ABSTRACT
There has been significant research interest over recent years in the use of public digital displays and in particular their capability to offer both interactivity and personalized content. A promising approach is to use cell phones as a means to interact with displays, but also as a small, high quality screen to complement the larger public display. The use of a dual screen approach offers a number of intriguing possibilities including a potential solution to the problem of managing conflicts that arise when a screen is shared in a public setting or providing a means to show targeted and personalized information. However, to date, there has been little investigation into the impact for users of having interfaces distributed across this type of dual screen setup. In this paper, we report on a series of experiments carried out to determine quantitative or qualitative effects on user performance when interaction is split across large public and smaller private screens. Our position is that using mobile devices as an auxiliary device for interaction can boost user experience when interacting with large displays.

Categories and Subject Descriptors
H.5.2 [Information Interfaces and Presentation]: User Interfaces – evaluation/methodology, interaction styles, theory and models.

General Terms
Design, Experimentation, Human Factors, Verification.

Keywords
Interactive large displays, small devices, distributed user interfaces, user study.

1. INTRODUCTION
Large public displays are becoming increasingly prevalent and rapidly replacing conventional static methods of presenting information to the public. The growing use of large public displays is partly driven by the flexibility that digital displays offer, such as dynamic and remote updates using broadband networks [1], and partly by significant price reductions of such devices [10][11]. Recent research work has investigated this trend and in particularly explored the possibilities afforded by interactive large public displays [11], which can be customized for targeted groups or individual users. This approach offers the opportunity for large public displays to also be considered as large information scale appliances (LISA) [1][11], playing an alternative role to PDAs for accessing information. Although a variety of interaction approaches, such as touch-based interaction, gestures and body orientation [11], and user movement [10] has been explored, smart phones are quickly being adopted as the interaction device of choice with large public displays [1].

Extending interactive large public displays (LD) with small devices (SD) such as smart phones has been discussed in earlier research [9]. The main idea behind this Dual Display approach [9], is to distribute a user interface across the LD and SD to take advantage of input and output capabilities of both device types. Current research work with large public displays rests on the assumption that interaction feedback and user requested information (output data) can be presented on the LD, SD, or a combination of both. However, to the best of our knowledge, there has been no formal study on how well users respond to the separation of user interface widgets concerning input and output between the LD and SD.

This paper builds on our previous research [6] on the use of dual displays and explores how well users comprehend the nature of interaction in a dual display environment. If we can find evidence for the assumption that there is no significant difference in user performance, user satisfaction, and user preference for both conditions (LD SD, or mixed LD/SD) then, designers can take full advantage of the dual display approach when it comes to designing for such environments [9]. We report on a series of user studies conducted at the University of British Columbia where participants used smart phones to interact with multimedia applications to solve a series of tasks.

2. RELATED WORK
In this section we present a number of research projects that utilize the combination of large displays and small devices. Only a few of these projects have conducted user studies to verify their design concepts.

Jin et al. [5] introduce an approach in which the combination of a handheld device and a large public display is used in order to share and manage the information on the handheld device. The authors use QR-Codes to provide the information for connecting to the display using the PDA. Users can then transfer content between the LD and the SD. Content can be shown on both the LD and the SD based on user’s choice. Although this approach
takes advantage of both device types, it has not yet been validated through any formal user study.

Echtler et al. [4] have evaluated collaborative interaction concepts for a game application conducted between touch-based tabletops serving as large displays and small devices such as PDAs. Their user studies results showed that users perform equally when using either the handheld device or the table top. Their users did not show any significant preference in using either the tabletop or the handheld device to interact with their application.

Carter et al. [3] envision a scenario in which users can annotate content shown on a large display in order to encourage collaboration and discussion. Users are able to download content from the LD to the SD, annotate the content, and push it back to the LD to present to others. Based on this design, they conducted a user study in which users indicated interest in receiving and storing the content on the SD so they could preserve a copy when leaving the interaction scene.

As shown in the brief review above, while there have been a number of investigations into the use of dual displays there is limited research into the interaction between large display and small devices. To the best of our knowledge, the examination of input and output capabilities using the LD and SD, which forms the core of our research, is largely unexplored.

3. DISTRIBUTED USER INTERFACE DESIGN

The primary research question in this paper is to verify if users benefit from executing an application across large displays and small devices taking advantage of input and output capabilities of both devices. In other words, we would like to understand if and how splitting interface entities (user interface widgets) across the LD and SD affects user task performance.

According to Norman’s seven stage model [7], different mental activities are associated with the input and output. Therefore, widgets allowing users to enter input might exhibit different design constraints compared to output widgets. Hence, we denote widgets associated with system input as interactive widgets and those associated with system output as non-interactive widgets. Non-interactive widgets are in general used to present system states to users while interactive widgets are used to accept user input to initiate system state changes. In addition, these widgets often provide instant feedback indicating that an input has been received such as a change in a button widget’s appearance every time a user clicks on it. Such feedback helps users verify the correctness of their inputs, revealing possible mistakes or slips.

There is considerable complexity concerning the placement of non- and interactive widgets when designing a distributed user interface across the LD and SD. Imagine a simple interactive application containing only a Button widget that triggers a Text widget to print “Hello World”. The Button, as an interactive widget, can be placed either on the LD, SD or on both. The same holds for the Text, as a non-interactive widget. Hence, for this very simple application we can already come up with 9 possible settings (see Figure 1). Each setting might provide different solutions for interface issues a designer has to solve.

We can come up with several basic design strategies to address this complexity for distributing interactive and non-interactive widgets across the LD and SD. Two of the prominent design strategies are designing only for the LD or splitting it between the LD and SD.

- **LD mode**: With this design strategy, users employ their smart phone to directly interact with widgets placed only on the large public display. Although simple, in a multi-user scenario, problems can arise where more than one user wants to access the same interactive widget. Furthermore, a sequence of actions might require a user to interact with several widgets over a longer time period and so requires space or ‘real estate’ on the LD. A designer has to find the correct balance between real estate, and content quantity/quality to properly serve the audience.

- **LD-SD mode**: In this design strategy, some widgets are placed on the LD and some on the SD. The advantage here is that every user interaction has a defined entry point, which is in this case the LD. On the other hand, an interactive widget arrangement that is partly across the LD and SD may cause user confusion. Content that might be interesting to the entire audience can be presented using non-interactive widgets on the LD. Content, which is specific to users who request it and of less interest for the audience can be placed on the SD.

To reiterate, if we want to offer designers the flexibility of choosing among these modes, we must first verify that changing from the current strategy (LD mode) to a different mode (LD-SD mode) will not lead to a real and perceived degradation of user performance when executing a sequence of actions. That is, users have to be able to interact with interactive widgets and perceive outputs from the non-interactive widgets in the same manner regardless if we place them on LD or SD.

4. APPLICATIONS

For our user studies we developed three applications whose interfaces were capable of utilizing just the LD or distributing itself across both the LD and SD.

**Polar Defense** is a game where users begin by placing six defense towers on a 9 x 9 grid. Once the towers have been placed, enemies begin to cross the grid. Depending on the strategic placement of the towers, a number of enemies will be prevented from crossing the field as the towers attack nearby enemies. Users score based on how many enemies they prevented from crossing the field. Figure 2a shows the Polar Defense game.

**The Eyeballing Game** presents a series of geometric figures that have to be adjusted by the users based on given instructions. In order to do so, users control a pivot point on the geometric object, which could be a corner, a point along a line, or a point in space near the object. An example instruction is to find the centre of a circle by nudging a point inside the circle that starts off slightly
offset from the centre. Users score base on how close they are able to nudge the point to the correct result by “eyeballing” it.

The Interactive Directory Application enables users to browse a set of categories in order to find venues of interest in a city area (e.g.: hotels, restaurants, theatres). Initially a map of the city area is displayed. Users then select a category which triggers the appearance of a set of markers on the map, each one representing a venue in that category. For instance, selecting the category “restaurants” would show all restaurants in the city area and their location on the map. Users can then select a venue and read information and view pictures of that venue (see Figure 2b).

More details on our developed applications can be found in [8].

Figure 2: (a) The Polar Defense Game (b) The Interactive Directory Application

5. USER STUDIES

Participants. Using the three applications, we designed three within-subject user studies and recruited 16 participants (12 males and 4 females, aged 18 to 39), including 11 in computer science/engineering, 1 in another engineering area, and 4 in humanities and social sciences. Around 62% of our participants considered a display bigger than 30 inches as a large display, yet only 38% had previous experience interacting with a large display, and their interactions with the large display had happened only by using a remote controller.

Apparatus. We used a projector to create an interactive large display (LD) with a resolution of 1024 x 768. A laptop computer was connected to the projector to run our applications. A Nokia N95 smart phone was used as the small device (SD) with a screen resolution of 320 x 240. The right and left soft keys as well as the phone’s joystick were used to control the applications in both LD and LD-SD modes. We tried to keep the visual angle across both displays consistent proportion to the content shown on the LD and SD.

Analysis. In all three designs, we measured error rate and time as quantitative dependent variables, and user satisfaction and personal preference as qualitative dependent variables. Time and error rate collection were application dependent. User satisfaction in all three designs referred to how much faster or easier it was to interact with the application in either of the two modes; and personal preference referred to which of the LD or SD modes were preferred by the participants when interacting with large displays. User preference and user satisfaction were measured through a post-experiment questionnaire completed at the end of the study based on Likert-Scale responses.

Experiments. We designed three experiments to evaluate the two design strategies, LD and LD-SD modes. In all three experiments, the LD condition has all the interactive and non-interactive widgets placed on the large display. Subjects interact with the applications using the phone but the changes and feedback all happen on the large display. In the LD-SD condition, some of the widgets are moved to the SD and some remain on the LD. Hence, users will need to switch between SD and LD when interacting with the applications. In this mode, the LD and SD always show distinct widgets.

Our overall hypothesis is that interaction in the LD-SD mode is not significantly different from the widely employed LD mode interaction. More specifically, users perform equally well or even better when some widgets are placed on the SD compared to having everything on the LD.

Experiment 1. Spatial Course Granularity

Polar Defense is used for this within subject experiment where the game interaction for placing towers is the independent variable. The interactive input widget for setting towers was placed either on the LD or SD depending on the condition, while game results are shown on the LD in both conditions. We consider the interaction a spatially coarse granularity interaction model because users have to place towers onto a large grid with defined positions. We asked the participants to write their desired strategy of placing towers on a piece of paper prior to entering it to the game. For error rate we measured how many times a participant removes a tower from the game field and repositions it to make it match the strategy written on the paper. For the time, the amount of time it takes for a participant to place the proper coordinates for the towers on the game field and send them off to the application during each phase of playing the game was measured.

Experiment 2. Spatial Fine Granularity

We used the Eyeballing Game for this experiment. It is very similar to the first experiment where an interactive widget for manipulating geometric figures is placed either on the LD or SD depending on the condition. Game results are shown on the LD for both conditions. In contrast to the Polar Defense, the movements of a cursor in this game are more fine-grained in that the cursor moves pixel by pixel as opposed to cell by cell, requiring more attention from the users. Thus, we consider interactions for the eyeballing game as spatially fine granularity interactions. For the error rate, we measured the rate for how close or far participants were to the actual position of the correct answer and for the time, we logged the amount of time it took each participant in each of the LD and LD-SD modes to choose the proper pixel they thought was the answer to the problem from when they were presented with the problem.

Experiment 3. Perception of New System States

The goal of this experiment was to determine where to place output user interface widgets to better allow users to perceive and evaluate new system states using the Interactive Directory. We still focus on two conditions. The research question we try to answer in this experiment is “do users perform better, or at least no worse, in perceiving system state changes when they are presented across LD and SD than if we just use the LD?” In the LD condition, the information window for the venue selected is shown on the LD, while in the LD-SD condition it is shown on the SD. The map navigation and category selection for both conditions are shown on the LD. In each step of the experiment the participants were asked to answer a question regarding the text
information shown for a specific venue or to a given picture related to the selected venue. As an example we asked the user to provide us with the operation hours of a museum from its information presented in LD or LD-SD mode or to count certain objects in an image related to the venue. Error rate was measured by counting wrong answers to the tasks related to the number of items in a text phrase or a picture or wrongly selected venues when searching for the correct venue. Time was measured from the point where a target venue, either correct or incorrect, gets selected up to the point where the participant finds the answer to the task and presses the submit button.

5.1 Results
For the coarse granularity interaction (Polar Defense) our results show that on average there is no significant difference in time error-rate when using the LD for placing tower in the Polar Defense game. Yet, participants had a higher degree of satisfaction when playing the game in the LD-SD mode. In the fine-granularity interaction case of the Eyeballling Game, the exact same results in terms of accuracy and time of interaction between LD and LD-SD modes were obtained (i.e.: no significant difference). However, unlike the case of Polar Defense, users thought they spent more time playing the game in the LD-SD mode compared to the LD mode. Finally, in the last experiment for perceiving the system state, our results show that users perform better in terms of their error rate for differentiating images presented in the LD-SD mode compared to the LD mode. However, the time spent in each of the two modes to go through the experiment was almost the same in both modes of experiment. Overall, our results show that participants preferred to interact with the LD-SD mode (in particular read and scroll text on the phones) rather than the LD display, although time and error rate did not show significant differences in all three experiments.

6. DISCUSSION & CONCLUSION
The main results we found indicate that users can perform equally well whether using large or small displays within our experimental settings. These results hold for user activities that occur within the stages of Norman’s model of interaction [7]. It is interesting to note that phones play a more significant role when more accuracy or privacy is required. In the case of the Eyeballling Game, users spent more time fine-tuning their game play for finding the answers. Similarly, users spent more time on the phone when it came to understanding information through counting elements or answering questions. Our post-experiment questionnaires show that phones provide users with a stronger feeling of possession allowing them to spend more time perceiving or fine-tuning the answers with less concern for social embarrassment. The demographics of our user study primarily reflect healthy and young adults. Older adults, who haven’t participated in our experiment so far, might perform differently, especially when reading text with smaller fonts on the SD.

In conclusion, our work supports the hypothesis that user interfaces can be distributed on both the LD and SD without a significant effect on user performance. We believe that this allows designers of distributed user interfaces to exploit dual displays (as suggested by Sas and Dix [9]) to improve end-user experience.

In the future we plan to run a more diverse population in our user studies and to generalize our work more by investigating more complex widget arrangements across the LD and SD. We also plan to further evaluate and investigate dual display scenarios based on our previous work [6] with a focus on exploring and understanding the dynamics of collaborative work using interactive large public displays [2][9].

7. REFERENCES