Mobile Applications for Open Display Networks: Common Design Considerations

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ABSTRACT
Mobile devices can be a powerful tool for interaction with public displays, but mobile applications supporting this form of interaction are not yet part of our everyday reality. There are no widely accepted abstractions, standards, or practices that may enable systematic interaction between mobile devices and public displays. We envision public displays to move away from a world of closed display networks to scenarios where mobile applications could allow people to interact with the myriad of displays they might encounter during their everyday trips. In this research, we study the key processes involved in this collaborative interaction between public shared displays and mobile applications. Based on the lessons learned from our own development and deployment of 3 applications, and also on the analysis of the interactive features described in the literature, we have identified 8 key processes that may shape this form of interaction: Discovery, Association, Presence Management, Exploration, Interface Migration, Controller, Media Upload and Media Download. The contribution of this work is the identification of these high-level processes and an elicitation of the main design considerations for display networks.

Categories and Subject Descriptors
H.5.2 User Interfaces: Theory and methods

General Terms
Design, Human Factors, Theory

Keywords
Public displays, open display networks, mobile applications

1. INTRODUCTION
Engaging people into some form of interaction is increasingly recognized as fundamental for the success of public digital displays. In recent years, a very broad range of interaction techniques have been explored to create all sorts of interactive experiences, allowing people, for example, to play games, display photos or download content. As inherently personal devices, mobile phones provide an interesting complement to the public and shared nature of public displays. They may be seen as coupled displays in a broader "*ecosystem of displays*" in which multiple users and multiple displays are linked in the interaction [15].

Given these strong synergies, one could expect a plethora of applications to be available from major mobile app stores to support several forms of interaction with public displays. A quick search through those stores is enough, though, to verify that such applications are not yet part of our everyday reality. The exceptions are custom applications that can only be used as remote controls for specific TV sets. We interpret this gap as a natural consequence of the lack of widely accepted abstractions, standards or practices for this form of interaction. Current display systems are mainly designed to deliver content and are operated as part of isolated display networks, each with its own set of technological approaches. While there are increasingly more examples of interactive displays, they can be seen as ad-hoc solutions specific to the assumptions of one particular system or interaction experience.

We envision public displays to progressively move away from a world of closed display networks to scenarios in which large-scale networks of pervasive public displays and associated sensors are open to applications and content from many sources [5]. As part of this open model, mobile applications should allow people to interact with potentially any displays they might encounter in their everyday life. Meeting this type of expectation requires an understanding of the dual nature of the processes that may compose the collaboration between mobile applications and display infrastructures. This involves the design of a rich mobile user experience and its multiple interaction patterns, but also the specification of the underlying system support and the type of capabilities that are needed to enable those various forms of interaction. A significant part of the mobile user experience cannot exist independently of system features and a broad view of the interaction patterns is needed to inform the design of generic systems support. We see these two perspectives and their interdependencies as fundamental for a global view of the key interaction processes that may occur between mobile applications and public display infrastructures.

In this research, we take a first step towards uncovering the key processes that may govern interaction between mobile applications and an open network of public displays. We have independently developed 3 mobile applications that explore different facets of this form of interaction, allowing us to identify some of the key common features and abstractions. We complemented this analysis with the identification of the interactive features described across 32 research papers on mobile interaction with public displays. These were then aggregated around a set of key categories corresponding to the major processes that may shape this form of interaction. The contribution of this work is the identification and characterisation of these high-level processes. By grounding on our own work in this area, but also on existing literature, we provide a broad, although not necessarily comprehensive, view of the key design considerations for mobile interaction with pervasive display networks.

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2. RELATED WORK

A very broad range of interaction techniques combining mobile devices and large displays has been previously explored in the research literature and is used as input to this study [11]. These techniques follow two major approaches. A first group is based on the use of dedicated applications designed for the specificities of a particular display system. They can be strongly optimized for those displays, but their assumptions about the features of a particular system make them useless with any other type of display. A second group relies on the communication functionality available in most mobile phones. SMS, MMS, touch-tone dialing, visual codes, NFC, or Bluetooth are now widely available in mobile devices and can easily be leveraged for interaction, using simple text-based control languages or forwarding cursor/selection interactions from the device input mechanisms. This form of interaction is very attractive in its ability to leverage upon existing resources to support almost universal interaction. However, it is limited in its ability to frame the interaction with regard to personalization and the shared meaning of the interaction.

The design space for the interaction between a mobile device and a public display has been studied by Ballagas et al. [3]. It organizes input techniques around the graphical subtasks they are capable of performing. Their main purpose is to help designers select the most appropriate input technique for their interaction scenarios. Dix and Sas [7] also examine several synergies and opportunities between personal mobile devices and public displays, addressing issues such as the physical size of the situated display, the use and purpose of the mobile devices, the level of integration of the public and personal devices, the movement and physical contact within the interaction, the spatial context of the situated display, and the social context. Rukzio et al. [13] analyse the specific case of mobile phones for personalized interaction with public displays. They consider three levels of personalization: personalized information not to be shown in public; personalized information that can be shown in public; and personalized information that can be shown in public if no link to the initiator can be drawn. These studies are mainly focused on how to best combine interaction between mobile devices and large displays to more effective achieve specific interaction goals.

A number of models for engagement with public displays have been created in the context of prior work. Streitz et al. presented a model consisting of three zones: an ambient zone, a notification zone and an interaction zone [14]. Vogel et al. refined this model by separating the interaction zone into a subtle and a personal interaction phase [17]. Brignull and Rogers presented a model of the public interaction flow and explore how groups socialize around a display, how they walk up to the display and how they change their role [4]. Müller et al. presented the audience funnel which focuses on observable audience behaviour [12]. It consists of different subsequent phases for each of which a conversion rate can be calculated as the user moves to another phase.

These models have been created for specific purposes. The *zone models* are geared towards information *presentation and focus on single-user interaction. The interaction* flow model focuses on explicit, multi-user interaction, and considers people moving forward and backward trough the phases. The *audience funnel* is meant to quantify the success of public display content or application through conversion rates. In contrast to prior work, we assume that interaction is supported by a mobile application and we also consider the implications for the display infrastructure.

3. RESEARCH APPROACH

Our research approach combines our own experience in developing three mobile applications for interaction with public displays with the systematic analysis of interaction techniques described in the research literature.

3.1 Experiences with Mobile apps for Open Display Networks

As part of our on-going research on public displays, we have developed three mobile applications for interaction with public displays: Instant Places, Tacita, and Digifieds. These applications were inspired by the principles of open display networks and the idea that they could be used in many diverse usage settings. Also, they were developed independently, each with its own design goals and assumptions, and each for its own display infrastructures. This resulted in very distinct applications that explore different facets of the interaction with public displays, making them a valuable source of lessons on the key processes supported by these mobile applications.

Instant Places is a web-centric platform for place-based screen media that explores new paradigms for situated publication on public displays, more specifically pins and posters [8]. Personal profiles allow people to control what they publish on the displays and manage their self-exposure. A mobile application enables people to signal their presence in the places where the displays are located through a check-in, enabling them to subsequently mark the place as favourite, manage their level of self-exposure, recommend content to the local place owner, or retrieve content. The mobile application was designed to serve as a generic tool for interaction with any instant places display, thus avoiding assumptions about the nature of the display and the respective apps.

Tacita is a system to allow mobile users to express personalisation preferences to nearby public displays [10]. In contrast to other personalisation systems, Tacita avoids sharing user's location and personalisation data with the display infrastructure, instead using trusted application servers to make the personalisation requests. Using an Android mobile client, a user can discover nearby displays, determine the set of applications available, and trigger personalisation. Using the client's knowledge of display locations and capabilities allows the user to see personalized content when within the proximity of a display without revealing their location, and sending the personalization parameters directly to the application to be shown prevents the display from building up a profile about any individual.

Digifieds is a digital and networked public notice area designed to support passers-by when creating, sharing, and retrieving classified ads on public displays [2]. A main research objective of the Digifieds project is to explore intuitive mobile interaction techniques for exchanging content between the phone and the display. An Android-based mobile client allows content to be created on-the-go and enables augmenting posts with photos and videos taken with the mobile phone. Content can be exchanged with the display using QR codes, alphanumerical codes, or a phone/display touch feature, where the screen is simply hit with the phone. We deployed Digifieds as a finalist of the UbiChallenge 2011 on a public display network in Oulu, Finland where it is still in operation as of today [1]. A preliminary lab study [2] and the deployment in Finland allowed us to evaluate Digifieds with regard to user performance, acceptance, privacy, and preferred content.

3.2 Uncovering Interaction Features

The second element in our study was the systematic analysis of interaction techniques described in the research literature that combine mobile devices with large displays. While potentially seen as ad-hoc solutions for specific displays systems, these techniques constitute an important source to understand broader interaction expectations and identify common interaction features. We thus selected a set of 32 research papers that describe specific approaches for this type of interaction [11]. To have a common reference for the analysis, the 3 papers describing our own mobile applications were also coded with the same procedure. We started by coding in all those papers any reference to an interactive feature supported by a mobile device. For each code, we added a short memo describing its meaning. When creating these codes and writing the respective memos, we focused on high-level concepts that described those interactions and created descriptions that were independent from the specificities of the particular application or system in which the interaction was inscribed. Overall, we had a total of 129 references to interaction features supported by mobile devices that were described using 58 unique codes. We then conducted an initial aggregation phase in which we grouped codes according to the similarity of the interactive features described. However, our purpose was not to create a taxonomy of interaction patterns for mobile devices and public displays, but rather to identify the key interaction processes and their implications for display networks. We thus went through a second aggregation stage in which we started by analysing each of the initial categories in regard to their system support implications. Based on that analysis, we merged the categories for which we were not able to identify a distinctive type of system support, but we also kept separate categories that seemed closer in regard to the interaction, but had very distinct implications for systems support, e.g. media upload and media download. The new set of categories emerging from this consolidation phase constitutes the high-level processes that shape the design space for the interaction between mobile devices and public displays.

4. DESIGN CONSIDERATIONS

As the result of our analysis, we have identified the following set of common interaction processes between mobile devices and public displays: discovery, association, presence management, exploration, media upload, interface migration, direct control and media download. Figure 1 depicts these various processes and how they may overlap between each other and with the engagement phases identified in the audience funnel [12].

4.1 Discovery

In an open display network, new displays may be added by different entities. A discovery process deals with the display network as a whole and is mainly concerned with identifying nearby displays and their properties.

Tacita includes a very explicit discovery process where the mobile application shows a map of the nearest public displays and their associated capabilities, as well as the user's own position. The goal is to allow people to choose a nearby display that may be suitable for accessing specific services. A similar feature is also available in Digifieds. Since the service design aims to preserve the locality of the displays by forcing people to personally go to the display before being able to post content, the mobile client provides an interactive map with the locations of nearby digifieds-enabled public displays, thus allowing people to more easily find a display where they can make a new post. In Instant Places, the nearby displays are also shown in the form of a list. In this case, the main goal is to facilitate association, allowing people to recognize and select the display they already intend to use. Still, the same process may also be used to find out about nearby displays.

The main implication of discovery in regard to the display infrastructure is the ability to support location-based queries of public displays. This means that the system should have a registry of existing displays that included their spatial location, one or more addresses to connect to the display, and a description of their capabilities.

4.2 Association

The association process creates a temporary session between the mobile application and a particular display environment. This session provides the context for framing subsequent interactions, enabling them to be interpreted as part of the information space associated with that particular display environment. We have identified three approaches for creating this type of association: implicit proximity, physical-virtual hyperlinking and selection.

Implicit proximity is an association process in which presence in the display environment is automatically sensed, e.g. through Bluetooth, and the association is created without the need for any indication from the user. However, this sort of automated mechanism has been shown not to provide a flexible solution in terms of deciding when a viewer intends to interact [6].

Physical-virtual hyperlinking is an explicit process association in which the user actively "clicks" on a reference physically available in the display environment. The use of visual tags is particularly common, e.g. Digifieds, and allows users to collect announcements by scanning the respective QR-code with the phone.

In the association by *selection*, the user explicitly selects a display environment from a list in the mobile application. The user needs to make the right connection between the names or descriptions shown on the list and the intended display. The physical space of a display environment may provide additional hints to facilitate that connection, similarly to what happens when scanning for WiFi hotspots on the phone. Instant Places uses this approach, providing users with a list of nearby places in which they can initiate a session through an explicit check-in process.

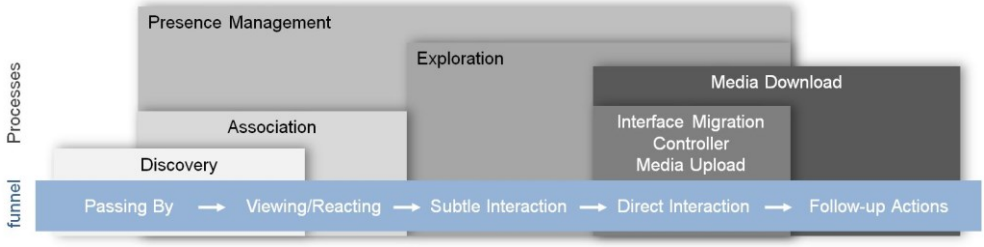

Figure 1 : Key processes and their distribution along the audience funnel

These different association approaches can be combined and several systems support more than one. Tacita, for example, supports implicit proximity (Bluetooth or NFC), hyper-linking (QR codes), and explicit selection from a map-based interface. A key property of the association process is the respective scope. Our three applications take different approaches as to what they consider to be the display environment to which the association is being created. Instant Places supports association with places, symbolic locations to which multiple displays can be attached to share a common information space. Tacita create associations with nearby displays, possibly also more than one. Digifieds enables association to be made directly with specific content resources on the displays, merging association with media transfer.

The main implication of the association process is enabling mobile applications to establish the link between a particular nearby display and the respective virtual address from which the display services can be obtained. Being co-located with the user, and possibly with the displays with which the association is being created, mobile applications can have a key role in the association process and support multiple alternative ways to accomplish the mapping between physical-virtual display resources. In particular, implicit forms of association, physical-virtual hyperlinking and location authentication claims may strongly dependent on specific technologies and be only available for certain displays or mobile devices.

4.3 Presence Management

Presence management enables users to signal their presence and control their level of exposure to the display environment. Even though this is often partly embedded in the association mechanisms, the two processes are clearly distinct in their goals and design implications. The main goals for presence management are the identification and representation of the different identities that are present in the display environment and also the personalization of the display by those people.

A few applications in our study rely entirely on a *repository* of personal information that is stored on the mobile device itself and, when appropriate, is shared with proximate displays to support personalization. In [9], a part of the device Bluetooth name is used for identity representation and the other part can be used to express personalization preferences. A second set of applications, including our 3 applications, rely instead on server-side *profiles* that can be managed independently from the specific user device. A server-side approach is more aligned with technological trends towards cloud services and multi-device support, and may be easier to connect with other social networking services.

Achieving the right balance between personalization and privacy is the key challenge for presence management and all applications in our study support some type of privacy settings to control personal exposure. In instant places, presence exposure is automatically initiated as part of the check-in mechanism, but users can have different personas to control the level of exposure in different situations. Tacita is distinctive in that it does not share any personal data with the display, but only with trusted applications. Users set their preferences on a per-application basis through the application. Based on user presence, the applications running on nearby displays adapt their content to those user preferences without exposing user information to the displays.

The main implication for presence management seems to be the existence of user profiles that can be used across multiple displays to support systematic presence management. The need to balance against the privacy risks that result from the potential ubiquity of open display networks also place a strong focus on explicit forms of presence management in which people are only "seen" when they really want it and in a way that they fully understand. Mobile applications can play a major role in this process by giving users full control and awareness of the process. The infrastructure should support different trust relationships, not forcing people to trust all the environments they might visit.

4.4 Exploration

Exploration is the process that enables users to find out about engagement opportunities in relation to any particular display. When facing an interactive display, the user may be motivated to interact, but not necessarily have any specific goal in mind. Exploration can fill this gap between interaction opportunities offered by the displays and user intentions by allowing the person to tune in into that display environment and its services, eventually finding valuable actions or information. Exploration normally occurs after an association process, but may or may not imply signaling presence. By supporting a form of browsing, exploration enables engagement beyond what is now being show on the display and can become an important enabler for the various forms of interaction described in the next sections, particularly content selection and media download.

The mobile applications in our study include a number of different approaches with regard to exploration features. The most obvious form of exploration is showing information about the content and applications that are available for selection or interaction. In Tacita, the mobile application allows users to browse the list of applications supported by a display, and later to personalize them. Instant Places allows users to access information about visited places, including information about who is around, recent interactions by others, and a list of applications available in a particular display. By appealing to curiosity, this information may become an important trigger for spontaneous interactions.

The main implication of the exploration processes is that the mobile application needs to have access to a description of the interaction opportunities in a particular public display. Display environments must therefore be able to describe themselves and their capabilities in a way that enables any mobile application to understand and act on that information. Providing information about locally available applications or their interaction possibilities further raise the requirement of having information about the applications associated with the environment and possibly the specific interaction features being made available by each of them.

4.5 Interface Migration

Interface migration is a process through which the display exports interface controls to the mobile application that are then used to obtain and return user responses. This process supports almost arbitrary direct user interaction with whatever functionality may happen to be available at any public display.

We have identified a group of mobile applications that support this process through abstract interface description languages. An interface description is fetched, interpreted and rendered by a custom module on the mobile application. They normally consider user interface controls such as text-entry fields, alert dialogues, confirmation dialogues, and selection lists. For example, the Mobile Service Toolkit (MST) [16] allows the mobile application to receive and render site specific interface controls, such as text-entry fields, alert dialogues, confirmation dialogues, and selection lists. A markup language similar to WML (Wireless Markup Lan-

guage) is used to export these controls over Bluetooth and return user responses. An alternative approach is to rely on web content by sending to the mobile application an HTML interface that is rendered by a web engine component. This approach is used in instant places to show the interaction controls of specific applications on the mobile device. Public display applications must be able to describe the mobile user interface and register its address on the display system. They must also implement an address for receiving input information. The mobile application should allow users to select which app they want to interact with and then obtain, interpret and render the respective interface.

4.6 Mobile Application as a Controller

The mobile application may support a direct control process in which the phone is used to emulate interaction mechanisms based on the manipulation of the interface on the display (e.g., call and select options). While possible using standard mobile phone features, e.g. connecting via DTMF, the use of a mobile application allows access to specific mobile phone resources, such as accelerometers, compass, camera, multi-touch, and communication channels, considerably extending the range of alternatives and helping to frame and contextualize those interactions.

The most common form of control is the use of a mouse/joystick control in which the mobile application allows users to directly manipulate elements of the public displays via gestures performed on the mobile device. Other alternatives include the use of coupled displays in which gestures on the screen of the mobile phone are mapped into actions on the public display.

The main implication is the exposure of control addresses to which the mobile applications may connect. The connection may be established transparently as part of the association process or explicitly as part of the usage of some specific application.

4.7 Media Upload

Media upload is the process through which media is transferred from the mobile application to the display environment. Media upload is often associated with the built-in features of mobile devices, either for generating the media, e.g., taking a photo, or to enable its transfer, e.g. Bluetooth. Still, mobile applications can considerably improve the process by automating some of the steps and by framing transfer with user identity and usage situation.

Mobile Interaction should help users create and manage content and select what they want to publish on the displays. In Instant Places, users can create posters using a web interface and then use the mobile application to distribute posters when visiting a place. In Digifieds, the mobile client enables users to retrieve digifieds, but also to create and later publish them on public displays.

The main implication for media upload is the ability of the display system to accept and properly integrate the content it receives. This raises important requirements in regard to moderation and trust, but also in regard to the integration of that content into meaningful media collections and presentation contexts. Mobile applications may need to generate or access media from the mobile device, including access to built-in functions for creating photos, videos, and sounds. Media upload may also add a set of requirements associated with content management, e.g. allowing authors to delete items they no longer wish to be displayed.

4.8 Media Download

Media download is the process through which media is transferred from the display environment to the mobile application. These retrieval or take-away functionality enables users to select an item from the public display and download it to their mobile device. We have identified three main approaches to support this feature: users select an item that is visible on the public display itself, e.g. by touching or pointing; the mobile application provides a list of items available from the public display, which users can browse and select; the item is implicitly downloaded by the mobile application, or pushed by the display, possibly filtered by users' preferences.

The main implication for media download is exposing display content as a resource that is accessible by the mobile application. For interoperability, media items should have standard protocols for addressing and retrieving. The use of unique identifiers that are common across multiple displays may further enable a mobile application to assess which items have already been downloaded.

4.9 Analysis

In line with previous findings on audience engagement, we observed that interaction with public displays does not start with interaction itself. Discovery and association may clearly be seen as pre-steps for interaction. In particular, association may be seen as supporting the transition to a phase where a particular display becomes the focus of user interactions. In contrast to previous work, however, we observed that engagement with a network of open displays through a mobile application may occur even before the audience is passing by a display, as people may actively want to discover displays with particular services. Despite some potential sequentiality, none of these processes seems to be mandatory and many of them may clearly overlap. Therefore they should not be seen as subsequent phases in the interaction process. Discovery can be shortcuted, e.g. with a favourite displays list, and is not needed when a person already knows what the intended display is. Association or presence management are often merged into a single technique that encompasses the functionality of more than one process, e.g., when downloading content directly from a QR-code on the display. In these cases, they still occur, but from the interaction point of view they do not exist as separate actions. Exploration, Interface Migration, Controller and Media Upload are different alternatives for the interaction of a mobile application with the public display. Regardless of the different interaction paradigms that they can support, they are described as different processes mainly because of their different implications for system support. While these interaction processes may be seen as being mainly meant to allow people to control the display behaviour, media download may be seen as a different type of interaction that is closer to the meaning of a follow-up or take-away action.

5. CONCLUSIONS

The results of this work constitute an initial step towards identifying the core processes that may support the use of mobile applications for interaction with arbitrary public displays. With this work, we do not claim to be anywhere near the specification of standards that may actually enable these forms of open interaction. We see this set of processes as a first approximation to the issue of how to structure generic interactions between mobile applications and public display networks. While not necessarily comprehensive, these interaction processes are grounded on what seem to be the most common interactive features in previous work and constitute a set of common design considerations that pervasive display networks should be able to address to support interaction between mobile applications and any public display. Still, we also acknowledge that there are limitations that result from this partic-

ular research approach. Issues such as authentication, security, software maintenance or energy consumption, would be fundamental to a production system but are clearly underrepresented in research literature. The same can be said about large scale issues, such as the social dynamics around these interactions, which are not relevant in the small prototype systems that are described in related work. An additional analysis of these design considerations is needed to reach a more comprehensive view of the full set of processes.

Our argument for the standardization of the services offered by displays networks to mobile applications should not be understood as implying a standardization of display concepts or mobile application features. Even very diverse displays concepts should offer mobile apps some common ground by being designed around a common understanding of the interaction space and by being able to describe their interactive features in a standard way. Similarly, mobile applications may also vary considerably in the range of processes they support. Depending on their specific purpose, some applications may follow a more horizontal design and try to cover all the processes, while others may take a more vertical approach and be optimized for the specific sub-set of processes that they really need. Even if based on a common set of system services, application development should remain a space for creativity and innovation around mobile user experiences with public displays. Finally, a common understanding of the core interaction processes should also shape the fundamentals of the interaction with public displays in a way that would allow people to reason about their interaction with the displays even when using very different apps or very different displays.

6. ACKNOWLEDGMENTS

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