# Storage Bins: Mobile Storage for Collaborative Tabletop Displays
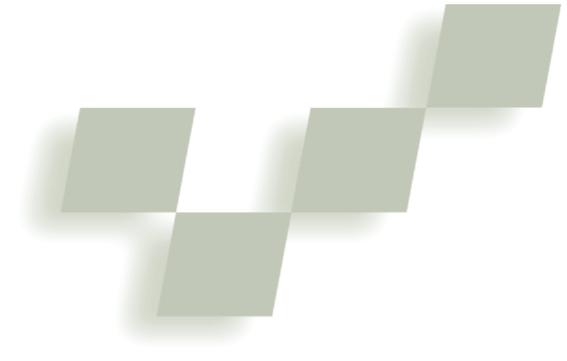
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Traditional tables have long been the preferred work environment for many collaboration tasks such as planning, scheduling, brainstorming, design, and layout activities. Unfortunately, collaborating at current digital tabletop displays is often awkward and frustrating. This might, in part, stem from a lack of suitable tools for organizing and sharing information. The ability to store resource items anywhere in the workspace and move them around can be critical for coordinating task and group interactions on a table. However, existing casual storage techniques for digital workspaces only provide access to stored items at the periphery of the workspace, potentially compromising collaborative interactions at a digital tabletop display. To facilitate this storage behavior in a digital tabletop workspace, we developed the storage bin mobile storage mechanism, which combines the space-preserving features of existing peripheral storage mechanisms with the capability to relocate stored items in the workspace.

A mobile storage mechanism enables access to stored items in the digital workspace. A user study explores the utility of storage bins on tabletop display collaboration.

Tabletop displays and collaboration

While interest in tabletop displays began over a decade ago,[1] recent technological advances have increased the feasibility of these displays and fueled renewed interest in this research direction.[2-4] Borrowing ideas from tiled-projector, high-resolution walls[5] and using recent touch-input technology (http://www.smarttech.com), we assembled a tabletop display that is large (5×4 feet), high resolution (2,048× 1,280 pixels), and supports input from two simultaneous touches. However, constructing a tabletop display is only the first step to providing interactive support for col-

1 State ambiguity is introduced by viewing a button from opposite sides of a tabletop display.

laborative tasks. Accessing digital information via a standard software interface displayed on the tabletop surface can be awkward for a single user and extremely frustrating for a group of users.

While increasing the size of the display surface offers more space for collaborative tasks, standard software interfaces that place items at the display's edges can cause these items to be physically difficult to reach. Altering the display further by placing it horizontally on a tabletop introduces orientation issues because people can approach the display from different sides. Textual information can be difficult to read when viewed upside down or at an angle. Furthermore, the state of standard interface components can become ambiguous when viewed from different angles. For example, the same button can look ready to press when viewed right side up, yet look depressed when viewed upside down (see Figure 1). Thus, we need to reconsider the fundamental components of tabletop interfaces.

We approached this issue by observing how people interact when using traditional, physically based media during tabletop collaboration. We studied collaborators' tabletop interactions during game playing[6,7] and collaborative design[7] activities. These observations help us understand what activities and interactions tabletop groupware should support and help ground our interface designs.

During these investigations, we repeatedly observed the practice of casual piling to facilitate organization and sharing of task resources. This practice involves creating and moving piles in the workspace to facilitate various task activities. Piles were often placed in the periphery of working areas when the contents of the pile were not in use. People also piled items elsewhere in the workspace, actively using the contents of a pile to perform their main activity. For example, during a furniture layout task, collaborators moved piles of paper furniture icons around in the main work area so that different group members could obtain items from the pile as they were creating furniture arrangements.[7]

The ability to relocate piles on the table played a key

role in coordinating task and group interactions during the collaborative activities. In general, when someone moved a pile of items close to him- or herself (that is, to their personal territory[7]), the pile was reserved for use by that person. In contrast, when someone moved a pile of items to a more central location—such as the middle or edge of the table (that is, to the group territory[7])—the pile was typically available for use by all group members. People also took advantage of piling items on convenient and easily movable surfaces, such as the inside of a physical puzzle box lid, to facilitate access to resources where and when they needed them without disturbing other materials in the workspace.

The practice of piling is also useful for individual work. Piles help people organize their work, remind each other of work still to be done, and provide a cognitively lightweight mechanism for storing items that are otherwise difficult to classify.[8] During collaboration, such lightweight organizational methods allow people to focus on the main task activity and their interactions with other group members.

An existing technique for casually storing items in a digital workspace involves scaling workspace items placed inside a visible storage area along the periphery of the main workspace. For example, on Stanford University's interactive wall, any workspace item moved into a storage area spanning the top edge of the display, called the ZoomScape, is scaled to 25 percent of its original size.[5] Similarly, application windows placed in the storage area surrounding the main workspace of the Scalable Fabric desktop system are also reduced in size.[9] Shrinking stored items can help minimize search issues because many small items can often be spread out in an available space before occlusion becomes an issue.

Storage bin basics

We designed storage bins with characteristics that combine design criteria that arose from our observational studies with participant responses during pilot studies. A storage bin's mobility and adjustability in size and shape allow people to share resources and transition between activities. Moving a storage bin allows a person to bring a collection of stored items in and out of the current focus of activity. Expanding and collapsing a storage bin allows people to dynamically customize their working area. When they are actively using a collection of stored items, the storage bin can be expanded to provide easier access to those items. When they are finished with the collection, the storage bin can be collapsed to free up that area of the workspace.

Container capabilities

The contents of physically based media piles during tabletop collaboration often change over time. People create piles of resource items, add and loosely arrange individual items, and remove items individually or as a group (for example, a handful of items might be removed at once). Therefore, storage bins provide the capabilities of a container, allowing people to add and remove items as a group or individually. We also made them resizable to easily accommodate varying amounts of stored items.
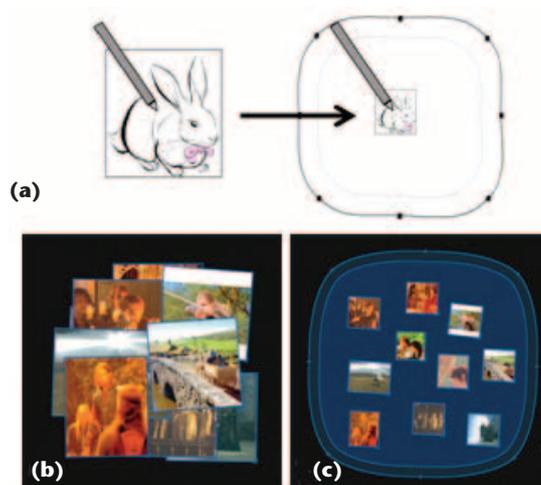
2 (a) Storing an item in a storage bin. (b) The same pile of photos is shown at full size and (c) stored in a storage bin.

Mobility

Our previous observations indicate that the location of a pile of stored items is strongly connected to the items' relationship to the main task. Moreover, piles of items are often moved when someone wants to have easier access to their contents or when they are in the way of the main task. Leveraging the container metaphor, users can relocate all items in a storage bin simply by moving the storage bin.

Visual characteristics

Storing items and accessing stored items are typically peripheral activities. These activities should support the main task but not pull attention away from it. Therefore, we incorporated transparency to make storage bins only slightly visually distinguishable from the background rather than visually dominant. With physically based media, piles of stored items are often loosely and amorphously arranged and are often changing. Similarly, storage bins have loose, curved, and adjustable boundaries. Figure 2c shows a storage bin; note the casual shape and the minimal color usage.

Storage

Borrowing from the ZoomScape[5] and Scalable Fabric[9] storage techniques, we designed storage bins to reduce the size of items placed in them to conserve screen real estate in areas where the main task activity is being performed and to minimize item occlusion. Pilot tests involving participants previously unfamiliar with storage bins confirmed the usefulness of this feature. Based on their feedback, we refined the feature so that, in general, reduction in size is proportional to the object's original size (to 35 percent), but a minimum size (of 80×80 pixels) is maintained to facilitate recognizability. Items are considered to have entered the storage bin when the current touch point (for example, current location of the user's finger or pen) is within the storage bin. Figure 2a illustrates the act of storing an item in a storage bin, and Figures 2b and 2c show two views of the same 10 images, demonstrating how the size reduction can help with occlusion. The full-sized images (see Figure 2b) have considerable overlap and

3 Screen shot of the peripheral storage area.
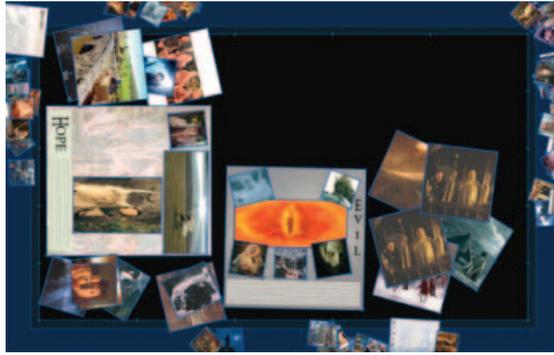
the reduced-sized images in a storage bin (see Figure 2c) are not occluded.

Scaling items as they enter and leave a storage bin requires consideration of how and when the scaling should occur. The pilot tests revealed that people found abrupt scaling jarring; thus, we introduced animated transitions. Scaling animations can be implemented spatially, as an item crosses a particular region, or temporally, during a short period of time upon entering the storage bin. Adding a rim to the storage bin, as shown in Figure 2c, provides a spatial transition zone. However, it's possible for a part of an item to be over the storage bin without the item being considered inside it, since an item is not stored unless the touch point enters the storage bin. If a subsequent touch occurs on a region of the item that is over the storage bin, a timed scaling animation is applied to produce a smooth scaling change since the touch point did not cross the transition zone.

Exploratory user study

To investigate the usability of storage bins, gather design information, and understand the advantages and disadvantages of mobile and peripheral storage mechanisms, we conducted an exploratory user study. In this study, six pairs of university students performed a collaborative photo layout task on our digital tabletop, containing either storage bins or a peripheral storage area that spanned the perimeter of the tabletop workspace.

Layout task

We asked participants to create several photo layouts in a tabletop groupware application. During each task trial, we provided participants with four theme pages (512×512 pixels each) and 100 photos (125×125 or 256×256 pixels each) loosely clustered in the middle of the tabletop workspace. The photos and layout themes used for each task trial related to a popular television show or movie. The goal of each task trial was to create a photo layout for each of the four theme pages in the allotted time.

Collaborative tabletop workspaces

Participants performed the layout task using two digital tabletop workspaces: one containing a peripheral storage area, and one containing several storage bins.

Figure 3 shows the peripheral storage area used in this study. Storing an item (or group of items) in the

peripheral storage area is identical to storing an item (or group of items) in a storage bin. Unlike the storage bins, though, the peripheral storage area is permanently fixed to the workspace edge. Participants could create a larger or smaller storage area by resizing the peripheral storage area. They could resize each side independently, allowing for different-sized storage areas on each side of the table.

Figure 2c shows the storage bins used in this study. We provided nine storage bins in the workspace: one in each corner and five clustered directly between the participants' initial seating positions. The latter five storage bins were intentionally positioned between collaborators, and likely in the way, because we were interested in whether people would move them to a more suitable location and, if so, where that would be.

The tabletop groupware application we used for this study was implemented in Microsoft Visual C# and OpenGL, using the Tao.OpenGL library (http://www.taoframework.com). The application ran on a Xeon 2.80-GHz Windows XP PC and was displayed on our high-resolution tabletop display. To provide software support for multiple users at the tabletop display, we used Tse's DViT-toolkit (an extension of the SDGToolkit[10]).

Aside from the storage mechanisms described previously, the tabletop groupware contained several features useful for performing the layout task. Participants could easily resize the photos and theme pages via a resize handle on the lower right corner of each item. Users could create groups by dragging a bounding box around several items. To address tabletop orientation issues, interactions with items or groups of items used a mechanism called Rotate 'N Translate (RNT).[6] RNT enables an object to be simultaneously rotated and translated in a single fluid motion using a single touch point. For our software, we extended RNT to provide the ability to toss items across the workspace with a flick action performed on an item, allowing users to pass items to someone else or discard them across the table.

Procedure

Participants sat at adjacent sides of the table during the study and stood when it was necessary to reach something across the table. One pair ended up standing on opposite sides of the table for the majority of one of their sessions. All pairs performed the layout task using both storage mechanisms. Half of the pairs used the peripheral storage area first, while the other half used the storage bins first. For each storage mechanism, we first showed each pair how to use the storage mechanism and then gave them 15 minutes to perform a practice session involving one theme page and 45 photos. In the actual task trial, we gave pairs 20 minutes to create the four theme layouts.

We logged the participants' interactions in the workspace to a data file as well as captured them on videotape. Participants also completed a questionnaire after each experimental trial to elicit reactions to each storage mechanism, as well as a postexperiment questionnaire to obtain overall opinions once participants had used both storage mechanisms.

Findings

In general, participants found the storage mechanisms helpful for performing the layout activity. They frequently used each type of storage mechanism during their layout sessions. Participants stored at least half of the 104 photos and layout pages at some stage during the 12 layout sessions. In nine of the sessions, they stored at least 98 percent of the items, and in six sessions, they stored all 104 workspace items.

While participants frequently used each storage mechanism for storing and retrieving items, they manipulated the storage bins more often than the peripheral storage area. Only one pair adjusted the peripheral storage area at all. This pair enlarged the storage area in front of each person by about 25 percent (see Figure 4a) at the beginning of their trial and left it that way for their entire session. Conversely, all six pairs manipulated the storage bins. They used the move feature most often: Across all six trials, the storage bins were moved 75 times. How often the storage bins were moved varied widely between pairs: Some pairs moved them only a few times, while other pairs moved them more than 20 times. The storage bins' reshape and resize features were used less often (reshaped twice and resized 11 times across all trials), but appeared to be extremely helpful when used.

Analysis of participant behavior revealed that two distinct types of organizational activities emerged during the layout task: coarse grained and fine grained. Each trial began with roughly 10 minutes of coarse-grained organization of the workspace where participants sorted photos into theme piles. The second stage of the trial involved actually assembling the photo layouts. This stage involved more fine-grained organizational activities such as arranging the theme pages and candidate photos in the workspace, passing and sharing items, and manipulating the storage mechanisms to gain access to stored photos or to create more room in the workspace.

Each storage mechanism provided different advantages and disadvantages for supporting each organizational activity.

Coarse-grained organization

All six pairs used the storage mechanisms extensively while sorting the photos. A pair typically placed each theme page in a storage bin or in a separate region of the peripheral storage area. For each photo, if it related to one of the four themes, participants stored it with the appropriate theme page. If not, they discarded it into a separate storage bin or in a separate region of the peripheral storage area.

In general, participants used fast, casual interactions during the coarse-grained organization of the workspace. People spent little time tidying up the theme piles. Once they classified a photo, they typically dragged or tossed it quickly into the appropriate pile. Consequently, the large target area provided by the peripheral storage area was well suited to the sorting activity. People were able to quickly drag or toss items across the long, continuous boundary, and the table edge stopped the items from going beyond the storage area. When using this storage mechanism, pairs typically established two
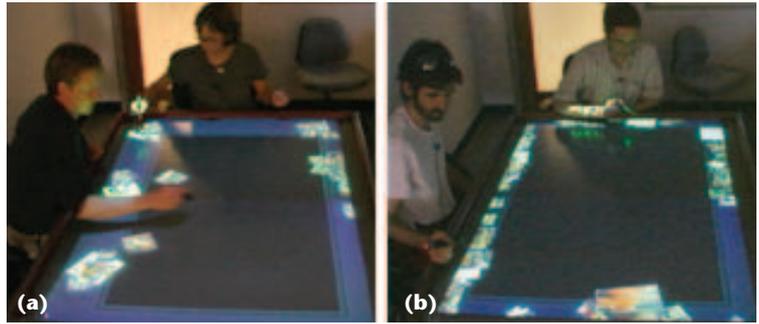
4 Teams sorting photos into theme piles in the peripheral storage area: (a) enlarged storage area in front of each person and (b) two theme piles near participants with piles of discarded photos along the opposite sides.


5 Teams sorting photos into theme piles in the storage bins.

theme piles in the peripheral storage area near each participant, and established one or more piles of discarded photos along the sides where neither participant was seated (see Figure 4b).

Sorting the photos using the storage bins required more accuracy because of their smaller size. Each pair used a separate storage bin per theme and one or more storage bins for the discarded photos (see Figure 5). Although the sorting process could be slower because more accuracy was required, several participants reported that they preferred this storage mechanism for organizing content and moving groups of items. They felt that having distinct storage spaces made grouping easier.

Fine-grained organization

The next stage of the task involved creating the theme layouts. During this stage, participants retrieved photos from the storage mechanisms and then arranged them on the theme pages. When they finished a theme layout, people typically placed the assembled layout and leftover photos back into the storage mechanisms to create space to work on the next theme layout. This stage involved a mix of careful manipulation of the theme pages, photos, and storage mechanisms, and of casual discarding of photos not incorporated into the final layouts. In general, the storage bins supported this mix of activities more effectively than the peripheral storage area. The storage bins provided greater flexibility for supporting the variety of individual and collaborative working styles used by the participants while they were creating the theme layouts.
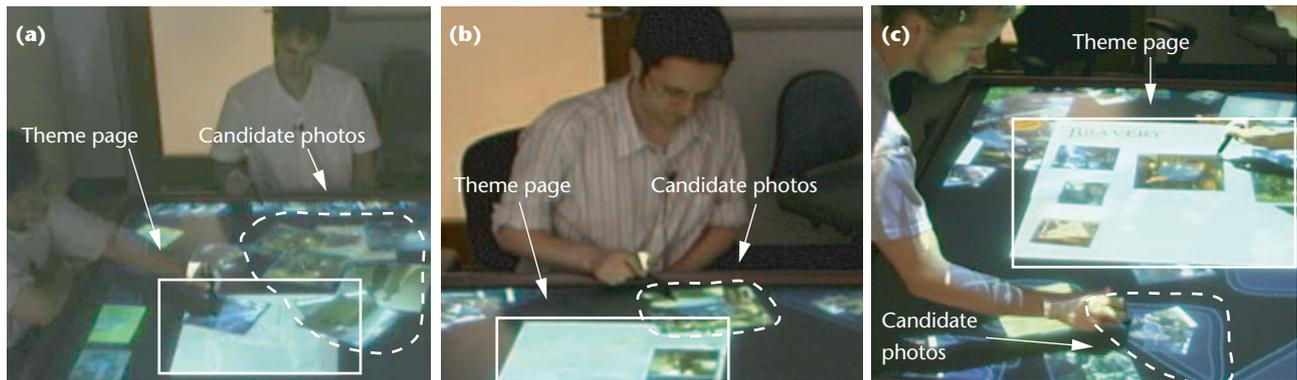
6 The three organizational methods: (a) traditional, (b) previewing, and (c) within storage. In (a) and (b) the candidate photos are being viewed in the main workspace, but in (c) the candidate photos are selected from inside a storage bin.

Organizing the candidate photos. To create the theme layouts, groups had to choose several photos (typically five to eight) from the pile of candidate photos (typically 15 to 20) that they had originally categorized into the particular theme. Participants used several methods to organize the candidate photos in the workspace to facilitate the photo selection process: traditional, previewing, and within storage (see Figure 6). The traditional method involved participants retrieving a group of candidate photos from storage and then choosing from the pile of full-sized photos in the workspace. The previewing method involved participants retrieving one candidate photo at a time from storage for full-size viewing before deciding whether or not it was appropriate for the layout. If so, they added the photo to the layout. If not, they stored it again and retrieved another candidate photo until the layout was complete. The within-storage method involved participants choosing candidate photos directly from within the storage mechanism to add to the layout.

Participants tended to move candidate photos close to the theme page, often just beside it, allowing them to make easy visual comparisons between the current layout and the candidates. When items were stored in the peripheral storage area, participants typically used the traditional method to compare candidate photos with the current layout (see Figure 6a). They also used previewing, but much less often. Participants rarely used the within-storage method when using the peripheral storage area. While the photos in the peripheral storage area were close, and thus easily viewed, people tended to want to view the candidate photos directly to one side or the other of the theme page. Because the photos stored in the peripheral storage area were typically located at the bottom of the theme page, this might explain the more frequent use of the traditional and previewing methods for choosing photos.

In contrast, storage bins easily supported all three methods of organizing candidate photos. People could move a storage bin out of the way if they needed more space for creating a pile of full-sized photos or space to preview photos beside the layout. They could also move storage bins directly beside the theme page (see Figures 6c and 7a). Furthermore, they could expand storage bins to show more candidate photos at once. People often added photos directly to a photo layout from within a storage bin. Choosing photos from within storage allowed people to minimize the space occupied by candidate photos, thus reducing overlaps and facilitating the photo selection process. In general, storage bins provided more support for customization of the workspace, letting people use the organizational method they preferred.

Collaboration styles affect workspace organization. The style of collaboration used by the different pairs also affected which organizational method they used for choosing photos for the layout. Half of the pairs used a divide-and-conquer strategy, with each team member working independently to create a theme layout. The remaining pairs worked together on a single layout at a time.

Participants working together on the same layout tended to use the traditional and previewing methods for choosing photos, regardless of which storage mechanism they were currently using. These methods facilitated group discussion of the candidate photos better than the within-storage method because full-sized photos were easier to share among group members than small, stored photos. Only one pair working together on a layout selected photos directly from within storage (see Figure 6c). This pair was also the only pair that stood during their session, which might have made it easier to share the smaller items because they could easily lean over the workspace.

Participants working independently in the workspace used all three organizational methods. However, the particular method they used during each trial often depended on the current storage mechanism they were using. When using the peripheral storage area, they tended to use the traditional and previewing methods. When using the storage bins, they tended to use the within-storage method. This difference likely resulted because the peripheral storage area provided limited access to stored items across the whole workspace: As mentioned previously, restricting the stored items to the periphery did not suit everyone's working style.

Supporting various collaboration styles. In general, the storage bins were more effective at supporting variations in collaboration styles than the

peripheral storage area because the storage bins enabled localized storage interactions. The mobility of the storage bins let groups working together on a layout position a storage bin centrally so that both participants could access the stored items (see Figure 6c). Also, the combined adjustability and mobility of storage bins allowed people to bring a pile of stored photos into and out of the main focus of activity without interfering with their partners' activities. Several participants took advantage of these features to provide easier access to stored photos and to create more space when photos were no longer needed.

7 Localized use of the storage bins: (a) participants select photos from separate storage bins, (b) the participant on the left collapses a storage bin, and (c) then he selects photos from a different storage bin while his partner continues using the same storage bin.

Figure 7 shows an example of this behavior. This figure shows a sequence of interactions where a participant (on the left) first selects photos from an expanded storage bin (see Figure 7a), then he collapses the storage bin (see Figure 7b), and finally selects photos from a second expanded storage bin which he has repositioned from the opposite table edge to the area in front of him (see Figure 7c). Notice that in Figure 7c he has moved the first storage bin (labeled 1 in the figure) out of the way. This episode illustrates that his interactions have not affected his partner's access to the stored photos in the upper left corner of the table. In contrast, if he had collapsed the first group of photos in a peripheral storage area in front of him, collapsing this group would have collapsed all photos being stored along that table edge, including the photos his partner was using in Figures 7b and 7c. The localized behavior of the storage bins frees each team member from worrying about interfering with their collaborators' interactions.

Design insights

Through this study we gained many insights into design improvements that would be worth investigating. Such issues include

- using of menus and direct manipulation for accessing and manipulating the storage bins,
- facilitating casual, rapid storage interactions while maintaining mobility advantages, and
- including of more spatial organization possibilities.

While participants used the storage bins extensively throughout the layout sessions, the observational data indicated that they might have more frequently moved and resized storage bins if the interface had been more intuitive.

Because tabletop orientation issues make traditional menu selection methods problematic, we chose to use a radial marking-style menu to access the move, resize, and reshape functionalities for storage bins (see Figure 8) and for the resize functionality for the peripheral storage area. For example, moving a storage bin involved touching the control point to reveal the menu, then dragging the touch point to the move menu icon, and then moving the touch point to the new location. We
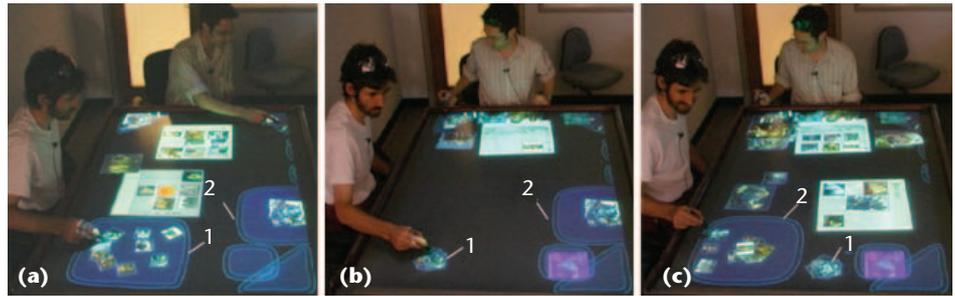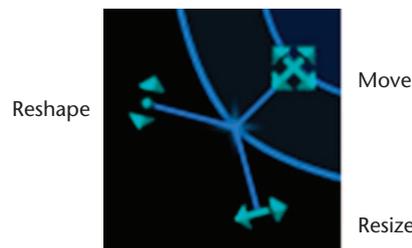
8 Marking-style menu for the storage bin.

chose this menu design because it offered an orientation-independent control, and similar marking-style menus have proved useful on other touch-input large wall displays.[5]

However, the video data revealed that many participants did not find these menus intuitive. Several participants repeatedly tried to move the storage bins by touching an empty area in a storage bin and dragging. This might have occurred because the photos and theme pages could be moved by a touch-and-drag action. Several people also tried to resize the storage areas by dragging the control point itself instead of selecting the resize menu. Providing direct-touch interactions that involve dragging on any empty area inside the storage bin to move it and dragging on a control point to resize would appear to provide a more intuitive interaction based on participants' behavior. Few people attempted to reshape the storage bins, though it's not clear whether this was due to the difficulty of using the menus or whether reshaping was an unnecessary feature for this task.

The video data also revealed that we need to reconsider the method for handling stored items during resizing operations. Collapsing a storage bin currently uses a physical metaphor of collecting up the stored items as the boundary sweeps inward, pushing photos toward the center. However, when the storage bin is subsequently expanded, the photos remain clustered in the center (see Figure 9, next page). This metaphor facilitates creating space for new items; however, it requires manually spreading out the clustered items if someone wants to later search the items.

One alternative to the current expand-and-collapse interaction is to use a stretchy fabric metaphor, which would keep stored items at the same relative distance from each other and the storage bin center as the boundary moves. Another alternative is to return all displaced
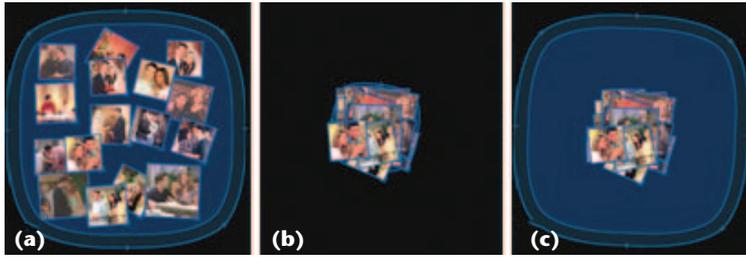
9 Collapsing and expanding storage bins: (a) the initial storage bin, (b) the collapsed storage bin, and (c) the storage bin re-expanded.

10 Attachable storage bin docked to the edge of the workspace.

items to their original locations when a group is subsequently expanded after a collapse. These alternatives need further investigation.

The video data also revealed that including both spatial and temporal transitions for scaling is likely unnecessary. Participants typically placed items either completely inside or completely outside of the storage bins, rarely leaving them in the transition zone. When tossed photos landed in the transition zone, people typically pushed them fully inside. Thus, it appears that scaling items using only the timing mechanism might be sufficient for boundary crossings. Timed scaling alone provides a smooth visual effect and eliminates the spatial transition zone, freeing up additional space.

Creating a hybrid storage mechanism could provide the benefits of both mobile and peripheral storage mechanisms. Extending the mobile storage bin design to allow it to dock to the workspace edge would provide the advantages of both storage mechanisms (see Figure 10). The concept of an attachable storage bin is similar to a toolbar that can float or be docked to a window edge, often seen in many popular development applications.

While participants found storage bins useful for selecting photos during the layout task, enhancing them with pile management features could provide further support for organizing and searching large collections of items. Several participants commented that they would have liked the ability to automatically arrange the stored photos so they did not overlap.

Pile management techniques could help users automatically spread the pile for easier visual scanning. For example, stored items could be arranged in a grid formation, potentially ordered by some criteria, such as the date of a photo[11] or by how recently an item was stored. Alternatively, a spreading gesture[12] used over the stored items to invoke a spacing algorithm would automatically arrange the stored items to minimize occlusion.

Conclusions

The development and preliminary evaluation of the storage bins mobile storage mechanism highlights several important issues for the future development of collaborative tabletop interfaces. This work demonstrates that interface tools like storage bins must be flexible enough to support the evolving needs of a group task. Also, tabletop interfaces must support the numerous individual and collaborative approaches used to complete a group task. Our future work in this area will focus on providing tools that support variations in individual and group interaction styles, as well as enabling localized interactions in the workspace, as this feature appears to provide group members the freedom to perform both independent activities and joint task work during tabletop collaboration. ∎

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