# Content Sharing Between Spatially-Aware Mobile Phones and Large Vertical Displays Supporting Collaborative Work

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**Abstract** Large vertical displays are increasingly widespread, and content sharing between them and personal mobile devices is central to many collaborative usage scenarios. In this chapter we present *FlowTransfer*, bidirectional transfer techniques which make use of the mobile phone's position and orientation. We focus on three main aspects: multi-item transfer and layout, the dichotomy of casual versus precise interaction, and support for physical navigation. Our five techniques explore these aspects in addition to being contributions in their own right. They leverage physical navigation, allowing seamless transitions between different distances to the display, while also supporting arranging content and copying entire layouts within the transfer process. This is enabled by a novel distance-dependent pointing cursor that supports coarse pointing from distance as well as precise positioning at close range. We fully implemented all techniques and conducted a qualitative study documenting their benefits. Finally, based on a literature review and our holistic approach in designing the techniques, we also contribute an analysis of the underlying design space.

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# 1 Introduction

Hardware advances are making very large vertical displays more common in a variety of scenarios. Thanks to their size, they support collaborative work [25]. At the same time, personal devices such as mobile phones have become ubiquitous over the last decade, as they allow people to conveniently manage their digital identities and content. In combination, the two device classes provide the advantages of both settings: among others, personalized interaction, on-demand data sharing, and collaboration. In this context, there is a need to be able to effectively copy and share digital content between mobile phones and large displays. Thus, it is not surprising that data exchange across such devices has been explored before (e.g., [15, 34, 38]). Still, important issues have not been sufficiently addressed, including seamless support for interaction at varying distances [3, 21], casual versus focused and precise interaction [31], the distinct support of multi-item transfer, and working with layouts on large displays.

This becomes evident when we consider that the context of a transfer operation directly influences the vocabulary of interactions. The following scenarios illustrate this: Single-item distant transfer using pointing [37] might be suitable when sitting in a meeting and close-range transfer by touching [35] is adequate for precise interactions. At the same time, a presenter at a software design review might prefer transferring a multitude of items in a predefined layout (Figure 1b), while people casually showing holiday photos might find the option attractive to 'spray' them on the large display in quick succession. Alternatively, they might like to select the images to show based on a map of photo locations (Figure 1c). In still other contexts (e.g., after brainstorming sessions), participants might want to transfer complete layouts to their mobile devices to preserve the spatial relationships between the different items. Finally, in the case of a public display showing product information (Figure 1d), one could imagine quickly transferring interesting groups of items using coarse pointing with the mobile phone.

Using a holistic approach, we explored the aforementioned challenges and scenarios to develop *FlowTransfer*, a set of five novel interaction techniques. Our exploration focuses on three main aspects: multi-item transfer, interactions at varying distances, and casual as well as precise interactions. In addition, the contributed multiway transfer techniques integrate item layout and require a minimum of gaze

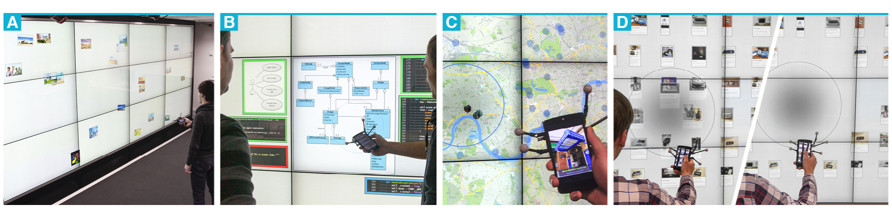


**Fig. 1** *FlowTransfer*, a set of bidirectional transfer techniques using the spatial display configuration. (a) Study setup. (b) Item layout *(Layout and SnapshotTransfer)*. (c) Metadata-based transfer *(RevealingTransfer)*. (d) Fast multi-item transfer *(JetTransfer)*.

switches [33]. Furthermore, they do not require a touch-sensitive display wall, since touch is not available or appropriate in numerous situations. The techniques all exploit spatially-aware mobile devices: by assuming devices that have knowledge of their location and orientation, we can exploit phone-based pointing and mid-air gestures, among other features. Accordingly, one of our contributions is a novel distance-dependent pointing cursor that supports physical navigation by allowing coarse pointing from distance as well as precise positioning at close range.

Besides the *FlowTransfer* techniques themselves, we contribute a fully functional prototype implementation as well as a qualitative user study. Finally, based on a careful analysis of prior work as well as our own experiences and studies, we present a comprehensive design space for content sharing techniques between large displays and mobile devices, which can inform the design and development of future systems. We conclude with a discussion of the implications of our design decisions.

## 2 Related Work

Interaction with large displays and personal mobile devices (e.g., content creation, content sharing, object manipulation) is an active research field. In the following, we discuss local and distant transfer techniques, which have been explored in prior work as well as research on distant pointing.

***Interaction with Large Displays.*** For a general introduction to interaction with wall-sized displays, we refer to overviews by Müller et al. on public displays [25] and Andrews et al. on data visualization [2]. Additionally, Marquardt et al.'s work on Gradual Engagement [24] provides a design framework for integrating the relative positions of the devices involved in cross-device interaction. A related notion is Greenberg et al.'s Proxemic Interaction (e.g., [14]), in which interactions are based on spatial relationships between people and devices. Ball et al. [3] examined Physical Navigation—moving the body for interaction—and found that locomotion significantly improves performance when interacting with large displays. Rädle et al.'s work on Navigation Performance [32] finds that the effects are most pronounced when the task exercises spatial memory, e.g., in navigation tasks not involving zooming. At the same time, Jakobsen and Hornbæk [18] found no advantages for locomotion; their task did not involve spatial memory.

***Data Transfer.*** Much of the work on cross-device data transfer considers single-item transfer in close proximity. Rekimoto's Pick-and-Drop [34] is early work on cross-device data transfer using a pen as interaction device. More recently, Schmidt et al.'s PhoneTouch associates touches on a large display with a mobile phone by correlating the phone's motion sensor signals, covering both the technology [35] and numerous interaction techniques [36]. In SleeD [42], von Zadow et al. use an arm-worn device; transfer involves touching the large display with the hand the device is strapped on. With WatchConnect, Houben and Marquardt [17] provide a toolkit for developing cross-device applications with smartwatches. Alt et al. [1] compare content creation for and exchange with public displays using multiple modalities, while Seifert et al. [38] introduce a number of interaction techniques that allow privately selecting the data to share before performing the actual transfer.

With regard to data transfer operations at a distance, several researchers investigated the use of the mobile device's camera [4, 5, 8, 9]. In Shoot and Copy [8], image recognition on the camera image is used to extract semantic data, while Touch Projector [9] and Virtual Projection [5] explore remote interaction through a live video image on a mobile device. Distant transfer using device gestures has also been investigated several times [12, 16]. Dachselt and Buchholz's Throw and Tilt [12] utilizes expressive gestures for data transfer, while Hassan et al.'s Chucking [16] is interesting because it also supports positioning of items on the large screen. Finally, CodeSpace [10] integrates distant transfer in an application case, using a depth-sensing camera to support positioning, and Jokela et al. [19] compare transfer methods. However, none of the above approaches sufficiently address layouts for transferred items or focus on transfer at varying distances and locations. To our knowledge, neither differences between casual or focused interactions nor gaze switches are focused on in prior work.

***Distal Pointing.*** Distal pointing allows selection and positioning of items and is therefore significant in our context. Hand pointing is investigated in early work by Bolt [7], and, more recently, by Vogel and Balakrishnan [40]. Nancel et al. investigated distant pointing using handhelds; the authors contribute several techniques for precise selection from a distance [27, 28]. In PointerPhone [37], Seifert et al. investigate the interactions possible when remote pointing is combined with interactions on the phone. Myers et al. [26] found that in distant pointing, precision suffers because of hand jitter. Most techniques that support positioning either live with this restriction (e.g., [7, 37]) or introduce a second step for improved precision (e.g., [9, 26, 27]). Particularly, Myers et al. [26] use the mobile phone's camera to copy an area of interest to the small display, allowing touch selection on the small display. Peck et al.'s work [30] is one of the few that combines pointing and physical navigation. Furthermore, Lehmann and Staadt [23] propose different 2D manipulation techniques that use varying interaction precision based on the user-display distance. To our knowledge, however, a cursor that maps distance to pointing precision has not been presented in prior work.

## 3 Development Process and Design Goals

As part of an iterative design process, we developed the concepts and improved our implementation supported by a preliminary user study. In this preliminary user study (12 participants, laboratory setting, sessions lasted around 60 minutes), participants tested an early prototype that supported two single and two multi-item transfer techniques and provided initial user feedback. Participants explored transfer techniques, performed technique-specific tasks such as transfer all images with specific features to the mobile device, and completed a questionnaire. Based on the results of this study and prior work, we specified formal design goals, refined our concept and developed an improved, fully functional prototype. Finally, a qualitative user study was conducted to evaluate the final implementation and verify its usefulness.

In the following, we present six design goals, referred throughout the paper as D1-D6. These goals informed our design; we examine the implications and results in our qualitative study and the discussion that followed. Of our six design goals four (D1, D2, D3, and D4) correspond directly to the three aspects (casual/focused interaction, interactions at varying distances, as well as multi-item transfer and layout) we focused on from the outset. The last two design goals (D5 and D6) are grounded in the preliminary study as well as our analysis of related work.

(D1) *Adapt to user's level of engagement*: The scenarios presented in the introduction show that users have different requirements and priorities in different situations (e.g., speed vs. precision). Therefore, we would like users to be able to "control the level to which they engage" [31]: our techniques should enable effortless and casual (e.g., coarse positioning) as well as focused (e.g., precise, exact selection on a crowded display) interaction.

(D2) *Support interaction at varying distances*: Related work shows the benefits of locomotion in terms of performance [3] and spatial memory [32]. Therefore, content sharing techniques should bring out the benefits of working at varying distances; they should work well with both the overview that users have at a distance and the detailed view they have when close to the display, and they should adapt seamlessly.

(D3) *Adapt to number of items transferred*: The scenarios mentioned above as well as transfer operations in conventional desktop systems show that considering both single-item and multi-item transfer is necessary to cover a wide range of use cases. Support for this is largely missing in the literature.

(D4) *Support item arrangement*: As illustrated by some of the scenarios and as we learned from desktop techniques such as drag and drop, item positioning and layout naturally complement data transfer. We assume that the huge workspace provided by large displays will make seamless positioning and layout support even more important. Furthermore, this aspect has not been investigated in the literature. Therefore, we aim to integrate layout functionalities into our techniques.

(D5) *Minimize gaze switches*: Gaze switches are an integral part of working with multi-display setups. However, our preliminary study as well as the literature [33, 39, 42] show that they are disrupting and time-consuming. Therefore, we aim to minimize the number of necessary gaze switches.

(D6) *Map user movements to appropriate parameters*: To develop both comprehensible and easy to remember techniques (and help to bridge the gulf of execution [29]), the devices' movement directions should correspond to changed parameters, thus avoiding a mental break between user movements and system reactions. Examples include mapping precision to the distance from the large display (corresponding with D2) or mapping an upwards flick on the mobile phone to transfer towards the large display.

## 4 FlowTransfer Techniques

To explore the space of cross-device data transfer with large displays, we developed five novel techniques. Besides the goal of developing individual techniques, we were interested in exploring the underlying design space. Therefore, we focused on the design goals described above during development.

The only single-item technique, *FlickTransfer*, is an incremental improvement on prior work and serves as baseline. With *JetTransfer*, *LayoutTransfer* and *SnapshotTransfer*, we present three techniques that work with groups of items and their arrangement (D3, D4). JetTransfer sequentially transfers a multitude of items to the large display, LayoutTransfer adds the possibility to evenly arrange items on the large display along a motion path upon transfer, and SnapshotTransfer preserves the layout of items on the large display when transferred to the mobile device. The final technique, *RevealingTransfer*, illustrates the combination of different techniques and allows selection of transferrable items based on predetermined locations.

All *FlowTransfer* techniques share a number of characteristics including: common feedback mechanisms, a unified approach for minimizing gaze switches (D5), and a new distance-dependent pointing cursor controlled by the mobile phone (representing the focus of interaction on the large display). Visual cues on the large display include an unobtrusive cursor visualization in the form of a shaded circular area (e.g., Figure 1d). To inform users of different application states, this cursor visualization dynamically makes use of different visual properties (e.g., border color for transfer activities, border width for current transfer rate). Furthermore, when transferring to the large display, a preview is shown at the destination (Figure 3a). We propose to blur this preview in order to avoid privacy issues in multi-user scenarios. To also address both privacy and visibility, the strength of this effect can depend on user positions. Items selected for transfer from the large display are highlighted (e.g., border color; Figure 3b). Finally, the prototype delivers vibrotactile feedback whenever the selection is changed and upon transfer.

The techniques are designed to allow users to focus on the large display, minimizing the need for gaze switches (D5). This precludes giving essential visual feedback on the mobile phone during transfer operations. For the same reason, we avoid traditional GUI elements such as buttons on the phone; instead, our techniques use touch gestures that can be performed while focusing on the wall. However, when transferring items to the large display, users will generally select the items to be transferred on the mobile phone for privacy reasons [38]. We expect the details of this to be application-specific. Possibilities include employing classical, widget-based techniques to select contiguous or non-contiguous ranges of items, or using search techniques to select items that satisfy desired criteria. In any case, we generally assume a single gaze switch after the selection.

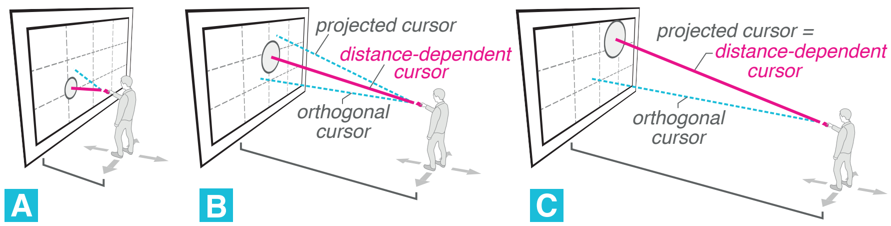


**Fig. 2** *Distance-dependent pointing cursor* at different user positions: (a) close distance, (b) intermediate distance, (c) overview distance.

## *4.1 Distance-dependent Pointing Cursor*

Central to transferring data to a large display is the specification of a target position. Building on previous work in distal pointing (e.g., [22, 23, 40]), we developed a *distance-dependent pointing cursor* that provides a smooth transition between projective and orthogonal pointing (Figure 2). It is designed to bring out the benefits of working at varying distances (D2) and compensate the effects of hand jitter [27]. The pointing cursor works using three distance zones: at overview distance (when they can see the complete display), users can directly point at a target (i.e., projective pointing or ray-casting; similar to PointerPhone [37]). At close distance, the orientation of the mobile is ignored and an orthogonal projection is used to determine the selected position, thus increasing precision of cursor control and reducing jitter. At intermediate distances, we interpolate linearly between the two projection methods (reducing motor space from 6 to 2DoF), thereby ensuring smooth transitions between the aforementioned zones. The goal was to allow users to employ various distances (D2) to implicitly transition between modes of control and thus determine the level of precision they require (D1, D6).

The cursor position is directly used as destination position when transferring items to the large display. In the opposite direction, we use an area cursor [20] to target items: The item closest to the center of the activation radius (e.g., visible in Figure 3a, right) is selected. Initial user feedback showed that this technique allows for coarse, less precise pointing (D1) when compared to simply selecting the image under the cursor, compensating for hand jitter. Finally, to support varying interaction distances (D2), the activation radius (size) of the cursor continuously scales with distance (Figure 2).

## *4.2 Individual Transfer Techniques*

This section details the proposed five data transfer techniques and discusses design implications. Please also refer to the accompanying video illustrating the dynamics of the interaction techniques[1].

[1] see https://imld.de/flowtransfer/

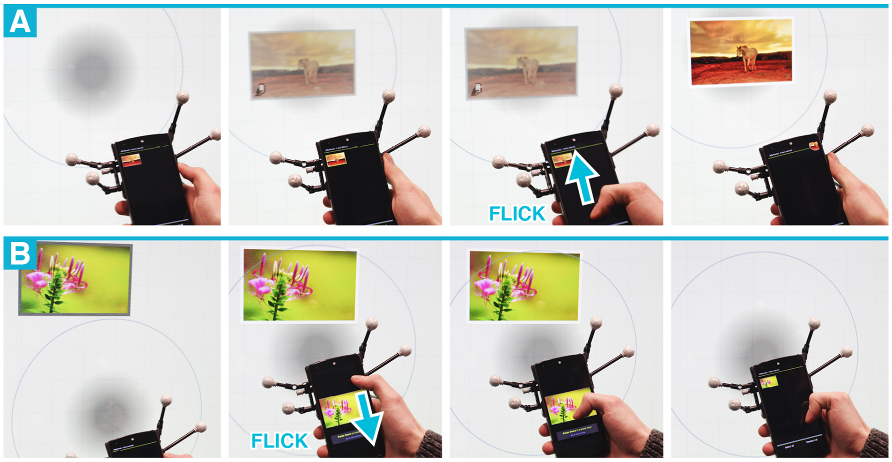


**Fig. 3** *FlickTransfer* is a state-of-the-art technique for single-item transfer.

***FlickTransfer*** is a simple technique for single-item transfer that uses phone pointing and flicks (swipes) on the mobile phone. To transfer an item to the large display, users first select it on the phone, then point the device towards the large screen and flick upwards (i.e., towards the destination) to initiate the transfer (Figure 3a). Conversely, flicking downwards transfers the currently selected item from the large display to the phone (Figure 3b). We considered alternative gestures, but the only significantly simpler solution—tapping the screen—does not allow the user to distinguish between transfer directions. To increase pointing precision, an additional damping mode can be activated by a hold before the flick gesture. In this mode, the pointing cursor movement is decreased greatly.

FlickTransfer is an incremental improvement over techniques presented in prior work (e.g., [10, 11]). The technique extends existing approaches by using our pointing cursor as well as the blurred preview, and providing an additional damping mode. Development of this technique allowed us to focus on and refine the common feedback mechanisms, the operation of the pointing cursor, and the minimization of visual attention switches. In FlickTransfer, precision and thus level of engagement (D1) can be controlled by moving towards or away from the screen (D2). Furthermore, the mapping of flick direction to transfer direction is designed to be direct and easy to understand (D6), since users simply flick in the desired direction of transfer.

***JetTransfer*** transfers multiple items in quick succession using 'spray paint' and 'vacuum cleaner' metaphors. Transfer to the large display is initiated by touching the phone, sliding the finger upwards and holding it. While holding, selected items are transferred in quick succession, using the pointing cursor position as drop point (Figure 4a). The transfer rate is specified by the distance between the initial and the current touch position, i.e., the length of the slide motion. By moving the phone, items can be 'sprayed' on the large screen. Conversely, transferring items back to the mobile phone involves a 'vacuum cleaner' mode (similar to [6]) that is activated by

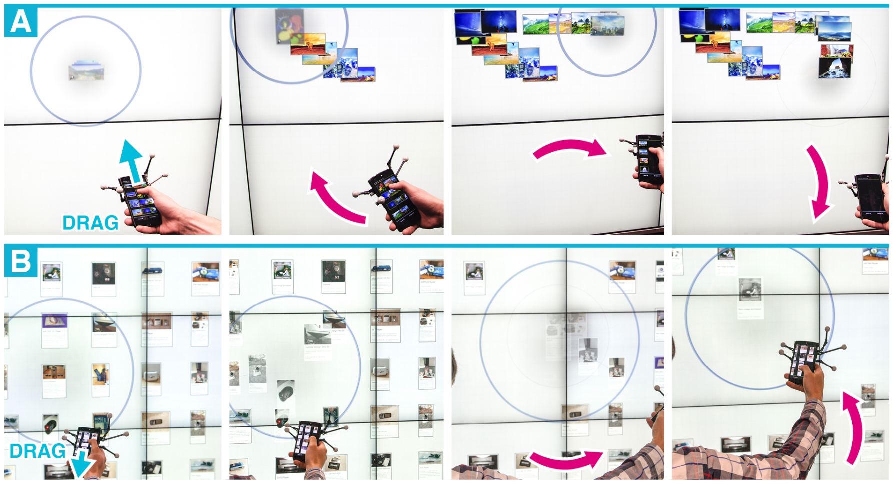


**Fig. 4** *JetTransfer* uses rough and casual positioning for multi-item transfer.

touching and sliding the finger down. Items in the cursor's active radius are attracted towards the center (shown using moving grayscale previews, Figure 4b); when they reach it, they are transferred. If the touch is released or the cursor is moved so the item is outside of the active radius, attracted items snap back to their original positions.

Again, parameter mapping is designed to be direct and easy to understand (D6): the radius of attraction increases with the distance to the large display (D2), and transfer rate is based on thumb-dragging on the phone screen, specifically the distance between the initial touch point and the current thumb position. This allows users to choose between speed and precision (D1). Both very fast bulk transfer of items (farther away and with fast transfer speed) and slower, more controlled transfer of single items (close to the large display with slow transfer speed) are possible. Furthermore, it supports casual spatial arrangement of items (D4). A typical use case is the transfer of multiple images with different subjects, with the images loosely grouped by subject on the large display.

***LayoutTransfer*** enables users to effectively create an orderly layout for a group of items. It expands upon FlickTransfer and employs a phrased gesture design (see the corresponding state diagram in Figure 5) to transfer items to the large display. Interaction begins by touching and holding the mobile phone. Users can determine the number of items to transfer and their arrangement on the large display by moving the pointing cursor. The type of layout is determined by the initial direction of movement (State 1, shown in Figure 6a), and the number of items is determined by the movement distance (State 2). Layout parameters can be adjusted when the finger is released from the phone screen (State 3): Pointing cursor position controls item spacing and phone distance controls item size (Figure 6b). Users can switch between number of items (State 2) and layout parameter (State 3) modes at any time by touching and releasing the mobile phone. Finally, flicking upwards on the phone confirms the transfer, while flicking downwards aborts it.

LayoutTransfer was inspired by some of the NEAT multi-touch gestures [13]. Its phrased gesture design allows users to interleave several interaction sub-tasks seamlessly while allowing abort at any time. This makes it possible to quickly set multiple parameters for spatial arrangements (D4): number of items, layout type, item spacing and size can all be set in a phrased interaction, making it useful when working with organized, sorted groups of data items (D3).

***SnapshotTransfer*** allows users to easily transfer multi-item layouts from the large display to the mobile phone and back. Similar to selection techniques in conventional desktop systems, users create a rectangular selection area by pointing the phone towards one corner of the layout, touching and holding the phone screen, and pointing towards the opposite corner (Figure 7a). Alternative methods for a more refined selection include using a lasso metaphor or running the cursor over all items to select them. Releasing the finger transfers the items and their layout as a single entity (Figure 7b). The user can move the cursor back to the initial position and release the touch to abort at any time. The layout can be transferred back to the large display using FlickTransfer. In this case, the complete group of items is shown as preview (Figure 7c).

SnapshotTransfer provides a quick and easy way to preserve item layouts created on the large display (D4). It is also useful if complete layouts need to be moved from one place on the large display to another.

***RevealingTransfer*** supports transfer of items to predetermined locations on the large display based on item metadata (e.g., the transfer of geotagged photos to a map). Transfer proceeds in two phases: metadata of items are automatically transferred first, allowing the large display to show item marks (here: blue circles) at corresponding positions. To preserve privacy, item previews are not revealed before the pointing cursor reaches their location (Figure 8a, b). For the actual transfer, we incorporate elements of FlickTransfer and JetTransfer to support single and multi-item transfer (D3): Tapping the mobile phone transfers the item closest to the pointing cursor (Figure 8c) while flicking upwards transfers all items contained in the cursor radius (Figure 8d). Additionally, a swipe and hold transfers a sequence of items along the cursor's path (JetTransfer).

RevealingTransfer is designed for situations where the selection and positioning of items is influenced by their metadata. Furthermore, it illustrates the combination of different techniques using simple touch gestures to switch modes.

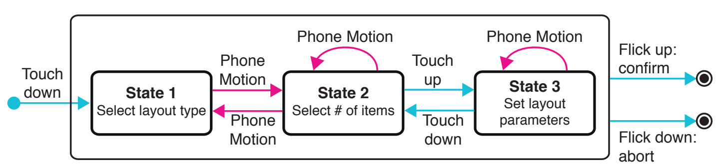


**Fig. 5** *SpanningTransfer* state diagram: All states can be accessed at all times. The operation can be confirmed with a swipe up or aborted with a swipe down gesture at any time.

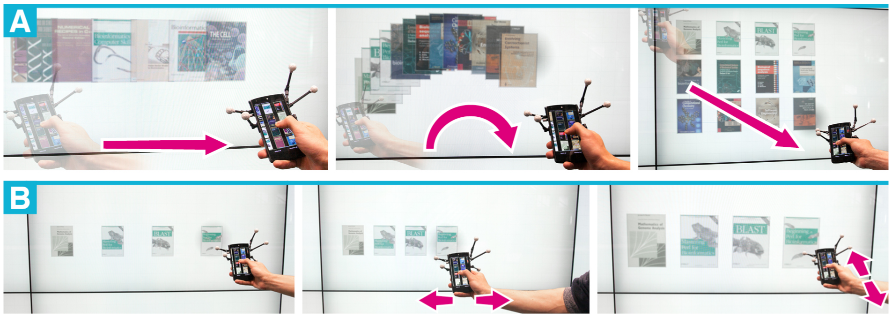


**Fig. 6** *LayoutTransfer* enables simultaneous transfer and arrangement of multiple items.

## 5 Implementation

Our prototype runs on a $5 \times 2$m large display wall, consisting of twelve 55" 1080p displays (Figure 1a) driven by a dual-processor Xeon workstation running Ubuntu. As a mobile device, we use an LG Nexus 5 smartphone with a 5" display running Android. We track the phone's absolute position in space using 12 infrared OptiTrack[2] cameras; accordingly, the phone is instrumented with reflective markers. On the software side, we use the Python-based libavg[3] framework for the user interface. The OptiTrack system runs on a separate stand-alone computer, which streams the phone's 3D position using the OSC[4] protocol.

Implementation-specific parameters are as follows. The pointing cursor uses raycasting at a distance of 3.5 meters and more; at 1.0 meter or closer, it uses orthogonal pointing (Figure 2). Layout parameter adjustment in LayoutTransfer scales the images by a factor of 2 for every 10 cm of distance change. FlickTransfer's damping mode only applies 2.5% of the current cursor movement, while JetTransfer allows

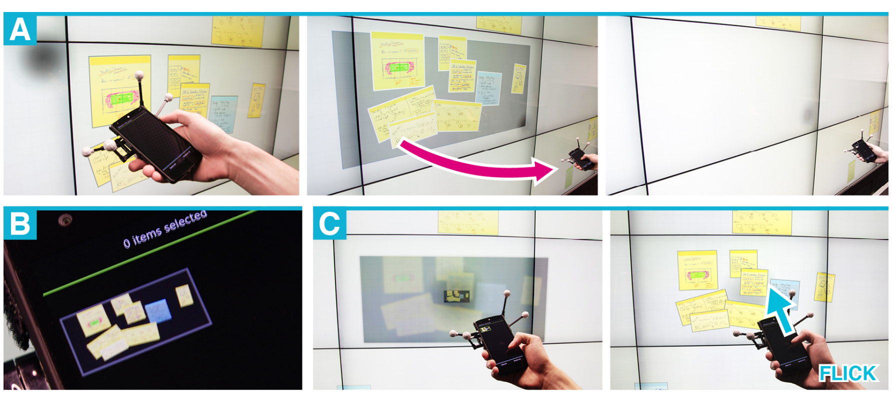


**Fig. 7** *SnapshotTransfer* copies multiple items and their layout.

[2] http://www.optitrack.com/
[3] https://www.libavg.de/
[4] http://opensoundcontrol.org/

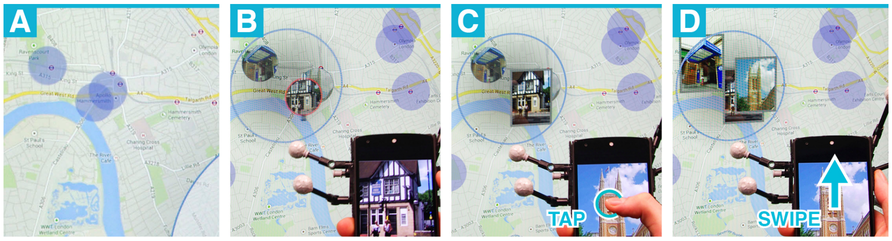


**Fig. 8** *RevealingTransfer* combines techniques and allows metadata-based transfer.

transfer speeds between 4 to 15 images/sec (to the large display). Depending on the distance, the size of its active radius continuously scales from 15 to 60 cm. In the case of SnapshotTransfer, the current prototype only supports rectangular selection. We implemented a minimal item selection interface on the phone: items are arranged in a scrollable grid and selectable by tapping. As data items, we use sets of images appropriate to the individual use cases[5].

# 6 User Study

To evaluate our techniques and identify practical implications, we conducted a qualitative study in a laboratory setting. Among other things, we wanted to know how well varying distances were supported (D2), what impact eyes-free interaction had (D5), and if the parameter mapping was indeed comprehensible and easy to understand (D6). Furthermore, we wanted to ascertain that the distance-dependent pointing cursor worked as intended and the visual feedback given was helpful.

Since our techniques span a variety of application cases and user scenarios, differ in complexity, and useful prior work for comparison was not available in several cases (e.g., multi-item or layout transfer), we opted against a quantitative study comparing techniques for performance. Instead, we focused on the design goals mentioned above, investigated usefulness and acceptance of the techniques, and collected rich feedback for all of them.

***Method.*** Seven students from the local university (1 female, 1 left-handed) volunteered for the study, which took on average 75 minutes per person. The average age was 25 years (M= 25.14, SD= 2.59). All participants use smartphones and computers daily. Two use monitor-sized touchscreens daily, and six had already used a wall-sized display.

To evaluate our techniques, we developed a within-subject and repeated measures study design. To ensure a natural progression of techniques and due to interdependencies between them (e.g., RevealingTransfer utilizes elements of FlickTransfer

[5] Photos from Flickr by @dhilung (https://www.flickr.com/photos/dhilung), @mualphachi (https://www.flickr.com/photos/mualphachi), and @duncanh1 (https://www.flickr.com/photos/duncanh1), Map by GoogleMaps (https://maps.google.com).

and JetTransfer), we did not counterbalance the order of presented techniques. The procedure was the same for each technique: A short training phase was followed up by technique-specific tasks, a brief phase of free exploration, a discussion, and a short questionnaire. About half of participants' time (approx. 35 minutes) was spent on the actual tasks. Besides an overall rating of a technique, we asked participants to rate understandability, easiness, control, target compliance, and perceived speed. We further integrated questions on performance, physical demand, and mental demand based on NASA TLX. For all these ratings we used a 5-point likert scale (1 - strongly agree, to 5 - strongly disagree). We logged phone motion data, recorded the sessions on video and asked participants to think aloud. Each session was accompanied by two researchers, with one exclusively observing behaviors of participants and taking notes.

Tasks were specific to the use cases of the corresponding techniques and were tailored to verify that the techniques' specific capabilities worked as intended. For FlickTransfer, we asked participants to transfer five tagged monochrome images from the mobile phone to corresponding target areas on the large display and subsequently five tagged colored images back to the phone. For JetTransfer, the phone initially contained multiple colored images (20) followed by monochrome images (20). Participants had to transfer colored images to the left and monochrome images to the right half of the large display. Next, the large display showed a widespread mixture of colored and monochrome images; participants had to transfer all monochrome ones to the mobile phone. The task for LayoutTransfer was to create specified matrix ($5 \times 3$) and row (9) layouts from images stored on the phone. In the case of SnapshotTransfer, participants had to transfer a specified group of notes (6 items) to the phone and back to a different location on the large display. For RevealingTransfer, the large display showed a map of London with 53 markers of transferrable geotagged images. Participants had to transfer all images taken at specific locations, e.g., 13 images along the River Thames.

***General Results.*** Altogether, we received rich and very encouraging feedback. Fatigue seemed not to be an issue; it was neither mentioned by participants nor noticeable in the videos. Participants realized the effects of physical navigation (D2). This was evidenced in comments implying, e.g., that they could gain an overview by stepping back and that walking around took time. However, we observed—and the motion data confirmed—that moving was generally avoided when possible. Users often moved closer to gain precision only after they had committed errors. In this respect, our results are similar to Jacobsen et al. [18], who also found that users do not prefer physical navigation. On the other hand, it is possible that this would change with longer usage as users learn to anticipate an optimal, task-specific distance, and that a study setup that required more precise interaction would have resulted in more physical navigation. By determining patterns of easily visible gaze switches through observation and video analysis, we could ascertain that the goal of minimizing gaze switches (D5) was achieved. This was also commented upon positively by five participants. Mobile phone usage was almost exclusively one-handed, indicating support for casual interaction (D1). The distance-dependent pointing cursor was commented on favorably by four participants, but most participants did not notice

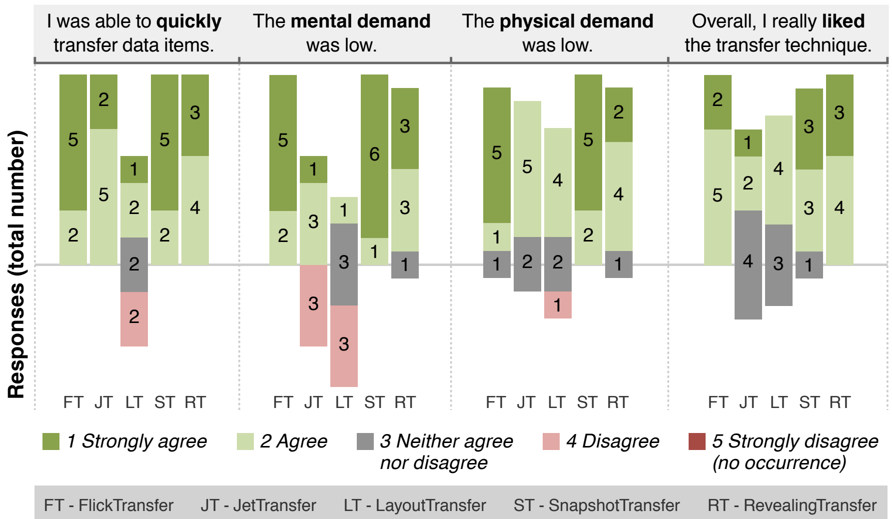


**Fig. 9** Selected ratings of the techniques.

the interpolation as such; instead, the increased precision at close distance was observed. Mapping the user's distance to cursor size was mentioned positively by two participants. However, we observed that touches on the mobile phone had a minor impact on the cursor position, affecting precision to a certain degree. FlickTransfer's damping mode helped here.

Furthermore, it became evident that our techniques provide sufficient feedback. Excepting JetTransfer, users generally had no issues determining what the current application state was or which item would be affected by the next action. The pointing cursor's circular feedback was commented upon favorably by three participants.

***Results for Individual Techniques***: Our observations and comments showed that participants were intrigued by the techniques and with few exceptions able to use them to achieve the goals. This is confirmed by the results of the questionnaire (selected results in Figure 9), which provide additional interesting insights as well. However, due to the limited number of participants the quantitative results do not allow generalizations.

*FlickTransfer* was described as simple and easy-to-use by six participants. Additionally, four participants commented favorably on the damping mode.

Participants found *JetTransfer* to be enjoyable, very fast and casual, but also inaccurate. The fun aspect was mentioned five times; it was also very visible in the reactions of several users. However, control suffered: all participants had issues stopping the transfer at intended items and the questionnaire results reflected this as well (avg. ratings: 4.00 for transfer of single items; 3.43 for control over the transfer). Accurate placement was difficult because the exact transfer time was hard to predict, and unclear visual feedback was mentioned twice as drawback. JetTransfer was introduced late in the development cycle, and we believe that controllability can be improved significantly by lowering the minimum transfer rate and improving feedback.

The general response to *LayoutTransfer* and the idea of transferring and specifying a layout in one seamless interaction was positive (five mentions). The technique has a clear learning curve (avg. rating understandability: 2.86) and is thus not suitable for walk-up-and-use situations. After a short time, however, users were able to use all features; three users commented that the technique was 'not too complicated'.

*SnapshotTransfer* was found to be very easy to use (avg. rating understandability: 1.29). The familiar selection method ("like under windows") was mentioned four times. Additionally, five users mentioned that a lasso mode could be useful, confirming our concept.

Regarding *RevealingTransfer*, it generally took users some time to grasp the concept of pre-located items. Once understood, however, the technique was viewed positively. Six participants commented favorably on the different transfer modes (single and multi-item).

## 7 Design Space

Based on the development of the transfer techniques, prototype implementation, and findings of the user study, we contribute a design space for content sharing techniques between mobile devices and large displays (Figure 10). We identify, refine, and systematically discuss essential design dimensions to abstract the specific interaction techniques into a reusable framework and to allow comparative discussions of existing techniques. Our aim is to support design decisions and allow the identification of gaps for the development of future techniques. In addition, Figure 10 maps content sharing techniques to the design dimensions and makes this assignment a subject of discussion.

***Distance to large display.*** This describes the usage of various distances during interaction (D2). This continuous dimension ranges from *close* (i.e., users can touch the large display) to *far* (i.e., users see complete wall).

***Casual interaction.*** Introduced by Pohl and Murray-Smith [31], this dimension describes the user's level of engagement for interactions (D1). This continuous dimension ranges from *casual* (i.e., only minimal attention is required) to *focused*.

***Gestural complexity.*** This describes the level of complexity of gestural input needed to initiate and control transfer actions. For instance, the number of involved devices or body parts (cf. [41]) affects gestural complexity. This continuous dimension ranges from *low* (e.g., tap a virtual button) to *high* (e.g., draw a complex shape using touch). While complex input often requires much of the user's attention, it usually provides more interaction capabilities, for example, define and manipulate the arrangement of transferred items (LayoutTransfer, D4).

***Function of spatial location.*** This describes the higher-level function and usage of the spatial location of mobile devices in relation to large displays. We distinguish three values: *irrelevant*, *discrete*, and *continuous*. Spatial location is irrelevant if applications are not aware of or ignore locations of mobile devices, e.g., trans-

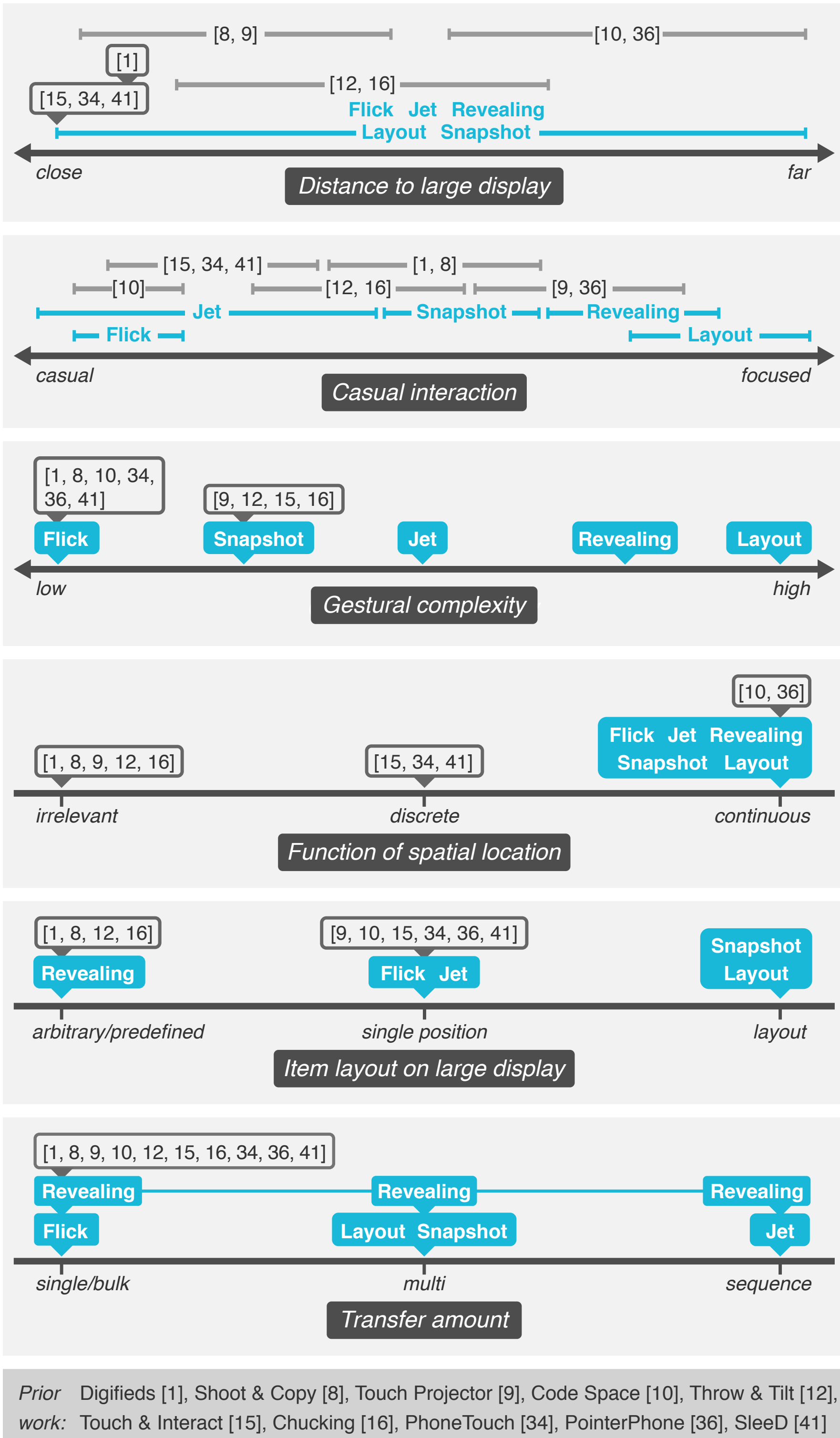


**Fig. 10** Dimensions of the design space for content sharing techniques involving mobile devices and large displays. Existing techniques (gray) and techniques presented in this work (blue) are mapped to the dimensions based on their characteristics as well as typical usage.

fers through a wireless connection or QR codes. Discrete location mapping can be used as on/off switches to control specific application states, modes, tools, or conditions [14, 24]. The mapping is continuous if location controls a cursor [15, 34, 36], pointer [27, 37], or another continuous application-specific parameter.

***Item layout on large display.*** This describes the use and type of item positioning for transfers to large displays. This dimension spans three discrete values: *arbitrary/predefined* if techniques do not allow users to specify an item position, *single position* if an item can be positioned, and *layout* if multi-item arrangements—possibly including layout parameter adjustments (e.g., size, spacing) are supported.

***Transfer amount.*** This describes the number of items that can be transferred in a single interaction step (D3). With respect to discrete items (e.g., images, files), this dimension distinguishes three discrete values: *Single/Bulk* represents techniques that focus on transfer of individual items (e.g., photo, song) or data containers (e.g., folder), *Multi* includes techniques with 'distinct' support for a collection of items while considering or specifying additional item attributes (e.g., spatial relation), and *Sequence* techniques support the successive transfer of multiple items. For data of continuous nature (e.g., movies, music), this would describe whether users can specify a portion of an item to be transferred.

## 8 Discussion

The proposed techniques are influenced by various concepts including physical navigation [3], casual interaction [31], and proxemic interactions [14]. Since the techniques cover a broad range of different characteristics, we believe that they highlight the variety and richness of the underlying design space. At the same time, the design space reveals that our techniques fill out existing gaps (e.g., transfer amount, item layout). In this section, we further discuss the relationship between different design space dimensions, design issues, and valuable lessons learned.

### *8.1 Design Space Parameters and Consequences*

Gestural complexity of user interactions seems to correlate strongly to many of our design goals and design dimensions. Both casual and almost eyes-free interaction (D1, D5) can be realized by using simple input gestures, because they require less attention and are easy to learn and remember. Utilizing physical navigation as well as mapping movement to an appropriate application parameter (e.g., input precision, zoom) seems to encourage people to perceive interactions as easy and simple (D2, D6).

For most transfer techniques, Figure 10 shows a correlation of casual interaction and gestural complexity. Furthermore, there is also a correlation between casual interaction and distance to the large display, since distant interaction is very likely more casual, whereas close proximity interaction is often associated with focused input. By utilizing the flexible pointing cursor, our techniques scale and support both casual interaction at a distance and focused interaction at close proximity (D1, D2); this is not directly visible in Figure 10.

## *8.2 Interaction Design*

Complex interactions involving multiple parameters and modalities require careful interaction design. Mode switches can clear up a cluttered gesture space and thus allow reuse of input dimensions. As demonstrated by LayoutTransfer, this in turn allows mapping of, e.g., device movement to changing but always appropriate parameters (D6). The manner of mode switching is important: An early prototype utilized the orientation of the mobile phone to switch transfer techniques, but mandatory hand postures (preventing a casual interaction style, D1) were not received well by users. Instead, RevealingTransfer demonstrates that mode switching using different touch gestures is a simple and viable solution. Similar techniques for mode switching could be used to switch between transfer modes copy and move as well.

Similarly, LayoutTransfer maps distance to the large display and pointing cursor position to unrelated parameters (item spacing and item size) in layout mode. This requires fine motor control when the goal is to adjust only one of the parameters without affecting the other. Therefore, we already improved the prototype by locking changes to the predominant movement direction (e.g., ignore distance changes when users move the pointing cursor across the wall and vice versa). An alternative option would be to map parameters to different modalities. This is demonstrated by JetTransfer, where we successfully combined device movement (for positioning) with touch input (for transfer direction and speed).

Our study showed that we were successful in minimizing gaze switches (D5), and from early prototypes as well as prior work [33, 39, 42] we know that this has a positive effect on usability. We believe that our corresponding design principles, e.g, placing visual feedback on the large display and only gestural touch input on the phone (as opposed to GUI-based), were instrumental in achieving this. As presented, our techniques implement item selection on the phone and thus require a single gaze switch after selection. This was done to avoid privacy issues. In a trusted setting, private images could be shown on the large display and the selection performed there, avoiding even this gaze switch. Conversely, in RevealingTransfer, we show blurred preview images on the large display to facilitate selection. This would not be possible in a situation where privacy is very important, and if privacy is not an issue, it might not be necessary to blur previews at all.

## 9 Conclusion & Future Work

In this chapter we presented *FlowTransfer*, a set of five novel interaction techniques that allow users to transfer data between mobile devices and large displays—which is central to many collaborative usage scenarios. Our multiway transfer techniques combine concepts from physical navigation [3] and casual interaction [31]. They address various challenges at once, among them the rapid or slow transfer of both single and multiple items, the creation and transfer of sophisticated layouts, as well as the handling of gaze switches. In addition, the *FlowTransfer* techniques adapt to the user's level of engagement by allowing a smooth transition between casual and more focused interaction.

In the context of multi-user scenarios, our techniques support people collaboratively sharing digital content with a large display. Due to the usage of our distance-dependent pointing cursor, multiple users can transfer objects from dynamic and individual positions, thus addressing occlusion issues and allowing to work in parallel or together. Furthermore, we also consider the separation of private data on the personal device and shared data on the large display, e.g., by selecting items to be transferred on the mobile device and showing only a blurred preview of selected items on the large display.

We described our design goals and iterative design process, presented a fully functional prototype implementation of the proposed techniques, and reported on a qualitative user study. Based on the design process and study results, we contributed a design space for content sharing techniques between mobile devices and large displays. The presented dimensions of this design space, such as distance to large display, casual interaction, item layout on large display, and transfer amount, provide support for the development of future data transfer applications. Furthermore, we look forward to research that extends the space.

Our proposed distance-dependent pointing cursor was successful in the context of the transfer techniques, and allowed users to control precision by varying their distance to the large display. However, there is still room for tuning parameters such as the minimum and maximum distance for interpolation. Therefore, we believe that it deserves further analysis. Furthermore, we want to thoroughly examine the capability of the distance-dependent pointing cursor and compare it to other existing approaches.

Regarding sensing the phone's position, our current setup requires separate tracking equipment. However, we expect upcoming mobile devices to integrate reliable positional and rotational sensors (or inertial location using depth-sensing cameras) that make external sensing unnecessary. For future work, we plan to explore different strategies for a seamless selection of appropriate transfer techniques depending on specific tasks or goals. We already took a first step in this direction by developing the RevealingTransfer technique.

Finally, we believe that our techniques and the proposed design space represent both a solid foundation and inspiration for the development of future user interfaces in the expanding space of applications combining large displays and personal mobile devices.

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