

Column Major Pattern: How Users Process Spatially Fixed Items on Large, Tiled Displays

Anton Sigitov

Bonn-Rhein-Sieg Univ. of Applied Sciences
Sankt Augustin, Germany
anton.sigitov@h-brs.de

Oliver Staadt

University of Rostock
Rostock, Germany
oliver.staadt@uni-rostock.de

André Hinkenjann

Bonn-Rhein-Sieg Univ. of Applied Sciences
Sankt Augustin, Germany
andre.hinkenjann@h-brs.de

Ernst Kruijff

Bonn-Rhein-Sieg Univ. of Applied Sciences
Sankt Augustin, Germany
ernst.kruijff@h-brs.de

ABSTRACT

Large, high-resolution displays demonstrated their effectiveness in lab settings for cognitively demanding tasks in single user and collaborative scenarios. The effectiveness is mostly reached through inherent displays' properties - large display real estate and high resolution - that allow for visualization of complex datasets, and support of group work and embodied interaction. To raise users' efficiency, however, more sophisticated user support in the form of advanced user interfaces might be needed. For that we need profound understanding of how large, tiled displays impact users work and behavior. We need to extract behavioral patterns for different tasks and data types. This paper reports on study results of how users, while working collaboratively, process spatially fixed items on large, tiled displays. The results revealed a recurrent pattern showing that users prefer to process documents column wise rather than row wise or erratic.

CCS CONCEPTS

• **Human-centered computing** → **User studies; Empirical studies in HCI;**

KEYWORDS

Fixed spatial data; Information interaction; Tiled displays; Co-located work; User Study

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1 INTRODUCTION

Large display environments like high-resolution, tiled displays are highly suitable for co-located collaboration. The enlarged display real estate provides enough room to accommodate synchronous activities of multiple users. While approaching complex tasks, users can fluidly adjust the tightness of collaboration through allocation, shifting, merging, and splitting of physical and virtual workspace areas. The vast number of pixels allows for visualization of complex datasets making it possible to display high-resolution details in the context of an overview. Promoting embodied interaction by means of physical navigation and gestures, the displays enable (a) establishment and maintenance of correspondences between users' spatial position/orientation and visualized data elements, (b) the use of virtual and physical landmarks for objects finding, as well as (c) increasing of workspace awareness for better work coordination [1, 8]. Finally, systems incorporating large displays often implement a whiteboard or tabletop metaphor with novel interaction techniques and devices to resemble well-known collaboration principles used in real-life communication [6, 12].

Yet, datasets continue to grow in all application domains making analysis and sense making tasks even more complex, while displays' size and pixel density reach the limits of humans' visual acuity. This raises the need for new approaches of user support. One possibility to ensure such support is to improve user interfaces. For instance, intelligent user interfaces [10] driven by an artificial intelligence could be utilized. These interfaces will understand user activities in the context of the task and predict users' intentions. Based on the prediction, the system can pre-calculate complex visualizations, load necessary data, or pre-calculate possible next steps of the user and execute them beforehand. To build better interfaces for large, tiled displays, however, we need to acquire understanding of how such displays and their properties (e.g. display size, bezels, curvature, etc.) affect users' work, users' behavior, and user-information interaction.

In our study, we observed users working collaboratively on fixed-position data in front of a large, tiled display. Among other findings, we detected a virtual navigation pattern of how users process spatially fixed items. The analysis revealed that users navigated significantly more often column wise in comparison to row wise or erratic navigation. We believe this insight might help software engineers to implement better intelligent interfaces.

2 RELATED WORK

In this section we provide a brief overview of related studies that investigated effects of large, tiled displays on users' effectiveness, efficiency, and behavior.

Ball et. al [3] investigated what effect different display sizes have on users' behavior and task performance. They found that increased display size caused increase in physical navigation and better performance time, thus having impact on users' behavior.

Andrews et. al [1] compared how users conduct a sense making task in front of large, tiled displays and in front of a common desktop display. They observed that users made extensive use of space for management of documents and applications.

Liu et. al [9] investigated what effects display size and navigation type have on a classification task. They compared physical navigation in front of a large display with virtual navigation on a common desktop display. The study revealed that desktop displays are more suitable for easy tasks, while large, high-resolution displays is significantly more efficient for difficult tasks.

Bi et. al [4] investigated effects of tiled display interior bezels on user performance and behavior by visual search, straight-tunnel steering, and target selection tasks. Three types of large displays were simulated and compared with each other: 1x1 - display with no interior tiles; 2x2 - large, tiled display consisting of four 40" display units; 3x3 - large, tiled display consisting of nine 26" display units. They found that interior bezels did not have impact on visual search, and target selection performance. Both tasks utilized fixed-position items. On the other hand, interior bezels hindered straight-tunnel steering performance and affected steering behavior. Moreover, they observed that users tend to apply a grid-by-grid search strategy, as an entire surface was divided into grids.

Wallace et. al [15] investigated how bezels impact magnitude judgement, an important aspect of perception especially for applications with spatially fixed data. They detected an increase in judgement error for conditions where bezels were wider than 0.5 cm. In a subsequent study, Wallace et. al [14] investigated how the presence and width of interior bezels impacts visual search performance across tiled displays. They could not detect significant differences in visual search time, though, they found that participants were more accurate in test conditions where targets were split across a bezel. They hypothesized that this improved performance was ascribed to a change in the user's behavior: the participants performed more accurate two-phase search.

Ball and North [2] observed and analyzed users' actions in front of a high-resolution tiled display. They detected that most users have found bezels inconvenient and irritating. Yet, users tended to use bezels to partition the display into regions with specific semantics and dedicated these regions for certain applications.

There are several other studies that investigated effects of large, high-resolution displays on users' performance at different tasks (e.g. [13, 16]). In our study, however, we were more interested in how users interact with data so we could extract behavioral patterns. Such behavioral patterns might be useful for improving user interfaces that in a trivial case will provide a more thorough arrangement of visual elements, and in an advanced case will be able to predict users' next move.

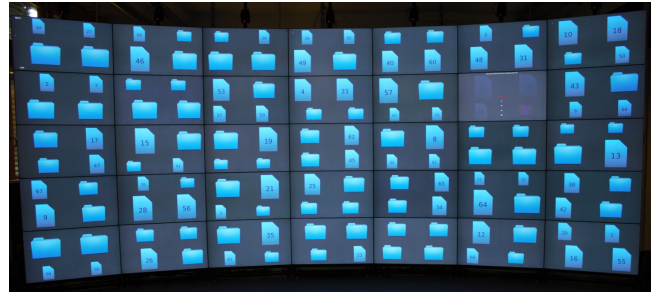


Figure 1: Visual representation of the task: 140 symbols of folders and documents representing unprocessed and processed question. The window in the top right corner shows a question with proposed answers.

3 STUDY

In our study, we investigated users' behavior during a collaborative task in front of a large, high-resolution, tiled display. In this paper, we present results regarding users' behavior in the context of fixed-position items processing. During the study, we gathered quantitative data encompassing participants' position in front of the display (logged every 100 milliseconds), pointer positions (logged on every position change), and task related system events like opening of a question, answering of a question, connection of documents etc.

3.1 Task

The task resembled the facts gathering activity. This activity is an integral part of a typical visual analytics task that involves processing of multiple documents (e.g. [1, 7]). Since our focus was on fixed spatial data, the documents in our task had fixed positions on the display. A real-world use case for such scenario, might be a situation, where analysts must investigate a series of events at specific geographic locations (e.g. investigation of home burglaries).

During the task, the participants had to process 70 documents. For each document the participants had to open it and answer the contained question. In total, 140 fixed-position symbols were shown to the participants: 70 symbols were folder symbols while other 70 symbols were document symbols with IDs (see Figure 1). Symbols varied in size and had fixed positions. Each display unit contained four symbols. The symbols were placed in a way that no bezels occluded any symbol. The folders represented unanswered questions, while documents represented answered questions. To answer a question the participants had to choose from four proposed answers the correct one. Alternatively, they could close the question to answer it later. Once a question was answered correctly its' folder symbol was exchanged for the document symbol with a correct ID, otherwise the document symbol with an incorrect ID was shown. The system did not allow to re-answer questions. No time constraint was set and the task ended as soon as all questions were answered. The system notified participants of task completion through background color change.

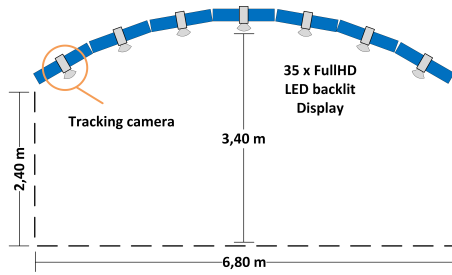


Figure 2: Apparatus: a curved display built of 35 Full HD displays with 7 tracking cameras on it that allow for tracking in front of the display within an area of around 20 square meters.

3.2 Apparatus

The study was performed at a large curved tiled display (henceforth display) comprising 35 LCD displays (henceforth display units) ordered through a seven (column) by five (row) grid. Each column had a relative angle difference of 10 degrees along the Y-axis to adjacent columns, as such creating a slight curvature (see Figure 2). Each display unit had a bezel of less than three millimeters, minimizing the visual rim effect. The displays units were 46" panels with a 1080p resolution, resulting in a total of 72 megapixels.

We used an array of seven infrared cameras (see Figure 2) together with head-worn helmets to track user positions within an area of around 20 square meters directly in front of the display. For interaction purposes, two available smartphones (LG Nexus 5X and Acer Liquid E700) with similar performance characteristics were utilized.

3.3 Participants

The experiment was performed with 12 groups with two randomly assigned participants each, aged between 18 and 39 years ($M = 25.08$; $SD = 4.90$), with normal or corrected-to-normal vision. There were 11 female participants and 13 male participants. The participants were paid for taking part in the experiment.

3.4 Results

At the beginning of the task, 2 out of 12 groups decided to work tightly and process the documents mutually. Both groups started on a random display unit, switched, however, soon to the most left/right column, and proceeded the documents in a column by column manner. Figure 3 (bottom) exemplifies the behavior, since the participants opened documents alternately the pointer position maps of individual users complement each other. The remaining 10 out of 12 groups went for divide and conquer strategy, and partitioned the display into the "left" and the "right" regions. Each participant oversaw one region depending on his spatial position relative to the display and to the partner. No distinct boundaries between these two regions were observed. Within the region. Figure 3 (top) depicts the behavior.

While participants proceeded with solving questions, we could recognize a recurrent behavior. Multiple participants tried to solve all questions inside one display unit before moving to the next one.

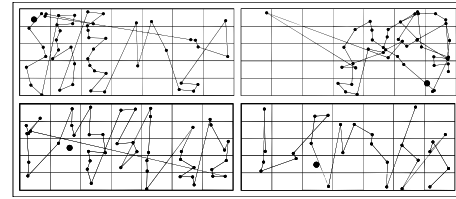


Figure 3: Logged pointers' positions during OpenTask-Events, each line connects two consecutive events: (top) participants A (left) and B (right) working loosely; (bottom) participants A (left) and B (right) working tightly.

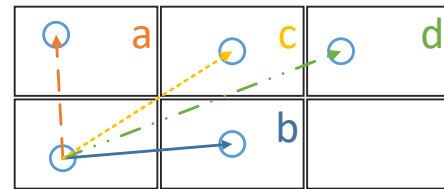


Figure 4: Transition types: (a) direct vertical neighbor; (b) direct horizontal neighbor; (c) indirect neighbor; (d) jump.

Moreover, movement between display units was column oriented. For example, the participant started with the topmost display unit of the leftmost column, solved all the questions inside it, and moved the pointer to the display unit beneath the current one. Working in this manner the column was processed. Next, the participant moved the pointer to the column on the right and continued in the same manner, starting either again from the top or staying at the bottom and working upwards.

However, within the groups that worked loosely the workflow did not last to the end of the task, but rather until participants met in the middle of the display. From there, participants either switched the sides to answer the questions left by their partner, or started to work tightly-coupled and answered remained questions mutually. To compare different strategies for virtual navigation we logged what documents on what display units and at what time were opened. We classified each transition from one display unit to another into four groups (see Figure 4):

- Direct vertical neighbor - the participant transitioned to a display unit direct above or beneath the current display unit.
- Direct horizontal neighbor - the participant transitioned to a display unit direct to the left or direct to the right of the current display unit.
- Indirect neighbor - the participant transitioned to a diagonally adjacent display unit.
- Jump - the participant transitioned to a non-adjacent display unit.

To examine if there are any differences between occurrences of individual virtual navigation strategies, a Friedman test was carried out. The result showed a significant difference, $\chi^2(3)=40.269$, $p < 0.001$. Dunn-Bonferroni post hoc tests were carried out and revealed significant differences between the types: indirect neighbor and jump ($p = 0.026$), indirect neighbor and direct vertical neighbor (p

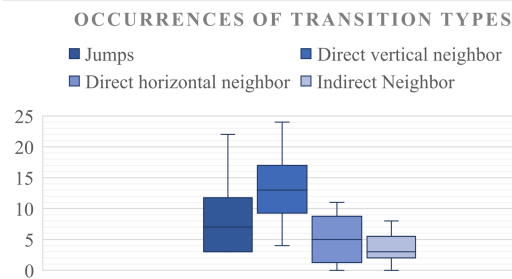


Figure 5: Occurrences of transition types: Y-axis represents number of transitions.

< 0.001), direct horizontal neighbor and direct vertical neighbor ($p < 0.001$), jump and direct vertical neighbor ($p = 0.015$). Thus, we can conclude that the participants navigated significantly more often vertically (direct vertical neighbor) in comparison to other patterns. The tendency for direct vertical neighbor pattern is also visible in the box plot diagram (see Figure 5). We also questioned the participants regarding interior bezels. 23 participant stated that the bezels were barely perceived and not distracting.

4 DISCUSSION

We have several explanations for the observed column major pattern. These are based on psychological and physical factors.

One possible explanation could be that visual boundaries of display regions formed by bezels induced feeling of element grouping according to the gestalt principle of common region [11]. Thus, participants would like to finish work in "one" region before moving to the next one. Similar perception of the display area was observed by Andrews et. al [1] and Grudin [5]. Such workflow would also ease tracking of progress for users, since the display could be used as external memory [1] in that case.

Column oriented movements could be motivated by large display size in conjunction with tendency to reduce physical navigation, as row oriented workflow would require more walking. Like with display units, column oriented movement allows easier tracking of progress for participants and reduces search activity. For example, the participant always knows that all questions left to the column she is currently working on are processed. Since the pattern was observed by tightly working groups as well as by loosely working groups, we can exclude the possibility of second user presence affecting the pattern.

Although, the interior bezels were barely perceived by most of the participants, they seemed to have a vigorous effect on the participants' behavior. Thus, interior bezels could be exploited by user interface designers to better support users or direct them in a desired way. For instance, one can group elements of a graph using bezels to highlight their relationship. Moreover, knowing what effect the bezels and display size have on the users' behavior, designers become able to predict users' actions, and as a result build more intelligent interfaces. For instance, the system can pre-load complex data, pre-calculate a complex visualization, or do some other pre-processing for those elements which the user will open next.

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