Interacting in Multi-Display Environments

Sebastian Boring

University of Munich, Media Informatics
Amalienstrasse 17, 80333 Munich, Germany
sebastian.boring@ifi.lmu.de

Abstract. With the introduction of mobile devices as well as large public displays, we are surrounded by multiple displays at any time during the day. In addition, interacting with displayed information on one screen at a time is very common. The interaction between multiple displays simultaneously is rather difficult due to reachability, hard-to-use techniques or limited input capabilities. In my work I will investigate and propose new techniques that allow copying, moving or manipulating information across multiple displays. In addition, I will explore ways to allow remote control of (partially) unreachable displays.

1 Introduction and Motivation

Display technologies become increasingly available at low prices and blend thus into our everyday lives. Besides large-scale public displays known from airports, train stations or shopping malls, several screen technologies are also common in homes. A couple of years ago, people just had a television and a computer monitor. Today most people have a lot more devices providing additions displays. Those include mobile phones, personal digital assistants, laptops or tablet PCs. In addition, several new display technologies will be developed bringing further screen real-estate into our homes. These might include larger television screens, digital projectors or interactive tabletops. Secondary, screens are not only intended to display information but people should be able to interact with them. Thus, several input technologies for a variety of displays have been developed and there is no indication that this will change.

In addition to large and novel screen technologies, displays embedded into mobile devices such as personal digital assistants and mobile phones serve as ubiquitous information screens. In contrast to large and hence stationary devices, people can carry data with them. Furthermore, the mobility offered by those allows interaction at any place with additionally available screens. These devices bear great challenges due to their limited size, input capabilities and computational power. Integrating them into multi-display environments is thus an open research issue in ubiquitous computing.

The specific needs of information units regarding their sensitivity and display requirements also strengthen the necessity of interaction techniques across several displays. While displays are categorized into public, semi-public and private displays by their size and accessibility, information cannot easily be classified in the same way. However, it is important to know the privacy level of data as private information must not be displayed on public screens with their original representation unless the user actively allows an operation like this. Further, keeping information on small-screen devices is not always feasible as manipulation is a rather difficult.

In my research I will address two main issues. First, I will classify different interaction levels in terms of the displays used. Second, I will investigate and propose new interaction techniques across multiple devices in order to have instrumented environments with all their integrated displays acting as a single one.

2 Problem Statement and Research Questions

The consideration of several displays in an instrumented environment leads to a variety of different screen technologies. These displays are distinctive regarding a wide range of attributes, such as screen real-estate, computational power, input technologies, mobility and power requirements. Thus, it is necessary to identify properties of involved displays followed by a classification of their cooperation. The challenges regarding interaction in multi-display environments are: (1) physical attributes of displays; (2) input-independent cooperation; (3) physical relationship between devices; (4) reachability of displays; (5) utilization of additional screen capabilities; (6) ensuring privacy throughout the entire interaction.

Displays and their computing devices have most varying attributes. This is of fundamental importance in order to look at multi-display environments. While some screens are not movable at all (large-scale wall screens), others are highly mobile (mobile phones and personal digital assistants). Increasing mobility decreases available power supply. Thus, if mobile devices need to have a long operational time without being recharged they have lower processing power to save power consumption.

> **Spatial attributes:** *Interaction techniques in multi-display environments need to consider the single displays' attributes, such as screen real-estate, resolution and mobility. They have to support users in using additional displays if needed.*

Another important issue is the input mechanism a device uses. While standard computers use well-known mouse and keyboard input, mobile devices only offer a limited set of input opportunities. For example, mobile phones only offer key input whereas PDAs allow pen-based or finger input. In correlation to the input technology and accuracy, the screen real-estate is of high importance. Interacting with a finger on a small display appears to be more difficult than on a tabletop. In addition, some large screens are not capable of any direct input mostly because they cannot be physically reached. Interacting with different displays hence might be impossible using the same input technology. In addition, the environment needs to be aware of the number of hands used for an interaction on a specific screen. An interaction technique must either be supported on both the origin and the destination display or offer additional options for interaction.

> **Input-independent cooperation:** *Interaction techniques in multi-display environments need to ensure that all displays are able to work together. The transition between multiple input technologies needs to be transparent to the user.*

Besides their different sizes, display qualities and input technologies the physical relationship between multiple devices is an important aspect. This becomes more and more relevant if one is considering direct manipulation as technique for moving data. In multi-display environments, the mobile displays' positions might change more often. Thus, the relationship must be determined frequently by the environment to allow the correct movement of information units. It is significant to adapt new interaction techniques to different situations. If two devices do not have the same orientation (e.g. perpendicular to each other) moving information between those might not always be the user's desired action. If they are located in the same two-dimensional plane, but have different rotations it is important whether the information keeps its three-dimensional orientation. The relationship between devices is also important if a user wants to use additional screen capabilities. This is necessary if the device currently holding and displaying the information is not capable of the desired interaction.

> **Physical relationship:** *Interaction techniques in multi-display environments need to consider the relationship between involved displays. Thus, position and orientation need to be known during the interaction process.*

Another possibility is to transfer the data remotely. In this case, the relationship is of importance in order to support the user by selecting the second display. Once choosing the device is done, the user needs to be able to decide how the information will be shown. This includes the placement of data as well as other parameters, such as orientation or size. Using an icon-based representation of secondary screens might not completely solve this issue as it only allows the placement of information. Thus, users need to able to remotely control the other display. Another approach might be to show a smaller representation of the screen content on the primary device which is not useful on small screens. Thus, other options need to be examined. This highly depends on the placement and size of displays. In addition, the range between the user's display and the destination display is of importance.

> **Reachability:** *Interaction techniques in multi-display environments need to consider reachability and distance of involved displays. A technique should be aware of unreachable displays in order to offer a variety of options.*

In the mobile computing era, displays and devices are getting smaller. This increases mobility of users but also decreases screen real-estate, processing power and input capabilities. Once users have documents or pictures on personal devices it might be necessary to open or modify them. This often is an impossible or at least a very challenging task. Applying new interaction techniques in multiple displays environments could support users by allowing them to use additional screen size or more accurate input opportunities. Vice versa, large displays could serve as an overview while mobile devices can act as a tool for detailed manipulation.

> **Utilizing additional screen capabilities:** *Interaction techniques in multi-display environments need to offer additional displays in order to interact with the information in a way the first device cannot handle in parts or at all.*

Securing privacy of information in the environment is also an important part of interaction techniques that support multiple screens. While sensitive information might be displayed on personal devices, they should be hidden or at least be shown in an encrypted way on (semi-)public ones. Using their personal device, users can change the state and appearance of their private information. Hence it is necessary to clarify the privacy level of involved displays leading to limitations regarding the destination device. For example, if a person wants to open a sensitive document on a mobile phone causing the environment to use an additional screen for display, it is only allowed to take displays into consideration that are rated private or at most semi-public. In addition, interactions might need to be hidden from other users and hence should be processed in a way that other people are not able to see what is going on.

> **Conservation of privacy:** *Interaction techniques in multi-display environments need to ensure that sensitive information stays private throughout the entire interaction unless the user wants to show the data in public.*

As shown, interaction within instrumented environments can have different levels and complexity. Thus, it is useful to classify different interaction techniques in order to build multiple instances. First, users need to be able to copy or move information units between several devices. Second, users should be able to utilize additional screen and input capabilities of other devices. Third, displays need to be controlled remotely, especially if they are not (partially) reachable. Fourth, a multi-display environment needs to handle different privacy levels according to the involved displays.

3 Related Work

In order to create seamless transitions between several displays, one has to make underlying technology transparent to the user. People should not be aware of the different computers involved in the process as they only want to know whether the information has been moved (virtually) from place *A* to place *B* or modified in place.

Nacenta et al. [6] introduce several techniques for multi-display reaching. They designed a framework based on nine attributes to characterize the techniques. Example attributes are *Range* (“Is the information reachable by using a technique?”), *Feedback* (“Does the origin or the destination machine give feedback?”) or *Input device* (“Are origin and destination machine able to recognize the input device in the same way?”). In addition, this work illustrates possibilities that solve some issues related to multi display environments. Their classification inspired several attributes that are part of my initial design space.

Rekimoto et al. introduce the concept of *Augmented Surfaces* [7] that allows users to interact between computers, projected surfaces and physical objects. Physical and virtual objects can be combined in order to allow carrying digital information “stored” on a real world object. This system provides a shared workspace in addition to personal laptops and is controlled by mice attached to several laptop computers. In addition, Rekimoto et al. describe the *Pick & Drop* [8] technique that allows transferring data from one display to another by using pens. While data is coupled virtually to the pen's ID users get the feeling that they actively carry information on the pen. A further approach taken by Kohtake et al. is called *InfoPoint* [5]. This extension to *Pick & Drop* also allows visualization on the pen while carrying it.

The *Stitching* technique [3] allows users to extend the given screen real-estate of mobile PCs by using pen gestures. Coupled devices span a single virtual screen the user can interact with as it would be one physical display. This work also defines several multi-device commands, such as the remote postfix menu. This allows having the menu on another device than the object the menu is associated with. Tandler et al. [10] describe a system that allows tables being coupled together to form a larger display. While users can work individually on the single table, they can work cooperatively and simultaneously when the tables are connected. The connection of these tables is done by simply placing them next to each other. This creates a shared workspace while hiding the individual one until the tables are pulled apart.

Rukzio et al. compare techniques in order to select devices that can then be controlled using a mobile phone [9]. They describe three basic interaction techniques called touching, pointing and scanning that allow a selection of the device to be controlled. While touching (described by Want et al. [11]) requires reaching the appliance of interest, pointing and scanning can be done without moving physically to it. Pointing (described by Fitzmaurice [2]) instead uses a laser pointer to mark the desired device whereas scanning simply lists all available appliances within a network-covered area. This leads to interesting new thoughts regarding the coupling of multiple displays in order to use them as one device.

Based on this several interaction techniques have been developed. Most of them are headed towards direct interaction across two displays. Mostly they do not allow the combination of various device types as well as coupling more than two devices. My techniques will address the issue of having a room acting as one display to the user regardless of the number of physical devices and screens in the environment.

4 Approach and Methodology

My research will be conducted on both experimental and theoretical level. Currently, I build a communication architecture based on an existing infrastructure [4]. With this, all displays (stationary as well as mobile) in our instrumented room will serve as one single device. The architecture will support ad-hoc connections in order to allow fast changing display situations in the environment. The system will allow programmers to access each device in the environment regardless of the computer they are connected to. These devices include all displays (fixed screens, the steerable projector and mobile devices), input technologies (Smartboards, hybrid widgets, keyboards or mice) and tracking technologies (steerable and fixed cameras as well as sensors). In the user's point of view the environment then acts as a single device.

Besides building this infrastructure I extensively study related work. I have started to create a classification of multi-display interactions based on literature and own experiences. In addition, I have already identified fundamental operations a person wants to use in these environments: (1) moving, copying or manipulating information across multiple displays; (2) utilizing additional screen capabilities to overcome input limitations found on specific displays; (3) remote control available and possibly unreachable displays by using a personal device. I am aware about the fact that further operations might be possible and I will add them to this list once they arise.

I then plan to create several instances of the mentioned interaction techniques. These prototypes should address at least the following issues: First, I plan to observe how people would use one of the three options to transfer or copy their data. Second, I will examine how people use these interaction techniques in combination with the different device capabilities. Third, I plan to research people's point of view regarding privacy in these environments. After comparing the different instances to traditional and today's techniques, I plan to run a comparative study between the different prototypes. The expected contribution will be a classification of interaction techniques in multi-display environments in combination with several areas of applications. These will be built after identifying new research areas in the design space. Finally, I will propose guidelines that state which technique could be used according to the situation.

5 Research Conducted and Preliminary Results

Based on the challenges stated earlier, I have developed an initial design space in order to identify interesting new research fields. This might help classifying multi-display interactions in the future. Figure 2 summarizes the design space. Each row in the design space represents a dimension. The shaded area indicates where the *Shoot & Copy* prototype – described in the following – fits into the design space.

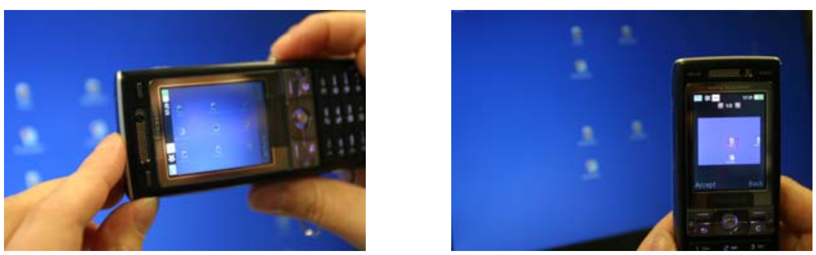

Figure 1. The *Shoot & Copy* prototype. Left depicts the user taking an image of the desired information. Right shows the presentation of the result.

After classifying interactions in multi-display environments, I have built and initially evaluated a first prototype called *Shoot & Copy*. The idea of this interaction technique is to retrieve information from a large public, unreachable display known from train stations (see Figure 1). The user is able to capture an image of the information of interest using a mobile camera-phone. Besides having the captured information on the phone, the prototype also gains access to underlying data related to the captured information. Hence, the user does not need to memorize content (usually leading to a loss of information) s/he views on public displays. As the prototype does not rely on visual markers, the technology vanishes out of the user's focus whereas taking a picture using a camera-phone is a common task for most users. The additional information will be downloaded automatically using a standard personal computer or laptop in combination with the mobile phone. Because of recent changes in technology (wireless LAN and high storage capacities on mobile phones) the prototype can be modified in order to directly transfer captured items such as music files, images or video files on the mobile phone. Employing wireless LAN will also help increasing the speed of data transfer. This leads to interesting questions in the field of economics.

The evaluation of this prototype showed a high interest among several people. They mostly stated that they like the idea of keeping information on the mobile phone because they usually have this device on-hand at all time. Furthermore the participants in the study mentioned that their privacy was not affected. This is mainly because everybody in the environment sees that a user is capturing information from a display, however, nobody could see *which* information has been photographed. Users also liked the interaction with the camera-phone as they were used to digital cameras.

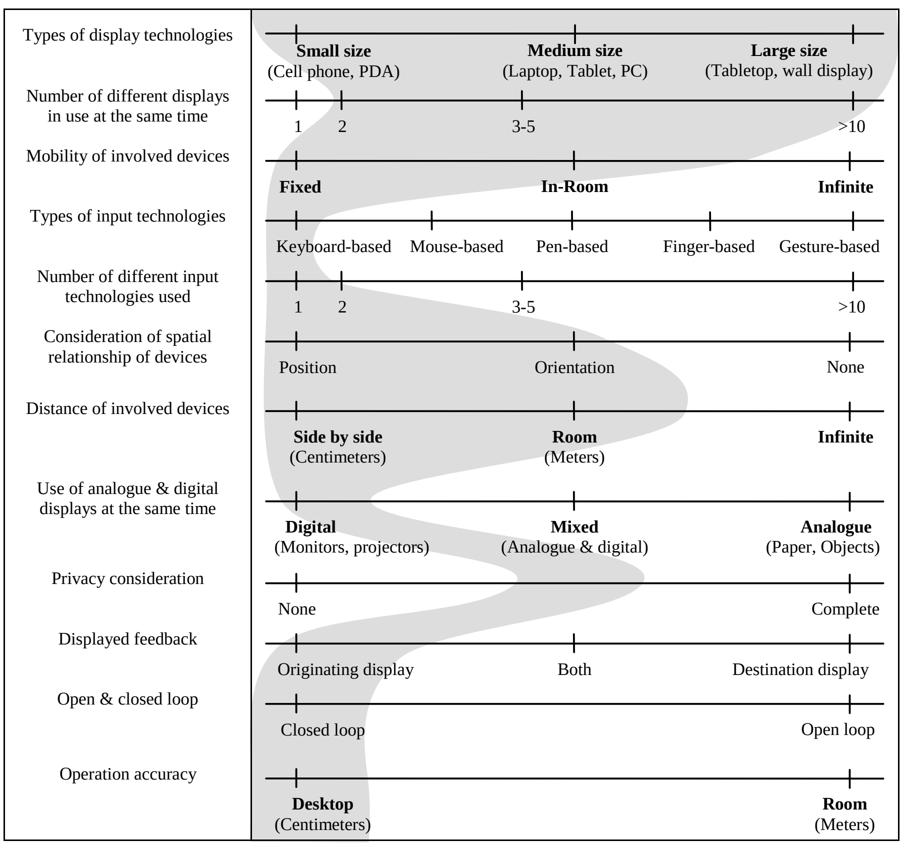

Figure 2. Design space for multi-display interaction (inspired by Fitzmaurice et al. [1]). The shaded area indicates where the *Shoot & Copy* prototype fits into the design space.

6 Summary and Future Steps

The illustrated approach is still in an early stage at this time. I have built and evaluated an initial prototype to get insights on how people would use such technologies. Further, I have developed an initial design space for interactions in multi-display environments. In the next few months I will build more instances of the desired approach starting with scenarios to gather information from the large display surfaces. These include all sizes of displays as illustrated in the design space considering in-room mobility of some displays involved. Subsequently, I will build further prototypes to investigate the option of utilizing additional screen capabilities. I will then examine how displays can be coupled together in order to allow remote control of a desired display. With the prototypes I will address several challenges stated earlier.

After building the prototypes, I will develop a method for comparing the implemented prototypes. One possibility might be to test them against existing, well-known techniques such as standard information transfer provided by operating systems. These evaluations will be conducted regarding the design space as well as the users' acceptance. In addition, I will compare these techniques against each other to identify guidelines that state which technique suits best in specific situations. The evaluation is still an open question which I would like to discuss in the colloquium.

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