SketchTop: design collaboration on a multi-touch tabletop

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ABSTRACT
Computer mediated group collaboration, particularly in the design and engineering disciplines, is in need of better applications that suit the needs of effective exchange of information. Multi-touch surfaces offer the capabilities to augment and better enable face-to-face interaction with digital content and applications. This paper presents the design, development and testing of SketchTop, a multi-touch sketching application for collocated design collaboration.

Author Keywords
Multi-touch tabletop, Design, Collaboration

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H.5.3. [Information Interfaces and Presentation]: Group and Organization Interfaces---*Collaborative computing*

General Terms
Design, experimentation.

INTRODUCTION
Studies have shown that groups using interactive technologies to facilitate and enhance collaboration produce better results than individuals [6, 8, 15, 20]. However, few studies have examined the use of multi-user interactive surfaces for complex design activities in which interdisciplinary teams work by sharing visual information [11, 12, 13-14]. Despite its collaborative nature, design is typically a linear process where information is passed sequentially between team members who contribute their own unique expertise [11, 16]. The design process is often a series of design and redesign iterations that involve passing work between domains, which can be time-consuming and costly, and can result in poor final outcomes [9].

On the other hand, interactive collaboration enables team members to share expertise synchronously during the design process. This reduces time and cost and results in better design outcomes [16]. Multi-touch tabletops can facilitate and enhance interactive collaboration by bringing collaborators together during the design process. Although interactive tables can enable real-time sharing of design information, usability issues such as the orientation of objects, definition of territories, and access to input devices can significantly affect the collaborative experience [18]. Our research explores when and how digital tabletops can be used in the collaborative design process. This paper reports on the design, development and testing of SketchTop, a multi-touch tabletop system that supports collaborative design through synchronous communication, and the creation and sharing of design sketches.

BACKGROUND
We synthesize research from the domains of collaborative design work and tabletop collaboration.

Collaborative Design
Based on our background research, 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 type of work is sketching [1]. Detailed mockups are usually made individually after the initial ideation phases [2]. Therefore, digital tabletops are suited to facilitate and enhance the kind of interactions designers use to develop and communicate ideas at the beginning of a project. By bringing disciplines together for this phase of design, the process can be flattened and major design issues can be uncovered early.

Previous collaborative tabletop systems have focused on the combination of real and digital objects [5], the spaces and tools required for collaborative design [3], and the organizational aspects of collaborative work [7]. SketchTop focuses on the interaction design for a simple sketching interface to support interdisciplinary design teams during ideation and brainstorming by facilitating simultaneous editing of content and manipulation of interface objects.

Tabletop Collaboration
Previous research shows that factors such as orientation of objects on the table, definition of territories and access to input devices effect collaboration on tabletop systems.

Orientation of Objects
The problem of orientation is that objects can appear upside down depending on where people are located around a table. Kruger discusses different ways systems solve this problem: automatic orientation based on user location or screen position, or manual orientation either through direct manipulation or GUI-like tools. Based on user studies of these techniques, Kruger suggests several important factors in the orientation of objects on the table. Objects should be manually orientable to any angle. Rotation interactions should be lightweight so that they do not interfere with group communication, and users should be able to control the orientation of their own objects [10]. SketchTop uses a two-point, manual, rotate-translate-resize interaction as a flexible way to manipulate interface elements [4].

Definition of Territories
Studies have demonstrated that collaborators partition tabletop workspaces into three types of territories: personal, group, and storage [19]. Personal territories are primarily used for thinking. The group territory is for sharing information, and storage territories organize information or hold it to be recalled later. People are adept at partitioning workspaces; therefore lightweight and flexible mechanisms for moving and resizing objects can facilitate the definition of territories [19]. By giving users complete control over the location and orientation of all screen objects, SketchTop allows users to define territories as required by the state of the collaboration.

Access to Input Devices
In order to facilitate group-work, tabletops should provide the ability for multiple users to interact with the system simultaneously [18]. Marshall compared different combinations of interface devices: single mouse, multiple mice, single touch, and multi-touch, to determine the effects of equity of access with user participation [17]. The results show that multi-touch supports more equitable participation with respect to group members' contribution to the work. SketchTop combines true multi-touch with the use of light pens, ensuring that all users can work simultaneously.

CONCEPTUAL DESIGN
Based on our research, we developed an initial design for a tabletop application, Figure 1, that we implemented as a paper prototype and evaluated in a pilot study.

Design Criteria
In general, the design needs to support territoriality, provide mechanisms for reorienting content and tools for sketching, and allow simultaneous input from multiple users. The initial design provided four personal spaces, a group space and a mechanism for tagging sketches along a timeline,
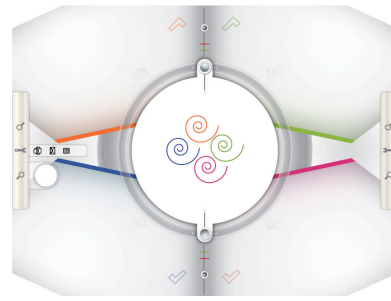

Figure 1: SketchTop's initial interface

which acts as a storage space. Users sketch inside their personal space then drag the sketches into the group space for sharing. Shared tools on the short sides of the table access features such as exporting sketches. Tagging and history tools are on the long sides of the table. The group space rotates using a set of handles, providing manual control of the orientation of shared objects. The entire group space rotates, giving users the ability to present sets of sketches to the rest of the team. The multi-touch capability of the table provides the ability for all users to sketch and share sketches simultaneously. The groups negotiate the use of shared resources as they would at a standard table. The ability to create and share sketches provides users the type of support for collaborative work afforded by pen and paper, whiteboards, and other sketching media with the added benefit of digital editing, storing and version tracking of their sketches.

Pilot Study
We produced and tested a paper mock-up of our design to study the usability of the interface and how well the application facilitated interdisciplinary design collaboration. Groups of two, three, and four people from design and engineering backgrounds came to the lab. We asked them to show us how they would perform certain actions using the interface; then, we gave them a tutorial on the interface and asked them to perform a design task as a group. Afterwards, they answered a questionnaire about their experiences and took part in a group interview.

RESULTS
The pilot study revealed three main issues with the design: the size and shape of group and personal spaces, the location and ownership of tools, and the clarity of the interface. The group and personal spaces needed to be similarly shaped and resizable to facilitate transitions between individual and group work. They also needed to be flexible to support movement around the table. Rotating the entire group space proved unintuitive, and users often rotated individual sketches instead. Users confused the functions of shared tools, and wanted personal sets of tools that they could place in a location near where they stood. The use of the tagging and history features was not clear, although users did consider them valuable.
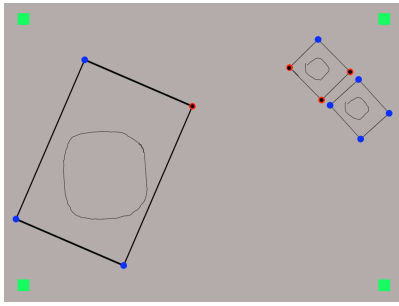
Figure 2: The fluid SketchTop interface

Figure 3: Copying a canvas

Based on these results, we refined our design to provide floating, resizable canvases, which allow users to create their own territories as needed, and simultaneous access to tools and canvases. We removed the history feature based on the focus of the user study and time constraints.

THE SKETCHTOP SYSTEM
The SketchTop application, shown in Figure 2, aims to be as flexible as possible to give users the ability to move around the table as they work and define territories as the design process progresses. SketchTop runs on a 50-inch, diffused illumination based tabletop running the reacTIVision engine for tracking touch input. The pens emit infrared light and are treated as touches by the system.

User Scenario
SketchTop is designed for groups of designers and engineers to brainstorm about a design. When a group approaches the table, each member creates a new canvas by touching one of the green new canvas buttons in the corner of the screen. One of the designers asks what features the device they are designing needs to have and begins writing a list on one of the canvases. During the discussion of features, another designer begins sketching an example of his idea about ergonomics. He then copies his sketch and passes it to one of the engineers to see if the form poses any problems for the hardware design. The engineer turns the sketch so it is facing him and resizes the canvas so he has room to sketch the hardware design. After hashing out some of the design issues, the group decides to make a more detailed large format sketch, so one of them creates a new canvas and resizes it so that it takes up the entire screen. They then draw on this canvas together, illustrating the shape of the device and the placement of the features. The final sketch is then exported and emailed around for review.

Features and Interactions
SketchTop provides a natural interface by eliminating standard GUI tools and replacing them with objects that mimic the behavior of pen and paper. Users sketch with a light pen on the page, within the frame of the canvas, and they manipulate the size, orientation, and location of the canvas using different combinations of the handles. Touching and dragging any combination of two handles simultaneously resizes and rotates the canvas. To delete a
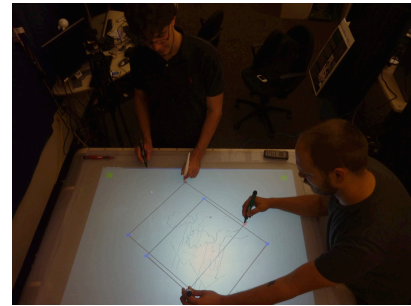
canvas one user touches two handles, and a second user touches and drags a third handle. The copy appears near the original as shown in Figure 3.

USER EVALUATION
We conducted a user study that compared using SketchTop with pen and paper for a collaborative design task.

Methodology
We assigned one group each of five, three, and one person to use either a standard table or SketchTop to design an electrically augmented toilet for people with disabilities. After an interface tutorial, the groups had 30 minutes to complete the task. We recorded their work and observed their collaborative actions. After the session, each group member filled out a questionnaire about the collaboration and the interface. Finally, as a group, the participants took part in an interview about their experiences.

Results
As a collaborative design tool, SketchTop succeeds in providing the ability to communicate ideas to a group. While pen and paper do result in higher-fidelity sketches, due to hardware limitations of our system, the nature of the collaboration remained the same across both systems. Groups used sketches to illustrate ideas, and document design progress the same regardless of the interface they used. They also used the same types of verbal and non-verbal communications across interfaces. For this task, groups collaborated the same way, spent the same amount of time collaborating, and produced equivalent results regardless of the interface.

Users found that creating new canvases, and moving, resizing and rotating them was clear, usable, and useful. Deleting the canvas was not clear, but it was useful once they understood the interaction. Copying canvases was not clear or easy, and therefore, was not used, even though users did consider it important. Furthermore, users would prefer to copy parts of sketches instead of entire canvases. Users also wanted to use the entire frame for manipulating canvases instead of discreet handles, and an active frame could make interactions easier and more obvious.

Discussion

The nature of collaboration changed very little between pen and paper and SketchTop. The desire for features like copy and paste that are not possible with pen and paper indicate how digital tabletops might improve the design process. Given that, the user study illustrates that digital tabletops have the potential to be effective tools for design collaboration and that they can augment collaborative work in ways that people do find useful, but there is still work to be done concerning the implementation of these systems. Towards that end, SketchTop illustrates an interface design that allows simultaneously editing the content of objects and manipulating them.

The study also pointed out another level of interactions that need to be designed and implemented. Users require the ability to interact with parts of sketches to erase and copy and paste single elements. The canvas and page metaphor does work for most people and provides a solid base for designing the interactions and implementing the features that could make SketchTop a viable tool.

CONCLUSION AND FUTURE WORK

SketchTop furthers the research in tabletop application design by showing that an appropriately designed tabletop application can support collocated collaborative design by providing users with the ability to communicate and iterate ideas generated during early phases of the design process. This understanding can lead to further work in how digital tabletops can augment the design process by making it more interactive across disciplines and eventually about how tabletops can play a role in remote collaboration. Furthermore, it develops and points to research that must be done on interaction levels within applications of this sort.

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