Coordinating User Selections in Collaborative Smart-phone Large-display Multi-device Environments

Paul Craig[1], Xin Huang[1], Yu Liu[1]

[1] Xian Jiaotong Liverpool University, Suzhou, Jiangsu Province, China

Abstract. This paper evaluates alternative view coordination methods for linked smart-phone large-display multi-device environments and proposes an approach whereby selections made using different displays can be coordinated in order to facilitate different degrees of autonomous and collaborative working. This involves different types of selection made by users on individual private mobile devices being combined on the main public display with individual users having the option to press a button and retrieve another user's selection from the main display. Our proposed method is developed and evaluated using the HotelFinder application which runs on several smart-phone devices connected to a large-display and allows users to find a hotel using coordinated map and scatter-plot views showing hotel location, price and review statistics.

Keywords: Information Visualization, Collaborative Visualization

1 Introduction

Face-to-face collaboration is an important component of most human activities. Whenever collaboration isn't absolutely necessary, it generally helps us to do a better job or have a better experience. Up until now, however, technological limitations have meant that the most common form of computer assisted working is that of one-device one-user with people normally working on their own. When people do work together they either use separate machines or one person has total control of the machine with the other looking over his or her shoulder. In either case users are not collaborating as effectively as they could do if they were able to spend more time face-to-face and focus more on interpersonal communication rather than a computer screen [1, 2].

A new development that promises better support for co-located collaboration is the rise of ubiquitous computing [3] and the development of new advanced mobile computing technologies [4] for the burgeoning smartphone market. Key components are mobility, touch control, improved display technologies and improved connectivity. Mobile devices mean that computing is no longer tied to a physical location so that people can move to meet each other and carry their data with them [4], large displays facilitate better face-to-face communication [5, 6], and better network connectivity means that data and resources are more easily transferred and shared between devices and users [7, 8].

Despite the technical advances that facilitate better combined functionality for connected large-displays and mobile devices, interfaces for multi-device co-located collaboration linking large-displays and mobile devices are still rather limited [1]. This can be attributed to device limitations such as screen space and input peripherals [9], social factors [10, 11], and the complication that every aspect of an interface (interaction, security, display etc.) has to be operable by multiple users at the same time [11]. Natural sharing of control and display space together over multiple devices is an important consideration that has not been addressed adequately by current research [12]. On the other hand we have seen that information visualization techniques show great promise for overcoming device limitations [13, 14] and managing collaborative working with multiple users [9, 15-17].

This paper builds on our previous work where we investigate the feasibility of adapting information visualization techniques for co-located synchronous collaboration on large-displays connected to hand-held mobile devices [18, 19] by evaluating different methods for coordinating selections made on mobile hand-held devices with large wall-mounted displays in a collaborative multi-device environment.

2 User Requirements Analysis

A focus group with twelve potential users (aged twenty-one to twenty-five) allowed us to gain some insights into user expectations of how a multi-device collaborative information visualization with multiple mobile devices linked to a single large display should work. The case-study used for this study was the HotelFinder application designed to run on a large-display or display-wall with connected mobile devices allowing users to find a hotel using coordinated map and scatter-plot views showing hotel location, price and review statistics. Users have a common broad objective and different knowledge to bring to the problem with varying ideas of how to find a solution. This allows us to consider different degrees of autonomous and cooperative working with different users' attention shifting between different screens, and each other, as the task progresses.

Toward the end of our focus group session after introducing and discussing the overall concept of the HotelFinder application, we asked our user group to help us identify the most important factors that would be likely to affect their experience with this type of system. This discussion allowed us to compile a list of seven factors the users considered important for multi device collaboration. These were Communication (how well the interface facilitated communication within the group), Harmony (avoiding negative disruption or irritation between group members), Inclusion (how well the interface included all group members in the task), Learnability, Ease-of-Use, Effectiveness, and Satisfaction. Of these factors, three related specifically to collaboration and four related to general usability.

While learnability and ease-of-use can also be considered important factors for usability in general [20], our potential users told us they considered them to be particularly important when multiple users worked together on the same interface. Our potential users especially didn't want to be made to feel foolish if they couldn't operate the interface or be distracted by too many options while trying to communicate with the rest of the group. These feelings are consistent with the findings of other researchers who specify that interaction with this type of interface should be fluid and seamless [21] and that mobile interfaces should feel natural and focus on interaction with the data rather than including too many menus and options [22].

3 View Coordination

Having determined the user requirements for our HotelFinder mobile-device and large-display multi-device environment, the next stage was consider the different options for coordinating selections on different device displays. The result of a selection, also known as a data-brush, can either highlight, label or filter elements of the data. The different options considered for coordinating selections between devices used in our HotelFinder application are as follows.

Independent displays. Meaning that devices are not coordinated and each device responds independently to its own user interaction. This would support independent working on individual devices, but if a user wanted to share a selection made on their own device they would need to repeat the selection on the main display.

Complete coordination. This means that any selection made by any user on any device would automatically appear on all connected devices. Effectively the connected devices would act like a single device with fully coordinated views on multiple screens.

Automatic Coordination on main display (AS). This would mean selections made on mobile devices being automatically sent to the main device but not other mobile devices. Users would be able to view the other users' selections on the main display but not on their own personal mobile device. The main device would act as a shared space showing either the latest user selection or the union of all user selections.

Manual send and retrieve (MS-MR). A forth option is provide users some action by which they are able to send selections to the main device or retrieve selections from the main device onto their personal devices. This has the disadvantage of adding an additional step for each user if they want to share a selection. The advantage is that it offers more control over the timing and content of view coordination events.

Automatic send and manual retrieve (AS-MR). The final option considered is for user selections to be sent to the main display automatically with an explicit action to retrieve selections from the main display. This option should work like *Automatic Coordination on the Main Display* allowing the user move quickly between independent working on their private device and collaborative working on the main device, with advantage that they are able to move selections made by the other user to their own device through the large shared display.

These different options are implemented in our prototype HotelFinder application and evaluated according to the metrics derived from our user requirements analysis.

4 Prototype Design

The prototype HotelFinder application is shown in figures 1 to 3. The interface runs on a large display with any number of connected mobile devices. The smart-phones can be connected to the large display by scanning a QR code to initiate an android Socket connection which facilitates communication over a shared Wi-Fi connection.

The mobile display of our prototype (see figures 1 and 2) is designed according to the guidelines for interactive mobile visualization presented by Craig et al [23]. The interface uses a horizontal orientation so that the device can be held in both hands with the user selecting items with their thumbs. When items at the edge of the display are selected to be labelled, labels are displayed toward the center of the display so they are not obscured by the user's thumbs. Buttons aligned along the right hand side of the display allow the user to choose interaction tools (to label or select hotels), switch between the scatter-plot and the map view, or retrieve other users' selections from the main display.

Our large-display view is shown in figure 3. This uses multiple-linked views of the data with a map view on the left zoomed into the current user selection. A smaller map in the top right corner provides an overview of the data. A scatterplot view of hotel room-rate against hotel-rating is shown in the bottom right of the large-display view to give the user an indication of factors such as hotel quality and value-for-money.

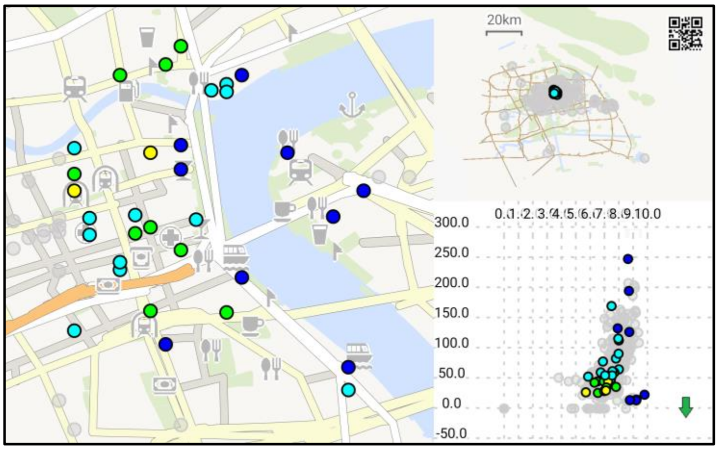

Figure 3: Large-display interface.

Having previously considered the relative advantages and disadvantages of different methods of coordinating user selections on different devices (discussed in section 3) we decided to implement four different methods in order to evaluate them to determine which works best for potential users. These are *no coordination between devices*, *complete coordination* (where all selections appear on all devices), *coordination on the large display* (where all selections appear on the large display) *and automatic send with manual retrieve* (AS-MR). The results of the evaluation are discussed in section 5.

Figure 1: Mobile device interface with the map zoomed out to show all of Shanghai with the labelling tool (left) and zoomed in to show the airport (right).

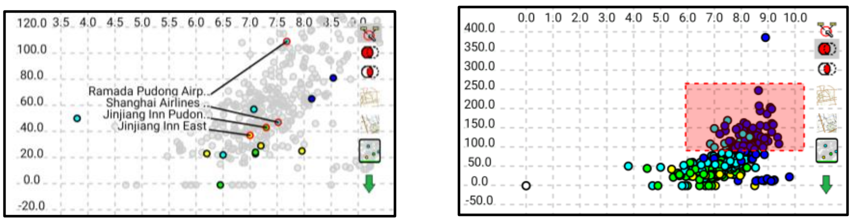

Figure 2: Mobile interface with the scatter-plot used to label (left) and select hotels (right).

5 Evaluation

In our evaluation we tested the overall utility of the proposed method and compared four different methods for of coordinating user selections on different devices as discussed in section 3. This involved a task-based analysis session followed by a questionnaire and interview session based on the factors our potential users consider ed important for multi device collaboration as described in section 2.

The evaluation involved twenty-four users in total and did not include any of the users included in our original requirements analysis. The users were divided into four groups each with three members. The sample included sixteen males and eight females all between ages of twenty and twenty-five. Each group was asked to find a suitable hotel with a different type of view coordination and according to a different criteria (such as attending a football match, sight-seeing, or attending a business conference). Each group used the different types of coordination in a different order spending approximately 15 minutes testing each configuration making up around 1 hour 30 minutes in total for testing (including the time taken for instructions as well as time taken to fill out the questionnaire and a short group discussion). Task criteria and methods for view coordination were randomized so that no set of criteria would be used with the same view coordination more than one time.

The methods for coordinating views were rated according to the users' response to questions asking them how much they agreed with a statement related to each factor considered important for multi-device collaboration. The seven statements were as follows.

Communication. The environment facilitates communication within the group.
Harmony. Interaction between group members is harmonious.
Inclusion. The interface encourages all members of the group to be involved.
Learnability. The interface is easy to learn.
Ease of Use. The interface is easy to use.
Effectiveness. The interface helped us to find the right hotel.
Satisfaction. I would be encouraged to use this type of interface again.

In order to analyze the results each answer was given a numeric value. A score of -2 was given for a response of 'strongly disagree', -1 for 'disagree', 0 for 'no opinion',1 for 'agree' and 2 for 'strongly agree'. The average value for each type of interaction was calculated from these values and the results tabulated.

It can be seen from the collated results (Table 1) that coordination on the main display, with and without manual retrieval of selections from the large display, tends to score higher for the metrics determined by our focus group. AS-MR scores slightly higher for the metrics related directly to collaboration but slightly lower for learnability as it took the users some time to familiarize themselves with the *retrieve* button. Overall effectiveness and satisfaction were highest for the AS-MR method. Ultimately the users felt that this method allowed them to switch between independent and collaborative working most effectively. It was felt to make working more efficient and less disruptive when the interest of different users diverged.

The complete coordination method scored badly for most metrics apart from communication. This is perhaps because having all the devices fully coordinated compelled the users to work together as if they were working on the same device. The users did not however feel that this type of working was particularly effective or satisfying.

Table 1. Different view coordination methods rated according to factors considered important for multi-device collaboration

Factor	None	Complete	Main display	AS-MR
Communication	-1.00	1.08	1.33	1.50
Harmony	0.17	-0.33	1.42	1.42
Inclusion	-0.42	-0.83	1.17	1.25
Learnability	0.25	-0.25	0.58	-0.08
Ease of Use	0.08	-0.50	0.50	0.25
Effectiveness	0.75	-0.67	0.83	1.33
Satisfaction	-0.25	-0.75	1.25	1.33

The devices running without view coordination scored reasonably for most factors apart from communication and satisfaction, the users felt that they could certainly achieve the task this way but they didn't feel that the working this way was particularly easy or satisfying and it certainly wasn't considered conducive to teamwork. It is notable that no-coordination is considered preferable to complete coordination but not as good as coordination only on the main display either with or without being able to manually retrieve another users selection.

6 Conclusion

This study has allowed us to develop and evaluate alternative view coordinate methods for linked smart-phone and large-display multi-device environments. Critically, we discovered how selections made using different displays can be coordinated in order to facilitate different degrees of autonomous working when user-selections are disjunct, and closer collaboration when the users' area of interest overlaps. This involves different types of selection made by users on individual private mobile devices being combined on the main public display with users als having the option of pressing a button to retrieve another user's selection from the main display in order to collaborate by refining the selection on their mobile device. We called this the automatic-send manual-retrieve method (AS-MR) and would recommend this for similar applications.

In general our results demonstrate the power of multi-device information visualization to facilitate collaborative working in a multi-user multi-device environment. In the future we plan to further develop our methodology by looking at different methods for showing different user selections in the main display and working with different applications (with different numbers and types of users) using the same mobile-device and large-display set-up.

Acknowledgements

The work presented in this paper was supported by Xi'an Jiaotong Liverpool University Key Program Special Fund project KSF-E-10.

References

[1] S. D. Scott, T. Graham, J. R. Wallace, M. Hancock, and M. Nacenta, "Local Remote Collaboration: Applying Remote Group AwarenessTechniques to Co-located Settings," in *Proceedings of the 18th ACM Conference Companion on Computer Supported Cooperative Work & Social Computing*, 2015, pp. 319-324.

[2] B. Ens, R. Eskicioglu, and P. Irani, "Visually Augmented Interfaces for Co-located Mobile Collaboration," in *Distributed User Interfaces*, ed: Springer, 2011, pp. 169-176.

[3] K.-Y. Chung, "Recent trends on convergence and ubiquitous computing," ed: Springer, 2014.

[4] M. Satyanarayanan, "Mobile computing: the next decade," in *Proceedings of the 1st ACM workshop on mobile cloud computing & services: social networks and beyond*, 2010, p. 5.

[5] P. Isenberg, D. Fisher, S. A. Paul, M. R. Morris, K. Inkpen, and M. Czerwinski, "Co-located collaborative visual analytics around a tabletop display," *IEEE Transactions on visualization and Computer Graphics,* vol. 18, pp. 689-702, 2012.

[6] J. Seifert, A. Simeone, D. Schmidt, P. Holleis, C. Reinartz, M. Wagner*, et al.*, "MobiSurf: improving co-located collaboration through integrating mobile devices and interactive surfaces," in *Proceedings of the 2012 ACM international conference on Interactive tabletops and surfaces*, 2012, pp. 51-60.

[7] X. Huang, P. Craig, H. Lin, and Z. Yan, "SecIoT: a security framework for the Internet of Things," *Security and Communication Networks,* vol. 9, pp. 3083-3094, 2016.

[8] Y. Sun, R. Bie, P. Thomas, and X. Cheng, "Advances on data, information, and knowledge in the internet of things," ed: Springer, 2014.

[9] S. S. Salim, "A systematic review of shared visualisation to achieve common ground," *Journal of Visual Languages & Computing,* vol. 28, pp. 83-99, 2015.

[10] C. Gutwin and S. Greenberg, "The mechanics of collaboration: Developing low cost usability evaluation methods for shared workspaces," in *Enabling Technologies: Infrastructure for Collaborative Enterprises, 2000.(WET ICE 2000). Proeedings. IEEE 9th International Workshops on*, 2000, pp. 98-103.

[11] S. D. Scott and S. Carpendale, "Theory of tabletop territoriality," in *Tabletops-horizontal interactive displays*, ed: Springer, 2010, pp. 357-385.

[12] S. G. Sakamoto, L. C. de Miranda, and H. Hornung, "Home control via mobile devices: State of the art and hci challenges under the perspective of diversity," in *International Conference on Universal Access in Human-Computer Interaction*, 2014, pp. 501-512.

[13] J. B. Kennedy, K. J. Mitchell, and P. J. Barclay, "A framework for information visualisation," *ACM SIGMOD Record,* vol. 25, pp. 30-34, 1996.

[14] P. Craig, "Interactive animated mobile information visualisation," presented at the SIGGRAPH Asia 2015 Mobile Graphics and Interactive Applications, Kobe, Japan, 2015.

[15] P. Craig, N. Roa-Seïler, A. D. O. Cervantes, M. P. T. Velasco, and M. R. García, "Information Visualization for the Collaborative Analysis of Complex Data," in *1st Conference on Research and Partnership for Development*, 2013.

[16] P. Craig, A. Cannon, J. Kennedy, and R. Kukla, "Pattern browsing and query adjustment for the exploratory analysis and cooperative visualisation of microarray time-course data," in *International Conference on Cooperative Design, Visualization and Engineering*, 2010, pp. 199-206.

[17] P. Craig and J. Kennedy, "Concept Relationship Editor: A visual interface to support the assertion of synonymy relationships between taxonomic classifications," in *Visualization and Data Analysis 2008*, 2008, p. 680906.

[18] Z. Shakeri Hossein Abad, C. Anslow, and F. Maurer, "Multi surface interactions with geospatial data: A systematic review," in *Proceedings of the Ninth ACM International Conference on Interactive Tabletops and Surfaces*, 2014, pp. 69-78.

[19] P. Craig, X. Huang, H. Chen, X. Wang, and S. Zhang, "Pervasive Information Visualization: Toward an Information Visualization Design Methodology for Multi-Device Co-located Synchronous Collaboration," in *Pervasive Intelligence and Computing (PICOM)*, 2015, pp. 2232-2239.

[20] J. Nielsen and R. Molich, "Heuristic evaluation of user interfaces," in *Proceedings of the SIGCHI conference on Human factors in computing systems*, 1990, pp. 249-256.

[21] J. C. Roberts, P. D. Ritsos, S. K. Badam, D. Brodbeck, J. Kennedy, and N. Elmqvist, "Visualization beyond the desktop--the next big thing," *IEEE Computer Graphics and Applications,* vol. 34, pp. 26-34, 2014.

[22] B. Lee, P. Isenberg, N. H. Riche, and S. Carpendale, "Beyond mouse and keyboard: Expanding design considerations for information visualization interactions," *IEEE Transactions on Visualization and Computer Graphics,* vol. 18, pp. 2689-2698, 2012.

[23] P. Craig, "Interactive animated mobile information visualisation," in *SIGGRAPH Asia 2015 Mobile Graphics and Interactive Applications*, 2015, p. 24.