Codex: A Dual Screen Tablet Computer

Ken Hinckley[1], **Morgan Dixon**[1], **Raman Sarin**[1], **Francois Guimbretiere**[2], **Ravin Balakrishnan**[1,3]
[1]Microsoft Research, Redmond, WA; [2]University of Maryland; [3]University of Toronto
{kenh, ramans}@microsoft.com; mdixon@cs.washington.edu; francois@cs.umd.edu; ravin@dgp.toronto.edu

ABSTRACT
The Codex is a dual-screen tablet computer, about the size of a 4"x6" day planner, with a self-supporting binding and embedded sensors. The device can be oriented in a variety of *postures* to support different nuances of individual work, ambient display, or collaboration with another user. In the context of a pen-operated note taking application, we demonstrate interaction techniques that support a fluid division of labor for tasks and information across the two displays while minimizing disruption to the primary experience of authoring notes.

Author Keywords
dual screen, sensors, pen, tablet, mobility, collaboration

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: Input

INTRODUCTION
Dual-display electronic books ("ebooks"), laptops, and tablet computers offer an intriguing form factor for mobile computing. Although well suited to tasks that benefit from a book-like metaphor [9], two bound displays also excel in tasks with an intrinsic division of labor that leverages the interconnected yet distinct nature of the two screens.

Analyses of information work reveal that tasks often have a natural division of labor. Reading occurs in conjunction with writing, with frequent cross-references between information sources [1]. Users partition their work between multiple monitors [13] and devices [2,10,26]. Finding, gathering, and using information encountered on the web should not interrupt the user's primary task [18,22]. Collaborative work has inherent design tensions between shared public representations and private views of information [12,33,35,39]. A dual display device may offer fresh design leverage to many of these problems, particularly if it can support facile transitions between such usage contexts with minimal burden on the user.

Our goal here is to research physical affordances and interactive techniques for pen-operated dual-display devices. We present the Codex, a dual-screen tablet computer with a hinged binding and embedded sensors that detect *postures* (hinge angles plus the orientation of the device) to facilitate lightweight transitions between usage contexts. The folding form-factor offers an inconspicuous, highly mobile kit similar to a small day planner. Detent hinges enable each face to articulate in stable positions, resulting in a rich design space of postures that afford many nuances of private individual work, ambient display, or public collaboration with another user (Fig. 1). Novel interaction techniques support a fluid division of labor between the screens for tasks such as note taking combined with gathering content from reference documents [1,7,18,22,32], navigational structure plus content, private plus public views of information, and other partitions of interface elements and tasks across screens.

Fig. 1. Codex dual-display tablet. **(a)** The book posture. **(b)** Codex folded up for mobility. **(c)** Face-to-face collaboration. **(d)** The displays detach.

RELATED WORK
The vision of dual-screen information portals dates back to Vannevar Bush's 1945 *Memex* [6]. Alan Kay and his *DynaBook* vision inspired a dual-screen mock-up for the Apple Knowledge Navigator concept video in 1987 [3].

Several papers suggest a role for multi-screen devices, but few designs appear in the literature [5,9,19]. Price et al. suggest "additional displays in conjunction with an XLibris tablet" to show more than one page without burdensome window management [28]. Adler et al. [1] analyze work-related reading and find that tasks such as reading in conjunction with writing often span documents. Berg et al.

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show a mobile phone design with two touchscreens [5]. Marshall and Bly [22] discuss how people clip information, and conclude "interfaces need to support secondary interactions like clipping without interrupting primary activities like reading." A dual screen device enables clipping information from one screen to a "web scrapbook" [18,32] on the other screen, without disrupting the primary reading or note-taking task.

Chen et al. [9] describe an ebook reader with two motion-sensing, detachable faces that communicate wirelessly. Users can browse through a text using explicit gestures such as fanning the pages or flipping the book over. Users liked detaching the screens, which motivated us to include this capability in the Codex. But the gestures did not fare well, so the Codex instead uses implicit *background sensing* [8,15,16] to adapt to the current physical posture. Rather than two screens in support of linear texts, the Codex emphasizes a partition of roles, such as hunting for information [7] in conjunction with writing notes and gathering hyperlinked digital clippings. Dual screens may enhance many such sensemaking tasks [7,18,22,31,32].

The Nintendo DS [24] has a touchscreen on the bottom, and a view-only screen on top. Although only one screen has input, game designers have used the screens in many creative ways. For example, one program shows a full-screen view of a painting on the top screen, and a zoomed-in view for brushing details on the bottom screen (http://tinyurl.com/6oeph2). One study of the DS finds that it creates private individual gaming contexts within larger social gaming contexts [36]. Other commercial devices such as cell phones now often include auxiliary screens to show critical information while the device is closed.

Several dual-screen design concepts with pen or touch input on both screens have recently emerged [11,25,27,38], but few details are available. We present a unified design space that illustrates the postures suggested by many of these devices, with several unique to the Codex (Fig. 2).

Multiple Monitors and Multiple Devices

Grudin [13] studies how desktop users employ multiple monitors. Why have two divided screens rather than one large one? Grudin observes that "a single large space is not always preferable" because multiple monitors support partitions of "space with a dedicated purpose, always accessible with a glance." Without a physical partition, ad hoc decisions and cumbersome window management drive placement of information. Multi-monitor tasks often involve information from multiple windows [20], but users avoid placing windows across screen boundaries [13]. Users also employ mobile devices for secondary tasks such as monitoring email, browsing the web, or showing a presentation on a laptop while taking private notes [10,26].

Transitions between Individual and Collaborative Work

Luff and Heath [21] emphasize the micro-mobility of artifacts (small adjustments to the position and orientation of paper or mobile devices) to support "delicate shifts in the accessibility of information, from the individual to the collaborative." For example, they observe that doctors hold paper patient records, reposition them, orient them towards the patient, and prop them on the desk to become the focus of gestures and remarks; but this "ecological dexterity is not found with […] portables, [which are] still cumbersome and rigid" [21]. A dual-screen device sensitive to its posture and orientation may alleviate some of this rigidity.

Collaborative interaction leads to design tension between personal and public views [35]. Greenberg et al. encourage "designs that will let people fluidly shift their artifacts from personal to public and the many gradations between in subtle and lightweight ways" [12]. Combinations of mobile devices and fixed displays offer one approach [12,21,23,29,33], but chance encounters drive collaboration during local mobility [4]. Two-screen devices afford partitioned personal and public views while fully mobile, rather than disrupting collaboration with a transition to a fixed installation (if any is present at all). One screen can be split into public vs. private areas [30,33], but this may not afford simultaneous input and viewing by two users.

Several systems envision dynamic assembly of devices. Connectables [37] support face-to-face meetings using two tablets. Stitching [17] supports several ways for users to join tablets to suit varying social distances and relative body orientations [34]. These sociological concerns, known as *proxemics* [14], also motivate collaborative postures of the Codex. While "dynamic assembly of mobile devices" offers a general strategy, the special case of two screens, both carried by one user and supporting a fixed set of physical postures, affords a different semantic of sharing than bringing together devices owned by separate users.

TAXONOMY OF DUAL-SCREEN POSTURES

The following taxonomy organizes the principle classes of postures for dual-screen devices (Fig. 2). References to related work show devices (many of which are design concepts rather than working implementations) that have considered each posture. We can immediately discern that few prior devices have supported collaborative postures, with *Face-to-Face* and *Corner-to-Corner* unique to the Codex. The Codex is the only device that automatically senses transitions between the full set of postures.

Our design space is primarily organized by the angle between screens. *Concave* postures have inward-facing screens that lend themselves to individual use scenarios. *Convex* postures have outward-facing screens that afford two users with different viewpoints. *Neutral* postures, where the devices lie flat on a table, lie in between and can be suitable for either single user or collaborative tasks, depending on how the screens are oriented. Thus the physical openness of the device naturally corresponds to a range of proxemic distances from the sociological literature [14,17], which enables the user to express a nuanced gradation of private vs. public interactions [12], as appropriate for a given task, mood, or social situation.

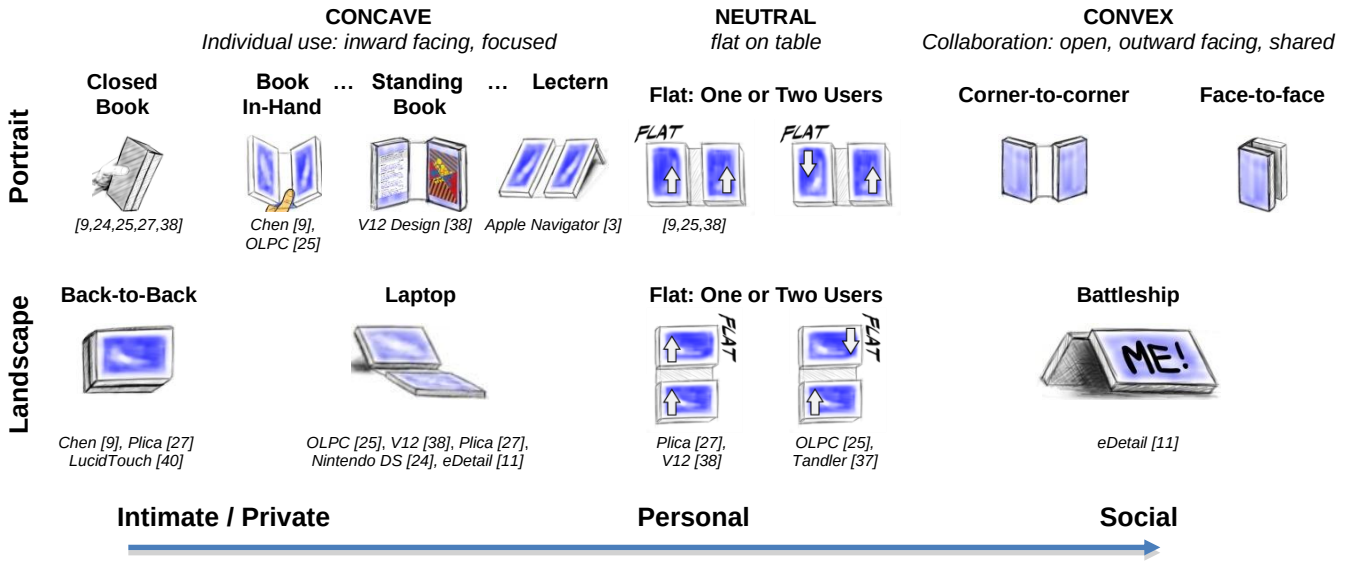

Fig. 2. Design space of dual-screen postures, for individual and collaborative use, supported by the Codex.

A Brief Tour of the Postures

Closed Book. Completely private, with the device inactive.

Book In-Hand. For private tasks. The handheld, inward-facing screens create an intimate cocoon [2,26] that serves to isolate the user from other persons [36].

Standing Book. For ambient display. Like a picture frame its stance invites some observation by others, but the screens still face inwards towards a primary user.

Lectern. Because this posture has a preferred orientation towards a primary user, the Codex treats it as a posture for individual use by default. The Lectern can be used for side-by-side collaboration by manually selecting one of the collaborative postures (to override the sensors).

Battleship. For collaboration across a physical barrier such as a table, on adversarial or competitive tasks [34] (e.g. the popular game *Battleship* - "You sank my battleship!").

Face-to-Face. A portrait version of the Battleship posture, with each screen oriented vertically.

Corner-to-Corner. Supports collaboration across the corner of a table. Corner-to-corner seating is conducive to casual conversation and studies show that it encourages increased communication [34], thus motivating our support for such seating arrangements.

Laptop. Supports landscape-format pages. It also affords informal presentations: the top (angled) screen displays the public slides, while the presenter controls the presentation (and jots private notes) from the bottom (horizontal) screen. The horizontal surface can be angled slightly to provide a more ergonomic writing angle (see Fig. 4, right).

Back-to-Back. For focusing on a single screen [9]. With a multi-touch screen, this posture could afford back-of-device interactions such as LucidTouch [40].

Flat. This neutral posture does not dictate any particular use, which is both a strength and a weakness. On the Codex, transitioning to *Flat* always maintains the mode from the previous posture. For example, setting the Codex flat from the *Battleship* posture produces a *Flat* posture with the screens facing in opposite directions in landscape format, while keeping the collaboration features active. Setting the Codex flat from the *Laptop* posture instead keeps the screens facing in the same direction. Setting the Codex flat from *Corner-to-Corner* supports collaboration side-by-side with another user.

Detached. Our taxonomy does not show detached screens, because the user can position them arbitrarily. When the user detaches a screen, it keeps the properties of the posture from which it was detached.

Other Taxonomic Axes

To fully support the design space mapped out above, this paper focuses on the design space of dual-screen devices with symmetric displays and input/output capabilities. However, we reconsider other design dimensions of interest in the Discussion section of this paper.

PAPER PROTOTYPE STUDY

We constructed several foam-core and paper prototypes to investigate different sizes of dual-screen devices (Fig. 3), as well as different postures. To get feedback on the design concepts, we recruited 10 mobile professionals from a large technology company, including two pairs of users to probe collaborative scenarios. We first collected information on the devices and accessories carried by each user. Next we showed the users dual-screen mock-ups in three sizes: *small* (9.3 x 14.2), *medium* (13.2 x 21 cm), and *large* (21.6 x 27.9 cm, the size of standard 8½ x 11" paper). We constructed these from gutted paper notebooks with foam core "screens." We showed users foam core models of various postures, and invited users to attach screen captures to tell stories of how they might use a dual screen device.

Fig. 3. Paper prototype study. Left: The small, medium, and large form factors. Right: prototyping task scenarios.

Results

The participants were excited about the notion of a dual-screen "notebook." One user commented "I feel rude using my laptop [in a meeting]. This device would be perfect because I can take notes and have the slides to write on too." Three users did request ways to treat the two screens as a single unified space, but most users saw advantages for logically distinct screens: "The fact that there are two separate surfaces really lets me divide up what I'm doing." All users carried a laptop and a cell phone; paper notebooks were carried by 6 of the users. One user stated "Paper notebooks are for unorganized thoughts and ideas… I carry it because by laptop is too big and I can't input notes quickly on my phone."

Users' preferences were split between the medium (6 users) and small (4 users) form-factors. None of the users preferring the large size; users consistently expressed doubts about its portability ("it wouldn't be easy to carry around"), its similarity to laptops ("I could just carry my laptop instead and have a nice keyboard"), and its lack of rapid in-hand mobility ("I like the small ones because I can just grab them and go, and hold them in my hand").

Users consistently ranked the *book* and *laptop* postures as the most useful. Many users saw ways that other configurations "serve specific purposes," but "it would just come up, it's not something I would plan ahead." Eight of the ten users felt detaching the displays would be useful, to allow configuration of the device however they like. Users saw a role for postures even with detachable screens. For example, one user commented "I like that I can pass this around or just set it up on the table. [When I work] in the field, I need an easy way to share my ideas and get the ideas from everyone without a projector."

HARDWARE PLATFORM & SENSORS

We anticipate a future of thin and light interactive displays with a wide viewing angle and low power consumption. Rapid progress on technologies such as bi-stable "e-ink" displays suggests these will soon exist [9]. We focused on the smaller size because users expressed interest in both the *small* and *medium* sizes, and because we desired to make the prototype as mobile as possible. Also, the market lacks a suitable medium-sized slate Tablet PC with an active digitizer. We chose the pen-operated *OQO Model 02 computer* as an off-the-shelf prototyping vehicle for a small dual-screen device. The OQO Tablet PC is 8.4 x 14.2 x 2.5cm thick and runs Windows Vista. With our custom case, this leads to a dual-screen form factor of 12 x 18.1 x 6.5cm thick, which folds out to a maximum area of 28.6 x 18.1cm. The screens are separated by a 9.2cm gap, dictated by the OQO's thickness and its screen bezel.

Detachable Screens & Detent Hinge Design

The Codex allows detaching screens, while also providing a hinge with distinct detents to afford facile articulation of the screens (Fig. 4). Each screen is held in place by a base plate, made from the bottom of the "Executive Case" accessory for the OQO Model 02 computer. A firm pull on the screen pops it out of the base, and a firm press pops it back in. The Codex case can still be used as an input device to specify postures even if one or both screens are detached.

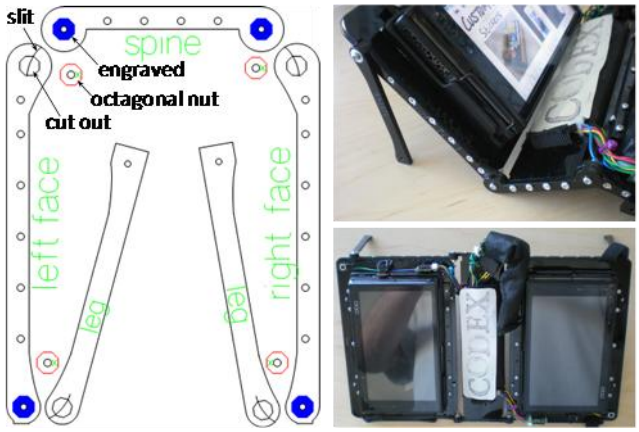

Fig. 4. **Left**: Exploded view of the detent hinges and support legs. **Right**: Articulation of the hinges and extension of support legs makes many ergonomic variations possible.

Our hinge is laser-cut from 1/8" delrin, a strong and flexible self-lubricating plastic. At the joints, two strips of delrin are joined, with an octagonal nut jammed into a cut-out in one of the delrin pieces (Fig. 4, left). When the user rotates the pieces, the octagonal nut forces the cut-out to expand slightly as it rotates. The delrin provides a strong spring force that holds the resulting detents at 45° increments. We use 45° increments because they allow all the postures in our design space to be realized with a minimum of complexity. A leg piece can be extended from each end of the hinge assembly (Fig. 4, right).

Sensors

We constructed a sensor module based on the *Arduino* prototyping board. We use a three-axis accelerometer (Freescale Semiconductor #MMA7260Q) to determine the orientation of each face relative to gravity, and a flex sensor (Spectra Symbol #SEN-08606) to determine the angle between faces. A micro-switch senses screen detachment. The Arduino samples the sensors at 20Hz and exports the sensor data via a Bluetooth connection. The OQO also has an internal two-axis accelerometer, which we use to sense orientation when a screen is detached.

Automatic Posture Sensing & Manual Posture Settings

We combine all of the sensors to determine the posture of the device. To prevent transient states while the user is handling the Codex or shifting between postures, we suppress new postures while the device is moving.

Movement is determined by a simple sum-of-squares function between samples that decays over time. We also wait 500ms before switching when a new posture is sensed. If the posture starts to change again during this interval, we cancel the transition to the new state. When the user repositions the Codex to a new posture, the software provides feedback via a "splash" animation showing the sensed posture. It then rotates the screens if necessary.

The automatic sensing offers a convenient way for the user to implicitly specify the role of the screens. We also provide a Posture Settings dialog because there may be cases where the user wants to explicitly override the Codex's default mapping of functionality for each posture. The user just taps on a thumbnail of the desired posture.

CODEX SOFTWARE PLATFORM

The Codex software is based on the *InkSeine* note-taking application [18], which provides a core set of inking, searching, and information gathering functionality that is critical to the Codex as a pen-operated tool for sensemaking tasks. InkSeine has been downloaded by over 10,000 Tablet PC users; its search features and "floating tool ring" for scrolling and taking screen captures (Fig. 5) have been particularly well received. The Codex software adds support for sensing postures, network synchronization of user interface actions, and dual-screen operations. Since our prototype is based on two independent computers, all cross-screen operations are achieved via wireless (802.11) networking via .NET Remoting.

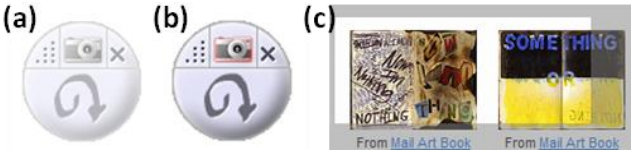

Fig. 5. (a) The floating tool ring; (b) tapping on the capture button; (c) sweeping out a rectangle to capture (see [18]).

INTERACTION TECHNIQUES FOR DUAL SCREENS

The Codex implements a number of general dual-screen capabilities that can be used in both individual use and collaborative postures. Sensing of the Codex posture is used to tailor the functionality of each technique so as to allow a single user to sprawl out their work across two screens, while a collaborating pair of users has more compartmentalized interactions so as to avoid unintended disruption of one another's screens.

Core Dual-Screen Interactions

Synchronized Clipboards and Tool Modes

The clipboards of each screen's notebook application are synchronized by default, so that the user can copy and paste objects across screens. Tool modes (i.e. lasso selection, pen, highlighter, or eraser) are also synchronized so that the pen applies the same tool regardless of which screen the user writes on. The pen's barrel button can be used as a shortcut for the lasso mode. During collaboration, the screens maintain independent clipboards and tool modes so that the users do not interfere with each others' actions.

Split Page Navigation Model and Sending Pages

The book-like form factor of a dual screen device makes a two-up page model (with the screens displaying successive pages [9]) alluring., but this is an artificial restriction of the traditional model of sequential linear texts. Since our emphasis is not on lengthy texts, but rather on partitioned tasks such as writing in conjunction with reading web pages or short documents, we use a split page navigation model.

Each screen has independent page controls in the form of *Next Page* and *Previous Page* icons. These only turn the page shown on the current screen; they do not affect the page shown on the other screen. This makes it easy for the user to view separate notebooks, or separate pages from within the same notebook, without tedious interactions. If the user wishes to synchronize the views of the screens, we provide a *Send Page to Other Screen* icon. Tapping this icon mirrors the current page to the other screen.

Hunting and Gathering Information with Dual Screens

A key task scenario for the Codex is to support *writing* notes on one screen in conjunction with *reading* on the other screen. However, reading and writing themselves are part of a larger task: how does content come to populate the other screen in the first place? The user must hunt for that information, open it, and then gather useful pieces back into their writing [1,7,18,32]. Our software supports this hunter-gatherer workflow. The user starts by writing a phrase on the primary screen. When the user lasso selects the phrase and chooses the Search command, the Codex shows the results. Clicking on a search result opens the web page on the secondary screen (Fig. 6).

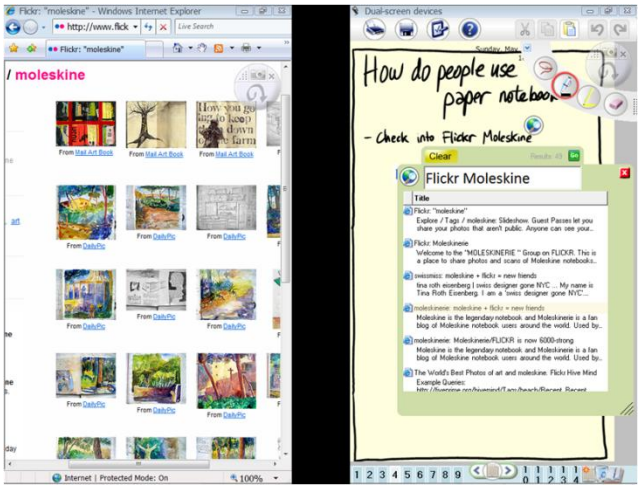

Fig. 6. Bringing up a web page side-by-side with a notebook page.

Each screen hosts its own tool ring (Fig. 5) for scrolling and screen captures, so that a tool ring is always close at hand. When the user takes a screen clipping, the Codex determines which notes page has been used most recently, and the clipping automatically appears there, complete with a hyperlink back to the original web page. The user can tap the Paste icon to insert the clipping elsewhere.

If the user later uses the hyperlink attached to a clipping to revisit the original web page, it again opens up on the secondary screen. During collaborative use, links open on the same screen so as not to disrupt the other user's view.

Dual Screens or a Single Screen?

Of course, a single-screen device could provide split-screen functionality that emulates these software functions. But as Grudin observes, the physical partition between multiple displays influences the placement and use of screen real estate, so the user would have to remain disciplined enough to avoid resizing windows or placing other windows across the virtual boundary. In existing web browsers one can open pages in other windows or tabs to avoid interrupting one's browsing stream, but this is not quite the same as having the content open in a separate secondary screen. It would be very interesting to explore such nuances in future quantitative studies to better understand how physically separate screens differ from single screens, and how existing techniques for multi-monitor systems can best be leveraged in a mobile dual-screen form factor.

Page Links: Navigational Structure + Content

The user can create a hyperlink to any page of their notes by dragging a page tab (the numbered tabs at the bottom of each screen) onto the drawing canvas. This creates a round hyperlink icon, with a thumbnail of the linked page attached to it. Stroking down on the icon opens the link and navigates to the page on the *opposite* face of the Codex. In collaborative postures, page links open on the same face.

Fig. 7. Previewing a page link with the screens in landscape orientation. Selecting a link on the bottom page previews the linked page on the top screen.

To enhance lightweight, temporary viewing of pages, the user can also preview a page by tap-selecting a page link. A transparent green cone emitting from the page link provides feedback that the page is temporarily being "projected" onto the other screen (Fig. 7). The preview remains visible until the user taps elsewhere (to deselect the link). We also experimented with hovering over the page links to trigger the preview on the other screen. However, it is difficult to keep hovering the pen over a small page link icon while directing one's attention to the other page. Showing the preview on selection avoids this divided attention problem.

Page links enable users to author navigational structure on one screen, while viewing linked content on the other screen. Examples include a table of contents (see Fig. 1), references and footnotes, and links to related pages.

The software does not currently implement a *Back* function to undo page link navigation. With two screens a *Back* feature is not needed to return from a single level of hyperlinking, because the original page with the navigational structure remains visible. With a single screen, navigating to the content occludes the navigational structure, leading to tedious window management tasks such as tabbed browsing or opening links in new windows.

Fig. 8. A storyboard authored using Codex Sidebars.

Sidebars: Overview + Detail

In traditional magazines and books, sidebars are a distinct section of a page that augments the main text with auxiliary information. Codex Sidebar objects take inspiration from this. Sidebar objects use the other screen to show the auxiliary information, while scaling it to the maximum aspect-ratio preserving size. For example, the user can employ Sidebars to author a storyboard page (Fig. 8), with shrunken-down thumbnails of key sections from their notes. To expand a Sidebar onto the other screen, the user tap-selects it. The user steps through the storyboard by tap-selecting the thumbnails in sequence. Thus, Sidebars demonstrate how views can be partitioned by scale, with a zoomed-out overview on one screen, and zoomed-in details of specific content expanded on the other screen.

To create a Sidebar, the user lasso-selects the desired ink strokes and screen captures, and then chooses the *Make Sidebar* command that is available from a marking menu on the selection. This groups the selected objects together. The

user can then scale down the group and position it wherever desired, such as in the storyboard cells illustrated above.

Presentation from Laptop Posture: Public + Private

When the Laptop posture is used for informal presentations, it nicely illustrates a partitioning of the screens into public versus private roles. From 2-3 users can sit so that they can see the angled screen, and the presenter can drive an over-the-shoulder presentation from the horizontal screen. By connecting to a desktop display, the presenter can drive a presentation that gets mirrored to the desktop as well. Alternatively, the presenter can hook up the top screen to a projector (but the OQO device does not rotate its video output to correspond to the current screen orientation, so the projector must be able to rotate the screen image to achieve the desired results).

The user can employ Page Links, Sidebars, and the *Send Page* icon to control his presentation on the bottom screen. Since only the top screen is "projected," the user may view speaking points or take private notes on the bottom screen.

PowerPoint has a presenter mode that allows a laptop to control an external display, allowing a similar separation of roles, but the Codex naturally integrates this functionality into the posture of the device and allows the user to employ the pen to directly interact with either screen.

COLLABORATION WITH THE CODEX

The Codex can act as a sensemaking tool for informal or impromptu collaboration, which frequently involves small groups (2-3 people). The folding form-factor of the Codex enables each screen to be viewed by a separate user. The *Battleship*, *Face-to-Face*, and *Corner-to-Corner* postures are the three primary collaborative postures of the Codex. The software does not draw functional distinctions between these states, other than to place the screen in landscape for *Battleship*, and in portrait for the others.

The Codex offers a few simple collaborative tools. The innovation is not the particular collaboration features, but rather the selective activation of appropriate collaborative functionality, and the tailoring of other features to suit collaborative use of the dual screens, based on the context given by the posture of the device.

All of the features described in the preceding sections adapt their behavior to suit collaborative postures of the Codex. For example, by default hyperlinks to web pages open up on the same screen, rather than the opposite screen, when users are engaged in a collaborative posture. Sidebars are currently not supported in the collaborative postures.

Synchronous and Asynchronous Collaboration

By default, the Codex offers a synchronous whiteboard when a user places it in one of the collaborative postures. The Codex displays the same page on both screens so that the users may start collaborating from a common ground.

In synchronous mode, whenever one user flips to a new notebook page, the other device follows to show the same page. As a general principle we rely on the users to employ social protocol to mediate such actions, which we find works well, rather than complex interaction techniques that prevent users from interfering with one another.

Note that there exists an initial ambiguity as to which of the two screens should be mirrored to both sides. Rather than popping up a dialog to ask the user, which we found annoying, the Codex always favors the primary screen and mirrors that page. The user can assign either the right or left screen to act as the "primary" screen. If this turns out to be the wrong choice in some cases, the users can simply tap on a different page, which then mirrors that page instead.

Synchronous mode immediately echoes ink strokes drawn on one screen to the other screen. Since a user can no longer see the other screen, after each stroke an "explode and fade" animation of a radar pulse plays to emphasize that the ink strokes are being sent to the other screen. Each user's cursor is surrounded by a spotlight, which can be used to direct the other user's attention to an area of the screen while gesturing with the pen in the hover state. Each user has a different colored spotlight.

The Codex also supports asynchronous collaboration. The user may tap on the *Send Page to Other Screen* icon, which doubles as a modal control during collaborative postures, to drop out of synchronization. The user is then free to flip through his notebook pages without mirroring those pages to the other device. The user can also send notes to the other screen by lasso selecting them and then stroking the projector icon from the selection's menu options.

DETACHING SCREENS FROM THE CODEX

If the user pulls a screen out of the Codex, the screen retains the properties of the posture it was detached from. Upon detachment, the Codex activates the device's internal accelerometer, but this is only used for automatic rotation of the screen between portrait and landscape formats. It does not change the posture settings (e.g. for the individual versus collaborative use scenarios). Thus, detaching keeps the simple virtues and clear semantics of the dual-screen posture while enabling complete freedom in terms of screen orientation and placement of the device.

With the separating screens of Chen et al. [9], pulling away one screen requires changing the posture of both screens, but the Codex hinge remains intact when one or both screens are removed, allowing the device to remain in specific posture (e.g. "standing book") when the screens are removed. This allows the user to change the behavior of a detached device by changing the posture of the binding. Some of our test users found this desirable.

Detaching screens has compelling uses in both individual and collaborative task scenarios. For example, to watch a video in landscape orientation while taking notes on the other screen in portrait orientation, the user simply detaches one of the screens and sets it horizontally, as illustrated in Fig. 1(d) and in the accompanying video.

During collaborative work, detachment offers the ability to simply hand a screen to another user to mitigate issues of social distance or ergonomics. Note that this operation carries a very different semantic of sharing than sending a file to another user's personal device. Since both screens are part of the Codex, they both belong to one user. A user can thus show information to another user without actually giving that person an electronic copy of the file, which implicitly prevents the other user from copying or editing it. The user also does not have to worry about figuring out how to connect to a potentially untrusted device.

THE CODEX AS A COMPANION DEVICE

The Codex can act as a companion to a desktop computer in two ways. First, the *Standing Book* posture acts as an ambient display. Transitioning to this posture places email on the secondary screen of the Codex, so that the user can get his inbox out of his face while doing focused work on the desktop. Meanwhile, the primary screen of the Codex displays a slideshow of the user's note pages, so that the user can maintain peripheral awareness of previous ideas.

Second, if the user wirelessly connects the Codex to his desktop, then a tool ring (Fig. 5) appears there. When the user employs the tool ring to take a screen clipping from the desktop, the clipping (with an automatic hyperlink back to the source) appears in his Codex on the most recently used notebook page. This enables the Codex to act as a "Web scrapbook" [32] for collecting ideas and inspiration while the user primarily works with a desktop computer, similar to the way that some people use paper notebooks to jot down ideas and reminders.

USABILITY EVALUATION

Participants

We recruited eight mobile professionals from a large technology company, with four users participating as individuals, and four users participating as pairs. None of the users had participated in our paper prototyping studies. For the single-user sessions, the experimenter collaborated with the participant in the collaborative scenarios. All users were right-handed.

Method

For each participant we first demonstrated the core features of our note-taking software using an 18" Wacom Cintiq display tablet. The participants used the tablet until they felt comfortable with the software. Each user searched for a topic of interest, grabbed a clipping from a web page, made a sidebar, and created a page link.

We then demonstrated the postures and basic functionality available in each posture. We also demonstrated the Posture Settings dialog box for explicitly choosing a posture without the sensors. Half of the users saw the automatic sensing first, and the other half saw the explicit dialog first. Once users saw the postures, they were free to handle the device (with care) themselves; this approach was necessary due to the fragility of our current prototype.

In each posture, users explored our pre-generated content, but most users also created their own new content. For example, one user gathered football ticket prices, seat locations and game times. He collaborated with the experimenter to choose seats and then presented a summary of everything he had found to the experimenter.

Results and Observations

Users were excited about the dual screens, the automatic sensing of postures, and the ability to detach the displays. Users also appreciated the concept of postures. For example, one user commented "configurable postures is a good idea" and another stated that "it definitely makes sense to take the [Codex] and change the posture."

Automatic Posture Sensing vs. Explicit Dialog

All eight users preferred the automatic sensing of postures to the manual dialog for picking a posture, even though users just had to tap on a picture of the desired posture. But all users wanted to keep the explicit dialog. Many also requested the ability to customize the default mappings of functionality to postures ("each mode should have a default and a user customized setting"). As one user explained, "I would prefer automatic posture sensing almost all of the time as default. Manual dialog would be for special cases."

Division of Tasks between the Screens

Users liked the Codex's division of tasks into two screens because "one screen would not provide the separation of thought like two [screens] does." Another user commented that "[I] love the intelligent dual display action. Large single screen [is] not useful to me most days […] This is great because the device knows what mode I'm in and will update automatically." A couple of users did ask for a way to unify the screens into a single workspace, but only as an adjunct to the dual-screen functionality: "[It] could be nice […] to join the screens for a big screen scenario. Otherwise, it is very nice to separate the displays."

Collaboration and Detaching the Screens

Collaboration was seen as a desirable capability ("the big key is the collaborative aspect between the two devices"). Users only envisioned using the Codex for small-group collaborations, where it would be "intuitive but […] only for one-on-one discussion". The informal small-group discussions afforded by the Codex also seemed to resonate with users. "I like that it's not formal like PowerPoint. I can just draw my own notes and pictures, and easily show them to 1 or 2 other people."

After choosing a posture, detaching the displays was important to make collaboration work well. One user explained that "it definitely makes sense to change the posture [and then] take them out of the case when I'm working with someone. I can set them so that we are most comfortable and it's automatically ready for collaboration." Many users commented that they would otherwise feel physically confined or stuck in an awkward position.

Detaching the screens was described as "very important" or "must allow" by 7 of the 8 users so that they could exploit the ergonomic and social comfort of holding the device in their hand. The remaining user still considered detachment

"useful." Several users liked changing the posture of the hinge to control the mode of detached devices. However, some users indicated they would prefer the explicit posture dialog in this case: "I would use the automatic sensors when using the device as one package, but once the screens were taken out I would rather use the dialog box." Users also seemed to appreciate the different semantics of sharing that detaching the screens affords: "I can just hand one display to someone to show them my notes." Two users also suggested detaching both screens and giving them to family members. "I could hand the two devices to my kids and they could watch two separate movies."

Page Links, Sidebars, and Collecting from the Desktop

The ability to hyperlink to pages, and open or preview those links on the opposite screen, was very well received "for quickly checking my notes or grabbing bits of content." One user explained that page links would be "excellent in any sort of scenario where related topics are discussed […] It's good that I can see what the pages say without going to them."

Many users also liked the concept of Sidebars, which were "useful in that it provided a way to group and 'store' items." However, the Sidebar concept was sometimes unclear to users at first: "The name 'sidebar' didn't make sense to me… once I saw what it did I understood it, and think it would be useful." Several users wanted the content in sidebars to be more interactive when expanded on the other screen, such as to "group pictures or even songs together so that it will be displayed on the other screen as slideshow or [a] playlist." This would be an interesting capability to add. Some users felt that sidebars would be less useful on a larger screen.

The ability to grab screen captures from the desktop and have them appear in the Codex was very popular: "I like that I can grab [screen captures] from my desktop on the fly." Desktop-to-Codex capture seemed particularly useful for quick and lightweight transactions such as getting a phone number or reminder onto a notes page.

Areas for Improvement

Many users felt that the screen was a little bit too small, making it difficult to interact with at times. This echoes our paper prototyping study, where a majority of the users favored the medium-sized screen, but the OQO's offered the best compromise on the market to quickly build a dual-screen device. Users also desired a thinner form-factor.

One particular postural transition, from the *Face-to-Face* posture to the *Flat* posture, did not test well because our current implementation places the two screens in portrait, but facing in opposite directions. Users felt it would be more intuitive to leave the screens facing the same way, and detach one of the devices to flip the screen around if desired. However, this was not the case for the transition from *Battleship* to *Flat*, which places the screens in landscape with the screens facing in opposite directions. Users found that transition to be a natural one.

When viewing the screens in the *Standing Book* posture, the viewing angle of the OQO displays is fairly narrow, which made this posture less useful than it might have been. Many users also wanted to choose a different default behavior for this posture, such as showing a slideshow of photos, instead of email and past pages from their notes. In general, users wanted more options, or possibly a pop-up dialog, to customize exactly what functionality or application views to trigger when transitioning to a new posture.

Some users did not like the *Corner-to-Corner* posture. On a device with the ability to detach the screens, the Battleship and Face-to-Face postures may be sufficient.

DISCUSSION

Echoing the findings of Chen et al. [9], users viewed the ability to detach the screens of a dual-screen device as a must-have feature, particularly if the device is to support effective collaborative roles. As a pragmatic issue, it may be difficult to realize fully detachable screens in a commercial device without increasing the weight, technical complexity, and cost-of-goods. On the other hand, since detachment appears to have significant value to users, approaching the design of future dual-screen devices with a modular approach that enables two or more identical slates to be physically interconnected may offer increased economy of scale. Another way to play this trade-off may be to consider asymmetric designs where only one of the screens is detachable.

In general dual-screen designs could be asymmetric in terms of display technology, input vs. output capabilities, the physical configuration of the screens, and other axes:

- *Display Technologies:* Designs that mix displays, such as fully interactive color OLED display plus a second e-ink or Anoto paper surface, are intriguing for future research because the differing display properties allow a single device to offer a wide range of design tradeoffs.
- *Input vs. Output:* While the Codex has a pair of read-write screens, in general each screen could offer read-only (e.g. e-ink), write-only (Anoto paper), or read-write capabilities.
- *Physical Configurations*: One can also combine large and small screens (e.g. [11]), screens that swivel between portrait and landscape, screens bound along the short edge of the "pages" rather than the long edge, and so forth.
- *Software Relationship between the Screens:* The Codex illustrates a mix of many of different strategies, but more are possible. For example, relationships include: screen 1 mirrors screen 2, screen 1 acts as a second half of screen 2, screen 1 and screen 2 are independent, screen 1 shows zoomed in details of screen 2, and so forth.

Finally, quantitative studies are needed to better understand dual-screen interactions. We envision experimental studies

that build on the existing multi-monitor and multi-device literature to probe strengths and weaknesses of divided screens in specific tasks of interest. A longitudinal study that collects log data of actual Codex usage, or interviews that probe shifts in user behavior with the device over time, would be particularly intriguing.

CONCLUSION

Dual-display devices appear to have a well-motivated role to play in the ecosystem of mobile devices. The related research that we have discussed on how people approach sensemaking tasks such as reading in conjunction with writing, our own contributions of new techniques and automatically sensed postures for dual-screen devices, and the comments from users in our paper prototyping and usability studies together make a good case that dual-display devices have a promising future. The two screens of the Codex afford a separation of concerns in reading versus writing, public versus private, and other partitions of task roles and views. By supporting facile transitions between usage contexts, the Codex enables such a future without constantly encumbering the user with complex window management and mode switching tasks.

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