

PaperFold: Evaluating Shape Changes for Viewport Transformations in Foldable Thin-Film Display Devices

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ABSTRACT

In this paper, we investigate the use of shape changes in a multi-segmented mobile device for triggering viewport transformations in its graphical interface. We study PaperFold, a foldable device with reconfigurable thin-film electrophoretic display tiles. PaperFold enables users to attach, reorient and fold displays in a mobile form factor that is thin and lightweight even when fully collapsed. We discuss how our design was informed by a participatory study that resulted in 14 preferred shape changes. In a subsequent study, we asked users to rank the utility of shape changes for triggering common view operations in map and text editing applications. Results suggest participants were able to attribute specific view operations as automated responses to folding, attaching, reorienting or detaching displays. Collated or full screen views were preferred when users collocated two displays. When adding a third display, alternative views such as toolbars or a list of apps were suggested. Showing 3D views was strongly associated with folding PaperFold segments into a three dimensional structure.

ACM Classification Keywords

H.5.2. [Information interfaces and Presentation]: User Interfaces - *Interaction Styles, Evaluation/Methodology*.

Author Keywords

Human Factors; Organic User Interfaces; Flexible Displays; Foldable User Interfaces.

INTRODUCTION

For reasons of portability, mobile devices have displays that are limited in size and constrained by weight. Despite increases in resolution, such size restrictions have resulted in sequential interaction paradigms for mobile platforms, in which apps are opened and closed one by one. By contrast, the display size of paper documents can be modulated easily

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TEI '15, January 15–19, 2015, Stanford, California, USA.
Copyright 2015 © ACM 978-1-4503-3305-4/15/01...\$15.00.
<http://dx.doi.org/10.1145/2677199.2680572>



Figure 1. PaperFold prototype folded into a 3D Hull.

through folding, tearing or combining multiple page elements. Such properties allow paper documents to be navigated and organized more efficiently, allowing concurrent access to multiple documents [19]. Paper is also very thin, durable and lightweight, perceived advantages in the mobile design space. As such, the development of electronic paper computers that adopt certain qualities or metaphors of interacting with paper documents has been an enduring research goal [9,19]. While initial research was aimed at mimicking form factors or interaction techniques of paper documents using rigid display devices [1,8], in recent years, progress has been made towards developing computers made of flexible E-Ink displays as thin and lightweight as paper [4,22].

In this paper, we investigate how thin-film, paper-like electrophoretic mobile devices [4,5,12,22] might adopt dynamic modulation of screen real estate through folding and tearing techniques in a prototype device called PaperFold¹ (Figure 1) [5]. A number of paper metaphors served as inspiration to the design of our prototype, which, like paper, allows for multiple display segments to be folded into smaller form factors. Books use folding as both a navigational and space saving technique. Paper maps use display size modulation via folding techniques of increasing shape resolution [17]. PaperFold combines the benefits of context-aware multi-display devices with paper-like thinness and familiar interaction metaphors.

Why Thinness and Light Weight are Relevant

We believe thin, flexible displays are essential when trying to mimic the kind of tactile-kinesthetic navigation, expandable screen real estate and lightweight multi-display experiences that paper offers to users. The kind of folding seen in today's mobile devices [3,20] or previous explorations [1,2,7,8] cannot be regarded as similar because the thickness of individual display segments impacts the total thickness of a folded device, while the weight of each display segment impacts overall portability. Although none of the known flexible display technologies are capable of employing creases like paper, tessellation of flexible displays allows for size modulations that approximate those of foldable paper maps. While we aim to produce more complex folds, we limited ourselves to what can be achieved with current flexible technology.

Contribution

In this paper, we evaluate the effectiveness of shape changes as viewport transformations. We present PaperFold, a prototype device consisting of 3 flexible display segments that can be combined in arbitrary configurations. We discuss interaction techniques that utilize shape changes to perform view operations, e.g. adding a display segment extends a document's view; folding segments such that they can be viewed by others produces shared views. We report on a participatory design study that resulted in 14 shapes that can be produced with PaperFold, and a subsequent study in which participants ranked view operations to changes between shapes. Results suggest participants were able to attribute specific view operations to specific shape changes. We conclude with design recommendations for matching shape changes to view operations in reconfigurable mobile devices.

RELATED WORK

While there has been research into folding displays into various form factors, most of the display technologies in prior studies were either simulations with paper mockups [14], projection [9,10,11], or thick and rigid display devices that are not particularly suitable for folding [1,2,7,8,15,18]. Other explorations focused on interactions with single displays that were stacked or placed in close proximity [4,22]. PaperFold bridges the tradeoff between portability and increased screen real estate by introducing a reconfigurable mobile display device with thin-film screens that stay within acceptable boundaries of weight and thickness.

Slate Display Form Factors

There is a large body of work on book form factors involving rigid dual-screen form factors that can orient around one axis. Pocket Edge [3] combined a tablet computer and an eBook reader in a dual-display interactive device. Sony Tablet P [20] featured interoperating hinged displays. Chen et al. [1] discussed an e-book reader featuring two displays mounted on two separate slates that can be used in side-by-side or detached configurations. Their design supported embodied navigation techniques like folding, flipping, and

fanning. Their findings suggested that having additional displays offers a better support for lightweight navigation.

Multi-display Form Factors

Chen et al. [2] evaluated a multi-slate reading system, aimed at understanding how increased screen real estate across multiple devices can enhance navigation and interaction techniques in reading activities. Their results indicated that multi-slate reading systems have the potential to recapture many of the affordances associated with physical documents, while providing functionality that surpasses that of paper. Hinckley et al. [7] showed the use of tablet PCs for spanning contiguous images across multiple display surfaces. The system used simultaneous deceleration as a means for detecting connections, and was capable of performing simple view operations such as collating two displays, or spanning an image across two displays upon connection. Hinckley et al.'s [8] Codex, a dual-screen tablet computer, was an exception to the above work in that its displays are detachable and reconfigurable into various form factors. Codex can be oriented in a variety of postures to support individual work, ambient display, or collaboration with another user. The authors demonstrate interaction techniques supporting division of labor for tasks across displays. Their findings identify several benefits for detachable displays systems (i.e. *Division of Tasks between Screens*; *Collaboration between devices*; *Sidebars*). Siftables [15] demonstrated a series of networked compact devices with embedded displays that could be physically manipulated as a group to interact with digital information. Although it was able to span visuals across multiple displays, Siftables lacked connective hinges and featured thick screen objects. The rigidity and thick form factor of the displays employed in the above explorations posed real drawbacks in terms of portability and physical effort.

Thin-film Display Form Factors

DisplayStacks [4] presented a system for physically interacting with digital information via stacks of thin-film displays. It introduced tools for navigating digital documents using piles of physical display windows. DisplayStacks combined affordances of paper documents with electronic content. PaperTab [22] later featured an environment in which multiple thin-film displays work together through proximity sensing to mimic a physical paper desktop experience.

Foldable Thin-film Designs

Lee et al. [13] explored image projection on foldable materials to simulate flexible displays with variable form factors. Their findings suggested that devices that can incorporate large surfaces in a small collapsible volume offer advantages for mobile contexts. Xpaaand [10] featured a handheld device encapsulating a rollable display. The authors explored dynamic resizing as a means of interacting with digital contents. Their results indicated that having the ability to physically manipulate screen real state may effectively improve interaction with handheld devices. FoldMe [11] simulated thin-film displays on the front and

back sides of a mockup device foldable along predefined hinges. Their results suggested folding navigation techniques could improve manipulation of information for portable devices. Folds in this system were limited to a pre-defined axis. Paddle [16] used projection to represent highly deformable mobile devices that can be transformed into various special-purpose controls. Their results suggested benefits over touch interaction techniques commonly used on mobile devices. We borrow from the aforementioned explorations, in designing a multi-segmented reconfigurable mobile device that can be attached and detached into arbitrary configurations along multiple axis, noting that none of the above systems used real flexible displays.

DESIGN RATIONALE

We believe that building a prototype using real flexible displays is valuable due to their unique properties in terms of thinness, lightweight and malleability. Current displays are too thick and heavy to be able to achieve the kind of shape transformations seen in our study without significant physical effort by the user. Additionally, to our knowledge there has not been a systematic exploration of three-way folding in multi-display systems. To inform the design of a multi-segmented reconfigurable mobile device, we used the following design criteria:

Use of Folding to Modulate Screen Size

Our first goal was to allow users to modulate the size of screen real estate of the device between folded conditions and expanded shapes. While there have been examples of rollable devices [10], we consider folding to be a more natural metaphor as it allows the overall form factor to be similar to that of current smartphones. We believed unfolding would typically be used to expand the size of an existing view.

Reconfigurability and Tile Geometry

Hinged displays can only be folded along one dimension. In order to increase the number of form factors, we explored attachment/detachment on multiple sides of the displays. This allows users to go from, e.g. tablet form factors to paper notebook while maintaining a simple folding interface. Unlike [1,2,8], our work explores view-transformations beyond 2 segments while preserving portability. Detachability also allows users to increase or reduce the number of displays dynamically, and implement concurrent usage scenarios with multiple displays. In particular, our design aimed to increase the subset of shapes demonstrated in previous explorations.

Orientation

The ability to alter the orientation has been used in smartphones to switch between landscape and portrait viewports. In PaperFold, orientation takes on a different role as re-orienting the device may dramatically alter the affordances of a shape, as well as visibility of information on the displays. We hypothesized that orientation of the device would therefore affect the function of the device.

Number and Angle of Tiles

The number of display segments creates a tradeoff between shape resolution and portability of the device. More display segments result in complex cable management, since currently available flexible displays are not wireless. As we will discuss in our participatory study, folding a four segment device into a one segment device alters the shape geometry of the device along two concurrent dimensions, making it more difficult for users to (un)fold the device. Shapes created by 3 segments are primarily determined by their geometry and angle of displays towards one another.

3D Shapes

Using a minimum of three displays allows users to simulate certain known display shapes through simple morphological mimicry. A flat configuration resembles a book or map form factor. Bending the displays inwards simulates a concave display that might mimic gaming or virtual reality scenarios. Bending the displays outwards, users can simulate a segment of a spherical display. A 60-degree angle between 3 displays creates a closed 3D hull. A 90-degree arrangement resembles a portion of a cube [21]. One of the questions we were interested in investigating was whether users would associate such shapes with 3D objects.

Sharing

Different orientations of display segments may cause them to be visible to the user, other users, or hidden altogether. According to Hinckley [8], configuration of tiles could be a design parameter for determining whether a shape indicated shared or private interactions.

Matching Shape Changes to Viewport Transformations

Segments of PaperFold form building blocks that can be “shaped” into an application. We investigated the relative transformation between shape states as an interaction technique. If we generalize the above discussion, we note that shape transitions in PaperFold typically appear to affect its viewport. To further investigate this, we conducted a participatory study.

USER STUDY 1: PARTICIPATORY STUDY

Our methodologies were inspired by Hinckley et al., who evaluated the affordances of pen-operated dual-display devices [8], Chen et al. [1] who compared a dual-display reader with single-display devices in typical reading tasks, and Khalilbeigi et al. [11], who studied functions that can be assigned to mockup double-sided displays with pre-defined hinges. To investigate what would be the most functional shapes of a foldable device, we conducted a participatory design session in which subjects were presented with 4 *10x15x0.15cm* 3D printed tiles without displays. Each tile contained magnets that allowed participants to interconnect as well as hold shape at right angles.

Task & Participants

To determine what configurations users would find appropriate for particular tasks, they were asked to imagine a device in which the tiles featured displays showing apps similar to those on their mobile phones. Users were told that

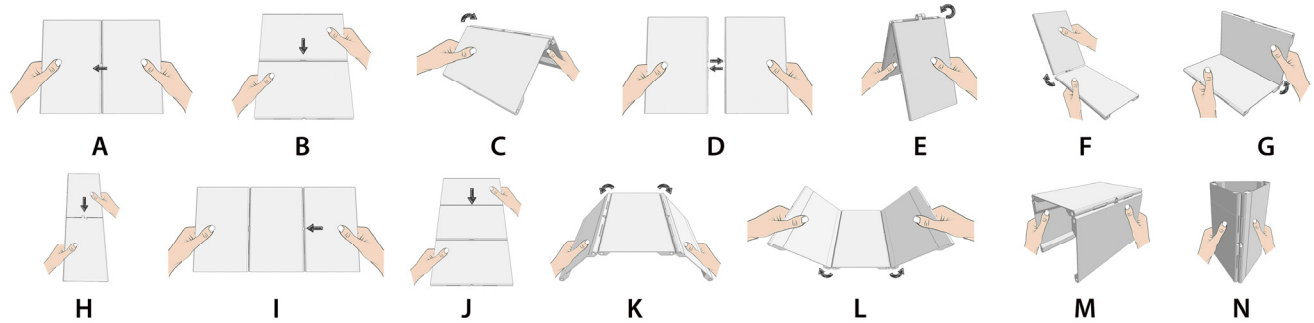


Figure 2. The 14 participant defined shape configurations used in matching shape changes to view operations.

apps could span multiple displays. They were then asked to create what they thought of as the most useful transformations of shape for a 2 display hinged/detachable device. We then repeated the exercise imagining 3 displays and 4 displays. For each shape, we asked participants to propose an associated functionality. 15 participants volunteered for this study (6 females, 9 males; mean 23 years). Subjects received \$10 for 1 hour of participation.

Results

Results suggest that participants had difficulty relating to the 4 tile configurations. All participants preferred using a maximum of 3 tiles. Most participants carried multiple devices, such as smartphones, tablets and laptops on a routine basis (*Mean*: 4.07, *s.d.*: 1.16). However, they preferred to use a single device with different form factors, if this was possible (*Mean*: 4.73, *s.d.*: 0.46). Figure 2 shows the most common shape changes produced by participants for 2 and 3 tiles configurations: Holding the display in portrait (A,E,F,K,L), landscape (B,C,H,J) and 3D (M,N) orientations; Attaching displays horizontally (A,I) and vertically (B,F,J); Detaching displays (D); Bending Displays Inwards (L) and Outwards (K); Folding the displays into triangular (E,N), perpendicular (G,N) and cube-like structures (M). When asked what functionality these shapes or shape changes might have in a device, participants comments almost exclusively referred to view operations that are common in GUIs. We synthesized these comments into a list of potential view operations, shown in Figure 3.

APPARATUS

PaperFold is a foldable thin-film device with 3 detachable flexible display tiles. The design of our prototype was informed by the results of our participatory design study. Each tile consists of a flexible thin-film E Ink display, and a flexible 3D printed substrate with embedded sensors that allows the system to determine the orientation and connections of individual tiles (Figure 4).

Flexible Displays

Each PaperFold segment features a flexible 6.5" E-Ink display. Magnetic hinges allow a continuous data connection between displays. Each display is coupled to a driver board connected to a computer controlling the logic and interface graphics.

3D Printed Tiles

PaperFold's flexible 3D printed segments measure 15x10 cm with a thickness of 1.25mm. Magnetic hinges allow PaperFold tiles to be attached in a variety of configurations (Figure 4). Note that the increased thickness at the extremities of the tile is only a function of the required size of the embedded magnets. Hall Effect sensors in the tiles monitor the magnetic field in their vicinity, allowing our system to detect distinct connections among various tiles. A 9DOF IMU calculates the absolute orientation of each tile. Using this information, we are able to determine what view operations should occur upon distinct shape configurations.

Sensing Touch

E-Ink displays pose challenges to sensing touch, as their functioning requires pixels to be applied with positive or negative charges to produce the desired graphics. Readily available touch solutions have shown to interfere with the screen refresh mechanism of e-ink displays. We designed flexible printed circuit layers to sense touch input by measuring changes in capacitance between direct touch and the electrode pads.

USER STUDY 2: MATCHING SHAPE CHANGES TO VIEW OPERATIONS

In a subsequent experiment, we evaluated the use of our PaperFold prototype for effecting view operations via shape changes. We asked participants to rate the match between each shape change and the list of view operations suggested in our participatory study. Due to the nature of the participatory design session, we used a different set of participants to avoid bias towards choosing view operations our first subset of users had suggested.

Shape Changes

Figure 2 shows the 14 shape transformations used in our second study. Note that some are applied to different orientations but topologically identical. Another defining factor was the orientation of the hinge location: vertical or horizontal. To illustrate, a vertically hinged portrait display looks like a notebook. A horizontally hinged portrait display looks like a book.

View Operations

In our study, we asked participants to match the list of 12 view operations in Figure 3 to the most frequently performed shape changes derived from our participatory design session.



Figure 3. A list of view operations in GUIs suggested by participatory design session.

Task

For each shape change, we asked participants to rank each of the 12 view operations for appropriateness using questionnaire items with a 5-point Likert scale (Strongly Agree-Strongly Disagree) that answered the following question: “When I change the shape of this device in this way, it [View Operation].”

Experiment Design and Participants

All participants experienced all shape changes in the same order. To avoid bias, the list of view operations was presented in random order. 12 participants took part in the experiment (6 Female; 6 Male; Mean Age: 21.3). All participants received \$10 for 1 hour of participation.

Procedure

During training, each of the 12 view operations were demonstrated in a GUI desktop application to avoid biasing participants with PaperFold examples. Increasing the size of the window and revealing more of an image demonstrated *Collate/Extend View*. *Show Full Screen* was demonstrated by showing a full screen window containing an entire photo. *Show Thumbnails* was demonstrated by showing thumbnails of the photo library; *Zoom In/Out* was demonstrated by zooming in and out of a photo without changing the window size. *Duplicate View* was demonstrated by showing two windows with the same image. *Show 3D View* was demonstrated by showing a 3D model of the object on the photo. Other view operations were demonstrated by showing: a keyboard; a toolbar; a phone keypad; a photo in one window and a notepad in another; and an empty window.

Participants were then introduced to the prototype, instructed on the task and given the questionnaire. A display showed a list of image transformations from which each view operation could be constructed on PaperFold. This list was similar to the images shown in Figure 3. The experimenter then loaded the first image onto the first display, after which participants were asked to make the first shape change in Figure 2: Attaching a second display horizontally. Participants were asked to go through the questionnaire and pick a favorite operation to perform upon this shape change, if there was one. They were then asked to select the images

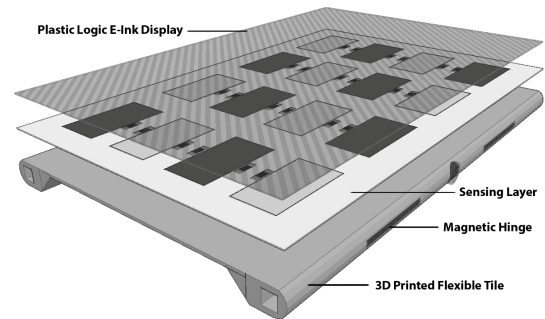


Figure 4. Exploded view of a PaperFold segment.

on the display that would best show this operation on the prototype. They then rated the view operation on the questionnaire, and were asked whether there were any operations in the list that they thought would match this shape change. If so, they were given the option to show these on the prototype and rate them.

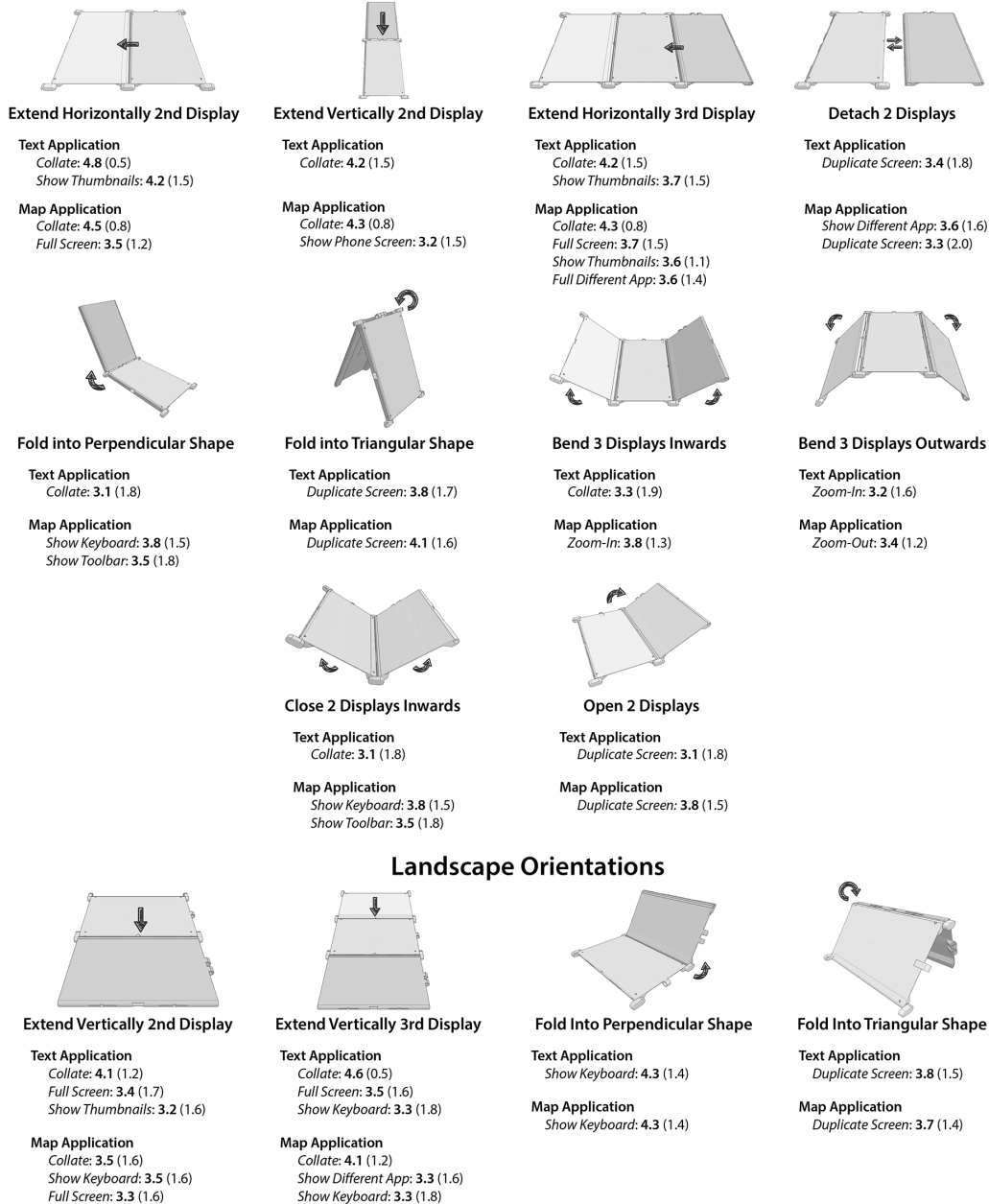
Applications

All shapes were repeated for each of two applications: 1) A text editor showing pages of a scientific paper 2) A Google map application showing a map of London. We based our choice on applications described in previous work: [1] focused on reading activities on dual-display devices; [8] presented a pen-operated note taking application; and [11] demonstrated interaction techniques for browsing maps using mockup foldable displays. Additionally, the results of our participatory design study showed a strong user preference for these application scenarios.

RESULTS

Figure 5 shows the means and standard deviations for the scores matching view operations with shape changes, for portrait, landscape and 3D conditions in both application scenarios. A non-parametric analysis of variance (Friedman Test evaluated at $\alpha < .05$) showed significant differences between view operation scores for each shape change in the text application (Friedman’s $\chi^2(11) > 21.11$, $p < .05$), with the exception of *Fold 3D Triangular Hull* (Friedman’s $\chi^2(11) = 18.436$, $p = 0.072$). In the map application, results also showed significant differences between view operation scores for each shape change (Friedman’s $\chi^2(11) > 23.9$, $p < .05$). Due to the exhaustive nature of possible comparisons, and because we intended our results as design heuristics, we did not perform further post-hoc tests. Instead, we assigned the highest ranked viewport for any given shape change as a best match, but only if it had a positive rating, i.e., higher than 3.0. Note that by picking the top match, we interpreted our data at the ordinal level of measurement. Approximately half our top matches in the *Text Editing Scenario* had a score above or equal to 4.0, suggesting strong preferences for these particular view operations. Optional alternative view operations, with scores between 3.0 and 4.0, are also displayed. Finally, note that in the below section, whenever we make a statement such as: “users preferred”, we do not suggest such statement scientifically accurate, but rather as a trend that informs the design process.

Portrait Orientations



3D Orientations

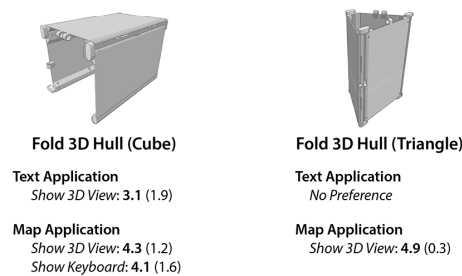


Figure 5. Mean ratings and (standard deviations) for matching view operations to presented shape changes for both applications

User Agreement

Since we expected multiple view operations to match any one particular shape, we decided against calculating a measure of agreement. Instead, because the Likert scale deployed does approximate an interval level of measurement, we examine the standard deviations as providing some indication of user agreement. In the text application, standard deviations, as shown in Figure 5, were low in most cases, averaging 1.33. In the map application, standard deviations averaged 1.3. This suggests users generally agreed well on rankings for both applications.

Matching View Operations to Shape Changes

Text Application

Extending the display, in both orientations, was strongly associated with the *Collate* operation. In portrait conditions, participants preferred *Show Thumbnails* as an alternative. In landscape conditions, *Full Screen* or *Show Keyboard* were suggested. Neither bending 3 displays inwards or outwards had a strong user association in the case of the text application. Bending inwards was associated with *Collate*, while bending outwards was associated with *Zoom In*. Users had a weak association with *Show 3D View* in the landscape condition. In portrait mode, there was an equally weak association with folding the display into a perpendicular shape as pertaining to *Collate*. However, in the landscape condition, there was a strong preference for *Show Keyboard*. In portrait conditions, Folding Displays into a triangular shape was associated with *Duplicate Screen*. Finally, for Detach Displays, *Duplicate Screen* was preferred.

Map Application

Extending the displays in the portrait condition was highly ranked for the *Collate* operation, in both horizontal and vertical conditions. For the third display, *Show Thumbnails*, *Show Keyboard*, *Show Different App* and *Duplicate Screen* were also ranked positively. In the landscape condition, second display, participants split their top ratings between *Collate* and *Show Keyboard*. For the landscape, third display, there was a clearer preference for *Collate*, with *Show Thumbnails*, *Show Keyboard* and *Show Different App* ranked positively. Bending 3 Displays Inwards, Outwards and Fold 3D Hull (Triangle) were all associated with *Show 3D View*. In the landscape condition, there was a strong preference for *Show 3D View* for Fold 3D Hull (Cube), with *Duplicate Screen* considered an alternative. In both c, there was a clear association between folding the display into a perpendicular shape and *Show Keyboard*. In both portrait and landscape conditions, Folding Displays into a shape was associated with *Duplicate Screen*. Finally, for Detach Displays *Show Different App* had the strongest rating, with *Duplicate Screen* and *Show Phone* considered weaker alternatives.

User Comments and Observations

Throughout the experiment, participants were encouraged to verbalize their thought processes, which were noted by the experimenters. Overall, participants liked having the ability to arrange PaperFold in various configurations, thus being able to dynamically alter viewports. “I would like to be able

to customize the functions of different shapes.” [P2]. There were benefits identified for using PaperFold as a multitasking system. “I enjoyed having the ability to distribute different applications across displays and access them concurrently.” [P5, P8]. While browsing through maps, users were particularly impressed with the 3D View features of our system. “3D shapes with multiple displays lead themselves to viewing 3D models.” [P11]. Additional benefits identified include adding peripherals [P4,P10]; thumbnails/toolbars [P3,P11]; or using PaperFold as means for distributing information, by physically detaching and sharing panels [P12].

DISCUSSION

For both application scenarios, results suggest that users associate shape changes of PaperFold’s screens with specific view operations. Some shape changes are, however, more ambiguous than others. For example, extending PaperFold with a 3rd horizontal display rates above neutral on 4 different view operations. But even in those cases, generally only one or two view operations rank highly for each shape change. We will now discuss differences in trends between the two application scenarios, trying to generalize our results into design recommendations for viewport behaviors in folding multi-display user interfaces.

Horizontal Extensions

When extending the displays horizontally, the most highly ranked view operation was consistently *Collate*. In the case of the text editor, where a contextual overview of data objects is applicable, participants ranked *Show Thumbnails* higher than a *Full Screen* operation. In the map browser, which has no clear delineation of specific data objects, participants were more inclined to try and fit the data on two screens. Observations of image selections during the experiment strongly suggests that participants preferred to extend a thumbnail display with a second display showing a full screen view of the first thumbnail. Since participants chose to extend a full screen display with a collated view they overwhelmingly chose *Collated View* as the highest rated answer for both cases. Only when a third display was attached, did participants widen their options, with scores for collated views ranking lower and thumbnails higher.

Vertical Extensions

For vertical portrait extensions, *Collate* generally appears the preferred option. *Collate* is also the highest ranking option for vertical landscape extensions, where keyboard is also a strong option.

3D Shapes

Bending three displays inwards or outwards was much more highly ranked for *Show 3D View* operations in the map application, where data elements were not inherently limited to 2D. Observations confirmed that in the text editor scenarios, participants had difficulty relating any 3D operations to the inherent 2D nature of the data element. In general, folding the displays into a 3D hull was the shape change most strongly associated with *Show 3D View*. This

suggests that users associate the shape of the device with known objects of similar form factor.

Detach

Detaching a screen was less easily generalizable: In the map application detaching the displays was most strongly associated with *Show Different App*. In the text editor application *Duplicate Screen* was preferred. View operations that were not ranked positively for any shape change in either application scenario included: *Zooming*; *Show Toolbar*; and *Show Phone*.

DESIGN RECOMMENDATIONS

We derived the following recommendations for the design of segmented, foldable, multi-display devices:

1. Automated view operations appear to work well as responses to folding, attaching or detaching displays.
2. Consider a Collate operation when users extend a first display in Full Screen View with a second display.
3. Consider alternative views such as keyboards/toolbars or different apps when extending a 2nd display with a 3rd display.
4. Provide mechanisms for users to choose view operation functions, or allow them to set preferences.
5. Consider showing a keyboard on the lowest display when the device is folded into a perpendicular shape.
6. Consider mirroring the displays when the device is folded into a triangular shape.
7. Consider showing a 3D view of the data when users bend displays inwards or outwards, or into a 3D hull shape.

LIMITATIONS AND FUTURE DIRECTIONS

We note that the above recommendations are based on heuristics and can be considered valid only within the limitations of the presented device and user study. We do believe that results are sufficiently clear to generalize to other application scenarios and device morphologies. We recognize that our PaperFold prototype has shortcomings that did not allow us to evaluate use by multiple users outside a laboratory environment. In particular, an important future direction is to remove the dependency on cables and extraneous equipment for what is supposed to be a mobile device.

CONCLUSIONS

We evaluated PaperFold, a mobile device with flexible display segments that can be folded into arbitrary configurations. Our design was informed by a participatory study that resulted in 14 preferred shape transformations. A subsequent study investigated the effectiveness of shape changes for viewport transformations. We evaluated how participants ranked the utility of shape changes for triggering common view operations in map and text editing applications. Results indicate that participants were generally able to select specific view operations as automated responses to folding, attaching or detaching displays. User feedback from our study indicates benefits from having multiple detachable displays. Advantages include better support for performing tasks that traditionally

require multiple devices, as well as physical manipulation and sharing of views.

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