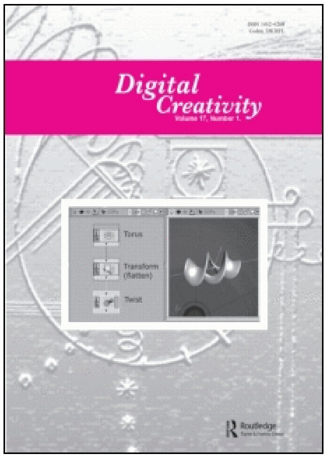

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Interacting with piles of artifacts on digital tables

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Interacting with piles of artifacts on digital tables

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Abstract

Designers and architects regularly use piles to organise visual artifacts. Recent efforts have now made it possible for users to create piles in digital systems as well. However, there is still little understanding of how users should interact with digital piles. In this paper we investigate this issue. We first identify three tasks that must be supported by a digital pile—navigation, reorganisation and repositioning. We then present three interaction techniques—called *HoverDeck*, *DragDeck* and *ExpandPile* that meet these requirements. The techniques allow users to easily browse the piles, and also allow them to move elements between and within piles in an ad-hoc manner. In a user study that compared the different interaction techniques, we found that *ExpandPile* was significantly faster than the other techniques over all tasks. There were differences, however, in individual tasks. We discuss the benefits and limitations of the different techniques and identify several situations where each of them could prove useful.

Keywords: digital piles, early stages of design, interaction techniques, pen input, seamless interfaces, tabletop interaction.

1 Introduction

Most designers and architects collect sketches, drawings and photos over time and use them as inspirational material for new projects. They often flip through their collections to remind themselves how they approached an earlier project, or to find images that might inspire them for their current work. Typically, people spread out these collections on tabletop surfaces to look for useful material (Keller 2005).

As a designer's collection of visual material grows, s/he tends to pile them into loosely structured groups and leave them on a work surface. In general, designers do not explicitly title these piles, and do not arrange the materials in any particular order (Malone 1983). Piles of artifacts, therefore, can create a cluttered desk—and yet, when any change is made to the apparent muddle of material, serious disruptions often occur to workflow (Kidd 1994).

There are several advantages to piling documents. The most obvious is that piles allow designers to easily access required materials (Kidd 1994): the spatial layout conveys important information about the relevance of the pile to the current task, and actively used piles are closer to the designer's active work area while piles that are rarely used are farther away. Furthermore, piles serve as inspirational and creativity supporting tools (Keller 2005; Muller 2001) and also overcome the need to explicitly classify or categorise new material. Finally, piles serve as external representations of context, reminding the designer of ongoing tasks and projects

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(Bondarenko and Jensen 2005).

Recognising these benefits of piles, recent digital systems have started allowing designers to pile relevant materials. For example, in the *VIP* system (Aliakseyeu 2003), designers are allowed to load images into the system and maintain workbooks of related images, with each workbook acting as a digital pile. While these systems allow users to create piles, however, they do not adequately capture the flexibility and interactional fluidity that is evident with physical piles. For example, one of the benefits of piles is that users can easily rearrange the elements of a pile—but most digital piles do not allow direct and simple rearrangement.

In this paper, we identify three basic interaction tasks that should be supported by digital piles (navigation, reorganisation, and repositioning), and then present three new pen-based interaction techniques (*HoverDeck*, *DragDeck* and *ExpandPile*) that meet these requirements. In the first two techniques, the user opens a pile like a deck of cards and interacts with it by hovering or dragging the pen. The third technique is an extension of the *Cabinet* system (Keller, Hoeben and van der Helm 2005) and opens the pile into thumbnail images that the user can quickly scan and rearrange. All three techniques allow users to easily move material within and between piles.

To determine basic differences between the three new techniques, we carried out a user study with professional designers and design students. We gathered both performance and subjective data. We found that *ExpandPile* was the fastest interaction technique overall, and that most users preferred it. However, both preference and performance varied with the task. We discuss the implication of these findings for the design of digital piles, and present a set of design recommendations.

2 Piles and knowledge workers

With the concept of a paperless office still remaining a distant dream, many researchers have studied the organisation of physical desks and personal document management systems (Malone 1983; Kidd 1994; Whittaker and Hirschberg 2001; Bondarenko and Jensen 2005). Independent of this, many researchers have also looked at the designer's work area and made many suggestions on how to design tools that provide better support for the early stages of design (Aliakseyeu 2003; Keller 2005). We find that looking at the literature in both areas can give us a rich set of requirements for interacting with digital piles.

Knowledge workers solve problems and generate outputs largely by resorting to structures internal to themselves rather than by resorting to external rules or procedures (Kidd 1994). From the above descriptions, it is clear that designers and architects are excellent examples of knowledge workers and most findings on desk organisation for knowledge workers should hold for this group as well.

Malone (1983) identified two major units of desk organisation—files and piles. In files elements are explicitly titled and organised in some systematic order sometimes with the file itself having a title. On the other hand, in piles elements are not explicitly titled and generally not arranged in any particular order. Most often the pile itself has no title. Kidd (1994) analysed the typical desk organisation of a knowledge worker and notes that many have extremely cluttered desks and floors filled with different piles and yet are seriously disrupted by changes made to this apparent 'muddle'.

In (Bondarenko and Jensen 2005; Whittaker and Hirschberg 2001) the authors note that most knowledge workers look through a pile and sometimes move an element to the top of the pile as a reminder of a certain activity or move them to another pile to better manifest their internal representation of the relationship between elements.

Many authors (Kidd 1994; Bondarenko and Jensen 2005; Keller 2005) have noted that when interacting with piles users usually have some other task at the center of their attention and momentarily require inspiration from the elements of the pile. Furthermore, Kidd (1994) and Bondarenko and Jensen (2005) note that most piles are scattered in the users' working area and the spatial location of the pile carries important contextual information about the value and use of the pile. For example, 'hot' piles are closer to the users' current work area, while 'warm' piles are farther away from their active work area. It is thus desirable that users can interact with the piles irrespective of their screen location.

3 Piles and the creative process

Creativity is a mental process involving the generation of new ideas or concepts, or new associations between existing ideas or concepts (Wikipedia 2006). There is extensive literature on creativity. Shneiderman has presented three perspectives on creativity according to different approaches: the structuralists, situationalists and the inspirationalists (Shneiderman 2000). Structuralists see creativity as the result of orderly approaches, stressing the importance of studying previous work and using methodical techniques to explore the possible solutions exhaustively. Situationalists see the social and intellectual context as key factors in creativity. According to Shneiderman, Csikszentmihalyi's view on creativity falls under the approach of situationalists. Csikszentmihalyi claims that creativity does not happen inside people's heads, but in the interaction between a person's thoughts and a sociocultural context (Csikszentmihalyi 1993). Inspirationalists emphasise the "Aha!" moments in which dramatic breakthrough magically appears. Brainstorming, free association, lateral thinking and divergence are promoted by inspirationalists. De Bono's lateral thinking (De Bono 1973) advocates strategies for looking at the problem with different eyes, from a different perspective in order to break away from the existing mind set. Within this framework, designers use different techniques to help them support their individual creative processes. As an example, lateral thinking is promoted by techniques such as the use of mood boards (Garner 2001), which designers have identified as an important activity for their work (Lucero 2006). Mood boards promote creativity by using photographs and other expressive aids that designers collect over time. The ability of being inspired by these materials and the environment where the materials are kept seems to be an important aspect in relation to creativity for designers.

In design, creativity mainly relies on visual thinking (McKim 1980). Often designers make situational discoveries by inspecting different visual materials like sketches, photos and drawings, they see/discover new relations and features that suggest ways to refine and revise their ideas (Suwa and Tversky 1996; Aliakseyeu 2003). Moreover visual materials are often used by designers to get inspired for new ideas and for creating collages (Muller 2001; Aliakseyeu 2003; Keller 2005).

Many studies of designers have confirmed the importance of visual information and collections of different visual materials (Keller 2005). These materials are often stored at the workplace itself, in highly individual and (semi)-organised ways (Kolli et al. 1993; Keller 2005). Keller (2005) observed several workplaces of professional designers and found that workplaces contained different ways of storing visual materials of different types (see Figure 1):

cupboards filled with visual materials; stacks on the floor; posters, notes and artifacts on the walls; reading tables filled with magazines (both stacked and laid out).

This organisation of materials is similar to the earlier description and analysis of piles for knowledge workers.

Figure 1. Workspace of a designer.

Piles, therefore, in addition to the advantages identified in the previous section, are also creative tools for designers. Piles support situational and inspirational encounters while browsing through materials, as opposed to the standard structured folders where the chance for such encounters is quite low. Piles can thus be viewed as not just an inspirational tool but as a brainstorm tool that boosts the creativity of the designer. It is therefore essential for designers to be able to create and interact with digital piles in a manner that is as easy as the real-world counterpart.

3.1 Requirements for pile interaction

Based on our review of the literature on desk organisation for knowledge workers and early stages of design we can synthesise the main requirements for design of techniques for interacting with digital piles.

1. [Reorganise] Able to easily regroup elements to form new piles.
2. [Reposition] Facilitate fast re-structuring of elements within a pile.
3. [Navigate] Facilitate fast navigation within a pile.
   - [Browsing] Unstructured navigation without clear goal.
4. Support the above functionalities without making the users reposition the spatial location of the pile.

4 Interacting with hidden content

If a user needs to interact with a digital pile s/he needs to be able to quickly assess the hidden elements of the pile and navigate through them. Several approaches have been proposed in the literature and commercial systems to address the issue of revealing and interacting with hidden content for both desktop applications and for design specific applications.

A popular approach among research systems is to use transparency to show obscured content (Bier et al. 1993; Harrison et al. 1995; Cox et al. 1998; Gutwin et al. 2003). Bier et al. (1993) proposed an idea of a see-through interface, which allows a user to see and interact with a canvas through interface widgets. Cox at al. (1998) proposed a system where the global overview of the large visual workspace (for example, a map) is showed semi-transparent on top of the viewport, through an exploratory study they found that people can use such a system and are able to switch between the two layers. Ishak and Feiner (2004) presented an idea of a content-aware transparency where parts of the window that are assumed to be unimportant are made transparent. Baudisch et al. (2004) show that rather than using single transparency value, using multi-blending with different blending parameters for different interface features results in better user performance. While some of these approaches are specific to desktop applications, the key idea here is that transparency and multi-blending can be used effectively to reveal hidden materials in the piles.

A different approach has been adopted by some of the commercial software packages. The *Mac OS* spring-loaded stacks use a spring metaphor. By clicking on (or dragging over) a stack it springs vertically showing all images (documents) that are in the stack (Mandler et al. 1992).

A similar idea of showing all hidden elements by expanding it is taken by the research prototype system *Cabinet* (Keller, Hoeben and van der Helm 2005) which allows users to create and maintain collections of images. Images are kept in piles (stacks), and a user can interact with an element of any pile by expanding it. When the pile is expanded all images that are in this pile are presented in the form of thumbnails. The key aspect of this approach is to use more screen real-estate to reveal all the content to the user.

The two approaches have their benefits and limitations. Using transparency allows users to perform the interaction without disrupting other parts of their workspace. It also means we can support interaction techniques that are more subtle and lightweight using pen pressure (Ramos and Balakrishnan 2005; Ramos, Boulos and Balakrishnan 2004), hover or tilt (Wigdor and Balakrishnan 2003) sensors. When users expand the pile to interact with them they would need to initiate interaction explicitly with the pile and the pile expands to occupy portions of the workspace that were not previously used by it. This active engagement leads to a more explicit interaction with them which might be faster but require more user effort.

It is not clear if there is a clear preference for one interaction style over the other. In the next section we describe some of the techniques we developed to study the benefits and limitations of the different styles to interacting with digital piles.

5 Proposed interaction techniques

The techniques described here are based on how the pile reveals its elements to the user and how the users can interact within and between piles.

We used two different concepts to reveal the elements of the pile. The first is to expand the pile to reveal all its elements making it clear to the user what its contents are. In the second case we used transparency to allow users to look through the various elements of the pile. The pile opens like a partially revealing deck of cards and the user can at any time change the transparency to view the top content of the pile or directly access a partly revealed element by selecting it.

We describe three techniques; two of them—*HoverDeck* and *DragDeck* are based on the transparency idea, while the third *ExpandPile* is based on the idea of expanding the entire deck to reveal its elements. *HoverDeck* uses a lightweight gesture using the pen hover mode while the others use a more direct interaction gesture by dragging and using pen pressure to interact with the elements.

5.1 *DragDeck*

The user starts interacting with a pile by touching the pile with the pen. Upon touching, the side closest to the pen slides open to reveal the hidden elements of the pile (see Figure 2). When the user continues to maintain contact with the surface and move the pen s/he will browse toward the bottom of the pile. The pen contact is used to indicate to the system that the user intends to browse (see Figure 2) through the pile while the pen movement indicates browsing direction. As the user moves the pen the visible layers become transparent to reveal hidden layers along the direction of the pen movement. After sliding open a pile the user may also quickly browse to any particular image by directly clicking on a visible part of it.

By pressing the pen button a user can reposition the currently visible image to the top of the pile, and by moving the pen orthogonal to the browsing direction the visible image can be dragged out of the pile for reorganising or active use. The user can move active images to different piles by a simple drag-and-drop. Dropping a new image onto a pile results in the image being added to the top of the pile. Table 1 shows the user's action corresponding to the main interactions of 'navigate', 'regroup' and 'reorganise' identified in Section 2.1. In this technique the pile itself does not occupy a large screen real-estate.

5.2 *HoverDeck*

In the *HoverDeck* technique users start with opening the pile in a similar way to the previous technique. Once the pile is open (Figure 2) the user can browse through the pile by hovering (see Figure 3 and Table 1) the pen on top of the pile. The hover direction decides the direction in which the hidden images become visible. When an interesting image is visible the user can select the image by touching it. A selected image can be repositioned to the top of the pile by lifting the pen off the surface. The selected image can also be moved out of the pile by dragging the pen out of the pile. When the image leaves the pile it becomes an active image that can be used by the user or can be reorganised in another pile. When a new image is dragged into the pile it is placed on top of the pile.

5.3 *ExpandPile*

In this technique when the user touches a pile, the entire pile expands to reveal all its elements in a manner similar to the *Cabinet* system. Elements are scaled to fit within the workspace or the designated area for the pile. The images can be collated to reform the pile by clicking on empty parts of the workspace or click any of the images. If the pile is closed by clicking on a particular image this image will be repositioned to the top of the pile. Users can remove an image from the pile by touching the image and dragging the pen on the workspace without lifting it. An image that is removed from the pile becomes an active image that the user can work with or can be reorganised into a new pile by dropping into the pile. When a new image is dropped onto a pile the image is placed at the top of the pile. Table 1 shows a sequence of actions the user performs when using the *ExpandPile* technique.

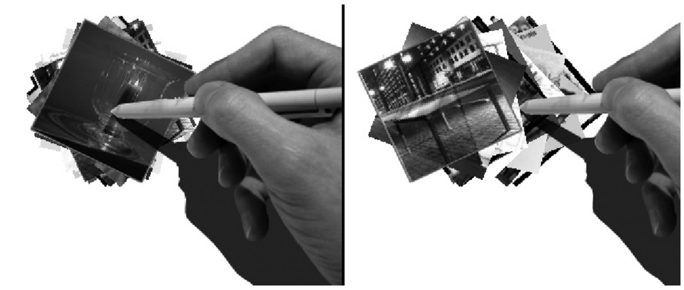

Figure 2. Different views of piles, *DragDeck*. A closed pile (left) and an open pile ready for browsing (right).

Figure 3. Different views of piles, *HoverDeck*. A closed pile (left) and an open pile ready for browsing (right).

Figure 4. The pile expands to reveal all hidden images. Left: pile is closed with 45 images. Right: pile is expanded when the user touches the top image of the pile.

		Interaction Technique		
Task	**Actions**	***DragDeck***	***HoverDeck***	***ExpandPile***
Navigate	Open pile	*touch with pen*		
	Browse	*drag*	*hover*	*look*
Reposition	Put image on top	*press button on pen*	*1.touch with pen 2. lift pen*	*touch with pen*
Reorganize	Remove from pile	*move orthogonal*	*touch with pen*	
	Move to other pile	*Drag*		
	Release	*lift pen*		

Table 1. Summary of interaction techniques, tasks and actions.

Figure 5. Experimental setup.

6 User study

We conducted a user study to compare these three interaction techniques all of which allowed users to navigate, reposition and reorganise piles.

6.1 Apparatus

A tabletop system was set up using a desktop PC, projector and UltrapadA2 Wacom tablet. The PC controlled a top-down projector projecting an image of size 65 x 45 cm (1024x768 pixels) on a pen-based Wacom digitiser also connected to the PC (Figure 5). The size of the digital table reflected the average size of a typical medium-sized desktop table.

6.2 Tasks

As was pointed out earlier, the most important and relevant tasks while working with piles are navigate, reposition and reorganise. It is also important that users are able to perform these activities without repositioning the piles. In order to test performance in these three activities we varied the task in a way that forced participants to perform all three activities.

Navigating

The first task was to browse through the pile and find an image which contained a certain shape. In addition to this specific shape the image also contained a button code (for example [F1]). The subjects were asked to click this button on a keyboard. The subjects were informed in advance about possible button options (from [F1] to [F6]). This was done to reduce the time needed for locating a specific button on a keyboard. Trials were considered successful if the correct button was pressed. We varied the buttons so that the user had to put more effort into browsing the images rather than just attempt simple pattern recognition. In general, users don't know exactly what they are looking for until they find it and this task reflects that situation.

Repositioning

The second task was to organise a pile. Two numbered images (1 and 2) were hidden in the pile. Subjects were asked to find these images and put them on top of the pile, so that the image with number '1' is on top of the pile followed by the image with number '2'. This reflects how users sometimes browse through a pile and move certain elements to the top of the pile to actively remind them of certain activities or serve as inspiration material. In our trials users were asked to hit the [Enter] key to complete the trial. This was done so that they can judge that the task is finished rather than let the system make this judgement for them.

Reorganising

The third task was to reorganise two piles. Subjects were asked to compare two piles, find the image that is common to both piles and move it from pile one to pile two so that at the end of the task pile two contained two copies of the same image. In our trials users were asked to hit the [Enter] key to complete the trial. This was done so that they can judge that the task is finished rather than let the system make this judgement for them.

6.3 Design

The experiment was conducted with 8 subjects (1 female and 7 males) between the ages of 18 and 31. We had 3 left-handed and 5 right-handed subjects. We did not test them for handedness but they used their most preferred hand to control the pen. All subjects had previous experience with graphical interfaces and were either professional designers or students from an industrial design department. All users were tested individually. The experiment used a 3x3x2x3 within-participants factorial design with a variety of planned comparisons. The factors were:

- technique (*DragDeck*, *HoverDeck*, *ExpandPile*);
- task (sort, reorganise, navigate);
- size of the pile(s) (15 images, 45 images);
- location of pile (top left, top right and center).

The number of trials per technique, task, size and location was different depending on the task. This was done to limit the overall time taken to complete the experiment to within one hour. For the first task participants completed one training trial and five test trials, in the second and third tasks participants completed one training and 3 test trials, for a total of 54 training trials and 198 test trials. The order of techniques, locations and size of piles was mixed to balance any learning effects. The order of tasks was: navigating, repositioning and reorganising. The entire experiment took about 70 minutes.

At the end of the experiment participants were also asked to complete a questionnaire to rank the different techniques in order of preference and comment on the overall usefulness of the techniques in their workplace. Trial completion time was used as the main quantitative measures to compare the different techniques.

7 Results

We used two performance measures to evaluate the different interaction techniques—mean completion times, and subjective preference scores.

A total of 35 trials were deleted from the analysis due to errors in task completion. Errors occurred for different reasons in each task. In task 1 errors occurred when the users pressed the wrong key. A total of 17 errors were committed (7—*HoverDeck*, 2—*DragDeck*, 8—*ExpandPile*). In tasks 2 and 3 errors occurred when the users hit the [Enter] key by mistake before completing the task. A total of 18 such errors were committed (10—*HoverDeck*, 2—*DragDeck*, 6—*ExpandPile*). The trials were deleted because we felt this was a consequence of the experimental design and not of the interaction technique itself. We discuss this further in the next section.

7.1 Time

Overall performance

The overall mean completion time across all conditions was 9.920 seconds (standard deviation = 8.643 seconds). One-way repeated-measures ANOVA showed that interaction technique had a significant effect on the trial completion time ($F_{2,69}=11.228$, $p<0.001$). *ExpandPile* was significantly faster than the other techniques, followed by *DragDeck* amd *HoverDeck*. There was no significant difference between last two techniques.

Navigating

The mean completion time for navigating was 7.911 seconds (standard deviation = 7.999 seconds). One-way repeated-measures ANOVA showed that the interaction technique did not have a significant effect on the trial completion time for navigating task ($F_{2,21}=0.703$, $p<0.506$).

Figure 6 shows the mean trial completion times with standard error for all interaction techniques in this task. As can be seen from the figure, *ExpandPile* was the fastest technique, followed by *DragDeck* and *HoverDeck*. The differences are, however, not significant.

Repositioning

The mean completion time for the repositioning task was 8.518 seconds (standard deviation = 6.149 seconds). One-way repeated-measures ANOVA showed that the interaction technique had a significant effect on the trial completion time for repositioning ($F_{2,21}=12.339$, $p<0.001$). As seen in Figure 6, *ExpandPile* is significantly faster than other techniques followed by *HoverDeck* and *DragDeck*. There was no significant difference between *HoverDeck* and *DragDeck*.

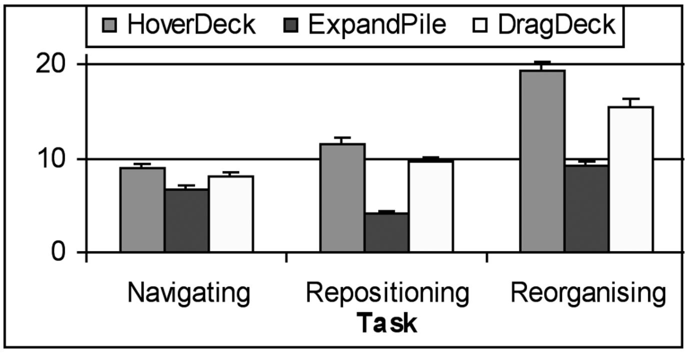

Figure 6. Mean trial completion times with standard error of interaction techniques for navigating, repositioning and reorganising tasks.

Reorganising

The mean completion time for reorganising was 14.660 seconds (standard deviation = 9.943 seconds). One-way repeated-measures ANOVA showed that the interaction technique had a significant effect on the trial completion time for reorganising task ($F_{2,21}=11.961$, $p<0.001$).

As can be seen from Figure 6, *ExpandPile* was the fastest technique, followed by *DragDeck* and *HoverDeck*.

Effect of pile position

One-way repeated measure ANOVA showed that pile position did not have any effect on trial completion times ($F_{2,21}=0.668$, $p<0.523$). Figure 7 shows the mean trial completion time per pile position.

Effect of pile size. One-way repeated-measures ANOVA showed that the size of pile had an overall significant effect on the trial completion ($F_{1,14}=13.737$, $p<0.001$). Separate analysis of each technique also showed the significant effect of pile size (*ExpandPile*—$F_{1,14}=20.170$, $p<0.001$, *DragDeck*—$F_{1,14}=12.180$, $p<0.004$, *HoverDeck*—$F_{1,14}=7.226$, $p<0.018$). Figure 8 shows the mean trial completion times with standard error for all interaction techniques for two pile sizes.

7.2 Subjective preference

At the end of the experiment participants were asked to rank each technique based on perceived control, tiredness, speed, overall preference and preference for each task. Each technique was assigned a number from 1 to 3 with 1 being best and 3 being worst. *ExpandPile* and *DragDeck* were ranked first by the same number of participants (4), *HoverDeck* was least popular (none ranked it as a most

preferable technique). However, in ranking the techniques for each task, for the navigating task, four out of 8 participants preferred *HoverDeck*, while *DragDeck* and *ExpandPile* were each only preferred by 2 participants. For the repositioning task, *ExpandPile* was preferred by all participants and for reorganising, *ExpandPile* and *DragDeck* were equally preferred (each was ranked first by 4 participants).
Figure 9 shows the mean value for the ranking of each technique.

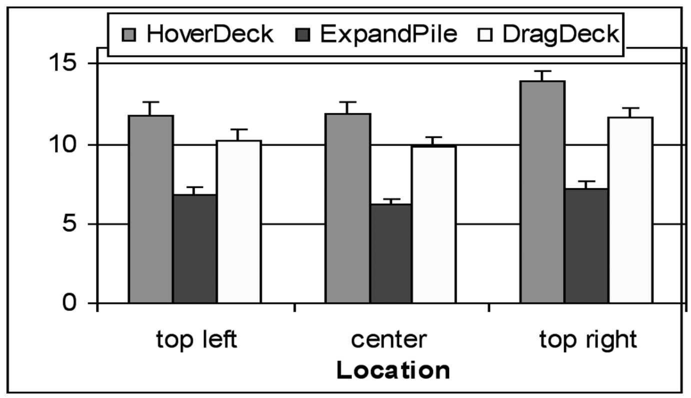

Figure 7. Mean trial completion times with standard error for different locations.

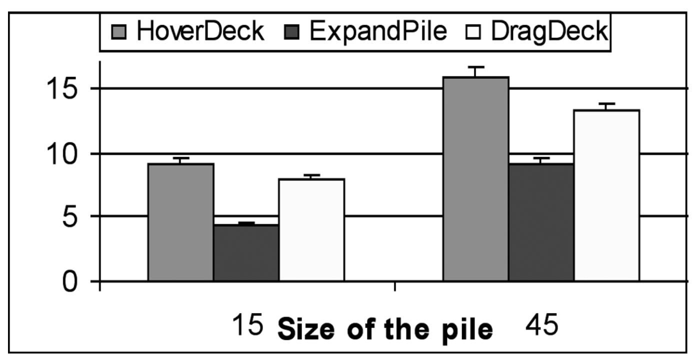

Figure 8. Mean trial completion times with standard error for different pile sizes.

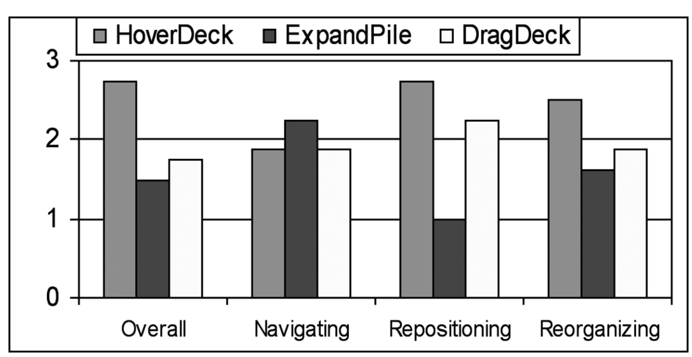

Figure 9. Mean values for the preference ranking of each technique in overall and for each task separately.

8 Discussion

8.1 *ExpandPile*

Our results show that overall *ExpandPile* was the fastest technique. Users could easily get an overview of the various elements of the pile. These results are in line with the recent findings of Cockburn and Gutwin (2006) on scrolling techniques, where they show that expanding the pages allows users to scroll faster than traditional scrolling techniques.

However, our study also showed that, when navigating piles, *ExpandPile* was not significantly faster than the other techniques. Thus when browsing through piles for inspiration without having to select any elements there might not be any performance benefit to using *ExpandPile*. We also found that users preferred the *HoverDeck* technique over the others for this task. *ExpandPile* was significantly faster and most preferred when repositioning elements of a pile. So when frequent repositioning of documents is required, it might be a powerful technique to use.

Overall users were split between their preference for *ExpandPile* and *DragDeck* even though *ExpandPile* was faster than *DragDeck* in most tasks. Many users had a greater feeling of control when using the *DragDeck* technique and commented it was “Pleasant to interact” and visually pleasing to use.

8.2 Effect of location and size on performance

We found no significant differences in performance between three different positions. However we observed that with deck techniques the left-handed subjects had preferred to open the pile to the left, while right-handed subjects preferred the right. In the third task, where two piles were presented to the subjects, it was not possible to open the outermost pile to the left when the task was performed at the top left part of the table, and to the right when the task was performed at the right side of the table. In this particular case left-handed subjects had more problems at the left side of the screen and right-handed subjects had more problems at the right side of the screen.

Figure 8 shows the difference between performance time for piles with 15 and 45 images. *ExpandPile*, while still being faster than other techniques, suffered more from increasing pile size than the other techniques. When the number of images increases, the size of each thumbnail in *ExpandPile* decreases making it harder for the user to recognise the images. For example, in the navigation task average times for *ExpandPile* with 15 images was 3.59 sec. and with 45 images it was 9.86 sec.

For the deck techniques the number of elements in a pile affects the browsing speed. The deck opens by a fixed amount irrespective of the number of images in it. So if the deck has 45 images, moving the pen 1 cm. results in browsing through larger number of images than when the deck has 15 images. This does not create much of a problem when browsing but it becomes harder to select images. Using the *HoverDeck* technique has the added disadvantage that when bringing the pen down to select an image the user might displace the pen horizontally beyond the preset threshold value. This can result in the user browsing through the image unintentionally just before selecting it. These problems can be easily addressed by incorporating a smart algorithm to couple the threshold value based on the speed of pen movement in the vertical direction.

8.3 Task differences

We found that the reorganise and reposition tasks took the longest time to perform. This is not so surprising. But what is interesting is the strategy users employed to perform each task. We have observed that when using the deck techniques for navigating, users were usually browsing with a higher speed then when repositioning or reorganising. The subjective ranking of the technique also showed that deck techniques are more preferred for navigating then for repositioning and reorganising. As discussed earlier, one reason for this may be the fact that selecting an image from the pile and moving it out of the pile image was more difficult to perform with deck techniques than with *ExpandPile*.

8.4 Error rates

In our analysis we deleted about 35 erroneous trials. The trials were deleted because we felt these were a consequence of the experimental design and not of the interaction technique itself. However, it is interesting to note that only 4 out of the 35 deletions resulted when using the *DragDeck* technique. *HoverDeck* and *ExpandPile* resulted in 17 and 14 deletions respectively. The main reason is that users had better control when using the *DragDeck* technique. Further, in the *DragDeck* technique users could see what was happening to the elements of a pile until the very last minute, giving them ample opportunities to recover from inadvertent errors. However, in the case of *HoverDeck* and *ExpandPile* techniques users frequently removed the pen from the surface of the table and re-engaged with the table. This constant movement of the pen resulted in more errors. This is, however, only speculative at this point and needs to be studied closely in future studies.

8.5 Browsing for supporting the creative process

Browsing, which is similar to the navigation task without a clear goal, is one of the methods that designers use to come up with new ideas or refine existing ones.

Our study shows that *ExpandPile* was not significantly faster than other techniques in the navigation task, and it might not be preferable for navigating. Even though we did not test the techniques for browsing (or accidental discoveries) we noticed that users were better able to get an overview of the contents of a pile with *ExpandPile* than with other techniques. Users tend to prefer *DragDeck* and *HoverDeck* due to their resemblance to real-world browsing. It is however not so uncommon to observe users spreading out the contents of a pile on a large work-surface to explore them carefully. We therefore believe that *ExpandPile* is a technique that is better suited to stimulate the designer's creative process when browsing though digital piles.

8.6 Design recommendations

Based on the analysis of the literature, results of our user study and its ensuing discussion we can make the following recommendations for the design of digital piles.

- For effective use of digital piles, systems designers should allow users to navigate, reposition and reorganise.
- When supporting navigation in digital piles, it is worthwhile to consider techniques like *HoverDeck* which are lightweight over technique like *ExpandPile*. Users prefer *HoverDeck* and it is not significantly slower than *ExpandPile*.
- When supporting techniques for repositioning and reorganising elements of a pile, *ExpandPile* is a powerful technique to consider.
- When it is important to give users a feeling of greater control over the interaction, designers should consider techniques like *DragDeck* that seemed to be well received by the users of our study.

9 Conclusions

This paper investigated interaction techniques for supporting tabletop piles. We first analysed the literature to synthesise a set of tasks that are useful for interaction with digital piles. We then developed three different interaction techniques that can support the above mentioned tasks in a tabletop setting. Our techniques—*ExpandPile*, *DragDeck* and *HoverDeck*—are based on competing paradigms for tabletop interaction. Through a user study we could identify the benefits and limitations of each technique. We found that even though *ExpandPile* was significantly faster than other technique for reorganising piles it was not the most preferred technique. Similarly, even tough *HoverDeck* was on average slower than other techniques for browsing/ navigating piles it was the most preferred technique. Based on the results of the study we make many recommendations for the future design of digital pile interaction techniques.

One of our future directions is to evaluate pile interaction techniques using other performance measures like engagement, effort, etc. that might better quantify the user's preference for different interaction techniques. We are also looking more in depth on how piles in general, and interaction techniques in particular, can affect the creative process. We are also investigating how users could use other subtle cues to create lightweight interaction techniques. Some promising trends are to explore the use of tilt and pressure sensors.

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