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Katherine Everitt, Chia Shen, Kathy Ryall and Clifton Forlines

TR2005-110 October 2005

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IEEE International Workshop on Horizontal Interactive Human-Computer Systems

IEEE International Workshop on Horizontal Interactive Human-Computer Systems (TableTop), January 5-7, 2006. (pp. 27-34)
IEEE Computer Society Order Number P2494
ISBN 0-7695-2494-X
http://ieeexplore.ieee.org/xpl/tocresult.jsp?isnumber=33359&isYear=2006
(Digital Object Identifier 10.1109/TABLETOP.2006.23)

MultiSpace: Enabling Electronic Document Micro-mobility in Table-Centric, Multi-Device Environments

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Abstract

Although electronic media has changed how people interact with documents, today's electronic documents and the environments in which they are used are still impoverished relative to traditional paper documents when used by groups of people and across multiple computing devices. Vertical interfaces (e.g., walls and monitors) afford a less democratic style of interaction than generally observed when people are working around a table. In this paper, we introduce MultiSpace, a research effort which explores the role of the table as a central hub to support ad hoc collaboration in a multi-device environment. The table-centric approach offers new interaction techniques to provide egalitarian access and shared transport of data, supporting mobility and micro-mobility [11] of electronic content between tables and other devices. Our observations show how people use these techniques, and how tabletop technology can support and augment collaborative tasks.

1. Introduction

Electronic content is everywhere today. It is, however, used more easily by individuals than by groups. When collaborating in a face-to-face setting, colleagues often use large surfaces such tables, as well as walls and whiteboards, as the physical location for paper-based information. In contrast, electronic documents (e-documents) are usually located on devices designed for individual use, accessed by input mechanisms such as mice and keyboards that can only be used by one person at a time. When sharing information from such devices (e.g., laptops), people commonly project it onto a large display, usually vertically oriented at a distance from the group; this collaboration is often uneven, as one person becomes the "scribe" or "information gatekeeper," able to manipulate the document. Sharing information horizontally on a table creates a different collaboration dynamic; access is more equal, with everyone able to reach documents.

Today's e-documents are also limited in terms of their location, and shared environments do not support mobility-related techniques such as on-the-spot sorting or piling. Thus although today's meeting spaces are a reasonable setup for presentation of e-documents, they are less suited to other kinds of meetings, such as brainstorming or content creation, in which the electronic artifacts to be used are brought in by each participant and where groups need to work together with e-documents in situ to collaboratively create composite draft documents.

In an informal study of the working style of a CEO from a large office furniture company, we learned that he regularly conducts meetings with small groups of people; meetings usually involve shared review of documents, drawings, and slides kept in MS Journal on a tablet PC. From among two years of content, he would like to be able to lay out different subsets of pages on large surfaces in different patterns, piles, and arrangements at each meeting. His meeting space is typified by a table with a few seats and a nearby wall-mounted whiteboard. Limited by today's technology, he frequently resorts to projecting his content on the whiteboard in a linear sequential fashion.

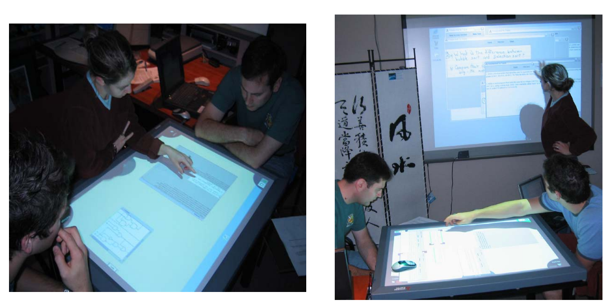

Figure 1: Participants using MultiSpace. They fluidly transitioned from tabletop interaction (left) to wall-and-table interaction (right).

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Our goal is to create support for e-documents, combining the electronic capabilities inherent in the media with the same sort of interactions that traditional paper documents have always provided. Paper documents afford the ecological dexterity [11] of re-orientation, markup, ease of passing amongst participants, and even the option of tearing off of part of a page of a document so it can be re-arranged and reassembled with respect to other pages. These capabilities are of the utmost importance in face-to-face settings [11]. With today's technology it can be quite awkward to select content of arbitrary granularity and move it between different devices.

To address contemporary limitations of support for e-documents in collaboration spaces we propose MultiSpace, a table-centric, multi-device environment which contains interaction techniques to facilitate the sharing and transport of electronic content (Figure 1). This paper makes two specific contributions. First, we examine the use of different devices in a specific collaborative task. Our environment provides a multi-user touch-sensitive tabletop in concert with a shared, touch-sensitive wall display and connections for personal mobile devices such as laptops or PDAs. Each device may serve a different function as part of a larger, collaborative activity. Second, we provide methods to transfer content between commonly shared devices and personal devices *at flexible levels of granularity*. This micro-mobility of content has not been addressed in other interactive workspaces to date.

In this paper we present our participatory design which followed from informal observations of the CEO described above. This has furthered our understanding of the interaction techniques necessary to support collaborative working meetings. We follow with a discussion of the design, implementation, and observational user study of the MultiSpace prototype before presenting conclusions and future work.

2. Related Work

Our work is the first that we are aware of to address e-document micro-mobility by fluid, visible transfer of documents at multiple levels of granularity amongst devices in a heterogeneous computational workspace. We build our conceptual framework and system design upon three areas of past research: collaborative work settings, interactive workspaces, and micro-mobility.

Luff and Heath [11] examined the importance of micro-mobility of artifacts (e.g., paper documents) to collaborative activities. Their ethnographic studies of medical consultations uncovered the importance of the ecological flexibility of documents in face-to-face work meetings. The necessary functionality they identified included *relocation and manipulation of documents*, to allow participants equal access to the information, and *the ability to continuously configure the artifacts* in response to the shifting demands of the activity. Thus documents for collaborative use should be portable, manipulable, divisible, and able to be reassembled for various purposes in situ. While the traditional computer desktop metaphor fails to support e-documents in the ways in which paper documents are used for collaborative work, interactive tables are ideal.

Much research over the past decade has explored interactive surfaces, workspaces, and rooms for collaborative activities [1, 2, 8, 9, 14, 18, 25]. Most have focused on the advancement of the shared usage of electronic whiteboards and vertically projected screen spaces. Although i-LAND [25] contained tabletop displays and the transport of whole documents from the wall display to tables, it did not support the level of micro-mobility of e-documents which MultiSpace provides, and there has not been any multi-user evaluation reported.

None of these earlier efforts offers the level of micro-mobility for multiplicity of in-meeting documents that Luff and Heath advocated. Some of them have provided mechanisms for moving whole documents or applications amongst the different display devices. Others allow redirecting inputs, or controlling the display from many different personal devices – but mostly from a cursor, mouse and keyboard based interaction paradigm.

A number of systems [10, 13, 15] have explored interactive whiteboard displays, focusing on support for sketches, and grouping and structuring of scribbles. BlueBoard [20] provides methods for walk-up informal information. Interactive Mural [6] supports a high-resolution wall-size display for collaborative designers with paper scanning using cameras to integrate physical documents into the electronic world; it is a single-device environment.

In UbiTable [4, 23] we examined the design of a walk-up shared tabletop workspace, and identified the need for more flexible workspaces and fewer constraints on document access for collaborative work. UbiTable did not address e-document micro-mobility, nor did it include vertical surfaces. Our experience with UbiTable forms the foundation and inspiration for the work presented in this paper. Rogers and Lindley [19] offer a set of observational user studies comparing vertical and horizontal interactive displays. Walk-up device support was not part of the study setup, and their tabletop was not multi-touch.

Recent work has started to look at document micro-mobility in desktop settings. WinCuts [26] offers a mechanism to cut any portion of an active window for effective spatial organization of information with

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limited screen space. Our DocuBits [5], which we evaluate in this paper, provides a similar mechanism but different usage model (see Section 4.3). Synchronizing Clipboards [12] allow two computers to share a clipboard, supporting mobility of files and ASCII text in an "invisible" fashion; it is best suited to a single user with multiple machines. ScreenCrayons [16] supports annotations of screen captures, providing capability to annotate, classify, and highlight notes; it is designed for a single user on a desktop machine.

Finally, we note that recent research (e.g., [7, 17]) explores new dynamic walk-up connection schemes for across-device inter-connection. Since our focus is on the content-level transferring and sharing, we can use any advanced connection and security schemes as they come into maturation.

3. Iterative and Participatory Design

The MultiSpace system has come to realization through an iterative design process. MultiSpace focuses on content selection and movement with multiple granularities (i.e. pieces of documents and multiple documents can be moved as easily as the documents themselves.) The question we now ask is: When given the choice between tables and other devices, which surface or device will users use for a given task?

3.1. User study

We performed a participatory design process over a period of several months to understand and support our chosen user group, teaching assistants (TAs). TAs frequently work in teams that meet to discuss, create, and edit content (e.g., homework, assignments, and tests.). These tasks are common to many collaborative activities. Three computer science TAs from different institutions, one female and two male, participated in the two-part participatory design described below. Before the first meeting, the TAs were asked to draw a TA meeting room. From these drawings (Figure 2), we determined that TAs meet in a variety of different spaces, but that tables are almost always available.

Part I/Focus Group: In the first two-hour focus group meeting, we identified three frequent tasks that are under-supported by current technology: scheduling, creating an exam, and grading. We decided to focus on the problem of creating an exam, as it the most creative process and the one that requires the most intra-group discussion.

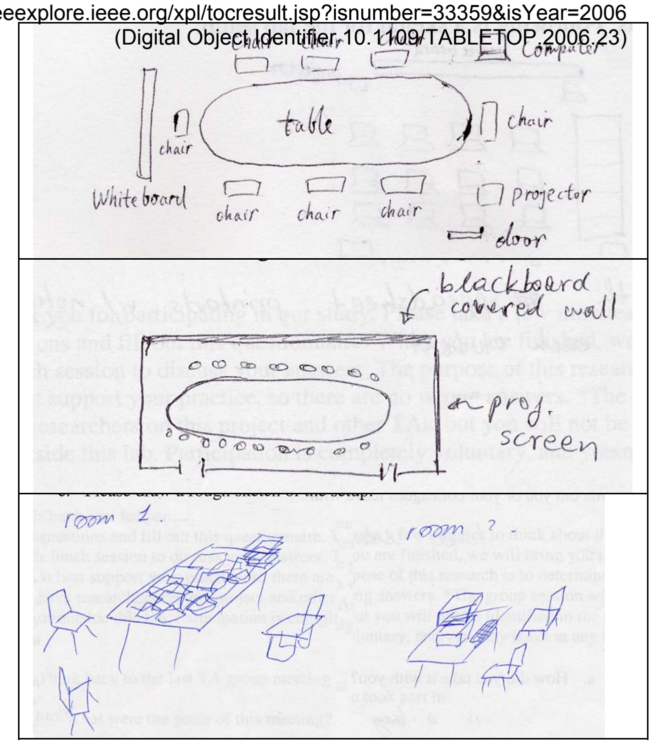

Figure 2. TA meeting room sketches.

Creating an exam begins by bringing in documents in many different forms, including old exams, textbooks, course material, course webpage, a syllabus, draft questions, problem sets, and solutions. One of the main challenges in creating a draft exam is comparing potential questions from multiple TAs. People often come to the meeting with a set of overlapping potential questions and a syllabus or exam template describing the final exam format. This content arrives in different forms, some of it digital.

Current practice is to print individual copies for everybody, so that all participants have a copy that can be annotated and arranged. Sections of questions are commonly removed, reworded, and combined with questions from other sources to create the final content for the exam. Paper is chosen over an electronic medium because of its increased micro-mobility in a collaborative environment. The paper draft, however, must be retyped and recombined after the session, requiring an extra step where most of the group doesn't have input. An alternative is to type during the session, which changes the collaboration dynamics by giving one person more power, as the meeting outcome is filtered through the "scribe."

A second challenge in meetings of this type is in versioning and numbering of questions and drafts. With multiple versions and a great deal of content, it was often difficult to keep track of what document was which, at what time it had been created or edited, and

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where it had come from. We also found that in their meetings TAs sometimes had to do electronic tasks. Looking up constants, using statistical or mathematics programs, or looking at course material on the web often required going to a different room or turning away from the group.

Part II/A Design Session: In part two of the participatory design, we held a two-hour design session where the TAs blueprinted their ideal new workspace using large pieces of paper, colored pencils, post-its and scissors. This session expanded our understanding of the exam creation task, how they would ideally like the workspace structured, and the information flow it should support. Their design was very general, but included the need for a table and wall space. The TAs described two distinct uses of space: personal and public. In the personal workspace directly in front of them, they would edit and formulate new questions and work out solutions to problems. In the public space on the walls and in the center of the table, they would compare documents, edit, pull apart, and combine questions; they would also pile and sort content. These findings match the use of tabletops seen in [22].

3.2. Results

In addition to the task-specific findings above four themes emerged. (1) A computationally augmented space would ideally include both tables and wall devices: people would like to continue to use the spaces to which they are already accustomed. (2) Support for e-documents is needed to facilitate their use: clearly current practices rely on paper-based documents because of their ease of use. In particular, there is a need for moving and sharing e-documents (or parts of e-documents) across devices. (3) Different devices should be used for different tasks: personal devices would be best for content creation (i.e., individual TAs creating initial question drafts), a table would be best for organization, providing a shared-space for people to share information, and the wall would be best for presentations (i.e., by one person to the group). (4) There was a need to provide support for task parallelism: sometimes people will want to work collaboratively, and other times they will want to work independently and in parallel.

4. MultiSpace Prototype

In this section, we present the design choices and the interactions we developed to solve the problems and needs outlined by the TAs, and the implementation of the MultiSpace prototype.

4.1. Design Decisions: Table as a central hub

MultiSpace incorporates multiple devices (e.g. tables, walls, laptops). We map the virtual configuration of devices to their physical relationship, as in Aris [1]. We designated the table as the central hub for the meeting space; it is centrally located and accessible to all. This decision is validated by our user study in which a central table is depicted in all three TA drawings (Figure 2). The table has the added advantage that it supports multi-user direct-touch input. Direct-touch provides awareness cues that are not available when the groups' input and interactions are physically separated from the display space. The physical position of arms, hands and pens in relation to a document provide a clear indication of user focus, support deictic pointing, and are a natural cue for coordination.

Documents remain "open" (not iconified) on the table so that people can track documents by their location the same way they do with paper documents. This matches the table and paper metaphor. In our current prototype, documents may be resized manually using handles at their corners. Using physical location for documents also supports micro-mobility work practices such as piling and sorting documents, and supports transfer between devices. They can be fluidly placed at almost any location on any device instead of moving "behind the scenes," which can cause confusion with traditional transfer.

4.2. MultiSpace Infrastructure

As shown in Figure 1, MultiSpace currently provides two fixed surfaces, a table and a wall. Our 107cm-diagonal sized rectangular DiamondTouch multi-user interactive table [3] supports multiple simultaneous interactions, and identifies which touches come from which users (i.e., identifiable user input). We use this feature to determine where users are seated at the table in order to control orientation of documents. Furthermore, DiamondTouch is debris tolerant; objects (e.g., laptops, teacups, papers, briefcases) can be placed and used on the table without causing noise. MultiSpace thus supports paper artifacts as well as e-documents. The displayed content is projected from above with a high-resolution 1280x1024 Hitachi projector. The interactive wall is a PolyVision "Walk&Talk" board [27] with a front-projected resolution of 1024x768. It is a single user technology that accepts input in the form of a stylus, finger or remote wireless mouse and keyboard.

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The MultiSpace table software uses the DiamondSpin Toolkit [24], which provides the support for rotation and translation of documents and multi-user input and interaction techniques. The software used on other devices including the wall is implemented using Java Swing. Both wall and table have a dedicated computer. The wall is linked over the wired network to the table; personal devices connect to the table via Java Sockets using wireless LAN.

The table and wall interfaces are not identical; we chose to provide the best interface we could for each device rather than limit the functionality of one of these surfaces. For example, the wall supports remote operation via the mouse but not document rotation.

4.3. MultiSpace Interactions

The MultiSpace system provides micro-mobility [11] of documents enabled by (1) fluid, portal-based transfer techniques amongst surfaces and devices, (2) a tabletop interface built with DiamondSpin [24] that supports arbitrary orientation and positioning of documents, and (3) mechanisms allowing users to easily grab sections of documents, images or text and operate with them on the same level as full documents. Figure 3 shows a sample tabletop screenshot.

The following is a brief discussion of the basic mechanisms used in our study. A more detailed discussion of how DocuBits and Containers work can be found in [5]. Our focus and contribution in this paper is different; here we detail the development and evaluation of these techniques and examine their use in a heterogeneous multi-device interaction environment.

DocuBits: DocuBits offer a metaphor of "a scanner for e-documents" – a portion of screen "bits" from any parts of visible display can be cut, grabbed, and sent onto a different display surface or device. The resulting captured DocuBits are in two forms: images or editable text, making DocuBits portable on any platform. DocuBits are effectively a snapshot in time, which can be compared to each other to review versions. Each DocuBit contains meta-data about as to its creation location and time, and can be reorganized using the Container.

MultiSpace Documents: MultiSpace supports three types of documents: Text, Containers and Images. MultiSpace supports the amalgamation of documents (and DocuBits) into draft documents, called "Containers." The Container object thus supports micro-mobility by providing a mechanism to recombine objects. We have implemented two forms of Containers: as a list of objects (as shown in Figure 4), and a more flexible collage of items. We used the list implementation in our evaluation to simplify usage.

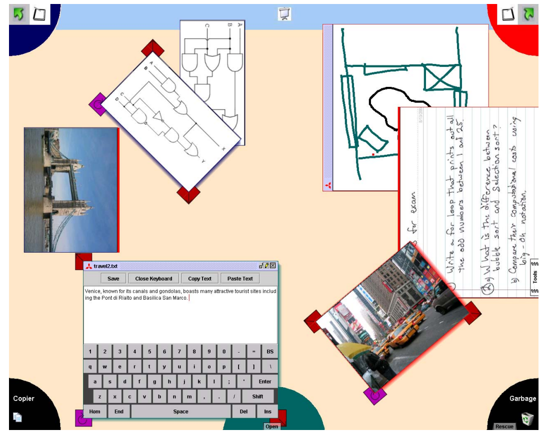

Figure 3: MultiSpace Tabletop screenshot with a text window and virtual keyboard, diagrams, sketches, and images. The wall portal is along the top, the laptop and USB portals in the top corners and bottom center, the Copier and Garbage in the lower corners.

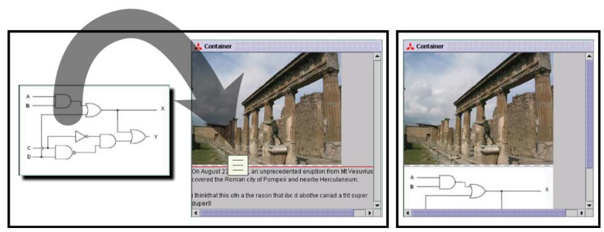

Figure 4: Using the Container: As the user drags a document over a Container, the document iconifies. If the user lifts her finger, the document de-iconifies and is inserted at the location indicated by the red line.

A user can "drop" an object into the Container list by sliding and object over it and releasing, or "grab" an object out of the list by using three or more fingers. Containers can be copied, deleted, and moved between devices; in essence they are a new e-document. When saved on a personal device, a Container, in the form of an HTML document with meta-data, contains a record of where the pieces came from and could also contain information about who edited which parts. The html format is easy for after-meeting portability and viewing.

Multiple Input Channels: The electronic whiteboard and mobile devices are off-the-shelf single-user systems, while the table offers multi-user support for up to four users. Documents on the table can be annotated with digital ink, and text documents can be

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edited with a virtual keyboard (see Figure 3). Text can be selected, cut, and pasted between documents. Each user is provided with their own virtual clipboard for text, supporting simultaneous editing. The Multiple Clipboards feature is an extension to the DiamondSpin Toolkit [24]. Multiple Clipboards present the metaphor of text "in my hand."

Interactive Tabletop: For convenience we provide *Tool Spaces:* spaces on the table with specific functionality (Figure 3). The *Copier* and *Garbage* are used by dragging a document onto them and releasing. These functions are also available via a pop-up menu on a document for when the Tool Space is out of reach.

Linking Devices: Portable devices can be linked to the table on-the-fly using dynamic portals similar to those used in [23]. This creates a virtual link between the corner on the table closest to the device's user and the in/out list on the device. Objects dragged onto a portal will be copied and a representation will appear on the linked device. The table and wall are virtually linked with a thin strip of matching color along the closest edge of each surface, a fixed portal. Objects can be dragged between the table and the wall by sliding to this virtual seam.

It is important to make the distinction between connection and linking. Our research focus is not on connection technology, and future iterations of our software can utilize any advances in wireless and wired technology. Our focus is on creating an integrated workspace by the semantic linking of spaces.

5. Observational Study

We conducted a user study to observe how users performed shared tasks using the electronic table, how they collaborated with different devices, how the micro-mobility capability of documents was used and for which tasks users chose to use the table.

5.1. Method and Tasks

Our subjects consisted of three groups of three users, who had experience with TAing or taking a CS course at a second year level. Members within a group knew each other prior to the study. Two groups had a female participant; the third group was all male. The study was conducted in our lab, where each session was videotaped and lasted approximately one and a half hours. After a tutorial to familiarize participants with MultiSpace capabilities and interactions, each group performed two tasks using the system and completed a post-study questionnaire and interview. Our evaluation tasks are representative of common collaborative work meeting dynamics, in which (1) common meeting room facilities and furniture are present, (2) contents are brought in several forms and on heterogeneous devices, and (3) both discussion and collaborative composition are necessary.

The group sat around three sides of the table, with the fourth side facing the wall (see Figure 1, right). Each person was randomly assigned a personal device (a Compaq laptop computer, a Toshiba tablet PC, or a USB drive fob). The person with the fob was seated across from the wall. Written and verbal directions were given for each of the two tasks.

Task 1: The first task was to assemble seven images and their matching text descriptions into a Container on the table. Each user's device had two random images and text sections, and the seventh was to be created on-the-fly by the group. They could create the new image use using any of the devices or by searching the web.

Task 2: The second task was to create a draft exam for an introductory CS course. Participants were given an outline for a three-part exam, and were asked to assume the role of course TAs. For Part A the participants were asked to decide on three out of six prepared questions; each person's device contained two prepared example questions. In Part B they were asked to modify a circuit diagram to create a logic question. For Part C they were asked to create a question from scratch to evaluate understanding of stacks and queues.

5.2. Observations

All three groups completed the task in the time allotted: ten minutes for Task 1 and thirty minutes for Task 2. We found document micro-mobility interactions in our prototype were very useful in this type of collaborative group work and that the participants carried out the linking interaction smoothly between their personally assigned device and the table. From the post-test questionnaire, the most reported worst thing about the system was "Wanting to see more functionalities being provided on the tabletop" and the most seen best thing was "Ease and convenience of collaborating, and fast to communicate [inter-personal and inter-device content] in the MultiSpace setting". Our goal was to provide a coherent workspace and facilitate micro-mobility of content. Our observational user study verified many of our design choices, and also revealed a number of unanticipated user and group interactions.

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Different Devices for Different Tasks: We observed that the groups used different devices for different tasks, but not necessarily in the ways we had expected. As we expected, participants used the table for layout and organization tasks. For example, during Task 1 one group used the table to group matching documents (i.e., image plus appropriate description) together before assembling them into the Container. People also used the table to sort exam questions into categories of keep, edit and discard. Piling and sorting show the power of micro-mobility as they allow documents to serve two purposes: as a container of content and as a placeholder associating it with other documents (e.g. Sarah's documents), a task (e.g. to look at) or a role (e.g. Question 3). Somewhat unexpectedly, the wall was used for comparison tasks. People often moved documents sent from their devices to the wall as a first step in collaboration. Their reasoning was that the wall had the same orientation for everyone, and as a large surface could display many documents.

Task Parallelism: The MultiSpace device arrangement supported an easy way to switch between parallel tasks and collaborative work. Users sometimes worked in parallel on their own devices to complete the task, but easily switched to a group focus when their colleagues' interaction caught their interest.

Supportive Collaboration: An interesting observed behavior was that whenever a user had trouble on the wall or the table, the others were always able to see immediately that their colleague was having difficulties and offer suggestions. However, when users had trouble doing similar tasks on the tablet PC or laptop, they did not receive help.

Different Interaction Styles: When working on the table, participants worked both individually and collaboratively. When working on the wall, the groups primarily worked collaboratively, although one person usually took control. There was a strong relationship between the person who controlled the wall, and who controlled the meeting. The wall could be controlled remotely by a mouse and keyboard, or directly by a stylus. In two groups all participants stayed seated, and one person controlled the wall remotely. In another group the leader stood at the wall. We did not observe multiple users sharing control of the wall.

In contrast, table interactions were much more democratic; we observed a more shared style of interaction. When working on the wall, it was rare for group control to change. When working on the table, it was quite common, and there was much more turn-taking behavior. Although the table supports concurrent multi-user interaction, our participants did not often interact with documents on the table simultaneously (partly due to the nature of the task, which required them to come to agreement on the exam questions). However, while they only occasionally worked in parallel at the same time, they frequently pointed and gestured at the documents. Common gestures were deictic and suggestion of an action (e.g. "place that document there").

Device Limitations: We found that it was more difficult for the users to indicate various text and images on the wall than on the table. In one example, a seated user without the mouse tried to point at a section of text on the wall, but since the person with the mouse could not understand, he needed to describe the document location ("no, to the left", etc.) This process was much more time consuming than if he had been able to directly gesture or do the action himself. One group had one user stand at the wall. This person had more control, and was better able to physically point at objects to assist discussion. A laser pointer might also aid users in this setting.

One disadvantage we identified for the table was problems with overlapping documents that are being actively edited. Even when working with shared spaces, people like to maximize their current document to fill the space. We also saw this behavior on the wall, but it caused no problems. The table is quite large, but it is shared between people; conflicts may arise between what one user perceives as her personal space and others perceive as public or their personal space on a small table. Other research [21, 22] has explored the issues relating to table size.

Our results confirm many of our design choices: table-as-central-hub, the different roles and usage of interactive walls and tables, and the importance of micro-mobility. They also raise new questions for collaborative e-document use in this setting.

6. Conclusions and Future Work

MultiSpace advances the state of research in computationally-augmented meetings spaces by reducing the spaces that divide different devices in these environments, facilitating flexible shared use of e-documents. We have demonstrated that the concept of micro-mobility used in paper documents can transfer to e-documents; our lightweight transfer of documents within a multi-faceted workspace provides e-document micro-mobility for collaboration, thus allowing the users to choose the right device for any task. Our user study explored the relationship between the task and tabletop use in a co-located collaborative work setting.

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This paper presents the outcome from the first known user study that allowed user groups to freely use a multi-user direct-touch tabletop surface in concert with an interactive wall and portable devices. We have found that shared tables support a more democratic collaboration, but that users choose which surface they will use depending on the task and style of interaction preferred. While the particular system we implemented focused on teaching assistants, the tasks involved use many common actions such as comparing, rewriting and annotating content, and presenting ideas in different forms. We believe our results will generalize to other collaborative situations. Furthermore, the combination of personal devices and surfaces in our infrastructure is a common component for most meeting environments.

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