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TR-2003-49 September 2003

Abstract

Despite the mobility enabled by the plethora of technological tools such as laptops, PDA and cell phones, horizontal flat surfaces are still extensively used and much preferred for on-the-move face-to-face collaboration. Unfortunately, when digital documents need to be shared during collaboration, people are still mostly constrained to display surfaces that have been designed for single users, such as laptops and PDAs. Technologically there is a lack of computational support for shared digital document access, browsing, visualization and manipulation on horizontal surfaces. We believe support for such serendipitous meetings will play a critical role in future ubiquitous computing spaces. Our UbiTable project examines the design space of tabletops used as scrap displays. Scrap displays support kiosk-style walk-up interaction for impromptu face-to-face collaboration. Our design offers the affordances of a physical table. It provides the flexibility by allowing users to layout shared documents with desired orientation and position; at the same time it augments traditional paper-based interactions by providing a flexible gradient or shades of sharing semantics. UbiTable addresses visual accessibility vs. electronic accessibility of documents, an issue which is critical to ubiquitous environments.

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Publication History:

1. First printing, TR-2003-49, September 2003

UbiTable: Impromptu Face-to-Face Collaboration on Horizontal Interactive Surfaces

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Abstract. Despite the mobility enabled by the plethora of technological tools such as laptops, PDA and cell phones, horizontal flat surfaces are still extensively used and much preferred for on-the-move face-to-face collaboration. Unfortunately, when digital documents need to be shared during collaboration, people are still mostly constrained to display surfaces that have been designed for single users, such as laptops and PDAs. Technologically there is a lack of computational support for shared digital document access, browsing, visualization and manipulation on horizontal surfaces. We believe support for such serendipitous meetings will play a critical role in future ubiquitous computing spaces. Our UbiTable project examines the design space of tabletops used as *scrap displays*. Scrap displays support kiosk-style walk-up interaction for impromptu face-to-face collaboration. Our design offers the affordances of a physical table. It provides the flexibility by allowing users to layout shared documents with desired orientation and position; at the same time it augments traditional paper-based interactions by providing a flexible *gradient* or *shades* of sharing semantics. UbiTable addresses visual accessibility vs. electronic accessibility of documents, an issue which is critical to ubiquitous environments.

1 Introduction

In this day and age of high technology, there is still an important role for face-to-face collaboration. Many meetings are on the road, and may be spontaneous events with no a priori planning. Flat, horizontal surfaces are natural for people to meet around and collaborate on. Figure 1 (a), reproduced from [4], shows two people sitting face to face at a table in the airport collaborating through their two laptops. However, the laptop screens are oriented toward their owners, and are difficult for the collaborator to view. Wouldn't it be more natural if their collaborative materials were simply laid out on the tabletop! Ad hoc, spontaneous collaborations are often seen around work places, in waiting areas at airports and train stations, as well as in cafes and lounges. People use flat, horizontal surfaces as the basis of their collaboration, with the ancillary support of tools such as laptops, PDAs, and paper documents.

The Fifth International Conference on Ubiquitous Computing
UbiComp 2003, October 12-15, 2003 Seattle, Washington USA

(a) (b)

Fig. 1. (a) Collaboration at an airport (reproduced from [4]) (b) Collaboration around an UbiTable

The goal of the UbiTable project is to provide efficient walk-up setup and fluid UI interaction support on horizontal surfaces. We wish to enable spontaneous, unplanned, collaboration where the participants share contents from their mobile devices such as laptops and PDAs. We draw technological underpinnings from peer-to-peer systems [4], ad hoc network protocols (such as 802.11 ad hoc mode, or Bluetooth), and existing authentication and encryption methods. Our focus is on design solutions for the key issues of (1) a model of association and interaction between the mobile device, e.g., the laptop and the tabletop, and (2) the provision of three specific *shades* of sharing semantics termed *Private, Personal and Public*. This is a departure from most multi-user systems where privacy is equated with invisibility. Figure 1 (b) shows the current UbiTable setup. Note that UbiTable also provides a variety of digital document manipulation functions, including document duplication, markup, editing, digital ink for drawing and annotation. The elaboration of these functionalities is out of the scope of this paper.

1.1 Observational Studies in Serendipitous Collaboration Around the Table

Recent field observations and user studies of research prototypes have provided invaluable insights into some of the fundamental design issues and key requirements for collaboration on shared surfaces such as tabletops.

Brodie and Perry [1] carried out fieldwork observations of current mobile collaboration practices on horizontal surfaces in public spaces, including at airports, on a train and in hotels. Their key findings include: (1) The extensive use of flat surfaces and tables in mobile face-to-face collaboration, and (2) current forms of mobile face-to-face collaboration can be undemocratic and hence less effective and less productive because of the technology involved.

On the issue of orientation of contents on a table during collaborative work, Kruger and Carpendale [6] conducted an observational study on horizontal displays. One of the key findings indicates that orientation can be used to designate space according to social protocol. In groups, the group decides on the orientation. Private documents are oriented toward their owner. Orientation changes can represent a change in the privacy level for the document. For example turning a document to-

wards someone else means that you wish for them to access or interact with it. In face-to-face meetings, participants use body language, document orientation, and gesture to transition their documents from private to public.

Greenberg et. al. [5] used their prototype called SharedNotes as a starting point for observing how people move from individual to group work, how personal artifacts and public artifacts are handled and moved back and forth. Important observations include: (1) user preference for the ability to move things back to private state after they have made them public, and (2) people would like to be able to shift their personal artifacts from private to public with intermediate shades between private and shared.

2 The Design, Usage, and Implementation of UbiTable

In this section we discuss the design for UbiTable, provide a typical usage scenario, and give implementation details. The guiding principles, supported by the observational data, in the design of UbiTable are:

1. **Shared scrap display:** (a) Simple walk-up utility for collaboration setup. (b) Easy and visible association between users, documents, and laptops. (c) Fluid content movement between laptops and the tabletop.
2. **Separation of privacy from visibility:** (a) A well defined gradient of three sharing semantics, *Private*, *Personal* and *Public*. (b) Shared interaction, with equal input capability to public documents, but owner controlled document distribution and replication.

Our goal is to provide an easily accessible scrap table that supports sharing of documents and ad hoc collaboration while maintaining user control over documents and gradations of privacy and visibility.

2.1 Shared Scrap Display Supporting Walk-up Serendipity

UbiTable is designed for easy walk-up usage. At the same time, people collaborating around the table will temporarily *own* the table during their usage session. That is, the table can serve as a true scrap display device. Thus, we must provide means for people to feel secure while putting their content onto the table.

When a user walks up to the table and starts the UbiTable application, the laptop carries out the initial exchange of handshaking protocol with the tabletop to prevent eavesdropping from passersby. This can be done in the same fashion as the security layer in Speakeasy [4]. A short message between the table and the laptop across a trusted channel (e.g., IR) can be exchanged, and then subsequently be used to authenticate all further communication across the wireless connection among the table and the laptops. Once this exchange is completed, the laptop is connected to the table.

Figure 3 shows the UbiTable application screen on the laptop and Figure 4 is the UbiTable display on the tabletop. All interactions with the tabletop are done naturally by touching the table. When a laptop is connected to the table, an icon appears on the tabletop that represents this particular laptop. To associate the laptop with the side of

the table adjacent to her, the user drags her laptop's icon into the side area of the tabletop. This side is then designated as her *Personal* space. The UbiTable mechanism used to translate physical contact with the tabletop into digital events allows us to associate the laptop and its *Personal* space with the user [3]. Thus we can uniquely identify users and give them appropriate control over documents.

2.2 Separation of Privacy and Visibility: Public, Private and Personal Areas

Most current desktop multi-user systems provide a binary notion of public and private data. Things in the shared space are equally visible and accessible by others, while private data is neither visible nor accessible to others. In most cases, private data is kept on one's own desktop or laptop, or viewed with special private viewing device [8]. Observations of people collaborating around a table with physical artifacts (such as paper documents) show well understood social protocols defining semi-private personal documents. These documents may be shared later in the meeting, used for reference purposes, or they may be personal copies of meeting records. They are located on the side of the table adjacent to their owner, and while visible to all, are oriented toward the owner to show they are personal and not meant to be accessed by others. Truly private documents are not visible at all (e.g., kept in one's briefcase), while publicly shared documents are usually placed in the center area or oriented in such a way that other participants feel comfortable accessing them.

UbiTable provides a similar gradient of *Private*, *Personal* and *Public* sharing models: *Private* data is not visible or accessible to others, *Personal* 'on-my-side-of-the-table' data is semi-private (it is visible but not electronically accessible by others), and *Public* data allows shared visibility and access. Moreover, a user maintains explicit control over the distribution and replication of his document even after the document has been placed in the public shared area. In essence, UbiTable separates the notion of privacy from visibility.

As shown in Figure 2, the display on the laptop is divided into two regions, *Private* and *Interaction Record.* The tabletop display consists of a shared public circular region in the middle, and two to N *Personal* regions at the edges. Figure 3 shows a tabletop with two *Personal* regions, one at each side. We use color or pattern as a visible means to indicate identity and ownership. The color or pattern of a user's laptop *Interaction Record* space matches that of the side of the table designated as his *Personal* space. For example, as shown in Figures 2 and 3, the laptop with striped display *Interaction Record* background is associated with the striped *Personal* side of the tabletop. Documents display an ownership bar of their owner's pattern across their top. When a user touches a document on the tabletop display, a shadow of his color or pattern appears around the document.

Only documents in the *Private* space (i.e., on the laptop) are saved on permanent storage. All documents on the tabletop remain transient, and documents in the *Interaction Record* space (the top pane on a laptop) are also transient.

Our design provides a gradation of private to public spaces. Documents can be 'published' to the *Personal* semi-private space on the table, shared in the *Public* space, or granted to other users. Users can take their documents back to their *Private*

space from the *Public* space at any time. Documents retain knowledge of their owner, and transferring to a more public space (increasing the visibility and accessibility of the document) requires an explicit action on the part of the owner. In addition, by definition of *Public* space, all documents that are brought into the *Public* space from public origins, e.g., web pages from the Internet, can be accessed, copied and manipulated freely by all UbiTable collaborators.

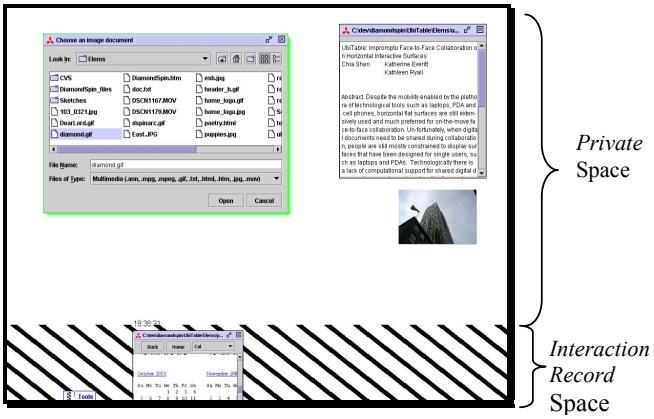

Fig. 2. Screenshot of Laptop A

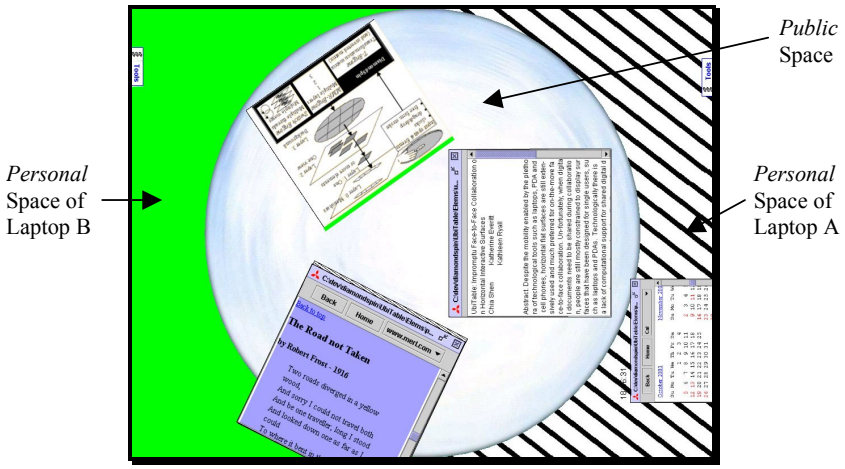

Fig. 3. Screenshot of UbiTable tabletop

The above description sounds more complicated than the actual interaction that a user will experience when using UbiTable. Both the direct manipulation style on the table and the explicit mapping of laptop color to the user color on the tabletop require

very light cognitive load on the user part during interaction with the system. We believe the interaction design and visual environment allow for an intuitive process for sharing documents between the spaces, similar to natural practices of sharing physical documents.

2.3 A Usage Scenario

JoLan and Nadine meet in an airport and wish to discuss Nadine's notes for her upcoming paper. They both connect their laptops to an adjacent UbiTable. Nadine is designated pink, JoLan is designated green. Nadine opens her notes in her *Private* space, the lower pane of her laptop (colored pink). She quickly checks them for confidential data before JoLan can see them. Then she drags (using the mouse) the notes into the *Interaction Record* space, which is the top pane of her laptop screen (with a picture of the table as a visual cue). A time-stamped record of the notes document stays in her *Interaction Record* space, and the document is copied and published to her semi-private *Personal* space, the pink side on tabletop. Nadine also opens her personal calendar and publishes it to the tabletop for reference. She adjusts her personal calendar and reads off the deadline of the paper while JoLan opens a web browser within the shared space on the tabletop and locates the conference webpage. So that JoLan can interact with the notes, Nadine shares them by sliding them into the central *Public* space of the table. Sliding on the table involves pressing lightly on the electronic document and sliding one's finger to the new location. The notes document allows both users to interact with it but it maintains knowledge of its owner: it displays a pink ownership bar across the top of its frame. Nadine and JoLan take turns editing the document. Figure 4 shows the shared UbiComp webpage, JoLan editing Nadine's notes, and Nadine editing a diagram that JoLan provided. Note the pink bar at the top of Nadine's notes, indicating her ownership, and the green shadow around the notes, indicating that JoLan is currently interacting with them.

JoLan tries to take a copy by moving the notes to his green *Personal* space. The document jumps back to the *Public* space. Nadine gives him the document by pushing it into his personal corner. At the end of the collaboration, Nadine moves the document to her *Personal* side, causing a time-stamped copy to appear in her laptop's *Interaction Record* space. When they leave, the table clears all copies of their documents to preserve privacy.

2.4 Implementation

The UbiTable software is entirely written in Java. The interactive tabletop user interface is built using DiamondSpin, a freely available UI toolkit [2]. The toolkit provides facilities for continuous, arbitrary orientation of documents, managing rotation sensitive and rotation insensitive UI components, document resizing, digital ink for free-form strokes, context sensitive popup menus, as well as creating multiple virtual tabletops on the same physical table.

The underlying communication is implemented with TCP/IP over wireless LAN. The physical table (shown in Figure 2) is a DiamondTouch [3] multi-user touch sensi-

tive surface which provides the capability to identify individual users. The DiamondTouch tabletop is connected via USB to a PC running Windows 2000. The laptops and the table communicate via ad hoc 802.11 with authentication and encryption.

3 Related Work and Summary

There have been many research projects on supporting people working together on shared displays and surfaces. The PARC CoLab project [10] enabled brainstorming meetings using prototype liveboards as shared workspaces connected with workstations. People on individual workstations can simultaneously put up their ideas on the shared workspace. The i-Land roomware project [12, 13] provides interactions on a large wall display called DynaWall, and interactive tables called ConnecTables that can be reconfigured for rapid sub-grouping in an office environment. Rekimoto in [7] explored shared continuous work space among walls, tabletop and laptops and examined the interaction techniques of hyperdragging. The system is enabled by LCD projectors and cameras which track objects tagged with visual markers, including laptops. Objects in their system can migrate freely among different computers using Java RMI and Java's object serialization mechanism. However, data that is displayed in the shared space cannot be directly manipulated and they do not deal with the ownership and visibility issues that UbiTable emphasizes. The BlueBoard project [8] is a vertical electronic touch-sensitive display[11] used as a communal large information appliance that supports both individual usage and small group sharing of personalized content. It has similar objectives as our UbiTable in terms of rapid walk-up access and simple interaction style. However, the personal content needs to be set up beforehand and stored as web-content, and accessed via a URL. Their work with transient data has inspired our treatment of data moved onto the scrap display tabletop.

The goal of our UbiTable project is to provide support for impromptu chance encounters where people need to collaborate on-the-go without prior preparation. Assuming the availability of personal laptops and PDAs, this requires approaches that can afford easy and efficient set up of shared workspaces such that users can conveniently move contents among private, personal and public spaces. The nuances between personal and public data movement resemble how people interact with paper when collaborating around-the-table. Shared social protocols offer clues to user's intention. None of the earlier research projects described above address these issues.

Our research on interactive surfaces is in some sense complementary to the peer-to-peer network, data transport, and security services that Speakeasy [4] offers. UbiTable addresses the issues of shared workspaces on horizontal surfaces, and the semantics of private, personal and public data access and exchange. Speakeasy can be used as our underlying ad hoc peer-to-peer discovery protocol and network service infrastructure.

In summary, we have presented our design and implementation of UbiTable, an interactive horizontal surface where people can walk up, share their content, and exchange data. This ubiquitous computing environment supports impromptu face-to-face collaborations for small groups of people, and provides the best of both physical and digital worlds. By designing our system to exploit many of the social protocols

already commonly used in tabletop environments, UbiTable provides a comfortable and familiar interface.

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