Multi-User, Multi-Display Interaction with a Single-User, Single-Display Geospatial Application

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ABSTRACT
In this paper, we discuss our adaptation of a single-display, single-user commercial application for use in a multi-device, multi-user environment. We wrap Google Earth, a popular geospatial application, in a manner that allows for synchronized coordinated views among multiple instances running on different machines in the same co-located environment. The environment includes a touch-sensitive tabletop display, three vertical wall displays, and a TabletPC. A set of interaction techniques that allow a group to manage and exploit this collection of devices is presented.

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BACKGROUND AND MOTIVATION
In recent years, geospatial applications [4,6,7] have generated a large amount of interest. These interactive atlases allow the user to navigate to any position on the globe, and augment satellite images with geo-registered information such as roads, hotel locations, and political boundaries. Using these tools, individuals plan trips, locate businesses, or simply explore new areas from a bird’s-eye-view.

Teams of intelligence analysts, civil engineers, architects, and city planners often work face-to-face around a tabletop on which they view and manipulate printed geospatial information, often surrounding themselves with additional materials hung on the walls of the room. Such a team wishing to use one of the geospatial applications described above will run into many problems, which stem from the single-vertical-display, single-user assumptions that most application developers make.

In this paper, we present an adaptation of Google Earth [4] that meets the needs of small groups working in a co-located, multi-device environment, such as that described by Streitz et al. [10]. We describe several of the challenges that arise with this type of adaptation, and present a set of interaction techniques that mediate these issues. Our wrapper application coordinates multiple instances of Google Earth running on different machines in the same space. No changes to the Google Earth application code are needed. While we believe that ultimately developers will design and implement their applications with multi-device environments in mind, we feel that the adaptation of existing tools to take advantage of these spaces is a worthwhile endeavor.

RELATED WORK
Adapting single-user applications for multi-user settings has been the subject of much research. Greenberg [5] surveyed and discussed a large body of research performed with the goal of providing shared-views across distributed sites. In this work, the research focuses on ensuring that the same view is displayed on different remote machines so that separated users have a shared context for collaboration. A more recent research effort reported by Tse et al. [11] proposed an architecture that enables multi-user speech and gesture interaction for co-located collaboration on a single shared-display with existing applications.

Our approach in this paper is to help groups take advantage of different views displayed on multiple machines in a co-located space. Much of the state of the Google Earth instances is synchronized across machines; however, subtle differences are maintained and controlled by the users so that each of the machines’ displays and input devices is best exploited.

Figure 1: Two people working with our multi-device, multi-user adaptation of Google Earth [4].
The transformation of POVs is informed by the differences among the physical displays of the different devices in the space. A POV that is appropriate for one type of display may be inappropriate for another. For example, using a POV other than a bird’s-eye-view on a horizontal tabletop results in a disorienting image for many of the group members sitting around different sides of the table. A tilted view of the scene is more appropriate for a vertical display with which everyone in the room shares the same “up” vector. Figure 2 shows the table and two walls focused on the same geospatial location, but viewing it from different POVs that are appropriate to each display’s orientation.

**Visually Separating Layers**

Google Earth provides users access to many geospatially registered layers of information. Figure 2 illustrates how each display in our environment can be augmented with a different layer of information so that the end result is a spatially multi-plexed, temporally-synchronized multi-layered display. In a multi-user visualization application, each member of a group may find different layers of information valuable to their participation. For example, a plumber may be most interested in the location of pipes while an electrician would want to know the location of buried wires under city streets. Simultaneously displaying these multiple layers on a single-display would produce a visually cluttered and less-useful image, and switching amongst these layers sequentially might also impose high levels of cognitive load on the users. As pointed out by Roberts [9], by simultaneously displaying the data in multiple ways a user may understand the information through different perspectives, overcome possible misinterpretations and perform interactive investigative visualization through correlating the information among views. Currently, the visibility of layers on each wall display is controlled locally on that machine, but future work will include methods for controlling the visibility of layers on the wall displays from the tabletop.
will often switch between working together and working two sites can be examined side-by-side. Similarly, a group they navigate to and inspect a second site. In this way, the bridge may want to leave one site visible on one wall while examining potential sites for the construction of a new section of views [1], which feels like the most natural relationship between views, although not the only useful one.

On the table, each wall display is represented with a small proxy camera whose position indicates the wall display’s rotation and tilt relative to the table’s POV. Users manipulate this proxy to edit the POV transformation. By changing views in this manner on the table, users not only avoid the need to stand up and walk to a distant display to manipulate its view, but also are able to perform input on wall displays that may have no input mechanism of their own.

Dragging a proxy around the center of the table in either direction rotates the wall’s POV, and dragging the proxy toward or away from the center of the table changes the tilt of the wall’s POV. By constraining POV transformations to rotation and tilt, there is a natural mapping between the 2-DOF touch input on the table and two values in the POV.

While altering the POV on wall displays allows a group to view different angles of a scene, it can quickly become difficult to understand the relationship between what is displayed on the walls and the table once a group changes the initial CAVE-like arrangement. We lessen this confusion with two pieces of visual feedback to help group members understand the relationship among the displayed POVs. When camera proxies on the table are touched, an ellipse is drawn on the table indicating the tilt and orientation of the remote display (Figure 2). The table’s title-bar and navigation-panel appear on the wall display as if the wall display were projecting a view of the tabletop.

**Detaching & Re-synchronizing Views**

Oftentimes, groups may want to break the coordination between a wall display and the table. For example, a group examining potential sites for the construction of a new bridge may want to leave one site visible on one wall while they navigate to and inspect a second site. In this way, the two sites can be examined side-by-side. Similarly, a group will often switch between working together and working separately, so being able to unlink views is valuable for these periods of independent work. Our interface provides a simple tacking gesture to lock a camera proxy in-place and break the link between the table and wall application states [3]. Subsequent navigation on other machines does not affect the POV of the tacked wall display. To re-link the wall display, a second tacking gesture refocuses the wall display on the table’s point of interest. An unimplemented alternative would be to click-and-hold a tacked proxy to return all machines to the POV of the tacked wall.

**Annotations**

The simple act of annotation is a major activity with geospatial information. Our application implements a simple multi-user annotation tool on the table and a single-user annotation tool on machines that support input. Our tool paints into a transparent overlay and polls Google Earth for the geospatial location of the current point-of-view so that annotation strokes can be geospatially registered. This way, when the team is finished annotating, the strokes are passed over the network to other machines and displayed in the correct location regardless of the machine’s current or future POVs. Specifically, we create a KML file detailing geospatial location of the bitmap file, and send both files over the network to the other machines. Other machines then open the KML file, which inserts the bitmap into the GE rendering pipeline. Figure 3 shows the sharing of geospatially registered annotations across different displays.

**Working Together, Working Alone**

A major benefit of a shared display is the common context that it provides the group; however, situations arise in which the use of a shared display is a liability. Google Earth, like other single-user applications, assumes that it is safe to repurposes large portions of the screen for sub-tasks. If the (single) user’s mind is occupied on a task, what is the danger in annexing much of the display for that task? For example, when a user wishes to turn layered information on and off, they open the layer control panel, which occupies up to 1/3 of the screen. If the team is working closely together, the opening of this menu would be expected and not cause an interruption; however, when working independently, opening this large menu is a disruptive action for other members of the group.
Our interface mediates this particular disruption by moving the layers menu off of the table and onto a group member’s TabletPC (Figure 4). Our wrapper application polls the visibility of each layer in the GE application, and upon detecting a change sends a message to the appropriate machine. In this manner, the visibility of all of the layers is kept in sync between the table and tablet, allowing an individual to issue these commands without annexing large portions of the tabletop. A single shared display may also have the drawback of discouraging exploration on the part of individual group members. By allowing an individual to annotate privately on their TabletPC, they may be more comfortable to try out variations on an idea in private before they are ready to share their sketches with the group.

Figure 4: This user operates the layers menu on their TabletPC to view the roadways in this scene (yellow lines). The visibility of layers is synchronized between the tablet and table, the result being that this user can issue commands without covering large portions of the shared tabletop.

**Touching to Navigate, Touching to Reference**

Because most applications assume a single user, many commands are not well defined when performed simultaneously by multiple people. In our example application, how should the system respond when one person navigates to the left, and another to the right? By making one person the “driver”, others’ touches can reference items or annotate rather than change the view. “Driver” status can be passed around. First to touch is a simple means of conflict resolution for driver designation [8]. For those not driving, telepointers [2] are used to visualize touch-through from applications can run within a multi-heterogeneous-display. In this manner, the visibility of all of the layers is kept in sync between the table and tablet, allowing an individual to issue these commands without annexing large portions of the tabletop. A single shared display may also have the drawback of discouraging exploration on the part of individual group members. By allowing an individual to annotate privately on their TabletPC, they may be more comfortable to try out variations on an idea in private before they are ready to share their sketches with the group.

**CONCLUSION**

Enabling multi-device multi-user interactions using widely deployed single-user commercial off-the-shelf applications creates new uses for existing tools. In this paper, we presented our adaptation of the Google Earth application. While many of the portions of this system are specific to Google Earth, others were designed with the wrapping of other applications in mind. We hope that this tool will provide an example for how other single-display, single-user applications can run within a multi-heterogeneous-display, multi-user environment without the need for major code modification, and we are currently investigating generalizing some of these solutions for use with other prototypes.

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**REFERENCES**


