Holy Smartphones and Tablets, Batman! Mobile Interaction's Dynamic Duo

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ABSTRACT

It is becoming increasingly more common for people to own botha smartphone and a tablet, providing a design opportunity to leverage the combination of these two formfactors. Our work aims to explore this by: a) defining the design space of distributed input and output solutions that rely on and benefit from phone–tablet collaboration, both physically and digitally; andb) reveal the idiosyncrasies of each particular device combination via interactive prototypes. Our research provides actionable insight in this emerging area by defining a design space, suggesting a developer's framework and implementing prototypical applicationsin such areas as *distributed information display*, *distributed control* and various configurations of these. For each of these, we present several example techniques and demonstrate an application that combinessuch techniques.

Author Keywords

Design; Human Factors; Device; Screen; Mobile; PDA; Smartphone; Tablet; Content; Context-aware Computing;

ACM Classification Keywords

H.5.m Information Interfaces and Presentation (e.g., HCI): User interfaces - *Haptic I/O;Input devices and strategies;Interaction styles; Direct manipulation*

General Terms

Human Factors; Design; Theory

INTRODUCTION

At 2007's *All Things Digital* Conference, in front of a large audience in a panel shared with Steve Jobs, Bill Gates shared his vision of the future of portable digital devices, "I think you'll have a full-screen device that you can carry around … in the tablet form factor … And then you'll have the device that fits in your pocket"[39].Gates' vision has largelysince become a reality, as the connected and internet-savvynow often carry botha tablet and phone-sized device[24] (Fig. 1).

When compared with devices of other form factors (such as watch-sized devices, desktop computers andinteractive tabletops), the multi-touch tablet and phone-sized devices are ideal for mobile use, striking a balance between portability and function. These two form factors have enjoyed tremendous success in the market as a result [22].

The phone-sized device is highly portable,being easily tucked into a pocket or held to the ear for conversations. Its size, comparable with that of point-and-shoot camera, makes it a convenient camera replacement. It is well suited for viewing digital content in mobile environments, where one can comfortably hold the device in one hand. Its limited screen space, however, reduces both the ability to control input and forsharedviewing experiences.

The tablet-sized device, while also optimized for portable usage, has a larger screen and input area.It allows for greater control when working with various forms of digital content such as images, videos and electronic documents. The larger screen is also more attractive for sharing content with friends or in meetings with clients. As a result, the software can offer more in both form and function.

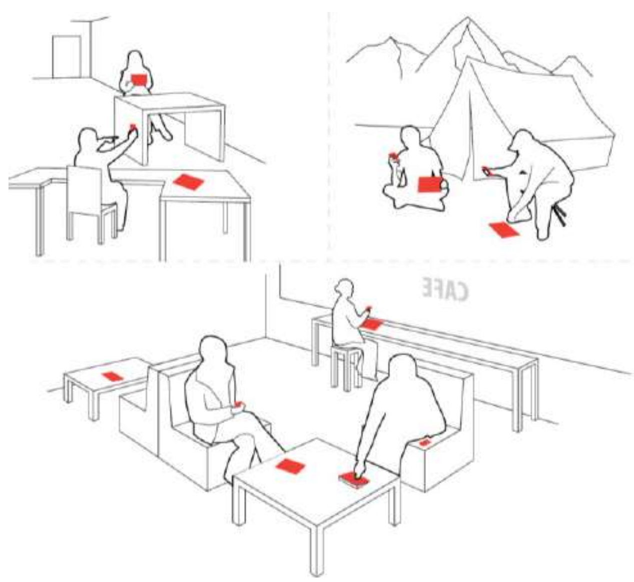

Figure 1: Mobile settings and uses of portabletechnologies:office,camp, café.

While phone- and tablet-sized devices have complementary input, output and interaction style properties (Table1), current usage scenarios with these devices sometimes treat them as isolated units. Thisimpliesthat their embedded sensorsmay not be leveraged optimally. Research is needed to study how to effectively combine the complementary na-

APCHI '13, September 24 - 27 2013, Bangalore, India
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http://dx.doi.org/10.1145/2525194.2525205

ture of both devices in an integrated environment,rather than as two separate devices.

While there have been efforts showing the potential of systems that leverage the combination of multiple devices (Fig. 2) [5], these combinations often focus on pairing similar mobile devices [19], orcomplementary multi-device systems that combine mobile devices with stationary devices such as tabletops or large displays for office and public settings [2, 21].

Our work combines mobile phones and tablets, a pairing that we call the *Dynamic Duo*, and we believe its complementary and mobile characteristics make it a unique multi-device system that deserves a separate and systematic investigation.

Phone-sized devices	Tablet-sized devices
Input (Control)	
Mostly finger gestures.	Finger and hand gestures.
Interactive surfaceallows for single- and dual-touch interactions with short trajectories.	Interaction surface significantly larger than in phones,permitting multi-touch interaction vocabularies comfortably.
Smaller formfactormakes these devices convenient for activities that require physical movement.	Larger formfactor makes these devices less comfortable than smaller ones for isotonic input requiring lifting or moving of device.
Output (Display)	
Display surface is typically no larger than an average-sized palm.	Display surface at least twice that of a phone, permitting a greater display of information.
Interaction Style	
Typical interaction at elbow-length or closer usingone or bothhands.	Typical interaction at arm'slength or closer mostly using both hands.
Mostly handheld.	Either placed on a surface, onthe user's lapor held with both hands.

Table 1: Complementary input, output and interaction style properties of phone-sized (left) and tablet-sized (right) devices.

In this paper we present an exploration of the design space of *Dynamic Duo* using touch-based tablets and smartphones. As an initial investigation, we focus on single-usage scenarios. Several of our techniques have already been introduced in a work-in-progress paper [29] and a video figure [30]. *Dynamic Duo* enables novel and powerful scenarios such as device-size-specific manipulation schemata and application, dedicated bi-manual input styles, master-slave role switching, highly personalized apps and novel gaming features. Our contributions consist of: a) defining the design space of distributed input and output solutions that rely on and may benefit from the physical and digital collaboration of phones and tablets, b) suggesting a mobile platform, including a developer's toolkit and c) exploring this space through conceptual prototypes, each aiming to reveal the idiosyncrasies of a particular device combination. We believe our research provides actionable insight into this emerging system and interaction design space.

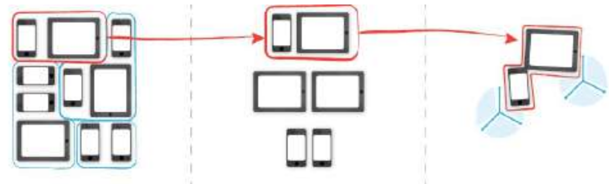

Figure 2: Tablet–phoneassortment (left), potentialcombinations (center) and *Dynamic Duo*pairing (right).

BACKGROUND AND RELATED WORK

A single-user interface spread across multiple devices (knownas *multi-machine user interfaces*) is not new [25]. Extensive research has been carried out in this area, which can be categorized in two themes: 1) exploring the combination of small, personal devices with larger, shareddevices in office or public settings; and 2) investigatingthe working combination of two or more equivalent devices in mobile scenarios. We have complemented our background research with an online survey to bring it more in line with the mobile-touch marketplace.

Small personal deviceswith a stationary large device

ForLensMouse, a touch-sensitive phone was strapped to a computer mouse [38]. The touch screen replaced the need for mouse buttons and allowed for interaction with auxiliary elements displayed on the smartphone. Similar commercial mobile applications transform a phone into a secondary display [33]or an enhanced-input touchpad [1]. In Sweepand Point and Shoot [3], Lorentz et al. used smartphones as pointer and text-entry devices to control personal computers or to interact with large screens at a distance [21].

Other device combinationsalso support collaborative-work.In Augmented Surfaces [32], digital information could be exchanged between portable computers, tablets and vertical displays by dragging and dropping across devices using a shared mouse.Forelines et al. adapteda single-display, single-user commercial application for use in a multi-device, multi-user geospatial system[13].Perspective Cursor, and later E-conic, examined perspective-aware interaction for multi-display environments [27, 28]. In Pick-and-Drop from 1997 [31], PDAs worked with desktop and wall-sized displays via a pen interface.

While these scenarios explore the complementary nature of different device types, the setting typically involves a large stationary device, limiting the dynamic interaction between devices. *Dynamic Duo* seeks to enable a new set of interactions in the combination of two popular complementary *mobile* devices,the phone and the tablet.

Multiple equivalent devices in combination

The second category of research on multi-machine user interfacesfocuses on combinations of equivalent devices,such as smartphones with smartphones.

Hinckley et al. investigated distributed sensing techniques for mobile devices using synchronous gestures on tablets [15, 17].Chen et al. examined navigation techniques for dual-display e-book readers [10]. Bonfire combined a laptop computer with two laptop-mounted micro-projectors thatoperated as a self-contained mobile computing system [18].

Severalprojects have networked PDAs together to create a system for interactive educational games [5, 11, 34]. Similarly, Kauko and Häkkilä showed how two handheld devices could be paired to create a shared game area[19]. Maciel et al. suggested that two interconnected tablet PCs forming an enlarged desktop could assist in information exchange in face-to-face meetings [23].

The Codex project systematically explored both personal and collaborative usage scenarios of twoequivalent PDAs [16].Edge and Blackwell [12] analyzed ways in which mobile devices could be used to represent and control digital information[6].

Although there has been considerableworkexploring the possible combinations of two devices, these scenarios were designed for devices of the same type,andperform similar functions. *Dynamic Duo* is a specific but important multi-machine scenario in which the devices play complementary roles.The new integrated device benefits not only from the attributes of each component device,but also from newly available attributessuch as the relative position and orientation of the devices. We also suggest interchangeable roles for each device, if appropriate for the application domain.

Online survey

We conducted an online survey to map current usage patterns involving the combination of smartphones and tablets. Over a period of one month, 150subjects (102 males and 48 females in anage range of 20 to 60, and a mean age of 30) responded to our survey. 40% of the respondents owned both a tablet and a touch-sensitive smartphone. Within this 40%, subjects showed a strong tendency to usethe smartphone (4.6 in a 5-point scale from "rarely" to "very often") more often than the tablet (3.3). Also within this 40%, the tablet and smartphone combination was preferred to other combinations because of its versatility, portabilityand complementary nature.The devices are carried together more than occasionally (2.6),and mainly for reasons of work or leisure. Almost half of the 40% already use their smartphone and tablet at the same time.Overall the desire for a tighter integration between the devices was strong (3.9 in a 5-point scale from "weak" to "very strong")both regarding communication between devices and between applications.The survey shows a significant interest in tablet–phone combinations and establishes *Dynamic Duo* as an important device combination for our study.

DYNAMIC DUO DESIGN SPACE

To understand the ways in which the two devices can interact, we explore the design space of phone–tablet combinations, inspired by Card et al. [7]. This design space could be considered a sub-set of interaction techniques used for object movement in multi-display environments [26]. Within multi-display settings, researchers have for instance examined device-mounted marker clusters for spatial inputandpico projectors for output[8, 9]. In our case, aiming for simplicity, our choiceis fiducialmarkers; here byte tags,to capture relative device position and orientation. Hence, we combine relative spatial awareness and touchfor input, and use the device screens for output.

Each device can play one of three possible roles: primarily as an input device (I), as an output device (O), or as both an input and output device (IO). While we focus mostly on touch input and screen output, the devices we study are shipped with a range of sensors (such asmicrophone, infrared, accelerometers, gyrosor ultrasound) and actuators (such as audio, tactile or force feedback) [35, 42].

Crossing the two devices with the three possible roles yields nine possible combinations (C1-C9) (Fig. 3). The design space proposed here is able to accommodate for any device sensor or actuator when placing it in the matrix. Four cells in this matrix are counter-intuitive, showing an ecosystem of portable devices that provideno feedback with interaction (input only) or without means for user interaction (output only). These are cells where both devices are used only for input or only for output (C5 and C9) and the cells where the larger device is used for input only (C7 and C8).

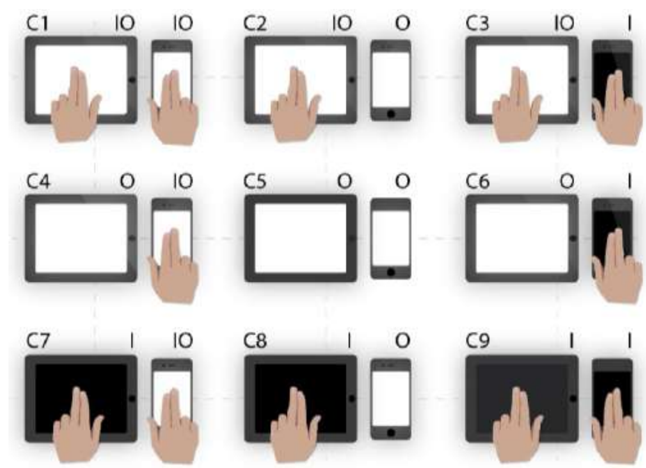

Figure 3: Tablet–phone combinations codedwithhands to denote input (I) and a whitescreen to denote output (O).

When the two attributes of input and output functionality are paired with the two devices, they enable*distributed informationdisplay* (output: C1, C2, C4, C5), *distributed control* (input: C1, C3, C7, C9) or both (C1). While distributed display or control is common in multi-machine user interfaces, this configuration of complementary devices gives them new meaning. We list three scenarios for each case,distributed information display (output) and distributed control (input). Because we consider the complementary formfactors in the *Dynamic Duo* to have fewer implications for distributed information displaythan for distributed control, and as it appears that display has been researched to some extent, our investigation will focus most on control.

Distributed information display (output)

Atablet may be the primary (foreground or focus) display while thephone is the secondary (background or context) display, a configuration we explore in a *reading* task. Or, the tablet may be a public or contextual display while the phoneis the private or focus display.In a third scenario, itis possible to have novel behavior when one device is in front of the other,such as having the phone act as a lens to reveal additional information within the tablet like a magic lens or a Toolglass[4].The mobile handheld can act as a physical information and interaction overlay. A physical overlay can also turn into a proxy for information collection and sharing, as seen inmediaBlocks [37] or Candy Dish in co-located situations [17].

Distributed control (input)

The phone can function as the main controller andthe tabletasa supplementarycontroller or pure output device.Or, the tablet can be the main controller while the phoneis a supplementary controller or pure input device.In a third scenario, the tablet and phone can work together providingnovelcombined controls.Each of the three scenarios is explored herein a gaming task, a drawing task,a *circular menu* techniqueand a*slide-under* technique.

Combining distributed information display (output) with distributed control (input)

Making use of distributed information display and distributed control in one application should yielda range of design possibilities. To indicate this potential we present one example,*painter*, where we employ drawing, the circular menu technique and theslide-under technique with distributed information display.

DYNAMIC DUO MOBILE PLATFORM

The *Dynamic Duo* multi-device mobile platform [29, 30] consists of one or more tablet-sized devices (such as the iPad or an Android tablet) and one or more phone-sized devices (such as an iPhone, Samsung Galaxy mobile phone or PDA). For this initial exploration, we focus primarily on a scenario with one phone and one tablet.

The two devices are connected so that information can be freely transmitted between them. Both devices are aware of input and output events happening in the other. Furthermore, the two devices may also be aware of the position, orientation and distance of the other device relative to its current location. We have developed a prototype system to illustrate such a concept.

System implementation

In the current realization of the*Dynamic Duo* prototype, we have picked devicesthat share the same operating system, iPhones and iPads running iOS 5.1.To implement position tracking we have employed the tracking capabilities of a Microsoft Surface usingbyte tags attached to the back of each device. Each device is thus uniquely identified by its own byte tag, with which we observe position, distance and orientation, relative to other byte tags.

Figure 4: System structure and communication diagram between devices and Microsoft Surface.

Network and middleware layers

The communication between devices, and between the devices and the Microsoft Surface, happens through UDP packets exchanged over a wireless network connection (Fig. 4) containing several kinds of messages.Each device queries the Microsoft Surface for the position and orientation of all other devices through device descriptor messages. Once the device descriptor messages are received, each device identifies itself and all other devices using the byte tags. It then sends back to the Microsoft Surface its own IP address and its byte tag identifier. A device would then query the Surface again for a list of IP addresses belonging to other devices. The pair of byte tag and IP address is delivered as a device information message. Once a device has the descriptor and the device information message for another device, it can then communicate directly by sending application-specific messages. This enables the support of a flexible ecosystem of devices where each device can be added to the system in an ad-hoc fashion. New devices need no prior knowledge of previous ones.

Developer's toolkit

We have developed two software libraries using the techniques presented in this paperto help with the creation of prototypes. The first library enables the sending and receiving of byte tag information (device descriptor and device information messages). The second library facilitates the broadcasting of messages used for inter-device communications. We have also developed a Microsoft Surface application that acts as a tracker and central connection point of the system, as well as a network server for the message exchanges. We are planning tooffer this as an open-sourcedeveloper's toolkit.

CONCEPTUAL PROTOTYPES

We created a range of conceptual prototypes showing distributed information display, distributed control and combinations of them all based on the mobile platform presented here.

Distributed information display

An important motivation for multiple device interaction is the distributed information display (many scenarios have already been explored [4, 17, 37]). Here, we examine the tablet as a primary (foreground or focus) display while the phone is the secondary (background or context) display. We illustrate this with a *reading*task using hyperlinks.

Reading is an activity that benefits from a largedisplay surface.While reading can be done comfortably on a small screen, it is anarguably poorer reading experience than reading a book on a tablet.Reading often occurs alongside contextual activities that complement the main task,such aslooking up definitions or opening hyperlinks to related information before returning to the main article.These can be well accommodated on a separate, supplementary device that avoids occlusion and minimizes interrupting the flow of the main reading activity(Fig. 5).

Reading: We developed a prototype of a multiple-device hypertext reading application where the user is presented with a webpageon the tablet device (Fig. 5). Normally, when opening a link the page would change or scroll to the link's anchor. In this demo application the contents of the link are displayed on the secondary device.

Fig. 5: Concept (top) and realization (bottom) of reading text with hyperlinks.

Distributed control scenarios

Another usage scenario for multiple device interaction is distributed control and distributed interaction. We envision scenarios in which user interaction alternatesbetween devices or at the sametime on both devices.

Gaming:Thephone can beused as the main controller while thetablet is asupplementarycontroller or pure output device. While many games exist for what Weiser called"foot-sized devices" [41] (devices about the size of one imperial foot, presumably one square foot), the interaction style is often revised and adapted to touch sensitive interfaces, deviating from their counterparts on other platforms. Changes can involve replacement of binary buttons or direction pads with other forms of user control, often through gestures. Such approaches completely eliminate any need for tangible interaction, including holding a control devicein the user's hand such as a joystick.

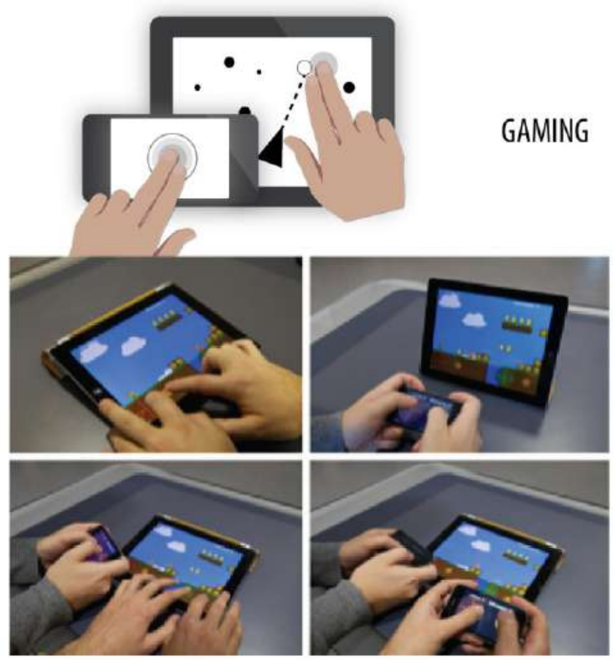

Fig. 6: Concept (top) and realization of handheld controller for single and multi-user gaming.

We suggest that a smaller device such as a phone can be used as a primary input source, whereas the tablet can be used for display purposes (output), secondary input purposes (such as to select a game level) or by a second player if needed (Fig. 6). The phone can provide a rich set of inputs including accelerometers and gyros, comparable to state-of-the-art joysticks.

To demonstrate this technique we have create a game that allows for distributed control (Fig. 6). The phone can be used as a controller for game characters on screen. Other players can join and use the onscreen control widgets on the tablet or their own phone, to avoid hand–screen occlusions. This technique also helps to avoid obstruction problems and the discomfort of a cramped play environment [14].

Drawing: The tablet can be used as a main controller while the phone is the supplementarycontroller or pure input device.This setup is suggested to facilitate sketching and drawing. The tablet is considered the primary input and output device for the majority of actions. The phone can be used to extended input and output spaces, allowing for bimanual [20] interaction modalities. This scenario also takes advantage of the tablet's stationary posture on a horizontal surface, which allows for stable input while the phone can provide additional input and output (Fig. 7).

Fig. 7: Concept (top) and realization (bottom) of drawing on the phone and control on the tablet.

To demonstrate this technique we implemented a multiple-device drawing prototype system where the canvas fills the entire tablet display. The phone is used for brush control, such asbrush size and stroke opacity. The main input activity, drawing, is performed on the tablet while drawing settings are adjusted on the phone. A pinching gesture on the phone controls brush size, showing a potential use of natural user-interface gestures. A slider widget controls stroke opacity.

Distributed control techniques

Thus far we have investigated control through on-screen manipulation, distributed control can also be achieved through manipulation of device-relative orientation or position. In this way, the tablet and the phone can work togetherto providedynamic, combined controls. In*reading*,*gaming* and *drawing*we presented applications thatcombine the properties of each device in a straightforward manner.Next, wesuggest two interaction techniques that leverage mutual position, distanceand orientation between devices.Orientation control is exemplified through a circular menu, position control through aslide-under technique.

Circular menu:This technique offers circular control through device-relative spatial awareness. Each device is aware of the position of the other with respect to its center (Fig. 8).Surrounding space is partitioned into discrete slices just as in radial menus. Moving one device across the slices of another can selectively trigger different functionalities on the device itself, on another device, or both. Furthermore the relative orientation of the device can be used to further differentiate user input.

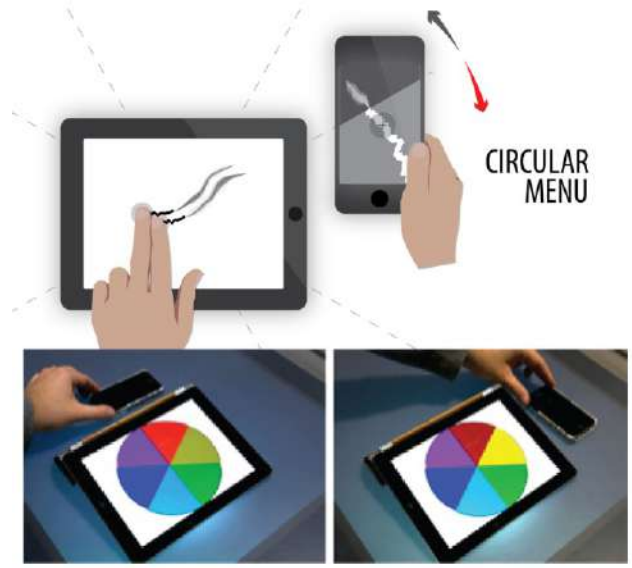

Fig. 8: Concept (top) and realization (bottom) of circular menu with multiple devices.

For demonstration purposes we created a simplecircular menu application. A circular menu with six items is displayed on the tablet's screen, whereeach menu item has a given color thatbecomes brighter when activated. For example, when the phone is next to the dark red item, this item turns light red. When the phone next to the dark yellowitem, that item turns light yellow (Fig. 8).

Slide-under: This technique is a tangible user interface inspired by the magic lens and Toolglass see-through interfaces [4].Slide-underoffers device-relative position control using the distance between the centerpoints of the devices. Many protective covers for tablets allow the device to be comfortably positioned horizontally and tilted slightly rather than laying flat. This technique takes advantage of the small gap between the device and the support surface created by this position, allowing a phone to be inserted underneath.The phone can be compared somewhat to a desk drawer that is opened or closed to reveal and hide additional features (Fig. 9). When physically inserting one device underneath anotheris not possible, this degrades gracefully to a docking technique.

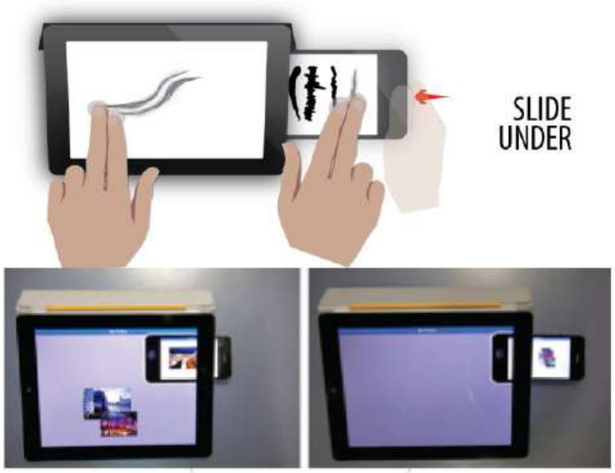

Fig. 9: Concept (top) and realization (bottom) of slide-under with phone inserted and extracted.

To demonstrate the principles of this technique we have created a photo-sharing application prototype. When the phone is inserted under the tablet, a replica of the phone is presented on the tablet screen and the user can drag and drop photos onto it. Once photos have been moved to the phone the user confirms the selection by double tapping and extractingthe phone with the transferred photos.

Combining distributed display and control

Distributed displays and controls can work together to form more complex and novel interactions. In *painter*, we combine an instance of drawing, circular menu and slide-under while employing distributed information display.

Painter:This composite applicationtakes advantage of the circular menu technique by selectively presenting either a brush-control widget or a color-palette widget on the phone. While the technique offers a configurable number of items (Fig. 10), we have configured the menu with four itemsmaking use of the left, right and bottom sectors (the top sector is not used here). When the phone is in the right (or left)sector, the brush control widget is presented.Moving the phone to the bottom sector invokes the color palette.Employing the slide-under technique reveals a widget for controlling brush shapes.

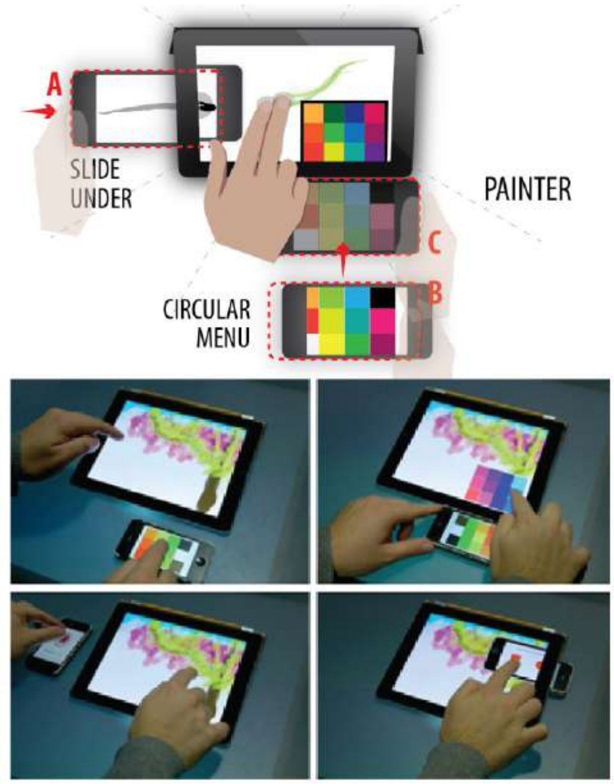

Fig. 10: Concept (top) and realization (bottom) of *painter* combining circular menu and slide-under. Movement A is slide-under; B to C is docking the color palette.

As we compare the *Dynamic Duo* withCodex, we note the following differences:while in Codex both devices have the same size and functionality, in *Dynamic Duo* these and further factors are complementary. Even though Codex allows for the two devices to be separated and to play self-same roles, in *Dynamic Duo*the two devices play completing roles.

USER FEEDBACK

We conducted an informal observational study with twelve subjects to gather initial usability information about the different device configurations and system design. We recruited three female and nine male subjects from ages 23 to 47, with a mean age of 27. All subjects were computer-savvy and regularly used a smartphone and tablet.We tested only the circular menu technique, the slide-under technique and the painting application. For each technique, the subject was given a demo and approximately five minutes to familiarize themselves with it. The painting application was shown and the subject was given another ten minutes to experiment with it. At the end, subjects were asked to give informal feedback. The questions asked by the experimenter were: “What did you like about the system?”“What did you dislike about the system?” and “What is your opinion of this combination of devices?”

For the painting application, several subjects appreciated how the combination of devices could save screen realestate on the tablet, distributing control widgets to the phone.

Most subjects found that docking worked well with the color palettes—users seemed to like this way of expanding the available options.

For the circular menu,users mentioned that this would allow collaboration with multiple phones, where every user has his or her own, and could work together on the common canvas.

For the slider-under technique, subjects appreciated the solution applied to a real-world problem of data transfer between devices.They reported perceiving the coupling as highly direct, in the sense of visual manipulation of objects [36]. They also stated that they found the corresponding mental model to be clear and to embody a valid metaphor. One subject found the "magic" factor of the slide-under appealing. This subject also found that "there is a whole new layer of discovery when the devices work together, and it's very much exploratory to reveal functions around the tablet, under it, closeby, etc."

In general,subjects liked the combined power of *Dynamic Duo*.The slide-under technique was especially popular due to its simplicity. As part of the painting application, users reported that the slide-under technique could help navigating a wider canvas or could have revealed further painting layers or a clipboard.

SUMMARY AND CONCLUSION

We have investigated how a phone can be paired with a tablet to form a multi-device mobile computing platform, something we callthe *Dynamic Duo*. We have outlined nine types of device combinations (C1-C9) enabling distributed display, distributed control or both. We presented examples and implemented working prototypes for each of these three possibilities. We also presented an application that combinesseveral of these. To enable this work, we developed two software libraries and a server application,which we intend to share publicly. Our user study revealed that the slider-under technique appealed the most to users,and showedgreat potential. While the circular menu was also praised, users found it challenging to discover its different features and mode of use. For some users, not being able to understand the full functionality of the techniques or application without prior exploration was seen as a challenge. There is work needed in the visibility of the actions [36].

While we mostly examined device collaboration here, we only presented one example of human collaboration; multiuser gaming. Human collaboration—local or even remote—is a rich field of design and engineering challenges that we have not yetfully explored. In remote collaboration, the combination of a videoconference channel with a shared application may benefit from two devices that have not only distributed display and control, but also offer the dynamics presented here.

Beyond our initial focus of low-mobility environments such as a living room or office, we also see potential applications in tasks that have an inherently higher level of mobility, where location is important, such as navigation while walking or driving, maintaining a factory floor, or time-sensitive tasks, such as production or logistics, and doctors in a field setting or hospital [40].

ACKNOWLEDGEMENTS

Tommaso Piazza and Morten Fjeld would like to thank the Swedish Foundation for International Cooperation in Research and Higher Education (STINT) for Initiation Grant IB2011-4523. AsimEvrenYantacwould like to thank the Scientific and Technological Research Council of Turkey (TUBITAK) Post Doc fund that enabled him to spend a period at Chalmers. Morten Fjeld would like to thank the Swedish Foundation for Strategic Research for the mobility grant SM11-0009. The research leading to these results has also received funding from the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme FP7/2007-2013/ under REA grant agreement n°290227. Thank you very much to Peter Kun for his support in gathering user feedback. Thank you to Erik Tobin, Allen Smith, Pawel Wozniakand Barbara Stuckey for language correction and proofreading. And thanks to David NG McCallum for hiseditorial work.

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