Direct Intentions: The Effects of Input Devices on Collaboration around a Tabletop Display

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Abstract

This paper explores users' interpersonal interactions during collaboration around a tabletop display, in order to better understand the affordances offered by this medium. We investigate participants' collaborative interactions, particularly related to the type of input device provided. Stylus, mouse, and touch-based interactions were provided to allow multiple people to simultaneously interact with tabletop systems in a series of studies, and we observed how the choice of direct or indirect input device affected collaboration. In this paper we discuss how direct and indirect input affect natural interactions, ergonomics, territoriality, gestures, and awareness of both intention and action. The findings from our studies are valuable for those who deploy and design tabletop systems, by providing them with guidelines for appropriate choice of input device.

1. Introduction

Tabletop displays have been explored by many researchers (see Scott et al. [10] for a comprehensive overview). Within the area of tabletop collaboration, one area that has not been examined is how the choice of input device affects interaction between group members. From a non-technology perspective, a table provides an excellent environment to support group interactions and is often an integral piece of furniture for co-located, cooperative work. In general, large, horizontal computing surfaces afford different kinds of interactions and uses than desktop computers. At the heart of these differences is the way people interact with the technology and each other.

Although researchers have demonstrated many potential uses for tabletop displays, we are just beginning to understand how people interact with them and how to best design interfaces that maximize their potential [3, 6, 9, 10]. However, in order to explore new collaborative tabletop interfaces, researchers must first build a suitable tabletop display system. This involves making decisions about appropriate input and output devices [10].

Little is actually known about the benefits or drawbacks of common input devices, such as mice or styli, when used with tabletop displays. What effect do direct and indirect input devices have on collaborative interactions? What are the tradeoffs between choosing one input device over another? This paper addresses these questions through an investigation of collaborators sharing a tabletop workspace while using different input devices.

We first present related research on supporting co-located collaboration and tabletop systems. We then describe our studies and results. In particular, we discuss our observations on how direct and indirect input devices affect natural interactions, ergonomics, territoriality, gesturing, and awareness of intention and action. We also present a summary of the advantages and disadvantages, and considerations that must be taken into account when developing a tabletop system for collaborative use. Finally, we present directions for future work.

2. Related work

Ubiquitous computing supports the notion that technology should be designed to fit into our natural human environment. Providing natural interfaces that facilitate rich interpersonal communication between humans is essential for computer supported collaboration. For example, desks and tables are used extensively to work with physical artefacts such as paper, books, and pens. However, more and more of our work is conducted using desktop computers. Previous literature suggests that tabletop display systems can bridge the physical and digital environments. A wide array of tabletop systems have been proposed, developed, and evaluated; see Scott et al. [10] for a detailed review of these systems.

Researchers are exploring the potential of tabletop displays to support collaboration. The InteracTable [14], Stanford's Interactive Table [2], and the DiamondTouch [1] were designed to support cooperative work of dynamic teams. Tabletop systems have also been developed for teaching collaborative problem-solving [15] or for small group browsing and sharing of digital information such as photos and documents [12, 13].

Tabletop displays have been used with a variety of input techniques. Wellner's Digital Desk [18] system used a vision based-system to track the user's finger and enable pointing at objects in the system. The Urp [17] system uses vision to track physical objects. The InteracTable [14], DiamondTouch [1], Responsive Workbench [5] and the Pond [13] use touch-sensitive displays while the TractorBeam [7] uses a hybrid point-touch interaction technique. Several other systems have utilized tangible objects to interact with digital information, such as metaDesk [16], Caretta [15], and SenseTable [8]. Other tabletop installations utilize traditional desktop input devices such as mice and trackballs [5].

Two main reasons for the wide disparity in choice of input devices are the variety of tasks that can be performed using a tabletop display, and the inherent strengths and weaknesses of the input devices. In addition, there is a lack of understanding concerning users' interactions with the tabletop display and various input strategies. This clouds the decision as to which input device would be most appropriate.

More recently, there has been a heavy focus on novel interaction techniques for tabletop displays. Several techniques have been proposed to enhance manipulation and access of tabletop items [3, 7, 11]. However, all interaction techniques are still fundamentally impacted by the type of input provided.

3. Research studies

We have conducted a number of studies on co-located collaboration, including studies with tabletop displays. Through our experience, we have observed a number of common behaviours that collaborators exhibit when using tabletops. This paper focuses on three specific studies that shed light on how input devices affect collaboration.

4. Study 1: Input devices and collaboration

This first study was exploratory, with two main objectives: to gain general insights into users' interpersonal interactions when they collaborate around a tabletop display, and to investigate how different input device parameters impact these interactions. To investigate these goals, we observed users performing a collaborative card-matching game on a tabletop display. Participants used both mice and styli to interact with the tabletop. Our analysis focused mainly on participants' non-verbal communication.

The task used for this study was a collaborative "Memory Game". The game involved twenty face-down playing cards, which contained ten matching pairs. Players searched for matches by turning over cards; only two cards could be face-up at a time. If the cards matched, they disappeared. If the cards didn't match, they were turned face down again after a brief pause. Figure 1 shows a screenshot of the memory game.

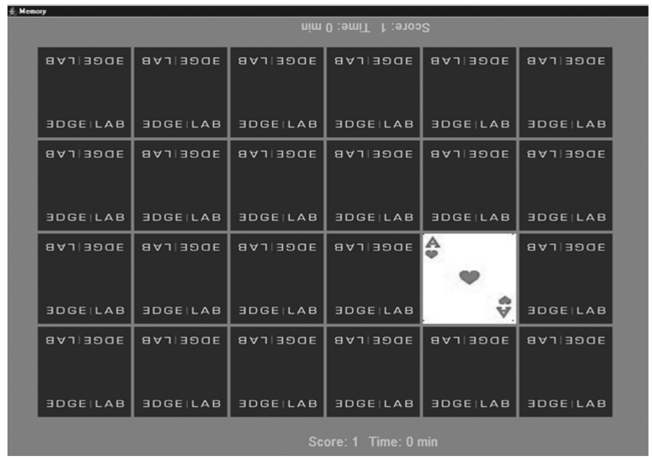

Figure 1: Screenshot of the Memory Game software.

Each time a card was turned over, one point was recorded. The goal of the game was to find all matches while minimizing the total number of points. Both users were able to turn over cards at any time. This allowed pairs to develop their own strategy for playing the game.

A pair of styli and a pair of mice were used for input. Participants interacted with a top-projected tabletop display consisting of a white laminate surface onto which a 103x79cm display with a resolution of 1024x768 was projected (see Fig. 2). Polhemus Fastrak receivers were used for the styli and were tracked in 3D space. Moving the pen tip within 0.01cm of the table registered a selection. For the two-mouse condition, the MID toolkit [4] was used to capture events from each mouse.

4.1. Experimental design

Twelve pairs of university students (12 male and 12 female) participated in this study. Each pair completed three games in each of four conditions: shared mouse, shared stylus, two mice, and two styli (12 games in total). The order of the conditions was counterbalanced to minimize order effects. Participants were given the opportunity to practice the game once before the trials began. Observation data for this study were collected using video and preference data were gathered using post-condition and post-session questionnaires.

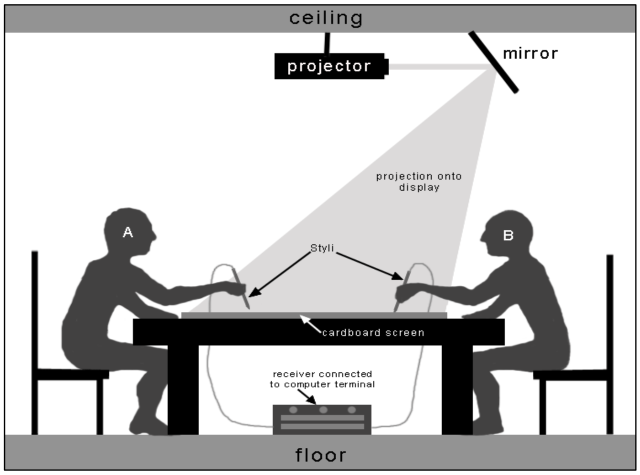

Figure 2: Styli setup using Polhemus Fastrak

4.2. Results

Although a number of general insights were gathered on users' interpersonal interactions around a tabletop display, this section reports on the results pertaining to the impact of input device parameters on participants' interactions.

4.2.1. Gesturing. Non-verbal gestures (both physical and virtual) were analyzed from the video data. A gesture was defined as a motion with the hand or input device, used to communicate information about a specific artefact in the Memory Game. Physical gestures include all gestures where the user physically reached their hand or arm towards the item of interest. Virtual gestures were gestures where only the cursor was used to convey information about the item of interest (i.e. mouse gesture).

Not surprisingly, participants exhibited significantly more physical gestures using the stylus (55) than when using the mouse (15), $F_{1,11}$=25.88, p<.000, η_p^2=.70. When using styli, participants often used the stylus itself as a gesturing tool, and hand gestures were made using both the hand holding the stylus as well as the other hand. When using a mouse, participants' physical gestures were primarily with the hand not holding the mouse, as they rarely removed their hand from the mouse.

In lieu of gesturing with their mouse hand, participants frequently used the mouse cursor to make virtual gestures towards artefacts in the application. The average number of cursor gestures per session for both participants was 30. This was less than the amount of physical gesturing with the stylus (41), although this difference was not statistically significant ($F_{1,11}$=1.90, p=.195, η_p^2=.15).

4.2.2. Natural interactions. Despite the fact that mouse-based input is the most common type of interaction on desktop systems, 15 out of 24 participants rated the stylus as being more natural, and 17 out of 24 rated it as being easier to use than a mouse when working on a tabletop. (8 rated the mouse more natural, while 3 rated the mouse easier.) From the video, we observed that when participants used mice, they seemed less physically engaged with the table. Participants tended to lean back or sit motionless, primarily interacting through the mouse. Conversely, when using styli, the participants seemed considerably more dynamic. Their increased physical activity included reaching, pointing, and leaning. One participant commented on this aspect in the post-session questionnaire: "the stylus was easier than the mouse, more direct; you point and click rather than move your wrist in small motions to put a cursor in the correct place". Note however, that this increased physical activity may be distracting, as it draws attention away from the display, and can obscure portions of the display.

4.2.3. Awareness of Intention and Action. Although virtual gesturing with the mouse cursor was common, it was problematic given the increased cognitive load involved in following a small cursor on a large display surface. Several participants commented on this problem in the post-session questionnaire, particularly with multiple cursors on the screen. They claimed that it was difficult to keep track of the mouse cursors, that it was difficult to distinguish between multiple cursors, and that the presence of multiple cursors was distracting.

In the styli conditions, the results suggest that the use of the stylus, in conjunction with the tabletop display, helps to promote participants' awareness of intention and action. Participants commented that "the position of the pen enabled me to guess what my partner wants us to do" and that "the stylus was… less confusing as to who was pointing at what when there were two input devices".

5. Study 2: Awareness of intention

To further investigate whether the type of input impacts users' awareness of intention, a second study was conducted. A slightly modified Memory Game was used. In this version no score was recorded. Instead, players were simply encouraged to finish the game as quickly as possible. We felt that this approach would motivate users to more closely monitor their partner's intended actions to avoid the inefficiencies of collisions.

5.1. Experimental design

Twelve pairs of university students (19 male, 5 female) participated in this study. Each pair played a practice game, followed by 10 games (with a short break halfway) in each of two conditions: mouse input and stylus input. The order of the conditions was counterbalanced to minimize order effects. Timing and mouse click data (time and position of cursor) for this study were collected using computer logging, and preference data were gathered using post-condition and post-session questionnaires.

5.2. Results

This section reports on how participants partitioned the tabletop display space (and associated objects) as well as the amount of awareness participants had of their partner's intentions.

5.2.1. Territoriality. Analysis of the participants' territorial behaviour revealed that the tabletop was divided very cleanly across the mid-line when styli or mice were used. However, this division was much more marked in the stylus condition. Figure 3 shows the average breakdown of selection behaviour for both members in a pair. The percentage on each card indicates the percentage of selections made by the most active user for that card.

For both the mouse and the stylus conditions, the majority of selections per card were performed by the person sitting on the side of the table closest to that card. When using mice, the most even divisions occurred in the centre-most rows of the table. For example, two cards in these rows are quite evenly split, at 52/48 percent and 60/40 percent. On the far edges of the table, the divisions were more extreme, ranging from a 71/29 percent split to a 88/12 percent split.

This division was even more pronounced under the stylus condition. The most equitable divisions also took place in the centre-most rows, with the most even split being 74/26 percent (less even than mouse interaction). On the far edges of the table, the inequity is more dramatic: the divisions range from 94/6 to 97/3 percent.

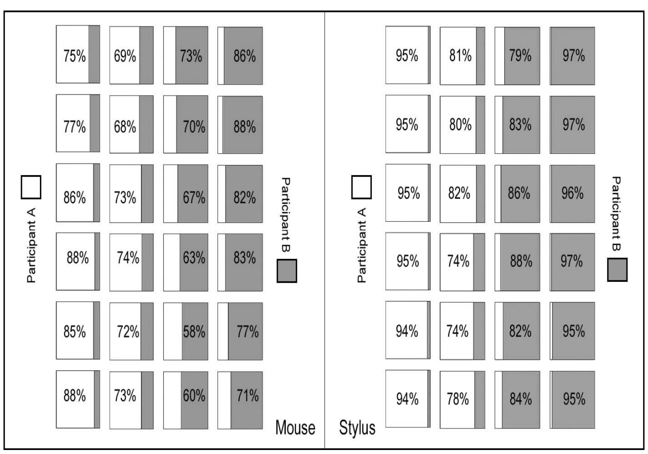

Figure 3: Division of card selection in study 2 (the Memory Game), for both mouse and stylus conditions.

5.2.2. Awareness of intention. We wanted to find an observable behaviour that would provide a good metric to indicate increased awareness of intention between partners. Observations from study 1 suggested that the number of collisions that occurred between participants (i.e. two people clicking on the same card) for both the mouse and styli conditions might be a good indicator.

Interestingly, instead of maintaining an awareness of their partner's actions to minimize collisions, participants in this study instead partitioned the display into distinct territories (as discussed above) and employed turn-taking behaviours. This enabled them to effectively avoid interference, and therefore we observed very few collisions in either the mouse or styli condition—a total of 64 and 68 respectively, over all games.

The turn-taking approach that participants adopted meant that the number of collisions was not a useful indicator of awareness of intention. Despite these results, the majority of our participants (17 out of 24) felt that the stylus was better than the mouse for providing overall awareness of what their partner's intentions were. Further research is required to see if this result can be objectively validated.

6. Study 3: Awareness of action

We were also interested in whether the type of input would impact users' awareness of each other's *actions*. We therefore conducted an additional study to investigate whether the type of input impacts users' awareness of actions carried out on the tabletop. We measured the time taken to notice and respond to a partner's actions as an indicator of awareness of action.

The task used in this study was a search game where a pair of users **competed** to find images within a large set. Users were each given the same set of five images, and they were asked to find all five images, in order. (The images varied in colour as well as design, and were symmetric across the horizontal axis). Once a user found an image, he would select it; and then move to the next image. A screenshot of the game is shown in Figure 4. The object of the game was for a player to find all five items faster than their partner. We expected that players would "copy" the move after their partner found an image, so having greater awareness of actions would make their overall search times quicker.

A top-projected DiamondTouch touch-sensitive tabletop display was used, onto which a 90x60cm display with a resolution of 1024x768 was projected. In one condition, two USB mice were used for input. In a second condition, the DiamondTouch serial tabletop display [1] was used to provide multi-touch input (users could select an item by just touching it with their finger). We hypothesized that the intervals between discoveries would be shorter with touch-based input than with mice.

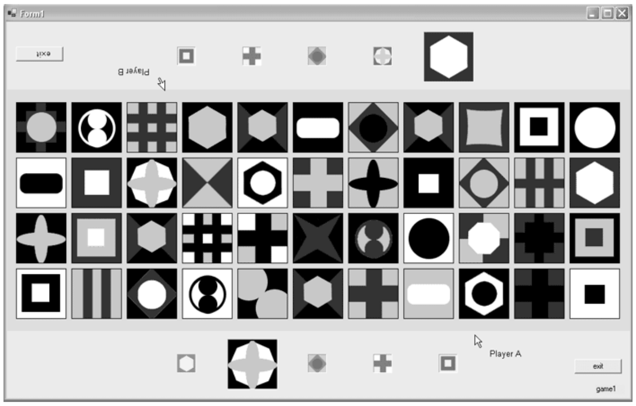

Figure 4: Screenshot of the Search Game application (Study 3). The large icons in the top-most and bottom-most rows are the ones that the users are currently looking for.

6.1. Experimental design

Twelve pairs of university students and staff (18 male, 6 female) participated in this study. Each pair played a practice game, followed by 10 games (with a short break halfway) in each of two conditions: mouse input and touch input. The order of the conditions was counterbalanced to minimize order effects. Timing and mouse event data for this study were collected through computer logs. Preference data were gathered through post-condition and post-session questionnaires.

6.2. Results

This section reports on how natural participants felt the input techniques were, and the amount of awareness participants had related to their partner's actions.

6.2.1. Natural interactions. Participants enjoyed interacting with the touch-sensitive display; when asked whether they preferred touch-based or mouse-based input, 15 out of 24 preferred the touch-based input. Their comments included: "User friendly and…natural response"; "It is more instant, more direct." Of the remaining nine participants who preferred mouse input, two people cited a dislike of physical collisions; one stated that "…there was no chance of collision with the partner's hand." In total, six participants expressed concern about physical interference and collisions that occurred in the touch input condition.

6.2.2. Awareness of action. Data logging for the Search Game recorded time intervals between one participant's discovery (and selection) of an item and their partner's discovery (and selection) of that same item. Our hypothesis was that the large physical gestures required by direct input (i.e. touch) would make the selection more obvious, and thus a partner would notice (and respond to) a selection faster in the touch condition than with indirect input with a mouse.

A repeated measures ANOVA was run on input device (mouse, touch) with order of condition as a between-subjects factor. The results revealed that participants responded significantly faster to their partner's actions when using touch input (1508ms) than when using mouse input (2830ms), ($F_{1,10}$=6.06, p=.034, η^2=.37). Condition order was not found to be significant.

7. Discussion

The results gathered from these studies provide important insights on how the choice of input technique can impact users' interactions with tabletop displays as well as with collaborators.

7.1. Natural interactions

One of the most compelling results of all three studies was how naturally the participants interacted with each other and the table. Many of their gestures and interactions on the tabletop display system were akin to those exhibited when sitting around a table. Pointing was utilized by every participant. They pointed and touched the virtual artefacts on the table in the same manner as if they were physical objects, often using both hands.

Although this is consistent with previous research [10], the results in this paper demonstrate that the use of direct input further promotes natural interactions. For example, when people used direct input (with styli or touch input), these interactions occurred in the surrounding physical space. As such, users were able to transfer everyday knowledge of how to interact with both the physical world and with other people to the tabletop display environment. These innate interpersonal communication skills help to interact in a rich manner and take advantage of intuitions to gain awareness of others' intentions and actions when using digital media.

7.1.1. Touch sensitive displays. A touch sensitive display is an obvious choice for a tabletop display system. Intuitively, when people first approach a tabletop system, the first thing they want to do is touch it to interact with it. There are, however, drawbacks to the use of touch sensitive displays that may impact their usefulness, such as unintentional selections. Any part of a person's body may elicit responses from a touch sensitive display. In our studies, many participants rested their fingers on artefacts with no intention of selecting them and leaning on the table was a common occurrence. One participant commented that it was "nice to be able to point with your finger and not activate anything". Other participants instinctively leaned in and rested their arms on the table as they engaged in the activity, especially when using styli. It is important to not interpret this contact as an interaction with the system. This behaviour must be incorporated into the design of all displays and tabletop applications. In addition, absently-placed coffee cups, papers, or pens should not unintentionally elicit a reaction from the table.

7.1.2. Stylus input. Many participants also found the stylus to be an intuitive input device for a tabletop system. Comments included: "[the] stylus is a lot easier to use and is much more natural"; "I could point out my selections better with a stylus"; and "[the] stylus did feel more natural due to its pen-like design".

There were however, drawbacks to the use of the stylus for direct input. The stylus users in studies 1 and 2 (Memory Games) inadvertently selected cards when they were gesturing (with the stylus) close to a card. While it can be helpful to have a sensitive input device, this ease of selection is a double-edged sword. Many participants also found that direct input methods led to frequent occlusion of the display, more so than with the mouse. People who lean forward to rest on the table may block the part of the tabletop closest to them.

7.1.3. Mouse input. The participants in these studies were comfortable using a mouse on the tabletop display and many expressed familiarity as its primary benefit. Using a mouse, however, had other drawbacks; because of the physical constraints when using a mouse, some participants sat in an awkward position rather than taking the necessary time to configure their physical setup.

7.2. Territoriality

In order to coordinate actions on a shared tabletop display, users may partition their interaction by space and/or by time. Territoriality refers to the group members' division of the workspace into regions: for example, into areas that "belong" to each individual [9].

In studies 1 and 2, participants were able to reach all cards, and both participants were free to turn over any cards they wished (although only two cards could remain turned over at any one time). Thus, both people were free to partition the work and the display in any fashion they chose. However, in study 3, the task was competitive and required individual work; hence, it was not possible for participants to partition the work.

The participants displayed a conspicuous hesitancy to reach across the tabletop to make selections. It is unclear how much of this reticence is due to physical obstacles (i.e. the effort required to reach across tabletop), and how much is due to territoriality (i.e. the belief that those far objects "belong" to the other person). Reaching distant objects obviously requires more effort with direct rather than indirect input devices. Our experiment revealed that a territorial division occurred with both styli and mice; however, the degree of territoriality was different depending on the type of input used—people were more territorial when using direct input.

Participants' comments shed some light on this question. In study 2, after they had completed both conditions (mouse and stylus), they were asked "Were you more likely to interact with the objects on your 'partner's side' of the table when using the mouse or stylus?" Not surprisingly, 20 out of 24 participants chose 'mouse'. When we asked for justification, the most commonly-cited reason was ease of use (not having to reach across the table). However, six participants provided reasons based on coordination: specifically, territoriality and wanting to avoid physical collisions with their partner. Examples included, "Don't feel like you are intruding on their 'space'"; "With pointer I don't feel any invasion to…partner's territory, but with my hand yes"; and "because it was easier to point at cards on his side without the potential of bumping our hands/stylus in the process."

This suggests that there is some desire to partition the physical space that goes beyond simple ergonomics, and would exist even if all parts of the display were easily accessible to both partners.

7.3. Ergonomics

The choice of input device also has an effect on the ergonomics of a tabletop system. Direct input devices have drawbacks in terms of physical interaction with tabletop displays. Both the stylus and touch-based interaction techniques in our studies were reported by many participants as being tiring. In the particular, several participants preferred using the mouse, stating that the mouse was less tiring, required less effort, and/or made it easier to reach objects on the far side of the table.

Occlusion of the display is another drawback when selecting object using direct input as users' arms, and hands cover parts of the display. The physical placement of the mouse may also occlude some elements on the display, unless the tabletop is sufficiently large to allow for blank space. Note that even when there is space for the mouse at the edges of the display, users may drag the mouse onto the display area. This behaviour was observed repeatedly in our research

7.4. Gesturing

Gesturing is a rich communicative activity that is often heavily used when people collaborate. The results of our studies clearly indicate that the type of input utilized has an impact on gesturing. Although the amount of gesturing was similar across the different conditions, a significant portion of these gestures are virtual when a mouse is used. This may be problematic because virtual gestures do not have the same level of physical presence that physical gestures do and can impact users' awareness of their partner's actions and intents.

7.5. Awareness of intention and action

A notable feature of working on a tabletop display was the ease with which users communicated actions and intentions. This communication between participants is an important component for successful collaborative environments. Because we are already capable of communicating our intent naturally in our everyday lives, we should leverage these skills when developing co-located collaborative technologies.

Our results suggest that one of the strengths of direct input is in supporting the ability to communicate actions naturally to collaborators in a tabletop setting. This may indicate that the hand gesture, conspicuous and explicit, provided better direction to the partner. In study 3, participants' comments bore out this observation: when asked which input method (mouse or touch) was more helpful in communicating what their partner was doing, 20 out of 24 people selected "touch." Comments included: "It was easier to keep track of where my partner's hand was than where the mouse cursor was", and "you were more aware of their hands than the cursor when they used the mouse." In addition, we believe that direct input may also support the ability to communicate intention; however, in study 2, we were unable to objectively measure this phenomenon and validate the assumption.

It was much more difficult to see and track virtual gestures such as mouse cursor movement with an indirect input device. For instance, when using two mice, participants frequently encountered collisions. In study 1, two participants commented: "sometimes we made mistakes, both clicking on a card as the 'first' card" and "my partner and I clicked at the same time while using different mice".

We were able to draw some additional conclusions about awareness of intention and actions from this set of studies. For example, indirect input devices require attention, which can decrease awareness. Even when using a mouse, the lack of proprioceptive feedback makes it necessary for a person to focus on the cursor in order to interact with the table. As a result, people in our studies found it difficult to gesture effectively with the mouse cursor while looking at their partner. Furthermore, participants could not interpret a mouse gesture without shifting visual attention between the display and their partner. To provide more awareness information on a tabletop display, mouse cursors could be modified (i.e. made larger or more distinct). However, given that the mouse is an indirect input device, its operation is in a different physical location than the cursor, and thus the aforementioned problems will likely persist.

8. Summary: Pros, cons and considerations

Our studies highlighted a number of ways in which direct and indirect input devices affected collaboration around a tabletop. These results have implications for practitioners, in particular those who design tabletop applications and those who incorporate tabletop displays into their environments. We summarize our key findings below, in terms of their advantages, drawbacks, and any special considerations that must be made when choosing an appropriate input device:

8.1. Direct input devices

Pros:

- support natural, fluid gestures
- support coordination through greater awareness of intention and action
- allow for noticeable gestures

Cons:

- user may become tired
- items on far side of table are difficult to reach
- noticeable gestures may be distracting
- input device may obscure display
- users may physically collide in workspace

Considerations:

- device may be seen as "invasive" into partner's territory on display. This may improve coordination, or may unnecessarily restrict activity in some regions of the display

8.2. Indirect input devices

Pros:

- allow items on far side of table to be easily accessed
- do not require much physical effort to use
- may be more familiar to users
- small pointer does not obscure elements on display

Cons:

- reduce the amount and range of gestures
- subtle gestures may go unnoticed
- lesser support for awareness of intention and action may impede coordination and collaboration
- multiple cursors may be distracting or confusing

Considerations:

- space must be left on tabletop to accommodate device (close to user)
- user likelier to cross territorial boundaries with indirect device than with direct device

9. Conclusions and future work

As we continue to embrace new technologies in our everyday lives, tabletop displays hold potential for supporting collaborative interactions. In order to realize the potential for tabletop displays, we must be able to make informed choices about appropriate types of input. Our results demonstrate how different input device parameters can impact users' interactions.

Overall, direct input on tabletop displays supports natural gesturing and helps users to notice their partner's actions. In addition, it can provide rich interpersonal interactions, enabling users to both impart and understand each other's intentions seamlessly. The naturalness of these interactions makes it possible to utilize our existing capabilities for interaction in the physical world in the digital domain. This, in turn, allows us to leverage users' inherent communication and interaction skills for use in new media environments.

Indirect input devices, on the other hand, have ergonomic advantages. They may be more comfortable and allow easy access to all regions of the tabletop. Indirect devices can prevent physical interference and avoid occlusion of the display. These qualities can be taken advantage of in tabletop displays as well as other types of single display groupware.

Our ongoing work will continue to investigate how people interact collaboratively around a table, and how we can effectively support this process through technological innovation. We plan to investigate which tasks may be well suited for a tabletop display and how to best design these multi-user environments. In the short term, we plan to explore issues related to new input techniques, to find more meaningful measures for awareness of intent, and to examine new metaphors for tabletop interfaces.

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