How Screen Transitions Influence Touch and Pointer Interaction Across Angled Display Arrangements

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ABSTRACT
Digital office environments often integrate multiple displays in a variety of arrangements. We investigated the combination of a horizontal and a directly connected vertical display, which together form a digital workspace. In particular, we were interested in the effect of the physical transition (bezel, edge or curve) on dragging. In a study participants performed dragging tasks across both display planes with direct touch as well as a pointing device. Contrary to our expectations, we found no significant effect on task completion time. Only regarding accuracy the curved transition performed better than edge and bezel. Interestingly, the subjective judgment did generally not match the objective results. These findings suggest that we need to rethink our understanding of display continuities in terms of usability as well as user satisfaction.

Author Keywords
Display connection; interactive surfaces; transition; dragging; tabletops.

ACM Classification Keywords
H.5.2 [Information Interfaces and Presentation]: User Interfaces - Input Devices and Strategies;

General Terms
Design, Human Factors.

INTRODUCTION

In today's computerized offices, a variety of display arrangements can be found. While the most common combination of two or more displays is a horizontal row, other display combinations are possible. An assembly of conventional displays will mostly involve crossing (a) a screen bezel [15] or (b) a hard edge [4] connecting the displays. Recently also (c) a curved segment was proposed as a display connection [14, 16, 17]. Current research mainly focuses on the effects of screen bezels in horizontal display arrays [13]. Apparently, users tend to organize their data according to display borders, since these prevent the usage of combined displays as one large screen [2, 7].

CHI'12, May 5–10, 2012, Austin, Texas, USA.

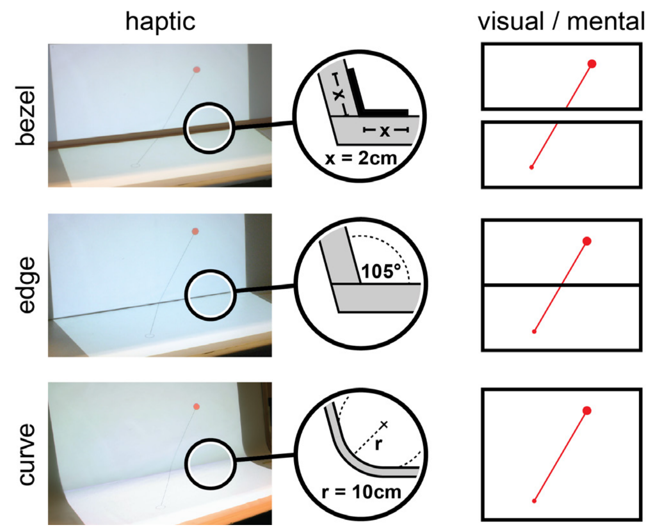

Figure 1: Three different connection types with different levels of haptic, visual and mental continuity: bezel, edge and curve.

Bezels affect both pointer and direct touch input. Pointer interaction is influenced by bezels as the pointer might jump from one display to the other in an unexpected way [3]. For touch interaction, the haptic continuity of the display arrangement is essential. Screen bezels of systems such as the Acer Iconia [1] present a clear obstacle for direct input while displays without such barriers offer a more continuous input [4]. Curved display combinations aim to maximize the degree of haptic continuity using a curved connection area [14, 16, 17].

We present a study in which we investigated the effects of these different connection types between two angled displays on touch and pointer interaction. We built three otherwise similar display setups with different connection types: a bezel, an edge and a curve (see Figure 1). Participants had to complete different dragging tasks across the connections. Against our expectations we did not find strong objective differences between the three setups. However, we identified several effects on the users' subjective perception of touch and pointer interaction across displays, which did not generally match the objective results. As a conclusion we propose to rethink the understanding of display connections and their influence on touch and pointer interaction.

RELATED WORK

As our work uses dragging tasks to judge direct and indirect input mechanisms on a large display, it largely draws on prior evaluations based on such tasks. Foley et al. proposed a taxonomy of general task types for graphical user interfaces [5]. Pathing tasks were fundamental in their description as they continuously involve time in contrast to simple positioning or orienting tasks. Forlines et al. used a dragging task to evaluate the difference between pointer and touch interaction on interactive surfaces [6]. Weiss et al. evaluated the effects of the curved connection on their BendDesk on touch input in different dragging directions [16]. Due to the underlying large interactive surface in our study we also considered the entire human arm as a chain of actuators as described by Guiard [8].

EVALUATION

We conducted a user study to examine the effect of the three different connection types (bezel, edge, curve) on dragging tasks across display borders. The following research questions were investigated: (RQ1) To what extent does the type of display connection affect the input accuracy? (RQ2) To what extent does the type of display connection affect the task completion time? (RQ3) To what extent does the type of display connection affect the subjective assessment of the display and the input?

Participants and Design

In order to keep all parameters other than the connection type fixed (overall: width: 120cm, internal angle: 105°; horizontal display: height 72cm, depth 35cm; vertical display: height 38cm), we used a reconfigurable display setup based on rear-projection and FTIR touch sensing. As the reconfiguration of the interactive surface took too long for a within-subject design we conducted a between-group study with *connection type* as the between-group factor. Each connection type was tested with 16 participants. Consequently, 48 people participated in the study (21 females and 27 males, aged between 22 and 35, 46 right- and 2 left-handed). We used touch as well as pointer interaction with two different task conditions (constrained, unconstrained). This combination of within-subject factors (*input*, *task*) was counterbalanced using a 4x4 Latin Square.

Task and Procedure

Each participant was initially seated centered in front of the display. They had an extensive training phase prior to the study, which included two runs of each *input* x *task* combination. Only the third run was used for statistical analysis. In the end, each participant completed a questionnaire based on ISO 9241-9:2000 [10].

Connection Type

To emulate the most common connection – two monitors placed with bezels next to each other – our (1) *bezel* setup consisted of two acrylic plates. We used a wooden strip (height 4cm, thickness 3mm) within the connection area to separate both display planes. By removing the strip, we created a direct connection between both displays with an (2) *edge*. For the third type of transition we exchanged the acrylic plates. The new plate had a continuous (3) *curve* with a radius of 10cm connecting both planar display segments (see Figure 1).

Input

We tested direct (1) *touch* interaction with FTIR sensing and indirect (2) *pointer* interaction with an optical mouse. To allow dragging a virtual object between the display planes even without a direct connection, we combined two interaction techniques for both inputs: Flick [12] and Stitching [9]. The dragged object could be flicked across the connection and picked up again afterwards. In addition users could beam the object to the other surface in a small area next to the connection similar to the pen-based Stitching described by Hinckley et al. [9]. The bezel in the respective setup consisted of a wooden strip mounted in front of the edge connection. Consequently the pointer had to bypass the occluded display area behind the bezel to simulate a real bezel. As we did not want the resulting pointer movement to suffer from a warping effect, but rather be fluid and understandable, we derived the last-known pointer movement direction near the bezel and beamed the pointer to the other display in that direction similar to the Mouse ether technique [3]. This enabled dragging the object fluently across the bezel connection.

Dragging Tasks

We varied the task conditions for each input modality (see Figure 2). In the first task the user had to drag an object from a starting point on the horizontal plane to a target area on the vertical plane and vice versa (1) without any constraints. In the second task the users were (2) constrained as they were asked to follow the shortest virtual path shown between both points as fast and accurately as possible. No further constraining mechanisms (e.g. a constraining force) were used. To obtain meaningful data we used a two-way path design based on ISO 9241-9:2000 [10]. In the bezel condition the length was extended by the height of the bezel to assure that distances of equal length had to be covered on the display itself.

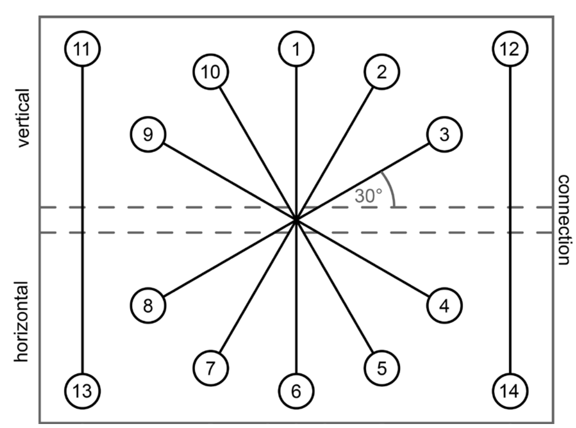

Figure 2: Arrangement of the dragging paths across the display: participants dragged from each point to its counterpart - with and without a constraining path shown.

Measures

There were two sources of objective data. In order to assess the accuracy, the path deviation (PD) was calculated. It is defined (as in MacKenzie et al. [11]) as the mean distance between the user input and the shortest virtual path along a line perpendicular to that path, and it is measured in pixels. Second, the task completion time (TCT) was measured. It is defined as the time between starting the dragging motion and releasing the object in the target area.

In addition, post-questionnaires were used to assess the participants' opinion regarding display configuration and in particular the connection types. We used 5-point Likert scales ranging from '1' being the best to '5' being the worst rating for all questions.

Statistical tests and analysis

All objective data (PD, TCT) were analyzed with a 3x2x2 analysis of variances (mixed ANOVA) with the between-groups factor *connection type* and the within-subject factors *task* and *input.* Subjective ratings were combined into three categories: 'acceptable' ('1', '2'), 'neutral' ('3') and 'not acceptable' ('4', '5') for further analyses. To give a general overview we only report the subjective ratings with the help of the 'acceptable' category.

RESULTS

We combine and compare objective data as well as subjective ratings and observations in four categories: *accuracy*, *speed*, *convenience* and *further findings*.

Accuracy

For the accuracy in terms of PD we found a significant effect of the connection type, $F(2, 45) = 4.509$, $p<.05$. Post-hoc tests (Bonferroni) revealed a significant difference between edge (M=36.5px) and curve (M=27.9px) with $p<.05$. No other significant differences between the connection types (bezel: M=30.3px) were found for these conditions. Further investigations using a 3x2 mixed ANOVA only for the constrained task show significant differences of PD between curve and edge, $F(2, 45) = 201.883$, $p<.05$, for both inputs. There were also significant effects ($p<.05$) of task ($F(1,45) = 176.526$) and input x task ($F(1,45) = 15.320$) on user's accuracy. No further significant effects (e.g. connection type x input) were found.

The percentage of participants who rated the touch accuracy as "acceptable" on the entire display (bezel 62,5%, curve 56,3%, edge 37,5%) and within the connection area (bezel 31,3%, curve 31,3%, edge 12,5%) is in line with our measurements. Interestingly the ratings for mouse input are reversed: edge receives a lot of good ratings for the entire display and the connection area (81,3%/68,8%) while bezel (43,8%/37,5%) and curve (37,5%/43,8%) are rated worse.

Additionally we created plot diagrams from participants' input data. They show various effects of the connection and perspective: (1) We found deviations for touch input from the shortest virtual path for all connections in the unconstrained task just as Weiss et al. [16]. Beside this we also noticed that the dragging paths are much more scattered across the transition in the edge setup compared to curve and bezel. (2) With pointer input in the constrained task participants tend to drag along an inwards bulged trajectory in the upward direction (13-11 and 14-12, see Figure 2) on the horizontal display. Interestingly the trajectory is bulged outwards for the downward direction between the same points. (3) There is a general tendency towards curved trajectories in both task conditions and all task axes with pointer input despite the centered vertical axes (1-6, 6-1, see Figure 2). We assume that this tendency, which is stronger for the unconstrained task as expected is caused by two factors. First, perspective distortion on the large display seems to be mainly responsible as all except the centered task axis are affected. Second, a problem with users' mental model of indirect pointer movement seems to have an influence on the trajectories. Obviously pointer interaction on the horizontal display plane is much more affected than on a vertical display to which users are accustomed. Further pointer movement was in line with common knowledge (e.g. target overshoots).

Speed

Although the mean TCT for each connection type tended to decrease from bezel via edge to curve, we didn't find a significant effect of connection, $F(2, 45) = 2.415$, $p>.05$. But as expected there was a significant effect of task ($F(1,45) = 41.057$, $p<.05$). Participants completed the unconstrained task (M=9869.4ms) faster than the constrained one (M=11705.1ms). Additionally we found a significant effect of input ($F(1,45) = 222.001$, $p<.05$). Pointer input (M=8134.3ms) was faster than touch input (M=13440.2ms) which might be caused by the relatively small movement of the mouse compared to direct touch.

Despite the lack of a significant difference, the perceived interaction speed was rated differently. Mouse input was generally rated acceptable concerning the entire display (curve 93,8%, edge 93,8%, bezel 81,3%) and the connection area (edge 93,8%, bezel 81,3%, curve 81,3%). However, more participants were satisfied with a curve regarding the speed of touch input on the entire surface (curve 75%, edge 50%, bezel 37,5%) as well as the connection area (curve 37,5%, edge 18,8%, bezel 12,5%).

Convenience

Curve is rated best (75,0%) followed by edge (56,3%) and bezel (31,3%) regarding the oddness of transition for pointer and touch input (curve: 62,5%, bezel: 43,8%, edge: 6.5%). Asked about the haptic convenience within the connection area they preferred the curve to bezel and edge (curve 50,0%, bezel 37,5%, edge 25,0%). Bezel's bad ratings for the connection area might be caused by rather unnatural arm poses described in the next section.

Further Observations

In the edge setup users tend to keep contact with the interactive surface for the entire touch-based dragging task, even across the connection, although transition techniques

(Flick and Stitching) were introduced to them. It seems to encourage the users to interact as close to the edge as possible due to its visual output until the edge. This led to extreme finger and wrist poses during the dragging tasks in the connection area. In addition to a bent wrist, users had to rotate their arms to continue dragging through the transition. This rotation was obviously also done to avoid occlusion of the surface by the user's arm. Although there was no mention of increased arm or wrist fatigue these postures looked rather unnatural.

CONCLUSION AND FUTURE WORK

Our results reveal actual as well as perceived effects of the different connection types on cross-display interaction. We showed how the connection influences the user's perception of touch and pointer interaction and the way users interact across a connection. Based on the results of our study we argue for using a curved connection in angled display combinations for touch input. It received good subjective ratings, allows the highest dragging accuracy and avoids any hard visual breaks. In contrast to this there is no clear preference for pointer input as users rated all connections similarly using a mouse. Maybe the effect of the large planar display areas, which are quite similar to traditional displays normally used with pointer input outweigh the effect of the rather small connection area. Our study also revealed that the objective results regarding time and error rate are not necessarily in line with the subjective user ratings for the connections. Therefore we propose to not only rely on objective criteria such as accuracy or task completion time but also on the users' assessment of the display connection while developing new display setups.

Although a curved connection seems to be preferable compared to a bezel or an edge another display angle might influence the results. As the haptic break of an edge connection becomes smaller with an increased angle this could lead to different subjective results and even different accuracy measures. Consequently future studies definitely need to investigate this matter. It will also be interesting to investigate other aspects of such display combinations such as their size, curve radius and different transition techniques revealing their effects on usability and user satisfaction. In addition, we suggest investigating the influence of different haptic and visual continuities of display connections on user satisfaction with touch input. Connections with a low haptic continuity (e.g. an edge) but a comparatively high visual continuity might trouble the user. In contrast to this a bezel provides two separate display planes that are visually and haptically separated and therefore gets better ratings. As pointer input is not influenced by haptic continuity it is obviously not affected by this difference. Future studies with a rounded edge could provide further insights on this.

ACKNOWLEDGMENTS

We'd like to thank our patient study subjects for their time and the CHI reviewers for a fruitful rebuttal phase.

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