Xpaaand: Interaction Techniques for Rollable Displays

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ABSTRACT
We present a device concept and a prototype of a future mobile device. By featuring a rollable display, its display size and its form factor can be dynamically changed. Moreover, we investigate how physical resizing of the display can be used as an input technique for interacting with digital contents and present a set of novel interaction techniques. Evaluation results show that physical resizing of the display can improve the way we interact with digital contents on mobile devices.

Author Keywords
Tangible interaction, mobile device, rollable display, screen, scroll, resizing, input technique.

ACM Classification Keywords
H5.2. User interfaces: Graphical user interfaces (GUI), Input devices and strategies, Interaction styles.

General Terms
Human Factors

INTRODUCTION
The screen real estate of today's mobile and handheld devices is limited by the size of the device. Given the rapid advances in thin and flexible OLED displays [5] and flexible circuitry, it is very likely that this restriction can be overcome. In the near future, high-resolution electronic displays will be available that can be rolled in and out in a way very similar to ancient paper scrolls. This will enable the production of devices that have a very small form factor in a collapsed state yet can be expanded dynamically to feature a larger screen (Fig. 1).

Xpaaand is a prototypical realization of a handheld device in which the screen real estate can be dynamically adjusted. Employing a passive display approach, we introduce a set of novel interaction techniques for such devices and examine how dynamic display size changes can be used as an input technique for interacting with digital contents.

We start by briefly discussing related work. Next we present the device concept and our physical prototype. Then

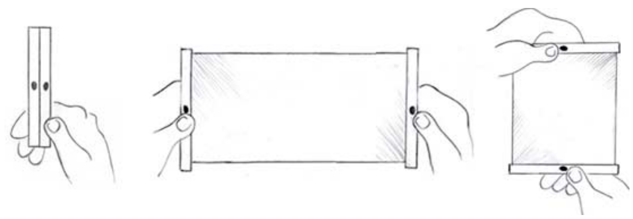

Figure 1. Xpaaand provides for dynamically resizing the mobile device and its display

we introduce novel interaction techniques and conclude with results of a user study.

RELATED WORK
Our work is situated in the area of embodied interactions for mobile and handheld devices. Small and Ishii [1] presented different concepts for scrolling through content on a mobile device by turning physical cylinders, tilting, and moving the display. Gummi [2] introduced a set of interaction techniques for bendable displays, which support scrolling and zooming. However, these devices have a fixed-size screen.

Chen et al. [3] introduced an e-book reader which features two displays. By folding and unfolding the device, the visible screen real estate can be decreased and increased by a factor of two. In contrast to this discrete resizing, rollable displays provide for continuous resizing.

Our work is particularly inspired by recent industrial prototypes of rollable OLED displays [5] and by the work of Lee et al. [4]. Lee et al. used a tracking and projection system similar to the approach taken by PaperWindows [6]. They demonstrated four types of foldable and resizable displays, including a rollable display. However, they examined resizing only as a means for altering the size and the aspect ratio of the viewport, similar to resizing a GUI window. Our goal is to improve upon this previous work by exploring the design space and proposing appropriate interaction techniques. Furthermore, the empirical results of a user study on deformable displays [8] influenced our design decisions.

DEVICE CONCEPT
We envision an ideal Xpaaand device (see Fig. 1) as a thin, lightweight appliance, equipped with on-board power supply. It features a high-resolution display that the user can (un)roll for dynamically resizing the display. Two handles on two opposing sides of the display provide for hold-

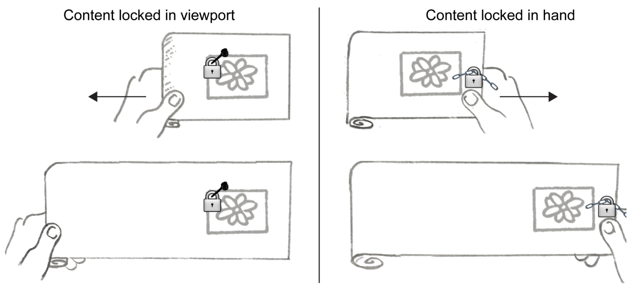

Figure 2. Metaphors for rollable displays

ing the device in a comfortable manner, either in landscape or in portrait mode, with one or two hands. The device, and hence the display, can be physically expanded in one dimension by pulling both handles apart. It can be collapsed by pushing them together. Once the device is resized it maintains its new size.

In this paper, we focus on the design space of dynamic resizing as a novel input technique. We advocate this interaction concept not to replace, but to complement the existing techniques (e.g. touch and pen input).

By embedding accelerometers in both handles, the device can sense which side is actuated. We distinguish three types of resizing: Pulling-out or pushing-in the left side of the display, the right side, or both sides (symmetric). These three types can be mapped to different functionality.

Inspired by the physical behavior of traditional paper scrolls and the work by Song et al. [7], we propose two metaphors for interacting with contents. These are depicted in Fig. 2. Considering a traditional scroll, the side at which it is pulled out or pushed in matters: either content remains at a fix position in the user's view (*content locked in viewport*) or it remains at a fix position with respect to the user's hand (*content locked in hand*). Interfaces for rollable displays can overcome this physical inconsistency and use either of these metaphors consistently for interactions on both sides.

We consider the *content locked in viewport* metaphor to be better suited in most cases, as it allows users to increase the display to the side on which they want to see more contents. In some specific cases which we will discuss below, *content locked in hand* is more adequate. For switching from the standard locked-in-viewport mode to locked-in-hand, the Xpaaand device offers a physical button on each handle. By pressing the button on either side, the user can lock the content, which is displayed at that side, in his hand.

XPAAAND PROTOTYPE

Despite the recent advances in flexible displays, the components required for realizing such a device are not available at the moment. Therefore, we followed a passive display approach and developed a prototype that emulates the most important properties of the envisioned device, i.e. the rollable display and physical resizing.

Our system tracks the physical position of the Xpaaand prototype with a 6-camera OptiTrack system using IR retro-

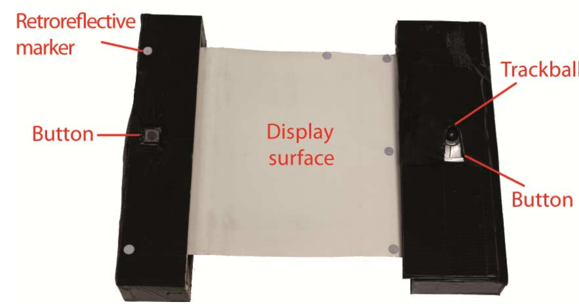

Figure 3. The Xpaaand prototype

reflective markers. A Full-HD overhead projector is used to display digital content on the device. This permits naturally moving the prototype in the high-resolution projection frustum of approximately 100 * 60 * 40 cm^3.

The Xpaaand prototype (Fig. 3) consists of a physical scroll made of white foil, where display content is projected. It can be resized to widths from 5 to 39 cm at a fix height of 18 cm. It is 4 cm thick and weights about 900g. A box is attached at each of the two ends. These boxes act as physical handles for easily grasping the device; they contain the scroll and electronic components. A physical button is positioned at the center of each of the boxes. As our current prototype does not support touch input and to support navigation on the display while it is held with two hands, a trackball is integrated into one box. It can be manipulated with the dominant hand (left-handers can rotate the device by 180 degrees). Wireless communication links the prototype to a nearby PC that hosts tracking software and applications. To keep the device stable, straight, and stiff at different display sizes, we fixed an expandable strut on the back of device.

INTERACTION TECHNIQUES

In this section, we introduce a set of interaction techniques that are based on resizing of the display. They enable users to accomplish common tasks for manipulating digital information. We explore expanding as a means for displaying more contents or more detailed contents. Moreover, we examine how additional screen real estate, created on-the-fly, can be used for exposing additional or different functionality. We developed and implemented the following interaction techniques. They are also demonstrated in the video figure accompanying this paper.

Viewport resizing Expanding or collapsing the display increases or decreases the viewport. In contrast to GUI windows, additional content appears or disappears either on the left, the right, or both sides of the current viewport, depending on which side is actuated (Fig. 4 a). This interaction facilitates common activities such as deeply focusing on a single item, comparing adjacent items, or getting a quick overview on many items. Moreover, scrolling can be performed by iteratively expanding the display on one side and collapsing it on the other side. For scrolling through longer lists, users can use the trackball. In order to examine this technique with different types of information we have

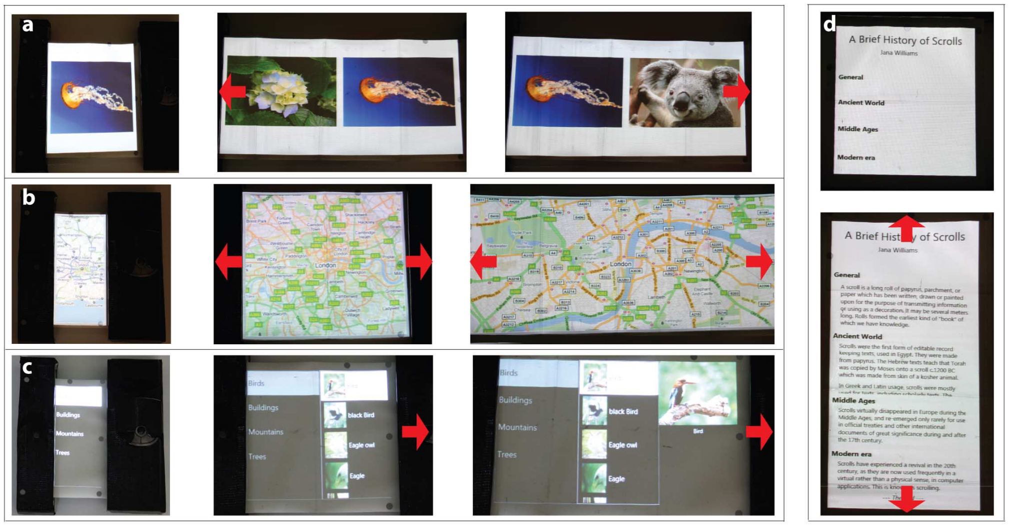

Figure 4. Selected interaction techniques: a) Viewport resizing, b) Geometric zooming, c) Menu navigation, d) Semantic Zooming

implemented it in a simple photo viewer (Fig. 4 a), a map viewer (4b) and a text viewer (using the scroll in portrait mode) (4d).

Zooming Zooming in or out is performed using the locked-in-hand metaphor. By pressing both buttons simultaneously, content gets locked-in-hand at both sides. While resizing the display, content on the viewport then gets "stretched" or "shrunk", which is mapped to zooming. This interaction is inspired by the findings of [7] on stretching gestures. For navigating to very deep zoom levels, which cannot be reached by pulling out the display once, the user can iterate over zooming and viewport resizing several times (similar to lifting a mouse to move the device but not the cursor).

This technique reduces a problem of zooming on fixed-size screens, where magnifying the view results in losing context information. In contrast, enlarging the viewport while zooming in enables seeing the detailed view *and* still having more context visible in one dimension. We have implemented applications for zooming in a 1D (semantic zoom within text, Fig. 4 d) and a 2D information space (geometric zoom within maps, Fig. 4 b).

Navigation in hierarchies This technique supports the physical navigation through hierarchical lists, e.g. menus and folders (see Fig. 4 c). In order to open a selected item, the user pulls the display out in the direction of the dominant hand. This selected item (e.g. the next menu level or contents of a folder) is displayed on the newly created display area, resulting in an overview + detail view. Going back in the hierarchy is performed in the reverse direction. As a further advantage in addition to the more direct experience of physically opening and closing items, the full navigation hierarchy is always visible.

Accessing additional information This technique provides for accessing additional information which is embedded within a document, e.g. a hyperlink within a web page. The user selects the hyperlink by pressing the button on the dominant hand's side and simultaneously expands the display. The link target is expanded in-place, within the context of the original document, leveraging the newly created display space. We have implemented an application for accessing additional images within a text.

Temporarily holding elements This technique leverages dynamically created additional display space for temporarily holding an information element. This allows the user to compare items and creating a *visual clipboard*. By locking one information element in hand (pressing button) while expanding, the element is moved to the clipboard region, which appears on the fly. Moving the item back (e.g. for pasting) is performed with the reverse action. Collapsing the display without pressing a button hides the visual clipboard (locked-in-viewport metaphor). We have implemented an application for cut and paste with photos.

Application switching Different applications require a different amount of screen real estate (e.g. phone app vs. web browser). This technique allows users to easily switch between a small number of frequently used applications by resizing the display to the size which is associated with a specific application. A similar approach can be taken for exposing or hiding functionality within one application.

EVALUATION AND DISCUSSION

To evaluate our concept, we conducted an explorative user study with 11 volunteer participants (5f, 6m) in single user sessions (each 1h, think-aloud protocol, videotaped). We were particularly interested to see how easy it is for novice users to understand the novel interaction style of Xpaaand. After 5 min. of introduction, participants explored the interaction techniques and were asked to perform the following tasks in the horizontal mode: searching and comparing photos using viewport resizing, finding certain photos in different albums using the navigation technique, performing multiple times the cut and paste operation with the aim of the visual clipboard, and performing application switching while thinking aloud. In the vertical mode, participants had to perform a reading task with and without the semantic zooming technique followed by revealing a hidden figure using the accessing additional information technique. The session ended with a semi-structured interview.

All 11 participants appreciated the possibility of changing the display size dynamically. Physical expanding and collapsing of the display for interacting with contents was found to be very *"intuitive"* and enjoyable. P3 commented that *"it is great and makes so much fun because it imitates something physical and has haptic feedback"*. P4 stated: *"I have just done it, without thinking, […] it feels more active to me"*. Although *"it is really unusual to pull out"* (P2), all participants quickly got accustomed to the resizing technique and performed it with ease and confidence after a few minutes. The locked-in-viewport metaphor used for viewport resizing was appreciated by all participants. One participant (P2) commented: *"It is so intuitive because the contents remain entirely unchanged. The rest is just temporarily hidden in the scroll."*

Almost all users (10) reported that dynamic and continuous resizing helped them in searching and comparing items in a list. For a search task in the photo application, 7 users intuitively enlarged the viewport to gain a broader view before scrolling through the list. Moreover, 8 participants explicitly stated that the comparison of items was much easier in the flexible display size. 9 users enlarged the viewport before comparing adjacent items. This helped them to directly engage with more than one item while maintaining the full resolution of each item. P3 commented: *"I intuitively resized it to a size which allowed viewing two photos one besides the other."* Even though users had enough physical space for expanding the display to its full size, we observed some instances of collapsing the display to focus on a specific location of the viewport. Furthermore, during the interviews 3 users explicitly mentioned to envision that they can effectively use the device in restricted space very much like one handles physical maps or newspapers. These results indicate that intuitive resizing of the display eases search, comparison and serendipitous discovery of contents.

Besides simple viewport resizing, the techniques for zooming and hierarchy navigation were particularly well received. The participants appreciated the combination of resizing the display and basic interface operations (e.g. open, close, zoom) that provide for a rich physical experience of going in and out (7 users) and keeping the context visible (3 users). Participants reacted very positively to the technique for temporarily holding an element, which eased visual comparison. Application switching was found simple, but most participants needed 1-2 minutes for getting accustomed to this technique which does not use any of the metaphors of physical scrolls.

Most of the time users held the device easily with their two hands, their arms placed on the table. However, 7 users felt that the prototype was too heavy for comfort, particularly for holding in the vertical orientation when widely expanded. Five participants had concerns related to physical fatigue. Physical resizing *"is great but [it] might become a sport doing it too often or for a long time"* (P5). With one single exception in the photo application, all these comments were raised during navigation in hierarchies when users desired to repetitively and quickly switch between several folders. The physical effort of repeatedly collapsing the device for going up one level and expanding again was considered too high, particularly because the device eventually had the same size as before. Several users stated that in this specific case they prefer having alternatives to the proposed technique.

The issue of physical fatigue emphasizes the need for an appropriate trade-off between user experience, efficiency and physical effort. We believe that this limitation will become less severe with future devices that are more lightweight than our prototype and provide alternative input techniques.

Finally, as an unexpected advantage collaborative uses of the device were suggested. This comprised temporally enlarging the display for showing photos to other people (P2, P10) or games (P9) whereby each of two users holds the display at one side.

CONCLUSION AND FUTURE WORK

We have presented a device concept and a set of interaction techniques that leverage physical resizing of a rollable display. Our findings show that physical resizing of the screen real state creates a rich physical experience and can effectively improve interaction with handheld devices. Future work should compare this technique in more detail with existing input and navigation techniques for mobile devices with fixed-size displays, such as touch input, orientation sensitivity or peephole navigation. Future work should also investigate how resizing can be effectively integrated with these techniques.

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