Investigating a Design Space for Multi-Device Environments

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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. While a number of interaction technologies have been investigated, a promising approach has been the use of the ubiquitous cell phone which not only offers a means to interact with displays, but increasingly offers a small, but high quality screen to complement the larger public display. However, to-date there has been little investigation into the impact on users when interfaces are distributed across this type of dual screen setup. This paper reports on a series of experiments we carried out to determine if there is a significant quantitative or qualitative effect on user performance when interaction is split across large public and smaller private screens.

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

Investigating a Design Space for Multi-Device Environments

Introduction

Large public displays are becoming increasingly prevalent, rapidly replacing paper-based methods of presenting information to the public. Extending interactive large displays (LD) with small devices (SD) such as smart phones has been discussed in earlier research efforts (Dix & Sas 2008, Finke et al. 2008, Raj et al. 2004, and Greenberg et al. 1999). The main idea behind this approach, which is also known as the *Dual Display* approach (Vogel & Balakrishnan 2004), is to execute a user interface across LD and SD to take advantage of input and output capabilities of both device types at the same time. Dix and Sas (2008) argue that such an approach could help designers solve GUI design issues due to multi-user interaction with large public displays.

Current research work with large public displays rests on the assumption that interaction feedback and user requested information (output data) can be presented on LD, SD, or a combination of both. Furthermore, it is assumed that coupling LD with SD during interaction helps to reduce the load of information presentation on the LD and increases users' ability to manage content on large displays, mainly because of users' inherent experience in using their phones. What seems to be missing from the current research work is identifying differences in design requirements for interactive and non-interactive widgets depending on whether they are placed on LD or SD. There is lack of clear guidelines on how users respond to placement of elements in a user interface on LD or SD. We build on our previous research (Finke et al 2008, Kaviani et al. 2009) into the use of dual displays and explores how well users comprehend the nature of interaction in a dual display environment where both input and output interface widgets are distributed across LD and SD to provide design guidelines for widget placement in SD/LD environments.

Related Work

Current research work with large public displays rests on the assumption that interaction feedback and user requested information (output data) can be presented on LD, SD, or a combination of both. For example, Dix & Sas (2008), and Dix (2005) argue that LD/SD distributed interfaces may help designers solve GUI design issues due to multi-user interaction with large public displays. Furthermore, it is assumed that coupling LD with SD during interaction helps reduce information presentation load on the LD and increases users' ability to manage content on large displays, mainly because of users' inherent experience in using their phones. However, little user study research has been performed to verify their design concepts.

Jin et al. (2006) explored the combination of SD/LD interface to: share and manage the information on the SD, allow content transfer between LD and SD and reserve real estate on the display directly associated with a specific user, creating a personal space. This approach takes advantage of both device types, but was not validated through any formal user study. Myers et al. (2008) and Biehl and Bailey (2006) also explored separating interactive widgets on SD and non-interactive widgets on LD using PDAs instead of a mouse and keyboard to interact with displays in a collaborative office environments and home environments.

Carter et al. (2004) and Greenberg et al. (1999) envision scenarios where users annotate content on a large display to encourage collaboration and discussion. Users can add content to the LD, download content from the LD to the SD, annotate the content, and push it back to the LD. Based on this design, Carter et al. (1999) conducted a user study in which users indicated interest in receiving and storing the content on the SD even when they walk away from the LD. In both studies, LD and SD are viewed as independent devices for interaction without any considerations for combined use of the two displays (Greenberg et al. 2004).

Distributed User Interface Design

Our primary research motivation is to explore the possible UI design choices for dual display environments and to understand how splitting interface entities (user interface widgets) across LD and SD affects user task performance. Earlier research shows (Norman 1988) that different mental activities are associated with the input and output. 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. However, interactive widgets 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.

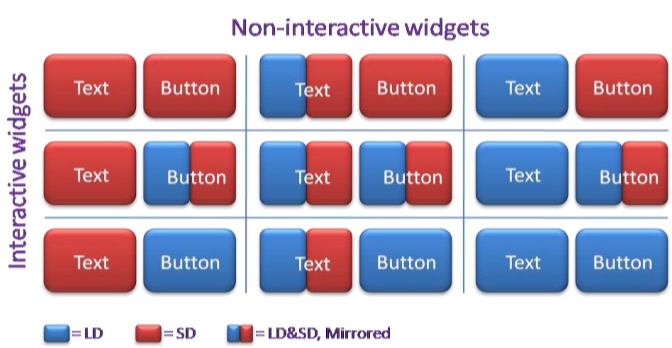

Figure 1: Potential placement options for interactive and non-interactive widgets.

There is considerable complexity concerning the placement of non- and interactive widgets when designing a distributed user interface across LD and SD. Imagine a simple interactive application containing only a *Button* widget that triggers a *Text* widget to print "*Hello World"*. The text and button widget can be placed either on the LD, the SD or on both. Hence, for this very simple application we can already come up with 9 possible settings (see Figure 1). This suggests that the design space for distributing widgets across LD and SD grows exponentially (based on the three widget placement possibilities for LD and SD) as the number of widgets increases. Within this complex design space, are often driven by designers' intuitions, usage scenarios, level of collaboration among users, and simultaneous use. The complexity of the design space could be reduced if we deal with the placement decisions for each individual interactive or non-interactive component in the user interface separately. Below, we elaborate on these details.

Interactive & Non-interactive Widget Placement

When creating a distributed user interface using a smart phone as the primary input or output gateway, a designer has to make the additional decision of where to place the interactive and non-interactive widgets. Considering multi-step interactions and perception steps that involve more than one interactive or non-interactive widget, we can come up with four basic design strategies for widget placement. For interactive widgets we can have : *i) LD mode:* smart phone is used to directly interact with widgets on the large public display. 'Real estate' could be an issue in such a design when multiple users interact with the LD; *ii) SD mode:* Moving interactive widgets to the SD will free up real estate on the LD. It will also help ameliorate the multi-user access problem but adds to the complexity of LD and SD; *iii) LD-SD mode:* Interactive widgets are split between the LD and the SD. The advantage is that every user interaction has LD as the entry point but it may cause user confusion; *iv) Mirrored mode:* This design strategy introduces redundancy into the distributed user interface by placing the same widgets on both LD and SD. We do not solve real estate or multi-user access problems, but users can make their own choice of selecting the display between LD and SD.

Similar to placement decisions for interactive widgets, for non-interactive widgets we can have: *i) LD mode:* This is the classic design strategy used by the majority of today's interactive large public display installations. From the design point of view the LD is challenging because it requires the right balance between available real estate and the quantity and quality of content; *ii) SD mode:* Forcing users to rely solely on a SD defeats the purpose of large public display installations. However, in some circumstances (e.g., privacy constraints) utilizing this mode may be useful for implementing certain aspects of a large display application; *iii) LD-SD mode:* This mode combines the advantages of LD and SD. User specific content is presented on LD while general purpose content can be presented on LD; *iv) Mirrored Mode:* In this mode the same content is presented on both the LD and SD. As listed above, the overall design strategies differ in the way they serve and apply to distributed user interface concepts and issues.

User Studies

In this paper, we report on three user studies conducted at the University of British Columbia whereby participants used smart phones to interact with multimedia applications to solve a series of given tasks. The multimedia applications are based on two main design conditions in the design space. In the first condition, the entire user interface runs on the LD. In the second condition, the exact same user interface runs across LD and SD. We measure real and perceived user performance for both conditions and discuss our findings.

To analyze the effects of moving interactive widgets between LD and SD we developed two game applications requiring user interactions (i.e., user input) with the large display, namely the *Polar Defense Game* (Finke et al. 2008) and the *Eyeballing Game* originally by Wandel[1]. The design of the Polar Defense game relies on coarse grained interaction with the display where changes in the representational states of the GUI happen in the form of coarse and noticeable feedback. In contrast, the Eyeballing game focuses on fine grained interaction where changes in

[1] http://woodgears.ca/eyeball/, *The Eyeballing Game* by Matthias Wandel

the representational state of the GUI are much smoother than, and potentially not as noticeable as, coarse grained interaction. By covering coarse-grained and fine-grained interaction patterns, we aimed at covering the two extremes on the spectrum of possible interaction styles using a mobile device and a large display. To explore the placement of non-interactive widgets affects we developed an interactive directory application providing information about points of interest (POIs) on a map (output information), either by showing the information on the LD or by pushing the information to the interacting SD.

Participants

For our three applications, we designed three within-subject user studies and recruited 16 participants (12 males and 4 females, aged 18 to 39). Eleven of them were majoring in computer science/engineering, 1 in another engineering area, and 4 in humanities and social sciences. 69% of our participants indicated that they work more than 40 hours/week with a computer whilst 57% of them spend less than 5 hours watching TV. 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. When it came to phones, all but one of our participants had a phone in their possessions and 47% of them knew the brand and the model of their phones.

Apparatus

<u>Controller:</u> For both design conditions we used a Nokia N95 smart phone as the input device. The right and left soft keys as well as the phone's joystick were used to control the applications in LD or SD modes. There was no difference between LD and SD with respect to the phone keys in use. We used WiFi to establish network connection between LD and SD.

LD version (condition 1): We used a projector to create an interactive large display (LD) with a resolution of 1024 x 768. We also used a desktop computer with a ~3GHz processor, connected to the projector, in order to run our applications. All applications were written in Flash CS3 and communicated through a message-oriented middleware (Blackstock et al. 2010).

SD version (condition 2): A Nokia N95 smart phone was used as the small device (SD) with a screen resolution of 320 x 240. For each design, a FlashLite 3.0 application was developed and installed on the Nokia N95 smart phone realizing the exact same user interface that we developed for the LD version of the application.

Display and Font Sizes: In order to obtain a proper proportion for the content shown on LD and SD, we tried to keep the visual angle consistent across both LD and SD designs. The CSS2 reference document on W3C's website[2] indicates that "for a nominal arm length of 28 inches, the visual angle is 0.0213 degrees", giving us a pixel size of 0.26mm for our Nokia N95 smart phone with a display resolution of 320 x 240. Considering the size of the room where the user studies were happening, we required the participants to stay 3.5m away from the display, which, taking the visual angle into account, requires us to have a pixel size of 1.3mm for the large display. Considering the resolution for our projector (i.e. 1024 x 768), we set the height of the projected display equal to 1m (i.e., 768 x 0.0013 = 0.9984m) in order to obtain the pixel size of 1.33mm and guarantee an identical visual angle between our LD and SD experiments. These ratios were kept the same across all three experiments we report on here. To obtain the best reading rate for our participants, we set the font size equal to 12pts across all designs.

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[2] http://www.w3.org/TR/CSS2/syndata.html#length-units

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. While collecting time and error rate were application dependent (see the Analysis section for each design), 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. In order to measure user preference and user satisfaction in using LD or SD, at the end of each user study, we provided our participants with a post-experiment questionnaire. For each question, we used five Likert-Scale responses (ranging from strongly disagree to strongly agree) which were then converted to numeric values (i.e., 1=strongly agree and 5=strongly disagree). For each design we asked our participants to provide their responses within the range of 1 to 5 to questions like the followings, *"I prefer to interact with the interface on the cell phone rather than on the large display", "I took more time to complete the task on the cell phone compared to doing it on the large display",* etc. For each question, we calculated the mean of participants' responses in order to analyze their overall opinions.

Experiment 1: Placement of interactive widgets

In order to measure the effects of distributing input widgets across LD and SD, we focus on multi-step interactions where users execute a sequence of actions in the application in order to trigger a change of the system state. Single-step interactions are not considered during this experiment mainly because they don't give a long lasting feeling of interaction with the device or display to the user and the change in the system state is often mixed with the feedback received from interacting with the application.

If we could find evidence that users perform better or equally well with widgets placed on SD compared to widgets placed on LD, we can move the long-lasting multistep interactions to users' phones to free up more real estate on LD and allow for more audience-oriented use of real estate on LD. This will, in turn, allow more users to plan their interactions on their phones before sending them off to a large display, potentially giving users a better sense of privacy. We propose the following hypotheses to be evaluated by conducting the first experiment: ***H1:*** *Users perform equally well or even better if they interact with widgets placed on SD compared to LD;* ***H2:*** *Users make fewer errors during interaction, if interactive widgets are on SD (only for Design 1);* ***H3:*** *Users prefer to carry out interaction on the SD compared to the LD.*

Design 1: Spatial Coarse Granularity Experiment

The experiment design is a within-subject design with device type (i.e., LD vs. SD) as the one and the only independent variable. For the first design of this experiment we developed a user interface for a strategic game. In this game, called Polar the experimental focus is on the part of the game where users have to interact with the user interface in order to place towers on the game field through multi-interaction steps (Figure 1a). We have two design conditions. In the first condition the interactive user interface widgets are on the LD and in the second one the same user interface widgets are on the SD. The interactive widget is a 9 x 9 grid where users can use phones arrow keys to switch between grids.

Procedure

During the experiment, participants were first trained for 30 minutes on how to play the game and then were given four strategies in a paper form for their game play. Participants then used the smart phone they were given as a controller to enter their strategies and play the game based on what they had written on their paper forms. They repeated this procedure a second time giving them the chance to increase their high score by defining new strategies and also to overcome the learning curve. For each condition the participants were given 8 strategies, which resulted in 16 strategies in total (for LD and SD). Half of the participants started with the LD condition and half with the SD before switching to the other condition.

Quantitative Data Collection & Results

For *error rate* we measured how many times a participant removes a tower from the game field and re-positions it in order to produce the coordinates s/he had originally written on 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 was measured. We further recorded the time of the last key stroke before the *Send* key was pressed that terminated the user input. This allowed us to determine the interaction time it took to place the towers on the field.

In order to be able to analyze the overall interaction time per game play we counted every key stroke due to the tower placement. Knowing the exact number of total key strokes per game played we then were able to normalize the overall interact time. We call the resulting measurement unit *Time per Key Stroke (TKS)*, which defines the average time between two consecutive key strokes on the smart phone. On average there was no significant difference of the TKS value for participants with respect to the interaction time needed to place six towers on the LD (M=730ms, SE=34) compare to the SD (M=669ms, SE=32, $t(15) = 1.497$, $p < 0.155$, two-tail). Data supports our first hypothesis (H1).

Since participants had to write their tower placement strategy on paper prior to the actual game play, we were able to log how many times participants removed a tower due to misplacement. As a result for the SD condition, participants misplaced 1.82% of the towers set during the experiment (M=1.82, SE=.73). Participants for the LD condition misplaced 4.03% of towers (M=4.03, SE=1.04). A paired samples T-Test analysis showed ($t(15) = -1.672$), $p < 0.115$, two-tail) no significant difference between the two data sets and so we had to reject our hypothesis (H2) that users make fewer errors while interacting with the SD.

Analyzing the results of the post-experiment Likert-scale questionnaire, however, revealed that, even though there hasn't been any significant difference in terms of their interaction time or accuracy from our logged data, participants preferred more to interact in the SD mode (mean = 3.62). Our participants also thought they made fewer mistakes when in the SD mode (mean = 3.56); yet our collected logs did not validate their perception.

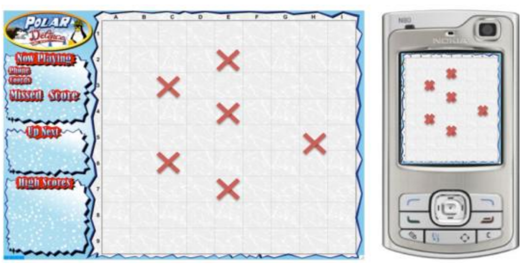

Figure 1a. Polar Defense Game interface on LD and SD, design 1.

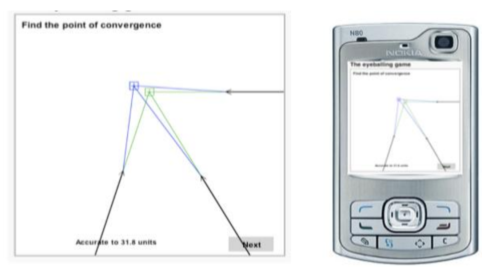

Figure 1b. Eyeballing Game interface on LD and SD, design 2.

Design 2: Spatial Fine Granularity Experiment

In our second design analyzing the placement of interactive widgets, again we conducted a within subject experiment design with the same independent variable as for the first design (i.e., screen type). In this experiment we re-implemented "the eyeballing game" whichpresents a series of geometric figures that have to be adjusted by the users based on a given instruction. (cf. Kaviani et al. 2009). In the eyeballing game, in contrast to the polar defense, the movements for the cursor are spatially fine-grained in that the cursor moves pixel by pixel as opposed to cell by cell, thus giving the users more flexibility in moving the cursor around whilst requiring more attention from the users. We believe combining the results from these applications enable us to cover potential input interactions in case of LD/SD interactions.

Procedure

The design of the eyeballing game shares the same characteristics as for the polar defense. There is, however, one major issue to be considered while conducting this experiment. The eyeballing game (Figure 1b) by design has the characteristic that for the SD mode, users can rotate the device to obtain more accurate results. However, since this behavior is not generalizable to all other applications offering spatial fine granularity interactions, we prevented participants from rotating the small device by using a custom stand for the phone. Similar to the previous experiment we spend 30 minutes training the participants on playing the game.

Each round included six geometrical figures which had to be adjusted based on six given tasks. Consequently, participants had to play four rounds with six tasks each resulting in 24 game plays. Half of the participants started in the LD mode and half in the SD mode before switching to the other condition.

Quantitative Data Collection & Results

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 SD modes to choose the pixel they thought was the answer to the problem from when they were presented with the problem.

Every participant had to play an entire game, which included six geometric tasks to be solved. Since the tasks were the same for everybody a normalization procedure was not necessary to be able to compare the recorded interacting times. However, we conducted normalization, since a T-Test should show the same result regardless of whether we take into account the total number of keystrokes associated with the measured interaction time.

Participants for the SD condition used on average 17.025 seconds to complete each task ($M = 17.025$, $SE = 19.97$). For the LD condition we measure an average time of 14.770 seconds.

A paired samples T-Test analysis of the two data sets shows no significant difference between the two conditions ($t (15) = 1.763$, $p < 0.099$, two-tail). After normalizing the interaction time measured with the total number of key strokes we obtained a TSK (*Time per Key Stroke*) value of 0.504 second for the SD condition (M = 504, SE = 26.9) and a TSK value of .446 second for the LD condition (M = 446, SE = 30.5). A paired samples T-Test analysis for these data sets ($t (15) = 1.752$, $p < 0.100$, two-tail) shows almost the exact result compared to the non-normalized analysis. Both results support our first hypothesis (H1).

Similar to our findings for design 1, the post-experiment questionnaire showed that participants thought they made fewer mistakes when interacting with the application in the SD mode (mean = 3.62). They also found the interaction with the application more natural when doing it on SD (mean = 3.62). However, unlike the previous experiment, they didn't think they were faster in the SD mode (mean = 2.25), nor were they in favor of using SD over LD for interaction (mean = 3.37) as strongly as in design 1.

Experiment 2: Placement of non-interactive widgets

Unlike the first two experiments focusing on placing interactive widgets, in this experiment we focus on the placement of non-interactive (i.e. Output) widgets. As described earlier, the output widgets can be distributed across LD and SD in four modes; LD only, SD only, LD-SD, and Mirrored, out of which we design our experiment to deal with the first two modes (i.e., LD only and SD only). The goal of this experiment is to determine where to place output user interface widgets to better allow users to perceive and evaluate new system states. Thereby, we focus on two conditions. In the first condition, all widgets that constitute the presentation of a new system state are placed on the LD and in the second condition we separate these widgets and place them on the SD. So 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?

Design 3: Perception of New System States

In this experiment, we chose a within-subject design with one independent variable, device types (LD or SD). For this experiment, we designed an interactive information directory application (Figure 2a) enabling users to browse through a set of categories in order to find a venue of interest (e.g., hotels, restaurants, etc.) and receive information and pictures about their venue of interest. (cf. Kaviani et al. 2009). We designed the experiment to work in two conditions. In the first condition the *detailed information window* and the *general information window* would both appear on the LD. In the second condition, we kept the *general information window* on the LD but presented the *detailed information window* on the SD. If users could perform equally well or better when the detailed information window was presented on the SD version, we can argue that it is possible to split the content between LD and SD without affecting user perception. So, more real estate can be freed up on the large display. We consider the following hypotheses for this experiment: ***H1:*** *Users make less errors when reading content on the SD compared to LD;* ***H2:*** *Users perform equally well or even better if they read content on the SD compare to the LD;* ***H3:*** *Users prefer to have the output presented on the SD compared to having it displayed on the LD.*

Procedure

Participants were first introduced to the tasks and were trained for 30 minutes to use the application appropriately. They were given a list with 26 tasks written on a sheet of paper (e.g. Figure 2b). Each task required the participant to select a specific venue item from the venue list, then select a venue on the map and search for a specific piece of information in each tab of the detailed information window (text and picture tabs). The tasks included finding an object in an image (5 tasks), counting the number of objects in an image (7 tasks), finding a word from a piece of text to fill a phrase (5 tasks), and counting the number of words in a piece of text (7 tasks). Upon finding the answer for the task, the user would write the answer down on the sheet. Once the task was completed, the participant would press the submit button on the phone in order to confirm task completion. Half of the participant group starts with the LD condition and half with the SD before switching to the other condition. In order to measure the error rate, we designed specific tasks in which the participants would count the number of objects in a picture when they were in the slide-show mode or the number of words when they were in the text mode. By having the correct number of items in the picture or words in the text already counted, we measured the error rate for the participants in each mode.

Quantitative Data Collection & Results

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 when the participant finds the answer to the task and presses the submit button.

We measured the error rate of the experiment based on the number of correct solutions for the given tasks. For each condition the high score was 13. For the LD version participants achieved in the average 10.873 scores ($M = 10.87$, $SE = 1.25$). For the SD condition participants achieved 11.75 scores in average ($M = 10.87$, $SE = 1.12$). A paired samples T-Test analysis of the two data sets shows no significant difference between the two conditions ($t(15) = -2.004$, $p < 0.063$, two-tail). However, this result shows a high tendency in favor of the SD condition in terms of a better scoring rate. As a result of this analysis we have to reject our hypothesis (H1).

The time period we measured and report here includes time used for interactions such as scrolling through text or switching between pictures in our design of interactive directory. In general, the average time period for perceiving and evaluating the content presented inside a tab for the LD condition was 17,28 second until the submit button was pressed (M = 17.28, SE = 15.44). For the SD condition the average time was 16.29 second (M = 16.29, SE = 13.01). A paired samples T-Test analysis of the two data sets shows no significant difference between the two conditions ($t(15) = 1.123$, $p < 0.279$, two-tail). The data set strongly supported our hypothesis (H2). Analyzing the results of our post-experiment questionnaire revealed that our participants would like to get detailed information on their phones (mean = 3.86) and in particular read and scroll text on the phones (mean = 3.73) rather than on the large display. Moreover, in almost all cases, our participants were deterministically able to figure out switching modes between LD and SD during their interaction (mean = 4.13). However, we were not able to validate whether participants found interaction on SD easier than LD (mean = 3.13) or if they preferred perceiving images on SD over LD (mean = 3.13).

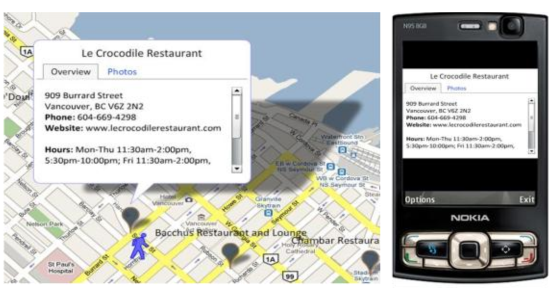

Figure 2a. Interface Showing the Interactive Directory application for design 3.

1. Select category item "Restaurants"
2. Select the venue restaurant "Le Crocodile" from the set of shown restaurants on the map
3. Select the text tab from the detailed information window and look for the missing word in the following sentence:
4. "The owner of Le Crocodile started his [... missing word ...] in 1979."
5. Press the submit button after finding the answer and click submit.

Figure 2b. A sample task for analyzing the non-interactive widgets

Discussion & Conclusion

Our main results indicate that users can perform equally well using either large or small displays within our experimental settings. Furthermore, regardless of the type of interaction (i.e., fine-grained or coarse-grained) with large displays, users favour the use of small devices for both interacting with the LD and receiving feedback. Given that there is no negative effect on the overall results of interaction when migrating some interaction widgets to the LD, one major design guideline is to co-locate the point of interaction with its feedback on small devices when designing a dual display. Another guideline suggested is that coarse-grained interactions will have less cognitive load for users when placed on SD while placing fine-grained interactions on SD will reduce the level of social embarrassment for users, allowing them to more easily breach the interaction barriers to get engage with the content. We recommend designers migrate information to the SD in cases where there is individual interaction or when screen real estate on the LD is limited. Given that users can equally be able to read and interpret data on their devices as well as on LD, we suggest data targeted for a large audience be presented on LD while individual and specific data delivered to users' mobile phone. Based on our findings, there would be no cognitive barrier for users to understand how data migrates from LD to SD and back when they need to read and interpret the output data between the SD and LD. This provides the designers with enough flexibility to decide about what to present where based on the size of their target audience and the required feedback they need to receive from their audience. These results hold for user activities that occur within our discussed design space and with respect to the decisions made for placing interactive and non-interactive widgets across the LD and the SD.

The demographics of our user study primarily reflect healthy and young adults; however, we anticipate that older adults may perform differently, especially when reading text with smaller fonts on the SD, suggesting that a different blend of SD/LD distribution may be effective. In our experiments we used Nokia N 95 smartphones whose primary means of interaction with large displays are through control keys on the phone. While the model of interaction in this generation of Nokia smartphones promotes discrete step by step interaction with large displays, we believe our results for placement of interactive and non-interactive widgets on large displays would still hold irrespective of the type of smartphones used. However, the new generation of touch-enabled smart phones (e.g.. iPhone and Android Phones) could bring new meanings to the concept of dual display interaction in terms of easier methods of data exchange and content manipulation between LD & SD. We anticipate this will result in increased willingness to use smartphones for interactions with large displays. This will further strengthen the necessity for using a dual display design for interaction with large displays and augment the value of the findings presented in this paper.

At this stage, we used simplified user interface designs to emphasize particular areas of the design space. Our next steps are to: *i)* continue with simplified user interaction paradigms to allow us to control particular parts of the space and *ii)* Develop complex user interaction applications for study to provide ecological validity to the guidelines that result from the more controlled environments. In conclusion, our work supports the hypothesis that LD and SD can be combined without a significant effect on user performance, allowing designers of distributed user interfaces to exploit dual and multiple displays to improve the end-user experience. Based on our studies to date, we have listed a number of different design strategies that designers may use to solve design issues for interactive large display applications using small devices.

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