MemTable - Contextual Memory in Group Workspaces

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Abstract

This thesis presents the design and implementation of MemTable, an interactive touch table that supports co-located group meetings by capturing both digital and physical interactions in its memory. The goal of the project is to demonstrate hardware and software design principles that integrate recording, recalling, and reflection during the life cycle of a project in one tabletop system.

MemTable's hardware design prioritizes ergonomics, social interaction, structural integrity, and streamlined implementation. Its software supports heterogeneous input modalities for a variety of contexts: brainstorming, decision making, event planning, and story-boarding. The user interface introduces personal menus, capture elements, and tagging to help identify the context of meeting interactions. It records the history of the implicit and explicit events during meetings. A preliminary evaluation is presented of user feedback on the capture and recall features.

A longitudinal design plan outlines a framework for future work that integrates review and reflection functions into a comprehensive system. Additional features are presented for browsing and searching prior meeting data, visualizing long term work patterns, and integrating meeting data with external web services.

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CHAPTER 1. INTRODUCTION

"Instead of making us work in the computer's world, let us make it work in our world." -Pierre Wellner, 1993

If the surfaces we use for meeting and collaboration were capable of recording and annotating the context of our interactions, our environments would be transformed into rich repositories of historical information. MemTable began with a simple proposition: *What if the surfaces we use in our environments were capable of having a memory?*

Vannevar Bush's design for the Memex (Bush, 1945) or "memory extender" presented the notion of unique personal trails shared through a memory desk. As computational hardware evolved, our personal computers and laptops have enabled us to create localized personal histories, but have not supported the creation of shared histories during group collaboration.

MemTable was intitiated by the desire to create a group memory extender, enabling people to link and annotate information together in an environment that learns and collects information from us as we collaborate in it.

This thesis presents the design and implementation of a tabletop system that supports co-located group meetings which incorporate both digital and tools and artifacts. The purpose of the MemTable is to capture the implicit and explicit content of user discussions, and organize this content for searching and browsing at subsequent meetings. MemTable utilizes the potential of a large multi-touch surface to allow workgroups of 4 to 8 people to simultaneously capture, record, discuss, and recall information relevant to their discussions.

1.1 Problem Statement

A rich history of tabletop systems have been developed in research labs, but few have been designed to provide support for the long term interactions of small workgroups. Many of these projects (see Chapter 2 for a history of tabletop systems) focus on interaction techniques, but do not present a long term vision for how to integrate the history of the interactions into the system's memory. Applications must provide lasting utility to groups to be adopted into their work practices. They must increase efficiency during use and provide utility after their use. Two primary considerations are lacking from current tabletop systems:

1) Their form factor is not designed for extended use by small work groups. The ergonomic, structural, and spatial design of the hardware is inappropriate for collaborative use in a small group workspace environment. They are often too small and the sides of the tables are closed, preventing people from sitting and working together for long durations.

2) The software interfaces of current tabletop interfaces present novel and inspirational techniques for specific short term scenarios but neglect serious inquiry into the design principles and infrastructure required for extended and repeated use. Many questions remain about how we can capture and recall the historical content that results from previous interactions with each other.

1.2 Proposed Solution

This thesis outlines the design and evaluation of a more ergonomic and functional multi-touch table for the social context of small group meetings. It is designed for sitting or standing, at a height that increases productivity. The table allows for the users to sit comfortably for hours, placing their legs underneath the surface, without hiding the technology underneath and provides enough space for 4-8 simultaneous users. It is also designed to adapt to the "paper-full office" (Sellen, 2003) (with laptops, paper, books, coffee cups, and bodies all competing for space) by supporting and incorporating references to those objects into the memory of the table.

Meetings are important for workgroups to plan and coordinate goals, facilitate long term social cohesion, make decisions, and resolve conflicts. However there are frequently problems that arise: low participation, poor efficiency, and poor documentation. MemTable attempts to increase the value of meetings within the workgroup by supporting multiple scribes in a meeting, implicit and explicit recording, providing a timer feature, representation of discussion elements, digital and analog capture, and integration of recall functionality.

The three primary software functions of the MemTable are: recording, recalling, and reflection (The three R's). The recording feature of the MemTable is designed to support workgroups by enabling *anyone in the group to act as a scribe*, capturing and representing information as it is discussed. Recall allows users to reuse content from previous meetings during a discussion. The reflection mode offers tools to visualize group work patterns, social connections, and associations between content from different meetings.

Figure 1a. The MemTable in two group meetings.

The software system of the MemTable is designed to support the long term work habits of groups by providing a flexible interface for content capture, identifying users, and recording any changes in content. It features five primary input modalities: audio recording, drawing, typing, imaging, and sharing of information from personal computers. The features where chosen by observing diverse toolsets used in real meetings in our laboratory. By satisfying as many input modalities as possible, we encourage creative and unique content generation specific to the needs of different contexts at the table. The user interface is designed to identify input that originates from individualized menus docked near the location of each user. All user actions, both explicit (creating new content) and implicit (altering the properties of the content) are recorded and saved in a database.

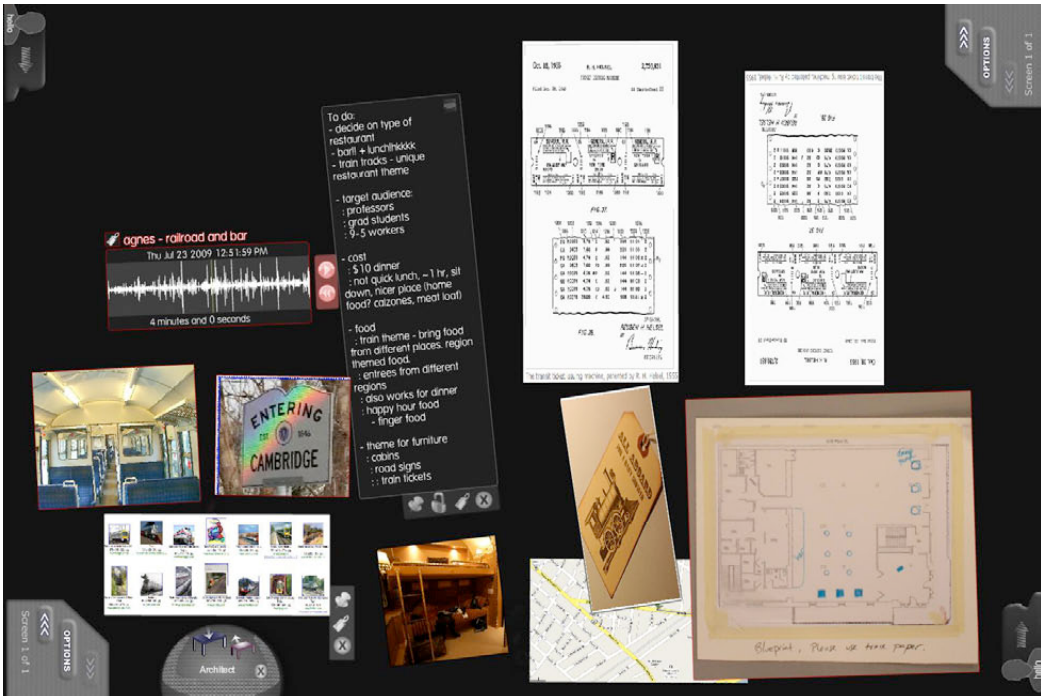


Figure 1b. A screenshot of the MemTable application during recall of a previous meeting.

The longitudinal design plan in Chapter 6 proposes that the cumulative actions of the group provide a repository for the development of practical recall of content from meetings and reflection on the work patterns of groups over time. It outlines a vision to integrate the content generated at the table with web services, so that it can be reviewed both on and off of the table.

1.3 Example Usage Scenarios

The primary function of MemTable is to support group meeting annotation by bridging the gap between digital and analog recording processes. Although the table may be used in any context convenient to the group meeting, its most practical use is the capture and recall of brainstorming, decision making, progress reports, and event planning in small groups. In addition it may be used for design, documentation, group feedback, and story-boarding.

The scenario we chose for our user study provides a good example of context of use. Please see Chapter 5 for the full scenario. Below is a concise summary:

Four people in a small design group are meeting over the course of the next 16 weeks to develop a plan to renovate a building in their community and turn it into a restaurant. The group consists of an architect, a chef, a designer, and a food planner. Each week they meet to make progress on their project and resolve issues such as floor plan layout, food choices, financial implications, and decor choices. At the end of the 16 week period, they plan to review and evaluate the merits of contents of their discussion and collaboratively agree on an investment plan.

During the meetings the group uses the table to capture key points in the group discussion with the audio buffer, discuss images of related restaurants, view a map of the area, draw on the physical blueprints and capture those with the camera, explore potential table and chair layouts, make lists of names and themes, and respond to ideas as others members are speaking.

At the end of the meeting, group members summarize by typing a conclusion, and tagging elements for search later. They also arrange the content spatially for later decision making purposes before closing the session.

In the third week the group meets to discuss a Spanish style cuisine. Many of the layouts the designer made during a Cuban scenario are brought back into the discussion. She opens her review pane and brings some images from a previous session into the current one.

At the end of the 16 week planning period, the group meets for a convergent brainstorming meeting to decide on a final investment plan. They review all of the previous meetings, reflecting on their ideas from the capture screen, dragging the best ones into the current session. The group lays out their options and discusses the pros and cons of different themes.

As outlined in the longitudinal design plan (see Chapter 6), additional tools are provided to give feedback to the group members about their contributions and frequency of use. While the table is not being used, it visually reflects on common threads between meetings and plays these back in different sequences, re-contextualizing previous ideas at the table and facilitating general awareness of group process.

After the final week, individual members asynchronously review the last meeting from their personal computers and each member drafts their portion of the investment plan.

1.4 Contributions

This thesis makes contributions in several areas, namely the design of the form factor of the physical table, the input modalities, and the software to support multiple scribes recording, recalling, and reflecting in the same interface.

Ergonomics & Hardware Contributions

Special consideration and research was given to the physical design of MemTable. We prioritize the ergonomic and social aspects of the design over other technological considerations. It is large enough to accommodate groups of 4-8 people. The components are modular, sturdy, centralized, and coupled with a set of matching chairs. The table allows users to place their laptop and other objects on a large border, and their feet on an 8 inch footrest. The 40 inch elevation of the table increases productivity and facilitates natural social interactions between standing and sitting users. The centralized layout of the equipment prevents overlap and allows people to place their legs underneath.

Detailed documentation of an emerging sensing technique called Diffuse Surface Illumination (DSI) is included in this thesis. An experimental material called EndLighten was utilized with custom light strips and aluminum frames. This significantly reduces the complexity and labor involved in building a touch table and allows for more diverse sensing: finger detection, fiducial pattern, and object recognition. The technical specifications in chapters 3 and 4 may be useful to researchers interested in developing their own systems.

User Interface Design Contributions

This thesis presents a set of design principles for meeting support that include supporting heterogeneous types of input, protecting privacy of the users, keeping the interface efficient and consistent, and recording the "who", "what", and "when" of modifications to content on the table.

MemTable introduces modular data elements for the integration of a heterogeneous set of input types including: audio, drawing, text, and images. These are saved in a database for history recall. By combining modalities, new forms of interaction are made possible between the physical and digital, such as incorporating a physical storyboard with a digital one and adding audio annotations.

The software presents new design metaphors to differentiate between users, input information, and tag elements. Personal menus for inputing and recalling information from the table are introduced. Menus are active, like hockey pucks, and can be tossed to any side of the table. They allow for a flexible way for users to move around the table, check in and out of a meeting, and generate and retrieve content from the table.

Content elements are introduced, containing a set of standard options such as remove, pin, lock, crop, and erase. These options are made available in each elements and add flexible, efficient control for the users. The design considerations for the content elements are discussed in Chapter 4.

Chapter 6 completes the discussion by presenting the design of the recall systems. These may also be useful for researchers to consider. This section also outlines an architecture for a system where the information entered into the table is also available for recall from a web server, making the information available to the "cloud".

1.5 Thesis RoadMap

Chapter 2 covers background and related work, including previous work on memory augmentation, group meeting support, and tabletop systems. The design considerations and functionality for the MemTable are described in Chapter 3. Details about hardware and software implementation are covered in Chapter 4. An evaluation of the input modalities, software interface, group dynamics, effects of the technology, and memory recall assistance are discussed in Chapter 5. A longitudinal design plan is outlined in Chapter 6 that covers the portions of the MemTable currently under development, including sketches of the proposed work to develop the output visualization and retrieval and review systems. The final chapter discusses the long term vision proposed for integrating historical content into our shared spaces.

CHAPTER 2. BACKGROUND AND RELATED WORK

During the last forty years researchers, product developers, and artists have developed technologies to support group interaction with digital information and the archiving of that information. This section traces the history of related tabletop systems from early experimental work to current commercially available systems. Next, key sociological research on computing systems to support co-located collaboration and group awareness are outlined as they relate to the design and functionality of the MemTable. Last, memory software projects are covered to provide a framework for understanding how computational systems can introduce new ways of integrating historical data into our work practice.

The vision of the MemTable is to build on the research in all three areas: tabletop design, CSCW systems, and temporal/historical data visualization systems. It aims to provide a system that is integrated with the environment and social work-patterns of small groups: facilitating meetings, capturing and saving content, and helping the group reflect on their long term work practices.

2.1 Tabletop Systems

The introduction of computing systems into our everyday lives in the mid-eighties came primarily in the form of the personal computer because of its affordability, mass-production, and practicality as an interface for accessing and manipulating digital information. The keyboard, mouse, and screen paradigm also introduced many constraints and limitations for the types of interaction we can have with digital information, particularly in collaborative settings. Research has shown (Rosenburger, 1998) that when people collaborate they use artifacts (physical objects) to bridge communication barriers, and are more engaged when they can interact gesturally with the information.

To address these limitations, for thirty years researchers have been designing systems that support physical participation and simultaneous interaction with digitally represented information. These systems are generally culturally and socially contextual to a particular situation of interaction, and their success can be judged by how well they improve the fluidity of interaction in that domain. From small mobile devices such as Siftables, (Merrill, 2007) to large surfaces designed for interaction with high resolution data (Guimbretière et al. 2001), the context of interaction is dependent on the scale and form of the interface.

Tabletops are the primary surfaces we use to exchange information, food, and support the work objects (laptops, paper, tools) of our daily lives. They are culturally and socially embedded into our environments, providing a rich opportunity for the integration of contextually specific information interfaces. Existing research has shown that people's interactions around tables are fluid and dynamic (Bly, 1988; Tang, 1991)

A survey of the history of tabletop systems is provided here as a framework for understanding the benefits and constraints of tabletop systems. This understanding allows for the projection of a vision illustrating of how we might interact with horizontal surfaces when the technology becomes affordable and transparent. The interaction with information on large surfaces will be integrated into our social, cultural, and workplace environments and these projects will provide a foundation for the new Human Computer Interaction (HCI) standards. The survey begins with key projects that introduced the technology and highlights related work to and the state of the art today.

2.1.1 Origins of Tabletop Systems

One of the primary problems using the body as an input device was determining how to get discrete information about its state and translate this into digital manipulation. Video provided a rich source of data, but proved to be a daunting task to interpret, and using it is a computationally expensive endevour. Despite these initial limitations, this was first demonstrated by Myron Krueger from the Artificial Reality Corporation in the Videodesk (Kruger, 1985) system (an extension of the VideoPlace System): Videodesk consists of a large surface over which you move your arms, hands, and fingers. A video camera mounted over the desk picks up these movements and use them as input to the computer which then shows then as an outline on the display, allowing the users to draw various forms on the screen via hand gestures.

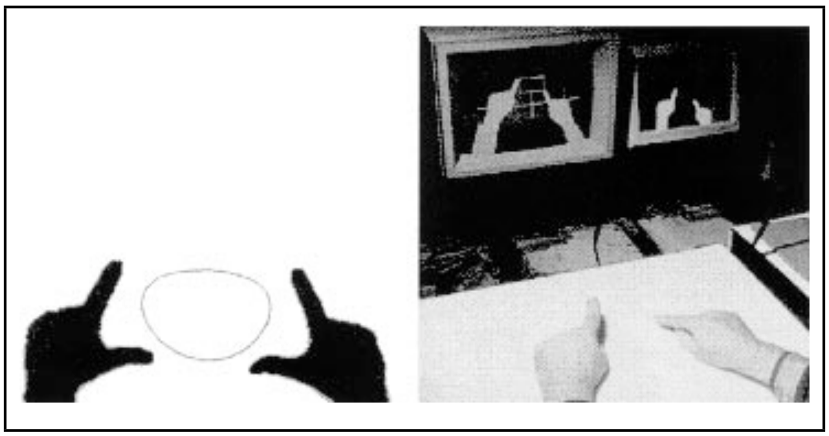


Figure 1b. VideoDesk System by Myron Kruger, 1985

Although Kruger's system does not give direct visual feedback on the desktop itself, it is worth mentioning as a pioneering visionary project of its time. Kruger's vision for more fluid interfaces in the VideoPlace project has been inspirational to designers and developers for its uncompromising merger of the digital and physical domains by using the human body as an input device.

Pierre Wellner blurred the boundaries between the physical and the digital spaces in 1991 with the introduction of the DigitalDesk (Wellener, 1991). Wellner integrated the paper based archival information in our environments with the desktop computers of his time. He considered the limitations of scanning, typing, and translation of paper documents an expensive and tedious process. Instead he proposed an office with a top mounted camera and a projected display on the desktop that would integrate with the users PC.

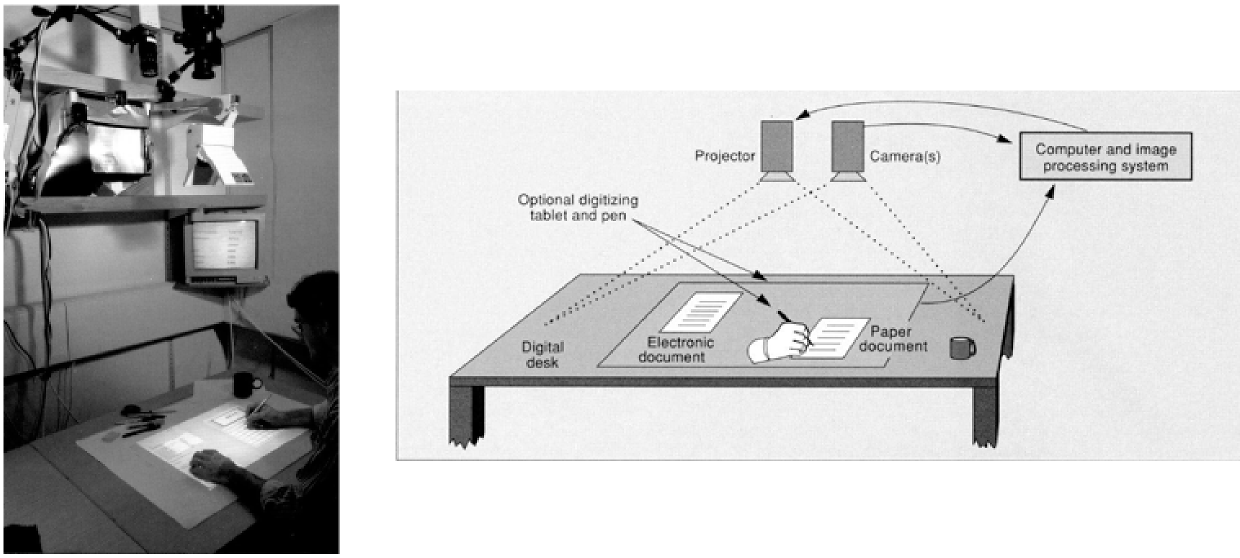


Figure 2. DigitalDesk, courtesy of Pierre Wellner, 1991

The user points to a document and taps on the area directing the video camera to take a snapshot of the content on that document. The system would then take a high resolution image and convert that into a digital file for the computer to process. Due to many limitations in the motion tracking algorithms and the text recognition processing that were used in the project, the system has distinct drawbacks. Nevertheless, Wellner presented a vision of an office where the surfaces of our environments adapt to our existing practices with paper and other artifacts and tries to seamless integrate them together in the same space.

Jun Rekimoto and Masanori Saitoh expanded on the integration of surfaces by introducing the concept of hyper-dragging in the Augmented Surfaces project. (Rekimoto et al, 1999) The project focused primarily on the interaction technique of using the mouse beyond the laptop screen, and giving feedback through projection around the room to create a spatially continuous environment.

This technique was named "hyper-dragging" and allowed for people to exchange and collaborate from their personal computers to the tabletops and the walls around them, incorporating an expanded vision of our environments as potential places for modification and discussion of information. By presenting the metaphor of the table as a server, users could drag files to and from the table effectively sharing them with each other.

Figure 3. Rikimoto et al. 1999, Augmented Spaces

Bill Buxton did extensive research on bi-manual input from 1991-2001 and is considered a leading expert on multi-touch interaction techniques. His work at Xerox, Alias/Wavefront Toronto, pioneered the research on how to interpret the touch data from multiple input systems into meaningful information. In his work on large displays for automotive design (Buxton, 1999), he introduced the Active Desk, a rear projected surface that designers can use with a stylus to draw and interact with data on the surface that encourages natural collaborative interaction at the drawing surface.

Figure 4. Bill Buxton, Active Desk 1999

MemTable also attempts to recapture many of the collaborative properties of analog tabletop meetings before personal PCs became common at meetings. Many aspects of transparency, sharing, and collaboration are compromised by the personalized nature of the PC.

2.1.2 Tabletops in Work Environments

During the nineties the rise of the personal computer (PC) diverted the attention of many researchers to the development of the GUI environments for personal PCs. The number of projects in the mid nineties that integrated environmental surfaces with computer systems is low, but rose again as standards for PCs became established after the late nineties.

Integrated environments and platforms introduced from 1999-2003 are introduced here as relevant to the MemTable project. The iRoom, Roomware, and DiamondTouch systems are highlighted as early initiatives that presented a vision for the integration of smart tabletops into collaborative offices and design studios for brainstorming, meetings, and presentations.

In 1999, the iRoom, Figure 5, (Streitz, 1999) began as an experimental space for interactive group brainstorm sessions. Originally conceived by Terry Winograd for use in civil engineering, the space has three SMARTboards, and a GyroMouse for navigating between displays. In addition, there is a rear projected table with a built in 3' x 4' display that was custom designed to look like a standard conference room table. The room also has cameras, microphones, wireless LAN support, and a variety of other interaction devices.

Figure 5. Stanford iRoom, 1999

The space was designed to explore different usage scenarios focused primarily on moving data between devices, switching control between users, and coordination between different software programs. The emphasis as it relates to MemTable, was on supporting a wide variety of heterogeneous tasks, devices, and activities. Using the iROS software (http://graphics.stanford.edu/papers/iwork-overview/) they conducted general HCI experiments and brought in outside groups like IDEO (http://www.ideo.com/) and SpeckDesign to utilize the iRoom to address design problems requiring displays of large amounts of information.

A more corporate version of an interactive meeting table in a smart environment was introduced by the Fraunhofer GMD-IPSI. Roomware (2003) is a research project that integrates a table called the InteracTable, a plasma display allowing multiple document views and touch based workspace rotations on the surface. The environment also contained DynaWall, CommChair, and ConnecTable components of a future office environment.

Figure 6. RoomWare Environment, including the InteracTable

The RoomWare project originated as the i-Land project, early prototypes of the design scenario presented above. Streitz et al. 1999 envisioned that the workplace of tomorrow would take the form of the environment in Figure 6. Today we see elements of their vision emerging in our office spaces and museums, but we have not yet reached the elegant design and interconnected infrastructure they proposed in the project.

The InteracTable (Strietz et al. 2001) is one of the earliest prototypes of a table to address some of the design issues around group interaction. The InteracTable is a mobile interactive table that is designed for creation, display, discussion and annotation of information objects by a group of two to six people standing around it. It was projected from an LCD projector, and supported single touch interaction, wireless keyboard input, and pen input capability. MemTable supports similar, but expanded input modalities and further develops many of the ideas presented by the InteracTable.

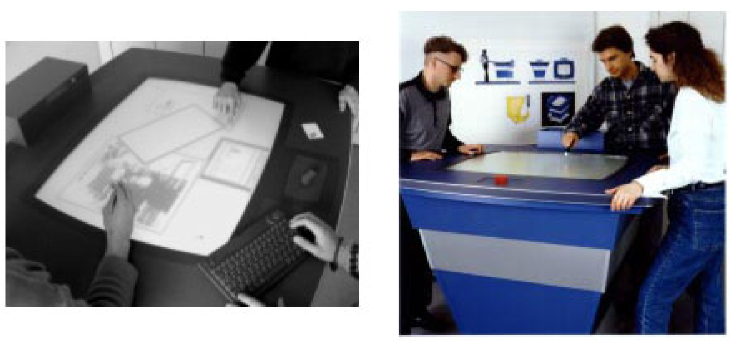


Figure 7. The InteracTable (working prototype) 1999

In 2001, Strietz's group proposed 'Ambient Agoras: Dynamic Information Clouds in a Hybrid World'. As part of its initiative 'The Disappearing Computer' (Strietz et al, 2002). 'Ambient Agoras' was proposed. It aimed at turning every place into a social information marketplace of ideas and information where one can interact and collaborate with people in a co-located environment.

Another important development in 2001 was introduced by Deitz and Leigh of MERL. DiamondTouch (Deitz. and Leigh, 2001) is a system that detects touch input on a table surface by using a capacitive tracking technology. Inside the table surface, a grid of wires transmits unique electric signals to different regions. When a user touches the surface, the signal flows through the user's body into a receiver. This way, the system is able to determine multiple user touch input simultaneously. The system requirement to be grounded on a touch-pad is a considerable drawback because if a user gets up from their seat to reposition themselves they can not longer interact with the screen. Differentiating between users was a novel innovation but also required that the information be top projected onto the display system, a cumbersome setup in office environments.

Figure 8. DiamondTouch System, 2001

The DiamondTouch platform provided a ready-made accurate input system for many research institutions to begin experimenting with multi-user interactions and study many of the interaction issues associated with tabletop design. One drawback of the system is that it requires capacitive coupling with the floor or a seat near the table, and users cannot touch each other in order for the system to identify them correctly. The reliability of their system and integration of the DiamondSpin Platform into existing operating systems, allowed MERL to conduct a user study of thirteen months of extensive use of their platform (Widgor et al. 2007).

2.1.3 Current Commercial Tabletop Systems

During the last two years several companies have released a standard tabletop system for limited markets in the US. Microsoft, Philips, and SMART have developed multi-touch platforms and met to talk about standards for software development at CHI in 2009. During the discussion, many researchers indicated their objections to a de facto standard emerging due to the commercial dominance of Microsoft in markets. This discussion illustrates an example of how the focus of the tabletop community is on interaction rather than applications. MemTable is a forum where I present a context for applications with increased utility.

The form factor and application markets of these platforms are briefly covered to provide a context for understanding the advantages of the MemTable hardware for small workgroups.

In 2001, Stevie Bathiche of Microsoft Hardware and Andy Wilson of Microsoft Research began working together on various projects that took advantage of their complementary expertise in the areas of hardware and software. In one of their regular brainstorming sessions, they began talking about an idea for an interactive table that could understand the manipulation of physical objects.

Although there were related efforts happening in academia, Bathiche and Wilson saw the need for a product where the interaction was richer and more intuitive, and at the same time would be practical for everyone to use. During the development process from 2001-2003 more than 80 prototypes were initiated by Andy Wilson's Team (Wilson, 2006).

The result of their efforts, the so-called "Surface" table, has been released in select restaurants, hotels, and entertainment venues (such as casinos).

Figure 9. Microsoft Surface Platform

At a cost of between ten and fifteen thousand USD per unit, Surface is still not available to the general public and has a limited market.

SMART technologies also released a similarly sized table for children to use in an educational setting. It was designed as a robust platform to accompany the SMART Whiteboard, the most widely used electronic whiteboard in classrooms today. Over 100,000 whiteboards have been adopted and so a natural market existed for its SMART Table release. Designed to encourage collaboration, discussion and consensus building, the table gives early primary students a gathering place to explore digital lessons, play educational games and work on interactive learning activities. Groups of students can simultaneously touch objects on the surface and enjoy a playful kind of learning.

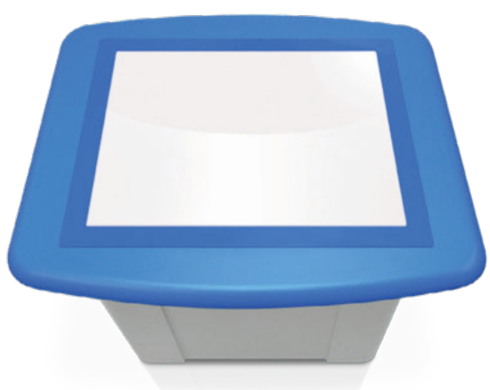


Figure 10. The SMART Table, 2008

Activities supported by the table include multiple choice, painting, math problem solving, puzzles, sorting, and educational media. Children do not have any preconceptions about how to interact with surface information and are the correct height for ergonomic interaction with the surface. The design of the applications indicates clear benefits of collaborative work in educational settings.

In 2006 Philips began development of the Entertainable (Hollemans, 2006), a medium sized LCD screen with an array of IR LEDs and Photosensitive diodes. When fingers block the light a touch is sensed. The advantages of this technology are that it allows the screen be adapted to any height, supporting better interpersonal interaction and allows users to arrange the interface appropriately.

Figure 11. The Philips Entertainable, 2007

The Entertainable is aimed at the gaming markets, and children 12-18 years of age. The portability of this platform and the decreasing cost of large monitors may create a potential for high resolution OLED or LCD display with multi-touch capability that could replace the equipment under the MemTable.

2.1.4 Related TableTop Projects

Several recent research projects precede and inform the design of the MemTable. These projects establish a context for a dialogue about the importance of tabletop interfaces as facilitators of creative collaboration, social awareness, and memory recall. Presented in chronological order, the LiMe (Stathis et al, 2002) and PDH (Shen et al. 2002) projects utilize tabletop interfaces for the collection and organization of social histories. Similarly, the Shared Design Space (Haller et al. 2006) and Pictionare (Hartman et al. 2009) projects explore input techniques during creative collaboration and design.

The Living Memory (LiMe), was a project sponsored by the European Commission and developed by a consortium of five partners between 1997 and 2000. It was a communication system prototype to provide members of a local community with a means to capture, share, and explore their collective memory and experiences through a network of interfaces embedded in public meeting areas like cafes and bus stops. The motivation for the project was that people could come across local knowledge incidentally and peripherally in their everyday locations, instead of having to go to their personal computers to obtain that awareness. The interfaces supported the expression and contribution of information, and the discovery of information left by previous visitors.

Figure 12. LiMe Project, Philips Memory Table

Figure 12 depicts the Philips Memory Table or LiMe table, one of the hubs prototyped for the exchange of public information between people. The coffee corner is a metaphor for a public place, where people meet informally and spend some time in social interaction. For these places they developed interactive tables, each displaying communal content, such as announcements of lost cats on a screen that forms part of the surface of the table. The LiMe table is an example of the kind of static device that facilitates information dissemination in a way that is unobtrusive, but also very accessible. Sometimes, useful information can be discovered serendipitously while the people sitting around the table are engaged in social discourse (de Bruijn and Spence, 2001). At other times, the LiMe table itself may become the focus of social interaction between the people sitting around it.

The LiMe project presented a software infrastructure to monitor and build awareness and memory in public spaces in more of a billboard style than an integrated system with enrolled users. MemTable operates with the presumption that it is adopted intentionally by a workgroup with a common initiative or goal, such as a company or design group, where people frequently collaborate with each other. This facilitates more specific visualization and linking possibilities, but MemTable is also designed to be unobtrusive when people are engaged in social discourse.

The Personal Digital Historian (PDH), initiated by Chia Shen et al at MERL in 2002, is a tabletop system that allows users to explore digital archives of shared materials such as photographs, video, and text. It is designed to help organizations, families, and institutions evolve a shared culture and history through conversation and reflection. The authors collected a ten year history of their laboratory and provided an interface for people to search through the data by “who, what, where, when” parameters - and arrange stories about the lab in a flexible manner on the screen. The system also incorporated a bookmarking feature that would allow people to return to a previous state later, and user evaluation revealed that the environment was suitable for sharing historical community information.

Figure 13. Personal Digital Historian, Shen et al. 2002

In the PDH project, developers worked with a local memoir writer to collect and archive a history of the group, rather than embedding a system to collect that history over time. In this way, they were able to explore the features necessary for the review and contextual interpretation of historical data. MemTable incorporates a similar "who, what, when" approach to each piece of information collected in the system.

Tabletops serve as good spaces for meeting to discuss and retrieve information but also have potential to collect information by supporting more fluid interactions between the physical and digital domains. In the Shared Design Space built by Haller et al. in 2006, collaborators share a common workspace and combine virtual and real 2d drawings in the same space. Using the Anoto pen system, the Shared Design Space allows users to select colors from physical palettes, and line thickness from a digital menu in a single fluid gesture.

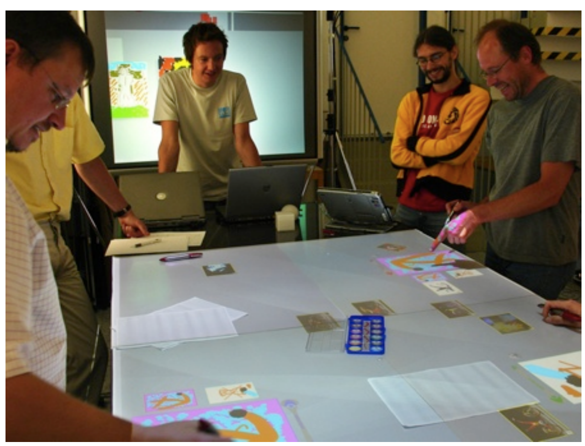


Figure 14. The Shared Design Space, 2006

Users can create, transfer, and manipulate data with the Anoto pen system, pickup and drop pictures onto a canvas and annotate those pictures. Haller et al. extended this research with the FLUX project (Haller et al. 2009) an interactive touch-sensitive tilting surface that can be used either as a sketching board, as an interactive discussion table, and as a digital presentation whiteboard. The surface, based on a rear-projection screen, supports both multi-touch interaction as well as multiple pen interaction with individual identification of each pen.

Figure 15. FLUX Multi-touch and Pen Support with tilt adaptation

In 2009, Hartman et al., a Stanford HCI student interning at Microsoft, researched and built the Four by Six platform (48" x 72"), a medium resolution display equipped with a high resolution camera. Hartman also presents a scenario of shared design for prototyping, incorporating drawing on whiteboards, digital capture of physical objects and drawings, and multi-touch input from the surface platform. Hartman also uses wireless mice and keyboards on the surface, tracking them as physical objects and increasing the options for the users to control content with their hands or with the mouse when more precision is needed, or the user wants to select content from across the table.

Figure 16. 4x6 Platform and Pictionaire Application, 2009

The application uses the camera to capture sketches and changes in scene and immediately incorporate them into animations and elements in the workspace. Hartman captures the session history by taking a snapshot of the entire scene, and later making that snapshot available for recall. This is useful for the purpose of summarizing and reporting a meeting, but only as a representation of the interface. MemTable incorporates many of the input modalities presented in Pictionaire, but designs the system to log all explicit and implicit changes and provide a timeline to view the temporal data of the interface. Subsequently, viewers can recall and reinstate discrete elements from previous sessions.

2.2 Group Support Systems

The field of Computer Supported Cooperative Work (CSCW) combines the research of social psychologists, sociologists, and computer scientists to design computer based technology that supports cooperative work between individuals.

MemTable constitutes a groupware application within the CSCW field, when examined from the lens of co-located collaborative work environments. The goal of groupware is to assist groups in communicating, collaborating, and coordinating their activities. Specifically, CSCW researchers define groupware as: "computer-based systems that support groups of people engaged in a common task (or goal) and that provide an interface to a shared environment" (Gibbs et al. 1991).

CSCW systems are commonly classified by the context of system use (Johansen 1988, Shen 1991). Generally, applications are understood along two dimensions, time and location. Is the application co-located or distributed? Is it synchronous or asynchronous?

These distinctions are not exclusive, but do radically influence the design parameters of the application. MemTable is a co-located application for face-to-face interaction in a synchronous environment. It is designed to support and augment existing interactions in a workplace, introducing creative collaboration in the same workspace, subsequently enhancing group awareness within that environment.

This section first reviews key (primarily co-located) meeting support systems in the CSCW field, then defines group awareness and discusses awareness from a historical CSCW perspective. It concludes with related systems that support dynamic vs. historical feedback and discusses important differences in those systems.

2.2.1 Meeting Support Systems

In the late eighties and early nineties, researchers such as Xerox Parc and other research institutions began designing collaborative environments to support co-located meetings. Systems such as Colab (Stefik, Foster, Bobrow, Kahn, Lanning, and Suchman, 1987) were the basis for the CaptureLab (Mantei et al. 1988) designed at the University of Toronto.

CaptureLab was a system of eight personal workstations arranged in a semicircle and a large shared screen at the apex of the workstation arrangement. The system supported users rotating control of the shared screen and contributing content from their personal screens to the shared screen space.

Similar to the Shared Design Space (Haller et al. 2006), the CaptureLab system relied on a distinct separation between shared and private workspaces. Researchers found that a rotating scribe role evolves within the meetings even when meetings begin with a predesignated scribe. This supports a more democratic arrangement of power and an increased contribution of the group to the annotation and encapsulation of important information from meetings. (Mantei et al, 1988)

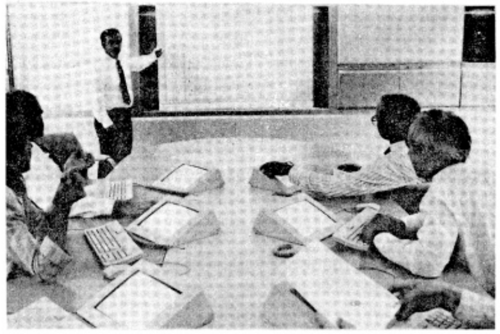


Figure 17. CaptureLab System, 1988

Researchers describe the difficulties encountered while evaluating the system resulted from not having enough support for the social aspects of group collaboration. They describe using a mixture of sociological research and empirical research to address a heterogeneous sets of needs in different groups.

> "Not only is it necessary to deal with the individual's cognitive processes and model of the computer aided task, but also to build software to support human - human communication with all the underlying socialization and group dynamics that this communication implies." (Mantai, 1988, p. 269)

The question of how much a system supports and provides behavioral feedback to users about their participation, dominance, emotional state has been shown to reverse the low frequency of interactions that occur when a technological system is introduced (Losada ,1990). This will be further studied in Section 2.1.3, but early research implies that designers consider more deeply the social context in their application design.

Recording a history in the CaptureLab system required the understanding that the system requires annotation, and someone in the group to act as a scribe at any given time. Researchers noted that in groups of 8 the role of the scribe rotated frequently, especially when group members were given feedback about participation.

The LiveBoard system (Elrod et. al, 1992) provided a similar interface for collaboration that extended the interface to include co-located participation through a stylus on the same whiteboard. Researchers noted the need for support of multiple simultaneous inputs, and a sufficiently robust system for users to adopt its use. They noted an increase in participation when users are engaged in the same workspace, and the rich possibilities for recording traditional blackboard activities in the digital domain. They found that of all the possible scenarios for the use of a shared board space, meetings were the most common (50%). No mention was made of the archiving and recall capabilities of the system.

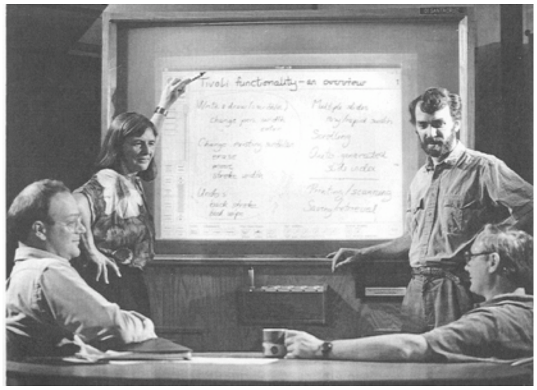


Figure 18. LiveBoard System, 1992

The Session Capture and Replay System (Manohar & Prakash, 1994) and the Intelligent Collaborative Transparency System (Li & Li, 2002) focused primarily on the workspace awareness that is facilitated by the recording of history for asynchronous collaboration. These systems contribute important technical information to the design of the MemTable software in terms of recording via a time and event based metaphor. The ultimate goal of the MemTable system is to combine the dynamism of co-located collaboration with an awareness of group history, allowing users to integrate that history into their interactions with others as they use the system.

IDEO has developed a system to record and track all the ideas that come up during their brainstorming meetings (Hastings, 2008). Reed Hasting at the University of Chicago studies the effectiveness of group meetings and has found that unless there is a system for tracking and encapsulating the agendas of meetings, they are ineffective in decision making, instead serving the function of creating consensus and long term social cohesion in the group. If ideas generated in group settings are to be fully utilized, we need a system to track these ideas.

The main criticism of these systems by Gross (2005) is that they focus primarily on a single user paradigm of learning and reflecting on temporal data streams. They provide a realtime stream of events from users, without an implicit description or encapsulation of the used strategies. Gross suggests that visualizations like bar charts, flow diagrams, and other historical tools would increase the awareness of the activities with significantly more efficiency. We hope to accomplish some of this with the reflection features of the MemTable proposed in Chapter 6.

2.2.2 Group Awareness in CSCW

Understanding awareness and context in CSCW Systems permits the evaluation of MemTable in terms of its ability to engender awareness in a small workgroup. Since 1987 awareness has been a primary focus of CSCW work, but the cohesiveness of these initiatives have varied from project to project. In 2005 Tom Gross, Chris Stary and Alex Totter (Gross et. al 2005) attempted to outline a definition for awareness and context - outlining a taxonomy of projects done in this area.

Awareness is the ability of users to determine the visibility of objects, services, roles, and others (Dey & Abowd 1999). Awareness determines how a group implements and manages its tasks, roles, and services. It increases the role orientation of individuals within groups, and the effectiveness of their work. Awareness increases individual understanding of the context that characterizes a group task. Context is defined by Dey and Abowd (1999, pp. 3-4) as “any information that can be used to characterize the situation of an entity. An entity is a person, place or object that is considered relevant between the user and the application, including the user and application themselves”.

Essentially, awareness is an understanding of the activities of others, which provides a context for your own activity. This context is used to ensure that individual contributions are relevant to the group’s activity as a whole, and to evaluate individual actions with respect to group goals and progress. The information provided by an awareness interface, then, allows groups to manage the process of collaborative working.

Dourish and Bellotti (1992) outline three primary ways that people collaborate in coordinated workspaces: through direct messaging, taking roles within a particular activity, and presenting feedback regarding individual activities. MemTable provides a shared workspace, where the role of the scribe can rotate between users.

GroupDesign (Beaudouin- Lafon & Karsenty 1992) and REDUCE (Shen & Sun 2002) support drawing facilities for a large number of people collaborating on graphics. They encourage awareness of each other’s changes, awareness of objects currently being edited, and have a built in history mechanism to review all changes during that session.

Clearboard (Ishii et al, 1994) is a shared drawing interface for two remote users that takes into account gaze awareness and workspace awareness. Other systems such as Polyscape, VRooms, and Portholes (Borning & Travers, 1991-2) are focused on connecting remote media spaces and engendering awareness of activities, availability, and presence between media spaces. Most awareness systems are designed for connecting remote or asynchronous activities. MemTable is designed for synchronous use, facilitating awareness by establishing previous context, and by providing tools for reflection and visualization of group history.

2.2.3 Behavioral Feedback Systems

An important and perhaps under-examined aspect of introducing technology in meeting scenarios is the social impact of the system and consequently, ways by which one might counteract any loss of communication that occurs. For example, if the system distracts or interrupts group members during discussion, it may reduce the efficiency and effectiveness of the meeting.

Systems that provide direct behavioral feedback are limited in scope, not addressing many of the creative collaboration possibilities provided by the interface. If a flexible operating system for tabletops were commercially developed for meeting scenarios it would include behavior feedback, creative input, and the integration of historical data.

A few tabletop systems have been developed to provide dynamic feedback about participant behavior in a group meeting. Joan DiMicco, built systems to inform users of the amount of speech they were having in a meeting, exploring a number of scenarios with private and public feedback. In the Second Messenger Systems (DiMicco et al. 2007), she found that speakers with the highest level of frequency decreased the amount they spoke, individuals who did not have critical amounts spoke less, but individuals who contributed less did not increase their contributions.

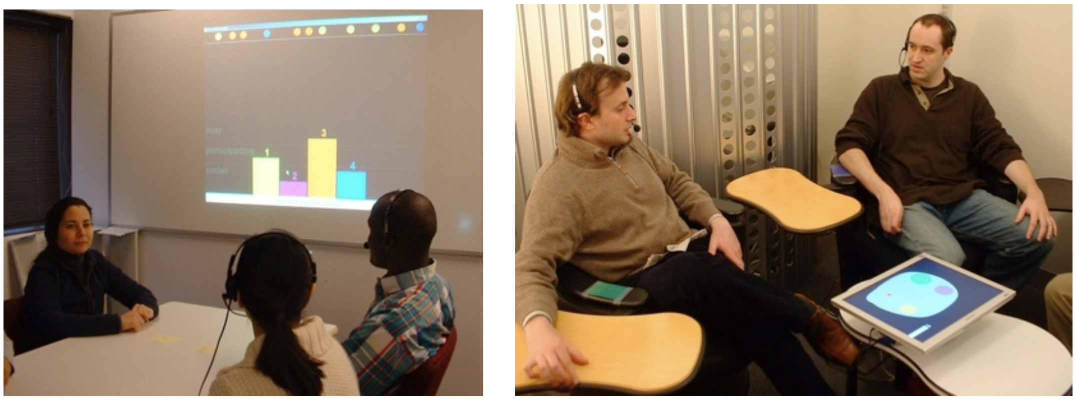


Figure 19. Second Messenger I and II, MIT Media Lab, 2006

DiMicco also studied groups who saw a visualization of their group interactions after the meeting had occurred. She found that reflection on the visualization significantly improved the group dynamics greatly benefiting those who felt they were ineffective in previous meeting scenarios. This research suggests that collecting historical information and presenting a group visualization aafter the meeting has taken place is more effective at creating group awareness than dynamic feedback.

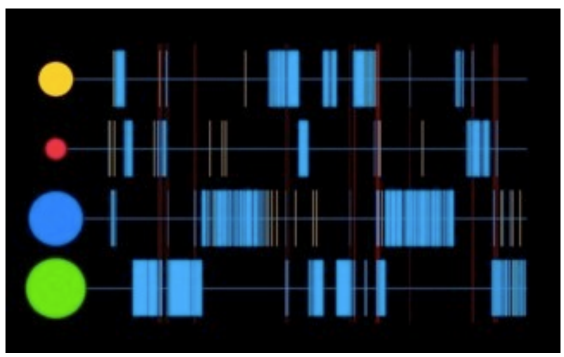


Figure 20. Visualization of Meeting, DiMicco, 2006

In a similar vein, Karrie Karahalios and Tony Bergstrom created social visualizations of aural group conversation in a tabletop setting. Conversation Clock (Karahalios & Bergstrom, 2006) visualizes conversation of up to four participants around the same table. Each person is represented as a distinct color. As users speak over an interval of time, their audio participation is represented as a rectangle where the length corresponds to the average amplitude of their volume. This stream of rectangles grows clockwise over time; a complete circle is formed in one minute. As time progresses, the outer circles move towards the center, and the current conversation circle is at the periphery of the table.

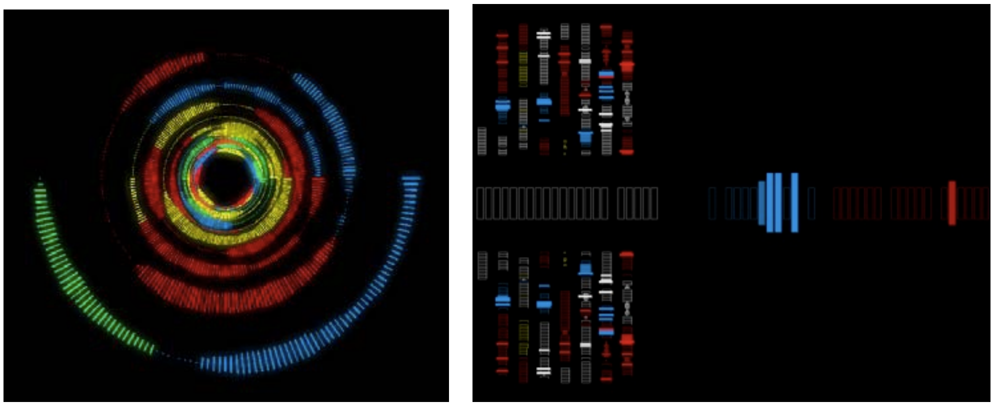


Figure 21. The Conversational Clock after several cycles and Conversational Votes, 2006

Conversational Votes (2006) provided handheld devices where users could indicate their level of agreement dynamically during a meeting. Karahalios presents a graphical rendering that encapsulates a conversation - providing a way for people to reflect on their patterns of interaction, an abstraction that focuses on the behavioral aspects of the meeting rather than the content being discussed.

2.3 Memory Augmentation Systems

The Roomware project has its origins in the i-Land project (Streitz, N. et al, 1999) described as "and interactive landscape for creativity and imagination". The i-Land project imagined the following scenario:

> "Imagine meeting a colleague by chance in the hallway and starting a discussion that might result in the intention to explain something by drawing a sketch on the wall and annotate it by drawing. Besides the fact that this is usually not accepted in office buildings, traditional walls do not support storing and later modifying the elements of the discussion. It is also not possible to search for related information in a background information base and to link this information to the sketch and the scribbles on the wall. In the future, we like to be able to turn to the wall and do just this. Think of the wall as an "interactive wall" or as one being "covered" by a high resolution electronic wallpaper providing the functionality needed." (Streitz, N. et al, 1999 p. 121)

This vision, proposed ten years ago, encapsulates one of the motivational questions behind the MemTable: If the walls and surfaces of our environment were capable of recording and recalling our interactions in them - how might this transform our interactions with each other? If in ten or twenty years we have an affordable version of Streitz's wallpaper, where and how might we use it together?

Understanding memory and examining software systems focused on memory and environment provide a context for recording and recalling memory. By understanding how cognitive scientists and computer scientists have approached memory, new hybrid forms of temporal visualization will be proposed.

2.3.1 Defining Memory

Endel Tulving was a scientist who devoted his career to the study of memory and introduced the distinction between "episodic memory" (stories) and semantic memory (vocabulary of things). He introduces memory in his book as follows:

> "Memory is the capacity of nervous systems to benefit from experience. It is a ubiquitous presence in all higher life forms. It takes many forms, from simple to complex, from highly specific to most general, from trifling to fundamentally important. In its manifold expressions it is being observed, investigated, and measured in numerous organisms, at many different levels of analysis, from a variety of vantage points, and relying on many different approaches and techniques. It reaches its evolutionary culmination in human beings." (Tulving, 2000)

One of Tulving's major contributions to memory theory is that of "encoding specificity". This is especially interesting to interface designers who are interested in facilitating retrieval. The theory emphasizes the fact that memories are retrieved from long-term memory by means of retrieval cues. The theory of encoding specificity states that the most effective retrieval cues are those that were stored along with the memory of the experience itself (Tulving 2005). This implies that the best place to record and replay a memory would be in the place where the memory occurred (in a co-located environment).

Research has also shown that memory is fallible, and that individual episodic recall diverges dramatically as time passes within groups (Ackerman, 1988). In evaluative studies on organization memory, Ackerman found that organizational memory is both object and process - and there is no such thing as organizational memory, only something called the supra-individual, (distributed cognition) in many places and with many people.

A number of projects have emerged in the CSCW and HCI communities to record, review and reflect on historical information effectively attempting to augment the accuracy and ease of memory recall for individuals and groups.

2.3.2 Memory Augmentation Projects

Bradley Rhodes' Remembrance Agent (Rhodes, 2003) is an Emacs plug-in that suggests information relevant to what the user is reading or writing. It is a tool for associative memory. Suggested documents are displayed in a buffer at the bottom of the Emacs window, and are updated every few seconds based on the last hundred or so words surrounding the cursor. Documents are pulled from text documents, and Remem's internal indexer can parse email archives, HTML, LaTex and plain-text documents.

Sunil Vemuri's primary research is devoted to helping people remember things. Sometimes called a "personal memory aid" or a "memory prosthesis", he has developed semantic applications beginning with iRemember (Sunil, 2006) and now reQall (2008). These are mobile applications that record everything on a smart phone and perform speech to text recognition, parsing relevant events for search and recall later.

A similar product, Evernote (http://evernote.com/) attempts to allow the user to remember everything from an image recognition and device integration standpoint. Evernote collates items chronologically from multiple devices: cameras, laptops, phones. It then parses through the images to collect relevant text information, and makes the information available for search on the Internet.

Deb Roy's Human Speechome Project (Roy, 2008) has been recording via cameras in his home a detailed history of the language development in his son from birth to three years old. This data provides many new opportunities to understand the fine-grained dynamics of language development. The analysis of the data presents new techniques for analyzing a large corpus of images and historical data.

Rob Poor (Poor, 2001) designed an Ambient Chair which listens to the sounds in the environment and plays back a history of the interactions around the space. Ted Selker's research (Selker, 2005) on context-aware design and interaction in computer systems contributes to research on memory and context-aware objects in workspaces.

2.3.3 Visualizing Historical Information

A variety of projects tangentially related to the proposed visualizations on the MemTable exist in the field of visualizing temporal and historical information. At least forty researchers met at a CHI 2009 workshop devoted to the subject of temporal visualization. The primary purpose of the meeting was to establish a context and set of tools whereby researchers could share resources. A few influential projects are listed below for reference later in chapter 6 on recall and reflection because of their unique visual and aesthetic approaches.

Martin Wattenberg & Fernanda Viegas developed History Flow (http://fernandaviegas.com/wikipedia.html), 2003, a tool for visualizing dynamic, evolving documents and the interactions of multiple collaborating authors.

Fernanda Viegas developed PostHistory, Mountain, and TheMail 2006; a series of projects that explore the notion of history in computer applications and online environments. She says: "By developing time-based visualizations of digital activities, we hope to raise questions such as: what is digital memory? How can we understand, interact with and, more importantly, share our digital history?" (Viegas, 2006).

In Scott Snibbe's 2003 work, Deep Walls (Snibbe, 2003) he creates a projected cabinet of cinematic memories. The name of the piece is a design pattern from architect Christopher Alexander's "Pattern Language" (Alexander, 2001). His admonition to architects is to build the walls of homes thick, so that cabinets, drawers and windows can perforate the interior space, providing areas to store, display, slice through and ultimately provide more meaning within the home. In the spirit of Alexander, this work gradually absorbs the contents of its environment onto its surface (see figure 89 in Chapter 6).

Lincoln Shatz, a professional artist in Chicago, produces generative portraits that collage histories and video paths for periods of up to eight years at a time. For example, 'Cluster' (Shatz, 2006) evolves over eight years, daily accruing thin slices of video from its environment and storing them onto a computer.

CHAPTER 3. DESIGN AND FUNCTIONALITY

This section outlines the design methodology behind the current version of MemTable's hardware and software. It begins with the hardware considerations and conceptual guidelines from current literature. The software section presents currently implemented features: user interface, input modalities, and the MemTable database model.

For technical implementation details, please see chapter 4. Software and Hardware specifications, our implementation, and a discussion of technical limitations are presented separately from the design and functionality section. If twenty years from now a researcher is reviewing this thesis, we hope that chapter 3 will be highly informative and relevant, and chapter 4 will be outdated and serve as a benchmark of technical progress.

3.1 General Functionality and Design Goals

The overall goal of the MemTable is to support a succession of meetings that occur during the life-cycle of a project in workgroups of 4-8 people. The table is designed to capture the digital and analog contents meetings and make them available for subsequent recall in later sessions.

MemTable's longitudinal design goals are to support three basic modes of interaction at the table: recording and capturing elements of meetings, recalling contents of previous meetings, and reflecting on individual and group work processes. Recording, recalling, and reflecting (the three R's) are the MemTable's primary functions.

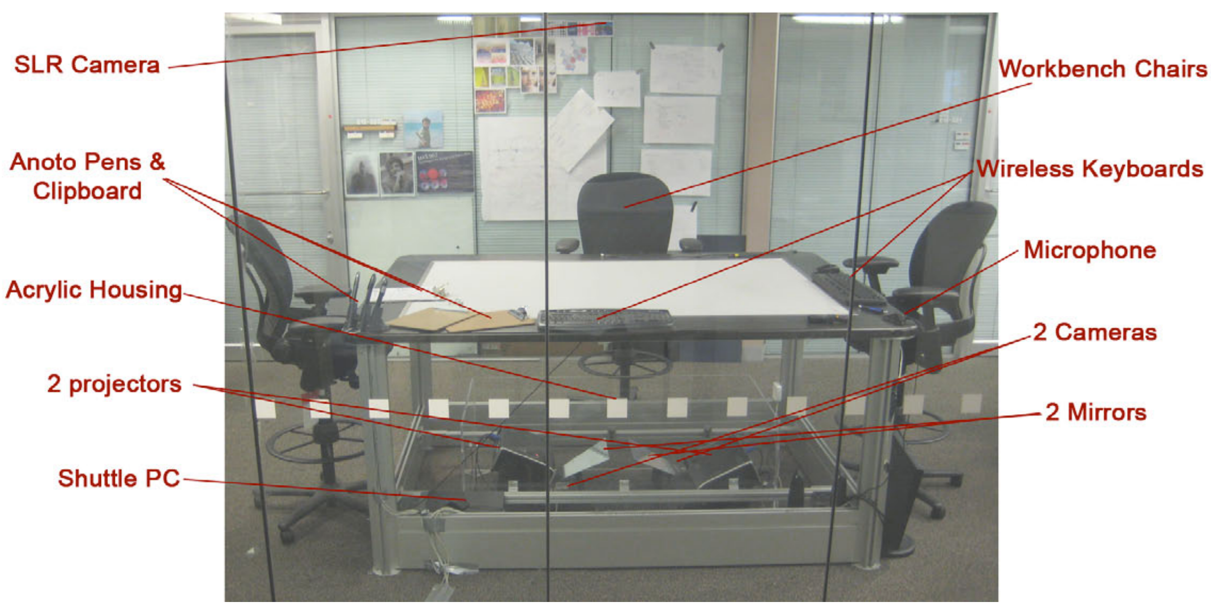


Figure 22a MemTable component diagram with interior technology and exterior input hardware

This Chapter focuses primarily on the recording modalities supported by the system. These input modalities are: text input, audio input, camera input, laptop input, and drawing (note taking). The five input modalities are represented by "data elements" on the table. Users can create a data element from personal menus docked on the perimeter of the table. The menus allow users to access all the recording, recall, and reflection functions that will be built in the table. Please see section 3.3 for a detailed overview of the user interface.

The following general design principles informed the overall design of the MemTable:

1) Support heterogeneous types of input during group meetings for different contexts.
2) Protect the privacy of users by only recording explicit actions and giving them control of the system.
3) Design the interface to be efficient and consistent as possible, with a minimal number of steps to input and recall information from the system.
4) Keep the coexistence of physical to digital content as fluid and seamless as possible.
5) Try to record the context of events: who, what, and when something is created and modified for subsequent recall.
6) Prioritize the ergonomic and social aspects of the design over immediate technical considerations.

Section 3.2 describes in more detail the design principles of the hardware, and Section 3.3 provides a detailed overview of the software interface.

3.2 Physical Table Design

During the initial stages of brainstorming for this project, we had to decide on a hardware platform for prototyping applications. We utilized the technical experience from the WordPlay (Hunter and Maes, 2008) table, and reevaluated our needs. In tabletop research, the hardware and software designs are interdependent. Surface area, resolution, hardware positioning, and materials all have different affordances and set limitations on the subsequent interface design and features supported by the system.

We choose to build our own platform for three primary reasons:

A) *Ergonomics:* The table needed to be comfortable to work at, for developers and for users of the table in the workspace. A multi-touch table should be as comfortable to use as a typical group meeting table.

B) *More collaborative space:* Group collaboration and meeting require greater surface area. The table should be large enough to support existing tools for meetings like pens, keyboards, laptops and paper.

C) *Flexibility and Transparency:* Existing options (Microsoft Surface, DiamondTouch, SMART) are closed platforms. Due to technical constraints, they do not support reconfiguration for customized installation. MemTable is transparent, exposing the underlying hardware.

The hardware section starts by summarizing the guidelines for tabletop systems presented by Stacy et al. in 2003 and its influence on the MemTable design, continues with a brief comparison to contemporary technology, and concludes with documentation and discussion of the resulting table and its use in the workspace.

3.1.1 Generalized Tabletop Design Guidelines

Referenced often in tabletop literature is the paper: *System Guidelines for Co-Located, Collaborative Work on a Tabletop Display* by Scott, Grant, and Mandryk, 2002. It provides a benchmark and comprehensive guidepost for the collaborative requirements that an ideal tabletop system will support and outlines important areas for future research.

Tabletop systems at that time were beginning to mature, but it was unclear what type of system would be suitable for different contexts of use. Deciding which tabletop system to build was the focus of a workshop at CHI and helped Scott et al. outline the following important guidelines:

Tabletops should support: (1) natural interpersonal interaction, (2) transitions between activities, (3) transitions between personal and group work, (4) transitions between tabletop collaboration and external work, (5) the use of physical objects, (6) accessing shared physical and digital objects, (7) flexible user arrangements, and (8) simultaneous user interactions (Scott et al, 2002).

The subsequent development of tabletop platforms has not adequately addressed what an ideal form is for small group meetings of between 4-8 people at an interactive surface. In addition to the physical form of the table, we should consider contextual considerations: social and cultural, activity, temporal, ecological, and motivational - all of which influence its software, physical form, and connectedness (Wallace & Scott, 2008). With these eight tabletop guidelines and contextual considerations in mind, we attempted to redesign our collaboration table to address as many needs as possible in a shared meeting context.

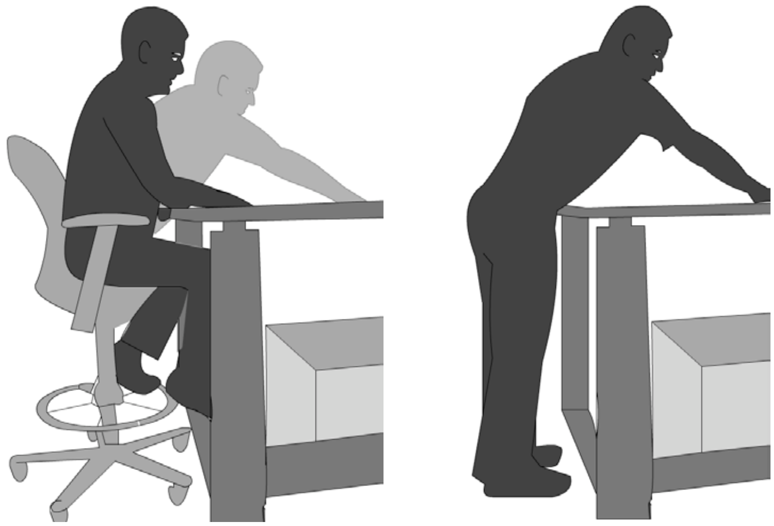


Figure 22b. MemTable chair height during meetings, sitting or standing, with two places for feet to rest and 32" reach.

In particular, the hardware design incorporates more natural interpersonal interaction (1) by addressing ergonomics (Figure 22b) and because users are elevated to a height of 40 inches, a natural height for seated interaction with standing users. The design also supports the use of physical objects and shared objects (5)(6) by incorporating an eight inch border around the edges. Transitioning between collaboration and external work is addressed in chapter 6. (2)(3)(6)(7)(8) are discussed in sections 3.2 and 3.3.

Observations of our Workspace

We began by observing how people use tables in our laboratory and documenting these scenarios as they naturally occurred. A typical scenario is shown in Figure 22c, with users gathering in a circle and focusing primarily on personal workspaces and laptops. Collaborative scenarios are shown in Figures 23 and 24, where participants are gathering to discuss, brainstorm, and plan activities together.

We observed that: (a) people use tables as a primary place for meetings and discussion, (b) a variety of objects - utilitarian and social - are included in the workspace, (c) people typically utilize the amount of space that they are given in an environment, and (d) the use of personal laptops is ubiquitous throughout the workplace.

Figure 22c. Typical workgroup environment in our lab

We also observed that for meetings and discussions, a horizontal display was more democratic and afforded a greater variety of activities. While the authors in (InkPen, 2005) conclude that vertical displays may be better for short and focused tasks, horizontal displays may be more appropriate for longer discussions. This implies that vertical whiteboards are more effective for a group standing in front of it, while a horizontal display is better suited to a group is sitting around it (Rauterberg, 1988, Rogers, 2004, Wallace, 2008). A combination of vertical and horizontal displays would best serve all contexts of interaction, including presentation style meetings.

Figures 23, 24 Collaborative Activities: a Group Brainstorming Session and a Story-boarding meeting.

Although much of our work now takes place on a laptop, the majority of our collaborative activities are still analog and require cumbersome processes to be incorporated into our group work archives. We noted in particular activities involving story boarding and brainstorming required the arrangement of objects on the table and the modification of those objects with drawing implements.

3.1.2 Design for Natural Interaction During Meetings

Before building the table the author visited the headquarters of Steelcase in Michigan to consult with them regarding their existing prototypes and material designs. We met with an ergonomics specialist regarding height considerations and choices for chairs and building materials. Steelcase builds tables for meetings with space for laptops and VGA inputs for each member of the team, similar to the CaptureLab system of 1988 (see Section 2.2). Their design incorporates a footrest, margin for laptops, external display and a 39 inch height with beveled edges. We choose to use the same chairs as their design and a similar width for conference meetings.

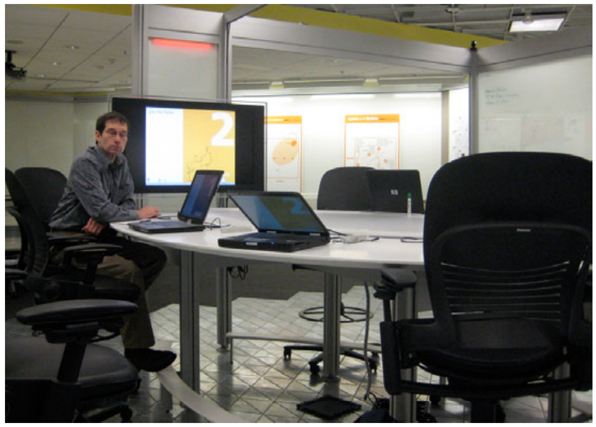


Figure 25. Steelcase advised the table design

The goal during our visit with Steelcase was to investigate how the form of the table could improve the facilitation of natural interpersonal interaction (guideline 1). MemTable is workbench height (40 inches) and is designed for Steelcase architectural chairs (Figure 25). This supports users sitting or standing and maintaining comfortable eye contact and gestural awareness.

Figure 26. MemTable during development. Note footrest in a seated position and standing participant.

Bill Buxton observed in his designs of Large Automotive Design Displays that:

> "while drafting tables encourage a shared awareness of what others are working on, looking over colleagues' shoulders at their monitors has more in common with reading a newspaper over someone's shoulder—for the most part, it's socially unacceptable. Hence, the benefits of moving toward larger format drawing surfaces that are closer to drafting tables than to conventional computers go beyond simply giving a larger display surface on which to draw and view one's own work. They include recapturing some of the social and collaborative properties of the design studio that were lost during the first generation of computerization." (Buxton, 2000 p.70)

Facilitating this type of natural social interaction, and integrating a table that is comfortable to work at were our primary considerations. Wallace also observes that appropriate table size is also influenced by cultural and age considerations: the distance at which people are comfortable interacting with others varies across age and culture. In formal or informal meetings between adults people are shown to be more comfortable at large tables when interacting with strangers (Wallace, 2008).

3.2.3 Ergonomic and Other Practical Considerations

Although we often take for granted the form of a prototype this is often comprised more by technological consideration that ergonomic ones. Scott et al., 2008 observes that tabletop systems that have bulky components under the table, such as projectors and mirrors for bottom-projected displays (Ullmer & Ishii, 1997; Agrawala, 1997; Leibe et al., 2000) often require users to stand or sit awkwardly for extended periods of time, potentially impacting the comfort level of users and the naturalness of the interactions between users.

In the first system we built, Wordplay (2008) a tabletop interface for brainstorming and decision making, we observed many issues with comfort during development and while participants were utilizing the table. Primarily, users were not able to put their legs under the table and even while standing did not have a kick space or an overhang for the feet to naturally rest under. As a result, many people would lean heavily on the thin wooden frame that lay over the FTIR display. This caused the frame to split, and eventually damaged the electronics in the display. People saw the system as primarily for short term use, rather than integrated into the workplace in a cohesive and considerate way.

Figure 27. WordPlay was a good height for standing interactions but was difficult to use for extended periods.

The accuracy and responsiveness of this table is superior to our system, but we found that natural integration with our office furniture and typical usage scenarios were ergonomically frustrating. This is in part due to the height of the table, but also to its small size and lack of kick space for the knees and feet. Figure 28 shows casual observations of use in our lab for work and for a meeting. Note the extended seat cushion in Figure 28 left and the participant with his knee to the left in Figure 28 right. MemTable addresses this problem by raising the height of the table. See Figure 28a for a drawing of height consideration for sitting and standing users, with equal support and reach.

Figure 28. Everyday uses of the Surface Table in our laboratory, soldering and a meeting

In both these cases, the table does not have sufficient function to augment the interactions between people, or assist in the documentation during the process of working on a project. There are two primary reasons for this according to Andy Wilson, via a personal conversation. Inside the surface table are 5 IR led cameras, and a series of IR floodlights. The cooling and computing system are built into the unit, and it is designed to be calibrated once installed. The closed walls keeps the light conditions constant for the cameras and prevents the equipment from being altered or damaged. The height of the table enables users of all ages to interact and is a fair compromise between a lobby and a coffee table. Because their intended venues are bank lobbies, casinos, and commercial resale venues this height satisfied most of their needs.

The design considerations for meeting tables had considerably fewer stringent requirements. We researched and choose to use side-lit Acrylic called EndLighten (see section 4) simplifying the IR Illumination requirements underneath the table. For dual projection we choose short throw projectors that could be centered in the middle of the table allowing 12 inches of foot space before the path of the camera and projectors intersect with the path of the participants knees.

Figure 29. MemTable Hardware centered and Protected inside the frame

The projectors, cameras, and mirrors are protected by a custom made acrylic housing and reinforced by 80/20 supports. The table is constructed from aluminum components and is modular. It has five modular parts: The wooden border at the top, the acrylic surface, the leg & footrest unit, the acrylic housing, and the equipment unit. It is designed to be deconstructed with a single Allen wrench and could be transported and reassembled in a matter of hours.

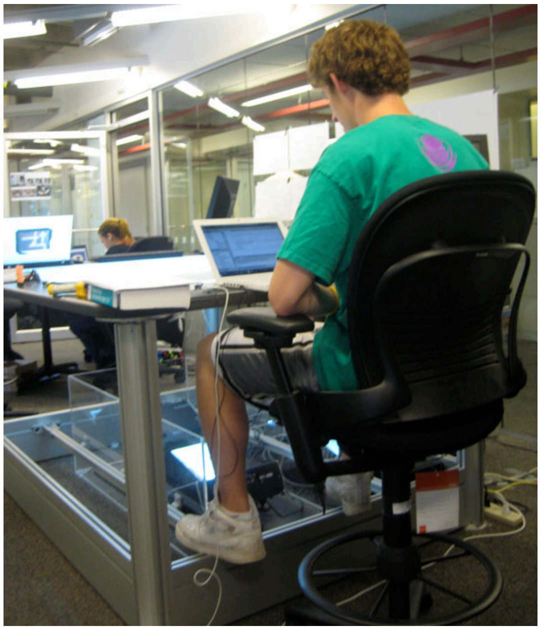


Figure 30. Ergonomic workbench style and footrest

The footrest serves as the primary source of stability for the table, coupled with the support provided by the 1.5 inch plywood top. An 8.5 inch border is provided around the outside of the table to support laptops, monitors, pens, clipboards and other objects that may be a integral to the combination of digital and physical objects in the same space. The footrest also satisfies the need for comfort when seated at the table. Except in extreme situations when a user crosses their legs in unusual ways, the table is largely unaffected by its open and transparent design. This is beneficial because it acts as a natural diffuser for the heat that is emitted by the bulbs of the projectors and eliminates the need for a complex cooling system like the one in the surface table. One detraction of this design is that stray light sometimes reflects off of the mirrors and presents some issues with glare in the space.

3.3 User Interface

This section documents the design strategies and features implemented in the meeting software of the MemTable. Through a series of iterative sketches we proposed a number of metaphors and elements that allow the user to fluidly join and leave sessions anywhere on the table, maintain a balance between public and private space, capture input, and manage global options during a session.

Our conceptual guidelines for the interface were as follows:

A) Provide a flexible and expressive set of UI Options for heterogeneous groups meeting in different contexts.

B) Keep the interface simple, intuitive, consistent, and iconic. Minimize the number of steps to input information into the system.

C) Make all graphics and elements reconfigurable, docking functional features on the perimeter of the table.

D) Tag all content elements with "who" and "when". Provide an option for users to tag "what" content elements are.

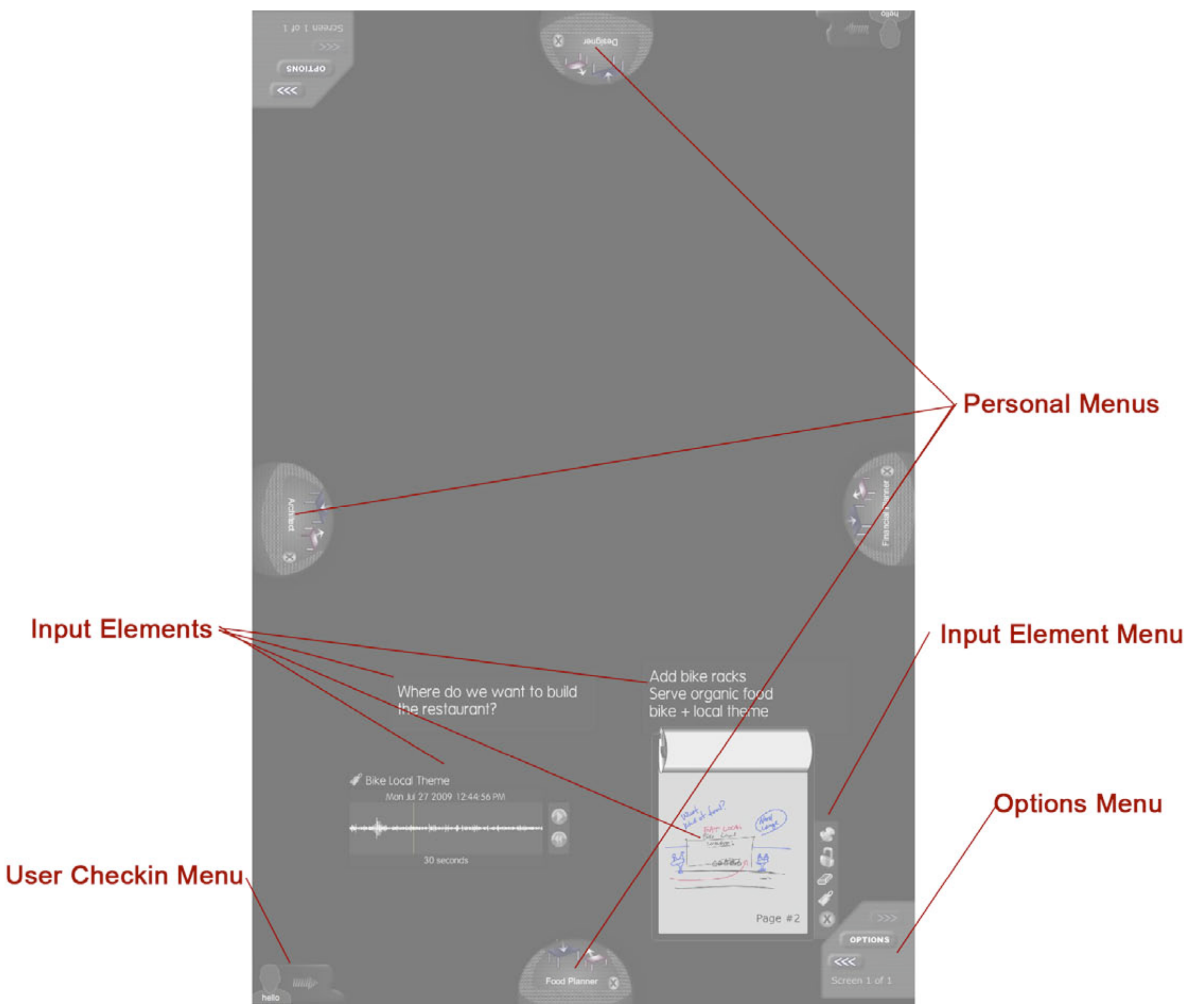
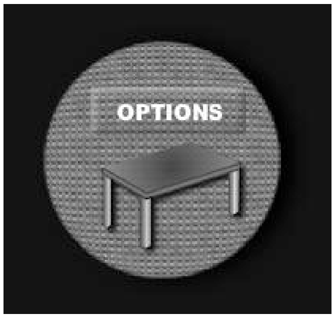


Figure 31. A screenshot of the user interface, with major components labeled.

Figure 31 shows a diagram of the elements in the user interface to provide a context for subsequent explanations of the software features in this chapter. This section will discuss each one of the elements in this diagram in order of use during a meeting. A session begins with one person initiating a session from the options menu. Users then check-in to the session by opening the check in menu. A personal menu is generated and can be docked on the perimeter of the table. Personal menus allow users to create input elements. Input elements have embedded menus for modifying and tagging the content of the meeting. Each of these components is described in the following sections.

3.3.1 Options/Start Menu

At the beginning of a session, a floating options menu drifts about the table waiting for someone to touch the surface. At this point the options menu is attracted to the area of the table with the most touch points and the longest touch duration. The options menu allows you to either start a new session or conFigure the narrative of historical content being played in the background (see chapter 6.4).



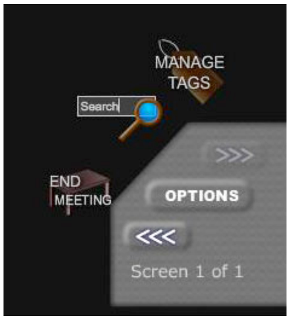


Figure 32. Floating options menu to start a session,
and docked menu in the bottom right corner.

When no one is using the table, it "reflects" about how people have used it previously. Reflection is still under development (chapter 6.4), but consists of public sessions and contributions to the table with similar tags or similar users participating. Reflection is intended to contribute to workspace awareness and allow people visiting the workspace to get a sense of the workplace when others are not present.

3.3.2 Check-In System

The check-in system is positioned on the lower left and upper righthand corners of the table, and allows users to slide the head from left to right to trigger a lineup of each of the users in the workspace. We incorporated an RFID system with custom cards for each of the users but found that they did not use this because it required them to have their wallets, take them out and place them on the table. We observed that users were not interested in using cards to check-in to the system if a software option to do so is available, however if security required RFID tags, this would be relatively easy to implement.

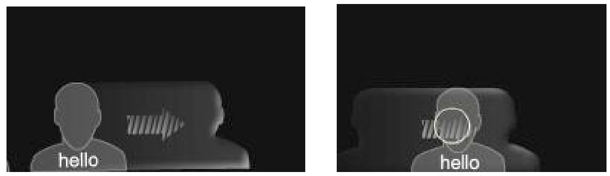


Figure 33. Check-In menu slide to open

The functionality of the check-in menu is a legacy of the iPhone, but serves the purpose of protecting the table from unintended events triggered by paper items or a stray arm on the interface. In general, we noticed that this is a problem throughout the interface and incorporated locking and pinning features for each of the items on the interface to try and counteract problems that may arise as a result of unintended interaction. As the accuracy of the hardware increases this will be less of a problem.

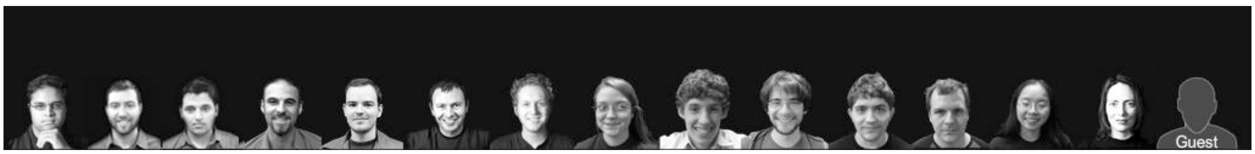


Figure 34. Check-In menu with the pictures of users enrolled in the workgroup

Pictured above are each of the users in our workgroup. When the check-in menu is extended, users touch their face to trigger a hockey puck like menu with their name on it. We nicknamed this a “halo” menu because eventually it will be docked next to the users body on the edge of the table, a virtual extension of the body position.

3.3.3 Personal Menus

Personal menus jump from each of the users faces onto the canvas of the table. For visual consistency they include grips (indicating the element can be repositioned) and shadows (to help differentiate between elements). They hover above the surface, waiting to be thrown to an edge of the table.

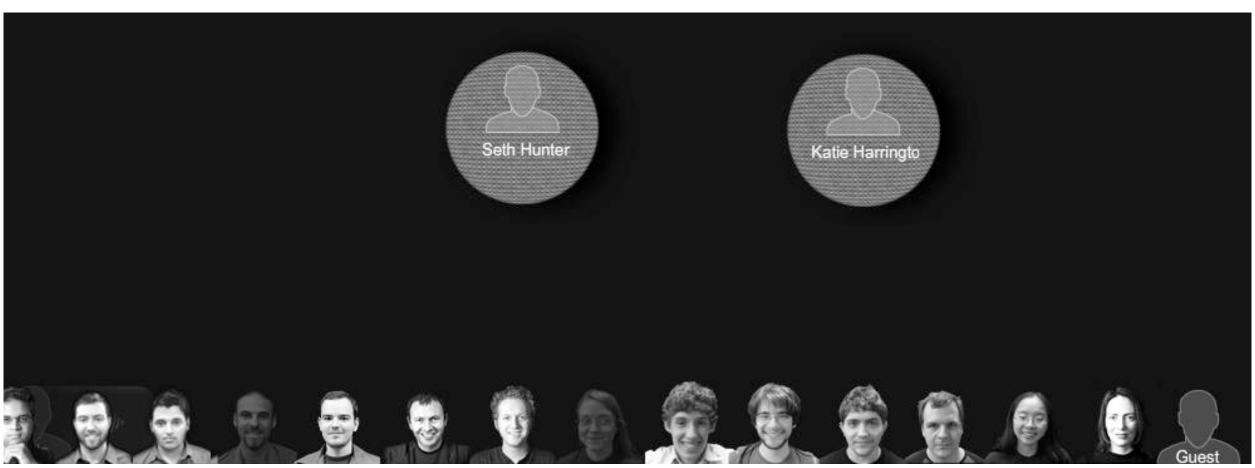


Figure 35. Halo Menus triggered from the check-in menu system.

Each personal menu has velocity but no friction, so that if a menu is triggered in a particular direction, it will continue in that direction towards the edge. This interaction is playful and encourages initial engagement with the table. When users are experienced, it is intuitive and requires minimal effort to place a menu on an edge of the table.

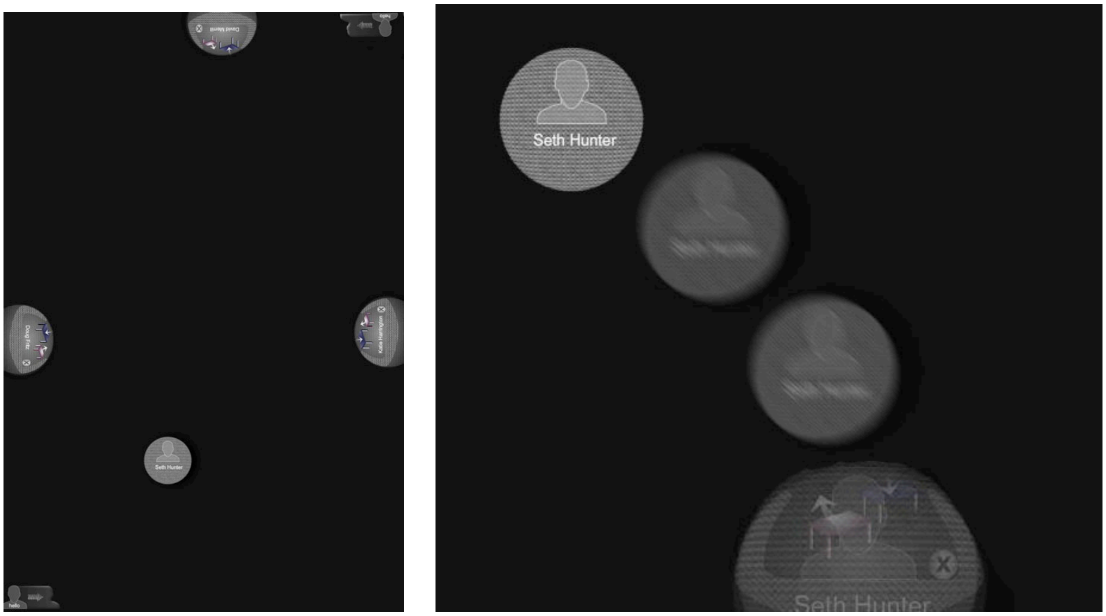


Figure 36. Menus checked in around the table, and a frame by frame of a menu docking.

Docked menus have an algorithm that prevents overlap between menus and ensures that users have space for personal interaction. The function gives priority to the currently docking menu and shifts the others according to an average of the amount of space left. The maximum amount of menus comfortable for the table is ten. The table has a ratio of 2:3 and the menus should be arranged on each side according to this ratio.

Figure 37. Checking out of a meeting.

If a participant wants to exit a session at any time, they can click on the “x” on the lower right-hand corner of the halo at any time. We found that if we did not include confirmations for close actions of elements and menus, users would often inadvertently close their menus during their initial explorations of its features. The texture on the menus was designed to distinguish button trigger areas from grippy areas for modifying the position.

3.3.4 Input/Output Menus

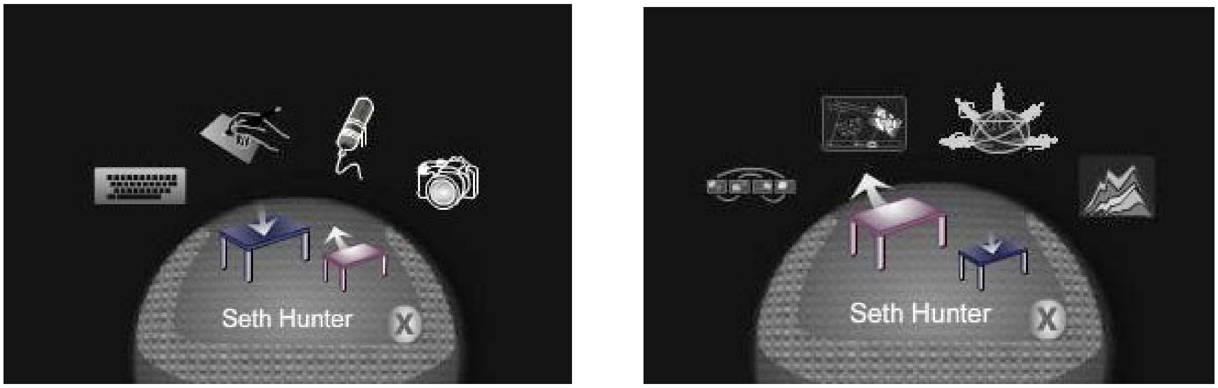


Figure 38. Input (left) and output (right) Menus on the Halos.

Figure 38 illustrates the input and output menus. Menus are triggered when a user touches the blue or red table on the personal menu. The blue icon with the arrow pointing down at the surface indicates "putting things into the table". The red table indicates "taking things out" of the table, or pulling information from its memory. Each of the input modalities spring from the tables, animated to indicate they come from touching that button. Each of the icons has a 50 percent fade on touchDown providing immediate feedback to the user. The large area of the icons provides some margin of error for minor calibration issues at the edges of the table, but allows for continuity at the edges.

By linking the content generation to each person's menu, the system is able to identify who is generating content and make some general assumptions later when retrieving content. From left to right in Figure 38, the input menu triggers each of the input modalities: type annotations, drawing with the Anoto pens on a clipboard, going back in time to capture a previous audio comment, and taking a snapshot of the table surface.

The output menu features are currently still under development, details are covered in Chapter 6. From left to right, the icons represent: find similar content from the tables memory to this session, recall annotation by browsing previous session, visualize my relationship with others at the table, and show me the frequency of my history of use with other people in my workgroup.

3.3.5 Content Elements

There are four primary types of content elements built into the system. These are drawing, audio, text, and photo containers. Each content element has its own options menu, which we nicknamed the UIPane (see lower righthand corner of each content element in Figure 39).

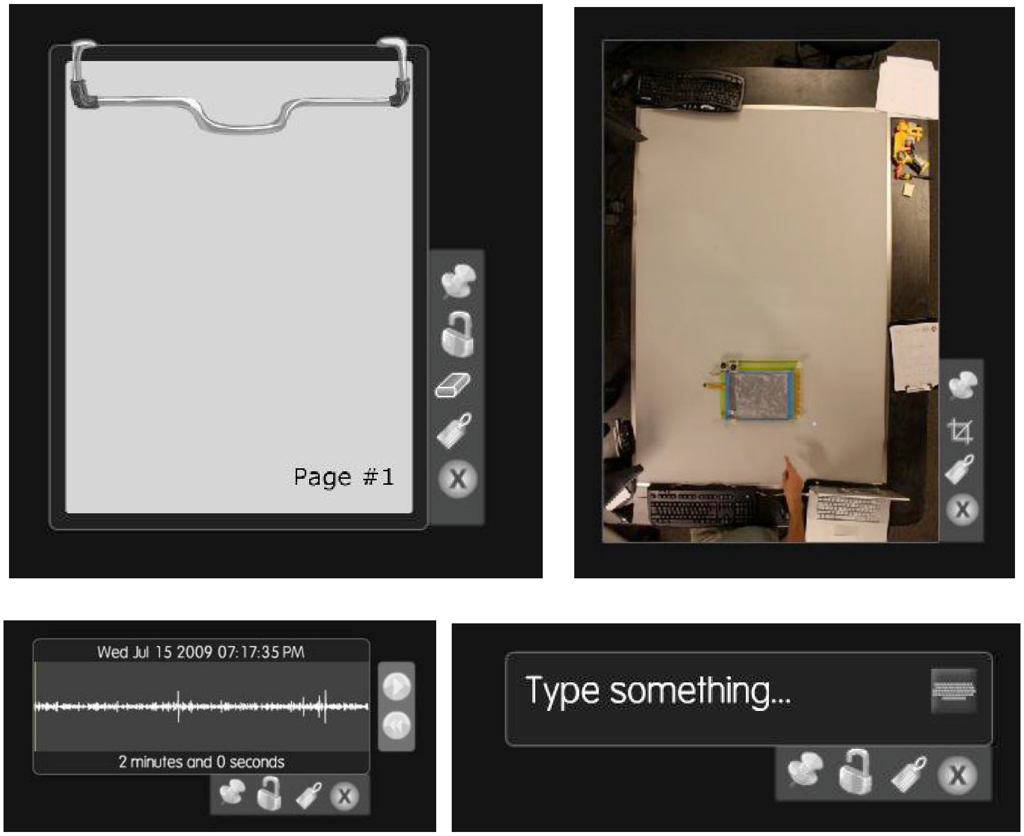


Figure 39. Each of the content elements and their respective options. Drawing, photo, audio, text.

Each of the content elements rotates, scales, and minimizes using standard bi-manual gestures adopted by most contemporary multi-touch platforms. "Locking" indicates that an element is no longer in edit mode, but can still be repositioned. A locked element indicates that the user who created it no longer wants to edit the content. "Pinning" a element prevents it from being moved or scaled thereafter. This feature is extremely important to prevent unwanted overlapping between elements but can sometimes cause confusion. To reduce any confusion that might have resulted from a element not responding to touch, elements are toned red after they have been pinned.

All menus on the elements fade away after they have been inactive for 20 seconds. This reduces clutter on the table, and also gives the user feedback when they activate a element indicating what state it is in. Each pane contains an "X" function with a similar remove confirmation when a user is finished with the content. Removing a element does not remove it from the system. All content can be retrieved from the review panel, even during a current session.

"Tagging" is covered in the next session, and is indicated by the "tag" icon. UI panes do not scale, and stay attached to the lower right of each element. The photo and drawing elements contain additional specific features such as cropping and erasing.

3.3.6 Tagging System

The tagging feature is intended as a means of labeling and later searching for content that is not text. Our expectation is that users may use the tagging feature at the end of a session before closing the meeting. Although not everyone will use the tagging system, any contributions with help the MemTable make more accurate associations between annotations.

The tagging menu allows the user to choose one of three options: create a new tag, edit an existing tag, and delete a tag from this item. Tags are stored in the database, and once a tag has been added to a session, it is available for tagging other content elements in that session. When a user chooses to create a new tag, a virtual keyboard appears onscreen. We decided to include this in addition to the wireless physical keyboard present on the table to make it easier for all users to tag.

Figure 40. Tagging pane, virtual keyboard, and tags attached to a element.

A scribe would typically not use a soft keyboard to type or take notes. Evaluative research has shown that virtual keyboards reduce efficiency by 40% or more in most cases (Hinrichs, 2007). Our observations and research correspond with these findings.

Once a tag has been created, it is appended or labeled below the element in use. This is useful for identifying audio content, for example, because the audio waveform is not enough to distinguish annotations from each other, and the tag will act as a memory cue later during recall and retrieval.

3.4 Input Modalities

Tang et al. argues for a multi-modal approach to collaborative work in collaborative workspace activity. Observations of traditional tabletop collaboration have shown that people's interactions are fluid and dynamic on a tabletop (Bly, 1988; Tang, 1991), and that collaborators are physically animated during these interactions. He says:

> "A conventional view of workspace activity may be characterized as concerned only with storing information and conveying ideas through text and graphics. Empirical evidence shows that this view is deficient in not accounting for how the workspace is used: a) in a group setting, rather than by an individual, and b) as part of a process of constructing artifacts, rather than just a medium for the resulting artifacts themselves. An understanding of workspace activity needs to include the role of gestural activity, and the use of the workspace to develop ideas and mediate interaction." (Tang 1991)

To support a variety of creative approaches to annotation and collaboration, there are five primary ways users can contribute content to the MemTable. These modalities are drawing, speech, text, photos, and laptop sharing. We chose these modalities by observing existing meetings and taking an informal poll in our laboratory of what types of tools people use for scenarios like brainstorming, event planning, and decision making.

3.4.1 Text Input

Text annotations are primarily for a scribe to take notes during the meeting or to add an identifying tag next to an audio, drawing, or photo item. Ultimately, we would like to have multiple keyboards so that the role of the scribe can rotate between users around the table without having to pass the keyboard.

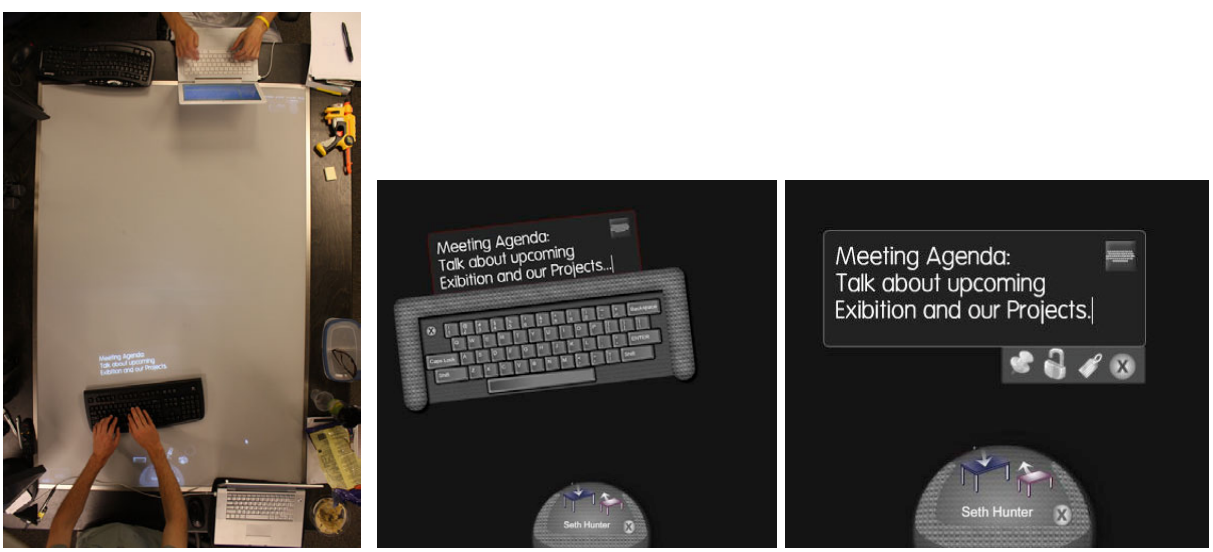


Figure 41. Three ways to enter text, on screen, virtual keyboard, or offscreen typing.

We found that virtual keyboards are useful as an alternative for participants that are on the other side of the table, but significantly reduce the efficiency of text input. Our primary use for the virtual keyboard is for adding tags to content elements.

The text element aligns just above the physical keyboard when you place it on the surface (see Figure 41). By using a black keyboard and a large fiducial pattern on the bottom of the keyboard we were able to identify its position and orientation. Although this feature is nice to demo, most people prefer to have the keyboard offscreen to increase the space available to work with digital content.

We also added code to allow users to select text with their fingers - an important and intuitive feature that many users expect when initially using the interface. By touching a text element, you activate the keyboard to that element. At first we tried using the locking feature as a way of indicating you are finished, but this feature was not intuitively understood by our pilot users.

3.4.2 Image Capture

The image capture feature is intended as a way of incorporating the physical tokens of the meeting into the digital workspace and annotating them. It also documents the arrangement of people in the space, the context of the workspace, and the objects on the perimeter of the table. This feature provides useful information without violating the privacy of the users, or making them feel self-conscious.

Users choose one of two options when taking a picture. Just tangible objects, or tangible objects and the surrounding graphic interface. These are indicated by the two icons in Figure 42. Choosing the option for just physical objects fades a mask over the background until the picture has been taken.

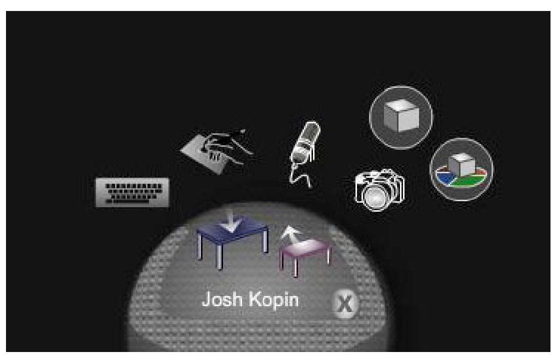


Figure 42. Two options to choose a Photo

The image element captures the image in high resolution and immediately generates two additional copies: a thumbnail version of the table and a medium resolution version for the user to preview on the table. We imagine that people using blueprints, or models when planning a scenario will want to take snapshots at key moments, and zoom in on those photos.

Figure 43. Three sample Photo captures with the Image capture system. (elements are shown)

Even with a ten mega-pixel camera, the resolution is not adequate for reading text or to scan on the surface of the table, it allows for a medium resolution image that captures the context of the workplace without clear detail. One way to overcome this might be to allow users to use the camera freely rather than positioning it on the ceiling.

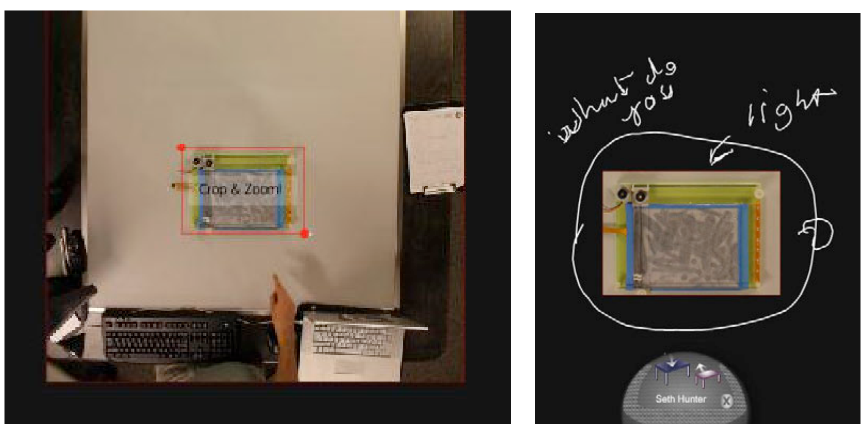


Figure 44. Using the crop feature to zoom in on a prototype and drawing around it with the light pen.

We added a crop feature for users to zoom in on content in the scene. They can use their fingers to drag red lines over the portion of the image they want, and then click on a button in the center of the image when they are ready to capture it. A separate image is generated by finding the coordinates in the high resolution image and returning the zoomed version.

3.4.3 Audio Buffer

The audio buffer is a program that runs in the background keeping a running loop of the previous ten minutes. The data is not saved, it is available for saving when something significant happens and a user wants to go back and archive that audio. When the user touches the audio microphone a snapshot of the audio waveform appears with buttons overlaid to chose the increment of time to save. We choose to make the buttons bigger around the two minute mark, because in our pilot studies this was the amount of time people would wait while someone was making a point before pausing to annotate it.

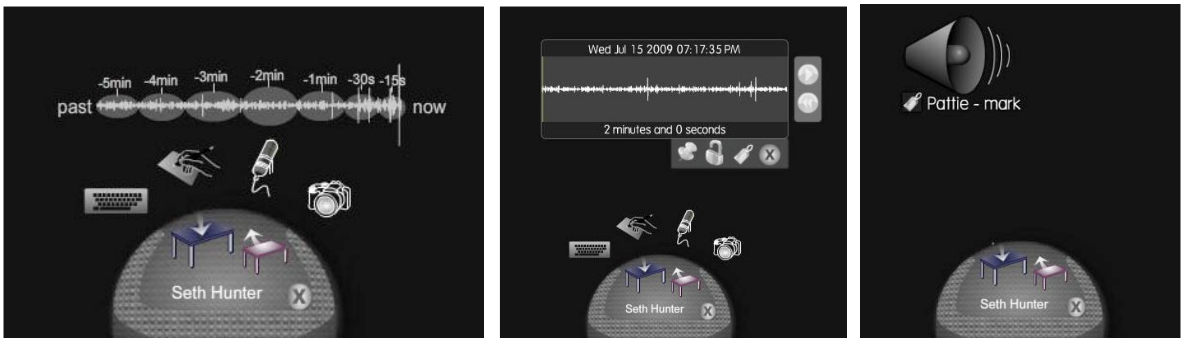


Figure 45. Audio visualization menu, playback element, and minimized state.

Once the user has chosen a length of (previous) audio to save, an mp3 file is generated, saved in the database, and loaded into the audio element. The audio element has play and pause functions and touching it at any point along the audio spectrum will cause the audio to jump to that point in the playback sequence. The time and length of the file are shown in the element, providing as much information as possible without tagging, but tagging and minimizing (far right, Figure 45) features are included and recommended for spatial reasons on the work canvas.

3.4.4 Note Taking and Drawing

Three clipboards and three Anoto pens are provided with the table for users to take natural notes during a meeting. The Anoto pens have the advantage of being accurate and responsive, as well as providing direct and natural feedback during the process. As notes are being taken on physical paper, they are synchronized with their digital counterpart. Participants also can take their physical notes with them as an immediate reference from the meeting, but don't need to bring them for the next meeting.

Placing a clipboard on the table positions the digital clipboard to the left or right of the physical clipboard. One advantage to this system is that we are able to save all the raw data coming in from the pens, and could later use that data in a different temporal context such as the reflective screen-saver.

Each of the clipboards contains three pages with unique identifications, corresponding to similar pages on the digital clipboard. Each of the pages also has a color chooser, line thickness, and brightness option located at the bottom of the page. These change the color and stroke in the parallel digital representation.

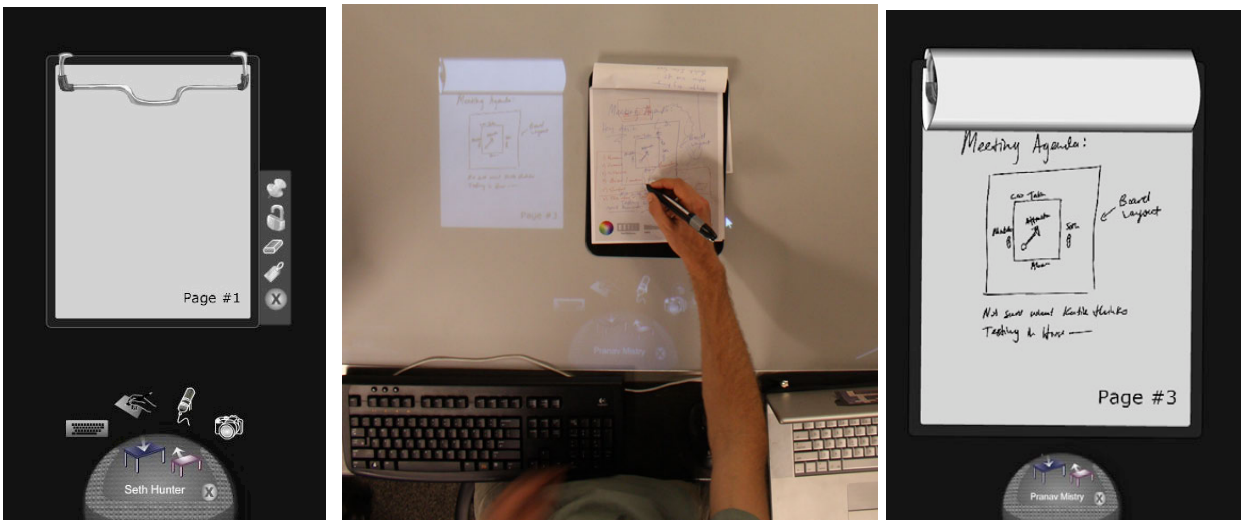


Figure 46. The Drawing element, Annotation clipboard, and the resulting digital annotation.

Also included in the clipboard element is the ability to erase things with your fingers. We are currently developing ways to pull a drawing off the clipboard into the general workspace so that drawings can be overlaid with photos and other annotations.

We have also experimented with using a light pen as a way to draw directly on the surface for this purpose. The low resolution and slow response rate, 24 hz, of the pen prevents this from being as satisfying as drawing on paper, but could be useful for grouping and marking around annotations in a gestural manner. This problem could be solved by replacing the cameras with 60 or 120 hz cameras if the drivers allow the amount of data transfer. Please see chapter 7 for more information on future features.

3.4.5 Sharing content from external computers

The MemTable has an FTP server and an account for each of the people enrolled in the system. Each person also has an executable on their personal laptop that allows them to click on an icon and select any part of the screen they would like to share in the workspace. In this way users can work on their personal computers during a meeting and share results, or highlight something from a presentation that may be relevant later in the meeting archives.

Large images are imported at full resolution and are rescaled. A hyper-dragging application such as the one presented by Reikimoto et. al, would make image placement between the screen spaces more fluid, but we were unable to implement this within the duration of the thesis.

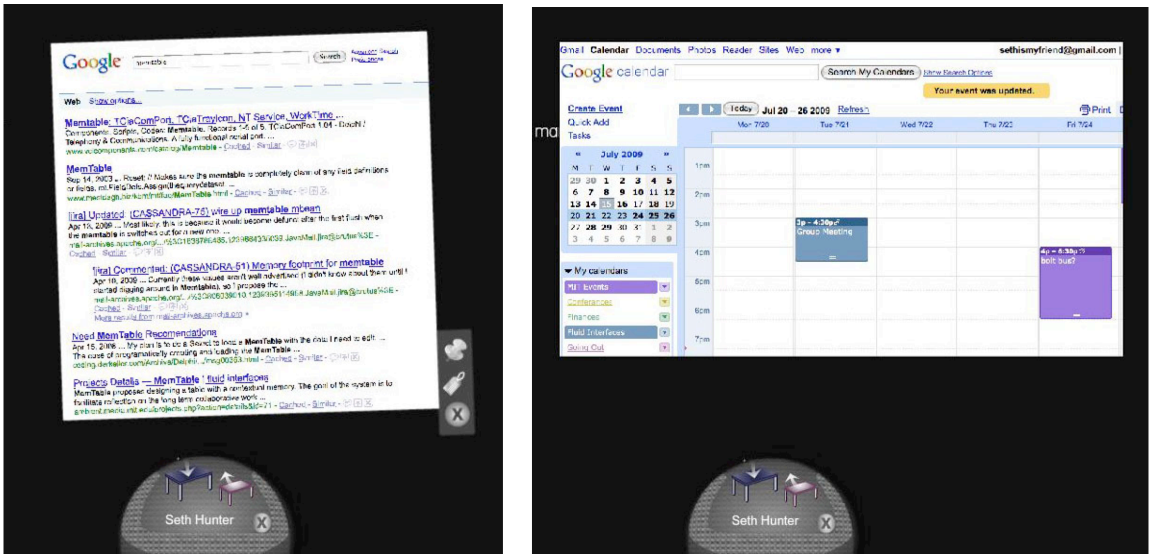


Figure 47. Sharing a webpage or a calendar from a personal laptop

The ability to share documents and edit them collaboratively would require a custom operating system supported by Microsoft or Apple with a framework for translating touch events and compensating for the imprecise (12-15 pixel accuracy) of fingers when compared to a mouse. A seamless blend of collaborative systems and personal computing would make the technical difficulty of exploring collaborative work feasible, but would require a paradigm shift within these companies from single user applications to supporting multiple synchronous inputs.

CHAPTER 4. IMPLEMENTATION

This chapter covers the technical implementation and structural design of the MemTable hardware, software, and database. It includes the design process that led to many of the choices we made, and a discussion of limitations, advantages, and contributions the system may have to tabletop researchers interested in designing their own hardware and software platform.

The scope of the MemTable project extends beyond this thesis, because of the time required to collect and analyze historical data in a tabletop system. We are finished with the input modalities and the data collection, and are working to implement the recall and visualization features. These are covered in Chapter 6.

4.1 Hardware

The materials, specifications, and building process behind the form of the MemTable may serve as a useful reference for anyone interested in constructing a tabletop system from the ground up. This section is written as a rough guide highlighting many of the technical choices that have led to a more robust, ergonomic, and integrated table in our work environment.

There are many companies that provide the hardware and software needed to implement an entire system. TacTable (http://www.tactable.com) in Cambridge, Massachusetts is a company that specializes in custom hardware and software tabletop systems. Henry Kaufman has generously committed time, energy, and software that made it possible for use to implement the MemTable during the past 9 months.

4.1.1 Materials and Components

After we determined what the dimensions of the table would be we consulted with Steelcase to use leftover components from their Post and Beam Collection (http://www.steelcase.com/products). Steelcase generously donated parts to the project from previous prototypes that had been recycled.

Memtable is composed primarily of components made of extruded aluminum with standard set screws and an internal post with screws for attaching legs. The advantage of this system over the 80/20 systems that have been used in other projects is that it has fewer parts, is more adjustable, and is designed to handle heavy loads. The weight of the components also contributes to the stability of the platform because there are relatively few vibrations. In our previous setup, the calibration of the equipment would drift after one week of use due to changes in the screw alignment, people bumping the projector, and sometimes, the whole table shifting. The MemTable has been operating for 4 months without re-calibration. This is, in part, due to the weight of the platform, but also due to the RAM mounts (Figure 48) with rubber ball bearings, and the fact that the equipment is not attached to the frame of the table.

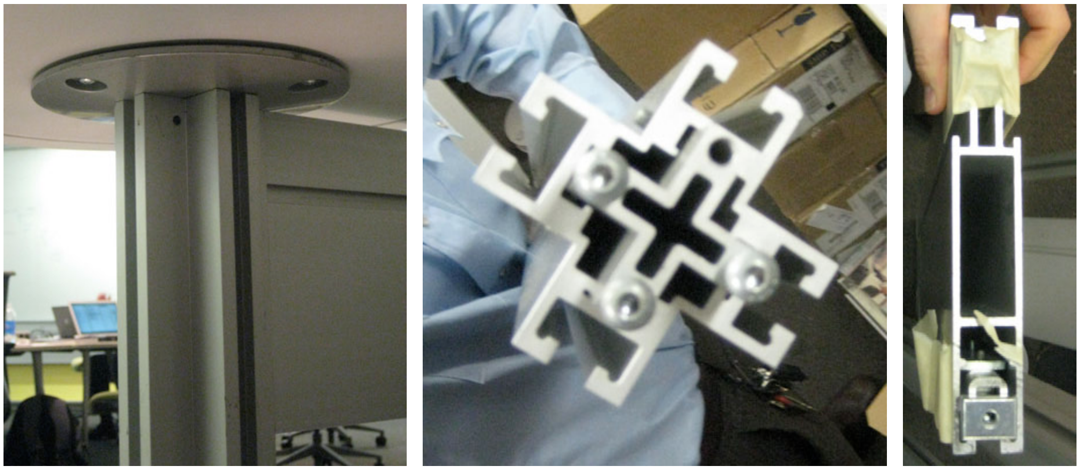


Figure 48. Post and beam connection components from SteelCase.

The next step in building the table was to choose which type of sensing technology was appropriate for our setup. Currently there are four primary approaches to camera/light based sensing: Frustrated Total Internal Reflection (FTIR), Rear Illumination (RI), Diffuse Surface Illumination (DSI), and Laser Illumination (LI).

In an ideal system, a transparent capacitive array would provide sensing technology, but this is still in research and development and would require a major company to manufacture them. We chose to use Diffuse Surface Illumination (DSI) for the MemTable because it allowed us to see fiducial patterns, finger events, and a light pen - all requirements of our system. DSI also simplifies the implementation of the hardware system and allows for a more centralized sensing system under the table.

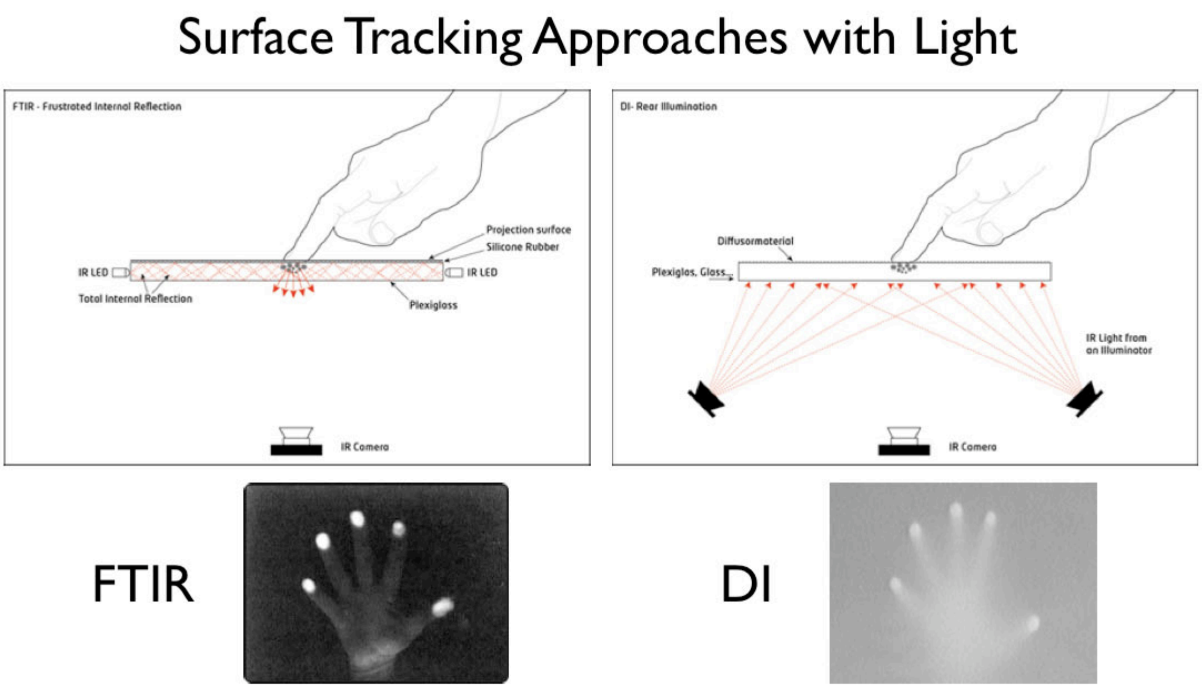


Figure 49. Two approaches to surface tracking. Courtesy of NUIgroup: (http://nuigroup.com/forums/viewthread/1982/)

Frustrated Total Internal Reflection (FTIR) used by Jeff Hann in 2005 is the primary choice of hobbyists in the Nuigroup forum. Infrared light is projected into the side of an acrylic panel (most often by placing IR LEDs on the sides of the acrylic). The light is trapped inside the acrylic by internal reflection. When a finger touches the acrylic surface this light is "frustrated" causing the light to scatter downwards where it is picked up by an infrared camera. A silicone rubber layer is often used as a "compliant surface" to help improve dragging and sensitivity of the device. When touching bare acrylic, one must press hard or have oily fingers in order for FTIR to work. With a complaint surface (like silicone rubber) the sensitivity is greatly improved.

In Rear Diffuse Illumination systems, infrared light is projected at the screen from below the touch surface. A diffuser is placed on top or on the bottom of the touch surface. When an object touches the surface it reflects more light than the diffuser or objects in the background; the extra light is sensed by a camera. One advantage of this method is that it can also detect hover as well as objects placed on the surface.

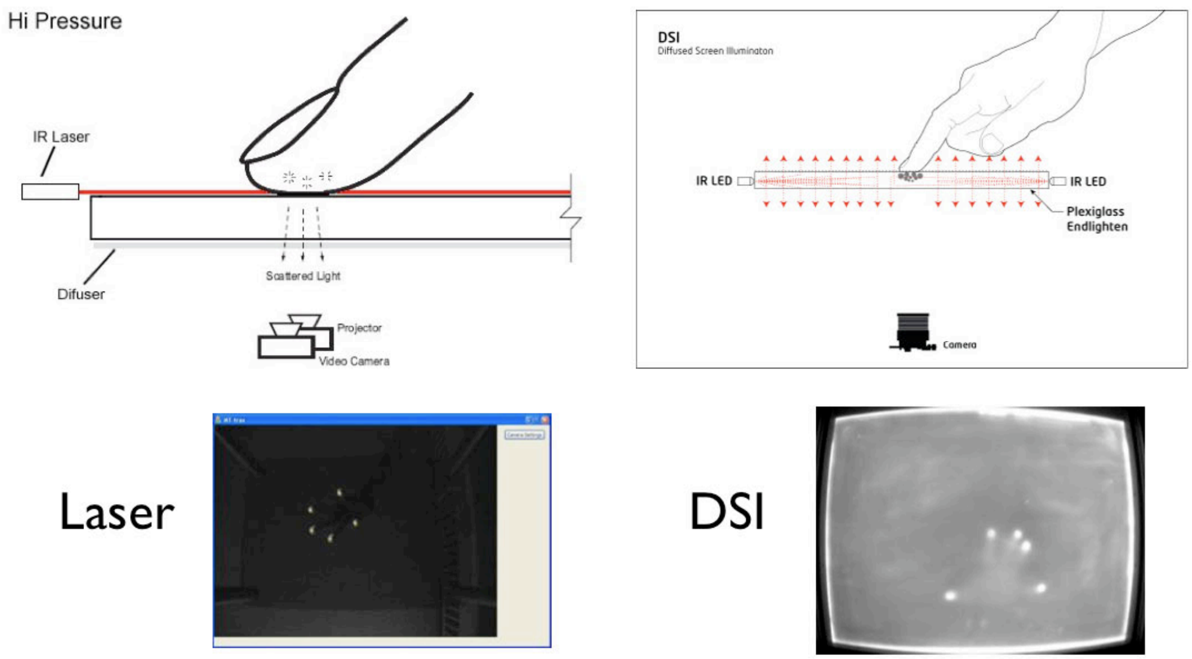


Figure 50. Two more approaches to surface tracking. Courtesy of NUIgroup: (http://nuigroup.com/forums/viewthread/1982/)

In laser based systems, IR light is beamed just above the surface. The laser plane of light is about 1mm thick and is positioned right above the surface, so when the finger touches it, it will reflect off of the tip of the finger and register as a blob.

DSI uses EndLighten (CYRO http://www.cyro.com) acrylic to distribute the IR evenly across the surface. It is like a standard FTIR setup with an LED Frame (no compliant silicone surface needed), and just switch to a special acrylic. This acrylic uses small particles that are inside the material, acting like many small mirrors. When you shine IR light into the edges of this material, the light gets redirected and spread to the surface of the acrylic. The effect is similar to DI, but with even illumination, no hotspots, and utilizes the same setup process as FTIR.

Although the blobs obtained in a DSI setup have less contrast than in FTIR setups, with the right software, accuracy issues can be overcome. The advantages of DSI are: simplicity of setup, object and finger recognition, and no lighting technology under the table. In FTIR setups a silicon layer must be carefully poured to have no bubbles, and is to subject to cleaning problems, and scratching from exaggerated pressure. DI setups generate hotspots and require careful positioning of diffusely illuminated lights underneath the table. This could prevent all the equipment from being located in the center and would require that the inside of the table be painted black.

Figure 51. Aluminum channeling, IR waterproof strips, Embedded Frame with EndLIghten Acrylic

During our research we corresponded with Environmental Lights, a California based lighting specialty company that worked with selected researchers in the multi-touch development community. We were one of the first people to adopt the 850 nm. waterproof light strips pictured below. If coffee or tea is spilled on the surface, the lights remain impervious to liquid, and the waterproofing surface acts as a protective element in the corners of the frame.

Figure 52. Environmental Light Strip Kit, 850 nm IR lights.

The cost of the EndLighten material, produced by a company called CYRO based in New Jersey is prohibitive in small orders. A sheet of 120" x 80" is 1,000-1,600 dollars depending on the distributer, and orders of less than 15 sheets are discouraged. The material is used primarily for advertising billboards and bus signs where content needs to be illuminated on both sides of the sign. We found a distributer and split the cost among three interested research groups since the pieces are so large.

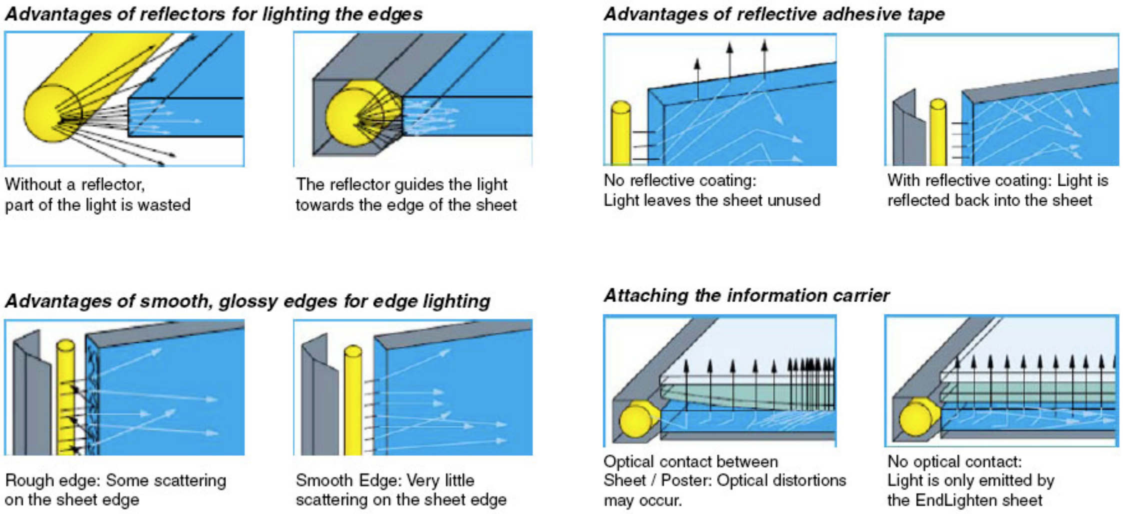


Figure 53. Diffusive illumination properties of the EndLighten with different materials

Figure 53 illustrates how to prepare EndLighten for maximum light diffusion. EndLighten's unique properties could simplify setups like Microsoft surface, and consume considerable less energy. In large quantities the cost of the material would be reduced, and provides a flexible platform for experimenting with computer vision based interactive surfaces.

4.1.2 Building the MemTable

This section documents our design process and the physical assembly of the table. After our visit with Steelcase we did a series of sketches to get a sense of desired table dimensions, and different scenarios for its use.

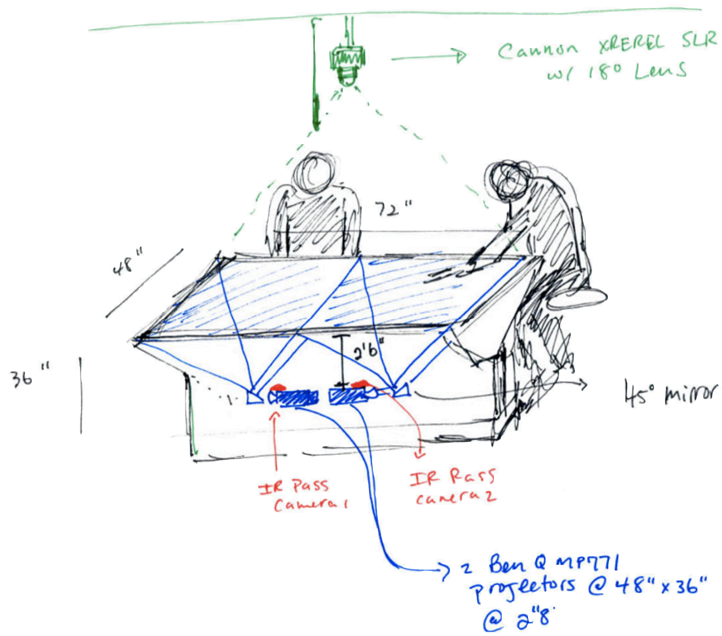


Figure 54. Early sketches of the MemTable platform.

We wanted a setup that would be easy to build but provide optimal space for all the people present during a meeting of 4-8 people. In building models it became clear that the table would need thick industrial legs, and we were able to position models of the projectors and mirrors under the table to determine the technical requirements for its height.

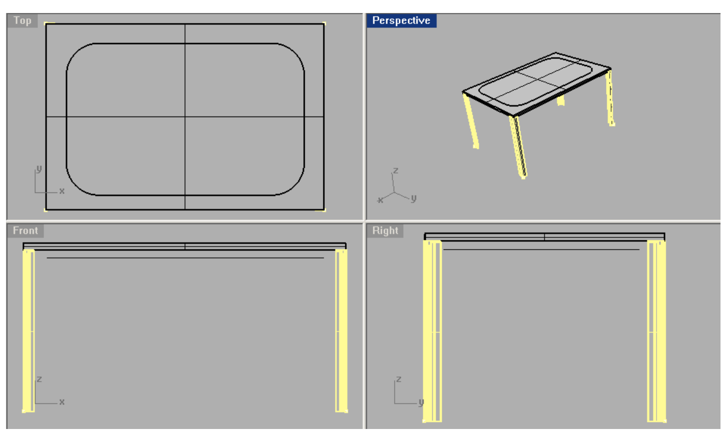


Figure 55. An early 3d sketch

Later, once we had determined the correct dimensions for the top based on the throw distance calculator of our Toshiba EX20 projectors (a maximum throw of 42 inches is possible from a distance of 2 feet 8 inches at a 3:4 ratio) we determined that a 42 x 64" surface would be possible with a height of 38 inches, allowing 10 inches for the positioning of the projectors.

Figure 56. Final 3d Model of the MemTable

With this model we were able to determine appropriate dimensions for the top of the table, which we wanted to have as one solid piece for stability. We allowed an 8 inch border around each side for the positioning of objects like keyboards and laptops and for the large round mounts that come with the post and beam system.

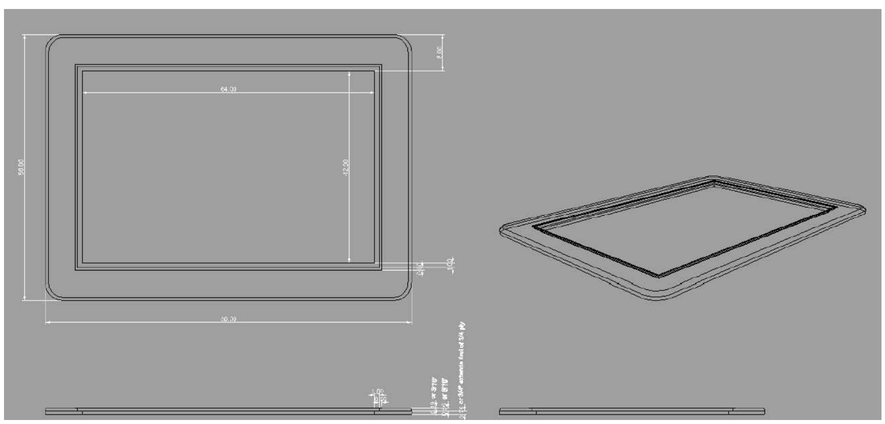


Figure 57. Cut Layout for the top frame.

We made the table 1.5 inches thick to allow for an inlay cut where the EndLighten frame could rest on the inside the table. With correct planning we were able to use the buffer where the rubber wraps around the light strips as a gasket, allowing for a 1/16th inch give, or a pressure fit for the frame on the inside of the table.

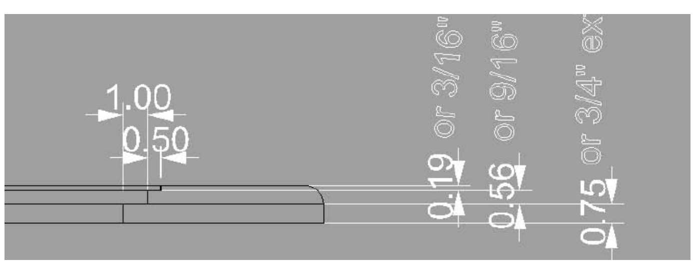


Figure 58. Thickness of the table edge in inches and inlay cuts.

While we were waiting for all the components to arrive, we began testing our setup to ensure that we had correctly predicted our dimensions, and so that we could order mirrors of an appropriate size for reflecting the image underneath the table.

Figure 59. Alex and Emily testing the projectors

Building the frame required cutting the Steelcase components down to 39 inches and resetting all the hardware that allows the pieces to connect. We did this in our lab, but recommend outsourcing this, if possible, due to the tedious nature of tapping holes and making sure the cuts were perpendicular.

Figure 60. Putting together the steel frame

Once the pieces are cut - assembly only took about 3 hours. The hardware is adaptable and using a set screw system provides flexibility found in systems like 80/20.

Figure 61. The supporting housing ready for equiptment

Preparing the EndLighten material requires sanding and buffing the edges of the acrylic to permit the light to enter the material. This process is time consuming, and took us about 4 hours. When this was finished we peeled the edges of the protective covering off of the acrylic and assembled and tested our lights in the frame.

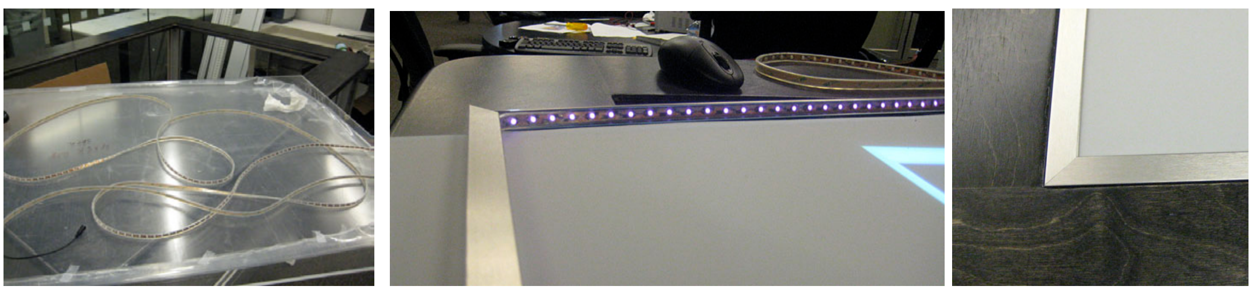


Figure 62. Preparing and testing the EndLighten with IR light strips and the final inlay.

The final step to assemble the frame was to create an acrylic housing to protect the equipment, and act as a heat sink and ventilation system.

Figure 63. Building the protective housing

The resulting acrylic frame was glued and mounted on 80/20 strips. The frame prevents hot air from the projectors from blowing directly on peoples legs, and helps distribute heat throughout the underside of the table. It also provides a view to curious users of the internal technology, taking away any mystery about what is inside.

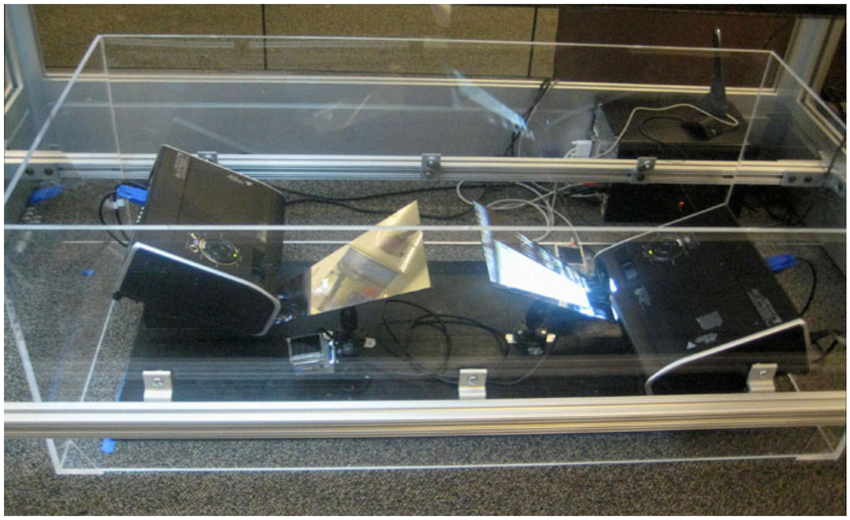


Figure 64. Projectors, cameras, and Mirrors underneath the Table.

In 10 years this equipment will be outdated, but principles like centering the equipment to provide knee space on all four sides will remain relevant. By cutting the mirrors in a trapezoidal shape, we were able to reflect the true spectrum of the projectors and give the cameras a greater field of view on either side of the mirrors.

Figure 65. After alignment and calibration, a view of the table and our team developing on the table.

After a weekend of manual adjustments and playing with the graphics setting on the drivers and projectors, we were able to align the projectors within about 8 pixels. Without custom software in windows Vista, alignment is not perfect and is very difficult to accomplish. We are working with Scalable Displays, a company in Cambridge MA to install the EasyBlend software which interfaces with the graphics drivers and blends projectors that have a minimum overlap of 10-15%.

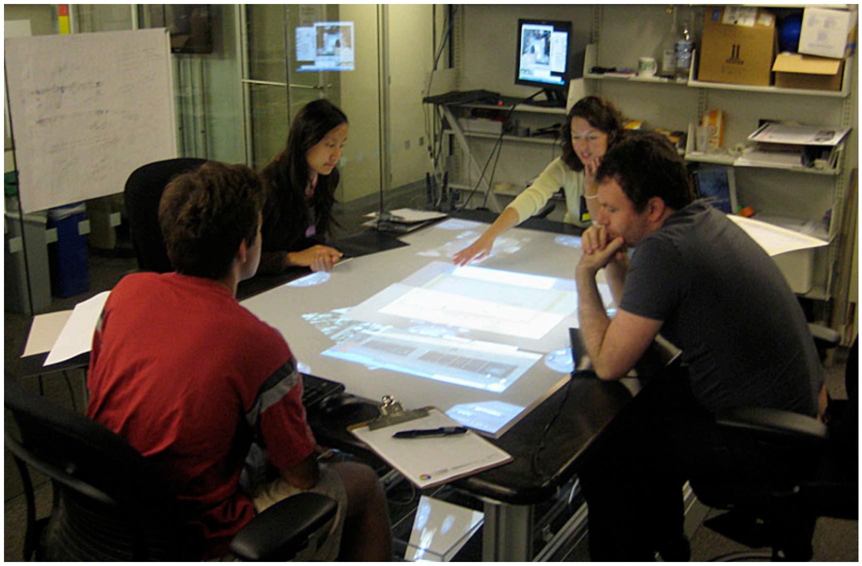


Figure 66. MemTable during a meeting.

The contributions of this table to the tabletop community include our findings with the EndLighten Acryclic, light strips, centered setup, and robust and ergonomic frame design. We have been very happy with the results, although we would like to improve the resolution of the display by replacing the XGA projectors with short throw HD projectors when they become available.

4.1.3 Hardware Specifications

Our choices for hardware were based on affordability, capability, and function. The primary components in the system were the two projectors, two cameras and computer processor used to run the MemTable system.

Figure 67. Hardware: Fire-I Camera and lens, Shuttle PC 3600, and Toshiba EX20 Short Throw Projector

The Fire-I camera is a good candidate for vision based research because of its API and support in the vision community by drivers such as the 1364 Camera published by Carnegie Melon's Computer Science group. We found that we could order custom lenses pictured above from Videology.com. Using a fixed lens gives better image quality, and of the four lenses we ordered we choose to use the 3.1 mm lens for its field of view and lack of lens distortion for fiducial pattern recognition.

The shuttle PC 3500 is a quad core processor and is a good tabletop computer because it is only eight inches high and fits nicely with the footrest on our system. This allows the computer to be nested inside the table, reducing the number of cords needed to run to components. Shuttle PC's are between 1,200 and 1,500 USD, making them an affordable alternative.

Our projectors, the Toshiba EX20, were only 1,100 USD each and although they are bulky provide a 2000 lumen image with decent focus capabilities. We choose them because of their extreme short throw lens, which would allow them to be positioned in the center of the table facing each other. The complexity of setups required with high end HD projectors dissuaded us from choosing these as an option, although these would provide a higher resolution setup and more functional table in a higher end system.

Figure 68. Universal Projector Mount from Peerless, and Universal RAM Mounts

The mounts (Figure 68) we used were extremely helpful in the manual alignment process, because of their adaptability and reliability. Over a period of months we graduated from duct tape, to velcro, to screws, and finally these mounts. Special thanks to Henry Kaufman for making us aware of these indispensable additions to our setup.

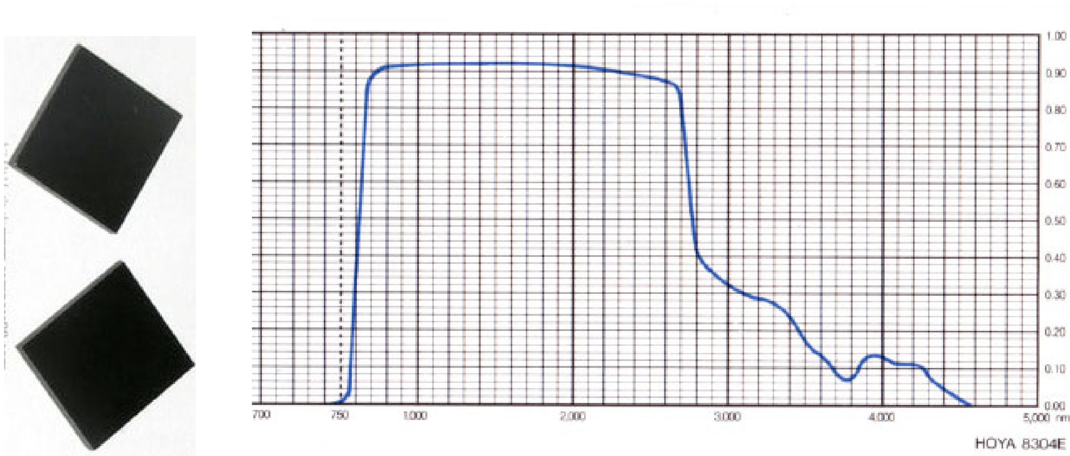


Figure 69. Transmitting properties of the IR filters at 850 nm.

IR Filters for cameras with a wide angle lens need to be considerably larger than one might intuitively expect. Companies like Omega make custom IR Bandpass filters for around 200 USD each, and at 25mm were not large enough for our setup. We found that standard Hoya IR80 glass was sufficient for filtering out light below 800nm, peaking at 850nm.

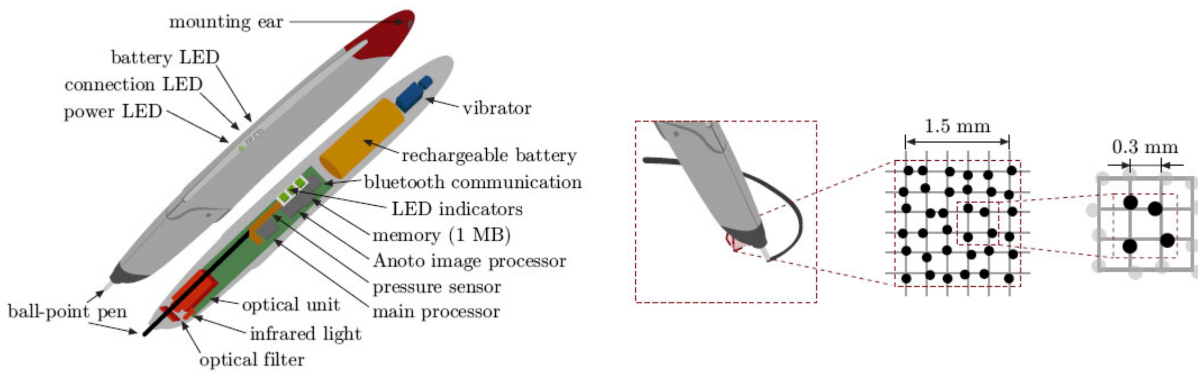
Figure 70. Auxiliary equipment chosen for the input modalities.

The table also has a number of accessories which are required for the touch table's use, namely a camera, an RFID reader, Anoto pens, and a microphone. (see Figure 70)

The Cannon Rebel XI is mounted on the ceiling above the table. It is a 12 megapixel camera that interfaces with the canon SDK so that you can control its features from a PC or a Mac via a USB connection. It has manual aperture and shutter adjustment features necessary for controlled light conditions, and comes with an 18mm lens for wide angle views.

Phidgets (http://www.phidgets.com) makes an RFID reader with interface components and cards that allow for easy integration with flex or a myriad of other systems.

We worked with the Media Interaction Lab in Austria via Michael Haller to purchase a license to use the Anoto pattern in our project. The technology used to track pen input on the PenTable tabletop surface was developed by Anoto. Figure 70b depicts a schematic view of the electronic components of a digital pen. An infrared diode and camera are built into the tip of the pen. The camera recognizes a dot pattern printed on paper, as shown in Figure 70c.



Figures 70b, 70c. Schematic of Anoto components and Anoto Pattern. Courtesy of Jacob Leitner, MIL, 2008

This purchase allows us to use the pens for other projects and to experiment using the Anoto pattern in a variety of contexts similar to the Shared Design Project by Haller's group. Their platform supports multiple synchronous pen inputs, and the generation of the pattern for unique page ids. It is written in C# for Windows Vista.

An omnidirectional microphone is placed in the center of the table and is sufficient for recording the context of the workspace. It interfaces as a mono input on the windows platform, so two microphones could be placed on either side of the table for two channel recording and processing. The flat pyramid shaped microphones are non-obtrusive additions to the tabletop environment.

4.2 Software

This section describes the general choices for our software architecture, outlines the system architecture for the system, and describes in more detail the class hierarchy for the graphic front end of the table system. Our implementation of the MemTable prototype is described along with limitations of the system in terms of robustness. In our laboratory we build things to explore the implications of the user interface but employ more rapid prototyping than deployment procedures.

4.2.1 Software Development Process

MemTable has a dedicated Shuttle PC embedded in the system running windows Vista. We choose this operating system because in our previous deployment on OSX for the WordPlay (Hunter & Maes 2008) we encountered problems with software support and had to split the application onto two separate machines. By keeping the application on a single machine, lag times are reduced when communicating over a socket, and system maintenance and backup are more simplified and manageable.

The system can be started from a single BAT file and closed with another BAT file which load background processes that manage inputs from the audio, pen, camera, keyboard, and RFID modalities and send those as XML events to a Flex front end, built with Flex Builder 4, an integrated version of the Flash Development Platform that builds Adobe AIR desktop applications. The AIR applications perform better than earlier versions of flash and have fewer issues with the security sandbox. For example, we were able to read and write files to the hard drive, a feature previously (and grievously) missing from the Flash development API.

Our development process has been evolving for approximately eighteen months including hardware and software components, but the specific work on the MemTable components described here took eight months to develop. The complexity of managing multiple inputs significantly increases the debugging stage of application development due to the need to test the table in situations with two to four people, in multiple contexts. In addition, base classes to manage and interpret the gestural input are necessary and must be written before UI components can be developed.

At the 2009 CHI Tabletop Group Discussion this year, the topic discussed was establishing standards for gestural input. Microsoft and SMART were leading the charge in establishing de facto standards by virtue of releasing their platforms. The disparate efforts of academic research are eclipsed by the commercial influence of companies that produce and manufacture hardware with embedded software. For standards to emerge that will incorporate the research, clear and open communication needs to exist between both parties. It is also interesting to note that a discussion meaningful of applications with clear utility to users is still lacking in the community.

The software development was initiated and developed by the author with the dedicated assistance of undergraduate researchers along the way. Alex Milouchev worked on the drawing API and the gestural components, Emily Zhao helped develop elements and did UI design during six months of the project. Jamie Karraker assisted in the user studies, evaluation data processing, and light drawing. Katie Harrington was a primary developer and worked on improving the overall design as well as contributing creatively to system design and UI design.

Special Thanks to Henry Kaufman of TacTable.com for his coding, guidance, assistance in getting the event architecture running, and thinking about the overall design of the system.

4.2.2 Software Component Outline

An overview of the software system is diagramed below in Figure 71:

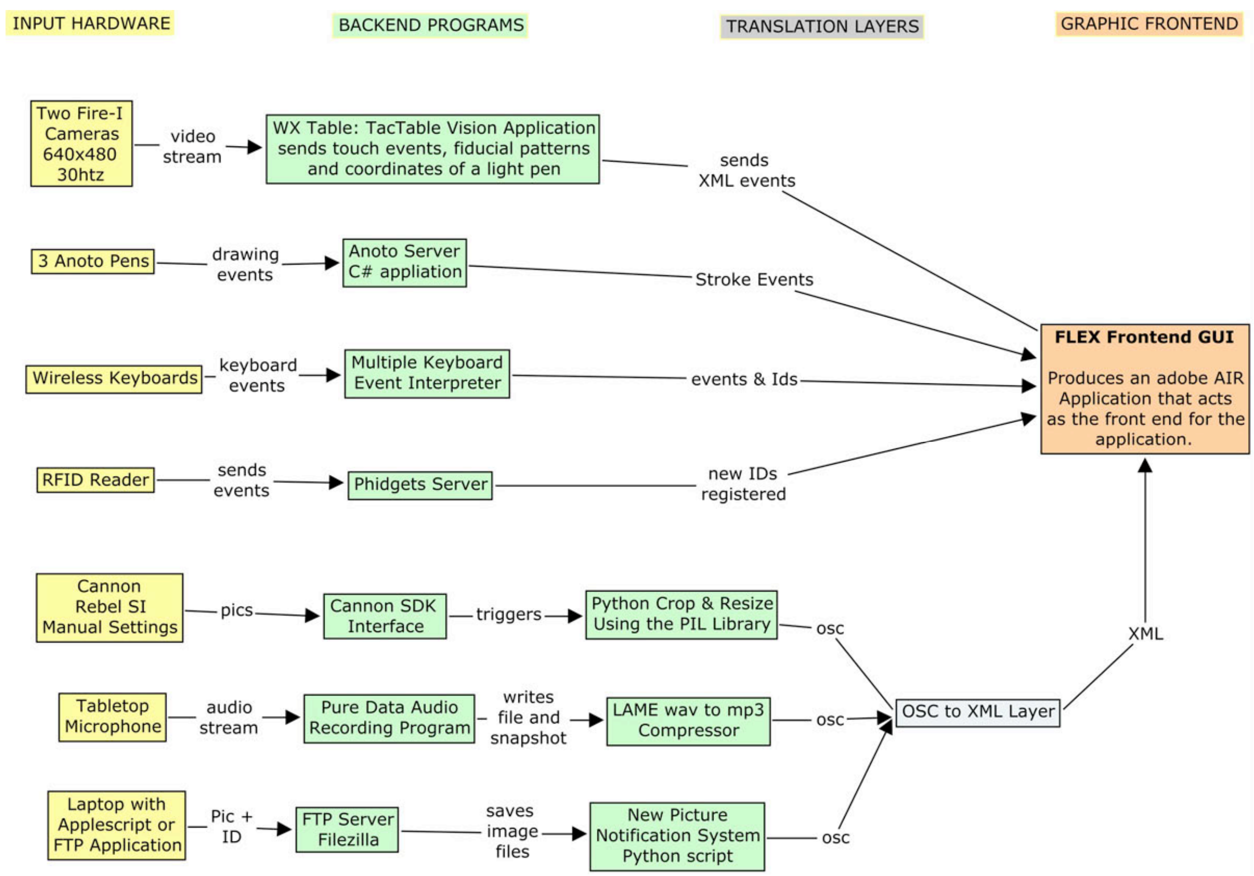


Figure 71. System Diagram for the MemTable Software Architecture

The system can be divided into three basic components indicated by the colors in the Figure 71. Input components (yellow), back-end programs (green), and the front end GUI, which is what the user sees when they interact with the system. Input components are described in Chapter 3, and the Hardware is described in Chapter 4.1.

The back-end components are the engines that supply and save content generated by users at the table:

The Vision system was designed and written by Henry Kaufman of TacTable. It is written in C++ using the open CV components and utilizes a patented focus algorithm for recognizing finger event in proximity to a diffusive element. This algorithm is especially effective with the EndLighten material because of the low contrast between blobs, providing a clear advantage to a system that uses a focus based algorithm over contrast segmentation. The program can be customized for different install environments and is setup to work with a two camera system in our setup, allowing us to double the resolution of our previous system. It sends a stream of XML events similar to the TUIO (Kaltenbrunner, 2006) protocol that represent the x and y positions, and tracking ID, the type of event (finger down, drag, or finger up) and other relevant information for fiducial tracking events.

The Anoto server was developed in coordination with the work of Michael Haller's research group at the Media Interaction Lab in Austria. The Shared Design Space (Haller et al, 2006) and the FLUX Table (Haller et. al 2009) utilize a low level pairing program for the bluetooth pens. We used the same libraries and wrote our own interpreter and xml socket system to send pen stroke events to our front end. The program was developed in C# using Visual Studio 2008. Anoto patents their patterns, so a license must be obtained through an authorized distributer. Patterns can be printed on a standard laserprinter at 600 dpi, but must be output through a postscript interpreter like GhostScipt to avoid distortion in the pattern and subsequent pen failure.

We are developing a system in C# to support multiple keyboards. Although this task sounds trivial, we have not found a good solution for pairing multiple keyboard with elements in an application if they are offscreen without overlapping events. This is still under development.

Phidgets makes an elegant integration package for RFID readers. Our system is limited to one reader currently because their software does not support overlapping signals. If RFID is incorporated into a table, each corner should be outfitted with a reader. In an ideal system, users could walk up and their id's would trigger a menu without them having to perform any actions.

Following a recommendation from Bjeörn Hartmann we decided to use the Cannon SDK for image integration. It allows you to control all aspects of the camera from the computer programatically. The SDK examples are difficult to work with and no server for sending and receiving remote events to the camera currently exists. Our interface is a modification of the example that comes with SDK, emulating the interface elements without activating the GUI components to simulate camera control and sending a message with the subsequent file name to the GUI front end.

The Audio recording buffer was written in Miller Puckett's Pure Data framework. It receives one of three types of requests: an audio file, a snapshot of the previous 10 minutes of audio, or an array that represents the visual spectrum of the sound for scanning and playback. A limitation of the Flex framework is that the sound elements will not open wav or aiff files. This is a legacy of earlier versions of Flash, and adds considerable hassle and delay to incorporating sound into this engine because the sound must be compressed and uncompressed before it can be returned to the user.

We wrote a simple Applescript application for the Mac OS that allows users in our lab to double click on an icon and select any part of their screen for sharing on the table. Ideally, users could share their computers in real time with the tabletop system and select content gesturally, but we found that users were able to use this system well due to its relative simplicity.

Most additional tasks were handled by Python scripts, such as resizing images, or opening high resolution images and returning a cropped portion of that image to the front end of the system. Python has the advantage of being relatively simple and efficient, and quickly deployable on a locally running system.

4.2.3 User Interface Code Implementation

The bulk of development time for the software system was spent working in the Flex API by Adobe, which allows the user to compile AIR desktop applications. The advantages of this platform for us are all the graphical components developed in the flash platform during its ten years of development. The graphic components also scale well because the system renders everything as vectors. Actionscript 3 is a significant improvement over Actionscript 2 because it does not require the flash IDE and can be completely script based. Flex is built on top of the Eclipse IDE, one of the most popular development platforms for Java development because of its support of plugins and its integrated debugger and profiler. This was an additional impetus for our adoption of the platform into our development.

The WPF framework used by a lot of other developers is another viable alternative. Our developers had web development backgrounds and preferred flex for its ease of implementation. We observed several limitations to our approach that would make us consider the WPF framework or a C++ framework like the openFrameworks for our next project. First, flex is single threaded. This makes it difficult to solve memory management issues, especially when multiple users are interacting with the system at the same time. Second, loading raw video, raw audio, or images that are outside the "sandbox" of the system is cumbersome. External media is required to be in a web format for AIR applications, which run on the desktop where streaming is not an issue. We sincerely hope that Adobe will address this in future releases of the flex API. Third, the security sandbox introduces an unnecessary level of confusion. Components not located within the projects local directories present permissions issues and debugging is not intuitive.

Figure 72 is an outline of the code written to interpret events and trigger changes in the user interface:

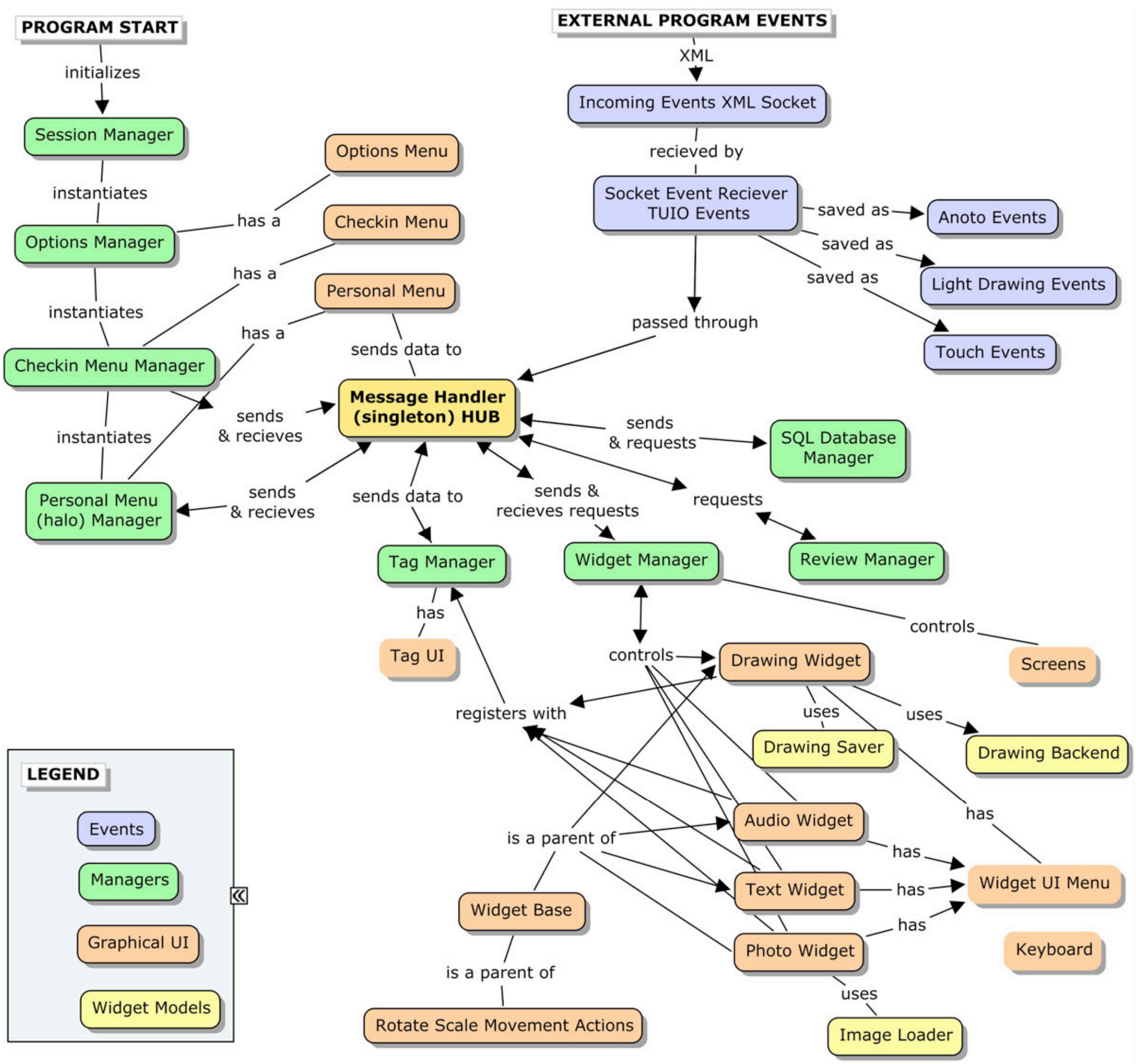


Figure 72. Flex Program Class Architecture for the Graphic Front End of the MemTable

In this diagram there are four types of classes, similar to the Model-View-Controller approach to a code design. Instead for a multi-touch system we present a Event - Manager - Graphics categorization.

Events are received from the programs running in the background, specifically the Anoto pens, the vision system, and occasional notification messages from hardware inputs. Events are stored until they can be disposed of and use the event notification system built into the Flash platform. This is especially useful for touch events which propagate down the display list to each of the elements.

All events pass through the MessageHandler, a singleton class that acts like a hub between different parts of the system, helping to make the confusion of debugging event propagation more human readable. The managers in the system (green items) keep track of display items (elements) that have been created and contain the logic for relating them to each other.

The graphical items (orange) define the look and feel of the interface, the touchable portions, and the movement, scaling, and rotation of the items. The author has a design background, and spent a considerable portion of the development time focusing on the aesthetics of the interface. See chapter 3 for more information about the design of the Interface.

4.3 Data Infrastructure

The "memory" of MemTable is stored in a database. The design of the database is presented here for the purpose of helping other developers integrate history into their applications. We focus specifically on aspects of design which can help improve the recall and instantiation of elements that result from user interactions.

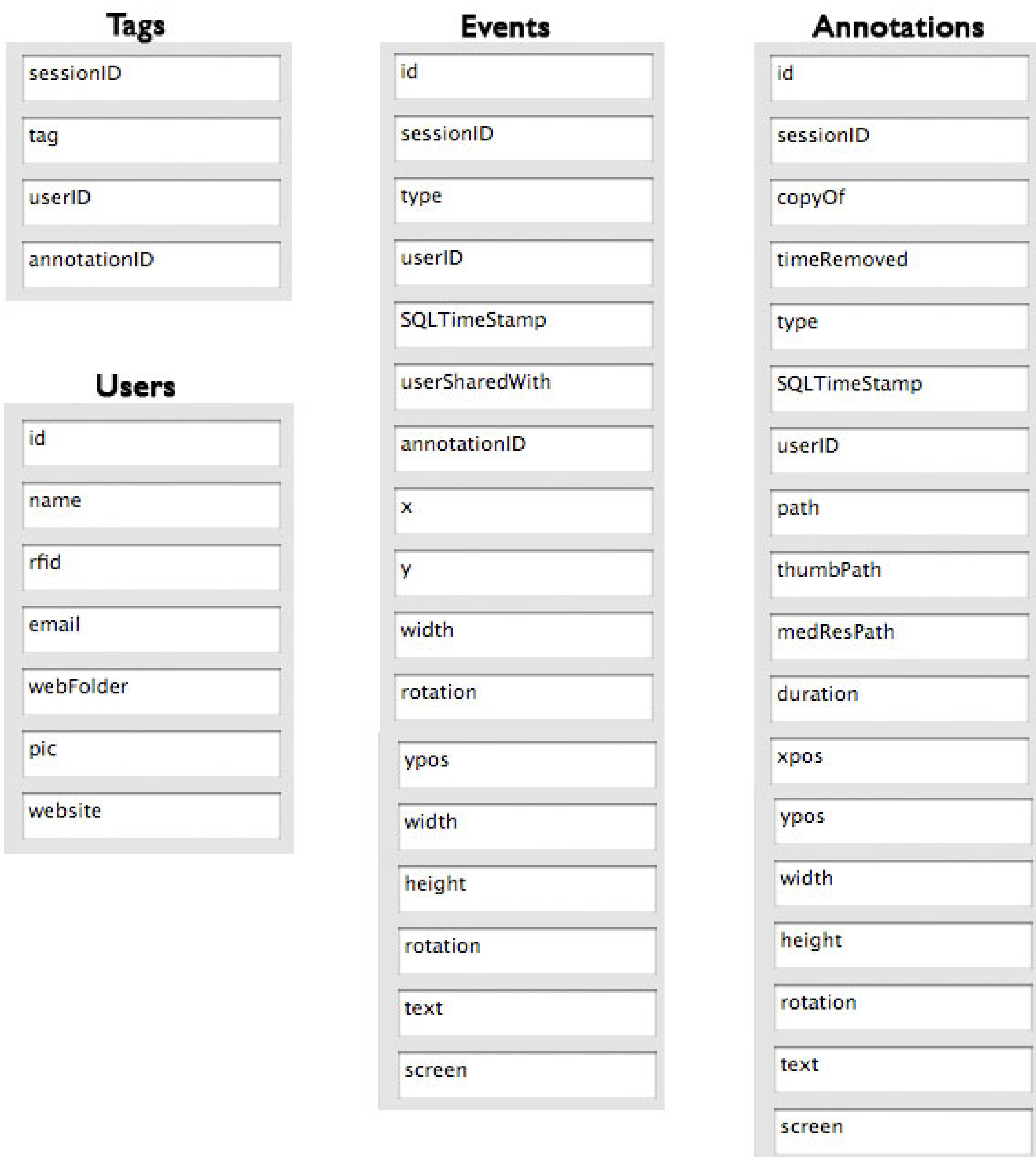


Figure 73. Database Layout for the MemTable System

In practice we tried to design the database to be as simple as possible, creating a row in the *Annotations* Table for each item of a meeting capture, and recording the properties (position, path, location, screen, time, and relationship to other elements) when items are explicitly created.

Every 30 seconds our system polls the existing items on the active canvas for changes, if a change is found it is noted in the *Events* table. The events table uses the index of the annotations table and notes any differences with a time stamp marking when the change occurred.

The *Tags* table creates a row for every tag applied to an item on the table. This can later be used to quickly index and search through items.

The *Users* table contains information about the participants enrolled in the system. This includes their picture, email, and user ID.

Designing UI elements to be brought back onto the canvas as they are created requires the elements to be consistent in their design, and dynamic. The loading and creating of elements requires that they be portable and savable. For example, when recalling something that was drawn on the canvas, a rich amount of information exists by saving each point drawn and re-rendering accordingly, but information about what was erased in the drawing may be lost if you don't save a hybrid of bitmaps and vectors as you are recording the drawing. We have found that saving more information up front as you are working with elements, provides you with a more flexible data set to use when recalling elements to the stage.

CHAPTER 5. EVALUATION

Our initial evaluation of the MemTable was focused on usability and the potential of the interface for use in a small workgroup. It was designed with four objectives in mind:

1) To gather feedback on the usefulness of the capture features: text annotation, audio recording, camera images, laptop capture, and note taking.
2) To observe use of the design of the general interface: menus, elements, tagging, and other software features.
3) To understand the difference between paper-based meetings and digital meetings and observe the effects of the technology on social dynamics, participation, contribution, effective note taking.
4) To determine if the table facilitates the rotation of the role of scribe between members of the meeting.
5) To test the effectiveness of the MemTable for as a tool for assisting memory and recall.

This chapter starts by outlining the design of the study and the demographics of our participants. It proceeds to examine each of the stated objectives from qualitative observations of the video transcriptions, and quantitative data from the user survey, the active badges (as discussed in section 5.2.3), and the MemTable capture database.

5.1 User Study Procedure and Scenario Description

The user study consisted of 24 participants. Users were divided into 6 groups of 4. All groups were presented with the same scenario.

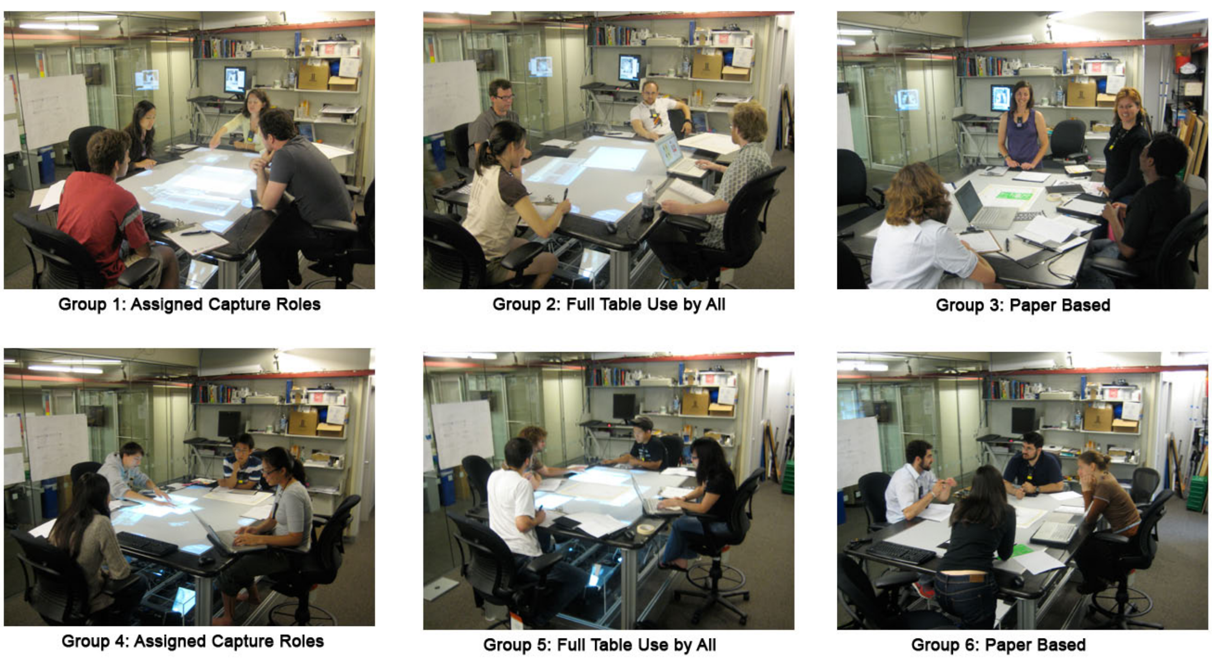


Figure 74. User groups participating in the restaurant planning scenarios.

The groups were divided as follows:

1) *Paper Based Group*: two of the groups used only paper based tools to meet.
2) *General Training Groups:* in the next two groups, all members were trained to use all the features available.
3) *Role Based Training Groups:* the last two groups were also trained to use all features of the MemTable, but each group member was assigned the role of scribe for one of the five input modalities and given additional training time on that feature. (This was to insure that participants were adequately trained during the demo session in the general training groups.)

All of the members were given an Active Badge (Pentland et al, 2007) a device designed by the human dynamics group at the MIT Media Lab to assess group dynamics such as who is talking when, how loud, and to whom they are talking.

There were 11 females and 13 males between the age of 18 and 42 with an average age of 25. All participants were fluent in English. 68% of the participants were students and 32% were non-students. Users were very comfortable with existing technology, spent an average of 7.5 hours a day on a computer with a high variance between users. There was a high variance of experience with touch tables, users rated their experience from 1 (no experience) to 7 (very experienced). The groups had a 4.2 mean with a 2.5 standard deviation.

The study took 1.25 hours to complete for each of the four MemTable groups and 1 hour for the paper-based control groups. All sessions were video taped and transcribed for significant events. Identical procedures were followed for all groups excluding the technology training for paper-based groups. The table below outlines the procedure followed in terms of time allotment and activity.

Time	Activity
2 min.	Formal introduction stating the function and purpose of the table and of the study.
10 min.	Formal demonstration of the following features: Menu system, all 5 capture features, how to move, scale, and pin elements, tagging, and clearing screen functions.
10 min.	Individual training with the assistance of two other experts. Time to play and try each of the capture functions on their own.
3 min.	Sign release and put on active badges.
5 min.	Introduce brainstorming scenario and assign roles to each of the participants and pass out dossiers.
30 min.	Group discussion with no intervention. 10 min and 5 minute notifications were given.
15 min.	Wrap up survey consisting of 36 questions. (see appendix)
15 min.	(1 week later) Return to answer a memory recall survey.

Figure 75. User study timetable

We choose a scenario where participants are designing a restaurant in an empty warehouse located in a busy throughway in Cambridge, Mass. Users choose one of four roles: Architect, Food Planner, Interior Designer, and Financial Planner. Participants were provided with an equal balance of physical and digital resources related to each of their roles: blueprints, markers, color pickers, a budget, table layout templates, links to restaurant web pages, lighting design sites, and maps of the nearby area.

The scenario was designed to be familiar to all members of the group and provide a structure whereby group members could contribute equally to the discussion. Each group was read the following text and then given a dossier with information related to their role:

The four of you own partial shares in a joint venture to transform a building located at 618 Main St. The building is outfitted with a kitchen capable of serving 125 people. You have been given a modest budget to renovate the space and open a restaurant in 12 months.

This meeting is the first of 16 weekly meetings that you will have during the initial stages of planning. You will be meeting at this table for all your planning - and using it to capture and record all of the ideas and considerations as you decide how to renovate the space.

Your group consists of an architect, a food planner, a designer, and a financial planner. The four of you each have distinctive concerns and information you bring to the discussion. The group plans on using the table each session to record significant ideas. At the end of the 16 week period you will recall all recorded ideas, considerations, and information added to the table to inform your final investment plan.

During each session of each week your group wants to decide on one possible theme and function for the restaurant and then explore the ramifications of that particular theme in terms of food, design, function, and financial cost. Document and record this process.

General Questions to answer in the first 10 minutes:
What is the theme and function of the restaurant. Can you reach a consensus on this?

Specific Issues to Address:
Function
Do you want this to be a romantic dining, lunch facility, or event hosting facility, bar or other food venue? Given these considerations would you add any walls to the blueprint? What types of tables and chairs will you use and how will you arrange the tables and chairs? Explore possible arrangements.

Food Menu
What is lacking in this area of town? What types of food items would you like to include on your menu? How will the food work with the theme of the restaurant?

Design
Given the theme of the restaurant what colors and decor might contribute to this theme? What type of lighting do you plan on using?

Cost
Do these proposals fit into the budget designated for this project. Speculate as to possible costs of the building renovations, food, and design equipment.

The scenario was designed to explicitly state that this was the first of 16 weekly meetings, and that at the end of those meetings the group would use their notes to decide on a plan. This provided incentive for people to keep a record of their ideas. Although this idea is implicit to the design of the table, we wanted to emphasize the importance of recall in this particular scenario to encourage users to consider how the features of the table might augment their discussion.

Our observation was that people genuinely liked the scenario. They were animated, excited, and even got hungry while planning their restaurant. The data from the video transcriptions and active badges also validates this observation. Groups were generally satisfied with the outcome of their discussion, with a mean of 5.5, where 1 is unsatisfied and 7 is very satisfied.

5.2 Results

The results of the study are presented in order of the objectives stated in the introduction of this chapter and utilize four primary data sources:

1) Observations of the video recordings of user sessions, and transcriptions of key events from the video.
2) Data from the MemTable database from each of the meetings.
3) User feedback and evaluations of the initial survey and the follow up survey after users were asked to recall key events.
4) Data from the Active Badges regarding speaking levels, and speaking times.

5.2.1 Meeting Capture Feature Analysis

Users were asked to report for what purpose they chose to use the table. The users answered as follows:
58% used it for capture purposes.
54% used it record significant events.
54% used it to record thoughts as others were speaking.
50% used it to arrange content.
50% used it to alter content for others.
47% used it refer to previous point.
38% used it to compare alternatives in discussion.
5% used it because they lost interest in the discussion.

Users were also asked to rate the usefulness and the amount they actually used the modality during the meeting (see Figure 76). Ratings were based on a scale of 1 to 7 from "not useful" to a 7 being "very useful".

	usefulness	actual use	observations
audio input	4.5 (1.3)	1.6 (1.4)	*not used frequently*
text input	5.5 (1.4)	4.4 (2.3)	*used by one or two people generally for notes*
laptop capture	6.7 (0.5)	6.1 (1.6)	*universally used*
camera capture	5.7 (1.2)	4.3 (1.6)	*used for blueprints and for table layout*
paper note streaming	5.7 (1.8)	4.2 (2.7)	*some groups used extensively, some not at all*

Figure 76. User feedback regarding usefulness where 7 indicates a high usefulness rating.

In general, *usefulness of capture modalities corresponded with their use*, except in the case of the audio capture feature. Individual members reported that they either forgot to use the audio feature, or felt they needed to ask before recording a key point into the system. In our original design the audio feature is explicit, only saving what users note as important. We were concerned about privacy, but users reported no concerns of privacy in our study. In the next version of the table, we plan to keep an implicit audio buffer, and provide a window of audio around each element users generate. A system like this would utilize principles present in the Livescribe pen system (http://www.livescribe.com), which links audio with note taking and uses the notes as recall cues.

The text input feature was used at least twice by all the groups, primarily by users with access to a wireless keyboard. In our study we only provided one keyboard. Multiple users noted the difficulty they experienced when using our virtual keyboard, occasional letters being triggered by stray fingers. This is a limitation of the DSI detection system and caused users to hen peck with one finger, an unsatisfactory experience. This affirms our hypothesis that adding multiple physical keyboards to the system would improve overall recording capability of the group.

Laptop capture was a primary source of information for discussion in our scenario. Users found menus, pictures, maps, satellite images, and street views of the building in discussion. Many users suggested integrating a browser with touch based input into the system, similar to the iPhone browser. A browser with touch input capability could be useful but using a mouse based browser on the table might accomplish the same goal of allowing everyone in the meeting to see what you are browsing.

The camera and cropping features were useful for recording drawings on the blueprint, and to capture the social dynamics of users around the table. Many groups used the camera in a playful as well as utilitarian manner. We observed that fading the background of the table caused confusion in the masking mode of picture taking, a social cue was needed before a user took a picture. Keeping the camera on the table and allowing users to utilize it from any angle may improve the frequency of use of the camera and allow users to take advantage of its high resolution capacity.

We observed that the *choice of input modality was contextual to each group's individual skill-sets, and the context of their discussion*. Note taking and sketching was used primarily by two of the groups, multiple members sometimes sketching together and expanding the virtual clipboard to fill the screen. Users sketched quickly and fluidly on the paper, explaining possible layouts of the bar, or ideas they had for lighting. Some users used the notepads to take personal notes throughout the meeting, preferring this over the wireless keyboard, or choosing it because another group member was using the keyboard. Two of the groups did not use the clipboards at all, instead taking extensive notes with the text element, and bringing many images in from their laptops.

The initial division between the generally trained groups and role trained groups was designed to test the effectiveness of the training. We observed that role based groups felt limited by this constraint and a majority of the time used whichever input modality seemed convenient to the discussion. It appears that *general training is sufficient for future user studies, and encouraging users to utilize the system in their own creative way seems to increase group participation* and frequency of capture (see Section 5.2.3 discussion).

5.2.2 General User Interface Analysis

After the initial training and experimentation session of 20 minutes, users accommodated to the novelty of the interface, and felt that the table was relatively easy to use (6.28 mean). Many users reported that the interface reminded them of the iPhone, many of the gestures such as rotation, scaling, toggling, flicking, and sliding transferred naturally for them to our software interface.

Question	Mean
Intuitive: Personal Menus	6.09 (0.9)
Intuitive: Movement of Elements	5.81 (1.2)
Intuitive: Scaling of Elements	6.18 (1.1)
Useful: Pinning Feature	4.9 (1.5)
Useful: Locking	4.81 (1.6)
Used: Tagging	43% of users
Would Use More Time: Tagging	87% of users
Useful: Tagging	5.21 (1.5)
Difficult to Not Difficult: Ease of use of the table	6.28 (0.7)

Figure 77. User ratings of table features as intuitive or useful. 7 indicates a high usefulness or very intuitive rating.

The interface was generally intuitive to the participants. Personal Menus were rated with the highest intuitiveness, in part due to their simplicity and similarity to the dock on Mac OSX (two users commented on this). Movement and scaling were rated as intuitive, both in experienced and inexperienced members of the groups.

Each of the features was judged for usefulness in the survey. Pinning was considered less useful, but was rated as more useful in groups that added more content to the table such as Groups 2 and 4, the groups generally trained in all the input modalities. Tagging was only used by 43% of the users but most users said they would tag if they had more time. Their discussion was only 30 minutes and many of the users talked up to 35 minutes before concluding. Tagging generally occurred at the end by groups that were able to reach a consensus more quickly.

5.2.3 Group Dynamics: Observations and Analysis

Group performance, outcome satisfaction, individual contribution to discussion, and efficiency ratings were very similar for both the paper control groups and the MemTable groups. Both paper and table based groups were equally familiar with other members of their group.

Question	paper mean	table mean	ALL mean
Familiar with Group	4.87 (1.5)	5.0 (1.7)	4.95 (1.6)
Difficultly: Group Task	4.12 (1.4)	4.59 (1.3)	4.43 (1.4)
Group Performance	5 (1.0)	5.21 (1.2)	5.14 (1.2)
Satisfied with Outcome	5.5 (1.0)	5.5 (1.1)	5.5 (1.1)
Group Efficiency	4.93 (1.0)	5.03 (1.3)	5 (1.2)
Satisfied group process	4.75 (1.1)	5.31 (1.1)	5.12 (1.1)
your contribution to group decision	5 (0.9)	5.62 (1.0)	5.41 (1.0)
your contribution to capture	3.75 (1.6)	4.31 (1.3)	4.12 (1.4)
how much: contribute to discussion	4.87 (1.1)	4.71 (1.3)	4.77 (1.1)
awareness; changes in the table		5.56 (1.0)	5.56 (1.0)
table disruptive during discussion		2.43 (1.5)	2.43 (1.5)

Figure 78. Survey data from participants on perceived group dynamics. See Appendix for full questions.

A general trend for more positive satisfaction with individual contribution to capture was observed in the groups using the MemTable. MemTable groups also exhibited a trend towards being more satisfied with group process. To account for these differences, we studied the videos and considered the differences between the paper based scenario and the capture scenarios. A larger population would need to be studied to make any significant claims about social dynamic satisfaction correlating with table use.

Our most significant observation was that *higher ratings of satisfaction with the group process correlated with frequency of capture at the table*. For example, group 2 and group 5 (the open table groups) reported the highest satisfaction ratings: 5.75 (1.1) and 5.76 (.95) with 7 being the highest satisfaction. They also had the highest frequency of capture: 23 capture elements and 19 capture elements and the highest frequency of changes (rotation, scaling, moving, editing, and deleting) to the elements: 86 modification events, and 69 modifications. The other two table based groups, group 1 and group 4 had a lower frequency of capture: 13 capture elements and 47 modifications, and 16 capture elements with 56 modifications. This seems to indicate that groups who used the table extensively were the most satisfied with the outcome of their decision.

In the two paper based scenarios, users ended up gathering on one side of the table, and arranging content primarily on that side so that they could draw from the same orientation, or use the computer together. This limited the interaction of some of the participants on the outskirts of the discussion, and made the interaction considerably less formal than the table interactions. All four table interactions were structured by the personal menus, which could move but users generally did not switch seats after picking a side of the table.

Group Number	Group Type	Group Mean Speaking Time	Group Solo Speaking Time	Group Mean Overlap TIme	Std. Dev of Speaking Time Between Users
group 1	role training	21%	16%	4%	4.5%
group 2	general training	41%	25%	16%	2.3%
group 3	paper based	43%	23%	19%	1.1%
group 4	role training	24%	16%	8%	3.0%
group 5	general training	32%	21%	10%	2.3%
group 6	paper based	57%	22%	34%	4.4%

Figure 79. Active Badge data on speaking time of the participants. Percentages are out of the total session time.

The active badge data in Figure 79 indicates that the paper based groups spoke more than the rest of the groups and had higher group overlap time, were excited about the discussion, and there was high energy in the groups. The video data confirms this, but also confirms that these groups took less notes, an activity which increases the amount of silence. The generally trained groups had higher speaking times than the role trained groups and mean group overlap times. Most notable were the standard deviations of speaking time. With the exception of group 3 (who were remarkably polite and had an existing business relationship) the generally trained groups had the most even distribution of speaking time and the most even distribution of contribution.

We observed that the *role of scribe rotated frequently between group members*, allowing some to take notes or draw while others were speaking. In some cases, someone would suggest jotting something down and another group member would respond by doing so. In other cases users would volunteer to do so without any prompting. This also helped *structure a more balanced dialog* between group members. In contrast, the role of the scribe was not as transparent in the paper based scenarios. With no one assigned to be the scribe, many of the notes taken during the meeting were not recorded. Because the MemTable was introduced as a capture device, it seems natural that it would structure and increase the contributions of participants. Our users were trying to use it for its intended purpose. The table also makes legible the actions of others in a common space, allowing for more non verbal communication and awareness of capture as it is happening.

The four groups using the table reported that the table was not very disruptive to the discussion. One of the table groups reported a higher rating of disruption, but this was due to a technical problem where one user with long legs placed his feet on the glass area around the projectors and triggered some stray events on the table. This happened twice during their session, indicating that either users would have to learn about this flaw in the system, or additional acrylic will need to be installed at a diagonal angle.

5.2.4 Memory Recall Results

After the initial study, the mean rating of usefulness of the table for capture was 6.09, however only 43% of the users said that they actively changed their behavior because of the recall features. This may be a result of the limited scope of this study, a comprehensive study would account for multiple weeks of use with the recall functions and we hypothesize would increase the awareness of the recall function.

Our follow up study consisted of asking participants to answer an additional survey ten days after their initial discussions with the help of the table or their paper notes. MemTable users returned to the table and were presented with the content (Figure 79b, 79c) that they generated during their meeting as a aid to recall. Users who did the paper based study were sent scans of their notes and pictures of the drawings they made and asked to use these to answer their questions.

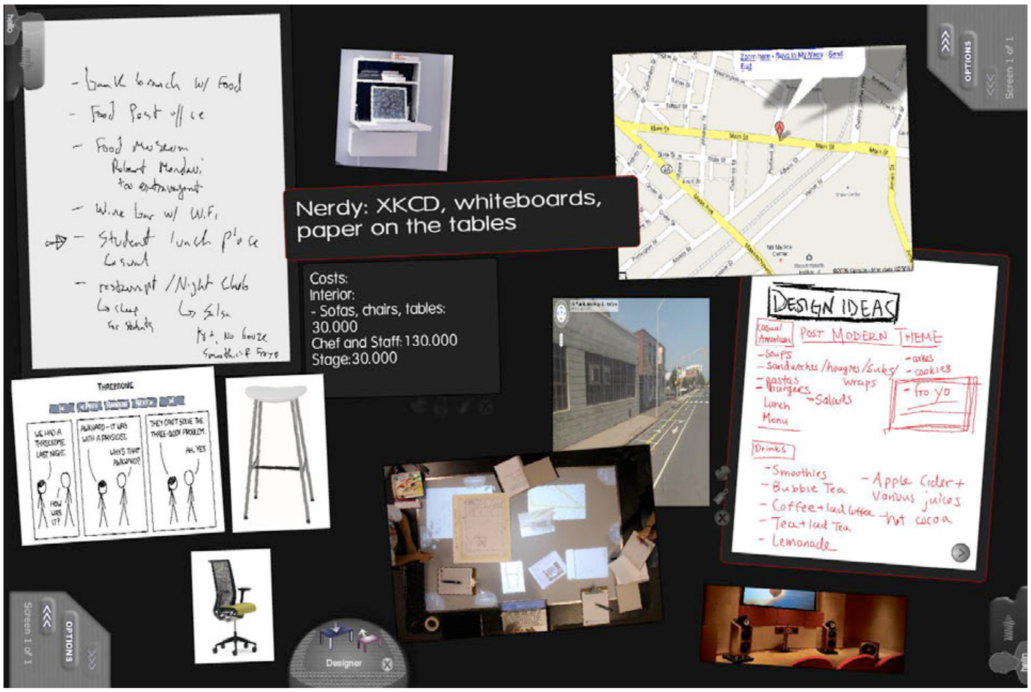


Figure 79b. An example session from one of group 2's recall, using clipboard extensively.

An assistant who was not present during the sessions was asked to choose the questions and provide answers after watching each of the videos and taking notes on the sequence of events. The same types of questions were sent to each group. For example, significant points of agreement were noted along with who made the point. Details about the actual plan were also noted as group members made them. Groups were asked 6-7 questions about the session. The accuracy of their answers was rated by the assistant where 1 could not remember, 3 is remembered vaguely, 5 is remembers some details, and 7 is remembered very accurately. Please see the Appendix for the questions asked of each group.

Group Result	Quantity M, SD	Comments
General and Role Groups (16 people)	6.11, (0.34)	general trend to recall more details
Paper Groups (8 people)	5.05, (0.47)	less notes taken

Figure 80. Accuracy of recall means with 1 being inaccurate and 7 being very accurate.

The general trend of the groups using the MemTable was to recall more accurately and with more detail. This is substantiated by looking at the word count average of the groups using the table, vs. the groups in the paper based study. Groups using the table wrote an average of 27 words in their recall responses and groups in the paper based study wrote an average of 14.5 words. This is likely the result of having more information from the capture features of the table to add descriptors to their answers. The accuracy of the table groups was somewhat better than the paper groups (see Figure 80).

In addition, we solicited users for general feedback (Figure 81) about desired features and their perception of the usefulness of proposed features.

Feature	Mean Rating	STD of Ratings	Comments
Usefulness of proposed timeline	6.2	0.69	very useful
Usefulness of proposed implicit audio feature	4.8	1.35	mixed responses, useful but not often
Usefulness of tagging elements with user names.	5.3	1.65	mostly useful

Figure 81. Predicted usefulness of proposed features with 1 being not useful and 7 being very useful.

Users indicated that an implicit audio function built into each element would only be useful for resolving discrepancies, and instances of this would be rare. The linear format of audio also makes the time cost of reviewing high, another potential detractor. Two users suggested embedding a video scrubbing feature to add visual feedback to the audio review process, but its unclear if this would reduce the potential time investment.

Participants also indicated a need for recall of individual items, and the ability to start a new session from the end-state of the last session. Some users said they would start with a blank canvas and pull things in from the previous session, while others said they would want to start where they left off during the last meeting.

Tagging elements with "who" created the content was rated as mostly useful by participants. Some stated that they were concerned people would be concerned about ownership, or feel that content belonged to that person. In practice, elements could have two tags: a "created by" tag and "recalled by" tag, with that persons name printed above the content element.

General feedback from the follow up survey included new suggestions to make the elements smaller for more room on the canvas, enable the ability to align all elements to a particular orientation of the table, speed up the responsiveness of drawing (currently 30 Hz), and add audio feedback to button presses.

5.2.5 User Feedback and Suggestions for Improvement

In general participants *enjoyed using the table and said they would return to use it* for subsequent meetings. Participants found it intuitive and easy to use. Our user group provided a lot of feedback because 40% of the participants had experience in user interface design. This section summarizes their feedback and discusses the possible improvements they imply.

User Suggestions/problems	Possible Implementation/solution
1. difficult to use on-screen keyboard	add more wireless keyboards
2. streaming screens from laptop	possible wall based screen
3. drawing on pictures	add light pen, increase camera speed
4. add a timer to increase efficiency	implement a set time interface in global options
5. drawing element not triggered by using the pens.	make icons glow each time an unpaired pen is drawing asking users to choose their drawing icon if they want the digital equivalent to show up.
6. associate elements with the person who created them	add name of the person who created the element to the tags.
7. increase resolution	wait for HD short throw projectors to become available.
8. allow for throwing of elements between people	add a function to throw and rotate content flicked at a high velocity.
9. add a browser	allow external apps to be used on the same screen with a mouse.

Figure 81. User suggestions and implementation analysis.

These suggestions are very helpful for laying out a future works section. User suggestions 1,3,4,5,6,and 8 are under development and the rest have been noted as possible implementation projects.

5.3 Summary of Results

General feedback from our participants, observations of capture strategies during our meetings, and comparisons of statistical data between group populations indicate a number of findings which will influence future work on the MemTable and may be relevant to other researchers:

1) Participants found the user interface legible and intuitive. They indicated that they would return to use the table for subsequent meetings. Personal menus and capture elements were used frequently. Advanced features such as tagging, cropping, locking, and pinning were used selectively but rated as useful.

2) Users found the MemTable to be comfortable and ergonomic during meetings.

3) General training of 20 minutes is sufficient for future user studies, and encouraging users to utilize the system in their own creative way seems to increase group participation.

4) The perceived usefulness of capture modalities corresponded with their actual use except in the case of the audio feature. Features that connect laptops to the tabletop were rated as the most useful. Features that require more time to review were the least useful.

5) The frequency of use of input modalities was contextual to each group's individual skill-sets, and the context of their discussion. Modality choices differed widely among groups.

6) There was a general correspondence between frequency of use of the capture features and satisfaction with group process.

7) The role of the scribe generally tended to rotate between group members depending on who was speaking.

8) Groups using the MemTable were able to recall more details about the discussion with moderately higher accuracy.

The MemTable provides a structure for more formal interactions during group meetings, allowing users to combine digital and analog assets in the discussion. This structure may increase the efficiency and satisfaction of meetings, more extensive studies will need to be conducted to draw a definitive conclusion. The process of recording is immediately apparent when a user is adding content, allowing fluid rotation of the role of scribe. At the very least, it demonstrates the effective service of recording all information captured in the discussion and providing it for subsequent recall.

Participants volunteered suggestions for improving the MemTable by adding additional features. These are shown in Figure 81. Overall, users found their experiences with the table to be positive, and we are encouraged by the potential demonstrated in this initial study. After improvements described in Section 7.1 are made, a more extensive study will be conducted to examine the integrated recall feature. The visualization features described in Chapter 6 will also provide features for reflection on group process, and will require a more longitudinal study.

CHAPTER 6. LONGITUDINAL DESIGN PLAN

One of the primary motivations for beginning this project was to try to create an application that increases in utility to groups as they interact with the system. Just as our personal computer and mobile devices have become integrated into our work-patterns and lives, tabletop systems could help augment the exchange and storage of information during social collaboration.

Many of the applications and demos at the IEEE Tabletop Conference in 2008 lacked a vision for how they might aid group awareness, recall previous interactions, and reflect on work process. Their primary focus was on the innovation of new interaction techniques, gestural vocabularies, hardware sensing, and studying user interactions. This work is critical in establishing the tools of the technology, and understanding guidelines for its implementation, but what is the content of these interactions and how does it impact its users over time?

As mentioned in the introduction, the goal of the MemTable is to capture the digital and analog contents meetings and make them available for subsequent recall in later sessions. The table is designed to support recording, recalling, and reflection on the data generated during meetings. This thesis has covered recording features in detail and evaluated their usefulness, but has not addressed recall and reflection features.

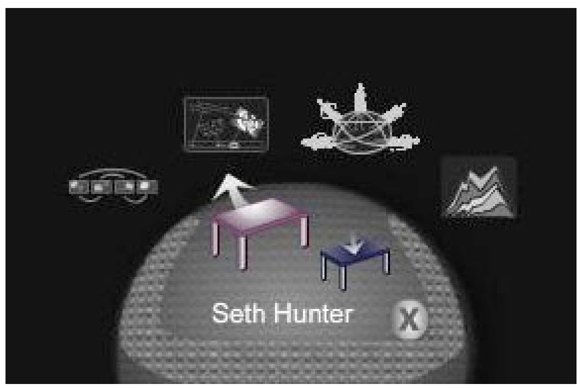


Figure 82a. Output menu. From left to right: reflection mode, recall system, social visualization, frequency of use

This section presents a set of drawings and software prototypes for the recall and reflection features that we are currently developing for the MemTable system. Each of these is linked to the icons in Figure 82a, the output features of the table. The first section presents our design for the recall system and how it is integrated with the existing software. The next section discusses visualizations of group work patterns and social connections over time. The third section presents strategies for associating media in the system and representing it in new aesthetic ways. The final section argues for a system which integrates temporal representations of meetings and collaborations at the MemTable into a web service for personal computers.

6.1 Recall System

The most immediate benefit of memory integration is the recall of information generated in previous meeting sessions. Cognitive research on memory recall (Tulving, 2000) indicates that users rely on both temporal and semantic methods of association. Browsing through sequential representations of significant events relies on our episodic memory. Searching for things using a search engine utilizes our semantic memories, and requires a different user interface. We present sketches for both browsing and searching here. We are currently developing the browsing recall component and expect to be finished in September of 2009.

When the user touches the "output" icon on their personal menus, one of the icons that spring out of the output is a recall button. (see Figure 82a) Choosing recall triggers a list of sessions with a preview of the end state of those sessions, which are scrollable like a rolodex. When the user finds the session they are looking for, they tap it twice and an enlarged version of that session appears with a timeline indicating all the changes that occurred during that session.

We have begun writing the code to prototype this timeline. See Figure 83. The timeline has 4 layers for each type of input: pictures, text, audio and drawing. Each modality is color coded and as the user scrolls back and forth along the timeline content appears with a line linking it to that point on the timeline.

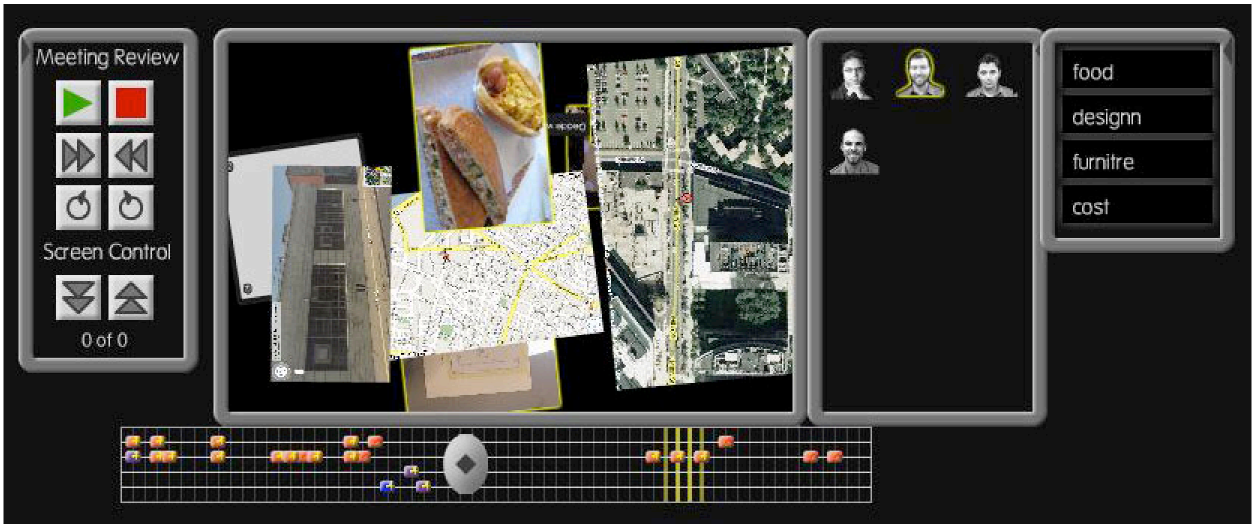


Figure 83. Navigation timeline showing type and duration of meeting capture.

The preview window is a 1/4 size version of the table, allowing a current session to continue while a previous session is recalled. The user then has the option of dragging individual items off of the preview window, or reinstating the whole session at a particular point by selecting more than one thing from the preview window.

Selecting something from the recall window is noted in the database. This increases its likelihood of being activated later when the table is in reflection mode looking for associations between content. If a user recalls different annotations over the course of a few weeks, the table can weave together the history of their recall events with their input events to note significant items later.

Searching is similar to browsing, but with a text input field that narrows the results to only those sessions with relevant tags or text items to the search term the user enters. The search would jump to points within the session that may be relevant and highlight the item you are searching for in yellow.

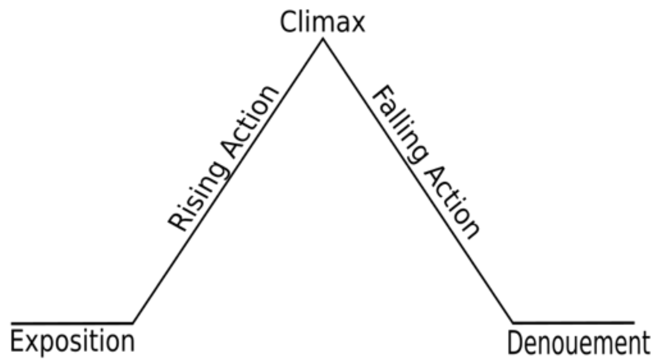


Figure 84. Freytag's Pyramid

During the temporal interactions workshop at CHI 2009, we prototyped an interface that would allow you to push the timeline up or down to indicate the significance of events as you are reviewing. Freytag's diagrammatic plot maps provide a reference for how to map the dramatic impact or emotional significance of events in a qualitative way. We are proposing that the user can push up significant events, creating visual peaks in the timeline the next time that session is reviewed. This action would be similar to bookmarking or rating, but with more precision.

6.2 Designs for Reflection Visualizations

In order to quickly visualize how the table is used and who the primary users are we propose building a sand chart in the style illustrated below, which would demonstrate total activity, individual engagement, and daily patterns of use over time. This chart will be subdivided into each week, with a sand chart at the top for the entire period the table is used.

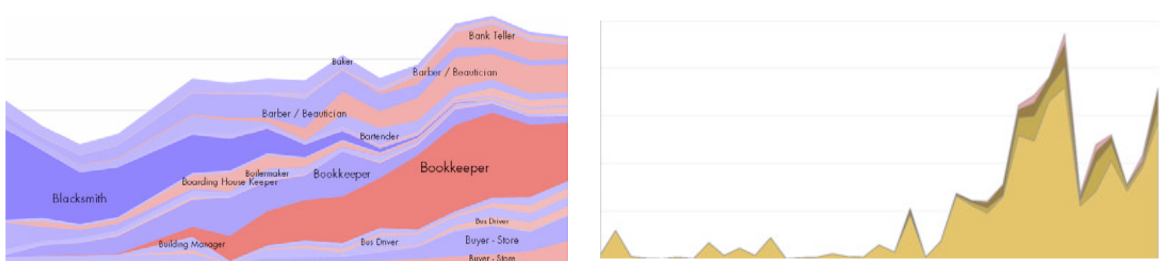


Figure 86. Example Time of Use chart showing members in different colors, weekly, and over 2 months.

Another important question is: Who am I most connected with, and who meets with whom at the table? This visualization would show a circular chart illustrating which people are connected to each other and to what degree, providing a portrait of the aggregate group activity in one picture.

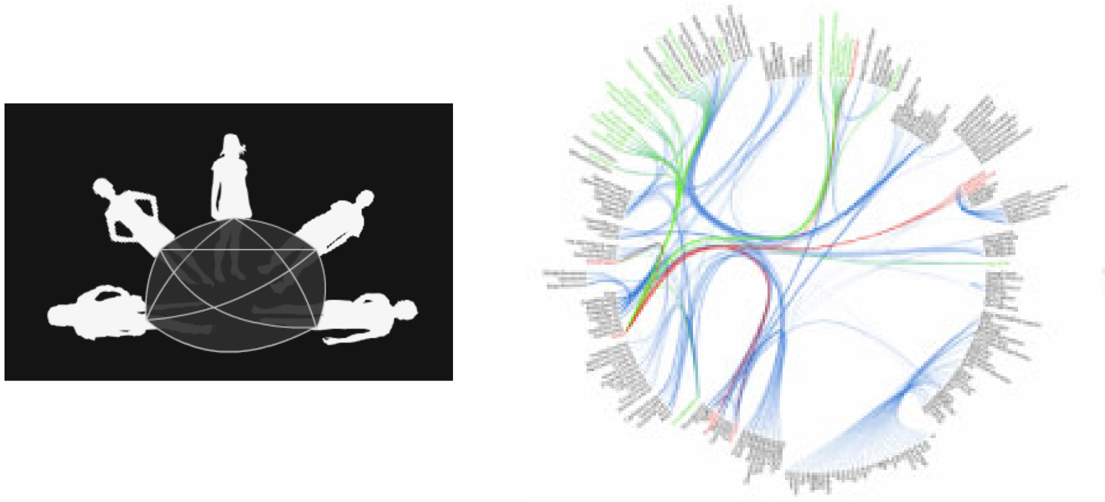


Figure 87. Social relationships icon and circle visualization techniques from the flare libs. (UC Berkely)

This shows everyones connections to each other, complicating the diagram but perhaps revealing more information about the overall social patterns of the group use of the table. A variant of this visualization is: Who am I connected with?

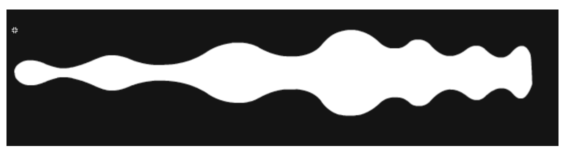


Figure 88. Example of a stream

in this reflection you are placed in the center of the circle and the strength of your connection with others is indicated by line thickness in the shape of a stream. The stream gets wider at points of frequent interaction and narrower when the interaction in infrequent.

6.3 Weaving Threads: Associating Content

In Donald Schon's influential book, "The Reflective Practitioner" (Schon, 1983), he emphasizes the need to bring reflection into the center of an understanding of what we do, looking at our experiences, and building new understandings from historical data. He introduced the notion of Double-Loop learning, which occurs when patterns are detected and we make changes that modify our underlying assumptions.

This reflective process can be catalyzed by the re-presentation of content from the perspective of the computational artist. We draw inspiration from more artistic approaches to describing how a space is used. For example, Lincoln Shatz and Scott Snibbe (Figure 89) take recordings of a space and weave them together in beautiful and provocative ways that transcend temporal boundaries and activate the space with its own history.

Lincoln Shatz, Cluster 2006

Scott Snibbe, Deep Walls, 2003

Figure 89. Artist create collages of the participants who contribute to their work.

In a similar vein one avenue we would like to explore on the MemTable is taking the history of content contributed to the table and remixing it in an aesthetically provocative manner. A simple version of this would be to take all recorded drawing strokes and replay consecutive drawings together based on common users in a session. Threads could be woven and displayed as a collage by looking at the tags, recall actions, and co-located content contributions of users.

The reflection mode would present content from user sessions that are closely related but previously unknown to the participants involved. For example if two groups were meeting to discuss how they might utilize a new API, or they mentioned the same subject in a discussion, content from those discussions might get juxtaposed in the reflection screen saver. It also would present a playful representation of group activities in an asynchronous manner. This keeps the content fresh and more aesthetically interesting to contemplate.

6.4 Integration with Google Wave, Recalling Data Outside the Table

How can we connect the content from the MemTable with participants personal computing devices? The straightforward solution to this is to build a web application with a server that allows users to link to content generated at the table, browse sessions, and note important content.

If the data from the off-table interactions is also incorporated into the MemTable database, it can be used to highlight information while it is being recalled and find more meaningful associative threads between content. For example if Henry accesses a particular item from a session on his laptop at night after our afternoon meeting, the next day that item will be highlighted in his recall pane at the table. The table might also suggest other items from previous meetings that relate to the item that Henry recalled.

Generating an off-table recall system requires mirroring data generated at the table, and developing a web interface for accessing that data. One concern we have about making yet another web service is that it would soon be forgotten by users as their workflow gets more streamlined with services like Google Wave or Apple's cloud computing services.

Over the last two years our group has tried to use Delicious (http://www.delicious.com) , Twine (http://www.twine.com), and Evernote (http://www.evernote.com) to link common threads of conversation for later access. Without active agreement and enforcement by the group to a specific service, we have defaulted to a group calendar and email. Our initial research has been on Google Wave (http://www.preview.google.com/wave/), a service which aims to blur the distinction between chatting, email, SMS, and document sharing by integrating them into a single service. We propose sending items from the table to a Google Wave, by simply touching an icon on element menu of that item and confirming upload.

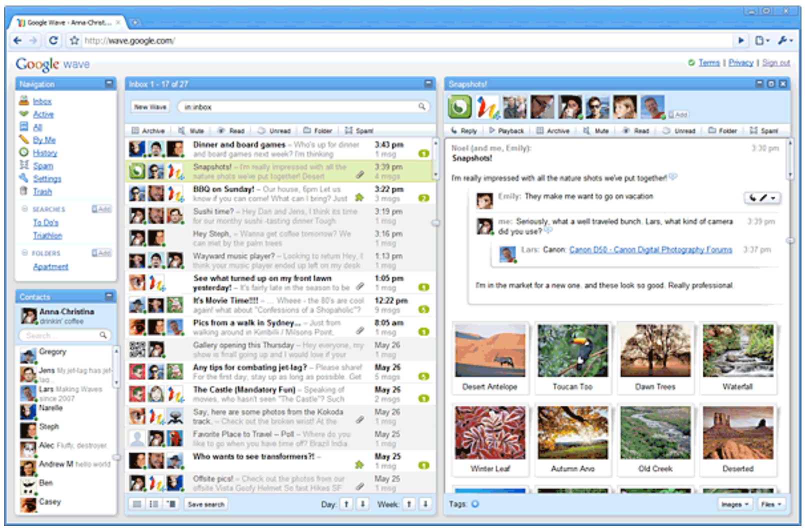


Figure 90. Google Wave preview. Content represented as a group conversation.

During the next 6 months, Google will allow developers to write applications for their API. We are proposing a gadget for Google Wave that would allow us to embed flash content generated at the table in conversations on Google Wave. This would provide seamless integrations with email, calendar, and search engine services that many people in our group already use from Google.

CHAPTER 7. CONCLUSION

This thesis presented the design and implementation of a tabletop system that supports co-located group meetings which incorporate both digital and tools and artifacts. The purpose of the MemTable is to capture the implicit and explicit content of user discussions, and organize this content for searching and browsing at subsequent meetings. MemTable utilizes the potential of a large multi-touch surface to allow workgroups of 4 to 8 people to simultaneously capture, record, discuss, and recall information relevant to their discussions.

MemTable builds on a history of tabletop research, meeting support systems, and memory support applications - integrating aspects of all three domains into its design. In contrast to many tabletop applications, this approach takes into consideration the long term implications of user interactions at the table. It builds a history of data, increasing in utility as it is used.

It presents an original hardware design that utilizes new materials to improve the interaction for small workgroup meetings. The design simplifies and improves the technology, allowing for a more ergonomic seating arrangement by centering the sensing equipment. MemTable's design leaves the sides open for legs and knees, increases the surface area for multiple users, and elevates the height of the table for more natural social interactions.

The software system incorporates audio recording, laptop capture, drawing, image capture, and typing in the same interface. Combining input modalities to support heterogeneous interactions supports the meeting styles of many different types of groups. Brainstorming, decision making, event planning, design, progress reports, and group feedback are made possible by providing a diverse set of tools to participants and letting them choose the tools for each context.

This thesis presents interface design strategies that consider identifying users through personal menus, tagging content, and recording the implicit changes in interface elements in order to recreate the temporal interactions at a later time - features necessary for understanding historical context and presenting cues for memory recall.

7.1 Future Work

The initial design and implementation of the MemTable framework allows us to collect and record the small group meetings of workgroups at the MIT Media Laboratory and improve the system over the next 12 months. This work will take place in two stages: immediate work and long term initiatives.

The immediate work improvements that resulted from our user study:

1) Add multiple keyboards and build a server to identify keyboard IDs and link them to elements.
2) Make audio recording more implicit and always on during a session. Users can click an icon in the element menu to view a window of audio contextual to when that element was created.
3) Detect when a user wants to pass an element to another user by detecting an accelerated change in its position and subsequently rotating the element towards the other user.
4) Improve the response of using a light pen directly on the table by trying cameras with a faster frame rate. Group line drawings together by "time grouping" and add functionality by using the pen as a tool for organizing and grouping elements.
5) Fix the small pixel overlap of the displays using software from Scalable Technologies that allows for a 10% overlap between projectors.
6) Add a timer to the global settings allowing users to monitor time elapsed during the meeting. This was requested by many users to help increase the efficiency of the meetings.
7) Add the name of the person who created an element as a tag on the content to improve recall.
8) Experiment with allowing the camera to be mobile to increase resolution of content and encourage more creative use of that modality.
9) Add a vertical display for presentation style meetings and experiment with the interplay of vertical and horizontal displays. Add a feature to determine the orientation of content elements and reorient them for different displays.

Our long term vision for the MemTable is to have a fully integrated recall and reflection system. Towards this initiative we have four primary goals:

1) Build a comprehensive recall system that allows users to browse through the temporal creation, modification, and deletion of content, and recall that content into current meetings.
2) Provide visualizations of group work patterns and social connections for reflection on long term work practices.
3) Experiment with strategies for associating media and weaving thread through that media for collages and screen-saver applications.
4) Connect the table with integrated collaboration web services such as Google Wave so that users can access the content generated on the table from their personal computers.

For more detailed information and sketches of these initiatives please see chapter 6.

7.2 Example Contexts for Adoption Beyond the Laboratory

During the development of the MemTable, the author has discussed the table to with people from a variety of backgrounds. Many have suggested contexts where they could use a table with capture input and memory recall. This section is included to illustrate a few examples of potential use of this project beyond its initial development. These contexts are related by a common need to have a system which supports inputting information critical to a group and recalling in the context of subsequent meetings. A wealth of possibilities exist, but two straightforward examples are included here: local communities with transient workers, and professional workgroups with critical planning facilities.

1) *Communities with transient populations yet with a clear mission:*

Educational institutions, church organizations, and community centers are all examples of groups where maintaining perspective on the group goals, and documenting the efforts of the transient members of the group may help provide more of a continuum between past events and future planning.

A friend said of her church, "We have to look to the past to envision the future". If she could welcome a new member by showing them images and notes from previous meetings, drawings the children made during Sunday school, or agendas from planning sessions, that member could more quickly understand the context goals and vision of the organization.

2) *Workgroups with mission critical planning and recall needs:*

Architecture firms, movie set directors, community planners, and government organizations like NASA all meet at tables to plan events and try to coordinate the efforts of multiple people planning and executing a large project. The difficulty of recalling those meetings without a system in place for annotating events while they are happening provides an opportunity for a smarter table.

Figure 91. Deep sea exploration planning table

NASA utilizes EVA Traverse Planning & Debrief sessions (Figure 91) for Extra Vehicular Activities such as deep sea exploration, and target points for mars rover expeditions. The success of these missions depends largely on the effectiveness of communication during co-located meetings. If the table could provide a means of generating a plan from annotations, and then compare actual events to the ones planned, communication would improve.

7.3 Relational Interfaces: Collaborative Interaction Spaces of the Future

"Our grandchildren will not distinguish between the digital and physical" - Nicolas Negroponte, 1991

The interfaces of the future will become more flexible and appropriate to our natural ways of relating to each other and exchanging information. We have unconsciously adapted to mobile devices and personal computers to access digital information, and are compromising the quality of our interactions with each other in order to facilitate more efficient transactions.

As an addendum to this thesis, I would like to postulate principles of design that would ideally be embodied in the shared interfaces of our future:

1) Displays will look like magazine covers during the day, and light appropriately at night. They will adapt to the ambient light in the environment. They will approach the limit of perceived resolution: 1200 pixels per inch.

2) Surfaces will be flexible, rolling and unrolling like board games. We will use them for games, to study complex data, to perform related operations synchronously, and to record and capture our social activities in an unobtrusive manner.

3) The interface will disappear. Interactions with information will be so natural that we will forget about the display and focus more on the information we are exchanging -- and the social dynamics of the people we are exchanging it with.

4) Information will be more streamlined and contextual to our social networks. Services will emerge to assist us in recalling the content we browse and exchange with each other.

5) The history of an organization will be a part of it's architecture. Large surfaces will be integrated into our environment to tell the stories of who, what, and when people were interacting in those spaces.

The MemTable is just an instance along a chain of small innovations that contribute to a future where the potential of computational assistance and visualization is not perceived as a social inhibitor, instead it is integrated into our social environments in a seamless and transparent manner. The ultimate instantiation of a social surface with a memory will draw on interaction principles from projects mentioned in Chapter 2 and lessons learned in this thesis as we progress away from cumbersome technical implementations.

7.4 Contribution Summary: Building Histories in our Shared Spaces

MemTable demonstrates a new way of designing tabletop systems that bridge digital and physical work-practices and support long term interactions in the workplace by incorporating a memory. Accomplishing this requires a comprehensive approach to the design: taking into consideration typical contexts of use, the ergonomics of the hardware, the usefulness of input modalities, and the fluidity of the software interface.

Although the broad scope of the design of the MemTable precludes conclusive empirical claims about recall and reflection, the comprehensive approach of the project establishes a framework for the study of recall and reflection with a state of the art shared interface. It introduces principles of design that consider the long term implications of user interaction in a social context and how that information may be more valuable to the groups who live and work with the table.

In summary, the most significant findings and contributions of this thesis are:

The MemTable system contributes guidelines that improve the physical design of tabletop systems for small workgroups to be more ergonomic and encourages natural social interactions.

As an interactive meeting support system MemTable augments both existing analog and digital work practices, such as working on laptops, using physical keyboards, and taking notes on paper - by incorporating them into the design.

We have outlined principles of design in Chapter 3 to keep the touch interface of the system legible, consistent, and intuitive allowing users to quickly adapt their meeting styles to include the table functions.

Our observations indicate that input modality choices vary widely across groups with different skill sets. Including a diverse set of tools for input supports a heterogeneous set of users, and increases overall participation.

In the user study, we observed that if the user interface is adaptable the role of the scribe can rotate between group members, potentially increasing efficiency and participation.

The user study also presents findings that demonstrate a potential utility for recall and reflection systems in small workgroups. MemTable provides a context for recalling the content of meetings with greater detail and shows a general trend towards greater accuracy. Chapter 6 describes a longitudinal plan for the development of these features.

This thesis argues for a more comprehensive approach to interactive meeting support systems:

As hardware for sensing multiple inputs becomes more pervasive and displays approach higher resolutions we will begin to see more surfaces integrated into our environments that are capable of supporting group interactions. The significance of these applications will in part depend on how the content is saved and reintegrated into future interactions between users.

Designers and researchers must consider the entire life-cycle of a meeting support system. A resulting design must incorporate appropriate hardware, fluid interaction techniques, memory storage and recall, and reflection in their design for it to be successfully adopted and broadly utilized.

APPENDIX A - Group Scenario and Individual Dossiers

Group Scenario:

The four of you own partial shares in a joint venture to transform a building located at 618 Main St. The building is outfitted with a kitchen capable of serving 125 people. You have been given a modest budget to renovate the space and open a restaurant in 12 months.

This meeting is the first of 16 weekly meetings that you will have during the initial stages of planning. You will be meeting at this table for all your planning - and using it to capture and record all of the ideas and considerations as you decide how to renovate the space.

Your group consists of an architect, a food planner, a designer, and a financial planner. The four of you each have distinctive concerns and information you bring to the discussion.

The group plans on using the table each session to record significant ideas. At the end of the 16 week period you will be able to recall all recorded ideas, considerations, and information added to the table to inform your final investment plan.

During each session of each week your group wants to decide on one possible theme and function for the restaurant and then explore the ramifications of that particular theme in terms of food, design, function, and financial cost. Document and record this process.

General Questions to first Answer:
What is the theme and function of the restaurant. Can you reach a consensus on this?

Specific Issues to Address:
Function
1) Do you want this to be a romantic dining, lunch facility, or event hosting facility, bar or other food venue? Given these considerations would you add any walls to the blueprint?

2) What types of tables and chairs will you use and how will you arrange the tables and chairs? Explore possible arrangements.

Food Menu
3) What is lacking in this area of town? What types of food items would you like to include on your menu? How will the food work with the theme of the restaurant?

Design
4) Given the theme of the restaurant what colors and decor might contribute to this theme? What type of lighting do you plan on using?

Cost
5) Do these proposals fit into the budget designated for this project. Speculate as to possible costs of the building renovations, food, and design equipment.

Role 1: Architect

You are to take on the role of the architect - which means that your focus is on how to arrange the space so that lighting, tables and chairs, and walls will work together with the theme that your group decides on.

Physical Tools: Use the blueprint, markers and trace paper to explore possibilities for how the restaurant might be arranged. You have table templates, and other tools available to explore and discuss possibilities.

Be sure to document ideas, considerations, and layout sketches for future reference.

Digital Resources: Here is a link to the location: Location of the building: 618 Main St: http://tinyurl.com/mdjdtp

Are there any green, or historical consideration you might want to add as factors to the discussion?

Questions you are in charge of considering:

1) Do you want this to be a romantic dining, lunch facility, or event hosting facility, bar or other food venue? Given these considerations would you add any walls to the blueprint?

2) What types of tables and chairs will you use and how will you arrange the tables and chairs? Explore possible arrangements.

Role 2: Designer

You are to take on the role of the designer - who is focused on the decor, theme, color scheme and lighting of the space.

Physical Tools: You have a color palette, markers and pen and paper to take notes or make sketches. You can take notes on a Clipboard if you like.

Given the theme of the restaurant what colors and decor might contribute to this theme? What type of lighting do you plan on using?

Digital resources:

Lighting:

Designing with Light [http://www.designingwithlight.com]
Allows designers to explore lighting solutions online and easily assemble comprehensive project information in a personalized project folder. 10/06

Lighting Center [http://www.thelightingcenter.com]
Lighting manufacturers and detailed product information. Includes links to a variety of categories such as "energy, government, and utility lighting programs," "light pollution articles," "light source comparison and reviews," and "lighting, electrical and miscellaneous organizations."

Lightolier [http://www.lightolier.com]
The site features complete product specification information for Lightolier¹s comprehensive product line, links to authorized distributors and Lessons In Lighting, an accredited online educational program. Visitors can also browse an extensive collection of photos highlighting a variety of product applications.

Role 3: Food Planner

You are to take on the role of the food planner - you are focused on designing a menu, and figuring out the appropriate cuisine and dietary choices for the restaurant.

Questions you are considering:
What is lacking in this area of town? What types of food items would you like to include on your menu? How will the food work with the theme of the restaurant?

Tools: you can make lists, draw, or select existing menus from online to contribute to the discussion. Consider a number of possible food options, and how this might influence the design of the restaurant.

Suggestions:
Ask the person with the computer to help you find possible menus along the lines of the theme you choose.

Electronic resources:

Different types of cuisine:

Dali: http://www.dalirestaurant.com/

Toro: http://toro-restaurant.com/

Oleana: http://www.oleanarestaurant.com/

Middlesex Lounge: http://www.middlesexlounge.us

Role 4: Financial Planner

You are to take the role of the financial planner. Estimate costs (take rough guesses, don't worry too much about acuracy) as different items in the discussion arise.

Your budget is 416,000 $ for the project. Consider tagging items as expensive, mid-range, and inexpensive - and categorizing them into the budget areas below as the meeting discussion unfolds.

Make a list of possible factors to consider and add this to the table.

Question for you to Consider
Do other group members proposals fit into the budget designated for this project. Speculate as to possible costs of the building renovations, food, and design equipment as they are discussed.

Your Operating Budget for the Year: 416,000

Current Estimated Project Costs

Provide estimate sheets for all service and equipment costs.

- Architect cost..$5,000 - 10,000
- Kitchen consultant cost ....$1,000 - 5,000
- Dining equipment cost.................................$30,000 - 70,000
- Design and Building contractor cost ....$100,000 - 200,000
- Misc. cost – Smallwares/disposables............$10,000
- Hiring Costs, Chef and Staff Members...........130,000 - 190,000

Total Project Cost ....$320,000 - 510,000

APPENDIX B: User Study Survey

MemTable Wrap-up Survey:

Please comment in margins at any time during the survey for clarification. This survey is intended to help us improve the application and the more accurate our feedback the better.

1. What is your Name? ______________________________

2. What was your Role?

___ Architect
___ Designer
___ Food Planner
___ Financial Advisor

Meeting Capture Feature Analysis:

3. Please rate the following features in terms of how useful you think they are for meeting capture and note (your) frequency of use:

Recording Audio from the recent past

3a. Not at all Useful	1	2	3	4	5	6	7	Very Useful
3b. I did not use at all	1	2	3	4	5	6	7	Used Frequently

Text capture:

3c. Not at all Useful	1	2	3	4	5	6	7	Very Useful
3d. I did not use at all	1	2	3	4	5	6	7	Used Frequently

Picture/Camera Capture:

3e. Not at all Useful	1	2	3	4	5	6	7	Very Useful
3f. I did not use at all	1	2	3	4	5	6	7	Used Frequently

Clipboard Note Taking:

3g. Not at all Useful	1	2	3	4	5	6	7	Very Useful
3h. I did not use at all	1	2	3	4	5	6	7	Used Frequently

Laptop Image Transfer:

3i. Not at all Useful	1	2	3	4	5	6	7	Very Useful
3j. I did not use at all	1	2	3	4	5	6	7	Used Frequently

4. Did you feel that your group accurately captured key points during the discussion?

Not accurate 1 2 3 4 5 6 7 Very Accurate Unsure

5. Did you feel any confusion as to which member of the group would capture a key point?

not confused 1 2 3 4 5 6 7 Very confused

6. Do you have any comments or suggestions about the capture process or suggestions for desired features?

Interface Use

7. How comfortable were you using the personal menus?

Not Comfortable 1 2 3 4 5 6 7 Very Comfortable
if uncomfortable, please explain:

8. How intuitive was the movement of capture elements?

Not Intuitive 1 2 3 4 5 6 7 Very Intuitive

9. How intuitive was the scaling of capture elements?

Not Intuitive 1 2 3 4 5 6 7 Very Intuitive

10. How useful did you find the pinning features on each capture element?

Not at all Useful 1 2 3 4 5 6 7 Very Useful

11. How useful did you find the locking features on each capture element?

Not at all Useful 1 2 3 4 5 6 7 Very Useful

12. Did you use the tagging feature at any time? Yes ___ No ___
Would you use tagging if you had more time? Yes ___ No ___
Tagging is:
Not at all Useful 1 2 3 4 5 6 7 Very Useful

13. How difficult was it to learn to use the table?

Very Difficult 1 2 3 4 5 6 7 Very Easy

14. How much experience to you have with Touch Interfaces/ Tabletop Interfaces?

No Experience 1 2 3 4 5 6 7 Very Experienced

15. How comfortable are you using technology (laptops, phones, etc) in your daily work practice?

Not Comfortable 1 2 3 4 5 6 7 Very Comfortable

16. Did you find anything confusing or disorienting about the interface?

17. Do you have any suggestions for making the interaction more natural to use?

Group Activity:

18a. How familiar are you with the people who were in your group?

Not familiar 1 2 3 4 5 6 7 Very familiar

18b. How difficult was the group task?

Very Difficult 1 2 3 4 5 6 7 Very Easy

19. How well do you think the group performed on the task you were given?

Very Poor 1 2 3 4 5 6 7 Very Well

20. How satisfied are you with the outcome of your group discussion?

Very Unsatisfied 1 2 3 4 5 6 7 Very Satisfied

21. How efficiently did the group work together?

Very Inefficient 1 2 3 4 5 6 7 Very Efficient

22. How satisfied are you with the group process used during the task?

Very Unsatisfied 1 2 3 4 5 6 7 Very Satisfied

23. Are you satisfied with your contribution to the group decision?

Very Unsatisfied 1 2 3 4 5 6 7 Very Satisfied

24. How much did you contribute in terms of meeting capture and note taking?

Not Much 1 2 3 4(same) 5 6 7 A lot

25. How much did you contribute to the discussion in relation to others in the group?

Much Less 1 2 3 4 (same) 5 6 7 Much More

Interactive Table:

26. Did you maintain awareness of the changes in the table during the discussion?

Not Aware at all 1 2 3 4 5 6 7 Very Aware

27. Did you find the interactive table disruptive during the discussion with others?

Not disruptive 1 2 3 4 5 6 7 Very Disruptive

28. What prompted you to use the table during the discussion? (check all that apply)

__ To arrange and organize my elements
__ To record a significant event during the discussion
__ To refer to previous points made in discussion
__ To record my own thoughts while others were speaking
__ I lost interest in the discussion and wanted to play
__ To make an annotation for recall later
__ To alter my content for the connivence of others
__ To compare alternatives in discussion
__ Other: ____

29. How useful did you find the features on the table for meeting capture during the meeting?

Not at all Useful 1 2 3 4 5 6 7 Very Useful

30. Did you discuss the Interface during the brainstorming scenario?

Yes ___
No ___
If yes, please explain what you discussed:

31. How representative did you feel the content your group generated on the table was of the discussion?

Not representative 1 2 3 4 5 6 7 Very representative

32. If you were going to continue to meet with your partners weekly to develop this scenario, would you want to return to the table for your meetings?

33. Did your awareness that the table will be able to recall each meeting capture created later influence your behavoir?

Yes ___
No ___
if yes, how?

34. Did the knowledge that you will later review the information from the discussion influence your frequency of meeting capture?

no influence 1 2 3 4 5 6 7 large influence

35. How important would it be to be able to review the meeting notes generated at the table on your laptop or phone after the meeting?

Not at all Useful 1 2 3 4 5 6 7 Very Useful

36. Were you concerned about privacy during the discussion?

Yes ___
No ___
if yes, how did this concern influence your interaction with the system?

37. Imagine you are planning to have many more meetings with the same table about this project over the next 6 months. Would you find it useful for these meetings? What features would make it more useful?

Final Demographic Questions

1. Sex: Male ________ Female: ________
2. Age: ________________________
3. Citizenship: ________________________
4. Employment: Student: ________ Non-Student: ________
5. Hours online everyday (on average): ________________________hours

Do you have any final comments about the technology, regarding its appearance,
its features, or your interaction with it?

APPENDIX C: User Study Follow Up Questions

Questions for Group 1

1) What was the primary customer base that you decided to focus on during the discussion?

2) Who suggested that people order from their computers?

3) Please describe what you remember about the discussion regarding adding a bar to the building.

4) What was the approximate estimate that Amit proposed to the group for the cost of the bar and interior?

5) What details can you remember from this part of the discussion?

6) What were some of the menus that your informed your group decision?

Questions for Group 2:

1) What were some of the menus that your informed your group decision?

2) Who mentioned that they wished there was a cuban restaurant in the area?

3) What was the name that your group decided on?

4) What was Noah's suggestion regarding an online component?

5) What type of layout did your group discuss during the scenario? What was the type of chairs that Ben suggested for the warehouse space?

6) Did your group decide to make any changes to the building? If so, what were they?

7) Who suggested focusing on local food? What were some of the ideas your group came up with on this thread?

Questions for Group 3:

1) What two types of restaurants did Emily suggest might be suitable for the location during the beginning of the discussion?

2) What types of food did your group decide to put in the restaurant? Where there concerns about where the food comes from?

3) Who suggested putting a bar in the restaurant? What was his/her reason for suggesting it?

4) What kind of color palette did your group choose?

5) You group suggested having live music. What was the context of this suggestion? (who made it and how would the music work with the place)

6) At the end of the discussion, you settled on a daytime and nighttime function for your space. What were each of these?

Daytime:
Nighttime:

Questions for group 4:

1) What general theme did your group choose for the restaurant?

2) What types of food did the group suggest serving during the discussion?

3) What were some of the decor suggestions to make the bar fit your theme? Who made these suggestions?

4) How did you decide to layout the space. Describe what you can remember from the discussion of the footprint of the space.

5) What was the approximate price range for dinners suggested by Anges?

6) Did your group decide to serve alcohol or not? What was the context of serving alcohol or not in your restaurant?

Questions for Group 5:

1) The group proposed a multi-use space after the first few minutes of the discussion:

What was the daytime proposal?

What was the nighttime proposal?

2) Who proposed adding a slide and a ballpit?

3) What were some of the suggestions about furniture you remember? Who made those suggestions?

4) What drinks did the group propose serving? Who made these suggestions?

5) Describe what you remember about the discussion of the layout - what were some of the ideas for the bar and stage for example?

6) What were some of the budget allocations Daniel proposed during the discussion?

7) What were some of Margaret's proposals for the food menu?

Group 6: Follow up

1) Your group settled on a theme quickly. What was the theme?

2) Who suggested bringing in expert chefs from impoverished countries?

3) What two types of food did your group primarily discuss?

4) Stephanie suggested an alternative to making money on food, what was that?

5) What were the lighting decisions that nadeem and amanda came up with?

6) What was Ali's suggestion for an additional attraction at your restaurant?

7) What were the final prices that Nadeem and others settled on?

APPENDIX D: User Study Follow Up Survey

1) We are working on a design that would allow you to scrub through a timeline of your meeting and view all the annotations as they were created, changed, and removed. How useful would you find this feature?

not useful 1 2 3 4 5 6 7 very useful

2) We found in our initial study that people did not use the audio function frequently. Instead we are considering continuous recording and attaching the audio to each of the capture widgets (text, pictures, etc). The audio widget would attach a window of audio to each widget, 1 minute before it was created and 1 minute after. (2 minutes of audio)

not useful 1 2 3 4 5 6 7 very useful

Would you use this feature? Why or why not?

3) What further suggestions do you have improving the recall, and note taking?

4) If you were having a second meeting with your group, would you want to select certain items from the previous meeting, or start with the end state? How do you imagine the recall features would be used in your meeting?

5) How useful would it be to see who created each of the content items from the previous meeting. Would this feature have helped you with your ability to remember the context of the previous meeting?

not useful 1 2 3 4 5 6 7 very useful

6) Any final/general comments?

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