Real Time Scalable Visual Analysis on Mobile Devices

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ABSTRACT

Interactive visual presentation of information can help an analyst gain faster and better insight from data. When combined with situational or context information, visualization on mobile devices is invaluable to in-field responders and investigators. However, several challenges are posed by the form-factor of mobile devices in developing such systems. In this paper, we classify these challenges into two broad categories - issues in general mobile computing and issues specific to visual analysis on mobile devices. Using NetworkVis and Infostar as example systems, we illustrate some of the techniques that we employed to overcome many of the identified challenges. NetworkVis is an OpenVG-based real-time network monitoring and visualization system developed for Windows Mobile devices. Infostar is a flash-based interactive, real-time visualization application intended to provide attendees access to conference information. Linked time-synchronous visualization, stylus/button-based interactivity, vector graphics, overview-context techniques, details-on-demand and statistical information display are some of the highlights of these applications.

Keywords: Mobile Visual Analytics, Information Visualization, Mobile Visualization, Real-time Visualization

1. INTRODUCTION

Visual analytics is the science of analytical reasoning facilitated by interactive visual interfaces.[1] Mobile visual analytics seeks to extend the definition to include analytical tasks performed on mobile devices, enabling faster analysis and response on-site. Currently, visual analytics software tools are limited to stationary knowledge discovery tasks because they have been designed for desktop systems and, therefore, have not been used to address the knowledge needs of professionals operating in the field, such as first responders, investigators, and other mobile knowledge consumers. Adapting current visual analytic techniques and creating new ones for mobile appliances is an open, largely unexplored, but extremely important area of research, since these devices are becoming standard equipment for field personnel. By harnessing this technology to support decision making, mobile visual analytics systems have the potential to increase the effectiveness of in-field personnel, potentially saving lives and property. As such, the main goals of this paper are to classify and categorize the important issues and considerations for designing mobile visual analytic situations for in-field applications and to illustrate some of our preliminary results in developing its basic technology. We begin by providing some background on common characteristics of in-field applications, reviewing related research, discussing and classifying the main challenges involved, and finally, describing two basic mobile visual analytic applications that we developed.

2. BACKGROUND

Two important tasks for which mobile visual analytic (VA) systems are used are - *in-field response* and *in-field investigation*. The characteristic requirements for both these tasks are real-time data access and interaction, ability to perform preliminary data analysis, decision-making and problem-solving and scalable visualization on multiple devices. Real-time data access complements and enhances decision-making and analysis by providing latest knowledge of the current situation. Real-time interaction helps the analyst explore the data to extract meaningful information quickly. Scalable visualization helps an analyst to view consistent version of the

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Multimedia on Mobile Devices 2008, edited by Reiner Creutzburg, Jarmo H. Takala
Proc. of SPIE-IS&T Electronic Imaging, SPIE Vol. 6821, 682102, · 0277-786X/08/$18

application in various situations on multiple devices without compromising the visualization quality. Further motivation for the design issues of mobile VA systems can be obtained by a detailed scoping of in-field response and investigation scenarios.

2.1 In-field Response using Mobile Devices

Actions taken at an event location during the event occurrence is collectively referred to as *in-field response*. Evacuation, system troubleshooting/repair and resource management are some examples of typical in-field response activities and the personnel involved are called *first responders*.[2] First responders usually operate through a *dispatch process* when performing reach-back tasks to get external information. The responder requests information from a dispatcher through a query. The dispatcher could either be a computer system or a person with access to such systems. In the former case, the responder has direct access to information where as in the latter case, he typically radios in to the dispatcher (usually because the responder is in a remote location). In either case, while the dispatcher works on processing the query, the responder either switches attention to other issues or wastes valuable time waiting for information before he can proceed with his duties. When the information has been gathered, the dispatcher notifies the first responder which can result in another query. This same interrupt-driven reach-back process should be harnessed by mobile visual analytic tools.

In many cases the computations occurring behind the scenes of visually interrogating an information space involves complex data access along with significant data abstraction and transformation processes. After a query has been issued, the device will notify the responder when the requested information has been processed. Utilizing the dispatch model can alleviate many of the demands that come with having to support a system where the first responder is continually focused on the mobile appliance while waiting for an answer. Another alternative would be to provide watch and warn services to initiate a dispatch operation. For instance, a graphical depiction of the current situational awareness can be maintained and the responder notified when regions or topics of concern change.

Mobile devices can also be useful tools in coordinating the work of various dispatchers especially during critical incidents. A critical incident can be a localized event, cover a large geographic area or even multiple locations. Responders, investigators, and command personnel can be distributed across these locations and their only link is typically the dispatch personnel. Communications and data relay can become more complicated if dispatchers from multiple agencies have to coordinate information before transmitting back to the respective responders. The speed and effective use of mobile devices can greatly improve the process of real-time data flow to all parties in such situations.

2.2 In-field Investigation using Mobile Devices

While in-field response takes place during, and immediately following an event, *in-field investigation* refers to tasks done after the event is over and involves either short-term or long-term uncovering and analysis of information to generate better situational understanding to prevent a reoccurrence or provide a relevant factual basis for prosecution. These tasks are performed by *investigators* and require the same analytical capabilities as for first responders.

Consider the case of law enforcement officers. They need to piece together chains of evidence, determine how crimes and suspects are associated, and keep on top of developing information. Simple, easy-to-use visual analysis can help officers and crime analysts discover patterns of related crimes and create shared understanding. To validate these assumptions we are beginning a pilot deployment of mobile visual analytics tools with the Automated Regional Justice Information System (ARJIS), a San Diego-area law enforcement information network. In addition to analytic tools like data clustering and temporal trend analysis, it also provides support for collaborative investigation using handheld devices. The officers can retrieve information such as warrants and booking photos in the field and share it with colleagues immediately. Using multimedia capturing tools on these devices, an officer can collect information (photo, audio, video) in the field and possibly tag it with GPS coordinates before distributing it to other members of the task force.

The investigators have the opportunity for in-field, deeper analysis of information that may have been previously collected over a much longer period of time. Mobile devices offer some unique advantages for in-field investigation that can significantly impact immediate decision-making. By providing the investigators with interactive and exploratory tools in the field on these devices, they can function effectively without having to take the time to return to a central point of operations.

3. RELATED WORK

Recent advances in mobile hardware and software have made them popular for a variety of applications. The mobility factor is of great advantage for enhancing location specific services with the appropriate context. As such, they are useful for in-field response and investigation applications. However, presenting information for analysis with the devices' limited form factor is quite challenging. Effective mobile visual analytics system design draws upon previous research in the related fields of mobile information visualization, mobile user interaction and visual analytics in general. We describe briefly some of the relevant work in these areas here.

3.1 Mobile Information Visualization

Most of the previous work in this area deals with the important aspect of effective representation and visualization on small screens. Chittaro, et. al.[3] describe a checklist of steps and a variety of existing techniques for creating a mobile visualization application. However, these guidelines are for a general setting and we wish to extend it to the specific setting of visual analytics incorporating issues such as real-time visualization, coordinated visualization, time-dependency and frequency of visualization updates.

In-field visual analysis can greatly benefit by following the "visual-information seeking mantra" by Shneiderman[4] to get an overview of the current situation, zoom into the information space, filter by query and later request detailed information. Our example applications illustrated in this paper were guided by this mantra and the techniques to solve the "presentation" problem described by Chittaro.[3] Specifically, the NetworkVis application we developed, was motivated by the "AppLens" and "LaunchTile" techniques developed by Karlson, et. al.[5] They describe two effective techniques to display content from multiple programs on handheld devices in an overview mode and let users zoom into a desired program for detailed information.

Visual scalability is another desirable quality in mobile applications, since it helps users to view the visualization on devices with various screen resolutions without compromising display quality. However, not many existing mobile systems are designed to scale nicely with the resolution. This scenario is changing due to the recent advances in lightweight libraries for 2D vector graphics such as OpenVG[6] and SVG Tiny.[7] It has led to the development of some relatively fast and scalable applications such as the mobile emergency response system developed by Kim, et. al.[8] Both NetworkVis and InfoStar systems (examples illustrated in this paper) have been designed to be scalable using OpenVG and FlashLite respectively to deliver vector graphics based visualization.

3.2 Mobile User Interaction

User interactivity is critical to Mobile VA applications because of both the urgency of the operating situation as well as the necessity for investigative exploration. User Interaction can focus either on the physical (stylus, keypad, thumb gestures) or the software tools allowing interactive data exploration.

While most of mobile visualization applications focus on stylus interaction, a few of them (ZoneZoom,[9] Applens and LaunchTile[5]) present designs suitable for both keypad and stylus/thumb gesture based interactions. Work by Hirotaka et. al.[10] describe better design for keypad interaction on cell phones which can be leveraged for the higher end smartphones that lack touch screens. One of our examples, NetworkVis, borrows ideas from these works to develop a hybrid (stylus/keypad) interaction mode.

Another aspect of user interaction is the software interface provided for data exploration. Primarily, notification cues are important to both responders and investigators to identify any abnormality. Campbell, et. al.[11] describe different types of notification cues for mobile response teams according to their situational capability. While responders need more immediate cues (audio, tactile), investigators can be notified using visual cues during data exploration for an interrupt-driven reach-back process (Sec. 2.1). We use such visualization cues that indicate abnormal system states in our examples which primarily cater to investigators.

3.3 Mobile Visual Analytics

Traditionally mobile devices have been used to assist in-field operations, because their unique mobility factor is the key to situational awareness. However, the main role of mobile devices in this area has been limited to data entry, communication and basic text display. More recently, systems have started to use the local graphics capabilities on these devices for visual analysis in the field. Systems such as the "Mobile Path Engine"[12] use mobile devices with GPS and orientation sensors to assess risk and gather information about surroundings and display them in a virtual environment setting. Its virtual GIS system can also be used as an information sharing tool for collaboration among responders. Another similar effort from NASA Smart Systems Research Lab[13] describes a mobile based system enhanced with location sensors to improve situational awareness of responders and commanders. However, this system is targeted towards higher end mobile devices like Tablet PCs and restricts itself to only a text-based display for handheld phones and PDAs. The mobile emergency response system by Kim, et. al.,[8] on the other hand, utilises both 2D and 3D graphics capabilities on PDAs and smartphones for information analysis and tracking. Features and functionalities of these systems coupled with the visual analytics agenda[1] helped motivate some of the design challenges we identified.

4. CHALLENGES FOR VISUAL ANALYSIS IN A MOBILE ENVIRONMENT

The creation of visual analytics tools for mobile environments has several challenges. While some of these challenges are common to general research in mobile computing, there are some specific issues that are unique to designing visual analysis systems adapted to small devices. Here we categorize and describe these issues.

4.1 Challenges Common to General Mobile Computing

Mobile computing has numerous unique challenges compared to stationary desktop computing. Some of the common challenges can be broadly classified into the following:

4.1.1 Connectivity

Connectivity and bandwidth are critical challenges as visual analytic applications can involve large (up to hundreds of terabytes) data sets and require extensive computational needs. In the case of first responders, maintaining continuous connectivity is more important than actual download speed. For the casual user, providing quick access through always-on devices, like cell phones, could be the difference between using and not using mobile applications.[14] Waiting for an appliance to turn on, connect to service, and start the application can take so long the user would rather use other sources of information or just rely on their current understanding of the situation.

4.1.2 Data Access and Storage

Creating effective displays of information from streaming data sources is necessary to enable in-field decision making. In doing so, we face several unique limitations that must be overcome in mobile analytics like data connectivity (as mentioned earlier) and limited storage and processing capabilities. Given these constraints, we have to consider a client-server architecture for efficient data transmission. A more powerful, well-connected server receives all of the streaming data and integrates the data into a unified representation. Basic analysis, extraction, and abstraction of the information are performed on the server to determine which data and at what rate it should be sent to the mobile client. The client processes all user interactions and creates the appropriate visual display for the user and his task, allowing in-field analysis and exploration of the information. Based on the data source and storage method on the server, it can be transferred to the client device using a variety of methods, such as web services, remote data access (RDA), merge replication, etc.

4.1.3 Interface, Display and Screen Resolution

Non-conventional input devices force us to move away from conventional interactive graphics supported by region picking, hyperlinks, mouse-over events etc.[15] These are, nevertheless, important issues in the design of interfaces for ubiquitous computing devices.[16] Moreover, limitation and variation in screen size and resolution across devices forces us to look for alternative solutions to provide satisfactory and consistent experience to users. Using data abstraction techniques is the key to displaying all the necessary information in a limited display. Data grouping, data filtering, visual metaphors and level of detail are some effective data abstraction techniques to represent data compactly.

4.2 Challenges Specific to Visual Analysis

Apart from the above mentioned generic challenges, we also have to be aware of issues that are more specific to mobile visual analytics, including issues related to task and user adaptation, temporal analysis, real-time streaming input, appropriate update frequency, multiple situational environments, cross-system context, and adapting desktop-based visual analytic techniques.

4.2.1 Task/User Adaptation

There are a wide variety of information needs dependent on the type of user and the task to be performed. For example, a fire-fighter's main task is to rescue people and property, while a police officer at the same scene helps to maintain order and direct people. So, a fire-fighter needs immediate results with more perceivable audible and tactile cues showing information about source, spread of fire and location of trapped individuals. The police officer at the same time, needs information from a larger area, such as traffic flow, evacuation routes and smoke/wind direction, allowing for some degree of interaction to query and filter information.

In general, such adaptive design requires a careful scoping of the problem space being addressed and a realization of whether and how the results apply to other situations.[11]

4.2.2 Appropriate Update Frequency

Real-time streaming data can be vital to making effective decisions, but when all incoming data is presented to the user, this can be a detriment to decision making. The military refers to this problem as paralysis by analysis[17] and has observed this in situations where commanders wait for the next piece of information before making their decision based upon the current incomplete picture of the event. This same situation applies to emergency response in crisis situations. Presenting relevant information for decision-making at the appropriate rate is crucial.

4.2.3 Multiple Situational Environments

Mobile users do not have the luxury of using applications only in controlled environments such as a parked car. Interfaces need to support a range of techniques to accomplish the same task in a range of conditions ranging from walking in a congested environment using a cell phone to sitting in a café with a laptop. Selection of the appropriate interaction technique depends on the needed level of control and situational capability of the user to use the interface.[11]

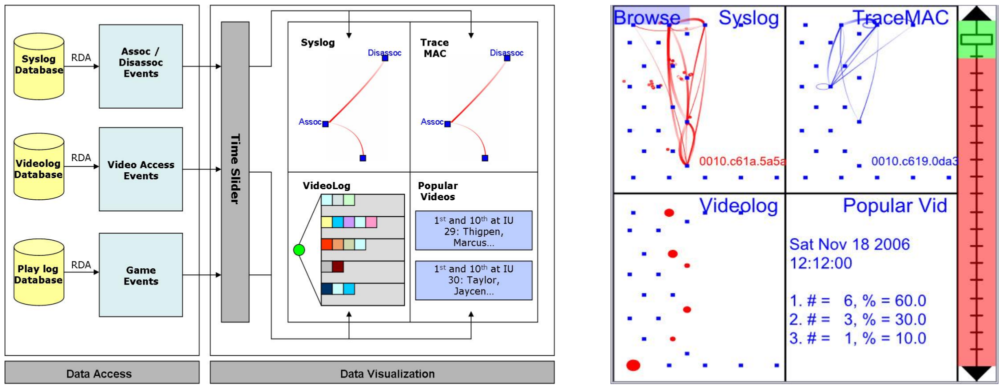
4.2.4 Maintaining Context Across Systems

For many applications it is unlikely the mobile appliance will be the primary workplace. For instance, mobile appliances are often used to handle e-mail while out of the office, but with their limitations prevent their use as the primary e-mail tool. Visual analytical tasks can easily become complex and involved. While mobile devices will allow users to perform a subset of tasks, a more capable system is likely to serve as the primary analysis tool.

To improve the usefulness of mobile analytical tools, they need to have similar visual and interaction metaphors to those of desktop tools. By maintaining context between systems, users should be able to more readily switch between them and spend less time acclimating to each system.

4.2.5 Adapting Existing Techniques

Many visual analytics techniques have been developed for desktop systems. Adapting these for use on mobile devices represents a potentially large set of unexplored challenges stemming from the previously mentioned issues of limited form factor of these devices. For example, traditional cluster visualization and scatter plots show nodes as points on screen. However, these can easily overwhelm the available mobile display even for a moderately sized dataset. Hence, we would need to look for alternatives such as hierarchical data presentation, details on demand visualization, etc. Similarly, we would need to adapt existing techniques considerably to match the interaction tools and computational power of these devices.



(a) (b)

Figure 1. (a)NetworkVis System Architecture. (b)Overview/Context Screen from the system.

5. TWO MOBILE VISUAL ANALYSIS SYSTEMS

We illustrate various techniques that were developed to address the generic and specific challenges through two mobile based systems - NetworkVis and InfoStar.

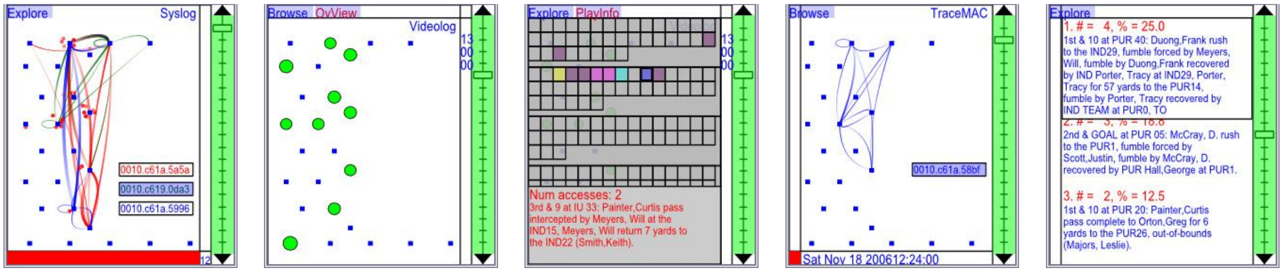
5.1 NetworkVis

The NetworkVis system serves as an example of the Responder-Investigator scenario mentioned in Sec. 2. This was developed as a complementary analytic system to the existing *eStadium*[18] project at Purdue University. *eStadium* is a long-term, large-scale, collaborative project with the main aim of providing football spectators a great game day experience and in the process solve problems in on-demand delivery over a wireless network of multi-media applications to football fans' PDAs, cell phones, or other portable devices. The system (described in detail in our earlier work[19]) uses the network and video logs recorded by various Access Points (APs) when fans connect to the network and access *eStadium* applications using mobile devices. Using this system, an analyst/in-field responder can detect and discover abnormal association/disassociation patterns or overloaded APs and take appropriate troubleshooting measures immediately.

Figure 1(a) shows the structure of our visualization system. The system has two components: Data Access and Data Visualization, which are explained in detail. In the following exposition, we highlight the specific techniques that were employed to solve some of the issues mentioned earlier in sec. 4.

5.1.1 Data Access Component

Data for our system comes from several sources, including data acquired from APs (hereafter referred to as "syslog" messages), video messages collected by streaming video servers ("videolog" messages), and a manually-logged play-by-play description of the sporting event in progress ("gamelog" messages). The messages are logged into a remote SQL database. Mobile devices can pull filtered data from the remote SQL database into SQL Server Mobile database using the Remote Data Access (RDA) technique. RDA technique is fast because it does not handle data conflict resolution and thus helps to overcome the connectivity/bandwidth challenge (4.1.1). The client-server architecture enables us to overcome the storage issues (4.1.2) since we only pull the necessary and filtered information from the database onto our local storage on the device. Even though RDA is a fast technique, we cannot have it enabled all the time because it would be detrimental to interactive display rates. So, in our case, we decided to enable RDA upon the users' request or a fixed regular interval whichever comes first (Appropriate Update Frequency - 4.2.2). This decision was appropriate in our case because the system involves only a small number of data streams in non-critical decision making environment. For more complex streaming data and time-critical decision-making, more robust techniques need to employed including event-triggered updating, feature and task analysis.



(a) (b) (c) (d) (e)

Figure 2. Detailed views of the four different regions. Other regions are compressed and a summarized information, if relevant, is shown. (a)**Syslog data** - top three active devices, with MAC addresses (b)**Videolog data** - Downloaded video statistics (c)**Detailed video statistics** for each video downloaded. Text description of corresponding video is also shown. (d)**TraceMAC** - Trace of device shown in the screen. (e)**Popular Video** - Three most popular videos, with a zoom window for those descriptions that cannot fit in the original screen.

5.1.2 Data Visualization Component

Two important aspects of the visualization component are: Data Abstraction & Aggregation and the Visualization itself. Data Abstraction helps to address the issue of limited display on portable devices (4.1.3), while Visualization addresses the perceptual issues, interaction and synchronized representation of multiple data modes with time.

Data Abstraction & Aggregation: The system handles several data modes such as syslog, video and text. Depending on the type of information to be conveyed, we employ various abstraction methods mentioned in the sec. 4.1.3. Syslog data contains network association and disassociation events of each PDA device in the stadium. By representing these events, we can see the network connection patterns of individual PDAs over time and identify any anomalous behavior. We employ Data Grouping (4.1.3) by combining the events between a pair of APs in a particular direction and representing them with a single curve whose thickness is proportional to the number of such events. We also appropriately display events from only the most active (in terms of number of such events), or the top few active devices in each time interval depending on the level of detail (Data Filtering - 4.1.3). This can help in tracking a particular device's pattern over time.

Video logs from the eStadium test bed contain information about how a client downloads and views videos during a game. Displaying all the minute statistics might not be of any practical use since it can crowd the screen. We visualize the number of video accesses from each AP for each different video to provide an overview. We provide different levels of display detail presented to the user on demand (Level of detail - 4.1.3).

The game logs keep track of play-by-play events with links to video replays for game highlights. We display the text statistics and color code actions (touchdowns, field goals, etc.), from this log (Visual Metaphors - 4.1.3). Also, based on user accesses, we determine and display the three most popular videos in each time interval (Data Filtering - 4.1.3).

Data Visualization: Our visualization system closely follows the AppLens technique introduced by Karlson, et. al.[5] While their technique had three modes of views - overview, context and detail, we have only two modes - overview/context view (Figure 1(b)) and detail view (Figure 2). This visualization paradigm helps us to overcome the difficulties of a limited display by employing multiple levels of detail. It also serves as an example of task/user adaptation (4.2.1) since the system users suggested that they would like to view a summary of all critical information while being able to view details upon demand.

In the context view, we divide the screen into 5 sections as can be seen in Figure 1(b). In this view, we don't allow much user interaction except for the time slider and to request for detailed information. The first section, time slider, enables a user to scroll through discrete time intervals and see the corresponding visualization. The green fill indicates the time until which data is available. The time slider is especially useful for network analysts (users of the system), since they need to be able to navigate in time to compare and contrast network patterns/anomalies over time (user adaptation - 4.2.1). Rest of the screen space is divided into 4 regions (which we will refer to as top-left (TL), top-right (TR), bottom-left (BL) and bottom-right (BR)). In the TL, TR and BL regions, we show Access Points arranged according to their relative physical locations (shown as blue dots) in the stadium.

The TL region displays syslog data (Fig 1(b)). At the overview level, this region displays only the association/disassociation patterns of the most active device in each time interval (Data Filtering - 4.1.3) and its MAC address. The BL region displays videolog data (Fig 1(b)). In the overview level, we represent only the denied videos from each AP (Data Filtering - 4.1.3) as a red circle with area proportional to the number of such videos (Visual Metaphor - 4.1.3). The TR region (Fig 1(b)) displays association/disassociation movements of a selected device in the stadium. The BR region (Fig 1(b)) shows the current time stamp and a list of statistics about the three most popular videos downloaded and viewed by fans in the corresponding time interval.

The detail view screen is displayed when a user zooms into the information space from the overview screen using either spatially intuitively mapped keys (on smartphones) or a stylus (on PocketPCs). Enabling interaction through multiple input devices (keypad, stylus and mouse) demonstrates how the NetworkVis system can be used in multiple environments on various devices (Multiple Situational Environments - 4.2.3). Once a particular region is zoomed into, the rest of the regions on the screen are compressed to show only the most critical information for context.

When a user zooms into the TL region (i.e. syslog), he is presented with association/disassociation events of the top three most active devices (along with their MAC addresses), each in a different color (red, green and blue in order of decreasing activity of the device) as seen in Figure 2(a). The increasing opacity of the curves indicates direction of a device's disassociation point to association point (Visual Metaphor - 4.1.3). Thickness of the curves is proportional to the number of movements of a device between two APs.

The detail view for BL region shows the number of videos accessed from each AP as a green circle around the corresponding AP with its area proportional to the number of videos (Figure 2(b)) (Data Grouping - 4.1.3). It also overlays the information about denied videos as a red circle. A user can select an AP and view detailed information on all videos downloaded from that point as shown in 2(c). Further, he can select a particular video to view access details and description of the video.

The TR region (Figure 2(d)) shows the association/disassociation events of the device selected for tracking from either the TL region or from a scrollable list.

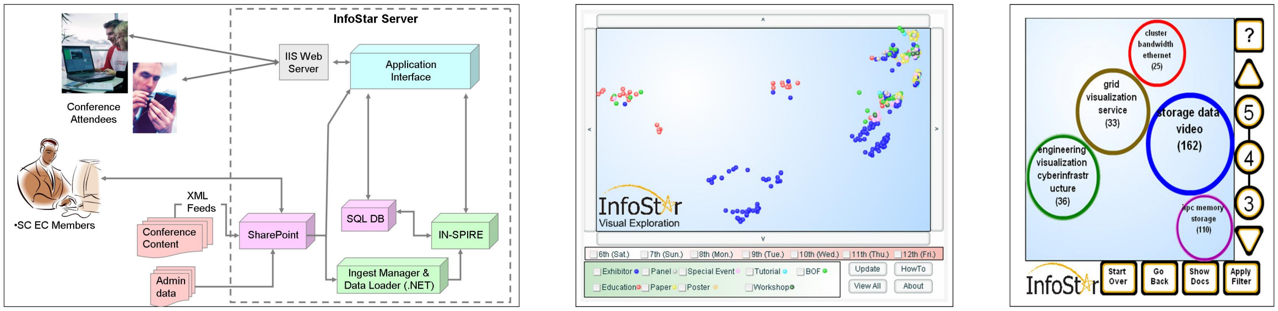
The Bottom Right (BR) region in detail view (Figure 2(e)) shows text descriptions of the most popular play videos apart from the statistics shown in the overview mode of this region. Users can scroll through these and view the entire play text, if they have been cut short due to lack of space (details on demand - 4.1.3).

5.2 InfoStar

InfoStar is another example that serves as an example for in-field visual analysis on mobile devices. It was first introduced at Supercomputing 2004 (SC2004) and continues to be developed and expanded on. The InfoStar platform and its underlying technology has been used to provide real-time mobile access to scheduling and venue information at conferences like Supercomputing and to law enforcement agencies. The application was designed to work at different levels on multiple devices (like desktops, laptops, Tablet PCs, PDAs or cell phones) (4.2.3, 4.2.4). Its client-server design minimizes the amount of data transfer and local storage (4.1.2) and the data abstraction back-end allows for hierarchical information exploration (4.1.3).

5.2.1 System Architecture

InfoStar relies on HTML and CSS for text display since most of the devices (including most PDAs and cell phones) offer support for these protocols by default. For the graphics part, it uses Macromedia Flash since it comes pre-installed on most devices, and is supported across multiple platforms (4.2.4, 4.2.3). Moreover, Flash also has the ability to query web services, manipulate XML and perform complex interactions. The system interfaces to a wireless network for its data access, allowing users to interact with it from anywhere at anytime (4.1.1). InfoStar has four distinct component layers: Data Feed, Data Aggregation, Data Analysis and Data Presentation. A graphical summary of the system components is shown in fig. 3(a).



(a) (b) (c)

Figure 3. (a)InfoStar System Architecture. (b)InfoStar cluster visualization on big displays. (c)InfoStar cluster visualization adapted for display on small screen devices

Data Feed Layer: Data feeds come from a variety of sources, including XML streams and spreadsheet files. All data feeds are stored in a Microsoft Sharepoint database which provide a one-stop content access point for all InfoStar components and conference personnel who need special data access (system administrators, conference executives and content owners). Data feeds range from static files updated periodically to interactive databases where exhibitors can enter data regarding events in a *just in time* fashion.

Data Aggregation Layer: Data from the various feeds are collected by a custom application (the *Ingest Manager & Data Loader*, see fig. 3(a)), and combined into a single source XML file. The data is retrieved using web services (4.1.2). This layer involves renaming/modification of key attributes to ensure a consistent format for all events.

Data Analysis Layer: At this layer, the Ingest Manager application feeds the aggregate XML file into PNNL's IN-SPIRE[20] software for contextual analysis. IN-SPIRE groups abstracts into clusters based on its analysis of their topical similarity, and returns a set of two-dimensional coordinates for graphical representation (4.1.3). The Ingest Manager stores these coordinates along with event data such as times and locations. A table then maps the event time and location with the clustered abstract information in a SQL server database (in tandem with a raw XML file).

Data Presentation Layer: Data is presented to users in a variety of forms including text-only representations, or for more capable client platforms, a Flash-based *Visual Exploration* page. As in the data aggregation layer, the presentation layer receives its data from the Ingest Manager application by way of web services. The use of web services for data transfer between the various layers allows for maximum flexibility (4.1.2).

5.2.2 Features and Functionality

The SC2004 InfoStar system features an interface with a streamlined layout comprising five major sections and several minor sections divided by task or feature. The major sections (namely *Maps*, *Schedule*, *Exhibitor List*, *Search* and *Visual Exploration*) provide most of the information about the conference. Other sections offer attractive additions or standard features such as *help*, *about*, *contact* pages and a real time view on the exhibition floor (via a collection of web cams).

The function of the *Maps* section is to display maps of interest to conference attendees, e.g. the layout of the conference halls and the exhibitors' area. Maps are provided for all major areas in the conference center and each room on a map has links to information about events occurring in that room. This includes the technical venue and the exhibitor show floor.

The *Schedule* section provides scheduling information. Users can select conference events based on the day or events currently underway. The initial list shows summary information but provides access to all information on the event, thus providing details-on-demand and preventing information overload on the user (4.1.3). The *Exhibitor List* section provides information about conference exhibitors. Exhibitor content, including sponsored events, can be accessed through an alphabetical list. *Search* section allows users to search events by type and time, including events in progress.

The *Visual Exploration* section incorporates an existing visual analytic technique. This provides an interactive scatter plot view of the events taking place at the conference. Events that are more strongly related are closer together on the plot. Groups of strongly related events are referred to as clusters. Using Flash and the output from the IN-SPIRE engine, events can be displayed as a 'galaxy' of elements that are color-coded by event type. The user can zoom in to view clusters of documents in greater details (4.1.3) and restrict the scope of the information displayed by selecting specific days and event type, as shown in fig. 3(b).

Passing the mouse over an event would reveal its title and offer the option to receive more information about the event or find similar events. Selecting the option to find similar events would issue an IN-SPIRE query which would in turn generate an interactive galaxy visualization or a text list of events related to the event under analysis. It serves as an example of appropriate update frequency issue that we mentioned in sec. 4.2.2.

While this visualization worked for larger displays it was problematic for smaller form factors. In those cases an adapted technique was used that presented only high-light information based on primary clusters within the scatter plot. This is a classic case of adapting existing techniques for larger screens to fit small screen devices (4.2.5). Figure 3(c) shows an example of the reduced visualization technique. In this visualization, users can choose the number of clusters by selecting a number on the right hand side. By selecting a cluster itself from the visualization the system would drill down to create a new visualization of the document relationships within just that subset (Data Abstraction - 4.1.3). This technique allows the user to explore the document space and then view the text of a refined set of documents.

To provide multiple ways of accessing information, all major sections have been linked together in an intuitive manner so that the user can seamlessly move from one section to the next, drilling down to find more information about a specific event, or broadening the search to find and visualize similar events. Each event description has links to the map, the schedule of that day, similar events, events of the same type, and the visual exploration.

As an application, InfoStar is rich in features, but it is designed so that the most important ones were most visible, and the flow from one section to another is seamless. Lacking a strong user profile, the goal was to interleave a robust set of more traditional text lists and new visual exploration functionality. This would provide users the opportunity to self-select a preferred information access technique based on the situation and environment.

6. CONCLUSIONS AND FUTURE WORK

We have shown the potential for mobile visual analytic tools in a wide range of applications, including both time-critical analysis and more detailed, investigative analysis. We have also presented a number of issues that must be addressed in developing these tools so that they can become effective tools for actionable decision making.

We plan to expand this work in several ways. First, we plan to formally characterize the decision making tasks of several in-field investigative and emergency response situations. Working in partnership with first-responders and investigators will allow us to fully understand their needs and the constraints of their decision-making environment. It is apparent that providing actionable, relevant, live information can increase situational awareness and increase responder safety and effectiveness. Second, we are also currently adapting our techniques to make them more intuitive and simple to use to better support the chaotic environments of first responders. We are also expanding support for geo-referenced information and time series analysis. Finally, we plan to expand our work in mobile analytics to more general knowledge workers (e.g., business analytics), where the tasks are less defined. We will also investigate what type of visual analysis tasks would be suitable for mobile devices in general.

ACKNOWLEDGMENTS

We wish to thank the reviewers and the people at the Battelle Pacific Northwest National Lab for their suggestions and helpful comments. We also thank the Center for Wireless Systems and Applications at Purdue University for providing us with network data for NetworkVis. This work has been funded by the U.S. Department of Homeland Security's Regional Visualization and Analytics Center (RVAC) program.

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