CROSS-DEVICE INTERACTION BETWEEN MOBILE DEVICES

SW1011F13
Master Thesis

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Synopsis:

This report explores how collocated cross-device applications can support social interaction between people.

We implement and evaluate three use cases for this: A photo exploration system called JuxtaPinch, a “Where’s Waldo” application, and a card game. Common for these is that they utilize several mobile devices to make up a single system. JuxtaPinch joins the screens of several devices to form one larger screen, that can be used for viewing and sharing photos. The “Where’s Waldo” application utilizes the screens of two iPads to explore a big Waldo picture. Finally, the card game uses a tablet as a playing table and smartphones for player hands.

The three systems are separately evaluated through user tests, for a total of 88 people participating altogether for the evaluations. Our evaluations suggest that the three collocated cross-device applications supports social interaction and strengthen the relationships between the people involved.

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Preface

This collection of papers is the result of our master thesis, as software engineers, in Human-Computer Interaction, at the Department of Computer Science at Aalborg University.

The theme of our master thesis is *cross-device interaction between mobile devices*. This report covers the research of two semesters, 9th and 10th. Our 9th semester (pre-master thesis) was documented as a full report and presented in January 2013. However, it has been slightly rewritten, as a paper, and included in this report, to contribute to the common objective of this master thesis. Note that only little has changed from the 9th semester report, it has merely been fitted for a paper version. This collection contains a total of three papers.

The reader is expected to have knowledge equivalent to what is expected for a 10th semester student in computer science.

A CD containing the source code of the developed systems is supplied together with this report. The CD also contains a digital copy of this report as well as appendices with e.g. interview transcriptions. Additionally, it contains all logged numbers used for the quantitative analysis, enclosed as database exports.

We would like to thank Mikael B. Skov, Associate Professor at Aalborg University, for providing ongoing feedback and guidance throughout the project.

Contents

1 Introduction

In only a few short decades, the ways in which people interact with the digital has undergone a remarkable evolution. The perception of how we use our devices, which devices we use, and the context in which we use them, has changed countless times. From the earliest portable computers which improved the mobility of workspaces, to modern tablets and smartphones which give their users access to such a degree of functionality, wherever they are, that the necessity of dedicated workspaces is starting to erode. This development has not only increased the power of mobile computing, but also made it more widespread. Especially have we seen a massive shift to different kinds of mobile devices.

People bring their mobile devices with them everywhere. This means that a social meeting is not only a gathering of people, but also of mobile devices. This ubiquitous presence of devices can be used to enhance ordinary social situations. E.g. by providing a mediator for games or for topic of conversations. Using solely a single device for this, however, has its limitations. Mobile screens are small, and only a few people can simultaneously make use of it [5, 10]. Using several of the already present devices as one single system provides a whole new range of opportunities for social interaction. We define this as: *Cross-device interaction*. Hence, a mobile cross-device system is: A system that utilizes several co-located mobile devices as one single system.

Research has focused on interaction techniques for several years [3, 9]. With the emergence of new technology, we need to understand how existing and new interaction techniques perform in use, e.g. in terms of usability, like task completion time, or in terms of user experience, like user satisfaction. Having interaction across several devices (cross-device interaction), requires thus further understanding. Research studies have started to investigate how to support this new use of technology [1, 2, 4, 7, 8]. However, as the opportunity to employ cross-device interaction has emerged within the last decade, only little research exists.

Inspired by this, we want to explore the area of collocated cross-device applications and it's interactions, in social settings. We seek to answer the following research questions:

RQ1: *"Which interaction techniques can be used for cross-device interaction?"*

RQ2: *"Which social situations can be supported by cross-device interaction?"*

2 Papers

To answer the two research questions raised in the introduction, we have developed and evaluated three different cross-device applications. As a result of this, the following three papers were produced.

2.1 Paper #1: JuxtaPinch: Investigating Collocated Photo Sharing through Cross-Device Interaction

As smartphones and digital cameras have become consumer items, we have seen them outmatch the rollfilm camera. Photos can be now be viewed and shared instantly after capture, on the devices or through online photo sharing services, such as Facebook and Flickr. All this without the hassle and cost of film roll development. Online photo sharing however, lacks the richness of the social interaction that occurs when people share photos face-to-face [6]. Collocated photo sharing remains important for people to evolve their self-image, and to strengthen the relationships within social groups [11].

We designed JuxtaPinch - a system for collocated photo sharing. The system utilizes multiple devices, namely smartphones and tablets, to form one larger display for photo sharing. The devices can be repositioned at any time, through move and pinch interactions, to reconfigure the combined display. The photo being viewed will adapt to the display, making the system highly flexible. To make JuxtaPinch unique from other collocated photo sharing applications, we implement it such that it supports: 1) Flexible positioning, 2) Partial viewing of photos, and 3) A wide range of different devices. We studied JuxtaPinch through a lab condition and a field condition. Shared aims for both conditions were to examine the experience of showing photos on a collocated collaborative photo sharing application that supports flexible positioning and partial viewing of photos. 40 people participated in the evaluation, 22 for the lab condition and 18 for the field condition. Participants used their own photos and own devices for the evaluation.

Our evaluation showed that participants sometimes experienced their own familiar photos in new ways – also sometimes referred to as defamiliarization. We identified three causes for this: Isolating parts of a photo on one device, scaling photos smaller or larger, and hiding the main objective of the photo, such that only secondary objectives were visible. We also saw two different strategies for building the viewing display: Participants would either build a rectangular display for viewing the entire photo, or they would construct a creatively shaped display to view only part of a photo. Participants expressed no concerns about sharing their personal devices. However, numbers from the lab condition showed that more than half of the movements and more than half of the pinches were made to one's personal device. This suggest that people have an unconscious connection to their own devices.

2.2 Paper #2: Where's Waldo? Cross-Device Collaboration Between Children

Tablets have found their place in the household over the last few years. They are often utilized as shared devices for leisure activities in the household. Tablets are not reserved for the adults of the family, but are also used by the children for leisure activities as well as educational gain. Many schools in Denmark have already acquired iPads for precisely this reason, and more schools will most certainly follow. This provides opportunities for using these tablets in new ways for children.

We developed a "Where's Waldo" collocated cross-device application intended for children. The application is built on top of JuxtaPinch, with the difference from JuxtaPinch being that the "Where's Waldo" application show pictures as their actual size, where JuxtaPinch would scale the picture to fit the connected screens. With the "Where's Waldo" application we studied collaboration strategies between paired dyads of children. A total of 22 children participated in the study. Two iPads were used for the evaluation. We also brought along a paper version of "Where's Waldo" to better understand the observations of the children when using the iPads.

Our study found that the children collaborated when using our application, whereas they worked independently on the paper version. We identified five different collaboration strategies between the children: Divided ownership of iPads, divided interaction, turn based, driver & navigator, and no strategy. With no strategy, it seemed random who controlled, moved, and pinched and it sometimes ended in chaos. Some groups would also alternate between these strategies depending on their current state of mind. We also observed that it was difficult for the children to gain an overview of the Waldo picture with such an application. No group covered an entire Waldo picture with the iPads. They navigated along borders easily, but had a hard time navigating when there were no clear indication of their current location in the picture.

2.3 Paper #3: Cross-Device Interaction Techniques for Card Games

Just as the mouse presented new interaction styles when introduced, so do the emerged new technologies. E.g. the touchpad for the laptop, the multitude of different touchscreen technologies, the motion sensing technologies and the gyroscope inside many smartphones. Cross-device applications does further add to the vast number of interaction techniques. To our knowledge, little research has been conducted in cross-device interaction techniques for the smartphone-tablet setting, in a private leisure context.

We developed a cross-device card game, inspired by the great opportunities for cross-device interaction techniques between smartphones and tablets. We identified and systematically evaluated six interaction techniques. Three for playing a card: Hold, swipe and wrist-whip. And three for drawing a card: Direction-swipe, tap-tap and drag. A total of 26 people participated in the evaluations. Hold, from the play card category, and direction-swipe from the draw card category were implemented in a cross-device card game which was finally tested for its usefulness.

Our evaluations showed that tap-tap was the fastest and least error-prone interaction technique for drawing a card, however, users preferred direction-swipe in terms of entertainment, preference, naturalness, and usefulness. For playing a card, hold was the fastest and wrist-whip was the least error-prone interaction technique, but users preferred hold. The usefulness study showed that it was possible to play a card game on the system. However, there was still room for improvement.

3 Conclusion

Smartphones and similar mobile devices have become ubiquitous. People bring their mobile devices with them everywhere, creating opportunities for cross-device interaction in social settings. Based on this, we implemented and evaluated three applications for use in three different collocated cross-devices settings: A photo exploration system, JuxtaPinch, a "Where's Waldo" application and a card game.

The photo exploration application, JuxtaPinch, showed that combining screens of several devices to form one larger display entailed a different user experience than a single big screen would have. In the case of photo exploration, we saw that isolation, scaling and hidden main objectives caused users to experience their photos in a new way. Hence, mobile collocated cross-device applications can be used to incite new experiences.

The "Where's Waldo" application showed that children collaborated far more when locating items on a digital Waldo picture, compared to a paper version of "Where's Waldo" . Hence, mobile collocated cross-device applications can be used to support collaboration between children.

The card game application showed that a mobile collocated cross-device application could be used for playing card games. The main focus for this application was, however, to examine different cross-device interaction techniques and we found that different interaction techniques each have their advantages and limitations.

Our aim with this project was to answer the two research questions:

> RQ1: *"Which interaction techniques can be used for cross-device interaction?"*
>
> RQ2: *"Which social situations can be supported by cross-device interaction?"*

We will answer these in the following, starting with RQ1.

Through our studies of the three applications we evaluated several cross-device interaction techniques. We have grouped these into three categories of interaction techniques: Connecting devices together, disconnecting devices, and transferring content. We present usable interaction techniques for each category in the following.

> **Statement:** *Cross-device pinching can be used for connecting two devices together. One-hand pinching was preferred over two-hand and two-step pinching.*

In JuxtaPinch, we used cross-device pinching techniques to connect two mobile devices. We supported three types of pinching: One-hand pinch, two-hand pinch, and two-step pinch. Participants could freely use the pinch technique of their choice, and we observed that one-hand pinch was the most used pinching technique with over half of the pinches, followed by two-step pinch with one third of the pinches. However, we also observed that the preferred pinch technique was dependent on the group.

The "Where's Waldo" application implemented the one-hand pinch from JuxtaPinch to connect devices together. We observed that children in the age 9-11 years could successfully perform the one-hand pinch.

> **Statement:** *Device movement can be used for disconnecting devices. It provides seamless disconnect that feels natural.*

Both JuxtaPinch and the "Where's Waldo" application successfully used device movement to disconnect devices from the system. It provided users the possibility of disconnecting a device seamlessly without any explicit action, as the devices, in the two applications, had to be moved anyways.

> **Statement:** *Swipe, hold, wrist-whip, direction-swipe, drag, and tap-tap are all applicable interaction techniques for transferring content cross-device. However, they have each their advantages and limitations. Hold is the fastest, but direction-swipe is the preferred interaction technique by users for transferring content.*

All of the above interaction techniques were used in the card game for either playing or drawing a card from a tablet to a smartphone or vise versa. It was observed that different techniques have different advantages and limitations. With our implementation of the interaction techniques, we found swipe and direction-swipe to be fluctuating in performance, and significantly the most error prone interaction techniques. Hold was the significantly fastest interaction technique for playing cards. Drag was the significantly slowest interaction technique for dealing cards. When asked, the majority of the users preferred hold for playing a card and direction-swipe for dealing a card.

Now, we move on to answer RQ2. Through the evaluations of the three applications we observed that cross-device interaction can be used in at least three social situations: Collocated photo sharing, collocated gaming, and collocated collaboration.

> **Statement:** *Cross-device interaction can support collocated photo sharing. Through flexible positioning of devices and partial view of photos, cross-device renews or enhances the perception of familiar photos.*

JuxtaPinch was developed exactly with the purpose of supporting collocated photo sharing. However, one must not mistake JuxtaPinch for merely a bigger screen for photo sharing. Due to the flexibility of JuxtaPinch, photos may be distorted and manipulated in many ways, granting the users with a whole new experience of sharing photos. In some cases, the perception of familiar photos were changed, also known as defamiliarization.

> **Statement:** *Cross-device interaction can support collocated gaming. Different cross-device setups allows renewed gaming experience of several classic games, such as Whist or "Where's Waldo".*

Through our evaluations we saw that cross-device applications can be used for collocated gaming. Both the "Where's Waldo" application and the card game supported collocated gaming. The "Where's Waldo" application showed that children in the age of 9-11 years can utilize cross-device to renew the challenge of the "Where's Waldo" game. The card game showed how mobile devices could be utilized to simulate a classic deck of cards for use when e.g. one does not have a deck of cards at hand.

We saw that games can be implemented in different cross-device settings. E.g. the "Where's Waldo" application used two tablets to be shared between the participants, whereas the card game used one shared tablet, and then one personal smartphone for each participant.

> **Statement:** *Cross-device interaction can enhance collocated collaboration. By using devices as shared units, cross-device applications can coerce both children and adults to collaborate to achieve a common goal.*

Both JuxtaPinch and the "Where's Waldo" application supported collocated collaboration. When all mobile devices becomes part of a shared pool of devices for use to reach a common goal, it is required by the participants to collaborate in order to complete the goal. Different collaboration strategies for this was observed between both the adults and the children. Common for both were that when they got too eager, they sometimes interacted at the same time, causing unwanted results.

Although the three implemented applications are quite different in nature, we have seen common tendencies throughout our evaluations of the three. General responses to the applications was a feel of novelty and innovation. Collocated cross-device applications are a new way of utilizing common technologies that are already at hand. People already use their smartphones in social collocated situations, however, not as a shared device. By connecting these to function as one single system, whether it is for playing a game of cards, exploring photos, or to find Waldo, it seems that these applications support social interaction and strengthen the relationships between the people involved.

We see a great potential in this topic and believe that there are many more use cases to explore.

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Paper #1:
JuxtaPinch: Investigating Collocated Photo Sharing through Cross-Device Interaction

JuxtaPinch: Investigating Collocated Photo Sharing through Cross-Device Interaction

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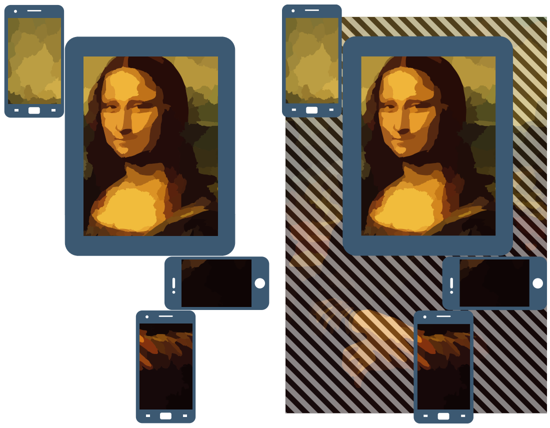
ABSTRACT
In this paper we explore collocated photo sharing with smartphones and tablets. We develop a cross-device cross-platform application, JuxtaPinch, that allows a group of collocated users to share photos ad-hoc, utilizing the screens of their smartphones and tablets as one big screen. The application allows users to add and remove devices during use, which grants them the opportunity to play with and explore photos in a new way. We evaluate the system both in a controlled laboratory setting and in the field. Our evaluations show that JuxtaPinch incite defamiliarization by isolating, scaling, and hiding the main objective of the photo.

Author Keywords
Cross-Device; Mobile Device; Interaction; Multi-Display; Touch Screen; Collocated Photo Sharing;

INTRODUCTION
Smartphones have, over the last few years, become common consumer items. Originally, mobile phones were designed to function as portable phones. However, today mobile phones are portable digital switcher knives allowing consumers to perform a wide range of tasks. These tasks range from the originally intended purpose of making a phone call, to texting your friends, surfing the internet, and watching blockbuster movies. One widely used blade of this digital switcher knife is the digital camera, which together with digital cameras has outmatched the rollfilm camera. This wide adoption of digital imaging technologies was the trigger for people to make more photos than ever before [18]. This is based on three major features of today's digital imaging technologies. First of all, availability. Camera phones and the like are easily available at hand to capture all sorts of photos: Unexpected events, humorous sights, or even photos of everyday life. Second, another aspect of availability, is the easy access to viewing and sharing the photos. There is no need for film processing. Photos can be viewed and shared instantly after capture, on the devices or through online photo sharing services, such as Facebook and Flickr. Moreover, these online photos are available for review at a later point in time, from any online



(a) Without hidden parts. (b) With hidden parts shown.

Figure 1: JuxtaPinch

device, may it be a smartphone, tablet, laptop, etc. [18]. This leads to the third of the digital imaging technologies features: The low cost. Compared to non-digital photo making, there is little cost in capture and viewing digital photos. No rollfilm is needed for storing the photos at capturing, and no processing of the rollfilm is needed to view the photos.

The easy access and low cost of photo making, and sharing, has had a huge impact on the way people interact with photos. The online photo sharing services, such as Instagram, have become a part of some people's daily routines. These people share photos of their food, their feet, their pets, and so on. The standard of photos to share has drastically changed. These online services challenges the traditional face-to-face sharing of photos. They offer many beneficial features, including sharing to a wide audience, letting all your friends and family view your photo through one share. Additionally, you can even show them your holiday photos in real time, as sharing from a distance is no bother. Lastly, asynchronous sharing enables people to view photos on demand, letting them view the photos whenever they want.

However, online photo sharing lacks the richness of the social interaction that occurs when people share photos face-to-face [9]. Collocated photo sharing remains important for people to evolve their self-image, and to strengthen the relationships within social groups [18]. Inspired by this, we develop, present, and evaluate a system for collocated photo sharing. The system, JuxtaPinch, utilizes multiple devices, namely smartphones and tablets, to form one larger display for photo sharing.

This paper is structured as follows. First, we review related work. Then, JuxtaPinch is presented in terms of design and functionality. We then present the evaluation and findings, which is followed by a discussion and a conclusion of the paper.

RELATED WORK

Three main related work areas have influenced the design of JuxtaPinch: Cross-device, collocated photo sharing, and collocated photo sharing applications. These will be presented in the following.

With the arrival of smartphones and tablets, and the adoption of these into the domestic household, several devices are nearly always in range of people. This provides a great number of cross-device interaction opportunities.

Several researchers have exploited these opportunities to explore cross-device applications. For instance, *Pass-Them-Around* by Lucero et al [10], *Junkyard Jumbotron* by Borovoy & Knep [13], and *Pinch* by Ohta and Tanaka [12].

Pinch allows the surfaces of mobile screens placed next to each other to be combined into one singular screen using pinch gestures. Their multiple-screen layout can be changed dynamically, allowing for great interactivity. The content on the screen will adapt to the size of the screen. They provide an API for their system such that it can be used for several different multi-screen applications, such as viewing videos and playing games. However, the system is implemented for iPhone and iPad devices only. Their focus is on the underlying technology behind the dynamic screen. Consequently, the *Pinch* system has only been exposed to users at conferences resulting in a shallow feedback on the user experience using handed out iPhone devices. To our knowledge, no thorough user evaluation has been made of the *Pinch* system.

Collocated Photo Sharing

Collocated photo sharing is important even in todays technologically-mediated, distributed, digital world, where online photo sharing services such as Flickr and Instagram are widely used [3, 5, 7]. Van House [18] discusses three reasons why collocated photo sharing is popular.

The first reason is *memory, storytelling, and identity*. Memories and narratives attached to a photo is dynamic and changes over time. How we remember the story attached to a photo may not be the same today, as it will be in five years from now [18]. The tales that are told about the photos help to construct the individual's and the group's self-image. When we tell our stories to others, we make sense of our lives for ourselves.

The second reason that collocated photo sharing is popular is *relationships*. Sharing photos and stories face-to-face enacts the relationships between owner and viewer. Several papers [1, 5, 18] distinguish between two kinds of co-present photo sharing that enacts relationships, namely *reminiscing* and *storytelling*. Storytelling is a one-sided situation where a person presents a personal photo of an event, where the viewers were not present for the event depicted. Story-telling often happens around photos where the owner feels that the viewers should have been present. On the other hand, reminiscing happens when the photo portrays a group event where all viewers were present. They relive their shared past through conversation and thereby reinforce their relationships in the present moment. This second reason is confirmed by Stelmaszewska et al [17] who find that relationships are strengthened between friends when they share photos.

The third reason that collocated photo sharing is popular is *orality*. When collocated, people tell their story orally rather than written (as seen in online services such as Flickr). Oral storytelling gives dynamic control over the story told in the moment. Hence, it allows the storyteller to adjust the story according to the specific audience and their interests [18].

In today's digital world, people have most of their photo collection right at hand at all times [18]. The increased photo making caused by digital technologies such as smartphones, tablets and small digital cameras has entailed that a wide selections of photos are available right on our smartphones for spontaneous collocated photo sharing [10, 18]. Combining the popularity of collocated photo sharing and the availability of photos on our smartphones, we see a lot of collocated photo sharing on smartphones.

Collocated Photo Sharing Applications

One widely used method for sharing photos on smartphones is to pass the smartphone around from viewer to viewer, letting them see the photo person by person or in smaller groups [17]. However, studies point out several limitations to this approach. First of all, smartphone screens are small for viewing photos [4, 17]. The small screen makes it hard to identify what is happening on the photo, and details may be lost entirely. Second, one cannot point-and-tell and all viewers cannot see the photo at the same time [17]. Only people in close proximity have a chance to see what is pointed at, and it is difficult for the others to follow any of the stories told about the photo - leaving the rest of the group as outsiders. Both of these, to some degree, impair the sharing experience and how we perceive a photo.

A vast body of literature has studied different approaches adressing these limitations. Schmidt et al [14] and Greaves and Rukzio [6] suggests transferring the photos to larger viewing areas such as an interactive surface or a projector. However, such facilities are not as likely to be available as smartphones. A solution proposed by Kun and Marsden [1] suggests transferring the owners photo to all viewer's smartphone and then simultaneously show the photo. This allows for simultaneous viewing, but complicates point-and-tell. Also, the challenge of small screens remains. Stelmaszewska et al [17] proposes combining several mobile screens to compose one screen. This allows for simultaneous viewing, easy point-and-tell, and a big viewing surface. A number of approaches as how to connect smartphones and other devices into one bigger display have been suggested.

Systems such as *Phone as a Pixel* [15] and *Junkyard Jumbotron* [13] uses a high resolution camera to identify devices participating in the display and their position. By displaying either a color code [15] or a QR-code [13] each device is identified by the high resolution camera and the appropriate photo parts are transferred to the device. But as the approaches suggested by Schmidt et al [14] and Greaves and Rukzio [6], a thirdparty-device is needed, the camera, and thus makes this type of approaches equally cumbersome.

Pass-Them-Around [10] is a prototype of a collocated photo sharing application. *Pass-Them-Around* is a system where devices can be combined into one larger display by a pinching gesture, but only four juxtaposed devices can be connected at once. Additionally, the devices can only be connected side-by-side meaning restricted interactivity, as opposed to the *Pinch* system [12]. However extensive structured testing has been performed on the system. Groups of four friends evaluated *Pass-Them-Around* in a controlled setting where different tasks of storytelling and reminiscing were performed on four handed out Nokia N900 mobile devices. Even though they use the handed out devices, they conclude from user remarks that people are willing to share their mobile phones for collaborative use.

Based on the above literature, we see three shortcomings in the existing applications for cross-device collocated photo sharing. 1) Flexible positioning. *Pass-Them-Around* is highly limited in terms of dynamic photo construction. On the other hand, *Pinch* is highly dynamic, but, to our knowledge, is not implemented for photo sharing. 2) Partial viewing of photos. *Pass-Them-Around* is designed to show the entire photo, such that white space will appear on the screens if the photo has a different aspect ratio than the viewing screen. We see the opportunity for an application where the photo fills the screens completely and thereby cuts the photos instead, leading to partial viewing of photos. 3) A wide range of supported devices. This is inspired by Lucero et al [10] who conclude that people are willing to share their mobile phones for collaborative use, even though they use handed out devices in their evaluation. We feel that this statement needs to be further examined to prove valid. This requires an application that supports a wide range of devices.

This paper is inspired by the dynamic nature of the *Pinch* system and the extensive user evaluation of *Pass-Them-Around*. We want to conduct an extensive user evaluation of a dynamic system for collocated photo sharing. We want to examine in a lab setting how storytelling and reminiscing talk is shaped when using such a system. We want the users to bring their own devices. This allows us to further examine the statement from [10] that people are willing to share and connect their smartphones in collaborative interactions. It also allows us to study the interaction flow between people's own devices and other people's devices. Lastly, we will conduct a 14-day field-evaluation to investigate how people would use such a system as part of their daily lives.

JUXTAPINCH

JuxtaPinch is an application based on the above challenges in previous research. To make JuxtaPinch unique from other collocated photo sharing applications, we implement it such that it supports: 1) flexible positioning through pinching of perpendicularly juxtaposed devices. 2) partial viewing of photos by scaling the photo to fill all available screens. This can cause part of the photo to be hidden. 3) a wide range of different smartphones and tablets.

JuxtaPinch combines *juxtapositioning* and *pinching*. *Juxtapositioning* is the act of positioning objects side by side and *pinching* is connected to the action of stitching something together. Hence, the name JuxtaPinch, as the system utilizes pinching for unifying juxtaposed devices.

We utilize cross-device pinching, which, according to Otha and Tanaka [12], is extremely simple and intuitive. They argue that pinching can be easily connected to the action of stitching something together. Lucero et al [10] also found that the pinch technique is thought to be natural for connecting two devices.

JuxtaPinch combines the screens of several devices to appear as one. This means that a photo shown on the system will extend over a multitude of devices, as illustrated in Figure 1a. The system will always fill the screens, so there can be no white space on a screen. Hence, some part of the photo may not be shown. This is illustrated in Figure 1b. However, users can rearrange the devices at any time to change how the photo is being shown in order to explore the photos.

JuxtaPinch is based on three interactions; Choosing a photo, connecting devices, and disconnecting devices. These will be explained in detail in the following.

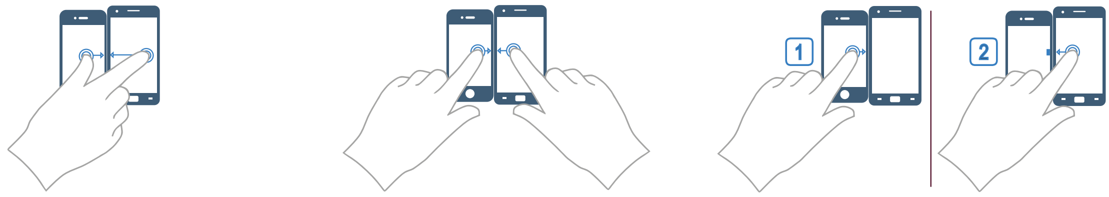
Choosing Photos

JuxtaPinch allows the users to change the shown photo during use. They can access the gallery of their device and choose any photo from it. When a new photo is chosen, all connected screens will detach such that the system provides a clean screen to build the new photo.

Connecting Devices: Pinch

A cross-device pinch technique is used to connect the devices together, as seen in Figure 2. JuxtaPinch allows for three cross-device pinching techniques: One-hand pinching, two-hand pinching and two-step pinching. *One-hand pinching* inspired by Otha and Tanaka [12] uses one hand, with the thumb and index finger on each their device. The fingers are then slided towards each other, connecting at the joining edge as seen in 2a. This technique is similar to the non-cross-device pinching technique commonly used to zoom in photos. *Two-hand pinching* inspired by Lucero et al [10] uses two hands. It uses one index finger on each screen and leads them towards each other as seen in Figure 2b. In addition, we developed a *two-step pinching* technique during the testing phase of JuxtaPinch. This is a two-step technique that uses one hand. The index finger slides to the edge of one screen and then afterwards slides to the edge of the other screen, as illustrated in Figure 2c. It originated from performing a great amount of pinches, as we feel this is the least motor demanding, as well as the most precise way to pinch. All three pinch techniques are supported by JuxtaPinch, letting the users use their preferred technique.

Disconnecting and Moving Devices



(a) One-hand pinch [12]. (b) Two-hand pinch [10]. (c) Two-step pinch.

Figure 2: The three implemented pinching techniques.

To reposition a connected device, the users merely need to move the device and then pinch it back on to another connected device. This is because JuxtaPinch detaches a device from the joined screen when movement is being recognized from that device. Movement is recognized as both tilting the device from side-to-side or top-to-bottom as well as acceleration in all axes. This repositioning technique is inspired by Otha and Tanaka [12]. We implemented it in order to further enhance the flexible feeling. The accelerometer and gyroscope is used to detect when devices are being moved around, in order to disconnect the moved device from the photo.

Scenario: *Imagine a user Alice. She wants to show a photo of her newly bought flowers to her friend Bob. She has combined three screens already using JuxtaPinch and she and Bob can see most of the photo of the flower. This is seen in Figure 3a. Alice wants to show Bob a detail in the leaves, so she connects a fourth device in order to make the photo bigger. This is seen in Figure 3b, where device number 4 has been added. However, Bob wants to tease Alice, so he disconnects device 2 from the photo, which shows the detail in the leaves. The photo is now shown as in Figure 3c. Alice laughs, she grabs her phone and walks away as she is heading home to make dinner, disconnecting it from the system and leaving the photo as shown in Figure 3d.*

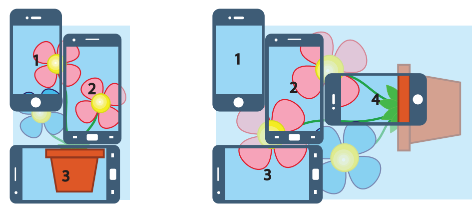
The scenario in Figure 3 illustrates how pinching and movements affect the photo. First, when adding a device that exceeds the existing border, the photo will get bigger, as seen in Figure 3b. However, when removing a device in a border position, the photo will get smaller. This is seen in Figure 3d. Moving a device that does not touch the border will not change the size of the photo. This means that holes can occur in the system, as seen in Figure 3c. Likewise, Adding a device that does not exceed the borders will not change the size of the photo. If the viewing area changes aspect ratio to be e.g. broader but lower than the previous one, the photo rotates to present as much as possible, e.g. when adding a device to the structure in Figure 3a, such that it resembles the structure of Figure 3b. Then we see that the photo have rotated.

EVALUATION

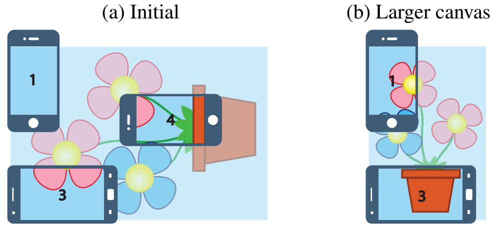
As previously mentioned, we implemented JuxtaPinch to support: 1) Flexible positioning, 2) Partial viewing of photos, and 3) A wide range of supported devices. To evaluate the impact of these features, we conducted a study of the system through two conditions. A laboratory condition and a field condition. Shared aims for both conditions was to examine the experience of showing photos with JuxtaPinch. Also, we wanted to investigate the impact of a wide variety of different devices for this, as Lucero et al [10] found that users were concerned about different types of devices for such an application. In the lab condition, we wanted to examine the collaboration between participants. Also, we wanted to further investigate the claim by Lucero et al [10] that people are willing to share their mobile phones for collaborative use. Finally, through the field condition, we wanted to investigate whether such a system is usable in everyday life. Specifically, the time and place, as well as people and context.

Implementation

We implemented JuxtaPinch as a web application to provide cross-platform support. An internet connection is needed to use the application. Android and iOS wrappers were developed to let the users experience the system as a full application, but it is also possible to use the system directly from the browser. JuxtaPinch was implemented using the socket.io library for a Node.js websocket server. The client-side was implemented using HTML5 technologies. The accelerometer and gyroscope was used to detect when devices were being moved around, in order to disconnect the moved device



(a) Initial (b) Larger canvas



(c) Creating a hole (d) Smaller canvas

Figure 3: Different outcomes of removing, moving or adding a device.

from the photo. The Hammer.js library was used for detecting *swipe*, *drag* and *hold* gestures. We implemented pinch as swiping or dragging on two devices in opposing directions. A 500 ms *hold* is used to access the photo uploader.

We implemented the four-step algorithm from Ohta and Tanaka [12] to determine how to position the devices on a photo. For more information on the algorithm, see Ohta and Tanaka [12]. The following information is gathered, through JavaScript, from each device when a pinch is performed: Screen size, resolution, pinch location, and pinch direction. This is used to determine the device positions in relation to each other. From positions and sizes, we calculate the joined size of all connected devices that make up the viewing display. The relation between the size of the viewing display and the size of the photo is then used to determine the corresponding photo scaling and rotation.

A database implementation has been developed to automatically log information about connected devices, pinches, photo coverage, etc.

Participants

40 people aged between 16 and 49 (M= 27.15) participated in the evaluation. We recruited through Facebook and our extended network. Participants were required to use their own device during the evaluation. This meant that we only recruited participants with smartphones and/or tablets with iOS 6+ or Android 4+.

22 people (6 female) participated in the lab condition. The participants aged between 21 and 49 (M = 27,64), and had varying backgrounds. 12 university students from mixed educations, two ph.d. students, one employed software engineer, two high school students and five employed college graduates. The lab condition was conducted with six groups. Four groups of four participants and two groups of three participants. Groups consisted of friends, family, couples and roommates. We used snowball sampling to recruit groups of three to four people who had social relations and had experienced an event together, from which there existed photos. We raised these social requirements to create a realistic setup for photo sharing, as Stelmaszewska et al [17] and Miller & Edwards [11] report that people primarily share photos within their social network.

18 people (5 women), aged between 16 and 49 (M=26.56) participated in the field condition. We recruited four main participants, who were allowed to use the system with whoever they wanted during a test period of 14 days.

Apparatus and Location

Participants brought their own smartphones and tablets for the evaluation. This resulted in a great variety of devices. A total of 35 smartphones and 13 tablets were used in the two conditions. Three different types of iPhones, 11 different Android smartphones, two different types of iPads, three Android tablets, and an Android padphone.

In the lab condition, a total of 20 smartphones and seven tablets were brought along by participants. Halfway through the test, we would provide them with two additional smartphones (Samsung Galaxy SII) and three additional tablets (the New iPad, Nexus 7 and an Acer Iconia Tab A200).

The lab condition was conducted in the usability lab at the Department of Computer Science, Aalborg University. The lab allowed us to video record the tests for detailed examination, and also, the lab provided a quiet room for using JuxtaPinch. This is motivated by Stelmaszewska et al [17], who find that people feel more relaxed and comfortable sharing photos in a private environment. Both because a private environment provides the needed silence for talking together, as opposed to a noisy place. And because there are no strangers walking by that can intrude on their personal photos. A tall table with a plastic cover was placed in the lab, such that the participants would stand up during the test, for mobility.

In the field condition, the participants used their own devices. A total of 13 smartphones and three tablets were used in this condition. They were allowed to use the system wherever they wanted, resulting in use ranging from around the coffee table at home, to use on the job in breaks and once at a bar.

Method: Lab Condition

Participants were asked to bring at least two photos each: one personal photo for story-telling and one group photo for reminiscing talk. The photos had to be located on their own device, which allowed JuxtaPinch to access the photos during the test.

Since they brought their own devices, each session featured different combinations of devices, ranging from a session where every participant brought their own smartphone, to a session where every participant had brought both a smartphone and a tablet. Including different combinations of devices within this spectrum.

For each session we measured the following: Number of photos, number of pinches, the used pinch technique, and the number of moves. In addition, for both the number of pinches and the number of moves we noted the following properties: Own, other or public device. Smartphone or tablet.

A session in the lab condition lasted approximately one hour and was divided into four parts. First, an introduction to the system was given (10 minutes). The introduction consisted of a welcoming talk and an introduction to the system. They were introduced to the three types of pinches, how to connect and move devices, and how to upload a photo. The participants then got a few minutes to explore JuxtaPinch to get comfortable with using the system and the pinching techniques. Second, the participants were asked to share their own photos (20 minutes). They were asked to talk aloud about their photos. The participants decided which order to view the photos in, themselves. Thirdly, when all participants had shown both their personal and their group photo, we handed out the five additional devices to the table. The participants were now told to play freely with the system and choose any photos of their choice to share (10 minutes). After having used the system, the participants were handed out an AttrakDiff questionnaire and a semi-structured interview was conducted (20 minutes). The interview consisted of a set of open-ended questions. The goal of the interview was to dig into the experiences the participants had during the session. Also, we wanted to ask into their relationships to each other, to their photos and to their own vs. other's vs. public devices.

Method: Field Condition

In the field condition each main participant were given their own personal website, with all information regarding the test. We asked them to use the system at least four times during a period of 14 days. They decided for themselves where and when they wanted to use it. The website also provided information on how to install the application, how to use JuxtaPinch, how to contact us, and how to report back after use. We provided both an online form for feedback and a printable version. The users could then use what format they wanted. They were asked to fill this out after each session. The feedback form included contextual questions such as who participated, which devices were used, types of photos, date, time, and location. It also included questions about the experience.

After the 14 day evaluation period, we conducted an interview with the four main participants, using the feedback to drive the questions. The first part of the interview was designed with the everyday use of the system in mind. We were particularly interested in when the system was used, with whom it was used, and on which occasions it was used. Also, we were interested in how easy it was to explain the concept of the system to new participants, how the system felt to use in everyday situations, and if repeated use made it easier to use. The second part of the interview was a revised version of the interview from the lab condition, for comparison between the two conditions.

Data Collection and Analysis

For both conditions, we automatically logged the number of photos, pinches, and movements into a database. For the lab, we also recorded the sessions on video tape, for later analysis of pinches and movements, dependent on: Own, other or public device. Smartphone or tablet. The recorded video also allowed us to examine the collaboration and the conversations that took place during the sessions.

The video was cut into segments, each containing interaction with a single photo. Each segment was then analyzed quantitatively with regards to pinch techniques, movement of devices and if these included personal devices, others devices or public devices. The interviews were analyzed from a partial transcription, by grouping answers for each of the 23 questions. Homogeneous answers were color-coded to emphasize repeated answers. We used inductive analysis for analysing the qualitative data. Through repeated assessment of the interviews and viewing of the videos, several qualitative topics and themes emerged. We identified a number of common themes, which will be presented in the following section.

FINDINGS

In the following, we will present the findings of the evaluation of JuxtaPinch. Participants have been renamed for anonymity.

In total, lab and field combined, 17 sessions were conducted where 60 photos were viewed, 1207 pinches were made, and 968 device movements occurred.

In the lab condition, the most used pinch technique was one-hand pinch with over half (55,62%) of the pinches. Second is two-step pinch, with a third of the pinches (34,86%), and only one out of ten (9,52%) were two-hand pinches. The used pinch technique seemed connected to the group. E.g. one group used two-step pinch 96,43% of the time during their session. Another group used one-hand pinch 93,55% of the time and a third group used two-step pinch 88,89% of the time. This is probably due to the unconscious mind looking for social validation.

Looking only at the numbers for the second part of the test (as the first part did not include tablets for some of the groups), we see that smartphones were moved 64% of the time. Hence, smartphones were moved more often than tablets.

In the following, we present the identified qualitative findings: Defamiliarization of familiar photos, selected viewing display configurations, playfulness, collocated photo sharing, and the contribution of the field study.

Defamiliarization of Familiar Photos

Our evaluation showed that participants sometimes experienced their own familiar photos in new ways – also sometimes referred to as defamiliarization. Defamiliarization was originally proposed by Shklovsky [16] in 1917 as a technique for presenting something familiar in an unfamiliar or "strange" way. Seeing an object several times means that we begin to recognize it, and when that happens, we stop perceiving the object. It will continue to be the object that we have previously recognized. In such a situation, defamiliarization have the power of letting us renew our perception of an object. Our study showed that participants often would uncover new details of an otherwise familiar photo while using JuxtaPinch. Originally, Shklovsky invented the term to describe how art could defamiliarize. However, more recently, defamiliarization have been used in several different areas, and also within HCI [2, 8].

We identified defamiliarization in several situations. In the lab condition, all groups experienced defamiliarization. In the field, three of the four main participants reported situations which we see as defamiliarization. Defamiliarization happened in three ways: By isolation, by scaling, and by hiding the main objective. First, defamiliarization by *isolation* happened when parts of a photo was isolated on a device, such that details would pop out, and be emphasized by the isolation and framing of a device. Second, defamiliarization by *scaling* happened when adding devices to JuxtaPinch, as it scaled the photo, which could magnify new details of the photo. Thirdly, defamiliarization by *hiding the main objective*. The main objective could be hidden and the remaining part of the photo would then be emphasized, leaving secondary objectives as new main objectives. Through isolation, scaling, and hiding the main objective, JuxtaPinch renews the perception of photos, which has become familiar or has been taken for granted.

As an example of defamiliarization by isolation, a group was looking at a photo through JuxtaPinch as seen in Figure 4b. The original photo is seen in Figure 4a. They were chatting about the photo when Carl from the group asked *"What is that there?"* as he pointed at the lowest screen. The lowest screen had isolated a part of the photo that looked strange by itself. All participants leaned in to look deeper at the screen and after a short thinking break, Oscar, the owner of the photo, answered *"Aaah, it's a t-shirt with a Nicki Minaj print on it. Because it is black outside the print* [points at the black spot and the print]*, it looks as if he has cleavage."* . A female participant, Alice, adds: *"It looks very weird"* and the group laughs.

The situation was elaborated during the following interview.

> "*It* [JuxtaPinch] *was brilliant for experiencing new details in a photo you already know, because they suddenly appear on a single screen.*" - Carl.

> "*For instance, Daves t-shirt – I never noticed before that it looked weird.*" - Oscar.

This example shows how defamiliarization can occur when using JuxtaPinch. The t-shirt was not the main objective on the original photo and therefore had not gotten any attention before. However, as the t-shirt was now isolated on one of the screens, it was emphasized and therefore noticed.

A participant in the field, Victor, was showing a photo of an ambulance bus to two colleagues during a break from work. They noticed a new detail on the bus, indicating defamiliarization by isolation and scaling. He describes the experience as:

> "*Suddenly, someone noticed that you could read the full technical specification of the bus on the right front wheel of the bus, because it appeared on one screen. Those kinds of small details which would otherwise disappear in the entirety are suddenly visible. You get some random shots highlighted sometimes.*" - Victor.

The group noticed the technical specification of the bus, which they had not seen before. However, as it was now isolated on one screen, they suddenly noticed it. Victor mentions in his description that it happens randomly. Ivan, from the other group, said the same thing: "*It is of course random when it happens.*". Our findings support that randomness can be used to incite defamiliarization, which is in agreement with the results of Leong et al [8] who uses randomness to provoke defamiliarization in photos.

Finally, defamiliarization by *hiding the main objective* happened e.g. to a group that was looking at a kayak at sea. Often, only the sea or the sky was visible on the display and the group noticed that the main objective occupied very little of the photo.

JuxtaPinch incite defamiliarization by 1) isolating parts of a familiar photo on separate screens, 2) by scaling photos, 3) by hiding the main objective of the photo. Thereby, highlighting details or the background of the photo, rather than the entirety of the photo. This allows users to enhance or renew their perception of their familiar photos.

(a) Original photo. (b) JuxtaPinch displaying the photo.

Figure 4: Defamiliarization by isolation.

Selective Viewing Configurations

Some groups were eager to create a rectangular viewing area simulating a larger screen, in order to view the photo as a whole. Other groups positioned the devices in creative structures, which emphasized parts of the photos, or hid specific details.

From our observations, it seemed quite clear that participants would, with the first photo displayed with JuxtaPinch, try to imitate a rectangular screen as much as possible. However, some of the groups would keep constructing rectangular structures throughout their session. A group even repositioned the devices beforehand to display as much of the photo as possible. This is seen in the following example.

Before showing his photo, the owner, Hans, said: "*Now we want to try something else, because this is a tall one* [the photo]" and he restructured all the devices. "*Now you are making it long*" said Walter. Hans responded: "*Yes, it is on purpose. It* [the photo] *is long and tall*". said Hans as he pinched all the screens together. However, this structure did not allow the group to view the full photo, so Hans now said: "*Maybe, one of these* [the tablets] *should have been positioned over here*" and Justin explains: "*To see all of the good stuff*". Hans agrees: "*Yes, exactly*". He restructured all devices again to create a not-as-long rectangular viewing display, whereafter he pinched all devices together again. He left the photo like this as he told his story about the photo.

This example shows that some users wanted to construct the viewing display before showing the image to the other members of the group. A feature that makes JuxtaPinch unique from *Pass-Them-Around*, is its ability to display partial views. Participants used the flexible positioning to creatively shape irregularly viewing displays, as e.g. seen in 5a. Others arrange the devices to see some specific part of a photo, as seen in Figure 5b, where the devices are arranged to show the hose of a beer bong.

(a) Non-rectangular viewing display, showing the face of a green monster.

(b) Selective partial view of a photo, to show the hose of a beer bong.

(c) Playfulness. A person has been moved from the photo.

Figure 5

Playfulness

We found that JuxtaPinch created an environment for photo playfulness. Three motivations for this were identified: to show specific parts, to hide specific parts, and to create funny views.

Funny views were created on purpose by five out of six groups in the lab condition, using the flexible positioning feature in JuxtaPinch. Devices were placed to forcefully make a face span between two devices, which in some situations would make for humorous optical illusions due to the gap between the actual screens.

As an example of the creation of a funny view, a female field test person, Zoe, mentioned that by positioning the devices in different structures, she was able to partition the photo in ways which made the photo humorous to look at.

> "*In an old photo of me I took with my mother's iPad, I have a bill in my mouth I could* [by repositioning] *get the bill to be on one device and my face to be on another, which was quite funny to look at.*" - Zoe.

This example shows how participants purposely positions devices to create humorous situations.

New or unintended uses of the system were also observed to create fun or interesting structures and photo views. Participants discovered that if they carefully moved the device around, it would not detach from the photo, and they could carefully rearrange devices to e.g. switch bodies of two persons. Also, pinching with a device not positioned to the edge of device, i.e. an "illegal" pinch, meant that the photo would be showed more like a swap-tile puzzle.

Other groups used the flexible positioning of JuxtaPinch to reconfigure the viewing display repeatedly. One group in particular would constantly change positions of the devices to either display other parts of the photo, or hide parts that were currently visible. This was a family (mother, daughter, and son in law) who were looking at a photo from a family trip. The photo contained a lot of people from the family. As they played around with the photo, a new family member appeared on the display several times, which was rejected by the son in law. This is illustrated in the following example: "*well, that was lovely!* [ironic] *Now Trudy is in the photo again. That was not the plan*" said the son in law and he quickly repositioned the device showing Trudy. "*There we go! Much better! Now I am in focus!*", cheered the son in law. For several photos, the family kept repositioning devices to hide certain parts and to display other parts.

This family situation exemplifies how JuxtaPinch was utilized for flexible exploration of photos. Another example with the family, that illustrates playfulness, is where they have moved part of the photo, to remove the father. This is seen in Figure 5c. The family members interacted lively with the photos to both show and hide specific parts of the photos. It also shows how JuxtaPinch can drive a conversation of a photo, as seeing this photo in the original way would definetly not have caused this kind of conversation.

Collocated Photo Sharing

We observed different collaboration behaviour between the groups during the first part of the lab sessions. One group was organized and took turns. If the participant was the owner of the photo, they controlled the construction process. Other groups were more chaotic and experienced several errors due to too many actions at once from different participants. One group had one tablet and each their own smartphone. Here, the tablet functioned as a stationary unit, whereto the participants connected their smartphone. However, during part two, when public devices had been handed out, it was chaotic for every group.

Our participants generally argued that they found it unproblematic to interact with other participants' devices. It was also stated from all groups that there was no problem when the other participants interacted with their personal device. All groups stated that no thought were put into this during the session. It was added that the setting; safe surroundings and people they trusted (friends and family), made it a non issue. However, the numbers recorded in the lab condition suggest otherwise. Well over half (66.32%) of the total pinches included own devices, and over half (53,79%) of the movements were made to own devices. This is a lot, considering that each participant's device(s) represented only a small fraction of the whole.

Field versus Lab

In the field, we saw great variation in the duration time of a session, as opposed to the lab. In average, a session in the field lasted 6 minutes and 28 seconds and 1.2 photos were viewed. The shortest session lasted 1 minute and 10 seconds, whereas the longest session lasted 29 minutes and 18 seconds.

However, our qualitative data does not indicate what caused this variation.

What we also observed from the field condition was, that participants used the system in several different locations and that use of the system, in some occasions, emerged spontaneously. The most common context was in the living room while having friends or family visiting. However, we also saw locations like the workplace and even at a bar. As the bar differed, we had the participant, Victor, elaborate on the experience. The incident happened spontaneously as he saw one of his friends sitting at a table with an iPad. It was a day with only a few people in the bar. Victor got curious how JuxtaPinch would behave with an iPad connected and he decided to convince his friend to join a session. Victor stated that sitting at a table in a corner of the quiet bar was a great environment for viewing photos with JuxtaPinch.

From the collected feedback we saw that JuxtaPinch was mainly utilized in private quiet environments and with friends and family. This is in agreement with Stelmaszewska et al [17] who both found that people primarily share photos with their friend and family and that people are more relaxed and comfortable with sharing photos in private environments.

The field condition contributed with other aspects of JuxtaPinch that could not have been seen in the lab. The lab was a controlled environment and the participants were forced to be a part of the session with a fixed duration. The field showed us which situations and contexts people would use such a system, with whom they would use it, and how they would use it in everyday life.

AttrakDiff Questionnaire

The result of the AttrakDiff questionnaire showed that JuxtaPinch scores above-average in both *Hedonic Quality - Stimulation* (HQ-S) and *Attractiveness* (ATT). Above-average on HQ-S means that JuxtaPinch stimulates the users, awakens curiosity and motivates the users. Words such as *inventive*, *creative* and *captivating* are rated high by the users to describe JuxtaPinch in terms of HQ-S. Above-average on ATT means that the overall impression of the product is very attractive.

DISCUSSION

Our aim was to develop an application for flexible collocated cross-device photo exploration and study how such an application would be embraced in a social group. We found that the unification of screens, as proposed by several researchers [4, 10, 12, 13, 15, 17], can change the perception of familiar content. Hence, combining the screens of several devices does not necessarily equal the same experience as a bigger screen. While this is one contribution for this paper, the unique features of JuxtaPinch also formed the basis of additional topics that constitute a second contribution of this paper. In the following, we will discuss these additional themes.

Wide Range of Devices

A unique feature of JuxtaPinch is the support for a wide range of devices. Lucero et al [10] found concerns about different properties of devices which would be a part of cross-device situations. The different form factors of the devices, different screen types and the underlying technologies could give rise to challenges. In our studies we observed three main impacts: Different display quality, the device frames, and the screen sizes and aspect ratio. The *different display quality* included factors such as different lighting and different coloring of screens. It could be challenging at times for the participants to recognize whether the screens were pinched correctly together, as the screens reproduced the photo in slightly different ways. The *device frames* caused the photos to be distorted as e.g. a head would look taller if spanning two devices. Participants suggested hiding the corresponding part of the photo "behind" the frame to avoid this, but they also expressed concerns about parts of the photo being hidden. The *different screen sizes and aspect ratios* caused participants to interact with devices differently. We observed a tendency that larger devices were stationary in the middle of the table, whereas smaller devices were moved around like satellites. However, all three impacts: Different display quality, the device frames, and the screen sizes and aspect ratio, contributed to defamiliarization.

Partial Viewing of Photos

JuxtaPinch's feature of partially viewing a photo meant that participants got creative in their construction and composition of the viewing area in order to view specific parts of a photo. This was seen in Figure 5b where the display was constructed to show a beer bong. We observed that participants welcomed the challenge of assembling the display to show specific parts of a photo. The system scaled and rotated the photos during construction and it seemed to challenge the participants even further. However, they seemed stimulated by this challenge, as if they were solving a puzzle. This is in agreement with the results of the AttrakDiff questionnaire where JuxtaPinch scored above average in the HQ-S dimension.

Sharing One's Own Device

Another unique feature of JuxtaPinch is the possibility to use one's own device. The main question raised by Lucero et al [10], was if people were willing to share their own personal device. They conclude that people are willing to share their own device. However, this is based on comments alone, as their evaluation included only handed out devices. Our findings partly agrees. Participants commented that, as long as they were sharing with familiar people, it was okay, but they would probably not share with strangers. This is in agreement with Stelmaszewska et al [17] who found that photo sharing occurs rarely with strangers, as people do not trust strangers. Furthermore, our findings shows that people have an unconscious connection to their own device, so even though they express their willingness to share, it seems that they are a bit unwilling anyways.

CONCLUSION

We have implemented and evaluated the JuxtaPinch application for flexible collocated cross-device photo exploration. JuxtaPinch has been implemented with web technologies, working on a wide range of different tablets and smartphones. The application allows users to combine several mobile screens to form one larger display for viewing photos. JuxtaPinch will scale and rotate the photos to continually show as much of a photo as possible. Our evaluation showed that participants sometimes experienced their own familiar photos in new ways sometimes referred to as defamiliarization. We identified three causes for this: By isolating parts of a photo on one device, by scaling photos smaller or larger, and by hiding the main objective of the photo, such that only secondary objectives were visible. We also saw two different strategies for building the viewing display. Participants would either build a rectangular display for viewing the entire photo or they would construct a creatively shaped display to view only part of a photo. Participants expressed no concerns about sharing their personal device, however, numbers from the lab condition showed that over half of the movements and over half of the pinches were made to one's personal device. Suggesting that people have an unconscious connection to their own device.

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Paper #2:
Where's Waldo? Cross-Device Collaboration Between Children

Where's Waldo? Cross-Device Collaboration between Children

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ABSTRACT
In this paper we explore collaboration between children during cross-device image exploration. We develop a collocated cross-device application for "Where's Waldo" that allows users to explore a Waldo picture. Users must physically move two iPads around in order to explore different parts of the picture. We evaluate the system on 22 paired children at the age of 9-11 years. Our evaluations show that the system supports collaborative interactions between the children, and five different collaboration strategies are identified.

Author Keywords
Cross-Device; Mobile Device; Interaction; Multi-Display; Touch Screen; Children; Collaboration;

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

General Terms
Human Factors; Design; Measurement. If you choose more than one ACM General Term, separate the terms with a semi-colon.

Figure 1: The "Where's Waldo" application.

INTRODUCTION
Tablets have, over the last few years, become common consumer items. They are often utilized as shared devices for leisure activities in the household. Tablets are not reserved for the adults of the family, but are also used by the children for leisure activities as well as educational gain. Many schools in Denmark have already acquired iPads for precisely this reason, and more schools will most certainly follow. What is not new, however, is the fact that collaboration is important for children in order to develop themselves socially [5].

Over a decade ago, Inkpen et al [3] studied collaboration between children, when solving a puzzle on a PC with two mouses connected rather than one. They found that the level of activity, engagement, and motivation could be heightened when collaborative interactions were supported. Also, they suggested that future technology had the potential of heightening the cooperative activity even further. Collaboration between children when using mobile devices have been studied by e.g. Als et al [1], however, only with one mobile device – not cross-device. The need for collaboration, combined with the wide adoption of smartphones and tablets in the children's space, provides opportunities for cross-device collaborative applications for children. Recently, Fails et al [2] studied how children in the age of 8-9 years collaborate when using a cross-device application for reading children's stories on mobile devices. Their motivation for doing this is to overcome the limited screen space of mobile devices. They compare two settings of such an application: Split content and space sharing. In the split content setting, text is on one screen and a picture is on another screen. In space sharing, the text and the picture is spread across two devices. They focus on how easy it is to read a story in these two settings, and conclude that split content is easier for reading than space sharing.

Our research on JuxtaPinch [4], a cross-device application for photo exploration, inspired a "Where's Waldo" application for children. JuxtaPinch joins the screens of several devices to form one larger display. The screens can dynamically be moved around to change the content of the display. Implementing "Where's Waldo" on top of JuxtaPinch, such that only parts of a Waldo picture is revealed at all times, requires the children to collaborate in order to find Waldo and his cohort. Using the "Where's Waldo" application, we examine how children collaborate in a situation where they have two tablets and need to reach a common goal. To our knowledge, no research has yet been conducted in this area of collaborative cross-device picture exploration between children.

THE "WHERE'S WALDO" APPLICATION

The "Where's Waldo" application is built on top of JuxtaPinch [4]. This means that several mobile devices can be connected to form a single, larger screen. The screen can then be used to view pictures. Devices can be attached and detached dynamically during use to change the picture on the screen. In order to connect a device, a cross-device pinch interaction is used. To detach a device, one needs merely to move the device and the movement sensors will let the system know to detach the device. The only difference between the "Where's Waldo" application and JuxtaPinch is that the "Where's Waldo" application shows pictures as the actual size of the picture. JuxtaPinch, on the other hand, would scale the picture to fit the connected screens. Figure 1 shows two iPads connected through the "Where's Waldo" application to reveal part of a Waldo picture.

STUDY: WHERE'S WALDO?

We conducted a study to examine the collaboration between children when using the "Where's Waldo" application.

Experimental Design

We used a within-group design, with two conditions: iPads and paper. Two different Waldo pictures of the same size were used (store and gluttons). We could change the picture on both the iPad and on the paper, to counter any learning effects. This lead to a total of four (2x2) combinations.

Participants, Apparatus, and Location

22 children (9 girls) at the age of 9-11 years (M=9.9) participated in the study. The children were paired in dyads, meaning that 11 sessions were conducted. The children were recruited through two after school centers in the vicinity of Aalborg.

At the first center 12, children (6 girls) in the age of 9-10 years (M=9.58) were recruited, all from third grade. All the groups were formed by a boy and a girl. At the second center, 10 children (3 girls) in the age of 10-11 years (M=10.29) were recruited, all from fourth grade. Three groups consisted of two boys, one group of two girls, and one group of a boy and a girl. At both centers, the daily leader was asked to pair the children for best collaborative performance.

15 participants used iPads on a daily basis, 6 on a weekly basis and one used it less. Only two of the participants had never played a game of "Where's Waldo", but knew the concept from other, similar games.

We used two of the new iPad (9.7" retina screen) to evaluate the system. In pilot tests of the system, we observed that a multitude of devices was confusing for children. Therefore, we decided to use only two devices to make it comprehensible for them. It was also observed that the small screens of smartphones (smaller than 7") showed too little of the Waldo picture, hence, we decided to use tablets.

Paper versions of the Waldo pictures were printed and brought along. We used these for comparison with our system to better understand what was going on. The pictures measured 118.8cm by 73.5cm and was glued to a hard surface for durability reasons. The paper Waldo had the same size as the Waldo picture on the iPads.

The evaluation took place in a room at their after school center, where two tables were set up, one for the "Where's Waldo" iPad version and one for the "Where's Waldo" paper version. This can be seen in Figure 2.

(a) iPad table. (b) Paper table.

Figure 2: Setup.

Procedure

First, the children were asked questions to gather demographic data. This included e.g. their age and how often they used tablets.

Then, two tasks were performed: "Where's Waldo" on our system and "Where's Waldo" on a paper version. The objectives of both tasks was to locate as many as possible of the following five items: Waldo, the dog, the lady, the wizard, and the thief. The children were given six minutes for each task. A paper with illustrations of the five items were placed beside them for easy referencing. Lastly, we asked a few questions about their opinion towards the two types of "Where's Waldo?".

Before the iPad task, the children were introduced to the system with a test Waldo picture. Interaction techniques were introduced and the children had a minute of free play to familiarize themselves with the system.

During the tasks, we logged the start time and the times for every found item. Furthermore, we observed how the children collaborated on the tasks and what their strategies were. We automatically logged the number of pinches, number of movements, number of restarts, and the locations of the iPads on the pictures, into a database.

FINDINGS

A total of 264 pinches and 264 movements of devices were made. In average, each group performed 24 pinches, 24 movements, and 2.18 restarts. A restart happens when both iPads are moved at the same time as they both disconnect from the picture. When pinched together again, they start over at the center of the picture.

The number of pinches ranged from 15 to 49, but most groups performed around 20 pinches. The same was true for movements, which ranged from 14 to 44. The group with 15 pinches studied each new visible part thoroughly and they used a lot of time to discuss strategies. The group with 49 pinches, on the other hand, were eager to find all five items and interacted quickly to achieve their goal as fast as possible.

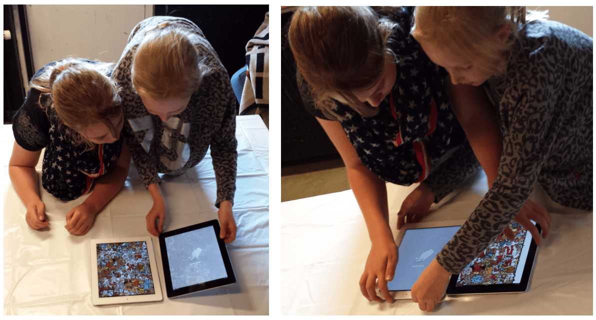
Our participants found fewer items when using our iPad system compared to the paper version. On average, when using the paper setup, four of five items are located, where only three out of five are found when using the iPads. Every item is located more times on the paper than on the system, except the dog. The dog was found five out of 11 times on both paper and on the iPads.

Both the tablets and the paper were placed on tables of the same size, and it was possible to freely move around the tables. We observed that when using the paper setup, only four groups would move around the table to get a closer look at the top of the picture. The rest of the groups would stand at the bottom of the picture, side by side, and in some occasions they would switch places. On the other hand, when using the iPads, even though the pictures would be of the same size, 10 out of the 11 groups would move lively around the table. This was both to get a better look at what the new part of the picture illustrated and to be in close range of the iPads for interacting with the system.

Collaboration Between the Children

A substantial difference between the iPads and the paper setup was the extent to which the children collaborated. When using the iPads, the children would lively discuss where to put the tablet next, and in what direction to work their way towards. Only a single group did not communicate at all when using the iPads. When using the paper method only four of the 11 groups talked about where to look, and then divided the paper into sections. The rest of the groups worked separately in silence, and only communicated when finding an item, and when listing the items left to be found.

We identified and named five different collaboration strategies: Divided ownership, divided interaction, turn based, driver & navigator, and finally, no strategy. In the *divided ownership* the children collaborated by controlling an iPad each. This meant that when a position was decided upon, the "owner" of the iPad that should be repositioned, moved it and reconnected it with a pinch. *Divided interaction* is almost an identically strategy, however, here the children are responsible for an interaction and not an iPad. This means that when the new location were agreed on, one would move the iPad, and the other would reconnect it with a pinch. In the *turn based* strategy, both the moving and the pinching would be done by one child and they would take turns. They would still agree upon the position prior to their turn. The *driver & navigator* collaboration strategy work much like a rally driver and his navigator. One child would decide the location of the next movement, and the other would then move the iPad and reconnect it with a pinch. Finally, for some groups we observed *no strategy*. It seemed random who controlled, moved, and pinched. This often happened when the children got eager and both would move or pinch the iPads at the same time. This caused a few restarts. Groups would also mix between several of these strategies, as seen in Figure 3. One participant controls the movement in Figure 3a, whereas they get a bit eager and end up in a more chaotic situation as seen in Figure 3b.



(a) Controlled movement. (b) Chaotic movement.

Figure 3

Movement of Devices

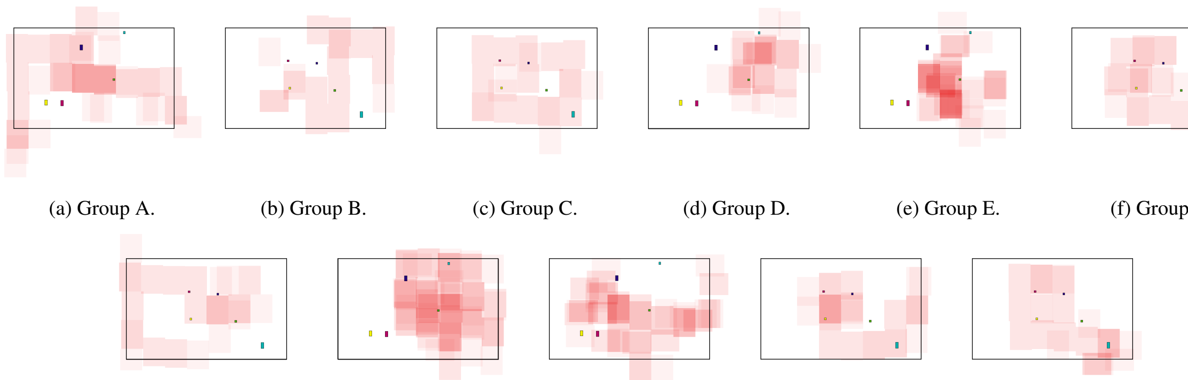
None of the 11 groups uncovered the entire Waldo picture, as seen by the movement traces from the iPads in Figure 4. This suggests that it is difficult for the children to systematically navigate around the picture. The traces seen in Figure 4 are the recorded positions from each session. Every time a position have been visited the color gets more red.

We observed that when the participants reached an edge, they started following that edge. This is clearly visible in Figure 4g and Figure 4a. We reckon that this is due to a "rail" kind of effect. When an edge was visible, they had a sense of where on the picture they were, e.g. seeing the bottom edge would tell them that they are at the bottom of the picture. To avoid losing that sensation, the edge was followed like a guiding rail. By following the edge, they could keep a sense of direction, and the course was only changed when a corner was reached.

Some participants would get stuck in the same parts of the picture, as seen by the dense coloring for group E and H in Figure 4e and Figure 4h. This is probably due to the nature of a Waldo picture. The pictures are designed to be confusing, with a lot of details, homogeneity, and a lot of repetition. When navigating around such a picture using the system, not much sense of location or overview are gathered. However, we observed that the children recognized when they ended up somewhere they had already been. They would say to each other: "We have already been here", or "We have seen that changing room, we have to go higher". Since these children would get stuck in some parts of the picture, they obviously did not create an overview.

Finally, we observed that most of the participants had a tendency of placing the iPads right next to each other or one above the other. We see this for e.g. group C and K in Figure 4c and Figure 4k. They did not utilize the possibilities of diagonal placement to explore the picture askew to e.g. quickly escape an already explored area. This again indicates a lack of overview.

DISCUSSION



(a) Group A. (b) Group B. (c) Group C. (d) Group D. (e) Group E. (f) Group F.

(g) Group G. (h) Group H. (i) Group I. (j) Group J. (k) Group K.

Figure 4: Movement traces.

The children understood the concept of exploring the picture by moving the iPads, but they had a hard time maintaining an overview. This may partly be due to the complexity of a Waldo picture, but may also be caused by the young age of the children.

The children expressed their opinion on which they liked more – iPad or paper version. There were a general consensus towards the iPads. They commented that the two versions were very different, but that not “just looking” and actually have to interact with the iPads by moving and positioning them, made the game more challenging, and fun. Only three children commented that they preferred the paper version. They argued that the overview made it easier and thus more fun. For these participants, their preference seemed connected to their success-rate. If they got stuck or only found few items on the iPad, they preferred the paper version. Also, if their teammate was dominant on the iPad task, they preferred the paper version. For those children that preferred the iPad version, our impression were that they were highly attracted to the iPads – the most often mentioned reason for liking the iPad the most, was simply because they moved iPads around. The second most mentioned reason was that greater challenge. This is in agreement with the findings of the JuxtaPinch [4] evaluation, that found partial viewing of a photo to be challenging like a puzzle.

CONCLUSION

This paper explored a cross-device “Where’s Waldo?” application for collaboration between children. The application was evaluated by 22 children at the age of 9-11 years. The evaluation showed that the application supported collaboration between the children. While using the application, all the children would discuss strategy and move lively all around the table. Compared to an equal paper version of “Where’s Waldo?”, most children were silent and hence, did not collaborate. They searched through the picture separately. Also, they moved around only on one side of the table, namely at the bottom of the picture. We identified five different collaboration strategies between the children: Divided ownership, divided interaction, turn based, driver & navigator, and finally no strategy. Our findings suggest that cross-device applications can be used to foster collaboration between children.

ACKNOWLEDGMENTS

We would like to thank the children that participated in our study. Also, a great thanks to the managers at the two participating after school centers.

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Paper #3:
Cross-Device Interaction Techniques for Card Games

Cross-Device Interaction Techniques for Card Games

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ABSTRACT

In this paper we research interaction techniques for card games in a cross-device setup where a tablet functions as the playing table and smartphones act as the player hands. We held a workshop with nine participants to generate ideas for different interaction techniques in the cross-device card game. A user experiment was conducted with 18 participants to test the usability of the interaction techniques. From the results of the user experiment we implemented two interaction techniques in a cross-device open world card game system. The card game was developed using the newest web technologies to ensure cross-device cross-platform functionalities. The final card game was exposed to a pilot test to examine the usefulness of the interaction techniques.

Author Keywords

Cross-Device; Interaction Techniques; Card Game.

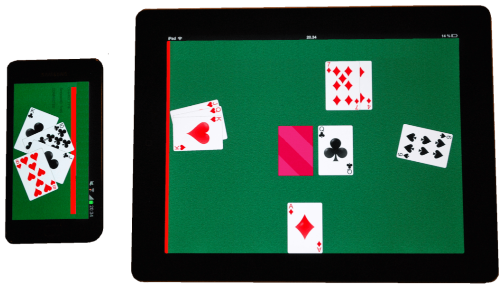


Figure 1: The cross-device card game.

INTRODUCTION

Cross-device interaction is currently becoming more and more important and relevant as different technologies and devices are being adopted in different domains. Especially have we seen a massive shift to different kinds of mobile devices. Smartphones and tablets in particular provides opportunities for cross-device interaction in the domestic space, as they are commonly used in many private homes.

Research in the area of cross-device has been around for a number of years, with different types of devices reaching from smartphones through tablets, and smart-TV's to interactive tabletops and public displays. Even though these studies apply different techniques they all consider aspects of cross-device interaction as they deal with interactions between multiple devices.

At present time we face a high number of interaction techniques. As the mouse presented new interaction styles when introduced, so does the emerged new technologies, e.g. the touchpad for the laptop, the multitude of different touchscreen technologies, many motion sensing technologies or the gyroscope inside many smartphones. Cross-device applications, does further add to the vast number of interaction techniques, and use cases.

Inspired by the great opportunities for cross-device interaction techniques and smartphone-tablet cross-device applications, we develop a cross-device card game and evaluate six interaction techniques for this. To our knowledge, little research has been conducted in cross-device interaction techniques for the smartphone-tablet setting in a private leisure context. We will aim our research on identifying and systematically testing interaction techniques, in such a cross-device setting.

This paper is structured as follows: First, we present related work. Then we present the six interaction techniques. After that, we present the usability evaluation of the six interaction techniques and the findings from it. Then we present the usefulness study of the card game and the corresponding results. Finally, discussion and conclusion.

RELATED WORK

Several studies within cross-device research consider interaction in related settings, between either equal devices (tablet-tablet) or between smaller personal devices to public larger devices (smartphone-tabletop). However, not only the devices in the cross-device setup have an influence on how we interact. The context also have an impact on which interaction techniques are appropriate, and how people are positioned in relation to each other.

For instance, Marquardt et al [11] and Alsos et al [1] have researched cross-device interactions in a work environment. Marquardt et al [11] researches cross-device interaction for co-present collaboration. They consider tablet-to-tablet interaction. They use F-formations and micro-mobility, two known sociological constructs for determining when the interaction is relevant. An informal evaluation of the system showed that techniques using a small tilting angle were well liked, whereas larger angles could be difficult to perform. The evaluation also showed that the F-formations were appropriate, and enabled the participants to share using the interaction techniques. Alsos et al [1] research multi-device interaction techniques for using handhelds and PCs together in a clinical setting. They systematically compare seven interaction techniques for viewing x-rays, and conclude that physicians prefer GUI elements on the handheld device and using the stationary display for showing media content.

Cross-device interaction techniques have also been researched in general. Boring et al [2] researches this in an environment where a phone is used to control a pointer on a public display (a TV). They identify three interaction techniques, *scroll*, *tilt*, and *move* as cross-device interaction techniques between the mobile phone and the public display. They systematically test and compare the three interaction techniques on usability for task completion times and error rates. Their results shows that the techniques using motion have better performance regarding task completion time, but suffers from high error rates. They argue that with more experience these error rates will slowly drop, and suggests that these type of interaction would be ideal for game input.

Döring et al [4] explores the idea of shared and personal devices. They construct and implement six case studies, which explore the potential of using the smartphone as an input device for a larger interactive surface. They suggest that having a personal device (e.g. a smartphone) for personal or secret information and a public device (e.g. an interactive surface) creates some powerful design opportunities.

Furthermore, commercial products that utilise cross-device interaction are available. E.g. PadRacer [13], mentioned by Itzkovitch [7], is a cross-device arcade game which uses the smartphone as a controller to navigate a racecar around a track on a tablet. The smartphone's motion sensor is used to steer the racing car. PadRacer can only be played on Apple devices.

The above research explores a number of cross-device interaction techniques in a number of different setups and with different devices. However, to our knowledge, none have yet systematically explored and evaluated interaction techniques, for a collocated cross-device card game.

INTERACTION TECHNIQUES

This section identifies and describes interaction techniques for use in a cross-device card game. We held a workshop with the aim of generating interaction techniques for cross-device card games. Nine master students from the Department of Computer Science at Aalborg University participated in the workshop. This resulted in 44 interaction techniques for nine card game interactions. We selected six of these interaction techniques for testing; three for playing a card and three for drawing a card. These will be described in detail in the following.

Play Card

We selected three interaction techniques for playing a card: *Swipe*, *hold*, and *wrist-whip*.

Swipe is a common motion in touch association. When turning a page on a tablet, or scrolling through content this interaction technique is often used [6]. The idea is to briefly let the finger touch the surface of the device in a line motion. For playing a card, the motion should start at the card meant to be played, and continue towards the edge where the tablet, acting as the table, is placed. *Swipe* can be seen in Figure 2a.

The *hold* interaction is also common in touch association [12]. The *hold* interaction should be performed on the card meant to be played. After a short period of time holding down on the card it should be played. *Hold* can be seen in Figure 2b.

The *wrist-whip* is the idea of imitating a card throw as one would do in a normal card game. The card up for play is selected and a whip-like movement with the wrist is performed to mimic the throw. This interaction technique incorporates the use of the smartphones motion sensors to register the wrist-movement. Different motions with the device is starting to mean different things [14]. But to our knowledge *wrist-whip* has no universal meaning as of yet.

Draw Card

We selected three interaction techniques for drawing a card: *Direction-swipe*, *drag*, and *tap-tap*.

The *direction-swipe* technique is, as also mentioned in the swipe for "play card" description above, a common technique. The brief line swipe to the surface of the device must start at the deck. The swipe direction must then continue toward the edge of the physical placement of the player receiving the card. *Direction-swipe* can be seen in Figure 2d.

The *drag* technique, shown in Figure 2e, is also a common technique, and not only in touch associations. The *drag* technique is a part of the direct manipulation described by both Dix et al [15] and Shneiderman [3]. The technique is a continuous hold on the card while sliding the finger across the screen, "dragging" the card, towards the edge at which the player is seated. By holding down the finger on the object and then moving the finger over the surface of the device, the object will follow. The start point for the drag, when drawing a card is on the deck on the tablet. The drag movement is then to the edge to which the player drawing the card is placed. The card must touch the edge in order to be played.

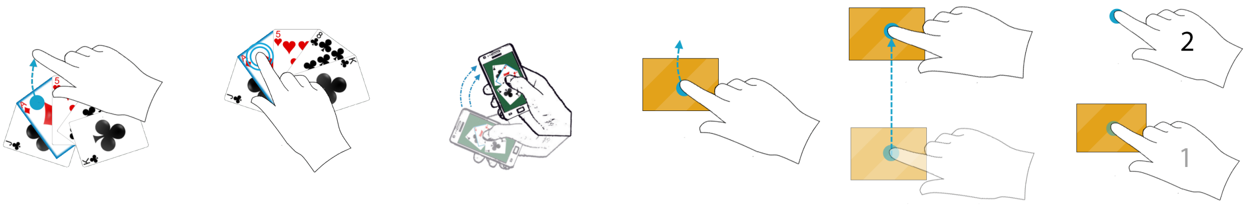
Tap-tap is a series of the common tap technique [12]. First the deck in the centre of the table is selected, with a tap, as to indicate that a card is drawn. Then a base, which indicates where the player is seated, is selected with a tap.

STUDY #1: USABILITY

Study #1 aims to test the usability of the six interaction techniques.

Participants

18 people participated in our experiment. 13 men and five women, aged between 22 and 37 (M = 27,11 SD=4,06). 16



(a) Swipe. (b) Hold. (c) Wrist-whip. (d) Direction-swipe. (e) Drag. (f) Tap-tap.

Figure 2: The six implemented interaction techniques.

were right-handed and two were left-handed. 14 had smartphones and four did not. Eight of the participants were computer science or software engineer students, three were students from other faculties. Six were industry software developers. The last participant was a graphics designer. The participants were recruited through our social network.

Apparatus

One tablet and one smartphone were used for the experiment. The tablet was an Acer A200. The smartphone was a Samsung Galaxy S2. The experiment was conducted in the usability laboratory at the Department of Computer Science at Aalborg University. This allowed us to videotape the experiment, in case issues or questions should come up after the experiment. A couch and a coffee table were placed in the usability lab, to create a habitual setup for the use of a smartphone and a tablet.

Experimental Design

We utilized a within-subject balanced Latin Square experimental design, with the six interaction techniques as an independent variable, and dependent variables included task completion times and errors. We measure the following times (seen in Figure 3) when playing or drawing a card:

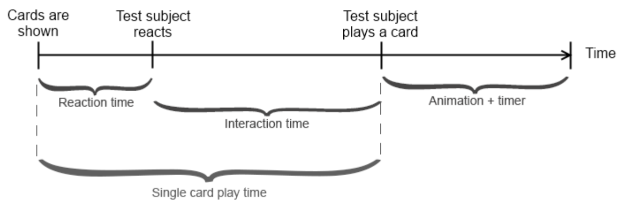


Figure 3: The different times of a single card play.

- **Single card play time:** The time it takes from the cards being shown on the screen to the test subject playing, or drawing a card (a card is played/drawn when the system has recognised that the current interaction technique has been performed on a card). This time does not include the animation and timer (1 second for the animation + 200 milliseconds for the timer).
- **Reaction time:** The time from the cards being shown on the screen to the first time the user touches the screen. I.e. The time it takes for the test subject to react. This is thought to be the time it takes for the test subject to recognise the lowest ranked card on the hand or the target player.
- **Interaction time:** This is the time from the test subject touching the screen for the first time until they have performed the interaction technique and it is recognised by the system. I.e. the time used to play/draw a card. This can reflect the difficulty of performing the interaction technique.

Besides these three times, we also measure the total task completion time:

- **Total task completion time:** The time it takes for a test subject to complete a task. A task consists of playing or drawing a card 30 times. Hence, the total task completion time is 30 times a single card play time.

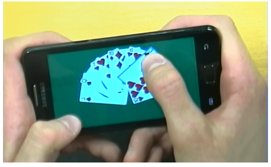
We also measure the following errors:

- **Interaction errors:** This is the number of gestures made before the expected interaction technique. This indicates how difficult it can be to perform the interaction technique. Gestures counted as interaction errors are: Touch, swipe, drag, tap, transform, hold and wrist-whips. They are only counted, if they are not the current interaction technique being tested.
- **Playing errors:** A playing error is when the test subject plays the wrong card on their hand (on smartphone) or draws a card to the wrong player (on tablet).

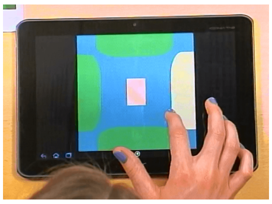
Implementation

Five of the interaction techniques (swipe, direction-swipe, hold, tap-tap and drag) are implemented using the JavaScript library Hammer.js [5] using the default values provided by Hammer.js. The last interaction technique (wrist-whip) has been implemented by using the accelerometer of the smartphone, through the HTML5 device orientation API [8]. Wrist-whip is recognised by the system when the front-to-back tilt is greater than 40 degrees, and the z-axis rotation is greater than 140 degrees.

The interaction techniques were implemented in two test systems that we developed exclusively to test the interaction techniques for playing and drawing cards. One system for playing a card from the hand and one system for drawing a card from the table. The play card system was developed to test the mobile-to-tablet interaction. The draw card system was developed to test the tablet-to-mobile interaction. The two systems will be described in the following.



(a) The play card screen.



(b) The draw card screen.

Figure 4

Play Card

A "play card" system was developed to test the three interaction techniques for playing a card. The idea is that the test subjects are presented with a number of card hands and they must then play the lowest ranked card on the hand as fast as possible with as small a number of errors as possible. A screenshot of the system can be seen in Figure 4a.

The test itself consists of three sessions. One for each interaction technique. A session consists of a learning round and a real round. Hence, the test subject will learn the interaction technique and then perform the test right after. Buttons are available on the screen to start each round. The test monitor asks the test subject to click the button when they are ready. Having clicked the "Test" button, the user will be presented with a fan of seven random cards from a regular deck of cards. The cards are chosen and placed at random for each hand. The test monitor will let the test subject know which interaction technique to perform. The test subject must then play five cards with the current interaction technique. The test subject must play the lowest ranked card available. Ace is the lowest ranked card and king is the highest. When the test subject is done with the learning round, a "Start" button will appear, which the test subject must click when they are ready for the real round. This time, the system logs the performance of the user. A real round consists of 30 laps of playing a card.

Draw Card

The draw card system was developed to test the three interaction techniques for drawing a card. The test subject is presented with a squared tablet view representing a playing table. For each side, there is a marking that reflects a player on the table. In the middle is a deck of cards. The idea is that the test subject must deal cards from the deck to one of the four players on the table. A screenshot of the table is shown in figure 4b. The player that should receive a card is yellow and the other players are green. Card-receiving players are randomly selected. The distance from the middle of the deck to the border of a player is equal for all players, to ensure consistent play times. Again, the test subject gets a learning round where they must deal five cards. After the learning round, the test subject starts a "real" round, where they must deal 30 cards.

Tasks

Play a card from the hand using each of the play card interaction techniques; swipe, wrist-whip and hold (30 times each). Deal a card to a player using each of the deal card interaction techniques; direction-swipe, drag and tap-tap (30 times each).

Procedure

First, the participant was guided to his place in the couch (where the cameras pointed). Then the test monitor gave an introduction to the participant to let him know that he was being videotaped and what he was supposed to do during the test. After this, the test monitor collected demographic information through an interview. This was implemented in the system such that the test monitor typed the answers into the system, and the demographic information was thereby directly saved into our database. Then the systems were set up to give the interaction techniques in the order required by the participant's position in the Latin Square. Testing of the interaction techniques then began. The test subject received the device with the first interaction technique and the test monitor explained the interaction technique to the test subject. The test subject then had to play 5 learning laps. To start the learning laps, a button labeled "test" had to be pushed. This could either be done by the test monitor or by the test subject. After this, the test subject had to play 30 real laps. A button labeled "Start" had to be pushed to start the real round. This could again be done by either the test monitor or the test subject. This was repeated for all six interaction techniques. The test monitor switched the devices for the test subject, such that the test subject performed the interaction techniques in the required order. When the test subject was done with the six interaction techniques, they were asked to fill out a questionnaire. The interaction technique testing took approximately 15 minutes and the questionnaires took approximately 15 minutes to fill out. In case of time issues, the subjects filled out the questionnaires outside the usability lab.

Data Analysis

All of the dependent variables were logged automatically by the test system and saved into a database. However, the interaction errors for the wrist-whip were partially logged manually. All the interaction errors when interacting with the screen were logged by the test system, but the whip motions could not be logged automatically, and were thus counted manually by observation. The results were analysed with a *One-way repeated-measures ANOVA for 3 correlated samples* using the web service by Richard Lowry [9]. If the ANOVA showed a significant difference between the three interaction techniques, a *Tukey HSD Test for Post-ANOVA Pair-Wise Comparisons in a One-Way ANOVA* was conducted to determine between which of the interaction techniques the significant difference was. For the Tukey HSD post-hoc test we used another web service provided by Richard Lowry [10].

STUDY #1: RESULTS

In the following the findings of our experiment will be presented. First the task completion time results will be presented, followed by the task errors results.

Task Completion Time

The results for task completion time will be presented in the following.

Play Card

The interaction technique efficiency was expressed by total task completion time. Each interaction technique was performed 30 times and expressed in seconds. Our experiment, see Table 1, showed differences in total task completion time where participants using *hold*, taking 71.59 seconds, were 12.49% less then *swipe*, taking 81.81 seconds, and 15.72% less then *wrist-whip* taking 84.94 seconds. This difference in total task completion time between the three interaction techniques, is significantly different according to a one-way repeated-measures ANOVA, $F(2, 34) = 4.34$, $p < 0.021$. A Pair-Wise post hoc comparison via Tukey HSD Test showed that the difference in total task completion time was significant between *hold* and *wrist-whip* ($p<.05$). *hold's* significantly lower total task completion time compared to the *wrist-whip* technique can be explained by the fact that *wrist-whip* is a two step interaction technique where the card is first selected and then the whip motion is performed. Whereas *hold* is performed in a single 500ms hold. We see the standard deviation to be surprisingly high for the *swipe* technique. Suggesting some participants have trouble using this technique.

Each play card interaction is called a Single card play and is expressed in seconds. A Single card play starts as the cards are shown, and ends when a card is played. Single card play completion times reflect the findings in total task completion time. Participants using *hold* shows 12.23% less time usage than *swipe* and 18.41% less than *wrist-whip*. According to ANOVA, $F(2, 34) = 4.32$, $p < 0.021$ the difference is, not surprisingly, significant. The post hoc test shows again that significant difference lies between the *hold* and the *wrist-whip* ($p<.05$) techniques.

Within each lap the reaction time was logged. This time is expressed in seconds from the cards are shown to the participant first interacted with the screen. We see from Table 1 that the there is little difference between these three. *Hold*, using only only 1.85 seconds before interaction is the fastest. However this is only 4.87% faster than *wrist-whip* and 0.54% faster than *swipe*. An ANOVA, $F(2, 34) = 0.43$, $p < 0.654$ confirms that these three interaction types are not significantly different in regard to how fast people are in reacting.

The time between the player reacting and until the card is played is called the interaction time. This time is not logged per se, but is calculated by subtracting the reaction time from the lap time. From table 1 we see a significant difference between both the *hold* and *wrist-whip* 64.82%, and the *hold* and *swipe* 61.11%. An ANOVA, $F(2, 34) = 5.68$, $p < 0.007$ with a post hoc test confirms this.

Draw Card

The total task completion time on the tablet was logged, in seconds, in exactly the same manner as total task completion time for the smartphone. Each interaction technique was also performed 30 times. Our experiment, see Table 2, showed that *drag* is a slow interaction technique, with its 39.38 seconds against *direction-swipes* 33.86 and *tap-taps* 32.87. An

	Hold (n=18)	Wrist-Whip (n=18)	Swipe (n=18)
Total Task	71.59 (12.67)-	84.94 (17.94)+	81.81 (19.18)
Lap	2.39 (0.42)-	2.83 (0.60)+	2.73 (0.64)
Reaction	1.85 (0.43)	1.94 (0.55)	1.86 (0.35)
Interaction	0.54 (0.05)-	0.89 (0.20)+	0.87 (0.56)+

Table 1: Phone times. -/+ indicates a significant difference.

ANOVA, $F(2, 34) = 6$, $p < 0.006$ confirms that there are a significantly difference between the three. A post hoc test show the the significant difference appear both between *drag* and *direction-swipes* ($p<.05$), and *drag* and *tap-tap* ($p<.01$).

	Direction-Swipe (n=18)	Tap-tap (n=18)	Drag (n=18)
Total task	33.86 (9.47)-	32.87 (4.45)-	39.38 (7.92)+
Lap	1.13 (0.32)-	1.10 (0.15)-	1.31 (0.26)+

Table 2: Tablet times (part 1). -/+ indicates a significant difference.

The lap completion times reflect the findings from total task completion time. An ANOVA $F(2, 34) = 6.1$, $p < 0.006$ shows that a significant difference is present between these three times, as well. The post hoc test shows that, as in the total task completion time, the significant difference appears both between *drag* and *direction-swipes*($p<.05$), and *drag* and *tap-taps*($p<.01$).

	Direction-Swipe (n=17)	Tap-tap (n=17)	Drag (n=17)
Reaction	0.79 (0.15)	0.72 (0.12)	0.79 (0.21)
Interaction	0.33 (0.22)-	0.37 (0.11)+	0.53 (0.14)+

Table 3: Tablet times (part 2). -/+ indicates a significant difference.

A technical error means that some data was not recorded for one of the participants. The participant in question's data has been removed from all three interaction techniques in the statistical analysis of both reaction time and interaction time. Thus n=17 for these tests, which is also reflected in Table 3. The ANOVA $F(2, 32) = 1.54$, $p < 0.230$ run on the reaction times confirms the same as on the smartphone. There is no significant difference in the time participants take in reacting, no matter the interaction technique they are using.

The interaction times for *direction-swipe*, *tap-tap* and *drag* can all be seen in Table 3. We see that *direction-swipe* is significantly faster than both *tap-tap* 12.12% and *drag* 60.60%. The ANOVA $F(2, 32) = 8.14$, $p < 0.001$ confirms this, and post hoc also. A tendency is starting to show. We see that the *direction-swipe* is significantly faster, but also has the highest standard deviation, suggesting that some people may find this interaction technique difficult. This tendency of high standard deviation is also seen in the *swipe* technique from the smartphone. However, this is not surprising as it is the same implementation of the actual swipe motion.

Summary

On the smartphone, *hold* is a fast and safe interaction technique. Whereas participants could have difficulty with the *wrist-whip* and *swipe* techniques. On the tablet the *drag* is the slowest of the three. *direction-swipe* and *tap-tap* are nearly identical in terms of total task completion time, but with *direction-swipe* having double the standard deviation of *tap-tap*. On both the smartphone and on the tablet no significant difference are to be found in the reaction time, suggesting that the interaction techniques do not have a influence on this.

Task Errors

The finding for the two dependent variables concerning the errors can be seen in Table 4 for the smartphone and Table 5 for the tablet.

Play Card

The difficulty of an interaction technique is expressed by the number of interaction errors a participant creates. Gestures counted as interaction errors are touch, swipe, drag, tap, transform and hold. That is, if they are not the current interaction technique being tested. Our experiment, see Table 4 showed that participants using *swipe* had a significantly higher error rate, ANOVA $F(2, 34) = 22.63$, $p < 0.001$, confirms this. With interaction errors on average 17.94 for 30 play cards the *swipe* have 1190.65% more errors than *hold*, which a post hoc test confirms is significant ($p<.01$), and 1433.33% more errors then the *wrist-whip* which, according to the post hoc test, is also significant ($p<.01$). *swipe* is the interaction technique which users have the most difficulty performing. However, we see from *swipe's* standard deviation in Table 4 that the spread in how people perform is extremely diverse.

	Hold (n=18)	**Wrist-Whip** (n=18)	**Swipe** (n=18)
Interaction errors	1.39 (1.58)-	1.17 (1.29)-	17.94 (14.70)+
Playing errors	1.11 (1.32)	1.39 (2.25)	1.44 (1.50)

Table 4: Phone errors. -/+ indicates a significant difference.

Playing errors are defined as "when the test subject plays the wrong card on his hand". The figures seen in Table 4 are the sum of all the playing errors which occurred during the 30 interactions. Even though we see a significantly higher interaction error rate on *swipe*, compared to both *hold* and *wrist-whip*, there is no significant difference in the playing errors ANOVA $F(2, 34) = 0.21$, $p < 0.812$. We see that all three interaction techniques have high standard deviation, suggesting that some participants have created more errors than others. The reason for this may be the graphics on the card, which may have cause mix-ups between picture cards and ace cards.

Draw Card

The same technical error which forced us to remove data from a participant in Table 3 also had an effect on the collection of interaction errors. Hence, we see the n=17 in table 5.

	Direction-Swipe (n=17)	**Tap-tap** (n=17)	**Drag** (n=17)
Interaction errors	4.94 (4.43)+	0.61 (1.46)-	1.28 (1.64)-
Playing errors	0.17 (0.38)	0.82 (2.18)	0.18 (0.39)

Table 5: Tablet errors. -/+ indicates a significant difference.

From the figures in Table 5 we see that *direction-swipe* has an interaction error rate of 4.94 errors per 30 interactions. This is a 709.84% increase from *tap-tap's* 0.61 and a 285.94% increase from *drag's* 1.28. An ANOVA $F(2, 32) = 11.28$, $p < 0.001$ confirms that this is a significant difference, and a post hoc shows that the difference is in fact between *direction-swipe* and *tap-tap* ($p<.01$), and *direction-swipe* and *drag* ($p<.01$). The *direction-swipe* and the *swipe* are implemented with the same swipe motion. *Direction-swipe's* rate of interaction errors reflects the findings from interaction errors in *Swipe*. The complications of the *swipe* and *direction-swipe* are discussed further in the discussion.

Playing errors, shown in Table 5 are, according to a ANOVA $F(2, 32) = 1.48$, $p < 0.243$ not significantly different. Again, we see that all three interaction techniques have high standard deviation. Suggesting that some participants have created more errors than others.

Summary

Direction-swipe for the tablet, and *swipe* for the smartphone are the two techniques which give rise to the most interaction errors. However, we saw no significant differences between the three interaction techniques on neither the tablet or the smartphone when it came to play errors.

Questionnaire

The results from the questionnaire will be presented in the following. Each statement will be followed by a number representing the amount of users who chose that statement.

Performance: Play Card

The perception of the fastest interaction technique for playing a card is a draw between swipe and hold (7) whereas hold was thought to be the least error prone (13). They thought that wrist-whip was the slowest interaction technique for playing a card (9) and wrist-whip was likewise thought to be the most error prone (8), closely followed by swipe (7). A comparison with the logged results can be seen in Table 6.

	User perception	**Test result**
Fastest	Swipe and Hold	Hold
Least errors	Hold	Wrist-Whip
Slowest	Wrist-Whip	Wrist-Whip
Most errors	Wrist-Whip	Swipe

Table 6: User perception compared to test results for the performance of smartphone interaction techniques.

Performance: Draw Card

The users felt that direction-swipe was the fastest for drawing cards (9) whereas tap-tap was thought to be the least error prone (12). They thought that drag was the slowest interaction technique for drawing cards (11) and direction-swipe was the most error prone (10). However, many test subjects mentioned that they did not make any errors at all on the tablet. A comparison with the logged results can be seen in Table 7.

	User perception	Test result
Fastest	Direction-Swipe	Tap-tap
Least errors	Tap-tap	Tap-tap
Slowest	Drag	Drag
Most errors	Direction-Swipe	Direction-Swipe

Table 7: User perception compared to test results for the performance of tablet interaction techniques.

User Perception

A summary of the user perceptions can be seen in Table 8.

	Play Card	Draw Card
Most entertaining	Swipe	Direction swipe
Most preferred	Hold	Direction swipe
Most natural	Swipe	Direction swipe
Most demanding	Wrist-whip	Drag
Most useful	Hold	Direction swipe

Table 8: User perception of the interaction techniques.

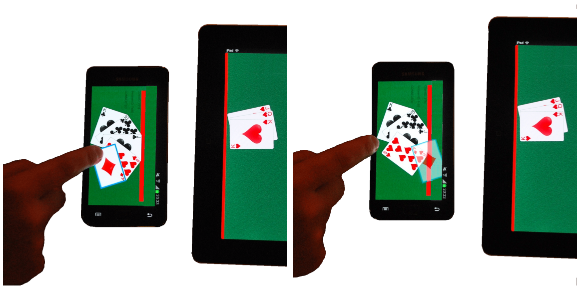
STUDY #2: USEFULNESS

Study #2 aims to test the usefulness of a cross-device card game. The study consisted of three informal tests held with friends and family during the christmas holiday get-to-gether. The intent of this study was to test whether *hold* for play card, and *direction-swipe* for draw card, were useful when actually playing a card game. It was also to identify if the game is at all playable and to identify any bugs or obviously missing features. As the game is created as an open world without any rules, the participants was asked to decide between themselves upon which game they wanted to play. Hence, we did not decide which games they would play in the pilot test. At the end of each test, a quick interview was held to ask the participants about any thoughts on the system.

Implementation

The system is a card game system where up to four players can play a game of cards. There are no rules in the game. Players may decide for themselves which card game to play. The game system is an open world system, and it is therefore the responsibility of the players to maintain the rules. They can play and draw cards as they like. When the game starts, the tablet shows a deck of cards and the smartphone is empty, because no cards have been dealt yet. Color bars indicates the positions of the users. A game with one player connected where several cards have been played is shown in Figure 1. It shows both the interface of the smartphone and the interface of the tablet.

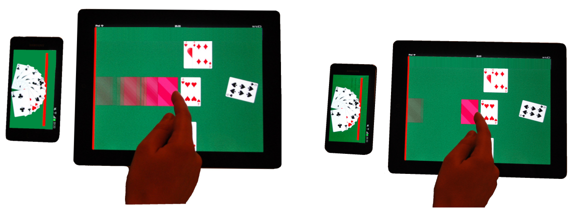
The player's user interface on the smartphone is a hand of cards, as in the usability test. In addition, there is a color bar on top of the screen to indicate the player's position around the table. A player can merely play a card from here. Hold is the interaction technique that plays a card. Once a card has been played, it will animate out of the screen. Figure 5 shows the hold interaction technique in use in a card game. On the



(a) Hold initiated. (b) Card being played.

Figure 5: Playing a card with the hold interaction technique in a card game.

tablet, each border has a color corresponding to a player's color. The tablet only shows color-borders for the number of players that have joined the game (maximum four). Players are assigned locations around the table as follows: player 1 left, player 2 right, player 3 up, player 4 down. A player must swipe the deck in the direction of his own color to deal a card to himself. The card will fly to the border of the corresponding player, in an animation, once a card has been drawn. This applies to both deck and pile cards. Figure 6 illustrates cards being drawn from the deck. From the tablet it is also possible



(a) Drawing several cards from the deck. (b) The last card has almost reached the player border.

Figure 6: Drawing cards from the deck.

to rearrange the cards on the table. Drag is used to move the cards around on the table. Tapping on a card in a stack will put that card on top of the stack. A transform gesture is used to rotate the cards.

Participants, Apparatus, and Procedure

Three groups participated in the study.

Group A

Group A consisted of three participants, all between 50 and 55, regular card players and each had a smartphone. The test was performed with a New iPad as the table and a Samsung Galaxy S2, a Huawei Ascend P1 and a iPhone 4 as the three player hands. The three participants first played a game of

"President and the Bum". The game was played 10 cards per player and the player who first got rid of all their cards had won. The game is, besides dealing the cards, primarily interaction with the smartphones. The second game played was the well known "Go Fish", where each person starts with 7 cards and has to get as many tricks as possible by asking the other players for cards. Here interaction is mostly on the table. When a player gets a card from another player, the card is played to the table and picked up from there. When a player has to "Go fish" a new card is drawn from the deck. When a player gets a trick all four cards are played to the table and arranged in a stack at the players edge.

Group B

Group B consisted of two women aged 24 and 27. They rarely played cards and they both had a smartphone. The test was performed with The New iPad as the table and a Samsung Galaxy S3 and a Samsung Galaxy S2 as the two player hands. The two participants played a card game called "zero". Each player is dealt seven cards. The participants takes turns where they draw one card and then play one card i.e. they exchange a card on the hand. When a player thinks he has the lowest hand he may knock on the table and a last round is played whereafter the players must show their hands to identify the winner of the round. The winner gets one card less on the hand for the following rounds. This continues until a player has zero cards on the hand and wins the game.

Group C

Group C consisted of three men all aged 25. They rarely played cards and they all owned a smartphone. The test was performed with The New iPad, two Samsung Galaxy S2 and one Samsung Galaxy S3. Group C chose to play President and the Bum (like Group A). A picture of group C playing can be seen in Figure 7.

Figure 7: Group C playing.

Data Collection

We collected results through observations and interviews. During the pilot test, we did not participate in the game ourselves. Instead, we observed their behaviour and use of the system to gather implicit feedback. Pictures were also taken during the observations. At the end of each test we held a quick interview to gather the participants explicit feedback.

STUDY #2: RESULTS

The pilot test showed that it was possible to play several card games using our system. As described, we decided to use *hold* for playing a card, and *direction-swipe* for drawing a card. All participants learned to use both of the interaction techniques rather quickly, but at times mixed up where to use what (i.e. used *swipe* for playing a card). Using *direction-swipe* on a played card (a card which can be manipulated on the table by drag) was no challenge. Arranging tricks on the table by dragging the cards did not reveal any difficulties. However, one or two times the drag was recognised as a *direction-swipe* and the player receiving the card would have to play it back to the table. Participants were seated toward the edge at which they had to *direction-swipe* to draw a card. It was observed that participants makes the swipe gesture towards themselves. Meaning that if they sat at an angle, the gesture would be directed towards them and not perpendicular to the edge. Some participants had difficulty telling apart the different cards because of the graphics. The open world structure of the game where no rules are provided, and players can play, draw and arrange cards on the table whenever they feel like, makes for interesting observations. Every game starts with a discussion of the rules of the game, which means that people are in agreement of this exact version of the game, and makes the game run smoothly.

Participant Comments

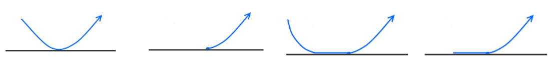
After the pilot test, a joint interview with the participants was conducted to get any comments on the game, bugs, annoyances, opinions and suggestions. All participants requested the ability to arrange the card on the hand. Manual arrangement by dragging the cards left or right or automatic arrangement on either rank, suit or both was suggested. Group A was delighted with the open world structure of the game, and commented that "being able to decide upon the rules by themselves made the game more playable". But also commented that because of the limitations with one deck of cards and the inability to customise which cards were in the deck, the games they were able to play was limited. Group B and C requested rules in the game. A feature for automatically dealing x number of cards to all players in the beginning of each round was suggested. This would save some time, but not be strictly necessary. One participant from group B mentioned that it would be nice with some highlighting for newly played cards to emphasize that a card has been played. This could make it easier to recognise whose turn it is. One participant from group A mentioned that not being able to see how many cards the opponents had left, impaired his ability to strategise. It was suggested that the number of cards a player had in his hand be shown on the edge of the player, either as a card hand with the back showed, or simply as a number. Another participant added to this that she normally could read how the opponent arranged the cards on their hand, and it was suggested that if the cards was shown on the table with the back up, an animation to see how people arranged the card could be added. Group C mentioned that they liked the color bars that indicated their position. They suggested the possibility of moving the bars around to change the position of the players.

DISCUSSION

We identified several interaction techniques through the idea generation workshop. Some interaction techniques required only interaction with one device, some required interaction with different devices in turn, and some required the interaction to be performed simultaneously on multiple devices. Only interaction techniques which interacted with a single device were tested in our experiment. Some may argue that these types of interaction techniques, which only interact with a single device do not count as cross-device interaction techniques. However, we argue that as long as the interaction is meant for another device, (e.g. if a player needs another card on their hand, the player must interact with the tablet to get one.) it falls under the cross-device interaction technique category. Also, Alsos et al [1] who researched multi-device interaction techniques for a clinical setting, (using a PDA and a PC display) found that the test subjects preferred the two interaction techniques that required only the PDA, or only the PC display to be used (where the PDA was preferred over the PC display). Hence, we suspect that this is true in the card game context as well. This is also in agreement with the discussions from our workshop-participants, who claimed that they preferred to control everything from the smartphone. However, it would be interesting to see the results of the interaction techniques that required two devices to be used simultaneously.

Swipe and Direction-Swipe

Many participants had difficulty performing the swipe gesture. Both on the smartphone with the *swipe* interaction technique, and on the tablet with the *direction-swipe* interaction technique. The gesture have a *maximum swipe time* of 200ms and a *minimum drag distance* of 20 pixels. This means, for the *swipe* and the *direction-swipe* one must create a very brief gesture that touches and drags the screen for more than 20 pixels, but doing it in under 200 ms. The correct gesture can be seen in Figure 8a We observed different challenges



(a) Swipe. (b) Not swipe. (c) Not swipe. (d) Not swipe.

Figure 8: To swipe or not to swipe.

with the swipe gesture. The most recurrent can be seen in Figure 8c where the maximum swipe time are exceeded and Figure 8d where another interaction technique are registered first. The challenge where the minimum drag distance is not fulfilled, as seen in figure 8b were however less recurrent. We believe that the challenges with the swipe gesture occurs due to the participants being accustomed to different implementations. We reckon that a careful re-implementation of the swipe gesture, where we allow for the transition from the hold and drag gestures to the swipe gesture, would improve, if not altogether remove, the challenges in Figure 8c and 8d. Another possibility would be to tweak the *maximum swipe time* and the *minimum drag distance* while testing to see if it improves the results.

Hold

Hold was the most effective of the three interaction techniques for *play card*. *Hold* proved to be a “safe” interaction technique. The low standard deviation in Table 1 on page 5, and the low numbers of errors in Table 4 on page 6 show that all participants had a nearly identical interaction time and suggests, that hold is a “safe” and non-tricky interaction technique to perform. During the usability test, comments of dullness when using the hold for 30 repetitions was expressed. This however does not correlate with the results of the questionnaires. We presume that this is due to the fact that 30 repetitions with that simple a technique is just instimulating. The low standard deviation for this interaction technique indicates that the 500ms hold time, which was the standard hold time provided from the Hammer.js library, was a viable amount. We can however not conclude if it is the optimal amount of time, for such an interaction technique.

Wrist-whip

Wrist-whip was the slowest of the three interaction techniques for *play card*. We thought this to be a “tricky interaction technique” as the motion with the wrist had to be right. However, as we can see from table 4 the number of interaction errors is actually lower than those of the “Safe” *hold* technique, but not significantly lower. We argue thus that the reason for the slow task completion time, seen in Table 1, is due to the fact that the technique requires is a concatenation of two techniques, first a *tap* to select a card and then the *whip-motion*. The questionnaire revealed that the test subjects found *wrist-whip* to be the most demanding, the least useful, and least natural interaction technique. This is in agreement with the results of Alsos et al [1] who finds that using proximics for interaction between a PDA and a PC display in a clinical setting is awkward for the users.

Drag

Drag was the slowest of the of the three interaction techniques for *draw card*. This is not surprising, as the technique requires one to perform the interaction technique the whole distance from the center of the screen, until the center of the card is within the player-base, which is a minimum of 250px. Compared to *direction-swipe*, which has a minimum drag distance of 20 pixels, the time difference is understandable. We observed that moving the finger too quickly while dragging, or having touched too close to the edge of the card, would result in the participant losing the card and have to perform a new drag. Additionally, participants would occasionally release the drag before the center of the card was within the player-base, meaning that a new drag must be performed, moving it the rest of the way. The latter problem could be corrected by e.g. making the player-base light up when the card is within the boundaries.

Tap-tap

Tap-tap was the fastest and the draw card interaction technique, with the fewest interaction errors. We see in Table 5 on page 6 that *tap-tap* is significantly lower than *direction-swipe* in the amount of interaction errors, but when we look at Table 2 on page 5 we see no significant difference between the two, with regards to total task completion time. We conclude from this that *tap-tap* is the safest of the three. But as the *hold* interaction for play card, comments were made that performing *tap-tap* repeatedly was dull. This is unfortunate , as dealing cards may be performed repeatedly in a game.

Limitations

We realise that there are limitations to our research. First of all, the workshop was held for only computer science and software engineer students. A different result could be obtained by mixing them with people from other areas of expertise. The same goes for the usability test where 14 of the 18 participants studied or worked with computer science. Another limitation for our research is the implementations of the interaction techniques. Implementing the interaction techniques differently could likewise lead to alternative results. We especially suspect that this is true for the swipe gesture.

CONCLUSION

We held a workshop with nine participants to generate ideas for cross-device interaction techniques. The workshop resulted in 44 interaction techniques. Out of these, two interactions were selected for testing, namely *play card* and *draw card*. We selected these two because they are the two most used interactions in a card game. For each of the interactions, three interaction techniques were selected. Hence, we ended up with six interaction techniques to test. For playing a card: *swipe*, *wrist-whip*, and *hold*. For drawing a card: *direction-swipe*, *drag*, and *tap-tap*.

We implemented the six interaction techniques in a system that we developed solely with the purpose of testing the usability of interaction techniques in a cross-device card game. We used the system in a user experiment. The six interaction techniques were the conditions of the user experiment. We used a within-subject design with a balanced Latin Square design. 18 persons participated in the experiment. The experiment showed *swipe* and *direction-swipe* to be fluctuating in performance, and significantly the most error prone interaction techniques. *Hold* was the significantly fastest interaction technique for playing cards. *Drag* was the significantly slowest interaction technique for dealing cards. When asked, the majority of the users preferred *hold* for playing a card and *direction-swipe* for dealing a card. Based on the results of the experiment, we selected two interaction techniques, *hold* for playing a card and *direction-swipe* for drawing a card. These two were implemented in a cross-device card game system. We conducted a pilot test on the card game system to get a feel of the real usefulness of the two interaction techniques and the card game cross-device use case. The pilot test suggested that the *direction-swipe* implementation should be changed.

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