From Small Screens to Large Displays: Understanding Interaction in Multi-Display Environments

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ABSTRACT
Devices such as tablets, mobile phones, tabletops and wall displays all incorporate different sizes of screens, and are now commonplace in a variety of situations and environments. Environments that incorporate these devices, multi-display environments (MDEs) are highly interactive and innovative, but the interaction in these environments is not well understood. The research presented here investigates and explores interaction and users in MDEs. This exploration tries to understand the conceptual models of MDEs for users and then examine and validate interaction approaches that can be done to make them more usable. In addition to a brief literature review, the methodology, research goals and current research status are presented.

Author Keywords
Multi-display environments; multi-surface environments; multi-display interaction; cross-device interaction; tabletop; touch; mobile-devices;

ACM Classification Keywords
H.5.2. Information interfaces and Presentation: User Interfaces – Interaction styles, evaluation/methodology, user-centered design.

General Terms
Human Factors; Design; Experimentation

CONTEXT AND MOTIVATION

The recent explosion of digital devices in daily life has had a widespread effect in many areas in our life. From transportation to shopping to film, these devices now all play a central role. An important note about this explosion is the variety of devices that have resulted from it. Tablets, mobile phones, wall displays, tabletops are all devices that are a part of this explosion, and incorporate advances in multi-touch technologies. In a similar fashion, systems that track the location of individuals have advanced significantly and accordingly dropped in cost. Technologies such as the Microsoft Kinect [10], Nintendo Wii [14] and Sony PlayStation Move [18] are all commonplace in homes today.

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Figure 1. A User interacting with an Apple iPad and a Smart Board in a Multi-Display Environment.

A Multi-display Environment (MDE) is a system that aims to integrate many of these devices and optionally motion tracking systems, into a unique interactive environment. Interaction is typically spread amongst devices in the environment, as shown in Figure 1. We define interaction as methods in which users can interact with the devices in the environment. This encompasses methods such as gestures with devices, on the devices or without devices. With such variety in devices in the MDE, capabilities of the devices themselves also become a centerpiece in interactions, as each device has its own screen size, resolution, mobility and position. Incorporating these unique capabilities is technically possible, as seen by prior work [2, 4, 8, 22]. It is important to note that many of the systems and interactions that have been seen in the MDE space were designer built or may have been technically constrained, due to available technologies at the time. This means, that there hasn't been a real examination of the conceptual models users have in the MDE domain. As MDEs and the technologies within them become more advanced, understanding interactions from the user perspective is essential.

Papanek once stated, "the ultimate job of design is to transform man's environment and tools and, by extension, man himself". My thesis work presented here aims to follow this philosophy and facilitate the creation of future MDEs that are truly immersive and interactive experiences for users and assist them in a variety of domains.

RELATED WORK

In the interaction space of MDEs, a primary problem in their design is the movement of content between devices, which can include applications, interfaces and even devices themselves. In addressing this problem, designers can then build environments that can easily facilitate a user and their tasks, much more than any single device could. As with the possibilities of devices in an MDE, there have been a multitude of approaches to address this problem.

Considering the Environment

An early approach to this problem, was considering the MDE space as spatially connected and continuous. Rekimoto designed a system that allowed users to move content across screens by only requiring they know the physical relationships between computers and a projected tabletop [15]. Nacenta et al., expanded upon this approach by building a perspective-aware system and examining its effectiveness [12]. The concept of a personal and shared space is another similar approach, done by MacKenzie et al. [9]. In this concept, users have discrete workspaces that are personal and can be "published" to a shared workspace for other users to access. An entirely opposite approach to these is to treat the environment as discrete and disconnected, as done by Johanson et al. [6]. In both of the approaches however, there is no real distinction given to the capabilities of the displays or the devices in the environment, despite potentially mapping well to a particular conceptual model for users.

Another interesting approach is to not only considering the displays in an MDE as discrete, but to allow users distinct techniques for content transfer, as done by Streitz et al. [19]. In their approach, they allowed users to "dock" information or use physical tokens to facilitate content transfer. Wilson et al. later extended this approach and entirely removed physical tokens and allowed users themselves to be become the tokens that facilitate content transfer. Other approaches that consider the environment as a whole include world-in-miniature or menu-based techniques [1,21].

Interaction Techniques

Some of the earliest work in interaction within MDEs was done by Rekimoto, where he transferred the pick and drop metaphor to the digital space [16]. It allowed users to pick up digital objects with a pen gesture and then drop them by tapping on a target display. This approach tried to conceptualize the mental model of picking up and moving physical objects and many other techniques followed in the MDE space that mimicked real world interactions [3,4,20,23].

More recent approaches have shifted from focusing on translating particular interaction metaphors to focusing on the environment itself. These approaches examine relationships between people and devices and are proxemics in nature. As proxemics considers factors such as orientation, position, identity and movement, many of them are potentially far more intuitive. Bragdon et al., designed interactions around pointing and flicking digital objects in an MDE [2]. It allowed users to point a device at another device and then perform a flick gesture on the pointing device to transfer the digital objects to the pointed at device. Voida et al., devised a set of interaction techniques based upon flicking, throwing and pointing gestures [20]. In contrast, techniques by Dachselt et al. and Doring et al., utilized devices themselves as the means to move the digital objects, by flicking or moving them in the environment [3, 4]. Hinckley et al. devised interactions in an MDE that allowed users to dynamically tile devices to share content or bump devices with each other to transfer content [5].

Designing Interactions

Many of the aforementioned interaction techniques were created by system designers and while they may or may not be novel and intuitive to users, the issue becomes, does the conceptual model of the user match those that the designer had when creating interactions.

To create effective interactions in an MDE, it would make sense to elicit interactions from the users themselves. In prior work, Nielsen et al. developed a procedure for user-defined gestures [13]. In this procedure, tasks are defined by system designers for users to perform. From these tasks, a vocabulary is constructed and then benchmarked to validate if users prefer the gestures chosen. This technique was applied to the tabletop domain by Wobbrock et al. [24] with a modification in that users before performing a task were shown a visual outcome of the result of the task. As a result, a set of gestures was created. Morris et al then followed this work by means of validation and showed that these gestures were indeed preferred by users and mapped to their conceptual model of interaction with tabletops [11].

This same technique has been applied to the MDE space, with Kray et al., but instead examining not just gestures, but what interactions could be done with mobile phones in an environment that consisted of tabletops and wall displays [7]. Although there was no extraction of gestures or interactions in this work, it was found that users produced an enormous amount of different gestures, suggesting that the interaction space and potential gestures for MDEs is quite large. Subsequent work by Kurdyukova et al., elicited interactions for an MDE consisting of a tabletop and tablet, and a number of interesting interactions were found, but not statistically analyzed [8].

RESEARCH GOALS AND METHODS

In our work, we reflect upon the problems and successes of systems in the MDE space and try to explore the notion of building interactions from the perspective of the users they are meant for. Specifically, this work explores the notion of interaction in MDEs to

(1) Understand what users think while they are engaged in various activities (which may include other users in collaboration) in an MDE,

(2) Understand what users think when interacting with different technologies in the MDE space that are supporting their activies, and

(3) Map the aforementioned understandings to interaction design to assist future MDE designers in building more usable systems.

To address these goals, user studies need to be conducted and much like prior work, these studies need to be designed in an elicitation manner followed by Wobbrock et al [24], to extract meaningful interactions and then benchmarking them for validation. The user tasks in these studies should mimic those of real-world tasks, where users may be asked to send or retrieve from other users or devices. This would result in a better understanding of the conceptual models users have in MDEs.

THESIS STATUS

Thus far, I have completed one large user study, focused on eliciting gestures within MDEs. This study, tried to understand (1) are there some common gestures that users have in an MDE, (2) what impact do factors such as devices and distance have with users and their gestures in the MDE space, and (3) do users have a common conceptual model that designers could use or build upon for future MDEs. In the study, participants were recruited to perform gestures in an MDE and they were not excluded based on experience with technologies such as tabletops or motion tracking systems. Users were shown outcomes of various tasks to perform and then asked to perform gestures that would result in the outcomes. To examine the impact of factors, these tasks were based upon Voida et al. [21], in which tasks were to be performed at varying distances. In addition, device type and direction (sending or retrieving) were also varied. Analyzing the information from these gestures and their impacted, we discussed a few key findings and results in the paper [17]:

(1) Users didn't have a consistent mental model to draw upon for designing gestures, as a wide variety of them were seen. This meant that after quantifying the results, it was not possible to create a common set of gestures for users in an MDE.

(2) The gestures that were seen in the study were classified into four conceptual themes, which are as follows:

- *Close Contact:* When the positions of devices are close or there is contact during a gesture. An example of this theme is bumping or placing an object above another.
- *Moving Objects:* When a gesture mimics the metaphor of moving a physical object in space. Examples include flicking or shake gestures.

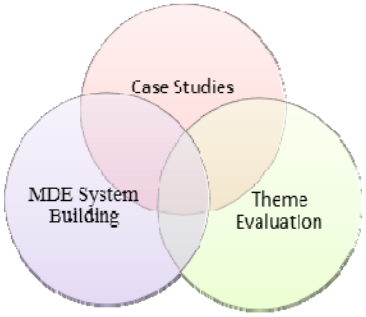

Figure 2. Research Approach

- *Selection:* When a gesture is used to actively select another object, which can include persons or devices. Pointing with a device at a person or other device is an example of this theme.
- *Borrowed Interactions:* When a gesture mimics interactions that already exist with other technologies. Using a device as a camera or mirror are examples of this theme.

These themes provide a basis for designers building interactions in future MDEs.

(3) Users often chose the same gesture for multiple tasks, despite the gestures chosen being different. As a result, it was suggested that designers should use aliasing to provide users with more than one gesture for any given task in an MDE.

The next stage of our work will mainly focus on evaluating the conceptual themes that were a result of the first study and applying the understandings to real MDE design.

NEXT STEPS

Figure 2, highlights the research components that comprise the next stage of our work. This stage is focused on evaluating and designing for the conceptual themes by means of a "Research through Design" cycle [19]. Horvath describes research through design in 3 distinct phases; Explorative Research, Creative Design Actions and Confirmative Research Actions. The first stage of the research for this work was focused on exploration of interactions, through literature reviews and an explorative user study for interactions within MDEs. The next stage will require building a prototype MDE system that not only allows for many of the gestures in the conceptual themes, but for other unique gestures to be created. This then intertwines the design and confirmation (through evaluations) of the themes and interactions in an iterative approach. Additionally, case studies with a domain such as oil and gas will be done to apply the research.

OPEN QUESTIONS

Although the first set of experiments has been completed, design modifications of the second phase of the research

have not been completed. Receiving feedback from expert interface designers, system designers and design researchers would be very beneficial in designing a set of experiments or methodology to test the conceptual themes in an MDE. Furthermore, it would also be useful to know how this research could be further transformed to be most useful to designers of MDEs and as well as a valuable contribution to the scientific community of intelligent user interfaces and information systems.

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