WorkTop: A Multi-touch Tabletop Collaborative Sketching Application for Interdisciplinary Design

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Abstract

The WorkTop application, as part of the larger WorkTop project, shows that multi-touch tabletop computers are in fact useful tools collaboration in the workplace. This is a step on the way to developing a system comprised of multiple tabletops and tablet PCs that will increase the sense of presence experienced by people who are collaborating remotely. The design of the WorkTop application synthesizes research about collaborative work, multi-touch tabletop interaction design, and sketching as a communication tool as well as data from our own pilot studies in order to provide a simple and effective tool for an interdisciplinary team of designers to use during the brainstorming phases of a project. By providing discreet, floating, resizable, and rotatable canvases, WorkTop solves both the orientation and territory problems inherent to tabletop collaboration. Features such as the ability to copy canvases add value to the application as compared to standard pen and paper. Ongoing user testing measures both the utility of the application for collaboration as well as that of the interface components. The WorkTop application provides a solid foundation for future development and testing to meet the requirements of the project.

Introduction

The explosion in technologies for interacting with digital media is simply a quickening of pace of a progression that has been present throughout the history of digital technology. Each new way to interact with technology from punch cards to the iPhone brings with it new design challenges and opportunities. The challenges and opportunities related to digital tabletop computers stem from the fact that they are often meant to be viewed from any place around the table by multiple people simultaneously. This means that they have the potential to become a very useful tool for collocated collaborative work; however the applications need to be designed in ways that allow for multiple orientations and locations of the same information, as well as fulfilling users expectations of standard table [15].

The WorkTop application synthesizes previous research in the area of digital tabletop interaction design, collaborative work, and sketching as a communication and thinking tool, in order to provide a useful tool for collocated design collaboration. The WorkTop application is part of a larger project, also called WorkTop, that seeks to design a system to support remote collaboration for people with disabilities comprised of tabletop computers and tablet PCs. Based on background research and brainstorming sessions with actual design professionals, we discovered that most collaborative design work occurs during the ideation phases of a project, and a primary tool used for communication and thinking during this work is sketching [1, 2, 5, 17]; therefore the WorkTop application is a sketching tool designed to facilitate and augment collaborative brainstorming. By understanding the types of actions people take during collaborative work around tables, such as the creation of personal, storage, and group workspaces we were able to, through revision, create an interface that enabled those actions with a digital interface [14]. The combination of different techniques for solving the orientation problem inherent in tabletop application design led to a design that takes advantage of people's real world expectations to create a natural interaction that fits Ben Schneiderman's construct of direct manipulation [11, 12, 16].

The benefits of moving from traditional pen and paper based sketching to a digital sketching interface for design collaboration include the ability to copy sketches, track the history of the design process, export the sketches for further work or distribution, and to work with people in remote locations on a shared interface. While the WorkTop application in its current form only facilitates one of these, now that the WorkTop project has shown that digital tabletops are effective collaborative tools, future development can focus on the best way for the project to augment the design process.

Background

The design of the WorkTop application applies research from three main areas: sketching, collaborative work, and tabletop interaction design. By synthesizing findings from this research, the WorkTop application is able to provide a tool that facilitates and augments interdisciplinary design collaboration.

Sketching

Design and sketching are inarguably linked. Designers use sketching not only as a means present their ideas to others, but as a way to think about their designs [1, 2, 5, 17]. Furthermore, most collaborative work is traditionally performed during the early phases of design using pens and whiteboards, paper, and tables. Detailed mockups are usually made individually after the initial ideation phases [9]. Based on this research, the WorkTop application morphed from a tool designed to facilitate a very specific task, room planning for HVAC engineers and inspectors and 3D mockups for industrial designers, Figure 1, to a general tool meant to facilitate the kind of napkin sketches designers and engineers rely on for the initial stages of a project, shown in Figure 2.

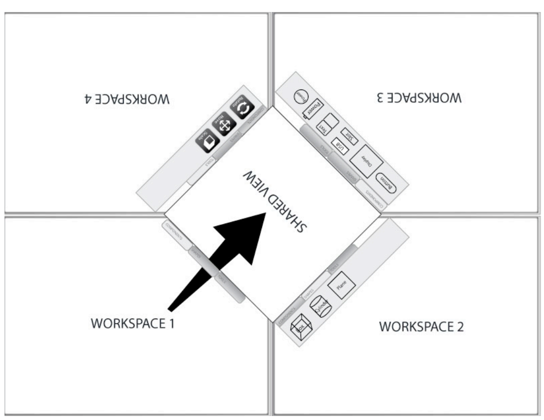

Figure 1: 3D Mockup Interface Design

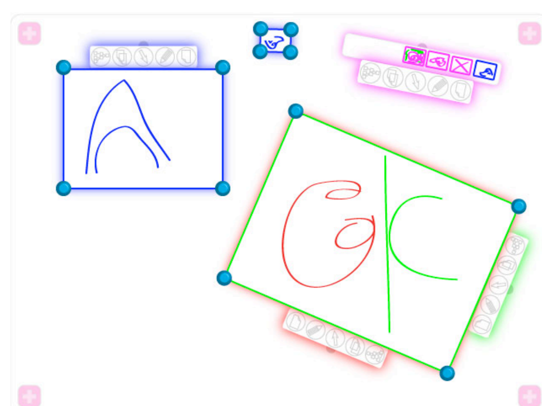

Figure 2: 2D Sketching Interface Design

Collaborative Work

The specifics of collaborative work differ depending on the environment, tools and task that make it up. Tabletop Collaboration has been the primary focus of much of Stacey Scott's research. Through her research, she has outlined eight guidelines for the design of collaborative tabletop applications: "(1) support interpersonal interaction, (2) support fluid transitions between activities, (3) support transitions between personal and group work, (4) support transitions between tabletop collaboration and external work, (5) support the use of physical objects, (6) provide shared access to physical and digital objects, (7) consider the appropriate arrangements of users, and (8) support simultaneous user actions" [15]. The WorkTop application meets all of these guidelines in its current state except for number four; however, the addition of an export feature will solve that problem. By bringing people together around a tabletop and providing simple interaction methods, the WorkTop application meets guidelines one, two, five, and six. By objects, Scott means everything from cups of coffee to architectural models. When people work on a table, they expect to be able to place these objects on them and use them, when needed, as the focus of shared attention. Furthermore, by being simple to use, the WorkTop application does not get in the way of standard communication practices like discussion and gesturing that take place during meetings around tabletops [7]. By virtue of its flexibility, the WorkTop application handles guidelines three and seven. People can reach all the controls from anywhere on the table and orient and position items appropriately based on where they are standing. Also, being able to reposition items facilitates the creation of territories, which is important for distinguishing group and personal work [10, 14]. The application design and the tabletop hardware support multiple simultaneous touches, thereby meeting guideline eight. Many people can edit the same canvas concurrently, or everyone around the table can edit different canvases, all at the same time.

Other work by Scott has shown that during collaborative work, people create three types of territories: personal, storage, and group. Attempts to support the creation of these territories have included partitioning the workspace in applications, both rigidly and flexibly, and providing separate displays as personal workspaces [14]. Initially the WorkTop application provided rigid territories; however, after conducting a paper based pilot study with the interface in Figure 3, we discovered that rigid territories do not account for people's desire to stand anywhere and move around the table. By transitioning to a completely fluid interface, the WorkTop application now takes advantage of people's ability to partition the space as they see fit by moving and orienting the sketches [10, 14].

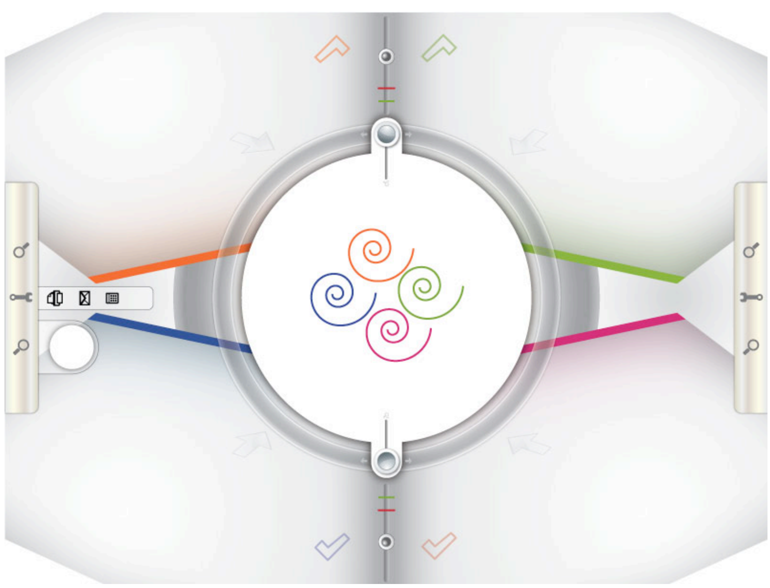

Figure 3: Initial 2D sketching interface with rigid territories

Interaction Design

For collaborative work, interactions need to be designed in such a way as to not inhibit communication amongst the system's users [7]. They also need to provide a standardized set of actions for accomplishing tasks that adheres to users' preexisting expectations of the behavior of a table [15]. The main interactions in the WorkTop application are moving, resizing and rotating the canvas, and sketching. Research about how to facilitate moving objects on tabletops has focused on making the interactions more natural by making the objects behave similarly to real-world objects, like sheets of paper [11, 12]; however, these studies have focused on objects that cannot be edited by the user, photographs for example. Using the TNT system, dragging an object using one finger simultaneously rotates the object, as can be experienced when interacting similarly with a piece of paper. The design of the WorkTop application incorporates this interaction, while also providing a mechanism for translation, rotation, and resizing all at the same time using two touches. However, since the content of the object is editable, the WorkTop application requires separate touch points for manipulating the canvas, hence the handles. The handles are on the corners to minimize accidentally touching them while editing the sketch, but for certain interactions, creating a frame around the sketch that acts like the handles but that can be touched anywhere might work better.

Sketching interfaces have been designed using pens and fingers. Notably, CollabDraw implements a collaborative sketching interface for creative expression and creates an entire set of gestures for control, that only uses fingers [13]; however the advantages of finger sketching versus pen sketching on digital interfaces seems to have not been well researched. In the case of the WorkTop application, a combination of pens and fingers would provide the most seamless interaction scheme, but our hardware does not currently support it. Therefore, we have chosen to work with only with pens, since they provide the most natural interaction for sketching as well as a smoother experience on our hardware. Multi-touch interactions, such as resizing and copying the canvas are currently handled by giving each user multiple pens to work with. Copying the canvas is seen as primarily a collaborative action, and the third pen is thought of as being held by a collaborator. Future revisions to the software and hardware could address this issue in different ways.

Related Work

Many of the components of the WorkTop interface have been implemented in other applications. By combining elements of these applications the WorkTop application provides a tool that is useful across disciplines and tasks for collaborative design.

Hinrichs' and Scott's Interface Currents, shown in Figure 4, explores a novel solution to the orientation problem and provides user configurable storage spaces for the organization of information on the table [8]. Information continuously moves around the border of the table, changing orientation as it reaches a different side. The border can be resized so that as an object approaches a user it grows for closer inspection. Users are able to create arbitrarily shaped storage containers that can be resized for inspection that objects flow around inside as they did around the table border. The Interface Currents application proved useful for information sorting tasks; and user created storage spaces have been shown to be effective mechanisms for these tasks. However, in the case of WorkTop, it is important that all objects remain static, so that users can edit the sketches or inspect them more closely. Also, since the application is not populated with information from the start, the table border would be wasted space. Separate storage spaces are designed for future implementation in the WorkTop application.

Figure 4: Interface Currents

Mark Gross and Ellen Do's Electronic Cocktail Napkin and RT^2, shown in Figure 5 and Figure 6 are sketching interfaces designed to aide the design process by understanding the design context and providing supplemental information or toolsets to facilitate the task [4, 6]. Often design does require the input of supplemental information and the addition of features like those implemented in the Electronic Cocktail napkin could benefit WorkTop greatly; however, the implementation of them is beyond the scope of this iteration. The RT^2 application seeks to turn sketching into a much more detailed design process. Giving the computer the ability to recognize shapes and lines and refine the sketches, or translate them in to 3D objects could be extremely useful and offer a further way to augment the design process in the WorkTop application.

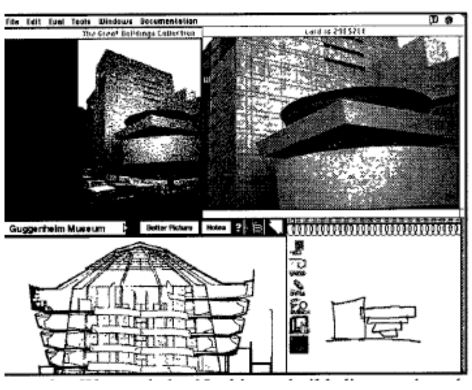

Figure 5: Electronic Cocktail Napkin

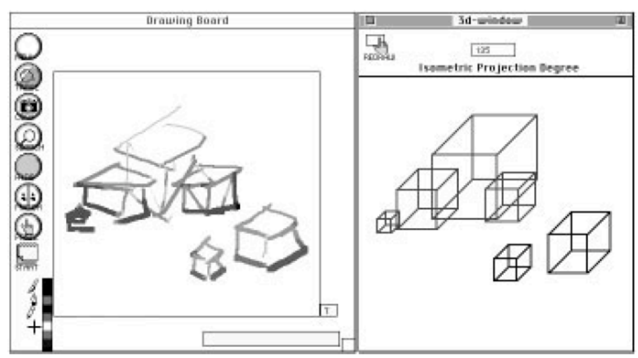

Figure 6: RT^2

The DiamondTouch table is the first multi-touch surface that also tracks individual users [3]. It accomplishes this by having receivers beneath the chairs that the users sit in. When the user touches the table it completes a circuit that includes the receiver, thereby finding the touch coordinate and the associated user. This means that users are not free to move around the table and that they only have access to information that is directly in front of their seats. While user tracking would be useful in the WorkTop application for logging design history and visualizing the design process, it is more important for users to be able to move around the table and share information fluidly.

Application Design

In the final iterations of the design of the WorkTop application, it became clear that the primary design goal was to create a simple interface that mimicked and augmented sketching with a pen and paper on a standard table and to provide as natural an interaction scheme as possible. To this end, the canvases and the interactions used to manipulate them became the focus. Resizing and rotating using any two handles redraws the canvas based on the location of the fingers manipulating it. To move the canvas across the screen the user can simply touch one corner and drag it to where he wants it. To copy the canvas, the user anchors two points and drags a third, revealing the copy in the place of the original.

The decision to eliminate all the tools familiar to people who use computer based drawing software came with the realizations that most of the actions they perform either are for creating production quality works of art, or that their functions can be duplicated using natural interaction techniques and contextual gestures. In future versions of the application, the addition of some tools may become necessary, at which point they can be added to a contextual menu, much like the one called up using a circular gesture in the applications designed by Perceptive Pixel seen at the beginning of this video, http://www.youtube.com/watch?v=c6AArJgbxTg. Examples of tools that may be added are accessing the history feature, and exporting canvases.

Certain features have been designed but not implemented in this version and are described in the Future Work section of this document. The following walkthrough describes the current implementation of the application.

Walkthrough

When the application is first launched the user sees the interface shown in Figure 7.

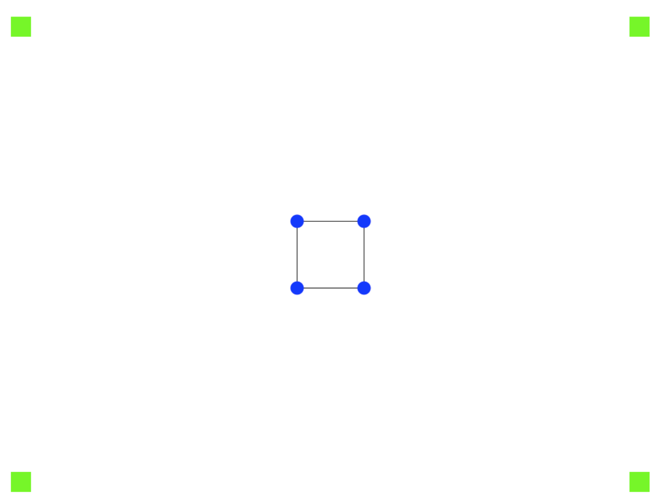

Figure 7: Initial Interface

The canvas in the middle of the screen consists of a page, on which the user can sketch by using a finger or an infrared light pen as seen in Figure 8, and four handles for performing other actions with the canvas. The black circles in the following images show the position of touches on the interface.

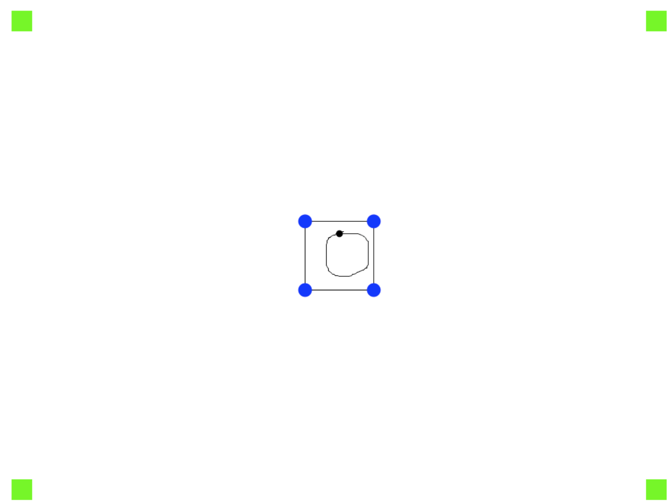

Figure 8: Sketching on the Canvas

Touching and dragging one handle moves the canvas as in Figure 9. Touching any two handles and moving them simultaneously resizes and moves the canvas, shown in Figure 10. The sketch stays the same size, and in future versions it will be panable and zoomable using a separate set of gesture interactions.

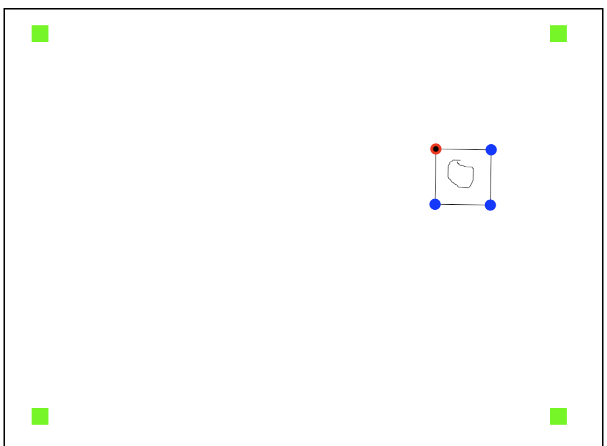

Figure 9: Dragging the Canvas

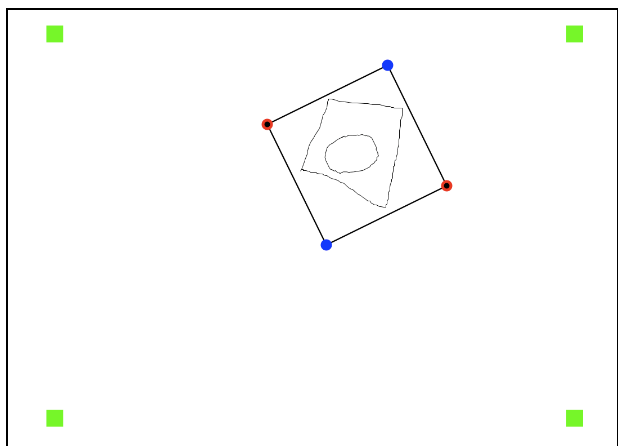

Figure 10: Resizing and Rotating the Canvas

Touching three handles and moving one of them creates a copy of the canvas as seen in Figure 11. Currently the copy appears offset from the original, but in future versions dragging the third handle should drag the copy out from beneath the original similar to the use of carbon paper.

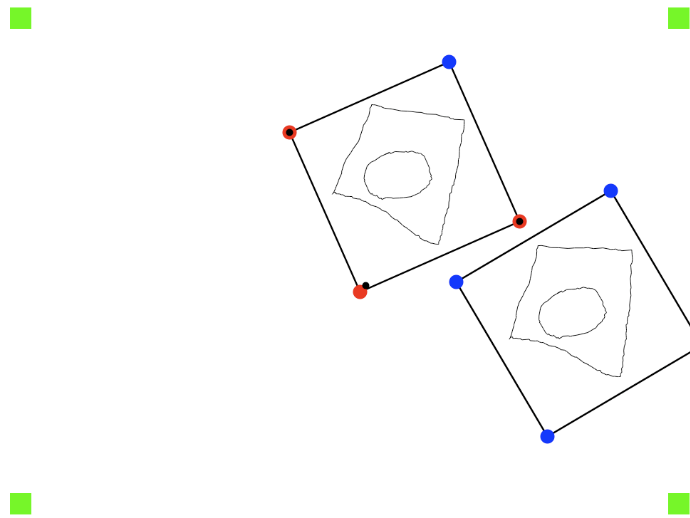

Figure 11: Copying the Canvas

By shrinking the canvas, using two corners, to a point where the width and height are nearly zero, the user can delete a canvas from the screen, illustrated by Figure 12 and Figure 13.

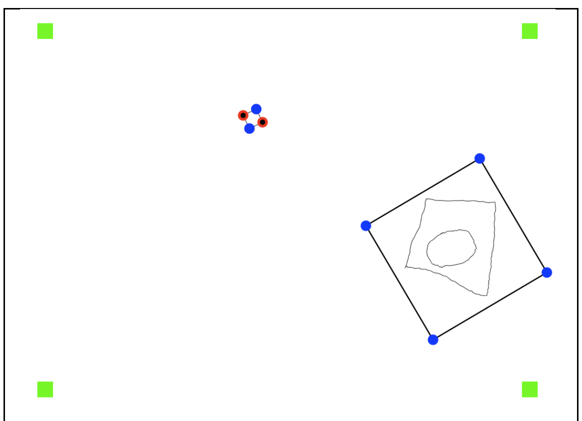

Figure 12: Deleting the Canvas

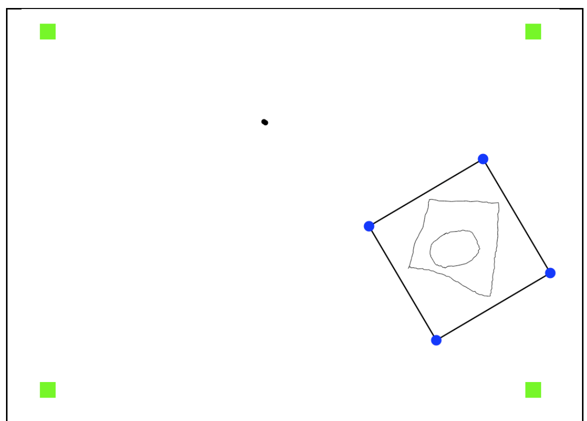

Figure 13: The Canvas Deleted

To create a new blank canvas, the user touches one of the add canvas buttons in the corners of the screen as shown in Figure 14.

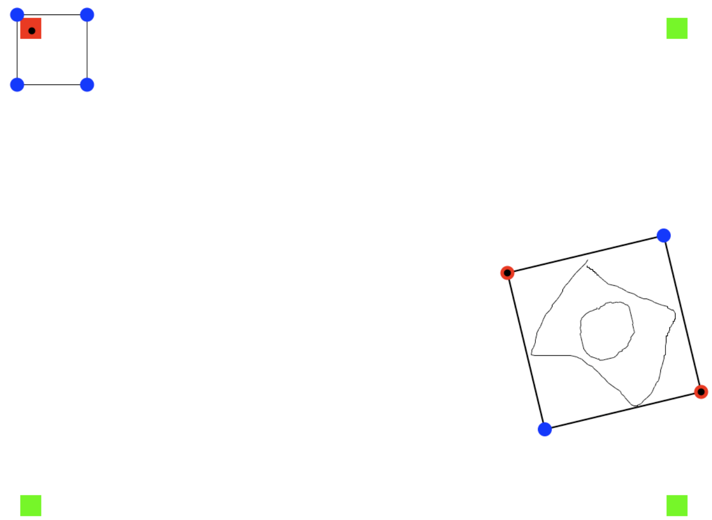

Figure 14: Creating a New Canvas

Technology

The technology used for WorkTop involves a hardware and a software component. The hardware is a DI (diffuse illumination) based multi-touch tabletop computer that has been well documented elsewhere; however, I will discuss certain modifications made to the table that increase the usability of the application. The software is written in Processing and uses the TUIO protocol for communication with the reacTIVsion engine that handles the computer vision aspects of touch tracking on the table.

Hardware

The tabletop computer in Synlab was primarily designed for object tracking using the reacTIVision engine. Therefore, certain modifications had to be made for it to handle touch tracking well. The first modification reduced the glare from the infrared lights that created blind spots on the surface. By moving the diffuser material from the top of the surface to underneath it, the infrared lights no longer reflected off the bottom, exposed face of the surface material and the blind spots became less of a problem.

The next modifcations increased the sensitivity of the table to touches. The fist thing I tried was changing the settings of the reacTIVision engine. Since WorkTop does not require the use of object tracking, I increased the setting for the amount of light analyzed by the engine to make small finger objects more visible. This helped, but not enough to make the touch interactions smooth. To support sketching and increase the visibility of the touches, we began using infrared light pens, which the engine sees as fingers. I increased the size of a touch in the engine to take in to account the larger diameter of the light source and turned off the infrared lights inside the table, since the pens do not need to reflect light to be seen by the camera. This eliminated the blind spots and made the interactions smooth.

These modifications do introduce new limitations that could be problematic for the application, but in this case, the tradeoffs seem worth the cost. Without IR backlighting, finger and object tracking are no longer available. This means that currently each user needs at least two IR pens and possibly three, to perform all the canvas actions. Furthermore, object tracking could be a good solution for developing an erase feature by attaching a fiducial marker to the eraser side of the light pen. Other members of Synlab are currently working on designing hardware that will handle light pen, finger, and object tracking better, which will improve the experience with the current generation of the WorkTop application and provide opportunities for designing more refined features in future versions.

Software

The software development for WorkTop involved three main phases: software architecture, graphics programming, and features coding. Each of the phases, in reality, was ongoing and the effects of changes to one affected the other; however this is a approximation of how the development process proceeded and provides a good framework for explaining the choices I made while coding.

Architecture

Processing is a Java-based programming language; therefore WorkTop is designed to adhere as closely as possible to the object oriented goals of encapsulation and inheritance. Also, since our table runs the reacTIVision engine, WorkTop implements the TUIO library for Processing, which provides a set of event handler methods for tracking objects and touches. It also provides objects, TuioCursors, which contain all the information required for analyzing touch locations and paths. WorkTop uses these as its primary data object for transferring information between objects. Figure 15 illustrates the WorkTop system architecture.

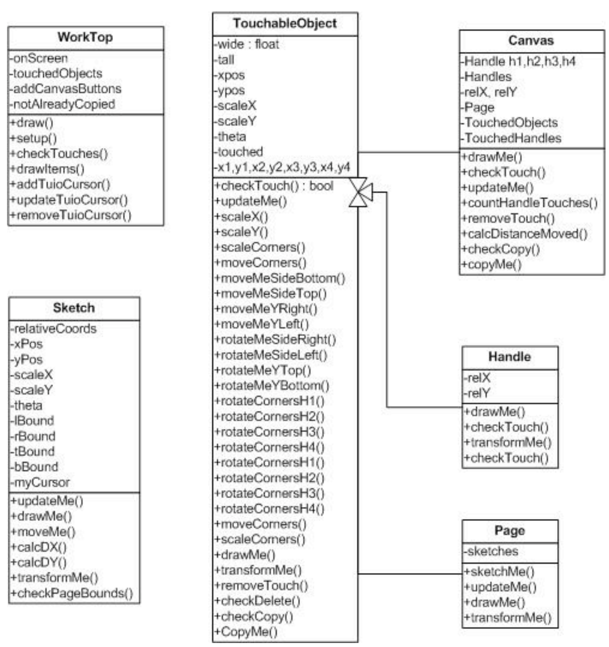

Figure 15: WorkTop class diagram

Graphics

Coding the interactions for simultaneously translating, rotating, and resizing canvases required the use of standard computer graphics techniques. By making each canvas a standard object and then calculating how it should be transformed based on the coordinates of the touches on the table, the canvases can appear to follow along with the users fingers or pen. In this case, I coded all the transformations myself, but the development of a graphics library to handle the kinds of interactions would aide designers and developers to create applications like this in the future.

Interactions

Once the graphics issues were solved, coding the interactions became much easier. The resize and rotate interactions became exercises in checking and tracking which handles were touched and calling the appropriate transformation methods. One-handle dragging followed a similar route. The process for copying involved checking for a three-handle interaction and then going through all the instance variables and classes that make up a canvas and creating new instances of them. This required some effort to create an appropriately deep copy because if any of the instance variables, such as the sketch coordinates, were shallow copies, changes to the original or the copy would be reflected in both on the screen. Deleting canvases takes advantage of Java's automatic garbage collection. When the size of a canvas is less than 0.08 times the size of the original, the application removes all references to the canvas from the ArrayLists in the main class, and it gets removed from the screen and memory as a result.

Adding new canvases required a separate logic in the main class, since the canvases needed to be added to the appropriate data structures for drawing and tracking. Therefore, they reside in their own ArrayList, which is checked for touches before the canvases. If one of them is touched, its addCanvas method is called, which calls the Canvas constructor and returns the constructed instance of canvas, which is then added to the onScreen ArrayList. This is an example of how the addition of certain features to the code created minor changes to the application architecture. Given my background and the relative complexity of this application, the designed architecture and the adherence of the final application to the tenants of object-oriented programming came out nicely. The design of the architecture was as much of a learning experience as the design of the interactions and interface, and as valuable a component to the end result.

User Study

The WorkTop user study has two main goals: to show that a multi-touch tabletop computer is an effective tool for workplace collaboration and to evaluate the application design. The study has been designed to accomplish both of these simultaneously through the choice of design tasks, metrics, and reporting. The user study is still in progress, so this document covers the methodology. The results will be reported in a future paper.

Methodology

The study will compare the use of the WorkTop application to complete a design task with that of pen and paper on a standard table. One Group each of five, three, and one person are assigned to use either a standard table or the WorkTop application to design an electrically augmented toilet. After a short tutorial on the interface, the groups are given 30 minutes to complete the design task. Their work is recorded from above and various collaborative actions are observed and timed. After the session, each group member fills out a questionnaire about their experience with the group and the interface. Finally, as a group, the participants participate in a discussion about their experience with the interface.

The observations of collaborative actions and the interview questions aim to show that groups spend the same amount of time collaborating on both interfaces and that their experience of collaborating is similar. The questionnaire and other interview questions focus on specific interface elements and features of the WorkTop application. If certain interactions are not usable in a work context or if important features have been left out of the design, the study should give me a way to direct future development of the application.

Future Work

WorkTop is an ongoing project. The development and testing of this application are just the beginning of a project attempting to develop a system for remote collaboration that helps people who cannot commute to work feel more present and have a greater level of participation in the workplace. Besides adding additional features to the tabletop application, WorkTop will require the development of a networked version, so that groups working on two separate tables can collaborate on the same documents, and the design and development of an application running on a tablet PC that interfaces with the application on tabletop. Each stage of the project will require testing and will in the end show that tangible interfaces are part of a system that makes teleworking more viable for people with disabilities.

Additional Features

The following features have been designed but not implemented in this version of the WorkTop application:

- Erase – By flipping the light pen over, like a pencil, the user can erase lines on the canvas.
- Panning and zooming the page inside the frame – By adding robust gesture recognition to the application, the user can use a set of gestures to enlarge or shrink his sketches as well as move them around in the frame, creating an infinitely large page that is only partially visible depending on the scale.
- Exporting sketches – Using a menu accessible by using a gesture or simply a touch on part of the interface that is not a canvas or a button, the user can save the sketch as an SVG file for use in a program like Adobe Illustrator or print or email the sketch for distribution and future reference.

- History tool – Based on the copies of canvases made during the design process, the application creates a branching visualization of the history of the design. This feature is accessible through the menu and allows the design team to quickly remember why they made particular design decisions.
- User tracking – Using either top down computer vision or active pens which broadcast some information about themselves to the engine, the application can keep track of which user is making edits to the canvas. This can be visualized in the history tool or on the canvases themselves and should aide in conflict resolution and annotation tasks.

While useful, and ultimately necessary to make this application something that might actually be placed in a work environment, these features are not necessary to illustrate effectiveness of tabletop computers as collaborative tools and given the time constraints and limited development resources they have been omitted from this version. However, they are to be implemented as development progresses depending on the focus of the project.

Conclusion

The WorkTop application furthers the research in tabletop application design in three main ways: it adds to the research on rigid versus flexible boundaries for territories; it illustrates a new type of interaction for simultaneously translating, rotating, and resizing an object on the table that has editable content, and it shows that digital tabletops can support collocated collaborative work.

By conducting user studies in which people perform the same task using rigid and flexible territories, we have seen that people prefer flexible territories. While this question requires further inspection, our preliminary observations are valuable to the field.

Previously, most tabletop work has involved objects with fixed content, like photographs. Since sketches need to be edited by the users constantly, in order to keep from using GUI tools to toggle the state of the application, I designed a set of interactions that use just the corners of the frame to manipulate the object on the screen.

By synthesizing background research, design, and development, and conducting user studies, I have shown that the tabletop can be useful for collaborative workplace tasks. This provides a groundwork that research in the field of digital tabletop collaboration can use as a stepping of point.

Future work on the WorkTop project will show that technology such as digital tabletops not only support, but also augment collaboration, both collocated and remote, in such a way that people feel a greater sense of presence and control, whether they are together in the same room, or at home because they cannot commute due to a disability, or anywhere else from where they can connect to the workplace.

References

Works Cited

[1] Arvola, M. and Artman, H. Interaction walkthroughs and improvised role play. *Design and semantics of form and movement*, 42.
[2] Bly, S. A. A use of drawing surfaces in different collaborative settings. In *Proceedings of the 1988 ACM conference on Computer-supported cooperative work* (Portland, Oregon, 1988). ACM, New York, NY, 1988.
[3] Dietz, P. and Leigh, D. DiamondTouch: a multi-user touch technology. In *Proceedings of the 14th annual ACM symposium on User interface software and technology* (Orlando, Florida, 2001). ACM, New York, NY, 2001.
[4] Do, E. *The Right Tool at the Right Time--drawing as an interface to knowledge based design aids*. 1996.
[5] Do, E. Y.-l. Drawing marks, acts, and reacts: Toward a computational sketching interface for architectural design. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing* (2002) 16, 149-171.
[6] Gross, M., D and Do, E. Y. L. Demonstrating the electronic cocktail napkin: a paper-like interface for early design. In *Proceedings of the Conference companion on Human factors in computing systems: common ground* (Vancouver, British Columbia, Canada, 1996). ACM, New York, NY, 1996.
[7] Gutwin, C. and Greenberg, S. The mechanics of collaboration: Developing low cost usability evaluation methods for shared workspaces. In Proceedings of (Year). Published by the IEEE Computer SocietyYear.
[8] Hinrichs, U., Carpendale, S., Scott, S. and Pattison, E. Interface currents: Supporting fluent collaboration on tabletop displays. In *Proceedings of the Smart Graphics '05* (2005). Springer-Verlag New York Inc, New York, NY 2005.
[9] Klemmer, S. R., Newman, M. W., Farrell, R., Bilezikjian, M. and Landay, J. A. The designers' outpost: a tangible interface for collaborative web site. In *Proceedings of the Proceedings of the 14th annual ACM symposium on User interface software and technology* (Orlando, Florida, 2001). ACM2001.
[10] Kruger, R., Carpendale, S., Scott, S. and Greenberg, S. How people use orientation on tables: comprehension, coordination and communication. In *Proceedings of the ACM Group 2003 Internation Conference on Supporting Group Work* (November 9-12, 2003). ACM, New York, NY, 2003.
[11] Kruger, R., Carpendale, S., Tang, T. and Scott, S. Fluid orientation on a tabletop display: Integrating rotation and translation. *Department of Computer Science, University of Calgary* (2004), 747-712.
[12] Liu, J., Pinelle, D., Sallam, S., Subramanian, S. and Gutwin, C. TNT: improved rotation and translation on digital tables. In Proceedings of (Year). Canadian Information Processing SocietyYear.
[13] Morris, M., Huang, A., Paepcke, A. and Winograd, T. Cooperative gestures: multi-user gestural interactions for co-located groupware. In Proceedings of (Year). ACMYear.

[14] Scott, S., Sheelagh, M., Carpendale, T. and Inkpen, K. Territoriality in collaborative tabletop workspaces. In *Proceedings of the 2004 ACM conference on Computer supported cooperative work* (2004). ACM, New York, NY 2004.
[15] Scott, S. D., Grant, K. D. and Mandryk, R. L. System guidelines for co-located, collaborative work on a tabletop display. In *Proceedings of the ECSCW 2003: Proceedings of the Eighth European Conference on Computer Supported Cooperative Work* (2003). Kluwer Academic Publishers, Helsinki, Finland 2003.
[16] Shneiderman, B. Direct manipulation: A step beyond programming languages (abstract only). In *Proceedings of the Proceedings of the joint conference on Easier and more productive use of computer systems. (Part - II): Human interface and the user interface - Volume 1981* (Ann Arbor, MI, 1981). ACM1981.
[17] Whittaker, S. and Schwarz, H. Back to the future: pen and paper technology supports complex group coordination. In *Proceedings of the Proceedings of the SIGCHI conference on Human factors in computing systems* (Denver, Colorado, United States, 1995). ACM Press/Addison-Wesley Publishing Co.1995.