

TEAM STORM: Demonstrating an Interaction Model for Working with Multiple Ideas During Creative Group Work

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ABSTRACT

Informal design tools can provide immense value during the creative stages of the design process, e.g., by transforming sketches into interactive simulations. Two key limitations of informal and many other design tools are that they do not promote working with multiple design ideas in parallel or collaboration. In this paper, we present a new interaction model that allows a team of designers to work efficiently with multiple ideas in parallel. The model is grounded in theories of creativity and collaboration, and was further informed by observations of creative group work practice. Our interaction model is fully demonstrated within a new system called TEAM STORM. Results from an initial evaluation indicate that design teams are able to effectively utilize our system to create, organize, and share multiple design ideas during creative group work. The benefit of our model is that it demonstrates how many existing single-user design tools can be extended to support working efficiently with multiple ideas in parallel and co-located collaboration.

Categories & Subject Descriptors

H.5.3 [Information Interfaces and Presentation]: Group and Organization Interfaces – collaborative computing, computer-supported cooperative work, theory and models.

Keywords

Collaboration, Creativity, Reflection, and Re-interpretation.

INTRODUCTION

Computational tools have the potential to provide immense benefits for designers during the early, creative stages of the design process. For example, the emerging class of informal tools [24] can be utilized to rapidly externalize conceptual ideas [18], transform ideas into interactive simulations to enhance communication [2], and manage numerous design iterations [21]; all of which help foster the creative process beyond the use of physical tools (e.g., pencil/paper) alone.

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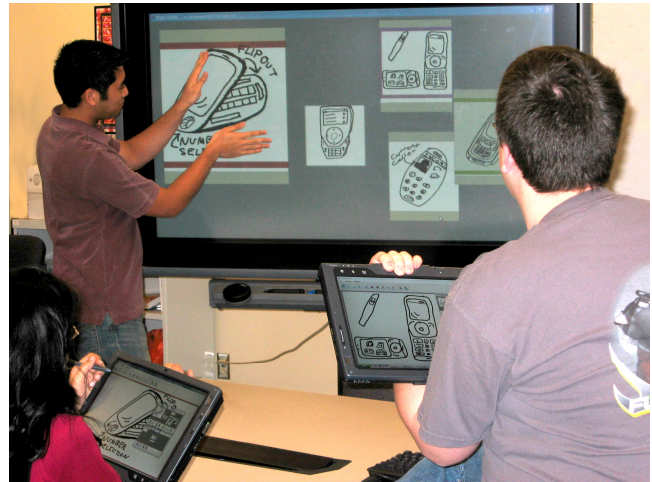


Figure 1. Three designers are using our TEAM-STORM system to explore concepts for a new form factor of mobile device. Our system allows the group to work with multiple design ideas in parallel, supports individual and joint work, and allows designs on the shared display to be edited/controlled from local devices.

Two critical limitations of this class of tools, and many other design tools, are that they do not promote working with multiple ideas in parallel or real-time collaboration. Working with multiple design ideas in parallel allows for re-interpretation of ideas (perceiving new meaning) [22, 25, 34, 37] and reflection-on-action (retrospective thinking) [36]. Designers are thus able to better generate new ideas from existing ones, reframe the design problem from new perspectives, and further understand the inter-relationships between the design problem space and potential solutions.

When considered in context of a design team, the benefits of working with multiple ideas are amplified as members of the team are able to not only re-interpret and reflect on their own ideas, but also *each other's* ideas [25, 37]. The ability to perceive and consider divergent perspectives can help generate new cognitive thought [17], thereby increasing the creative output of the individual and the group [12, 32, 46].

In this paper, we present a novel interaction model that enables a team of co-located designers to work efficiently with multiple design ideas in parallel. The model tightly adheres to a set of broadly applicable design requirements that are grounded in theories of creativity and collaboration

(e.g., see [9, 11, 13, 15, 17, 25, 28, 33]), and were further informed by observations of creative group work practice.

We demonstrate our model within a new, fully functional system (Figure 1) called TEAM STORM (TEAM Support Tool Oriented to Realization of Multiple Ideas). As a core part of our system (model), it provides the use of interactive 2D spatial maps for organizing design ideas and reflecting on the design space, at the level of both the individual and the group; as well as for lightweight transitioning between personal and group work. Our system also integrates use of personal devices for performing individual work in parallel with a large display for joint reflection and discussion.

Our system is grounded in the domain of *sketching*, as it is a common and accepted form of externally conceptualizing ideas for complex design problems [26]. Results from an initial evaluation indicate that design teams are able to effectively utilize our system to create, organize, and share multiple ideas during creative design problem solving tasks.

The foremost contribution of our interaction model is that it demonstrates how existing informal and many other single-user design tools could be extended to support working with multiple design ideas in parallel and co-located group work, which foster the creative process. Also, our existing system can be used in any design or other creative problem solving domain in which sketching, working with multiple ideas, and/or co-located collaboration are paramount.

RELATED WORK

We describe creativity and the creative process, and how our work facilitates that process; and describe how our work builds upon and extends tools that support the creative process and systems that support co-located group work.

Creativity and the Creative Process

Creativity can be characterized as achieving an outcome regarded as innovative relative to existing knowledge [13]. Cognitively, this requires that people be able to form novel associations between disparate memory locations [17].

Creativity can be studied from the perspective of the product, person, or process [46]. For example, researchers have studied factors that correspond with creative products [6] and personality traits and work habits of creative people [8-10]. In contrast, our work seeks to facilitate the creative *process*, from the perspective of the individual and group, as this is where digital tools can have the most impact.

The creative process is often described as a rapid cycle of idea generation and evaluation [45]. As part of this cycle, numerous ideas are generated in rapid succession, followed by periods of incubation and reflection before existing ideas are refined or new ideas are created [17]. Others refer to this as divergent followed by convergent thinking [14].

There are at least four critical elements that, to the quality supported, facilitate the creative process; externalization, the use of alternative representations, working with multiple ideas, and collaboration [24, 25, 32, 34]. Externalization is a process of capturing emergent design ideas, but the *act* of

capturing those ideas often leads to new ideas. Schön refers to this as reflection-*in*-action, where the materials talk back to a designer [35]. Use of alternative representations allows a designer to see emerging ideas from different perspectives (e.g., a 2D floor plan vs. 3D walkthrough), helping to form associations in memory that may not otherwise occur [22].

Working with multiple design ideas in parallel can facilitate the creative process in two notable ways. First, having multiple design ideas immediately available allows for *re-interpretation* [25], where new meaning is perceived [34]. This new meaning can then lead to new ‘moves’ on existing designs or the generation of new designs altogether [9, 35]. Second, being able to view the entire range of diverse ideas attempted enables reflection-*on*-action, a process by which designers develop deeper understanding of the design space and form new directions and perspectives to pursue [36].

Collaboration has at least two considerable benefits for the creative process; decomposition of complex problems into manageable units [1] and the ability to generate a larger number of distinct ideas [27]. The latter enables members of the team to re-interpret and reflect on not only their own ideas, but also *each other’s* ideas. Studies show that groups can produce more creative outcomes than individuals [25, 32, 43], assuming social inhibitors are minimized [12, 29].

Many tools support externalization (e.g., [3, 18, 24]) and alternative representations (e.g., [1]), but there has been little research at the rich intersection of collaboration and working with multiple ideas. Our work demonstrates a new interaction model that fosters these two critical elements of the creative design process; allowing co-located groups to work efficiently with multiple design ideas in parallel.

Tools that Support the Creative Process

Computational tools can add immense value to the creative design process beyond the use of physical tools alone. For example, the emerging class of informal tools can foster the creative process by allowing rapid externalization [18], transforming rough ideas into interactive simulations to aid communication [2], and providing explicit support for managing design iterations [21]. Informal tools generally attempt to combine the rapid and natural interaction of pen and paper with the affordances of computational tools [24].

Two critical limitations of these types of tools in terms of the creative process are they do not support collaboration or working with multiple design ideas in parallel. Our work demonstrates an interaction model that allows a team of co-located designers to work with multiple ideas in parallel. The benefit is that our model could be integrated within existing informal or other design tools – allowing groups to work with multiple design ideas *and* still leverage the value that these tools add in the design process beyond paper.

Researchers have also explored interactions that support working with fine-grained variations of ideas (e.g., images) in existing interfaces [44, 45]. In contrast, our work shows how

to support working with multiple, coarse-grained design ideas in conjunction with co-located collaboration.

Systems that Support Co-located Group Work

Our work leverages and extends research on groupware for co-located users. Groupware provides systems, interfaces, and interactions that allow groups to work with individual and shared artifacts [19]. Many systems support co-located groups, including Co-Lab [39], Dolphin [40], Caretta [42], i-Land [41], Pebbles [31], Dynamo [23] and UbiTable [38]. This area of work has focused primarily on supporting group dynamics, but less on fostering the creative process.

We leverage this area by integrating lessons for supporting flexible group dynamics into the groupware aspects of our system. For example, our system allows groups to quickly share design ideas [16], maintain awareness of each other's ongoing work [20], coordinate group communication [5], and transition between individual and shared work [28].

Our work extends this area of research by demonstrating a new interaction model that allows co-located designers to work efficiently with multiple ideas in parallel. Our model utilizes a large display as a shared visual workspace and interactive 2D spatial maps for sharing, organizing (in both space and scale), and accessing content on the large display. Though 2D maps have been explored in [7, 47], our work is using 2D maps as a means for managing multiple design ideas at the level of both the individual and group; and as a proxy interface for accessing content on a distant display.

OBSERVATIONS OF CREATIVE GROUP WORK

There are many basic requirements for building groupware systems (e.g., [28]), but less is known about how groups work with multiple ideas during creative design tasks. To gain further insights into this practice, and what types of interaction designs might best support it, we conducted observations of several groups working on creative tasks.

Groups

Six groups (3 users each) participated in the study that had already been working together in course or other projects, ensuring that they had an established working relationship.

Groups were recruited from two design domains, three from a course on UI design and three from a course on building design and architecture. These domains were selected as they typically pose challenging, ill-structured problems; require numerous ideas to be generated, shared and refined; and often result in conflict about which direction to pursue.

Users were remunerated for participating, and an additional monetary incentive was offered to the group in each domain that received the highest score, computed as an average of the number of ideas produced and the perceived creativity of the final outcome (as judged by independent experts).

Design Tasks and Materials

For UI design groups, the task was to generate a usable interface for sharing media (audio, images, and video) with friends and for retrieving recommendations on which media

to view. For architecture groups, the task was to produce an original design for a themed restaurant ("space cowboy"). A few parameters of the design task were provided, e.g., descriptions of the target audience, but groups were told that they could pursue any direction desired and should not be concerned about implementation detail or construction costs. Rather, they should focus on exploring creative ideas.

Numerous physical tools were provided; including pencils, colored pens, tracing paper, a large corkboard with pins, colored post-it notes and various sizes of paper. The tasks were performed in a small conference room with a wall-mounted whiteboard and meeting table. Groups were informed that they could use any of the materials as desired.

Procedure and Measures

Groups met with the experimenters to go through informed consent and schedule a time for the task. Design tasks were e-mailed to users the night before the scheduled session, and they were asked to begin thinking about and capturing potential solutions. At the start of the session, groups were given access to the workspace and materials, provided with instructions, and left alone to start working. Sessions were videotaped (with audio), and lasted about 60 minutes.

After the session, users completed a questionnaire asking about their process, how well existing tools support that process, and what type of computer-based environment they would want when working on tasks similar to the one just completed. For the latter, users were asked to sketch and explain their ideal environment as best as possible.

DESIGN REQUIREMENTS

From our observations of the group work, discussions with the users, and a review of the design, problem solving, and brainstorming literature [1, 8, 10, 12-14, 16, 29, 30, 34, 37, 41], we produced a set of requirements for enabling real-time collocated collaboration on creative design tasks:

- R1 *Keep multiple design ideas visible simultaneously.* This allows quick and fluid transitions between divergent (glancing at alternatives) and convergent (refining a design) thinking [17]. For example, during our study, we observed designers placing some (but not all) of their design ideas face up in front of them and, later, pausing work on the current design, glancing at their own or other's ideas in a shared area, and continuing with the same or different design. This rapid cycle of divergent/convergent thinking may be inhibited if too much interaction is needed to access ideas. Designers typically kept each idea on a separate sheet of paper.
- R2 *Provide clearly delineated personal and group spaces* [28]. For example, during the study, designers naturally maintained two work areas. One was a public area in front of (or around) them where design ideas were placed such that anyone could view them. The other area was immediately close to them where they kept design ideas that were not yet ready for public viewing or had been 'discarded' based on prior discussion. A system needs to

support at least these two spaces and allow design ideas to be quickly moved between them.

- R3 *Allow multiple levels of sharing* [38]. In our study, we observed three subtle yet very distinct levels of sharing: *personal*, *show*, and *share*. Personal refers to designs that were kept out of reach and view of the other group members. Show refers to when a user presented an idea by raising the artifact vertically so as to create a shared orientation and maintain the group's focus while still retaining ownership. Share refers to when a design was placed within view and reach of others, allowing them to view or grasp it for editing. A system should provide these levels and enable quick transitions between them.
- R4 *Shared ideas should always remain in the collective consciousness*. A common principle of brainstorming is to defer judgment of ideas for as long as possible [25]. Interestingly, during our study, designers never threw away 'discarded' ideas, only moved them out of sight. During discussions, many designers were adamant that once an idea was created, especially if it had been placed in a shared area, it should always be available as a group resource. Allowing individuals to delete shared ideas would inhibit others from re-interpreting it and be considered socially inappropriate (e.g., a person should not be allowed to delete the ideas shared by others).
- R5 *Allow rapid access to personal and shared designs*. As ideas are often fleeting and short-term memory is very fragile [35], it is imperative for designers to be able to access personal and shared ideas quickly. For example, in our study, designers would create or switch among their own or each other's designs surprisingly often

(every few minutes), shuffle through their evolving stack of personal designs to find a particular artifact, or keep recent designs in front of them for rapid retrieval. Each user often employed their own personal method for organizing their privately-held design ideas.

- R6 *Minimize social inhibitors of group work*. Three inhibitors of creative group work include production blocking (unable to capture fleeting ideas); evaluation apprehension (uneasy about sharing ideas for fear of being judged); and free riding (contributing little to the group task) [12]. For example, when an idea was being discussed, we observed that one designer was typically "in control." Though others would gesture over the design, they did not sketch on it due to not wanting to invade that person's space. But sometimes the designer would lean back, hinting that it was now acceptable to modify the design. Systems should thus allow designers to work jointly on a single idea as well as individually on separate designs to prevent production blocking. Allowing designers to choose when to share ideas (R3) can minimize evaluation apprehension. Though free riding often depends on intrinsic motivation [29], a system could reduce it by showing who has contributed and when / where they have modified shared designs.

These design requirements provided a basis for developing our system. Though our system adheres to other established requirements for groupware (e.g., those in [28, 33]), we felt the above requirements would most influence the design of our system and other systems that seek to support creative group work. Existing systems may address smaller subsets of these requirements, but our contribution is demonstrating an interaction model that more fully addresses all of them.

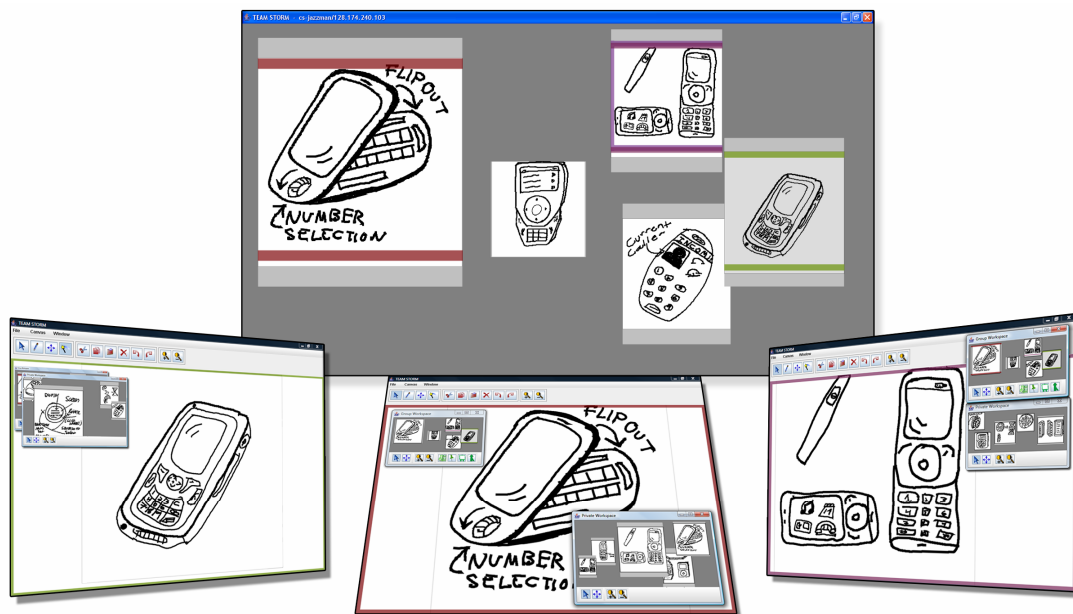


Figure 2. The interface screens on each designer's Tablet PC in Figure 1, and the large display (top middle). The tablets, along with our system, allow designers to sketch on the same or different designs in parallel while the large display provides a shared visual workspace for showing, reflecting on, and discussing design alternatives. The interface on each personal device provides a personal and group workspace window, each of which offers an interactive 2D spatial map for organizing and reflecting on design ideas.

TEAM STORM

TEAM STORM is a groupware system that allows co-located designers (2-5) to work efficiently with multiple design ideas in parallel during the early stages of design, see Figure 2. Our interaction model (interface and device configuration) was developed to address the requirements previously described as well as lessons learned from our study of creative group work, an iterative design process, and feedback from designers on early functional prototypes.

In the next sections, we describe the interface components of our system and how these components support group dynamics during creative work. The interaction design of our system is illustrated in Figures 2-4. In these figures, three designers are exploring form factors and interactions for a next-generation mobile device. However, designers could use our system for any design problem where early ideas can be effectively conceptualized through sketching.

The reader should keep in mind that the contribution of our work is demonstrating an interaction model that allows a design team to work with multiple ideas. The model can be used to extend many existing single-user design tools that add value in the design process (e.g. interactive simulation).

User Interface Components

Our system has 3 main components; canvases for sketching designs, personal workspaces for organizing private designs and a group workspace for organizing shared designs.

Canvases

A canvas represents a single design idea in our system, consistent with many other design tools. For example, in Figure 2, each designer has a canvas selected for editing. A canvas is analogous to a sheet of paper, but offers infinite zooming along with controls for pan and zoom navigation. A designer can sketch directly on the canvas via a Tablet PC or other device that offers pen-based input. As the focus of our work is on working with multiple ideas, we provide a sketching environment that offers only basic operations, but that are sufficient for externalizing conceptual ideas. A designer can create as many canvases (designs) as desired.

Personal Workspace

Each designer has a personal workspace that provides an interactive 2D spatial map for organizing designs in space and scale dimensions. For example, the bottom of Figures 3 and 4 show two designers' personal workspace each with multiple design thumbnails. Like a canvas, the workspace allows for infinite zooming to allow it to grow, as the number of designs and personal organization style require. When a canvas is newly created, a thumbnail representation appears in the personal workspace, and selecting (tapping) a thumbnail makes it the current design in the sketch editor. An important property of the personal workspace is that all designs can be visible simultaneously, to the scale desired, or just a subset selected by zooming and panning the view.

The spatial metaphor offers significant advantages over alternatives such as a temporal or list view. For example,

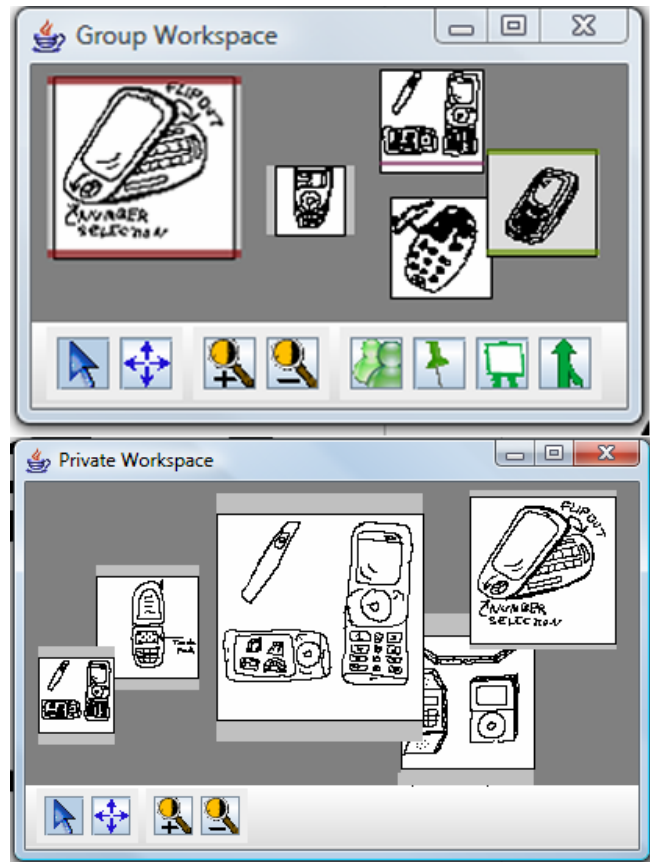


Figure 3. A designer's personal and group workspace window from Figure 2 (middle bottom). She has copied two designs from the group workspace to her personal workspace. Note that she can position and scale the representations in her own personal workspace independent of the other group members to reflect her own perspective on the importance of each idea.

within the workspace, the thumbnail representations can be interactively positioned and scaled to reflect current design thinking or historical progress. Alternatively, if a design idea falls out of favor, its representation can be scaled down and positioned away; whereas when an idea comes into favor, it can be scaled up and positioned near the center. Designs can also be spatially arranged or piled to reflect semantic relationships among them. If desired, a designer may arrange designs temporally (e.g., left to right), or future work could provide controls for switching among various layouts. Further, it allows designers to reflect on specific ideas in relation to the larger collection of ideas generated.

A disadvantage of using the 2D map for organizing ideas is that it requires some screen space. However, the workspace window itself can be interactively resized, which scales the content; repositioned; and opened/closed via menu controls.

Group Workspace and Shared Display

The group workspace allows members of the design team to collectively access, organize, and maintain awareness of the shared designs. It offers the same interaction and resulting benefits as the personal workspace, but now extended to the group. Designers can thus use the group workspace (and their

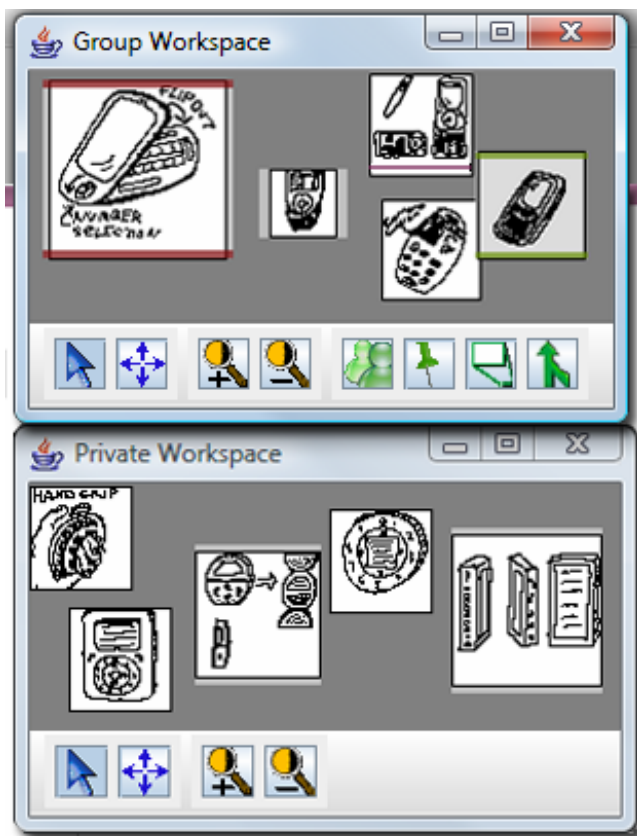


Figure 4. Another designer’s personal and group workspace window from Figure 2 (right bottom). This designer’s view of the group workspace is the same as the one shown in Figure 3, but the personal workspace contains several unshared designs.

personal workspaces) to reflect on and interpret shared understanding of the ongoing design situation [35]. For example, the windows shown at the top of Figures 3 and 4 are of the group workspace, and show how designs have been scaled and positioned to reflect shared understanding. A designer can edit any ‘shared’ design (see next section) by selecting its thumbnail in the group workspace. The group workspace only becomes available when the client application connects to a machine executing our server.

As a designer positions or scales design representations within his group workspace window, e.g., to reflect changes in the group’s favor of the designs, the interactions are fed through to all other designers’ group workspaces. Designers can position and scale different representations at the same time. Each designer is also able to manipulate their local view of the group workspace independent of the others, consistent with the concept of relaxed WYSIWIS [39].

Canvases in the group workspace are also displayed on a screen driven by a machine executing our server. This would typically be a large vertical display (e.g., projected or plasma display), thus offering a persistent shared view of the group workspace for joint reflection and discussion. The workspace on the large display is interactive, allowing any designer to physically move to the display and interact with designs on it.

This is shown in Fig. 1, where a designer has moved to the large display and is discussing a specific idea.

A vertical display is being used for two reasons. First, unlike a horizontal display, it provides common orientation for viewing design ideas, which is especially important for design tasks where numerous artifacts are present. Second, when users in our observational study were asked to sketch their ideal environment for creative group work, almost all of them drew multiple personal devices networked to a large vertical display. We believe that this was due in part to wanting common orientation for shared design artifacts.

A designer is also able to interact with the distant content shown on the large vertical display via the corresponding representations in the group workspace window (a proxy interface) on her local device. For example, as a designer positions and scales a design representation in the group workspace, the corresponding design can be seen moving and scaling on the large shared display (as well as in the other designers’ local group workspace windows). Our use of feedthrough and other awareness cues helps minimize any coordination conflicts. However, in the rare event that two or more designers attempt to move or scale the same shared design at the same time, the last interaction wins.

Supporting Group Dynamics for Creative Work

Our system offers lightweight interaction that supports flexible group dynamics for creative work. This includes the ability to show and share personal designs, re-interpret shared designs, support individual and joint work, present and gesture over designs, and collaborate across sessions.

Showing and Sharing Personal Designs

To discuss or share a design during a collaborative session, a designer drags the design’s thumbnail representation from her personal workspace and positions it within the group workspace on her local device. This causes the design to appear on the shared display at that same relative size and position, and its representation becomes available in the other designers’ group workspace window.

The design defaults to *show* mode, meaning that it can be viewed and positioned by anyone, but only the owner can edit it. This is indicated by graying out the representation in each designer’s group workspace, except the owner’s. For example, in the leftmost interface in Figure 2, the canvas being edited has been placed in *show mode*. On this display, the editing area appears white, while on the shared display (Figure 2) and in the other designers’ group workspace (Figures 3 and 4), the corresponding canvas appears gray.

Should the owner wish to maintain position and scale of the design, he is able to *tack* it to prevent repositioning and scaling. To remove a design in *show* mode from the shared display, its owner drags the representation from the group workspace and drops it back into her personal workspace.

When a designer is ready to fully share a design, he drags its representation to the group workspace (defaults to *show* mode), or selects the representation if already in the group

workspace, and selects the icon from the toolbar for *share*. This removes the disabled appearance of the corresponding thumbnail in the other designers' group workspace.

In our system, sharing a design is permanent, meaning that all notion of ownership is removed from the design and it can never be deleted from the group workspace. However, it can be scaled and positioned out of view, if desired. This interaction is consistent with users' actions and expectations expressed in our study. For example, this would prevent a designer from deleting designs that were shared by someone else, a scenario that was distressing for many of our users.

Re-interpreting Shared Ideas

If a designer wants to modify a shared design, he selects its representation within his group workspace window and it is immediately available for editing in the local interface. In this situation, since the designer is editing a shared design, all local interactions with the design are shown on the large display. This is particularly useful when a designer wants to sketch and verbalize thoughts to the rest of the group, as they can all direct their visual attention to the large display.

If a designer wants to edit a shared design privately, i.e., out of view of others, she drags its representation from within the group workspace to her personal workspace. The design is *copied* (not moved) to the local workspace, with the shared design remaining unchanged. The copied design can then be manipulated as any other design. Figure 3 shows a personal workspace in which multiple shared ideas have been copied. It should be noted that their relative size and prominence differ from the corresponding source designs in the group workspace (shown in Figure 2). By copying, not moving the shared design, it always remains available to the other group members, allows for side-by-side comparisons later in the design process, and preserves a visual design history to reflect on throughout the design process.

To perform a merge operation, a designer selects any number of designs within the group workspace, and then selects the merge command from the workspace toolbar. In response, the system creates a new canvas with the content from each of the designs (preserving originals for later re-interpretation). A disadvantage of our copy and merge approach is that a large number of designs may evolve over time. However the ability to interactively position and scale representations in an infinite zooming workspace should allow large numbers of designs to be efficiently managed.

Supporting Individual and Joint Work

A designer can select and begin modifying any design that is in their personal workspace or that has been 'shared' in the group workspace at any time. This allows each designer to sketch design ideas in parallel via their personal devices.

By selecting the same 'shared' design from their group workspaces, two or more designers can jointly sketch on the same canvas. Each designer is able to control her local view of the design independently, but if the views overlap, each designer's strokes and the bounds of their view ports are

rendered in the other designers' local interface and on the shared display to convey awareness [20]. Each designer is represented by a unique color that is used to render the bounding box. Figures show these colored lines and boxes depicting the view ports of each designer. To mitigate distraction, designers' strokes are queued for a few seconds, and then fade in together. Similarly, when a new canvas is placed in the group workspace, it fades in on all views.

Fostering Group Communication

In our study, we observed that groups would often engage in discussion around a single design idea. To facilitate this, a designer can place any design in the group workspace in *full screen* mode using a command on the toolbar. The design is scaled to fill the large display, drawing the group's attention to it and facilitating manipulation of the idea on the large display. In this situation, each designer's group workspace is not modified to reflect the group display. This allows a designer to disengage from the joint session and work on another idea (it would otherwise be difficult or impossible to select another design in the group workspace as it would be occluded by the one in full screen mode).

Our study also highlighted that designers will often gesture to different parts of each other's designs. Thus, within the sketch editor, a designer can select a 'gesture' mode in which all subsequent strokes are temporarily rendered in the designer's assigned color and fade out over a few seconds. These strokes simultaneously appear and fade out in all interfaces that have a view of that part of the same canvas.

Collaborating across Multiple Sessions

Any designer can save a canvas or current group session via a menu control. Designs in personal workspaces are saved to the respective local machines and designs in the group workspace can be saved locally or to the server. This allows a designer to leave or join a session at any time. As designs in a personal workspace are saved locally, designers can later use the client application to create and refine designs in his office or elsewhere. When a session is re-established, as each client connects, shared designs previously saved are placed in the group workspace, and each designer continues to have access to designs in his personal workspace.

Implementation

Our system was implemented to offer as much flexibility as possible for creative group work. First, our system can be used with any large display, including a projected, plasma, or other display connected to a machine running our server.

Second, the system works with wired or wireless networks. The latter enables ad-hoc collaborations to be formed in any public/semi-public space where there is a large display driven by a machine executing our server. If a large display is not available, our server software could be executed on any machine, including any of the clients. Though a shared visual workspace would not be available, each member of the design team could still view, edit, and share each other's designs through their local group workspace window.

Third, our system was implemented using Java 1.5 and the Piccolo interface toolkit [4]. This should allow the client application and server to execute on any machine, though our system has only been tested on Windows XP to date. A client-server architecture is used and communication occurs using standard TCP/IP. As a result, designers may also connect to sessions from remote locations, if desired.

DISCUSSION

In this section, we describe how our current implementation has met our design requirements, initial user reactions to our system, and other design considerations for our system.

Meeting the Design Requirements

To allow multiple designs to be visible simultaneously, our system shows thumbnail representations of designs in a 2D spatial map. A designer can interactively position and scale the representations, and modify the current view, to see as many (or few) designs simultaneously as desired. Also, this can be achieved in both the personal *and* group context.

To delineate personal and group spaces, we provide two distinct non-modal workspace windows, one for interacting with personal designs and the other for interacting with the group's shared designs. Each window can be sized, moved, and controlled independently; giving a strong sense of two separate spaces. Our system supports three levels of sharing for a design; personal (only available to the owner), show (everyone can view, but only the owner can edit), and share (anyone can view or edit), derived from our observations of creative group work. Only the 'share' level ever needs to be set explicitly as the other levels are set when representations are dragged between the personal and group workspaces.

Rapid access to personal and shared designs is supported by allowing a designer to select a design for editing by simply clicking on its thumbnail within the respective workspace manager. To keep ideas in the collective consciousness, our system uses a model where, once a design is shared, it cannot be removed from the group workspace. If desired, the design can be positioned and scaled out of view. This eliminates the need for tracking ownership and fits groups' social expectations of how the system should function.

Finally, to minimize production blocking, our system allows each designer to utilize their own local device for sketching on any personal or shared design at any time. Our system helps minimize evaluation apprehension as each designer can work on a design on their own personal device, and only show it to others when desired. Free riding is partially addressed by showing cues of each user's activity within the shared space (e.g., which design they are currently editing).

Initial Reactions from Designers

An informal study was conducted to understand how well our system would support groups exploring multiple ideas for a complex design problem, gauge initial reactions to its interface, and understand how it could be improved.

Three groups (2-3 designers each) participated, and were asked to explore early concepts for a mobile device that could

be used by people with slight cognitive impairment. Groups were asked to generate as many realistic solutions as possible within 45 minutes. Afterward, feedback was provided via questionnaires and discussion. Our system also logged each designer's interaction to a file. A short training session was provided and groups were allowed to practice using the tool for a few minutes and ask any questions.

Overall, each group was able to create, share, and manage multiple design ideas with our system, as they worked towards a common solution to the design problem. One group created 23 designs, another group created 4 designs, and the third group created 7 designs. By the end of the sessions, most of the designs had been placed on the large display for group discussion. This was a positive outcome given that none of the designers used our system before.

Designers often utilized the space and scale dimensions in the workspaces as a natural means for organizing designs. For example, each designer averaged about 38 interactions with representations in their personal or group workspace, and zoomed in or out of their group workspace about 15 times each. Though it is difficult to interpret raw numbers alone, designers seemed enthusiastic about using the spatial maps for organization. As one designer wrote, "the ability to layout canvases in an organized way was very useful."

While many designers openly shared all of their design ideas on the large display, others appreciated the ability to work on designs privately. For example, one user wrote "[I liked the] ability to work privately and then share my ideas. I like to keep ideas to myself until it is ready enough to show to the group." Designers also like the ability to drag and drop thumbnail representation between the two workspaces.

Groups were also able to realize different work modes with our system. For example, one group used our system primarily in a joint work mode, where each designer simultaneously interacted with the same shared design. In contrast, the other two groups focused more on creating and interacting with their own personal ideas that would be occasionally shared with the group, but rarely edited jointly.

In addition to these positive reactions, we also discovered several opportunities for improvement. First, designers wanted to create "design groups" within the personal and group workspaces. This would allow each set of grouped representations to be scaled, positioned, and shared as a unit, rather than individually. Second, designers wanted more efficient methods for navigating personal and group workspaces, as panning and zooming became tedious as the number of designs grew. Last, designers wanted the ability to import and edit other types of content such as images and Web pages to complement ideas captured in the sketches.

Overall, results from our study provide very promising, but still preliminary evidence that groups are able to use our system to work efficiently with multiple ideas. Encouraged by these results, a formal study is now being conducted.

Other Design Considerations

The personal and group workspaces are each built using an infinite zooming canvas. As the number of designs grows, it may become increasingly difficult to efficiently navigate and stay oriented within these spaces. One solution would be to support spatial bookmarks, where a designer could navigate to specific landmarks that were previously tagged. Another solution would be to allow keywords to be attached to the designs, and provide a simple search interface.

Because scaled thumbnails are used in each workspace, it may be difficult to tell apart two designs that are similar. A reasonable solution would be to provide a larger callout of a design when a designer hovers over its representation. This would allow the current design to be maintained in the local sketch editor while being able to browse the other designs.

Finally, studies have shown that imposing certain structures on how a group generates ideas (e.g., swapping ideas in short intervals [25, 37]) can help facilitate creative output. However, these structures are often inconsistent with the flexibility that groups typically demand when collaborating with computer tools [28]. Our system was thus developed to provide as much flexibility as possible, rather than enforce any one particular structure of group work. But, if desired, a group could choose to adhere to a certain structure, e.g., share ideas periodically, and realize it using our system.

CONCLUSION AND FUTURE WORK

Informal and other design tools can add value to the design process, e.g., by transforming early sketches into interactive simulations. But many such tools do not adequately support working with multiple ideas in parallel or collaboration, two key facilitators of the creative process. Our work has made several contributions addressing these central limitations.

First, we leveraged design and creativity theory to motivate how working with multiple design ideas in parallel and real-time collaboration can facilitate the creative process, as this enables *re-interpretation* and *reflection-on-action*. Second, from observations of creative group work practice and a review of the design and problem solving literature, we produced a set of broadly applicable requirements for designing systems that support creative group work.

Third, we developed a novel system that largely satisfies these requirements. In particular, our system demonstrates an interaction model that allows groups to work efficiently with multiple ideas in parallel. A core part of the model is that it uses interactive spatial maps for organizing designs, reflecting on the design space, and lightweight transitioning between personal and group work. The model also combines the affordances of personal devices for individual work and a large display for joint reflection and discussion.

Our model demonstrates how informal and other single-user design tools could be extended to allow teams to work efficiently with multiple ideas, fostering creative work. Our system can be used in any design domain where sketching, working with multiple ideas, or collaboration are critical.

We have several directions for future work. First, we want to conduct longer-term studies of how groups utilize our system during the conceptual stages of design, eliciting further principles and interactions for supporting multiple design ideas. Second, we want to explore how to extend our system to support additional types of design artifacts, e.g., allowing thumbnails of Web pages, images, and documents to be manipulated within the spatial maps. Finally, we want to explore how to extend our system to better support asynchronous collaboration during creative group work.

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