Increasing Passersby Engagement with Public Large Interactive Surfaces

by

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AUTHOR'S DECLARATION

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

The DISCOVER interaction model introduced in Chapter 3, and the studies presented in the subsequent chapters, are the result of collaborative work between me and my research colleagues. It is often difficult to state the exact amount of each person's contributions or the exact evolution of the research. However, the following notes provide some indication for the amount of their involvement.

1. The DISCOVER interaction model was developed by me, in collaboration with Dr. Stacey Scott. An earlier, simplified version of this model was used by Mindy Seto in her thesis work (Seto, 2012) and a study on menu discoverability (Seto et al., 2012). I was the author and presenter of the paper describing the early stages of this model in a peer-reviewed international conference under the following citation:

   Cheung, V. (2014). Improving Interaction Discoverability in Large Interactive Displays. In *Doctoral Symposium of ITS 2014: ACM Interactive Tabletops and Surfaces*. Dresden, Germany, November 16-19, 2014.

2. The laboratory-based study methodology presented in Chapter 4 was developed by me, in collaboration with Dr. Stacey Scott. I was the lead author and presenter of the paper describing this methodology in a peer-reviewed international conference under the following citation:

   Cheung, V., Scott, S.D. (2015). A Laboratory-based Study Methodology to Investigate Attraction Power of Large Public Interactive Displays. In *Proceedings of UbiComp 2015: ACM International Joint Conference on Pervasive and Ubiquitous Computing*, p. 1239-1250. Osaka, Japan, September 7-11, 2015.

3. The pilot study presented in Chapter 5 was conducted by me, in collaboration with Dr. Stacey Scott and co-op student Frank Cento. The application used in the study was implemented by me, with the assistance from undergraduate research assistant Joanne Leong.

4. The improved study presented in Chapter 6 was conducted by me, in collaboration with Dr. Stacey Scott. The application used in the study was implemented by me, with the assistance from co-op student Shrey Khosla. I was the lead author and presenter of the paper reporting the findings from this study in a peer-reviewed international conference under the following citation:

   Cheung, V., Scott, S.D. (2015). Studying Attraction Power in Proxemics-Based Visual Concepts for Large Public Interactive Displays. In *Proceedings of ITS 2015: ACM Interactive Tabletops and Surfaces*, p. 93-102. Madeira, Portugal, November 15-18, 2015.

5. The field experiment presented in Chapter 7 was conducted by me, in collaboration with Dr. Stacey Scott and master's student Mojgan Ghare. The application used in the study was implemented by me. The video annotation analysis was performed in collaboration with undergraduate research assistant Caroline Wong.

Abstract

Despite the proliferation of Public Large Interactive Surfaces (PLISs), and their potential to provide a more engaging and interactive user experience, these surfaces often go unnoticed by passersby, or not immediately comprehensible in terms of usage. Current research in addressing this problem involves modeling the user-surface interaction through observational studies, and deriving recommendations for interface design to facilitate the interaction. This approach is often context-specific, requires elaborate setup, and lacks experimental control. To mitigate this problem, an interaction model, named DISCOVER, was developed by drawing ideas from classic usability research and focusing on the discoverability aspect of the interaction. This approach allows the model to serve as a lens for understanding and synthesizing existing work on PLISs, and to be used as an evaluation framework to assess effectiveness of potential designs. To accompany this evaluation capability, a laboratory-based evaluation methodology was developed to allow researchers to quickly implement and evaluate potential designs, particularly for the early stages of interaction that precede the more commonly studied explicit and direct interaction (e.g., touches, mid-air gestures).

Using the model and the evaluation methodology, a proximity-based interaction mechanism using animated content and shadow visualizations was designed and evaluated as an effective technique in drawing attention from unknowing study participants. A follow-up, more conventional in-the-wild study also verified this finding, and further demonstrated the usefulness of shadow visualizations in drawing attention from passersby, retaining them, and enticing playful interaction.

The goal of this thesis is to better equip researchers and practitioners of PLISs with tools that allow them to evaluate and improve existing interfaces, and to provide them with insights into designing future ones employing better and more engaging technologies.

Acknowledgements

Rome was not built in a day, nor was it built by one person. This thesis will not be possible without the generous help and support from many important people, whom I am deeply grateful. I will try my best to thank those who have made the most profound impact on this research and to me personally as I have spent countless days and nights to its fruition.

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I would also like to extend my thanks to my comprehensive examination committee, Dr. Karen Collins, Dr. Carolyn MacGregor, and Dr. Daniel Stashuk, for their feedback in shaping my thesis research early on, and their understanding in the time required for my research to complete. I would also like to thank Dr. Andrés Lucero for being my external examiner, and bringing new perspectives to my research.

I am also grateful to my funding sources, which have allowed me to focus my time and efforts on this research: Natural Sciences and Engineering Research Council of Canada (NSERC), NSERC Digital Surface Software Application Network (SurfNet), the Engineering School at University of Waterloo, and University of Waterloo.

I would also like to thank all the research colleagues I have had the pleasure of working with. To the people at Collaborative Systems Lab directed by Dr. Stacey Scott, the people at TouchLab directed by Dr. Mark Hancock, the people at Social Usable Interactive Technologies directed by Dr. Parmit Chilana, the people at Games Institute directed by Dr. Neil Randall, and the people at User Interface & Software Engineering at Otto-von-Guericke-Universität Magdeburg, Germany, directed by Dr. Raimund Dachselt. I would also like to acknowledge several people who have gone the extra metres for me during this time. To Yu-Ling Betty Chang, my lab-mate and good friend, who always gives me good insights into my research and writings, and feeds me with endless delicious snacks. To Diane Watson, my colleague and good friend, who brain-storms with me the craziest research ideas and shows me a person can both be an excellent researcher and cook. To John Harris, my colleague and good friend, who introduced me to the amazing world of game design and development that inspires my research projects.

This thesis would have never been completed without the continuous support of my family and friends. They have provided their support in each of their own special ways that no others can replace. Thanks to my parents Anita and Felix, and my brother Kelvin, for believing in me and their unconditional support in every aspect. Thanks to my family and friends for understanding it is not appropriate to keep asking a PhD student when he is going to graduate.

Lastly, to my Lord, who guides me through all stages of my life. May this thesis glorify His name.

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Chapter 1
Introduction

Throughout history human-kind has been using surfaces for numerous intellectual activities such as portraying visions, recording incidents, organizing concepts, and sharing ideas. These surfaces can be as crude as cave walls and clipboards, or as sophisticated as networked digitalized boards. They can have various physical configurations (vertical, horizontal, portable or stationary), and various sizes (tens of centimeters to a few metres). Surfaces of larger size and scale have long been used in public settings, and for a variety of purposes from museum exhibits to notice boards and scrolling billboards. Yet, the analog and static nature of these types of surfaces limits them to traditional “view-only” displays such as “signs” or “boards”. With advancement in technology, these once-static canvases now have the capability of being responsive to our actions, and can actively communicate with us through an interactive interface. One emerging implementation of such responsive technology is the Public Large Interactive Surface (PLIS), which is characterized by three main attributes: 1) located at an open setting accessible by the general public, 2) large in size so it is visible to people who are in various proximities, and can be accessed by multiple parties, and 3) responds to users’ inputs, both explicitly (e.g., waving at the surface) and implicitly (e.g. walking towards or away from the surface).

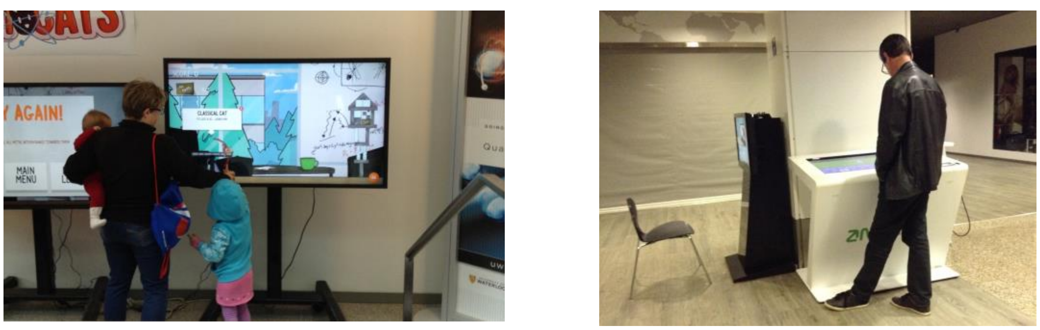


Figure 1-1. A large multi-touch interactive surface installed in two different places Left: at an open house event showcasing themed mini-games; Right: at an airport providing information.

PLISs have become an increasingly popular choice for content presentation in public spaces due to their ability to show content in dynamic and versatile ways (Figure 1-1). They can now be seen in various public venues, such as transportation hubs, museums, information centres and storefronts, where they are typically used to provide up-to-date content relevant to the particular location or to engage the public in a novel manner (e.g., hand gestures (Ackad et al., 2015), body movements (Müller et al., 2012)). Their interactive capability enables these public surfaces to expand their services from unidirectional (e.g., information broadcast) to bidirectional (e.g., interactive inquiry), and allows for a wider range of content format and purpose (e.g., mini-games for entertainment or learning). Together with advances in user interaction sensing technologies such as multi-touch overlays and depth cameras, PLISs provide novel and responsive user engagement that is not possible with their traditional static counterparts.

Yet, the deployment of such technology in a public setting poses unique design challenges that are atypical of personal computing or entertainment environment. Given the popularity of personal multi-touch surfaces (e.g., smartphones, tablets) and interactive home entertainment systems (e.g., big screen TV with Microsoft Xbox Kinect, Nintendo Wii U), interactive surfaces are ubiquitous commodities to many people in today's society. Thus, when first introduced in public spaces, PLISs were expected to be quickly adopted and immediately understood by the general public – their familiar form factor like advertising banners or notice boards, and similar interactivity as personal devices and home entertainment systems, should allow people to understand and feel comfortable to use. However, both short- and long-term studies in various contexts have found PLISs had a low utilization rate (Brignull & Rogers, 2003; Hinrichs et al., 2008; Ojala et al., 2012). These studies have revealed several contributing factors to this under-utilization; including people simply not noticing the PLIS (poor attraction power of the surface), lack of understanding of how to use the PLIS (the interface is hard to comprehend), and social inhibition to interact (people not wanting to embarrass themselves by making mistakes with the system in public). In contrast to the personal computing paradigm, where the system is assumed to have its user's attention, a PLIS may simply blend into the environment and be considered a non-interactive decorative object. Even when noticed, it is difficult to engage someone who has no knowledge of how to interact, and thus reluctant to make mistakes using such "new" system in front of others (Huang et al., 2007). These study findings highlight the challenges of designing for interactive surfaces in public settings: **the need to capture passersby's attention**, and **to provide an engaging and non-socially-inhibiting interaction experience**.

This thesis aims to address the above challenges, and is summarized in the thesis statement below:

> **To provide a systematic approach to model, evaluate, and design interactions for Public Large Interactive Surfaces with a focus on drawing attention and engaging interaction, thereby better informing the development of their interfaces, and ultimately improving their utilization.**

With the proliferation of PLISs in various venues and contexts, due to their versatility and maturing technologies, it is important to make sure they are being used as intended: to reach a large audience and engage them in an enjoyable and effective user experience. This outcome is both economically desirable (return of money spent on developing and implementing the technologies and their anticipated reach for a broader audience), and socially beneficial (people taking part in a more engaging experience, individually and collaboratively). In this regard, the findings in this thesis are both timely and impactful.

1.1 Research Problems

The steps to address the design challenges highlighted by prior research are not trivial, as they involve not only the hardware and software design of PLISs, but also the context in which they are deployed. This thesis approaches these challenges by first identifying three research problems, which are then addressed by their corresponding objectives.

Research Problem 1: Lack of transferrable recommendations across usage scenarios for PLISs

To understand the challenges, and subsequently devise interaction techniques to facilitate the interaction process unique to PLISs, various models describing stages of interaction have been developed, mostly based on field observations (Alt et al., 2012). While relevant to the context in which the surface was deployed, the derived design recommendations are often not transferrable to other scenarios. For example, having a human assistant drawing attendees' attention would be helpful in a conference setting, but would not be viable for a round-the-clock display in a transportation hub.

Research Problem 2: Need for efficient and focused evaluation methodologies for PLISs

When an interaction technique is devised, it is often not trivial to evaluate its effectiveness. This is because a technique is often focused on addressing one design challenge, and hence a particular part of the interaction process. However, the conventional methodology of evaluation, in-the-wild field study or field experiment, requires a fully functional system deployed in the target environment, which takes time and effort to set up, and lacks experimental precision (McGrath, 1984). Furthermore, deployments in a public place are typically subject to safety and sometimes branding considerations, which have to be dealt with before deployment can happen, and therefore require expertise and investments beyond interaction and interface design.

Research Problem 3: Little work in drawing attention towards and engaging interaction with PLISs

There has been a large body of work in addressing the challenge of providing an engaging and non-socially-inhibiting interaction process, for example, catering different forms of engagement (Jacucci et al., 2010), increasing cognitive effects (Alt et al., 2013), and incorporating interactive components (Hornecker & Stifter, 2006). Yet, there is little work addressing the challenge of capturing unknowing passersby's attention, and a lack of connection between this and the later stages of the interaction process. More specifically, the stage transitioning a passerby from beginning to realize the existence of the surface (and the content it is offering) to actively exploring its user interface, is often omitted. Such discrepancy leads to a low coherence in user experience (the passerby's perception of the surface and its content carries through the interaction process), and more importantly, renders much of the existing work focused on surface interaction irrelevant, as passersby need to first notice and be enticed to interact with the PLISs.

1.1.1 Research Objectives

The above research problems are addressed in this thesis through the following objectives:

- To establish a user-centric interaction model describing the interaction process with PLISs. The model should be complementary to existing models, and provide additional insights for evaluating and designing interfaces for PLISs. This was achieved by combining concepts from classic usability research, existing work on PLISs, and from my own observations and experiences designing for novel surface interactions.
- To develop a laboratory-based study methodology that complements the conventional in-the-wild study methodology. It should allow evaluation of interaction and interface designs for PLISs, and provide better experimental control while requiring less time and effort to setup. This research aimed to validate this methodology by demonstrating that it produced results consistent with the conventional methodology (in existing work, and in the follow-up field experiment also included in this thesis), as well as insights for further investigation.
- To explore potential overarching interaction techniques that can be used to bridge drawing attention and engaging interaction for PLISs. Their effectiveness in drawing attention and enticing interaction was evaluated using both the developed interaction model and study methodology developed in this thesis. Their connection to the remainder stages of interaction to provide a coherent user experience is discussed following the evaluation.

1.2 Research Methodology

This section describes the methodology used in this thesis. First, the informing research fields and their relationship with research in PLISs are introduced. Then, the steps taken to address the research objectives are overviewed, followed by a brief discussion on how they were achieved.

1.2.1 Informing Research Fields

The research in this thesis is informed by three main research fields: classic usability research, traditional human-computer interaction, and social science theories, which have recently been applied to public interactive systems from different perspectives. The intersection of these three fields constitutes the basis of this research in the particular form of large surfaces, as shown in Figure 1-2.

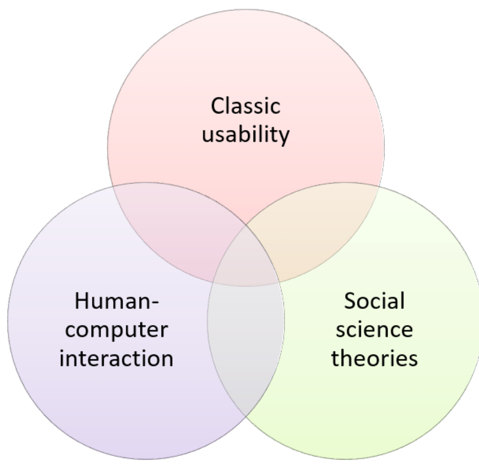


Figure 1-2. Three fields of research informing this research: Classic usability, human-computer interaction, and social science theories, under the context of public interactive systems. Each field provides a different perspective applicable to any systems including large interactive surfaces. Intersection of fields indicate work that draws concepts from the respective discipline.

Classic usability research mostly focuses on attributes of a system[1], for example, learnability, efficiency, memorability, and rate of error (Nielsen, 1993). Yet, many of them were originally used to gauge how effective the system is to improve work efficiency and accuracy. Under the context of public interactive systems these attributes have different purposes and priorities depending on the stage of interaction, and typically have a higher demand for them being immediately usable (Kules et al., 2004), that is, users will not have time to learn and be familiar with the system. These characteristics have greatly influenced the development of the interaction model in this thesis.

[1] A system is not limited to a computer system, as explained by Norman (2013). For example, light switches.

Traditional human-computer interaction (HCI) research mostly focuses on techniques that bridge the "gulf of execution" and "gulf of evaluation" (Hutchins et al., 1985) particularly for computer systems. These techniques have been specialized and evaluated in the context of public interactive surfaces from form factors (Inkpen et al., 2005) to input/output mechanisms (Vogel & Balakrishnan, 2004). On the other hand, a large body of work has explored how interactive systems, as a tool, support collaborative activities such as media sharing (Izadi et al., 2003), remote asynchronous iterative design (Lucero et al., 2009), and informal and non-urgent communication (Huang et al., 2006). The lessons learned on user behaviours towards such "novel" systems have informed the design of interface in other existing work as well as this thesis. In addition, the study methodologies designed and/or used in this thesis, followed closely to the standard procedures of HCI research, from study setup to data analyses.

Social science theories in the public interactive systems context refer to the behaviour of a person (or a group) under various social circumstances; for example, by oneself, amongst strangers, or in an unfamiliar environment, with the systems deployed. This line of research describes the interaction as a form of social behaviour (Reeves et al., 2005), and uses the cultural norms as design guidelines for interactions (Marquardt & Greenberg, 2012). The understanding of such behaviour helps the design of publicly available systems such as PLISs to be more approachable and usable, and has inspired the use of proxemics (a social theory) as a design concept in this thesis.

1.2.2 Steps Taken in Addressing the Research Objectives

Figure 1-3 shows the steps taken in addressing the research objectives in this thesis. Each step is informed by findings from the previous step, as well as related work.

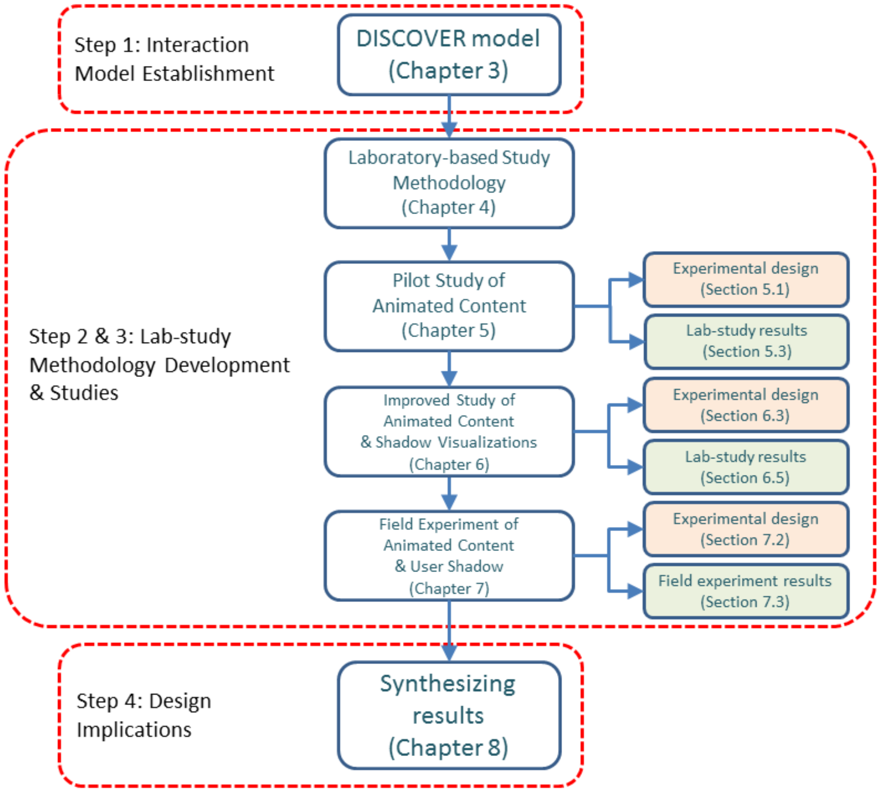


Figure 1-3. Various steps taken to address the research objectives in this thesis. Steps are grouped and ordered to highlight their relevance and implication to each other.

1.2.2.1 Step 1: Interaction Model Establishment

The interaction model in this thesis was established with two criteria: 1) be complementary to existing models to make the literature more comprehensive, and 2) to provide additional insights for evaluating and designing for PLIS systems.

Criterion 1 was achieved by extensive research in classic usability and review of prior work in interaction and interface designs for large interactive surfaces. I examined two complementing directions of HCI research (low-level interaction techniques and technologies, high-level use cases analyses) to gain a comprehensive understanding in different levels of system implementation. I also specifically looked into the theories in social science to understand how interaction was carried out in a public environment, and combined this understanding with my own observations and experiences in designing PLIS systems.

Criterion 2 was achieved by reviewing existing models and frameworks established by other researchers in the context of large interactive surfaces. These models and frameworks primarily focused on user behaviour within a very specific usage context. Thus, this prior work has limited transferability due to the application context being studied, or the specific technologies being used. My research, on the other hand, attempts to synthesize the knowledge gained from this prior work, representative of a number of contexts and technologies, as well as to incorporate internal cognitive states from classic usability literature as the underlying structure; thus enabling the development of a user-centric model that provided a more detailed view on the interaction process, particularly at the early stages such as notifying and intriguing passersby.

1.2.2.2 Step 2: Laboratory-based Study Methodology Development

A commonly used study methodology in the HCI field for PLISs is the in-the-wild field study, which typically involves deploying an large interactive surface in its target environment, with researchers taking the role of silent observers studying passersby's behaviour and reactions to the surface and its interface, and documenting the interaction process using computer log and video/audio recording for further analyses. While high in realism, this methodology inevitably has low generalizability and lacks precision (McGrath, 1984), due to the need for an undisturbed and naturalistic environment.

In this thesis I developed a laboratory-based study methodology focusing on evaluating a PLIS interface's effectiveness in drawing attention and engaging interaction. This methodology addressed the shortcomings of in-the-wild field studies by incorporating standard procedures of a laboratory study, including between- and within-participant conditions and in-depth questionnaires.

This way of evaluating the attraction power of the interface design (how effective did the interface draw an unknowing person's attention) had led to an interesting complication: the recruited participants could not be informed about the surface, as by doing so would bias their responses. To address this complication, I used experimental deception to conceal the real purpose of the study. This was achieved by providing a deception task to the recruited participants and omitted any mentioning of the surface being evaluated in the beginning of the study. The task was carefully designed to be interesting, believable, yet still allowed the researcher to study the attraction power of the interface design, and ask in-depth questions to further elicit participants' feedback.

1.2.2.3 Step 3: Studying Promising Design Concepts

To facilitate the development and validation of the interaction model and laboratory-based study methodology, I implemented several visual concepts (adaptive speed/trajectory, and shadow visualization) as experimental factors based on literature in cognitive science (low- and high-level visual stimuli) and social studies (proxemics theory), and applied them to the studies in this thesis.

Through the studies I found the shadow visualization (showing of the silhouette of a passerby while varying its contrast based on distance) to be effective in facilitating the early stages of interaction. This had led me to further explore its use through the entire interaction process, particularly to provide a cohesive user experience by building on people's familiarity and expectation of shadows.

1.3 Research Results

The established interaction model, DISCOVER, was instrumental in a number of ways. By presenting it as a state diagram, and annotating the transitions and states with clearly-defined system-actions and user-cognition states, it succinctly identified two application categories of PLISs: *opportunistic* and *task-oriented*. It was also applied as a lens for understanding and synthesizing existing work on public interactive surfaces, as a tool for performing gap analyses to identify discoverability aspects that need further study, and as an evaluation framework to assess the effectiveness of potential system designs.

This model also guided the development of the laboratory-based study methodology using deception, which helped minimize the time and effort needed for implementation and evaluation of potential PLIS interface designs, especially those targeting the early interaction stages. Using this methodology, a pilot and an improved study were conducted to evaluate the use of three visual techniques: adaptive speed, adaptive trajectory, and shadow visualization. The results revealed that combining shadow visualization with either adaptive speed or trajectory was effective to draw unknowing participants' attention, yet simply mirroring participants' movements did not communicate interactivity (what they could do with the surface) well. These results were consistent with existing field study findings, hence validating the methodology. Moreover, through the use of questionnaires, the study also provided further insights into participants' perception of the techniques.

A follow-up, more conventional in-the-wild field experiment was then conducted, which further verified the results. Shadow visualizations were again shown to be effective in drawing attention from passersby. Moreover, they were observed to be more effective in inviting interaction (e.g., mid-air playful gestures) with the surface.

More details of these results are provided in their corresponding chapters later in this thesis.

1.4 Thesis Contributions and Research Application

The research results contribute to the research in PLISs in the following aspects:

- Integrating three research fields, namely, classic usability research, traditional human-computer interaction, and social science theories into a systematic approach to model and analyze existing and future interaction and interface designs for PLISs.
- Providing tools, namely, an interaction model, and a laboratory-based study methodology to evaluate existing and future interaction and interface designs for PLISs, particularly in capturing passerby's attention and communicating interactivity.
- Reporting and analyzing experimental results of some of the prominent interaction techniques (particularly the application of *proxemics*, a societal phenomenon describing how distance between people impacted their behaviour (Hall, 1966), in designing the visual content of the interface), and discussing design implications and recommendations.

The immediate application of this research is timely and interactive content consumption in a public space, for example, surfaces showcasing upcoming events or points of interest in a university campus, and approach-and-use surfaces with mini-games for entertainment in lobbies. However, research has shown that these systems also offer promises in many other areas. For example, they could enhance collaboration and task execution in a working environment (Scott et al., 2003), and could facilitate formal uses in areas such as emergency response (Cheung & Scott, 2011; Jiang et al., 2004) and business meetings (Haller et al., 2010). They also could provide value in areas of education (Higgins et al., 2011) and entertainment (Cao et al., 2008). Though the sense of a public setting might be less in these areas, the facilitation of interaction with large interactive surfaces would also be applicable, especially in the aspect of notifying users and discovering the proper use of the surfaces.

Such introduction of interactive surfaces for intellectual activities into our working and living environments would enable the type of natural interaction we used to have over our history of using more traditional, non-digital surfaces, with enhanced effectiveness and efficiency due to their interactive capability and computational power, provided that the interfaces are designed properly.

It is hoped that this research improves the effectiveness of deployed PLISs, as well as enable early assessment of PLIS design concepts to aid the overall user-centred design development process.

1.5 Thesis Structure

In the remainder of this thesis, a general background of PLISs is first provided, followed by corresponding chapters providing an in-depth discussion for each of the research objectives. Finally, important lessons learned across the objectives, and potential future work, are discussed, along with a conclusion of this research work. The content in each chapter is as follows:

Chapter 2 – Background – outlines relevant research on large interactive surfaces primarily in public settings, including characteristic usecase scenarios, current hardware/software technologies, and challenges in the deployment of PLISs. Relevant work in attention, and background for the following chapters are also presented.

Chapter 3 – The DISCOVER Interaction Model – presents motivation and details of the interaction model established in this thesis, including comparison with existing work and application of the model to research and design of interfaces. Part of the model has been published in a peer-reviewed conference paper titled:

Cheung, V. 2014. Improving Interaction Discoverability in Large Public Interactive Displays. In Proceedings of the Ninth ACM International Conference on Interactive Tabletops and Surfaces (ITS '14). ACM, New York, NY, USA, 467-472.

Chapter 4 – A Laboratory-based Study Methodology to Investigate Attraction Power of Public Large Interactive Surfaces – presents motivation and details of the methodology design. The outcome of this chapter forms the foundation in conducting the studies detailed in Chapters 5 and 6. This work has been published in a peer-reviewed conference paper titled:

Cheung, V. and Scott, S. D. 2015. A Laboratory-based Study Methodology to Investigate Attraction Power of Large Public Interactive Displays. In Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '15). ACM, New York, NY, USA, 1239-1250.

Chapter 5 – Pilot Study of Animated Content – describes the experimental setup and procedures for the pilot study that employed the methodology presented in Chapter 4, and discusses results from the study. This study focused on measuring the effectiveness in drawing unknowing participants' attention to a large wall-mounted surface while carrying out a deception task, by animating the displayed content based on user-surface proximity. The outcome of this chapter informed the design of the improved study presented in Chapter 6.

Chapter 6 – Improved Study of Animated Content and Shadow Visualizations – describes the experimental setup and procedures for the improved study based on the pilot study, and discusses results from the study. This study had a similar focus as the pilot study, but also added the use of shadow visualizations based on existing research. A comparison of the results between this study and that from existing ones was made to demonstrate the usefulness of the methodology. The outcome of this chapter informed the design of the field experiment presented in Chapter 7. This work has been published in a peer-reviewed conference paper titled:

Cheung, V. and Scott S. D. 2015. Studying Attraction Power in Proxemics-Based Visual Concepts for Large Public Interactive Displays. In Proceedings of the 2015 International Conference on Interactive Tabletops & Surfaces (ITS '15). ACM, New York, NY, USA, 93-102.

Chapter 7 – Field Experiment of Animated Content and User Shadow – explores the use of content movements and shadow visualizations as inspired by the findings in the improved study, and describes the experimental setup and procedures for the field experiment used to further validate the study results in the improved study. A discussion of the results is provided to motivate further investigation in using shadow visualizations as an assistive tool in PLISs.

Chapter 8 – Discussion – summarizes lessons learned and findings from the studies described in Chapters 5, 6 and 7, and discusses the limitations of the approach taken in this thesis, in terms of the methodology itself, as well as the technological shortcomings. A set of design implications and recommendations is also provided for reference when designing interaction and interfaces for PLISs.

Chapter 9 – Conclusions and Future Work – revisits the contributions of this thesis in order to confirm each objective stated in Section 1.1.1 was addressed. This chapter concludes the thesis and discusses promising avenues for future research.

Chapter 2
Background

In this chapter, a background on the general usage of Public Large Interactive Surfaces (PLISs) is first provided, followed by a brief overview of the current technologies and their impact on the interaction mechanisms of PLISs. The consequent design considerations for PLISs are then discussed to motivate the subsequent chapters. Specific related work to each of these chapters is also presented.

This research also draws inspiration from a variety of practices in attention drawing and interaction design, from studies in human vision to applications including digital signage and gameplay. A brief discussion is included to provide breadth in the subject matter.

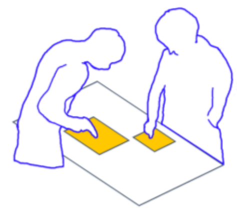
2.1 Large Interactive Surfaces in Public Settings

Early in the deployment of PLISs, researchers discovered that the nature of their usage is very different from the prevalent personal computing paradigm. For instance, there exists various social configurations (e.g., individuals, groups, strangers, and acquaintances) in system usage (Peltonen et al., 2008), user expectations and ways of interaction are diverse (Hornecker, 2008), and people's attention has to be drawn (Müller et al., 2010). This difference leads to new requirements when designing interfaces and interaction mechanisms for PLISs.

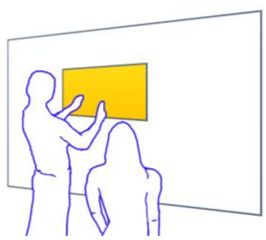
2.1.1 Variations in Social Configurations and the Honey-pot Effect

Being larger in size and publicly available, various types of user configurations are possible with PLISs, including individual as well as group configurations (see Figure 2-1). Marshall et al. (2011) observed how a multi-touch tabletop was used as a tour planner by visitors in a tourist centre, and identified several group configurations (i.e., individuals, couples, families, and strangers), leading to different group dynamics and usage patterns. For example, within a group there could be a "staggered arrival" with one person starting to use the tabletop, and between groups there could be tension between strangers when using the application simultaneously for different plans. Similar variety of configurations were also observed in other deployments of PLISs, such as a photo collage at a storefront (Peltonen et al., 2008), an installation in a museum (Hinrichs et al., 2008), and a "fun-fact" information display downtown (Memarovic et al., 2012), fostering different forms of interaction.

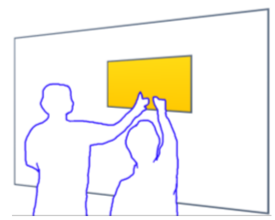
(a) An individual interacting with a tabletop. Typically the individual will be at the side where the text/image is properly oriented. Some interfaces faciliate all four sides by providing four sets of text/image properly oriented to each side.



(b) A group of two interacting with a tabletop. The individuals can be at opposite sides, adjacent sides, or same side. This depends on the size of the tabletop, as well as the relationship between them (e.g., strangers, friends).



(c) Two individuals in front of a wall display. One interacting while the other observing. The observer can be a stranger watching, or an acquaintance being shown what can be done with the display.



(d) A group of two interacting with a wall display. The two individuals can either be acquaintances or strangers, working together as a team. It is also possible to have multiple groups working on different regions of the display.

Figure 2-1. Various examples of social configurations in using horizontal PLISs (tabletop) and vertical PLISs (wall display). A tabletop affords interaction from all four sides, whereas a wall display only affords one side for interaction. Individuals can be actively interacting or observing others in doing so. Groups can be comprised of acquaintances (e.g., family members, friends) or strangers, and with a size between 2 and 5 for PLISs with a typical diagonal of 2 metres.

A frequently observed phenomenon, regardless of the social configurations and within- and between-group dynamics, is the "honey-pot effect", where the number of people in the vicinity of the system progressively increases (Brignull & Rogers, 2003). This phenomenon is based on basic human curiosity and has two main implications to the design of PLISs:

1. The sight of the "honey-pot" signifies the social affordance that people can stay and engage in something interesting, which is important from the physical design perspective to allow this configuration to take place (e.g., provide enough space for people to gather, install the surface high enough so people further away can see).

2. The arrangement of the "honey-pot" distinguishes involved users into active users and bystanders/observers based on their level of engagement (Brignull & Rogers, 2003; Peltonen et al., 2008). This distinction can be used to guide the interface design to facilitate different stages of interaction and the transition between them (Cheung et al., 2014).

Such variation of social configurations sets PLISs apart from the conventional personal computer interaction paradigm (typically assumes a fixed configuration – single user actively engaged in the interaction with the system), and fosters unique uses of public and personal space (Azad et al., 2012). Interfaces for PLISs have to take into consideration on what type of social configuration they may have to support, given the deployment context and tasks people may be performing.

2.1.2 Diversity of User Expectations and Methods of Interaction

In addition to variations of social configurations, there may also be variations in user demographics and any corresponding variation in expectations towards the system. As mentioned in Chapter 1, the form factor of PLISs is not unfamiliar in a public setting. It is therefore common for users to perceive the surfaces as something that they have already encountered before (i.e. exhibits, notice- and billboards). Müller et al. (2010) identified four mental models a user is likely to apply their perception on a PLIS (i.e., poster, window, mirror, and overlay) depending on the content and environment. Each mental model may lead to different expectations towards the surface. For example, with the poster mental model, a user sees the surface as an electronic version of a printed poster being vertically attached to a surface (e.g., photo collage (Peltonen et al., 2008)) showing text and graphics content typically featured in an analog poster, and might not expect to actively engage with the content directly; with the window mental model, a user sees the surface as a portal to a remote, often virtual location, inviting them to "look inside" through the surface, thus might expect a more involved interaction with the other location (e.g., remotely shared media spaces (Müller et al., 2014)). Any discrepancy between the interaction modalities and the user's perception of the surface will result in confusion, frustration, and hence resistance to system usage.

The public nature of PLISs also impacts the way people approach and interact with the system. Many people are reluctant to interact with a PLIS because they think they might break it, compromise its operation, or upset others in the vicinity (Ojala et al., 2012). Further, they may not want to embarrass themselves by acting foolish with others present (Brignull & Rogers, 2003; Reeves et al., 2005). Such reluctance prevents people from becoming active users, or worse, scares them away.

Meanwhile, advances in PLISs input/output mechanisms, such as multi-touch, body movement, and gestures have the potential to be fun and enhance the user experience (Reeves et al., 2005). Yet, these interaction mechanisms may be unfamiliar to some users, introducing additional barriers of use. Previous studies of PLISs have revealed that some people did not interact with the system simply because they did not know they could, a phenomenon described as "interaction blindness" (Ojala et al., 2012), or because they got confused when the system responded in an unexpected and conflicting way (Hornecker, 2008).

The diversity of user expectations and ways of interaction requires PLISs to be able to elicit the desired perception from their users, along with appropriate input/output mechanisms, and within a short time (typically a few seconds). This requirement is described as "immediate apprehendability" in exhibit designs (Allen, 2004) and PLISs deployments (Hornecker, 2008; Seto et al., 2012).

2.1.3 The Need to Draw People's Attention

Another often cited observation of PLIS deployments is the lack of attention being paid towards them. Despite their large size and typically animated content (e.g., moving images), many passersby tend to ignore them. For example, Peltonen et al. (2008) installed a 2.5-metre-wide wall-mounted interactive surface at a city centre showing photos related to the city, and reported occasions of people not paying attention to the surface (with their back facing it), even when the surface was in close proximity. Researchers have attributed this to "display blindness" (Müller, Wilmsmann, et al., 2009), which has also been reported in subsequent field studies (Müller et al., 2012; Ojala et al., 2012). Huang et al. (2008) investigated how the public looked at public surfaces (both interactive and non-interactive), and identified a number of internal (e.g. content format) and external (e.g. surface's position) factors affecting the likelihood for a surface to draw people's attention. They also noted the brevity when a passerby looked at a surface (a glance of 1-2 seconds), posing further challenges in drawing people's attention long enough to promote further interaction.

Dalton et al. (2015) took an empirical approach to investigate where people looked in a retail context using eye trackers. They argued that the term "display blindness" might exaggerate people's lack of engagement with the surfaces, and reported "all but one of the displays [surfaces] were looked at by a sizable proportion of the participants" (p. 3896). Building on this result, they recommended simple representations that can be apprehended and understood very quickly (even from a distance), which prompt for a "look back", or a possibly longer and more engaged "second glance".

Catching someone's eyes is an important step in attention drawing, but ideally it should be prolonged to lead to subsequent interest in engagement. However, facilitating such engagement is highly dependent on the context and the environment. For example, an information display in a train station can draw attention more easily by simply showing relevant information about trains and schedules in a concise manner; whereas an advertising display needs to be more visually appealing to capture attention and interest in a more serendipitous nature. These differing motivations have led to different strategies in drawing people's attention, as discussed in Chapter 3, and the designs for the laboratory studies and field experiment in this thesis, as discussed in Chapters 5, 6, and 7.

2.1.4 Other Issues in Interacting with PLISs

Upon examining the underlying technologies (discussed in detail in the next section) and physical configurations of PLISs, researchers have discovered several interaction issues with such systems, including occlusion (user's finger covers the target on a touchscreen device) and selection error (reduction of contact area to a touch point causes missing of the target), collectively known as "fat finger" problem (Potter et al., 1988; Wigdor et al., 2009), reachability issues (screen size is too big to reach) (Shoemaker et al., 2007), "gorilla arms" problem (arm fatigue due to prolonged mid-air gestures) (Hincapié-Ramos et al., 2014), and territoriality issues (spatial ownership of simultaneous users) (Azad et al., 2012; Scott et al., 2004). Much of the active research on PLISs (or large interactive surfaces in general) focuses on developing techniques to address some if not all of these issues, which only occur when there is a physical interaction with the PLIS.

This thesis, however, focuses on the early stages of interaction, specifically in drawing passersby's attention and enticing them to interact. These interaction stages occur before the physical interaction takes place, and thus may require other techniques to facilitate.

2.2 Current Technologies: A Technical Survey

Though only recently being deployed in public settings, interactive surfaces of a considerable size was first conceptualized in the early 1990s, as an electronic desk for work (Wellner, 1991). Albeit originally designed for a single user in a work environment, this concept introduced one important notion: direct interaction[2] with virtual objects of unscaled sizes through physical actions. Such style of interaction has strongly influenced the way PLISs are currently designed.

A core concept of direct interaction is the ability to manipulate virtual objects physically (e.g., using one's hands, body), which is realized by a number of sensing technologies, such as electronic circuitries and optical devices, in combination with an output screen where content is displayed. This section overviews some of these technologies, and discusses their implications on interaction design.

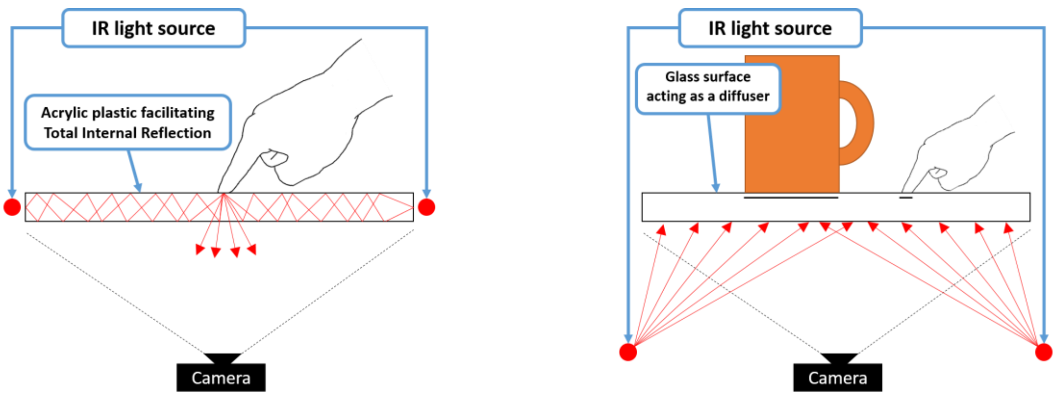
2.2.1 Multi-touch Surfaces

A multi-touch surface is a display screen capable of sensing and locating multiple touch points simultaneously. To date there are over 10 categories and over 30 variations of technologies achieving this capability (e.g. projected capacitive, analog resistive, surface capacitive, surface acoustic wave, etc.) (Walker, 2012). While the underlying mechanisms for each of the technologies are beyond the scope of this thesis, two of the more commonly used technologies will be highlighted to put the research presented here in context.

2.2.1.1 Vision-Based Sensing

Vision-based multi-touch sensing is a technology where touch points are being sensed via an optical device (e.g., camera, photodetectors). Instead of tracking the touches directly, the optical device looks for lights being blocked or reflected by the touches. To prevent interference from the content being displayed, Infra-Red (IR) light is used instead of visible light.

[2] A similar term, "Direct Manipulation" was first introduced by Shneiderman (1983) and later refined by Hutchins et al. (1985). The definition however only refers to a user action directly mapped to a system action (e.g. moving a mouse is mapped to moving a virtual document), rather than having both actions physically close to each other (e.g. moving a virtual document by moving one's hand via touch).



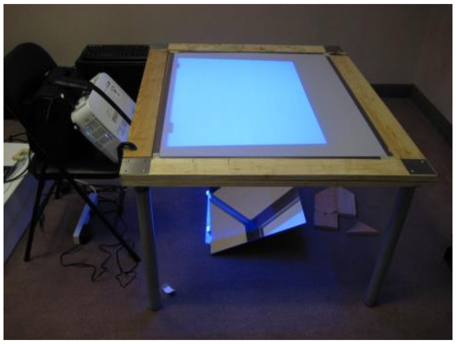
a) General setup of a multi-touch surface using Frustrated Total Internal Reflection (FTIR).

b) General setup of a multi-touch surface using Diffused Illumination (DI).

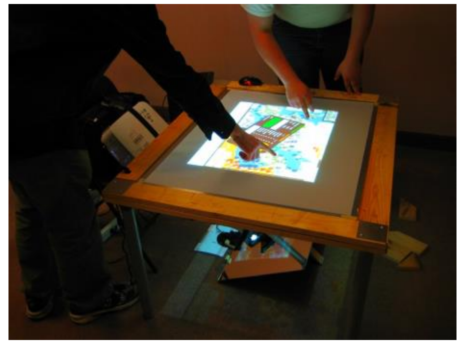
Figure 2-2. Simplified redraw of the general setup of multi-touch surfaces using various sensing technologies, based on the technical report by (Schöning et al., 2008).

The typical setup of a vision-based multi-touch surface includes an IR light source, a transparent surface panel for touches and screen projection, and an optical device for tracking (with some computer algorithms to filter out noise and distill touch incidents into programmable touch events). The advantage of such a setup is that the components are commercially available at a relatively low cost (within a few hundred dollars). Han (2005) proposed a low-cost hardware setup that could be built using acrylic plastic, IR strips, and a digital video camera with a matching band-pass filter that filtered out any non-IR lights (Figure 2-2a). An earlier, but similar setup placing the IR light source behind the projection surface was also proposed to not only sense touches, but also entities such as hands, bodies, and objects (Matsushita & Rekimoto, 1997) (Figure 2-2b). Due to the setup's approachable nature, an online community[3] was formed to facilitate enthusiasts and researchers to discuss and share their work, and has been active over the past ten years.

[3] Natural Interface Group, global research community focused on open discovery of natural user interface (http://nuigroup.com/). Last accessed, 30 December, 2015.



(a) A do-it-yourself multi-touch tabletop interactive surface (built to emulate a coffee table). Because of the lower height the projector had to be fitted at one side of the table, leaving only three free sides for interaction and without any legroom.



(b) The multi-touch coffee-tabletop surface in action. The IR camera was located at the bottom of the tabletop near the base of the mirror. Lights had to be dimmed to reduce ambient light, and for the projected screen to show.

Figure 2-3. A multi-touch tabletop interactive surface (coffee table) I helped build using the setup proposed in (Han, 2005). At that time a projector with normal throw-distance was used, hence the mirror at the bottom to increase the projection distance. The bottom of the tabletop was completely blocked for the projected screen and IR camera to work properly.

However, such setup requires the sensing optical device (and the projector for a back-projection configuration) to be positioned far enough from the back of the surface panel without any objects in-between for a complete and non-obstructed view. This requirement leads to a horizontal surface without any legroom underneath (see Figure 2-3), or a vertical surface requiring extra space into the wall. Moreover, it is also susceptible to ambient light sources that also emit IR light (e.g. sunlight), interfering with the sensing of the IR light representing touches, resulting in noise and false-positives.

More recently, interactive surfaces have begun using another technology that places arrays of IR light-emitting diodes (LEDs) and photodetectors on the inner sides of a frame, which is typically at about one centimeter in thickness and is mounted immediately above a surface (e.g., a projected surface or large LCD/LED screen). The IR LEDs emit a specific pattern of flashes which are captured by the photodetectors, and the shadows made by the touches are used to deduce where the touch points are. Figure 2-4 illustrates one possible configuration of the IR LEDs and photodetectors. Variations of this configuration are possible by different placements of the components (e.g., interlacing the LEDs and photodetectors).

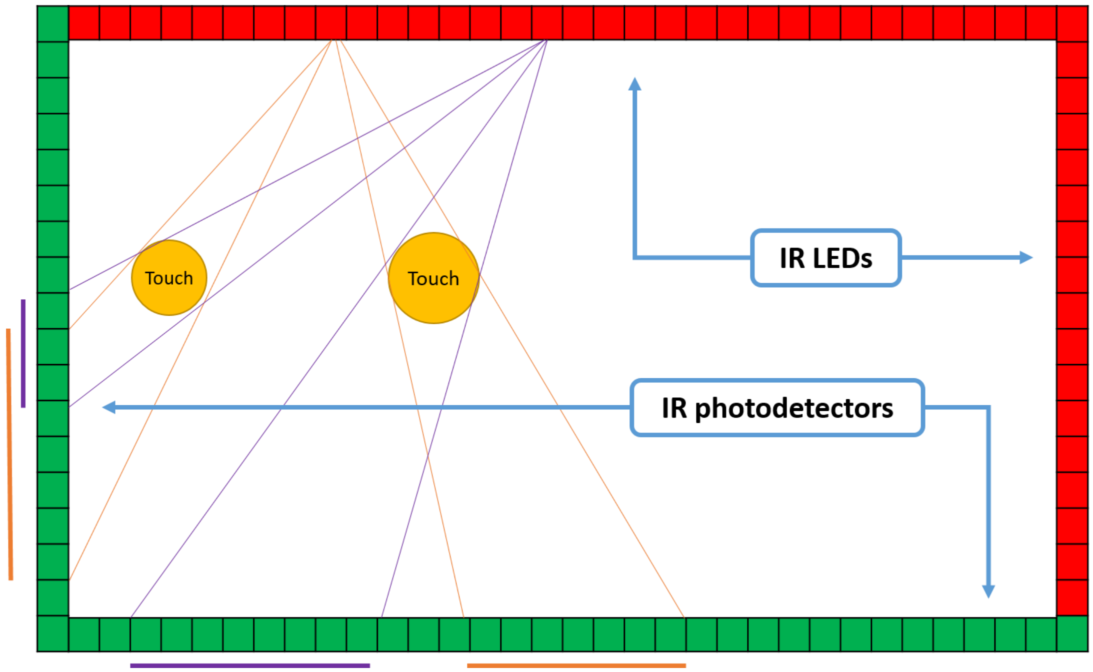


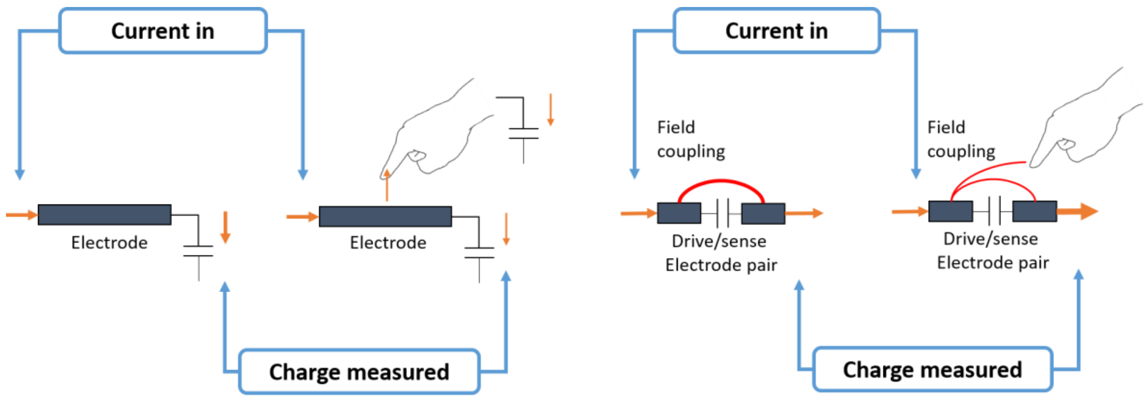
Figure 2-4. Simplified working principle of the vision-based multi-touch sensing technology using arrays of IR LEDs and photodetectors. Touches are detected when they create shadows on the photodetectors. Drawing is based on the technical review by Walker (2012).

The main advantage of this technology is its ease of installation. Since all the components are fitted inside a frame, it is available as an overlay, which can be placed on top of any display screen and transforms it into a multi-touch surface. Based on my own experience, the entire installation process can take less than an hour (which includes assembling the frame and attaching it to a display screen). In comparison to the above technology, this overlay removes the need for space for an IR camera, and is more customizable in terms of size and shape of the surfaces it supports through properly arranging the IR LEDs and photodetectors. The way the photodetectors are embedded within the overlay also allows the technology to be used in the presence of ample ambient light.

However, this technology relies on the accuracy and resolution of the shadows cast on multiple photodetectors, and therefore has limited resolution, speed, recognizable touch object size, and touch points (typically up to 20-40). It is also prone to false-positives caused by sleeves, or any object that hovers above the surface but is close enough to cast shadows on the photodetectors. PLISs using this technology should consider such limitations and be more forgiving with the touch accuracy, and robust to unintentional activations.

2.2.1.2 Electronic-Based Sensing

Electronic-based multi-touch sensing is a technology where touch points are being sensed via detecting changes in an electric field spread across the interactive surface. The underlying principle is when a conductive object (e.g., a human finger) is near an electrode (or a pair of electrodes), the capacitance of the prior changes the capacitance of the latter[4] (Figure 2-5). By measuring such change in capacitance in a grid of electrodes, the positions of touches can be calculated. Touchscreens using this technology are therefore generally called "capacitive touchscreens".



a) In self-capacitance technique, a finger touch increases the electrode's capacitance by drawing more current to an extra path.

b) In mutual-capacitance technique, a finger touch decreases the electrode's capacitance by coupling some of the mutual capacitance.

Figure 2-5. Simplified working principle of the electronic-based multi-touch sensing technology using capacitance. Touches are detected when changes in capacitance at the electrodes are detected. Drawings are based on the technical review by Walker (2012).

The main advantage of this technology is its ability to be fully integrated into the interactive surface without adding any discernable thickness and weight. Along with a smooth tactile feel provided by attaching the electronics behind a cover glass, it is the most-used technology in the consumer market (e.g., touchscreen monitors, touchscreen mobile devices). It also has a higher resolution and sensing rate than vision-based sensing (though in the order of millimetres and tens of milliseconds, and the gap is closing), and is not prone to interference from any light source.

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[4] An early alternative is to detect completion of a circuit created when a user touches the interactive surface (Dietz & Leigh, 2001). The setup can identify which user is issuing the touch with a more elaborate setup involving conductive chairs and floor.

However, electronic-based sensing relies on the precise layering of the electronics across the entire surface, and therefore is not as scalable as the vision-based sensing. To date the largest consumer capacitive touchscreen available is less than 75 centimetres diagonally, and is mainly designed for personal computing. Also, capacitive touchscreens can only detect touches from conductive objects, and thus are limited in modes of interaction (e.g., they cannot natively support tangible interactions).

In summary, multi-touch surfaces are the most-used technology in PLISs because of their availability and familiarity in interaction. The variety of technologies and their respective advantages allow them to be used in many situations, for example, big and small screen sizes, vertical, tilted, and horizontal orientations, indoor and outdoor. Additional input parameters such as pressure (Rendl et al., 2014) and angles (Schwarz et al., 2015) have also been explored starting with smaller screens. Yet, in all cases, interaction can only occur at a very close distance to the surface, and suffers from problems such as "fat finger" (finger obscures the content, imprecision in touch detection) (Potter et al., 1988; Wigdor et al., 2009) and "reachability" (some areas are out-of-reach) (Shoemaker et al., 2007), thus limiting the type of interaction PLISs can support with these technologies.

2.2.2 Gestural Surfaces

Gestural surfaces refer to those that recognize a more free-style input beyond mere touches, such as hand movements and body positions. Kurtenbach and Hulteen (1990) described this form of input as "a motion of the body that contains information". As an example, the authors explain that a goodbye-wave was a gesture, whereas a keyboard-press was not because the motion involved was irrelevant.

Technologies achieving gestural recognition typically involve using one or more cameras capturing the user's movements and relaying this information to the interactive system. In most cases the spatial location of the user is also included via depth-sensing cameras (e.g., Microsoft Kinect[5]) or motion-capturing systems (e.g., Optitrack cameras[6]).

2.2.2.1 Distance-Sensing Surfaces

Distance-sensing surfaces use the distance between a user and the surface as one of the parameters in interaction. The sensing is typically carried out by a depth-camera analyzing pattern reflected by the

[5] https://dev.windows.com/en-us/kinect. Developer's webpage of Kinect. Last accessed 14 January, 2016.
[6] http://www.optitrack.com/. Product webpage of the Optitrack system. Last accessed 14 January, 2016.

sensed space into which a known IR pattern is projected (Freedman et al., 2010). Since the pattern is predefined, and the objects in the sensed space distort the reflected pattern, it is possible to reconstruct the scene within the range of the camera (e.g., about 4.5m for Microsoft Kinect V2).

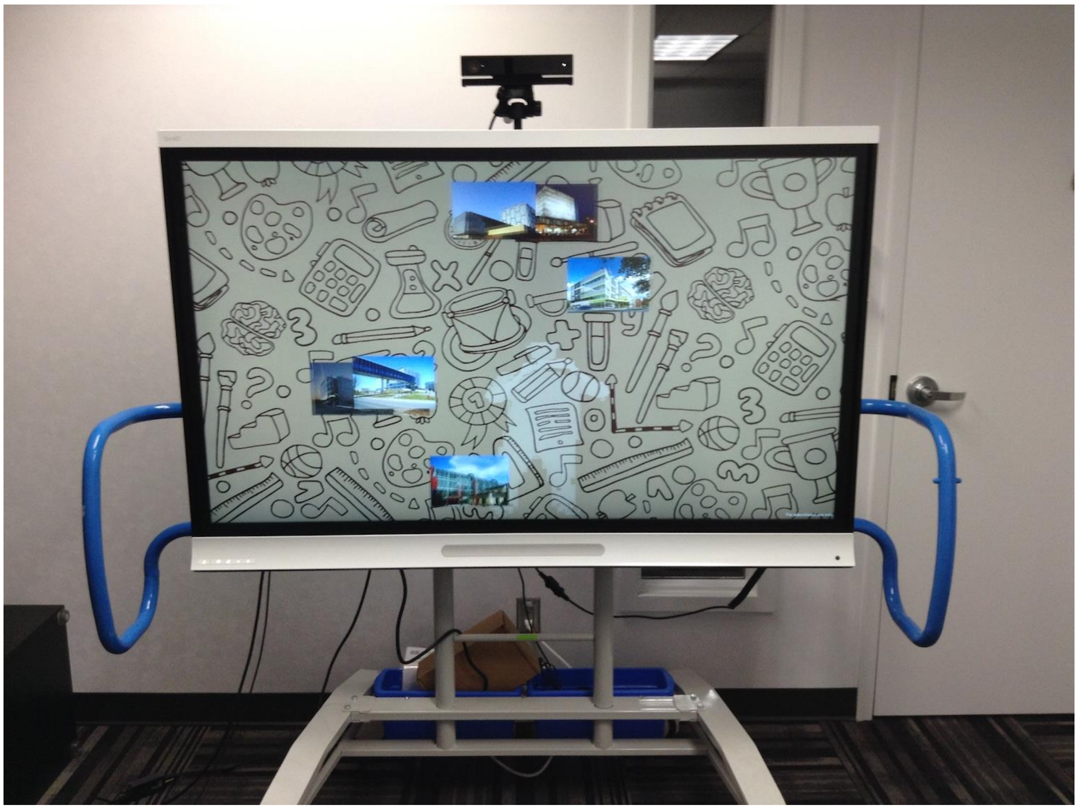


Figure 2-6. A setup for a PLIS using a depth-camera (black device on top of the screen supported by a tripod). The faint white shadow was a rendering of the tracked body directly extracted from the tracking parameters. In this interface design the distance was used to determine the contrast (transparency) of the shadow.

Figure 2-6 shows the setup used for the field experiment detailed in Chapter 7. The main advantage of this setup is that the depth-camera (Microsoft Kinect V2) mounted to the top of the screen is self-contained (no extra software setup is required beyond installing a driver to the computer) and comes with a software-development kit (SDK) provided by the manufacturer. The SDK provides access to various useful tracking parameters such as skeletal information (e.g. joint locations, up to 6 individuals) and distance from the camera (in the resolution of millimetres, up to 4.5m for reliable tracking). Because of this advantage this setup has also been used by many PLIS researchers and practitioners (e.g., Grace et al., 2013; Müller et al., 2012; Vermeulen et al., 2015).

The disadvantage of this technology is that a clear line-of-sight is required for the distance measurements. In a crowded public space this could be an issue as the system might need to be able to distinguish and switch between multiple tracked people. Also, distance alone may not be an accurate indicator of intention to interact, hence should not be used as the only mode of interaction.

2.2.2.2 Motion-Sensing Surfaces

Motion-sensing surfaces make use of a richer set of input parameters besides the distance between a user and the surface. These input parameters include orientation, movement, identity, and location (Greenberg et al., 2011), which can be used to create a more customized user experience.

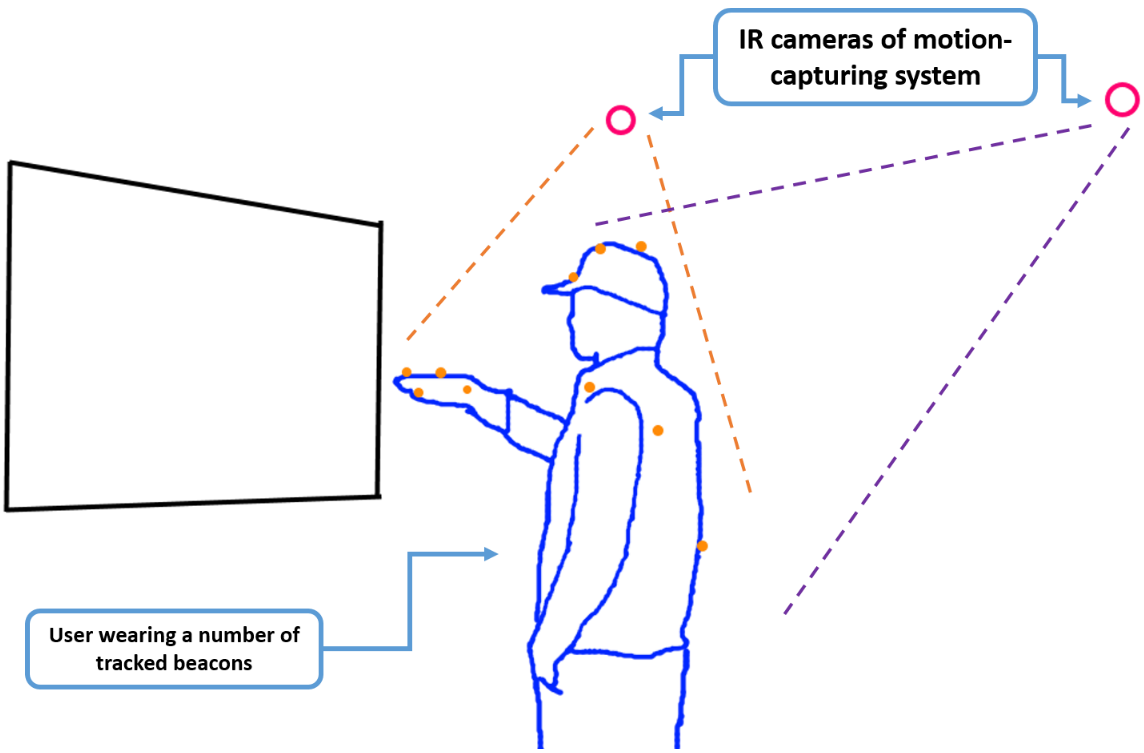


Figure 2-7. Illustrative setup of a motion-sensing surface. A rich set of input parameters, such as orientation and movement can be provided using the motion-capturing system. Using current technologies the user has to wear a number of IR beacons for tracking purposes. Redrawn from the ambient display system by Vogel & Balakrishnan (2004).

However, because of these additional input parameters, a more elaborate setup is required. This typically involves multiple cameras positioned for clear views at all angles, and a number of tracked beacons worn by the user, due to current limitations in tracking technologies (Figure 2-7). As a result, motion-sensing surfaces still remain as a proof of concept and are not functionally deployable in public settings. Nevertheless, studies have demonstrated their potential in providing better contextual sensing, including the “interruptibility” (openness of a person to receiving information) (Fogarty et al., 2005; Vogel & Balakrishnan, 2004), and level of interest (Wang et al., 2012).

In summary, gestures can be used to address some of the problems of multi-touch surfaces (e.g., reaching all areas (Shoemaker et al., 2007)), and provide new forms of interaction (e.g., interacting through spatial movements (Müller et al., 2012)). Moreover, in contrast to touches where the user explicitly performs an action towards the surface, gestures can be considered as an implicit form of interaction (Ju et al., 2008). For example, the gesture of the user walking towards the surface could be sensed by a gestural surface and interpreted as potential interest. Such inclusion of implicit interaction is particularly useful for interaction with PLISs, as will be elaborated in Chapter 3. Nevertheless, gestures are limited by their ability to provide affordance and feedback, and have the risk of being unnatural to their users (D. A. Norman, 2010). Care has to be taken when designing which gestures to use and how they may be perceived by their users.

2.2.3 Cross-Device Surfaces

Cross-device surfaces refer to a collection of inter-connected (ideally wirelessly) interactive surfaces, where some or all of them support multi-touch and/or gestural inputs. Such technology takes advantage of the surfaces by assigning different interaction modes to their respective form factors. For example, one or more large surfaces may be used for overview and multiple small surfaces for details-view (e.g., comparing map data (Spindler et al., 2010)), or multiple large surfaces for public information and multiple small surfaces for personal information (e.g., sharing and exchanging media content (Izadi et al., 2003)).

Cross-device surfaces were often explored as a means to better support collaborative work (Wallace et al., 2011), with a focus on collaborative sense making (Wallace et al., 2013), data visualization and exploration (Spindler et al., 2009), and information transfer (Marquardt et al., 2012). With the proliferation of mobile personal devices, researchers have begun investigating the combination of such devices and PLISs (e.g., browsing shops in a mall (Masuko et al., 2015)).

While similar to systems supporting collaborative work in terms of device composition (large surfaces and small personal devices) and modes of interaction within each individual devices (e.g., touch, movement), the overall interaction in the context of PLISs may be very different: *personal* *devices as representations of individuals directly interacting with the PLIS but not with each other* (c.f. all individual devices connected to each other (Hamilton & Wigdor, 2014), and a yard-scale one-few ecosystem where both the surface and personal devices are managed by users (Terrenghi et al., 2009)). Because of this difference, the typical inter-connection model is a client (personal devices)-to-server (the large surface) (Kaviani et al., 2009) instead of a peer-to-peer model, and the personal devices being used as "personal remote controls" (Figure 2-8). To further understand the implication of this model, I developed a taxonomy of interaction mechanisms for cross-device surfaces in the PLIS context (Cheung et al., 2014), summarized in Table 2-1.

Table 2-1. A taxonomy of cross-device surfaces interaction mechanisms in the PLIS context. Both the large surface (LS) and the person device (PD) can be used as input only (I), output only (O), or as both input and output (I/O). Direct interaction refers to both the physical and system actions take place at the same surface, indirect interaction refers to physical actions and system actions taking place at different surfaces.

***A detailed version with illustrative examples can be found in (Cheung et al., 2014).**

		Large Surface (LS)		
		I/O	**I**	**O**
Personal Device (PD)	**I/O**	Both LS and PD act as control and display, and provide in/direct interaction	Indirect control of PD, which still allows direct interaction	Indirect control of LS, with feedback and/or indirect interaction on PD
	I	Indirect control of LS, which still allows direct interaction	No output	Indirect control of LS, neither allow direct interaction
	O	Direct interaction on LS, PD controlled indirectly	Indirect control of PD, no direct interaction	No input

The most commonly used category within this taxonomy is the combination between a large surface being used as an output channel, and personal devices being used as both input and output channels (top-right in Table 2-1). This category closely mimics the "personal remote control" usage and is typically achieved by the personal devices sending interaction data (e.g., touch events, orientation angles) via an internet connection to a computer, which interprets the data and applies them as input to the content displayed at the large surface (Brignull & Rogers, 2003; Cao et al., 2008; Carter et al., 2004; Dearman & Truong, 2009; Izadi et al., 2003; Kaviani et al., 2009). In some cases the content would also be transferred back to the personal devices using the same connection (Dearman & Truong, 2009; Kaviani et al., 2009; Müller et al., 2008).

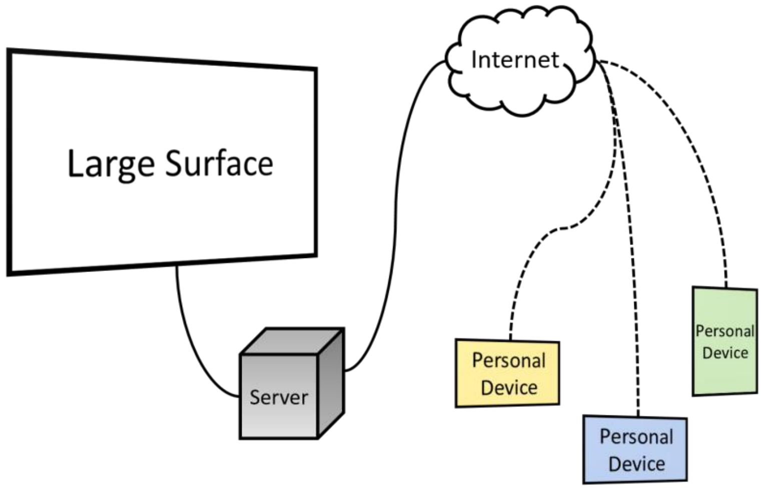


Figure 2-8. Typical client (personal device)-to-server (large surface) inter-connection model in the context of PLISs. Interaction data (e.g., touch events, orientation angles) are sent from each personal device to the computer acting as a server via the Internet (e.g., 3G, WiFi), and are interpreted and applied as input to the content displayed at the large surface. Personal devices are not connected to each other in this model.

In summary, cross-device surfaces provide a more personal experience in interacting with PLISs, as achieved by appropriately disseminating information to respective devices. They also allow a greater variety of interaction by appropriating interaction modes to the devices' sensing capabilities (e.g., content selection in the PLISs by tilting a personal mobile device (Pietroszek et al., 2014)). However, this technology relies on the availability of personal devices for a complete experience, and in most cases, a wireless connection (e.g., WiFi, mobile data), which might not be available at the deployed location. Also, additional application installation may be required on the personal device for more sophisticated interactions, which might deter usage given the serendipitous nature of many PLISs.

Understanding the advantages and disadvantages of the technologies available for the implementation of PLISs is crucial to their successful utilization. In this thesis, such understanding was used to inform the development of a PLIS system combining multi-touch and gestural surfaces. Specifically, visual elements were appropriated according to the capabilities of the multi-touch and depth-sensing hardware (detailed in Section 7.2.3). The design implications, as well as future research direction related to the use of and capabilities of these technologies, will be discussed in Chapters 7, 8, and 9.

2.3 Existing Models and Frameworks on PLISs Interaction

A number of interaction models between users and interactive surfaces have been proposed to describe the unique nature of PLISs' usage. These models are used to understand the nuances of interaction styles with PLISs, thereby providing insights into designing appropriate interaction mechanics. A consensus is that interaction with PLISs can be divided into phases within a spectrum of user engagement, from users being peripherally aware of the surfaces to users actively interacting. Understanding these phases can help derive design recommendations to facilitate users' transitions between phases, ultimately toward greater levels of engagement and effective use of PLISs.

Brignull and Rogers (2003) proposed an interaction framework of three distinct *Activity Spaces* characterized by the level of engagement and the activities involved: *peripheral awareness*, *focal awareness*, and *direct interaction*. This framework was developed based on their observations of the "Opinionizer", an opinion-collecting system deployed in public gatherings such as book launch events. Their analysis regarded the transitions between the activity spaces as the key source of bottlenecks in public interaction behaviour, which could be overcome by encouraging people to become more engaged with the interaction through, for example, positioning the surface near foot traffic flow, locating a helper to instill confidence with the surface, and providing lightweight and visible interaction for the users. Although the deployed surface received inputs from a laptop nearby instead of from the surface itself, the framework served as a good starting point for modeling public surface interactions and provided insights into how to encourage people to interact with a PLIS.

Streitz et al. (2003) proposed an interaction framework that utilized distance as an indicator of *Interaction Zones*: *ambient*, *notification*, and *interaction*, and applied the framework to their GossipWall system. They suggested the provision of progressively more expansive services within each *Interaction Zone* based on the assumption that the closer the user gets to the surface the more actively they would interact. In a public setting, however, this strictly distance-based approach may not be an accurate measure of intention to interact with the system, as people may be close to the surface simply because it is near their path of travel, another target destination, or a temporary shelter, as reported by Peltonen et al. (2008). The GossipWall system also assumed a single user or a cohesive group of users rather than simultaneous independent users, thus failing to cater to the variety of social configurations in PLISs. Nevertheless, the GossipWall system introduced the use of personal devices as part of the service provisions when a user was nearby, which helped address private data access concerns in public environments, and user-specific services.

In a study of interactive surfaces as public ambient displays, Vogel and Balakrishnan (2004) developed a framework describing a range of four *Interactive Phases: ambient display*, *implicit interaction*, *subtle interaction*, and *personal interaction*, and the types of user interaction that enabled a user to transition between these phases (body movement, body location, head orientation, gestures, and touch). This framework was similar to Streitz et al.'s model (2003), but further divided their "Interactive Zones" into "Subtle and Personal Interaction phases", and generalized their "Notification Zone" into "Implicit Interaction phase" to allow for a "wider range of implicit and explicit interaction techniques" (Vogel & Balakrishnan, 2004, p. 139), as well as supporting simultaneous users in their own interaction phase. The richer set of user interactions considered beyond the user's location (or distance from the surface) has provided more context for the user's behaviour, and helped address the issue discussed above where the user may simply be near the surface, but not intending to interact.

Based on observations of audience behaviour with a set of four large public surfaces utilizing gesture-based interaction in a city centre (Magical Mirrors), Michelis and Müller (2011) derived the *Audience Funnel* which described the transitions between six different phases: *passing by*, *viewing & reacting*, *subtle interaction*, *direct interaction*, *multiple interactions*, and *follow-up action*. They presented the transitions between phases in a quantifiable way, which inspired later work in evaluating their own surfaces (Ravnik & Solina, 2013). While the discussion provided insights in terms of evaluating and improving individual transitions, the reason why there was a funneling effect (fewer and fewer users remained as they progressed along the phases) was not included. Also, the framework was mostly used for self-evaluation rather than comparison of design concepts.

In summary, the models described above portrayed PLISs' usage as a progression of engaged interaction. Through separating such progression into phases, techniques have been proposed and investigated to support one or more phases, as well as to transition users from one phase to another. Some of these models have also led to systematic evaluation of PLIS designs. The interaction model (DISCOVER) developed in this thesis drew inspiration from this approach and modeled the interaction process as a progression of user states representing the cognitive states of a user, with transitions representing system actions connecting these user states. This model strived to describe the interaction as a discoverability process, and provided a comprehensive tool to better evaluate a PLIS system through different ways of application, as detailed in Chapter 3.

2.4 Studying Public Large Interactive Surfaces (PLISs)

To better understand the usage of PLISs and evaluate their designs, researchers have developed various ways to study them. Alt et al. (2012) comprehensively overviewed existing study methodologies for evaluating public surfaces, in terms of *types* (i.e., descriptive, relational, and experimental), *paradigms* (i.e., ethnography, asking users, lab study, field study, and deployment-based), and *tools* (i.e., questionnaires, focus groups, observations, and logged interactions). In this regard, the methodology described in this thesis (Chapter 4) focuses on *paradigms* specifically for evaluating prototypes, which allow implementation of novel and existing designs, and further elaborates the steps involved and trade-offs of each paradigm. Furthermore, McGrath's (1984) distinction between *field study* and *field experiment* is used to distinguish "in-the-wild" observational studies, so as to highlight the ability to control the study conditions in the field experiments.

2.4.1 "In-the-Wild" Field Studies

Because of the public nature of PLISs, in-the-wild field studies are often used to investigate passersby's natural behaviour in response to the surfaces. The in-the-wild methodology is based on an ethnographic approach (Blomberg et al., 1993) which involves deployment of the surfaces in the target location, with a completely working application running on the system. Researchers then observe and record (via field notes or video/audio capture, and/or system interaction log) how the surfaces are used, without interrupting the interaction process. On-site voluntary interviews/surveys may be conducted with an arbitrarily number of people who have interacted with the surfaces. This methodology has the advantage of being realistic and hence produces ecologically valid results. For example, Peltonen et al. (2008) deployed an interactive public surface at a storefront in a central city location, allowing anyone who passed by to interact with it. A month of system use was recorded via a combination of system interaction logs, web camera (with a mono soundtrack) overseeing the interaction, and a number of on-site interviews. A similar combination of data collection methods have been used by many researchers to analyze usage patterns, which can help elicit design requirements and identify usability issues (e.g., Brignull & Rogers, 2003; Hinrichs & Carpendale, 2011; Hornecker, 2008; Jacucci et al., 2010; Marshall et al., 2011).

Depending on the context the PLIS is designed for, the duration of field studies can range from a few hours (Brignull & Rogers, 2003) to days (Hinrichs & Carpendale, 2011) or even years (Ojala et al., 2012), resulting in various context-specific findings. In a paper describing a three-year long-term field study of multipurpose surface deployment, Ojala et al. (2012) discovered a difference between information needs stated by the public and how they actually used the information. Based on this difference the authors argued that there was a need for such longitudinal study for gaining more in-depth knowledge about the real-world use of PLISs. However, besides considerable time commitment, field studies inevitability have a low generalizability (McGrath, 1984), due to the fact that the system has to be in a designated location with the application tailored to its context.

Moreover, video/audio recordings, while being a major source of data, might not be always easily available. For example, environmental factors (e.g., sunlight, noise, and venue constraints) may hinder proper recordings. Also, due to privacy regulations in many countries, video collection may require prior informed, often written, consent, which is often difficult to collect from passersby and may hinder study participation (Hornecker, 2008).

2.4.2 "In-the-Wild" Field Experiments

By definition, in-the-wild field studies discourage any form of disturbance, including changing the interface of the application during study, so as to provide a naturalistic study environment. This requirement limits the ability to compare and evaluate different design concepts. In-the-wild field experiments address this limitation by allowing different versions of the deployed application to be shown at different times or in different locations. For example, Seto et al. (2012) investigated different menu invocation designs aimed to promote menu discoverability on a public digital tabletop, using various interface elements and animations. The authors deployed the surface in a museum and switched between four alternative interface design approaches during each day of the study. System use was documented through field notes, computer logs, and video recordings. Similarly, Kukka et al. (2013) investigated mechanisms for enticing interaction on public surfaces by developing eight versions of the same application with different visual signals, which were then deployed on eight public interactive surfaces at different locations. Apart from unobtrusive observation, interaction logs, and semi-structured interviews, the authors also collected demographic information and feedback by displaying a questionnaire on the surfaces upon touches.

Alternating between different versions of an application allowed researchers to control the design features being studied, thus allowing for comparative assessment. However, it is possible that the same set of people will be exposed to multiple versions throughout the study, thereby creating a carryover effect. One method to counter this effect is to conduct the study for a longer period of time, such that an adequately distinctive set of people can be exposed to each version. Yet, this approach requires a greater time commitment, and still suffers from the same data collection obstacles faced by the in-the-wild field studies. Another method is to have each version deployed in a different location, thus reducing the time requirement. However, this method requires multiple surface setups, which might not be as readily available as having just one single surface.

2.4.3 Laboratory Study

In a laboratory study, researchers gain *precision* by being able to control variables in the environment, thus allowing more rigorous qualitative and quantitative analyzes of study data. This is typically achieved by having the study set up and conducted inside a laboratory, with representative users recruited as participants and completing the same set of procedures. Comparative assessment of design concepts is possible by subjecting participants to versions of applications. Under modern ethics protocol, a laboratory study follows a predefined set of steps, including informing the participants about the purpose of the study, asking them to carry out certain tasks while being recorded, and allowing them to provide feedback about the task. In addition to improved precision, a laboratory setup poses less demand on application robustness, as it is used under controlled conditions. It also allows researchers to quickly prototype a system or part of a system for evaluation.

For example, Vogel and Balakrishnan (2004) developed a prototype motion-sensing system based on their proposed interaction framework for PLISs, and conducted an informal user evaluation in a controlled laboratory environment. To explore research questions such as "What techniques could be used to notify and communicate with users in a minimally intrusive, socially acceptable manner?" (p. 137), their participants were deliberately asked to explore the surface without any instructions given. Based on the user feedback and direct observations, the authors were able to evaluate the effectiveness of their design solutions and establish future directions. Notably, the authors highlighted that, despite the fact that the system was not technologically feasible for deployment in a real-world study due to hardware limitations, evaluating a prototype solution in a laboratory setting allowed them to iterate and refine their designs.

In the context of PLISs, laboratory studies are less frequently used. When used, they are typically used as a "pre-study" for empirical measurements, without much scrutiny on the implications from the results. For example, Müller et al. (2012) conducted a laboratory study, before a field study, to investigate the effectiveness of various visual representations of user embodiments to indicate interactivity. They used the laboratory study to quickly test through eight conditions and determine which representations were more effective, without in-depth inquiry of the rationale behind participants' reactions. However, it is possible to acquire a better understanding of the participants' behaviour through careful and comprehensive experimental design using laboratory studies. In contrast to field studies and experiments, laboratory studies are typically used to systematically compare and measure effects under various conditions. Hence, there is no distinction between laboratory studies and experiments. This thesis will solely use "laboratory study" for brevity.

This thesis used a combination of laboratory study and in-the-wild field experiment to provide a comprehensive evaluation of a PLIS system using visual concepts. In particular, a laboratory-based study methodology was developed and employed to target the evaluation towards the early stages of the interaction process (Chapters 4, 5, and 6). An in-the-wild field experiment was then conducted to further evaluate the visual concepts in a real-world setting (Chapter 7).

2.5 Use of Experimental Deception in Research Studies

Experimental deception (or simply, deception) has been extensively used in psychology as well as HCI domains. Here I overview literature that inspired the design of the deception for the laboratory-based study methodology described in Chapter 4.

2.5.1 Deception in Psychology to Study Attention and Perception

In the psychology domain, deception is often used as a means to retrieve unbiased data, including participants' attention and perception (Neisser & Becklen, 1975; Simons & Chabris, 1999). In the widely known "invisible gorilla" study (Simons & Chabris, 1999), the true purpose of the experiment (unexpected appearance of visual stimuli, a gorilla, among players passing basketballs) was withheld from participants, who were given an unrelated task (pay attention to a team passing basketballs and count). To ensure validity, participants who had heard of the experiment or phenomenon were replaced, and their corresponding results discarded after the study.

The laboratory-based study methodology in this thesis drew insights from the psychological study of attention by first withholding the true purpose of the experiment in the disguise of an unrelated task, and asking probing questions after the unrelated task is completed. However, instead of gradually revealing the existence of the visual stimulus (the gorilla was mentioned at the later part of the interview with the participant), the questions asked in this study methodology did not explicitly mention the type of visual stimuli used in the experiment to further elicit participants' perception towards the stimuli.

2.5.2 Deception in HCI to Study Behavioural Impacts

The HCI domain also makes use of deception to collect unbiased responses. However, deception is typically used as a means to control the behaviour of one or more "group members" in a group task. This is achieved by the use of a "confederate", who is a member of the research team (or a paid actor), playing the role of a study participant. The confederate typically follows a script or engages in predefined behaviour, unbeknownst to the real study participant(s) (e.g., awareness support in a computer-supported cooperative work (Convertino et al., 2004), impact of communication on online team dynamics (Dabbish et al., 2012)). However, confederate-based deception is not always applicable for the purpose of PLISs' studies, as public surfaces can be used by individuals as well as groups (Peltonen et al., 2008), making a confederate inappropriate (e.g., the confederate can become suspicious if staying for too long, and cannot create a scenario for individual interaction).

Deception has also been used in recent HCI studies of large interactive surfaces in the form of hidden tasks. Beyer et al. (2011) used various "distractor" surfaces in addition to their cylindrical screens under study, and gave participants little to no task instructions other than to explore the spaces containing the screens, followed by several questionnaires. Alt et al. (2013) deceived participants arriving for another (non-display) study by having them to wait alone, under no instructions, in a hallway (containing the display) under the "cover story" that the experimental room needed some final preparations. After several minutes, participants were led into an adjacent room and asked to participate in the display study by completing a questionnaire. Afterwards, participants were then led to complete the study (the non-display study) that they originally signed up for.

The deception strategies used in these studies were effective in withholding the specific purpose of the study from the participants, allowing researchers to gather relatively unbiased feedback. However, since participants were given little to no information about how to behave around the surfaces under study, confounds may have arisen that influenced results. For instance, some participants waiting in the hallway may have checked emails on their mobile phones, potentially affecting their exposure to and perceptions of the surface. This lack of experimental precision can be mitigated by a confederate-based deception to create consistent scenarios, which inspired the use of a "deception task" in the methodology discussed in Chapter 4.

2.6 Attention and Engagement in Other Practices

Drawing people's attention and engaging them in activities have been perennial topics of interest for many systems prior to the existence of PLISs. For example, to attract visitor's attention and retain them to museums artifacts, and to entice customers to a storefront. This section presents some of the related fundamental principles developed in cognitive psychology and vision, and their applicability to PLISs, followed by relevant practices in areas such as museum planning, retail, and gameplay that can shed light on the design of a PLIS system.

2.6.1 In Psychology and Vision Research

Modern views of attention capture in psychology describe attention as the first step in perception, which then leads to cognition, and can be driven simultaneously by bottom-up (low-level stimuli such as motion, contrast) and top-down (high-level stimuli such as goals, intentions) processing of the perceiver (Bodenhausen & Hugenberg, 2009). These mechanisms can be initialized externally and therefore be incorporated in the content presentation in a PLIS.

2.6.1.1 Low-level Visual Stimuli to Draw Attention

Low-level visual stimuli are appearance attributes that rely on instinctive responses from the perceiver (e.g., motion and scale (Franconeri & Simons, 2003), saliency (Steven Yantis, 2005)). Literature in vision research has investigated how such stimuli direct visual attention, and has developed models that explain the selective process of attention shifting (e.g., saliency map (Itti & Koch, 2000)) In particular, Yantis and Jonides (1984) have shown that abrupt visual onsets (e.g., sudden relative movement and flicker) are rapidly detected in visual search.

Because of the variety in appearance attributes, for example, colour, illumination, transparency, and shape, low-level visual stimuli are readily applicable to a wide range of content to attract viewers' attention as a visual grammar that can be used by content designers (Van Leeuwen, 2006).

2.6.1.2 High-level Visual Stimuli to Draw Attention

High-level stimuli refer to cognitive expectancies and goals that modulate selective attention, which can be driven by an active search of related object (e.g., an entomologist finding a particular insect species (Bodenhausen & Hugenberg, 2009, p. 3)), or surprised by "oddballs" (e.g., an observer spotting an octopus in a farm (Loftus & Mackworth, 1978)).

In contrast to its low-level counterpart, high-level visual stimuli require more effort to attain, as the context has to be created or known (e.g., the entomologist is looking for insects). However, recent work has argued that it might be a more effective mechanism to draw visual attention in real-world scenes (Henderson et al., 2007), and therefore also worth utilizing in content design.

2.6.1.3 Peripheral Vision

Research in vision has distinguished human vision system into central and peripheral vision, this separation is caused by the uneven distribution of photoreceptors (cones and rods) across the retina (density of cones is much higher than that of rods in the centre, and reversed at the peripheral (Purves et al., 2001)), and cones being superior in acuity. Hence, although normal human visual field is about 180-degree horizontally, and 150-degree vertically (Gibson, 1950), the level of attention and visual acuity decreases rapidly as an object's projection on the retina moves from the central to the peripheral retina area. Prior research has concluded that the peripheral retina area is capable of crude information processing only (e.g., form, motion), and is mostly used to guide foveal (central) vision to informative stimuli (Adams, 1971, p. 11).

Collier (1931) studied the ability of peripheral vision in identifying geometric figures (e.g., circles, squares, triangles), and reported that they were identified with different levels of correctness, with a tendency of their form being distorted. A later experiment by Shapiro, Lu, et al. (2010) studied the perception of motion in peripheral vision, and revealed that peripheral vision integrated first-order (spatial-temporal variations of luminance) and second-order (spatial-temporal variations in image attributes such as contrast or depth) motion perceptions, contributing to the motion distortion perceived by the observer. In addition, there is evidence showing that while capable, peripheral vision is not superior to central vision in detecting motion or discriminating velocity (McKee & Nakayama, 1984).

Peripheral vision is an important aspect for PLISs, as it is often the case for a public surface being at the peripheral view of a passerby, instead of their central view. When designing content that captures peripheral vision, it is useful to understand the change in quality of the content being perceived, for example, lower accuracy in shape recognition, and distortion in motion detection.

2.6.1.4 Audio Cues

A separate but often employed attention drawing technique is to use audio cues. Such techniques have often been used in museums in various ways (e.g., voice prompts, confirmatory sounds, and visitors' own sounds) to augment the visiting experience (Back & Cohen, 1998), or to promote better accessibility for the visually impaired visitors (Landau et al., 2005). However, audio might not be as applicable in public settings with frequent traffic, as it might not be heard in presence of other sounds or at a distance; or where sound is not permitted (e.g., in a library). Nevertheless, recent studies have shown that under the right circumstances (e.g., low ambient noise level for the cues to be audible) audio cues could also be used to raise awareness and entice interaction on PLISs (Kukka et al., 2016).

2.6.2 Application in Practice

Research in PLISs has applied techniques mentioned above on their interaction and interface design, especially visual techniques as they are more available in current display technologies. This section begins with a discussion on how low- and high-level visual stimuli are applied. Next, an overview of some of the existing practice found in public places, such as museums, is provided to illustrate how they can be applied to designs for PLISs.

2.6.2.1 Low-level Visual Stimuli in PLISs

Many of the low-level visual stimuli are directly transferrable to designs for PLISs. These include use of colours, animation, text and icons (Kukka et al., 2013). In interviews asking for influencing factors affecting whether people thought they would look at a display, Müller et al. (2010) identified “colourfulness” as the most important factor.

Moreover, there appears to be an interaction between low-level visual stimuli. In a recent study by Kukka et al. (2013) investigating the effectiveness in visual elements including colour/greyscale, animation/static, and icon/text, it was reported that when in greyscale, text was more effective when being static than animated; while when coloured, the opposite was true. In addition, the authors uncovered the role of gender in preference: women preferred greyscale to colour and static over animation; while men preferred colour to greyscale and icon over text. The authors made a note that their results might vary in different contexts and user demographics, which warrant further research.

2.6.2.2 High-level Visual Stimuli in PLISs

Müller et al. (2010) described high-level visual stimuli in PLISs as “motivation” giving passersby incentive for using the surfaces, and used this as the building blocks for their Magical Mirror system (Michelis & Müller, 2011). This system used an augmented mirror image of passersby to raise their curiosity. Later research compared the visual representation of the user in surfaces (realistic image of the user versus silhouette-style user shadow) and found both to be effective at drawing passersby's attention (Müller et al., 2014, 2012). Other examples of high-level visual stimuli can be found in installations at places such as museums (artist's catalog (Hinrichs et al., 2008)) and tourist information centres (tourist planner (Marshall et al., 2011)). Contextual oddballs are less common but were suggested in interviews and situated studies in various city locations (Müller et al., 2010), revealing passersby's desire to see content that were very different from what they expected.

Apart from the content design, an extension of high-level visual stimuli is to consider the spatial and social context of the surfaces, that is, how and where they are placed. These factors also affect the perception and hence expectations from the passersby. For example, Brignull and Rogers (2003) suggested placing the surface near traffic flow to increase the likelihood of it being noticed and facilitate the "honey-pot" effect. A similar suggestion was also made by Huang et al. (2008) in placing the surface based on the direction of people's movement, and enhancing the surrounding area. Surfaces made for a targeted audience can also be designed and placed according to their routines (e.g., coffee-corner that supports socializing (Wichary et al., 2005), installation that hosts a small group (Hornecker & Stifter, 2006)) for better utilization.

Meanwhile, researchers have also explored associating proximity to the surfaces with degree of visual effect (e.g., Ambient Display (Vogel & Balakrishnan, 2004), Proxemic Peddler (Wang et al., 2012), and Persuasive Public Display (Dietz et al., 2004)) to entice interaction and provide a more engaging experience to their users. While promising, such association poses a higher technological requirement on the surface's capability (e.g., detecting proximity requires a system to track its users), which has only become more available in recent years. This thesis explored its effectiveness in drawing passersby's attention and enticing them to interact with a PLIS system, as detailed later.

2.6.2.3 Attention and Interaction in Museums

One of the main objectives in museum exhibition planning is to "attract the visitors' attention and lead them systematically" (Bogle, 2013, p. 208), which can be achieved through careful artifact placements (to create a path), and colour selection (to create weight and balance). There has been a well-established understanding of museum visitor behaviour including short attention span (Bollo & Dal Pozzolo, 2005), appreciation of interactivity (Bitgood & Patterson, 1987), and taking an active role in creating meaning to the visit (Silverman, 1995).

Designs for PLISs can benefit from many of such understanding and application of the consequent design principles, for example, to include motion and increase visibility of the surfaces (Bitgood & Patterson, 1987), and to appropriate the amount and level of interactivity (Allen & Gutwill, 2004). However, it is also important to note the differences between PLISs and museum artifacts. For instance, a museum is a less distractive place dedicated to showcase exhibits, hence visitors will be more likely to stay and notice interactive artifacts. Also, artifacts in a museum are typically connected via themes and a path is therefore often necessary. In contrast, PLISs are typically stand-alone systems that do not have a "next stop", so techniques such as relative placements of artifacts for orientation and circulation (Bitgood & Cota, 1995) would not be applicable.

2.6.2.4 Attention at Storefronts

It is of crucial importance for stores to draw the attention of potential customers. Stores use their street-facing front to symbolize their merchandise and philosophy, to control shoppers' perception of the store, and to provide physical transition from the outside to the stores' interior (Green, 1986). An important factor in designing an effective storefront is to clearly and correctly reflect the concept and merchandise of the store, to a point that customers will quickly understand the store, and be "vacuumed" into the store (Barr & Broudy, 1990).

Physical design of PLISs can draw inspiration from the layout and communicative aspects of storefront designs. For example, use of identifiable visual elements, and spotlighting featured content. However, since the ultimate goal of a storefront is to convince customers to walk in and make purchases, it is not designed to retain passersby, hence some of the design guidelines (e.g., defining a passage way between the street and store interior) would not be applicable.

2.6.2.5 Attention at Digital Signage

As prices for large surfaces drop, digital signs have become a common sight at many public and semi-public places for both commercial and academic purposes (Clinch et al., 2011). For example, menus in fast food stores, event schedules in convention centres, and billboards on urban building facades. Some recent work attempted to incorporate sensors into these surfaces and adapt the content according to audience behaviour and their attention (e.g., Müller, Exeler, et al., 2009; Tamaki & Hirakawa, 2015; Wang et al., 2012). Yet, in most of these cases digit signage was characterized as means to provide push-based and context-specific content (Davies et al., 2014), with less focus on providing engaging user experience like deployments in libraries or museums.

Practices in designing for digital signage are informative for PLISs interface design, particularly in terms of drawing attention and disseminating information quickly[7]. However, as the main goal of digital signage is to provide information to its audience instead of enticing them to stay and interact, interactivity is typically kept minimal and less studied.

2.6.3 Visual Techniques to Communicate Interactivity

Provided that the attention is being drawn from an unknowing passerby, the interface should immediately communicate its interactivity, as being intrigued does not necessarily result in realizing interactivity ("interaction blindness" (Ojala et al., 2012)).

Building on the premise where a passerby's attention is drawn visually, several visual techniques, such as calls-to-action and attract loops (Kules et al., 2004), have been proposed. However, these techniques are typically language and culture dependent, or might mistakenly be associated with arcade games. Müller et al. (2012) evaluated the use of mirrored user images or silhouettes in communicating interactivity, and showed that they were superior over traditional call-to-action approaches. Ojala et al. (2012) evaluated the use of "Touch me!" animations but did not find any noticeable increase in interaction. These results suggest additional work is required to further understand how to convey interactivity.

A related area that PLISs can gain insights from is the interface design in gameplay, where players have to quickly learn about the controls through tutorials and help dialogs (Andersen et al., 2012). Interface design in gameplay is more relevant than in other conventional software applications because of its casualness and its entertainment aspect. In fact, some of the well-established design principles are directly applicable in communicating interactivity. For example, use of "attraction mode" (a series of graphics being displayed in a game when it is not being played), and "training wheels" (starting with a simplified level for early success) have been widely used in games to promote exploration and learning (Houser & DeLoach, 1998), and can be applied to the interface design of a PLIS system for a similar purpose.

[7] Some literature do not distinguish between digital signage, pervasive displays and public displays, treating them all as "collections of digital displays deployed in public or semi-public spaces" (Davies et al., 2014). This thesis takes a similar approach with the term PLIS to further highlight the interactivity of these displays.

2.7 Chapter Summary

In this chapter, I first illustrated PLISs' variety in social configuration, diversity in user expectations and interaction methods, and the need to draw passersby's attention. These topics have direct impact on the design and evaluation of the PLIS system developed in this thesis.

Next, I briefly overviewed some of the current technologies employed and their impact on PLIS design considerations, and reviewed in detail relevant research and practices in attention drawing and interaction design. These prior work has both motivated and inspired the research conducted in this thesis, particularly the formation of the DISCOVER interaction model, and the design and execution of the laboratory-based studies and field experiment.

Chapter 3
The DISCOVER Interaction Model

This chapter first describes a set of design considerations for Public Large Interactive Surfaces (PLISs). Then the DISCOVER Interaction Model that models the interaction process between a user and a PLIS is presented, explained, and compared with existing work. Finally application of the model to research and design for PLIS systems is provided.

This model was developed in collaboration with my co-supervisor Dr. Stacey Scott. Part of the model has been published in the Doctoral Symposium in the ACM International Conference on Interactive Tabletops and Surfaces 2014 (Cheung, 2014), where I authored and presented the paper.

3.1 Design Considerations for PLISs

Given the unique nature of PLISs' deployment, and the benefits and limitations of different available technologies discussed in Chapter 2, I have established a set of design considerations to guide the design of the PLISs. These considerations have direct impact on the deployment location, choice of technology, and form of content presentation:

- Support a variety of social configurations – PLISs are expected to be used by multiple users of different social dynamics simultaneously, and the duration is typically short (a few minutes).
- Support a variety of user expectations – Users tend to perceive the PLIS using their existing understanding of public exhibits/displays, this understanding is often influenced by the context they are in, and the physical appearance of the PLIS system.
- Support a variety of motivations in using the PLIS – Users interact with the PLIS for various reasons, for example, actively looking for information, out of curiosity or boredom.
- Consider environmental constraints – Characteristics of the location often pose limitations on the employed technology, for example, presence of direct sunlight, absence of internet connection, limited space available.
- Provide easy-to-learn interaction mechanisms – Commitment to interact with, and willingness of learning about interaction at the PLIS is often low.

- Draw attention in midst of other objects quickly – PLISs are often unoticed amongst other objects in a public setting. Attention has to be drawn proactively. The system must compete with many potential distractions from the environment.

An interaction model, DISCOVER, encompassing these considerations was developed to better communicate them for the purpose of system design and evaluating a PLIS in a heuristic manner.

3.2 Motivation for the Development of the DISCOVER Interaction Model

Review of existing models and frameworks on PLIS interactions revealed trends in establishing more detailed interaction phases, as well as incorporation of interaction modalities beyond distance from the surface. However, none of the work reviewed in Section 2.3 considered the usability aspect of PLIS interfaces, or how a user perceives the surface at different stages of interaction. Moreover, while being recognized as an important phase, the "*draw attention*" component is often treated as a single step without considering how attention is drawn and interest is evoked.

Based on these gaps in the previous research, I developed in collaboration with my supervisor the DISCOVER interaction model focusing on the cognitive states of the user to distinguish between the phases of interaction, in conjunction with the usability aspect of the interface. This provides more flexibility when considering environmental constraints or often subtle user behaviour. In addition, the transitions between states are characterized by how the interface impacts the user, instead of how the user triggers them. This is intended to inform the *design* of the interface to facilitate transitions using the terminology that is well-established and researched in the usability design area.

DISCOVER goes beyond the aforementioned models and frameworks in several ways:

1. It takes into account the situation where a user becomes frustrated with the interface, and discusses likely causes and possible solutions to address the situation.
2. It captures different motivations in using PLISs to provide a broader range of public settings by identifying two typical application categories (*task-oriented* and *opportunistic*).
3. It does not assume any specific technologies and physical configurations of a PLIS, and instead any type of large interactive surfaces that may be used in a public context.
4. It emphasizes the attention drawing, and interest evoking aspects of a PLIS.

3.2.1 Discoverability Process

The key concept behind the DISCOVER interaction model is the continuous discovery process undergone by the user of a PLIS. The user first *discovers* the system itself, then *discovers* its purpose and contents, and later *discovers* the interactivity it supports. This "discoverability"[8] attribute therefore greatly affects the utilization of a PLIS, and should be carefully examined from the very beginning to the very end of the interaction process. Previous work typically breaks the process into disparate phases exhibited by system usage (e.g., level of engagement), and connects them through system or user actions (e.g., level of content details, user's orientation). In contrast, DISCOVER aims to bring these phases together under the overarching concept of discoverability process.

3.3 DISCOVER: An Interaction Model for Public Large Interactive Surfaces focused on the discoverability process

The DISCOVER interaction model is a result of synthesizing existing literature and my own research in the area (Cheung & Scott, 2011). This model represents a novice user's interaction with a Public Large Interactive Surface, with a focus on the *discoverability process* pertaining to the discovery of the system as a whole and the interactivity it offers. The model is comprised of user states, and transitions between these states caused by various usability features of the interface, as detailed in Figure 3-1.

[8] The term "discoverability" was first used by Norman (2013) to describe the process during which a user is actively interacting with the system. In this thesis it is used for a broader interaction process including noticing the system. "Discoverability process" is used here to highlight this distinction.

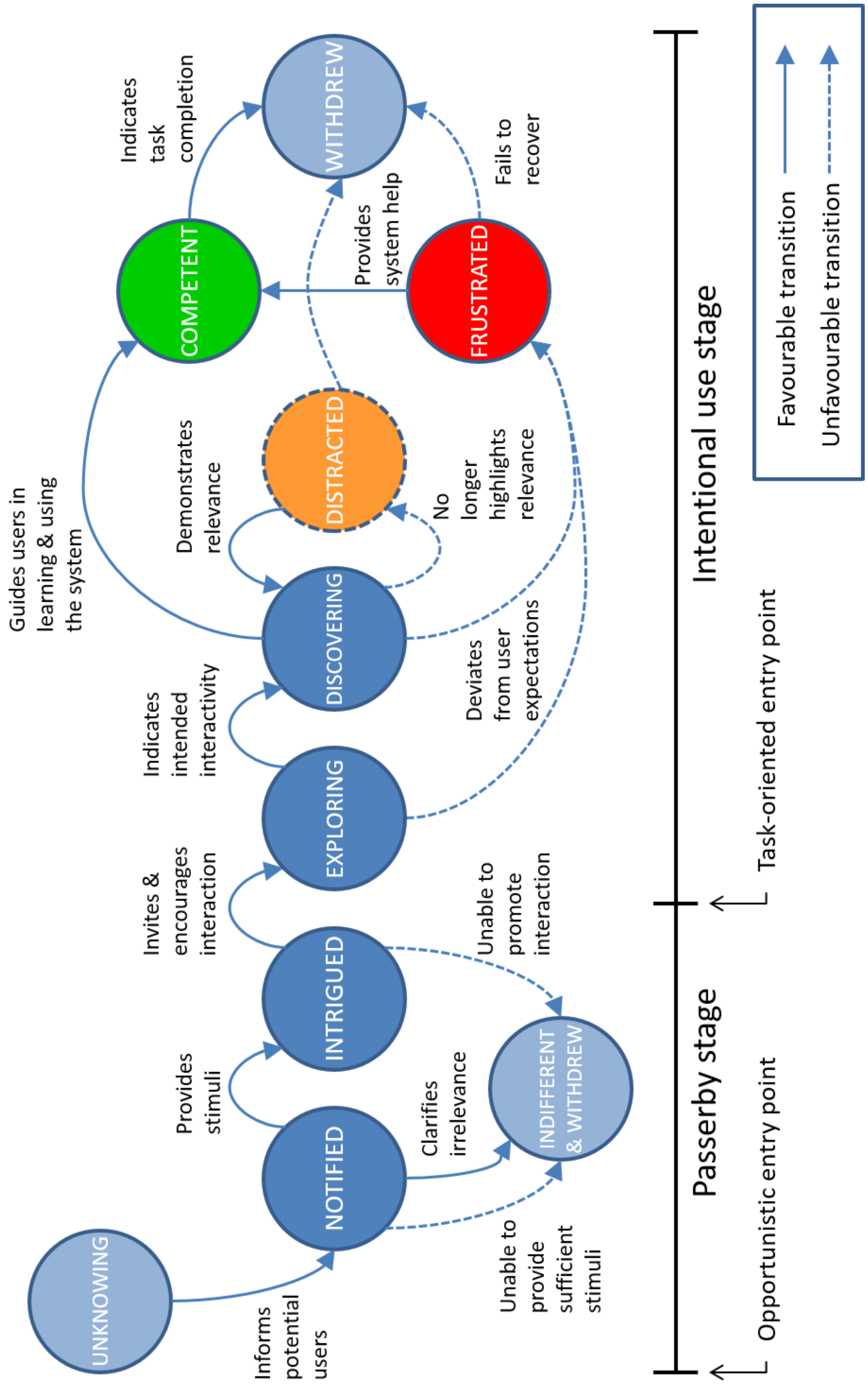


Figure 3-1. The DISCOVER interaction model for Public Large Interactive Surfaces describing the discoverability process of the system and the interactivity offered.

3.4 User States in DISCOVER

Each user state in DISCOVER describes the cognitive state of a user during the discoverability process. The term “system” is used to provide a more general description of the PLIS setup, which includes the physical surface itself, along with any other artifacts such as signage.

- **Unknowing** (user has no knowledge of the system) – In many scenarios the PLIS is not the focus of a potential user (a *passerby*), for example, information display on their commute, one of the many exhibits in a museum visit. It might also be a newly installed system which is not explicitly announced.
- **Notified** (user notices existence of the system) – The user is not directly interacting with the system, but with their attention being drawn towards the surface. This attention can be invoked by the interface, or presence of artifacts or other users.
- **Intrigued** (user thinks something interesting or useful can be done with the system) – The user is willing to interact with the system. At this point the user forms a mental model of the surface based on what they observe, and arrives at expectations of the system in relation to their interests.
- **Indifferent & Withdrew** (user has no interest in interacting with the system) – The user is under the impression that the system does not warrant interaction, or it is clear that the system does not provide information of interest. It is different from the final *Withdrew* state as there has not yet been any direct interaction with the system.
- **Exploring** (user intentionally interacts with the system) – The user realizes that they can interact with the system to further explore its content and interaction mechanisms, and believes the system may be relevant or interesting. The surface has presented itself as interactive, and/or the user observes others interacting.
- **Discovering** (user purposefully engages with the system) – The user interacts with the system and begins discovering the system’s features and capabilities, for example, a surface responding to touches. Depending on the usability of the interface or the relevance of the system, the user will transition into one of the following three states.
- **Distracted** (user pays attention to something else) – The user’s attention is drawn to other objects, people, or events in the environment. This may be caused by the interface’s inability to maintain the user’s attention due to poor design, or by simply the nature of the environment, where the surface is not the only focus for the user.

- **Competent** (user is able to accomplish a purpose) – With proper guidance from the interface, the user gracefully finds and completes all the necessary steps to accomplish a task with the system (e.g., find information, play a game). This task may be a predetermined one or a potential one discovered during the *Exploring* and *Discovering* states. Note that this does not mean the user is competent in all tasks supported by the system, but only the task(s) engaged during the interaction.
- **Frustrated** (user is stuck) – If the behaviour of the interface deviates from the user's expectation formed earlier in the interaction process, confusion arises and eventually leads to user frustration. Sometimes, the task can still be completed by watching or getting help from other users (characteristic of a PLIS supporting multiple users), or some recovery mechanisms of the system. However, in many public settings the user can leave the system anytime with little or no perceived penalty. Thus, most users have a low tolerance for frustration and will quickly decide to leave.
- **Withdrew** (user leaves the system) – Signifies the end of the interaction. This state can result from the user successfully completing the task, being distracted, or giving up.

3.5 Favourable and Unfavourable Transitions

The discoverability process is a series of transitions between the connected user states. As illustrated in Figure 3-1, there are two types of transitions: *favourable transitions* (represented by solid lines) and *unfavourable transitions* (represented by dashed lines). The favourable transitions and the corresponding user states can be used to help focus design efforts to facilitate users through a desired interaction pathway, leading to the successful utilization of the PLIS. The unfavourable transitions and the corresponding user states, in contrast, can be used to help identify potential failure points and prevent those transitions through effective usability design. Table 3-1 summarizes these transitions and describes how they are facilitated by the system's interface and represented at the PLIS.

Table 3-1. List of favourable transitions (FT) and unfavourable transitions (UT) in the DISCOVER interaction model. Each transition represents a change from a user state to another, as facilitated by the system's interface and represented at the PLIS.

Transition	Description
Unknowing to Notified (FT)	Very often the main attention of a passerby is not towards the system, the interface must first capture their attention by informing them about its existence. This could be facilitated by visual elements appropriated to the context of the deployed environment, dynamic enough to quickly catch their eye, or immediately recognizable.
Notified to Intrigued (FT)	After drawing a passerby's attention, the system must provide enticement for them to stay, and help them to form correct expectations. This could be facilitated by more meaningful content that can be consumed quickly, or showcasing what other users are engaged in.
Notified to Indifferent & Withdrew (FT)	In some cases the content provided is not relevant to the user, for example, advertisements to a user looking for train schedules. The system should honor this and facilitate the transition by clearly communicating its purpose.
Notified to Indifferent & Withdrew (UT)	An unfavourable transition where the system fails to provide sufficient stimuli to keep the user, even when the content provided is relevant to them.
Intrigued to Exploring (FT)	The system should invite the users to start interacting, and instill confidence that it will not "break" upon interaction. This could be facilitated by the inclusion of common interactive elements such as buttons, demo videos, or recognizable technologies.
Intrigued to Indifferent & Withdrew (UT)	An unfavourable transition where the system fails to promote interaction, which may be caused by content displayed in a seemingly non-interactable way, e.g., still images.
Exploring to Discovering (FT)	A user who starts exploring the system may not necessarily be aware of what they could do with the surface (the input modality), which they need to learn about. One useful strategy is the use of feedforward, where the interface shows what will happen if a certain action is performed (Djajadiningrat et al., 2002).
Exploring to Frustrated (UT)	An unfavourable transition where the system's behaviour deviates from the expectations formed by the user, e.g., interface components perceived as buttons not responding to touches/selections.
Discovering to Competent (FT)	The system should quickly transition a user who starts learning about the system's interface into being familiar with the operations, to allow completion of the task they wish to accomplish with the system. This can be facilitated by appropriate feedback and cues at the interface.
Discovering to Distracted (UT)	An unfavourable transition where the system loses the attention of the user. This could be caused by failure to highlight relevance, or distractions from the environment.
Discovering to Frustrated (UT)	An unfavourable transition similar to the "Exploring to Frustrated" transition. As the user continues to interact, the expectations towards the system's behaviour needs to be reinforced.
Distracted to Discovering (FT)	If the user's attention is drawn away from the system, the system should quickly regain it. This can be achieved by further demonstrating content's relevance in a more salient way, for example, using dynamic content.
Distracted to Withdrew (UT)	An unfavourable transition where the system fails to regain user's attention, resulting in an incomplete task.

Table 3-1. (Cont'd)

Transition	Description
Competent to Withdrew (FT)	The user has successfully completed the task by carrying out expected steps. The user has to be explicitly informed about the task completion and that they can leave the system.
Frustrated to Competent (FT)	The system is aware of user's frustrations in interaction through, for example, frequent errors or timeouts, and should provide assistance in resolving the frustrations.
Frustrated to Withdrew (UT)	An unfavourable transition where the system fails to assist a frustrated user to understand and use the system via its interface, leading to the user giving up.

3.6 Two Typical Application Categories

DISCOVER also suggests a distinction between two application categories: *task-oriented* and *opportunistic*. These two application categories describe the expected entry point into the model, that is, the degree of discoverability of the system and its features that need to be supported. In the task-oriented category, users seek out the system for a specific purpose, and thus, enter the model at the *intentional use stage*, skipping the *passerby stage* completely. In the opportunistic category, users have no prior knowledge of the system's existence, and thus enter the model at the passerby stage and only proceed into the intentional user stage if the system engages the user.

These different application categories suggest different foci to engage the target user. To illustrate, consider an opportunistic example of an "interactive storefront" designed to engage pedestrians passing by the store window, similar to the setting studied by Müller et al. (2012). Users typically begin as passersby without the knowledge of the interactive surface. The system must quickly grab their attention, and more importantly, communicate to potential users that the system offers interesting and relevant content with which they can interact. If successful, the users will engage with the system. Otherwise, potential users will simply walk away. To illustrate a task-oriented scenario, consider an interactive map in a shopping mall. Shoppers looking for directions typically seek out the system, and begin using it with the intention to engage with the system. The system should facilitate the users to quickly figure out how to use the system, and to find their destinations and directions for getting there. Here, the system must provide hints and cues for the users to learn the operations required to complete their tasks.

In both application categories, knowledge of interacting with the system is not assumed. This is due to the variety in expectations and ways of interactions within the users. Therefore, it is important for the PLISs to include expectation formation and interactivity communication in their interface design.

3.7 Applications of DISCOVER

DISCOVER is a versatile tool that can be applied to the design of PLIS in a number of ways: 1) a lens to help focus existing usability design guidelines, 2) a synthesizing language of existing work, 3) an analytic framework for gap analysis, and 4) an evaluation framework for assessing usability of an interactive surface system in a public setting. This section illustrates how each of these applications is accomplished, and discusses the outcome from carrying them out.

3.7.1 Application One – As a Lens to Focus Existing Usability Design Guidelines

To provide a satisfactory user experience with a system, designers must ensure that the interaction process motivates and sustains the task being carried out. In this regard, the favourable transitions of DISCOVER can be used to help focus existing usability design advice for PLISs.

Classic usability research and standards (Gould & Lewis, 1985; ISO, 2000; Nielsen, 1993) identify usability as a requirement for system acceptability, and mainly focus on improving task efficiency. While the main context of use and user composition of PLISs differ from those in the classic usability literature, which typically assumes attended-to tasks with clear goals, several relevant usability attributes can still be identified and adapted to the public use context. These attributes are expected to promote the favourable transitions in the model by catering to the usability needs of a novice user in particular.

- **Discoverability** – Refers to the ability of a novice user to recognize the possible actions within the system and its current state (D. A. Norman, 2013). In a public setting this also extends to noticing the system itself (transitioning the user to the *Notified* state), its potential benefits (transitioning the user to *Intrigued* or *Exploring* states), and its available contents (transitioning the user to *Exploring* or *Discovering* states). This principle is similar to the “Comprehension” design principle identified by Vogel and Balakrishnan (2004) where the system “should reveal meaning and functionality naturally” (p. 138), but differs by also including the discovery of the PLIS system in its environment. A high level of discoverability increases the presence of the system in an intrinsically distractive public environment, and hence its utility. This can be achieved by proper positioning of the system (Brignull & Rogers, 2003), and good use of visual stimuli (Bodenhausen & Hugenberg, 2009; Steven Yantis, 2005).

- **Learnability** – Refers to the ease of a novice user to acquire the skills of interacting with the system (Nielsen, 1993), both physically (capable of carrying out the action) and intellectually (knowing what the action entails). Such skills are needed to transition the user through *Exploring*, *Discovering*, and eventually *Competent* states. A high level of learnability gives the user confidence in using the system. This can be achieved by highlighting [perceived] affordances of interface components (D. A. Norman, 1999a, 2002), together with proper visual tools such as feedforward and feedback (Djajadiningrat et al., 2002) to communicate interactivity at the interface.

- **Understandability** – Refers to the ability of a novice user to comprehend the system, which includes its purpose (transitioning the user to *Intrigued* or *Exploring* states), the nature of the content presented (transitioning the user to *Intrigued*, *Exploring* or *Discovering* states), and what task stage the user is at (through the discoverability process). This is similar to the "intelligibility" attribute introduced for context-aware systems in ubiquitous computing environments (Bellotti & Edwards, 2001; Ju et al., 2008; Vermeulen, 2010), which is intended to inform users of how the system works and how the user information is being used, thereby instilling confidence in them to keep using the system and to mitigate adoption reluctance (Huang et al., 2006), but with a focus on the user's awareness of the system. A high level of understandability allows users to quickly understand what the system is offering, which is particularly important for "approach-and-use" contexts (where the majority of PLISs are at). This can be achieved by including proper response mechanisms and visualization methods (Wigdor et al., 2009), and promote "immediate apprehendability" by having the user experiencing early success (Hornecker, 2008, p. 116).

- **Satisfaction** – Refers to comfort and acceptability of use (ISO, 2000; Nielsen, 1993). In an "approach-and-use" context, more emphasis should be on applying the acquired skills to accomplish a task effectively, and thus, avoid the *Frustrated* state. A high level of satisfaction keeps the user engaged throughout the interaction process, and "feels good" when the interaction concludes. This can be promoted by early successful interaction (Marshall et al., 2011) that requires a "low commitment" and "be quick to do and enjoyable" (Brignull & Rogers, 2003, p. 7). This places a strong onus on designers to provide an enjoyable user experience, rather than simply providing useful system features.

Though all contributed to enhancing usability, these attributes should be prioritized depending on the DISCOVER user state the user is in. The opportunistic and task-oriented application categories suggested by the model can be used to illustrate this prioritization. In an opportunistic application, in order to effectively transition a passerby from the *Unknowing* state to the *Notified* state, a higher priority must be placed on making the interface discoverable, and its purpose understandable; learnability and satisfaction are not as relevant at this stage as the system is not yet being directly engaged with. Bringing a user from the *Intrigued* state to *Exploring* and later *Discovering* states are critical moments in initiating direct interaction and sustaining engagement, respectively. Thus, a high priority should be placed on learnability, discoverability and understandability. On the other hand, in a task-oriented application, more emphasis should be placed on learnability and discoverability of the interface, and thus smoothly bringing the user from the *Exploring* state through subsequent states and eventually the *Competent* state.

The notion of user states, attribute priorities for various transitions, and application categories allows designers to apply existing usability design advice to PLISs.

3.7.2 Application Two – As a Synthesizing Language of Existing Interaction Models

Prior work has investigated actual and simulated deployment of large interactive surfaces, and has developed interaction models and design implications based on the findings. These in turn inform the design of improved systems, from physical location to interface design, thereby better engaging the users. Yet, there is a lack of a unifying framework that describes all of these models and their implications, and that provides a language that can be used to synthesize existing literature and describe the underlying discoverability process.

DISCOVER aims to provide a foundation for such a unifying framework. As shown in Figure 3-2, its user states and transitions provide a set of vocabulary to portray levels of engagement throughout the discoverability process; the transitions are used to further establish usability attributes to promote a favourable progression. It therefore provides a language that can be used to represent the interaction and identify room for improvement.

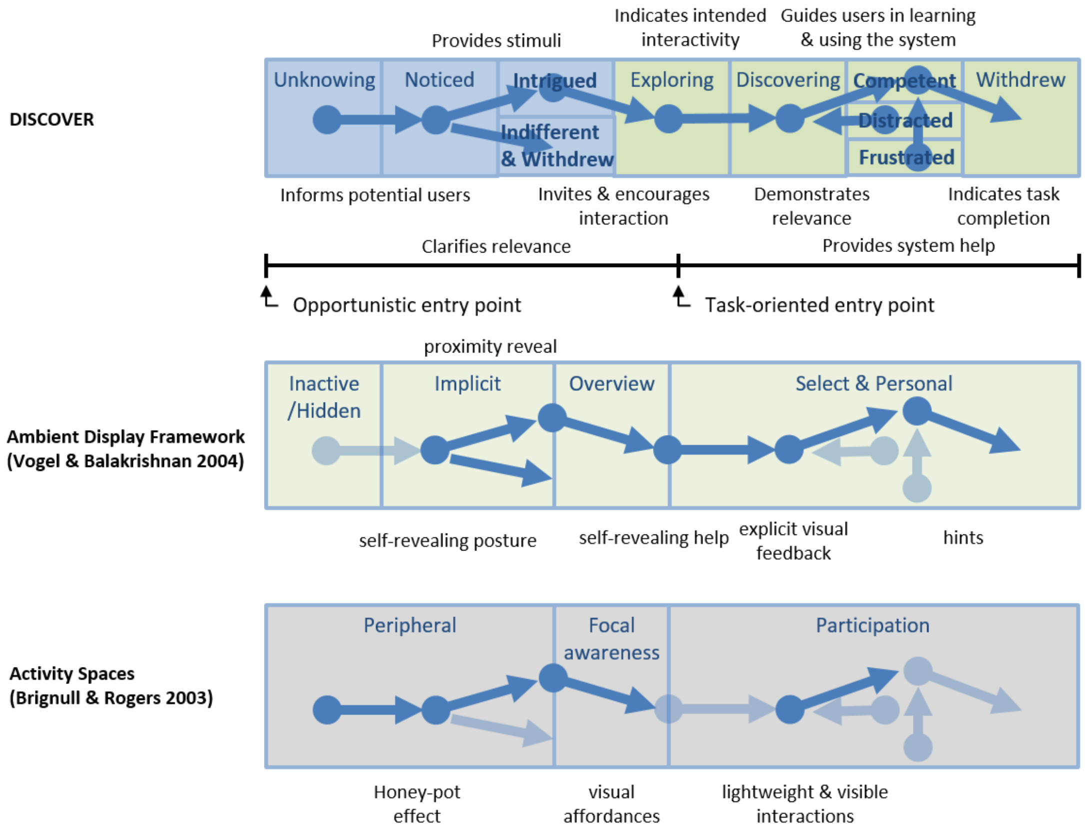


Figure 3-2. Visual comparison to two of the most cited models (both over 450 citations, source: Google Scholar, as of 1 February, 2016): Ambient Display Framework (middle), and Activity Spaces (bottom). The states of each respective model are shown in boxes surrounding the DISCOVER states to which they correspond. Solid arrows indicate transitions for which design advice is provided by the authors. The specific advice is provided in black text above or below the transition.

To illustrate, first consider the Ambient Display Framework (ADF) (middle row in Figure 3-2) by Vogel and Balakrishnan (2004) through the lens of DISCOVER. ADF is one of the more complete and detailed models encompassing phases of interaction with a large interactive surface system. In ADF, interactions are described from the system's point of view, with four state-groups (i.e., *Inactive/Hidden*, *Implicit*, *Overview*, *Select & Personal*) representing the behaviour of the surface. The transitions between these states are prompted by the physical actions performed by the user. For example, the action of walking towards the surface transitions the system from *Implicit* to *Overview*. To communicate this transition, the design advice according to ADF is to reveal visual cues triggered by postures (hand/body orientation and movement) on the interface.

DISCOVER complements ADF by describing interactions from the user's point of view, aiming to provide more flexibility and relevance for designers in terms of user experience and usability. Its user-centric perspective also highlights aspects that are not apparent from the system's perspective, for example, the branching after the *Notified* and *Discovering* user states, as the user might not find the content relevant, get distracted, or feel frustrated when errors are made. These branched user states provide a richer vocabulary to describe the situation missing from the system's perspective which tends to be more technically focused.

Next, consider the Activity Spaces (AS) model (bottom row in Figure 3-2) by Brignull and Rogers (2003), which is frequently cited by researchers for its insights into the interaction bottlenecks PLISs have to overcome. AS explicitly highlights the transitions by *encouraging* users to cross the *thresholds* of increasing engagement (denoted as *peripheral awareness*, *focal awareness,* and *direct interaction* activity spaces). These transitions have direct parallels with the favourable transitions in DISCOVER, for example, AS's *Peripheral Awareness* to *Focal Awareness* transition is in parallel with DISCOVER's *Unknowing* to *Notified*, and *Notified* to *Intrigued* transitions; and AS's *Focal Awareness* to *Participation* transition is in parallel with DISCOVER's *Intrigued* to *Exploring* transition. However, unfavourable transitions are only implied by the inability to overcome the mentioned bottlenecks, without any discussion on how these impact the user or how to avoid them. Also, how the user is transitioned out of the engagement at the end of the interaction process is not explicitly addressed.

DISCOVER differs from AS by further dividing AS's *Participation* activity space into two increasingly engaged and effective user interaction states: *Discovering* and *Competent* (and two auxiliary states: *Distracted* and *Frustrated* as the corresponding unfavourable transitions), to better reflect the levels of engagement in the interaction. Moreover, DISCOVER also includes a *Withdrew* state, which explicitly signifies the completion of the interaction process.

The combination of states, transitions, and the corresponding favourable and unfavourable transitions in DISCOVER provides a more comprehensive overview of the discoverability process for PLISs. Together with the two application categories, it provides a unified language to describe and compare interaction models, thereby enabling deeper analyses of existing literature to identify gaps in existing research, as discussed in the next section.

3.7.3 Application Three – As a Template for Gap Analysis of Existing Research on the Discoverability Process of PLISs

To date, researchers have studied interactive surfaces in various public contexts, resulting in a number of design recommendations related to various aspects of the discoverability process. Meanwhile, large interactive surface research situated in non-public contexts (e.g., workplace, classrooms) also offers valuable design advice, directed towards the latter phases of the discoverability process (the *intentional usage* stage in DISCOVER).

Yet, recent studies, as well as many of my own anecdotal observations, have shown that PLISs are still underutilized. A contributing factor is that much of the existing design advice is specific to a particular context under which the study was conducted, and therefore may not be applicable to other contexts. For example, one approach for attracting people (i.e., transitioning from *Notified* to *Intrigued* state) is to exploit the "honey-pot" effect, a phenomenon where people are attracted towards existing users at a surface. However, this approach is only effective when there is enough space in the environment for a group of users to gather around the surface, and the surface is visible to others.

Table 3-2 summarizes design recommendations and advice from studies in a wide range of contexts, including museum installations, storefront attractions, and conference booths, aiming to improve the discoverability of public interactive systems, and ultimately to foster successful and competent engagement with PLISs. Framing these recommendations and advice through DISCOVER provides a systematic mechanism for examining existing knowledge about how system designs can facilitate the entire discoverability process. It also helps identify gaps that warrant further research to expand our understanding of how to design for discoverability, as illustrated in the next section.

Table 3-2. A summary of existing design advice in facilitating DISCOVER's favourable transitions for PLISs. The last two transitions are not well-documented in prior work.

Transition	Existing design recommendations and advice
Unknowing ↓ Notified (informs potential users)	*User Interface or Interaction Design*: • Manipulate displayed content properties (e.g., colour, motion, graphics, orientation) (Kukka et al., 2013; Schmidt et al., 2013) • Vary level of user interface details depending on proxemics factors (e.g., distance, orientation) (Marquardt et al., 2012; Vogel & Balakrishnan, 2004; Wang et al., 2012) • Animate icons as a function of proximity to raise awareness of device presence (Marquardt et al., 2012) *External Surface Form or Physical Configuration*: • Strategically placed near traffic flow with empty space around (Brignull & Rogers, 2003; Marshall et al., 2011) • Manipulate form factor of surface (e.g., colourfulness or attractiveness, surface visibility and size, technology used) (Hinrichs et al., 2008; Müller, Wilmsmann, et al., 2009; Schmidt et al., 2013) *External Non-Surface Element*: • User a human helper (Brignull & Rogers, 2003) • Use interesting objects (e.g., robotic arm) (Ju & Sirkin, 2010)
Notified ↓ Intrigued (provides stimuli)	*Dynamic Content*: • Use video instead of text, animated text, or still images (Huang et al., 2008) • Mirror user's own image or silhouette, and/or additional non-content-related visual effects (Michelis & Müller, 2011; Müller et al., 2014, 2012) • Present information in a visually appealing way (Hinrichs et al., 2008) • Proactive animation of content (Seto et al., 2012) *Responding to Presence of Nearby User(s)*: • Connect to nearby user's personal device and display relevant information (Marquardt et al., 2012; Streitz et al., 2003) • Personalization of displayed information (Vogel & Balakrishnan, 2004) • Use visual elements (e.g., aura around user's virtual representation) to follow user's movements (Michelis & Müller, 2011) *"Honey-pot" Exploitation*: • Allow users to stay and watch others interacting from afar (Brignull & Rogers, 2003; Hinrichs et al., 2008; Peltonen et al., 2008) • Display users at remote location (Müller et al., 2014)
Notified ↓ Indifferent & Withdrew (Clarifies irrelevance)	*Enabling Op-out*: • Provide a mechanism (e.g., user blocking gesture) to allow user to indicate they wish to withdraw from system participation (Vogel & Balakrishnan, 2004)

Table 3-2. (Cont'd)

Transition	Existing design recommendations and advice
Intrigued ↓ Exploring (Invites & encourages interaction)	*Proactive User Training*: • Loop video sequence demonstrating available actions (Vogel & Balakrishnan, 2004) • Provide help functions on a hand-held device (Streitz et al., 2003) • Gradually reveal available content as proximity to surface increases (Marquardt et al., 2012) *Others*: • Clearly indicate that interaction will be a low commitment activity, will be quick to do, and enjoyable (Brignull & Rogers, 2003) • Provide users some degree of control over what information to view (Huang et al., 2008)
Exploring ↓ Discovering (Indicates intended interactivity)	*Proactive, Visible Interaction*: • Provide lightweight and visible interaction from the offset (Brignull & Rogers, 2003) • Provide visual cues to indicate possible interaction (Seto et al., 2012; Vogel & Balakrishnan, 2004) *Exploiting Prior User Experience*: • Use familiar interactive components (e.g., nodes resembling buttons) (Hinrichs et al., 2008; Seto et al., 2012) • Display content in familiar forms (e.g., content as decks of cards) (Marshall et al., 2011) *Reactive User Guidance*: • Interactive hints in response to user interaction (Brandl et al., 2008; Seto et al., 2012)
Distracted ↓ Discovering (Demonstrates relevance)	*Actively Track User Behaviour*: • Vary displayed content properties (e.g., size, movement) depending on proxemics dimensions (e.g., distance, orientation) (Wang et al., 2012)
Discovering ↓ Competent (Guides users in learning and using the system)	*"Honey-pot" exploitation*: • Allow participants to watch others using the interface (Brignull & Rogers, 2003; Hornecker, 2008) *Visual Feedback*: • Use liberal icons for gestures (Vogel & Balakrishnan, 2004) • Use animation to communicate proper gesture (Bau & Mackay, 2008; Brandl et al., 2008; Freeman et al., 2009; Hornecker, 2008; Wigdor & Wixon, 2011) • User subtle animation sequence of interaction (Hinrichs et al., 2008)
Frustrated ↓ Competent (Provides system help)	--
Competent ↓ Withdrew (Indicate task completion)	--

3.7.3.1 Gap 1: Capturing Users' Attention and Encouraging Interaction

There is considerable design advice related to transitioning users through the first few stages of the discoverability process, which involves capturing a potential user's attention, enticing them to approach, and then encouraging them to interact with the system. This design advice primarily focuses on appropriating external elements of the surface, or utilizing dynamic or visually prominent content on the surface. Yet, much of this design advice is based on researchers' observations of, or reflections on a deployed application, and is largely unsubstantiated empirically. A few notable exceptions include, the positive correlation between "honey-pot" effect and conversion rate (Müller et al., 2014), the effectiveness in enticing interaction through the use of informative text in the surface (Kukka et al., 2013), and improvement in discoverability of a system's capability through animation (Seto et al., 2012).

Some of these "validated" approaches, however, contradict common design advice, or other validated approaches, adding to the complexity of the design space. For example, Kukka et al. (2013) found that textual approaches were more effective than animated graphics for "communicating interactivity" of a public interactive surface. This finding conflicts with a commonly utilized, and even validated, approach of using graphical animation to communicate potential interactions in a public system[9] (Huang et al., 2008; Marquardt & Greenberg, 2012; Seto et al., 2012). Such confusion, or conflicting advice, may stem from over-simplification of the early stages of interaction in the discoverability process, commonly thought of as the "attract and entice" phase.

To mitigate this over-simplification, DISCOVER divides this phase into three separate states (*Unknowing*, *Notified*, and *Intrigued*) in order to help separate the design concerns for each of them. Using this separation, it is possible to make sense of the contradiction: graphical animation may be more effective to transition users through the earlier states (*Unknowing* and *Notified*), while instructional/informative texts may be more effective in the latter state (*Intrigued*). It is also possible, as Kukka et al. (2013) indicated in their article, that their findings might have been influenced by their user demographic (university students), or other situational factors. Thus, an important area for future research is a more systematic investigation of the recommended design approaches, even previously validated approaches, for capturing users' attention and encouraging interaction, in a variety of public

[9] Typically preferred over text that has limitations in terms language, for example, an exhibit in a museum for international visitors requires multiple translations, or some interaction mechanisms require more than a few words to describe.

contexts, user populations, and application content. It is expected that such variety will have significant impact on the choice of approaches, for example, virtual avatars with traditional input devices (keyboard in kiosk) might be more appealing to an older generation, and novel gestural input might be more approachable for younger ones.

3.7.3.2 Gap 2: Facilitating Interaction with PLISs

When touch-enabled surfaces first appeared, significant research and design focus were placed on developing minimalistic, gesture-based interfaces that were a large departure from traditional widget-based (and affordance-rich) desktop interfaces. These early touch-based interfaces are often criticized by usability experts (e.g., (D. A. Norman, 2010)) as they provide few visual cues to help users understand what types of interaction were possible and recognized. In light of these criticisms, as well as real-world user feedback for touch-based personal devices, recent advances have been made in the design of touch-based interfaces to help guide or scaffold users toward feature discovery and effective system use (Wigdor & Wixon, 2011). Such advances are also applicable in the context of public surfaces, particularly after the *task-oriented entry point* of DISCOVER (Table 3-2).

However, public surfaces have additional design concerns that have to be addressed. For example, unlike non-public surfaces, their public nature puts users “on display” or in a “performing” role when they attempt to engage with the interaction (Reeves et al., 2005). This introduces a unique barrier for PLIS utilization: social inhibition, where many users, particularly adults, are often concerned about “looking silly” when using these systems. This phenomenon, and the commonly reported avoidance behaviour it entails (Müller et al., 2010), is a significant concern that needs to be addressed to ensure system acceptance and adoption. Determining how to provide a “socially safe” way for potential users to learn and become competent with the system is vital for this community.

DISCOVER offers insights into how these concerns can be addressed through state transitions. Two promising approaches are 1) using personal devices (e.g., user’s mobile phone) to bridge the interaction with the public surface by, for example, providing help functions on the personal surface (Streitz et al., 2003), and 2) leveraging existing, well understood social norms to facilitate user interaction with the public surface, for example, by gradually revealing available content on the public surface as a user approaches, or emulating human spatial behaviour (Marquardt & Greenberg, 2012).

3.7.3.3 Gap 3: Supporting Re-engagement and Graceful Withdrawal

As revealed in Table 3-2, little work has been done in transitioning a distracted user back to discovering the system, or in transitioning a frustrated user to be competent with system use. This could be due to the limitation of current technologies in detecting such occurrences. Nevertheless, advances in environment tracking capabilities (Ballendat et al., 2010; Wang et al., 2012) and artificial intelligence-based user-modeling (Martinez-Maldonado et al., 2013) could potentially be used to detect, or predict, user frustration through behavioural patterns within or around the system, and to better assist user re-engagement. In the case of a distracted user, effective approaches utilized in earlier "attract and entice" phases (*Unknowing* and *Notified* states) could be reused, whereas approaches used to facilitate *Exploring* could be employed again to help re-engage a frustrated user.

In addition, being in public view at all times, PLISs have to provide a quick withdrawal mechanism so users can leave gracefully without disturbing the ongoing public activity (Brignull & Rogers, 2003), whether it is in the early stage (content is irrelevant) or later stage (user has finished interacting). DISCOVER considers this as dismissing users, which currently has not been considered thoroughly in the literature. Further research is needed to understand how to best manage graceful withdrawal in the system. Of particular importance to this aspect is understanding how to best deal with any personal information the user has shared with the system during interaction, and clearly communicating the policy upheld by the system (Bellotti & Edwards, 2001).

3.7.3.4 Gap 4: Validating Techniques for Specific Transitions in a Controlled Environment

There has been a growing trend towards conducting in-situ, or "in-the-wild", evaluations, where an interactive surface is installed in a public space and its usage being observed and reported (e.g., Brignull & Rogers, 2003; Hinrichs & Carpendale, 2011; Hornecker, 2008; Michelis & Müller, 2011). These studies are referred to by McGrath (1984) as "field studies" or "field experiments", with the deployed system installed in its natural context, and with as little disturbance from the researchers as possible. While this research approach provides a higher degree of realism to the intended system use, it lacks generalizability (the populations to which the results can be applied) or precision (control over extraneous variables that are not being studied) (McGrath, 1984).

Moreover, it is also particularly difficult to validate that a particular technique facilitates a specific transition, as typically there is no way to control the environment or accurately measure user responses, without intruding or interrupting. Deploying an interactive system in public, especially for the express purpose of conducting in-situ research, also presents tremendous practical challenges, including gaining access to a suitable public venue, ensuring (even temporarily) equipment is sufficiently robust and securely installed to withstand large-scale use and/or misuse, and safeguarding equipment from theft or vandalism. These practical issues present significant barriers to empirically validate design advice from Table 3-2, or other theoretically promising concepts.

Other research approaches, for example, laboratory studies, enable greater control of the environment and measurement, and thus, allow for more precise analysis of user behaviour. With such control, researchers can focus on a specific transition and precisely study the effectiveness of a particular technique. Moreover, laboratory studies provide researchers with more flexibility in prototyping and experimentation without having a fully implemented, or robust, system installed. A significant challenge, however, for studying any system in the laboratory environment is the attempt to emulate, as close as possible, key aspects of the intended system context, in order to mitigate the reduced realism in a laboratory. For example, a key issue in emulating the discoverability process in a laboratory is emulating the early stages of the process, that is, to provide an environment in which a study participant (the potential user) begins in the *Unknowing* state. Yet, in most academic research institutions such as mine, study participants must provide informed consent before participating. This process typically informs them of the study goals (understanding the usability or discoverability of the system) and the activities they will be conducting during the study, and thus inevitably transitioning them directly into the *Notified* state. Further research is needed to develop new research methodologies that can appropriately emulate the “novice”, unknowing user that is typical in real-world public spaces. Chapter 4 describes my effort in developing a methodology for this purpose.

DISCOVER provides a useful template for analyzing existing design recommendations and advice on facilitating the discoverability process. Categorizing this advice based on the favourable transitions through model helps identify which transitions are well understood and which areas of the process warrant further research.

3.7.4 Application Four – As a Tool for System Evaluation

Interaction models, such as DISCOVER, can also serve as a useful tool for the evaluation of proposed public interactive systems, for instance, to provide potential metrics against which the system can be assessed. For example, Michelis and Müller (2011) used their Audience Funnel framework to measure the decrease in users along the “funnel” in terms of *conversion rate,* or the percentage of successful transitions from one phase (or state) of the funnel to the next. Observed conversions (or lack thereof) are then used to identify opportunities to improve system design. Similarly, the user states and transitions defined in DISCOVER provide a set of useful measures for assessing how effectively a particular PLIS system supports favourable transitions through the discoverability process[10]. DISCOVER also provides a framework for identifying unfavourable transitions during system usage, which help to pinpoint possible failure points in the system design.

This evaluative application of DISCOVER can be illustrated by the questionnaires used in the laboratory-based study methodology described in Chapter 4, where its states and transitions before the *task-oriented entry point* were used as a template for evaluating the attraction power of a large surface (a 315cm-diagonal wall-mounted flat vertical surface, interactivity limited to distance affecting visual saliency of content). The focus in the early stages of interaction with PLISs is further detailed in Chapters 5, 6 and 7. The model was also used as a framework in summarizing the lessons learned and findings in this thesis in Chapter 8 to further demonstrate its evaluative capability.

3.8 Chapter Summary

In this chapter, I have presented the DISCOVER interaction model developed to help clarify the unique design considerations of PLISs. The model identifies and isolates stages of interaction with the system using user states, which are connected by transitions facilitated by the interface design. DISCOVER is designed as a multi-tool to inspire, guide, and facilitate further research and design of PLISs. The following chapters illustrate how the model was used for this purpose, particularly towards the early stages of interaction, where an unknowing passerby is transitioned into a notified, intrigued, and exploring user.

[10] An example of the DISCOVER interaction model being used as a framework to analyze study data for menu discoverability can be found in (Seto, 2012, pp. 38–51).

Chapter 4
A Laboratory-based Study Methodology to Investigate Attraction Power of Public Large Interactive Surfaces

This chapter, together with the subsequent three chapters, constitute Steps 2 and 3 of my thesis research illustrated in Figure 1-3. The primary focus of this chapter is the methodology developed and employed to study Public Large Interactive Surfaces (PLISs) in a laboratory environment.

This methodology was developed in collaboration with my co-supervisor Dr. Stacey Scott, and was published in the ACM International Joint Conference on Pervasive and Ubiquitous Computing 2015 (Cheung & Scott, 2015a), where I co-authored and presented the paper. This chapter uses, with permission, some of the figures and descriptions from this paper.

4.1 Motivation of the Laboratory-based Study Methodology

McGrath (1984) described the collection of research evidence as a "strategic dilemma" (p. 32), in which it was not possible to simultaneously maximize all three aspects of the evidence: *generalizability*, *precision*, and *realism*. The author demonstrated this struggle by categorizing research strategies into eight types, and listing the trade-offs involved.

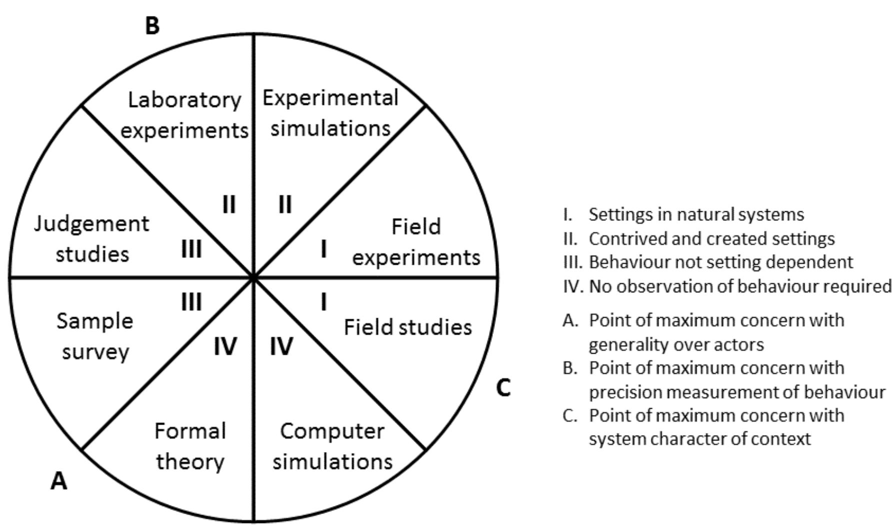


Figure 4-1. A redraw of McGrath's circumplex of research strategies. The spatial relations emphasize the dilemma where simultaneously maximizing all three aspects of research evidence (A: generalizability over population, B: precision in control and measurement of behaviour, C: realism of context) is not possible. Increasing any one of these desired features also reduces the other two, resulting in different limitations and flaws in any particular research strategy.

The in-the-wild study methodologies mentioned in Chapter 2 correspond to the "field experiments" and "field studies" shown in Figure 4-1. As pointed out by McGrath, both in-the-wild and laboratory study methodologies have their merits in allowing researchers to investigate PLISs' usage in different aspects. Depending on the research questions being asked and the implementation completeness of the system, researchers can choose between these two to better evaluate the system design.

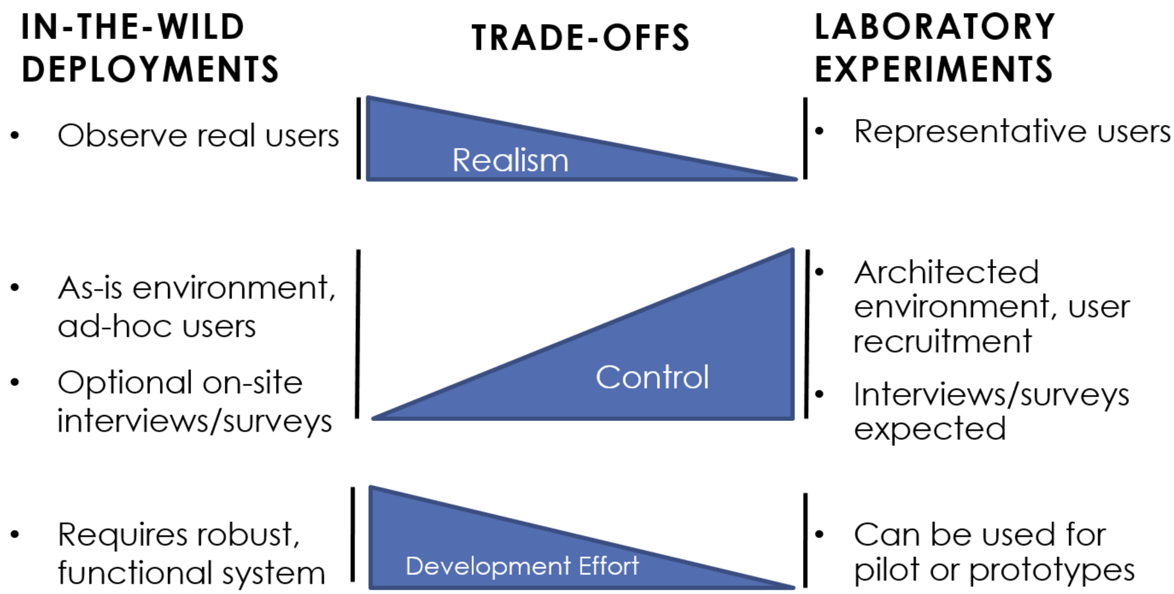


Figure 4-2. Comparison between in-the-wild and laboratory study methodologies. In-the-wild studies and experiments (deployments) possess a higher realism using real users, with the cost of lower control of the study, and more development effort to ensure a working system.

Figure 4-2 summarizes three prominent trade-offs, namely, *realism*, *control*, and *development effort*, between in-the-wild and laboratory study methodologies. Being conducted in the target location, in-the-wild field studies and experiments are high in realism, but provide little control over the environment. They also require more development effort as the interactive surface system has to be functional and robust to ad-hoc uses, likely throughout the entire day. On the other hand, laboratory studies have fewer requirements on the functionality and robustness of the system, and therefore suitable for evaluations of early prototypes. Laboratory studies also gain precision and control by following a standard set of procedures and being conducted within a controlled environment, with a caveat of lowered realism of the results. Moreover, the conventional laboratory study methodology informs the participants about the purpose of the study, and hence would not be applicable in scenarios where participants' knowledge about the PLIS is not assumed (e.g., the *Unknowing* state described in the DISCOVER interaction model). *Experimental deception* (or simply, *deception*), can be used to mitigate this shortcoming, as elaborated in the next section.

Section 4.2 describes the background and details of the special experimental deception developed in this methodology to achieve the following properties:

- To maintain realism of the study, and allow evaluation for early stages of interaction
- To require less setup time and effort for the study, compared to in-the-wild methodologies
- To provide high control of environment and precision in results

4.2 Use of Deception

The need to use deception in a study typically arises from the necessity to "make sure that the research participants are not aware of what aspect of their psychology is being studied in what way" (Bortolotti & Mameli, 2006, p. 260), and is carried out by withholding the true purpose of (or part of) the study from participants. While its morality has been substantially debated, deception does offer some benefits that are not only valued by researchers, but also by participants (Christensen, 1988). The codes of ethics of the American Psychological Association (2010), the British Psychological Society (2009), and the Canadian Tri-Council Policy Statement (2014) permit the use of deceptive methods, provided that the experiment fulfill a number of criteria. The notable ones are to allow participants to withdraw from the study at any time, and to debrief them with all relevant information about the true nature of the experiment when it is sensible to do so. Related work in using deception in research studies is discussed in Section 2.5.

4.2.1 Applying Deception to the Laboratory Study

The key idea of the deception used in this methodology is to omit any mention of the surface being evaluated, and create a consistent scenario across participants. It is achieved by framing the task under a relevant setup in which participants are led to believe it is the primary (and only) purpose of the study. To the participants the study (deception study) appears to be a one-factor within-participant experiment, where each participant completes two counter-balanced conditions[11]. In actuality, each participant is assigned to only one of the actual study conditions. The decision of having just one condition is based on the consideration that exposure to multiple conditions may take too long and raise suspicions about the true nature of the study. This decision also avoids learning effects across conditions. The mixed-study format is shown in Table 4-1.

Table 4-1. Mixed study design format of the methodology. The deception task is set as a counter-balanced one-factor within-participant study. In actuality it is a two-factor between-participant study.

***In this example two factors are being studied, hence a two-factor between-participant study.**

		One-factor within-participant design for deception study	
		Deception task (Condition A)	*Deception task (Condition B)*
Two-factor between-participant design for actual study*	*Control*	Condition 1A	Condition 1B
	Factor 1	Condition 2A	Condition 2B
	Factor 2	Condition 3A	Condition 3B
	Factors 1&2	Condition 4A	Condition 4B

To provide flexibility to the deception task to better simulate a desired scenario, and to keep the participants from discovering the deception prematurely, four criteria of choosing the deception task are established:

C1. **Believability** – Being a believable task which participants are already familiar with, and have experience in carrying out in a public setting,

C2. **Competitiveness** – Requires a certain degree of attention to compete with the surface,

C3. **Movement** – Includes a movement component to simulate passing-by behaviour, and

C4. **Surface Visibility** – Participants should have opportunities to look around in the environment by having the surface in their line of sight occasionally.

As the goal of the deception task is to emulate the type of natural distractions that may be present in a realistic public setting, the deception task designed using the above criteria will have parallels

[11] The decision of using a one-factor within-participant experiment as the deception study is due to the fact that it is one of the most generic approaches for an observational study. It is therefore possible to use other approaches as the researcher sees fit.

with “distraction” or “secondary” tasks used in HCI studies focused on attention and interruptions (e.g., Adamczyk & Bailey, 2004; Cutrell et al., 2001; Sasangohar et al., 2014). However, it possesses several key differences to those distraction tasks in terms of usage. First, in previous studies involving “distraction” or “secondary” tasks participants were always informed of both the primary and distraction tasks. Second, in those studies participants were required to actively engage with the distraction task, for example, to answer on-screen questions during the tasks. The goal of the deception task here is to make participants believe that the deception task is the primary, and only, task they are engaging with during the study. From the researcher’s perspective, the deception task serves as a typical distraction that may exist in a real world setting, and may prevent the surface from capturing (and ultimately holding) passersby’s attention.

4.3 Phases of the Methodology

The methodology can be broken down into four phases: *Preparation*, *Deception*, *Reveal*, and *Analysis*. The *Preparation* phase is performed once before the study; the *Deception* and *Reveal* phases are performed for each participant; and the *Analysis* phase is performed once after the study. In the remainder of this chapter, “display” is used synonymously with “surface” to maintain a consistent naming convention in the Appendices used for the study methodology.

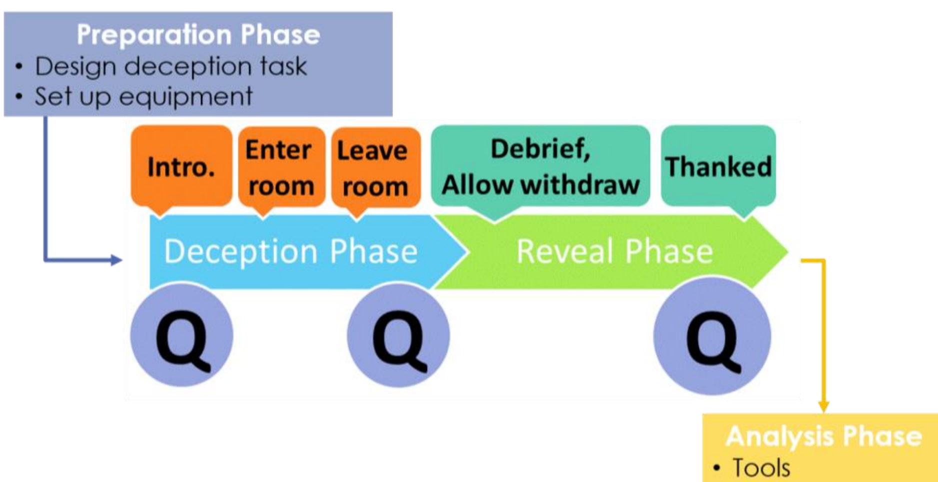


Figure 4-3. Four phases of the laboratory-based study methodology: Preparation (performed once before study), Deception, Reveal (performed in tandem with the Deception phase for each participant), and Analysis (performed once after study). Components with ‘Q’ indicates use of a questionnaire.

4.3.1 Preparation Phase

In the Preparation phase, the researcher designs the deception task used for the study by following the four criteria listed in Section 4.2.1, and recruits participants using the designed deception task. The description of this deception task, along with the actual study purpose, is then included in the ethics application, as required by the research institution (see Appendix A for reference, actual format depends on institution regulation). The researcher also implements a prototype that functions as the interface of a PLIS incorporating the design concepts that are being evaluated. Since it is a prototype, it is possible to implement only the parts of the application software relevant to the design concepts (e.g., the attention drawing parts for this thesis), instead of a complete system.

To further strengthen the deception task, the venue of the study (e.g., the experimental room for this thesis) has to be designed to exhibit features of the scenario described in the deception task. For example, labels as signage, and multiple surfaces as additional distraction.

4.3.2 Deception Phase

The Deception phase begins when a participant shows up for the study. The participant is first briefed with the deception task, including the fabricated motivation and procedures. After filling in a demographic questionnaire (designed to reinforce the deception task, see Appendix A.6 as an example), the participant is led to the experimental room with one of the displays already running the prototype, and the rest of the displays showing the control condition. The room is described as a multi-purpose research space with several on-going studies set up so the participant would feel comfortable with the surrounding displays, and more importantly, not question their presence. At no point are these displays introduced or set up in the presence of the participant. The deception task is then completed under the counter-balanced conditions (Conditions A and B in Table 4-1).

Before the study, the researcher assigns one of the actual conditions (Control, Factor 1, Factor 2, and Factor 1&2 in Table 4-1) to the participant, and sets up the displays accordingly. During the deception task, the researcher provides instructions related to the task, while observing how the participant responds to the factor(s) being manipulated. The displays are never mentioned.

Upon finishing the deception task, the participant is led out of the experimental room and asked to complete a post-session questionnaire. The questionnaire is designed to first ask questions closely related to the deception task, and then begins to probe for impressions of the surroundings. These questions are designed with close- and open-ended questions based on the transitions described in

DISCOVER, for example, whether the participant noticed the content on the displays, and what they think they can do with the displays (see Appendix A.7 as an example).

4.3.3 Reveal Phase

After the post-session questionnaire is completed, the researcher asks the participant probing questions to see if they have any suspicions about the study. Then, the researcher reveals its real purpose, and explains why this purpose is not provided in the beginning. Here the participant can decide if they wish to withdraw from the study, or wish the researcher to proceed with the remainder of the study. They are also provided with contacts of counselling services, to whom they can contact directly if they feel uncomfortable in any way. These steps are required as per the university's research ethics policies on use of deception in research studies.

Finally, a second post-experiment questionnaire with more elaborate questions about the displays is given to the participant to further elicit their perception towards the displays (see Appendix A.10 as an example). Upon finishing, the participant is thanked, paid (as promised in the recruitment process, and regardless of whether they complete the entire study or withdraw at any point during the study), and asked to not share their experience, or disclose the real purpose of the study to anyone.

4.3.4 Analysis Phase

The use of a laboratory experimental setup allows collection of data from the following sources: video (and audio) recordings, researcher notes, and questionnaire answers. These sources of data can then be analyzed qualitatively and quantitatively.

Analytical tools can be used to evaluate the data, generate results, and establish design implications. For qualitative data, tools such as Affinity Diagramming (H. Beyer & Holtzblatt, 1999), Grounded Theory and Coding (Strauss & Corbin, 1998) can be used to reveal usage patterns and recurring behaviours. For quantitative data, various statistical analysis tools (e.g., Analysis of Variance ANOVA) can be used to extract underlying relationships between data points.

4.4 Methodology Effectiveness

A pilot (Chapter 5) and an improved study (Chapter 6) were conducted to both evaluate this methodology and investigate the effectiveness of potential design concepts for increasing engagement with a surface. Regarding the methodology effectiveness, both studies indicated that the deception task had successfully kept the studies' true purpose hidden from the participants, who completed the deception task without signs of suspicion. After being explained to with the motivation behind the study, no participant expressed concern about the deception involved. Most participants were also able to recall the setup of the experimental room, elaborate on their answers, and provide suggestions (for the deception task during the *Deception* phase, and for the large surface during the *Reveal* phase).

As expected, the entire study took significantly less time and effort to setup compared to a full field deployment (weeks instead of months). First, the administrative effort of gaining access and permission to setup the large surface in a public setting was not necessary. Second, the physical effort of relocating surface hardware was not necessary. This was a significant benefit, as large-format surfaces, such as the front projected 315cm-diagonal screen installed in the experimental room for the study, were not trivial to safely and securely install in a public setting. As the large surface equipment was stationary and already available in the experimental room, safety, privacy, and legal concerns were minimized, which also led to a shorter turnaround time for institutional ethics approval than previous experiences in gaining approval for similar field studies. Finally, the methodology allowed focus on the early stages of interaction, eliminating the need for a completely robust and working system, as would be expected by users in a public setting.

As typical of a laboratory setting, significant control over the study was maintained. It was possible to have multiple sources of data, and ways to collect them. It was also possible to control which condition to experiment with, and apply the same scenarios repeatedly for each participant.

4.5 Chapter Summary

In this chapter, I have presented the phases involved in the methodology developed to evaluate the effectiveness of interface designs in drawing people's attention and communicate interactivity by a PLIS system. While this methodology is open for any number of potential design concepts (as factors in the between-participant study), this thesis evaluated two visual concepts, which were carefully chosen from prior research so the findings could be compared. Results from these studies were found to be consistent with reported findings from field studies of the design concepts, suggesting that the methodology effectively emulated relevant in-the-wild conditions for a public context. The results also provided additional insights (e.g., direct feedback from users about their perceptions towards the surface's interactivity) that were often not available in the prior research. These findings from using this methodology will be discussed in detail in the following chapters (Chapter 5 and Chapter 6).

Chapter 5
Pilot Study of Animated Content

This chapter describes the experimental setup and procedures for the pilot study that employed the methodology detailed in the previous chapter, followed by a discussion of the results from the study. The two main goals of the pilot study were: 1) to provide a proof-of-concept to the proposed methodology in terms of the setup and procedures, allowing the evaluation of its feasibility and aspects for improvement, and 2) to evaluate a number of potential animated content concepts for the more promising ones to be used in the next iteration of the study.

This study was conducted in collaboration with my co-supervisor Dr. Stacey Scott, and was published in the ACM International Joint Conference on Pervasive and Ubiquitous Computing 2015 (Cheung & Scott, 2015a), where I co-authored and presented the paper; and in the ACM International Conference on Interactive Tabletops and Surfaces 2014 (Cheung, 2014), where I authored and presented the paper. This chapter uses, with permission, some of their figures and descriptions.

5.1 Experimental Setup

This section describes the steps taken to set up the pilot study (the *Preparation* phase) as defined in Section 4.3. Specifically, the design of the deception task, and the potential animated content concepts being evaluated.

5.1.1 The Deception Task

The deception task was designed and advertised under the disguise of a study titled "Usage Pattern with On-the-go Mobile Applications", aiming at investigating how mobile app (e.g., calendar, clock, settings) usage was affected when a person was walking, and was described as follow:

> *"…an observational study on how different on-the-go mobile scenarios affect the usage of typical tasks (e.g., looking up information, check status updates) on one's own portable device (e.g., a smartphone, a tablet), particularly when the user is moving as opposed to remaining stationary."*

The two counter-balanced conditions were *with* and *without* using apps on the participant's mobile device. During each condition the participant was asked to walk between labeled points in the experimental room, and in the *with*-condition asked to use a number of apps during the walking sequence. This task was chosen because it satisfied all the four criteria established:

C1. **Believability** – Use of mobile app in a public setting is commonly seen nowadays,

C2. **Competition** – Using an app requires attention to the device,

C3. **Movement** – Participants were asked to walk between labels, and

C4. **Surface Visibility** – Walking instructions, in the form of destination label points, were provided as the task proceeded. The destination label points were selected so that the routes involved covered all the possible directions a passerby could take in relation to the surface (i.e., away, towards, across).

In actuality, this study focused on measuring the effectiveness in drawing unknowing participants' attention to a large surface while carrying out the deception task, as achieved by animating the displayed content's saliency (speed and/or contrast). The study format is summarized in Table 5-1.

Table 5-1. Mixed study design format of the pilot study. The deception task was set as a counter-balanced one-factor within-participant study of mobile app usage. In actuality it was a between-participant study of animated (adaptive) content speed and/or contrast.

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="2">Mobile App Usage Study
(Deception study)</th></tr>
<tr><td>Using apps
(Condition A)</td><td>Not using apps
(Condition B)</td></tr>
<tr><th rowspan="4">Study on effectiveness of animating saliency (Actual study)</th><td>Control</td><td>Condition 1A</td><td>Condition 1B</td></tr>
<tr><td>Adaptive speed</td><td>Condition 2A</td><td>Condition 2B</td></tr>
<tr><td>Adaptive contrast</td><td>Condition 3A</td><td>Condition 3B</td></tr>
<tr><td>Adaptive speed & contrast</td><td>Condition 4A</td><td>Condition 4B</td></tr>
</table>

Documentations included in the ethics application for this study can be found in Appendix A. One notable difference from typical ethics application for studies involving human participants was the inclusion of the "Use of Deception" section. This additional section was required, as in the beginning of the study its real purpose was withheld from the participant. A strict protocol of revealing the deception and re-acquiring consent afterwards was also included in the ethics application.

5.1.2 Potential Animated Content Concepts Evaluated

This pilot study evaluated the effectiveness of drawing people's attention using two animated content concepts, *speed* and *contrast*, both based on animating the saliency of the content using user's proximity towards the large surface as a parameter.

Drawing on previous literature in attention (presented in Section 2.6.1), two visual stimuli, *speed* and *contrast* of the displayed content, were used as the bottom-up saliency attributes, for their generalizability across various types of content. Inspirational quotes in the appearance of virtual Post-it notes, were used as context-relevant content, for their familiarity. The proximity dependent animation of the visual stimuli was inspired by the proxemics model proposed by Marquardt and Greenberg (2012), where interaction mechanisms adapt to the proximity of the user to the system. Here, only the first three of the four proxemics distance zones in the order of decreasing proximity (*Public*, *Social*, *Personal*, *Intimate*) were used due to their relevance to the early stages of interaction. Referring to the actual study in Table 5-1, the *Adaptive Speed* condition was designed as decreasing the speed of the virtual Post-it notes in a stepwise manner as the participant walked closer to the large surface, with the intent of making the content easier to see and interact with at lower speeds. Similarly, the *Adaptive Contrast* condition was designed as increasing the contrast against the background in a stepwise manner. To highlight the change, the large surface was divided horizontally into three even grids, so the change only appeared in the grid closest to the participant. More details of the prototype can be found in the next section.

5.1.3 Prototype and Experimental Room Setup

As one of the aforementioned methodology's advantages, a prototype implementing only part of the application software relevant to the design concepts was developed, saving much development time and effort. Institutional ethics clearance was also granted in a relative short time (a few weeks) as the study was designed very similar to a typical laboratory study.

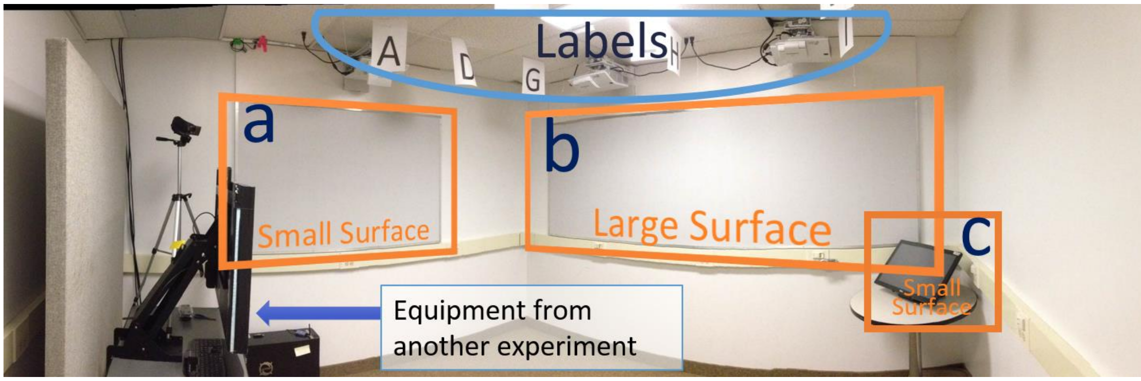


Figure 5-1. Laboratory setup of the prototype in the pilot study. Surface 'b' was the large surface, surfaces 'a' and 'c' were the additional small surfaces for distraction. Labels were attached to the ceiling to navigate participants. A camcorder was installed at the left corner to record the deception task.

a) The small surface 'a' shows photos of the university.

b) The large surface 'b' and small surface 'c' show inspirational quotes as virtual Post-it notes.

Figure 5-2. Content shown in the small and large surfaces during the pilot study.

Figure 5-1 shows the setup in the pilot study. Three active surfaces were used in the pilot study: a 178cm-diagonal small surface 'a', a 315cm-diagonal large surface 'b', and a 59cm-diagonal small surface 'c'. Both the small surfaces 'a' and 'c' were used as distractions and did not respond to participants' proximity. Although labelled as a "small surface", surface 'a' was adequately large enough to be considered as a large surface in a public setting, and was used as a competing surface against the large surface 'b' showing a different set of content (photos of the university, as opposed to the inspirational quotes as virtual Post-it notes, as illustrated in Figure 5-2). One Hitachi CP-AW251N ultra-short-throw projector was used to project the content to the small surface 'a' at 1280x800 pixel resolution; two projectors of the same model were used together to project the content to the large surface 'b' at a 2560x800 pixel resolution. The small surface 'c' was a monitor at a 1920x1080 resolution. Table 5-2 summarizes the equipment used in the pilot study.

Table 5-2. A summary of the equipment used in the pilot study. Additional surfaces and equipment were added to facilitate the deception task, and the comparative study nature.

Equipment	Placement	Purpose
A 178cm (70inch) diagonal small surface 'a' • Content displayed by a Hitachi CP-AW251N ultra-short-throw projector, at 1280x800 pixel resolution • Application running in a Windows 7 machine, written in Processing	On the left of the experimental room	As a surface competing for attention, showing a set of university's photos
A 315cm (124inch) diagonal large surface 'b' • Content displayed by 2 Hitachi CP-AW251N ultra-short-throw projectors, at 2560x800 pixel resolution • Application running in a Windows 7 machine, written in Processing	In the middle of the experimental room	As the large surface under study, showing inspirational notes; content's saliency was controlled according to the experiment conditions assigned to the session
A 59cm (23inch) diagonal small surface 'c' • Content displayed by a DELL S2340T touchscreen monitor (touch capability was not used), at 1928x1080 pixel resolution • Application running in an Android iStick device, written in Processing	At the front right corner of the experimental room	As a surface competing for attention, showing the same set of inspirational notes as in large surface 'b'
A web-cam connected to a Windows 7 computer in another room	At the back of the experimental room	To provide another experimenter with a live feed of the position of the participant, used as part of the Wizard of Oz approach
A vertical board with a static pattern used in another experiment	At the back of the experimental room	As a surface competing for attention, and reinforcing the deception task
A Sony high-definition camcorder	At the back left corner of the experimental room	To record the videos and audios during the session
Nine labels with alphabets A to I, arranged in a grid formation	At the ceiling of the experimental room	As navigation points for the participants to walk between, without the need to use the surfaces as references

In addition to the surfaces, a vertical board was positioned at the back of the experimental room. It was intentionally left there to promote the idea of the multi-purpose experimental room (equipment from another experiment) so participants would not ask about the equipment's specifics, and as an extra distraction artifact. The labels at the ceiling were used to instruct participants to navigate inside the experimental room without any mentioning of the surfaces, and to mimic heads-up direction signage in public places. A camcorder was positioned at the back of the experimental room to record the navigation performed by the participants. At the other corner (not shown in Figure 5-1) was a small chair and desk for the researcher to take notes and instruct the participants where to walk.

5.2 Execution of the Pilot Study

To further reduce development time for the prototype, a Wizard of Oz approach (Preece et al., 2002) was used to simulate the proximity sensing capability of a large interactive surface, which was in turn used to control the speed and contrast of the content at large surface ‘b’. This approach was achieved by installing a web-cam (shown as part of the equipment from another experiment) at the back of the experimental room, through which a research assistant in another room monitored the participant’s position and remotely controlled the speed and contrast of the content.

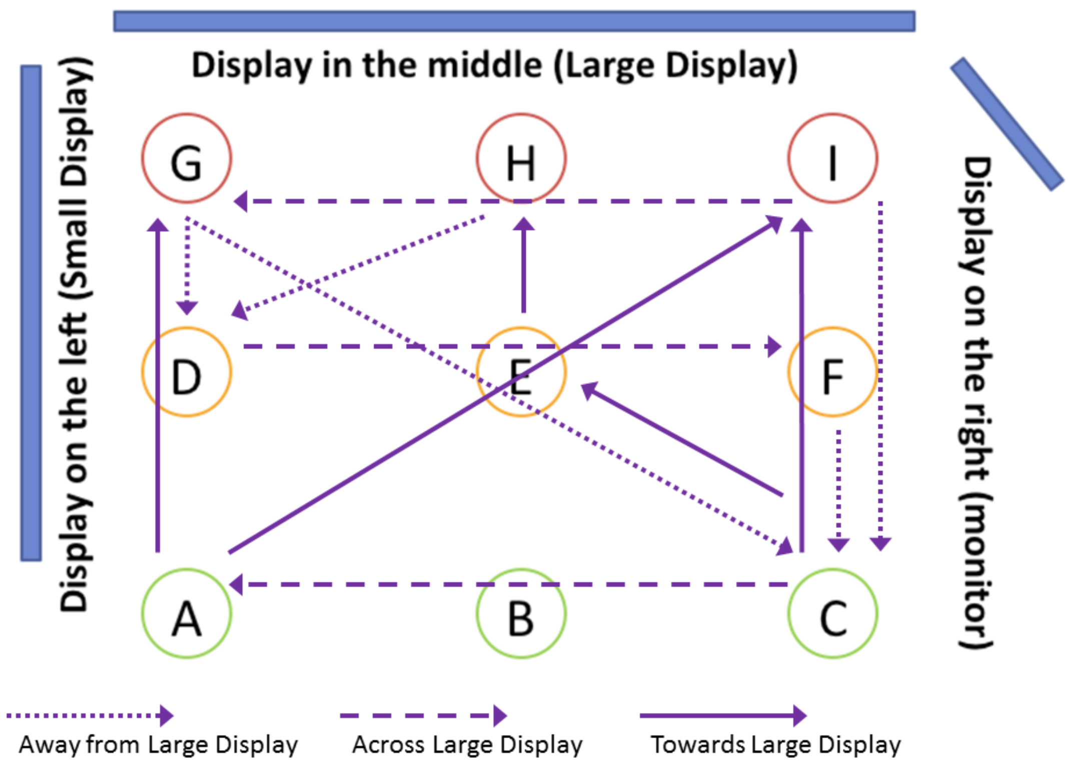


Figure 5-3. Floor plan of the experimental room in the pilot study. Labels were attached to the ceiling to not interfere with movements and made the participant look up for destinations, therefore having the displays* in their line of sight occasionally. Arrows in the figure indicates the paths taken by the participant, including away from, across, and towards the large display.

***The word “display” is used instead of “surface” to remain consistent with the terminology used in the study questionnaires.**

Figure 5-3 shows the placement of the labels used to navigate the participants during the deception task. Navigation instructions were given as one-stop routes (e.g., from A to E), or two-stop routes (e.g., from A to G, then G to H). These routes were designed to cover all possible movement directions in relation to the large surface (i.e., towards, away from, and across). Each route was presented after the other was completed, verbally by the researcher. The vertical positioning of the labels (from the large surface to the back of the room) created three proxemics zones with boundaries at approximately 1 metre and 1.8 metre away from the large surface, corresponding to the personal, social and public zones from the proxemics model.

Three sets of questionnaires were provided to each participant at various times as shown in Figure 4-3: a demographic questionnaire before the session to reinforce the deception task, a post-session questionnaire with probing questions about impressions of the surroundings, and a post-experiment questionnaire after revealing the deception for further input from the participant. Details of the questions can be found in Appendices A.6, A.7, and A.10.

The pilot study was conducted in March 2014 for one week with 16 participants (10 males and 6 females) recruited from the University of Waterloo. All the participants completed both the *Deception* and *Reveal* phases, in less than an hour each.

5.3 Findings from the Pilot Study

Statistical analysis (Analysis of Variance ANOVA) was used to evaluate the effectiveness of the animated saliency (adaptive speed and contrast) in drawing participants' attention to the large surface, and no significant results were found from the questionnaire answers. This was believed to be caused by the low number of participants (four for each condition); and the saliency being too subtle to notice, as reflected in the answers from the questionnaires. Nevertheless, based on participants' feedback and in-session observation, some key findings were summarized as follow:

- KF1: None of the participants suspected the undertaken task was a deception task. Some even believed that the surfaces were used to simulate traffic or roadside buildings.
- KF2: After being explained to with the motivation behind the study, no participant expressed concern or discomfort about the deception involved.
- KF3: After being led out of the experimental room to answer the post-session and post-experiment questionnaires, most participants were able to recall the setup, elaborate on their answers, and provide suggestions on what can be improved in attention drawing.

- KF4: While believable, the deception task of using mobile apps required too much attention from participants during the walking sequence, providing little opportunity to look around the environment. The labels were also too straight-forward for participants to glance quickly and walk without looking, which was less likely in a realistic public space.
- KF5: The virtual Post-it notes drew little attention beyond being recognized with some quotes on them, especially when compared to the close-by control surface (small surface 'a') showing photos of the university.
- KF6: The adaptive speed change (slowing down when a user was close) and contrast change (higher contrast when a use was close) were generally too subtle to notice and, thus did not evoke a feeling of interactivity.

Another interesting finding was that most participants did not consider any of the surfaces to be interactive. However, a few of them thought the touchscreen monitor (small surface 'c'), which displayed the same content as the large surface 'b', was interactive. This might be due to their familiarity with prevalent consumer touchscreen monitors.

5.4 Chapter Summary

In this chapter, I have presented details of the pilot study using the laboratory-based study methodology described in Chapter 4. As mentioned in the beginning of this chapter, the goals of this pilot study were to provide a proof-of-concept to the proposed methodology, and to suggest promising animated content concepts for the next iteration of the study. It served its purpose by providing some key findings, which were used as guidelines in re-examining and improving the study design, as described in the next chapter.

Chapter 6
Improved Study of Animated Content and Shadow Visualizations

This chapter describes the experimental setup and procedures for the improved study based on the pilot study detailed in Chapter 5, and discusses results from the study. This study had a similar focus as the pilot study, but also added the use of shadow visualizations based on existing research to the evaluation. A comparison of the results between this study and that from existing ones is made to demonstrate the usefulness of the methodology.

This study was conducted in collaboration with my co-supervisor Dr. Stacey Scott, and was published in the ACM International Conference on Interactive Tabletops and Surfaces 2015 (Cheung & Scott, 2015b), where I co-authored and presented the paper. This chapter uses, with permission, some of the figures and descriptions from this paper.

6.1 Proxemic Interactions Design Approach

Advances in sensing technologies have enabled interactive systems to be more perceptive to the environment and provide finer responses to their users. For example, depth sensors (e.g., Microsoft Kinect) can be used to track user movements and respond in real-time (e.g., Müller et al., 2014, 2012). With a more elaborate tracking setup, richer information such as distance, orientation, identity and location can be obtained (Marquardt, 2011), thus providing even finer responses tailored to the current user and situation.

6.1.1 Hall's Theory of Proxemics

The term *proxemics* was coined by Hall (1966), a cultural anthropologist, in describing the use of space in interpersonal communication. The proxemics theory correlates four proxemics zones (*Public*, *Social*, *Personal*, *Intimate*) to decreasing levels of proximity, each defined by a distance range (see Figure 6-1). This theory was originally used to describe how distance between people impacted their behaviour, but could be extended to how a person organizes their space (Hall, 1963).

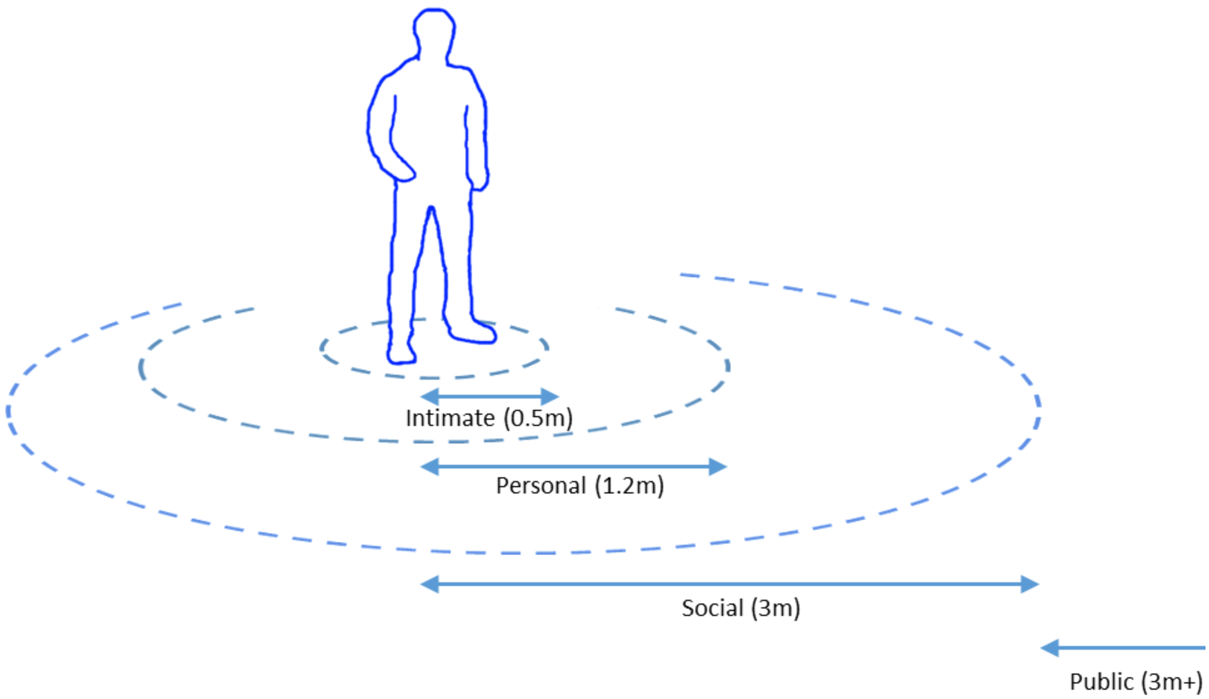


Figure 6-1. An illustration of Hall's theory of proxemics (Hall, 1966), describing the use of space in interpersonal communication. Four proxemics zones are defined by the distance from the person, leading to different social behaviour towards others.

Marquardt and Greenberg (2012) proposed associating the rich tracking information with the *proxemics* theory, and applied this combination to the interaction dialog between surfaces and users that resembled common proxemics social norms. Under this *proxemic interactions* design approach, contents of an interactive system adapt to changes in the sensed information (e.g., reveal more details as the user walks closer). This approach has received growing interest from the interactive surface community looking into increasing a system's power to capture and maintain attention (e.g., Proxemic Peddler (Wang et al., 2012)), or to facilitate more sophisticated and nuanced interaction forms that build on familiar social behaviour (e.g., cross-device information transfer (Marquardt et al., 2012), presentation content manipulation (Lucero et al., 2009), and notification management (Vogel & Balakrishnan, 2004)). A defining feature of this design approach is to provide different feedback, typically visual, in relation to the user's proximity to the surface, using either discrete distance "zones" (e.g., Brignull & Rogers, 2003; Lucero et al., 2009; Streitz et al., 2003; Vogel & Balakrishnan, 2004), or continuous distances to drive feedback changes (e.g., Wang et al., 2012).

6.1.2 Applying the Proxemic Interactions Design Approach in the Improved Study

After balancing between fidelity of sensed information and effort of equipment setup, proximity (to the surface) was used as the sole proxemics information for determining the degree of visual effects applied to visual stimuli in the improved study; instead of other proxemics information (e.g. orientation) that would require more elaborate setup. Specifically, the proxemics information was used to control two types of motion changes of content, namely, *adaptive speed* and *adaptive trajectory*. In addition, only the first three proxemics zones (*Public*, *Social*, *Personal*) were used for their relevance to the early stages of interaction with PLISs.

Also, learning from the findings in the pilot study (KF6 in the previous chapter) where speed and contrast changes were too subtle to notice, it was decided to only keep the adaptive content speed and increase the degree of change by adapting content trajectory (direction of movement). It was also decided to incorporate an additional visual stimuli using a shadow visualization of the participant (an abstract, white silhouette resembling the body shape of the participant, see Figure 6-6 as an example) into the improved study. Figure 6-2 shows how the speed, trajectory, and shadow were related the user's proximity to the surface.

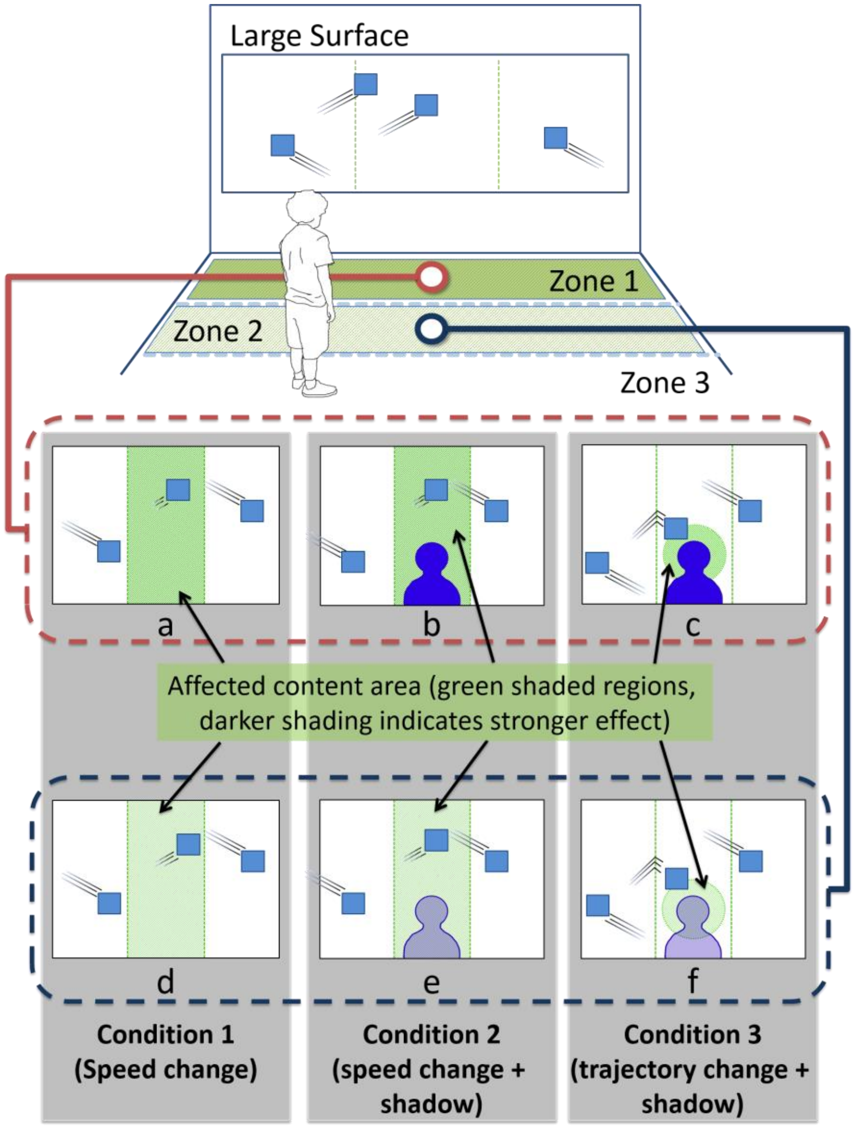


Figure 6-2. Application of the proxemic interactions design approach to the studied interface. Zone 1 (closest to large surface, shaded darkest) applies the strongest visual effect. Zone 3 (furthest from large surface, not shaded) applies no effect. Effects are only applied to the grid section on the large surface closest to the user. Parts a, b, and c represent the effects in Zone 1 and the middle grid. In Conditions 1 & 2, images within the grid section move much slower than elsewhere (a & b). In Conditions 2 & 3, a shadow with high contrast is shown (b & c). In Condition 3, images change trajectory towards the shadow (c & f) in relation to an invisible circular region around the head of the shadow (a "halo"), with speeds proportional to their own distances from the region. Parts d, e, and f show the more moderate effects applied in Zone 2.

6.1.2.1 Studied Visual Concept 1: Adaptive Speed

In adaptive speed, speed of content (images) decreased in a stepwise manner as the user walked closer to the surface, and crossed from zone to zone (specific speed values used in the study can be found in Appendix D). This relation between speed and proximity was based on the rationale of providing users with enough time to look at and interact with the content when they were within touching distance to the surface, similar to the Proxemic Peddler system (Wang et al., 2012). The stepwise (instead of continuous) change in speed was based on the findings from cognition literature stating that jerky content motions are more effective in capturing attention (Sunny & von Mühlenen, 2011).

6.1.2.2 Studied Visual Concept 2: Adaptive Trajectory

In adaptive trajectory, content (images) gravitated towards the user as they walked closer to the surface. Similar to adaptive speed, this change was triggered by the user crossing from zone to zone, and became more apparent at the zone closest to the surface. In contrast to the stepwise decrease in speed in adaptive speed, however, two modes of trajectory changes were used in relation to an invisible circular region (a "halo") around the projected position of the user: at Zone 2, a more moderate effect where the images changed their direction towards the user and then kept the same speed as they passed through the region; and at Zone 1, a stronger effect where the images changed their direction towards the user and then followed the user at the boundary of the region. In both cases, the speed was changed in proportion to the distance between the corresponding image and its designated position (centre of the region at Zone 2, boundary of the region at Zone 1).

6.1.2.3 Studied Visual Concept 3: Participant's Shadow

In adaptive shadow, a silhouette of the user was projected as part of the interface, as if the user was casting a shadow on the surface. Müller et al. (2012) used a similar technique to increase the attraction power of the surface and communicate its interactivity (therefore having the potential to address KF6 where interactivity was not well perceived). In this study, however, proxemics information was used to determine the contrast of the shadow: the closer the user was to the surface, the higher in contrast of the shadow (represented by the shadow's transparency continuously changed in relation to proximity, specific alpha values used in the study can be found in Appendix D). This design repurposed the use of contrast to a single but bigger target (user's shadow was much bigger than an image), and used the contrast to promote the idea of "come closer to reveal more".

6.2 Experimental Setup and Execution

The improved study used a similar structure as the pilot study, except a few modifications in effort to address some of the key findings from the pilot study.

To address KF4 (deception task requiring too much attention, labels being too straight-forward), the Mobile App Use task was replaced with a Navigation task using a mobile device, where participants were provided with walking instructions visually on the mobile device (Condition A), or verbally by the researcher (Condition B). The task description was thus advertised as:

> *"…an observational study on how different forms of navigating instructions affect the way a person arrives at a destination …to walk between several marked points while being provided with navigating instructions verbally and/or visually."*

Also, the labels that were originally attached to the ceiling were instead presented in a grid format (A-B-C in one direction, 1-2-3 in the other), as shown in Figure 6-3. Instructions were given to the participants as either one-step routes (e.g., from C1 to A1) or two-step routes (e.g., from A1 to A3, then A3 to C3), as shown in Figure 6-4. With these changes the task still fulfilled all four established criteria of a deception task, and increased the likelihood of the content on the surfaces being seen.

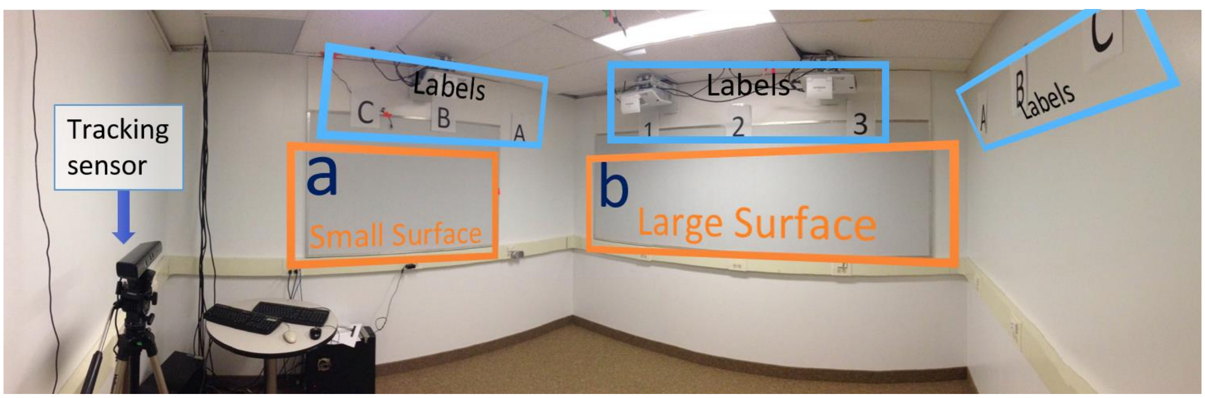


Figure 6-3. Laboratory setup for the improved study design. Labels were attached to the walls to better simulate signage, with a grid layout for a less straight-forward navigation. A Microsoft Kinect was used at the back of the room to capture the silhouette of the participant and measure depth, replacing the Wizard-of-Oz approach used in the pilot study.

The distance between the participant and the large surface 'b' was instead measured using a depth-sensing camera (Microsoft Kinect), replacing the Wizard-of-Oz approach used in the pilot study. The depth data from the camera was also used to generate the participant's shadow.

To address KF5 (content as Post-it notes drew little attention), all surfaces were set to show a unified set of photos of the university, with the small surface ‘a’ as the control condition at all times (content floating and bouncing off edges at constant speed, and without participant’s shadow). The monitor (small surface ‘c’) was removed to avoid additional distraction.

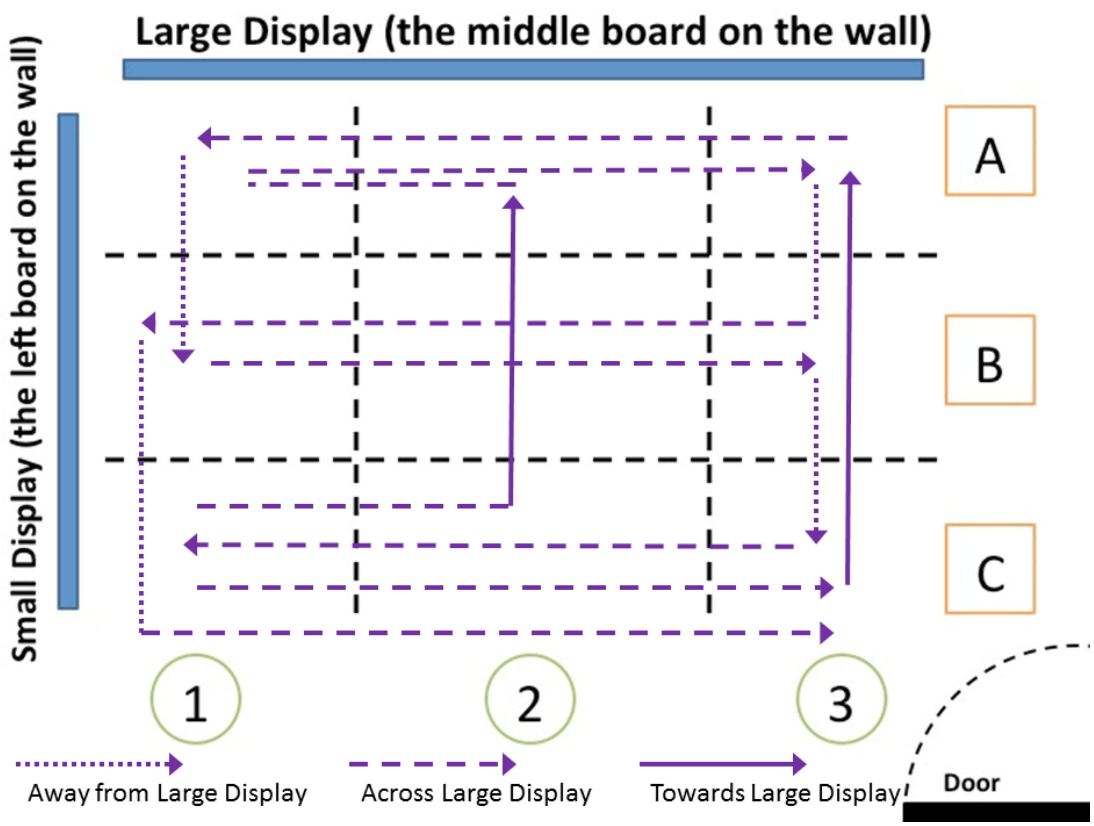


Figure 6-4. Floor plan of the experimental room in the improved study. Labels were attached to the walls as a less straight-forward grid to navigate. Arrows in the figure indicates the paths taken by the participant, including away from, across, and towards the large display* (Only 15 of the 21 paths are shown here, the full list of paths can be found in Appendix B.4).

***The word “display” is used instead of “surface” to remain consistent with the terminology used in the study questionnaires.**

By using the small surface ‘a’ as the control condition, the number of within-participant conditions were reduced from four to three (see Table 6-1).

Table 6-1. Improved study design . The deception task was set to walking with the navigation instructions provided verbally (by the researcher) or visually (on a mobile device). The small surface ‘a’ was used as a control in all conditions, thus reducing a condition in the actual study.

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Navigation Study
(Deception study)</td></tr>
<tr><td>Verbal (Condition A)</td><td>Visual (Condition B)</td></tr>
<tr><td rowspan="3">Study on effectiveness of animated content and shadow visualizations (Actual study)</td><td>Adaptive speed (Condition 1)</td><td>Condition 1A</td><td>Condition 1B</td></tr>
<tr><td>Adaptive speed & shadow (Condition 2)</td><td>Condition 2A</td><td>Condition 2B</td></tr>
<tr><td>Adaptive trajectory & shadow (Condition 3)</td><td>Condition 3A</td><td>Condition 3B</td></tr>
</table>

The same procedures were used as in the pilot study, except the questionnaires were modified to reflect the new navigation deception task, with one additional question in the post-session questionnaire asking specifically if the participant noticed whether the surface responded to them (and in what way). A condition-specific questionnaire was also added after the post-experiment questionnaire to further elicit any feedback or comments about the surfaces (see Appendix B.10 for full details of the questionnaires). All the questionnaires were still presented outside the experimental room so participants had to recall what they experienced.

6.3 Data Collection and Analysis

The improved study took place at the University of Waterloo in September 2014 for two weeks, where 30 participants were recruited (21 males, 9 females). Data were collected from the questionnaires, researcher’s notes, and video recordings. These data were analyzed for attention drawing by keeping the two deception conditions (verbal and visual) separated, so as to provide a clearer picture of the results and illustrate two possible scenarios: a passerby loosely focused on the surrounding environment (while listening for navigation instructions, hence verbal), and a passerby heavily focused on a separate object (the mobile device for navigation instructions, hence visual).

To analyze the effectiveness of visual concepts against the control condition (the small surface 'a'), repeated measures Analysis of Variance (ANOVA)[12] tests were applied on the collected Likert-scale responses within participants. To compare the visual concepts against each other, one-way ANOVA tests on the Likert-scale responses across participants was conducted. The open-ended questionnaire responses and video recordings were reviewed for emergent themes.

6.4 Results and Discussion

Similar to the pilot study, there was no indication of suspicion of a deception task (KF1), no participant expressed concern or discomfort when the deception was revealed (KF2), and most participants were able to recall the setup and answer the questionnaires (KF3).

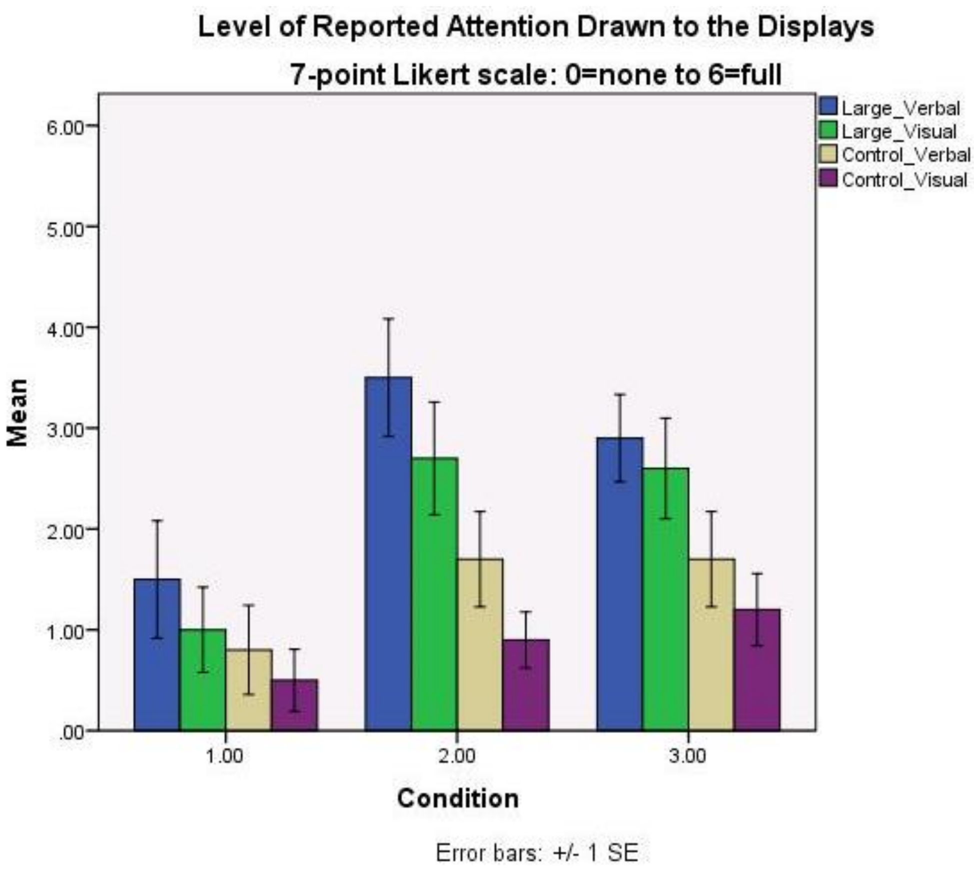


Figure 6-5. Level of reported attention drawn to the displays (surfaces) for each condition in the improved study: 1) adaptive speed, 2) adaptive speed & shadow, and 3) adaptive trajectory & shadow. "Verbal" and "visual" represent the navigation conditions used in the deception task.

[12] The validity of using ANOVA tests on Likert-scale data has been shown by (G. Norman, 2010).

The data analysis revealed that proximity-based content movement and user shadow were effective in drawing unknowing participants' attention to the large surface, and was consistent across the verbal and visual deception conditions. Yet, as shown in Figure 6-5, the effect of changing content's movement speed (Condition 1) was much smaller than that of the combine content speed changes and user's shadow (Conditions 2 & 3), when compared to the control.

6.4.1 Effectiveness of Visual Concepts over the Control

The question "*Please indicate how much each of the displays [small/large] drew your attention when the instructions were provided [vocally/visually]*", in the form of a 7-point Likert-scale from no attention (0) to full attention (6), was used to determine how much attention was being drawn to the surfaces. When only relating proximity to the surface with content's speed (Condition 1), there was a main effect in the verbal case: $F_{verbal}(1,9)=10.76$, MSE=.23, p=.01, but not in the visual case: $F_{visual}(1,9)=2.65$, MSE=.47, p=.138, *n.s.*. However, in both cases the difference in means was very small between the condition ($M_{verbal}=1.50$, $M_{visual}=1.00$) and the control ($M_{verbal}=0.80$, $M_{visual}=0.50$).

Adding the user's shadow to the surface (Condition 2) resulted in a larger difference in means between the condition ($M_{verbal}=3.50$, $M_{visual}=2.70$) and the control ($M_{verbal}=1.70$, $M_{visual}=0.90$). It has also led to a main effect in both the verbal case: $F_{verbal}(1,9)=16.57$, MSE=.98, p<.01, and the visual case: $F_{verbal}(1,9)=18.69$, MSE=.87, p<.01.

Replacing the change in speed with a more elaborate change in content's trajectory, while keeping the user's shadow (Condition 3), also resulted in a larger difference in means between the condition ($M_{verbal}=2.90$, $M_{visual}=2.60$) and the control ($M_{verbal}=1.70$, $M_{visual}=1.20$). Similar to Condition 2, it has also led to a main effect in both the verbal case: $F_{verbal}(1,9)=6.00$, MSE=1.20, p=.037, and the visual case: $F_{verbal}(1,9)=10.76$, MSE=.91, p=.01.

The small differences in means between varying content's speed (Condition 1) and no variation at all (Control) were consistent with the findings from the pilot study. The significant effect found in the case where verbal navigation instructions were given indicates a consistently higher ranking of attention drawn, and may be explained by a higher chance of the surface in the participants' view. Yet, a difference in means of less than a unit in the Likert-scale did not appear to be indicative of adaptive speed being an effective mechanism in drawing passersby's attention.

In contrast, the larger differences in means between adding user's shadow (Conditions 2 & 3) and the control, together with the statistical significance, strongly suggested that such mechanism was effective in drawing attention. In fact, some of the participants recalled that the shadow, in relation to their movements, "*followed [my] movements*", "*mirror [my] motions*", and "*got bigger when [I] get close to [the display] and was gone totally when [I] moved away from [the display]*". Interestingly, attention towards the small surface (Control) was also increased, as indicated in the higher means in Conditions 2 & 3. Though not explained in participants' feedback, it was possible that the increased attention towards the large surface also increased participants' attention towards the small surface.

6.4.2 Attraction Power of Content Motion and User Shadow

In both the pilot and this improved study, changing the speed of content movements in relation to surface proximity (Adaptive Speed) alone did not appear to have strong attraction power. However, when combined with the user's shadow, ANOVA revealed a main effect of the Conditions on reported attention drawn for both verbal and visual cases: $F_{verbal}(2,27)=3.65$, MSE=2.89, p=.04, $F_{visual}(2,27)=3.7$, MSE=2.463, p=.038. A linear contrast was then conducted to test the a-prior prediction that the conditions with shadow (2 and 3) would have a stronger effect than the condition without shadow (1). It was found to be significant for both the verbal and visual cases: $t_{verbal}(27)=2.58$, MSE=1.32, p=.015, $t_{visual}(27)=2.72$, MSE=1.22, p=.011. The use of contrast test was also supported by the answers from the participants, which indicated the majority of them were predominantly attracted by their own shadows but not the changes in content's motion.

The fact that the majority of the participants in Conditions 2 and 3 reported noticing their own shadows (19 out of 20), in contrast to only a few noticed the changes in content motion (5 out of 20), indicates that reflecting participants' shadows dominated their attention, resulting in the more subtle speed change being unnoticed. This could be explained by the fact that reflecting one's own live-sized shadow was unexpected and novel (an "oddball"), while floating images had been commonly seen being used as screen-savers or in decorative ambient displays.

6.4.3 Ability to Communicate Interactivity of the Surface

To realize a surface is interactive, one has to first notice the surface. Thus, in Condition 1 where the majority of the participants failed to notice the surface, most were not able to assess its potential interactivity. When being asked to indicate how interactive the participant thought the surface (both small and large) was, only one participant in this condition rated the surface as "somewhat interactive", while the rest rated it as having low interactivity or stated that they did not notice. In contrast, 17 out of the 20 participants in Conditions 2 and 3 rated the surface as "somewhat interactive" or higher. Yet, when asked what they thought they could do with the surface, only three of these 20 participants mentioned they could touch/move/interact with the content. This suggests that while the user's shadow may help indicate the interactivity of the surface, further cues are needed to communicate possible *types* of interactions (e.g., touch, body movements).

Overall, the results in the improved study suggested that including user shadows was able to increase attraction power and communicate *some* interactivity. But other forms of interface design were required to further bring the users through the interaction process with the interactive surface. This finding corroborated Müller et al's (2012) work that revealed that *representing* the user in the surface (via shadows or user images) was more effective at engaging passersby than simply changing content in *response to* user actions, similar to the changes in content motion in this study.

6.4.4 Ownership and Playfulness of One's Shadow

Displaying the user's shadow appeared to have another positive consequence to the interaction process. Analysis of video revealed that some participants, upon noticing their shadow, played with the shadow by moving their own body in experimental ways (Figure 6-6). The fact that the tracking and output were performed in nearly real-time allowed the virtual shadow to respond with similar behaviour to a person's real-world shadow. Analysis of questionnaire responses also revealed a similar "sense of self" theme in participants' open-ended responses about the surfaces. 18 of the 20 participants who experienced the user shadows used personal pronouns, adjectives, or possessives to refer to the shadows, indicating that most participants perceived the shadow as a representation of themselves in the interface. This observation suggested such use of shadow in PLISs has the potential to quickly invoke a sense of "self" and its ownership, leading to a more engaging user experience.

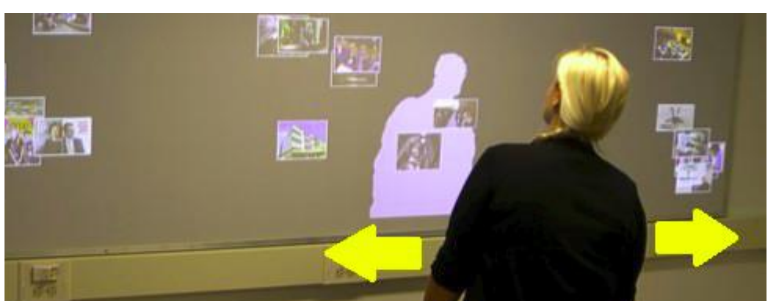


Figure 6-6. A participant experimenting with the shadow by "swaying", while watching her movements mirrored in the surface.

This sense of familiarity and ownership of the user shadows, and the playfulness (intrinsically motivated engagement that did not seem to have a direct goal (Huizinga, 1949)) also suggested that user shadows may provide a means to help lower people’s social inhibitions of interacting with a surface in public, which has been recognized as a barrier for public surface use (Cheung et al., 2014).

As an example, Disney recently exploited this playful aspect of user shadows in a marketing campaign[13] utilizing shadows to draw passersby’s attention, and invite them to interact with a large screen. With a Wizard-of-Oz approach, back-lit actors (dressed as famous Disney characters) mirrored passersby’s movements from behind the screen, and cast their shadows onto it. After capturing the passersby’s attention, the actors started to deviate from strictly mirroring passersby’s actions and formed an interactive dialogue, thereby creating an engaging experience.

6.4.5 Limitations of the Improved Study

The laboratory-based study methodology employed in this improved study provided precision and control of the experimental factors. However, this approach involved a cost of lower ecological validity compared to the more commonly used “in-the-wild” field experiment for evaluating public surfaces, as pointed out by researchers who also used a similar approach (Alt et al., 2012; Convertino et al., 2004). The use of a deception task helped mitigate this issue by emulating key aspects of public surfaces, such as participants being initially unaware of the existence or purpose of the surface, and providing a compelling distraction to compete with the surface for their attention.

Also, the presence of the researcher and camcorder might affect the way participants responded to the surfaces. Thus, to truly achieve a high ecological validity, a follow-up field experiment, with unobtrusive data capture methods, is needed to validate the results in specific public contexts.

Another limitation was the sample group of participants in the study, who were recruited through the university mailing list, and thus, were limited to a particular user demographic, including age, background, and more importantly, relatedness to the content and experience in using interactive surfaces. It was expected that by using similar visual concepts that were employed in other field studies (e.g., user shadows (Müller et al., 2012)), or based on previous psychological findings (e.g., jerky speed (Franconeri & Simons, 2003)), the results from this study would be applicable to a broader user demographic. Yet, deployment in other contexts is necessary to verify them.

[13] https://www.youtube.com/watch?v=Hd_2Y29_FLU. Video of Disney’s use of shadows in a shopping mall. Last accessed: 7 April, 2016.

6.5 Lessons Learned

Analysis of the collected data has also provided insights into design improvements and extensions that may increase the attraction and engagement power of the visual design, as listed below.

6.5.1 Provision of Continuous Proximity-based Feedback

One typical adaptation of proxemic interactions to the visual design of PLISs is to apply changes based on discrete proximity “zones” (Brignull & Rogers, 2003; Streitz et al., 2003; Vogel & Balakrishnan, 2004), thus emulating the discrete proxemics zones by Hall (1966). This discrete feedback approach may, however, have contributed to the limited attraction power of the content speed changes condition included in both the pilot and improved studies. This is because while the psychology literature has found this approach to be highly effective for capturing attention, the findings assumed that people have adequate opportunity to *observe* the speed changes. Yet, the application of the proximity-based feedback for the content speed here was designed to take effect at the proximity zone boundaries. It is likely that this limited amount of feedback changes, combined with the intentionally distractive deception task, provided even fewer opportunities for participants to notice the speed changes when they occurred.

In contrast, the proximity-based feedback changes for the user shadows were applied continuously, that is, the transparency level (hence contrast to the background) of the user shadow decreased linearly as the user approached the surface, making it more visible. This continuous feedback was observable at any position in the environment, not just at the zone boundaries, as long as the surface was in the person’s view. Thus, in a public setting, where the surface may have limited time and opportunity to capture a person’s attention, providing continuous proximity-based feedback is likely to be more effective at drawing their attention.

6.5.2 Placement of User Shadow

Although it was found that user shadows were visually compelling, the collected data revealed issues with their current implementation. In the current implementation, the mirror metaphor was used to simulate the appearance of a person’s reflection in a mirror, and was consistent to existing literature (Müller et al., 2012). Thus, when someone walked parallel to the surface, the shadow would appear directly beside them. This often placed the shadow outside their peripheral view, limiting its potential to be noticed. Moreover, delays in tracking or shadow update sometimes positioned the shadow slightly behind the person, further decreasing its potential visibility (see Figure 6-7). To address this limitation, the shadow could be shifted slightly ahead of the person's movement so it would appear within their visual perception field. Ideally this approach would be used when the person's orientation information is available, and only applied when they have turned parallel to the surface. Another possibility would be to enlarge the size of the shadow beyond the actual size of the person.

Figure 6-7. User shadow appearing beside the walking person like a mirror. In some cases, slight tracking or display update delays caused the shadow to lag behind the person, placing the shadow outside their peripheral view.

This alternative shadow placement may also help to address the "landing effect" observed by Müller et al. (2012), where passersby noticed (or understood) the interactivity of a surface after passing it, and had to back-up to interact with it.

6.5.3 Elaborate Use of Shadow

The study revealed the effectiveness of user shadows in capturing attention, but this effectiveness did not extend to communicating interactivity. The simple mirroring of the user's body movements did not appear to communicate how one might interact with the application content. On the surface, this finding was inconsistent with Müller et al.'s (2012) that user shadows effectively communicated interactivity. However, in their system, the only form of interactivity was to control one's shadow to hit the application content (virtual balls). Yet, in systems where other forms of interactivity were expected, user shadows did not appear to offer any information about those forms to the users.

Nevertheless, it may be possible to leverage people's sense of playfulness, familiarity, and ownership of shadows to improve a surface's ability to engage the users. For example, by dropping the strict "mirroring" nature of a shadow, it could provide a fun means of guiding user action, or providing new methods for interacting with the surface (e.g., shadow-based interactions for interacting with graphic objects (Krueger et al., 1985), reaching distant content on a large surface (Shoemaker et al., 2007), and interactive graphics to suggest full-body input (Snibbe & Rafle, 2009).

6.6 Chapter Summary

In this chapter, I have presented details of the improved study based on the findings in Chapter 5. Specifically, this study examined the use of content speed and shadow visualizations in conjunction with the proxemics theory. The study results showed that the inclusion of shadow visualizations had a significant effect on drawing people's attention, and could communicate a limited sense of interactivity. The study also revealed some playful reactions from the participants in the presence of their shadows rendered on the surface, suggesting potential use of user shadow to go beyond attention drawing and bring users further along the interaction process with PLISs.

Chapter 7
Field Experiment of Animated Content and User Shadow

This chapter explores the use of the visual concepts investigated in the laboratory study presented in Chapter 6 for attracting attention and inviting interaction in a field setting. A field experiment was conducted to further validate the laboratory study results. A discussion of the results is provided to motivate further investigation in using shadow visualizations as an assistive tool in PLISs.

7.1 Motivation of the Field Experiment

The laboratory study discussed in Chapter 6 provided an initial understanding of the effectiveness of the studied visual concepts in drawing participants' attention. However, while the results indicated a main effect in combining user shadow with adaptive speed (Condition 2) over adaptive speed alone (Condition 1), it was uncertain if user shadow alone could achieve a similar increase in attraction power, since it was not studied as a separate factor in the laboratory study. Furthermore, while the results in the laboratory study corroborated existing research, hence demonstrating its applicability in evaluating attraction power of a PLIS interaction and interface design, stronger evidence was desired to confirm that these findings would carry over to a real-world context.

To address these issues, a field experiment was conducted to further investigate the effectiveness of the studied visual concepts in attention drawing in a real-world context. Specifically, the field experiment separated adaptive speed and user shadow into two independent experimental factors to better understand their individual effects, and deployed these concepts in a public setting (university campus) for greater ecological validity. In addition, the study also investigated whether these visual concepts could further entice passersby to interact with a PLIS, as represented by the later parts of the DISCOVER interaction model presented in Chapter 3.

This field experiment can be viewed as a *partial replication* of the laboratory study discussed in Chapters 5 & 6, where implementation, experimental setup, and performance measures collected were adapted in an "in-the-wild" setting (Hornbæk et al., 2014). Replication is a commonly employed approach to confirm earlier studies' findings in scientific research (Jasny et al., 2011), and is encouraged in the HCI community as well (Hornbæk et al., 2014).

7.2 Field Experiment Design and Setup

The field experiment followed a conventional "in-the-wild" field experiment methodology, where the system to be studied (PLIS as a large interactive display) was implemented with different versions of the interface using the visual concepts, namely, *adaptive speed* and *user shadow*. Both the hardware and software were updated to better meet the requirements of a field experiment, for example, supporting multi-touch interaction and being more robust both physically and programmatically.

7.2.1 Experimental Conditions

To remain consistent with the experimental conditions in the laboratory study, *adaptive speed* was again implemented to respond to the proximity of a passerby in a stepwise manner: speed of content (images) decreased in a stepwise manner as the passerby walked closer to the surface, and crossed from zone to zone (Figure 7-1). However, because of the narrower width of the deployed surface than the large surface used in the laboratory study, changes in speed were applied to all the images instead of only those closest to the passerby. *User shadow* was again implemented by showing the silhouette of the passerby, and with a continuously increasing contrast as the passerby approached the surface.

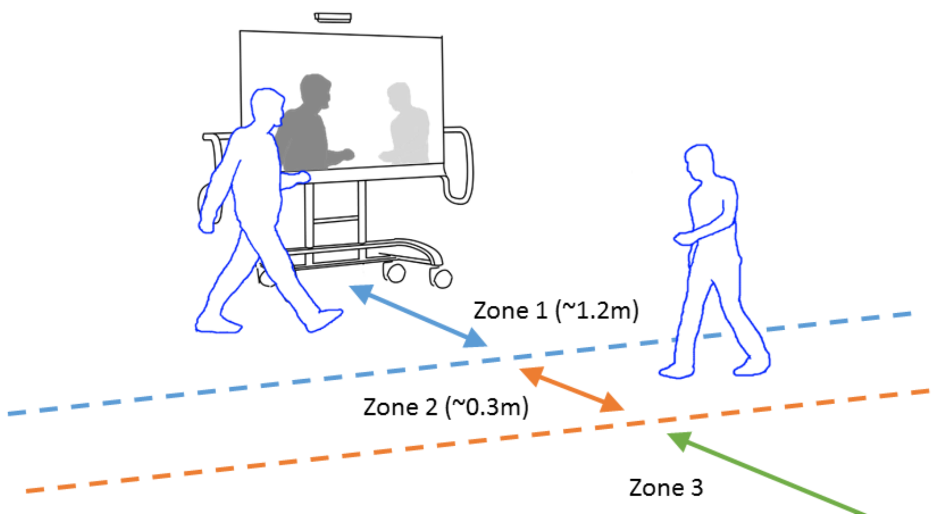


Figure 7-1. Zonal setup of the large interactive surface in the field experiment. Content speed changed in a stepwise manner as a passerby crossed any of the zone boundaries. Shadow contrast changed continuously in relation to the distance between the passerby and the surface.

7.2.1.1 Animated Content (Adaptive Speed)

Similar to the experimental conditions used in the laboratory study, the stepwise decrease in content's speed (specific speed values used in the experiment can be found in Appendix D) as a passerby approached was used to provide sufficient opportunities for them to interact with the content, and be more likely to notice the change. Other animations to the content were possible, for example, change in scale, or change in trajectory (used in the laboratory study). However, as no significant difference was observed between changing speed and changing trajectory in the laboratory study, it was decided to only focus on changing speed in the field experiment.

Combining the concept of proxemics zones and physical properties of the location, three zones were setup with boundaries of approximately 1.2 metres away, 1.5 metres away, and above 1.5 metres away from the interactive surface, as shown in Figure 7-1. These distances were used to closely approximate those used in the laboratory study (approximately 1 metre away from the surface for personal (Zone 1), 1.8 metre away for social (Zone 2), and above 1.8 metre away for public (Zone 3)).

7.2.1.2 User Shadow

A Microsoft Kinect V2 (as opposed to the original Microsoft Kinect used in the laboratory study) was used to detect and track passersby. This newer Kinect model provided a higher image resolution of the depth data (512x424 pixels, over 2.5 times of the original), resulting in finer-grained and more realistic user shadows. It also provided the ability to track up to six individuals simultaneously (as opposed to two with the original), providing more flexibility to handle a wider variety of possible user scenarios in the field. Finally, the Kinect device was mounted above the surface (rather than across the room in the laboratory study); this position coupled with increased multi-person tracking allowed for multiple shadows with various contrasts as a function of passersby's distances to be displayed.

Consistent with the laboratory study, a continuous change was applied to the shadows (alpha value 0 to 255 linearly mapped to 0.4 to 3.15 metres from the surface). The shadows remained as true reflections of the passersby without any added animations or modifications. This implementation of true reflections was also consistent with existing research using shadows.

7.2.1.3 Control Condition

In the control condition, content's speed was set to be the same speed as if a passerby was at Zone 3 and remained unchanged (i.e., no stepwise decrease), with no user shadow being displayed.

7.2.1.4 Deployment Design

The experiment used a 2 (adaptive speed) x 2 (user shadow) between-participant factorial design (see Table 7-1 for the condition assignment). The study was conducted across four consecutive days (3 (Tue) – 6 (Fri) November, 2015). Each day, the interactive surface was setup and its usage observed for a four-hour period from 10am to 2pm, with each condition occupying an hour of this period. The order of presentation of the conditions was counter-balanced using a Latin Square across the four days to ensure similar exposure to foot traffic (see Table 7-2 for the schedule).

Table 7-1. Assignment of the conditions in the 2x2 between-participant factorial design in the field experiment (Condition 1: control, Condition 2: Adaptive Speed, Condition 3: User Shadow, Condition 4: Adaptive Speed & User Shadow).

	Adaptive Speed absent	**Adaptive Speed present**
User Shadow absent	Condition 1 (control)	Condition 2
User Shadow present	Condition 3	Condition 4

Table 7-2. The schedule of the conditions presented for the duration of the field experiment, following a Latin Square to ensure similar exposure to foot traffic. Times are approximated as the switches were made at logical breaks between foot traffic.

	Day 1 (Tue) (3 Nov, 2015)	**Day 2 (Wed) (4 Nov, 2015)**	**Day 3 (Thu) (5 Nov, 2015)**	**Day 4 (Fri) (6 Nov, 2015)**
10am-11am	Condition 1	Condition 4	Condition 3	Condition 2
11am-12pm	Condition 2	Condition 1	Condition 4	Condition 3
12pm-1pm	Condition 3	Condition 2	Condition 1	Condition 4
1pm-2pm	Condition 4	Condition 3	Condition 2	Condition 1

To minimize disruption to interactions, switches between conditions were chosen based on logical breaks between foot traffic. These switches were very quick: done with a simple keypress on a keyboard behind the surface. Each condition was presented for an average of 60 minutes per day.

7.2.2 Study Location

To achieve higher ecological validity, the field experiment was conducted with unobtrusive data collection methods, where the researcher did not directly interact with the observed personnel, and instead took a silent observer role. Figure 7-2 shows the physical setup of the PLIS as a large interactive display at the designated public location.

Figure 7-2. Deployment of the PLIS as a large interactive display during the field experiment. It was positioned between the third floor lobby of the Engineering 5 building at the University of Waterloo (left) and the entrance of the bridge to another Engineering building (right). The researchers (not shown in the figure) were stationed opposite to the display without any indication of a study in progress.

7.2.2.1 Finding a Study Site

Several criteria had to be met when determining a location for the field experiment, including 1) had enough foot traffic while possible for passersby to stay for a short period of time to interact, 2) provided a place for the researchers to station unobtrusively for observation, 3) had power supply for the display to operate for several hours, and be accessible for transportation and storage of equipment over the duration of the experiment, and 4) be legally and institutionally accessible to the researchers.

After a few iterations on possible locations around the university campus, it was decided to be in a lobby area of an Engineering building on the campus that had an above-ground pedestrian pathway link between campus buildings. The display was set up near the entrance way to several classrooms and the pedestrian pathway. It was upon a frequently commuted area on the campus, used mostly by students between classes and staff members between meetings. Moreover, it was expected to be used frequently because of the colder seasonal weather and ongoing construction outdoors interfering with easy access to adjacent buildings. The lobby area also allowed the researchers to be stationed at a group of nearby tables commonly used by students for completing class work, while having a full view of the display and passersby interaction without drawing much attention.

7.2.2.2 Getting Ethics Clearance

Since the field experiment involved disturbance of a public space (placing an equipment and thus altering the space), and passersby's reactions were recorded, the study had to obtain clearance from the University of Waterloo's Research Ethics Office. This also involved obtaining permission to use the space for the study. This process took a few months (in contrast to a few weeks for the laboratory study) to finalize as multiple parties were involved, and it was the first time a study of this nature conducted within the university, according to the ethics administrator handling the application.

In particular, a digital camcorder was required to capture the interactions between passersby and the display, such as glances and shadow interactions. However, a passerby could not be notified about this recording in advance (as per normal ethics protocol) as it may affect their behaviour. After several meetings with the ethics office, it was decided that the camcorder would be positioned opposite to the display, so passersby would not be facing the camcorder if they were engaged in the interaction; their faces would also be blurred if any video footage or image snapshots be published. In addition, for a week after the study, a notice (see Appendix C.2) was posted in place of the display to inform passersby about the study, and offered to remove them from the recordings if they wished to.

7.2.3 Implementation of the Large Interactive Display

As mentioned in Section 4.1, "in-the-wild" deployments, like this field experiment, require more development effort as the display has to be functional and robust to ad-hoc use. Hence, to ensure a successful experiment, both the hardware and software application were updated.

7.2.3.1 Hardware

A 164cm (diagonal), vision-based sensing multi-touch surface (Kapp iQ 6065i) manufactured by SMART Technologies[14] was used as the interactive display. It recognized up to four multi-touches and reported them as touch events to a connected computer. The surface was made using reinforced glass with metal enclosure, making it robust to frequent use. It was mounted on a mobile stand of adjustable height (see Figure 7-3), and connected to a Windows 8 PC (3.5GHz CPU, 16GB RAM, NVDIA Quadro K2200 display card) running the application in 1920x1080 pixels resolution.

[14] http://smartkapp.com/en/products/kapp-iq. Product webpage of the Smart Kapp iQ 6065i. Last accessed: 7 April, 2016.

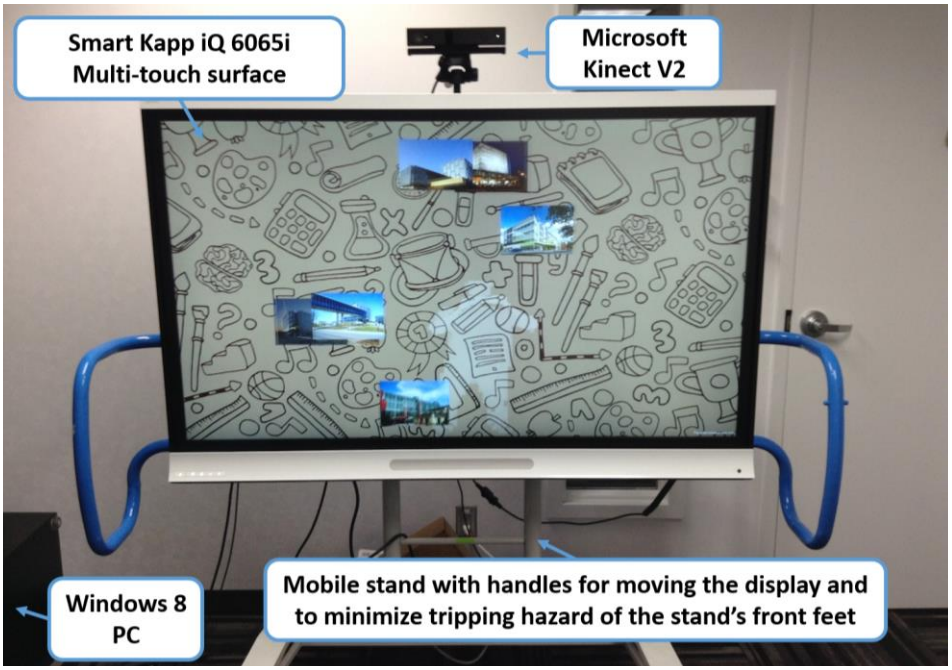


Figure 7-3. Hardware setup of the interactive display for the field experiment. The surface was a Smart Kapp iQ 6065i that supported multi-touch. Proximity-sensing was provided by the Microsoft Kinect V2 depth camera. The application was run in a Windows 8 PC.

A Microsoft Kinect V2 depth-sensing camera was attached to the top of the surface using a tripod. It was used to determine the proximity of a passerby to the display. The camera could keep track of up to six individuals simultaneously to a distance of 4.5 metres with a resolution of millimetres.

7.2.4 Software Application

The application was implemented using Unity3D[15] that supported multi-touch input from the surface, and depth data input from the depth-sensing camera. Figure 7-4 shows the development environment of Unity3D, where the left window shows the virtual 3D scene perceived by the application, and the right window shows the output to the display (with user shadow).

The application was designed to be easily switchable between conditions with a single key press to simplify switches in the field. Depending on which key was pressed, the application determined whether the speed of the images would be changed, and/or whether the user shadows would be displayed. Similar to the application used for the laboratory study (Chapter 6), the application interface contained a number of images that floated across the screen. These images included photos

[15] http://unity3d.com/unity. Website of the Unity3D software development tool. Last accessed: 7 April, 2016.

of various sites and buildings of University of Waterloo. To further increase visual interest, a background image was also used, depicting relevant “school” related cartoon-style sketched items. This background image was displayed in all conditions.

As shown in Figure 7-3 and Figure 7-4, a shadow of a person appeared in the form of a silhouette when a person was detected by the Kinect device and within a pre-defined distance (during Conditions 3 and 4). The silhouette was a graphical reconstruction from the infra-red data captured by the depth-sensing camera. Besides showing the visual content, the application automatically logged each individual being tracked, and any touch events on the surface.

Application functionality related to touch interaction was kept minimal, as the main purpose of the field experiment was to further investigate the results from the laboratory study: how visual concepts attracted and enticed interaction from the passersby. As shown in Figure 7-5, when a photo was touched by a passerby, it underwent a vertical flip animation, revealed an image informing the user about the purpose of the display, and invited them to further participate in the field experiment by following a link to an online questionnaire. After five seconds without any touch interaction, the image would flip back to the original photo, and continued its movement across the screen.

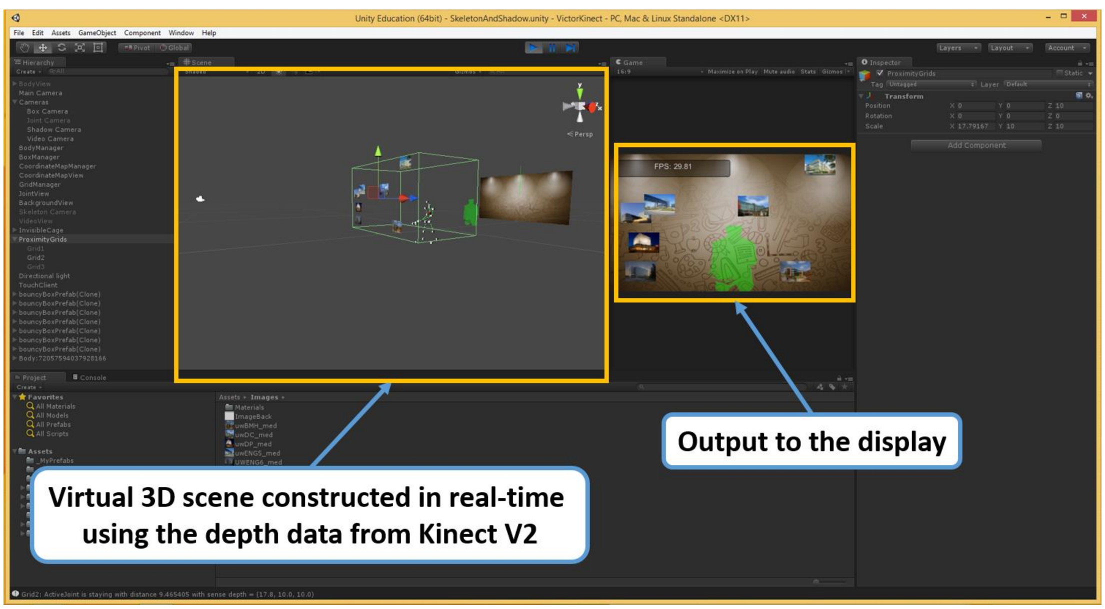
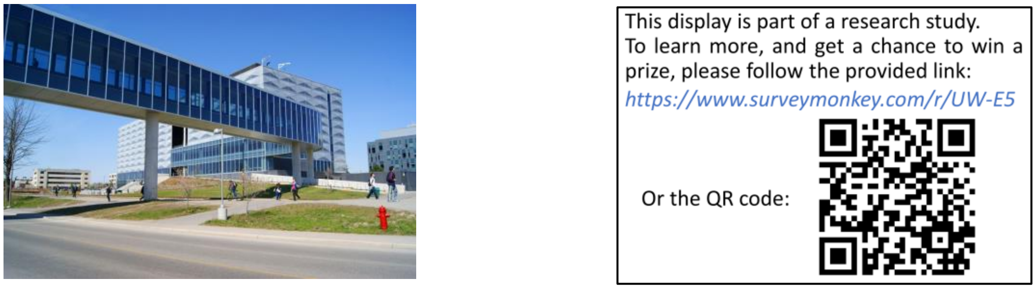


Figure 7-4. A snapshot of the Unity3D development environment for the application . The left window shows the virtual 3D scene constructed in real-time using the depth data, the right window shows the output of the application to the display*.

***The dialog indicating FPS (frames-per-second) was only used during development, and all silhouettes were shown in white during the field experiment.**



a) One of the photos of the university campus shown in the application (front).

b) The image shown when a passerby touches any of the photos on the display (back). The link and QR code take the passerby to a webpage containing further information and an online questionnaire.

Figure 7-5. Imagery content shown in the display. When a passerby touches a photo, it turns into the image shown in (b) for five seconds, informing them about the purpose of the display and inviting them to further participate in the field experiment. A chance to win a prize (details not shown to allow flexibility of prize during software development, but clearly stated in the online questionnaire) is offered to motivate participation.

7.2.5 Data Collection and Analysis

The field experiment was conducted in an "in-the-wild" field experiment manner (Section 2.4.2), where interactions between passersby and the display were documented using field notes, computer logs, and video recordings.

7.2.5.1 Field Notes

Field notes were taken by the researcher on-site during a total of 16 hours of display usage observation. Each note entry represented an incident of interest, including time, condition, description of the incident, and the researcher's comments. These incidents helped guide the qualitative analysis of the study data by providing additional context and focus.

7.2.5.2 Computer Logs

Computer logs were created automatically by the application. Each passerby being tracked was assigned a unique identifier together with the times of entry and exit of the tracked area. Touch events on the display were also logged, indicating whether any application content or the background was touched, and the time it happened. These data were used quantitatively to evaluate the attraction and holding power of the display under different conditions.

7.2.5.3 Video Recordings

Video recordings were made using a Sony HDR-MV1 handheld camcorder with a wide-angled lens, capturing the foot traffic from both left and right sides of the display, and the interaction between passersby and the display. The video footage was coded using the ELAN annotation software[16] for occurrences and durations of interaction, and were analyzed both qualitatively and quantitatively.

Occurrences of interaction in the video recordings were annotated using a closed coding scheme developed based on the attraction phase in the DISCOVER interaction model (Chapter 3), and the experimental conditions being studied, as shown in Figure 7-6. INDIV and GROUP were mutually exclusive entities in the Unit tier representing the social formation; GLANCE, NONE, STARE were mutually exclusive entities in the Approach Behaviour tier representing initial interaction with the display; TOUCH, SHADOW-PLAY, SHADOW-REACH, MOVE were entities in the Physical Interaction tier representing more involved interaction with the display, and could be coded in any combination multiple times for a passerby. In an effort to reduce bias, an external but experienced research assistant was hired to complete the annotation of the recordings.

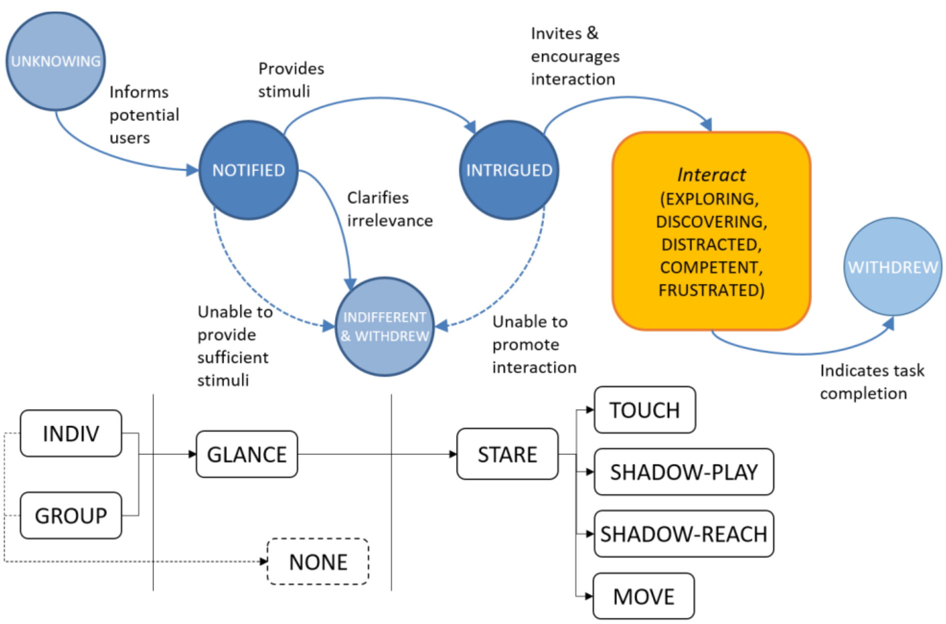


Figure 7-6. A closed coding scheme used to annotate the video recordings. The scheme was developed to represent various states of the DISCOVER interaction model, and taking into account for the interactivities afforded by the display (e.g., touch, proximity).

[16] https://tla.mpi.nl/tools/tla-tools/elan/, an annotation software for video-coding developed by the Language Archive at Max Planck Institute for Psycholinguistics. Last accessed: 7 April, 2016.

Table 7-3 summarizes the annotation codes used for the field experiment. Due to the observational nature of the experiment, user states in DISCOVER were mapped to observable occurrences such as glances, stares, and body movements, which were also similar to the observations made by Schmidt et al. (2013) in their field study on content readability. Also, as the focus of the experiment was the attraction power of the display, later states of the model were not used or measured.

In the analysis of holding power (Section 7.3.1), computer logs were used instead of the Duration of Stay tier for a more accurate measure of time.

Table 7-3. Coding scheme used to annotate interaction in the field experiment. Each code represents an observable occurrence of a user state in the DISCOVER interaction model.

Tier group	Code	Description	Corresponding user state in DISCOVER
Unit	INDIV	An individual with the display in their field of view (front oriented towards the display)	Unknowing
	GROUP	A group of individuals (>1 in proximity) with the display in their field of view	Unknowing
Approach Behaviour	GLANCE	The action of looking at the display but without stopping	Notified
	NONE	Shows no intention to look or pause with display in view, walks by as if it is not there	Indifferent & Withdrew
	STARE	The action of stopping and looking at the display	Intrigued
Physical Interaction	TOUCH	The action of touching the display	Exploring (and beyond)
	SHADOW-PLAY	The action of playing with one's shadow being shown in the display	Exploring (and beyond)
	SHADOW-REACH	The action of reaching to the Kinect V2 or attempt to interact with the content via shadow, or waving	Exploring (and beyond)
	MOVE	The action of moving forward/backward in attempt to interact	Exploring (and beyond)
Duration of Stay	START	The beginning of stay marked by stare or head-turn	Intrigued
	END	The ending of stay marked by leaving or not looking	Withdrew
	HEADTURN	The action of turning one's head towards the display	Not Applicable

7.2.5.4 Online Questionnaire

In addition, an online questionnaire (created based on the improved laboratory study's post-experiment questionnaire, see Appendix C.1) was created to elicit feedback from the passersby to examine their perception towards the display. To maintain the unobtrusiveness of the field experiment, the link to the questionnaire was briefly shown (for five seconds) after a passerby touched an image on the display (see Figure 7-5b), and on the notice replacing the display after the study period. A chance of winning one of ten $10 gift cards at a popular fast food restaurant (Tim Hortons) was provided to motivate participation. However, no participation was received through this channel. This questionnaire was therefore not included in the analysis.

7.3 Results and Discussion

The main goals in this field experiment were to empirically validate the results from the laboratory study, and to address some of its limitations. Hence, indications of attention capture and interaction were of particular focus in the analysis. The collected data were used to identify recurring behaviours by passersby when interacting with the display to better understand public surface interaction.

During the 4-day field experiment (16 hours in total), 2921 bodies[17] were tracked, out of which 1096 were coded in the video recordings due to their observable interaction with the display. Those who did not orient towards the display, or were staring at their own mobile devices/other distractions during the entire time were not coded. The online questionnaire was not included due to lack of participation, as mentioned in Section 7.2.5.4.

7.3.1 Holding Power (Length of Stay)

In museum studies, *holding power* is one measurement for determining the effectiveness of exhibits (e.g., Bitgood & Patterson, 1987), and is defined as the ratio (averaged over visitors) of the actual time spent at an exhibit to the minimum viewing time necessary to examine key elements (Sandifer, 2003). In some studies (e.g., Boisvert & Slez, 1995) holding power was measured simply by the *average holding time.* This thesis took the latter approach as the content being displayed was intentionally made simple (floating images, user shadow) so the necessary viewing time was minimal.

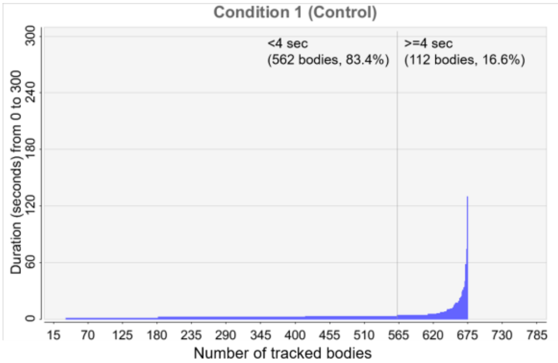
[17] The term "body/bodies" is used here to acknowledge that it was not possible to uniquely identify passersby; thus, the same person may have been tracked multiple times over the experiment period.

The holding time was the length of stay for each passerby, which was determined using the computer logs of entry and exit times of the tracked bodies (i.e., the time between the application identifying a body and losing track of it). Yet, due to the limitation of the tracking technology, it was not possible to distinguish repeating passersby; it was also not possible to determine the gaze direction of the passersby, so a shorter length of stay might simply be a walk-by without the display being noticed. Hence, only those with a length not less than four seconds (roughly how long it took to walk pass the display without stopping) were included as "stay" in this analysis, resulting in a total of 678[18] bodies. It is therefore important to take note that this is a conservative estimation of interaction.

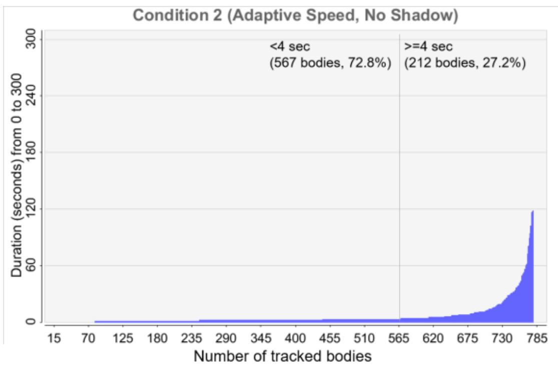
As shown in Figure 7-7, using four seconds to separate passersby between walk-by and stay, a higher percentage of stay (over 20%) was recorded in Conditions 2 to 4 than that in Condition 1, suggesting that visual concepts were effective in holding passersby. Moreover, there was a stronger skew (indicated as the 75th percentile in the >= 4sec group) in the number of tracked staying bodies towards the longer length of stay in Conditions 2 to 4 than that in Condition 1, indicating a higher number of passersby tended to stay longer in those conditions with visual concepts implemented (with Condition 4 using both Adaptive Speed and User Shadow resulting in the longest stay). This result was also supported by the boxplot shown in Figure 7-8 showing the median and quartiles of length of stay (the >= 4sec group) for each condition. Furthermore, the least variability (shortest box) and lowest upper quartile in the control condition suggested that when not seeing any visual elements, passersby gave up and left more quickly than when presented with any of the studied visual concepts.

A two-way ANOVA was conducted to examine the effect of Adaptive Speed and User Shadow on length of stay for each staying passerby. Both Adaptive Speed ($F(1,674)=4.427$, $p=.036$) and User Shadow ($F(1,674)=11.248$, $p=.001$) had a significant effect on the length of stay. No significant interaction effect was found ($F(1,674)=.751$, $p=.386$, *n.s.*) between the two visual concepts. This may be explained by these two factors being two disparate levels of visual stimuli (as detailed in Section 2.6.1): Adaptive Speed was a low-level visual stimulus, while User Shadow was a high-level visual stimulus.

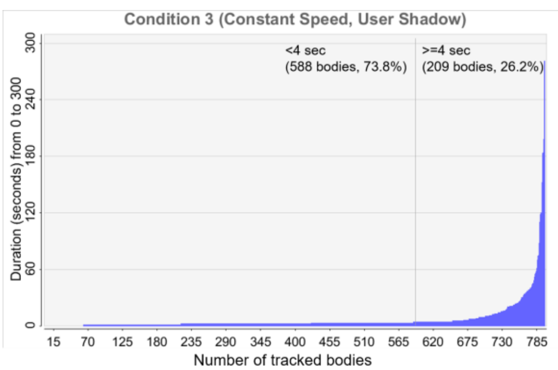
[18] This number is different from the video-coded data's number because: 1) it filters out glance occurrences, and 2) the computer log treats all bodies as individuals. However, it gives a more accurate result in terms of who stayed for a considerable length of time in front of the display.



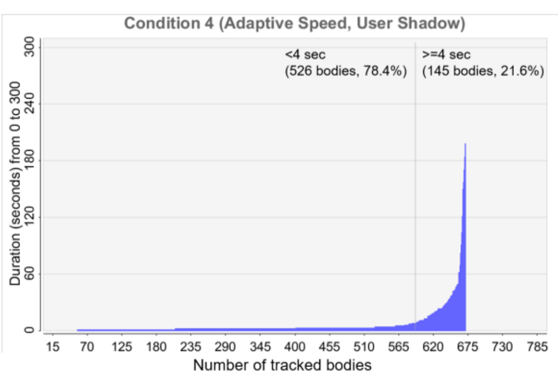
a) Control
(Condition 1)
Total number of tracked bodies: 674
Number of tracked bodies < 4sec: 562
Number of tracked bodies >= 4sec: 112
Mean length of stay: 10.67s
Standard Error: 1.48s
75th percentile in the >= 4sec group: 10s



b) Adaptive Speed
(Condition 2)
Total number of tracked bodies: 779
Number of tracked bodies < 4sec: 567
Number of tracked bodies >= 4sec: 212
Mean length of stay:17.45s
Standard Error: 1.52s
75th percentile in the >= 4sec group: 19s



c) User Shadow
(Condition 3)
Total number of tracked bodies: 797
Number of tracked bodies < 4sec: 588
Number of tracked bodies >=: 209
Mean length of stay: 20.31s
Standard Error: 2.40s
75th percentile in the >= 4sec group: 21s



d) Adaptive Speed & User Shadow
(Condition 4)
Total number of tracked bodies: 671
Number of tracked bodies < 4sec: 526
Number of tracked bodies >= 4sec: 145
Mean length of stay: 23.13s
Standard Error: 2.86s
75th percentile in the >= 4sec group: 25s

Figure 7-7. Comparison between 4 conditions on length of stay (between 0 and 300 seconds). Each figure is divided at the 4-sec interval, sorted by the length (duration) of stay.

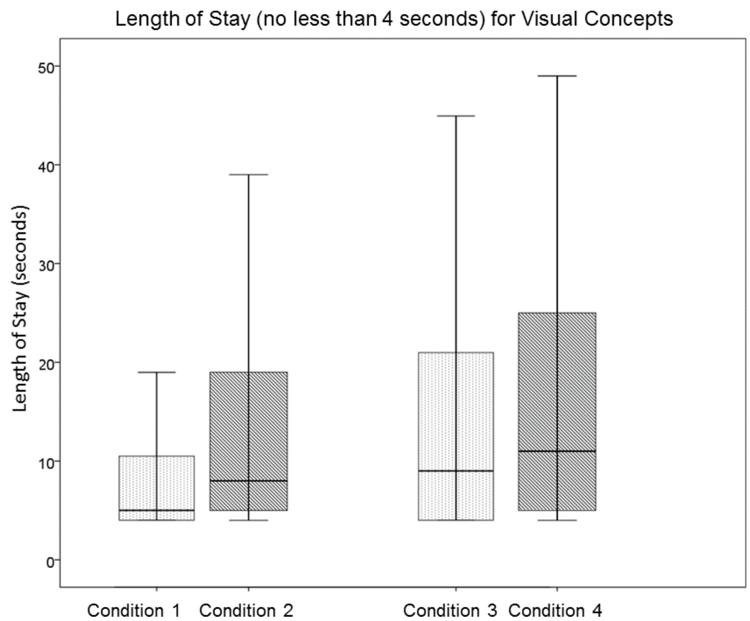


Figure 7-8. Boxplot of medians on passersby's length of stay using visual concepts. Condition 1: Control, Condition 2: Adaptive Speed, Condition 3: User Shadow, and Condition 4: Adaptive Speed and User Shadow. Outliers are not shown in the plot to better scale the boxes.

This result is consistent with the findings of the laboratory study that the combination of Adaptive Speed and User Shadow had a significant effect on the reported attention drawn, and further shows that each visual concept independently was effective in retaining passersby's attention. Beyond simply notifying passersby of the display's existence, these results also provide evidence of the holding power of these visual concepts.

7.3.2 Glances and Stares

Glances (GLANCE) and stares (STARE) were observable physical actions undertaken by passersby corresponding to the beginning of any display interaction. A glance was signified by a passerby walking pass the display with their head oriented towards the display. In contrast, stare was signified by a passerby stopping in front of the display with their head oriented towards the display. Figure 7-9 shows examples of a glance (a) and a stare (b). In addition, if a passerby had ample chance to notice the display (e.g., they were heading towards the display and were not pre-occupied with other things such as a mobile device), but showed no sign of orienting towards the display, their action would be treated as an occurrence of "none" (NONE). Note, because eye-tracking was not conducted, it is possible that some of these "none" instances were actually "glances". But due to the positioning of the camcorder, this was not observable.

a) A glance where the head of the passerby oriented towards the display while walking.

b) A stare where the head of the passerby oriented towards the display, and they stopped.

c) Treated as “none” if the passerby had ample chance to notice the display but showed no sign of head orientation.

Figure 7-9. Examples of a glance (a), a stare (b), and none (c). The main difference between a glance and a stare is whether the passerby stopped (stare) or not (glance).

Prior studies treated glances as one of the indicators of interaction with a PLIS (e.g., Alt et al., 2012; Brignull & Rogers, 2003; Dalton et al., 2015). For example, Michelis and Müller (2011) used a head-turn (i.e. a glance) as one of the observable reactions to the display to separate "viewers” from “passersby”, and reported approximately 640 to 650 (out of 660) viewers in their field study of the Magical Mirrors system. However, stares were not quantified separately. Using the DISCOVER interaction model as the basis of the video-coding scheme, glances and stares were coded separately in this analysis to reflect the different user states as demonstrated by the passersby’s behaviours.

The video-coded data revealed a similar distribution of GLANCEs (~80%), STAREs (~10%) and NONEs (~10%) across all four conditions (see Figure 7-10), indicating that the studied visual concepts had no effect on promoting further interactions (transitioning from *notified* to *intrigued* as described in DISCOVER). Meanwhile, the high proportion of glances with substantially fewer stares observed may be explained by the location of the display: a frequently commuted location. Thus, while noticing the display, most passersby may not have had the time to stop for it.

The duration of the glances tended to be very short, as it was carried out by passersby without stopping for the display. This behaviour corroborated with the brevity of most glances reported by Huang et al. (2008). Due to technical constraints it was not possible to report the exact duration of glances, but from field observations this varied from a quick second (c.f. average duration of fixation of less than one second reported by Dalton et al. (2015)) to about four seconds (the approximate time to walk past the display).

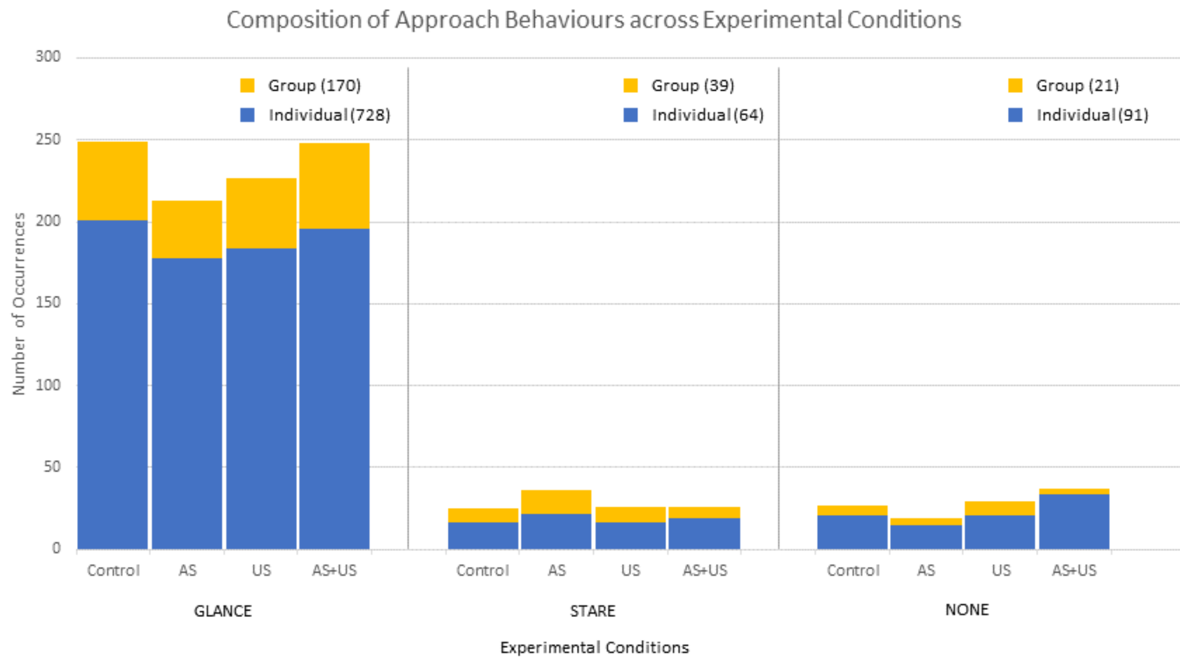


Figure 7-10. A comparison of composition of approach behaviour (glance, stare, and none) exhibited by the passersby across four experimental conditions: Control, Adaptive Speed (AS), User Shadow (US), and Adaptive Speed and User Shadow (AS+US). Each bar represents total occurrences from both individuals and groups. Numbers next to the legends represent unique counts of groups and individuals constituting the occurrences. Note that multiple occurrences (representing multiple clusters of actions) might come from the same group or individual.

For those passersby who did stop for the display, the video revealed that they spent most of the time staring at the content. Some, however, stared at the Kinect device, potentially trying to make sense of its presence. This observation was consistent with the interaction behaviours reported next.

7.3.3 Touch, Shadow Interaction, and Movements

If a passerby was sufficiently intrigued, they then tried to explore the display to see if they could do something with it. These further actions were considered *physical interactions* towards the display, in which passersby went beyond just staring.

The video-coding scheme categorized such physical interactions based on their form: TOUCH referred to a touch directly on the display surface; MOVE referred to back-and-forth body movements in front of the display; actions in relation to the shadow was broken down into SHADOW-PLAY where a passerby moved their limbs in the presence of a shadow in a playful, often random manner, and SHADOW-REACH where a passerby appeared to purposefully move their limbs as if to interact with the content or the shadow from a distance. It was observed that some passersby tried to wave at the display to trigger some responses, even when the display was not showing any user shadows (Conditions 1 and 2). SHADOW-PLAY and SHADOW-REACH were therefore expanded to include any limb movements to encompass such actions.

Figure 7-11 shows the video-coding results across all four conditions for physical interactions. The field notes indicated that, anecdotally, most of the passersby appeared to recognize the Kinect device, a consumer gaming product that recognized body gestures, above the display and therefore expected their movements to trigger some system responses. Uncertain what it actually was for, many passersby waved at a distance, hoping for some responses from the display. This could explain the unexpectedly frequent occurrences of SHADOW-REACH in the Adaptive Speed condition, where no shadow was shown, and the speed of the images did not change unless a passerby crossed from zone to zone. With such absence of visual feedback (no user shadow, and no speed change from waving), passersby were left unsure about the display's interactivity, resulting in giving up and walking away.

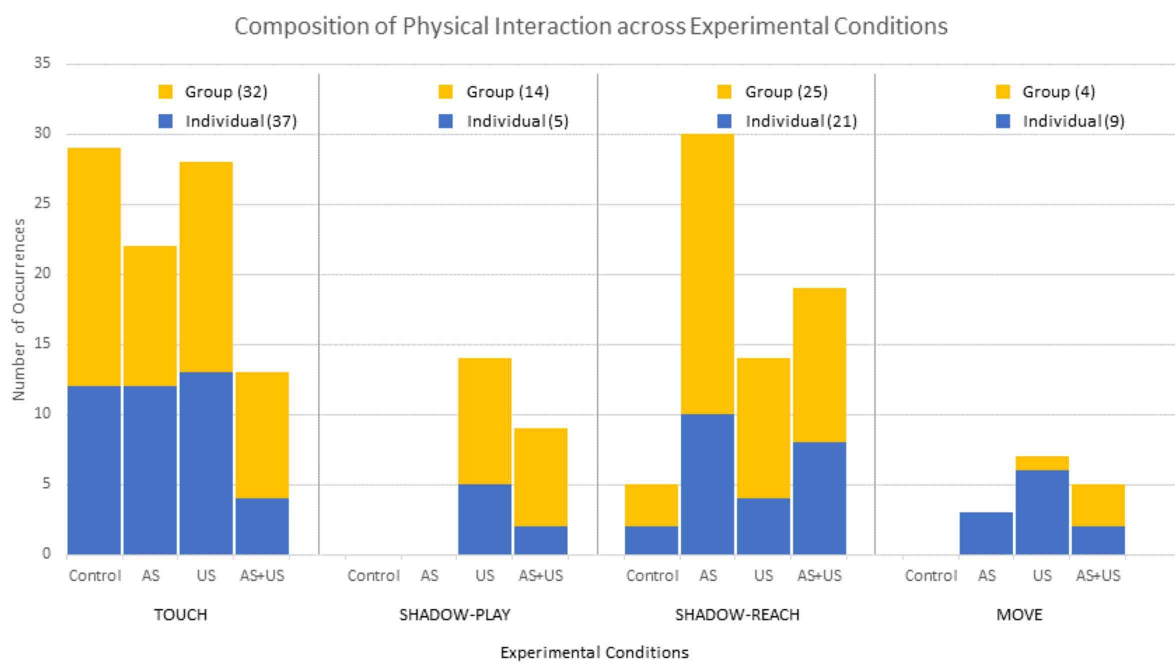


Figure 7-11. A comparison of composition of physical interaction (TOUCH, SHADOW-PLAY, SHADOW-REACH, and MOVE) used by the passersby to explore the display across four experimental conditions (1 to 4): Control, Adaptive Speed (AS), User Shadow (US), and Adaptive Speed and User Shadow (AS+US). Each bar represents total occurrences from both individuals and groups. Numbers next to the legends represent unique counts of groups and individuals, which might result in multiple occurrences.

Except in the Control condition, back-and-forth movements (MOVE) were designed to trigger proxemics responses (stepwise speed change of images and/or continuous contrast change of user shadow). However, this physical interaction happened significantly less than the other forms of interaction. This could be caused by passersby not noticing such system responses (also observed in the laboratory studies); or might be a result of the more prominent appearance of the Kinect device than in the laboratory study, leading to an assumption that it was the main input channel of interaction (commonly known for lateral body/limb movements, rather than proximity). It was, however, not possible to infer from the results of any other perceived interactivity facilitated by the visual concepts, due to the lack of questionnaire responses.

Regarding the touches logged by the application, in every condition about 20-30% of these touches occurred on the static background area, which did not respond to touches. One explanation could be that passersby tested the display to see what it would do in response to touches at random locations.

7.3.4 Transitioning from Approach Behaviour to Physical Interaction

While it was not possible to control the composition of groups and individuals in the field study – thus allowing evaluation of how such composition was affected by the interface design (e.g., which visual concept could better attract groups or individuals) – the results did allow for an examination of how groups and individuals transitioned into later parts of interaction.

Table 7-4. Ratio of interaction occurrences between groups and individuals, measured across four experimental conditions (1 to 4). An opposite group-to-individual ratio was observed in most of the interaction types in the physical interaction tier.

	Control Group:Individual	**Adaptive Speed Group:Individual**	**User Shadow Group:Individual**	**Adaptive Speed & User Shadow Group:Individual**
GLANCE	48:201 **(~0.24)**	35:178 **(~0.20)**	43:184 **(~0.23)**	52:196 **(~0.27)**
STARE	9:16 **(~0.56)**	14:22 **(~0.64)**	10:16 **(~0.63)**	7:19 **(~0.37)**
NONE	6:21 **(~0.29)**	4:15 **(~0.27)**	8:21 **(~0.38)**	3:34 **(~0.09)**
TOUCH	17:12 **(~1.42)**	10:12 **(~0.83)**	15:13 **(~1.15)**	9:4 **(2.25)**
SHADOW-PLAY	0:0 **(NaN)**	0:0 **(NaN)**	9:5 **(1.8)**	7:2 **(3.5)**
SHADOW-REACH	3:2 **(1.5)**	20:10 **(2)**	10:4 **(~2.5)**	11:8 **(~1.38)**
MOVE	0:0 **(NaN)**	0:3 **(0)**	1:6 **(~0.17)**	3:2 **(1.5)**

Table 7-4 shows the group-to-individual ratio of occurrences for the coded interactions. During the transition from approach behaviour (GLANCE, STARE, NONE) to physical interaction (TOUCH, SHADOW-PLAY, SHADOW-REACH, MOVE), there was a reverse in the ratio of occurrences in almost all the types of interaction, suggesting that staying groups were more likely to engage in further interaction types. This phenomenon may be explained by the typical dynamics observed amongst groups that stopped at the display: when one or more group members noticed the display and decided to interact with it, other members also noticed it and followed suit.

Such observation has parallels to the previously reported “honey-pot” effect (discussed in Section 2.1.1). Yet, anecdotally, the outcome of this effect appeared to be different between acquaintances and between strangers. In the case of acquaintances, the number of interacting users increased as a passerby joined their friend. In the case of strangers, the number of interacting users remained unchanged as an approaching passerby stood at a distance observing an already interacting user, either waiting for their “turn” or left before any further interaction occurred. The latter was more common for (apparent) strangers, likely due to the high-traffic nature of the deployment site. However, a closer examination of how the “honey-pot” effect operates in the presence of different social configurations (e.g., acquaintances versus strangers) and in different contexts (e.g., high-traffic areas versus resting areas) is required to better understand this phenomenon.

In addition, by examining the number of passerby unit (groups and individuals) that transitioned from approach behaviour to physical interaction (shown in Figure 7-12), a trend similar to the Audience Funnel described by Michelis and Müller (2011) was observed, where the number of interacting passersby decreased rapidly in the beginning, and remained fairly constant further along with more engaged interaction, across all four conditions.

Furthermore, by examining the composition of groups and individuals, it was observed that groups tended to be more likely to stay for more engaged interaction than individuals, regardless of what condition they were experiencing. This result also corroborated the reversal of group-to-individual ratio of occurrences phenomenon discussed earlier in this section.

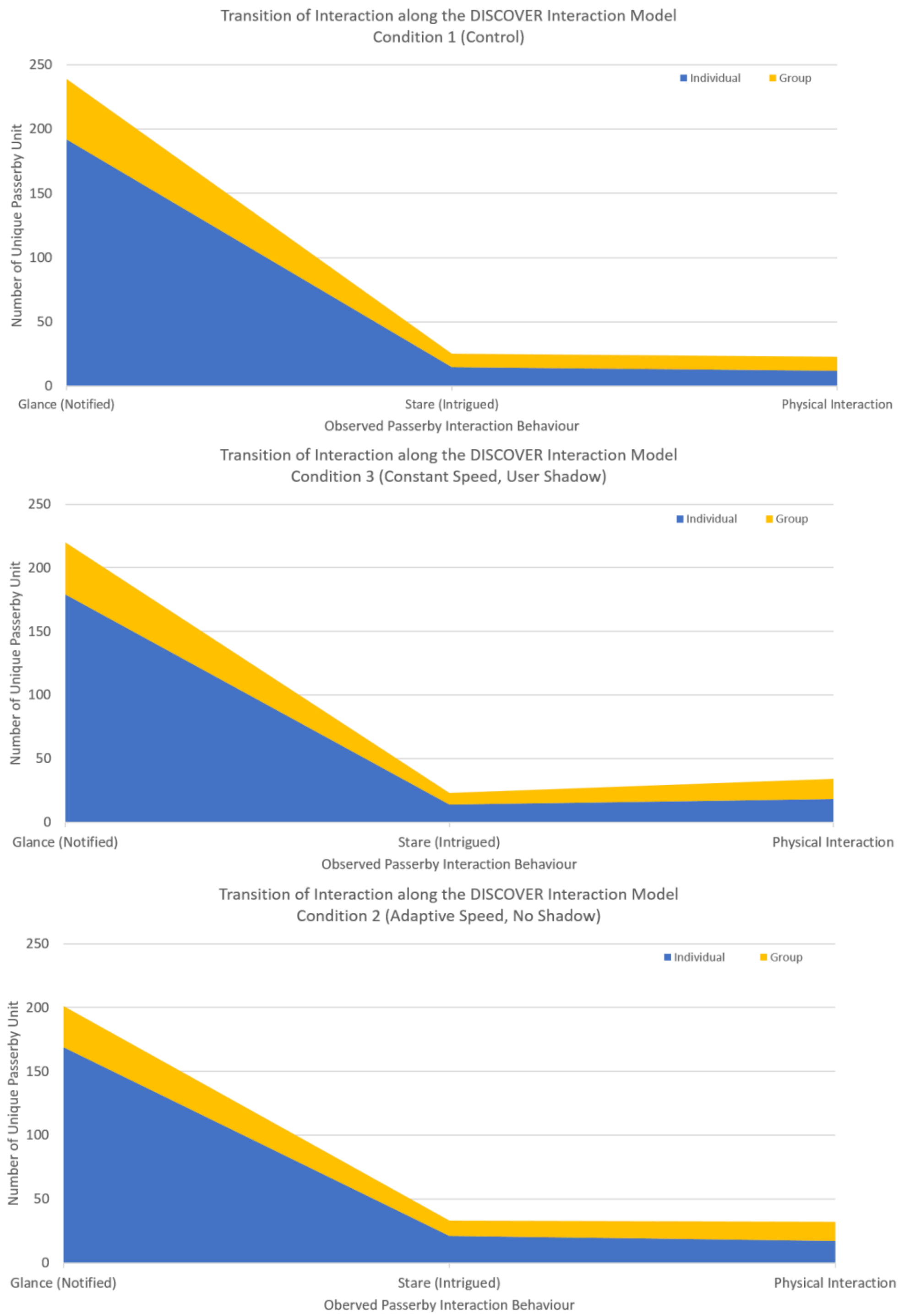


Figure 7-12. Transition of interaction in groups and individuals along the DISCOVER interaction model across four experimental conditions (1 to 4): (top to bottom) Control, Adaptive Speed, User Shadow, and Adaptive Speed and User Shadow. Physical Interaction includes any of the four interaction types in the tier.

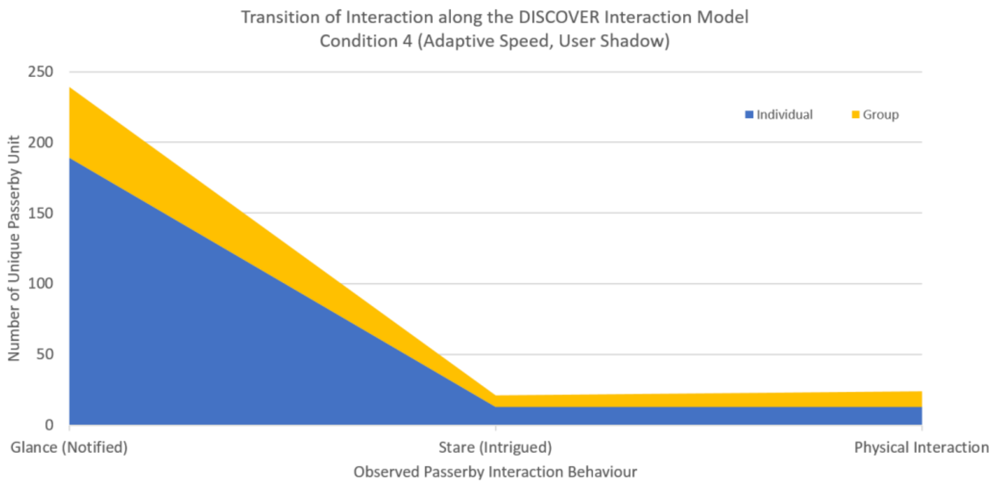


Figure 7-12 (Cont'd). Transition of interaction in groups and individuals along the DISCOVER interaction model across four experimental conditions (1 to 4): (top to bottom) Control, Adaptive Speed, User Shadow, and Adaptive Speed and User Shadow. Physical Interaction includes any of the four interaction types in the tier.

In summary, by examining individuals' and groups' behaviours separately, it was observed that there was a difference in how passersby reacted to the studied visual concepts depending on the social configurations (e.g., by oneself, with acquaintances, in the presence of strangers), thus affecting the progression along the interaction process with a PLIS.

7.3.5 Relating Results to Laboratory Studies

This field experiment was motivated by the need to further validate the results from the previous laboratory study (Chapter 6) in a real-world setting. It was also important to investigate the effectiveness of the studied visual concepts separately, and their ability to entice further interaction.

7.3.5.1 Drawing Attention

In the laboratory study, attention was measured based on participant responses to the post-experiment questionnaires. A similar questionnaire was used in the field experiment by inviting passersby to an online survey. However, this data collection method was not successful, possibly because the survey had to be answered elsewhere (with passersby's own computers), resulting in passersby not bothering or forgetting to do so. Thus, the field experiment was not able to gather participant perceptions of the studied visual concepts. Though it was disappointing that no participants completed the online survey, in reality this would have only represented the passersby who engaged with the display.

However, the field experiment provided other potential measures for drawing attention. First, glances, stares, and other coded physical interaction indicated the display drawing attention. Further, passersby's conversations overheard by the researcher (and in some cases captured by the camcorder) also indicated passersby noticing the display. Many such comments indicated that attention was drawn due to the physical appearance of the display (the digital whiteboard, the Kinect device). So while not being able to directly validate the attraction power found in the laboratory study, the field experiment has instead provided evidence in drawing attention with visible hardware.

7.3.5.2 Holding Power

Unlike the laboratory study, the field experiment allowed actual interaction with the display, enabling the measurement of length of stay of passersby, which in turn indicated the transition into user states beyond *notified* in the DISCOVER model. The separation of adaptive speed and user shadow into two independent experimental factors had made it possible to systematically evaluate their effectiveness.

Analysis of the computer logs revealed that both adaptive speed and user shadow were effective in holding the attention of passersby; with the latter being more effective through the more observable visual feedback as a silhouette, and its affordance of a more playful form of interaction, as anecdotally observed during the field experiment. To this end, the field experiment complemented the findings in the laboratory study by extending the evaluation of visual concepts to later phases of the interaction, particularly in retaining passersby for further exploration of the interface.

7.3.5.3 Interactivity and Playfulness of User Shadow

Another important finding from the laboratory study was the *limited* interactivity communicated by the user shadow, and the playful behaviour exhibited by the participants in the presence of their own silhouettes. A similar observation was also made in the field experiment: passersby moved their limbs and experimented with the display when their silhouettes were present. This carried-over behaviour provided evidence that the laboratory methodology was successful in simulating a commuting public scenario, and therefore promoted similar types of interaction.

One caveat, however, was the different placement of the Kinect device: it was placed on top of the display and thus was visible as part of the display, as opposed to at the back of the experimental room in the laboratory study, thus showing no connection to the display. This difference resulted in a few confused passersby trying to figure out the purpose of the display in the absence of their silhouettes (under the control and adaptive speed-only conditions), and will be discussed further in Section 7.4.

7.3.6 Limitations of the Field Experiment

This field experiment addressed the issue of lower ecological validity of the laboratory-based study described in Chapter 6 by being conducted in-situ using conventional "in-the-wild" observational study methodologies. Yet, the majority of the passersby were university students and staff, and a few groups of visitors. So while the findings were more generalizable than with recruited participants in the laboratory study, they could be further generalized to a wider demographic if the display was deployed in a more "public" location, such as a museum or mall.

Also, to maintain a naturalistic environment, no signage explaining the study's purpose was posted during the study period, and interviews were not conducted on-site. It was hoped that by providing an online questionnaire and motiving its completion by a monetary return, some insights of the perception towards the display could be gained to further verify some of the findings in the laboratory study (e.g., participants noticed the changes in the appearance of the user shadow in relation to their own movements). However, due to the lack of responses, such information was not available.

In addition, due to physical constraints of the environment, the Kinect device being used to capture passersby's proxemics information was positioned differently (on top of the display in the field experiment, opposite to the display in the laboratory study). As reported in the sections above, the device did draw some attention from the passersby, and appeared to suggest and prompt some actions known to be recognized by the device (e.g., waving). It also created some confusion when such actions were not responded to (in Conditions 1 and 2 where no user shadows were displayed). This might have confounded the comparisons between the studied visual concepts, giving raise to the absence of interaction effect, and fairly equal lengths of stay and occurrences of interactions. Another consequence of the environmental constraints was that the deployment site was a busy passage with relatively less space perpendicular to the display, which might have limited the movements and interactions exhibited by the passersby. On the other hand, the fact that the deployment site was a common "thoroughfare", and that a significant effect was found for the studied visual concepts on attracting and engaging passersby shows the potential of these of these concepts.

Finally, as the focus of the study was the ability to draw attention and engage interaction, content and its interactivity were kept minimal to the experimental factors. Hence, engaged passersby could at most play with the user shadows that mirrored their movements, and touch the images to reveal the link and QR code to the online questionnaire. Without any further functionality to be explored or utilized, passersby tended to lose interest quicker than one would expect (or hope) than at a real PLIS.

7.4 Implications

Overall, the field experiment provided further evidence of the effectiveness of the studied visual concepts in drawing passersby's attention, and provided additional data on their holding power (to retain passersby). The field experiment also provided some new insights into designing the interaction and interface with a PLIS system, in terms of the physical setup of the system itself, and the use of interface elements being presented to the passersby.

7.4.1 Hardware Setup as Interaction Cues

The highly visible placement of the Kinect device hardware enticed a higher degree of physical movements towards the display due to passersby's recognition and curiosity. It also appeared to instill certain expectation of how the display would behave in response to the known interaction mechanism. Failure to meet this expectation will create confusion and frustration, as evidenced in the field experiment that passersby giving up and leaving when the display system did not provide any indication of recognizing they actions (in Conditions 1 and 2 where no user shadows were presented).

The behaviour of passersby trying to trigger a response based on their understanding of a Kinect device suggested that when designing the physical setup of a PLIS system, the technology can be exploited as *interaction cues* to suggest interactivity. It is important to note, however, that the cues must be followed-through in the interface to reinforce the passersby's understanding and expectation.

7.4.2 Robustness of Display Equipment

In a study of content readability in a public display, Schmidt et al. (2013) reported some "technology exploration" behaviours, where passersby engaged in non-content driven actions such as inspecting items attached to the display, and investigating behind the screen. Similar behaviours were also observed in the field experiment, to a point where some passersby tried to move the Kinect device, or went behind the display and pressed the keyboard attached to the computer running the application.

Physical designs for PLISs must consider passersby's behaviours like these and be robust enough to withstand all forms of "technology exploration", ranging from harmless eye-inspection, to physical explorations such as poking, or unwelcomed adjustments that might affect the way the system functions. For example, touchscreens using reinforced glasses, cameras positioned behind protective screens, could be used to increase the robustness of display equipment.

Another approach would be to support interaction that is less susceptible to impairment due to physical contact. For instance, "touchless" interaction using video captures (e.g., via a Kinect device or a web-cam), or voice activating inputs. However, as these interaction mechanisms are more "invisible", PLIS systems must be designed to clearly communicate them to the passersby.

7.4.3 Vitality of Visual Content

As observed in the field experiment, a large proportion of passersby had their face oriented towards the display (i.e. glanced the display), meaning that the content was visually conveyed for the majority of the time. However, such glances tend to be very brief (a few seconds) as most of the passersby did not stop for the display, as reported in prior work as well (Dalton et al., 2015; Huang et al., 2008).

The consistently brief glances without stopping, across this study and others, suggest that readable and eye-catching visual content, for example, large and animated images, should be prioritized when designing interfaces for PLISs. This is also a useful approach for PLISs that are intentionally designed to be viewed briefly, for example, informational displays, and advertising billboards.

7.4.4 Extending User Shadow

The field experiment has provided ecological evidence in the use of visual concepts as a technique to draw attention and entice interaction. User shadow was shown to be effective to draw attention and retain passersby, and entice interaction (sometimes even playful) with the visible placement of camera hardware.

A promising next step is to extend such shadow visualizations into a more sophisticated interaction paradigm. For example, the shadow can be used later on in the interaction process as an assistive tool to actively guide a user to interact with the content, or to allow a user to perform virtual actions such as manipulating virtual objects, or remote access to other displays. Whether this extended use of user shadow could further facilitate passersby to carry through the entire interaction process, as described in the DISCOVER interaction model, warrants future investigation.

7.5 Chapter Summary

In this chapter, I have presented the details of the field experiment conducted in this thesis in investigating the effectiveness of animated content and user shadow, including the motivation, experimental design and implementation, as well as the analysis of the collected data. Due to the lack of responses to the online questionnaire, it was not possible to gather participant perceptions of the studied visual concepts to validate some of the findings in the laboratory study. However, the attention drawn and playfulness that participants exhibited in the laboratory study appeared to be carried over to the field experiment, suggesting that the laboratory-based methodology succeeded in fostering candid passerby behaviour from participants.

Moreover, the in-situ nature of the field experiment provided ecologically valid evidences in other aspects of the interaction process. For example, how the visibility of technology impacted passersby's behaviours and expectations, how the studied visual concepts affected the holding power of the display, and how the interaction proceed into later user states as described in the DISCOVER model.

Finally, in contrast to individual interaction in the laboratory study (conducted for each participant separately), the field experiment encompassed both individual and group interaction with the display. Besides more elaborate actions from individuals, variation in group dynamics (acquaintances versus strangers) was observed, thus broadening the findings in this thesis, and providing additional insights and implication into the design of interactions and interfaces for PLISs.

Chapter 8

Discussion

This chapter summarizes the lessons learned and findings from the studies[19] described in Chapters 5, 6 and 7, and discusses the limitations of the approach taken in this thesis, in terms of the methodology itself, as well as the technological shortcomings. A set of design implications and recommendations is also provided as reference for the design of Public Large Interactive Surfaces (PLISs).

8.1 Summarizing Study Findings

Using a combination of laboratory and field experiment methodologies, the previous three chapters examined the interaction process with PLISs, particularly its early stages including drawing passersby's attention and enticing them to interact. The findings provided both qualitative and quantitative evidence that corroborates prior research, and provides new insights into the perception of the system, as well as the utilization of the proxemics theory to the interface and interaction design.

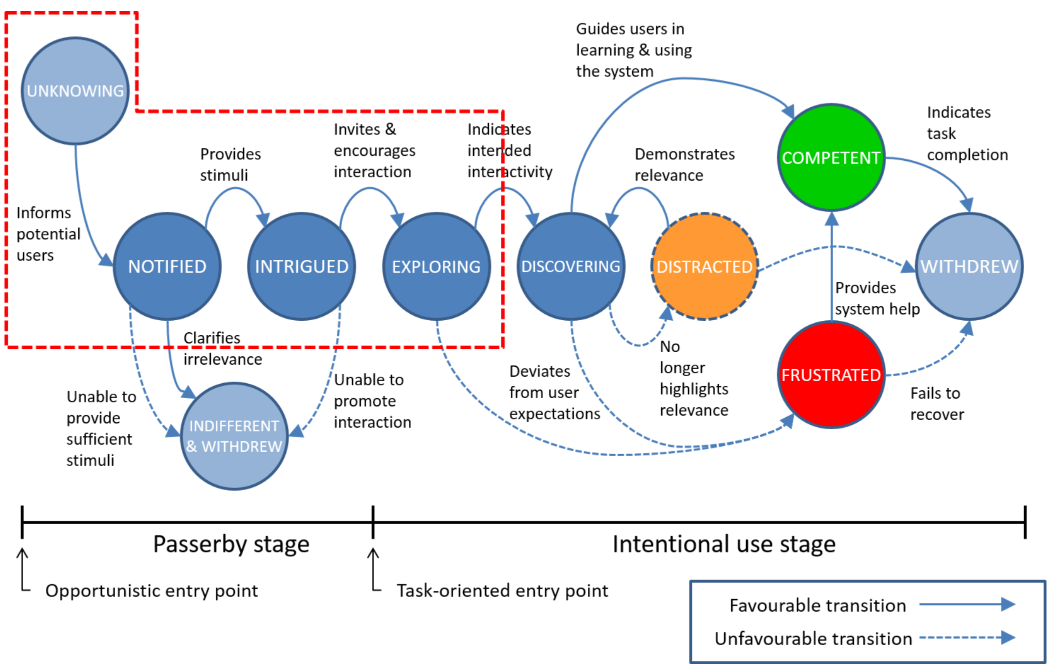


Figure 8-1. The DISCOVER interaction model helped direct the focus of this thesis to the opportunistic application of PLISs, as highlighted in the region bounded by dashed lines.

[19] Unless otherwise specified, "laboratory studies 1 & 2" and "field experiment" refer to the studies conducted in this thesis (Chapter 5 & 6 for laboratory studies 1 & 2, Chapter 7 for field experiment).

As discussed in Section 3.7, the DISCOVER interaction model can be applied to the design and evaluation of PLISs in multiple ways. This chapter uses it as a framework to situate the discussion. Figure 8-1 shows the region of DISCOVER corresponding to the start of the opportunistic application category. By separating the interaction into user states, it was possible to select and evaluate design concepts in terms of their effectiveness in facilitating individual transitions. As discussed below.

8.1.1 Notifying Passersby

The first transition in DISCOVER is to transition an *unknowing* passerby to being *notified*. Based on psychology and vision study literature (Section 2.6.1), low-level content motion (speed changes) and high-level "odd-ball" user shadows, both combined with the proxemics theory, were applied and evaluated in this thesis. Participants' responses from the laboratory study 2 indicated that adding user shadows to content motion was effective in drawing their attention (Section 6.4.2). Content motion, on the other hand, was only marginally effective by itself, and was typically overlooked due to its discrete changes, as well as the presence of the more visually prominent user shadows.

Though the online questionnaire created in the field experiment could not be used to investigate how unknowing passersby's attention was drawn to the studied visual concepts, the video analysis and observation made in the field experiment revealed a role played by the surface's hardware setup in notifying passersby: the appearance of the surface and the placement of the Kinect device appeared to draw many glances, which is consistent with prior studies (Dalton et al., 2015; Huang et al., 2008).

8.1.2 Intriguing Passersby

The favourable transition following a *notified* passerby is to have them become *intrigued*. Both the progressively slowing down of the content, and increasing visibility of the user shadows in relation to proximity were designed as stimuli to *intrigue* and invite passersby to approach and interact with the surface. Participants' feedback from the laboratory studies revealed a sense of familiarity of the images (recognition of the university's photos), and a sense of ownership (recognition of the shadows as their own) and playfulness with the user shadows (laboratory study 2, Section 6.4.4), suggesting that passersby could be notified and intrigued by these studied visual concepts.

The ability to intrigue passersby can also be reflected by the holding power of the surface (Section 7.3.1), as they would not stay if they had no interest in it. In the field experiment, both visual concepts were shown to be effective in retaining the passersby over the control condition, with user shadows having a stronger impact.

8.1.3 Inviting Passersby to Explore

The previous two transitions are related to an often observed design challenge in PLISs: display blindness (passersby not aware of the surface). Another often cited challenge for PLIS utilization is interaction blindness, where passersby do not know the surface is interactive (Ojala et al., 2012). Results from the laboratory studies suggested that content movement did not communicate any interactivity, mostly because the movement itself was not noticed from the beginning. In contrast, user shadows appeared to help indicate *some* interactivity (Section 6.4.3), which corroborates prior work using silhouettes but without any proxemics responses (Müller et al., 2012).

The field experiment provided a clearer picture of how passersby explored the surface. As discussed in Section 7.3.3, some passersby went beyond mere staying and looking (STARE, GLANCE), and started touching, waving and/or moving their limbs at the surface to experiment with the system (TOUCH, SHADOW-PLAY, SHADOW-REACH, MOVE). According to the field observation, these actions appeared to be largely caused by the passersby recognizing the Kinect device, and/or seeing their silhouettes on the surface.

8.1.4 Facilitating Discovery

Due to the focus on early stages of interaction in this thesis, and time and technological constraints, the interaction design of the application used in both the laboratory studies and field experiment was kept minimal. In the laboratory studies, interaction was limited to relating content's contrast (study 1), content's motion (studies 1 and 2), and user shadow's contrast (study 2) to participants' proximity to the surface. User shadows (study 2) were also designed to mimic participants' movements like a mirror reflection. In the field experiment, an interaction mechanism similar to study 2 was used, with the additional touch interaction afforded by the floating images.

As a result, the intended interactivity was simple movements in front of the surface and touches on the images, without more involved interaction mechanisms such as user shadows affecting image trajectories, or multi-touch manipulating the displayed content. The laboratory studies and field experiment therefore provided little indication of the intended interactivity. One rather unexpected finding from the field experiment, however, was that after recognizing the Kinect device, passersby tended to perform more limb movements that were commonly known to be sensed by the device, and less forward/backward movements that was part of the intended interactivity. In the absence of visual feedback (Conditions 1 and 2 in the field experiment where no user shadows were present), some passersby appeared to give up and then left, as discussed in Section 7.3.3.

8.1.5 Facilitating Transitions with Studied Visual Concepts

The above findings suggest that user shadows mirroring passersby's movements were effective in facilitating favourable transitions along the interactive process, as depicted in Figure 8-2. Adaptive speed, however, often went unnoticed and hence was less effective. In addition, having the Kinect device visible (recognizable hardware) helped draw a lot of attention and instilled expectations of interaction types (limb movements), to a point that when passersby did not see any visual feedback in response to their movements, they became confused, frustrated, and eventually left.

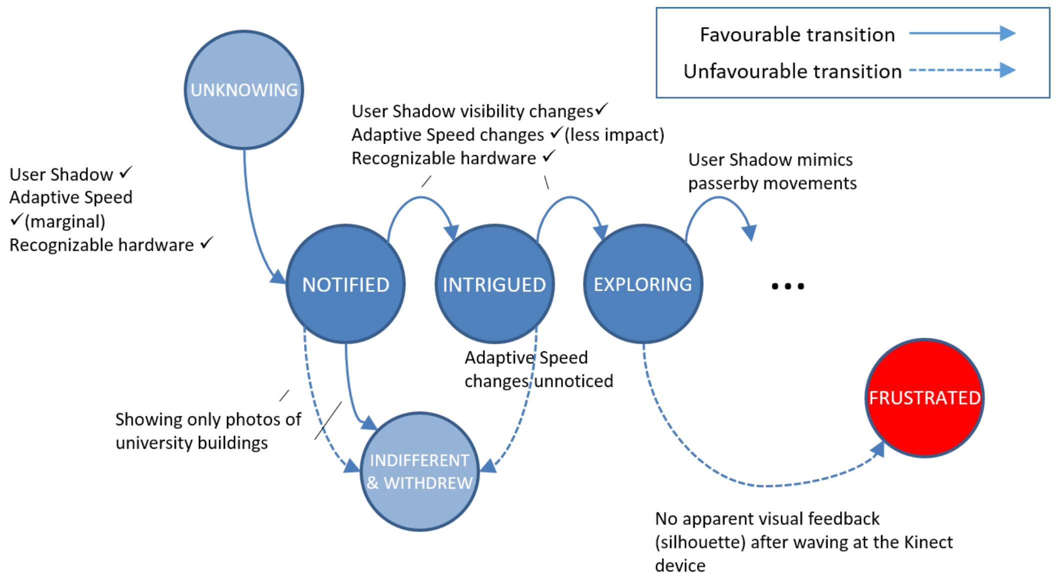


Figure 8-2. A summary of the effectiveness of studied visual concepts facilitating different transitions along the early stages of the DISCOVER interaction model. Later stages of the model were not studied in this thesis and hence are not included.

Limiting application content to only photos of the university had both favourable and unfavourable impact in transitioning passersby to the *indifferent & withdrew* state. As indicated in the laboratory studies, these photos were easily recognized, and were quickly determined as irrelevant content, or content without interesting properties by some participants.

8.1.6 Corroboration of Prior Research

Most existing studies on PLISs have been conducted "in-the-wild", where system usage by real users is observed at the deployment site; with a few laboratory studies evaluating the effectiveness of specific design elements. The study and experiment findings in this thesis have confirmed and provided further evidence in many of these areas, as detailed below.

- **Honey-pot effect** – In the field experiment, passersby often glanced or stared at the surface when someone else was already interacting with it, taking a "spectator" role (Finke et al., 2008). Some passersby who were using the surface even called their friends to join.
- **Brief glances and less frequent stares** – In the field experiment, a glance (head turn without stopping) was the most observed form of interaction, with a significant drop in a stare (stopped and looked) (c.f. Michelis & Müller, 2011). This could be due to the surface being deployed at a frequently commuted location, and the use of university's photos that quickly transitioned many passersby into the *indifferent & withdrew* state.
- **User shadows drew attention and enticed interaction** – The user shadow (silhouette mirroring people's movements) used in this thesis was inspired by art installations using shadows as content (Krueger, 1991), and recent work by Müller et al. (2014, 2012) using shadows to communicate interactivity in public surfaces. The findings in the laboratory studies and field experiment were consistent with that of prior work on the effectiveness of user shadows in drawing passersby's attention, and further demonstrated its effectiveness in retaining passersby's attention and engagement. Feedback from the laboratory study 2 suggested that passersby recognized the user shadows as their own; and as observed in the field experiment, often ended up interacting with them and exhibited exploratory behaviours (also reported in a recent work by Tomitsch et al. (2014) using a skeletal setup).

8.1.7 Design Insights

The combination of laboratory studies and field experiment in this thesis also offered new insights into the usage of PLISs for opportunistic applications, as opposed to task-oriented applications where passersby approached with a task in mind. Such usage puts the onus on better drawing the attention of passersby and enticing them to interact.

8.1.7.1 Go Beyond Honey-pot Effect

Although the "honey-pot" effect was observed in the field experiment, suggesting PLISs should be designed to facilitate such effect, it is important to also consider other techniques to draw attention. This is because the "honey-pot" effect relies completely on whether there already are people using the system, meaning that a PLIS has to at least be able to draw the attention of a passerby to start the effect. Also, in cases where foot traffic is frequent, passersby do not expect themselves staying for long, and are less likely to wait until the existing user withdraws to start their turn.

As illustrated in this thesis, visual content that can be recognized immediately is a very helpful means to draw the attention of a passerby, hence potentially starting the “honey-pot” effect. Yet, this perception is not equivalent to completely understanding the content. Passersby could be notified and intrigued by the presentation of slightly “mysterious” content (e.g. user shadow), thereby raising their curiosity. Expanding on this idea, audio cues, such as a distinctive sound effect, or a short phrase, could also be used to draw passersby’s attention and elicit their curiosity for further exploration.

8.1.7.2 Managing Expectations

After their glance, the passersby should have a perception of the displayed content and have formulated an expectation towards the surface. Some research has recommended “immediate apprehendability”, where people will understand the purpose, scope, and properties of the surface almost immediately and without conscious effort (Allen, 2004; Peltonen et al., 2008). Yet, some others recommended “engendering curiosity” by hiding results of an action (Reeves et al., 2005) or using metaphors (Hinrichs et al., 2008).

The studies in this thesis used photos of the university as the main content to provoke familiarity. Feedback from the laboratory studies indicated that the participants recognized the photos and formed a variety of expectations towards the surface’s purpose (e.g., “as a distraction”, “make students feel positive”, and “UW propaganda”). On the other hand, user shadows were used in the studies as a generic unexpected content that did not carry any information, resulting in curiosity and playful exploration. These results demonstrated that both kinds of expectations could be used at the same time, leading to different types of reactions from the passersby.

8.1.7.3 Proxemics as On-set Triggers

With the ability to sense passersby’s proxemics attributes (e.g., distance, orientation) in relation to the surface, some research has discussed using such information to determine the way (e.g., levels of details) content is presented on the surface (Marquardt & Greenberg, 2012; Wang et al., 2012), and making sense of user intention (Vogel & Balakrishnan, 2004).

This thesis used proxemics to control the visual appearance of the content on the surface, so as to convey the concept of proximity and the surface’s responsiveness to proximity, thereby encouraging passersby to approach the surface. Yet, the laboratory studies showed that not all changes could be observed (e.g., speed change of images). This might be explained by the other visual element (user shadow) dominating one’s visual attention; and the fact that speed change only happened when a distance threshold was crossed, requiring constant attention to the surface. Thus, while applicable as an interaction mechanism for PLISs, use of proxemics on multiple visual concepts has to be carefully designed to be observable and to avoid competing feedback cues.

For example, continuous proximity mapping could first be applied to the dominating high-level visual elements to draw unknowing passersby's attention. Then, when their attention is directed to the surface's content, discrete proximity mapping could be applied to the low-level visual elements (e.g., speed, contrast) of the content to further direct intrigued passersby, and guide them further along the interaction process with PLISs.

8.1.7.4 Visible Technology as a Technique

PLISs are often considered as "ubiquitous computing" systems as they are designed to be used as part of our everyday lives (Weiser, 1999). One main concept of ubiquitous computing is that such devices should be made "invisible" so their presence will not be noticed (D. A. Norman, 1999b). However, this might not be applicable to PLISs, especially when passersby's attention has to be drawn.

As observed in prior work, and in the field experiment, passersby's attention was drawn by the presence of the technology (e.g., cameras and projectors in Schmidt et al.'s Screenfinity (2013), digital whiteboard and Kinect device in this thesis), who even tried to interact with it. This indicates that making the technology visible could be an effective technique in drawing attention, and even communicate interactivity.

8.2 Design Principles and Recommendations for PLISs

Based on the findings discussed in the previous sections, two design principles are derived in this thesis for designing an effective PLIS system. A number of design recommendations are then established illustrating these principles. While targeting attention drawing and interaction enticing, these recommendations also facilitate other transitions along the interaction process with PLISs.

8.2.1 Design Principle One – Immediate Recognizability

In contrast to "immediate apprehendability" emphasized in prior work (Allen, 2004; Peltonen et al., 2008; Seto et al., 2012), this design principle focuses on the quality of making a passerby aware of and discern the system quickly. Instead of completely apprehending everything the surface has to offer, the passerby only needs to recognize some of the features of the surface, for example, a camera (commonly known to be able to track people), or a frame that looks like the borders of a tablet.

This principle allows a wider range of attraction drawing techniques such as "contextual odd-balls" (e.g., a physical robotic hand (Ju & Sirkin, 2010), curiosity-provoking artifacts (Houben & Weichel, 2013)) and "display of technology" to be employed, without "dumbing down" the interface of the system to simple primitive shapes and symbols.

8.2.2 Design Principle Two – Appeal to Agency

Reflecting on the use of user shadow in public surfaces in prior work (Müller et al., 2014, 2012) and this thesis, its effectiveness comes from passersby's realization that the surface is responding to *their own actions*. This perception of agency, defined as the sense of having "global motor control, including the subjective experience of action, control, intention motor selection and the conscious experience of will" (Blanke & Metzinger, 2009, p. 7), has roots in virtual embodiment (Nowak & Biocca, 2003) and has been suggested to be an effective technique in relating people to a system when increased (Coyle et al., 2012; Teras, 2015). PLIS designs should appeal to passersby's agency to increase passersby's relatedness, thereby enticing them to interact.

8.2.3 Design Recommendations

The following recommendations illustrate the above two design principles using existing work and the findings in this thesis as examples. They can be used individually or in any combination.

8.2.3.1 Use Recognizable Technologies for Interaction

The hardware used in the surface could be presented explicitly and quickly recognized by passersby. For example, a multi-touch surface that looks like an Apple iPad tablet (with a round button at the bottom and a uniform margin), a motion-sensing surface that has a camera clearly visible (a configuration advertised for Microsoft Kinect), and a cross-device surface that has a small surface placed in front of the surface (a configuration used in Opinionizer (Brignull & Rogers, 2003) and Dynamo (Izadi et al., 2003)).

This showing of technologies will better communicate the form of interaction supported by the surface, thereby instilling confidence in using it. However, designers should understand the context and the target audience of the surface, so as to choose the most recognizable technologies and match the interactivity with their corresponding interaction mechanisms.

8.2.3.2 Make Technologies Visible

There are cases where the technologies might not be easily recognized, for example, the target audience has a wide range of backgrounds, the environment does not allow the use of the more recognizable technologies, or the technologies themselves are novel and thus not widely known. In such cases, technologies could still be made visible to evoke curiosity from the passersby, through the use of low-level stimuli, such as light, animation, and recognizable shapes in the software application.

For example, Vermeulen et al. (2015) explored novel interaction techniques using the floor in front of the surface. To guide its users through the interaction process, the authors used bright LEDs and animated patterns to make the technology (interactive floor tiles) visible, and demonstrated the expressive power of this design in communicating proxemics-related interaction. In contrast to suggestions where technologies should be immediately apprehendable (Allen, 2004), there is evidence in museum studies suggesting that novelty and open-endedness would better hold visitors' attention (Sandifer, 2003), and might therefore be worth incorporating into the design of PLISs.

8.2.3.3 Provide Meaning to Exploratory Actions

A PLIS should consider initial exploratory actions, for example, poking the screen, waving of hands, as part of the interaction process. It should also provide meaning to these actions, such as touches generate ripples (Wigdor et al., 2009), and virtual contours bounce balls around (Müller et al., 2012).

At the stage of drawing attention such meaning does not have to be completely relevant to the content, but should raise passersby's curiosity and/or sense of playfulness, which have been shown to lead to further exploration and interaction (e.g., Houben & Weichel, 2013; Tomitsch et al., 2014).

8.2.3.4 Provide Immediate Visual Feedback

A PLIS should respond to passersby's actions as visual feedback as quickly as possible, which can be seen upon a brief glance, and preferably appealing to the perception of agency. An example is the user shadows mirroring passersby's actions in real-time in this thesis, thus creating a sense of agency.

As pointed out by Mitchell (1993), the perception of agency can be achieved by kinesthetic-visual matching (correlating own motion to the visual feedback), and appearance matching (recognizing resemblance between an image and oneself). Moreover, Nowak & Biocca (2003) suggested that the virtual representation did not have to be highly anthropomorphic (very human-like) for perception to occur, and was later confirmed by Müller et al. (2012) that a simple silhouette was as effective as a detailed mirror image, thus allowing more freedom when designing virtual representations in PLISs.

8.3 Lessons Learned from Applying DISCOVER to Study Designs

Another contribution of this thesis is the study methodologies that were employed. Through applying the DISCOVER interaction model to the design of the laboratory studies and field experiment, this thesis was able to evaluate the effectiveness of visual concepts at the early stages of interaction. This section describes the design process involved and how it can be extended.

8.3.1 Study and Experimental Design

The DISCOVER interaction model made it clear that a passerby begins with an *unknowing* state. This realization necessitated the use of the experimental deception in the laboratory-based study methodology detailed in Chapter 4. The key idea of the deception task used in the methodology was to prepare the participant in this state by omitting any mention of the surfaces prior to the study. Furthermore, the inclusion of a "mobile device" as one of the deception conditions, besides fulfilling the four criteria of a deception task for the methodology, simulated one of the toughest scenarios where the attention of a passerby was almost entirely directed away from the surfaces.

Feedback from the laboratory studies suggested that the experimental deception was successfully conducted, as none of the participants expressed suspicion nor discomfort; while most were able to provide responses and suggestions that were useful for understanding their perception towards the surfaces. In addition, the laboratory setup helped lower the setup time and effort, while maintaining a high control over study environment and precision in results.

Similarly, the field experiment was designed with the goal that passersby should not be artificially notified by the conventional field experiment methodology, which required signage indicating a study was in progress and video was being recorded. Fortunately, after several procedure iterations with the university's ethics office, this goal was respected and achieved with careful camera positioning (so faces of interacting passersby would not be seen) and post-study signage.

Using a combination of computer logs, video recordings, and field observations, the field experiment successfully captured the natural behaviour of passersby in the presence of a PLIS. However, as mentioned in Section 7.3.6, the online questionnaire presented as a link on the surface was unsuccessful in eliciting passersby's perception, and required a better method of presentation.

8.3.2 Questionnaire Design

As explained in Chapter 4 and detailed in Appendices B.6, B.9, and B.10, the questionnaires used in the laboratory study were designed to both facilitate the experimental deception (by asking probing questions), and elicit participants' feedback based on the states and transitions in DISCOVER. For example, in the first post-experiment questionnaire (Appendix B.6), participants were asked questions including "*did you notice the content in the [large/small] display where you were walking?*", "*what do you think you can do with the [large/small] display?*", and "*do you think of any displays are interactive?*" And in the second post-experiment questionnaire (Appendix B.9), participants were asked questions including "*please indicate how much each of the displays (small and large) drew your attention […]*", and "*please indicate how interactive do you think each of the displays (small and large) was*". These questions had direct parallels to the transitioning of passersby to the *Notified*, *Intrigued*, and *Exploring* states as described in DISCOVER.

The ability to ask these questions enabled direct evaluation of the attraction power the surface had, and its ability to communicate interactivity to its potential users, which may not be available in traditional observational studies.

8.3.3 Facilitating System Evaluation and Inspiring Future Work

Using the DISCOVER interaction model as a guide, the questions asked in the questionnaires allowed a systematic evaluation of the visual concepts in the studies, and provided a framework to compare the results from related work. For example, in Section 6.4.3, questions asking specifically about interactivity were used to compare to prior work evaluating interactivity communication (Müller et al., 2012), which corresponded to transitioning passersby to the *Discovering* state.

In addition, the separation of user states also allowed finer evaluation in the earlier interaction process. For example, as illustrated in Section 7.2.5.3, the user states were used to develop the annotation scheme in the video-coding process. These states were represented by observable behaviours such as head-turns, glances, and touches, which were also used in similar work in evaluating PLISs via field studies, and therefore producing comparable results.

Lastly, other parts of DISCOVER have also inspired future work in the study of PLISs, both regarding this thesis or the area in general, as discussed in the next chapter.

8.4 Limitations

Although PLISs can be installed vertically as well as horizontally (or tilted), the hardware used in this thesis was geared towards vertical orientation. Therefore, much of the findings and design recommendations are directed towards vertically installed PLISs, and might not be as applicable to other configurations. For example, the recommendation of providing immediate visual feedback (Section 8.2.3.4) assumes passersby see the visual feedback at glance even from afar, which is not always possible for horizontal installations as they will be blocked from view when someone is interacting. Yet, some other recommendations, for example, using recognizable technologies, are less prone to variation in orientation, and would be applicable for most PLISs.

Due to the limitation in tracking technologies, detailed proxemics information, such as head-orientation, and gaze direction, were not available during the study. The interaction and interface therefore could not make use of such information to provide more refined responses to further demonstrate the design recommendations made in this thesis. However, findings in this thesis using basic body tracking, and other work using similar technologies or advanced prototypes, have demonstrated the potential of using proxemics as a means to attract and engage passersby, and would guide its usage when more advanced tracking technologies become available.

The studies conducted in this thesis began with two rounds of laboratory-based studies (studies 1 and 2), each recruiting about 30 participants from within the university, then ended with a field experiment where no participants were explicitly recruited, resulting in close to three thousand tracked bodies, and within which about one thousand video-coded passersby (additional effort was made to manually filter out repeated passersby during the video annotation process). Since all these studies were conducted within the university campus, the demographic of the studies was limited to university population, such as, students, staff, and occasional visitors. While this still covered a range of education and cultural backgrounds, readers should also consider work with other demographics (e.g., pedestrians, museum visitors) for a comprehensive understanding of the literature.

8.5 Chapter Summary

In this chapter I have used the DISCOVER interaction model as a framework to summarize the findings in this thesis, leading to two design principles and four illustrating design recommendations. I have also discussed the lessons learned from the process of applying DISCOVER to the study design and evaluation methodology, followed by a reflection on the limitations of this process.

Chapter 9
Conclusion and Future Work

Motivated by the need to capture passersby's attention, and to provide an engaging and non-socially-inhibiting interaction experience at Public Large Interactive Surfaces (PLISs), this thesis has identified and examined stages of interaction with PLISs, as well as design concepts that facilitate the early stages of such interaction (attraction and engagement). It has also developed and validated a novel way to evaluate the attraction power of a surface design using experimental deception under a laboratory setting. The results of this research provide a knowledge base to inspire the interaction and interface designs of PLISs, and to help evaluate and predict the effectiveness of such designs.

This chapter revisits the contributions of this thesis in order to confirm that the objectives stated in Section 1.1.1 are achieved. It then concludes the thesis and discusses promising research avenues for future research.

9.1 Research Statement and Objectives

As stated in the research statement in Chapter 1, this thesis aimed to systematically model, evaluate, and design interactions for Public Large Interactive Surfaces with a focus on drawing attention and engaging interaction, thereby better informing the development of their interfaces, and ultimately improving their utilization. This statement was realized through a four step process that involved the following objectives:

Objective 1: To establish a user-centric interaction model describing the interaction process with PLISs complementary to existing models, and provide additional insights for evaluating and designing interaction and interfaces for PLISs.

Objective 2: To develop a laboratory-based study methodology that complements the conventional in-the-wild study methodology, allowing evaluation of interaction and interface designs for PLISs, and provides better experimental control while requiring less time and effort to setup.

Objective 3: To explore potential overarching interaction techniques that can be used to bridge drawing attention and engaging interaction for PLISs.

Each of these research objectives was successfully reached and demonstrated in the previous chapters. Moreover, the cumulative activities undertaken to achieve these goals have led to design principles and recommendations for the overall designs for PLISs, particularly for drawing passersby's attention towards the system and engaging them in interacting with it.

9.2 Contributions

This research builds on previous research in classic usability research, traditional human-computer interaction, and social science theories, and contributes additional knowledge to these fields for the designs for PLISs. There are three main contributions from this research, all of which deepening our understanding of PLIS usage and, in turn, help us to understand how to design for future PLISs.

9.2.1 Modelling of Interaction with PLISs

By reviewing relevant literature (Chapter 2) and validating through various studies (Chapter 5 to 7), this research has identified unique usage patterns of PLISs that are very different from traditional personal computing paradigms. For example, there are various kinds of social configurations within users, and there exists a number of barriers in initiating and maintaining interaction with the surfaces. This research focused specifically on understanding the stages of interaction and has summarized the findings in a model represented as a state diagram (the DISCOVER interaction model).

DISCOVER distinguishes itself from existing models by expanding the early stages of interaction, incorporating favourable and unfavourable transitions, and identifying two typical application categories of PLISs. Its use of cognitive mental states also allows the model to be less context- and technology-dependent, and therefore more transferrable and applicable to other existing or emerging technologies. Apart from identifying interaction stages, DISCOVER can be applied to four aspects of PLIS research: to focus existing usability design guidelines (Section 3.7.1); to synthesize existing interaction models (Section 3.7.2); to perform gap analysis on existing work (Section 3.7.3); and to evaluate existing and future PLIS systems (Section 3.7.4).

The model has proven its utility by helping evaluate related work, and the design and analysis of the studies conducted in this thesis. It is expected to be useful for other researchers and practitioners in a similar manner.

9.2.2 Methodology to Evaluate Existing and Future Designs for PLISs

Using DISCOVER as a template, and reflecting on user study methodologies, this research has developed a laboratory-based study methodology for evaluating existing and future interaction and interface designs for PLISs, focusing on evaluating the attraction power of the surface (Chapter 4).

This laboratory-based study methodology is motivated by the shortcomings of the traditional "in-the-wild" field studies/experiments, which are frequently used in PLIS research for their ecological validity. However, as pointed out in Section 4.1, they trade generalizability and control for realism, and require significant time and effort to implement a fully functional system for deployment. The methodology in this thesis was developed to address these limitations. The key aspect of this methodology is the use of experimental deception, which hides the purpose of the study (to evaluate attraction power) with a deception task. By comparing the study results using this methodology with results from existing research, this methodology was shown to be a valid means to evaluate PLISs. Moreover, with the carefully designed questionnaires in different phases of the study, it is shown to be able to further elicit participants' perception towards the designs, thus providing insights that are not easily available in traditional field studies.

It is important to highlight that this methodology is designed to complement the well-established "in-the-wild" field study/experiment methodology, thereby providing a comprehensive understanding in PLIS usage, and a tool to evaluate potential design concepts in drawing passersby's attention and engaging interaction.

9.2.3 Report and Analysis of Interaction Techniques

This thesis has reported a series of studies: a pilot laboratory study (Chapter 5), an improved laboratory study (Chapter 6), and a field experiment (Chapter 7), to examine the effectiveness of several visual concepts in drawing attention and engaging interaction. These concepts incorporated the proxemics theory first proposed by Hall (1966) and later adapted for interactive surfaces by Marquardt & Greenberg (2012). The pilot laboratory study began with two visual concepts:

- *Adaptive Speed* – Speed of content (virtual Post-it notes of quotes) decreases in a stepwise manner when a passerby approaches the surface.
- *Adaptive Contrast* – Contrast of content (virtual Post-it notes of quotes) increases in a continuous manner when a passerby approaches the surface.

Based on the key findings, the improved laboratory study replaced the two visual concepts with:

- *Adaptive Speed* – Speed of content (photos of the university as images) decreases in a stepwise manner when a passerby approaches the surface.
- *Adaptive Speed with User Shadow* – Speed of content (photos of the university as images) decreases in a stepwise manner, accompanied by appearance and increasing contrast of a user shadow in a continuous manner, when a passerby approaches the surface.
- *Adaptive Trajectory with User Shadow* – Direction of content (photos of the university as images) movement changes (towards the passerby) in a stepwise manner, accompanied by appearance and increasing contrast of a user shadow in a continuous manner, when a passerby approaches the surface.

The findings have demonstrated the effectiveness of user shadows in drawing attention, and have led to a more rigorous field experimentation of two visual concepts: adaptive speed, and user shadow. With a combination of qualitative and quantitative analyses, it was found that both adaptive speed and user shadow (speed of content decreased in a stepwise manner, and appearance of a silhouette on the surface of a passerby with increasing contrast, as proximity increased) were effective visual concepts in drawing passersby's attention, retaining them, and enticing them to interact. It was also discovered that the user shadows evoked curiosity and playful actions from the passersby, demonstrating potential enhancements in this concept to further facilitate interaction, as discussed in Section 7.4.4.

Summarizing the findings, two design principles were developed specifically to attract passersby's attention and engage interaction (detailed in Section 8.2.1-2):

- *Immediate Recognizability* – Focus on making a passerby aware of and discern the system quickly, instead of completely apprehending everything the surface has to offer.
- *Appeal to Agency* – Focus on providing a passerby with a sense of control and relatedness to the displayed content.

These two design principles were illustrated as the following four design recommendations (detailed in Section 8.2.3):

- *Use Recognizable Technologies for Interaction* – Present hardware/software explicitly that can be quickly recognized.
- *Make Technologies Visible* – Novel or embedded technologies that cannot be easily recognized could be made visible through low-level stimuli to invoke curiosity.

- *Provide Meaning to Exploratory Actions* – Consider initial simple exploratory actions as part of the interaction process.
- *Provide Immediate Visual Feedback* – Respond to passersby's actions in the form of visual feedback as quickly as possible.

9.3 Future Work

The results from this thesis suggest several directions that warrant further study. These directions relate to further understand the role of interaction and interface designs for PLISs, and point to potential improvements to the study methodologies.

9.3.1 Exploring Other Techniques in Attention and Engagement

This thesis selected two visual concepts to study, namely, animating content speed and showing user shadow. There is, however, a wide range of visual concepts that can be employed. For example, the content can be animated via looming, zooming, and blinking (Franconeri & Simons, 2003), or using a number of animation principles (Johnston & Thomas, 1995); the shadow can be animated on its own (Krueger, 1991), or even represents remote users (Müller et al., 2014). In a simpler manner, and if the venue permits, surrounding lights can also be used to draw passersby's attention and guide their interaction (Cremonesi et al., 2016; Pihlajaniemi et al., 2014).

Furthermore, depending on the context, environment, and availability of the technologies, content can be presented in other sensory channels such as auditory and even olfactory. For example, a short phrase or a distinctive sound can be played to draw the attention of a passerby (Kukka et al., 2016), and changes or becomes progressively louder as the intrigued passerby approaches; a certain scent can be projected to catch the attention of a passerby (Bradford & Desrochers, 2009).

The advancement of display technologies (e.g., more responsive visuals), and variety of content presentation channels, have opened up opportunities to extend the research conducted in this thesis.

9.3.2 Investigating Other Stages of PLIS Interaction

This thesis focused on the early stages of interaction with a PLIS system. Yet, as depicted in the DISCOVER interaction model, there are later stages of interaction that warrant further investigation. For example, how should the techniques used to draw attention be adapted to further the interaction, and how should the interface signify completion of the interaction process and facilitate withdrawal. Such research could also in turn be used to validate and strengthen the interaction model empirically.

Moreover, the early interaction stages are directly related to the opportunistic application category of PLISs (Section 3.6), emphasizing discoverability and understandability (Section 3.7.1). However, this emphasis changes in both the task-oriented application category and when a passerby engages in the interaction, into learnability and satisfaction. Further research is required to investigate how the interface should be designed to effectively promote these attributes. Design solutions may draw from the *user experience* literature, which focuses on users' evaluative judgment on system quality over time, instead of mostly instrumental and functional qualities of the system (Karapanos et al., 2009).

9.3.3 Multi-Person DISCOVER Encompassing Returning Passersby

Similar to other existing models, DISCOVER describes the interaction process between a PLIS and a user. As DISCOVER describes such process using the user's internal cognitive states, it is limited to a single user. A naïve way to address this limitation is to have multiple DISCOVERs in parallel, each for a user. However, this approach is too simplistic and does not consider inter-person interaction, for example, an interacting person calling her friends over, who therefore do not need to be transitioned to the *Notified* state by the system interface. A more refined approach would be to have additional non-system interface transitions as entry points into the later states of the model, for instance, a "direct friend's attention" transition into the *Intrigued* state. Alternatively, state transitions could be more broadly defined to incorporate both system and non-system triggers, such as social triggers.

Moreover, upon reflecting on the model after the field experiment, several possible entry points to DISCOVER could also be added. In particular, the current model does not consider returning *Intrigued* passersby, who might be in a hurry and hence leave before any actual interaction occurred (Section 7.3.4). In the same vein, the current model does not consider passersby who leave not because the system interface failed to promote interaction.

Therefore, while the current model successfully captures the majority of the interaction process with a PLIS, it can be refined by including more transitions that connect to multiple instances of itself, or describe other entry or exit scenarios.

9.3.4 Improving Study Methodologies

This thesis employed both laboratory study and field experiment methodologies to evaluate the attraction power of visual design concepts for PLISs. Besides modifications that could address the limitations mentioned in the respective chapters (e.g., limited demographic, minimal interactivity of content), additional work could be done to improve the variety, quality, and quantity of data collected.

For the laboratory-based study methodology developed and employed in this thesis, experimental deception was used to omit the mentioning of the surfaces in order to prepare the participants in the *Unknowing* state. A similar approach can also be used to prepare the participants in other states such as *Notified* (by directing them to the surface but omitting the purpose of the surface), and *Exploring* (by telling them to interact with the surface but omitting the interaction mechanism). By beginning the study with different states, researchers can quickly examine the effectiveness of the interface design in transitioning the participants from the state of interest.

For the field experiment methodology employed in this thesis, the use of an external hyperlink to an online questionnaire was not effective in encouraging passersby to participate in the survey, even with potential monetary return. Anecdotal observations made during the study revealed that some passersby simply did not have anything to write down the hyperlink, or were unsure about the QR code shown on the surface. Two often employed strategies in PLIS research for collecting such data are to have on-site interviews with a group of passersby (e.g., Peltonen et al., 2008) which tends to be limited in size (typically a few dozen); and to have a questionnaire temporarily shown on the surface upon interaction (e.g., Kukka et al., 2013), which tends to be very simple (typically a few Likert-scale questions)[20]. One possible way to capture a larger sample size with richer information could be to combine a short questionnaire on the surface with an invitation to participate in a longer online survey, where passersby can choose to participate by providing contact information with a potential monetary return. However, further work is needed to find a good balance between quality and quantity of the feedback (Goncalves et al., 2014).

9.3.5 Incorporating Cross-Device Technologies

Much PLIS research, including this thesis, focuses on “in-the-moment” interaction, that is, all interaction happens in vicinity of the surface. When the passerby leaves the surface, the interaction is concluded and nothing is taken away. This is partly due to the fact that most current PLIS systems treat the surface as a stand-alone, stationary installation, where all the technologies are installed within the surface. The form of interaction is therefore limited to being direct and close in proximity.

[20] These strategies were not used in the field experiment in this thesis because of the disruptiveness of having passersby stopped to answer questions, to an interviewer or at the surface, as the deployment site was a busy passage between classrooms and offices.

As personal devices (e.g., mobile phones and tablets) are becoming more pervasive, it is possible to consider them as part of a PLIS system. Inspired by work in cross-device interaction between personal devices and public surfaces (e.g., Echtler et al., 2009; Luojus et al., 2013; Masuko et al., 2015; Peltonen et al., 2007), I have initiated a project that included personal mobile devices as active interactive components with a PLIS (Cheung et al., 2014). This project used personal mobile devices as a means to overcome barriers that hindered a passerby to go through the interaction process with a PLIS, by minimizing the effort required to initiate, sustain, and withdraw from such interaction.

Extending this work, one can utilize cross-device interaction as a means to raise attention and engage interaction. For example, using Apple's iBeacon standard[21], mobile applications can be alerted as the device is close to a surface, which in turn notify a passerby, and provide incentive to interact. When the interaction concludes, the passerby can "take" the information with them by downloading the content. This is particularly useful in scenarios such as schedule look-up in transportation hubs, way-finding in a shopping mall, and exploration of content at a museum installation, thereby providing better and lasting utilization of PLISs.

Lastly, the cross-device interaction mechanisms taxonomy introduced in Section 2.2.3 focused on facilitating interaction with a PLIS, thus only included interaction between individual mobile devices and the public surface. Yet, by supporting device-device and device-surface content transfer (e.g., sharing and publishing comics strips (Lucero et al., 2012)), PLISs could be used to facilitate within- and between-group interaction, and be more effective in attracting and retaining groups.

[21] http://www.ibeacon.com/what-is-ibeacon-a-guide-to-beacons/. Information webpage of the iBeacon technology standard. Last accessed: 1 May, 2016.

9.4 Conclusion

This thesis has provided a comprehensive understanding of passerby interaction with Public Large Interactive Surfaces (PLISs), and has investigated the effectiveness of proxemics-driven visual design concepts in drawing attention and engaging interaction. It has contributed to the research field by establishing a versatile interaction model (DISCOVER), developing an efficient laboratory-based study methodology, and providing effective design principles and recommendations based on empirical study results. In particular, the results have revealed the usefulness of using proxemics-driven user shadow as an interface component to attract, entice, and retain passersby, and have suggested possible extension of such technique. Besides serving as a design reference, as discussed above, this research opens up a rich and promising future for innovation and exploration in PLIS research and practice.

Letter of Copyright Permission

Re: Request for permission to use co-authored work in Victor's thesis

Stacey Scott

Sent: Sunday, June 12, 2016 11:42 AM

To: Victor Cheung; Stacey Scott

Dear Victor ,

I, Stacey D. Scott, give Victor Cheung permission to use co-authored work from our paper(s):

Cheung, V., Scott, S.D. (2015). A Laboratory-based Study Methodology to Investigate Attraction Power of Large Public Interactive Displays. In Proceedings of UbiComp 2015: ACM International Joint Conference on Pervasive and Ubiquitous Computing, p. 1239-1250. Osaka, Japan, September 7-11, 2015.

Cheung, V., Scott, S.D. (2015). Studying Attraction Power in Proxemics-Based Visual Concepts for Large Public Interactive Displays. In Proceedings of ITS 2015: ACM Interactive Tabletops and Surfaces, p. 93-102. Madeira, Portugal, November 15-18, 2015.

for Chapters 4, 5 and 6 of his Ph.D. dissertation and to have this work archived in the University of Waterloo institutional digital repository.

Sincerely,

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Appendix A

Laboratory-based Study Materials (Pilot)

A.1 Recruitment Email Sent to Graduate Students List

Subject: Participants needed for a study on Usage Patterns with On-the-go Mobile Applications

My name is Victor Cheung. I am a graduate student from the department of Systems Design Engineering. My colleagues (with faculty supervisor Prof. Stacey Scott) and I are conducting a study titled: Usage Patterns with On-the-go-Mobile Applications.

We are seeking participants for an observational study on how different on-the-go mobile scenarios affect the usage patterns of typical tasks (e.g. looking up information, check status updates) on one's own portable device (e.g. a smartphone, a tablet), particularly when the user is moving as opposed to remaining stationary. Participants will be asked to complete a background questionnaire, be video recorded, asked to perform a number of tasks with a portable device while being asked to walk between several marked points, or standing still in a room, and complete post-experiment questionnaires. You will also be asked for demographic information and about the study tasks.

The study will take up to one hour. Participants must be aged 18 or older and have a mobile device capable of connecting to the internet. Participants will receive $10 for their participation.

The study will be held between January__ and February __ 2013.

Please contact Victor Cheung at victor.cheung@uwaterloo.ca if you are interested.

This study has been reviewed by, and received ethics clearance through a University of Waterloo Research Ethics Committee.

A.2 Recruitment Poster Printed and Distributed around University Campus

Department of Systems Design Engineering

University of Waterloo

Participants needed for research in

<u>Usage Patterns with On-the-go Mobile Applications</u>

We are seeking participants for a study on how different on-the-go mobile scenarios affect the usage patterns of typical tasks (e.g. looking up information, check status updates) on a portable device (e.g. a smartphone, a tablet), particularly when the user is moving as opposed to remaining stationary.

You will be asked to perform a number of tasks with your portable device while being asked to walk between several marked points, or standing still in a room. You will also be asked for demographic information and about the study tasks.

Participants must be aged 18 or older and have a mobile device (e.g. smartphone or tablet) capable of connecting to the internet. A study session will take approximately 1 hour.
Participants will receive $10 for their participation.

The study will be held between January__ and February __ 2014.

Please contact Victor Cheung at victor.cheung@uwaterloo.ca if you are interested.

This study has been reviewed by, and received ethics clearance through a University of Waterloo Research Ethics Committee.

A.3 Letter of Information Used in the Deception Phase

LETTER OF INFORMATION

Project Title: Usage Patterns with On-the-go Mobile Applications

You are invited to participate in a research project conducted by Victor Cheung, Joanne Leong and Dr. Stacey Scott (Faculty Supervisor), conducted at the University of Waterloo Systems Design Engineering Department. We will read through this letter of information with you, describe our experimental procedures in detail, and answer any questions you may have. The research is being funded by NSERC Surfnet Strategic Network.

This study aims at investigating how different on-the-go mobile scenarios affect the usage patterns of typical tasks (e.g. looking up information, check status updates) on a portable device (e.g. a smartphone, a tablet), particularly when the user is moving as opposed to remaining stationary. You will be asked to perform a number of tasks with a portable device while being asked to walk between several marked points, or standing still. The study will last up to 60 minutes.

Prior to the session, you will be asked to complete a questionnaire, including demographic and background information. During the study, you will be asked to perform some tasks using your portable device (e.g. lookup for general information from the internet). While performing the tasks, you will be video recorded, and other data about how you interact with the surrounding environment and the interface will be observed and recorded. You will also be asked to complete a post-experiment questionnaire afterwards about the tasks you completed and your experience during the study.

You will be given a $10 honorarium for your participation. The amount received is taxable. It is your responsibility to report the amount received for income tax purposes.

Your participation is voluntary. You may decline to answer any questions if you wish. If you wish to withdraw from participation at any time, please advise the researcher. Any data collected up to the point of withdrawal will be destroyed. Should you choose to withdraw, you will still receive the $10 honorarium for your participation.

While you may not benefit directly from this study, results from this study may improve the understanding of how on-the-go mobile applications are being used in different scenarios. Applications of this work are in the development of user interfaces of mobile applications.

The risks to participation are no greater than what you experience day to day. You will only be using typical portable devices and walking inside an experimental room. The only possible side-effect would be tiredness and fatigue resulting from using the device to complete the tasks. To ensure that you do not inadvertently stumble or walk into a wall or object while using your mobile device for the study, the researcher, who will be with you through the whole study, will also spot for you and stop you if necessary.

All information provided is considered completely confidential. Your name will not appear in any publication resulting from this study; however, with your permission anonymous quotations during the study session may be used. In these cases participants will be referred to as Participant 1, Participant 2, … (or P1, P2, …).

You will be asked to explicitly consent to the use of video and audio data captured during the study for the purpose of reporting the study's findings. If and only if consent is granted, this data will be used only for the purposes associated with teaching, scientific presentations, publications, and/or sharing with other researchers. Participants will not be identified by name, and their faces will be blackened.

Data collected during this study will be retained indefinitely in a locked cabinet or on password protected desktop computers in the Collaborative Systems Laboratory at the University of Waterloo.

We would like to assure you that this study has been reviewed by, and received ethics clearance through a University of Waterloo Research Ethics Committee. However, the final decision about participation is yours. Should you have any ethical comments or concerns resulting from you participation in this study, please contact the Director, University of Waterloo Office of Research Ethics (Dr. Maureen Nummelin, maureen.nummelin@uwaterloo.ca, 519-888-4567 ext. 36005).

Please retain a copy of the letter of information and consent form. If you have any questions, concerns or comments about this research, please contact any of the research team: Victor Cheung (v4cheung@uwaterloo.ca), Joanne Leong (jslleong@uwaterloo.ca), or Dr. Stacey Scott (s9scott@uwaterloo.ca, 519-888-4567 ext. 32236).

A.4 Consent Form Used in the Deception Phase

<u>INFORMED CONSENT BY SUBJECTS TO PARTICIPATE IN A RESEARCH STUDY</u>

Project Title: Usage Patterns with On-the-go Mobile Applications

I have read the information presented in the information letter about a study being conducted by Victor Cheung, Joanne Leong and Dr. Stacey Scott at the University of Waterloo. I understand that I will be participating in a research project using portable devices, and that I will be engaging in a study of which the procedures and risks are described in the attached letter of information. I have had the opportunity to ask any questions related to this study, to receive satisfactory answers to my questions, and request/receive any additional details desired.

Sometimes a certain image and/or segment of video recording clearly shows a particular feature or detail that would be helpful in teaching or when presenting the study results at a scientific presentation or in a publication.

I am aware that I may allow video and/or digital images in which I appear to be used in teaching, scientific presentations, publications, and/or data sharing with other researchers with the understanding that I will not be identified by name. I am aware that I may allow excerpts from this study to be included in teaching, scientific presentations and/or publications, with the understanding that any quotations will be anonymous.

I am aware that my participation is voluntary and that I may withdraw my consent for any of the above statements or withdraw my study participation at any time without penalty by advising the researcher.

This project has been reviewed by, and received ethics clearance through a University of Waterloo Research Ethics Committee. I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact Victor Cheung (v4cheung@uwaterloo.ca), Joanne Leong (jslleong@uwaterloo.ca), or Dr. Stacey Scott (s9scott@uwaterloo.ca, 519-888-4567 ext. 32236), and that if I have any ethical comments or concerns about the study I may contact the Director of the University of Waterloo Office of Research Ethics (Dr. Maureen Nummelin, maureen.nummelin@uwaterloo.ca, 519-888-4567 ext. 36005).

	Please Circle One	Please Initial Your Choice
With full knowledge of all foregoing, I agree, of my own free will, to participate in this study.	**YES**	**NO**
I agree to be video and audio recorded	**YES**	**NO**
I agree to let the video recordings, digital images, or audio recordings be used for presentation of the research results	**YES**	**NO**

Participant Name: ____ (Please print)

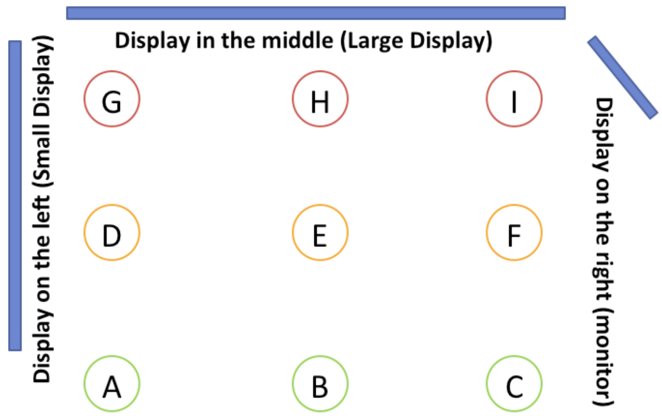
Participant Signature: ____

Date: ____

A.5 Routes and Tasks in the Deception Phase

WALKING SEQUENCE AND TASKS

Project Title: Usage Patterns with On-the-go Mobile Applications



For the "with mobile device" condition:

1.	Go from A to G	While looking up the contact info of a friend
2.	Go from G to C	While bringing back the home screen
3.	Go from C to I	While opening up your calendar/organizer app
4.	Go from I to G	While looking up today's agenda
5.	Go from G to D	While switching off your screen
6.	Go from D to F	While switching on your screen
7.	Go from F to C	While rotating your phone into landscape orientation
8.	Go from C to A	While rotating your phone into portrait orientation
9.	Go from A to I	While checking the current time
10.	Go from I to C	While setting your device in silence mode
11.	Go from C to E	While setting your device back to the previous mode
12.	Go from E to H	While setting your device to airplane mode
13.	Go from H to D	While setting your device out of airplane mode

For the "without mobile device" condition, perform the same 13 tasks with only the routes.

A.6 Background Questionnaire in the Deception Phase

Usage Pattern with Mobile Devices - Background Information

Background Information

Please fill out this questionnaire as accurately as possible. None of the information will be personally linked to you in any way. Please do not write your name anywhere on the questionnaire.

*** 1. Participant ID (to be filled in by researcher):**

*** 2. What is your gender?**

- ◯ Female
- ◯ Male

*** 3. What is your age?**

- ◯ 18 to 22
- ◯ 23 to 27
- ◯ 28 to 32
- ◯ 33 to 37
- ◯ 38 and above

*** 4. What is your occupation?**

5. If you are a student, what degree and program are you in?

*** 6. Have you used any portable devices before? If yes, please provide some examples (e.g. smartphones, tablets). For each please also indicate where you will**

usually use them (e.g. at home, bus stops ...etc).

	Location
Smartphones	
Tablets	

Other devices and locations

7. If your answer to Q6 is "yes" (skip if "no"), please indicate the how you would perform the following tasks when you are moving:

	I do not stop to perform it, I just do it while I'm moving	I stop from time to time throughout the process	I stop moving until the task is completely finished
Search for information (e.g. nearest restaurant, bus schedule)	○	○	○
Check status updates (e.g. Twitter, Facebook)	○	○	○
Send & Receive messages (e.g. text, email)	○	○	○
Take photos	○	○	○
Change settings	○	○	○

Other (please specify)

*** 8. If you have performed a task on your mobile device while you are moving, please briefly describe how you manage to divide your attention between the device and your pathway.**

Done

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A.7 Post-Experiment Questionnaire in the Deception Phase

Usage Pattern with Mobile Devices - Post Experiment Questionnaire

Post Experiment Questionnaire

Please fill out this questionnaire as accurately as possible. None of the information will be personally linked to your in any way. Please do not write your name anywhere on the questionnaire.

* **1. Participant ID (to be filled in by researcher):**

* **2. How did walking while performing a mobile task affect the way you performed the tasks (in terms of ease, time it took, ...etc)?**

* **3. How did walking while performing a mobile task affect the way you walked (in terms of ease, time it took, ...etc)?**

Next

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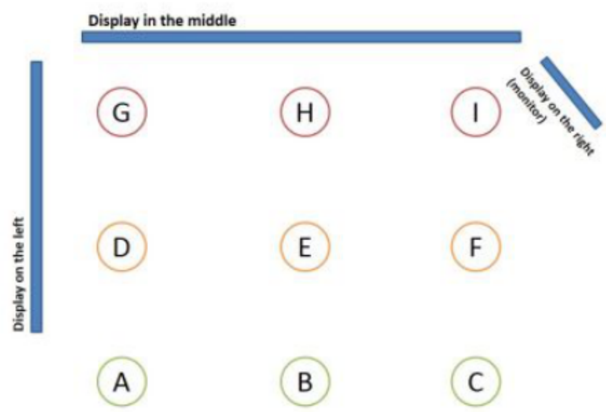
See how easy it is to create a survey.

Usage Pattern with Mobile Devices - Post Experiment Questionnaire

We are also interested to see how your attention to your surroundings is affected during mobile use.

Layout of the experimental room (for reference only)



*** 4. Did you notice the content in the display (the middle board on the wall) while you were carrying out your tasks with the portable device?**

- ◯ Yes
- ◯ No

If yes, briefly describe what the content was

*** 5. Did the display (middle board on the wall) affect the way you carried out your task? If so, how?**

* 6. Did the display (middle board on the wall) affect the way you walked? If so, how?

* 7. What is your impression on the display (middle board on the wall)?

* 8. What do you think the purpose of the display (middle board on the wall) is?

* 9. What do you think you can do with the display (middle board on the wall)?

* 10. Which part of the display (middle board on the wall) do you find most appealing or interesting?

Prev Next

A.8 Deception Debriefing Verbal Script

<u>RESEARCHER'S SCRIPT FOR VERBALLY DEBRIEFING PARTICIPANTS INVOLVED IN A DECEPTION STUDY (IN-LAB), USED WITH A POST-STUDY DEBRIEFING INFORMATION/FEEDBACK LETTER</u>

Study Title: Investigating Attraction of Animation on Large Displays

	Researcher's Script
Express appreciation to participant for taking part in the study.	**"**Thank you for spending the time helping us with our research. The research team greatly appreciates your participation in this study."
Probe for suspicion. (Optional)	"Do you have any guesses about what the study is really about? We would be interested in hearing any ideas you might have. Did anything seem strange or odd to you?"
Explain what participants were originally told.	"I would now like to tell you a bit more about the study. The debriefing letter that I gave you describes the details of the study. You can keep this copy. I will go over the main points with you now. When you began the study, you were told the purpose of this study was to investigate how different on-the-go mobile scenarios affect the usage patterns of typical tasks on a portable device. However, we provided you with information that misrepresented the real purpose of the study. What this means is the study was actually different than what we explained in the beginning. Some studies involve deception – that is, participants are lead to believe the study is about one thing when it is actually about something else. This is one of those studies. Do you have any questions?"
Outline the full purpose/objectives of the study and explain what the deceptions were and purpose of the tasks.	*Provide participants with an explanation of and information on the:* *a) full purpose/objective(s) of the study:* We are interested in whether a passerby, when commuting near an interactive wall display, will be attracted to its interface with the use of animation in response to their proximity. *b) background information on the area of research being conducted:* We hypothesize that, when used appropriately, animation is an effective mechanism to attract people's attention, even when in their peripheral field of vision. To be able to attract and engage users to an interface has been widely researched topic in the field of Human-Computer Interaction. *c) deceptive aspects of the study, and measures, study tasks, and various conditions:* In this case, we had to omit the fact that the interactive wall display that you saw was trying to attract your attention, and we were assessing your responses to various types of animation used in the interface, through video- & audio- recording and notes taken by the researcher.
Explain why deception was used in the study.	"The reason that we needed to use deception in this study was because we needed participants' behavior and attitudes to be as natural as possible. Thus, we could not give participants complete information before their involvement in the study because it may have influenced participants' behaviour in a way that would make investigations of the research question invalid. If participants knew the objectives of the study before hand their behavior and attitudes may have been influenced by this knowledge."
Summarize the full purpose of the study and	"I would just like to re-iterate a few things: 1. The purpose of this study was to investigate the effectiveness of

which aspects involved deception (e.g., use of confederates, use of false information, etc.)	animation in an interactive wall display interface in terms of attractive passersby's attention. 2. All the equipment we used for assessment has been mentioned in the briefing, and there are no hidden ones throughout the study. 3. The experimental setup was to simulate an environment where a person commutes between marked points, which includes the interactive wall display and other displays in the surroundings."
Express regret for deceiving participants.	"We apologize for omitting details and for providing you with fictional information about the purpose of and tasks in our study. We hope that you understand the need for use of deception now that the purpose of the study has been more fully explained to you. Do you have any questions about deception and why it was used in this study?"

Explain not all psychology studies involve deception.	"I would like to assure you that most Systems Design Engineering research does not involve the use of deception."
Explain who to contact if questions or concerns arise about participation in the study.	"Do you have any questions or concerns about the use of deception in this study? Would you like to speak with the one of the study investigators/faculty supervisor about your concerns or questions? After you leave, if you have questions, comments, or concerns about the study or any feelings of discomfort, please contact the study researchers or the Office of Research Ethics. Contact information is on the debriefing letter I gave you."
Explain reasons for not discussing study details with others and why.	"This study involves some aspects that you were not told about before starting therefore it is very important that you not discuss your experiences with any other persons who potentially could be in this study until after the end of the term. If people come into the study knowing about our specific predictions, as you can imagine, it could influence their results, and the data we collect would not be useable. Also, since you will be given a copy of this feedback letter to take home with you, please do not make this available to other persons."
Reiterate details from the information letter as to how the information collected will be confidentially retained and stored.	"Even though this study involved deception, the information given to you about confidentiality, data storage, and security still applies. All data collected is confidential and securely stored at all times. No one other than the researchers have access to the data. These details are outlined in the debriefing letter."
Explain why another consent form needs to be signed.	"Because some elements of the study were different from what was originally explained we have another consent form for you to read and sign if you are willing to allow us to use the information that you have provided. This form is a record that the purpose of the study has been explained to you, and that you are willing to allow your information to be included in the study. Will you allow us to use the information you provided?" *[Researcher gives participant post-debriefing consent form to read and sign. Participant returns signed consent form to the researcher.]*
Conclude with an expression of appreciation.	"We really appreciate your participation, and hope that this has been an interesting experience for you."

A.9 Deception Debriefing Letter and Consent Form

DEBRIEFING LETTER FOR STUDIES INVOLVING DECEPTION (IN-LAB)

Study Title: Investigating Attraction of Animation on Large Displays
(Usage Patterns with On-the-go Mobile Applications)

Faculty Supervisor: Stacey Scott, Systems Design Engineering,
519-888-4567 ext. 32236, s9scott@uwaterloo.ca

Student Investigator(s): Victor Cheung, Systems Design Engineering, v4cheung@uwaterloo.ca

We greatly appreciate your participation in our study, and thank you for spending the time helping us with our research. When you began the study you were told that the purpose of this study was to investigate how different on-the-go mobile scenarios affect the usage patterns of typical tasks on a portable device. However, the study was more complicated than we explained at the beginning. We hypothesize that, when used appropriately, animation is an effective mechanism to attract people's attention, even when in their peripheral field of vision. We are interested in whether a passerby, when commuting near an interactive wall display, will be attracted to its interface with the use of animation in response to their proximity.

Large, interactive surfaces have become a popular choice for content presentation in a public setting due to their dynamic presence, and support for multiple users. One design challenge is to have the interface attracting passersby's attention. We are interested in investigating how animation can be used to achieve that.

Throughout the study, while you were carrying out your tasks, we also assessed how you responded to various types of animation presented in the interactive wall display, as to measure the effectiveness of animation in the interface. In the remainder of this session, you will be asked to complete a questionnaire for us to better evaluate your impression on the interactive wall display interface. The information and answers you have provided earlier will be combined with your answers to this questionnaire to form a complete participant response, so that we can better understand your responses. The video and audio recorded, and other data collected earlier will also be included for the same reason.

We could not give participants complete information about the study before their involvement because it may have influenced participants' behaviour during the study in a way that would make investigations of the research question invalid. The reason that we used deception in this study was because we needed participants' behaviour and attitudes to be unaffected by the study objectives, particularly the knowledge about the interactive wall display interface trying to attract their attention. We apologize for omitting details and for providing you with fictional information about the purpose of and tasks in our study. We hope that you understand the need for deception now that the purpose of the study has been more fully explained to you. We would also like to assure you that most Systems Design Engineering research does not involve the use of deception.

We would just like to re-iterate a few things:

1. The purpose of this study was to investigate the effectiveness of animation in an interactive wall display interface in terms of attracting passersby's attention.
2. All the equipment we used for assessment has been mentioned in the briefing, and there are no hidden ones throughout the study.
3. The experimental setup was to simulate an environment where a person commutes between marked points, which includes the interactive wall display and other displays in the surroundings.

If any of the questions or exercises in this study caused you to feel uncomfortable, please feel free to contact Victor Cheung (v4cheung@uwaterloo.ca). You can also contact my faculty supervisor, Stacey Scott, at 519-888-4567 ext. 32236 or s9scott@uwaterloo.ca. Also please feel free to contact Dr. Maureen Nummelin, the Director, Office of Research Ethics, at 519-888-4567, ext. 36005 or maureen.nummelin@uwaterloo.ca if you have concerns or comments resulting from your participation.

The information you provided will be kept confidential by not associating your name with the responses. The data will be stored with all identifying or potentially identifying information removed. Electronic data will be stored on a password protected computer in E2-1303B. Printed data will be kept in a locked room in E2-1303B. The survey uses Survey Monkey™ which is a United States of America company. Consequently, USA authorities under provisions of the USA PATRIOT ACT may access this survey data. If you prefer not to submit your data through this platform, please do not participate in this research study.

Because the study involves some aspects that you were not told about before starting, it is very important that you not discuss your experiences with any other persons who potentially could be in this study until after the end of the term. If people come into the study knowing about our specific predictions, as you can imagine, it could influence their results, and the data we collect would be not be useable. Also, since you will be given a copy of this feedback letter to take home with you, please do not make this available to other persons. Moreover, because some elements of the study are different from what was originally explained, we have another consent form for you to read and sign if you are willing to allow us to use the information that you have provided. This form is a record that the purpose of the study has been explained to you, and that you are willing to allow your information to be included in the study.

We really appreciate your participation, and hope that this has been an interesting experience for you.

POST-DEBRIEFING CONSENT FORM FOR STUDIES INVOLVING DECEPTION (IN-LAB)

Study Title: Investigating Attraction of Animation on Large Displays
(Usage Patterns with On-the-go Mobile Applications)
(Navigating with the Help of Mobile Devices)

Faculty Supervisor: Stacey Scott, Systems Design Engineering,
519-888-4567 ext. 32236, s9scott@uwaterloo.ca

Student Investigator(s): Victor Cheung, Systems Design Engineering, v4cheung@uwaterloo.ca

During the debriefing session, I learned that it was necessary for the researchers to disguise the real purpose of this study. I realize that this was necessary since having full information about the actual purpose of the study might have influenced the way in which I responded to the tasks and this would have invalidated the results. Thus, to ensure that this did not happen, some of the details about the purpose of the study initially were not provided (or were provided in a manner that slightly misrepresented the real purpose of the study). However, I have now received a complete verbal and written explanation as to the actual purpose of the study and have had an opportunity to ask any questions about this and to receive acceptable answers to my questions.

I have been asked to give permission for the researchers to use my data (or information I provided), as well as the video- and audio- recordings, in their study, and agree to this request. I am aware that I may withdraw this consent by notifying the Faculty Supervisor of this decision.

I am aware this study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee and I may contact Dr. Maureen Nummelin, the Director, Office of Research Ethics at 519-888-4567 ext. 36005, if I have any concerns or comments resulting from my involvement in this study. By signing this consent form, I am not waiving my legal rights or releasing the investigator(s) or involved institutions(s) from their legal and professional responsibilities.

Participant's Name: ______________________________

Participant's Signature: ______________________________

Date: ______________________________

Witness' Name: ______________________________

Witness' Signature: ______________________________

A.10 Post-Experiment Questionnaire in the Reveal Phase

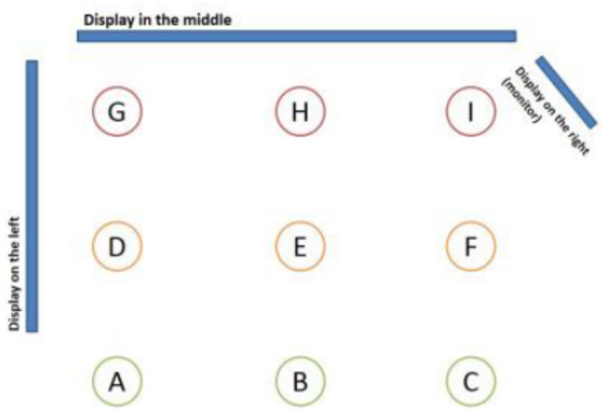
Attraction of Animation - Post Experiment Questionnaire2

Post Experiment Questionnaire

Please fill out this questionnaire as accurately as possible. None of the information will be personally linked to your in any way. Please do not write your name anywhere on the questionnaire.

* **1. Participant ID (to be filled in by researcher):**

Layout of the experimental room (for reference only)



* **2. Please indicate how much do you think each of the displays drew your attention while you were performing the tasks WITH your mobile device.**

	Did not draw my attention (0)	(1)	(2)	Drew some of my attention (3)	(4)	(5)	Drew my full attention (6)
The display on the left							
The display in the							

middle	○	○	○	○	○	○	○
The display (monitor) on the right	○	○	○	○	○	○	○

*** 3. Please indicate how much do you think each of the displays drew your attention while you were moving WITHOUT using your mobile device.**

	Did not draw my attention (0)	(1)	(2)	Drew some of my attention (3)	(4)	(5)	Drew my full attention (6)
The display on the left	○	○	○	○	○	○	○
The display in the middle	○	○	○	○	○	○	○
The display (monitor) on the right	○	○	○	○	○	○	○

*** 4. Please indicate how interactive do you think each of the displays was.**

	Did not pay attention	Not interactive (0)	(1)	(2)	Somewhat interactive (3)	(4)	(5)	Very interactive (6)
The display on the left	○	○	○	○	○	○	○	○
The display in the middle	○	○	○	○	○	○	○	○
The display (monitor) on the right	○	○	○	○	○	○	○	○

*** 5. Now that you know the real purpose of the study, do you have any particular comments beyond your previous answers?**

Done

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Appendix B
Laboratory-based Study Materials (Improved)

B.1 Recruitment Email Sent to Graduate Students List

Subject: Participants needed for a study on Navigating with the Help of Mobile Devices

My name is Victor Cheung. I am a graduate student from the department of Systems Design Engineering. My colleagues (with faculty supervisor Prof. Stacey Scott) and I are conducting a study titled: Navigating with the Help of Mobile Devices.

We are seeking participants for an observational study on how different forms of navigating instructions affect the way a person arrives at a destination. Participants will be asked to complete a background questionnaire, be video recorded, asked to walk between several marked points while being provided with navigating instructions verbally and/or visually, and complete post-experiment questionnaires. You will also be asked for demographic information and about the study tasks.

The study will take up to one hour. Participants must be aged 18 or older. Participants will receive $10 for their participation.

The study will be held between September__ and October __ 2014.

Please contact Victor Cheung at victor.cheung@uwaterloo.ca if you are interested by replying to this email.

This study has been reviewed by, and received ethics clearance through a University of Waterloo Research Ethics Committee.

B.2 Letter of Information Used in the Deception Phase

LETTER OF INFORMATION

Project Title: Navigating with the Help of Mobile Devices

You are invited to participate in a research project conducted by Victor Cheung and Dr. Stacey Scott (Faculty Supervisor), conducted at the University of Waterloo Systems Design Engineering Department. We will read through this letter of information with you, describe our experimental procedures in detail, and answer any questions you may have. The research is being funded by NSERC Surfet Strategic Network.

This study aims at investigating how different forms of navigating instructions affect the way a person arrives at a destination. You will be asked to walk between several marked points while being provided with navigating instructions, verbally and/or visually. The study will last up to 60 minutes.

Prior to the session, you will be asked to complete a questionnaire, including demographic and background information. During the study, you will be asked to walk between several marked points by following the instructions provided. While performing the tasks, you will be video recorded, and other data about how you interact with the surrounding environment and the interface will be observed and recorded. You will also be asked to complete a post-experiment questionnaire afterwards about the tasks you completed and your experience during the study.

You will be given a $10 honorarium for your participation. The amount received is taxable. It is your responsibility to report the amount received for income tax purposes.

Your participation is voluntary. You may decline to answer any questions if you wish. If you wish to withdraw from participation at any time, please advise the researcher. Any data collected up to the point of withdrawal will be destroyed. Should you choose to withdraw, you will still receive the $10 honorarium for your participation.

While you may not benefit directly from this study, results from this study may improve the understanding of how navigating instructions are being used in different forms. Applications of this work are in the development of user interfaces of mobile applications.

The risks to participation are no greater than what you experience day to day. You will only be using typical portable devices and walking inside an experimental room. The only possible side-effect would be tiredness and fatigue resulting from using the device to complete the tasks. To ensure that you do not inadvertently stumble or walk into a wall or object while using your mobile device for the study, the researcher, who will be with you through the whole study, will also spot for you and stop you if necessary.

All information provided is considered completely confidential. Your name will not appear in any publication resulting from this study; however, with your permission anonymous quotations during the study session may be used. In these cases participants will be referred to as Participant 1, Participant 2, … (or P1, P2, …).

You will be asked to explicitly consent to the use of video and audio data captured during the study for the purpose of reporting the study's findings. If and only if consent is granted, this data will be used only for the purposes associated with teaching, scientific presentations, publications, and/or sharing with other researchers. Participants will not be identified by name, and their faces will be blackened.

Data collected during this study will be retained indefinitely in a locked cabinet or on password protected desktop computers in the Collaborative Systems Laboratory at the University of Waterloo. The survey uses Survey Monkey™ which is a United States of America company. Consequently, USA authorities under provisions of the USA PATRIOT ACT may access this survey data. If you prefer not to submit your data through this platform, please do not participate in this research study.

We would like to assure you that this study has been reviewed by, and received ethics clearance through a University of Waterloo Research Ethics Committee. However, the final decision about participation is yours. Should you have any ethical comments or concerns resulting from you participation in this study, please contact the Director, University of Waterloo Office of Research Ethics (Dr. Maureen Nummelin, maureen.nummelin@uwaterloo.ca, 519-888-4567 ext. 36005).

Please retain a copy of the letter of information and consent form. If you have any questions, concerns or comments about this research, please contact any of the research team: Victor Cheung (v4cheung@uwaterloo.ca) or Dr. Stacey Scott (s9scott@uwaterloo.ca, 519-888-4567 ext. 32236).

B.3 Consent Form Used in the Deception Phase

INFORMED CONSENT BY SUBJECTS TO PARTICIPATE IN A RESEARCH STUDY

Project Title: Navigating with the Help of Mobile Devices

I have read the information presented in the information letter about a study being conducted by Victor Cheung and Dr. Stacey Scott at the University of Waterloo. I understand that I will be participating in a research project using mobile devices, and that I will be engaging in a study of which the procedures and risks are described in the attached letter of information. I have had the opportunity to ask any questions related to this study, to receive satisfactory answers to my questions, and request/receive any additional details desired.

Sometimes a certain image and/or segment of video recording clearly shows a particular feature or detail that would be helpful in teaching or when presenting the study results at a scientific presentation or in a publication.

I am aware that I may allow video and/or digital images in which I appear to be used in teaching, scientific presentations, publications, and/or data sharing with other researchers with the understanding that I will not be identified by name. I am aware that I may allow excerpts from this study to be included in teaching, scientific presentations and/or publications, with the understanding that any quotations will be anonymous.

I am aware that my participation is voluntary and that I may withdraw my consent for any of the above statements or withdraw my study participation at any time without penalty by advising the researcher.

This project has been reviewed by, and received ethics clearance through a University of Waterloo Research Ethics Committee. I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact Victor Cheung (v4cheung@uwaterloo.ca) or Dr. Stacey Scott (s9scott@uwaterloo.ca, 519-888-4567 ext. 32236), and that if I have any ethical comments or concerns about the study I may contact the Director of the University of Waterloo Office of Research Ethics (Dr. Maureen Nummelin, maureen.nummelin@uwaterloo.ca, 519-888-4567 ext. 36005).

	Please Circle One	**Please Initial Your Choice**		
With full knowledge of all foregoing, I agree, of my own free will, to participate in this study.			**YES**	**NO**
I agree to be video and audio recorded			**YES**	**NO**
I agree to let the video recordings, digital images, or audio recordings be used for presentation of the research results			**YES**	**NO**

Participant Name: ____ (Please print)

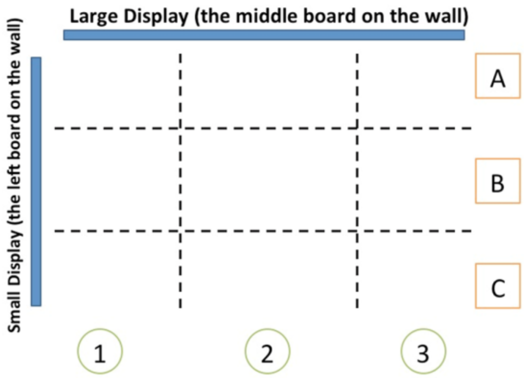
Participant Signature: ____

Date: ____

B.4 Routes in the Deception Task

<u>WALKING SEQUENCE</u>

Project Title: Navigating with the Help of Mobile Devices



For the “Verbal” condition, routes are spoken by the experimenter, for the “Visual” condition, routes are shown on the provided mobile device.

1.	Go to 1C
2.	Go to 3C
3.	Go to 3A
4.	Go to 1A
5.	Go to 1B
6.	Go to 3B
7.	Go to 3C
8.	Go to 1C
9.	Go to 2C then 2A
10.	Go to 1A then 3A
11.	Go to 3B then 1B
12.	Go to 1A then 1C
13.	Go to 3A
14.	Go to 3C
15.	Go to 2B
16.	Go to 2A
17.	Go to 1B
18.	Go to 1C

B.5 Background Questionnaire in the Deception Phase

Navigating with the help of mobile devices - Background Information

Background Information

Please fill out this questionnaire as accurately as possible. None of the information will be personally linked to you in any way. Please do not write your name anywhere on the questionnaire.

*** 1. Participant ID (to be filled in by researcher):**

*** 2. What is your gender?**

- Female
- Male

*** 3. What is your age?**

- 18 to 22
- 23 to 27
- 28 to 32
- 33 to 37
- 38 and above

*** 4. What is your occupation?**

5. If you are a student, what degree and program are you in?

*** 6. Have you used any mobile devices before? If yes, please provide some examples (e.g. smartphones, tablets). For each, please also indicate where you typically use**

them (e.g. at home, bus stops ...etc).

	Location
Smartphones	
Tablets	

Other devices and locations

7. If you have used mobile devices (skip if you haven't), please indicate if you have used your mobile device to help you navigate to a destination, and if so, how do you do it:

	I have never tried that.	I look at the screen for visual instructions most of the time.	I listen to the automated voice instructions most of the time.	I switch between listening to the voice and visual instructions.
Take a bus/train/taxi to a destination	○	○	○	○
Drive to a destination	○	○	○	○
Bike to a destination	○	○	○	○
Walk to a destination	○	○	○	○

Other (please specify)

*** 8. If you have used your mobile device while you are walking, please briefly describe how you manage to divide your attention between the device and your pathway (e.g. keep an eye on the surroundings, stop walking when using the device).**

Done

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B.6 Post-Experiment Questionnaire in the Deception Phase

Navigating with the help of mobile devices - Post Experiment Questionnaire

Post Experiment Questionnaire

Please fill out this questionnaire as accurately as possible. None of the information will be personally linked to your in any way. Please do not write your name anywhere on the questionnaire.

* **1. Participant ID (to be filled in by researcher):**

* **2. Please rate your level of confidence in completing the navigation task when the following types of instruction are provided.**

	No confidence (1)	(2)	(3)	Some confidence (4)	(5)	(6)	High confidence (7)
Voice-based (instructions provided in spoken words)	◯	◯	◯	◯	◯	◯	◯
Visual-based (instructions provided on device)	◯	◯	◯	◯	◯	◯	◯

Please briefly explain your selection.

* **3. Please indicate which type of navigation instruction you prefer.**

◯ Voice-based (instructions provided in spoken words)

◯ Visual-based (instructions provided on device)

◯ Equally

Please briefly explain your selection.

Next

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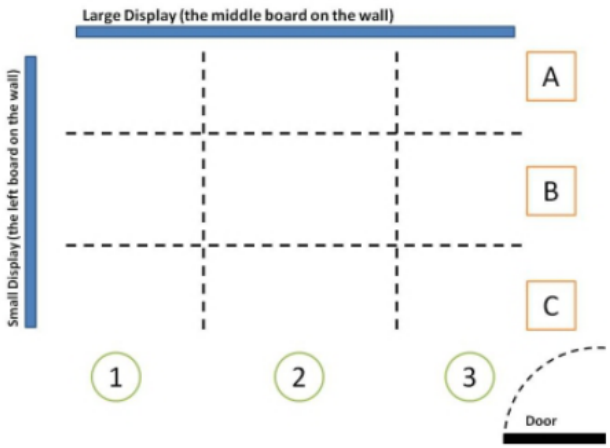
Navigating with the help of mobile devices - Post Experiment Questionnaire

We are also interested to see how your attention to your surroundings is affected during mobile device use.

Layout of the experimental room (for reference only)



The following questions refer to the large display (the middle board on the wall).

* **4. Did you notice the content in the large display (the middle board on the wall) while you were walking?**

◯ Yes

◯ No

If yes, briefly describe what the content was

* **5. Did the large display (middle board on the wall) affect the way you walked? If so, how?**

*** 6. What is your overall impression of the large display (the middle board on the wall)?**

*** 7. What do you think the purpose of the large display (the middle board on the wall) is?**

*** 8. What do you think you can do with the large display (the middle board on the wall)?**

*** 9. Which part of the large display (the middle board on the wall) do you find most appealing or interesting?**

The following questions refer to the small display (the left board on the wall).

*** 10. Did you notice the content in the small display (the left board on the wall) while you were walking?**

- ◯ Yes
- ◯ No

If yes, briefly describe what the content was

* 11. What is your overall impression of the small display (the left board on the wall)?

* 12. What do you think the purpose of the small display (the left board on the wall) is?

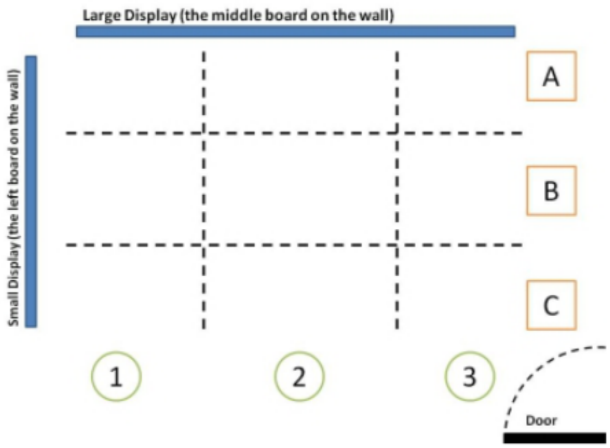
* 13. What do you think you can do with the small display (the left board on the wall)?

* 14. Which part of the small display (the left board on the wall) do you find most appealing or interesting?

Prev Next

Navigating with the help of mobile devices - Post Experiment Questionnaire

Layout of the experimental room (for reference only)



*** 15. Did you notice any of the displays responding to you? If so, in what way? Please specify which display (large or small) you are referring to.**

*** 16. Do you think of any of the displays are interactive? If so, how do you think you can interact with it/them? Please specify which display (large and/or small) you are referring to.**

Prev Done

B.7 Deception Debriefing Verbal Script

<u>RESEARCHER'S SCRIPT FOR VERBALLY DEBRIEFING PARTICIPANTS INVOLVED IN A DECEPTION STUDY (IN-LAB), USED WITH A POST-STUDY DEBRIEFING INFORMATION/FEEDBACK LETTER</u>

Study Title: Investigating Attraction of Animation on Large Displays

	Researcher's Script
Express appreciation to participant for taking part in the study.	**"**Thank you for spending the time helping us with our research. The research team greatly appreciates your participation in this study."
Probe for suspicion. (Optional)	"Do you have any guesses about what the study is really about? We would be interested in hearing any ideas you might have. Did anything seem strange or odd to you?"
Explain what participants were originally told.	"I would now like to tell you a bit more about the study. The debriefing letter that I gave you describes the details of the study. You can keep this copy. I will go over the main points with you now. When you began the study, you were told the purpose of this study was to investigate how different forms of navigating instructions affect the way a person arrives at a destination. However, we provided you with information that misrepresented the real purpose of the study. What this means is the study was actually different than what we explained in the beginning. Some studies involve deception – that is, participants are lead to believe the study is about one thing when it is actually about something else. This is one of those studies. Do you have any questions?"
Outline the full purpose/objectives of the study and explain what the deceptions were and purpose of the tasks.	*Provide participants with an explanation of and information on the:* *a) full purpose/objective(s) of the study:* We are interested in whether a passerby, when commuting near an interactive wall display, will be attracted to its interface with the use of animation in response to their proximity. *b) background information on the area of research being conducted:* We hypothesize that, when used appropriately, animation is an effective mechanism to attract people's attention, even when in their peripheral field of vision. To be able to attract and engage users to an interface has been widely researched topic in the field of Human-Computer Interaction. *c) deceptive aspects of the study, and measures, study tasks, and various conditions:* In this case, we had to omit the fact that the interactive wall display that you saw was trying to attract your attention, and we were assessing your responses to various types of animation used in the interface, through video- & audio- recording and notes taken by the researcher.
Explain why deception was used in the study.	"The reason that we needed to use deception in this study was because we needed participants' behavior and attitudes to be as natural as possible. Thus, we could not give participants complete information before their involvement in the study because it may have influenced participants' behaviour in a way that would make investigations of the research question invalid. If participants knew the objectives of the study before hand their behavior and attitudes may have been influenced by this knowledge."
Summarize the full purpose of the study and	"I would just like to re-iterate a few things: 4. The purpose of this study was to investigate the effectiveness of

which aspects involved deception (e.g., use of confederates, use of false information, etc.)	animation in an interactive wall display interface in terms of attractive passersby's attention. 5. All the equipment we used for assessment has been mentioned in the briefing, and there are no hidden ones throughout the study. 6. The experimental setup was to simulate an environment where a person commutes between marked points, which includes the interactive wall display and other displays in the surroundings."
Express regret for deceiving participants.	"We apologize for omitting details and for providing you with fictional information about the purpose of and tasks in our study. We hope that you understand the need for use of deception now that the purpose of the study has been more fully explained to you. Do you have any questions about deception and why it was used in this study?"

Explain not all psychology studies involve deception.	"I would like to assure you that most Systems Design Engineering research does not involve the use of deception."
Explain who to contact if questions or concerns arise about participation in the study.	"Do you have any questions or concerns about the use of deception in this study? Would you like to speak with the one of the study investigators/faculty supervisor about your concerns or questions? After you leave, if you have questions, comments, or concerns about the study or any feelings of discomfort, please contact the study researchers or the Office of Research Ethics. Contact information is on the debriefing letter I gave you."
Explain reasons for not discussing study details with others and why.	"This study involves some aspects that you were not told about before starting therefore it is very important that you not discuss your experiences with any other persons who potentially could be in this study until after the end of the term. If people come into the study knowing about our specific predictions, as you can imagine, it could influence their results, and the data we collect would not be useable. Also, since you will be given a copy of this feedback letter to take home with you, please do not make this available to other persons."
Reiterate details from the information letter as to how the information collected will be confidentially retained and stored.	"Even though this study involved deception, the information given to you about confidentiality, data storage, and security still applies. All data collected is confidential and securely stored at all times. No one other than the researchers have access to the data. These details are outlined in the debriefing letter."
Explain why another consent form needs to be signed.	"Because some elements of the study were different from what was originally explained we have another consent form for you to read and sign if you are willing to allow us to use the information that you have provided. This form is a record that the purpose of the study has been explained to you, and that you are willing to allow your information to be included in the study. Will you allow us to use the information you provided?" *[Researcher gives participant post-debriefing consent form to read and sign. Participant returns signed consent form to the researcher.]*
Conclude with an expression of appreciation.	"We really appreciate your participation, and hope that this has been an interesting experience for you."

B.8 Deception Debriefing Letter and Consent Form

DEBRIEFING LETTER FOR STUDIES INVOLVING DECEPTION (IN-LAB)

Study Title: Investigating Attraction of Animation on Large Displays (Navigating with the Help of Mobile Devices)

Faculty Supervisor: Stacey Scott, Systems Design Engineering, 519-888-4567 ext. 32236, s9scott@uwaterloo.ca

Student Investigator(s): Victor Cheung, Systems Design Engineering, v4cheung@uwaterloo.ca

We greatly appreciate your participation in our study, and thank you for spending the time helping us with our research. When you began the study you were told that the purpose of this study was to investigate how different forms of navigating instructions affect the way a person arrives at a destination. However, the study was more complicated than we explained at the beginning. We hypothesize that, when used appropriately, animation is an effective mechanism to attract people's attention, even when in their peripheral field of vision. We are interested in whether a passerby, when commuting near an interactive wall display, will be attracted to its interface with the use of animation in response to their proximity.

Large, interactive surfaces have become a popular choice for content presentation in a public setting due to their dynamic presence, and support for multiple users. One design challenge is to have the interface attracting passersby's attention. We are interested in investigating how animation can be used to achieve that.

Throughout the study, while you were carrying out your tasks, we also assessed how you responded to various types of animation presented in the interactive wall display, as to measure the effectiveness of animation in the interface. In the remainder of this session, you will be asked to complete a questionnaire for us to better evaluate your impression on the interactive wall display interface. The information and answers you have provided earlier will be combined with your answers to this questionnaire to form a complete participant response, so that we can better understand your responses. The video and audio recorded, and other data collected earlier will also be included for the same reason.

We could not give participants complete information about the study before their involvement because it may have influenced participants' behaviour during the study in a way that would make investigations of the research question invalid. The reason that we used deception in this study was because we needed participants' behaviour and attitudes to be unaffected by the study objectives, particularly the knowledge about the interactive wall display interface trying to attract their attention. We apologize for omitting details and for providing you with fictional information about the purpose of and tasks in our study. We hope that you understand the need for deception now that the purpose of the study has been more fully explained to you. We would also like to assure you that most Systems Design Engineering research does not involve the use of deception.

We would just like to re-iterate a few things:

4. The purpose of this study was to investigate the effectiveness of animation in an interactive wall display interface in terms of attracting passersby's attention.
5. All the equipment we used for assessment has been mentioned in the briefing, and there are no hidden ones throughout the study.
6. The experimental setup was to simulate an environment where a person commutes between marked points, which includes the interactive wall display and other displays in the surroundings.

If any of the questions or exercises in this study caused you to feel uncomfortable, please feel free to contact Victor Cheung (v4cheung@uwaterloo.ca). You can also contact my faculty supervisor, Stacey Scott, at 519-888-4567 ext. 32236 or s9scott@uwaterloo.ca. Also please feel free to contact Dr. Maureen Nummelin, the Director, Office of Research Ethics, at 519-888-4567, ext. 36005 or maureen.nummelin@uwaterloo.ca if you have concerns or comments resulting from your participation.

The information you provided will be kept confidential by not associating your name with the responses. The data will be stored with all identifying or potentially identifying information removed. Electronic data will be stored on a password protected computer in E2-1303B. Printed data will be kept in a locked room in E2-1303B. The survey uses Survey Monkey™ which is a United States of America company. Consequently, USA authorities under provisions of the USA PATRIOT ACT may access this survey data. If you prefer not to submit your data through this platform, please do not participate in this research study.

Because the study involves some aspects that you were not told about before starting, it is very important that you not discuss your experiences with any other persons who potentially could be in this study until after the end of the term. If people come into the study knowing about our specific predictions, as you can imagine, it could influence their results, and the data we collect would be not be useable. Also, since you will be given a copy of this feedback letter to take home with you, please do not make this available to other persons. Moreover, because some elements of the study are different from what was originally explained, we have another consent form for you to read and sign if you are willing to allow us to use the information that you have provided. This form is a record that the purpose of the study has been explained to you, and that you are willing to allow your information to be included in the study.

We really appreciate your participation, and hope that this has been an interesting experience for you.

POST-DEBRIEFING CONSENT FORM FOR STUDIES INVOLVING DECEPTION (IN-LAB)

Study Title: Investigating Attraction of Animation on Large Displays

(Usage Patterns with On-the-go Mobile Applications)

(Navigating with the Help of Mobile Devices)

Faculty Supervisor: Stacey Scott, Systems Design Engineering,

519-888-4567 ext. 32236, s9scott@uwaterloo.ca

Student Investigator(s): Victor Cheung, Systems Design Engineering, v4cheung@uwaterloo.ca

During the debriefing session, I learned that it was necessary for the researchers to disguise the real purpose of this study. I realize that this was necessary since having full information about the actual purpose of the study might have influenced the way in which I responded to the tasks and this would have invalidated the results. Thus, to ensure that this did not happen, some of the details about the purpose of the study initially were not provided (or were provided in a manner that slightly misrepresented the real purpose of the study). However, I have now received a complete verbal and written explanation as to the actual purpose of the study and have had an opportunity to ask any questions about this and to receive acceptable answers to my questions.

I have been asked to give permission for the researchers to use my data (or information I provided), as well as the video- and audio- recordings, in their study, and agree to this request. I am aware that I may withdraw this consent by notifying the Faculty Supervisor of this decision.

I am aware this study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee and I may contact Dr. Maureen Nummelin, the Director, Office of Research Ethics at 519-888-4567 ext. 36005, if I have any concerns or comments resulting from my involvement in this study. By signing this consent form, I am not waiving my legal rights or releasing the investigator(s) or involved institutions(s) from their legal and professional responsibilities.

Participant's Name: ____

Participant's Signature: ____

Date: ____

Witness' Name: ____

Witness' Signature: ____

B.9 Post-Experiment Questionnaire in the Reveal Phase

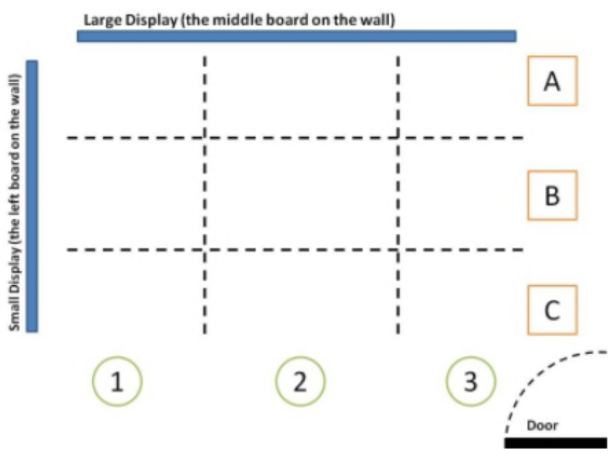
Attention Capture - Post Experiment Questionnaire2

Post Experiment Questionnaire

Please fill out this questionnaire as accurately as possible. None of the information will be personally linked to your in any way. Please do not write your name anywhere on the questionnaire.

* **1. Participant ID (to be filled in by researcher):**

Layout of the experimental room (for reference only)



* **2. Please indicate how much each of the displays (small and large) drew your attention when the instructions were provided vocally (through spoken words).**

	Did not draw my attention (0)	(1)	(2)	Drew some of my attention (3)	(4)	(5)	Drew my full attention (6)
The display on the left (small)	○	○	○	○	○	○	○
The display in the	○	○	○	○	○	○	○

middle (large)	○	○	○	○	○	○	○

*** 3. Please indicate how much each of the displays (small and large) drew your attention when the instructions were provided visually (displayed on the device).**

	Did not draw my attention (0)	(1)	(2)	Drew some of my attention (3)	(4)	(5)	Drew my full attention (6)
The display on the left (small)	○	○	○	○	○	○	○
The display in the middle (large)	○	○	○	○	○	○	○

*** 4. Please indicate how interactive do you think each of the displays (small and large) was.**

	Did not pay attention	Not interactive (0)	(1)	(2)	Somewhat interactive (3)	(4)	(5)	Very interactive (6)
The display on the left (small)	○	○	○	○	○	○	○	○
The display in the middle (large)	○	○	○	○	○	○	○	○

*** 5. Now that you know the real purpose of the study, do you have any particular comments beyond your previous answers?**

*** 6. What type of content, and how are they presented, do you think will draw more of your attention?**

* 7. How do you think the content should be presented if they are interactive (e.g. can be touched, moved around)?

Done

B.10 Post-Experiment Condition Dependent Questionnaire in the Reveal Phase

Attention Capture - Condition 1

* 1. Participant ID (to be filled in by researcher):

2. Did you notice the speed of content changed in the large display (the middle board on the wall)?

- No
- Yes

Please elaborate your answer.

3. Did you notice the speed of content changed in the small display (the left board on the wall)?

- No
- Yes

Please elaborate your answer.

Done

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Attention Capture - Condition 2

*** 1. Participant ID (to be filled in by researcher):**

2. Did you notice the speed of content changed in the large display (the middle board on the wall)?

- No
- Yes

Please elaborate your answer.

3. Did you notice the speed of content changed in the small display (the left board on the wall)?

- No
- Yes

Please elaborate your answer.

4. Did you notice the silhouette/shadow in the large display (the middle board on the wall)?

- No
- Yes

If Yes, describe its behavior in relation to your movement.

Done

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SurveyMonkey®

See how easy it is to create a survey.

Attention Capture - Condition 3

* 1. Participant ID (to be filled in by researcher):

2. Did you notice the speed of content changed in the large display (the middle board on the wall)?

- No
- Yes

Please elaborate your answer.

3. Did you notice the speed of content changed in the small display (the left board on the wall)?

- No
- Yes

Please elaborate your answer.

4. Did you notice the silhouette/shadow in the large display (the middle board on the wall)?

- No
- Yes

If Yes, describe its behavior in relation to your movement.

5. Did you notice the content moving towards or away from you in the large display (the middle board on the wall)?

- ◯ No
- ◯ Yes

Please elaborate your answer.

Done

Appendix C
Field Experiment Materials

C.1 Online Survey Information Letter and Questionnaire

Large Displays in a Public Setting

Information Letter

A Study Investigating Attraction of Animation on Large Displays in a Public Setting

Thank you for coming to this online survey, which is part of a research study conducted by the Collaborative Systems Laboratory at University of Waterloo, aiming at investigating attraction of animation on large displays in a public setting.

Large interactive displays capable of delivering dynamic content to broad audiences are becoming increasingly common in public areas for information dissemination, advertising, and entertainment purposes. A major design challenge for these systems is to entice and engage passersby to interact with the system. The claim is often made that animated content in response to passersby's movements would achieve such purpose. However, this claim is not often backed up with formal results and what aspects are more effective. We hypothesize that, when used appropriately, animation is an effective mechanism to attract people's attention, even when in their peripheral field of vision. We are interested in whether a passerby, when commuting near any interactive wall display, will be attracted to its interface with the use of animation.

To further understand how you perceived the display, we would like to invite you to answer a few questions in this survey, which will typically take less than 10 minutes to complete. This survey is designed to be anonymous so we will not be collecting any identifying data from you. All the data collected will be aggregated for analysis. In cases where a particular comment is to be quoted, identifiers such as Participant1, Participant2, or P1, P2 …etc will be used. The results of this research will directly benefit the scientific community through an increased understanding in public's perception of interactive displays, and help guiding the design of the said technology.

Please do not proceed if you are less than 16 years old.

This survey uses Survey MonkeyTM, which is a United States of America company. Consequently, USA authorities under provisions of the PATRIOT Act may access this survey data. If you prefer not to submit your data through Survey MonkeyTM, please do not participate in the survey.

In appreciation of the time you have given to this study, you can enter your contact information (email) into a draw for 1 of 10 prizes, each being a $10 Tim Horton's gift card. Your odds of winning one of the prizes is based on the number of individuals who participate in the study and decide to join the draw. We expect that approximately 200 individuals will take part in the draw. Information collected to draw for the prizes will not be linked to the study data for analysis in any way, and will be destroyed after the prizes have been provided. The amount received is taxable. It is your responsibility to report this amount for income tax purposes.

We would like to assure you that this study has been reviewed by, and received ethics clearance through a University of Waterloo Research Ethics Committee. However, the final decision about participation is yours. Should you have any ethical comments or concerns resulting from you participation in this study, please contact the Director, University of Waterloo Office of Research Ethics (Dr. Maureen Nummelin, maureen.nummelin@uwaterloo.ca, 519-888-4567 ext. 36005).

Next

Large Display in a Public Setting

Background

We would like to gather some general information to see if there is any relationship between that and perception towards the display.

*** 1. What is your gender?**

- ◯ Female
- ◯ Male
- ◯ Rather not say

*** 2. What is your age group?**

- ◯ 16-25
- ◯ 26-35
- ◯ 36-45
- ◯ 46-55
- ◯ 56+
- ◯ Rather not say

*** 3. Have you ever used a large display like this in a public setting (e.g., airport, library, shopping mall, museum)?**

- ◯ Yes
- ◯ No

Prev Next

Large Displays in a Public Setting

Perception towards the large display

We would like to know more about your experience when using the display.

*** 4. What time did you interact with the display? (you can approximate the minutes to 0, 15, 30, or 45 if unsure)**

	DD		MM		YYYY	hh		mm	AM/PM
Date / Time		/		/			:		-

*** 5. What initially drew your attention to the display (choose those apply)?**

- [ ] Saw someone using the display
- [ ] Drawn by content on the display
- [ ] The physical appearance of the equipment

Please elaborate your answer (e.g. who did you see using the display, what content drew your attention, or any other)

*** 6. What held your attention and made your approach the display (choose those apply)?**

- [ ] The people using the display
- [ ] The content on the display
- [ ] The physical appearance of the equipment

Please elaborate your answer (e.g. who did you see using the display, what content held your attention, or any other)

* 7. How confident were you before you touched the display that it was interactive?

	Not confident	--	Neutral	--	Very confident
Level of confidence	○	○	○	○	○

* 8. Before your touched the display, what type of interactivity did you think the display had (choose those apply)?

- ☐ Touch-screen (your touches on the display)
- ☐ Gestural (your movements in front of the display)
- ☐ Speech (your voice around the display)
- ☐ Was not confident that the display was interactive
- ☐ Other (please specify)

* 9. What do you think you can do with the display?

10. Additional comments?

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C.2 Feedback Notice Posted after Field Experiment

The display you saw the past few days was used as part of a research experiment investigating attraction of animation on large displays in a public setting. Please contact us via csl.studies@uwaterloo.ca if you have any questions.

This project has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee. However, the final decision about participation is yours. Participants who have concerns or questions about their involvement in the project may contact the Chief Ethics Officer, Office of Research Ethics at 519-888-4567, Ext. 36005 or maureen.nummelin@uwaterloo.ca.

Appendix D
Study/Experiment Parameters

This appendix provides details of the parameters used at the Large Surface in the Improved Study of Animated Content and Shadow Visualizations (Chapter 6) and in the Field Experiment of Animated Content and User Shadow (Chapter 7).

Study/Experiment (development software used)	**Large Surface specifications***	**Software-specific parameters****	**Physical parameters**
Improved Study (Processing 2.X)	D:309cm X:101cm R: 2560px X 800px ~0.12cm/px	(*Adaptive Speed*) Zone 1: 20px/sec Zone 2: 40px/sec Zone 3: 60px/sec	(*Adaptive Speed*) Zone 1: 2.4cm/sec Zone 2: 4.8cm/sec Zone 3: 7.2cm/sec
		(*User Shadow*) Transparency linearly mapped from 0.8-3.2m to 0-255 alpha values	(*User Shadow*) Transparency linearly mapped from 0.8-3.2m to invisible-solid
Field Experiment (Unity3D 5.X)	D: 142.8cm X 80.4cm R: 1920px X 1080px ~0.074cm/px	(*Adaptive Speed*) Zone 1: 0.2-0.4m/sec Zone 2: 0.6-1.2m/sec Zone 3: 1-2m/sec	(*Adaptive Speed*) Zone 1: 2.3-4.5m/sec Zone 2: 6.8-13.5m/sec Zone 3: 11.3-22.5m/sec
		(*User Shadow*) Transparency linearly mapped from 0.4-3.15m to 0-255 alpha values	(*User Shadow*) Transparency linearly mapped from 0.4-3.15m to invisible-solid

*D: Dimensions (Width X Height), R: Resolution (Width X Height)

**In Processing the default unit is pixel (px), in Unity3D the default unit is metre (m) in Unity3D's world space

Glossary

Public Large Interactive Surfaces	The system on which this thesis focuses. The order reflects the properties of the system in a layered, bottom-up manner: “Interactive Surfaces” represent interactive display surfaces in various forms such as flat, curved, vertical, and horizontal. This choice of words also reflects the title of the conference most relevant to this research: Interactive Surfaces and Spaces. “Large” represents interactive surfaces in a considerable size that are viewable at a distance, and support simultaneous users. “Public” represents the openness of these large interactive surfaces, allowing access by everyone who can either implicitly and/or explicitly interact with them.
Interactive Display/System	Refers to the physical installation of a Public Large Interactive Surface (PLIS). This includes both its input and output hardware, and the software application being presented. Unless otherwise specified, these terms are used interchangeably. The more technical term “Surface” in PLIS is sometimes replaced with a more general term “Display” to remain consistent with the cited work (e.g., Ambient Display Framework by Vogel & Balakrisnan (2004)), and the terminology used in the questionnaires (e.g., Sections 4.2 & 7.2). However, when appropriate, “surface” will be used to provide a more technical representation of the installation.
Interactive	Refers to the responsiveness of the system. An interactive system provides observable responses in the presence of user’s implicit and/or explicit actions.
Passersby/Users	The target audience of the system at different stages of interaction. “Passersby” refer to the target audience that are not aware of the PLIS, and are regarded as in the early stages of interaction. “Users” refer to the target audience that are actively interacting with the PLIS, and are regarded as in the later stages of interaction. It is used along with “System” in adherence to the Systems Design Engineering domain. In communities such as HCI they are more commonly referred to as “people” or “person”, and “artifact”, “prototype”, or “installation” instead.
Public Interactive Displays	Refers to a more general collection of interactive displays including smaller sizes. This term is often used in the related research community.