What goes where? Designing interactive large public display applications for mobile device interaction

Nima Kaviani, Matthias Finke, Sidney Fels, Rodger Lea, Hua Wang
University of British Columbia
Media and Graphics Interdisciplinary Centre
FSC 3640 - 2424 Main Mall, Vancouver, BC, Canada V6T 1Z4
{nimak, martinf, ssfels, rodgerl, hwang}@ece.ubc.ca

ABSTRACT

In this paper we describe our current research in the field of interactive large public displays with mobile device interaction. The core of our research is based on a user interface concept that takes advantage of input and output capabilities of interactive large public displays and mobile devices. We call this concept the "dual display" concept, which allows us to execute multimedia user interfaces across both large and small display types. By shifting parts of a user interface down to a personal mobile device we argue that we can solve a number of problems originating from limitations in large display real estate. As a result of our research we have defined a number of design strategies focusing on the concepts of interactive dual displays. We also report on applying these design strategies to our development of large display applications, which we deployed and tested in lab environments as well as in public settings.

Categories and Subject Descriptors

H5.2 [Information interfaces and presentation]: User Interfaces. - Graphical user interfaces.

General Terms

Interactive large public displays, mobile devices, smart phones, design concepts, design strategies, user model, multimedia applications, dual display concept.

Keywords

Large Public Displays, Mobile Interaction, Engagement, Conflict, Dual Display

1. INTRODUCTION

Large public displays are becoming more and more prevalent, rapidly replacing the conventional paper-based methods of presenting information to the public. This increasingly widespread use of large public displays is happening due to first, an evident reduction in the price of such devices [1][15], and second, the functionalities that such devices offer in terms of remotely updating their contents possibly by using broadband networks [12]. Further to updating content, recent research works are also trying to bring more usage into these large displays by enabling user interactions. As a result, the existing body of research on large public displays can be divided into ambient non-interactive displays and interactive large public displays [18].

While ambient non-interactive displays usually function as informative bulletin boards, broadcasting information to the public, interactive displays can be customized for targeted groups or individual users. This trend recently has made large public displays to be considered also as *large information scale appliances (LISA)* [15] playing an alternative role to PDAs for accessing information. It is thus important to encourage users to get engaged in interaction with these displays and provide them with a satisfactory experience so as to encourage continual use. This type of engagement usually requires special considerations for *calm aesthetic, comprehension, notification, short-duration fluid interaction, immediate usability, shared use,* and *privacy* [18]. To make the interaction experience satisfying for the users, careful design decisions need to address any interaction difficulty for interacting users (e.g., conflict in content) or viewing of interactive data (e.g., conflict in pace). Consequently care should be given to devising methods that can increase engagement and at the same time are neither obstructive nor obtrusive to other potentially interacting users.

Another challenge with using large public displays is that such displays don't give the feeling of ownership to their viewers or interacting users in the same way that desktop displays do. This in turn imposes difficulties for engaging users in interaction with large public displays. Some critical factors play critical roles to attract users' including installation of a large display with respect to its surrounding environment, the content that it delivers, and the way the content is delivered, play critical roles to attract users' attentions [18] and possibly may lead to user interaction. As a whole, the new domain of interactive large public displays requires investigation of interaction methods that have sound technological support and at the same time are appealing to the end users. We also need to study the ergonomic responses of users on how to interaction with such displays or manage presentation of content on large public displays in order to be able to come up with systems appealing to the end users.

Mobile devices, as interaction gateways to large displays, may be used for interaction as they widely adopted by people and can be relatively easily customized for the purpose of interaction with large displays. Interaction with large displays using mobile devices has special characteristics separating it from other forms

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of interaction with large displays, e.g., touch enabled interactions, and gesture-based interactions. First and foremost, mobile devices (mobile phones in particular) are completely personal devices which usually hold personal user information (e.g., contact records and user profiles). Unlike the inherent public exposure of large public displays, interaction with such displays using mobile phones can bring a certain level of privacy to the act of interaction.

In general, interactions with large public displays can be either overt or covert. In an overt interaction, it is explicit who is interacting with the large display, how, and what modifications he is making to the content on the display (if any). However, in a covert interaction, the user interacting with a large public display (called an *actor*) is not completely visible to other spectators or bystanders. A covert interaction can be considered as a way of hiding the identity of the actor from the audience watching the display, thus bringing more privacy. In a covert interaction however, since there is little indication about who is interacting with the large display, the spectators cannot see or infer much about how and under what circumstances interaction with the large public display is happening and thus the chances for learning by watching will be drastically reduced. While popular types of interaction with large displays mostly promote *overt interactions* (e.g., touch-based, gesture, mouse, and keyboard), mobile interaction with large displays can be considered *covert* [17] as long as the actor is willing to hide his/her identity, especially in crowded and busy environments. One of the research objectives in this area is to see how covert interaction with large displays can be leveraged so that while actors keep their identities private, the spectators can still learn from actors' interactions and get involved in the whole process of interaction with large displays.

In this paper we present our research in the area of designing interactive applications for public displays using handheld devices, such as cell phones or smart phones, utilized for interaction purposes. Our research has led to a set of design strategies taken from previous application deployments at public spaces. We show how these design strategies have been used to create a number of multimedia applications for interactive large public displays and discuss some of the results obtained from public deployments. The paper is organized as follows: in Section 2 we go over some of the related work utilizing mobile phones for interaction with large displays; Section 3 describes our classification and requirement analysis for the audience around a large display installation; in Section 4 we enumerate the design strategies we have discovered as a result of deploying our large display applications in public; in Section 5 we describe two of the applications that we have developed to validate our design strategies; Section 6 briefly covers our system architecture to support successful development and deployment of interactive applications; and finally we discuss our findings and conclude the discussion in Section 7.

2. DESIGN APPROACH

Our design approach focuses on public audience. Based on our previous work [7][17] we categorize the audience for a large public display scenario into three groups of stakeholders: *actors*, *spectators* and *bystanders*, (see Figure 1).

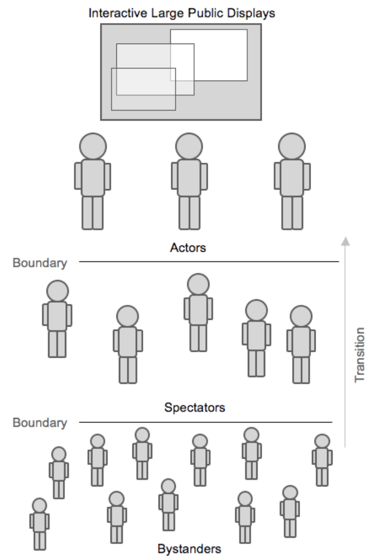

Figure 1: Actors, spectators and bystanders as users in a public space

Actors feel encouraged by the display environment to take an active role in the content. Actors may control and/or manipulate the content on these displays, e.g. by means of a hand held device, and so they can change the 'flow' and 'pace' of the presented content over time. *Spectators* are mentally engaged with the displayed content and surrounding environment, but are not actively manipulating the content on the display. *Bystanders* are individuals who have no strong interest in the presented content on the display installation. Dix and Sas [5] provide a similar classification for individuals around a large public display as people who *wittingly* or *unwittingly* either *participate* or *bypass* interaction with an installation. Brignull and Rogers [3] also group the audience around a large display installation into three groups of individuals with i) *peripheral awareness activities, ii) focal awareness activities,* and *iii) direct interaction activities*. When it comes to designing interactive applications for large displays that make use of handheld devices (mobile phones in particular), it is important to consider the requirements and needs of all these stakeholders to keep actors engaged with the act of interaction as much as possible while encouraging spectators and bystanders to break the interaction barriers and become active users of the large public display. Towards this end we consider two major goals while designing interactive applications for large public displays: *the short term goal is to decrease the barriers to interaction such as embarrassment, trust, and privacy and help spectators become actors smoothly and with a high level of confidence. The long term goal is to make the people around an interactive large display "knowledgeable bystanders"*, i.e., those who by heart know the intentions behind a large display installation and can purposefully interact with the display and carry on with their desired tasks.

For us to be able to analyze the design requirements for all stakeholders around a large display installation, we have chosen an incremental approach in which we start with the actors in a large display setting to discover the feasible set of interactions they can perform using handheld devices. Once the set of possible yet meaningful mobile interactions with large displays are identified, it is possible to push the research borders to also include spectators and bystanders and provide methods for supporting spectators to become better involved with large display interactions and to notify or even excite bystanders of interaction opportunities with large display settings. As a consequence, in this paper we have mainly narrowed our focus down to actors, trying to analyze how they can utilize the second device (i.e., the display it offers and its interaction capabilities using its keypad and joystick) to have sound and engaging interactions with large public displays.

2.1 Dual Display Approach

As mentioned earlier our general approach is to integrate mobile devices as interaction gateways to allow actors to interact with interactive large displays. Previous user studies we conducted in this research field [7] [17] provide evidence that handheld devices can be applied for user input purposes. Our current research is extending this approach in order to use handheld devices for output purposes as well. We call this approach the “dual display” approach, which enables us to execute applications across large displays and mobile devices utilizing the input and output capabilities of both device types.

The dual display approach suggests that some elements of a user interface can be placed on the large display and some elements on the handheld device, forming an application that is executed across both device types. These elements or widgets, as we call them in graphical user interfaces, can be categorized as *interactive* or *non-interactive*. Non-interactive widgets are in general used to present the system state or parts of the system state to users. However, interactive widgets accept user input to initialize state changes of a system image (user interface). In addition these interactive widgets often provide feedback that an input has been received. A button widget, for instance, changes it appearance every time a user clicks on it. This is actually not the presentation of an associated state change in the system but a feedback for receiving the input. Such feedback helps users verify the correctness of their inputs while revealing possible mistakes or slips. In some cases a feedback and a presentation of a new system state may happen at the same time (correlated in time). For instance, consider a game in which a user controls an avatar. A new position of an avatar tells the user that her or his input was accepted (instant feedback), but at the same time also reveals a new system for the game too.

2.2 User Requirements

The dual display approach requires new user interaction concepts since applications are not any longer tied to a single device/screen during execution. We use Norman’s seven stage model [11] to derive requirements imposed by our dual display approach on actors as our main stakeholders. We also briefly discuss how Norman’s model might be extended to also accommodate the requirements and needs of spectators in a large display installation.

Norman’s model is used in HCI to describe the *cycle of interaction* between human users and computers. The model identifies seven stages of execution and evaluation of user interaction (see Figure 2). The execution part of this model is about creating a sequence of actions and executing them. The evaluation part is about perceiving a new state of the system and evaluating whether a user’s goal has been achieved or if any further action is required.

Following Norman’s model we can state that in a dual display approach *actors* interact with a user interface representing a system image that is distributed across large displays and the display on handheld devices. So, besides forming a sequence of actions to be executed, actors need to know in addition where to execute the actions, which can be either on the large display or the small device. Furthermore, the new system state might be presented on the large display and/or the small device. Hence, the design concept is responsible to support actors achieving their goals with respect to the placement of user interface elements. Therefore, the dual display approach requires the actor’s mental model to not only include knowledge about the actions the system supports but also to understand where to execute these actions and where to perceive the new system state.

Spectators, described as mentally engaged but non-interacting users, might form the majority of the audience mentally involved in an interactive large public display installation. Furthermore, the spectators group holds potential actors who may become willing to interact with the system. Hence, it is important to accommodate spectators and make them an integral part of the user interface design concept as well. In general, spectators, just like actors, have their own goals when they are engaged in a large display installation. Unfortunately, their goals do not manifest in a sequence of actions causing a new system state. In other words, it is hard to tell from our perspective as interface designers whether (and if so, when) spectators achieve their goals. Nonetheless, regardless of their initial goals, spectators need to obtain and maintain an understanding of the system and changes in its state in order to become and remain engaged with the large display interaction. Meaning, they need to also acquire their own mental model of the system similar to what actors acquire. We argue that a primary requirement for designing interactive applications for large displays is to improve the design of a large public display interface to support spectators in the way they acquire their mental model of the system. Besides showing new system states on the large display, which result from actor’s interactions with the display, we believe that spectator’s mental model will also benefit if the cause of a system state change is presented as well. Understanding the cause of a system state change provides information about the actions a system supports and enables spectators to have proper explanations about changes in the system state and also be able to predict what changes may happen in the near future.

Going back to the original problem of offering sound and engaging interaction experience to actors and spectators, it becomes important how to solve conflict between actors who would like to access the same interactive widget or manipulate the same content simultaneously. For spectators too, it is important to be able to properly explain the changes in the state of an application and have reasonable predictions about forthcoming state changes. In the following section we enumerate a couple of design strategies that we have been implementing and evaluating to solve conflict situations and increase interaction engagement for actors and spectators of interactive large displays.

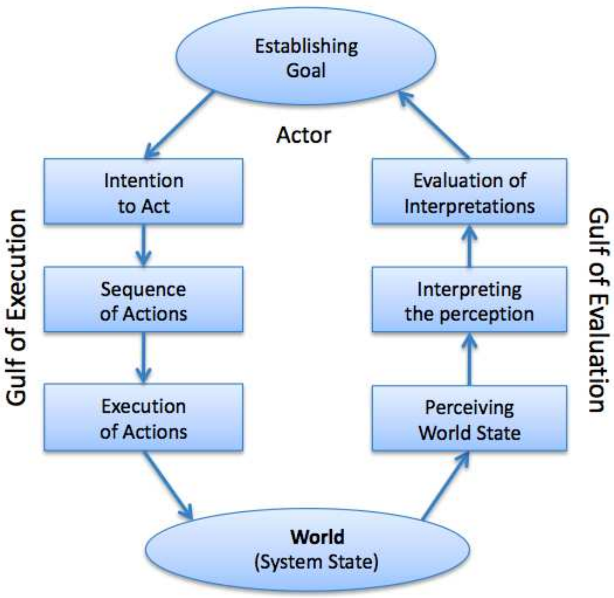

Figure 2: Norman's Seven Stage Model

3. DESIGN STRATEGIES

Conflict situations often happen due to space limitation of large displays when it comes to presenting modified content as a result of interactions done by actors. Peltonen et al. report that for their multi-touch large public display conflicts occurred quite often when actors worked in parallel and violated each others' "personal" space [13]. We can distinguish between two different forms of *conflict in space*, first, space conflicts that stem from running out of the space needed to provide visual feedback while executing a sequence of actions (interaction process) and, second, the space needed to present a new system state (content presentation). Conflict also occurs to spectators if they are unable to follow and understand system state changes presented on a large display. This *conflict of pace/flow* might occur if the time between consecutive system state changes is too short or if there is no feedback on why changes on the display are happening. To reduce these conflicts and provide better engagement for actors and spectators of a large display installation, we have defined four design strategies to utilize a mobile device, such as a smart phone, as the primary interaction gateway to help with solving such conflicts. These strategies assume multi-step interactions are carried out by actors, meaning, an actor interacts several times with an application in order to complete a given task.

3.1 Strategy 1: "Localized Interactions"

This strategy aims to reduce conflicts of space by banning the visualization of executing a sequence of actions (multi-interaction process) on the large display. The interaction process will entirely take place on small devices and only new system states will be revealed on the large display, keeping the intermediate system states (or feedbacks) that occur during the multi-interaction process on the small device (see Figure 3).

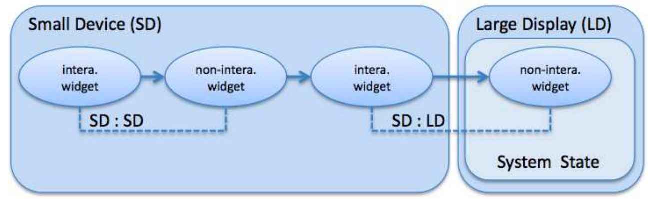

Figure 3: Multi-Interaction process on SD with resulting new system state on LD

3.2 Strategy 2: "Distributed System State"

Introducing *a level of detail* strategy might reduce space conflicts stemming from content presentation. Our suggestion is to reveal only general parts of a new system state on the large display and to keep detailed information on the small display. This strategy reduces the space required on large displays for content presentation, thus overcoming conflict in space (Figure 4).

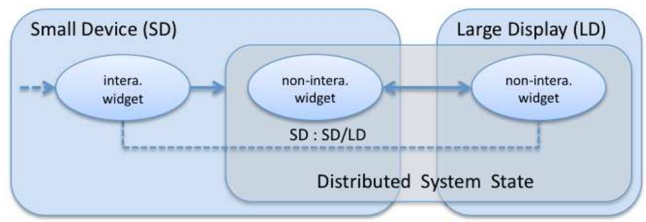

Figure 4: Presentation of new system state distributed over LD and SD

3.3 Strategy 3: "Providing Display Focus"

If the large display and the handheld device contain interactive widgets an actor can interact with, s/he has to be aware of which display is the active one and accepts user inputs. We suggest that both display types provide the actor with a visual cue that indicates its current mode announcing their active or inactive state. Such visual cues will help actors orient themselves with the application space and reduce the risk for wrong input entry. This is also beneficial to spectators during their viewing experience of the large display.

3.4 Strategy 4: "Cause Summary"

To reduce the conflict of pace/flow, we propose to provide visual cues on the large display summarizing the execution of a sequence of actions in order to display information about what causes the new system state. For example, imagine our *interactive information directory* application (see Section 5), which allows actors (i) to *select* a menu list, (ii) to *navigate* between different menu items and then (iii) to *click on* the item they wish to see. This interaction process could happen on a small device. The large display would then present the new system state as well as what causes it, e.g. "New Menu Item Selected: *Restaurants*", which summarize actor's interaction and provide at the same time a cue to the spectators indicating that the application allows users to select menu items such as *restaurants*.

4. EXAMPLES OF DUAL DISPLAY APPLICATIOINS

Following the design strategies identified in the previous section, we built a series of different applications to be deployed on large interactive displays and on mobile phones to examine the effectiveness of each strategy. For the first design strategy of *"localized interaction"* we modified our Polar Defense application [7] to work either on the large display or on the mobile phone. Polar Defense was originally designed in particular to invite a larger group of audience to compete in playing a game on a large public display. We aimed to make the installation entirely responsible for engaging the audience, informing them of how to play, and confirming user inputs using a feedback mechanism. The main objective of the *Polar Defence* game is to place towers on a virtual field, with the towers defending the field from oncoming enemies. Enemies traverse the field from left to right and are attacked by projectiles fired from defenders on top of the towers. Original design of Polar Defense used SMS for user input making the application playable by a wide range of people. SMS was chosen for interaction because of its wide acceptability and reliability by the public. SMS was also an enabler to identify individual game players on the large display through their phones numbers. To play the game, a user had to send an SMS message with six coordinates specifying the location of each tower on the field. Similar to a chessboard, the field coordinates range from *A to I* and from *1 to 9*. An example SMS text message for the game is "A3 D4 D5 F6 F9 H1" (spaces are not considered). The game starts by defender/tower units being placed onto the field. The enemies then walk across the field and the defenders automatically try shooting them down, both according to predefined algorithms, and no further user input is required.

In our redesign of Polar Defense we modified the game to support two other methods of placing towers on the game field. The first interaction model provides direct connections between the mobile client and the large display through using WiFi connection. Users control a pointer in form of an arrow on the large display, which they can move up and down or left and right to place a tower.

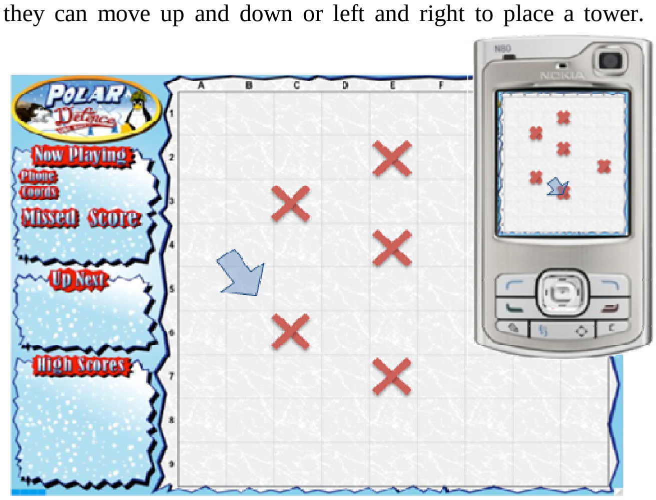

Figure 5: The Polar Defence Application

Once the tower placement is finished users hit a button on the phone to start the game play. We also developed the same application for the mobile phone in which the player receives a copy of the application field as well as the arrow pointer on the

phone and is able to move the arrow and place the towers on the mobile phone screen (see Figure 5). The final placements for the towers are sent off to the large display and the player can follow the game play on the large display. These modifications to the interaction methods were mainly to analyze the effects of performing direct multi-step interactions with the large display in a public versus a private setting as opposed to the previous indirect single step interactions (in case of SMS).

For the other three design strategies we created an interactive public information directory similar to that of a shopping mall which uses existing content provided by an authority figure (e.g., maps and venue locations) to assist users with finding information related to some predefined venues (see Figure 6). The interactive directory application consists of two fixed interactive widgets. The main widget (aka., the map widget) shows an abstract map view of an area by utilizing the Google™ maps API. The Venue widget provides a list of fixed venues (e.g., Restaurants, Museums, etc.) that a user can go through and select the category he or she would like to see. Upon selection of any of the venues, a series of markers appear on the map showing the interesting spots related to the selected venue (e.g., the restaurants or museums of interest). Selection can be done either by using VoiceXML and calling the phone number shown on the application interface or it can be done by connecting to the interactive directory application using a WiFi connection. To support the *"distributed system state"*, similar to the case of Polar Defense application, we provide two different implementation of interactive directory. In the first implementation the actors use the mobile device solely as an input device. Upon connecting to the interactive directory, the actor will receive a pointer on the venue list, which can be moved up and down using the joystick on the mobile phone.

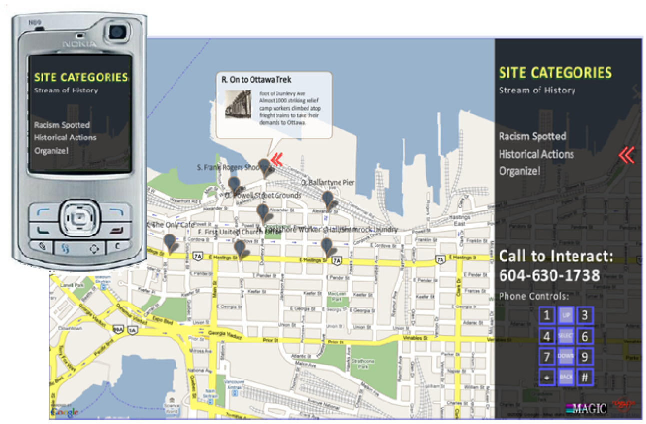

Figure 6: Interactive Directory Application

Once a venue gets selected, markers appear on the map and the user can move between markers to receive further detailed information about each of the spots on the map. The detailed information will appear in a smaller window on top of the map right above the marker, giving information as well as pictures about the spot of interest. In the second implementation examining the distributed system state, we have placed the venue list on the mobile device. The actor gets to select the venue of interest on the device and the points of interest will appear on the map. The actor again gets to toggle between the points of interest on the map. However, upon selecting a point of interest on the map the results will be delivered to the phone and will be shown only to the actor requesting the information about the selected spot. The mobile implementation promotes higher distribution on system state across the large display and the small device and the detailed information are only shown to the requesters of information. This approach also saves on the amount of shared real state on the large display by taking out the information previously shown in the bubbles and on the large display and presenting it on the mobile phone, freeing up some space on the large display. This makes the mobile device not only an input device but also an output medium to present the content about each point of interest on the phone.

In order to analyze the *"display focus"* design strategy we further refined the interactive directory application on the large display and on the phone to provide more interaction capabilities for the actors. In the case of the large display application, we modified the smaller window on top of the map showing the information about a location on the map to hold both a series of images about places on the map as well as some background information about those places. The users could select the bubble and decide whether to flip through the images or to scroll the text in order to read the background information about the spot on the map. For the mobile application, a similar approach was taken so that the actors could either choose to see the images on the phone or read the background information and scroll through the information on the mobile device. Not having proper notification on which display to interact with (the large display or the small display) would even confuse us when trying to identify where to look for the feedback from our interactions. It became clearly evident during our pilot studies that it is highly needed for applications both on the large display and the mobile device to explicitly indicate which interface has the current focus and accepts user input.

During our developments and heuristic evaluations for the second and third strategies, it became evident that spectators had difficulties understanding and comprehend what was happening on the display and where the changes were happening due to the absence of a reporting mechanism to the spectators. Following our "cause of summary" design strategy, we found it necessary to summarize the sequence of interactions done on the mobile device in a form understandable to the spectators, and then to transfer them to a non-interactive widget on the large display as a feedback on what has triggered the current state of the system to change. We considered three methods for this feedback mechanism (we refer to as *cause summary*): i) the feedback can be completely omitted resulting in no cause reflection reported to the spectators, ii) the feedback can be summarized and then reported to the spectators, and iii) a complete iteration of all interactions can be provided to the spectators. While the first and the last approaches are restrained or excessive strategies, the second one seems to be reasonable to be employed for supporting spectators in a dual display setting. We modified our *interactive directory* application to also reflect on the cause of changes on the display by providing a dedicated space on the large display to report on latest events and interactions with the display (Figure 7). Our initial evaluations of this feedback mechanism show great improvements to how cause summary can increase the awareness of spectators about possible opportunities for interaction with large displays and encourage them to become actively involved with interaction with large display settings.

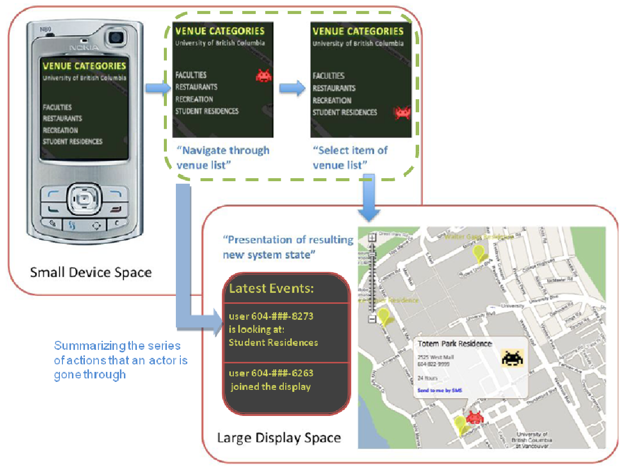

Figure 7: Cause summary on the large display

5. SYSTEM ARCHITECTURE

In order to support seamless message exchange between interactive and non-interactive widgets across large public displays and mobile devices, as shown in our example applications in Section 4, we developed a light weight modular message broker that supports protocol-independent communication between senders of a message (*message sources*) and receivers of that message (*message sinks*). Our developed middleware system, named OSGiBroker, provides enhancement to our earlier middleware system named RESTBroker [6] by supporting faster and more spontaneous message exchange between sources and sinks. Both RESTBroker and OSGiBroker use the notion of named channels to allow developers to associate individual programmable entities with a single message delivery channel so that messages broadcasted on a channel by one of the entities will be received by any other module listening on the channel. In this sense, RESTBroker and OSGiBroker follow a publish-subscribe design pattern to decouple message sources from message sinks. In RESTBroker, events are sent to a channel using HTTP and are received by named subscribers registered to a channel and capable of receiving messages through HTTP. RESTBroker is built as a J2EE model which goes on top of Apache Tomcat Server and provides a one-to-all message delivery pattern in which the messages sent by a message source to a channel will be perceived by all subscribers to that channel.

OSGiBroker is, however, built on top of Open Service Gateway initiative middleware (OSGi) and is part of a larger middleware platform we are developing for investigation of dynamic service composition [9]. OSGi is a centralized service-

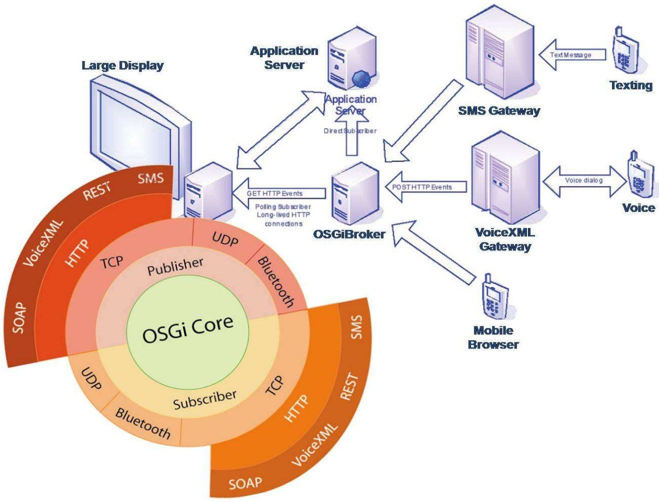

Figure 8: The overall architecture for our OSGiBroker and its layered service model

oriented component model enabling development of Java applications from modular units called bundles [8].

Each bundle can register one or more services with a *service registry* in the OSGi framework and registered services can discover and use one another by looking into the *service registry* and receiving notifications about changes in the status of services of their interest [12]. Benefitting from the modularity and flexibility of OSGi, OSGiBroker provides two independent but related services, one for publishing messages on a channel and another for subscribing with a channel. Whatever message sent to the publisher service under a channel name χ will be delivered to any subscriber that has used the subscriber service to register with channel χ. Several independent services extend the publisher API to support different communication protocols, resulting in having a TCP Publisher (including regular TCP sockets publisher, REST over HTTP, and SOAP over HTTP), a UDP publisher, and a Bluetooth publisher. Similarly the subscriber API has been extended to provide a TCP subscriber, a UDP subscriber, and a Bluetooth subscriber service. This new architecture has enabled us to connect any message source irrespective of the communication protocol it supports to any message sink regardless of its required communication protocol. As a consequence, we have been able to enable message exchange between mobile phones and interactive widgets on the large display using several communication protocols, including SMS, VoiceXML, SOAP and REST communications over HTTP, and direct TCP, UDP, or Bluetooth communications for smart phones. Figure 8 provides a high-level architectural view of the OSGiBroker system.

OSGiBroker also provides higher granularity in delivering messages to the subscribers of a particular channel. The source of a message can choose between delivering a message to all sinks on a channel (i.e., a one-to-all message delivery pattern), it can target a particular subscriber as the recipient of a message (i.e., a one-to-one delivery pattern), or it can exclude some recipients from the set of message receivers (i.e., a one-to-some delivery pattern). These three communication patterns proved extremely useful when developing our example applications. We used the one-to-many pattern to notify all our connected clients about changes in the state of a serving application (e.g., when the Polar Defense game starts or ends); the one-to-one pattern was used to inform one particular client about a state change in the server side objects corresponding to this client (e.g., the color of a pointer that a client controls in the interactive directory application), and the one-to-some pattern was used to inform some of the clients about the changes in the state of the serving application. (e.g., to notify only the clients acting as the application displays showing the view of an application, e.g. in Polar Defense).

6. RELATED WORK

Lack of research on combining mobile phone interaction with large public displays or combination of mobile device display with large public display is clearly perceivable from the few research works that have tried to combine mobile phones with large displays. This is even more exacerbated when we try to find user studies that have examined or analyzed interaction with large public displays using mobile phones. Our initial studies show that there is hardly any user study done to analyze how end users respond to interactions with large public displays using handheld devices (i.e., mobile -smart- phones). It gets even more challenging when we try to find studies that are related to engagement and conflict. Nonetheless, in this section we try to discuss the set of existing user studies done in this area and we also aim at finding some correlations between the conducted user studies and the concepts of engagement and conflict.

Zhang and Adipat [19] provide an interesting analysis of existing challenges and issues for usability analysis of mobile applications. They start with the difference in analyzing mobile applications compared to typical desktop applications and enumerate these difficulties as *mobile context, connectivity, small screen size, limited processing capability and power,* and *Data entry.* Considering these set of constraints and limitations when trying to define user studies for mobile applications, they also enumerate a set of research questions that have been widely used by researchers around the world to conduct user studies for mobile applications. These set of user studies are as follows: *i) Effective content presentation, ii) Simplicity for Navigation, iii) Ease of performing a variety of activities on mobile phones, iv) Effectiveness and efficiency of various data entry methods, v) Usability of mobile applications while being used in different context.* Zhang and Adipat also suggest the following usability attributes to be measured when evaluating the usability of mobile applications: *i) Learnability, ii) Memorability, iii) Efficiency iv) Error Rate and Errors, v) User Satisfaction, vi) Effectiveness, vii) Completeness, viii) Accuracy, iv) Simplicity and Degree of Comfort, x) Comprehensibility, xi) Learning Performance.*

Ballagas et al [2] provide a user study of interaction methods with large displays using mobile phones. In their paper, they analyze three factors from the above listed factors and compare them among three different interaction methods with large displays. The usability measures analyzed by Ballagas et al. [1] include *completion time*, *error rate*, and *subjective ratings of various input mechanisms.* They compare Point and Shoot, Sweep, and Joystick interaction with large displays as three possible methods of interaction. The first two are designed and developed by the authors while the third one is a common interaction method used for moving cursors or manipulating objects on the display. They evaluate these interaction mechanisms with 10 participants and reflect on the evaluation results. None of the above attributes is truly concerned about user interactions. Their results however show that the Sweep interaction technique is the slowest interaction method while Point and Shoot has more error rate.

However, the overall result for both of the approaches relates to the interaction method using the typical joystick available on Mobile devices.

Nestler et al. [9] in their collaborative problem solving approach introduce a small-scale lab study of how users respond to solving a Sudoku game in three different modes of *tabletop collaboration*, *face-to-face*, and *remote*. They have studied 16 people for their user study with the objective of solving five different Sudoku puzzles collaboratively in teams of four. Their quantitative results show that when using the table top device the users solve the Sudoku puzzle within 473 seconds in average whereas the face-to-face collaboration needed 585 seconds and the remote collaboration needed 566 seconds in average. In addition they report that the users on the table top were often disturbed by the hand-held users whereas the table top players were not that much disturbing for the hand-held players.

Carter et al [4] envision a scenario in which users may need to annotate the content shown on the large display in order to encourage collaboration and discussion. In their scenario a user can post content to the large display and other bypassing users will be able to provide immediate annotations to the system or provide offline annotations to a posted comment and later upload it into the system. Carter et al [4] in their digital graffiti for public annotation of multimedia content also conducted a very small field study of their approach at the ubiquitous computing conference. The field study consisted of only two active participants making their claim for conducting a field study for their approach questionable. Nonetheless, they report that neither of the two attendees in the user study returned to their public display installation but instead they used the private display exclusively to view content and post annotations. They infer from the experiment that their system has been useful but it is crucial to integrate content capture, aggregation and annotation. Also they report on the limited capabilities of UIs for mobile devices which make the integration of required features into the device difficult. However, they claim that given user interests in saving bookmarks to review and edit interesting content at a later time, mobile devices may not need to support content aggregation.

ContentCascade [14] does a similar approach in enabling users to download content from a public situated display placed in a shopping mall or a bookstore to a personal device such as a mobile phone. Users can download contents with different levels of detail to their mobile phone and also have a tradeoff between the quality of downloaded content and the presence time. It supports Bluetooth for communication with the display and requires a Java program to be installed on the mobile device to enable exchange of information. In ContentCascade [14] authors report on a small and informal user study to understand how far users usually stand while interacting with public displays. They place the public display prototype in a public meeting location and display content related to various digital movie posters (e.g., some movie clips, small advertisements, etc.) on the display. They observe thirty people within an hour and analyzed the behavior of four people who got engaged in interaction with the display. They report that most people tend to interact with the display at a distance of 3 to 5 meters. They argue based on this finding that the device has more communication range than required and that a device with lower communication range or low transmission power is more useful in such settings.

As discussed above, none of the studies conducted for evaluating user interaction with large public displays using handheld devices are concerned about engagement or conflict between the users. Studying user engagement in such installations is probably the first necessity before going into the study of conflict between interacting users, as for users to face conflict, they need to first get engaged in interaction with large public displays. Although attributes such as error rate or efficiency or interaction speed can have indirect relations with user engagement, they are not in particular studied to measure the level of user engagement with the installation in the above user studies. As a result, we were unable to infer much about evaluating or studying engagement in the above user studies.

7. DISCUSSION AND CONCLUSION

Even though extensive usability studies are on the way to validate the design decisions and strategies discussed in this paper, we have conducted some preliminary user studies to validate our decisions and guidelines.

We conducted a field study of the *interactive directory* application by installing it in an Art Gallery in downtown Vancouver from 9am to 4pm during a live video broadcasting event. About 300 people attended the video broadcasting event and we performed a video recording of the event, and the interactive directory application in particular, to analyze how people would respond to an installation of an interactive directory application controlled using mobile devices. The visitors were mainly the residents of the neighborhood around the art gallery with knowledge of below than average about mobile interactive applications. In order to facilitate interaction with the large display using phone we chose the simpler approach of using VoiceXML for interaction, asking the audience to simply call in to a phone number written on the venue list of the application and giving them a pointer to select a venue from the list and receiving the corresponding information on the map. The actors could use 4, 2, 6, and 8 on the phone's keypad to move left, up, right, and down, respectively, and they could select 5 to select a venue from the list or to receive more detailed information about each location in a venue.

The installation was designed to be entirely responsible for engaging the audience, i.e., *i)* to inform them of how to connect to the interactive directory application (by displaying a phone number and explicitly indicating on top of it "Call to Interact"), *ii)* to provide instructions on what each of the keys on a phone keypad does (by providing a keypad below the phone number and fading in and out the instructions about what each number on the phone does), and *iii)* to provide direct feedbacks about user interactions (by changing the location of the arrow on the display or showing the bubbles with detailed information once a location from a venue gets selected).

Despite all the efforts we placed into informing the audience about how to interact with the large display, our observations showed that we are far from having knowledgeable bystanders who by heart know about mobile interaction with large displays. We saw several users who reached the display and start touching the keypad, which we place on the user interface just to inform the audience of how to interact with the display using their own mobile phones (Figure 9). The fact that our visual explanation of the mobile phone keypad fitted the overall design of the large display reasonably well, led users assume that this was a real interactive widget accepting user inputs.

We clearly noticed the honey pot [3] effect during our field study. Once two of the audience figured out how to interact with the display, their interaction with the display soon started attracting lots of other users to the display, forming a huge group of people around the display (Figure 10). Even though we count some of the excitement for the technology buzz in the installation, it was still interesting to see how those giving minor attention to the display all of a sudden become interested in the display after noticing others interacting with it.

Figure 9 An actor trying to interact with the display by touching it

We even observed one of the first two people figuring out how to interact with the interactive directory application, explaining the application to another spectator. We believe this knowledge transfer can bring great opportunities for engaging other spectators with the interaction process and moving towards a community of knowledgeable bystanders.

Figure 10: The honey pot effect, attracting people around the interactive directory installation

To summarize, from our experience focusing on the dual display approach we found evidence that two display types can be utilized following our design strategies to reduce real estate requirements on large public displays. Our application examples proved to be effective in supporting our stakeholders (i.e., actors and spectators) when applying our design strategies to large public display installations. Additionally, we verified the new system architecture based on OSGi to provide real-time seamless information exchange between display types. The performance tests of our OSGiBroker showed improved efficiency in message delivery speed and proper support for wider range of communication protocols. Even though we have gained a lot of experience in the field of interactive large public display design, we are still at the starting point. More research and evaluations need to be done in order to further extend the set of design strategies we identified here. Our current work will lead us to a larger scale set of usability studies extending the pilot studies we have conducted up to this point which will be reported in the forthcoming publications.

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