MochaTop: Building Ad-hoc Data Spaces with Multiple Devices

Paweł Woźniak
t2i interaction lab
Chalmers University of Technology
Gothenburg, Sweden
pawelw@chalmers.se

Benjamin Schmidt
VIS HCI
University of Stuttgart
Stuttgart, Germany

Lars Lischke
VIS HCI
University of Stuttgart
Stuttgart, Germany

Zlatko Franjcic
Qualisys AB
Chalmers University of Technology
Gothenburg, Sweden

Asim Evren Yantac
Koc University
Istanbul, Turkey

Morten Fjeld
t2i interaction lab
Chalmers University of Technology
Gothenburg, Sweden

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Abstract
We present MochaTop—a system using multiple mobile devices that is part of our on-going inquiry into ad-hoc multi-device environments on tabletops. In this progress report, we describe the motivation for designing multi-device, ad-hoc systems for single and multiple users, and explain the design and implementation of our prototype system. We report on preliminary user studies made with focus groups and sandbox explorations of the prototype, with video analysis. By designing new interaction patterns, we focus on investigating if multiple mobile devices can be used to transform everyday settings into new environments for data exploration. Our research indicates that users value the extended interactive space created by multiple mobile devices.

Author Keywords
Multiple device environments, data analysis, mobile interaction

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

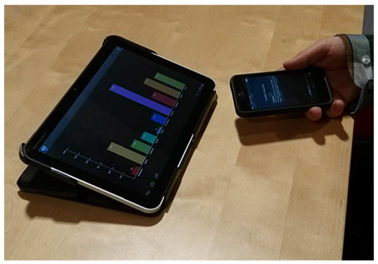

Figure 1. Exploring an information visualisation on a tablet and a smartphone with MochaTop

Introduction

Over the last years, smartphones and tablet computers have become commonplace in our everyday lives. For many people, it is normal to carry these devices simultaneously and use them in public spaces. While these two device classes serve common purposes (e.g. e-mail and web browsing), they are handled and controlled differently. The phone-sized devices can be easily used with one hand and fit comfortably in a pocket. The tablet works best when placed on a table and is less manoeuvrable.

In this report, we present our initial insights on how multiple mobile devices can be used to create ad-hoc environments to explore personalized data sets relevant to the user. We focus on how these devices can be used in future casual contexts, supporting both single and multi-user scenarios. We present works that served as our inspiration, two prototype designs we implemented, our preliminary studies, and finally how we aim to continue our inquiry.

Related Work

Extending interactive space by using more than one device has been a research theme for some time, drawn from classic work that explored the benefits to be expected from manipulating devices in physical space [6] and the increased potential for space multiplexing [2]. More recent work has looked at building collaborative spaces around multi-display environments. Many activities investigated the interaction patterns of multiple users in a control room setting (e.g. [4]). Support for professional data analysis and sensemaking was explored in VisPorter [1], and Spindler et al. made early attempts at making multi-display environments available to audiences beyond that of an expensive control room [8]. Spindler et al.'s work is even more relevant to ours, as they also use the concept of spatial awareness introduced by us in [5].

Our inquiry extends past work in two dimensions. Firstly, we want to venture outside of control rooms and professional spaces and investigate how multiple devices may be used in casual contexts. We look at cafes, bars, dining room tables, and the devices people already bring to these places. Secondly, we aim not to limit our inquiry to multi-user scenarios. A recent study of actual multi-device usage by Santosa and Wigdor [7] indicates a clear need for developing single-user multi-device interaction patterns for practical applications. Our work is an attempt to cater to some of those needs. Furthermore, we are inspired by the concept of an interactive tablecloth [3] and augmenting every horizontal surface with interactive capabilities. Lastly, mobile devices will soon be aware of their spatial surroundings through embedded ultrasonic sensing—it is high time to investigate the possible interaction patterns that may benefit from this capability.

Design

We set out to design a highly portable system that would use multiple mobile devices to facilitate ad-hoc interactions on horizontal surfaces. We decided to explore interactions in settings where users are likely to be sitting at a table e.g. in a coffee house, service area, at home, or even outdoors. In such environments, two (or more) devices are likely to be used at the same time. We suggest increasing the input/output space of the devices by (1) using the relative placement of the devices as a new input modality and (2) providing distributed output. The proposed system would be a tool for ubiquitous information access in a mobile, casual setting. MochaTop enables users to create an

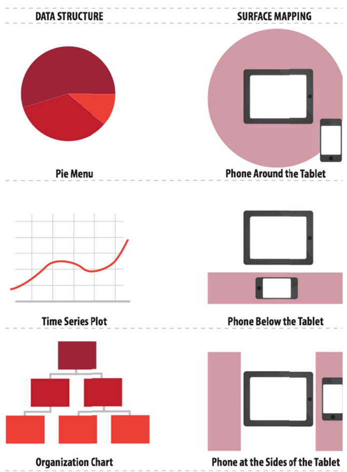

Table 1. Data structures and their respective spatial mappings used in MochaTop

Figure 2. The focus group study setup with paper prototypes to find intuitive ways of interacting with multiple mobile devices on the go.

ad-hoc tabletop interface on a regular table surface. Inspired by Weise et al. [9], we wondered how users can explore community-relevant data in a new way , fuelling discussions with information on the go. We then organized a series of design workshops to gain a better understanding of potential user needs.

Focus groups

We organised a series of design workshops with groups of users exploring different ways to interact with various forms of information representation, using spatially aware mobile devices. Overall, 25 participants aged 22-32 (mean age = 24.64, median = 25, 18 males, 7 females) participated in the study. The participants were remunerated with coffee and a sweet bun. We used a variety of paper prototypes to validate our concepts and encourage users to share their ideas. Participants were presented with paper versions of a tablet and a smartphone showing one of eight different visualisations. We introduced them to the concept of spatial awareness. The task was typically to find and select a single value in a given information visualisation. But we also had tasks such as controlling a view parameter, rearranging objects, or navigating through a visualisation. All of the sessions were video recorded, yielding a total video time of 4 hrs 7 min, which was then carefully analysed.

By counting the number of proposed solutions we were able to identify clear interaction preferences for some of the visualisations. But for more difficult ones the participants proposed a wide range of solutions where no concrete recommendation could be made.

First prototype

We then conducted an initial user study of a prototype, informed by a subset of the findings gathered from the focus groups. We designed a sandbox exploration application that presented information about coffee to be deployed in the setting of a hypothetical café—a specific usage scenario where users are likely to possess two mobile devices and often have time to spare. We partnered with a local Fairtrade group to ensure we provided community-relevant content.

The software uses spatial awareness to facilitate access to different information visualisations on two mobile devices. A key problem was how to map different visualisations to table spaces. Table 1 presents the data structures included in MochaTop and the way we mapped them to the table space. Crucially, the table surface is virtually divided into invisible zones—this is what the users in the focus groups anticipated.

Another issue was providing means to navigate with the application, i.e. switching between different pieces of information. MochaTop uses both zone-based and distance-based input. A touch-based solution was an obvious choice, but our intention was to investigate if navigation using spatial awareness was effective. Users were thus able to return to the top level information choice by increasing the distance between the two devices.

Implementation

We have already implemented two generations of prototypes which us different sensing methods that provide spatial awareness for the mobile devices.

The MochaTop system consists of two distinct software parts. The mutual spatial awareness and the inter-device communication are abstracted from user interaction. This should allow for swift modification and rapid prototyping.

In our first iteration, byte tags were affixed to the mobile devices so that they could be recognized by an

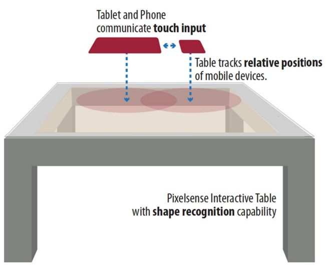

Figure 3. The first generation MochaTop prototype.

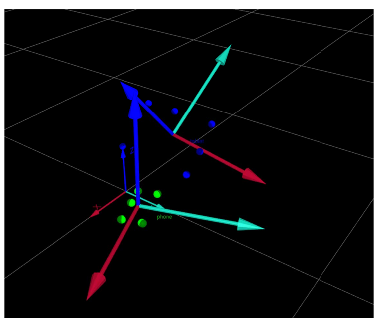

Figure 4. MochaTop's second generation where spatial awareness is provided with motion tracking.

interactive surface. We then placed the devices on a Samsung SUR40 (running Microsoft PixelSense). The table served as the spatial sensor for the devices (the table screen is always blank). The information about the devices is updated and broadcast continuously to avoid latency, enabling smooth communication between all the devices. Figure 3 presents the prototype setup. However, the dimensions of the interactive table are pre-defined and may be quite limiting. Our second-generation prototype uses industry-grade Qualisys motion tracking to obtain position information for the devices. Small, unobtrusive reflective markers are placed on the devices. While this setup requires a dedicated room, any table surface can now be used. Figure 4 presents the device view in real time. The six degree of freedom positional is broadcast over the network.

For managing devices and their positions, we use a central device concept. In our prototype, the tablet handles positional information of all devices, calculates the resulting views, and distributes the respective content to them. This enables on-the-fly adding or removing of devices as only one device, the tablet, is the sole information carrier. To add itself to this system, a new device sends a UDP broadcast over the network to register with the tablet. TCP is used for exchanging further information.

In our studies, we used a Motorola Xoom tablet and a LG Nexus 4 smartphone. Both devices are off-the-shelf products, and most participants are familiar with the form factors.

Preliminary studies

We conducted a more systematic exploration of this interactive space by conducting a sandbox-style user study with our first-generation prototype. The goal of this inquiry was to refine the concept of casual ad-hoc tabletops and identify the challenges for future work. We endeavoured to confirm MochaTop's feasibility and prepare for a future field study. Specifically, we decided to investigate the following issues affecting interaction with multiple mobile devices, motivated by past work with single devices:

- dynamics of the devices, i.e. the ways user place and manipulate them on a surface
- how continuous input, e.g. scrolling, can be achieved
- ways in which users grasp devices while moving them over the surfaces

Given the high-level nature of the questions and the exploratory stage of our work, we opted for an open-ended study where we recorded the participants using the prototypes from two angles.

We recruited participants from throughout our campus environment. The study included 23 participants aged 22-31 (mean age = 25.09, median = 25, 20 male, 3 female). Each participant was compensated with a small gift in the form of a USB fan. Sessions were conducted over the course of three days. In total, 5 pairs and 13 solo users generated 18 sets of video footage, each 15 minutes long.

The study consisted of an initial interview, about 15 minutes of sandbox interaction with the prototype, a single task for the participants, and a debriefing. The participants were invited to explore MochaTop in a semi-structured manner—we provided encouragement for exploring all parts of the system only if required. Next, we asked participants to use the system to extract numerical information from a time series chart. Lastly, we conducted a short interview in which we asked for a qualitative account of the experience and

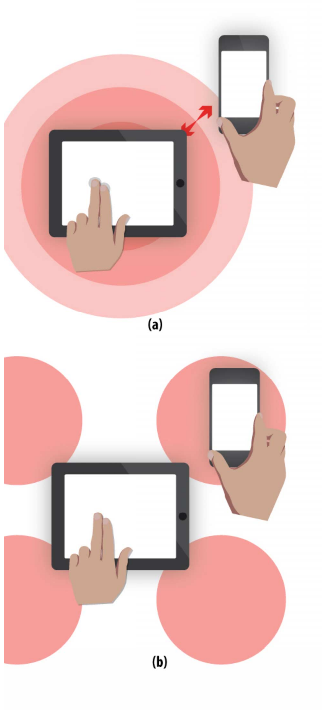

Figure 5. The rationale for zone-based input.

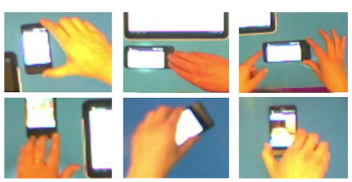

Figure 6. Six examples of alternative smartphone grips observed during the study (excerpts from actual study footage)

checked for content retention rates by asking them to provide the most basic information about the system.

Overall, we can conclude the prototype sparked interest among participants, as 61% (n = 14) of them expressed an explicit desire to further explore the application. Most importantly, the study showed that zone-based input was perceived as a more natural method of spatial awareness, as opposed to distance-based input. While all users had no problems using the distance-based functionality, instead of increasing distance between devices, they placed the smartphone in one of the table's corners in a single, fast motion (see Figure 5). Users were able to revert to the main menu by increasing the distance between the devices (Figure 5a). However, all of the study participants immediately repositioned the phone to one of the table's corners as if the corners were active zones instead of increasing the distance (Figure 5b). 35% (n = 8) of the participants would simply lift the phone from its current position and put it back in one of the table's corners. One subject placed the phone outside of sensor space. Observing participants work in pairs provided even more evidence of preference for zone-based input, as all of the pairs in our study divided the horizontal space into two sides, with each user interacting at each side throughout the study.

Challenges for Future Work

The main contribution of our preliminary study was to solidify what challenges need to be met if ad-hoc tabletops are to become reality.
The need to support extended input range is evident from our study. 57% of participants posed their hand awkwardly while moving the smartphone device. Once this happened, they abruptly repositioned the device to continue motion in the same direction. There is thus a clear need for researching an optimal clutching mechanism for the user to better understand how to interact with a multi-device system.
Supporting multiple device orientations on all axes is another issue. Our study shows that while some users are comfortable with laying down the devices on a horizontal surface and only changing their relative positions and orientations, some are likely to arrange the content on a table and then access it by picking up the devices. We have seen 57% (n = 13) of our participants change the device to a vertical orientation, in order to read, at least once. Proper contextualized support for picking up the devices and laying them back down on the table ("re-entering" the ad-hoc tabletop) is another design challenge.
Our work reveals some issues concerning the way mobile devices are physically handled on a horizontal surface. Figure 6 presents a subjective selection from the large number of grips observed during the study. We observed a multitude of approaches to manipulating the devices so that both screens would not be obscured. The fact that the novelty effect may play a significant role in this behaviour must be acknowledged, but it can be concluded that present-day smartphones are difficult to handle when placed on a surface. We thus see a need to address the device form factor design to support both horizontal and vertical interaction. Users must be able to handle the devices efficiently and with minimum screen obstruction. Tabletop proxemics will have to be readdressed for ad-hoc tabletops, as objects must in this case be directly manipulated, and hand placement will probably modify perceptions of personal space.

Conclusions

We have reported on our preliminary studies of MochaTop—a multi-device system designed to create ad-hoc tabletop interfaces in casual settings. We designed a system that enables users to explore information visualisations with spatially aware tablets and smartphones with distributed content. Our design was supported by a number of design workshops. We implemented two prototypes of our system that used an interactive table and motion tracking for positional sensing.

We then conducted a user study, which proved that there is potential for augmenting everyday interactive spaces with mobile tabletops. Observing and analyzing the behaviour of participants using MochaTop yielded a number of challenges facing future development of ad-hoc tabletops. Among these are: finding interaction patterns for exploring complex data structures, designing optimal clutching mechanisms, supporting both horizontal and vertical display of information, contextual support for handling the devices, and addressing mobile device form factors to facilitate manipulation on horizontal surfaces. We hope to inspire more research in ad-hoc tabletops and continue our own inquiry with a future field study.

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