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Investigating Device-Specific Visual Feedback for Cross-Device Transfer in Table-Centric Multi-Surface Environments

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ABSTRACT

Table-centric multi-surface environments (T-MSEs) that combine small multi-touch surfaces (e.g., smartphones and tablets) with large interactive tabletops provide people with both personal and shared workspaces to support various independent and collective tasks during group activities. This paper reports on the third in a series of studies exploring how existing interaction methods for cross-device transfer, such as the PICK-AND-DROP (P&D) method, can be adapted to T-MSE settings. The study examined the use of device-specific visual feedback to improve users' awareness of transferred content during P&D transfer. The tabletop feedback utilized the existing SURFACE GHOSTS P&D feedback approach (i.e. "ghosted" versions of transferred content were displayed in real-time under the user's hand). The tablet feedback consisted of a static "TABLET BRIDGE" feedback showing miniature versions of transferred content along the top edge of the tablet interface. The study found that providing both types of feedback significantly improved users' transfer awareness over providing SURFACE GHOSTS feedback alone. It also revealed that the TABLET BRIDGE feedback helped compensate for technical and usability issues associated with the SURFACE GHOST feedback design. Lessons learned from our combined series of cross-device transfer studies are reflected upon and relevant design implications are discussed.

KEY WORDS: Cross-device transfer; digital tabletops; multi-touch interaction; multi-surface environments; surface computing

1. INTRODUCTION

Direct-touch computing devices, also known as interactive surfaces, are becoming more ubiquitous in today's computing landscape. Large surfaces, such as digital tabletops and interactive walls, are ideal for collaborative activities, such as brainstorming, designing, and strategic planning and decision-making. Small surfaces, such as smartphones and tablets, are ideal for more personalized tasks such as personal scheduling, email, and everyday information and media tasks. The increased ubiquity of small, personal surfaces has spurred demand for their use in conjunction with large surfaces during collaborative activities. Consider, for instance, a design meeting participant sharing a design diagram they created on their personal tablet with the larger group by displaying it on a nearby tabletop or wall surface to facilitate discussion or critical review. This example highlights a key design requirement for multi-surface environments (MSEs): the ability to transfer digital content across the available personal and large surfaces.

Significant cross-device transfer research exists in the Human-Computer Interaction (HCI) and Computer-Supported Cooperative Work (CSCW) fields, particularly in the area of multi-device environments (MDEs) [16, 17, 20, 30, 31]. This research has yielded many useful cross-device transfer techniques (see Nacenta et al. [17] for a review). Yet, most of these techniques rely on mouse-based, or otherwise device-aided, input capability that is unavailable in

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touch-based MSEs. For example, a popular cross-device transfer technique, Rekimoto's [19] PICK-AND-DROP (P&D) technique, allows a user to "pick" up content on one display and transfer (or "drop") it to a different display using a digital pen as a "proxy".

To address this gap, we conducted a series of studies to systematically investigate how existing cross-device transfer techniques could be applied or adapted for use in touch-based MSEs. These studies focused on cross-device transfer in a tabletop-centric MSE (T-MSE) context, where a small group of people, each with an individual multi-touch tablet, were engaged in a joint activity around a multi-touch digital tabletop. This paper reports on the third and final study in this series, and reflects on lessons learned across the entire investigation.

2. INITIAL STUDIES ON CROSS-DEVICE TRANSFER

To set the context for the study reported here, we first summarize the findings from our initial two studies. The first study examined how two popular cross-device transfer techniques could be applied (or adapted) to a T-MSE setting [24]. The techniques included the aforementioned P&D technique and a "virtual portals" technique that allowed content placed on a virtual widget on one surface to appear on an associated widget on another surface device; thus, serving as a portal from one device to another (see Figure 1). The study found that both transfer techniques effectively supported transfer in the studied T-MSE, but that both techniques had advantages and disadvantages that led to evenly split participant preferences between the two techniques, depending on what features were more valued to individual participants, and how the features impacted the task (a competitive card game).

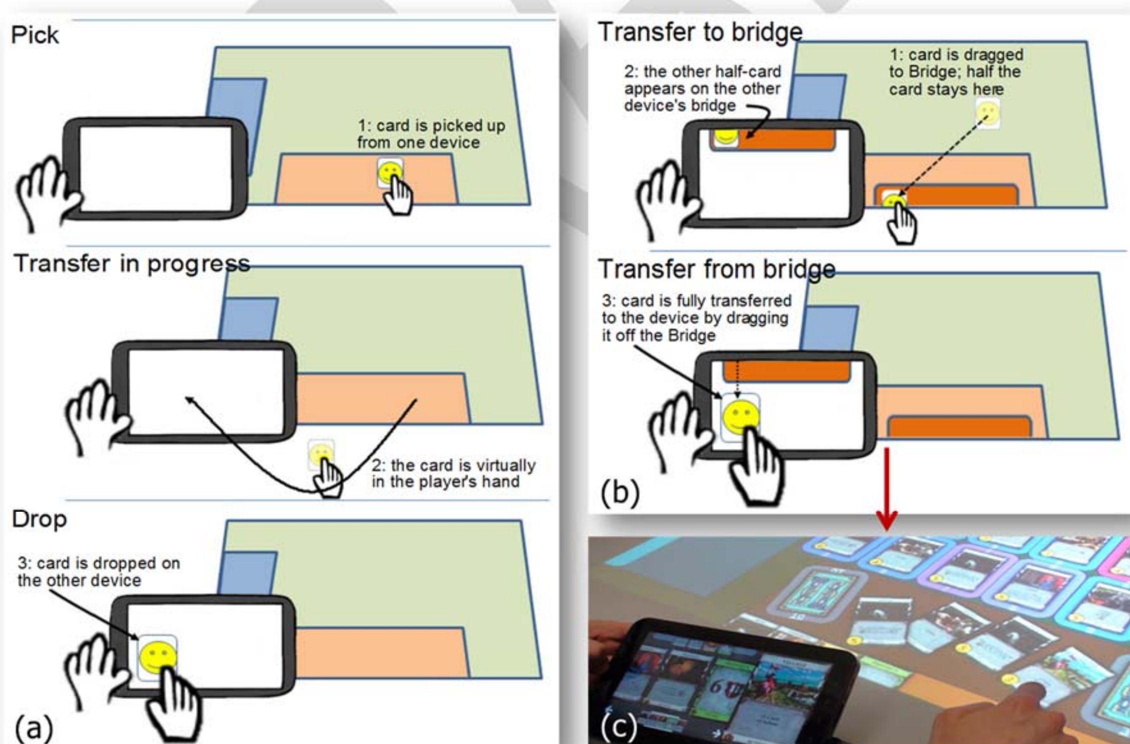

Figure 1. Our initial T-MSE cross-device transfer techniques: a) P&D transfer; b) a "virtual portals" technique (called BRIDGES); c) BRIDGES shown in the application context.

For instance, many participants appreciated the efficiency provided by P&D's point-to-point transfer process compared to the virtual portal's approach, which required transfer via the intermediary "portal" widgets on each connected surface. However, P&D was found to be more cognitively demanding than the virtual portals technique. In common P&D implementations [9, 19], users have a digital pen to act as a "physical proxy" of the transferred content and to help remind them—both physically and visually—that they are transferring content. However, in a multi-touch setting, users only have their hands as input devices. Thus, our multi-touch P&D adaptation allowed a user to "pick" up content with their hand and transfer it by subsequently touching the destination device to complete the transfer (i.e. "drop" the content on that device). This technique required users to mentally keep track of what content they were currently "holding" in their hand during transfer. Without a physical proxy object like a digital pen, holding transferred content looked (and felt) much like not holding content, and led to users sometimes forgetting they were holding content. So, it was surprising when a card suddenly appeared below their hand after a subsequent touch of a device. This lack of feedback was the leading cause of confusion during transfer, and participants' main reported issue with the P&D transfer technique.

Rekimoto's original P&D implementation [19] provided some additional visual feedback on the destination screen when the digital pen approached (within millimeters) of the screen. The content was displayed beneath the pen's location with a "shadow" underneath it to indicate the content was "hovering above" the interface. When the content was dropped on the display, the shadow disappeared to indicate the completion of the transfer. This shadow feedback was effective in communicating that this content would appear (or be "dropped") on the display if the pen was tapped at that location. Building on this approach, and similar visual feedback approaches for indicating "above the surface" interaction [11], we refined our multi-touch P&D technique to provide visual feedback during content transfer.

This feedback was shown as semi-transparent, greyscale versions of transferred content, called SURFACE GHOSTS, displayed in the tabletop interface underneath the user's hand as it moved over the tabletop surface during transfer in a T-MSE setting (see Figure 2). In a study comparing the original no-feedback P&D technique to two variants of P&D with SURFACE GHOSTS feedback—varied by how explicit "ownership" of transferred content was indicated in a multi-user setting—we found that both SURFACE GHOSTS designs significantly improved awareness of transferred objects, thereby improving the overall effectiveness of the P&D approach in a T-MSE setting [23]. However, the study also found that this "transfer awareness" was more prevalent in ***tabletop-to-tablet*** transfers than in transfers originating on the tablet. Moreover, the study found that the SURFACE GHOSTS design with more explicit "ownership" representation (in which a virtual arm shadow was included in the SURFACE GHOSTS visualization, see Figure 2 (bottom)) led to slower cross-device transfers.

This paper examines these limitations and details a modified multi-touch P&D design that provides additional feedback on the tablet in addition to the tabletop-based SURFACE GHOSTS feedback that aims to support effective cross-device transfers in both directions (***tabletop-to-tablet*** and ***tablet-to-tabletop***) for an improved overall transfer experience.

To provide further context for this work we first overview existing cross-device transfer mechanisms and discuss their limitations for touch-based MSEs. We then describe the DOMINION card game and our rationale for selecting it as a case study for our cross-device transfer investigations. Next, we detail our original SURFACE GHOSTS feedback design and its shortcomings. We then describe our new tablet-based feedback design, which after careful consideration, was designed to be significantly different in form and function from the tabletop-based SURFACE

GHOSTS feedback to better suit the use and functionality of the tablet interface. We then present a user study conducted to investigate how well this additional feedback supported transfer awareness during P&D transfer. The study also examined whether specific software improvements made to our multi-touch P&D technique resolved the slower transfer performance previously observed with the explicit ownership version of SURFACE GHOSTS.

The study found that both objectives were met: providing feedback on both the tabletop and the tablet improved transfer awareness in both transfer directions, and transfer timing delays were resolved for SURFACE GHOSTS with explicit ownership. Surprisingly, the study also found that providing feedback on the tablet not only improved transfer awareness for ***tablet-to-tabletop*** (as expected), but also improved transfer awareness for ***tabletop-to-tablet*** transfers compared to providing SURFACE GHOSTS feedback only. We discuss this unexpected finding and discuss its implications for the design of future cross-device transfer techniques. Finally, we reflect on our lessons learned from all three of our cross-device transfer studies and discuss their implications for cross-device transfer in T-MSEs.

3. CROSS-DEVICE TRANSFER IN MULTI-SURFACE ENVIRONMENTS[1]

Cross-device transfer is an active area of research in MSEs, and the broader area of multi-device environments. Also, to address reach and ergonomic issues related to dragging digital objects over a large distance, single-surface object transfer techniques have been developed that minimize the need for long drag-and-drop actions. This section first overviews these single-surface transfer mechanisms and then discusses the mechanisms used to move content across multiple devices. As all three studies explored the Pick-and-Drop (P&D) technique, this mechanism and its applicability to touch-based T-MSEs is discussed in detail.

3.1 Object Transfer across Large Surfaces (Within-Device Transfer).

Using direct-touch interaction to drag digital content across a large surface has several known ergonomic issues, including fingertip discomfort due to friction and arm and finger-fatigue. Moreover, some locations are difficult to reach. Therefore, drag-and-drop extensions have been developed for moving content across large surfaces, including techniques that move an object onto a distant object (e.g. a folder) or location [2, 4-6, 10]. Techniques have also been developed that leverage the physicality of direct-touch surfaces, such as tossing or flicking interaction gestures that use pseudo-physics to “propel” objects to distant locations [26, 32]. The aforementioned P&D technique has also been used to transfer objects from one location to another on pen-based interactive wall and tabletop surfaces [9]. Further, P&D has been shown to be more efficient than drag-and-drop in these contexts [18]. Another approach is to move objects from one surface location to another by using “virtual portals,” where an object placed on a portal (typically a virtual interface container or widget) in one location then appears on an associated portal in another location [3, 28]. The above single surface transfer techniques, especially those designed for direct-touch environments, provide useful inspiration for touch-based cross-device transfer.

3.2 Object Transfer across Multiple Devices (Cross-Device Transfer).

Existing cross-device transfer techniques broadly fall into three main categories: moving content across *contiguous virtual workspaces*, moving content via a *virtual portal*, and moving content via a *physical proxy*.

[1] Components of the background presented here were also reported, in full or in part, in our related work [21, 23].

Contiguous virtual workspace techniques are based on the physical configuration of displays in the environment. In this approach, displays are connected to a common software architecture that maintains awareness of the physical configuration of the displays (static or dynamic configurations are possible). This display configuration is then used to provide a contiguous virtual workspace across devices. Thus, moving an object off the edge of one display moves it to the nearest edge of the adjacent display [12, 13, 15, 20, 27].

A disadvantage of the contiguous virtual workspace approach for transferring digital objects between a tabletop and a personal surface is the asymmetric size of the displays. The large edges of the tabletop do not map well to the small edges of a tablet or smartphone. The *virtual portals* technique mentioned above can be used to resolve this issue by providing a dedicated portal area (typically much smaller than the display length/width) on each device for transferring content [1, 7, 12, 24]. In our first cross-device transfer study, described in Section 2, we implemented a virtual portals technique called BRIDGES, in which a TABLETOP BRIDGE widget was provided along the tabletop edge in front of each user and a TABLET BRIDGE was provided along the top edge of each personal tablet. To transfer objects from the tabletop to their personal tablet, the user dragged an object from its original tabletop location onto the TABLETOP BRIDGE. The object then appeared in miniaturized form with its top half displayed on the TABLETOP BRIDGE widget and its bottom half displayed on the TABLET BRIDGE widget. To complete the transfer, the user dragged the object off the TABLET BRIDGE into the main tablet interface.

The previous two cross-device transfer approaches require people to drag the transferred object to and from the virtual portal (or display edge) from its origin and to its destination. This can introduce the aforementioned ergonomic issue related to long-distance touch-based dragging. *Physical proxy* techniques eliminate this intermediary interaction step by using a physical object to manage the transfer. They allow for collection and placement of the transferred object directly from its origin to its destination on the respective displays by taking advantage of the 3-dimensional space around the displays. This approach involves binding a digital object to a physical object and then moving the physical object to the target display. This typically requires a system-recognized object to facilitate the binding/unbinding process, such as a digital pen [2, 9, 19, 24] or "puck" [14]. For example, the popular Pick-and-Drop (P&D) technique [19] allows someone to "pick up" a digital object at its original location using a digital pen and "drop" the object directly at the destination location with the pen. This technique evokes the commonly-used drag-and-drop concept, and bears strong similarity to the familiar action of lifting and relocating a physical object.

Given the more direct point-to-point interaction process, physical proxy techniques like P&D are highly desirable in T-MSEs. They reduce intermediary drag actions across a large tabletop surface, and so, provide more efficient interaction and avoid the ergonomic issue of long-distance dragging. Yet, the touch-based interaction and the multi-user nature of T-MSEs introduced difficulties for applying P&D in this context; we discuss these issues next.

3.3 Applying PICK-AND-DROP to Touch-based, Multi-User T-MSEs.

In touch-based surfaces, no digital pen (or other readily available physical object) is available to serve as the proxy for P&D transfer. In our previous [23, 24] and current work, we address this issue by using the user's hand as the physical proxy between the tabletop and a personal tablet. This allows someone to "pick up" the object using a menu or gesture on the originating surface, move their hand to the destination surface, and then "drop" the object by touching the screen. However, in a collaborative T-MSE, multiple people may wish to simultaneously transfer content between various devices. Thus, the system needs to associate the right picks with the right drops, which is only possible if the system knows who is doing what in the environment.

Because people often bring and, exclusively use, their own personal devices in a group setting, a reasonable design strategy in a T-MSE context is to associate a specific user with a specific personal surface (e.g., a tablet), and to assume that all interactions with that device are made by that person (i.e., the device "owner"). Using this strategy, we can then assume that all picks or drops on a given personal device are performed by the device owner. However, knowing who is doing what on the shared tabletop is more challenging. Indeed, most existing tabletop systems cannot distinguish between different users. Thus, automatically associating picks or drops with a given person is more difficult and requires either design adaptation of the P&D technique or additional user-identification system capabilities. We used the first approach in our original multi-touch P&D implementation [24], providing a visually demarcated "personal territory" on the tabletop in front of each user to provide a user-identified space in which a user could perform P&D pick and drop actions on the tabletop. In our revised multi-touch P&D design that incorporated SURFACE GHOSTS [23] and in this work, we used the second approach by augmenting the tabletop with user-identification capabilities, as described in Section 6.4. This capability allowed users to pick and drop content anywhere on the tabletop surface, not just in a pre-specified area.

4. STUDYING CROSS-DEVICE TRANSFER IN THE DOMINION CARD GAME

The commercial card game DOMINION[2] was selected as a case study task for studying cross-device transfer because it requires frequent card movement between cards located on the tabletop and each player's private "hand of cards" (located on their respective tablets). Also, DOMINION is a popular game, which facilitates recruitment of task "experts". Finally, similar strategic gaming contexts have been shown to elicit a high level of task engagement [21, 29]. The latter two points are important for the ecological validity of laboratory-based studies of interaction techniques, as expert users who become highly engaged in an activity are more likely to exhibit realistic, externally valid, behaviour. DOMINION is two-to-four person game that is typically played on a turn-by-turn basis, though players can conduct some activity during another player's turn. A typical turn comprises of a player drawing a minimum of five cards into their hand of cards from a set of card decks located on the tabletop and then making several card-based actions (e.g. playing a card to "buy" resources, "attacking" other players by forcing them to discard cards, or discarding unused cards). Players monitor their opponent's game actions and respond accordingly.

A custom T-MSE software application was developed of the DOMINION game to enable the study of cross-device transfer. The system incorporated a large multi-touch tabletop and several multi-touch tablets. The tablets provided each player with a private digital space to maintain their hand of cards. Cards on the tabletop could be freely moved and rotated using direct-touch manipulation. When two cards were moved to the same position, they were automatically stacked into a deck of cards. A card could be drawn from a deck of cards by touching and dragging the top card, while the whole deck could be moved by dragging its border. Cards and decks could be flipped using a contextual pie menu invoked by tapping on a card or deck. Decks could be shuffled with this menu. In both cases, a short animation confirmed the action. Card interactions on the tablet were constrained. Cards in the hand of cards where automatically arranged side-by-side on the tablet, and displayed in a fixed "up" orientation. Cards could be dragged left or right to change the ordering of cards in the hand of cards.

[2] Published by Rio Grande, used with permission.

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4.1 P&D Transfer within the Dominion T-MSE Game

P&D transfer was enabled through various, device appropriate, multi-touch actions. On the tabletop, "picks" were enabled via a contextual menu[3] that could be opened by tapping on a card or deck of cards. Successive taps on the menu allowed for multiple cards to be picked up and transferred together. Transferred cards originating from the tabletop could be dropped either back on the tabletop by tapping anywhere on the table or dropped onto the user's tablet. Dropping the cards on the tablet required a "swipe-down" gesture from the top of the tablet screen (i.e. a downwards drag action). For convenience, if the tablet interface was empty, the user could tap anywhere on the tablet interface to drop transferred cards. A "swipe-up" gesture on the tablet (i.e. an upwards drag action) initiated a "pick" action from the tablet. Several cards could be transferred together by performing multiple successive pick actions on the tablet before tapping on the tabletop.

5. PROVIDING VISUAL FEEDBACK DURING P&D TRANSFER

To improve players' awareness of transferred cards during P&D transfers we first developed the SURFACE GHOSTS visual feedback to be displayed on the tabletop during the transfer process. An initial study found this feedback approach was insufficient for supporting all T-MSE transfer interactions. So, we developed an additional feedback mechanism to be displayed on the tablets during transfers. We describe these two visual feedback designs below.

5.1 Original SURFACE GHOSTS Design

SURFACE GHOSTS were designed to provide a semi-transparent greyscale version, or "ghost", of a transferred card under the user's hand as it moved over the tabletop during P&D transfer. When multiple cards were picked up and transferred, SURFACE GHOSTS displayed a stack of cards and a counter displaying the number of cards being transferred (see Figure 2 (top)).

To accommodate concurrent multi-user card transfers, SURFACE GHOSTS were designed to convey ownership of transferred content. The basic SURFACE GHOSTS design provided several "implicit" indications of ownership, and was referred to as the IMPLICITSG design (see Figure 2 (top)): Upon pick-up, the SURFACE GHOST object would "fly" (via a brief animation) towards its owner, it was automatically oriented toward its owner, and it followed its owner's hand position in real-time on the tabletop. An "explicit" ownership ver-

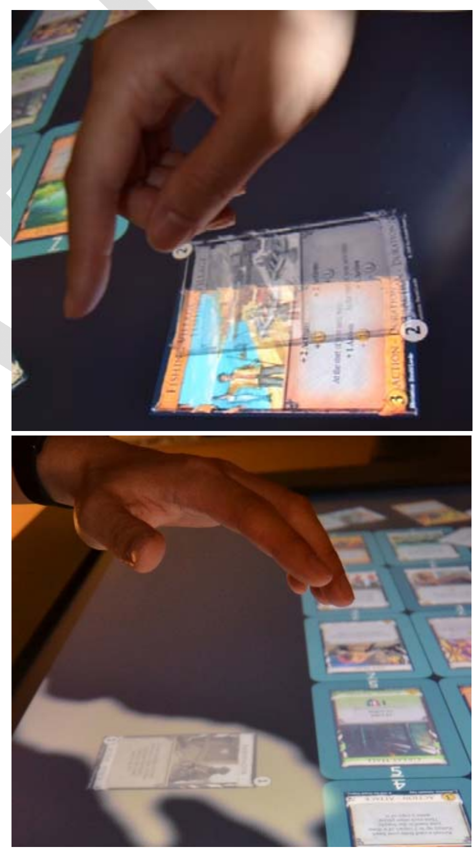

Figure 2. SURFACE GHOSTS visual feedback: SURFACE GHOSTS with implicit ownership (IMPLICITSG) (top); SURFACE GHOSTS with explicit ownership (EXPLICITSG) (bottom).

[3] While the use of a context menu for initiating the "pick" action was originally due to technique limitations in implementing a "pick-up" grab gesture in our original hardware and software, this approach later allowed for in-game efficiencies that were very popular and often requested by our players, such as multi-card pickup menu options, that would have been very difficult to achieve using gesture interaction.

sion, the EXPLICITSG design, displayed a semi-transparent white silhouette of the owner's arm on the tabletop beneath their physical arm as well as the "ghosted" content (see Figure 2 (bottom)).

Our previous study revealed that both IMPLICITSG and EXPLICITSG feedback significantly improved users' awareness of transferred content over our original no-feedback P&D design [23]. However, this awareness benefit was more prevalent during transfers originating on the tabletop, primarily due to the fact that users utilized SURFACE GHOSTS feedback most often during the "pick" phase of P&D transfer rather than during the "transfer" phase as we had originally anticipated. Since the user's hand was typically located outside of the active tabletop surface during pick operations on the tablet the SURFACE GHOSTS feedback was unavailable until the pick was completed and the user moved their hand over the tabletop during the transfer phase. Multi-card pick-up operations on the tablet required the user to repeatedly move their hand back over the tablet surface (and away from the tabletop surface) for each successive card pick-up. This sequence of actions delayed the appearance of the SURFACE GHOSTS feedback until the final card had been picked up. Consequently, the user had to rely on (sometimes subtle) changes in the arrangement of cards in the tablet interface to confirm the success of the pick operation. These changes were easy to miss if the tablet contained many visually similar cards.

5.2 New Tablet Feedback and Updated SURFACE GHOSTS Design

To address the ineffective tablet feedback, we considered various design solutions. We initially considered a variant of SURFACE GHOSTS on the tablet, but found it had several drawbacks. The first issue was technical: tracking a user's hand above a tablet—especially if a user moved the tablet—was highly challenging and not feasible in our tracking environment. Second, there was limited screen real-estate to display a useful SURFACE GHOST object or arm silhouette. Also, the user's physical hand would likely obscure such feedback due to steep viewing angles. Further, the feedback would likely be positioned off the display given the need for frequent near-edge interactions given the small size of the device and the layout of the cards in the tablet interface. Thus, we wanted to provide a more device-appropriate feedback mechanism that would serve the same purpose as the SURFACE GHOSTS feedback on the tabletop; feedback that conveyed *which cards*, and *how many cards* were currently being held by the user.

In our previous work comparing P&D and our BRIDGES virtual portals transfer method [24], BRIDGES was consistently reported to provide high levels of transfer awareness as cards were always visible during transfer—partially displayed on each of the TABLETOP and TABLET BRIDGE widgets. The location of the TABLET BRIDGE widget, along the top edge of the tablet interface, also coincided with the swipe-up and swipe-down gestures for tablet pick and drop actions in our P&D implementation. This location was also beneficial, as it was rarely obscured by the user's hand during tablet interactions. Thus, we hypothesized that providing tablet feedback with similar visual properties to the TABLET BRIDGE may also provide a high level of transfer awareness during tablet-based P&D interactions. So, we designed a modified version of the TABLET BRIDGE visualization (without the BRIDGE transfer functionality) to use as the tablet feedback for our multi-touch P&D transfer technique. Unlike the split card visualization used in the BRIDGES transfer technique, in this work we displayed miniature versions of entire cards along the top edge of the tablet during transfer (see Figures 3 and 4).

Figure 3. The TABLET BRIDGE feedback visualization. During transfer, miniature cards are displayed on the TABLET BRIDGE. When cards are dropped on the tablet, they then appear full size in main tablet interface below and disappear from the TABLET BRIDGE.

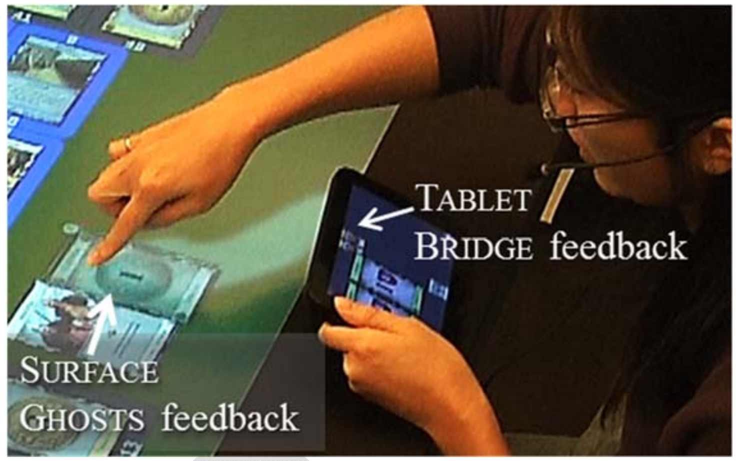

Figure 4. SURFACE GHOSTS and TABLET BRIDGE feedback on the tabletop and tablet, respectively, during P&D transfer. This image shows the scale of the TABLET BRIDGE feedback relative to the full-sized cards in the main tablet interface.

We also made several improvements to our original SURFACE GHOSTS feedback design and to the overall P&D interaction process to better support the DOMINION task. First, we fixed an interaction bug uncovered in our previous SURFACE GHOSTS study (detailed in Scott et al. [23]) that interfered with touch actions over the arm silhouette in the EXPLICITSG design. This bug likely contributed to the slower transfer times for the EXPLICITSG conditions observed in that study. We also displayed a second counter on the lower left corner of the SURFACE GHOST multi-card visualization to improve visibility of the counter. Finally, we added an option to allow users to pick up five cards at once from the tabletop to facilitate this frequent DOMINION game action.

6. STUDY METHOD

To determine whether the combination of SURFACE GHOSTS feedback on the tabletop and TABLET BRIDGE feedback on the tablets supported transfer awareness, in both transfer directions, we conducted a laboratory-based user study. The study utilized a mixed-methods research methodology that included quantitative and qualitative study measures. The study was conducted in a human-computer interaction laboratory environment at the University of Waterloo in Waterloo, Ontario, Canada.

6.1 Participants

Twenty-four participants (19 male, 9 female) ages 18-59 (M=30, SD=9) were recruited from the University of Waterloo student and staff population and from local board game stores' clientele through email lists, social media sites, and posters. Participants completed the study in pairs. To promote natural group behaviour, pairs of participants were asked to sign-up together and to have prior experience with the commercial DOMINION game.

6.2 Experimental Design

The study included two independent variables in a two-factor 2 (tablet feedback) x 2 (tabletop feedback) study design. To compare the effectiveness of adding the TABLET BRIDGE feedback, we included a tablet feedback factor with two levels: BRIDGE and NO BRIDGE conditions. To address a secondary goal of the study—to assess the timing performance of the modified EXPLIC-

ITSG design—we also included a tabletop feedback factor: EXPLICITSG and IMPLICITSG conditions. Due to practical concerns involved with playing full-length DOMINION games in each study trial, we chose to use a mixed within-subjects (tablet feedback) and between-subject (tabletop feedback) experimental design, rather than a fully crossed, within-subjects design, to minimize participant fatigue. With this design, each participant group completed three DOMINION game play sessions under three different visual feedback conditions. All groups experienced the EXPLICITSG tabletop feedback **both** with BRIDGE tablet feedback (EXPLICITSG+B) **and** with NO BRIDGE tablet feedback (EXPLICITSG+NB), and experienced **either** the IMPLICITSG tabletop feedback with BRIDGE tablet feedback (IMPLICITSG+B) **or** with NO BRIDGE tablet feedback (implicitSG+NB). Thus, each group only played one condition with the IMPLICITSG feedback on the tabletop (with or without the TABLET BRIDGE visualization).

6.3 Study Hypotheses

We hypothesized the following impacts of the study conditions:

Hypothesis 1 (H1): Our previous study found that SURFACE GHOSTS feedback alone was insufficient for promoting transfer awareness during ***tablet-to-tabletop*** transfers, primarily due to the lack of available feedback during tablet pick and drop operations. So, we expected the persistent availability of the TABLET BRIDGE feedback on the tablet to address this issue. Therefore, we hypothesized that the BRIDGE conditions would provide higher levels of transfer awareness than the NO BRIDGE conditions for ***tablet-to-tabletop*** transfers.

Hypothesis 2 (H2): Our previous study showed that SURFACE GHOSTS feedback effectively promoted transfer awareness during ***tabletop-to-tablet*** transfers. So, we expected it to be similarly useful for facilitating transfers originating on the tabletop in this study. We also expected that people would focus their attention on the tabletop during tabletop pick and drop actions—the key phases in which Surface Ghosts were previously found to be useful [23]—and, thus, not attend to the TABLET BRIDGE during these interactions. Therefore, we hypothesized that both BRIDGE and NO BRIDGE conditions would provide similar levels of transfer awareness for ***tabletop-to-tablet*** transfers.

Hypothesis 3 (H3): The previously observed slower ***tabletop-to-tablet*** transfer times related to the EXPLICITSG variant of SURFACE GHOSTS feedback was likely due to two contributing factors: a software bug that prevented users from interacting with the card/deck menu through the arm silhouette (forcing users to reposition their arm to perform multi-card pick-ups), and a smoothing algorithm that introduced a lag of up to 150ms in the positioning of the SURFACE GHOSTS content and arm silhouette feedback. In our previous study, it was observed that users sometimes waited for the arm silhouettes to "catch up" to their physical arms during EXPLICITSG transfer. However, since the SURFACE GHOST content feedback was positioned using the same smoothing algorithm and the IMPLICITSG design did not result in the same transfer delays, we posit that the software bug was likely the stronger factor. As our software improvements addressed this interaction issue, we hypothesized that IMPLICITSG and EXPLICITSG conditions would produce similar transfer times.

6.4 Equipment and Setting

The study utilized a custom-built multi-touch tabletop incorporating a 4K (3840x2160 pixel) resolution 55-inch flat-panel LED display fitted with a G4S PQLabs infrared multi-touch frame[4].

[4] http://www.multi-touch.com

Participants were each provided a 7-inch Galaxy Tab tablet and sat facing each other at the long sides of the tabletop. Each tablet had a fixed association with a specific player's position at the table to facilitate P&D transfer. Separate laptops were set-up on nearby desks for conducting study questionnaires, which were administered through the SurveyMonkey® online data collection service[5]. The DOMINION application used the TUIO API to process multi-touch input on the tabletop[6]. User identification of tabletop touches and above-the-table arm positioning was determined with a Microsoft Kinect sensor mounted 1.5m above the tabletop and a customized version of the KinectArm toolkit [8], as described in [23].

6.5 Procedure

Participants performed the main study activities together in a group of two, but completed written forms and questionnaires individually. Upon arriving, participants completed informed consent forms and a background questionnaire. The researchers then gave a brief demonstration of the experimental software and hardware systems, including training on how to transfer cards via P&D transfer. Each group played three games, one for each study condition, with the order of conditions counterbalanced. The DOMINION game can be seeded with different possible game cards that serve as "purchasable cards" during the game and influence the potential complexity of gameplay. Each trial used a unique, but similarly "complex", predetermined set of DOMINION cards[7], presented in the same order to avoid interference with the counterbalanced transfer conditions. Learning effects related to card sets were not anticipated due to players' previous DOMINION gameplay experience.

During each game session, groups typically spent four to five minutes reading the description of the available cards for purchase. After each condition, players completed a post-trial questionnaire. After completing the final post-trial questionnaire, groups participated in an interview with the researchers. Finally, participants were thanked and paid for their participation. The study was approved by the university's institutional ethics review process.

6.6 Data Collection and Analysis

As a mixed-methods study, quantitative and qualitative data were collected and analyzed. Participant interactions with the tabletop and tablets were captured in computer log files. Video data (with audio) and observer notes captured participants' verbal and non-verbal behaviour during the sessions. Background and post-trial questionnaires included closed- and open-ended questions. All post-trial feedback questions utilized a 7-point Likert-style rating scale to capture participant perceptions and experiences in each condition.

The video and open-ended participant responses were reviewed for patterns and emergent themes to provide context and deeper understanding of the quantitative results. The Likert-scale data from the post-trial questionnaires were analyzed using repeated-measures Analysis of Variance (RM-ANOVA). To account for the non-independence of group member responses, group was used as a dependent factor by using seating position at the table as the additional repeated measures factor. Thus a 3 (Condition) x 2 (Seating Position) RM-ANOVA was conducted. As seating position was not expected (and was not found) to impact the study measures of interest (e.g. awareness of cards being transferred, awareness of cards being transferred by a partner), we

[5] http://www.surveymonkey.com
[6] http://www.tuio.org
[7] Card sets were chosen from starter configurations available in the original Dominion game. Sets were selected based on their similar complexities and likelihood to produce a game length of ~30 minutes (based on pilot testing).

only report the main effects related to Condition in this chapter. No significant interaction effects were found. An alpha-value of $\alpha=.05$ was used to determine statistical significance.

Analysis of the awareness metrics only included data from the EXPLICITSG conditions to enable more statistically robust repeated-measures analysis of questionnaire responses, while analysis of the transfer timing metrics used both within- and between-subjects analyses across conditions, due to the numerous occurrences of card transfers available from the interaction logs.

7. RESULTS

Consistent with our previous cross-device studies, participants made substantial use of the P&D transfer mechanism for moving cards between the tabletop and their personal tablets during each DOMINION game. Less frequently, they also utilized the P&D mechanism to move cards between different tabletop locations, again consistent with our previous studies of P&D transfer.

The data analysis revealed that the TABLET BRIDGE feedback substantially improved the overall P&D transfer experience in the DOMINION game across study measures. Twenty-two out of 24 participants preferred having the BRIDGE feedback on the tablet (18 preferred EXPLICITSG+B; 4 preferred IMPLICITSG+B), while the remaining two preferred the NO BRIDGE conditions (1 preferred IMPLICITSG+NB, 1 preferred EXPLICITSG+NB). Post-experiment interviews revealed that the two participants who preferred the NO BRIDGE condition were strongly influenced by a minor interaction difference between the BRIDGE and NO BRIDGE conditions: the "tap anywhere to drop" convenience feature when the tablet was empty was inadvertently disabled in the BRIDGE conditions due to inherited functionality from the original BRIDGES transfer method (unfortunately not identified during pilot testing). Thus, users were required to always use the swipe-down drop gesture in the BRIDGES conditions. However, the lack of the "tap anywhere to drop" feature was not mentioned by most participants, who appeared to be satisfied with the swipe-down drop gesture. For the remaining few participants who also commented on this missing feature but still preferred the BRIDGES condition, it appeared they valued the high levels of transfer awareness provided by the TABLET BRIDGE feedback (detailed below) over the additional convenience of the "tap anywhere to drop" feature.

The data analysis also revealed that providing the TABLET BRIDGE feedback significantly improved participants' reported awareness of transferred cards, ***in both transfer directions***. Also, analysis of the transfer timing data found no differences between EXPLICITSG and IMPLICITSG conditions, suggesting that our software modifications addressed the transfer time performance issues related to the EXPLICITSG design uncovered our previous SURFACE GHOST study [23], supporting ***Hypothesis 3***. As the timing investigation was included to validate our software implementation improvements rather than our transfer method interaction design concept, timing results are not included here, but are detailed in an online technical report [22]. We expand on the transfer awareness results below.

7.1 Perceived Awareness of Transferred Cards

The RM-ANOVA[8] analysis of the post-condition questionnaire responses from the two EXPLICITSG conditions revealed the BRIDGE (EXPLICITSG+B) condition significantly increased reported transfer awareness compared to the NO BRIDGE (EXPLICITSG+NB) condition for both ***tabletop-***

[8] A t-test statistic would typically be applied to compare two conditions, but recall from Section 6.6 that tabletop position was included as a main between-subjects factor in the RM-ANOVA tests to account for the effect of group. No effect of tabletop position or interaction across main factors was found.

to-tablet and ***tablet-to-tabletop*** transfers. Table 1 summarizes the reported transfer awareness data and RM-ANOVA results.

Table 1. Average ratings on awareness-related post-condition survey questions (1=strongly disagree, 7=strongly agree).

Question	**Surface Ghost (Exp) w/o Tablet Bridge**	**Surface Ghost (Exp) w/ Tablet Bridge**	
I was always aware...	**Mean (SD)**	**Mean (SD)**	**RM- ANOVA**
*…when I had a card in my hand when moving from the **tabletop to my tablet***	4.7 (1.7)	5.8 (1.0)	F(1,11)=9.44, ***p=.011****
*…of how many cards I had in my hand when moving from the **tabletop to my tablet***	4.8 (1.6)	5.7 (1.3)	F(1,11)=6.29, ***p=.029****
*…when I had a card in my hand when moving from my **tablet to the tabletop***	5.1 (1.5)	6.0 (1.0)	F(1,11)=10.65, ***p=.008****
*…of how many cards I had in my hand when moving from my **tablet to the tabletop***	4.8 (1.9)	5.7 (1.3)	F(1,11)=8.93, ***p=.012****

*significant at α=.05.

These results support ***Hypothesis 1*** (The Bridge condition would better promote transfer awareness than the No Bridge condition for ***tablet-to-tabletop*** transfers), but do not support ***Hypothesis 2*** (The Bridge and No Bridge conditions would provide similar support for transfer awareness for ***tabletop-to-tablet*** transfers). They instead indicate that the addition of the Tablet Bridge feedback was perceived to be more effective at promoting transfer awareness that the Surface Ghosts feedback alone, in ***both transfer directions***. This result was confirmed by the many positive comments participants made regarding the utility of the Tablet Bridge in response to the open-ended survey question, *"What feature of the tabletop/tablet assisted the game play?"*, including:

- *"The visualization of cards at the top of the tablet greatly improved my awareness of when I had cards in transit." (P15 explicitSG+B),*
- *"You could see the cards on the tablet that were in transit." (P5 explicitSG+B),*
- *"The cards appearing on the tablet when in transit was helpful" (P24 explicitSG+B),*
- *"Not seeing the cards in transit on the tablet was a hindrance." (P11 implicitSG+NB).*

Review of the interviews, open-ended questionnaire responses, and video data also provided insights on the unexpected positive influence of the Tablet Bridge feedback on transfers originating from the tabletop. Participants reported extensive use of the Tablet Bridge feedback, when available, during ***tabletop-to-tablet*** transfers, as illustrated by the comments:

- *"The little bar on the tablet at the top to show what cards you took to the tablet [assisted the game play]." (P22 explicitSG+B questionnaire),*
- *"Sometimes you thought you picked up 5 cards when really you hadn't, and hav[ing] that additional feedback on the tablet was nice."(G7 interview),*
- *"In the second game they [cards on top of the tablet screen] disappeared…It was much more clear what you were transferring from the table to your tablet when you had them up at the top." (G1 interview).*

7.2 Benefits of TABLET BRIDGE Feedback

The video data revealed several specific benefits of the TABLET BRIDGE feedback during ***tabletop-to-tablet*** transfers. During DOMINION game play, players made extensive use of the "personal territory" near them in the tabletop interface. Players implicitly established these territories, similar to common tabletop usage in other contexts [25]. The consequence of this territorial behaviour was that pick and drop actions often occurred near the tabletop edge, commonly causing the SURFACE GHOST visual feedback to be displayed partially outside the interface. Due to poor touch detection near the tabletop edge on the tabletop system used in our previous studies, the active game play area in the DOMINION tabletop application stopped a few centimeters from the edge. However, since the projected area covered the whole surface, the SURFACE GHOSTS object and arm silhouette visual feedback continued to be displayed in the edge area. The upgraded tabletop used in this study provided improved touch detection across the whole surface. So, the active play area was extended directly to the tabletop edge to facilitate easier player access to game content. An unintended consequence of this change was that the SURFACE GHOSTS feedback was sometimes unavailable during pick/drop actions near the table edge. Participants used the TABLET BRIDGE feedback, when available, to overcome this issue.

The TABLET BRIDGE feedback also helped compensate for the positioning lag of the SURFACE GHOST and arm silhouette caused by the aforementioned smoothing performed on the imperfect Kinect tracking data. Once participants became familiar with the P&D transfer mechanism, they could perform card transfers very quickly (within milliseconds). Thus, sometimes a transfer was almost (or completely) finished before the SURFACE GHOST feedback would appear. In contrast, the TABLET BRIDGE was immediately, and persistently, available throughout the transfer process. Additionally, the new option to pick up 5 cards at once from a tabletop deck was used extensively. This substantially reduced the need for one-by-one multi-card pick-ups, which, in turn, reduced participants' use of the pick-up counter on the SURFACE GHOST multi-card visualization.

Finally, the TABLET BRIDGE feedback also helped participants cope with hardware input errors, such as errors in touch or gesture detection on the tabletop and tablet devices or errors in user tracking on the tabletop. Participants found the additional visual feedback on the tablet helpful for detecting and managing these issues, as illustrated by the comments, *"The slight finickyness [of the tabletop touch detection] was still a problem, but was helped by the display of cards being transferred at the top of the tablet ."* (P23 EXPLICITSG+B questionnaire) and *"[I] Felt the sensor wasn't working as well as the first game [a BRIDGE condition]. This could have been due to having less feedback when I picked up a card. Would have been nice to know how many cards were in transition."* (P13 EXPLICITSG+NB questionnaire).

7.3 Breaking the PICK-AND-DROP (P&D) Mental Model

Although the TABLET BRIDGE feedback was strongly appreciated by study participants and provided significant transfer awareness benefits over providing the SURFACE GHOST feedback alone, the qualitative analysis also uncovered some limitations. In particular, for some participants, it broke the mental model of cards "being in your hand" during P&D transfer.

Several participants mistakenly thought the appearance of cards on the TABLET BRIDGE after cards had been picked up from the tabletop indicated that the cards were already transferred to the tablet, as illustrated by the following participant comment, "*Having the cards appear automatically to the tablet made it flow faster/better."* (P5 EXPLICITSG+B questionnaire). The swipe-down gesture used to drop cards on the tablet potentially reinforced this notion, as the action typically coincided with the player's finger sliding directly over the cards on the TABLET BRIDGE—as if they were dragging the miniaturized cards into the main tablet workspace.

This misperception was problematic for several reasons. It was incongruent with the fact that P&D was also used for ***tabletop-to-tabletop*** transfers. Thus, a belief that cards automatically moved to the tablet upon a tabletop pick up may introduce confusion during attempted ***tabletop-to-tabletop*** transfers. It may also introduce confusion regarding the actual state of the cards when the SURFACE GHOST feedback was visible on the tabletop. This feedback was designed to reinforce the P&D metaphor of the cards being in the user's hand during transfer. This contradicts a false belief that the cards have already moved to the tablet, introducing inconsistent feedback and potentially increasing the cognitive demand on users.

Despite these potential issues, it appeared that most participants correctly understood the purpose and meaning of the TABLET BRIDGE feedback. Yet, the potential for misperception warrants further consideration for providing a clear and usable transfer interaction technique.

8. LESSONS LEARNED ON DESIGNING CROSS-DEVICE TRANSFER FOR T-MSES

Our experiences across the series of three studies investigating the P&D and BRIDGES (virtual portals) transfer techniques provided significant insights on supporting cross-device transfer in T-MSE settings. The studies also highlighted how point-to-point cross-device transfer techniques like P&D can be appropriated for within-surface transfers to help ameliorate usability issues related to dragging objects, especially across long-distances, on devices with imperfect touch input technologies (e.g. dropped objects due to lost or jittery input). We discuss these lessons learned below. For convenience, we refer to our original study comparing P&D and Bridges transfer methods [24] as Study 1, our first P&D with SURFACE GHOSTS feedback study [23] as Study 2, and this P&D with SURFACE GHOSTS and TABLET BRIDGE feedback as Study 3 in the discussion below.

8.1 Make Object State Apparent throughout the Entire Transfer Process.

The results of Study 1 uncovered the need for visual feedback during P&D transfer. However, Studies 2 and 3 highlighted the specific need to communicate the state of transferred content throughout the ***entire transfer process***, including the pick and drop phases of the three-phase P&D process (pick, transfer, drop). The limited visual feedback available on the tablet during pick operations in Study 2 hindered participants' perceived awareness for transfers originating on the tablet. Introducing the TABLET BRIDGE visualization in Study 3 provided persistent feedback during the entire P&D process: users could immediately see each picked card added to the row of miniature cards displayed on the TABLET BRIDGE, and see them disappear when cards were dropped on the target device. For ***tabletop-to-tablet*** transfers in Study 3, players could utilize either the SURFACE GHOST feedback on the tabletop or the TABLET BRIDGE feedback on the tablet to learn the state of cards involved in the transfer process, providing redundant feedback (when the SURFACE GHOST feedback was visible on the tabletop).

The BRIDGES transfer method from Study 1 provided similarly redundant feedback during the transfer phase, and persistently visible feedback during the entire transfer process. At the beginning, cards were visible as full-size active cards on the originating display. During transfer, cards were displayed on ***both*** tabletop and tablet devices (split across the TABLETOP/TABLET BRIDGES transfer portals). At the end, cards were visible as full-size active cards on the destination device. Accordingly, Study 1 participants consistently reported high levels of transfer awareness in the BRIDGES condition.

Future transfer mechanisms should be designed to provide similarly persistent, and potentially redundant, visual feedback of the content's current state (e.g. active or in transit) to help users maintain awareness of content being transferred from one point to another in the digital environment, either across devices or across a large display space.

8.2 Consider Efficiency at All Stages of Transfer: Beginning, Middle, and End.

While the Bridges transfer method from Study 1 provided excellent awareness of transferred objects, it was also found to be extremely tedious to use in the Dominion game because it required frequent object transfers. The need to transfer content via the intermediary Bridges portals added addition interaction steps to the overall transfer process. Participants found this especially effortful when performing multi-card transfers, a common action in Dominion.

The point-to-point nature of P&D transfer allowed for more efficient transfer, especially as our implementation allowed for multiple cards to be picked-up at the originating location and transferred at once. However, the frequent need in Dominion to pick up multiple (often 5) cards each turn introduced room for improved efficiency at the beginning of a multi-card transfer. Indeed, the "pick up 5 cards" option added to the tabletop menu in Study 3 was highly appreciated, and utilized, by players.

Introducing aggregated card transfer in the Bridges transfer method may be similarly useful for improving its efficiency, for instance, by allowing a deck of cards to be placed on the Bridges. This approach raises the design issue of whether the aggregated content (e.g. 5 cards) should be shown separately or in aggregated form on the Bridges containers. The existing "show all" approach allows users to remove individual items from the Bridge onto the target device, and provides a high-level of awareness of precisely which cards are being transferred. Displaying an aggregated view would only allow for an all-at-once end-of-transfer action, and may also reduce some of the positive awareness benefits of the Bridges method.

P&D transfer outperformed Bridges for end-of-transfer efficiencies as multiple cards being transferred at once would all drop at the target location. The "tap to drop" convenience feature on the tablet (available when the tablet was empty) also improved the drop efficiency of P&D transfer over the "swipe-down to drop" interaction, as it was more forgiving due to the bigger interaction target of the whole tablet screen (vs. the top edge for the swipe-down action) and the more robust touch detection in the central area of the tablets used in the studies. As mentioned above, end-of-transfer interaction, especially on the tablet, could be improved by providing a mechanism to allow all transferred items to be moved off the Bridge at once. This should be done in a task- and device-relevant way. For instance, in the Dominion game, the Tablet Bridge could be augmented with a button located to one side that, when pressed, incorporated all content on the Bridge into the hand of cards on the tablet. This would be fairly simple, as there was only one possible destination for cards fully transferred to the tablet. In contrast, automatically offloading the Tabletop Bridge would be more complex on the tabletop, as the intended destination may be less clear. Here, a specific drag gesture (e.g. a 2-finger drag) that allows players to manually move the entire contents of the Bridge to the intended location may be more appropriate.

In Study 3, it was anecdotally observed that some participants misinterpreted the Tablet Bridge visualization to mean that cards picked up on the tabletop were automatically transferred to the tablet. This misperception was actually a commonly suggested improvement across the three studies, and one we have received from others during public demonstrations of our system. This approach would resolve many efficiency issues discussed above. However, the approach assumes that players always intend to move cards to their tablet. Yet, our studies revealed frequent use of ***tabletop-to-tabletop*** transfers, thereby introducing complexities for inferring when cards should be transferred to one's tablet rather than be moved elsewhere on the tabletop. Nonetheless, the approach warrants further investigation as it has the potential to greatly improve the efficiency of ***tabletop-to-tablet*** transfers.

While our work involved the transfer of digital card objects, the need to consider efficiency during content transfer would also apply to other types of digital content, including, for instance, the transfer of multiple files or multiple components of a diagram. A similar "aggregator" operation should be considered, for example, a multi-select tool before or during the transfer operation, to facilitate multi-object transfers.

8.3 Consider Post-Transfer State, Utilize Context if Available.

Another limitation of the BRIDGES method from Study 1 is its inability to infer the target location, and hence intended purpose, during ***tablet-to-tabletop*** transfers. Consequently, the same post-transfer state was applied to each transferred card: Cards were always transferred face-up onto the TABLETOP BRIDGE to facilitate the common "reveal a card" action. However, this design decision was not universally appreciated, as it sometimes revealed information that players wished to remain secret. The inability to control the post-transfer card state with BRIDGES prompted highly competitive players to adopt a "partial transfer" strategy, in which they left drawn cards sitting on the BRIDGES. This allowed them to keep cards face-down on the tabletop at the cost of not being able to fully view, or manipulate, cards on the tablet. These players strongly preferred the context-dependent manner of determining the post-transfer state used by the P&D transfer method: Cards transferred to the tabletop took the face-up/down state of any deck/card they were dropped onto, or were placed face-up if dropped onto an empty area. This design decision was driven by the application task (i.e. the DOMINION game) and an early analysis of common game actions (and associated player intentions).

In the DOMINION game, the possible states of transferred objects were relatively limited: cards and card decks were the only application objects, card size and orientation[9] were fixed on both the tabletop and tablet, and cards were either face-up or face-down. However, in other task contexts, the possible object states that should be considered after transfer will vary. POssible states may include the scale (size) and orientation of content, whether content should be separate or aggregated, and for multi-dimensional objects, what side (or sides) is displayed. The size disparity between a large surface and smaller personal surface may play a factor. For instance, if a document that is currently being viewed on a smartphone display is transferred to a shared tabletop, it may be useful to display a larger portion of the document on the larger tabletop display than was visible on the smaller smartphone. Ultimately, if post-transfer state is determined automatically by the system, it should select a task- and device-appropriate state that best facilitates people's intended task activities. The selected state should optimize the overall efficiency of the transfer process by minimizing any necessary interactions to achieve a desirable post-transfer object state. Any contextual information available about the intended target location, transfer direction, task phase, etc. should be utilized to help infer a reasonable post-transfer state. Finally, simple interaction mechanisms should be provided to allow quick modification of object state in the event that the system infers an undesired post-transfer state.

[9] In Study 1, orientation of cards (and decks) on the tabletop was automatically determined based on their location on the tabletop. In Studies 2 and 3, cards (and decks) were automatically (orthogonally) oriented toward the table side of the "owning" user after P&D transfers or drag actions.

8.4 Consider Within-Surface Transfer on Large Surfaces.

Although our studies focused on cross-device transfer, they also highlighted the utility of a point-to-point transfer mechanism like P&D for within-surface transfers. In all three studies, participants commonly utilized P&D to move cards from one tabletop location to another. Almost all participants performed such ***tabletop-to-tabletop*** transfers. Analysis of the interaction logs for Study 2 showed no consistent pattern of participants' use of P&D transfer compared to drag actions related to the move distance: P&D transfers appeared to be as equally likely to be used for short-distance tabletop moves as for long-distance moves. Video data from Studies 2 and 3 revealed several possible motivations for choosing P&D over drag to move a card/deck on the tabletop. First, participants often appeared reluctant to drag cards/decks directly over other cards/decks, possibly due to uncertainty over the consequence of such actions (i.e. the deck/card may be disturbed). Thus, they sometimes dragged cards in a wide path around other tabletop content, or simply used P&D transfer to go above the tabletop content. Second, the imperfect touch detection on the tabletop sometimes caused the touch input to fail and cards to drop onto other content. One such instance in Study 3 prompted the comment, *"the deck just swallowed my cards"*. This type of input errors, unfortunately all too common in existing large-surface hardware, creates significant frustration for users. Long-distance drags are particularly vulnerable to lost-touch events. The fact that P&D transfer required minimal touch interaction on the tabletop provided a reasonable coping strategy for moving content, especially across a long distance, given the tabletop's imperfect touch detection.

9. CONCLUSIONS

The paper reported on a third study and overall lessons learned from a series of studies investigating the use of existing cross-device transfer methods in table-centric multi-surface environments (T-MSEs). This study specifically focused on improving multi-touch PICK-AND-DROP (P&D) transfer by providing device-appropriate feedback on both the shared tabletop and personal tablets during transfer. The study found that displaying a persistent static visualization of transferred cards along the top edge of the tablet interface (TABLET BRIDGE feedback) in conjunction with the dynamic representation of transferred content displayed under a user's hand on the tabletop (SURFACE GHOST feedback) improved participants' awareness of transferred cards for both ***tablet-to-tabletop*** and ***tabletop-to-tablet*** transfers over providing SURFACE GHOSTS feedback alone.

The benefit provided by the TABLET BRIDGE feedback during ***tabletop-to-tablet*** transfers was surprising, as we had previous found that SURFACE GHOSTS feedback alone promoted high levels of transfer awareness in this transfer direction [23]. The study indicated that the immediate and persistent feedback provided by the TABLET BRIDGE feedback helped compensate for several technical and usability issues associated with the SURFACE GHOST mechanism. The study also revealed that some participants misinterpreted the TABLET BRIDGE feedback and believed the cards were automatically transferred to the tablet when picked up from the tabletop. This misinterpretation breaks the P&D transfer metaphor of a card being "held in one's hand" during transfer, introducing possible confusion during transfer. A secondary finding of the study was that, unlike our earlier SURFACE GHOSTS study, no systematic differences were found in transfer times between different design variants of the SURFACE GHOST feedback, indicating that software improvements made to our experimental system resolved a previously observed performance issue.

This paper also reflected on the experiences we have gained across our series of cross-device transfer studies and discussed relevant design implications for future transfer mechanisms, including the need for persistent feedback throughout the entire transfer process, the need for efficient multi-object transfer, the need to consider post-transfer object state, including its implications for preserving information privacy when desired, and the need to support within-surface transfers on large displays.

While our studies revealed many useful insights, further study is warranted in a number of directions. First, players in our studies occasionally wished to transfer cards directly from one tablet to another, for instance, when the game required them to give a card on their tablet to another player. Moreover, one can imagine other task contexts, particularly during more cooperative group activities, where people might wish to exchange digital content directly between their personal devices. Similarly, someone may wish to pass tabletop content to someone else's personal device to allow closer review or editing. These additional transfer options would allow more cooperative transfer patterns between available surface devices than our current T-MSE allows. They also introduce new challenges for designing transfer mechanisms for multi-user environments, such as how to minimize potential interference when transferring content to someone else's device, that require further study.

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