Requirements and Design Space for Interactive Public Displays

Jörg Müller
Quality and Usability Lab
Deutsche Telekom Laboratories
TU Berlin
Ernst-Reuter-Platz 7, 10587 Berlin
Germany
joerg.mueller@tu-berlin.de

Florian Alt, Albrecht Schmidt
Pervasive Computing and
User Interface Engineering
University of Duisburg-Essen
Schuetzenbahn 70, 45117 Essen
Germany
{florian.alt, albrecht.schmidt}
@uni-duisburg-essen.de

Daniel Michelis
Anhalt University of
Applied Sciences
Strenzfelder Allee 28
06406 Bernburg
Germany
d.michelis@wi.hs-anhalt.de

ABSTRACT

Digital immersion is moving into public space. Interactive screens and public displays are deployed in urban environments, malls, and shop windows. Inner city areas, airports, train stations and stadiums are experiencing a transformation from traditional to digital displays enabling new forms of multimedia presentation and new user experiences. Imagine a walkway with digital displays that allows a user to immerse herself in her favorite content while moving through public space. In this paper we discuss the fundamentals for creating exciting public displays and multimedia experiences enabling new forms of engagement with digital content. Interaction in public space and with public displays can be categorized in phases, each having specific requirements. Attracting, engaging and motivating the user are central design issues that are addressed in this paper. We provide a comprehensive analysis of the design space explaining mental models and interaction modalities and we conclude a taxonomy for interactive public display from this analysis. Our analysis and the taxonomy are grounded in a large number of research projects, art installations and experience. With our contribution we aim at providing a comprehensive guide for designers and developers of interactive multimedia on public displays.

Categories and Subject Descriptors

H.5.1 [**Multimedia Information Systems**]: Information Interfaces and Presentation

General Terms

Design, Human Factors.

Keywords

Public Displays, Interaction, Requirements, Design Space.

1. INTRODUCTION

Traditionally, most multimedia applications can be found on personal devices, such as PCs or mobile phones. However, electronic displays are also rapidly permeating public spaces, increasingly augmenting and replacing traditional, static signs. This broadens the domain of multimedia beyond the personal space to also include the public, urban space. Although the vast majority of these displays are still not interactive, there seems to be a clear trend towards networked and interactive displays. While interactive networked displays are promising for deploying multimedia applications and content, many deployments seem to be plagued with much lower usage than expected by their designers [20]. It seems that although designers implement existing knowledge from HCI, like usability and affordances, there are additional issues unique to public displays that hamper their acceptance. The vast majority of interactive public displays proposes a 'poster' mental model to their audience, and allow for interaction via touch and / or keys only. This is despite several other mental models and interaction modalities have been proposed. In addition, many displays seem to fail to attract enough attention of passers-by, simply vanishing in the clutter of things in public space that compete for attention. If they capture attention, many displays seem to fail to motivate passers-by to interact, who have other goals in mind. If, finally, the audience has noticed the display and is motivated to interact, interactive displays seem to fail to deal appropriately with the public nature of interaction, where people may avoid interaction in order to maintain their social role and, e.g., not look silly. These requirements can be addressed by displays utilizing broader metaphors than just that of a poster, for example windows, mirrors, or overlays over the physical world.

*MM'*10, October 25–29, 2010, Firenze, Italy.

2. REQUIREMENTS ANALYSIS

While many findings from HCI also apply to public displays, simply guaranteeing utility, usability, and likability may not be enough to design public displays. In particular, public displays need to grab the attention of passers-by, motivate passers-by to interact with them, and deal with the issues of interaction in the public. Since most multimedia systems have been designed as personal devices or for use in home environments, these issues have not yet received sufficient attention. For public multimedia systems however, how the audience approaches them is crucial.

2.1 Interaction Phases

In contrast to many other computing technologies, interaction with public displays does not start with the interaction itself. Instead, the audience is initially simply passing by, without any intention for interaction. A model of the different phases of interaction has been presented in [39] (Figure 1). This model builds on the model presented in [9], but instead focuses on audience behav-

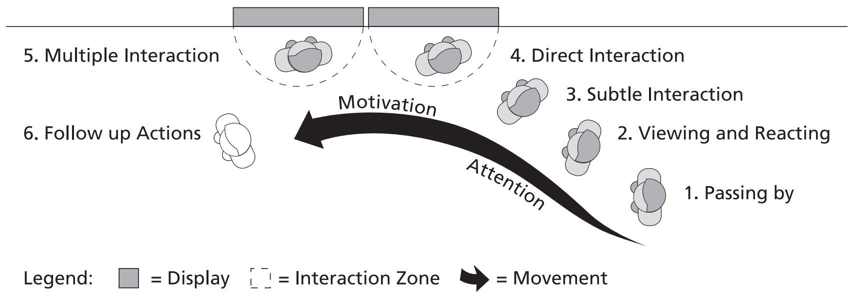


Figure 1: The Audience Funnel (adapted from [39])

ior that is readily observable by an outside observer. People pass through different phases, where a threshold must be overcome for people to pass from one phase to the next. For each pair of phases, a conversion rate can be calculated of how many people are observed to pass from one phase to the next, and different displays can be compared by these rates. In the first phase, people are merely passing by. In the second phase, they are looking at the display, or reacting to it, e.g. by smiling or turning their head. Subtle interaction is only available when users can interact with the display through gestures or movement, and occurs, e.g., when they wave a hand to see what effect this causes on the display. Direct interaction occurs when users engage with a display in more depth, often positioning themselves in the center in front of it. People may engage with a display multiple times, either when multiple displays are available or if they walk away and come back after a break. Finally, people can take follow-up actions, like taking a photo of themselves or others in front of the display.

Thresholds exist between the phases, such that for example not all passers-by will look at a display, and not all who look at it will engage in subtle or direct interaction. We propose that the major lever to overcome the first threshold is to raise the attention of passers-by. In order to overcome the second threshold, the curiosity of onlookers should be raised, and in order to overcome the other thresholds, people must be motivated. All of these thresholds may be raised by various consequences of the fact that the interaction happens in the public. Thus, adequate measures must be taken in order to mediate these issues and lower the thresholds.

2.2 Attention

Human-computer interaction often assumes that the user is aware of the computer in the first place. This is not necessarily the case for public displays. In contrast to other computing technologies public displays are not owned by their primary users (the audience). They are installed in public contexts, where they compete for audience attention with various other stimuli (like other signs, traffic, or people). There has been a discussion on how much attention ubiquitous computers should attract. On one hand, it has been argued that if the environment is filled with ubiquitous computers, they should better remain calm and slide effortlessly between center and periphery of attention [61]. On the other hand, it has been argued that they should engage people more actively in what they do [51]. If public displays fail to attract enough audience attention however, they may not be used at all.

2.2.1 Models of Attention

Generally, the information processing power of the human brain is limited, and at any point in time, more sensory input arrives at the brain than can be processed in detail. Attention denotes the process in which the human brain decides which of the numerous sensory inputs to apply the most computational power to. Visual attention is often modeled with a 'Spotlight' metaphor, in which a certain region of the visual field is selected for more detailed processing. This spotlight often coincides with the fovea, but can change in location and diameter. In general, attention is influenced both by bottom-up processes (external stimuli like a suddenly appearing error message) and top-down processes (like the goal of the user looking for a letter in a certain color).

A computational model for bottom-up attention is presented by Itti et al. [23]. The sensory input image is split into representations for colors, intensity, and orientations (in the human brain, specialized neurons exist for these representations). From the representations, various feature maps are computed, which are then normalized and combined into conspicuity maps. These conspicuity maps are combined into a single saliency map. In a winner-take-all process, the most salient region is selected to be attended and inhibited so that the next attended region will be a different one (inhibition of return). This bottom up model only takes into consideration the mere sensory input to the brain. Yet, this process is complemented by top down processes, in which the focus of attention is influenced by the current task, previous knowledge, and cues. An extended model of visual attention combining bottom up and top down processes is presented by Hamker [19]. In particular, internal goals are modeled to influence the attention process.

In addition to these neuro-computational models, applied models were postulated in particular to inform human-computer interaction design. Weiser and Brown [61] proposed a model of center and periphery of attention, where users could only centrally attend to one thing at a time, but could monitor multiple things simultaneously in the periphery of their attention. In their proposal for Calm Computing, Weiser and Brown suggested that devices should be designed so that they effortlessly slide back and forth between the center and periphery of attention. They suggested that thereby users could attend to more things simultaneously in the periphery of their attention, and take control over them by re-centering them in the center of their attention.

2.2.2 (Not) Attracting Attention

Among the general models that have been proposed of what attracts (visual) attention are *behavioral urgency* and (Bayesian) *surprise*. *Change blindness* can be used in order not to attract attention, and specifically for public displays, the *Honeypot effect* has been shown to strongly attract attention.

Franconeri and Simons [17] hypothesize that stimuli that indicate the potential need for immediate action capture attention. It has been found that abrupt appearance of new objects [25] and certain types of luminance contrast changes [15] capture attention. In addition, moving (towards the observer) and looming stimuli have been found to capture attention [17]. Since all of these stimulus properties may hint at potential need for immediate action (e.g., an animal approaching), behavioral urgency may be a useful model to predict how much attention a stimulus will attract.

Itti et al. [22] propose a model of Bayesian surprise for bottom-up visual attention. Surprise measures the difference between posterior and prior beliefs about the world. This is different from Shannon's concept of information, as instead of relying on objective probabilities it considers only subjective beliefs. They implemented a model of low-level visual attention based on Bayesian surprise to predict eye movement traces of subjects watching videos. The model performs better than other models predicting attention based on high entropy, contrast, novelty, or motion.

Change Blindness is an effect that shows how the attention attracting effect of changes can be avoided. In certain circumstances, people have surprising difficulty to observe apparently obvious major changes in their visual field, e.g., road lines changing from solid to dashed, or a big wall slowly changing the color. Effects that cause change blindness include blanking an image, changing perspective, displaying "mud splashes" while changing the image, changing information slowly, changing information during eye blinks or saccades, or changing information while occluded (e.g., by another person). Intille [21] proposes to use change blindness to minimize the attention a display attracts while updating content.

The Honeypot effect [9] has been described by Brignull et al. in the context of the Opinionizer public display that was shown during a party. Whenever a crowd of people had already gathered around the display, this crowd seemed to attract a lot of attention and other people were much more likely to also attend the display. Similar effects have also been observed with the Citywall display [46] as well as with the Magical Mirrors installation [37].

Although attention plays a role for any multimedia system, it plays a crucial role for multimedia on public displays, because of the strong competition for audience attention in public spaces.

2.3 Motivation

Traditional paper-based public displays have served as read only media (e.g., posters, billboards). With making displays interactive users need to be motivated to make use of these systems and need to find an incentive for using them. Typically people do not go out in order to look for a public display to use. They rather come across a public display (e.g. while waiting) and become motivated by external factors to use them. The entry of interactive displays into public space is part of a greater tendency: computer usage is spreading into public life and no longer restricted to mere task fulfillment at the workplace. While task-oriented theories simply regard the "how" of an activity but not the "why", they leave questions concerning underlying motivations unanswered [55].

Malone presents a distinction between tools and toys to differentiate systems that have an external goal from those who are used for their own sake. Tools are task-oriented. They are designed to achieve goals "that are already present in the external task." Toys either need to provide a specific goal or enable the user to create their own, emergent goal. A tool should be easy to use - a toy needs to provide a challenge to be motivating to the user [36].

In spite of its increasing significance in human-computer interaction, motivation has been only an isolated object for investigation. Up until now there exists a significant need for advancement in understanding the motivation behind the user's activity [35]. Particularly, only little is known about how the design of public displays will invite interaction [1].

In his Magical Mirrors prototype study Michelis identified the following building blocks for motivating interaction in Public Space [37]. His list of motivating factors is based on the work of Thomas Malone who investigated motivating principles for designing traditional human-computer interaction [35].

2.3.1 Challenge and Control

The first motivating factors, challenge and control, are based on the notion that the ability to master an interaction, while still being challenged, will increase motivation to carry out this interaction. Flow [12] has been presented as a state of mind where the user is fully immersed in an activity while feeling energized and focused. Simply said, flow can be achieved in a channel between too little challenge, leading to boredom, and too high challenge, leading to anxiety. In human-computer interaction people strive for an optimal level of competency that allows them to master the challenges presented by the application [8]. The Magical Mirrors study revealed that viewing the consequence of one's own interactive behavior was the most important element for challenge as a motivating factor. Here, the users were motivated to explore and master the interactive functions of the displays [37]. In addition to this visibility, the presence of an emergent goal to the interaction, in which a distinction between set and emerging goals can be made, also played an important role. Emerging goals arose from the interaction of the individual with the Magical Mirrors displays. Since emerging goals have a strong motivating effect, interactive environments should not only provide a set of goals but also allow the design of one's own emerging goals [8]. Moreover, the intrinsic motivating challenge of an activity appears to increase if, in interacting with the environment, a clear and direct feedback follows from one's own behavior and the attaining of the goal [35]. The results of the Magical Mirrors study supports the importance of emergent goals for motivation [37]. In order to turn an interaction into a challenge, the behavioral outcome should however be somewhat uncertain and the end result should remain unknown prior to being conducted. The motivating effect of control is based primarily on recognizing a cause and effect relationship, as well as on powerful effects and the freedom of choice in performing the interaction. For motivation the perception of control is more important than actual control. The subjective sense of control can even have a motivating effect if the person doesn't possess any actual control [4].

2.3.2 Curiosity and Exploration

As one of the most important foundations for intrinsically motivating behavior, curiosity is evoked through novel stimuli that present something unclear, incomplete or uncertain. The individual searches around for possible explanations within their environment and their behavior is motivated by a desire to avoid potential insecurities. Curiosity is described as a precursor to explorative behavior, through which people make accessible previously unavailable information about their environment. In accessing previously unavailable information about their environment, people utilize exploration as a means to avoid insecurities [13]. Specific explorations are attempts to reduce the degree of incongruity and therefore the level of stimulation. However, if the stimulation falls below an optimal level, the individual is motivated to make further explorations in order to re-establish the optimum. Curiosity appears to belong to the most important characteristics of intrinsically motivating environments. In order to stimulate curiosity and to influence motivation, the interaction shouldn't be designed in a way that is either too complex or too trivial. Interactive elements should be novel and surprising, but not incomprehensible. On the basis of his or her prior experiences the user should have initial expectations for how the interaction proceeds, but these should only be partially met [35]. In reactive environments a motivating optimum of complexity is hence also fostered through the interplay of surprising and constructive interaction. The desired behavior for the interaction can be initially activated by surprising elements and maintained through constructive elements. In contrast to perceptible changes that appeal to people's sensory curiosity, cognitive curiosity relates to anticipated changes. People are motivated in this way to optimize their cognitive structures [40]. To increase motivation through curiosity, it appears at first sufficient to convey to the individual a sense of incompleteness, discrepancy or dissipation and to present through the interaction the chance to abate these sensations. However during the interaction it should be made especially clear how to attain completeness [35].

2.3.3 Choice

Choice as a motivating factor is based on the observation that the motivation for a behavior appears to increase if in the process people can select between alternatives in behavior. The choice between alternatives enables them to control their behavior and to make active decisions regarding behavior for the individual situation. Preferable are those alternatives that best correspond to one's own preferences and through which not only the behavior itself but also the effects of one's own behavior can be controlled [24]. With an increase in the number of possible choices, the likelihood increases that a feeling suited to the individual can be found. Even with very trivial choices, or ones, which only exist in the imagination of the individual a motivating effect was clearly proven [24][8][11]. Given that the mere presence of choice appears to promote intrinsic motivation, it can therefore be established among other things that the sensation of autonomy and control increases as a result. The greater the number of choices perceived, the stronger one's own autonomy and control appears to be. On the other hand it was demonstrated that a number of alternatives that exceeds an optimal level [24] as well as the absence of choice and opportunities for control [27] lead in various ways to a reduction in intrinsic motivation. In sum, the offer or presence of interaction alternatives can be a strong motivating factor within human-computer interaction and encourages the performing and maintaining of specific interactions [56]. This could also be shown in the Magical Mirrors study [37].

2.3.4 Fantasy and Metaphor

In general, imaginary settings also appear to have a motivating effect on behavior. In these fantasy settings the constraints of reality are switched off so that one imagines possessing new abilities. In interacting with computers one of the initial user reactions is oftentimes the inspiration of fantasy; the extent to which interactive environments inspire fantasy determines their attractiveness and generates interest in the reception of the interaction [45]. The use of metaphors allows for operationalizing fantasy concepts [6]. By employing metaphors fantasy elements can be directly integrated into human-computer interaction. Since they refer to physical or other systems metaphors can help the user to comprehend the interaction prior to actual use, motivating him or her toward the reception of the interaction [28]. In the Magical Mirrors study, the metaphor used was the distortion mirror known from annual fairs and amusement parks [38]. Since the interaction bears resemblance to already known situations, it can be grasped more easily and utilized more efficiently. By doing so metaphors do not need to reproduce the world realistically, since the abstract, conceptual, or symbolic representation can prove equally effective as life images [30]. The significance of metaphors in human-computer interaction is supported by a series of research projects. If new forms of interaction are linked to familiar traditions, it appears easier for users to carry over already established behaviors.

2.3.5 Collaboration

In contrast to the first motivating factors, collaboration is based on the interaction with other human beings. A condition for its motivating effect is the opportunity that the individual can influence the interaction of other people [8]. This also appears to apply when multiple individuals engage in communal activities via the use of computers. With the linking of computers via the Internet, human-computer interaction was also expanded around a social component [14]. In addition to social interaction over the Internet, the use of interactive public displays increasingly plays an important role in collective interaction located in one place [34]. The motivation to collaborate is increased for example through functionalities that make visible the effects of one's own behavior. With a view toward cooperation and competition, differences can be ascertained between individualistic, cooperative and competitive orientations. While people with a cooperative orientation also hold the preferences of others important, people with a competitive orientation seek to maximize their own preferences in relationship to the preferences of others. In this case collaboration is especially motivating if individual behavior is recognized by others [59]. If the efforts and effectiveness of one's own behavior are recognized and valued, people are motivated to repeat this behavior again. If the collaboration is continued, the probability of sustained recognition is even greater. The visibility of one's own behavior is also one of the most important foundations for recognition [36]. The degree to which collaboration has a motivating effect is influenced by the personal experience of the individual and can strongly vary according to each particular situation. Alongside individual orientation cultural differences also play a role [26].

2.4 Interaction in the public

The third major issue that may hamper interaction of the audience with public displays is that this interaction happens in the public. People may want to give a certain impression towards others, avoid to be annoyed by displays or other people, not give out private information and simply be polite towards others.

2.4.1 The Presentation of Self

In his book "The presentation of self in everyday life" Goffman [18] reframes social behavior of people as a scene play. Everybody plays a certain role and a major goal of people is to maintain coherence of their role. The public space is divided into front stage and back stage. For example a salesperson may behave very differently in the sales room and in the storage area. A policeman may avoid interaction with a playful public display in order to maintain his role. Similarly, people may avoid gestures, which they believe would contradict their role, like bowing or kneeling.

A public display may well be perceived as a stage, and how people interact with it may depend on their personality traits. While an introverted or shy person may avoid interacting with a public display, in order not to attract attention, an extroverted person may take advantage of the opportunity and use the situation to present a show to the audience.

Figure 2: Hole-in-Space[1]

2.4.2 The Selective Control of Access to the Self
Privacy may be divided into the selective control of access to the self, and control over one's personal data. Privacy as the selective control of access to the self has been defined by Altman [3] as a dialectic and dynamic boundary regulation process. For example, people may not want to be approached offensively by a public display (which may be perceived as spam). Similarly, they may be afraid of standing in the public attention and possibly being approached by others when they interact with a public display.

2.4.3 The Control over one's Personal Data
Law in many countries guarantees privacy as the control over one's personal data. Langheinrich [33] explains the guiding principles of anonymity, access, locality, adequate security, notice and disclosure, and choice. E.g., anonymity as 'the state of being not identifiable within a set of subjects' should be guaranteed wherever possible. Hence, a display system may allow users to carry a personal RFID chip that stores a profile of their interests. When a single person passes by a display and some personalized information pops up, this information may be associated with the person by any bystander. If, however, multiple persons are in the vicinity of the display at the same time, it may not be obvious for a bystander which person to associate this information with.

2.4.4 Social Behavior
Finally, people may simply want to be polite to other people in the environment. For example, a certain public display may require them to stand in a thoroughfare when they are interacting. Probably, at least after a couple of people bumped into them, they will cancel their interaction in order not to stand in the way of others.

2.4.5 The Public Nature of the Space
Public space is characterized by not being controlled by individuals or small groups. It serves to connect private spaces as well as a multitude of overlapping functional and symbolic uses. This means in particular that the operators of a public display cannot control the space around it. For example, if a group of people lingers in front of the display and prevents its use, there is usually nothing a display operator can do about it.

Furthermore, the multitude of uses of public space means that most of the passers-by have something else to do when they pass by. They may be on their way to or back from work, go shopping, or visit someone. If the goal is leisure related, e.g. just strolling around, probability of interaction may be much higher.

Outdoor deployment of public displays also means that there may be physical constraints impossible to control. The sun reflecting on the display may make the display unrecognizable, and cold temperatures may make it impossible for passers-by to stay around the display for longer or take their gloves off to touch.

3. DESIGN SPACE
In the following chapter we present the design space for interactive public displays. We envision the design space to create a basis for discussing challenges and issues related to the design of interactive applications. It is based on an analysis of existing public display technologies, environments, and installations.

We observed that most existing approaches could be classified as to follow one of four mental models based on metaphors from the real world. In section 3.1 we will explain these mental models and report on how existing approaches use them to foster interactivity. Further, the advent of public displays and their diffusion in the mass market led to an integration with different kinds of sensors, enabling various types of interaction. In section 3.2 we outline interaction modalities based on currently available sensor technologies and show how they are deployed in current installations.

3.1 Mental Models
Understanding how users intuitively perceive the world around a display is essential for the design of interactive display applications. Hence we present the results of an analysis of existing public display applications. We identified four prevailing mental models: posters, windows, mirrors, and overlays.

3.1.1 Posters
Per definition a poster is a piece of printed paper (including text and graphics), which can be attached to walls or vertical surfaces. Though electronic posters allow for a more dynamic content, they often show a mere adaptation of content created for their analog counterparts. Nowadays posters are often enhanced with sensing capabilities, hence allowing for people in the vicinity to implicitly or explicitly interact with the content. Whereas most non-interactive displays, such as info screens, etc. follow the notion of (framed) posters, this model can also be found among many interactive installations. One example is *CityWall* [46], a large multi-touch display deployed in the city of Helsinki. The screen is deployed in a shop window and allows for multi-person interaction. The research focuses on phenomena arising from public deployment, e.g., parallel interaction, conflict management, and gestures.

Interactive content on public displays following the poster model aligns well with what users currently expect from public displays that is being digital counterparts of traditional posters. However, this leads to that posters tend to often be ignored by users due to the association with traditional advertising posters. Müller et al. have described this effect as display blindness [44]. Hence approaches following the poster model face the challenge that they need to put a special focus on grabbing a user's attention.

3.1.2 Window
Following the window metaphor, this mental model creates the illusion of a link to a remote, often virtual, location. In contrast to the poster, windows may work in two ways: users look inside, but windows offer the chance for the remote side to look outside as well. The public communication sculpture Hole-in-Space[1] (see Figure 2) used the window metaphor in 1980 to create a link between two remote US locations. Such a window metaphor may be

[1] http://www.ecafe.com/getty/HIS/

extended to other modalities, like punching. Remote Impact [42] allows two remote players to enter the identical interaction space.

3.1.3 *Mirror*

Mirrors in the real world are objects with a reflective surface. Several research projects follow the metaphor of a mirror to encourage interaction. For example, Magical Mirrors presented a mirror image of the audience and augmented that image with optical effects, like a ribbon following the user's hands. Other installations embed users within a different context, e.g., a scene at the beach or on top of a mountain. Schönböck et al. [54] showed that making users a part of the display has a strong potential to catch a user's attention as they pass by.

3.1.4 *Overlay*

Finally, projectors enable creating overlays, which allow for displaying content within another context. In contrast to the aforementioned models, overlays are frameless in that they can seamlessly integrate with the environment. Pinhanez et al. presented the Everywhere Displays Projector [47], an LCD projector, which allows for projecting on different surfaces of an environment (see Figure 3). One application, the Jumping Frog, presents a frog on any surface in the environment. If somebody tries to touch the frog, it 'jumps' to another surface nearby.

3.2 Interaction Modalities

The varieties of sensors, which are nowadays available on the market allow for sensing the environment, hence enabling many different types of interaction modalities. Such sensors include touch and light sensors, passive IR sensors (motion detection), microphones and cameras, but also Bluetooth / RFID scanners for presence sensing as well as GPS, GSM, or WLAN-based location sensing (for a more comprehensive overview we refer to [52]).

When it comes to user interaction in front of public displays, two different types of interaction can be distinguished. Whereas in *explicit interaction* the user tells the computer in a certain level of abstraction what she expects him to do [53], implicit interaction describes an action, which is not in the first case targeted towards the interaction with a computer but nevertheless considered an input. For example, a user may walk through a door, causing the lights to go on. Similarly, he may type on a keyboard, and his typing patterns may be used to authentify him. In the following we present 10 interaction modalities, which allow for both implicit and explicit interaction in the vicinity of public displays.

Figure 3: The Everywhere Projector [47]

3.2.1 *Presence*

A wide variety of sensors allows for sensing the audience in the vicinity of a display, e.g., cameras, microphones, Bluetooth and RFID scanners, pressure sensors, etc. Presence sensing is mainly used to trigger implicit interaction, often with the aim of getting the user involved into interaction with the display. A sample installation using presence sensing is Hello.Wall [49], an ambient display, which reacts to people as they pass by. Hello.Wall uses RFID-based ViewPorts carried by users for identification in the wall's proximity and triggers the emission of information based on light patterns on the wall itself.

3.2.2 *Body position*

In a similar way, cameras or pressure sensors in the floor can be used to not only identify presence but the exact position of a person in front of a display. Knowing the position allows for a more sophisticated way of interaction by displaying or updating content close or in relation to the user's position. Beyer et al. [5] use a camera for assessing a user's position in front of their cylindrical screen hence encouraging user to interact with content, which follows the user as she moves around the column.

3.2.3 *Body Posture*

Body orientation and position as well as proximity can be used to assess the way a user approaches a display and whether she faces it or simply passes by. Different technical solutions exist as to how body posture can be measured, such as motion tracking, 3d cameras, and low-frequency waves [62]. Vogel et al. presented the public ambient interactive display [58]. At the focus of this research is the transition between implicit and explicit interaction based on which different interaction phases are defined.

3.2.4 *Facial Expression*

Nowadays a variety of software and hardware is available which allows for recognizing facial expression. Commercial solutions include Samsung PROM[2]. Fraunhofer's SHORE includes means for recognizing whether a user's mood is happy, sad, surprised, or angry [32]. The eMir system classifies facial expression in order to encourage interaction with a public display [16].

3.2.5 *Gaze*

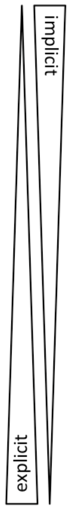
Whereas knowledge about the user's direction of gaze can on one hand be used to measure exposure to digital signage, sophisticated technologies such as eye-tracking allows not only for recognizing contact but to precisely trace a users' gaze path. From an interaction perspective, rough gaze detection can already be achieved with a simple webcam. Devices, such as Xuuk's EyeBox2[3], can precisely detect from a distance whether a user looked at a target object. ReflectiveSigns [43] (Figure 4) uses gaze detection to learn audience preferences of content in different situations.

3.2.6 *Speech*

Microphones in the vicinity of a display cannot only be used to sense keywords of ongoing conversations (allowing, e.g., for targeted advertising) but also enables an estimation of the number of people close by (single person, pair, multiple people). Based on this information, content can either be adapted implicitly or voice

[2] http://www.samsunglfd.com/solution/feature.do?modelCd=Samsung%20PROM

[3] https://www.xuuk.com/Products.aspx



Interaction Modalities \ Mental Models	Poster	Windows	Mirror	Overlay
Presence	Hello.Wall, BluScreen		Palimpsest, Videoplace, Vision Kiosk	
Body position	Cylindrical Screens			
Body posture				Jumping Frog
Facial Expression		Hole-in-Space	eMir	
Gaze	ReflectiveSigns			
Speech				
Gestures	Interactive ambient public display, Pendle		Magical Mirrors	Diaper Selector, Traveling TicTac-Toe
Remote Control	Touch Projector			
Keys	Opinionizer			
Touch	CityWall	ShadowBoxing		

Table 1: Taxonomy for Public Displays

commands could be used to let users explicitly control the content on a public display.

3.2.7 Gesture

Gestures have been subject to research for many years. Whereas several technologies enable gestures (accelerometers, touch sensors, mouse, gaze-tracking) cameras are most popular among public displays. Hand gestures are used for in-direct, explicit interaction, e.g., for manipulating objects or controlling the screen. The Pendle [57] is a gesture-based wearable device, which integrates environment-controlled implicit interaction and user-controlled explicit interaction.

3.2.8 Remote Control

Controlling displays is not always possible through direct interaction, especially if the display is at a distance or simply to large. Hence, remote controlling allows users for browsing, adding or modifying content. Current approaches are mainly based on mobile phones, which connect to the display, e.g., via Bluetooth or HTTP. Boring et al. presented Touch Projector [7], a system, which allows users for interacting with remote screens through a live video image on their mobile phone.

3.2.9 Keys

The aforementioned modalities are often not or not easily understandable at first glance, especially when it comes to explicit interaction. In contrast, a standard keyboard or mouse provides easy means for enabling interaction with a public display. Brignull et al. presented Opinionizer [9], looking into how people socialize around public displays. They deliberately use a keyboard as an interaction device to avoid any obligation for using the system.

3.2.10 Touch

Though touch interfaces are available since many years, their popularity increased with the advent of the iPhone and other mobile multi-touch devices. At public displays, touch sensors enable direct interaction. Users can explicitly interact with the screen by manipulating objects. A prominent example is CityWall [46], which allows multiple users for interacting with a large touch-enabled display in parallel.

4. TAXONOMY

In the previous chapter we presented several dimensions regarding the design of interactive applications based on which public displays could be classified. In the following we present our taxonomy of public displays based three dimensions:

Mental models: Public displays can be classified based on whether they support the notion of posters, windows, mirrors, or overlays. The decision for a certain mental model depends on the content and the environment.

Interaction modalities: A wide variety of interaction modalities exist and current public display installations are not limited in the number of modalities they support. However, there is mostly a primary interaction modality.

Type of supported interaction: Public displays can support implicit or explicit interaction. However, there is often not a clear distinction since the type of interaction might change during the different interaction phases. E.g., displays might react implicitly to passers-by whereas the interaction turns explicit as the user understands and actively starts interacting with the display.

Further dimension include, e.g., the amount of supported users (single, pair, multiple users) or the distinction between public, semi-public, and private displays. Yet, these dimensions are application rather than interaction-centric.

The taxonomy in Table 1 shows our classification of existing public display installations based on the dimensions *interaction modalities*, *mental models*, and *type of interaction*. Whereas the classification among mental models and interaction modalities is rather discrete (though one model could support different interaction modalities), the type of interaction depends to a large extent upon the chosen modality (some modalities support certain types of interaction better than others). The distinction both among different modalities (as is depicted using the arrows on the left side of the taxonomy) as well as within a certain modality is continuous. Gaze can, e.g., be implicit while it is analyzed by the display without the user being aware of it but may turn explicit as the users becomes aware of the effect his gaze might have upon the display's functionality. In the following we use several examples to

Figure 4: Reflective Signs [43]

Figure 5: Magical Mirrors [37]

explain how each of the mental models can be used to guide people through the interaction process.

4.1 Poster

With the digital advertising column, the display implicitly reacts to passers-by by showing flowers wherever people stand, using the modality of body position [5]. This implicit interaction serves to attract audience attention by objects popping up and moving. When passers-by look at the display and notice the adaptive behavior, they can initiate subtle interaction e.g. by changing the direction. Once they are sure the display reacts to them, their curiosity may be raised. They can start to directly interact and play with it by walking back and forth. At this point, optimally the display would support deeper interaction, for example, by touching.

4.2 Window

Hole-in-space serves as a window to another place. Here, the effect of the display depends entirely on the audience that is present at the other end. For a passer-by, the other audience may follow him with their eyes, which is also a form of implicit interaction. When the person looks at the display (and thereby the other audience), he may wave a hand to see whether the other audience reacts. If they react, both audiences may start direct interaction, using both gestures and the speech channel. Of course, if no audience is present at the other end, there is no interaction at all.

4.3 Mirror

Magical mirrors shows an augmented mirror image of passers-by [37] (see Figure 5). Implicit interaction is directly supported by the mirror model, as any passer-by will be reflected on the display. As the passer-by looks at the display, attracted by the movement, his curiosity may be raised by the augmentations on the mirror image. He may start to wave a hand in subtle interaction, to see how the display reacts. If his curiosity is still sufficiently raised, he may start to directly interact with the display using gestures and to explore the possibilities of the effects. Ideally, at this point deeper interaction should be available that challenges and engages the passer-by for a prolonged period.

4.4 Overlay

The Jumping Frog for the Everywhere projector [47] shows a frog on some surface in the environment. Implicit interaction is supported when a user accidentally steps nearby a frog displayed on the floor and the frog jumps away. This sudden movement may attract the attention of the passer-by, and may raise his curiosity. He may start waving a hand in subtle interaction to see whether the frog indeed reacts to his movements. If chasing the frog is challenging enough, he may spend more time engaging in this game.

4.5 Discussion

The presented examples show that there is not the "one" model, which is most suitable for guiding users through the interaction process. Posters so far received the most attention, probably due to the fact that people are most familiar with their analog counterparts. However, our analysis revealed that also applications following other mental models perform well during the interaction process. Though we cannot provide any evidence there are indicators that certain mental models have an advantage in different phases of the interaction process.

5. CONCLUSION

In this paper we have presented a taxonomy of public displays alongside three major issues to consider when designing them. Public displays can be perceived, either as displays, windows, mirrors, or overlays to the physical world, and support various interaction modalities. Interaction should slide effortlessly from implicit to explicit interaction and back. Furthermore, public displays need to balance to capture enough attention from people who might be interested while not annoying people not interested. They need to motivate people to interact with them by challenging them, raising their curiosity, giving them choice, engaging their fantasy and fostering collaboration. Finally, they need to enable people to maintain a coherent role in the public.

6. ACKNOWLEDGEMENT

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 244011.

7. REFERENCES

[1] Adams, R., Russel, C. 2007. Lessons from Ambient Intelligence Prototypes for Universal Access and the User Experience. In: Stephanidis, C., Pieper, M., (Ed.) ERCIM UI4ALL Ws 2006, LNCS 4397, Berlin, Heidelberg, pp. 229-243

[2] Agamanolis, S. 2004. Designing Displays for Human Connectedness. In: O'Hara, K., Perry, M., Churchill, E. (Ed.),

Public and Situated Displays: Social and Interactional Aspects of Shared Display Technologies (Cooperative Work, 2), Kluwer Academic Publishers, Norwell, MA, USA

[3] Altman, I. The Environment and Social Behavior: Privacy, Personal Space, Territory and Crowding. Brooks/Cole Pub. Co., Monterey, CA, 1975.

[4] Ajzen, I. 1988. Attitudes, personality, and behavior. Bristol

[5] Beyer, G., Alt, F., Klose, S. Isakovic, K. Sahami Shirazi, A., and Schmidt, A. 2010. Design Space for Large Cylindrical Screens. In Proceedings of the 3rd Workshop on Pervasive Advertising and Shopping, 2010, Helsinki, Finland.

[6] Blackler, A., Popovic, V., Mahar, D. 2003. The nature of intuitive use of products: an experimental approach. Design Studies, 24, 2003. pp. 491–506

[7] Boring, S., Baur, D., Butz, A., Gustafson, S., and Baudisch, P. 2010. Touch Projector: Mobile Interaction Through Video. In Proceedings of the 28th ACM International Conference on Human Factors in Computing Systems - CHI 2010, Atlanta, Georgia, USA.

[8] Brandtzæg, P. B., Følstad, A., and Heim, J. 2004. Enjoyment: lessons from Karasek. In: Blythe, M.A. Overbeeke, K. Monk, A.F., Wright, P.C. (Hrsg.) Funology: From Usability To Enjoyment, Norwell, pp. 55–65

[9] Brignull, H., and Rogers, Y. 2003. Enticing people to interact with large public displays in public spaces. In Proceedings of INTERACT'03, Zurich, pp. 17-24.

[10] Card, S. K., Mackinlay, J. D., and Robertson, G. G. 1990. The design space of input devices. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems: Empowering People (Seattle, Washington, United States, 1990). J. C. Chew and J. Whiteside, Eds. CHI '90. ACM, New York, NY, pp. 117-124

[11] Cordova, D.I., and Lepper, M.R. 1996. Intrinsic Motivation and the Process of Learning: Beneficial Effects of Contextualization, Personalization, and Choice", in: Journal of Educational Psychology, Vol. 88, Nr. 4, pp. 715–730

[12] Csikszentmihalyi, M. 1999. Flow: The psychology of optimal experience. Harper.

[13] Deci, E. L. 1976. Intrinsic Motivation. New York, London

[14] DePaula, R. 2003. A new era in human computer interaction: the challenges of technology as a social proxy. ACM International Conference Proceeding Series, Vol. 46, pp. 219–222

[15] Enns, J. T., Austen, E. L., Di Lollo, V., Rauschenberger, R., & Yantis, S. (2001). New objects dominate luminance transients in at- tentional capture. Journal of Experimental Psychology: Human Per- ception & Performance, 27, pp. 1287-1302.

[16] Exeler, J., Buzeck, M., and Müller, J. 2009. eMir: Digital Signs that react to Audience Emotion. In Proceedings of the 2nd Workshop on Pervasive Advertising, Lübeck, 2009.

[17] Franconeri, S. L., & Simons, D. J. 2003. Moving and looming stimuli capture attention. Perception & Psychophysics 65(7), pp. 999-1010.

[18] Goffman, E. 1959. The presentation of self in everyday life. Anchor Books, 1959.

[19] Hamker, F. 2005. The emergence of attention by population-based inference and its role in distributed processing and cognitive control of vision. Comput. Vis. Image Underst., 100(1-2):64 106, 2005.

[20] Huang, E., Koster, A. and Borchers, J. 2008. Overcoming assumptions and uncovering practices: When does the public really look at public displays? In Proc. of Pervasive 2008.

[21] Intille, S. 2002. Change Blind Information Display for Ubiquitous Computing Environments. In Proceedings of Ubicomp 2002. pp. 193-222.

[22] Itti, L., Baldi, P. 2008 Bayesian Surprise Attracts Human Attention. In: Vision Research 49 (10), pp. 1295-1306.

[23] Itti, L., Koch, C., and Niebur, E. 1998. A model of saliency-based visual attention for rapid scene analysis. In: IEEE Transactions on Pattern Analysis and Machine Intelligence, 20(11). pp. 1254-1259

[24] Iyengar, S.S., and Lepper, M.R. 1999. Rethinking the Value of Choice: A Cultural Perspective on Intrinsic Motivation. Journal of Personality and Social Psychology, 1999, Vol. 76, Nr. 3, pp. 349–366

[25] Jonides, J., and Yantis, S. 1988. Uniqueness of abrupt visual onset in capturing attention. In: Perception and Psychophysics 43(4), pp. 346-354.

[26] Joyner, L.A., TerKeurst, J. 2003. Accounting for User Needs and Motivations in Game Design. Interactive Convergence Conference 2003

[27] Kellar, M., Watters, C., and Duffy, J. 2005. Motivational Factors in Game Play in Two User Groups. Proceedings of DiGRA 2005.

[28] Kendall, J.E., Kendall, K.E. 1993. Metaphors and Methodologies: Living Beyond the Systems Machine. In: MIS Quarterly, Vol. 17, Nr. 2, pp. 149–171

[29] Korzaan, M. L. 2003. Going with the flow: "Predicting online purchase intentions", Journal of Computer Information Systems, 43(4), pp. 25–31

[30] Krueger, M.W. 1983. Artificial Reality, Reading, Massachusetts

[31] Krueger, M. W., Gionfriddo, T., and Hinrichsen, K. 1985. VIDEOPLACE—an artificial reality. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (San Francisco, California, United States). CHI '85. ACM, New York, NY, pp. 35-40.

[32] Kueblbeck, C., Ernst, A. 2006. Face detection and tracking in video sequences using the modified census transformation, Image and Vision Computing, Volume 24, Issue 6, 2006.

[33] Langheinrich, M. 2001. Privacy by design: principles of privacy-aware ubiquitous systems. In: Proceedings of Ubicomp 2001.

[34] Leikas, J., Stromberg, H., Ikonen, V., Suomela, R., Heinila, J. 2006. Multi-User Mobile Applications and a Public Display: Novel Ways for Social Interaction. In: Proceedings of the Fourth Annual IEEE international Conference on Pervasive Computing and Communications, Vol. 0, IEEE Computer Society, Washington, pp. 66-70

[35] Malone, T.W. 1981. Toward a Theory of Intrinsically Motivating Instruction. Cognitive Science, 4, pp. 333-369

[36] Malone, T.W., and Lepper, M.R. 1987. Making learning fun: A taxonomy of intrinsic motivations of learning. In: Snow, R.E., Farr, M.J. (Hrsg.), Aptitude, learning, and instruction: Vol. 3. Conative and affective process analyses, pp. 223–253, Hillsdale, N.J.

[37] Michelis, D. 2009. Interaktive Grossbildschirme im öffentlichen Raum: Nutzungsmotive und Gestaltungsregeln. Wiesbaden

[38] Michelis, D., Resatsch, F. 2006. Alice Through the Interface Electronic Mirrors as Human-Computer-Interface. Universal Access in Ambient Intelligence Environments 2006, LNCS pp. 88-98

[39] Michelis, D., Müller, J. 2010. The Audience Funnel. In: International Journal of Human-Computer Interaction, to appear.

[40] Moore, O. K., Anderson, A. R. 1969. Some principles for the design of clarifying educational environments, in: Goslin, D. (Hrsg.), Handbook of Socialization Theory and Research, New York, S.571-613

[41] Mueller, F., Agamanolis, S., and Picard, R. 2003. Exertion interfaces: sports over a distance for social bonding and fun. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (Ft. Lauderdale, Florida, USA, April 05 - 10, 2003). CHI '03. ACM, New York, NY, pp. 561-568.

[42] Mueller, F., Agamanolis, S., Gibbs, M. R., and Vetere, F. 2008. Remote Impact: Shadowboxing over a Distance. In CHI '08 Extended Abstracts on Human Factors in Computing Systems (Florence, Italy, April 05 - 10, 2008). CHI '08. ACM, New York, NY, USA, pp. 2291-2296.

[43] Müller, J., Exeler, J., Buzeck, M., and Krüger, A. 2009. ReflectiveSigns: Digital Signs that Adapt to Audience Attention. In Proceedings of Pervasive 2009, Nara, 2009.

[44] Müller, J., Wilmsmann, D., Exeler, J., Buzeck, M., Schmidt, A., Jay, T., and Krüger, A. 2009. Display Blindness: The effect of Expectations on Attention towards Digital Signage. In Proceedings of Pervasive 2009, Nara, 2009.

[45] Paras, B., Bizzocchi, J. 2005. Game, Motivation, and Effective Learning: An Integrated Model for Educational Game Design, Proceedings of DiGRA 2005

[46] Peltonen, P., Kurvinen, E., Salovaara, A., Jacucci, G., Ilmonen, T., Evans, J., Oulasvirta, A., and Saarikko, P. 2008. It's Mine, Don't Touch!: interactions at a large multi-touch display in a city centre. In Proceeding of the Twenty-Sixth Annual SIGCHI Conference on Human Factors in Computing Systems (Florence, Italy, April 05 - 10, 2008). CHI '08. ACM, New York, NY, pp. 1285-1294.

[47] Pinhanez, C. S. 2001. The Everywhere Displays Projector: A Device to Create Ubiquitous Graphical Interfaces. In Proceedings of the 3rd international Conference on Ubiquitous Computing (Atlanta, Georgia, USA, September 30 - October 02, 2001). G. D. Abowd, B. Brumitt, and S. A. Shafer, Eds. Lecture Notes In Computer Science, vol. 2201. Springer-Verlag, London, pp. 315-331.

[48] Pinhanez, C., and Podlaseck, M. 2005. To frame or not to frame: The role and design of frameless displays in ubiquitous applications. In Proceedings of UbiComp 2005 (Berlin/Heidelberg, 2005), M. Beigl, S. Intille, J. Rekimoto, and H. Tokuda, Eds., Springer, pp. 340-357.

[49] Prante, T., Rocker, C., Streitz, N., Stenzel, R., Magerkurth, C., Alphen, D.v., and Plewe, D. 2003. Hello.Wall - Beyond Ambient Displays. Video and Adjunct Proceedings of UBICOMP 2003.

[50] Reitberger, W., Meschtscherjakov, A., Mirlacher, T., Scherndl, T., Huber, H., and Tscheligi, M. 2009. A persuasive interactive mannequin for shop windows. In Proceedings of the 4th international Conference on Persuasive Technology (Claremont, California, April 26 - 29, 2009). Persuasive '09, vol. 350. ACM, New York, NY, pp. 1-8.

[51] Rogers, Y. 2006 Moving on from Weiser's Vision of Calm Computing: Engaging UbiComp Experiences. In Ubicomp 2006.

[52] Schmidt, A., and Laerhoven, K. 2001. How to Build Smart Appliances. IEEE Personal Communications (August 2001)

[53] Schmidt, A. 1999. Implicit human-computer interaction through context, 2nd Workshop on Human Computer Interaction with Mobile Devices, 1999, Edinburgh.

[54] Schönböck, J., König, F., Kotsis, G., Gruber, D., Zaim, E. Schmidt, A. 2008. MirrorBoard – An Interactive Billboard. In Proceedings of Mensch und Computer 2008. Oldenbourg Verlag Lübeck 2008, pp. 207-216.

[55] Shneiderman, B. 2004. Designing for fun: how can we design user interfaces to be more fun? In: Interactions, Vol. 11, Nr. 5, pp. 48–50

[56] Trevino, L. K., and Webster, J. 1992. Flow in Computer-Mediated Communication: Electronic Mail and Voice Mail Evaluation and Impacts. In: Communication Research, 19(5), pp. 539–573

[57] Villar, N., Kortuem, G., Van Laerhoven, K., and Schmidt, A. 2005. The Pendle: A Personal Mediator for Mixed Initiative Environments. In Proceedings of The IEE International Workshop on Intelligent Environments (IE 05), University of Essex, Colchester, UK, June 2005.

[58] Vogel, D., and Balakrishnan, R. 2004. Interactive public ambient displays: transitioning from implicit to explicit, public to personal, interaction with multiple users. In Proceedings of the 17th Annual ACM Symposium on User interface Software and Technology (Santa Fe, NM, USA, October 24 - 27, 2004). UIST '04. ACM, New York, NY, pp. 137-146.

[59] Vorderer, P., Hartmann, T., Klimmt, C. 2003. Explaining the enjoyment of playing video games: the role of competition. In Proceedings of the second international conference on Entertainment computing, Pittsburgh, Pennsylvania, 2003

[60] Weiser, M. 1991. The Computer for the 21st Century. Scientific American, September 1991.

[61] Weiser, M., and Brown, J.S. 1997. The coming age of calm technology. In: Beyond calculation: the next fifty years, pp. 75--85. Copernicus, New York, NY, USA, 1997.

[62] Yanagisawa, Y., Maekawa, T., Kishino, Y., Kamei, K., Sakurai, Y., and Okadom, T. 2010. A Relative Positioning Technique with Low-frequency Waves. In Adjunct Proceedings of Pervasive 2009, Nara, Japan.