Table-Centric Interactive Spaces for Real-Time Collaboration: Solutions, Evaluation, and Application Scenarios

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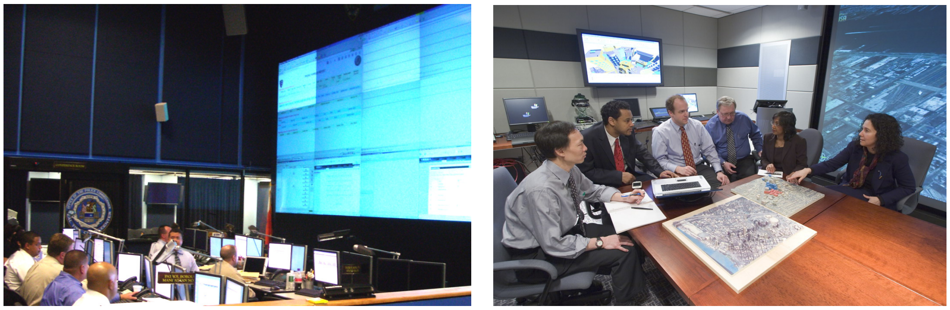

Figure 1. Existing multi-surface spaces: New York Police Department's Real Time Crime Center (left) and PB Cave.

Abstract

Tables have historically played a key role in many real-time collaborative environments, often referred to as "Operation Centres". Today, these environments have been transformed by computational technology into spaces with large vertical displays surrounded by numerous desktop computers. Despite significant research activity in the area of tabletop computing, very little is known about how to best integrate a digital tabletop into these multi-surface environments. In this paper, we identify the unique characteristics of this problem space, and present the evaluation of a system proposed to demonstrate how an interactive tabletop can be used in a real-time operations centre to facilitate collaborative situation-assessment and decision-making.

Introduction

Although centrally located tables have historically been the foci of collaborative activity, much of the research into computationally enabled interactive spaces [1, 2, 3, 4] has primarily concentrated on how to facilitate the transfer of data, redirection of application windows, and redirection of mouse and keyboard input amongst interactive whiteboards and personal computing devices. This body of research informs the design of interactive spaces for the common office environment, spaces in which collaborative brainstorming and spontaneous discussions dominate. The tasks carried out in these spaces are usually "open-ended" without stringent time constraints or the risk of catastrophic consequences associated with the collaboration.

This paper presents motivations for and evaluation of a system that enables complex and complete control over multiple display surfaces *solely* from an interactive table for task domains in which real-time collaborative situation assessment and decision-making are paramount. We believe that recent developments in digital tabletops [5, 6] can be exploited to enable a return to table-centric spaces which can be invaluable in supporting face-to-face real-time collaborative decision-making while simultaneously controlling and exploiting the additional information capacity of auxiliary displays. Our rationale for using a table-centric paradigm is three-fold:

1. From our collaboration with two organizations (Parsons Brinkerhoff Inc. and the New York Police Department, Figure 1), it is clear that the size of these centers are much larger than typical meeting rooms - many of the large screens are beyond immediate human reach.
2. The collaborative tasks and decision-making processes in these spaces can be time constrained, thus close face-to-face discussions are invaluable.
3. Observation of these spaces indicates that mere input redirection to the auxiliary displays is insufficient. Often, data from these displays needs to be brought within "arm's reach" to facilitate closer viewing and interaction.

In this paper, we first discuss previous work, and define the previously unexplored problem space for our present research. We then give an overview of the system we have designed [7], with an aim toward finding solutions to these open problems. Finally, we present a validation for our solutions in two forms. First, a user study is presented which shows that the system we designed can be quickly learned and used to perform interactive tasks with minimal instructions. Second, we present a scenario application of our system to the design of an interactive command and control center for the New York Police Department, and the positive reactions of high-ranking NYPD officials to the scenario and our system.

Related Work

Two configurations within the body of research exploring computer-augmented collaborative spaces are particularly relevant to our work: those with personal computer terminals augmented with shared, output only large-screen displays, and those featuring multiple types of interactive displays including interactive tables.

In the first type of environment, users are each equipped with a personal computer, generally at a nearly 1:1 computer-to-person ratio. Additionally, one or more large-scale screens may be used to display information of interest to the group as a whole, or as ancillary displays controllable from individual participants' workstations. In Engelbart and English's system [8], Begeman et al.'s Project Nick [9], and Xerox PARC's Colab project [10], participants are seated at workstations arranged around a table, leveraging some of the affordances of table-centred interaction, albeit without an interactive tabletop surface. Project Nick and Colab augmented these workstations with a large-screen display used to display information to the group. In Koike et al's *EnhancedTable* [11], and Rekimoto and Saitoh's *Augmented Surfaces* [12], personal workstations are enhanced with either tables or other vertical surfaces.

Tabletop computers have appeared in more recent multi-display collaborative environments. The iRoom project [3] extended CoLab in several ways. First, multiple SmartBoards are used so that users can interact directly with the vertical whiteboard. Second, an input redirection mechanism called PointRight was developed to redirect input to an arbitrary display. Third, a CRT embedded into a physical table allowed a single user to interact with a tabletop display using a mouse and keyboard. The i-Land project [13, 4] included personal workstations built into individual chairs, dubbed *CommChairs*, which could be positioned around and interact with a large-screen display called the *DynaWall*. Users interacted directly with either the CommChair or the Dynawall, but could manipulate the Dynawall from the CommChair using 'active synchronized views'. Objects were passed between the two using physical "passages". The i-Land project also included two types of interactive table, the larger, stationary *InteracTable,* and the smaller, more portable *ConnecTables* which could be connected together to form a larger surface. As with the CommChairs, objects are passed between tables and walls using the physical passage technique. In the MultiSpace system [1], users interact directly with a shared table, a laptop, or a wall-sized display, passing objects between the screens by dragging them to "conduits" or "portals" represented graphically on each device.

Problem Space

Although some of this research explored environments in which tables and walls were both included, there are several differences between our problem space and the prior work. In particular, we can classify the previous work along two dimensions: 1. whether the primary interaction area is a personal device or a shared table, and 2. whether the shared large-screen display(s) are controlled directly or via the primary interaction area.

Table 1. Classification of table-centred environments augmented with shared large display(s). Columns: how content of the large display(s) is manipulated. Rows: the nature of the primary work area for the collaboration.

	Control-point of large-display(s)	
Primary Interaction Area	Direct Interaction	From Primary Interaction Area
Personal device	#1: i-Land	#2: i-Land, Colab, Nick, iRoom
Shared table	#3 i-Land, MultiSpace	#4: Present work

From this classification, it is apparent that an area of collocated groupware has yet to be explored: the area in which one or more ancillary displays are controlled entirely from a shared interactive table. Also, these prior systems were aimed at facilitating spontaneous collaboration and allowed for dynamic reconfiguration of the work space. In contrast, ours is a dedicated table-centric fixed space intended to be the users' primary work environment. Figure 2 illustrates these differences.

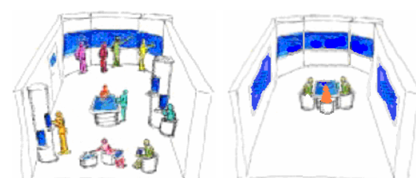

Figure 2. Left: an interactive space, including tables, desks, and vertical surfaces, meant to foster spontaneous collaboration [4]. Right: our problem space: an interactive table-centred collaborative environment with displays controlled from the table.

The prior work focused on multiple participants switching between collaborative and individual work, moving among and using the displays in a distributed manner. Although direct-interaction with the ancillary displays might provide more flexibility, it is important that the full-range of actions that can be performed on these displays be supported from the table in *real-time*. This is desirable for several reasons:

- all virtual elements remain within reach
- all participants can remain comfortably seated
- a consistent input paradigm is maintained
- leverages advantages of table-centred spaces

Given these advantages and opportunities in the design space, and recent developments in interactive tabletop input technology [5, 6], our goal is to explore the scenario where *all* interaction occurs on the tabletop, allowing multiple users to simultaneously interact – directly from the tabletop using multi point direct touch input – with the full content of multiple surrounding displays. Designing for this space will also augment environments in which support staff send information to the ancillary displays, and users work directly with those displays.

Design Solution

In [7], we examined design alternatives, investigated relevant concepts, and arrived at one particular design of our system. Here, we present an overview of significant aspects of that design, and refer the reader to [7] for a more thorough examination.

Visual Connectivity between Displays

To provide a sense of visual and spatial continuity and connectivity among the various spatially non-aligned displays in our interaction space, we created coloured connections between the displays. On the ancillary display, we placed a repeating pattern on the bottom edge of the screen, symmetrical to the pattern of a *proxy* to each ancillary display shown on the tabletop (Figure 3).

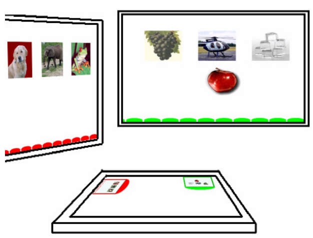

Figure 3. Schematic diagram of our system with screenshots overlaid: the matching colours and shapes of the repeating pattern on the walls and associated proxies on the table allows precognitive connections.

World in Miniature (WIM)

Although there exist several techniques that facilitate control over remote surfaces [14, 15, 16], the demonstrated utility [17] of radar views led us to explore its use in our interaction space. A radar view is a world in miniature (WIM) [18, 19, 13, 4], where a remote environment is displayed in a scaled format in the work area, and manipulations within the scaled miniature view are transferred to the original space. In our system, interactions performed on the WIM on the tabletop would directly impact the corresponding display region on the ancillary display.

WIMs were integrated into the proxy objects, such that a WIM of the ancillary display was shown below the matching circle. To allow users to dynamically reposition and reorient a WIM, we included a control to display a copy, visually tethered, which could be freely moved, resized and rotated about the table. Further, we surrounded the WIM with a graphical bevelled edge, shaded to match the color of the proxy (Figure 4).

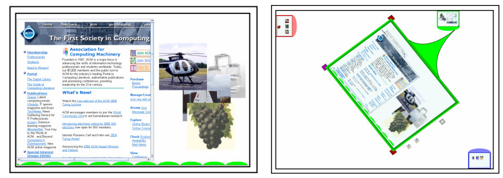

Figure 4. Left: screenshot of an ancillary display. Right: screenshot of the tabletop, including the WIM view of the ancillary display (top-right) and additional proxies and their WIM (top-left and bottom-right).

In some systems, a WIM approach is already being used to control large ancillary displays from a control terminal using software such as VNC (www.vnc.com), although not on a tabletop. Our work differs and enhances this approach in several ways. First, we added multiple telepointers, to provide a visualisation of the touches by users on the WIM. The point of contact on the WIM is shown on the shared ancillary display, providing a reference point to aid discussions with people not seated at the table. Second, as is illustrated in Figure 5, we have added a control to zoom the WIM.

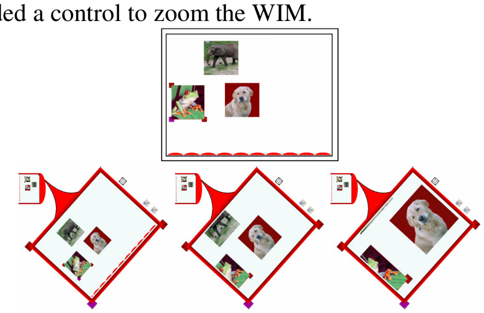

Figure 5. Top: screenshot of ancillary display, which remains static during a WIM zoom. Bottom: stages of a zoom of the WIM (partial screenshot of table).

A third innovation was to allow objects to be dragged to and from the ancillary display by dragging them to and from the appropriate WIM, as shown in Figure 6. This is a new design to enable the seamless and fluid movement and actual transfer of content between physically separate displays.

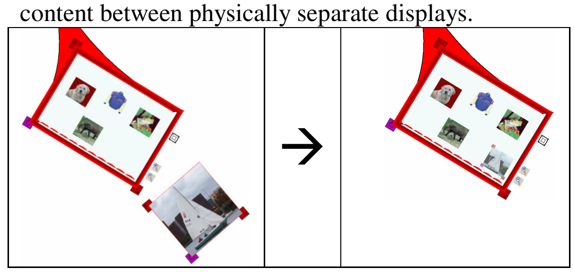

Figure 6. An object is moved from the tabletop to a display by dragging it onto a WIM. The orientation of the object is corrected on the vertical display.

Combined, these innovations make the WIM more appropriate for a table-centred control system. Despite its power, there are several disadvantages to a WIM approach: each requires a large amount of space on the table, and orienting the WIM for ease of both viewing and controlling a non-aligned display may be difficult. This issue is explored in our user study, presented later in this paper.

User Study

We conducted a study to evaluate the effectiveness of our designs. Given that the efficacy of a WIM for control of an ancillary display has been demonstrated by Nacenta et al. [17], we focused on the general usability of our interaction designs: how quickly and easily users can discover functionality without help or guidance, how effectively they can use each of the functions to perform a simple task, and how effectively the users can combine functions to perform a more complex task. This study represents a first step in the evaluation of our system: we did not attempt to mimic or otherwise reproduce a war-room environment. Rather, our intention was to discover the fundamental learnability and usability of the techniques we have developed, in order to ensure that they can easily be adopted by users in any environment.

Design

The study was conducted in three phases. First, we gave the participants minimal instructions and then asked them to explore the space which consisted of our interaction techniques running on four display surfaces: an interactive table, three large-screen plasma displays, and a projected display. On each display three images were shown, each could be moved, rotated, and resized as in [20]. They were given only the following instructions:

> *The system you will be using today is designed to allow you to perform basic operations, and move images on and between the various screens and the table. I will now give you 10 minutes to discover the functionality of the system. Please feel free to try anything you like, make comments, and ask questions. Do you have any questions before we begin?*

We deliberately kept the instructions to a minimum as we wished to determine which of the techniques users would be able to discover on their own. Additionally, we wanted to see if the colour and positions of the proxies would be sufficient to allow the user to understand the interconnectedness and topology of the system.

A video camera recorded the users' actions, and a post-task interview was conducted with each participant.

Once this first 10-minute discovery phase and post-task interview was complete, all the interface functionality was demonstrated to the participant to prepare them for the second phase. Here, they were asked to perform a series of basic tasks on photographs located on each of the displays in order to test their understanding of each of the system functions and interaction techniques.

In the third phase, each participant was given a more complex grouping and sorting task requiring the use of several functions in combination. 36 cards from a standard deck (2-10 of each suit) were randomly distributed across each of the ancillary displays and the table, each of which was uniquely labelled with one of the four suits. Participants were asked to move the cards such that each was placed, in order, on the display labelled with its suit.

Participants

Six participants (4 male and 2 female, aged 25-27) were recruited from the community. None had previous experience working with multi-display computer systems.

Results and Discussion

Results from the first part of the study indicate that nearly all aspects of the system are discoverable within a 10-minute exploratory period of using our system: all of the basic operations (resize, move, rotate) on system objects and on the WIMs were discovered by all participants. More importantly, participants were all able to discover and understand the proxy as the connection to the ancillary displays, matched by proximity, color, or both. All were able to discover the ability to move objects on and between the ancillary displays using the WIMs.

Two features of the system were not discovered by most of the participants: only one person discovered how to control the centre of the zoom on the WIM, and only two participants noticed the pointer displayed on the ancillary display while operating in the WIM. In the second phase, where users performed simple tasks following a demonstration of all functions, all participants were able to complete all tasks without further instruction.

In the third phase of the study, in which participants were asked to perform a more complex sorting task that required extensive use of all four displays, all participants were able to complete the task. Worth noting, however, was the trade-off that users seemed to experience between turning their heads and enlarging the WIM: of the three vertical displays, only one was positioned within 45 degrees of the centre of the user's field of vision when sitting at the table. For this display, participants tended to leave the WIM small, such that the suit of similarly coloured cards could not be distinguished (the two of clubs and the two of spades, for example, were not distinguishable through the WIM at this size).

Participants tended to look at the larger screen rather than at the WIM in this case. For the other displays, one situated at approximately 90°, and the other at approximately 135°, the participants tended to enlarge the WIM and not look at these screens at all. The disadvantage of enlarging the WIM is that it is more likely to occlude cards positioned on the table, necessitating frequent repositioning to access those cards – participants seemed more willing to move the WIM using their hands than to leave it reduced and turn their heads away from the table.

Example Usage Scenario

We have prototyped an application that utilises the design solutions presented in the last section. We used a DiamondTouch multi-touch table [5], top-projected with an 1248x1024 projector. The vertical displays are one 62" plasma display and one 76" PolyVision front-projected whiteboard.

Our prototype is for a police emergency management system that would be part of a larger emergency operation control centre in charge of ongoing situational assessment and operations deployment to deal with riots and high-priority criminal targets. At our table are seated the primary decision makers of the centre, such as high-ranking police and city officials. Although they are not included in the scenario, the presence of support staff to carry out supporting tasks is assumed.

Participants are seated around the interactive, touch-sensitive table, with two ancillary displays (Figure 10). On one wall (the *Video Wall*), a surveillance camera monitoring system is augmented with geospatial data to allow participants to monitor ongoing field situations using the visible contextual associations included in our system. The display (Figure 10b) can be controlled via a WIM on the table, and the video feeds can be moved on screen or dragged onto the table for closer viewing.

On another wall (the *Deployment Wall*), an application which monitors and allows changes to the location of deployed field units is envisioned. As seen in Figure 10c, the left-pane features an annotated satellite photograph, the center is a zoomed portion of that pane, replacing satellite photography with cartographic information. Unit positions can be viewed and changed by adjusting the positions of their icons on this map. A new unit is deployed to the field by moving its icon from the table onto the appropriate position on the map. Control of the wall is from the table via a WIM.

The final display surface is the interactive table, shown in Figure 10d. On the table non-deployed special-forces units are displayed as icons labelled using visible contextual associations. Also on the table is other information sent there by lower-ranking participants in the room, such as special bulletins (top-left), as well as the WIMs of the Video and Deployment Walls.

In this scenario, our interaction techniques are able to facilitate the identification, analysis, and ultimate resolution of a real-world scenario. In particular, the stages where discussion is required are enhanced by the table-centred interactive space, while still leveraging computing technologies to make tasks more efficient.

Figure 10a. The emergency management scenario: an interactive table augmented with two large displays (enhanced photograph). Figures 10b-d show details.

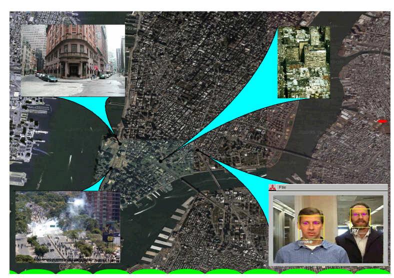

Figure 10b. Real-time surveillance video is displayed on the video wall. The video feeds are augmented with geospatial information to aid with field situation assessment.

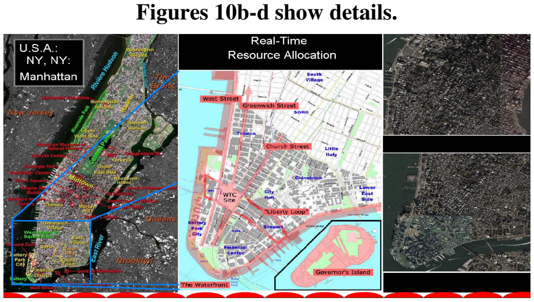

Figure 10c. An application to allow the monitoring and deployment of special police forces is displayed on the "deployment wall" and controlled from the table.

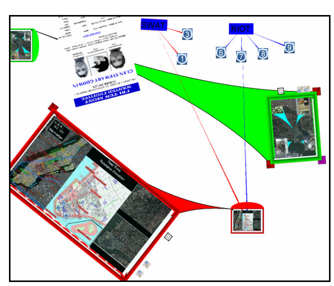

Figure 10d. The contents of the interactive touch-table, including police unit information, special bulletins, and control areas for the other surfaces.

Feedback on Example Scenario

During a visit to the New York Police Department's (NYPD) *Real Time Crime Center* (RTCC) we demonstrated our example scenario to several high-ranking members of the NYPD, led by Deputy Commissioner James Onolfo.

The system we envision, a table surrounded by several ancillary displays, varies significantly from the current design of the RTCC where all participants sit facing a single, large, shared display. Despite these differences, our scenario was highly praised: more than one potential user stated that providing the high-ranking officials with a collaborative, table centric system would allow them to more fully participate in processes currently being delegated to others, and that a system such as the one we envisioned could improve emergency management. It was noted that our system included collaboration facilities that supported better awareness of field situations for participants. In particular, Deputy Commissioner Onolfo told us that "this isn't the way we do things now, but it's the way we should be doing them".

Conclusions and Future Work

We have presented an exploration of table-centric interactive spaces focused on real-time collaboration, where interaction with both tabletop and multiple vertically mounted large displays are controlled solely from the interactive tabletop. Our contributions are twofold: identification of interaction and visualization issues that arise in the given problem space of single tabletop augmented with multiple ancillary displays, and the evaluation of a suite of interaction and visualization techniques designed to address those issues. The end result of this paper is a better understanding of how such table-centric spaces can be best utilized for collaborative applications and a prototype interface that facilitates such use.

In the future, we intend to integrate our designs with existing interfaces already in use in these spaces. The next steps in this research include supporting multiple tables, a variety of displays, and participation by users working away from the table.

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