledge of the state of elements in the environment and their status to such a degree that future actions can be predicted with accuracy, which requires acquiring Level I and II SA.

SA measurement is typically utilized in domains that are dynamic and information dense, may result in high cognitive workload, domain problems are ill-structured, and tasks are subject to time constraints (Pew, 2000; Uhlarik and Comerford, 2002). SA as a framework is a complex, but relatively well-defined topic (Dominguez, 1994; Endsley, 1988, 1995; Endsley and Garland, 2000; Fracker, 1988)) and has been applied in a number of application domains (e.g., Drury et al., 2007; Humphrey and Adams, 2010; Matthews and Beal, 2002; McGuinness and Foy, 2000; Regal et al., 1988; Vidulich and Hughes, 1991). An in-depth presentation of SA is beyond the scope of this dissertation.

Prior research has studied SA using map-based interfaces, resulting in the development of an SA assessment technique, LASSO, based on user utterances (Drury et al., 2007). This technique requires users to discuss their thought processes aloud while performing tasks, which may not be straightforward or ideal depending on the task. Drury et al. recommend using LASSO when performing within-subjects experimental designs to mitigate the effect of participants' differing amount of willingness to verbalize internal thought processes during trials (Drury et al., 2007). This method is not necessarily reliable, since numerous other confounding factors may be present, such as fatigue, increased concentration, and fluctuating levels of participant engagement during a particular trial, etc.

More generalized SA assessment methods exist outside of the realm of map-based applications. These methods fall primarily into three categories: implicit, explicit, and subjective (Hjelmfelt and Pokrant, 1998). Within each of these methods, numerous evaluation techniques and metrics can exist (see Gawron, 2008; Salmon et al., 2006, 2007 for more comprehensive reviews), the discussion will focus on representative measurement techniques from each of the above three categores.

Explicit techniques typically consist of interrupting the participant and requiring him/her to answer questions related to SA. The Situation Awareness Global Assessment Technique (SAGAT) is an objective, explicit SA measurement technique (Endsley, 1995). Explicit techniques are typically disruptive, requiring the user to halt the task in order to assess SA. Explicit techniques also may not effectively measure SA, but rather the participant's ability to simply recall information (Sarter and Woods, 1991). Explicit techniques can also fall victim to erroneous measures due to inaccurate participant beliefs (i.e., false understanding) and the decay of information (Fracker and Vidulich, 1991).

Subjective techniques require the participant to subjectively rate their own SA of a task after completion. An example of a subjective SA measurement method is the Situation Awareness Rating Technique (SART) (Endsley et al., 1998; Taylor and Selcon, 1990), which has been applied to map-based applications (Humphrey and Adams, 2010). Subjective techniques benefit from being easy to administer as post-hoc self-assessment tests (Taylor, 1990) and are well-suited to comparative system design evaluations (Selcon et al., 1991); however, subjective techniques rely on self-assessed ratings, and may be unreliable (Gawron, 2008).

Implicit techniques require deriving SA from task performance (Drury et al., 2007). An example of an implicit measurement technique is *mini-sitreps* (McGuinness and Ebbage, 2002). This technique uses customized, brief, objective situation awareness reports to provide an objective analysis of a participant's current understanding of the situation. *Mini-sitreps* utilizes probes that require concrete responses (e.g., the position of items in the environment, assessment of intent, and deviations from the original plan). *Mini-sitreps*, like all implicit techniques, can be problematic, since SA is not necessarily the sole contributor to task performance (Drury et al., 2007).

Real-time measurement techniques can provide objective measures of SA (Durso et al., 1999; Salmon et al., 2006), and have been applied to map-based applications in prior research (e.g., Humphrey, 2009; Zhang and Adams, 2011). The fundamental principle behind real-time SA centers on information reuse, with the assumption that SA has improved if information can be recalled (or rediscovered) more quickly by a participant than that information's initial discovery (Durso et al., 1999). The situation present assessment method (SPAM) is a real-time SA measurement technique first developed for air traffic control scenarios that uses query response time to objectively determine SA. Prior research determined that real-time probes are applicable when participant interruption is not desired (Jones and Endsley, 2000; Loft et al., 2013). One potential drawback of real-time SA assessment is that probes cannot be decoupled from the tasks being performed, thus workload measurements may not be accurate (Durso et al., 1999). Real-time SA measurement cannot be reliably coupled with workload measurement (Salmon et al., 2006), but if workload assessment is not required, real-time SA measurement is a worthwhile technique for assessing SA.

II.5 Summary

This chapter has investigated the role of information context in geocollaborative application design (see Chapter II.1) and demonstrated that, while information context is supported (see Table II.1), this support is incomplete and/or accomplished via multiple widgets that may divert attention and hinder usability (Rashid et al., 2012). Visual clutter reduction techniques that leverage information context were also discussed, but many of these techniques do not support all three types of information context efficiently using one unifying visualization method.

Prior research has developed tasks that can be used to evaluate the usability of a map-based application (Darken and Cevik, 1999; Darken and Sibert, 1996), and the impact of visual clutter on these applications (Phillips and Noyez, 1982). Situation awareness has also been evaluated for digital maps, and real-time situation awareness probing techniques (e.g., (Durso et al., 1999)) may prove useful in assessing situation awareness in map-based applications.

Feature Sets have been designed to address the shortfalls of previous geocollaborative applications and visualization techniques by supporting all three types of information context and supporting MSW design requirements. Subsequent chapters will serve to introduce, define, and evaluate Feature Sets.

CHAPTER III

Feature Sets Design and Implementation

III.1 Introduction

Feature Sets are visual containers that abstract POIs to areas of interest and group information based on geospatial location. Feature Sets were designed upon the core visualization concepts of providing information overviews, filtered information, and in-depth details on demand (Shneiderman, 1996). Feature Sets integrate multiple levels of detail within the same representation, which may be beneficial to user understanding (Keahey, 1998). Feature Sets' primary objective is to support the geospatial, temporal, and semantic contexts, while reducing visual clutter.

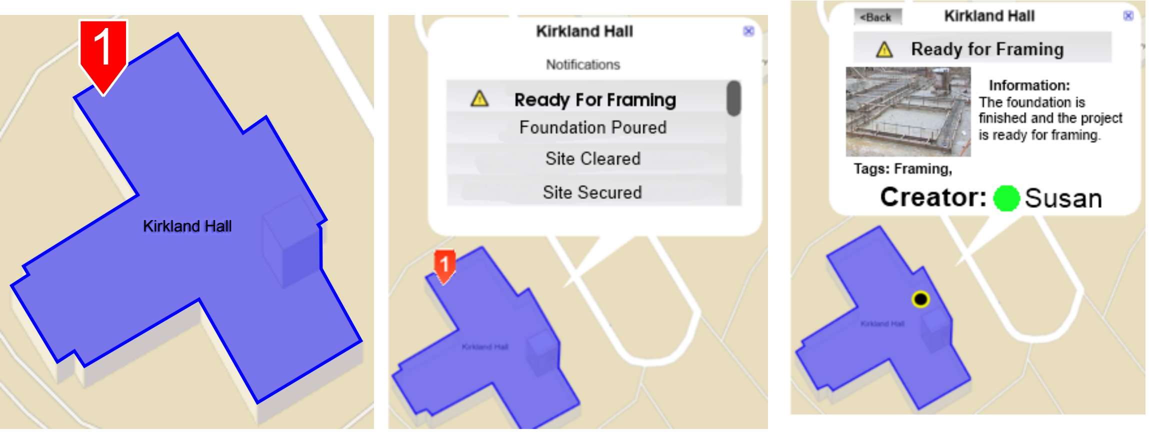
III.2 Information Grouping and Display

A Feature Set is a geospatial map region (e.g., a building, a road, a portion of wilderness) that can be used as a container to store information relevant to that region. A Feature Set abstracts the notion of POIs and can store information of different types related to the area. Since information added to a Feature Set can encompass more than a single POI (i.e., the information can be pertinent to the entire area), added information is referred to as an *information item*, or simply an *item*.

Feature Sets provide overview knowledge and support geospatial context by placing information into geospatially-related groups. Feature Sets tie information to the underlying geography, reducing the need for on-screen information to overlap. Newly added information can be placed directly into an existing Feature Set. A Feature Set's detailed information is accessed by tapping or clicking on the Feature Set (see Figure III.1).

A Feature Set's shape indicates the geospatial region associated with the Feature Set. When a Feature Set is selected (i.e., tapped or clicked), it enters the expanded state, that displays a chronological listing of the contained items (see Figure III.1b). The Feature Set enters the details state when an item is selected from the expanded view's item list (see Figure III.1c).

Information items are displayed in a chronologically ordered list in a Feature Set's expanded state (see Figure III.1b); with the newest item appearing at the top of the list. Chronological ordering provides a temporal context to the created information. Users can page through the item list to gain a temporal understanding of events that have occurred within the Feature Set. POI-based approaches, by default, do not support the temporal context, since no chronological ordering is used. POI-based approaches may also add information to the map directly on top of or nearby other information items, causing visual clutter. Presenting items in an



The foundation is finished and the project is ready for framing.

(a) Overview

(b) Expanded

(c) Detail view with creator name and online/offline status.

Figure III.1: The three visualization states of a Feature Sets when placed on a digital map. The creator name in (c) can be used as an interaction element to access messaging functionality.

ordered list reduces visual clutter by categorizing collocated information.

The detail state of a Feature Set provides detailed information for a single information item within the Feature Set (see Figure III.1c). The detail state can display an image or other media, such as video thumbnails, associated with the information item, in addition to the item's text description. Information regarding the creator of the item, such as the creator's name and connectivity status, is also displayed (see Figure III.1c). Further, the details state displays tags that provide classification for the information item and are beneficial for use as search keywords (see Chapter III.5 for a discussion of information tags).

Along with information context support, Feature Sets are designed to reinforce many of the previously mentioned MSW design requirements (see Chapter II.1). For example, *Messaging* can be provided by allowing the user to message the creator of the item through a shortcut within the item view (e.g., selecting the item creator's name in Figure III.1c). *Group Awareness* is supported by displaying the item creator's connectivity status within the item view. *Information Sharing* is facilitated by aggregating collocated information from multiple collaborators and providing a meaningful summary of the information in one convenient location, the Feature Set. Also, since information items and Feature Sets can be created by a single user, *Autonomy* is supported as the user can continue to add information items and Feature Sets even if network connectivity to the rest of the group is lost. If network connectivity is lost, Feature Sets become gray in color, to indicate a network connection is not present and displayed information may be stale (see Figure II.1). Since many of the MSW design requirements are supported, Feature Sets may be an applicable visualization technique for MSW applications.

III.3 Salient Notification

Feature Sets provide salient information updates to the user at the overview and expanded visualization states via notification indicators. Notification indicators are icons associated with each Feature Set that clearly display the number of items within the Feature Set the user has yet to view (see Figure III.1a). A notification indicator's count increases as items are added or modified within the Feature Set and decreases as items are viewed. When no new or modified information is present, the notification indicator is not visible. The expanded view displays unviewed information using boldface text in the Feature Set's information items list (see Figure III.1b). The use of boldface text visually distinguishes new or modified information items and alerts users to new information in a manner similar to the appearance of new e-mail indicators in an e-mail inbox.

Notification indicators can support *Information Sharing* in collaborative scenarios by alerting users to information that has been added or modified by other collaborators. Notification indicators remove the need to search for new information within Feature Sets without first knowing whether or not information has been updated within a Feature Set. Notification indicators have been designed to increase the discoverability of newly added information, providing a temporal context to individual Feature Sets.

Compared to POIs, notification indicators provide a more salient alternative to representing new information. When using a POI-based approach, new information is added to the map via adding a new POI or altering a POI that currently exists. Even if the POI is altered (e.g., highlighted, increased in size), such that the new information is more apparent, the POI can still be difficult to find if an area is visually cluttered. Feature Sets reduce visual clutter and provide information update knowledge via the notification indicator.

III.4 Feature Set Creation and Interaction

Feature Set creation is facilitated through sketching, which allows the user to draw any abstract shape to represent a Feature Set (see Figure III.2). Sketching is particularly useful for Feature Sets that represent abstract ideas or locations. For example, if a collaborator in an emergency response scenario finds a number of victims at the site of an explosion, the collaborator can draw a Feature Set that roughly encompasses the encountered victims. If a single item is created in an area with no Feature Sets nearby, a Feature Set can be automatically created to encompass it and the user can be prompted to provide a geospatial area for the item via sketching. If an item is created near more than one Feature Set, the user can select the Feature Set to which the newly created item belongs, or create a new Feature Set entirely. Utilizing drawing for Feature Set creation leverages common input mechanisms (e.g., mouse, stylus, finger) and provides the ability to create complex shapes quickly.

Feature Sets are designed to support unimanual interaction, making the technique suitable for use on

(a) Drawing a Feature Set using a finger.

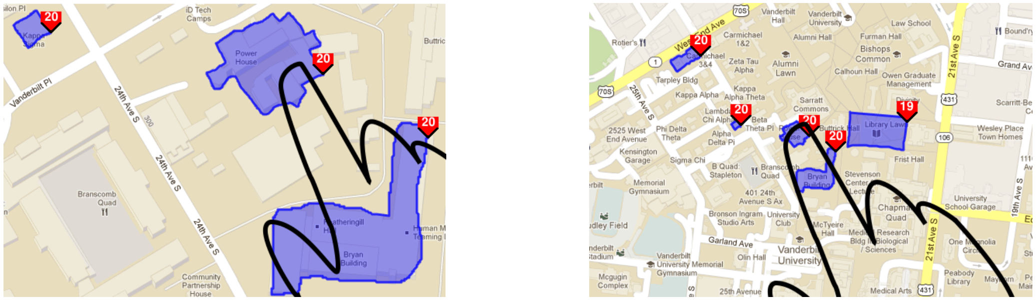
(b) The Feature Set's completed shape

Figure III.2: Feature Set creation as facilitated by sketching.

mobile devices. Unimanual interaction is preferable in MSW domains, since users are intended to be active in an environment and utilizing a mobile device. Bimanual interaction is not practical in MSW scenarios since one hand may be dedicated to supporting the mobile device; therefore, Feature Set creation and visual state changes can be accomplished using a single finger: a user taps a Feature Set to enter its expanded state, users can revert an expanded Feature Set to the overview state by tapping on the expanded Feature Set, and selection of individual information items in the expanded view is facilitated via tapping on the item of interest. A user can transition from the details state to the expanded state via a single tap on a back button that is displayed while in the details state (see Figure III.1c), and the overview state can be accessed by closing and reopening the Feature Set. The interaction design ensures that all levels of information (e.g., overview, expanded, details) are no more than two tap interactions from any other level.

Feature Sets are at a disadvantage from an interaction standpoint when compared to viewing the information of a single POI, since the information contained by a single POI can be accessed via a single interaction (i.e., tap or click). However, when a group of POIs are present, as many selections as POIs in the group may be required to find a particular item. Feature Sets, on the other hand, impose a much smaller upper limit on the number of interactions required to find a particular item by providing information in a sorted list and clearly indicating the presence of new information.

Another interaction disadvantage of Feature Sets is that they are inherently tied to the geography of the map. The Feature Set size will change as a user alters the map's zoom level, unlike POIs which typically retain the same size regardless of zoom level. This disadvantage is particularly problematic if the user zooms out a large distance (see Figure III.3). Feature Sets' reliance on the underlying geography to form their shape results in reduced visual clutter, but can introduce selection difficulties at higher zoom levels where Feature



(a) Low zoom level (b) High zoom level

Figure III.3: Selection of the same Feature Set demonstrated at low and high zoom levels. Selection of a Feature Set may become more difficult as zoom level increases, particularly when using touch interaction.

Sets may become too small to accurately select.

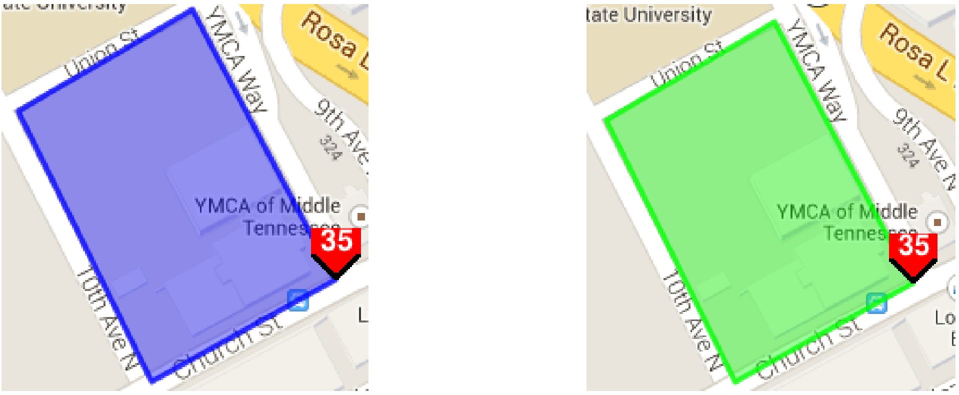
III.5 Information Highlighting

Feature Sets have been designed to reduce visual clutter; however, a large number of on-screen Feature Sets may cause interaction difficulties and cluttering. Even if a large number of Feature Sets are not displayed, reducing the amount of information a user needs to search in order to complete a task may improve usability. Feature Sets support a highlighting mechanism to allow users to emphasize information that may be important to the task at hand.

Emphasis is achieved via highlighting on-screen information as the result of user search queries. Information highlighting relies on user-supplied meta-data that is provided upon the creation of information items. This meta-data currently takes the form of tags, single words or short phrases that can be used to classify each information item. For example, in a construction management scenario, a user can create an information item that represents a request for additional workers at a site. That information item can be tagged with “worker” and “request”, such that it will be visible if the user searches for either or both tags later.

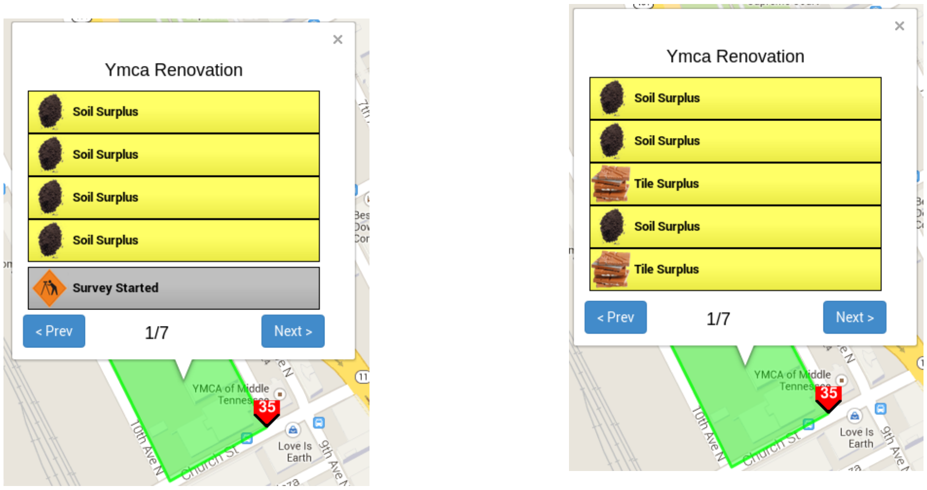
Highlighting impacts both Feature Sets and the items they contain. Feature Sets containing information that matches a search query experience a color change (see Figure III.4b). Information items that match a search query are moved to the top of the item list in the expanded of view of their parent Feature Set and are highlighted (see Figure III.4c). If information of multiple types matches the user’s search query, all matching items are moved to the top of item list and are highlighted (see Figure III.4d). Highlighted information items remain sorted temporally with respect to all other highlighted items in the Feature Set.

Highlighting can be accomplished through numerous methods. For example, a sorted list of allows users to choose relevant tags from a list, or type in tag names directly using a text field (see Figure III.5a). The ability to type in a search tag name is convenient if there are many potential tags from which to choose. An



(a) A Feature Set's default state

(b) A Feature Set's highlighted state



(c) Highlighted information in the expanded view.

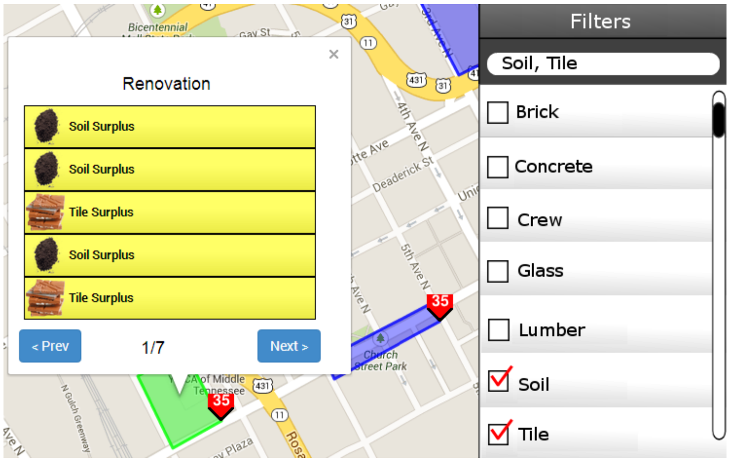
(d) An expanded view showing highlighting on two different types of information items, soil and tile.

Figure III.4: The four visual states of a Feature Set under the influence of search result highlighting. (a) A Feature Set not impacted by highlighting, (b) A highlighted Feature Set, (c) The expanded view with items of a single type highlighted, and (d) An expanded view demonstrating highlighting on two different types of items. Highlighting occurs based on search terms provided by the user.

alphabetically sorted button group (see Figure III.5b) may be preferred when there are fewer (i.e., less than ten) item types (Microsoft, 2014), since selecting a single button is arguably more efficient than text entry or scrolling a list to find the appropriate tag.

Figure III.5b also demonstrates the use of multiple button groups to highlight information based on differing levels of granularity. For example, in a construction management scenario, a user may create information items representing both the need for (i.e., Requests) and the excess of (i.e., Surplus) building materials. This additional tag level refines a search even further (e.g., Brick Requests as opposed to all Brick information items).

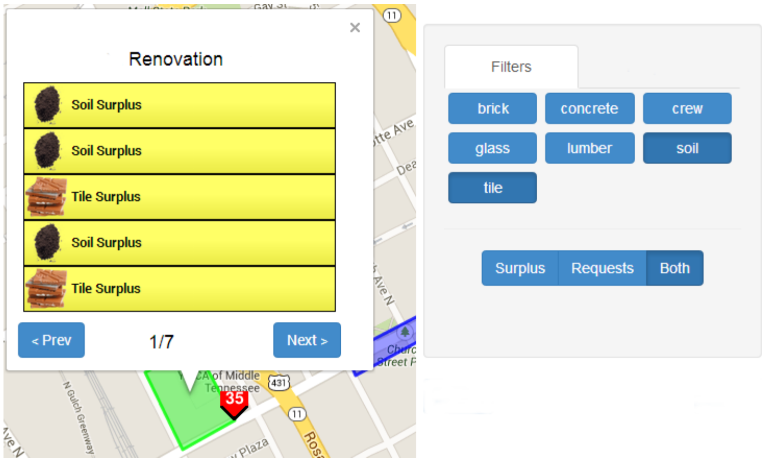
Highlighting is intended to primarily support the semantic information context, and facilitate the rapid discovery of information. Searching via tags can circumvent visual clutter by minimizing the need to search



Soil, Tile

☐ Brick
☐ Concrete
☐ Crew
☐ Glass
☐ Lumber
☑ Soil
☑ Tile

(a) Highlighting facilitated using a sorted list and search bar for text entry.



(b) Highlighting facilitated using a button group. This represenatation demonstrates highlighting at two different levels of granularity.

Figure III.5: Two different approaches for selecting tags: (a) a sorted list and search bar or (b) a button group.

the digital map's entire contents. Tags also provide an extensible method by which to organize data, and in appropriate domains, default tags can minimize the user's need to type new tags for common, domain-specific nomenclature. A potential limitation of tags is user frustration that may occur when a user must memorize tags or search for relevant tags using trial and error methods.

Tags can provide semantic context to information items and Feature Sets. For example, in a construction management scenario, if a user searches for the "concrete" tag, all Feature Sets containing items tagged with the word concrete are highlighted. Such a display can give the user an idea of how concrete resources have been allocated in an area (see Figure III.6). The user can perform a search using the concrete tag in order to discover associations (e.g., geospatial proximity of resources and surpluses) between Feature Sets that contain related information items.

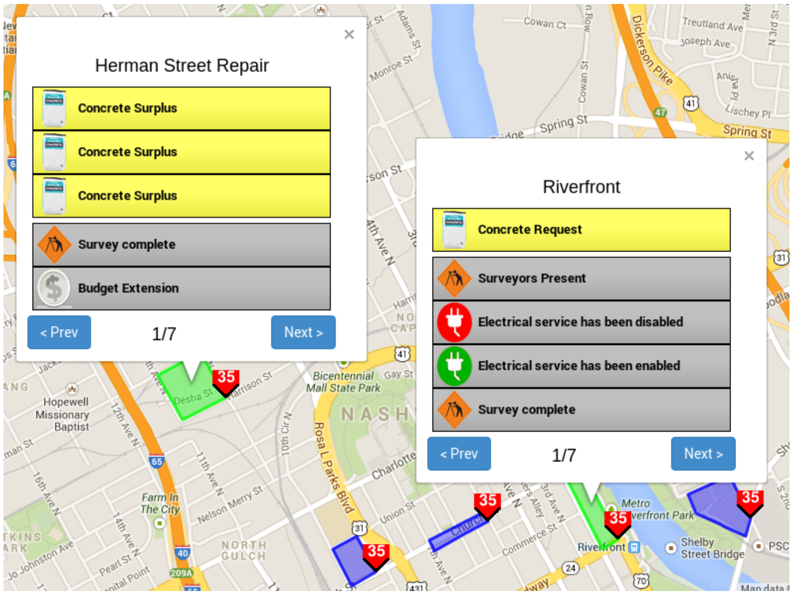


Figure III.6: Two Feature Sets displaying a surplus of and requests for concrete. Information highlighting in this example allows semantic context (e.g., the relationship between concrete requests and surpluses) to be used for quickly identifying inefficiencies in resource allocation.

III.6 Feature Sets Implementation

Feature Sets are implemented using responsive web technology (Marcotte, 2010) that can be rendered equivalently on tablets, smartphones, and conventional computers without the need for a unique per-platform implementation. The Feature Sets visualization technique is created using JavaScript for behavior logic, HTML 5 for layout, and Cascading Style Sheets (CSS) for content styling and appearance. Feature Sets are populated with data (i.e., information items) using JavaScript Object Notation (JSON) data structures (Romero, 2014).

The version of Feature Sets implemented for this research was supported via a Ruby on Rails (Hansson, 2014) back-end, which provided an abstraction layer to a MySQL database. The MySQL database provided data persistence for each Feature Set, including the geospatial container, the information items list, and the viewed state of each information item for each user of the application. MySQL also facilitated user account storage. Data access by the client was facilitated using Asynchronous JavaScript and XML (AJAX) (Garrett, 2005) requests to server-side Ruby on Rails controllers. Replies from AJAX requests came in the form of JSON structures used to dictate the display and content of Feature Sets. Despite Ruby on Rails and MySQL being used for the tested implementation of Feature Sets, a multitude of other back-end options are available, and Feature Sets' use of JSON ensures that any back-end that supports JSON can be used effectively.

Feature Sets currently use the Google Maps API (Google, 2012) for visualization on a digital map. As a result, Feature Sets and Google Maps are closely coupled. Feature Sets' geospatial areas are rendered using the Google Map's polygon class, notification indicators are Google Map's markers, and the Feature

Design	Context Geospatial	Temporal	Semantic
Feature Sets	areas of interest, Sketching	chronological item ordering	Highlighting, Tags
Convertino et al.	POIs, Sketching	*	Sketching, perspectives
Meyer et al. (CoMA)	POIs	*	*
Rodriguez-Covili et al.	POIs, Sketching	Time stamps	Sketching, Related Information
Velda et al. (SHARE)	POIs, 3D	Ontology	Ontology
Wu et al. (CIVIL)	POIs, Sketching	Annotation Browser	Sketching, Aggregation Chart

Table III.1: Summary of the methods that previous implementations and Feature Sets utilize to provide information context. *($*$ Indicates that visualization support was not explicitly stated.)*

Set expanded view is a modified version of Google Map's InfoWindow class. Due to this close coupling, Feature Sets are currently unable to be ported to a different mapping system, such as Open Street Map (OpenLayers, 2012) or Microsoft's Bing Maps (Microsoft, 2012). This is perhaps the main drawback to the current implementation, and a version of Feature Sets that can be used across multiple different mapping systems is essential if Feature Sets are to be reused.

Feature Sets were constructed entirely using Web technologies, allowing their use and display vis any modern web browser on many electronic devices (e.g., a computer, tablet, smart phone); however, in order to remove potentially distracting aspects of most modern web browsers (e.g., navigation buttons, text fields), and to provide more robust touch interaction support, a simplistic web browser, known as SimpleBrowser, was developed using C++ with the Qt toolkit. SimpleBrowser was developed solely for the use with the presented evaluations, but was robust and stable enough to be released into the open source upon completion (Hooten and Hayes, 2012).

III.7 Summary

Feature Sets are geospatial containers intended to reduce visual clutter and support information. Table II.1 summarizes how previously developed geocollaborative applications provide for information context, and has been updated to include Feature Sets in Table III.1.

Table III.1 shows that Feature Sets provide all levels of information context, and does so using a single visualization method. Feature Sets also meet the general requirements of an effective visualization technique by providing overview information, filtered information, and in-depth details on demand (Shneiderman, 1996).

Feature Sets utilize the geospatial information context by providing sketching functionality to support their creation and grouping collocated items into geospatial containers. The chronological item ordering present in the expanded view, for both highlighted and unhighlighted items, provides a temporal context to information contained within a Feature Set. Highlighting and information tagging allows users to emphasize relevant Feature Sets and information items by providing relevant search criteria.

Feature Sets are designed to support geospatial and geocollaborative work domains, but may be applicable to other domains that display information spatially. For example, 3-dimensional scatter plots can use Feature Sets grouping capabilities to group spatially collocated information. Feature Sets' expanded views can be used to provide summary information for the contained information (e.g., a description of the information, statistics, etc.), with detail views providing information for individual data points. Feature Sets, when applied in this case, may reduce visual clutter and result in the more straightforward recognition of trends within large data sets.

Chapter IV describes three comparative user evaluations conducted to determine the viability of Feature Sets as an information visualization and interaction technique. The first evaluation determines the performance benefits of Feature Sets as compared to POIs for presenting static information on the map. The second evaluation compares Feature Sets to POIs for presenting dynamic information via a simulated wayfinding task. The third evaluation implements four different levels of information highlighting and compares them against a control condition that utilizes no information highlighting.

CHAPTER IV

Feature Set Evaluations

IV.1 Introduction

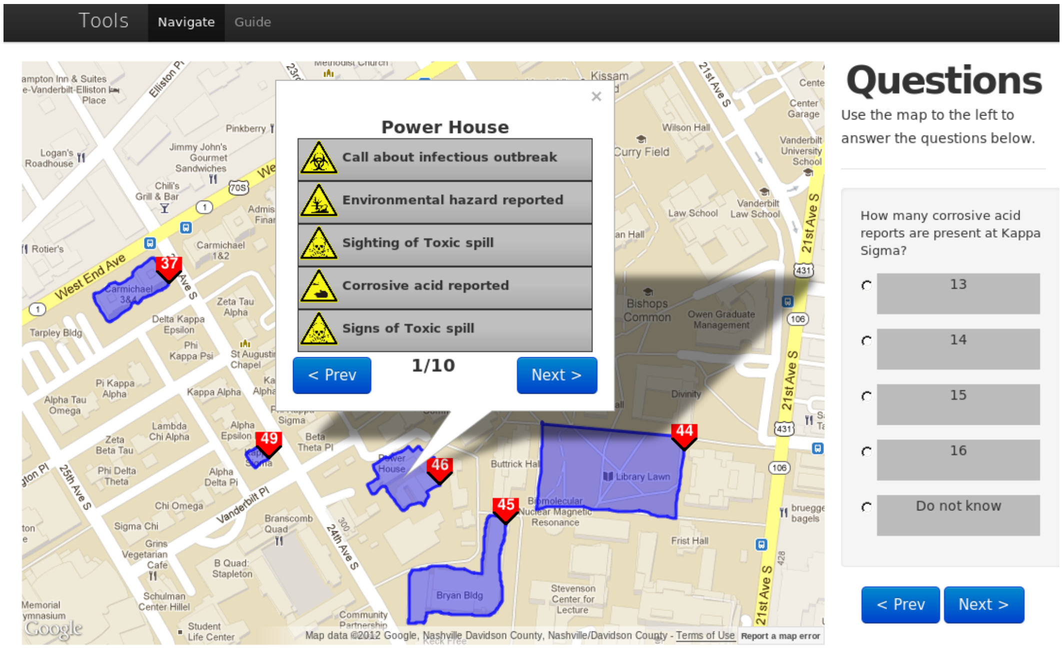
Three evaluations were conducted using Feature Sets, one for each of the three proposed information contexts: the Geospatial Context Evaluation, Temporal Context Evaluation, and Semantic Context Evaluation. The Geospatial Context Evaluation was intended to assess the benefits of Feature Sets as compared to POIs for static information display. The Temporal Context Evaluation assessed the benefits of leveraging temporal context for the visualization of and interaction with dynamic information. The Semantic Context Evaluation compared four information highlighting techniques and a base case in order to determine how information highlighting effected user's ability to utilize semantic context.

The Geospatial and Temporal Context Evaluations compared Feature Sets and POIs. Since POIs are a common visualization method to display information on digital maps, this comparison was a logical first step in evaluating the effectiveness of Feature Sets.

The Geospatial Context Evaluation verified the applicability of Feature Sets for a task typically performed by POIs: presenting static information on a digital map. The Geospatial Context Evaluation presented information at varying levels of *information density*. Both Feature Sets and POIs were used to visualize the same information at three levels of information density. Participants used POIs and Feature Sets to answer questions that were constructed in accordance with prior literature (e.g., Darken and Cevik 1999). The Geospatial Context Evaluation also tasked participants with finding particular locations on a digital map.

The Temporal Context Evaluation compared Feature Sets and POIs for a wayfinding task that supplied new information on the digital map dynamically throughout the experiment. The main purpose of the evaluation was to determine if Feature Sets provided better information discovery and salience than POIs when information is dynamically added to the digital map. The Temporal Context Evaluation primarily tests each visualization conditions' ability to inform users of new information.

The Semantic Context Evaluation implemented the four different highlighting approaches discussed in Chapter III.5 and compared them to a Feature Sets implementation that did not incorporate highlighting. These highlighting techniques were used to complete information location tasks and respond to real-time situation awareness probes. Each approach manipulated the effect of information highlighting in order to determine which method proved to be the most beneficial to task performance and situation awareness. The Semantic Context Evaluation was also used to determine the benefits of providing support for the semantic



Use the map to the left to answer the questions below.

How many corrosive acid reports are present at Kappa Sigma?

○ 13
○ 14
○ 15
○ 16
○ Do not know

Figure IV.1: The web application displaying the map for the Geospatial Context Evaluation's Feature Sets condition.

context.

All evaluations were primarily concerned with Feature Sets' ability to visualize and interact with information. Users were not required to create Feature Sets or add new information items to existing Feature Sets.

IV.2 Participants

Participants for all three evaluations were convenience subjects drawn from the Vanderbilt University vicinity. The Geospatial and Temporal Context evaluations were performed sequentially by all participants. The Semantic Context Evaluation was performed later, with a different set of participants. Participants completed a demographic survey before each evaluation assessing computer usage, touch device experience, and experience level with using digital maps. All participants reported a basic understanding of digital maps, with 50% reporting Good-to-Expert understanding. Participants' digital map, computer usage, and touch device experience had no effect on the results for any of the three evaluations.

IV.3 General Apparatus

The same general apparatus was used for all three evaluations and consisted of a web application, a web browser, and an electronic device. The apparatus was a mobile web application using Ruby on Rails, JavaScript, and HTML 5. The web application presented a digital map encompassing the leftmost three quarters of the display and a panel for questions and instructions, the Information Panel, on the rightmost quarter (see Figure IV.1).

The digital map was provided via the Google Maps JavaScript API Google (2012), and Google Maps' Road Map display view was utilized at all times. The minimum zoom level was thresholded to prevent participants from zooming out too far and potentially losing focus on the locations of interest. All presented questions were multiple choice, and answers were provided via radio buttons, as shown in Figure IV.1. Previous and Next buttons were located at the bottom of the Information Panel to facilitate question navigation, and participants were unable to proceed to subsequent questions without providing an answer to the current question. Upon providing an answer, tapping the Next button displayed a new question. The Previous button allowed users to revisit prior questions; however, no participant did so during any evaluation. This general apparatus was modified slightly to provide unique functionality specific to each evaluation, which are explained for each evaluation individually.

Information was provided in the form of reports, and a single report represented a single information item. The reports represented information that may be supplied by potential collaboators in a real world scenario. An example of a report, as visualized by both techniques (i.e., Feature Sets and POIs) is shown in Figure IV.2. Detailed information for a single report was accessed for Feature Sets by selecting a single report from the report list within an expanded Feature Set (see Figure IV.2b). The detail view for POIs was accessed via selecting a single report (see Figure IV.2c).

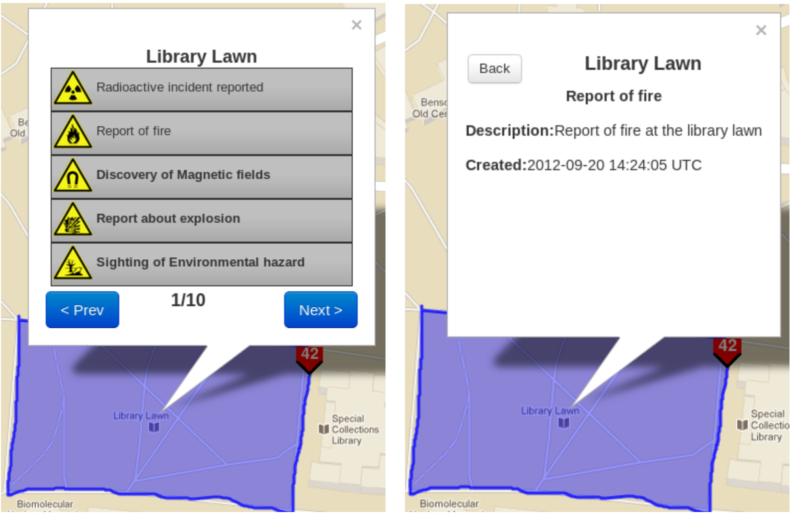
IV.4 The Geospatial Context Evaluation

The Geospatial Context Evaluation required participants to locate and count occurrences of information items on a digital map using both POIs and Feature Sets. The design was within-subjects, and required participants to perform tasks at increasing levels of information density in order to determine whether or not Feature Sets result in usability benefits as the potential for visual clutter increases.

IV.4.1 Test Apparatus

The Geospatial Context Evaluation utilized the general apparatus described in Chapter IV.3. The web application was presented on an ASUS EP121 tablet computer with a 12.1" screen, a 1280×800 pixel resolution and running Windows 7®. The ASUS EP121 was touch-enabled and participants panned the map using a single finger and zoomed the map using a two-finger pinch gesture.

Thirteen report types were used for the evaluation (see Figure IV.3). Each report type used a unique icon to facilitate identification. A first response scenario was used for the evaluation, and many of the report types were adapted from the Chemical, Biological, Radiological, Nuclear, and Explosive event domain. Additional



Library Lawn

Radioactive incident reported

Report of fire

Discovery of Magnetic fields

Report about explosion

Sighting of Environmental hazard

1/10

Library Lawn

Report of fire

Description: Report of fire at the library lawn

Created:2012-09-20 14:24:05 UTC

(a) Feature Sets (expanded)　　(b) Feature Sets (detail)

Discovery of Fire

Description: Discovery of Fire at the library lawn

Created:2012-09-20 14:24:06 UTC

Id: 13

(c) POIs (detail)

Figure IV.2: A Fire Report as visualized by Feature Sets; (a) expanded and (b) detail states. (c) A POI Fire Report.

(a) Bomb (b) Acid Corrosive (c) Environment Hazard (d) Explosion (e) Fire (f) Flammable Gas (g) Infectious Outbreak

(h) Laser (i) Magnetic Interference (j) Poison Gas (k) Radiation (l) Suspicious Person (m) Toxic Spill

Figure IV.3: The thirteen report types used in both evaluations.

	Operating System Experience			
Hours per Week	**Apple OS X**	**Windows XP/7/8**	**Linux**	**Other**
No time per week	8	4	29	30
Less than one	10	4	0	0
One to Ten	2	7	1	0
11 to 20	2	6	0	0
21 or More	8	9	0	0

Table IV.1: Participants' self-reported assessment of hourly computing device usage per week by operating system.

report types, such as the laser report, were added to introduce additional variety.

IV.4.2 Participants

Thirty (18 females and 12 males) participants performed the Geospatial Context Evaluations. All were convenience subjects and completed a demographic survey (see Chapter IV.2). A Shapiro-Wilk test determined that participant age deviated from a normal distribution $(W(30) = 0.87, p < 0.01)$. The participant median age was 20.5 years, the minimum reported age was eighteen years and the maximum reported age was thirty years. Twenty-seven participants performed the experiments using the right hand.

The demographic survey assessed participants' level of weekly computer use with particular computing platforms (see Table IV.1) and their self-reported map expertise (see Table IV.2). These demographic survey results were correlated to objective metrics of performance (see Chapter IV.5.4); however, no correlation to any performance metric was significant.

IV.4.3 Experimental Design

The Geospatial Context Evaluation compared POIs and Feature Sets using static information on a digital map of a moderately populated college campus. Reports were localized around five areas, as shown in Figure

Level	**Count**
None	1
Basic	13
Good	15
Expert	1

Table IV.2: Participants' self-reported assessment of map understanding.

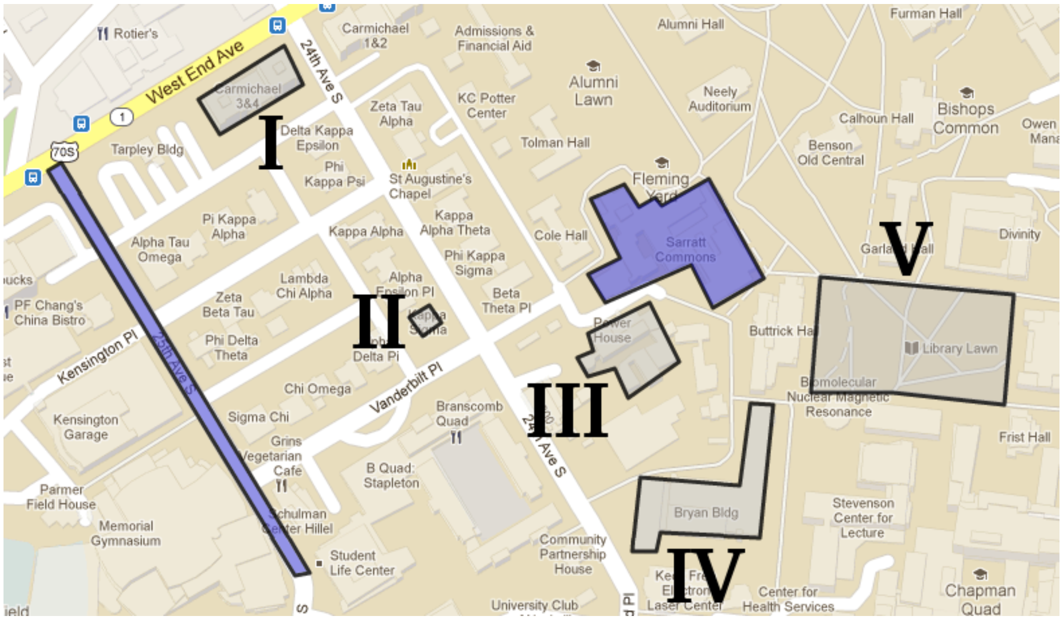
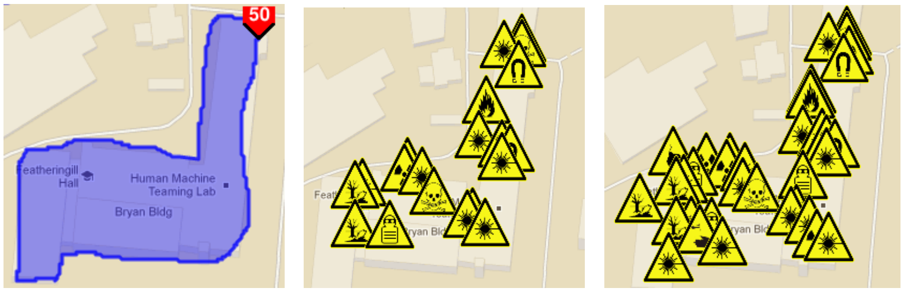


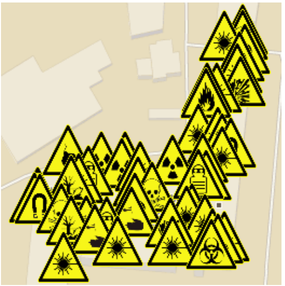
Figure IV.4: The Geospatial Context Evaluation map with the five locations where POIs and Feature Sets were displayed. Blue locations were for the training scenario only.

IV.4. These areas represent varying sizes and shapes, while remaining closely coupled to the underlying geography. The independent variables were the visualization condition used (i.e., POIs or Feature Sets), and the *information density* with which reports were presented. Three information densities were tested: Low, 20 discrete information items per cluster; Medium, 35 information items per cluster; and High, 50 information items per cluster. An example of a cluster of reports at each information density is shown in Figure IV.5. One information density and visualization presentation pair formed a single trial resulting in six total trials, which were performed in a fully randomized order.

POIs were distributed randomly within the five areas indicated in Figure IV.4 for each information density. Even though the distribution was random, POIs were required to occupy a unique geospatial location (i.e., no total overlap), and be fully visible at the highest zoom level, thus ensuring that all POIs at some zoom level were fully visible. Despite these requirements, items did overlap at lower zoom levels, causing visual clutter, with severity depending on the number of POIs occupying the area. The level of POI obscurity at the



(a) Feature Sets (b) POIs (Low) (c) POIs (Medium)



(d) POIs (High)

Figure IV.5: Report visualizations at each information density. (a) A Feature Set at all information densities. Note that the notification indicator reflects the High density trial. POIs at (b) Low, (c) Medium, and (d) High.

default zoom level is given for each test location in Table IV.3, which also provides the number of zoom steps necessary, relative to the default zoom level, to unobscure all POIs at a particular location. Since POIs were distributed randomly within each area, obscurity may not necessarily increase as a function of information density; however, total obscurity generally increases with increasing information density, ensuring that visual clutter causes information to become hidden as information density increases.

Both visualization methods displayed the same quantity of information distributed in the same manner; however, report types differed between visualization methods to mitigate learning effects. For example, a fire report located at the coordinate (-36.4532, 86.6543) in the POI condition was replaced by a report of a different type (e.g., a suspicious person report) at the same location in the Feature Sets condition.

Participants used the map and the visualized report information to answer six questions. Each question was one of three types: Primed, Naive, and Exploration (see Chapter II.4). The question format is provided in Table IV.4. Questions were presented in the same order for each trial. The answer selections were the same across visualization conditions at the same information density. Identical question answers and report locations ensured that participants performed tasks between visualization conditions in the same manner. Each participant received two questions of each type, resulting in sixty total responses per question type.

A “Do not know” response was provided and participants were encouraged to choose it only if they did not know the answer. The “Do not know” response was intended to limit the occurrence of lucky guesses.

				Obscurity Level		Zoom Level
Location	Density	Unobscured	Partially Obscured	Mostly Obscured	Totally Obscured	to Unobscure
I	**Low**	5	6	8	1	2
	Medium	2	2	5	26	3
	High	4	6	14	26	3
II	**Low**	1	2	3	14	3
	Medium	1	1	1	32	3
	High	1	1	4	44	3
III	**Low**	7	5	5	3	2
	Medium	1	2	8	24	2
	High	5	9	10	26	3
IV	**Low**	9	3	2	6	2
	Medium	5	2	5	23	2
	High	10	8	7	25	3
V	**Low**	11	4	2	3	2
	Medium	9	5	5	16	2
	High	12	10	9	19	2

Table IV.3: Obscurity of POIs at the default zoom level for each information density. *(Unobscured = completely visible, Partially Obscured = more than 50% visible, Mostly obscured = less then 50% visible, Totally Obscured = not visible.)*

Category	Code	Question Structure
Primed	**Primed How Many**	How many reports of type X exist at location Y?
	Primed Exist	Does report type X exist at location Y?
Naive	**Naive How Many**	How many reports of type X exist on the map?
	Naive Exist	Does report type X exist on the map?
Exploration	**Exploration Action**	Should action X be taken at location Y due to the existence of report type Z?
	Exploration Affected	Is location X affected by the existence of report type Y at location Z?

Table IV.4: Presented format for each of the given question types.

The questions were designed to promote different types of search behavior. The *Primed How Many* and *Naive How Many* questions were designed to elicit an exhaustive search of a particular region and the entire map, respectively. Participants were asked to count the occurrence of a specific report type, requiring participants to view each report. These two questions were designed to determine the effectiveness of Feature Sets' chronological item listing.

The *Primed Exist* and *Naive Exist* questions were designed to promote "at a glance" behavior and to be answered by finding a single specific item in a region and on the entire map, respectively. These questions were designed to leverage the inherent benefits of POIs, which display all information without any additional effort (e.g., selecting, scrolling); however, this benefit may be somewhat mitigated in the higher density conditions when some POIs overlapped.

Exploration questions were designed to require additional effort (i.e., determining the impact and meaning of report types). Participants were required to perform a search task to find reports(s) of interest and then determine additional outcomes as a result of the information. For example, the *Exploration Action* question may task participants with determining whether or not fire fighters needed to be dispatched to a certain area based on the occurrence of fire reports in the area.

	Hypotheses
H_1	POIs will result in faster task completion times than Feature Sets at the Low information density.
H_2	Feature Sets will result in faster task completion times than POIs at the Medium and High density conditions.
H_3	Feature Sets will result in more correct question answers than POIs in the High density condition.
H_4	More pans and zooms will be performed and more time will be spent panning and zooming during the POI condition.
H_5	Search time will be lower when using Feature Sets at all information densities.

Table IV.5: The Geospatial Context Evaluation's hypotheses.

The map's position and zoom level automatically centered the area of interest in the view for each question. *Naive* questions initially displayed the entire map area (see Figure IV.1). Automatically adjusting the map before each question ensured that participants attempted questions from the same starting map position and zoom level.

Participants underwent a ten minute training exercise that required answering questions similar to those used in the evaluations for both Feature Sets and POIs at a very low information density (i.e., five items per region). Participants were allowed to ask questions and receive assistance during the training. Training occurred in the same map region as the evaluation, but utilized different information items in different areas.

Participants experienced all report types and were encouraged to remember the icon that was associated with each report type. Leveraging iconography is an essential part of using POI-based approaches, and some form factors (e.g., smart phones) may provide too little screen real estate to display a legend alongside the map. Therefore, some memorization is inherent in order to remember what icon type corresponds to a certain report type. The Geospatial Context Evaluation viewed this memorization process as an inherent design flaw of POIs; therefore, when performing the POI condition, participants had to memorize the icon associated with each report type. Alternatively, participants were able to rediscover the association between icon and report type by interacting with the on-screen POIs, a functional equivalent to a legend.

IV.4.3.1 Hypotheses

Five hypotheses are made concerning the outcomes of the Geospatial Context evaluation. These hypotheses are summarized in Table IV.5.

POIs represent information "at a glance". At low information density, POIs can usually represent all information without visual clutter or additional map manipulation. Feature Sets inherently require an additional interaction (i.e., tapping on the Feature Set) before detailed report information can be seen, a disadvantage when compared to POIs in low information density conditions, thus it was hypothesized, H_1, that at the Low information density, POIs will result in faster task completion times than Feature Sets.

As information density increases, it is believed that excessively manipulating the map to interact with individual POIs will become detrimental and result in increased task completion times. Due to Feature Sets leveraging the geospatial context for data aggregation, Feature Sets are visualized and interacted with in the same manner regardless of information density; therefore, they may result in fewer map adjustments to view and interact with individual reports. It was hypothesized, H_2, that Feature Sets will result in faster task completion times than POIs at the Medium and High density conditions.

Increasing information density may also make questions more difficult to answer correctly. The High density trials may lead to information overload and increased incorrect answers for POIs. It was hypothesized, H_3, that Feature Sets will result in more correct question answers than POIs in the High density condition.

POIs can overlap, obscuring one another when placed close together; therefore, participants may perform additional map panning in the POI conditions. It was hypothesized, H_4, that more pans and zooms will be performed and more time will be spent panning and zooming during the POI condition.

POIs can also obscure underlying map geography. Feature Sets are semi-transparent, allowing the underlying geography to remain visible. It was hypothesized, H_5, that search time will be lower when using Feature Sets at all information densities. It is expected, but not hypothesized, that search time for the POI visualization condition will increase with increasing information density, but will remain relatively constant at all information densities when using Feature Sets.

IV.4.4 Metrics

Evaluation metrics were collected on a per-trial basis, where a single trial consisted of performing tasks using a single information density with a single visualization method. The objective metrics were the aggregated correct responses reported for each of the six questions and metrics representing map interaction. All objective metrics were logged automatically by the interface. Subjective metrics were obtained via a Likert scale rating survey administered after each trial and a visualization method comparison survey administered upon evaluation completion.

IV.4.4.1 Objective Metrics

The objective metrics for the Geospatial Context Evalution include:

- Correct Answer Percentage. The percentage of correct answers for each question type based on sixty total responses for each question type per trial.

- Correct Answer Duration. The time required to provide a correct answer, measured in seconds, and reported *per question*.

Question Code	Survey Question
Count Report Location	Determining how many reports of a specific type were in one location was...
Count Report Map	Finding how many of a specific report occurred on the entire map was...
Effect Report	Determining the effects of reports on neighboring geography was...
Find One Report Location	Finding one specific report in a given location was...
Find One Report Map	Finding one specific report on the entire map was...
Interacting Reports	Overall, interacting with reports was...
Selecting Reports	Selecting reports using a single finger was...
One Report Meaning	Determining the meaning of a single report was...

Table IV.6: Codes used for the subjective metrics and their corresponding questions from the Condition Rating Survey.

- Map Interaction metrics. Pan and zoom counts, as well as the pan and zoom durations measured in seconds.
- Find Duration. The time taken to find a particular location on the map, measured in seconds. Reported as the median duration of all find tasks performed for a particular trial.

The Correct Answer Percentage measures the effectiveness for both visualization conditions. Correct Answer Duration determines which visualization condition results in a shorter average time to achieve the correct answer. The average duration for each question type may vary greatly (e.g., finding a single report of a certain type may be performed significantly faster than counting every report type occurrence), thus the Correct Answer Duration results are reported for each question.

Map interaction statistics determine the number of map manipulations needed to perform tasks. A single zoom or pan count is defined as the entire duration of the gesture and may encompass more than a single zoom step. Pan and zoom duration is the time required for the entire gesture. Each of the Map Interaction metrics are averaged per participant.

IV.4.4.2 Subjective Metrics

A Condition Rating Survey was administered upon the completion of each trial to subjectively rate the performance of both visualization techniques at each information density. The Condition Rating Survey assessed participants' perceived performance using eight Likert scale questions that utilized a nine point scale, 1-very difficult to 9-very easy (see Table IV.6).

A Comparison Ranking Survey ranked the ease of using Feature Sets and POIs across seven factors (see Table IV.7). Ranking options for each factor were: Feature Sets, POIs, or "Both were equally easy".

Question Code	Question
Counting Reports	Counting occurences of a specific report type was easier using...
Determining Report Effect	Determining report effect on neighboring geography was easier using...
Finding Reports	Finding specific reports was easier using...
Interacting Reports	Interacting with reports was easier using...
Overall Preference	Overall, I preferred to use...
Selecting Reports Finger	Selecting reports using a finger was easier using...
Understanding Reports	Understanding the meaning of a report was easier using...

Table IV.7: Question codes and their corresponding questions as asked in the Comparison Ranking Survey.

	Low			Medium		
	Primed	Naive	Exploration	Primed	Naive	Exploration
Feature Sets	90.00	96.67	86.67	96.67	90.00	88.33
POIs	76.67	81.67	98.33	86.67	76.67	86.67

	High			Total		
	Primed	Naive	Exploration	Primed	Naive	Exploration
Feature Sets	93.33	80.00	96.67	93.33	88.89	90.56
POIs	75.00	45.00	90.00	79.44	67.78	91.67

Table IV.8: Descriptive Statistics for Correct Answer Percentage. The maximum number of correct answers for any single category is 60.

IV.4.5 Results

The Wilcoxon signed rank test was used for analysis, unless stated otherwise, since a Shapiro-Wilk test determined that data deviated significantly from a normal distribution. Non-parametric descriptive statistics (e.g., medians and ranges) are reported. Many of the reported objective metrics contain potential outliers that are quite far from the median for both Feature Sets and POIs. Further analysis of the data revealed that these outliers were not the result of a single participant's performance across all metrics, but were distributed among many participants; therefore, the outliers were preserved for all of the presented metrics and no participants were dropped from analysis as a result of performance.

IV.4.5.1 Objective Metrics

Feature Sets result in a higher Correct Answer Percentage for all question categories except the Exploration type at the Low information density (see Table IV.8). The results indicate that in cases where exact knowledge of an item's location is not needed (i.e., the *Primed* and *Naive* categories), Feature Sets outperform POIs. A significant difference was found for the Correct Answer Percentage metrics for the Primed tasks at the Low $(W(59) = 65, z = -1.77, p = 0.038)$ and High $(W(59) = 126, z = -2.23, p = 0.013)$ information densities, and for Naive tasks at the Low $(W(59) = 60, z = -2.16, p = 0.018)$ and High $(W(59) = 221, z = -4.12, p < 0.001)$ densities.

Feature Sets were expected to outperform POIs at higher information densities, since increased information density leads to visual clutter that inherently handicaps POIs. The Medium density descriptive statistics also favor Feature Sets, but no significant difference was found. An unexpected outcome, since Feature Sets outperformed POIs for many of the tasks performed at the Low and High densities.

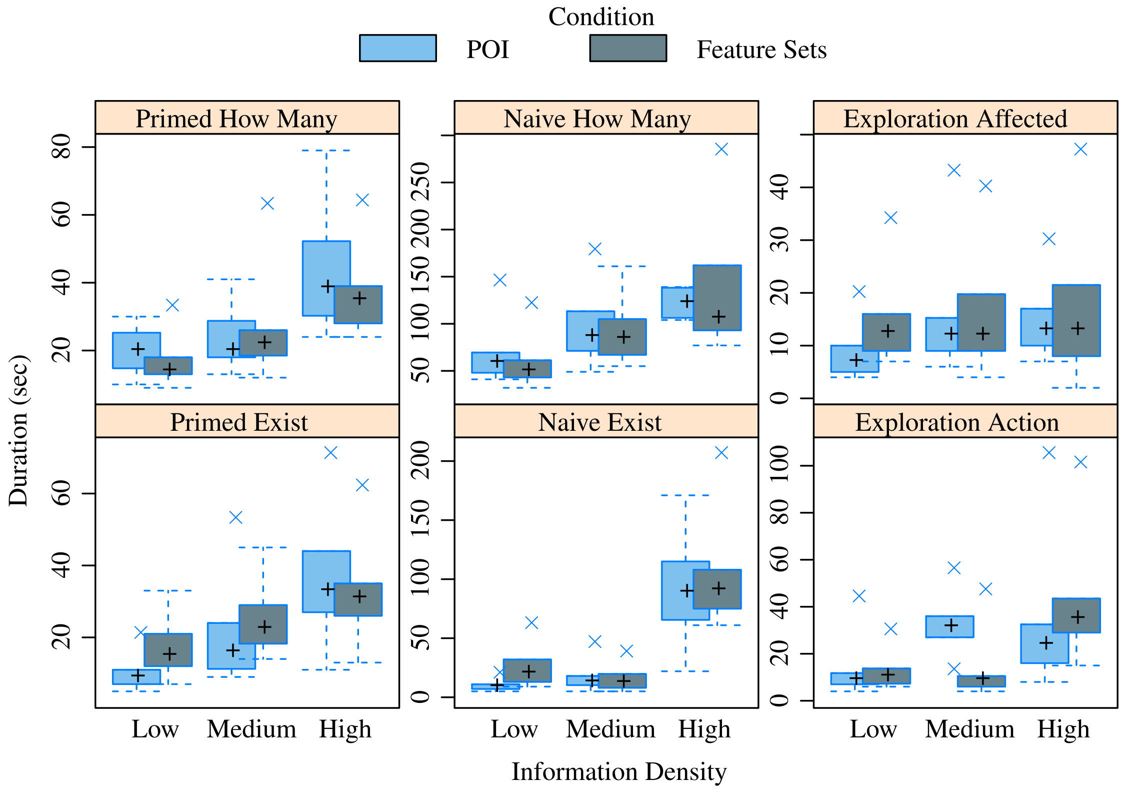


Figure IV.6: Correct Answer Duration descriptive statistics. Whiskers represent the variability of upper and lower quartiles, outliers are represented by an ×.

The Correct Answer Duration does not conclusively prove that Feature Sets result in lower task durations than POIs at higher densities; however, descriptive statistics do indicate a widening performance gap that favors Feature Sets as information density increases. Feature Sets also result in lower Correct Answer Durations for questions that require counting (i.e., *Naive How Many* and *Primed How Many*) at all information densities (see Figure IV.6). The differences are significant for the *Primed How Many* question at the Low density only ($W(29) = 124.5, z = -1.72, p < 0.036$), and no significant difference exists for the *Naive How Many* question at any density.

The relatively large upper quantile in the Medium and High density conditions for the *Primed How Many* question also indicates a large variance in participants' ability to count POIs in a consistent amount of time. Some participants were observed counting POIs repeatedly for the *Primed How Many* questions; demonstrating their propensity to check their result when using POIs, which led to a wider variability. This behavior was not exhibited for the *Naive How Many* at the High density case. The *Naive How Many* task was time consuming compared to *Primed How Many* question when using POIs; therefore, participants may have been much more reluctant to check their result by recounting POIs, which resulted in the decreased variance shown in Figure IV.6.

POIs possess lower Correct Answer Durations than Feature Sets at the Low and Medium densities (see Figure IV.6), with Feature Sets performing as well as or better than POIs at the High density for existence questions (i.e., *Primed Exist* and *Naive Exist*). POIs were significantly faster for the *Primed Exist* question at the Low ($W(29) = 704.5, z = -4.12 p < 0.01$) and Medium ($W(29) = 659, z = -2.94, p < 0.01$) densities; and for the *Naive Exist* question at the Low density ($W(29) = 804.5, z = -5.59, p < 0.01$). These results indicate that, in terms of Correct Answer Duration, POIs are better at supporting “at a glance” behavior, but as information density increases, Feature Sets begin to outperform POIs; however, the differences between the two are not significant.

The Correct Answer Durations were similar across visualization conditions at the Medium and High densities for the *Exploration Affected* question. POIs had a significantly lower Correct Answer Duration at the Low density ($W(29) = 124.5, z = -1.72, p < 0.036$).

Participants reported difficulty determining if map areas were affected by information items when using Feature Sets to answer *Exploration Affected* questions. This difficulty may be due to Feature Sets not displaying the exact location of reports, and can be remedied by providing the exact item location when displaying the item’s detail information. Despite this difficulty, Feature Sets possessed Correct Answer Durations equal to or better than POIs for the *Exploration Affected* question at the Medium and High density; further evidence of a widening performance gap between Feature Sets and POIs as information density increases.

Feature Sets possessed significantly lower Correct Answer Duration for *Exploration Action* at the Medium density ($W(29) = 33, z = -6.14, p < 0.001$), but POIs performed significantly better at the High density ($W(29) = 562.5, z = -3.33, p < 0.001$). The *Exploration Action* results favor POIs as information density increases, an inconsistency that may be due to not displaying items’ exact locations in Feature Sets.

The descriptive statistics for the Find Duration metric show that at all densities, Feature Sets resulted in a lower and consistent Find Duration (see Table IV.9). A two-tailed, paired Wilcoxon signed-rank test showed a significant difference between Feature Sets and POIs for the Find Duration metric at the Low ($W(29) = 212.5, z = -3.13, p < 0.001$), Medium ($W(29) = 147.5, z = -4.33, p < 0.001$), and High ($W(29) = 141, z = -4.44, p < 0.01$) densities, as well as the Total for both visualization conditions ($W(29) = 210, z = -3.45, p < 0.001$). This result indicates that, at all densities, finding locations on the map occurred more quickly when using Feature Sets.

The Find Duration metric was also calculated by presentation order to determine if presentation order had any affect on a participant’s ability to find locations on the map. A significant difference for Find Dura-

Density	**Condition**	**median**	**min**	**max**
Low	**Feature Sets**	5	2	16
	POIs	7	2	22
Medium	**Feature Sets**	5	2	16
	POIs	7	4	29
High	**Feature Sets**	5	2	17
	POIs	8	4	62
Total	**Feature Sets**	5	2	17
	POIs	7	2	62

Table IV.9: Descriptive statistics for the Find Duration metric. All durations are reported in seconds.

	Pan Count			**Zoom Count**			**Pan Duration**			**Zoom Duration**		
	W	**z**	**p**	**W**	**z**	**p**	**W**	**z**	**p**	**W**	**z**	**p**
Low	37	-7.54	< 0.001	16	-8.12	< 0.001	48.5	-7.23	< 0.001	4	-8.12	< 0.001
Medium	44	-7.35	< 0.001	25.5	-8.06	< 0.001	53	-7.12	< 0.001	–	–	–
High	0.92	-2.19	< 0.05	48	-7.49	< 0.001	6.5	-9.13	< 0.001	97	-6.29	< 0.001

Table IV.10: Paired Wilcoxon signed-rank test results for the Map Interaction metrics for Find Tasks ($df = 29$). Significant differences were shown between Feature Sets and POIs for every metric tested at every information density. A "–" indicates that values were not available to make the particular comparison.

tion on presentation order indicates a potential confound on the previous finding that Feature Sets result in significantly lower Find Duration. A paired, two-tailed Wilcoxon test revealed no significant difference for Find Duration when compared by presentation order at each information density; therefore, the significant difference in Find Duration can be attributed solely to the visualization method.

The descriptive statistics for the Map Interaction metrics for Find Tasks show that no zooms were performed for Feature Sets at the Medium information density (see Figure IV.7). The application automatically adjusted the map to center locations pertinent to the questions being asked, and *Naive* question types displayed the entire map; therefore, zooming was typically unnecessary for completing tasks when using Feature Sets.

At every information density there were fewer pan counts and zoom counts for Feature Sets. The median Pan and Zoom Durations were also lower for Feature Sets at all information densities. A two-tailed paired Wilcoxon found significant differences between Feature Sets and POIs for Zoom Count, Pan Count, Zoom Duration, and Pan Duration at all densities where data was available to perform a comparison (see Table IV.10). This result indicates that for Find Tasks, at all densities, Feature Sets require fewer Map Interactions. Such an outcome is attributed to the design of Feature Sets, which allowed participants to "see underneath" the Feature Set and easily interpret map geography.

The Map Interaction Pan and Zoom Duration descriptive statistics are provided in Figure IV.8. Feature Sets, in many cases, resulted in no zooms being performed by participants. When participants performed

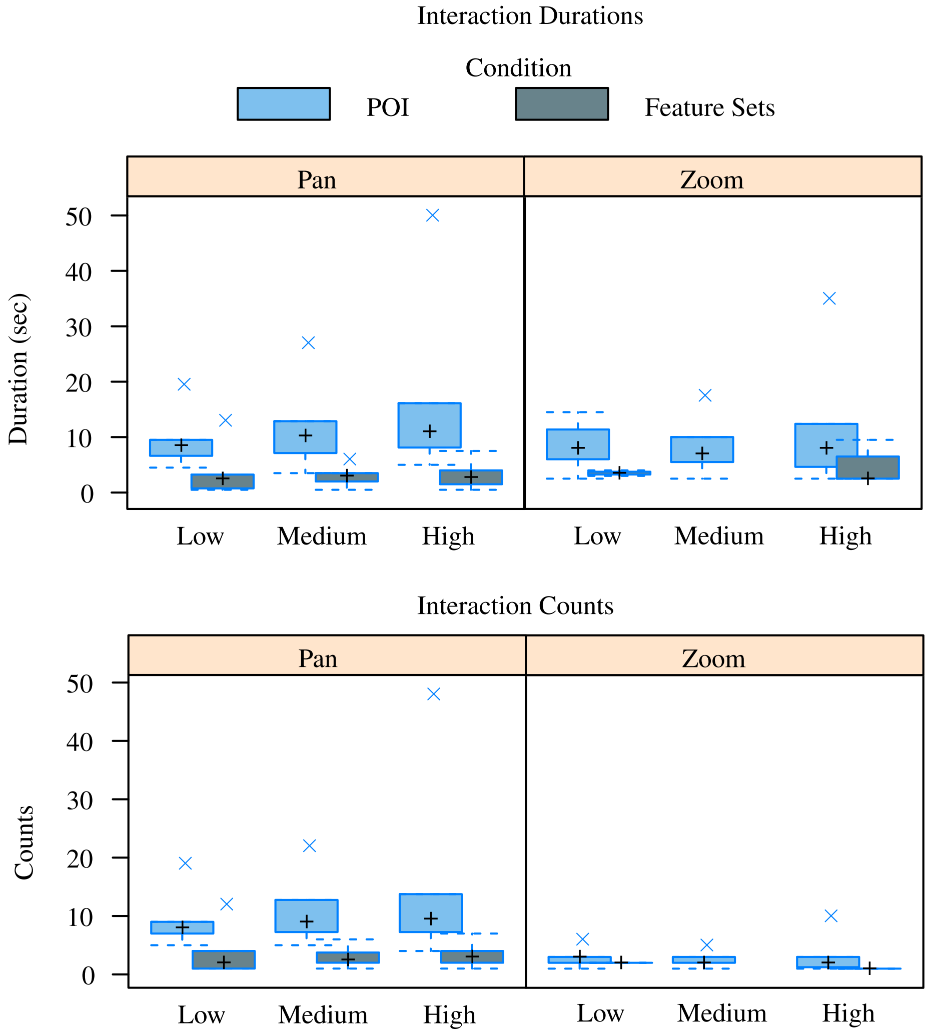


Figure IV.7: Descriptive statistics for the Map Interaction metrics for Find Tasks shown by information density. A single count corresponds to a single interaction; durations are measured in seconds.

zooming using Feature Sets (e.g., the *Naive* question type), Zoom Duration medians were lower than POIs. The Zoom Duration differences were significant for each question type at every information density (see Table IV.11). POI results were compared to a median of zero when no equivalent interactions were performed with Feature Sets. Feature Sets result in lower median Pan Durations for every question type and density (see Figure IV.8), with significant differences between POIs and Feature Sets in every case (see Table IV.11).

Feature Sets result in lower median Pan and Zoom Counts in cases where pans and zooms were performed (see Figure IV.8). Significant differences were found for both Pan Count and Zoom Count at every information density (see Table IV.11). POI results were compared to a median of zero when no equivalent interactions were performed with Feature Sets.

The Map Interaction results indicate that for all question types and for all information densities, partic-

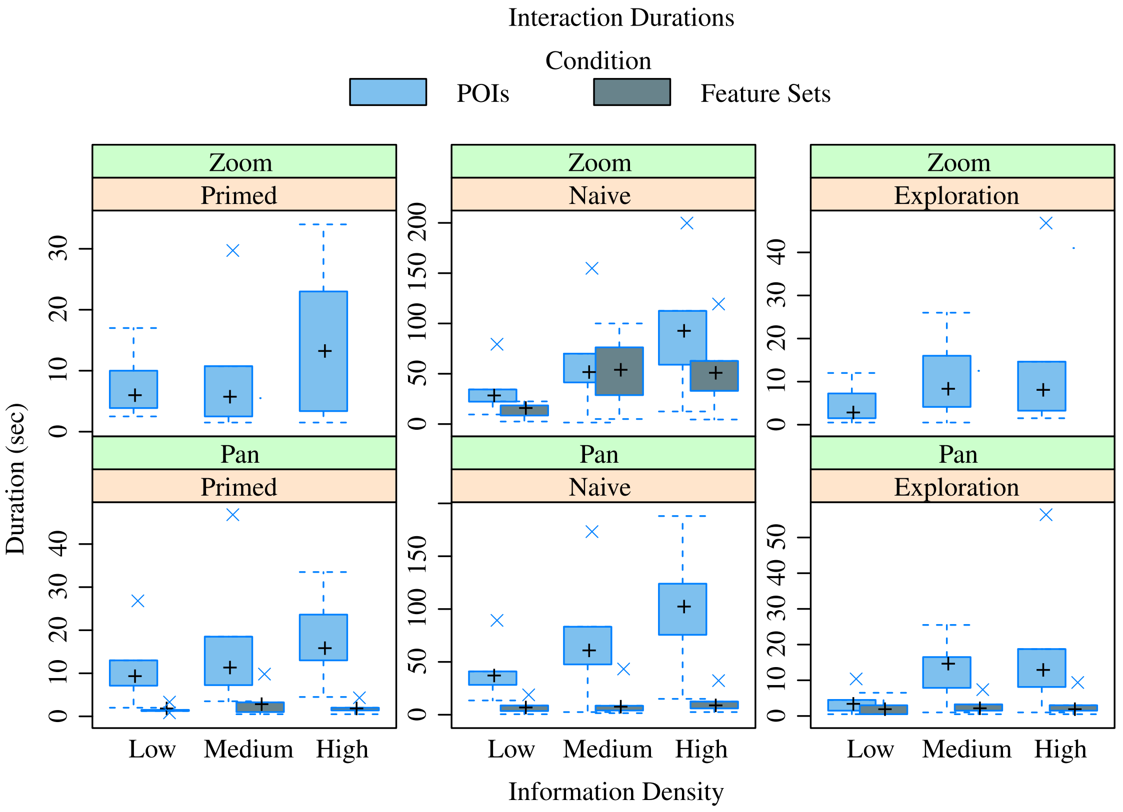


Figure IV.8: Map Interaction Pan and Zoom Duration descriptive statistics.

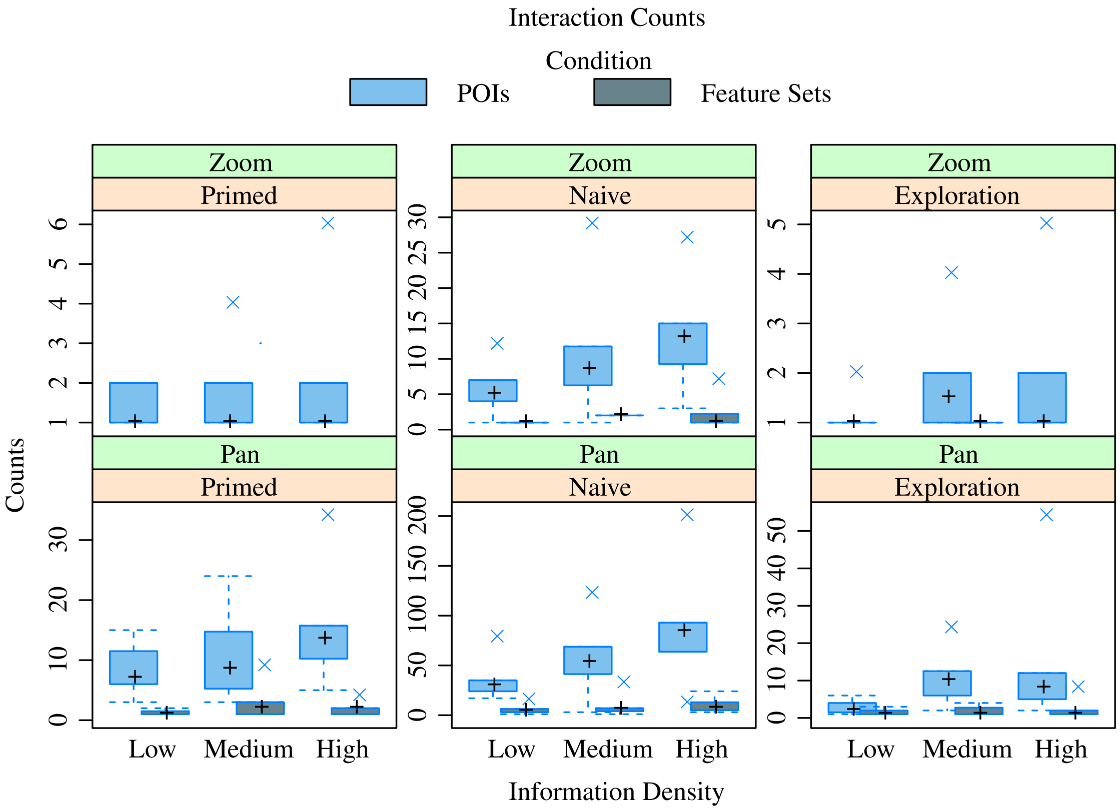


Figure IV.9: Map Interaction Pan Count and Zoom Count descriptive statistics.

Pan Count

	Primed			**Naive**			**Exploration**		
	W	**z**	**p**	**W**	**z**	**p**	**W**	**z**	**p**
Low	0	-5.42	< 0.001	0	-5.68	< 0.001	99.5	-5.39	< 0.001
Medium	17.5	-5.19	< 0.001	28.5	-4.75	< 0.001	15	-5.74	< 0.001
High	0	-6.09	< 0.001	8	-5.43	< 0.001	20.5	-5.76	< 0.001

Zoom Count

	Primed			**Naive**			**Exploration**		
	W	**z**	**p**	**W**	**z**	**p**	**W**	**z**	**p**
Low	0	-4.46	< 0.001	1.5	-5.51	< 0.001	0	-4.56	< 0.001
Medium	24.5	-5.01	< 0.001	3	-6.01	< 0.001	5.5	-4.51	< 0.001
High	0	-4.24	< 0.001	5.5	-5.02	< 0.001	11.5	-4.61	< 0.001

Pan Duration

	Primed			**Naive**			**Exploration**		
	W	**z**	**p**	**W**	**z**	**p**	**W**	**z**	**p**
Low	0.5463	-8.13	< 0.001	3	-8.13	< 0.001	0.7195	-4.52	< 0.001
Medium	0.6341	-5.25	< 0.001	28	-7.74	< 0.001	57	-7.93	< 0.001
High	0.4638	-6.04	< 0.001	9.5	-8.12	< 0.001	0.3596	-6.97	< 0.001

Zoom Duration

	Primed			**Naive**			**Exploration**		
	W	**z**	**p**	**W**	**z**	**p**	**W**	**z**	**p**
Low	0	-7.94	< 0.001	14	-8.12	< 0.001	0	-3.24	< 0.001
Medium	15	-8.09	< 0.001	51	-7.42	< 0.001	45.5	-5.83	< 0.001
High	26	-7.02	< 0.001	82	-6.55	< 0.001	38	-4.18	< 0.001

Table IV.11: Map Interaction Metrics comparison test results ($df = 29$).

ipants spent less time manipulating the map when using Feature Sets. This result supports the finding that Feature Sets require less map manipulation for accessing desired information. Cumulatively, the Map Interaction metrics provide strong evidence that fewer map interactions are necessary to locate required information when using Feature Sets. The superior performance of Feature Sets for each of the Map Interaction metrics is due to leveraging the geospatial context to aggregate information within Feature Sets. When information is aggregated, it is not obscured, and there is no reason to frequently adjust the map to see individual information items.

IV.4.5.2 Subjective Metrics

Feature Sets were ranked higher than or equivalent to POIs for all categories on the Condition Rating Survey, excluding the *Effect Reports* and *Find One Report Map* at the Low information density (see Figure IV.10). The *Effect Reports* question specifically tasks participants with determining whether or not a report at one

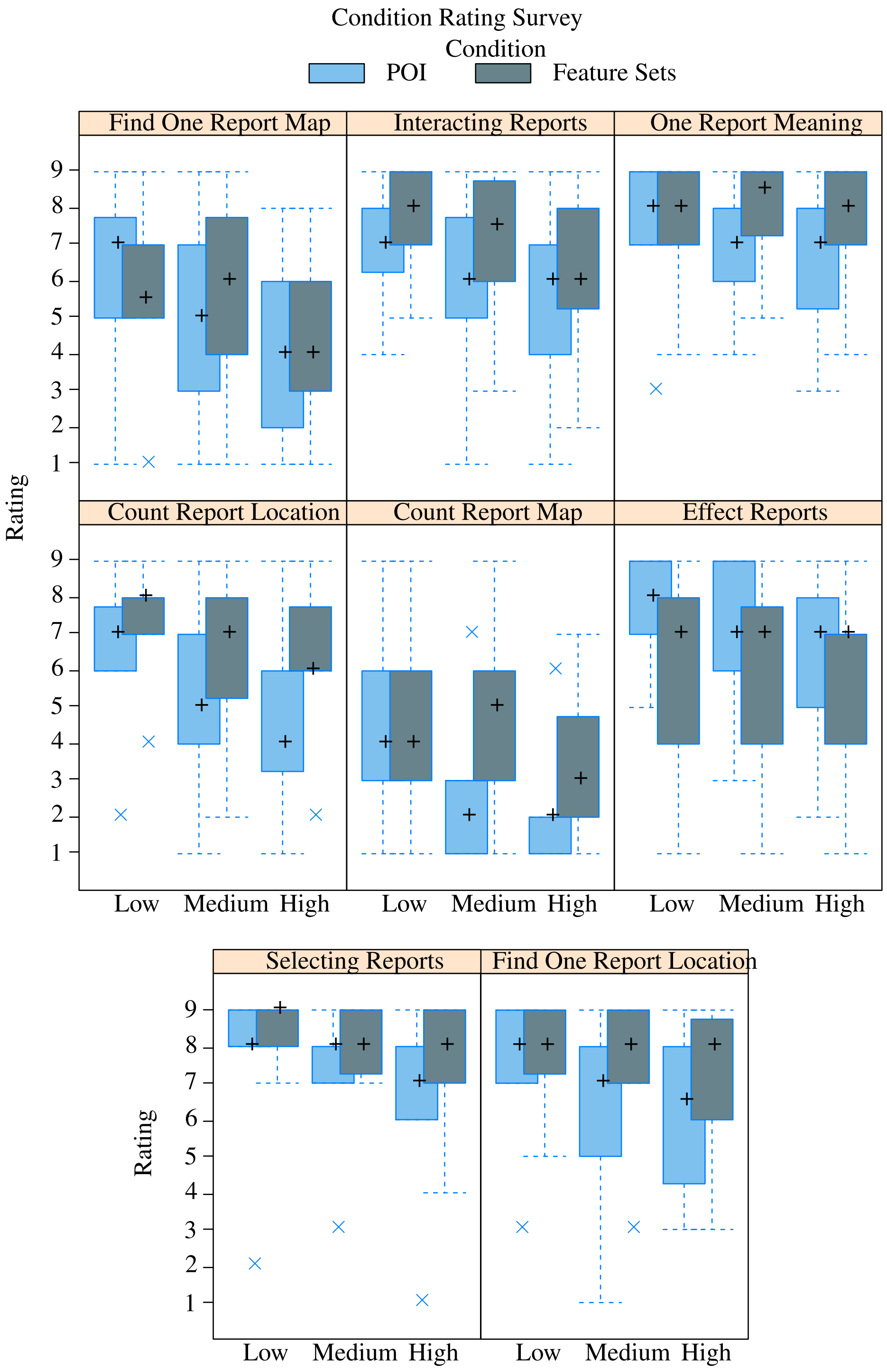


Figure IV.10: Condition Rating survey descriptive statistics shown by information density. Rating levels ranged from 1 to 9 with higher ratings being better.

location will have an effect on another location. Participants commented that when using Feature Sets, the exact report location was not displayed, leading to confusion when answering the *Effect Reports* question. POIs' higher ranking for the *Find One Report Map* question was expected, since at the Low density finding reports using POIs is very easy.

Feature Sets are subjectively preferred for the *Count Report Location* question at the Low $(W(29) = 590, z = -1.833, p = 0.034)$, Medium $(W(29) = 616.5, z = -2.26, p = 0.012)$, and High $(W(29) = 639.5, z = -2.64, p < 0.005)$ densities. POIs were expected to rate higher at lower information densities, where relatively little visual clutter was present. Feature Sets were subjectively preferred for the *Count Report Map* category in the Medium $(W(29) = 701.5, z = -3.72, p < 0.001)$ and High $(W(29) = 629.5, z = -2.54, p < 0.01)$ densities only, an expected outcome since Feature Sets were not subjectively preferred at the Low density.

No significant differences were found for the *Find One Report Location* and *Find One Report Map* questions. Feature Sets rated higher or equal to POIs, except for the Low density condition for the *Find One Report Map* question, POIs were expected to rate higher for questions that promoted "at a glance" search behavior.

Feature Sets subjectively rated equal to or higher than POIs for the *One Report Meaning* question, and the medians differed significantly at the Medium $(W(29) = 617, z = -2.33, p < 0.01)$ and High $(W(29) = 639.5, z = -1.74, p = 0.042)$ densities. This result indicates that, as information density increases, participants prefer Feature Sets for determining the meaning of single reports, perhaps because these reports are easier to find and interact with when using Feature Sets, a benefit of leveraging the geospatial context to reduce visual clutter.

POIs rated significantly higher than Feature Sets in the Low density for the *Effect Reports* question at the Low density $(W(29) = 296, z = -2.07, p = 0.019)$. This question required exact knowledge of an information item's location, which Feature Sets did not display.

Feature Sets rated significantly higher for the *Interacting Reports* question at the Medium density only $(W(29) = 611, z = -2.16, p = 0.015)$. This outcome is unexpected, but may be attributed to the number of interactions required at the High information density. Both Feature Set and POI conditions required a large number of interactions to find information at the High density, which may have frustrated participants and resulted in the somewhat low, a value of 6, identical median ratings. Feature Sets were rated significantly higher at the Medium $(W(29) = 586.5, z = -1.82, p = 0.036)$ and High $(W(29) = 609.5, z = -2.18, p = 0.015)$ densities for the *Selecting Reports* question, indicating that Feature Sets were preferred for selecting items as information density increased.

The Condition Ranking survey descriptive statistics show that in all cases except the *Determining Report Effect* and *Finding Reports* questions, Feature Sets were preferred (see Table IV.12). An equal proportions test

Question Code	**Feature Sets**	**POIs**	**Equally Easy**
Counting Reports	21	5	4
Determining Report Effect	3	20	7
Finding Reports	12	13	5
Interacting Reports	22	6	2
Overall Preference	23	7	0
Selecting Reports Finger	17	4	9
Understanding Reports	18	3	9

Table IV.12: Descriptive statistics for the Condition Ranking survey.

with a 95% confidence level determined that POIs were significantly preferred for the *Determining Report Effect* question (POIs: CI(0.5166, 0.7892)), indicating a preference for POIs when determining the effect of reports on nearby map areas. This result reinforces the *Effect Reports* finding from the Condition Rating Survey. A test of equal proportions determined preference for Feature Sets for *Counting Reports* (Feature Sets: CI(0.5506, 0.8163)), *Interacting Reports* (Feature Sets: CI(0.5854, 0.8427)), and *Overall Preference* (Feature Sets: CI(0.6210, 0.8682)).

IV.4.6 Discussion

Hypothesis H_1 states that POIs will result in faster task completion times than Feature Sets at the Low information density (see Table IV.5). The Correct Answer Duration metric does not support or refute this hypothesis, since POIs outperformed Feature Sets for only the *Primed Exist* and *Naive Exist* questions at the Low information density only. This outcome lends support to using POIs for low density data sets when "at a glance" behavior is required. POIs are disadvantaged even at low information densities when performing more rigorous tasks, such as counting. As information density increases, and visual clutter is more probable, the disadvantage of POIs becomes more apparent.

As the information density increased, Feature Sets outperformed POIs in many of the reported metrics, supporting H_2. Simply put, when visual clutter becomes problematic, it is necessary to provide an alternative means of displaying information, and by leveraging geospatial context to group collocated information, Feature Sets provided a better alternative to POIs.

Hypothesis H_3 was supported by the Correct Answer Percentage results. Feature Sets resulted in more correct answers, which is due to Feature Sets leveraging the geospatial context to reduce visual clutter. Information was easier to access in a more reliable manner (i.e., browsing an ordered list), while reducing the number of visible elements at any given time. This characteristic of Feature Sets ensured that participants were able to find and interact with information that was unobscured, resulting in more correct answers.

Feature Sets' geospatial context support resulted in a visualization that did not obscure underlying information. POIs required users to frequently adjust the map in order to find items of interest. Feature Sets minimize necessary map adjustments to find information, resulting in faster task performance, which supports H_4.

Find Duration results indicate that, at all densities, Feature Sets resulted in significantly lower Find Durations, supporting H_5. The reduced Find Durations were also shown to be independent of presentation order; therefore, this finding cannot be attributed to participant familiarity with the map. Find Durations were also constant for Feature Sets regardless of the information density. The lower Find Durations for Feature Sets is more than likely attributed to removing the need for participants to see underneath reports displayed on the map. Less interaction with the map is needed to find locations on the map, resulting in lower overall Find Durations and Map Interactions for Feature Sets.

Feature Sets were subjectively ranked equivalently or better than POIs in many cases. At the Low density, POIs were preferred when answering questions that required finding a single report on the entire map and for finding exact report locations. However, as information density increases, Feature Sets were subjectively preferred.

The Geospatial Context Evaluation validated Feature Sets as an interaction and data visualization technique for presenting data on digital maps. Feature Sets were shown to outperform POIs in many cases and, in cases where POIs performed better, the performance was not significantly better, except when the participant required exact knowledge of an item's location. Once Feature Sets are improved to show the exact location of information, it is believed that Feature Sets will be a worthwhile visualization method regardless of information density.

The results indicate the importance of supporting the geospatial information context. Feature Sets allowed for geospatial groupings of information, which reduced visual clutter and provided an overview level of information, features that were absent from the POI visualization method. The Geospatial Context Evaluation demonstrates that by leveraging the geospatial information context to provide overview information, user performance can be improved when using digital maps.

IV.5 The Temporal Context Evaluation

The Temporal Context Evaluation compared Feature Sets and POIs for a wayfinding task that dynamically added new information to the digital map, simulating a geocollaborative scenario during which information supplied by other collaborators appears within the user's interface. The purpose was to determine if Feature Sets, through leveraging temporal context, provided better information discovery and salience than POIs when information is dynamically added to the map. This evaluation used the same test apparatus and participants as the Geospatial Context Evaluation (see Chapters IV.4.2 and IV.4.1). Participants performed this evaluation after the Geospatial Context Evaluation and were permitted to take a ten minute break between evaluations.

IV.5.1 Apparatus

The Temporal Context Evaluation used an apparatus identical to that used in the Geospatial Context Evaluation (see Chapter IV.4.1). The iconography adapted from the CBRNE domain (see Figure IV.3) was used for all information items.

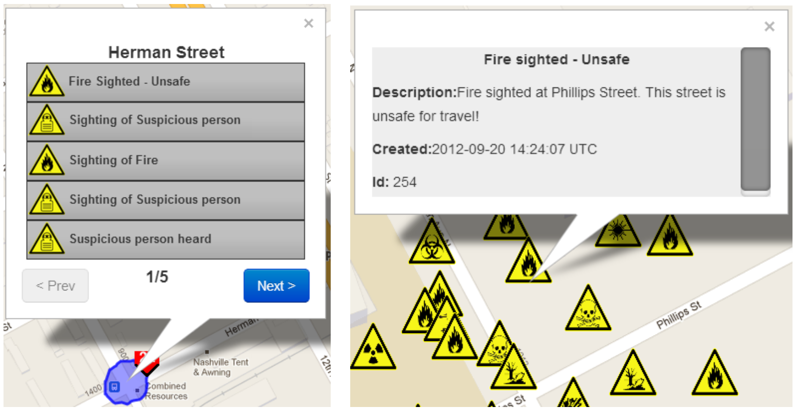
Additional functionality was added to the interface to allow participants to draw paths on the map. Paths were drawn using a single finger, and panning and zooming were disabled during drawing. The entire path was to be drawn using a single stroke. Upon releasing the stroke, the path drawing functionality was automatically disabled, and participants were able to pan and zoom the map. All tasks were designed to require drawing through only a single cluster of reports. Once a path was drawn, a green marker, the movement indicator, appeared on screen and transversed the drawn path. Participants were able to tap on the movement indicator to pause and resume its movement.

IV.5.2 Experimental Design

The evaluation was a within subjects design. The independent variables were the visualization condition, POIs or Feature Sets, and the task type of each performed task. The visualization condition presentation order was randomized. Both conditions visualized the same distribution of information items, which was centered around five locations. The report count at each location was set to a low value, twenty, to ensure that participants did not become frustrated and give up when looking for information on the map. No participant exhibited frustrated behavior during the evaluation. A single cluster of reports was represented by a single Feature Set, and as a group of twenty POIs for the POI condition. Groups of POIs occupied the same geospatial area as the corresponding Feature Set. The report types were altered between visualization conditions to mitigate learning effects.

Each condition incorporated five simulated wayfinding tasks. The wayfinding task displayed two markers, labeled A and B, and the participants were tasked with drawing the shortest route between the markers, while following streets. The shortest route always intersected one of the five clusters, ensuring that participants considered report information when selecting the route between markers A and B.

Participants were required to determine if the cluster of items was "unsafe" before drawing a path through it. An unsafe cluster contained the word "unsafe" in the report's detail information. The "unsafe" designation was visible in the expanded Feature Sets' view (see Figure IV.11); while the "unsafe" designation was visible after clicking on a POI to display its detail information. Participants were instructed not to draw through a cluster containing an unsafe report, even if the resulting path was the shortest. "Unsafe" reports were


Herman Street

Fire Sighted - Unsafe

Sighting of Suspicious person

Sighting of Fire

Sighting of Suspicious person

Suspicious person heard

Fire sighted - Unsafe

Description: Fire sighted at Phillips Street. This street is unsafe for travel!

Created:2012-09-20 14:24:07 UTC

Id: 254

(a) Feature Sets Expanded state

(b) POIs detail state

Figure IV.11: Unsafe information reports displayed using each visualization method.

described as information that may render a path unsafe for travel by human beings (e.g., the presence of a fire, toxic gas, or a bomb).

Participants were required to redraw a path when an “unsafe” report was placed dynamically along the drawn path, which ensured that participants must take action and leverage new information to complete tasks. Regardless of the path’s length, the movement indicator transversed the path in the same amount of time, ensuring that participants had the same time span across tasks to adjust a drawn path, if required.

A task was complete when the movement indicator finished moving from A to B, and participants proceeded to the next task. The A and B markers repositioned automatically, and the map adjusted to place the markers within view, such that participants did not have to search for the next task.

Four task types were used for each visualization condition. The *Appear Group Unsafe* task caused a single unsafe report to appear in a cluster of safe reports after the participant had drawn a path through the reports. This task required the participant to pause the movement indicator, search the cluster for the newly added report, determine whether or not the added report was unsafe, and draw a new path that avoided the cluster, if the newly added item was unsafe. Both visualization conditions supported this task differently. The Feature Sets condition incremented the Feature Set notification indicator for the cluster. The POI visualization condition added a new POI to the cluster. The new report appeared three seconds after the path was drawn for both conditions, ensuring that participants had the same amount of time to react. The *Appear Group Unsafe* task was correctly performed if the participant identified the unsafe report and drew a new path to avoid the cluster. This task was designed to determine which visualization method made new information more salient when information was added to an information dense map region. This task simulates an MSW scenario where new information is added to a mapped area that is highly active, and the user must determine what new information exists at that location.

	Condition	
Task	**Feature Sets**	**POIs**
1	Distractor	No Appear Group Unsafe
2	No Appear Group Unsafe	Distractor
3	Appear Group Unsafe	Appear Group Unsafe
4	Distractor	Appear Solo Unsafe
5	Appear Solo Unsafe	Distractor

Table IV.13: Task orderings for both the POI and Feature Sets condition.

The *Appear Solo Unsafe* task added a single new report along a drawn path, but not within a cluster of reports, which was intended to add information to the map without the influence of visual clutter. The Feature Sets condition created a new Feature Set to encompass the single report, while the POI condition added a new POI. The new report appeared three seconds after the path was drawn for both conditions, providing the same amount of time to react to the newly added report The participant must recognize the new report, determine if it is unsafe, and draw a new path that avoids the report in order to complete the *Appear Solo Unsafe* task successfully.

The *No Appear Group Unsafe* task placed a single unsafe report within a cluster of nineteen safe reports *before* the participant drew a path. The cluster had to be searched to find any unsafe reports and, upon finding an unsafe report, a path was drawn that avoided the cluster. An exhaustive search of the reports within a cluster was required. The intent was to determine which visualization condition more easily facilitated exhaustive search.

Two instances of a distractor task that did not add any new information were used in each condition. Non-distractor tasks were presented in the same order for both conditions, but the distractor task was introduced at different times (as the first and fourth task when using Feature Sets, and as the second and fifth task when using POIs) to mitigate learning effects (see Table IV.13). Tasks of the same type were designed to be identical in duration across the conditions.

A ten minute training exercise required participants to perform each task type once using both conditions. Participants were allowed to ask questions and receive assistance during the training, which used the same map region as the evaluation, but with different information and routes.

IV.5.3 Hypotheses

Four hypotheses are made concerning the outcomes of the Temporal Context evaluation. These hypotheses are summarized in Table IV.14.

Feature Sets' notification indicators provide instant notification of new information; therefore, participants may identify the presence of new information more quickly when using Feature Sets. It is hypothesized, H_1, that Feature Sets will result in lower times to determine that new information has been added to the map.

New information is added to the top of a Feature Set's item list in the expanded view. New POIs are added to the map, regardless of the POI density in the area, which may hinder the identification of new information. It is hypothesized, H_2, that Feature Sets will result in more occurrences of new information being identified.

It is expected that finding new information with Feature Sets will require less interaction due to the saliency of new information. It is hypothesized, H_3, that fewer interactions with the map (i.e., pans and zooms) will be required to perform tasks when using Feature Sets, and that less time will be spent interacting with the map (i.e., panning and zooming) when using Feature Sets. Reducing interaction time allows users to focus on interacting with information and engaging with the environment, rather than manipulating the software.

Feature Sets are designed to saliently present new information; therefore, it is expected that users will prefer Feature Sets over POIs. It is hypothesized, H_4, that Feature Sets will be subjectively preferred for both interacting with and discovering new information.

IV.5.4 Metrics

All metrics were obtained on a per-condition basis, where a single condition consisted of performing tasks using a single visualization method. Objective metrics were logged automatically and were aggregated from each successfully completed task, and the distractor task was excluded. Subjective metrics were obtained via a Likert scale survey administered after each condition and a comparison survey administered at the end of the evaluation.

IV.5.4.1 Objective Metrics

The Correct Task Percentage metric determines, out of the total number of questions, how many were answered correctly. This metric is the ratio of correct responses to all responses per task type and is calculated

	Hypotheses
H_1	Feature Sets will result in lower times needed to determine that new information has been added to the map.
H_2	Feature Sets will result in more occurrences of new information being identified.
H_3	Fewer map interactions and less time manipulating the map will be required to access new information.
H_4	Feature Sets will be subjectively preferred for both interacting with and discovering new information.

Table IV.14: The Temporal Context Evaluation's four primary hypotheses.

Question Code	Survey Question
Creating Paths	Creating paths was...
Determine Path Correct	Determining if a drawn path was correct was...
Find New Info	Finding new information once it was added to the map was...
Interacting New Info	Interacting with new information was...
Modifying Paths	Determining if a previously drawn path needed modification was...

Table IV.15: Codes used for the subjective metrics and their corresponding questions from the Condition Rating Survey.

Question Code	Question
Creating Paths	Creating Paths was easier using...
Detect New Info	Detecting newly added information was easier using...
Determine Path Correct	Determining if a path was correct was easier using...
Determine Path Need Modification	Determining to modify a path was easier using...
Interact New Info	Interacting with new information was easier using...

Table IV.16: Question codes and their corresponding questions as asked in the Comparison Ranking Survey.

for the entire set of responses. Thirty total tasks of each type were performed per condition.

The amount of time required to perform a task correctly, the Correct Task Duration, was measured in seconds. The Correct Task Duration metric determines the condition that results in the shorter average time for correct answers and is reported per task type.

Map Interaction metrics include pan and zoom counts and pan and zoom durations. These metrics were logged automatically and are reported per task type. A single zoom or pan count is defined as the entire duration of the gesture, from start to finish. Pan and zoom duration is measured in seconds.

IV.5.4.2 Subjective Metrics

The Condition Rating Survey, administered after each condition, assessed participants' perceived performance using five Likert scale questions that utilized a nine point scale, 1-very difficult to 9-very easy (see Table IV.15). A Comparison Ranking Survey was administered upon evaluation completion (see Table IV.16). Each question required the participant to specify which visualization condition was easier to use. The Comparison Ranking Survey provided three options for each question: Feature Sets, POIs, or "Both were equally easy".

IV.5.5 Results

Shapiro-Wilk tests determined that the data deviated significantly from a normal distribution; therefore, non-parametric statistical analyses were performed. A two-tailed, paired Wilcoxon signed-rank test was used for all comparison tests, unless stated otherwise. No multiple-comparison tests were performed on single

	Appear Group Unsafe	**Appear Solo Unsafe**	**No Appear Group Unsafe**
Feature Sets	90	100	96.67
POIs	20	96.67	86.67

Table IV.17: Correct Task Percentage by task type for the Temporal Context Evaluation.

	Appear Group Unsafe			**Appear Solo Unsafe**			**No Appear Group Unsafe**		
	median	**min**	**max**	**median**	**min**	**max**	**median**	**min**	**max**
Feature Sets	27.5	24	61	49.5	27	78	47	39	66
POIs	50.8	23.5	82.4	58.5	37	82	73	37	115

Table IV.18: Correct Task Duration by task type for the Temporal Context Evaluation.

data sets; therefore, no omnibus testing was used and there was no requirement to adjust for familywise error. Non-parametric descriptive statistics (e.g., medians and ranges) are also reported in accordance with the statistical analysis performed.

IV.5.5.1 Objective Metrics

The Correct Task Percentage descriptive statistics show that, for all task types, Feature Sets result in more tasks performed correctly (see Table IV.17). Feature Sets result in significantly more correct answers for the *Appear Group Unsafe* task type ($W(29) = 231, z = -4.76, p < 0.001$), indicating the superiority of Feature Sets when task completion is contingent upon recognizing the arrival of new information in visually cluttered map areas. This finding is supported by similar results for Correct Answer Percentage for the *Appear Solo Unsafe* task. When information is added in areas that contain no previous information, the addition is salient, regardless of the method used to visualize that information.

The descriptive statistics for Correct Task Duration show that, for all task types, Feature Sets result in lower durations to complete tasks correctly (see Table IV.18). An unpaired Wilcoxon signed-rank test determined that Feature Sets had a significantly faster Correct Task Duration for the *Appear Group Unsafe* ($W(45) = 389, z = -2.68, p < 0.01$), *Appear Solo Unsafe* ($W(45) = 117, z = -2.67, p < 0.01$), and *No Appear Group Unsafe* ($W(54) = 102.5, z = -4.81, p < 0.001$) tasks. A significant difference for *No Appear Group Unsafe* suggests that Feature Sets are faster when searching static information for specific information items, supporting findings from the Geospatial Context Evaluation (see Chapter IV.4.5).

The Map Interaction statistics are summarized in Figure IV.12 and show that Feature Sets result in significantly fewer Pan and Zoom Counts and lower Pan and Zoom Durations than POIs (see Table IV.19). Overall, Feature Sets require fewer interactions with the map to locate and interact with information.

Participants typically performed one or two zoom gestures to reach a comfortable zoom level for viewing

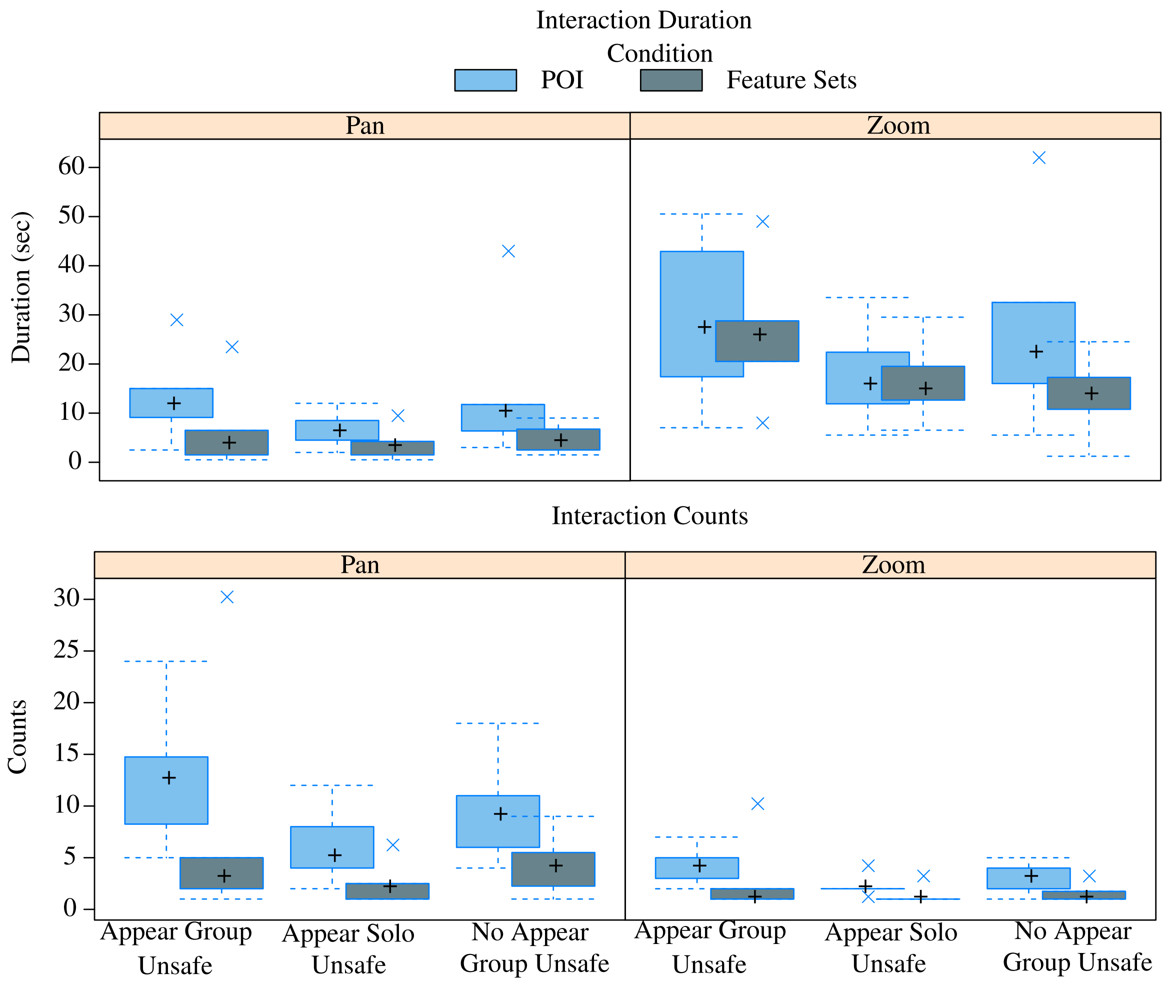


Figure IV.12: Map Interaction descriptive statistics for the Temporal Context Evaluation.

	Pan Count			**Zoom Count**		
	W(29)	**z**	**p**	**W(29)**	**z**	**p**
Appear Group Unsafe	58.5	-5.17	< 0.001	69	-6.05	< 0.001
Appear Solo Unsafe	86	-5.47	< 0.001	124.5	-5.68	< 0.001
No Appear Group Unsafe	79.5	-5.73	< 0.001	78.5	-6.04	< 0.001
	Pan Duration			**Zoom Duration**		
	W(29)	**z**	**p**	**W(29)**	**z**	**p**
Appear Group Unsafe	103	-3.83	< 0.001	-	-	-
Appear Solo Unsafe	141	-4.28	< 0.001	-	-	-
No Appear Group Unsafe	107	-5.1	< 0.001	184	-3.76	< 0.001

Table IV.19: Map Interaction comparison test results for the Temporal Context Evaluation.

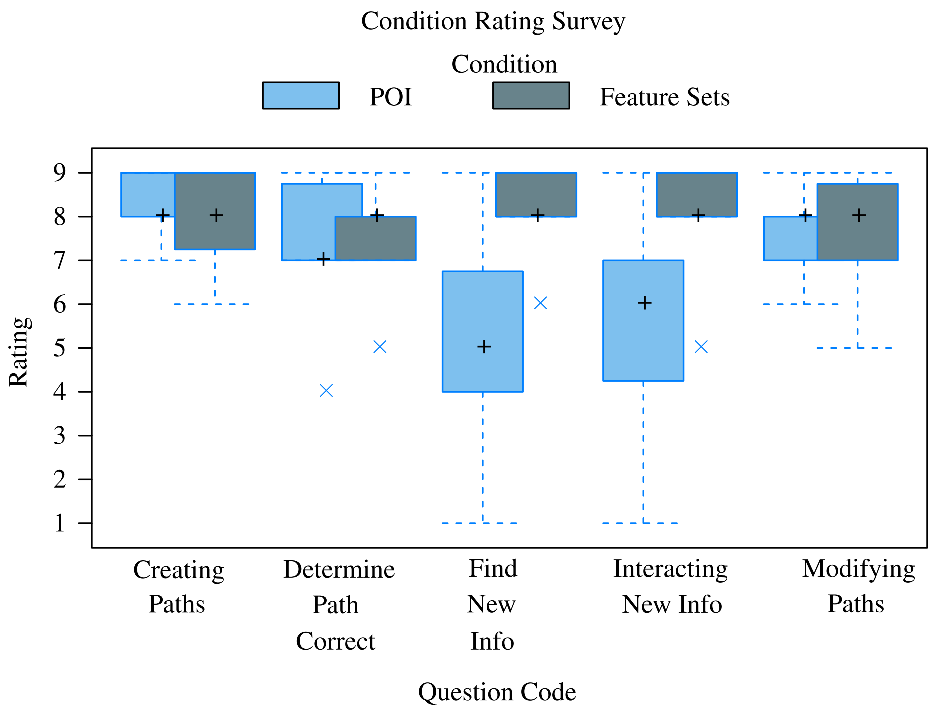


Figure IV.13: Condition Rating Survey descriptive statistics.

individual information, which participants did not alter when searching through information. This behavior was particularly true for POIs. The Zoom Count results show that participants performed more zoom gestures with POIs, indicating that perhaps more map adjustment was necessary to ideally view information.

IV.5.5.2 Subjective Metrics

The descriptive statistics for the Condition Rating Survey indicate that Feature Sets rate as good as or better than POIs for each question category (see Figure IV.13). It was expected that the drawing-based categories (i.e., *Creating Paths* and *Modify Paths*) will be rated similarly, since drawing was implemented identically for both conditions.

Categories concerned with the presentation of and interaction with information clearly show a preference for Feature Sets. Feature Sets were preferred significantly for the *Find New Info* ($W(29) = 777, z = -5.106, p < 0.001$) and *Interact New Info* ($W(29) = 734.5, z = -4.35, p < 0.001$) categories. Feature Sets had a higher preference for the *Determine Path Correct* category that was not significant. This result is puzzling, since determining the correctness of a drawn path requires finding and interacting with new information; two tasks for which Feature Sets were clearly preferred.

The Condition Ranking descriptive statistics indicate a clear preference for four of the five categories (see Table IV.20). A test of equal proportion performed at 95% confidence found Feature Sets ranked significantly

	Map Features	POIs	Equally Easy
Creating Paths	13	0	17
Determine Path Correct	16	0	14
Find New Info	23	5	2
Interact New Info	21	4	5
Modifying Paths	12	0	18
Determine Path Needs Modification	22	2	6

Table IV.20: Condition Ranking Survey Descriptive Statistics.

higher for the *Find New Info* (Feature Sets: CI(0.6210, 0.8682)), *Interact New Info* (Feature Sets: CI:(0.5506, 0.8163)), and *Determine Modification Needed* (Feature Sets: CI(0.5854, 0.8427)) categories. A significant difference for the *Determine Modification Needed* category supports the claim that Feature Sets are preferred for discovering and interacting with new information. The *Determine Path Correct* results may indicate that participants ranked their preference for determining the drawn path was correct in terms of direction and orientation (i.e, the path correctly moved from marker A to marker B), rather than determining whether or not the path correctly avoided unsafe items.

IV.5.6 Discussion

The results support the hypotheses (see Table IV.14). The significantly higher values for the Task Correct Percentage and Correct Task Duration metrics show that Feature Sets result in more tasks performed correctly and in less time than POIs. Performing tasks correctly required participants to find new information as it was added to the map, thus these results confirm H_1 and H_2. The ease of finding new information can be directly attributed to leveraging the temporal context to dictate the design of Feature Sets. Both notification indicators and chronological ordering in a Feature Sets' item list ensures that users were able to easily find new information as soon as it was added to the map. Incorporating temporal context gave Feature Sets a definitive advantage over the POI implementation.

The objective results for map interaction indicate that participants did not need to perform as many pans or zooms to find newly added information with Feature Sets, thus confirming H_3. Leveraging temporal context ensured that participants did not need to manipulate the map as frequently to search for new information, a benefit of the notification indicators and clutter reduction provided by aggregating items. Reducing map interaction is beneficial, since users spend less time interacting with the map and more time interacting with the environment and provided information.

Feature Sets are subjectively preferred over POIs when locating and interacting with new information, which supports hypothesis H_4. User preference for Feature Sets is likely due to the inherent design aspects (e.g., notification indicators and chronological ordering in the expanded view) that provide users with salient information updates, a direct result of leveraging the temporal information context.

This evaluation was conducted using a relatively low information density, twenty information items per cluster. It is expected that with greater information density, the benefits of leveraging the temporal context for enabling new information discovery and interaction will become even more apparent.

IV.6 The Semantic Context Evaluation

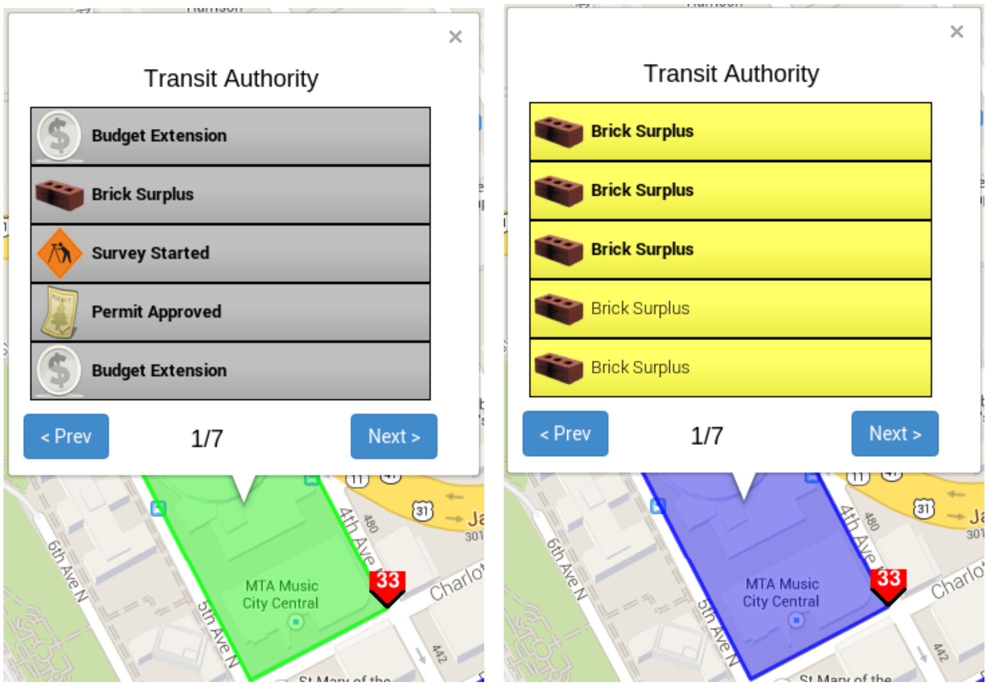
The Semantic Context Evaluation was designed to determine whether or not information highlighting, as implemented, leverages semantic context and improves overall usability. This evaluation analyzed four different types of information highlighting and a control condition that did not use highlighting.

The five highlighting conditions were: Feature Set, only Feature Sets were highlighted (see Figure IV.14a); Item, only information items were highlighted (see Figure IV.14b); Mixed, both Feature Sets and information items were highlighted, using separate controls (see Figure IV.14c); Combined, which highlighted both Feature Sets and information items using a single set of controls (see Figure IV.14c); and Control, which did not present any highlighting controls and displayed question responses at all times (see Figure IV.14d).

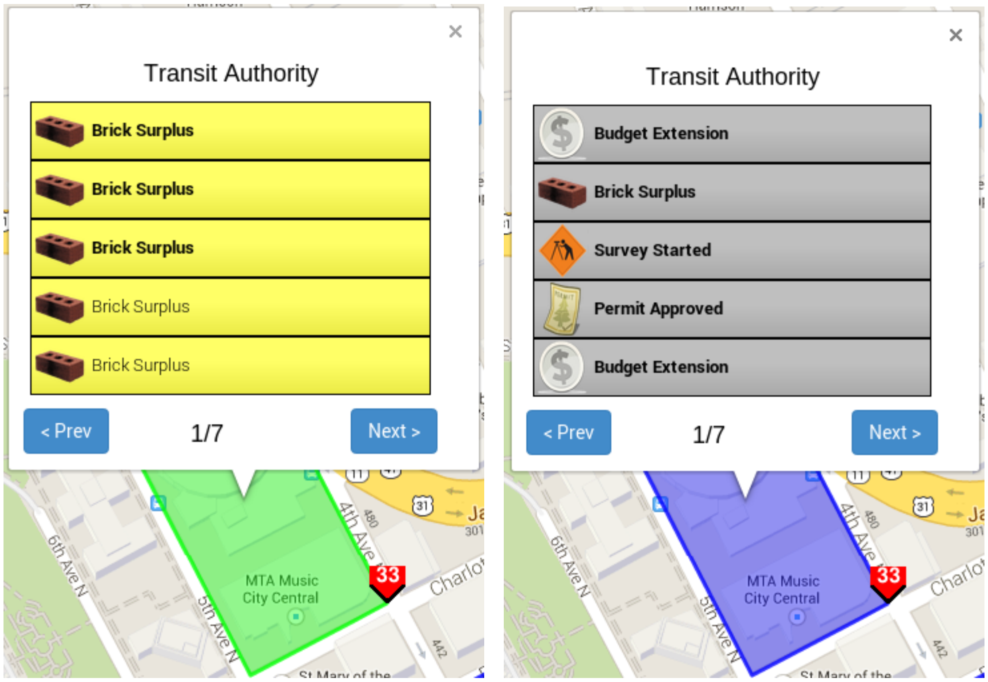
Each condition was chosen to provide varying levels of control for the highlighting functionality. Each technique presents a trade-off with respect to the type and amount of information highlighted and interaction time. For example, both Feature Set and Item highlighting only highlight one particular subset of the available information; however, highlighting either Feature Sets or information items can be accomplished quickly in a straightforward manner. A single button group can be used to activate each type of highlighting (see Chapter III.5). The Mixed condition provides more control over how information is highlighted, but requires additional interaction to highlight information items and Feature Sets simultaneously.

The Combined condition was added after pilot testing the other highlighting techniques. The Combined method permits highlighting both Feature Sets and information items using a single button press; however, some control is lost when compared to the Mixed condition. Using the Mixed condition, users have greater flexibility related to how information is highlighted; therefore, the Combined and Mixed conditions present a trade off between ease-of-use and flexibility.

Other factors of Feature Sets are investigated in addition to semantic context. The impact of information highlighting on situation awareness (SA) was assessed using real-time SA probes. The four highlighting techniques were also compared subjectively in order to determine user preference. Finally, the impact of highlighting on participants' ability to combine information from multiple Feature Sets was assessed in order to determine the benefits of the semantic context.



(a) Feature Sets Highlighting (b) Item Highlighting



(c) Mixed and Combined Highlighting (d) Control

Figure IV.14: Visualization states for each of the five highlighting conditions. Note that the Mixed Highlighting condition can display any of the above visualization states, depending on user input.

IV.6.1 Test Apparatus

The same general apparatus was used for the Semantic Context Evaluation as was utilized for the Geospatial and Temporal Context Evaluations (see Chapter IV.3); however, extensions to the Information Panel were required to provide highlighting capabilities.

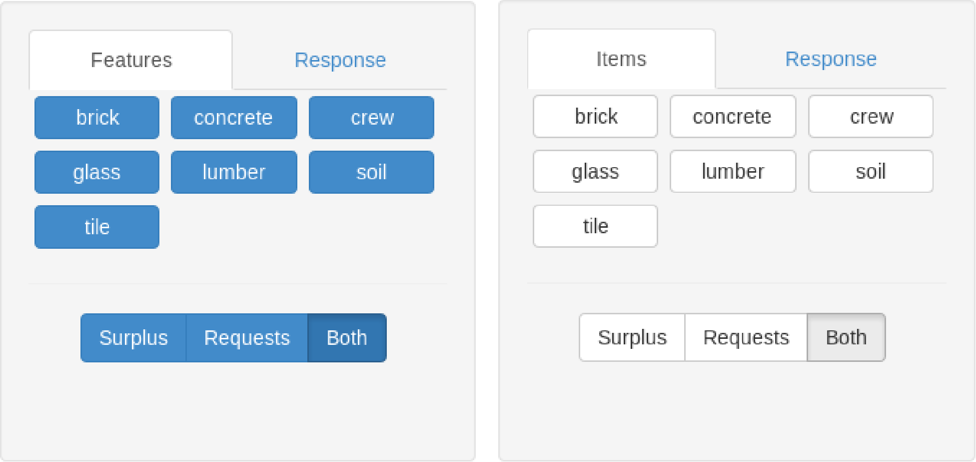
The Information Panel (see Figure IV.1) was extended to accommodate the interaction components required to support each highlighting technique. The extensions required adding additional tabs for highlighting button groups (see Figure IV.15), or altering the appearance of the button groups used for a particular highlighting condition. Five different configurations of the Information Panel were used, one for each highlighting condition and one for the control condition. Controls for toggling highlighting functionality were located within individual tabs on the Information Panel. A Response tab was added that contained the list of responses for the displayed question. If multiple highlighting techniques were present in a condition, a separate tab was provided for each technique.

The Feature Set condition uses a single button group (see Figure IV.15a). Buttons in this group are blue in color to provide a subtle visual clue indicating that the buttons enable highlighting on Feature Sets' geospatial containers, which are similarly colored. The Item condition uses a button group that is gray in color to indicate that the button group toggles highlighting functionality for information items, which are gray in color when not highlighted (see Figure IV.15b). The Mixed condition used both button groups, residing in individual tabs (see Figure IV.15c), to facilitate the independent highlighting of Feature Sets and information items. The Combined condition coupled Feature Set and information item highlighting into a single button group (see Figure IV.15d). Finally, the Control condition did not incorporate highlighting; therefore, contents of the Response tab was visiable at all times on the Information Panel (see Figure IV.15e).

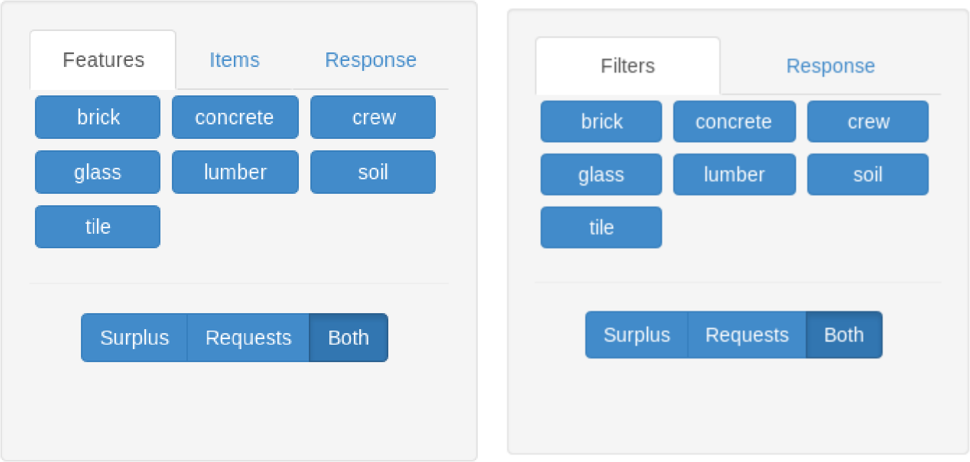
Highlighting was implemented identically to the discussion presented in Chapter III.5. The geospatial container of a Feature Set altered its appearance from blue to green when highlighted, and information items altered their background color from gray to yellow when highlighted (see Figure III.4).

A construction management scenario was used for the Semantic Context Evaluation that incorporated fourteen resource types (see Figure IV.16). The appearance of the Feature Sets' overview, expanded, and detail views was identical to prior evaluations (see Figure IV.2), unless information highlighting functionality was enabled (see Figure III.4).

The evaluation required participants to determine the status of resources at various construction sites on the map. Each construction site was represented as a Feature Set and individual information items were represented as reports. Each report was one of three types: Surplus, Request, or Distractor. Surpluses alerted participants to an excess of a particular resource type at a Feature Set, while Requests alerted participants to



(a) Feature Sets Highlighting (b) Item Highlighting



(c) Mixed Highlighting (d) Combined Highlighting

(e) Control

Figure IV.15: Information Panel display for each of the four highlighting conditions and the control condition. Note that in each case, highlighting specific controls are located in their own respective tabs and are presented as button groups.

(a) Brick (b) Budget (c) Concrete (d) Crew (e) Electricity On (f) Electricity Off (g) Glass (h) Machinery

(i) Lumber (j) Manager (k) Permit (l) Soil (m) Survey (n) Tile

Figure IV.16: The fourteen report types used in the Semantic Context Evaluation.

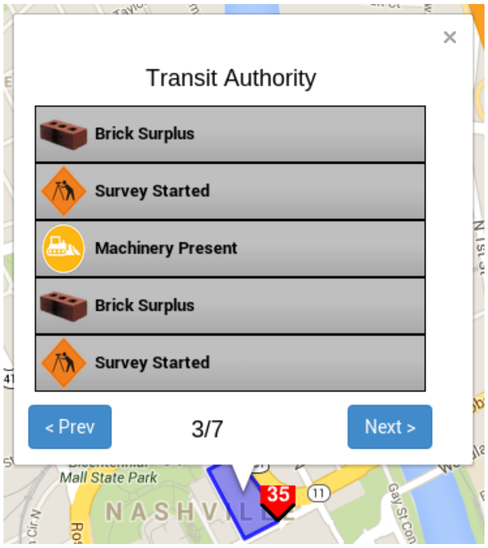
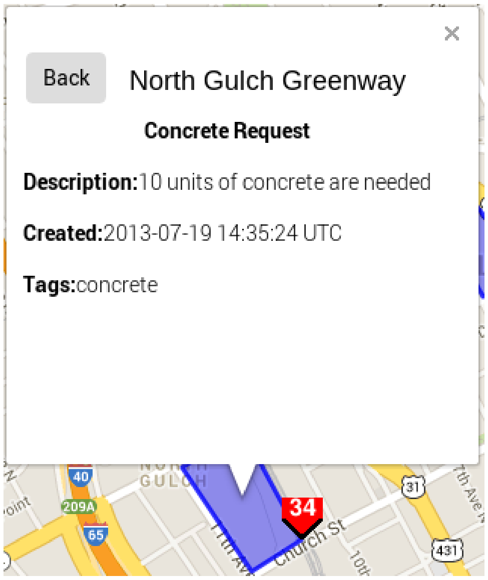


Figure IV.17: A Feature Set expanded view showing two Brick Surplus reports and three Distractor reports. Each report type leveraged unique iconography and text to make the report easily identifiable.



North Gulch Greenway

Concrete Request

Description:10 units of concrete are needed

Created:2013-07-19 14:35:24 UTC

Tags:concrete

Figure IV.18: A detail view for a Concrete Request report.

a site's need for a certain resource. Distractor reports did not indicate a request or surplus. Each resource type possessed an associated icon to make reports easily identifiable in the Feature Set expanded views (see Figure IV.17). Text placed beside each icon in the expanded view indicated if the report was a Surplus or a Request. Distractor reports did not contain the word "Surplus" or "Request" in the Feature Set's expanded view. Seven of the resource types shown in Figure IV.16 were used as Distractors (i.e., the Budget, Electrictiy On / Off, Machinery, Manager, Permit, and Survey resource types) and seven were used to represent Surpluses and/or Requests (i.e., Brick, Concrete, Crew, Glass, Lumber, Soil, Tile). Surplus and Request reports utilized resource types that represented building materials or personnel (e.g., bricks, concrete, and crew), while Distractor reports utilized types that represented actions and equipment.

The detail view of a Distractor report contained text relevant to the report type (e.g., "Heavy machinery is now present on the site" for a report pertaining to heavy machinery). The detail view of Surplus and Request reports contained a specific value of extra or requested resources (e.g., "ten units of surplus concrete are available at this site" for a Concrete Surplus report as shown in Figure IV.18). Some instances contained multiple identical Surplus or Request reports (e.g., multiple Concrete Requests), but never contained Surplus and Request reports for the same resource. The amounts depicted for surpluses and requests in the reports' detail views were additive for reports of the same resource type. For example, if a Feature Set contained three Concrete Requests with each report requesting ten units of concrete, the site required 30 units of concrete in total.

Distractor items added additional reports to Feature Sets and were not impacted by the highlighting tech-

Location Knowledge	Count
I cannot find these locations	2
I can find a few of these locations	12
I can easily find these locations	7
I can find all of these locations with effort	9

Table IV.21: Participants' self-reported assessment of their *a priori* knowledge of the geographic region used for the Semantic Context Evaluation.

niques. Distractor items essentially served as random noise to provide additional complexity and variety to the content of Feature Sets. Surpluses and Requests were impacted by highlighting techniques and were used to represent potential flows of resources between sites. Surpluses and Requests were used because they provided a straightforward approach to task design. For example, if participants were asked to locate the resources required to fulfill a Concrete Request report, searching other Feature Sets for Concrete Surplus reports was an intuitive first step.

IV.6.2 Participants

Thirty (15 females and 15 males) participants performed the evaluation. A Shapiro-Wilk test determined that participant age deviated from a normal distribution $(W(30) = 0.87, p < 0.01)$. The participant median age was 23.5 years, the minimum reported age was eighteen years and the maximum reported age was thirty-five years. Twenty-six participants performed the experiments using the right hand.

Participants were asked to rate their understanding of the map used for the evaluation. Participants were given the names of three locations on the map and asked if they were able to find these locations on an unlabelled map (see Table IV.21). 53.3% of participants reported the ability to find all three locations. 6.66% reported the inability to find any of the locations. Despite these ratings, *a priori* map knowledge did not effect the presented results.

A demographic survey assessed participants' level of weekly computer use with particular computing platforms (see Table IV.22) and their self-reported map expertise (see Table IV.23). These demographic survey results were correlated to objective metrics of performance (see Chapter IV.6.5); however, no correlation to any performance metric was significant.

IV.6.3 Experimental Design

The experimental design was a 5×5 Graeco-Latin square using Task Set as a blocking factor and highlighting condition as a treatment factor. A single trial consisted of an information highlighting condition and Task Set pairing. Each participant performed five pairings that represented a single "row" of the Graeco-Latin square

	Computing Device				
Hours per Week	**Desktop**	**Laptop**	**Tablet**	**Smartphone**	**Other**
No time per week	4	13	1	7	8
Less than one	5	7	9	14	1
One to Ten	8	9	2	6	21
11 to 20	6	1	2	1	–
21 or More	7	–	16	2	–

Table IV.22: Participants' self-reported assessment of hourly computing device usage per week by form factor.

Level	**Count**
None	1
Basic	8
Good	15
Expert	6

Table IV.23: Participants' self-reported assessment of map understanding.

(see Table IV.24). The row a participant performed was chosen at random. Since thirty participants performed the evaluation, each row was performed six times, and resulted in six complete replications of the Graeco-Latin square.

The independent variables in the Semantic Context Evaluation were the highlighting condition and the question type. Five individual information highlighting conditions were evaluated (see Chapter IV.6) and two question types were used: tasks and real-time SA probes (see Table IV.25). Tasks required participants to use the map, Feature Sets, and a highlighting technique (excluding the Control condition) to provide the correct response. Tasks were designed to require participants to search for new information in order to determine the effectiveness of each highlighting technique for *information discovery*. SA Probes were intended to asses situation awareness and were able to be answered using information to which the participant had already been exposed. The SA Probes were designed to determine the benefit of each highlighting technique for

Item I	Feature Set II	Mixed III	Control IV	Combined V
Feature Set III	Mixed IV	Control V	Combined I	Item II
Mixed V	Control I	Combined II	Item III	Feature Set IV
Combined IV	Item V	Feature Set I	Mixed II	Control III
Control II	Combined III	Item IV	Feature Set V	Mixed I

Table IV.24: The Graeco-Latin square design of the Semantic Context Evaluation. Each cell contains a single information highlighting condition and Task Set pairing. A single participant performed one row of the matrix.

Category	**Highlighting Condition**	**Task Structure**
Task	**Feature Set**	Which site has *X*?
		Which site can use *X* from site *Y*?
	Item	How many *X* are available at site *Y*?
		How many *X* are on the map?
	Mixed/Combined	Which site has reports for *X* and *Y*?
		How many sites have reports for *X* and *Y*?
	SA Level	**SA Probe Structure**
SA Probe	**One**	Are any *X* present at site *Y*?
		Are any *X* available on the map?
	Two	Does site *Y* have enough resource *X* to complete work?
		Can site *Y* begin a new job that requires resource *X*?
	Three	Is it likely that site *Y* will request resource *X* in the future?
		Which site seems likely to request *X* in the future?

Table IV.25: Examples of each of the tasks and SA probes asked within each Task Set.

information recall.

Participants were allowed to use all available tools to answer tasks and SA probes. Since SA probes required information the user had encountered previously during the trial, participants possessing a high level of situation awareness may be able to answer SA probes without using any of the available tools. Additionally, if participants recall information leveraged from performing tasks, but still use highlighting tools to answer a SA probe correctly, then response times for SA probes may be lower than if the participant did not recall prior information.

Five Task Sets were used for evaluating each of highlighting condition. Each Task Set presented twelve questions: six SA probes and six tasks (see Table IV.25). The six task questions were designed to leverage each highlighting technique, such that two tasks were performed more efficiently using Feature Set Highlighting, two were more efficient with Item Highlighting, and two were more efficient with the Mixed/Combined Highlighting.

Task questions were always presented before SA probes, such that information obtained while completing tasks was available for completing the subsequent SA probes. The presentation order of individual tasks and SA probes was partially randomized for each of a participant's six trials. Randomization was partially controlled to ensure that no participant encountered a SA probe without first performing the task that contained the relevant information to answer the SA probe.

Each Task Set contained twelve unique Feature Sets, and each Feature Set contained 35 unique reports. All Task Sets focused on the same geospatial area (i.e., downtown Nashville, Tennessee) and Feature Sets were evenly distributed throughout the area (see Figure IV.19). The task questions in each Task Set were designed to use the reports and Feature Sets associated with that Task Set.

All questions were multiple choice and the answer choice presentation order was randomized between participants by question. A "Do not know" response was provided and participants were encouraged only to choose it if they did not know the answer. The "Do not know" response was intended to limit the occurrence of lucky guesses.

The map's default position and initial zoom level was such that all Feature Sets were viewable. Upon the completion of a task or probe, the zoom level and map position reset to their defaults (see Figure IV.19), such that all participants began each question from the same starting map position and zoom level.

Participants underwent a ten minute basic training scenario prior to performing the evaluation that familiarized them with basic interface operation (e.g., map manipulation, providing question responses, and basic Feature Set usage). The basic training scenario introduced each of the report type icons (see Figure IV.16). Before each condition, a short, five-minute training scenario introduced the information highlighting technique to be used during the subsequent trial.

Participants were encouraged to leverage their memory whenever possible to provide answers to questions during each trial. The purpose of this approach was to encourage participants to rely on information recall when answering the SA probes.

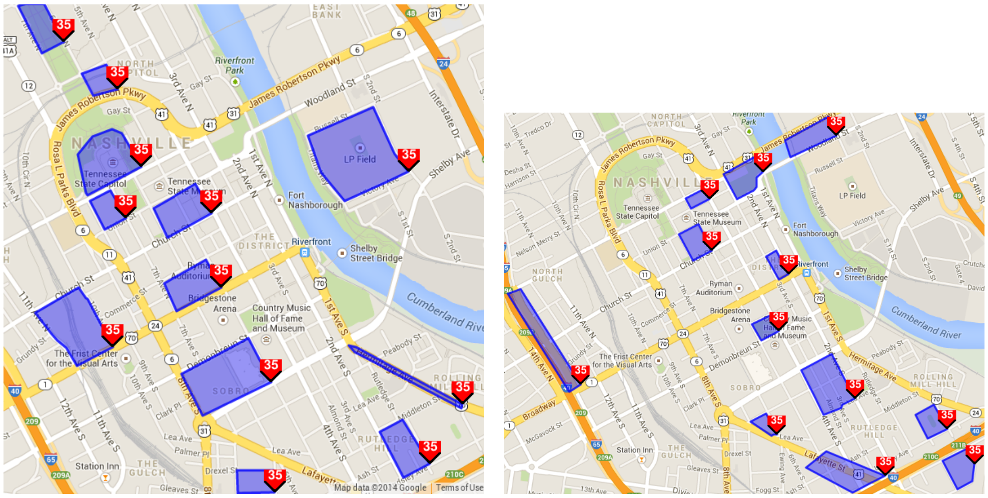
IV.6.4 Hypotheses

Five hypotheses were developed and are summarized in Table IV.26.

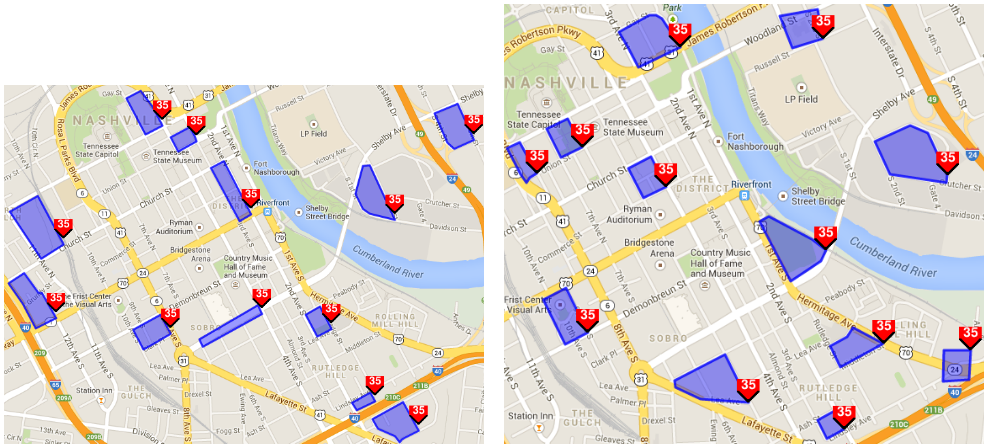
Each of the evaluated highlighting techniques provide benefits for identifying information when compared to the Control condition. Depending on the information highlighting technique, some aspect of information search (e.g., finding the appropriate Feature Set, finding the appropriate report) can be performed faster than when using the Control condition. It was hypothesized, H_1, that each information highlighting technique will

	Hypotheses
H_1	Information highlighting techniques will result in improved task completion times. the map.
H_2	Information highlighting techniques that alter the appearance of Feature Sets will result in the correct Feature Set being discovered more quickly.
H_3	Tasks and SA probes that require multiple information sources to be answered will be answered more quickly when using information higlighting techniques.
H_4	SA probes will be answered more quickly than tasks when no highlighting techniques are utilized.
H_5	Either the Mixed or the Combined condition will be subjectively preferred.

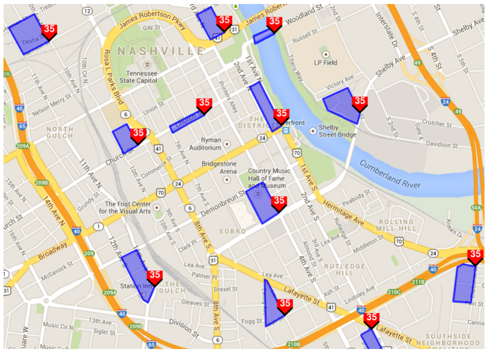
Table IV.26: The Semantic Context Evaluation's four primary hypotheses.



(a) Task Set I (b) Task Set II



(c) Task Set III (d) Task Set IV



(e) Task Set V

Figure IV.19: The Feature Sets used for each of the five Task Sets. Feature Set distribution was relatively uniform throughout the area of interest.

result in improved task completion times.

It is expected that information highlighting techniques that alter the appearance of Feature Sets (i.e., the Feature Set, Mixed, and Control conditions) will result in those Feature Sets being discovered more quickly by participants. It was hypothesized, H_2, that methods that alter the appearance of Feature Sets will result in the appropriate Feature Set being discovered more quickly than when using those techniques that do not alter a Feature Set's appearance.

The process of discovering multiple sources of information (e.g., multiple Feature Sets, multiple types of information items) efficiently is key to supporting semantic context (see Chapter II.1). A system designed to support semantic context must provide adequate measures for viewing and interacting with potentially related items. It is expected that information highlighting techniques will reduce the time needed to find and interact with multiple items simultaneously. It was hypothesized, H_3, that tasks and SA probes that require multiple information sources to be answered correctly will be answered more quickly when using information highlighting.

Participants were encouraged to leverage their memory as much as possible when performing each trial. Since the Control condition provides no effective means for accessing required information quickly, it is believed that participants will rely more on memory recall to answer SA probes than when additional tools (i.e., information highlighting techniques) are present. It is expected that memory recall will occur more frequently when using the Control condition, leading to a significant difference in response times between tasks and SA probes. It was hypothesized, H_4, that SA probe response times will be significantly faster than tasks when the information highlighting techniques are not used.

Both the Mixed and Combined conditions provide the functionality necessary to highlight Feature Sets and information items. Due to the ability to quickly discover information of both types (i.e., Feature Set and information item), it is believed that participants will subjectively prefer these techniques to the more limited highlighting techniques. However, since both highlighting techniques provide an ease-of-use and flexibility trade off, it is difficult to determine which condition, Mixed or Combined, will be preferred overall. It was hypothesized, H_5, that either the Mixed or Combined condition will be subjectively preferred by participants as compared to the other highlighting techniques.

IV.6.5 Metrics

The evaluation metrics were collected on a per-trial basis. The objective metrics were logged automatically during the trial and were aggregated from each of the task questions and the SA probes performed within each trial. The subjective metrics were obtained by a Likert scale rating survey administered after each trial and a comparison survey administered upon evaluation completion.

IV.6.5.1 Objective Metrics

The objective metrics for the Semantic Context Evaluation include:

- Correct Answer Count. The count of correct answers reported per condition. These counts are reported overall (Total Correct Question Count) and for questions requiring information from multiple sources (Multiple Source Correct Answer Count).

- Duration. The total time required to complete a single question, reported per condition and measured in seconds. The durations are reported overall (Total Duration), for tasks and SA probes (Task Duration and SA Probe Duration), and for questions that required information from multiple sources (Multiple Source Question Duration).

- Time to Find Feature Set (TFFS). The total time taken to find the appropriate Feature Set required to answer a question or probe, reported per condition and measured in seconds.

- Feature and Item Highlighting Count. The total count of how frequently a participant performed Feature Highlighting and Item Highlighting in the Mixed condition.

The Correct Answer Count measures the effectiveness for all conditions when answering task and SA probe questions correctly. Since each trial presents six task and six SA probe questions, the highest Correct Answer Count that can be achieved per trial is twelve.

All Duration metrics were measured from the time a new question was displayed until the participant provided an answer and pressed the “Next” button. The Multiple Source Question Duration was measured for those questions that required users to interact with multiple Feature Sets to determine the question’s correct answer. Time to Find Feature Set (TFFS) was measured from the time a new question was displayed until the time that the participant found the Feature Set required to answer the question. If a question required more than one Feature Set to be located, the time to find all necessary Feature Sets was recorded.

The Feature and Item Highlighting Count is reported for the Mixed condition only, since it is the only condition that allows participants a choice of highlighting technique. This metric serves to determine which highlighting method participants leveraged more frequently when presented with the option to use both techniques independently.

IV.6.5.2 Subjective Metrics

A Condition Rating Survey was administered upon the completion of each trial to subjectively assess the performance of each highlighting technique. The Condition Rating Survey assessed participants’ perceived

Question Code	Survey Question
Find Feature Sets	Finding Feature Sets relevant to answering questions was...
Find Specific Reports	Finding specific Surpluses and Requests on the map was...
Count Items Within	When required, counting the occurrence of a report type within a Feature Set was...
Count Sites Map	When required, counting the number of certain sites on the map was...
Find Multiple Sources	When required, finding multiple sources of information to answer a question was...
Perform Highlight	Performing the needed interactions to highlight necessary information was...
Interact Feature Set	Interacting with Feature Sets was...
Interact Map	When needed, interacting with the map (i.e., panning and zooming) was...

Table IV.27: Codes used for the subjective metrics and their corresponding questions from the Condition Rating Survey.

Question Code	Survey Question
Easiest General	In general, I found it easier to use...
Easiest Highlighting	When filtering information, it was easier to use...
Easiest Post-Highlight	Information was easier to use after filtering information with...
Easiest Map Interaction	The map was easier to interact with when using...
Easiest Feature Sets	Interacting with Feature Sets was easier when using...
Fastest Performance	I felt like I performed faster when using...
Correct Performance	I felt like I performed more correctly when using...
Easiest View	It was easier to view resources and surpluses when using...

Table IV.28: Question codes and their corresponding questions as asked in the Comparison Ranking Survey.

performance via eight Likert scale questions on a nine point scale, 1-very difficult to 9-very easy (see Table IV.27).

A Comparison Ranking Survey ranked each of the highlighting techniques and the control condition across nine factors (see Table IV.28). Ranking options for each factor were: Combined, Mixed, Feature Set, Item, and Control.

IV.6.6 Results

An aligned rank transform (ART) ANOVA (Wobbrock et al., 2011) was used to perform all omnibus testing. The Wilcoxon signed rank test was used for analysis, unless stated otherwise, since a Shapiro-Wilk test determined that data deviated significantly from a normal distribution. Non-parametric descriptive statistics (e.g., medians and ranges) are reported. The Holms p-value adjustment method was used when adjustments were needed to control familywise error. No participants were dropped from analysis as a result of performance.

IV.6.6.1 Objective Metrics

The Total Correct Answer Count medians are comparable for each highlighting condition (see Table IV.29). An ART ANOVA did not find a significant main effect for highlighting condition. This outcome is not surprising, since the evaluation was untimed, participants were permitted all the time necessary to answer questions.

The Total Duration medians (see Table IV.30) indicate that all highlighting conditions resulted in faster overall performance than the Control condition (see Table IV.31). An ART ANOVA found a significant main effect for highlighting condition ($F(4,116) = 121.6, p < 0.0001$), and all pairwise comparisons were significant (see Table IV.31). The Combined condition resulted in the fastest performance of all tested conditions.

The Task and SA Probe Duration medians demonstrate the difference between performance time for tasks and SA probes within each highlighting condition (see Table IV.32). The largest difference exists for the Control condition, which is significant ($W(179) = 857.5, z = 5.90, p < 0.001$). Significant differences were also found between Task Duration and SA Probe Duration for Item ($W(179) = 872.5, z = 6.13, p < 0.001$) and Feature Set ($W(179) = 611, z = 2.10, p < 0.017$), although the size of the effect for Feature Set is small. The large differences in Task and SA Probe Duration for the Control condition may indicate that participants used recall when answering questions, as opposed to leveraging the interface to rediscover information. Task and SA Probe Duration for the Combined condition indicates that participants may have used the interface to find information regardless of question type, perhaps because using the Combined highlighting was more convenient than recalling the information from memory. Conditions that highlight Feature Sets (i.e., Combined, Feature Set, and Mixed) possessed similar Task and SA Probe Durations. This result may indicate that the most time consuming aspect of answering a question is finding the correct Feature Set, and since the Combined, Feature Set, and Mixed conditions allowed participants to find Feature Sets quickly, performance time for tasks was similar to recalling needed information from memory.

The TFFS metric medians (see Table IV.33) indicate similar performance to the Total Duration metric. Highlighting techniques that leverage Feature Set highlighting result in similar time to find the appropriate Feature Set, independently of performing a task or a probe. A significant main effect was found for the highlighting condition for tasks ($F(4,116) = 11.1, p < 0.0001$) and SA probes ($F(4,116) = 22.1, p < 0.0001$). All familywise comparisons for tasks were significant, except for the Item - Control, Feature Set - Combined, and Mixed - Combined comparisons (see Table IV.34). All familywise comparisons for SA probes were

	Correct Answer Count		
Condition	**median**	**min**	**max**
Control	11.00	8.00	12.00
Combined	12.00	10.00	12.00
Item	11.00	10.00	12.00
Feature Set	11.00	10.00	12.00
Mixed	12.00	10.00	12.00

Table IV.29: Total Correct Answer Count descriptive statistics, where the reported median is calculated per trial and aggregated for all participants.

	Duration (sec)		
Condition	**median**	**min**	**max**
Control	587.00	479.00	878.00
Combined	216.50	141.00	303.00
Item	342.00	257.00	488.00
Feature Set	270.00	187.00	405.00
Mixed	235.00	151.00	324.00

Table IV.30: The Total Duration descriptive statistics, where the reported median is calculated per trial and aggregated for all participants.

	Control			Combined			Item			Feature Set		
	W(29)	**z**	**p**	**W(29)**	**z**	**p**	**W(29)**	**z**	**p**	**W(29)**	**z**	**p**
Combined	0	4.17	< 0.001	–	–	–	–	–	–	–	–	–
Item	2	4.17	< 0.001	881	5.49	< 0.001	–	–	–	–	–	–
Feature Set	0	5.49	< 0.001	760	3.24	< 0.001	163	3.74	< 0.001	–	–	–
Mixed	0	4.17	< 0.001	626	2.24	0.012	63	4.17	< 0.001	276.5	2.24	0.012

Table IV.31: The pairwise Wilcoxon results for the Total Duration metric.

		Duration (sec)		
Condition	**Type**	**median**	**min**	**max**
Control	SA Probe	21.00	1.00	117.00
	Task	71.50	1.00	167.00
Combined	SA Probe	14.00	6.00	57.00
	Task	14.00	7.00	54.00
Item	SA Probe	17.00	5.00	70.00
	Task	35.00	8.00	102.00
Feature Set	SA Probe	15.00	6.00	85.00
	Task	19.00	5.00	71.00
Mixed	SA Probe	16.50	3.00	81.00
	Task	17.00	2.00	89.00

Table IV.32: Descriptive Statistics for Task and SA Probe Duration per highlighting condition.

		TFFS (sec)		
Condition	**Type**	**median**	**min**	**max**
Control	SA Probe	0.00	0.00	6.00
	Task	9.00	1.00	20.00
Combined	SA Probe	3.00	0.00	7.00
	Task	2.00	1.00	10.00
Item	SA Probe	2.00	0.00	8.00
	Task	9.50	1.00	19.00
Feature Set	SA Probe	4.00	2.00	15.00
	Task	3.00	1.00	25.00
Mixed	SA Probe	4.50	1.00	27.00
	Task	5.50	2.00	17.00

Table IV.33: Descriptive Statistics for the TFFS metric.

	Control			**Combined**			**Item**			**Feature Set**		
	W(29)	**z**	**p**	**W(29)**	**z**	**p**	**W(29)**	**z**	**p**	**W(29)**	**z**	**p**
Combined	96	2.88	< 0.01	–	–	–	–	–	–	–	–	–
Item	*not sig.*			341.5	2.88	< 0.01	–	–	–	–	–	–
Feature Set	96.5	2.60	< 0.01	*not sig.*			108.5	2.44	< 0.001	–	–	–
Mixed	110	2.60	< 0.01	*not sig.*			112	2.60	< 0.01	404.5	1.98	0.023

Table IV.34: TFFS metric pairwise Wilcoxon signed rank results for tasks.

	Control			**Combined**			**Item**			**Feature Set**		
	W(29)	**z**	**p**	**W(29)**	**z**	**p**	**W(29)**	**z**	**p**	**W(29)**	**z**	**p**
Combined	592	3.78	< 0.001	–	–	–	–	–	–	–	–	–
Item	397	2.94	< 0.01	183	1.64	0.049	–	–	–	–	–	–
Feature Set	624	4.84	< 0.001	643	2.13	0.016	575.5	3.89	< 0.001	–	–	–
Mixed	603.5	4.73	< 0.001	606	1.91	0.023	549.5	3.59	< 0.001	*not sig.*		

Table IV.35: Pairwise Wilcoxon signed rank tests for the TFFS metric for SA probes.

significant, except for the Mixed - Feature Set comparison (see Table IV.35).

The Control condition reports a median TFFS of 0.00 sec for SA probes, indicating in many cases participants did not relocate Feature Sets before answering a probe. Instead, participants directly answered the probe using recalled knowledge, which did not occur with the other conditions (see Table IV.33). The TFFS for the Combined, Feature Set, and Mixed conditions is very similar for tasks and SA probes, indicating that performance time for locating new information is similar to recalling that information from memory when the highlighting condition incorporates Feature Set highlighting.

Item and Feature Set highlighting were used differently in the Mixed condition. Participants used item highlighting 6 (min: 1, max: 9) times and Feature Set highlighting 11 (min: 4, max: 12) times when performing trials with the Mixed condition. The difference between item and Feature Set highlighting was significant ($W(29) = 44.5, z = 5.93, p < 0.001$), indicating that, when presented with the opportunity to use either Item or Feature Set highlighting, Feature Set highlighting was leveraged more frequently to answer questions. This behavior may indicate that the task of locating Feature Sets was more difficult than locating the appropriate information item(s) in a Feature Set's expanded view, resulting in the increased usage of Feature Set highlighting.

Much like the Total Correct Answer Count metric, the Multiple Source Correct Answer metric is similar for all conditions (see Table IV.36). An ART ANOVA found no significant main effect for highlighting condition for the Multiple Source Correct Answer metric. The Multiple Source Correct Answer metric shows that, when given enough time, any technique will eventually lead to the correct answer.

	Correct Answers		
Condition	**median**	**min**	**max**
Control	4.00	2.00	4.00
Combined	4.00	3.00	4.00
Item	4.00	3.00	4.00
Feature Set	4.00	2.00	4.00
Mixed	4.00	3.00	4.00

Table IV.36: The Multiple Source Correct Answer Count metric descriptive statistics for questions that required gathering information from multiple sources. Note that 4 questions per trial required multiple information sources.

	Duration (sec)		
Condition	**median**	**min**	**max**
Control	53.50	2.00	167.00
Combined	20.00	9.00	57.00
Item	35.00	6.00	82.00
Feature Set	28.00	9.00	85.00
Mixed	25.00	8.00	81.00

Table IV.37: The descriptive statistics for the Multiple Source Question Duration metric.

	Control			Combined			Item			Feature Set		
	W(29)	**z**	**p**	**W(29)**	**z**	**p**	**W(29)**	**z**	**p**	**W(29)**	**z**	**p**
Combined	11	4.13	< 0.001	–	–	–	–	–	–	–	–	–
Item	112	3.86	< 0.001	832.5	4.09	< 0.001	–	–	–	–	–	–
Feature Set	50.5	4.13	< 0.001	695	3.11	< 0.001	245.5	2.90	< 0.001	–	–	–
Mixed	324	4.13	< 0.001	617	2.14	0.016	131	3.74	< 0.001	*not sig.*		

Table IV.38: Pairwise Wilcoxon results for the Multiple Source Question Duration metric.

		Duration (sec)		
Condition	Type	median	min	max
Control	Task	89.00	3.00	167.00
	SA Probe	40.00	2.00	103.00
Combined	Task	17.00	9.00	42.00
	SA Probe	25.00	9.00	57.00
Item	Task	38.50	10.00	82.00
	SA Probe	29.50	6.00	70.00
Feature Set	Task	19.00	9.00	47.00
	SA Probe	38.00	9.00	85.00
Mixed	Task	19.00	9.00	39.00
	SA Probe	30.50	8.00	81.00

Table IV.39: The descriptive statistics for the Multiple Source Question Duration metric shown for both tasks and SA Probes.

The Multiple Source Question Duration metric indicates that when some form of highlighting is used, response time is reduced for questions requiring information from multiple sources (see Table IV.37). An ART ANOVA found a significant main effect for highlighting condition ($F(4,116) = 63.4, p < 0.0001$), and a pairwise Wilcoxon test determined a significant difference for all comparisons of highlighting condition, except the Mixed - Feature Set comparison (see Table IV.38). These results indicate that highlighting techniques provide improved performance when information from multiple sources is needed. Among the evaluated highlighting techniques, the Combined condition resulted in the lowest Multiple Source Question Duration.

The results of the Multiple Source Question Duration metric exhibit large ranges, particularly for the Control condition (see Table IV.37). These large ranges may be due to the aggregation of task and SA Probe duration for each condition; therefore Table IV.39) shows the descriptive statistics for the Multiple Source Question Duration metric for tasks and SA Probes separately.

Table IV.39 shows a 101.00 second range for SA Probes in the control condition, and a 164.00 second range for tasks. The three second reported minimum for Task in the Control condition (see Table IV.39) is likely the result of participant's locating required information immediately. This occurrence is rare, but possible since no restrictions are placed on the order with which users interact with Feature Sets on the map. The Combined, Feature Sets, and Mixed conditions all show longer durations for SA Probes than tasks, indicating that participants used the interface to find previously encountered information again in order to answer SA Probes. This same trend is not seen for the Control and Item conditions, where Multiple Source Question Duration is less for SA Probes. This result indicates that for conditions that highlighted Feature Sets' geospatial containers, perhaps memory recall was not leveraged when performing SA Probes. Instead, participants opted leverage the interface to relocate relevant information.

	Control			Combined			Item			Feature Set		
	W(29)	**z**	**p**	**W(29)**	**z**	**p**	**W(29)**	**z**	**p**	**W(29)**	**z**	**p**
Combined	0.0	-4.78	< 0.001	–	–	–	–	–	–	–	–	–
Item	6.0	-4.65	< 0.001	465.0	4.78	< 0.001	–	–	–	–	–	–
Feature Set	0.0	-4.78	< 0.001		*not sig.*		14.5	-4.48	< 0.001	–	–	–
Mixed	0.0	-4.78	< 0.001		*not sig.*		0.0	-4.78	< 0.001		*not sig.*	

Table IV.40: Pairwise Wilcoxon results for the Multiple Source Question Duration metric for tasks only.

	Control			Combined			Item			Feature Set		
	W(29)	**z**	**p**	**W(29)**	**z**	**p**	**W(29)**	**z**	**p**	**W(29)**	**z**	**p**
Combined	51.0	-3.72	< 0.01	–	–	–	–	–	–	–	–	–
Item	99.5	-2.73	0.028		*not sig.*		–	–	–	–	–	–
Feature Set		*not sig.*		405.5	3.56	< 0.01	373.0	2.89	0.026	–	–	–
Mixed	85.5	-3.02	0.018		*not sig.*			*not sig.*			*not sig.*	

Table IV.41: Pairwise Wilcoxon results for the Multiple Source Question Duration metric for SA Probes only.

An ART ANOVA found a significant main effect on highlighting condition for both tasks $(F(4,116) = 98.6, p < 0.001)$ and SA Probes $(F(4,116) = 9.2, p < 0.001)$. A pairwise Wilcoxon signed-rank test determined significant differences between the Control condition and all highlighting conditions for tasks (see Table IV.40); however, the same was not true for SA Probes (see Table IV.41). Despite not being significant, SA Probe Multiple Source Question Durations for each of the highlighting conditions is still lower than the Control condition.

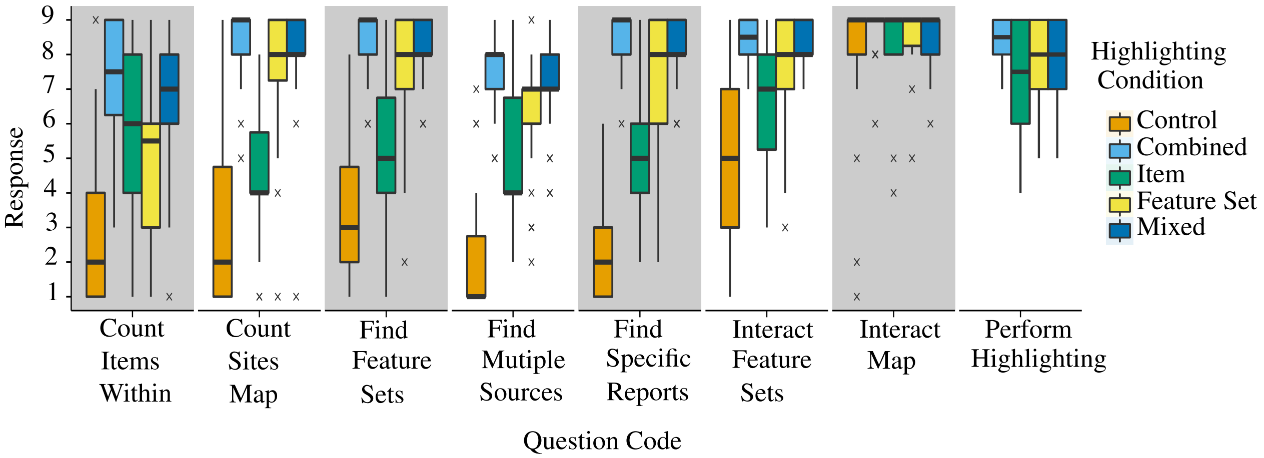


Figure IV.20: The Condition Rating Survey descriptive statistics.

	ART ANOVA	
Question Code	**F**	**p**
Count Items Within	33.97	< 0.0001
Count Sites Map	69.5	< 0.0001
Find Feature Sets	70.8	< 0.0001
Find Multiple Sources	59.5	< 0.0001
Find Specific Reports	90.6	< 0.0001
Interact Feature Sets	22.11	< 0.0001

Table IV.42: The ART ANOVA results for the Condition Rating Survey $(df_{num} = 4, df_{den} = 116)$. A significant main effect for highlighting condition was found for all questions except *Interact Map* and *Perform Highlight*.

IV.6.6.2 Subjective Metrics

Descriptive statistics for the Condition Rating survey show that all highlighting conditions rated higher than the Control condition for each question (see Figure IV.20). An ART ANOVA found a significant main effect for highlighting condition for six of the eight questions asked in the Condition Rating Survey (see Table IV.42), *Interact Map* and *Perform Highlighting* were not significant. Pairwise Wilcoxon tests for each Condition Rating Survey question (see Table IV.43) found that for the six questions, all highlighting conditions rated significantly higher than the Control condition. The similar performance across all conditions for the *Interact Map* question is not surprising, since the highlighting conditions had little to no effect on how a participant panned and zoomed the map. Each of the four highlighting conditions performed similarly for the *Perform Highlighting* questions, which indicates that, despite the effectiveness of each highlighting technique, all techniques were relatively easy to perform.

The Combined condition was subjectively rated the highest for all questions, with the Mixed condition rating similar to or slightly worse than the Combined condition in all cases. Participants seem to prefer functionality that highlights both Feature Sets and the associated information items, regardless of the level of control participants have over the highlighting technique.

The Combined condition was also ranked the highest on the Comparison Ranking survey (see Table IV.44). A test of equal proportions for each question found that the Combined condition was significantly preferred for each question (see Table IV.45). These results indicate that the Combined condition is the subjectively preferred method with which to implement information highlighting.

IV.6.7 Discussion

Hypothesis H_1 states that each information highlighting technique will result in improved task completion times as compared to not using information highlighting (see Table IV.26). Each highlighting technique performed significantly faster than the Control condition for Total Duration, supporting H_1. Despite the

		Control			**Combined**			**Item**			**Feature Set**		
		W(29)	**z**	**p**	**W(29)**	**z**	**p**	**W(29)**	**z**	**p**	**W(29)**	**z**	**p**
Count Items Within	**Combined**	843	5.35	< 0.001	–	–	–	–	–	–	–	–	–
	Item	753	3.90	< 0.001	296.5	1.37	< 0.001	–	–	–	–	–	–
	Feature Set	683	2.81	< 0.01	173	3.49	< 0.001	*not sig.*			–	–	–
	Mixed	794	4.96	< 0.001	*not sig.*			*not sig.*			666	2.81	< 0.01
Count Sites Map	**Combined**	848	5.51	< 0.001	–	–	–	–	–	–	–	–	–
	Item	654	2.35	< 0.01	35.5	5.73	< 0.001	–	–	–	–	–	–
	Feature Set	813.5	4.99	< 0.001	*not sig.*			811.5	4.99	< 0.001	–	–	–
	Mixed	827	5.20	< 0.001	*not sig.*			841	5.38	< 0.001	*not sig.*		
Find Feature Sets	**Combined**	888.5	6.14	< 0.001	–	–	–	–	–	–	–	–	–
	Item	708.5	3.30	< 0.001	74	5.23	< 0.001	–	–	–	–	–	–
	Feature Set	850	5.49	< 0.001	*not sig.*			750.5	3.98	< 0.001	–	–	–
	Mixed	885	6.05	< 0.001	*not sig.*			813	4.99	< 0.001	*not sig.*		
Find Multiple Sources	**Combined**	882.5	6.04	< 0.001	–	–	–	–	–	–	–	–	–
	Item	784.5	4.51	< 0.001	255.5	4.41	< 0.001	–	–	–	–	–	–
	Feature Set	843.5	5.46	< 0.001	385.5	2.23	0.013	634.5	2.12	< 0.05	–	–	–
	Mixed	873.5	5.92	< 0.001	*not sig.*			738.5	3.79	< 0.001	*not sig.*		
Find Specific Reports	**Combined**	899	6.31	< 0.001	–	–	–	–	–	–	–	–	–
	Item	779.5	4.46	< 0.001	41.5	5.69	< 0.001	–	–	–	–	–	–
	Feature Set	843	5.42	< 0.001	290.5	1.79	0.036	682	2.84	< 0.01	–	–	–
	Mixed	897	6.26	< 0.001	*not sig.*			833.5	5.30	< 0.001	*not sig.*		
Interact Feature Sets	**Combined**	777	4.33	< 0.001	–	–	–	–	–	–	–	–	–
	Item	619.5	1.57	< 0.001	202.5	3.07	< 0.01	–	–	–	–	–	–
	Feature Set	712	3.20	< 0.001	*not sig.*			*not sig.*			–	–	–
	Mixed	763	4.09	< 0.001	*not sig.*			677	2.72	< 0.01	*not sig.*		

Table IV.43: Pairwise Wilcoxon results for each question of the Condition Rating Survey. The *Interact Map* and *Perform Highlighting* are not shown because no comparison was significant.

Question Code	**Combined**	**Mixed**	**Item**	**Feature Set**	**Control**
Correct Preference	24.00	6.00	0.00	0.00	0.00
Easiest FS Interact	22.00	3.00	0.00	5.00	0.00
Easiest General	26.00	4.00	0.00	0.00	0.00
Easiest Map Interact	22.00	2.00	6.00	0.00	0.00
Easiest Post Filter	21.00	8.00	1.00	0.00	0.00
Easiest To Filter	25.00	5.00	0.00	0.00	0.00
Easiest View	23.00	7.00	0.00	0.00	0.00
Easiest View Specific	19.00	9.00	0.00	2.00	0.00
Fastest Performance	24.00	6.00	0.00	0.00	0.00

Table IV.44: Descriptive statistics for the Condition Ranking survey. Values represent the number of times a condition was preferred by participants for each question.

			CI	
Question Code	**Correct**	**Responses**	**Lower**	**Upper**
Correct Preference	24	30	0.6575	0.8929
Easiest FS Interact	22	30	0.5854	0.8427
Easiest General	26	30	0.7340	0.9387
Easiest Map Interact	22	30	0.5854	0.8427
Easiest Post Filter	21	30	0.5506	0.8163
Easiest To Filter	25	30	0.6951	0.9164
Easiest View	23	30	0.6210	0.8682
Easiest View Specific	19	30	0.5033	0.7613
Fastest Performance	24	30	0.6575	0.8929

Table IV.45: Equal Proportion test for the Combined condition for each of the questions in the Comparison Ranking Survey. The Combined condition was significantly preferred for all questions.

additional overhead required to manipulate the interface and use information highlighting, the information highlighting techniques provided a reduction to performance time, resulting in lower overall task performance times.

Highlighting techniques provide an efficient way for users to quickly find desired information; therefore, it is not surprising that each of the presented techniques result in faster performance than a control condition. More surprising is that the highlighting techniques did not result in increased correct answers when compared to a control condition. However, if a time constraint were present, it is anticipated that the highlighting techniques will result in more correct answers, since these techniques allow appropriate information to be found more quickly.

Amongst the highlighting conditions, the Combined condition yielded the fastest performance in terms of Total Duration. The Mixed condition was only slightly, but significantly, slower. Initially, it was believed that the Combined and Mixed conditions represented an ease-of-use and flexibility trade-off, and that the lack of flexibility produced by the Combined condition may lead to performance issues when compared to the Mixed condition; however, this was not to be the case. The Combined and Mixed conditions performed equivalently in terms of correct answers and the Combined condition resulted in faster performance for both tasks and SA probes. Based this outcome, it is difficult to recommend a mixed highlighting method over the combined approach; however, performance may have been specific to the type of tasks performed in this evaluation. It is unknown whether a combined highlighting technique will continue to be as effective as the types of information used as search terms for performing highlighting increase.

Large differences between Task and SA Probe Duration exist for highlighting techniques that do not alter a Feature Sets' geospatial container. The same is not true for highlighting techniques that alter the appearance of a Feature Set's geospatial container. This finding indicates that when geospatial highlighting is present, finding new information occurs as quickly as recalling that information from memory; therefore, highlighting techniques that highlight the Feature Set's geospatial container are perhaps the most useful.

Hypothesis H_2 states that highlighting conditions that alter the Feature Set's geospatial container (e.g., Feature Set, Mixed, and Combined) appearance will result in appropriate Feature Sets being discovered more quickly than when using highlighting conditions that do not do so. The TFFS metric results support this hypothesis and demonstrate the necessity of highlighting relevant information on a digital map. When new information is required, highlighting a Feature Set's geospatial container results in that particular Feature Set being discovered more quickly than without highlighting.

The same result is not necessarily true when required information was previously discovered. The TFFS metric for SA probes shows comparable performance times for all conditions, even when no highlighting technique is present. This finding indicates that participants may have leveraged recalled knowledge and answered SA probes directly when no highlighting support existed. Therefore, when there is no highlighting available, recalling information is more efficient than attempting to locate it again. This outcome may not be desirable in some situations, especially if users recall misinformation and perform tasks incorrectly, which can occur in situations where attention is divided (Craik et al., 1996), workload is high (Stone et al., 2001), or severe levels of stress occur (Bremner et al., 1995).

The same outcome is not true for the highlighting conditions, which possess a non-zero median TFFS for SA probes. When highlighting was present, participants chose to interact with the map to locate the appropriate Feature Sets before answering SA probes, which points to two possible outcomes. First, since highlighting conditions make specific information easier to find, users may be more likely to use highlighting to rediscover known information, as a means of "double-checking" their knowledge before providing a response. Second, highlighting may impact users' ability to store information and recall it later. If information is very easy to find, participants may be recalling the process through which that information was discovered, rather than the information itself (Durso et al., 1999). It is difficult to know which of these outcomes is correct.

Leveraging semantic context requires the ability to find multiple sources of information quickly and efficiently. Hypothesis H_3 states that information highlighting techniques will result in less time to correctly perform tasks requiring multiple information sources. Conditions that used highlighting performed significantly faster than those that did not, supporting H_3. This outcome was particularly prevalent for the Combined and Mixed conditions, which indicates that multiple sources of information were found and used more quickly when multiple methods of highlighting information were available. This outcome demonstrates the importance of information highlighting techniques for supporting the semantic information context. The ability to highlight multiple information sources simultaneously improves user performance and supports the semantic information context by allowing relationships between information to be recognized more quickly.

Hypothesis H_4 states that probe response times will be lower than task response times when information highlighting techniques are not used. The SA Probe Duration is significantly lower than the Task Duration for the Control condition, which supports H_4. Similar to the TFFS metric results, when no highlighting functionality is present, SA probes are more likely to be answered using recalled information, as opposed to manipulating the interface to rediscover known information.

Hypothesis H_5 states that either the Mixed or the Combined condition will be subjectively preferred. The results of the Condition Ranking survey indicate that, of all the highlighting conditions, the combined Feature Set and information item highlighting method was most preferred by participants, supporting H_5. The Mixed condition ranked second, but was still ranked subjectively worse than the Combined condition for all questions. Objective results supported the preference for combined highlighting, as it resulted in the fastest performance of all highlighting conditions. User preference may be due to the simplicity of the technique compared to the amount of information it conveyed. Techniques that only highlighted Feature Sets or information items were easy to perform, but still left part of the task of finding relevant information to the user (i.e., finding the correct Feature Sets or information items manually). The mixed highlighting technique afforded the same level of information to the user as the combined method with a greater level of control; however, mixed highlighting required additional interactions, which may have resulted in the technique not being as preferred as the combined technique.

When presented with the ability to highlight Feature Sets and items independently, participants used Feature Set highlighting significantly more. This result indicates that highlighting the Feature Set geospatial container may have been more useful to participants than highlighting items. When paired with the subjective ratings, it appears that participants found Feature Set highlighting more helpful than item highlighting, which may indicate that locating the appropriate Feature Set(s) was more complex than finding the appropriate information items.

The evaluation results reveal the overall importance of information highlighting for improving performance, by reducing the time needed to answer questions and perform tasks. Highlighting provided a flexible system to emphasize information based on type-based characteristics, making it easier and more efficient to determine the relationships between displayed information. The impact of emphasizing these relationships was improved user performance, demonstrating the importance of supporting the semantic context. This performance increase was particularly notable when questions required multiple sources of information to be answered correctly. Highlighting makes required information more salient and assists users with determining relationships between information, providing clear support for the semantic context.

IV.7 Conclusions

This chapter described three evaluations that demonstrate the benefits of information context in geospatial visualization and interaction method design. Information context was used to inform the design of Feature Sets. The results of each evaluation provide evidence that information context support is beneficial to the design of map-based information visualization techniques.

The Geospatial Context Evaluation showed that by leveraging the geospatial information context, visual clutter was reduced and task performance improved, while task durations were reduced. An added benefit of using the geospatial context to group information was that overall map interactions were reduced, indicating more efficient interactions when using Feature Sets. Participants also found locations on the map more quickly when using Feature Sets.

The Temporal Context Evaluation demonstrated the benefits of the temporal context. Feature Sets incorporate chronological information orderings and salient notification indicators to alert users to the presence of newly added information. This leveraging of the temporal context proved beneficial when compared to a POI-based approach that lacked temporal context. Participants required fewer interactions with the map, interacted with new information more quickly, and performed more tasks correctly when using Feature Sets.

The Semantic Context Evaluation demonstrated the benefit of information highlighting for geospatial visualization techniques. Information highlighting was shown to improve performance by lowering response times. Moreover, information highlighting was shown to improve performance on tasks that required multiple information sources, thus proving the relevance of information highlighting for supporting semantic context. The evaluation also determined that a combined highlighting approach is best for Feature Sets, as highlighting both Feature Sets and information items simultaneously was subjectively preferred and led to the overall best performance of all evaluated techniques. Despite the combined technique performing well in the whole, there may still be cases where other techniques perform more efficiently. For example, mixed or Feature Set highlighting may be preferable in cases where a user wishes to determine if certain information is contained within a Feature Set, but does not want to alter the default ordering of information items contained within the Feature Set.

The Feature Set evaluations demonstrate that by designing visualization techniques to support MSW design requirements, performance can be improved as compared to visualization techniques that do not. The outcomes of these evaluations not only support Feature Sets, but also quantitatively show the link between MSW design requirements, the temporal, geospatial, and semantic information contexts and user performance. The link between MSW design requirements, information context, and user performance is important, as these evaluations have shown the positive impact information context and MSW design requirements can have on new visualization methods. These evaluations also serve as the first occurrence of MSW design requirements being objectively validated by highly-controlled laboratory studies.

The POI implementation was basic, and many improvements to POIs exist that were suitable for evaluation (see Chapter II.2). The intent of the Feature Sets design is not to be the definitive method for aggregating data on a digital map, but to show that by designing using information context, beneficial data aggregation methods can be derived. Leveraging information context may also be beneficial to POI-based data visualizations. For example, providing temporal context to POIs (e.g., a salient cue when a new POI is added, such as with the GVA (Humphrey and Adams, 2010)) will very likely result in usability benefits; however, such an approach may still result in visual clutter. Feature Sets are also a fairly straightforward method for aggregating data on a digital map; however, despite the simplicity of the technique, the performance benefits as compared to POIs are evident.

The presented results may not adequately describe all populations that use digital maps. For example, those with limited computer usage experience, and/or limited map experience may perform worse overall than the sample population. The evaluations may not represent a typical digital map usage scenario. For example, rather than counting POIs in a real-world scenario, users may be given access to filtering and searching mechanisms, similar to those used in the Semantic Context Evaluation, that can greatly facilitate information search. Despite these evaluation limitations, visual clutter occurs during real-world geovisualization scenarios, thus the need to mitigate visual clutter and support information context on a digital map is still apparent. While the evaluations themselves may not adequately represent real-world scenarios, the research outcomes are still applicable.

Despite the evaluation and implementation limitations, results from each evaluation indicates the importance of leveraging information context when designing visualization techniques. The findings presented in this chapter have shown the benefit of the temporal, geospatial, and semantic context; and provide early evidence that these contexts may be suitable for visualization method design for digital maps in general.

CHAPTER V

Conclusions and Contributions

V.1 Review

This dissertation introduces and validates the initial design of Feature Sets. Feature Sets are geospatial containers that allow for non-type based groupings of information on a digital map. Feature Sets are designed to provide overview information, filtered information, and details on demand. Feature Sets are the first known visualization technique designed specifically to address MSW design guidelines (see Chapter I.1).

Information context is often used to provide information with additional meaning, which frames that information within an overall body of knowledge. Feature Sets are designed to explicitly leverage information context. Three types of information context were determined to be useful through an analysis of previously developed geocollaborative software systems: geospatial, the location of information on the map; temporal, time-based knowledge in relation to presented information; and semantic, knowledge concerning the relatedness between items (e.g., type similarity). These types of information context have been leveraged by prior systems, but had not been explicitly identified and used to design a single geospatial information visualization and interaction method.

Three user evaluations were conducted. The Geospatial Context Evaluation compared Feature Sets to POIs when information was static, while information density increased. Feature Sets were proven to perform as well as, or better than POIs for all cases except those that required exact knowledge of an item's location on the map. Feature Sets can be easily extended to display the exact location of information items on the map as part of that item's detail information. The subjective results showed that Feature Sets are preferred overall versus POIs, and Feature Sets tended to be rated more highly as information density increased. This evaluation showed that by leveraging geospatial context, visual clutter can be reduced and usability of a map-based interface can be improved. However, since Feature Sets are strongly coupled to their underlying geography, they may become difficult to select as zoom level decreases. Additionally, the potential exists for Feature Sets to overlap, which can lead to visual clutter; however, this issue can be remedied through thoughtful Feature Set placement or automated methods (e.g., overlapping Feature Sets can be automatically combined into a single Feature Set).

The Temporal Context Evaluation compared Feature Sets to POIs for the presentation of dynamic information and required participants to perform wayfinding tasks. The objective results indicated that Feature Sets result in more tasks performed correctly and more quickly than when using POIs. The subjective results indicated that Feature Sets are also subjectively preferred over POIs for the discovery of and interaction with new information on the digital map. This evaluation demonstrated the importance of using the temporal context for the display of and interaction with new information.

The Semantic Context Evaluation compared four different information highlighting techniques to a control condition that did not use highlighting. The objective results indicated that all highlighting techniques improved performance, as compared to no highlighting. The greatest performance benefit was provided by the combined highlighting technique. Highlighting resulted in participants aggregating and using information from multiple sources faster than when no highlighting tools were supplied; thus improving users' ability to use and extract meaning from seemingly disparate pieces of information. This finding directly supports the use of the semantic information context for geospatial visualization and interaction, while demonstrating the semantic context's positive impact on user performance. This evaluation demonstrated the importance of leveraging semantic context by developing methods that allow users to utilize semantic context to efficiently complete tasks.

V.2 Design Guidelines

The design methodology and implementation of Feature Sets has resulted in findings that are beneficial to the design of geospatial data visualization techniques in general. Specifically, Feature Sets have demonstrated that the use of MSW design requirements and information context to dictate the design of geospatial visualization techniques results in improved usability and user performance.

The generalized MSW design requirements proposed by Rodríguez-Covili et al. (2011) serve as illuminating design guidelines concerning geospatial data visualization and interaction. Among these requirements, perhaps the *Information Sharing* guideline is most important. MSWs, like all geocollaborative software interfaces, ultimately hinge on the ability of spatially distributed teams to communicate effectively, and supporting *Information Sharing* is paramount to effective communication. Feature Sets directly supported *Information Sharing* throughout their design. A primary example of this support was notification indicators, which provided temporal context and indication to users that collaborators were providing new information to the system. Supporting *Information Sharing* using notification indicators was shown to improve performance when visualizing dynamic information, and supports leveraging *Information Sharing* as a design guideline.

Other MSW design requirements, such as *Autonomy* and *Group Awareness* were provided for in the design of Feature Sets, but were not directly evaluated. These two requirements cannot be definitively proposed as design guidelines, but their inclusion is beneficial. Designing Feature Sets to incorporate these requirements has shown that *Autonomy* (e.g., continuing to work while disconnected from others) and *Group Awareness* (e.g., others are offline) can be provided for in a geospatial visualization technique design. Alternative approaches for displaying information related to *Autonomy* and *Group Awareness* (e.g., status updates displayed through pop-ups, dialog boxes) require widgets and indicators decoupled from the visualization, which divert attention from the data visualization and can negatively impact performance (Rashid et al., 2012). Therefore, while these two MSW requirements were not specifically evaluated for Feature Sets, prior research indicates that incorporating *Autonomy* and *Group Awareness* into a geocollaborative data visualization method is likely beneficial. Validating the applicability of the *Autonomy* and *Group Awareness* MSW design requirements to Feature Sets can also be pursued as future work.

The *Messaging* MSW requirement is likely only partially supportable through visualization technique design. Feature Sets provide access to collaborator messaging through a Feature Sets' detail view of information (see Chapter III.2 and Figure III.1c). However, messaging functionality may be complex, ultimately requiring an additional widget to facilitate messaging (e.g., a window containing an on-screen keyboard, or buttons to control audio levels for voice communication). Therefore, the complexity of providing *Messaging* functionality may prevent it from being fully integrated into a visualization method.

Some aspects of Feature Sets' design were due to the overlapping nature of the MSW design requirements and information context. For example, notification indicators were designed to provide a temporal information context, but simultaneously address *Information Sharing* by providing notification of collaborators' activity to the user. Therefore, the design of Feature Sets is also strongly dictated by the geospatial, temporal, and semantic information contexts. These three methods of information context were shown to be fundamentally important to the design of geospatial visualization and interaction techniques. These contexts can be considered design guidelines for future designs.

Feature Sets leveraged the geospatial context to reduce visual clutter by providing geospatial containers for collocated information. The benefits of this approach were proven and support the use of the geospatial context as a potential design guideline. The use of geospatial containers, even though they were shown to improve performance, is not necessarily the design requirement, since other methods of supporting geospatial context may be found to be more beneficial than geospatial containers. Geospatial containers provided performance benefits when used with Feature Sets, but it is geospatial information *in general* that is considered to be a design guideline. The results showed that when presenting information on a digital map, supporting how that information is geospatially related is of paramount importance.

Supporting the temporal context can be considered a design guideline. The temporal context was shown to be particularly useful when representing dynamic information on a digital map. Feature Sets supported temporal context via two primary methods: temporal ordering of information and notification indicators. Both methods were beneficial, particularly when compared to methods that do not directly support temporal context (i.e., POIs). Similar to the geospatial context, the application of temporal context was found to be useful for Feature Sets, but it is temporal context in general that must be considered a design guideline. Therefore, if information displayed on a digital map contains temporal characteristics, it is important to support these temporal characteristics directly within the information visualization technique.

Further, supporting the semantic context can be considered a design guideline. The semantic information context was shown to provide a direct benefit to user performance; particularly when knowledge of information from multiple disparate sources was necessary for completing a task. The semantic context was supported through information highlighting, which allowed users to emphasize multiple types of displayed information simultaneously. The ability to highlight information resulted in that information being found more quickly, allowing users to more readily and efficiently understand the semantic relationships between information. Highlighting, however, is not the design guideline as more effective methods for supporting semantic context may exist, and semantic information may be more robust than simply the type of information being presented. For example, the ability to view all of the information created by a single collaborator can provide semantic context, which was not directly supported by any of the implemented highlighting techniques. As well, highlighting may not be the ideal means of displaying such information. When displaying geospatial information, it is worthwhile to consider the relationships between that information and support the viewing of those relationships by the visualization technique.

The design guidelines and recommendations determined as a result of this research are summarized as follows:

- *Geospatial Information Context.* If geospatial relationships, such as proximity, exist between displayed information, provide explicit visualization support for the geospatial relationship.
- *Temporal Information Context.* If temporal characteristics (e.g., time of information creation, modification, or discovery by others) for displayed geospatial information exist, provide explicit support that saliently presents those temporal characteristics.
- *Semantic Information Context.* If relationships (e.g., item type, its creator, its relevance to a particular task) between displayed geospatial information exist, provide explicit visualization support that demonstrates the the nature and scope of those relationships.
- *Information Sharing.* If geocollaboration is a characteristic of the domain, provide salient knowledge of how collaborators are to interact (e.g., modifying, adding, deleting) with the displayed geospatial information.
- *Autonomy* and *Group Awareness.* If geocollaboration is a characteristic of the domain, provide a clear visualization communicating that a user is working while disconnected from others and notifying the

user of unreachable collaborators.

Feature Sets provide only one example of applying information context and MSW requirements to the geospatial visualization method design process. The Feature Sets' implementation is arguably simplistic and serves to prove the benefits of leveraging information context and the MSW requirements. The experimental results this dissertation presented clearly demonstrate the benefits of this design approach, and future geospatial visualization techniques stand to benefit from directly leveraging information context and MSW design requirements as design guidelines. The three information contexts were proposed, evaluated, and determined to be applicable as design guidelines. The MSW design requirements were shown to be, in part, applicable to the design of visualization techniques, not simply MSW systems in general. These two outcomes can be considered the primary contribution of Feature Sets with respect to generalizable, reusable design guidelines.

V.3 Contributions

The primary contribution of this research is the introduction of a novel visualization technique that improves user performance when interacting with geospatial data. Feature Sets provide an efficient and effective means of discovering, interacting with, and communicating information on digital maps. Additional contributions of this research are:

1. **The geospatial, temporal, and semantic context are directly applicable as design guidelines for geospatial visualization method design.**

   Information context has been used to directly guide and inform the development of a geospatial information visualization and interaction technique. This dissertation proposed three methods of supporting information context: geospatial, temporal, and semantic. Each of these contexts was shown to be crucial to Feature Sets' development and can be directly attributed to improved user performance when using Feature Sets. These techniques can be applied directly to future geospatial data visualization techniques as design guidelines. Leveraging information context may be beneficial when used to inform the design of visualization methods in general.

2. **Feature Sets are a direct improvement to POIs, a standard method for displaying and interacting with geospatial information.**

   The presented results indicate that Feature Sets are beneficial in and of themselves, and are a suitable interaction and visualization technique for map-based applications. Feature Sets can be directly applied to other geospatial domains and provide performance improvement compared to POIs, particularly at high information densities. While more advanced visualization methods using POIs exist; their existence does not detract from the benefit of Feature Sets as a technique that outperforms standard POI-based visualization techniques. Like the more advanced POI-based visualization techniques, Feature Sets serve as a better-performing improvement to the currently accepted standard and can be used by designers in situations where a POI-based may commonly be leveraged.

3. **The presented research is the first attempt to successfully demonstrate that MSW design requirements can be applied as design guidelines for geospatial visualization and interaction techniques.**

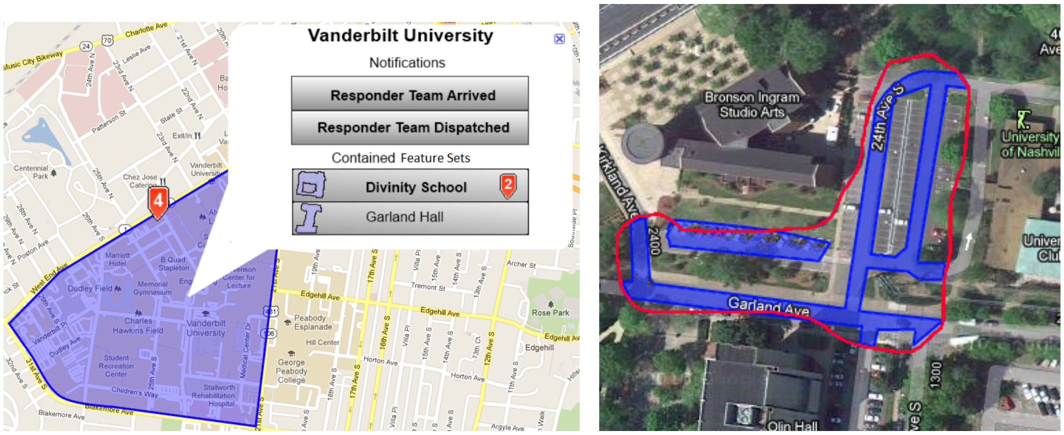
   The MSW design requirements developed by prior research were initially intended to provide a reference architecture for MSWs, in general. Feature Sets demonstrate the first attempt to apply these requirements as design guidelines for a geospatial information visualization and interaction technique. It was determined that, of these requirements, *Information Sharing* is crucial to design and is beneficial when directly supported by the visualization technique. The *Autonomy* and *Group Awareness* MSW requirements were determined to be beneficial to support directly within the geospatial visualization technique, but may not necessarily be required.

V.4 Future Work

Feature Sets serve as a preliminary attempt to design a geospatial visualization and interaction technique using information context. As a preliminary design, Feature Sets were shown to be beneficial; however, future work can refine the Feature Sets design and provide additional functionality. Three potential areas of future work are to improve Feature Sets, evaluate other design aspects of Feature Sets (e.g., their creation), and to apply information context to the design of new geospatial visualization techniques.

Feature Set improvements include abstraction and Feature Set recommendation. Feature Set abstraction is the aggregation of collocated Feature Sets into collections of Feature Sets represented by a single visualization. Aggregation of collocated Feature Sets can mitigate potential visual clutter issues when many Feature Sets are collocated in the same region (see Figure V.1a).

Feature Set abstraction will further reduce visual clutter compared to the current Feature Sets implementation, while continuing to support geospatial context. Geospatial context is improved, since Feature Sets contained in an abstraction represent a sub-grouping of information contained within the parent Feature Set. Geospatial regions can be composed into nested Feature Sets, allowing for a hierarchical visualization of a potentially complex area. For example, an abstracted Feature Set of the Vanderbilt University campus may contain individual Feature Sets that represent buildings or other structures. The resulting visualization forms a geospatial hierarchy, with the Vanderbilt campus at the highest level. This hierarchy can be viewed without concrete knowledge of the area, which is beneficial at higher zoom levels where important areas on the



(a) Feature Set abstraction (b) Feature Set Recommendation

Figure V.1: Concept images to illustrate potential future improvements to Feature Sets. (a) Abstracted Feature Sets contain smaller Feature Sets and support geospatial context, while limiting visual clutter. (b) Feature Set recommendation can provide suggested Feature Sets that fall within an area defined by the user, shown in red.

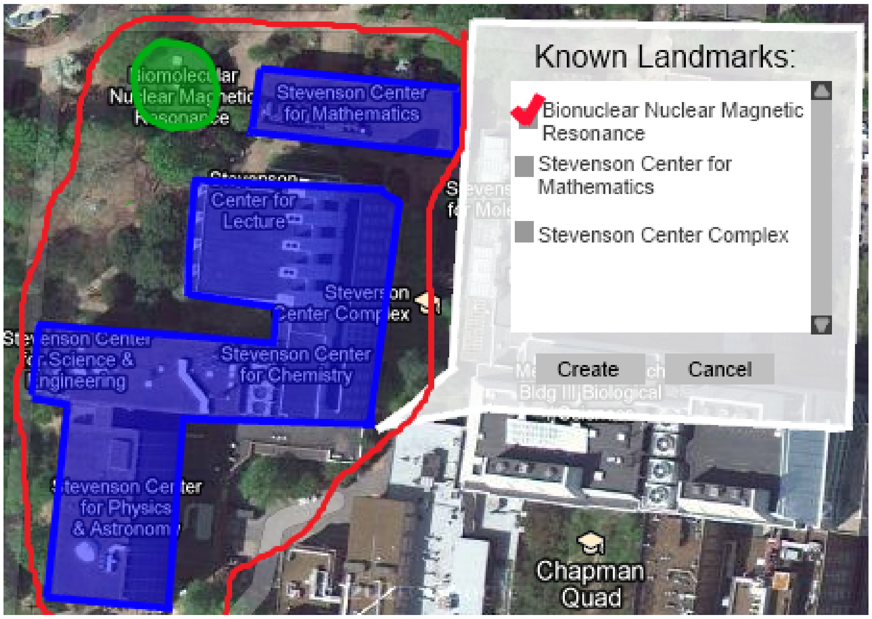
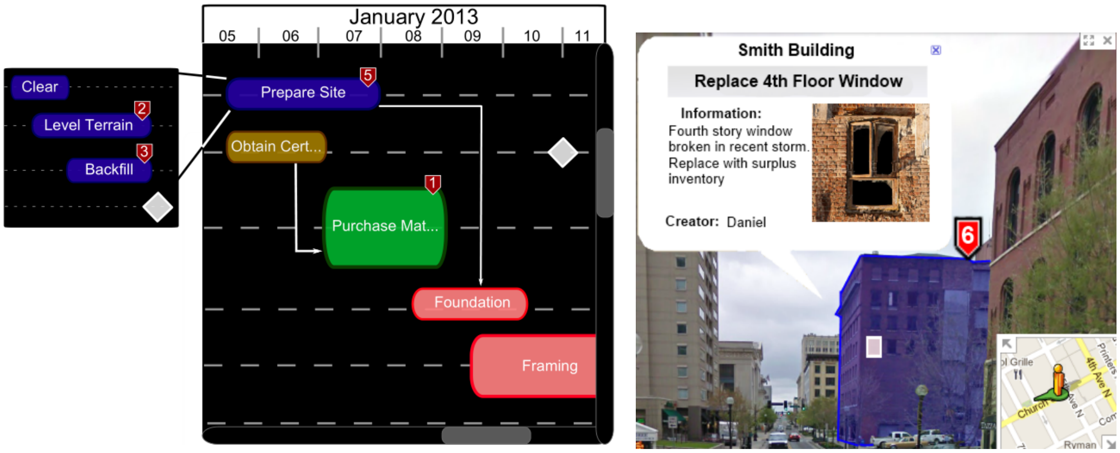


Figure V.2: Feature Set recommendation listing known landmarks that fall within a drawn area specified by a user. Potential landmarks are shown in blue, the currently selected landmark in green.



Smith Building

Replace 4th Floor Window

Information:
Fourth story window broken in recent storm. Replace with surplus inventory

Creator: Daniel

(a) Feature Sets used in a Gantt Chart (b) Feature Sets in a 3D environment

Figure V.3: Two potential applications of Feature Sets in (a) a non-geospatial domain that represents temporal information spatially, and (b) a 3-dimensional geospatial environment.A

map may be too small to be adequately visualized. Abstraction may also be beneficial for gaining survey knowledge of the map, since the approximate location of areas of interest can be determined without an exhaustive search of the map at lower zoom levels. Feature Set abstraction can be used to convey geographical information to the user at high zoom levels that may, by necessity, obscure and hide important map details.

Feature Sets are currently created by first drawing the geospatial container of the Feature Set and then supplying information items for that Feature Set. Feature Set recommendation can improve this process by more closely using underlying geography to recommend meaningful geospatial areas for Feature Sets without requiring the user to perform a potentially complex drawing task (see Figure V.1b). Furthermore, if underlying knowledge of the map is known, known landmarks that fall within a user's specified region can be suggested by the system as potential Feature Sets (see Figure V.2).

Further development and evaluation of the proposed information contexts is another avenue for future work. The information contexts developed through this research resulted in the design of a single geospatial visualization technique, Feature Sets. Future work can apply these contexts toward the development of new visualization techniques in order to determine their importance to geospatial visualization method design, in general. Additionally, the remaining MSW design requirements (i.,e. *Autonomy*, *Group Awareness*, *Messaging*) can be fully evaluated and their relevance as design guidelines determined.

Feature Set creation is currently unevaluated, and determining the benefits and shortcomings of Feature Set creation is a potential area of future work. Feature Sets were automatically created for each of the three presented evaluations and were typically very closely tied to underlying geography. For example, Feature Sets were frequently used to represent defined elements on the map (e.g., buildings, roads, etc.); which allowed for the straightforward recognition of what a Feature Set was meant to represent. However, it is unknown if usability difficulties will occur if a Feature Set does not closely correspond to underlying geography. For example, a Feature Set may be difficult to use or understand if it is placed within a large area (i.e., a field, body of water, etc.) with no immediately discernible boundaries. Future work will need to evaluate the performance of Feature Sets when they are not tied to discrete and easily definable elements on the map.

Feature Sets' geospatial containers have only been used to represent static regions on the map. It is unknown how effective a Feature Set may be if its geospatial container is required to represent a region that may change over time, such as the shape of an avalanche, flooded area, or large oil spill. It is anticipated that Feature Sets' geospatial containers can be made to change over time, either automatically with the addition of data related to the size and shape of a dynamic region, or manually through users' drawn input. An area of future work is to evaluate Feature Sets for dynamical changing geographic regions, and to design new techniques that allow Feature Sets to properly represent of such areas if necessary.

Finally, Feature Sets may be applicable to any domain that requires a spatial representation of information. For example, spatially ordered temporal visualizations, such as timelines and Gantt charts may benefit from using Feature Sets to group the presented information into spatially represented temporal containers (see Figure V.3a), as opposed to the geospatial containers of Feature Sets when rendered on digital maps. Additionally, Feature Sets may be applicable to domains that require a 3-dimensional rendering of the environment (see Figure V.3b). Both examples serve as domains where the Feature Sets visualization technique is directly applicable and may be beneficial.

BIBLIOGRAPHY

Andrienko, G., Andrienko, N., Jankowski, P., Keim, D., Kraak, M. J., MacEachren, A., and Wrobel, S. (2007). Geovisual analytics for spatial decision support: Setting the research agenda. *International Journal of Geographical Information Sciences*, 21(8):839–857.

Andrienko, G., Andrienko, N., Keim, D., MacEachren, A. M., and Wrobel, S. (2011). Challenging problems of geospatial visual analytics. *Journal of Visual Languages & Computing*, 22(4):251–256.

Anselin, L. (1989). What is special about spatial data? Alternative perspectives on spatial data analysis. Technical Report 89-4, National Center for Geographic Information and Analysis.

Auckland, M., Cave, K., and Donnelly, N. (2007). Nontarget objects can influence perceptual processes during object recognition. *Psychonomic Bulletin and Review*, 14(2):332 – 337.

Bar, M. (2004). Visual objects in context. *Nature Reviews. Neuroscience*, 5(8):617 – 29.

Biederman, I., Mezzanotte, R. J., and Rabinowitz, J. (1982). Scene perception: Detecting and judging objects undergoing relational violations. *Cognitive Psychology*, 14(2):143 – 77.

Bremner, J. D., Krystal, J. H., Southwick, S. M., and Charney, D. S. (1995). Functional neuroanatomical correlates of the effects of stress on memory. *Journal of traumatic stress*, 8(4):527–553.

Buszko, D., Lee, W.-H., and Helal, A. (2001). Decentralized ad-hoc groupware API and framework for mobile collaboration. In *Proceedings of the 2001 International ACM SIGGROUP Conference on Supporting Group Work*, pages 5–14.

Bylemans, I., Weyn, M., and Klepal, M. (2009). Mobile phone-based displacement estimation for opportunistic localisation systems. In *Proceedings of the* 3^{rd} *International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies*, pages 113–118.

Carroll, J. M., Rosson, M. B., Convertino, G., and Ganoe, C. H. (2006). Awareness and teamwork in computer-supported collaborations. *Interacting with Computers*, 18(1):21 – 46.

Cheverst, K., Davies, N., Mitchell, K., Friday, A., and Efstratiou, C. (2000). Developing a context-aware electronic tourist guide: some issues and experiences. In *Proceedings of the ACM Conference on Human Factors in Computing Systems*, pages 17–24.

Chi, E. (2000). A taxonomy of visualization techniques using the data state reference model. In *Proceedings of the 2000 IEEE Symposium on Information Visualization*, pages 69 – 75.

Christiansen, N. and Maglaughlin, K. (2003). Crossing from physical workplace to virtual workspace: Be aware!. http://books.google.com/books?id=1iHLXwAACAAJ. Accessed: 2013-10-10.

Convertino, G., Ganoe, C., Schafer, W., Yost, B., and Carroll, J. (2005). A multiple view approach to support common ground in distributed and synchronous geo-collaboration. In *Proceedings of the* 3^{rd} *International Conference on Coordinated and Multiple Views in Exploratory Visualization*, pages 121 – 132.

Convertino, G., Mentis, H. M., Rosson, M. B., Slavkovic, A., and Carroll, J. M. (2009). Supporting content and process common ground in computer-supported teamwork. In *Proceedings of the ACM Conference on Human Factors in Computing Systems*, CHI '09, pages 2339–2348.

Craik, F. I., Govoni, R., Naveh-Benjamin, M., and Anderson, N. D. (1996). The effects of divided attention on encoding and retrieval processes in human memory. *Journal of Experimental Psychology: General*, 125(2):159.

Darken, R. and Cevik, H. (1999). Map usage in virtual environments: orientation issues. In *Proceedings of the IEEE Conference on Virtual Reality*, pages 133–140.

Darken, R. P. and Sibert, J. L. (1996). Navigating large virtual spaces. *International Journal of Human-Computer Interaction*, 8(1):49–71.

Davenport, J. L. and Potter, M. C. (2004). Scene consistency in object and background perception. *Psychological Science*, 15(8):559–564.

Delort, J.-Y. (2010). Vizualizing large spatial datasets in interactive maps. In *Proceedings of the 2nd International Conference on Advanced Geographic Information Systems, Applications, and Services*, pages 33–38.

Dobson, M. (1980). The influence of the amount of graphic information on visual matching. *The Cartographic Journal*, 17(1):26–32.

Dominguez, C. (1994). Can SA be defined? In *Situation awareness: Papers and annotated bibliography*, pages 5–15. Armstrong Laboratory Wright-Patterson AFB, OH.

Dourish, P. and Bellotti, V. (1992). Awareness and coordination in shared workspaces. In *Proceedings of the 1992 ACM Conference on Computer-Supported Cooperative Work*, pages 107–114.

Dourish, P. and Chalmers, M. (1994). Running out of space: models of information navigation. In *Proceedings of the 1994 Conference on Human-Computer Interaction*.

Dragicevic, P., Bezerianos, A., Javed, W., Elmqvist, N., and Fekete, J.-D. (2011). Temporal distortion for animated transitions. In *Proceedings of the ACM Conference on Human Factors in Computing Systems*, pages 2009–2018.

Drury, J. L., Keyes, B., and Yanco, H. A. (2007). LASSOing HRI: analyzing situation awareness in map-centric and video-centric interfaces. In *Proceedings of the ACM/IEEE International Conference on Human-Robot Interaction*, pages 279–286.

Durso, F. T., Hackworth, C. A., Truitt, T. R., Crutchfield, J., and Nikolic, D. (1999). Situation awareness as a predictor of performance in en route air traffic controllers. Technical report, DTIC Document.

Ellis, G. and Dix, A. (2007). A taxonomy of clutter reduction for information visualisation. *IEEE Transactions on Visualization and Computer Graphics*, 13(6):1216 – 1223.

Endsley, M. R. (1988). A methodology for the objective measurement of situational awareness. In *Situational Awareness in Aerospace Operations*, pages 789–795. NATO-AGARD.

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 37:32–64.

Endsley, M. R. (2000). Theoretical underpinnings of situation awareness: A critical review. In *Situation awareness analysis and measurement*, pages 3–32. Mahwah, NJ: Lawrence Erlbaum Associates.

Endsley, M. R. and Garland, D. J. (2000). *Situation Awareness Analysis and Measurement*. CRC Press, 1st edition.

Endsley, M. R., Selcon, S. J., Hardiman, T. D., and Croft, D. G. (1998). A comparative analysis of sagat and sart for evaluations of situation awareness. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, volume 42, pages 82–86. SAGE Publications.

Ens, B., Eskicioglu, R., and Irani, P. (2011). Visually augmented interfaces for improving awareness in mobile collaboration. In *Distributed User Interfaces: Designing Interfaces for the Distributed Ecosystem*, pages 169–176. Springer.

Field, K. (2012). Using a binning technique for point based multiscale web maps. http://blogs.esri.com/esri/arcgis/2012/06/08/using-a-binning-technique-for-point-based-multiscale-web-maps/. Accessed: 12-12-2012.

Fisher, D. (2007). Hotmap: Looking at geographic attention. *IEEE Transactions on Visualization and Computer Graphics*, 13(6):1184 – 1191.

Foursquare (2011). About foursquare. https://foursquare.com/about/. Accessed: 10-11-2013.

Fracker, M. and Vidulich, M. (1991). Measurement of situation awareness: A brief review. In *Proceedings of the 11th Congress of the International Ergnomics Association*, pages 795–797.

Fracker, M. L. (1988). A theory of situation assessment: Implications for measuring situation awareness. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, volume 32, pages 102–106. SAGE Publications.

Fredrikson, A., North, C., Plaisant, C., and Shneiderman, B. (1999). Temporal, geographical and categorical aggregations viewed through coordinated displays: A case study with highway incident data. In *Proceedings of the 1999 Workshop on New Paradigms in Information Visualization and Manipulation in Conjunction with the* 8^{th} *ACM International Conference on Information and Knowledge Management*, pages 26–34.

Fuchs, G. and Schumann, H. (2004). Intelligent icon positioning for interactive map-based information systems. In *Proceedings 15th International Conference of the Information Resources Managment Association*, pages 1–8.

Garrett, J. J. (2005). Ajax: A new approach to web applications. http://www.adaptivepath.com/ideas/ajax-new-approach-web-applications/. Accessed: 2014-02-26.

Gawron, V. J. (2008). *Human performance, workload, and situational awareness measures handbook*. CRC Press, Boca Raton, FL.

Golledge, R. G. (1999). *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes*. JHU Press, Baltimore, MD.

Google (2012). Google maps javascript API v3. https://developers.google.com/maps/documentation/javascript.

Google (2013). Too many markers. https://developers.google.com/maps/articles/toomanymarkers. Accessed: 06-05-2011.

Gutwin, C., Greenberg, S., Blum, R., Dyck, J., Tee, K., and McEwan, G. (2008). Supporting informal collaboration in shared-workspace groupware. *Journal of Universal Computer Science*, 14(9):1411–1434.

Hansson, D. H. (2014). Ruby on rails. http://rubyonrails.org/.

Hayes, S., Hooten, E., and Adams, J. (2010). Multi-touch interaction for tasking robots. In *Proceedings of the ACM/IEEE International Conference on Human-Robot Interaction*, pages 97–98.

Hekimian-Williams, C., Grant, B., Liu, X., Zhang, Z., and Kumar, P. (2010). Accurate localization of RFID tags using phase difference. In *Proceedings of the 2010 IEEE International Conference on Radio Frequency Identification*, pages 89–96.

Herskovic, V., Ochoa, S. F., Pino, J. A., and Neyem, H. A. (2011). The iceberg effect: Behind the user interface of mobile collaborative systems. *Journal of Universal Computer Science*, 17(2):183–201.

Hjelmfelt, A. T. and Pokrant, M. A. (1998). Coherent tactical picture. *CNA RM*, 97(129):1998.

Hooten, E. R. and Hayes, S. T. (2012). Simplebrowser. http://github.com/hootener/SimpleBrowser. Accessed: 10-10-2012.

Hooten, E. R., Hayes, S. T., and Adams, J. A. (2011). A comparison of communicative modes for map-based tasking. In *Proceedings of the Annual Meeting of the Human Factors and Ergonomics Society*.

Hopfer, S. and MacEachren, A. M. (2007). Leveraging the potential of geospatial annotations for collaboration: a communication theory perspective. *International Journal of Geographical Information Science*, 21(8):921–934.

Humphrey, C. M. (2009). *Information Abstraction Visualization for Human-Robot Interaction*. PhD thesis, Vanderbilt University, Nashville, TN USA.

Humphrey, C. M. and Adams, J. A. (2010). General visualization abstraction algorithm for directable interfaces: Component performance and learning effects. *IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans*, 40(6):1156–1167.

Janssen, J. and Bodemer, D. (2013). Coordinated computer-supported collaborative learning: Awareness and awareness tools. *Educational Psychologist*, 48(1):40–55.

Jones, D. G. and Endsley, M. R. (2000). Can real-time probes provide a valid measure of situation awareness. *Proceedings of the Human Performance, Situation Awareness and Automation: User-Centered Design for the New Millennium*.

Keahey, A. (1998). The generalized detail-in-context problem. In *Proceedings of the 1998 IEEE Symposium on Information Visualization*, pages 44–51.

Kimelman, D., Rosenburg, B., and Roth, T. (1994). Strata-various: Multi-layer visualization of dynamics in software sysstem behavior. In *Proceedings of the 1994 IEEE International Conference on Visualization*, pages 172 – 178.

Klippel, A., Freksa, C., and Winter, S. (2006). You-are-here maps in emergencies -the danger of getting lost. *Journal of Spatial Science*, 51(1):117–131.

Klippel, A., Hirtle, S., and Davies, C. (2010). You-are-here maps: Creating spatial awareness through map-like representations. *Spatial Cognition & Computation*, 10(2-3):83–93.

Kolbe, T. H., Steinrücken, J., and Plümer, L. (2003). Cooperative public web maps. In *Proceedings of the International Cartographic Congress (ICC)*, pages 1062 – 1071.

Levine, M. (1982). You-are-here maps. *Environment and Behavior*, 14(2):221–237.

Löffler, J., Ernst, V. H., Schon, J., and Pottebaum, J. (2007). Intelligent use of geospatial information for emergency operation management. In *Proceedings of the 2007 International Conference on Information Systems for Crisis Response and Management*, pages 181–190.

Loft, S., Morrell, D. B., and Huf, S. (2013). Using the situation present assessment method to measure situation awareness in simulated submarine track management. *International Journal of Human Factors and Ergonomics*, 2(1):33–48.

MacEachren, A. and Brewer, I. (2004). Developing a conceptual framework for visually-enabled geocollaboration. *International Journal of Geographical Information Science*, 18(1):1 –34.

Marcotte, E. (2010). Responsive web design. http://alistapart.com/article/responsive-web-design. Accessed: 05-06-2012.

Markerclusterer (2009). Markerclusterer. http://gmaps-utility-library.googlecode.com. Accessed: 02-01-2014.

Matthews, M. D. and Beal, S. A. (2002). Assessing situation awareness in field training exercises. Technical report, DTIC Document.

McGuinness, B. and Ebbage, L. (2002). Assessing human factors in command and control: Workload and situational awareness metrics. Technical report, DTIC Document.

McGuinness, B. and Foy, L. (2000). A subjective measure of SA: The crew awareness rating scale (cars). In *Proceedings of the First Human Performance, Situation Awareness, and Automation Conference*.

Meyer, E., Wichmann, D., Büsch, H., and Boll, S. (2011). Supporting mobile collaboration in spatially distributed workgroups with digital interactive maps. *Mobile Networks and Applications*, pages 1–11.

Microsoft (2012). http://msdn.microsoft.com/en-us/library/gg427610.aspx.

Microsoft (2014). Radio buttons. http://msdn.microsoft.com/en-us/library/windows/desktop/aa511488.aspx. Accessed: 10-10-2013.

Monares, A., Ochoa, S. F., Pino, J. A., Herskovic, V., Rodriguez-Covili, J., and Neyem, A. (2011). Mobile computing in urban emergency situations: Improving the support to firefighters in the field. *Expert Systems with Applications*, 38:1255–1267.

Montello, D. R. and Freundschuh, S. M. (1995). Sources of spatial knowledge and their implications for GIS: An introduction. *Geographical Systems*, 2:169–176.

Neyem, A., Ochoa, S., and Pino, J. (2006). Supporting mobile collaboration with service-oriented mobile units. *Groupware: Design, Implementation, and Use*, pages 228–245.

Nielsen, C. W. and Goodrich, M. A. (2006). Comparing the usefulness of video and map information in navigation tasks. In *Proceedings of the First ACM Conference on Human-Robot Interaction*, pages 95–101.

Nivala, A.-M. and Sarjakoski, L. T. (2003). Need for context-aware topographic maps in mobile devices. In *Proceedings of the 2003 Scandinavian Research Conference on Geographical Information Systems*, pages 15–29, Espoo, Finland.

Nomura, T., Hayashi, K., Hazama, T., and Gudmundson, S. (1998). Interlocus: Workspace configuration mechanisms for activity awareness. In *Proceedings of the 1998 ACM Conference on Computer Supported Cooperative Work*, pages 19–28.

Nova, N., Girardin, F., Molinari, G., and Dillenbourg, P. (2006). The underwhelming effects of location-awareness of others on collaboration in a pervasive game. In *Proceedings of the 2006 Conference on Cooperative Systems Design: Seamless Integration of Artifacts and Conversations – Enhanced Concepts of Infrastructure for Communication*, pages 224–238.

Ochoa, S., Bravo, G., Pino, J., and Rodriguez-Covili, J. (2011). Coordinating loosely-coupled work in construction inspection activities. *Group Decision and Negotiation*, 20(1):39–56.

OpenLayers (2012). http://www.openlayers.org/. Accessed: 05-05-2011.

Owens, C. and Brewster, S. (2011). Discovering and classifying errors in way finding. In *Proceedings of the IEEE 3rd International Conference on Social Computing*, pages 1449 –1454.

Parush, A., Ahuvia, S., and Erev, I. (2007). Degradation in spatial knowledge acquisition when using automatic navigation systems. In Winter, S., Duckham, M., Kulik, L., and Kuipers, B., editors, *Spatial Information Theory*, volume 4736 of *Lecture Notes in Computer Science*, pages 238–254. Springer Berlin / Heidelberg.

Pew, R. W. (2000). The state of situation awareness measurement: Heading toward the next century. In *Situation awareness analysis and measurement*, pages 33–50. Lawrence, Erlbaum Associates.

Phillips, R. J. and Noyez, L. (1982). An investigation of visual clutter in the topographic base of a geological map. *The Cartographic Journal*, 19(2):122–132.

Rashid, U., Nacenta, M. A., and Quigley, A. (2012). The cost of display switching: A comparison of mobile, large display and hybrid UI configurations. In *Proceedings of the International Working Conference on Advanced Visual Interfaces*, pages 99–106.

Regal, D. M., Rogers, W. H., and Boucek, G. P. (1988). Situational awareness in the commercial flight deck: Definition, measurement, and enhancement. In *Proceedings of the Seventh Aerospace Behavioral Technology Conference and Exposition*, pages 65–69.

Rinner, C., Raubal, M., and Spigel, B. (2005). User interface design for location-based decision services. In *Proceedings of the 13th International Conference on Geo-Informatics, CD-ROM*.

Rodríguez-Covili, J., Ochoa, S. F., Pino, J. A., Herskovic, V., Favela, J., Mejía, D., and Morán, A. L. (2011). Towards a reference architecture for the design of mobile shared workspaces. *Future Generation Computing Systems*, 27:109–118.

Romero, D. (2014). http://www.json.com. Accessed: 01-15-2014.

Salmon, P., Stanton, N., Walker, G., and Green, D. (2006). Situation awareness measurement: A review of applicability for C4i environments. *Applied ergonomics*, 37(2):225–238.

Salmon, P. M., Walker, G. H., Ladva, D., Stanton, N. A., Jenkins, D. P., and Rafferty, L. (2007). Measuring situation awareness in command and control: comparison of methods study. In *Proceedings of the 14th European Conference on Cognitive Ergonomics*, pages 27–34.

Sammarco, C., Fitzek, F., Perrucci, G., Iera, A., and Molinaro, A. (2008). Localization information retrieval exploiting cooperation among mobile devices. In *2008 IEEE International Conference on Communications*, pages 149–153.

Sarjakoski, L. T. and Nivala, A.-M. (2005). Adaptation to context - a way to improve the usability of mobile maps. In Meng, L., Zipf, A., and Reichenbacher, T., editors, *Map-Based Mobile Services: Theories, Methods, Implementations*, pages 107–124. Springer-Verlag.

Sarter, N. B. and Woods, D. D. (1991). Situation awareness: A critical but ill-defined phenomenon. *The International Journal of Aviation Psychology*, 1(1):45–57.

Selcon, S., Taylor, R., and Koritsas, E. (1991). Workload or situational awareness?: TLX vs. SART for aerospace systems design evaluation. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, volume 35, pages 62–66. SAGE Publications.

Shneiderman, B. (1996). The eyes have it: A task by data type taxonomy for information visualizations. In *Proceedings of the 1996 IEEE Symposium on Visual Languages*, pages 336 –343.

Sidlar, C. L. and Rinner, C. (2009). Utility assessment of a map-based online geo-collaboration tool. *Journal of Environmental Management*, 90(6):2020 – 2026.

Stone, M., Dismukes, K., and Remington, R. (2001). Prospective memory in dynamic environments: Effects of load, delay, and phonological rehearsal. *Memory*, 9(3):165–176.

Taylor, R. (1990). Situational awareness rating technique(SART): The development of a tool for aircrew systems design. *AGARD, Situational Awareness in Aerospace Operations 17 p(SEE N 90-28972 23-53)*.

Taylor, R. and Selcon, S. (1990). Cognitive quality and situational awareness with advanced aircraft attitude displays. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, volume 34, pages 26–30. SAGE Publications.

Torralba, A., Oliva, A., Castelhano, M. S., and Henderson, J. M. (2006). Contextual guidance of eye movements and attention in real-world scenes: The role of global features in object search. *Psychological Review*, 113(4):766 – 786.

Uhlarik, J. and Comerford, D. A. (2002). A review of situation awareness literature relevant to pilot surveillance functions. Technical report, DTIC Document.

Velde, L., Chatzinotas, S., Larson, M., Löffler, J., and Paliouras, G. (2005). Interactive 2d - 3d digital maps for the support of emergency teams during rescue operations. In *Proceedings of the* 12th *World Congress on Intelligent Transport Systems*, pages 1575 – 1585.

Vidulich, M. A. and Hughes, E. R. (1991). Testing a subjective metric of situation awareness. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, volume 35, pages 1307–1311. SAGE Publications.

Viljoen, D. (1997). Topological and thematic layering of geological map information: Improving efficiency of digital data capture and management. In *United States Geological Survey Open-File Report 97-269*.

Wiener, J. M., Bchner, S. J., and Hlscher, C. (2009). Taxonomy of human wayfinding tasks: A knowledge-based approach. *Spatial Cognition & Computation*, 9(2):152–165.

Wobbrock, J. O., Findlater, L., Gergle, D., and Higgins, J. J. (2011). The aligned rank transform for non-parametric factorial analyses using only ANOVA procedures. In *Proceedings of the ACM Conference on Human Factors in Computing Systems*, pages 143–146.

Wu, A. and Zhang, X. (2011). Location-based information fusion for mobile navigation. In *Proceedings of the* 13^{th} *International Conference on Ubiquitous Computing*, pages 593–594.

Wu, A., Zhang, X., Convertino, G., and Carroll, J. M. (2009). CIVIL: support geo-collaboration with information visualization. In *Proceedings of the ACM 2009 International Conference on Supporting Group Work*, pages 273–276.

Yatani, K., Partridge, K., Bern, M., and Newman, M. W. (2008). ESCAPE: A target selection technique using visually-cued gestures. In *Proceedings of the* 26^{th} *Annual ACM Conference on Human Factors in Computing Systems*, pages 285–294.

Yelp! (2011). Yelp! http://www.yelp.com. Accessed: 05-05-2013.

Zhang, T. and Adams, J. A. (2011). Evaluation of a geospatial annotation tool for unmanned vehicle specialist interface. *International Journal of Human-Computer Interaction*, 28(6):361 – 372.