Through-the-Display Interaction in Heterogeneous Multi-Display Environments

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Abstract
With the introduction of mobile devices as well as large public displays, we are surrounded by multiple devices at nearly all times throughout the day. However, these devices are extremely heterogeneous regarding their input and output capabilities making it hard to seamlessly interact between them. In my dissertation work I explore novel interaction techniques that leverage the advantages of both mobile and stationary displays. I investigated existing techniques that allow copying, moving or manipulating information across multiple displays by paying attention to heterogeneity. Based on the results, I propose a design space and created a set of tools for multi-display interaction. I propose a form of interaction called "*superimposed displays*" which works for both reachable and unreachable displays.

Keywords
Interaction techniques, heterogeneity, multi-display environments, superimposed displays, studies

ACM Classification Keywords
H.5.2. Information interfaces and presentation: User interfaces – Evaluation/methodology, Input devices and strategies, Interaction styles; D.2.2. Software Engineering: Design Tools and Techniques: User interfaces.

Introduction and Motivation

Recently, display technologies became increasingly available at low prices and hence blend into our everyday lives. Besides large-scale public displays known from airports, train stations or shopping malls, a variety of display technologies can also be found in home environments (e.g. large-scale TVs, projectors or computer monitors). However, most of today's large displays are not directly interactive due to their relatively large screen sizes or protection against vandalism. Hence, most of these public displays are only broadcasting information to users nearby.

In addition to these large and stationary screens, small portable devices such as cell phones or personal digital assistants (PDAs) are by now usual companions in our everyday lives. In contrast to large screens, they offer a broad set of interaction capabilities but in turn have considerably small displays due to their portability. Several interaction techniques have been developed that take the drawbacks of small devices into account.

The synergistic effects of such heterogeneous displays are an open research question even though several projects are investigating this challenge. The main focus of my research hence deals with the synergistic effects of heterogeneous devices to create new interaction possibilities. For this, I will address three main issues: First, based on an extensive review of related work, I already classified different interaction levels regarding involved displays. Second, I generate a generic software architecture based on the classification for rapid prototyping of new interaction techniques. And third, I investigate the opportunity of superimposing small portable screens on large public ones.

Problem Statement and Research Questions

The combination of stationary and portable devices indisputably leads to a large variety of input as well as output technologies. I refer to this diversity of interaction capabilities as *heterogeneity of devices* which can be understood as the question of how different devices included in the interaction process are. This can be expressed by investigating the input (e.g. keyboards, touch screens, etc.) and output (e.g. display size, virtual and physical resolution, etc.) capabilities of each involved device. Furthermore, *heterogeneity* leads to a number of challenges in multi-display environments.

The largest *heterogeneity* can be found for small personal devices compared to large displays. The screen real-estates range from several feet to displays as small as couple of inches. While the small screen size might appear as disadvantage these displays have large physical resolutions allowing much more detail on a considerably small area. In addition, compared to large and mostly non-interactive displays, small devices usually come with a rich set of interaction capabilities such as keypads, touch screens or acceleration sensors. Hence, leveraging the capabilities of heterogeneous displays leads to synergistic effects that need to be researched more detailed.

Small displays can be further understood as personal information containers which are highly tailored towards single user interaction whereas large screens are intended for a broader audience. This leads to both personal and public *information spheres*. These spheres raise a crucial challenge as, for example, no personal item should be displayed in the public sphere, whereas public items might as well be shown in the personal sphere. Furthermore, the spheres have different types of interactions: First, multiple users can interact within the public spheres simultaneously creating concurrency problems. Second, when interacting in the personal sphere, other users should not be affected in their interaction with the public one. These spheres also influence on the way feedback is given. For example, the feedback on a public screen for one user should not affect others in their interaction process. It seems obvious that feedback in this case should be given on the personal device instead.

When several displays are involved (regardless of their size), the virtual screen arrangement is an important part in designing multi-display interactions. Typical settings include independent screen layouts as well as cloned displays. The latter one can be further subdivided into fully (i.e. completely showing another screen's content) and partly (i.e. showing both its own and another display's content) cloned screens. However, one possibility – namely *superimposed displays* – has not yet been investigated widely. This arrangement assumes overlaying one display with another one. The "top" display can render information more detailed or offer precise interaction.

Closely connected to virtual screen arrangements is their spatial relationship. Especially for physically superimposed displays, it is important that each display "up front" knows the position of the underlying screen in order to render the information that can be seen through correctly. "Side-by-side" interactions also rely on this relationship, for example, when a user drags an item from one screen to another with a relative pointing device. Another physical property of displays is their reachability. It describes whether a person is able to directly interact with the screen using touch. This parameter is influenced by the display's size (i.e. can one reach each position on it) as well as its placement in the public area (i.e. is the surface reachable at all).

These problems can be addressed using the concept of *superimposed displays* where the personal device is overlaid on top of a public one. In my work I want to give answers to the following research questions:

1) What are common interaction techniques that could benefit from superimposed displays?

2) What is the difference in having a horizontally or vertically mounted public displays?

3) Which influence does the distance between superimposed displays have?

To tackle these questions, I identified two main interaction tasks: First users need to be able to select another display (or information shown on its canvas) they want to interact with. Second, users need to manipulate the selected information subsequently. In terms of superimposed displays, these interaction techniques are carried out using the personal device.

Related Work

To create seamless transitions between multiple displays, one has to make the underlying technology transparent to the user. *Augmented Surfaces* [14] allows users to interact between computers, interactive surfaces as well as physical objects. *Anchored Cursor* allows users to extend the reach of their personal laptop's cursor ("side-by-side" interaction). They are able to drag items beyond the laptop's boundaries to nearby surfaces and vice versa. The *Stitching* technique [7] allows users to extend given screen real-estate of mo-

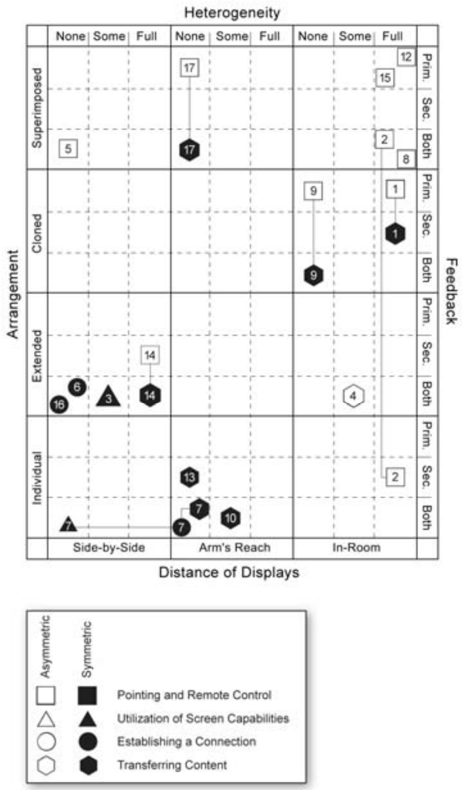

Figure 1. The design space of multi-display interaction with existing systems included. The numbers correspond to the references.

bile tablet PCs by using pen gestures. The relationship of displays is addressed as the pen stroke allows a good approximation. *Drag-and-Pop* and *Drag-and-Pick* [4] both illustrate techniques that allow accessing remote screen content through touch- and pen-operated devices. Tandler et al. [16] describe a system that allows interactive tables being coupled together to form a larger display by simply placing them next to each other. Similarly, *Synchronous Gestures* [6] allows the connection of displays by “bumping” them together.

When displays are not next to each other (interaction “at a distance”), other concepts need to be developed. *Pick & Drop* [13] was created for transferring content from one display to another without having them “side-by-side”. This system uses pens with virtual IDs that are utilized to associate data to them. Users get the feeling of actively carrying information on the pen. *InfoPoint* [10] allows a textual representation of the carried data. *Point & Shoot* [2] enables users point their phone’s camera towards digital items displayed on a large screen. When they take a picture of the desired content, they gain control of the respective item.

Other research projects investigate the usage of mobile phones for controlling a pointer on a remote display. *Sweep* [2] allows the control of such a pointer by the use of optical flow analysis. However, it is not necessary to point the phone towards the screen at all times. Similarly, *Direct Pointer* [8] requires the user to point on the desired position on the screen. However, both systems might be hard to use in case of a large number of users as all the pointers would clutter the canvas.

Another research area is the use of virtual representations of distant displays. *Bubble Radar* [1] allows users to interact in a representation map of remote displays with reduced resolution. The *Frisbee* [9] technique enables users to interact with screen regions that are beyond arm’s reach. A different approach is to superimpose displays to gain more interaction capabilities or advantages of visual output which then allows a richer set of interactions. *Ubiquitous Graphics* [15] allows users to obtain a detailed view of a larger screen’s sub region through their spatially aware mobile computer. Olwal et al. present a system that allows a higher level of detail on mobile phones that are located on an interactive tabletop [12]. Both techniques were influenced by the concept of *Peephole Displays* [17] as well as *Toolgalss and Magic Lenses* [5]. Further research has been done regarding *Focus plus Context Screens* [3]. This technique creates an area with high resolution output in the center of a larger screen.

Nacenta et al. [11] describe a theoretical framework in order to compare different multi-display interactions. It is based on nine attributes to characterize the techniques. Examples include *Range*, *Feedback*, *Input Device* or *Accuracy and Resolution*. Their classification had a strong influence on my design space.

Approach and Methodology

My research is being conducted on both experimental and theoretical level. After a careful study of related work and existing multi-display interaction techniques, I recently developed a set of tools which provides programmers with access to remote screens in the same way as local ones. The architecture allows ad-hoc connections which is necessary for integrating mobile screens. The input of each device can be transparently rerouted through the environment to the display that requested it. This toolkit is especially designed for su-

Figure 2. Top denotes the selection of a picture with *Shoot & Interact* through the viewfinder. Bottom shows the creation of a comment for it.

perimposed displays. Besides creating this architecture I extensively analyzed related work to create a classification of multi-display interactions.

I built several instances that pay close attention to selecting and manipulating information on underlying remote screens. These can be subdivided into two categories: First, the personal display is physically superimposed on a horizontal surface (e.g. a tabletop). And second, the interaction is carried out “at a distance” meaning that the public display is not reachable (i.e. not within arm’s reach) and mounted vertically. One other variable is the way of interacting with remote content. Either users virtually select and manipulate information (i.e. world of miniature) or they directly interact by “seeing through” the display.

Research Conducted and Preliminary Results

Based on extensively studying and analyzing related work and literature, I have developed a design space (see Figure 1) to classify multi-display interactions with special attention to *heterogeneity* of devices. As stated before, heterogeneity can be described as how diverse involved displays are regarding their input and output capabilities. Other factors are: *Arrangement* (“What is the virtual relationship between all displays?”), *Distance* (“How far are the displays from each other?”), *Reachability* (“Can I reach a display?”), *Feedback* (“What kind of feedback is given by which device?”) and *Symmetry* (“Can I operate back and forth?).

After creating the design space, I have developed and evaluated different interaction techniques that allow controlling a personal pointer on a remote display. The evaluation revealed that continuous techniques have faster target acquisition times for large distances. However, the *overshooting effect* (i.e. moving beyond the target’s boundaries) requires the user to correct the movement increasing these times again which mostly happened with acceleration-based techniques.

To allow higher scalability, I have built a superimposed selection and interaction technique. *Shoot & Copy* enables users to capture information displayed on a large public unreachable screen without relying on visual markers. A qualitative evaluation revealed that this technique is easy to use as taking pictures is a familiar task. Users liked the idea of using mobile device as information containers as they are always on-hand. One finding was the unaffected privacy of participants. Others see *that* they capture information, but no one recognizes *which* information has been captured. Based on a user needs analysis, I have developed an extension called *Shoot & Interact* (see Figure 2).

I have also investigated the concept of physically *superimposed displays*. I have built a prototype called *Lucid Display* that turns a tablet PC into a see-through interface when placed on an interactive table (see Figure 3). The tablet PC can thereby act in different ways: First, it can be used as dynamic focus plus context device by providing a higher physical input and output resolution. Second, the tablet PC can be used as toolglass to get a different view on the underlying content. This option allows the tablet’s usage as an application frame. Whenever a user places the tablet on top of an information item, the tablet PC can be used to manipulate it. And third, the tablet can be understood as an individual information container holding its own information. I have further investigated interaction techniques using *Lucid Display*. The user study revealed that two interesting insights: First, users prefer moving

Figure 3. The *ThruSight* prototype (top). Center shows the remote lens and bottom denotes the application frame.

the tablet PC *physically* over moving the content on the tabletop *virtually*. And second, the moving of information "through the display" versus across the display's bezel does not show any preferences by users.

Summary and Future Steps

The illustrated approach is in an advanced stage at this time. After an extensive study and analysis of related work, I propose a design space for multi-display interaction with a particular focus at heterogeneous environments. I have used this design space to create a toolkit for rapid prototyping in multi-display environments. With this, I have created several instances for the three identified fundamental operations. These prototypes have been evaluated against existing techniques and received an overall good feedback. Currently, I extend the discrete approach of *Shoot & Interact* to create a continuous, touch-based interaction technique that forms the concept of "through the display" interaction. This prototype will be evaluated against both external and internal existing techniques.

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