Improving Digital Handoff in Shared Tabletop Workspaces

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Abstract

Handoff of objects and tools occurs frequently and naturally in face-to-face work; in tabletop groupware, however, digital handoff is often awkward. In this paper, we investigate ways of improving support for digital handoff in tabletop systems. We first observed how handoff works at a physical table, and then compared the performance of tangible and standard transfer techniques on digital tables. Based on our observations, we developed a new technique called force-field handoff that allows objects to drift between pointers that are approaching one another. We tested force-field handoff in an experiment, and found that it is significantly faster than current digital handoff; no difference was found with tangible handoff. In addition, force-field handoff was preferred by the majority of participants.

1. Introduction

Digital tabletops are now becoming common, but tabletop groupware systems are only beginning to approach the flexibility and simplicity of collaboration around physical tables. In order to enable the smooth and fluid interaction that is visible in physical settings, tabletop workspaces must support the basic low-level actions and interactions that enable people to carry out tasks in a shared fashion.

One of these actions is handoff – the transfer of objects from one person to another. Handoff is frequent in face-to-face work: people hand over task artifacts to others, pass shared tools back-and-forth, and work collaboratively to move objects from one place to another. Handoff occurs for two reasons: first, because space is usually organized into territories [17], it is often more polite to ask for an object from another person's personal area than it is to reach in and take it, and second because people cannot reach all parts of the workspace, it is easier to share the task of reaching for an object than it is to walk around the table.

Handoff is a multi-person synchronous target acquisition task [13]. The first person brings the object or tool towards the second person, and holds it in position until the second person takes it. The second person then moves the object to a target region somewhere in their work area. The target for the first person, however, is variable, and may change based on the table or the activities of the receiver.

Handoff is also different from depositing objects or simple reaching. Handoff is a synchronous action whereas deposit is asynchronous – it is not necessary for the sender's release action and the receiver's grab action to happen at the same time. Similarly, handoff needs multiple users to coordinate whereas reaching involves only a single person. Handoff and deposit are both useful in different task settings, but it is not sufficient to simply replace one with the other.

Although handoff is a common action, little is known about its design in digital tabletop systems. In the real world, handoff happens naturally because both the sender and receiver can grasp the physical object, see the position of the real object, feel the other person's force on the object. In the digital world, however, there is no haptic feedback and no physical representation during object transfers.

In this paper, we look more closely at how handoff can be supported in shared tabletop workspaces. To find out how handoff occurs, we carried out an observational study that looked at how often and when people choose handoff and deposit in real-world tasks on regular tables. We later compared these instances of real-world handoff with traditional drop-and-grab digital handoff and found that a bottleneck occurs in negotiating the final stage of the object transfer on digital tables.

Based on these findings, we designed an enhanced 2D handoff technique – force-field handoff – that simplifies the final transfer stage by having the object drift from one cursor to the other when the cursors approach one another. We evaluated the design in a controlled experiment that compared force-field

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handoff with traditional digital and physical handoff. The new technique was significantly faster than traditional handoff, and was preferred by participants.

The paper makes three main contributions. First, we identify a fundamental action in tabletop collaboration, and show how that action occurs in real-world tasks. Second, we identify principles that can guide the design of digital handoff techniques. Third, we show that one new technique, force-field handoff, can significantly improve handoff performance compared with a traditional drop-and-grab implementation. Our findings suggest that the usability of tabletop systems can be substantially improved with interaction techniques that support the subtleties of collaborative actions.

2. Related work

2.1. Tabletop systems

Digital tabletop systems are now popular for research into co-located collaboration, and many systems have been developed to illustrate the applicability of the idea for shared work. For example, iLand [22] allows users to interact with artifacts on the table and with other 'roomware' components such as electric walls and computer-enhanced chairs. UbiTable [19] allows people to create a shared display space from existing displays such as personal laptops or PDAs. Personal Digital Historian [3] places work artifacts on a round table and provides easy-to-understand mechanisms and metaphors for content organization and retrieval. The DiamondTouch table [4] allows multiple touches, and can also identify which user is touching, which makes it possible for multiple users to simultaneously interact using touch-based techniques. DiamondSpin [20] is a toolkit that supports prototyping of rotatable tabletop systems for multiple collaborators.

Much of the design focus in tabletop displays is on making the computational spaces as flexible and easy to use as a physical table. Like real-world tables, many of these systems are lightweight enough to support serendipitous walk-up-and-use operation, and many implement simple ways to provide private, personal, and shared work areas [17,19].

2.2. Tabletop interaction techniques

A wide variety of research has been done into ways that users can interact with data and with each other through digital tables. Users can work together on tabletop displays using single input devices (such as tangible blocks, pens, mice, or fingers) or multi-touch input [4].

Because individual actions on a table are also public acts that are available to collaborators, the design of interaction techniques can have a large effect on collaboration. For example, Inkpen et al. [8] found that a stylus is better than a mouse for tabletop collaboration because direct pointing with the stylus provided more effective communication about people's actions. Similarly, Wu and Balakrishnan [12] present multiple-finger and two-handed gestures to allow users to collaborate in a tabletop. These gestures not only increase the input bandwidth, but also enhance the awareness of other collaborators.

Other research is focused on improving the efficiency of techniques for individual work – for example, Kruger et al. [16] present a novel technique to simultaneously rotate and translate an object on the tabletop.

Due to the size of a tabletop display, many researchers have also investigated interaction techniques for long-distance reaching and remote objects manipulation. For example, Parker et al. [7] designed TractorBeam, a hybrid point-and-touch technique that allows users to reach distant objects on tabletop displays. Other long-distance techniques originally developed for wall displays could also be applied to tabletops, such Drag-and-Pop [10] and vacuum filtering [1].

2.3. Handoff

Handoff is one of the mechanics of collaboration defined by Pinelle et al. [13], and they suggest that users need techniques that support handoff actions in shared workspaces. There are a number of factors that affect handoff on tabletop systems. First, Ryall et al. [9] found that every user has a private work area, and it seems rude for others to take objects directly from this space, even with the owner's permission. Participants in Ryall's study were reluctant to grasp objects that were near their partner, even when these were within their reach. Instead, they asked the partner to first pick up and hand off the object. Ryall also found that although long-range pointing techniques can solve the reach problem, users greatly prefer to manipulate objects directly on the tabletop, even if this means asking other users to take part in the transfer [9].

Ringel et al. [11] devised several gestures to support transferring objects on tabletop systems. This research found that a frequent action on the tabletop was transferring object from a personal area to a public area, so that another person could then move the object into their own personal area. This observation follows Scott et al.'s [18] guideline that interaction techniques must protect the transition between personal and shared areas.

Finally, Sallnas et al. [6] investigated handoff in a virtual environment with and without haptic feedback. They found that the time required for passing objects did not differ significantly between the haptic and non-haptic conditions; however, the error rate was significantly lower with haptic feedback.

3. Preliminary studies

Although studies of real-world tabletop activity have been carried out (e.g., [17,21]), there is still little understanding of how often participants use handoff and deposit, and what factors affect handoff in physical and digital spaces. To investigate these issues in more detail, we conducted two preliminary studies of handoff behaviour, one in a physical setting, and one digital.

3.1. Handoff on a physical table

We asked four groups of participants (two groups of three, and two groups of four) to carry out several tasks with physical objects on an ordinary 160x125cm table. The tasks included stenciling words onto a large sheet of paper, constructing storyboards using a variety of paper materials, and building a complex 3D puzzle. These tasks required people to regularly transfer tools and objects to other people. All activities were recorded on video for later analysis.

3.1.1. Handoff vs. deposit

We first analyzed the video to count the number of handoff and deposit actions. We found that object transfer occurred regularly in these tasks – on average, each user transferred an object to someone else nearly once per minute. Deposit-based transfer was slightly more frequent than synchronous handoff: participants used deposit 53% of the time, and handoff 47% of the time.

The 3D puzzle task had a higher percentage of handoff (55%), possibly since the workspace contained many groups of pieces belonging to different parts of the puzzle, and deposit would often have resulted in confusion between sender and receiver.

3.1.2. User roles in the handoff process

We identified three roles and stages to the handoff action. The *initiator* starts the handoff action by locating the object of interest and starting a conversation with the *follower* who has access to the object or who needs the object. The initiator can be either the sender or the receiver. *Observers* are other tabletop participants who are not interrupted by the handoff, but gain passive awareness of the coordination between the initiator and the follower.

The initiator and the follower engage in a dialogue that involves describing (or pointing at) the object of interest: for example, "Can I have the scissors?" or "I think this blue piece is yours." The dialogue continues until the participants start the handoff action.

The handoff action itself is a three step process that involves retrieving the object, coordinating the sender and receiver actions, and placing the object in its final location. The sender picks up the object and moves it towards the receiver. The receiver adjusts their movement toward the sender until both of them can grasp the object at the same time. This coordination action is needed to make hands meet as quickly as possible. The sender then releases the object, and the receiver continues to move the object to the target. Most people engage in these activities with very little conscious effort and do not need to think about the negotiation that takes place at the handoff site.

3.1.3. Handoff techniques

Handoff actions seldom occurred inside a personal territory without permission of the owner. Senders always picked up the object from their personal territory and the transfer occurred in shared space. We also observed that people employ two strategies to transfer objects. On some occasions both sender and receiver used the surface of the table to move the object, especially when the sender and receiver are close to each other. However, in most cases they used the space above the table to facilitate handoff. This allowed the sender and the receiver to transfer the object without interfering with other participants and other objects on the table. Overall, 132 of the 157 handoffs took place above the table surface.

3.2. Investigating 2D digital handoff

To determine basic differences between real-world and digital handoff mechanisms, we carried out a small study comparing physical handoff (using a tracked tangible block) to handoff with a standard digital pointer technique.

Digital handoff. Sensors were attached to both users' index fingers to allow users to point to and select objects on the tabletop. Objects were selected by touching a finger on the object; the object then follows the finger's movement until the user lifts their finger from the table surface. In this technique, handoff occurs when the receiver touches an object that is controlled by the sender. Unlike some digital handoff implementations, the sender did not have to release the object in order for the receiver to start moving; that is, the technique worked on a 'last-touched' principle.

Tangible block handoff. In this technique, a variation on the media block technique [24], a sensor was attached to a cardboard 'block.' Digital objects could be picked up by placing the block on the object;

when the block was on top of the object, it would become selected and could be moved by moving the block. To transfer the object, the sender and receiver transferred the physical block; the receiver then moved the block (and the object) to the target location.

3.2.1. Apparatus, task, and design

A top-projected tabletop display (155cm x 111cm) was used as the work surface. The transfer techniques were implemented using a Polhemus FASTRAK system, with the sensor attached either to the tangible block or to the participants' fingers.

Each trial was conducted with two users: a sender and a receiver. Senders selected a 6cm object from a start position, and transferred it to the receiver, who was instructed to move it to a final target. Subjects were asked to perform repetitions of the task for the two different handoff techniques, as quickly as possible. Audio feedback was given when the object was acquired, transferred, and placed inside the target.

Four pairs of participants took part in the study, and both participants played both roles. The experiment used a within-participants design with *handoff technique* (digital or tangible) as the main factor. Each pair completed 12 training trials per technique and 36 test trials. Users switched roles after completing all trials. The handoff locations, handoff times, and total completion times were recorded.

3.2.2. Results

We used two performance measures: completion time and handoff location. Handoff location measures the distance between the handoff location and the target, giving a measure of how far the sender and receiver each moved the object.

Completion Time: The overall mean handoff time was 1.41 seconds (s.d. 0.4s). A repeated measures ANOVA showed a main effect of interaction technique ($F_{1,143}$=21.43, $p<0.001$). Tangible handoff was faster than digital handoff by 0.07 seconds (about 6%).

Handoff location: The overall mean handoff-to-target distance was 38cm (s.d. 8cm). The total distance between sender and receiver was fixed experimentally at 70 cm in all conditions. A repeated-measures ANOVA did not show any effect of interaction technique on handoff location.

3.2.3. Bottlenecks in digital handoff

Negotiating the actual transfer between sender and receiver is the main bottleneck in both the tangible and digital handoff. Figure 1 shows a typical distance-over-time profile for each of the handoff techniques. The first half of the line represents the sender's motion, and the second half the receiver's motion. As can be seen from the figure, making the transfer from sender to receiver takes a disproportionate amount of time.

Our initial studies suggested that digital handoff techniques can be improved, and that one area for improvement could be simplifying the actual transfer between sender and receiver.

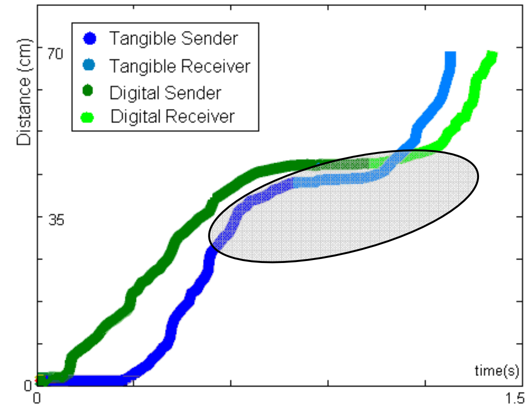

Figure 1. Distance-by-time profiles for each technique. The sender's motion is at left, the transfer occurs in the middle, and the receiver's motion is at right.

4. Force-field handoff technique

The force-field handoff technique simplifies transfers between sender and receiver by making the size of the object bigger as the two pointers approach each other. To accomplish this, we create a 'force-field' region around the object so that when the receiver's finger approaches the object (within three times its radius) the object starts drifting towards the receiver. This increases the effective width of the object, reduces the distance the receiver has to move to acquire the object, and keeps the object moving towards the receiver when handoff is being negotiated. The force-field technique is an adaptation of many similar approaches like the Black Hole and 'Sphere of Influence' approach proposed by Apted et. al [2] and shape-based manipulation proposed in SmarkSkin [25].

If the receiver does not take any action to grab the object, the object deforms in shape but does not automatically cause a handoff, and the sender retains control. Similarly, if the receiver moves out of the force-field zone the object drifts back to the sender's pointer. This prevents accidental handoffs in situations where the sender is merely depositing or reaching.

5. Evaluation of force-field handoff

We conducted an experiment to compare the force-field handoff technique with tangible handoff and standard grab-and-drop digital handoff.

5.1. Study methods and design

The apparatus and experimental task were similar to the earlier study. The experiment was conducted with 8 right-handed pairs between the ages of 18 and 40. For each pair one user was the sender and the other the receiver. The experiment used a 3x2x3x3 within-participants factorial design with a variety of planned comparisons. The factors were:

- Handoff technique (digital, force-field, tangible)
- Target Size (7cm or 16cm radius)
- Receiver Position (left, opposite, right of sender)
- Target Position (dominant, middle, and non-dominant side of each receiver position)

Each pair completed 12 training trials per technique and 4 test trials per factor (for a total of 216 test trials and 36 training trials). Upon completion the users switched roles and repeated the trials.

After the session, participants were asked to state their preference between the three techniques. The handoff location, handoff time, and total trial completion time were recorded per trial.

5.2. Results

We used three performance measures: completion time, handoff-to-target distance, and subjective preference.

5.2.1. Completion time

The overall mean completion time across all conditions was 1.47 seconds (s.d. 0.38s). A 3x2 repeated measures ANOVA showed main effects of both handoff technique ($F_{2,142}$= 13.05, $p<0.001$) and target size ($F_{1,143}$=179.1, $p<0.001$). As can be seen in Figure 2, the force-field technique was faster than the digital technique; in addition, small targets are slower than large targets.

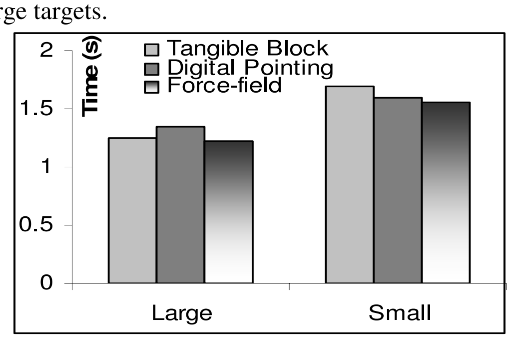

Figure 2. Average completion time for each technique.

There was also a significant interaction between handoff technique and target size ($F_{2,142}$=3.08, $p<0.05$). As shown in Figure 2, there was a bigger difference in handoff times between large and small targets when using the tangible technique.

A posthoc pairwise comparison showed that force-field technique was significantly faster than digital handoff for both small and large targets (all $p<0.05$). No differences were found between the force-field and tangible techniques.

There was no effect of different receiver positions on handoff time. However, we found that for large targets handoff was significantly faster ($p<0.002$) when the receiver was on the right side of the sender than on the other two positions.

5.2.2. Handoff-to-target distance

The overall mean handoff location across all conditions was 39cm from the destination (s.d. 10.6cm). A 3x2 ANOVA again showed main effects of both handoff technique ($F_{2,142}$=8.67, $p<0.001$) and target size ($F_{1,143}$=104.2, $p<0.001$). Force-field and tangible handoffs happened significantly closer to the sender than did digital handoff.

A posthoc pairwise comparison showed that there were differences between digital handoff and the other two techniques, but no significant difference between the tangible and force-field techniques.

Handoff-to-target distance for small targets was always smaller than for large targets. When targets were larger, handoff happened about 4cm closer to the sender than when targets were small.

There were no effects of receiver position on handoff location, and no difference in handoff locations for the three different target positions.

5.2.3. Subjective preferences

After each session, participants were asked to rank the handoff techniques based on their perceived speed, accuracy and overall preference. Each technique was assigned a number between 1 and 4 (1 best). Force-field handoff was the most preferred technique in all categories. Figure 3 shows the mean value for the ranking of each technique.

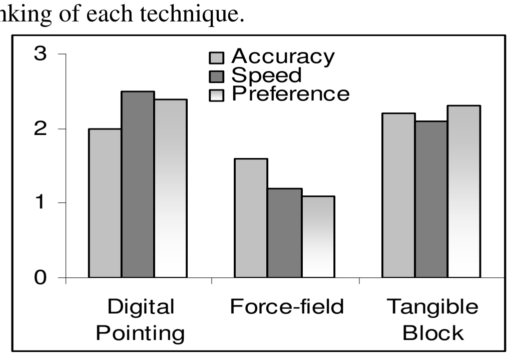

Figure 3. Average user preference scores for each interaction technique.

5.2.4. Handoff negotiation

Figure 4 shows a typical trace of time and distance for each of the three techniques. The chart highlights how the force-field technique alleviates some of the bottleneck in negotiating handoff. The main benefit of this technique is that users do not have to stop moving the object to negotiate handoff – they only momentarily slow down to allow the object to drift from the sender to the receiver.

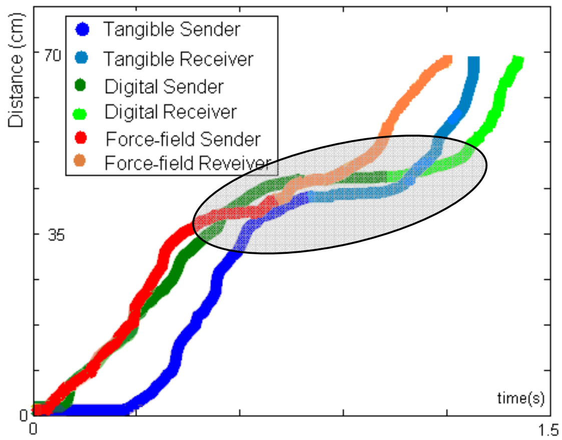

Figure 4. A typical path traced by the object from start to finish for each technique. The first part of the trace is by the sender and the second by the receiver.

Since handoff can happen within the force-field region, both sender and receiver need not pay as much attention to where the object is or whether their pointer is inside the object to click to complete handoff. They mostly paid attention to each others' hand locations rather than to the object itself.

6. Initial investigation of 3-D handoff

The observational study (reported in section 3.1) showed that people carry out both 2D handoff (on the table surface) and 3D handoff (above the table surface). The force-field technique described above is a 2D handoff technique only, and we were interested in whether we could extend it to use the space above the table as well. Researchers have started developing digital tables that exploit space above the horizontal work surface (e.g., [14,23]). As this sensing capability becomes more feasible, the question of whether 3D handoff can improve on existing techniques becomes relevant.

A naïve implementation of a 3D handoff technique would require the sender to select an object with her stylus and to move it toward the receiver in the 3D space above the table. To collect the object, the receiver moves his stylus toward the sender until the tips of their pens are nearly touching. The object would be handed over to the receiver when he presses the button on his stylus.

The handoff action described here would require extreme precision from the users and would lack the flexibility and ease evident in real-world tasks. To alleviate this problem, we extended the idea of the force-field technique so that it can be used in 3D space. Our approach creates a virtual sphere around each stylus. If the distance between two styluses is closer than the diameter of the virtual sphere, a handoff is initiated. For example, the sender and receiver can exchange objects when the receiver's stylus moves inside of the sender's stylus sphere.

We implemented this technique (3D force-field) using Polhemus Fastrak sensors to track the height of users' styluses. When the pens were on the table surface, the technique acted like the 2D force-field technique. We carried out observations with four pairs to determine whether people would use the space above the table for object transfer. We used a tabletop setup similar to that described earlier, and participants carried out a simple collaborative puzzle task.

We found that although users employed both 2D handoff and 3D handoff, they used the 3D technique much more frequently. On average, participants used the 3D-handoff technique 82% of the time (96 of 117 handoff events). All participants also said that they preferred the 3D version of the technique for transferring objects to the other person. The main reason given was that the 3D technique avoided the need to drag puzzle pieces across other artifacts on the table during a handoff.

7. Discussion

In this section we summarize our findings for the force field and tangible handoff techniques, and discuss underlying issues raised by the studies.

7.1. Force-field technique

Performance using the force-field technique was comparable to the tangible technique, and users preferred the force field over other techniques. The main benefit of the force field is the way in which the object drifts towards the receiver. The drift region is big enough to make a significant difference in negotiating handoff without affecting other tasks on the tabletop. An important advantage of this technique is that it is associated with the object, not with the input device. Therefore, it can work with different input devices, and can work differently for different objects. For example, frequently-transferred digital objects could have larger force-field zones, and private objects could have small or non-existent force fields to prevent inadvertent handoff.

7.2. Tangible handoff

Tangible devices allow users to perform handoff using their well-learned real-world skills. However, using tangible devices may not be convenient or feasible in all situations. In many tabletop systems where the collaborative task primarily involves pen or finger input, using tangible objects requires additional effort; that is, users would have to switch input devices to perform handoff. This adds to the overhead of collaboration and could potentially break the seamlessness of the collaboration. Further, once a tangible token is used to transfer an object, the token has to be returned to the sender to perform another handoff. This doubles the number of transfers when using tangible blocks for repeated object transfer.

We also found that for the tangible handoff technique, the handoff time is affected when the receiver is on the same side as the sender's dominant hand. However, there was no difference in handoff location for this technique. It should also be noted that even though the receiver is on the dominant side of the sender the total distance between object and target was still the same as in other receiver positions. One possible explanation for this is that it is easier to move objects on one's dominant side.

7.3. Handoff location

Handoff locations occur at specific distances from the sender and receiver. This distance depends on the interaction technique used and the size of the target. But we did not find any clear pattern in the handoff locations for any of the interaction technique. This makes it difficult to predict handoff locations in different settings.

When the destination targets are visible to the sender, the handoff location varied with target size. There was an intuitive sense of task difficulty that leads to load balancing between the sender and receiver for the different target sizes. As we saw in the first study, this disappears when the sender does not know the final destination of the object.

It is also possible that in many situations the most optimal handoff location occurs in one of the user's private spaces. To support such handoffs, it is necessary to be flexible in defining private and public spaces.

7.4. Limits to generalizability

The tasks chosen for our performance studies are fundamental actions that will happen in most handoffs that occur in real-world tasks. However, we see two minor limitations to generalizability that should be explored in future work.

First, in our study users were asked to perform handoff repeatedly, and the sender and the receiver were both aware that the task was going to be performed in this manner. However, in a collaborative setting, handoff is rarely performed repeatedly within the span of a few minutes.

Second, it is also possible that handoff can be influenced by who requests the transfer of an object. The initiator of the handoff might take on more responsibility during the transfer. Therefore, if the receiver asks the sender for an object, handoff might occur differently from when the sender initiates the transfer.

7.5. Lessons for designers

Our studies provide several guidelines that can be used by designers of tabletop systems:

- The force-field handoff technique allows significant speed improvement over traditional digital handoff, and was strongly preferred in our studies. The force-field technique should be considered in situations where object transfer will be common in the tabletop application;
- Designers should augment objects and tools with force fields that match their expected frequency of handoff;
- The 3D version of the force-field technique deserves additional consideration, particularly in situations where there are many objects on the table surface;
- Tangible handoff also performs well (also significantly better than traditional handoff), but has some limitations, particularly for multiple transfers;
- Senders and receivers have an intuitive understanding of the overall workload involved and use that to agree on handoff locations, which means that handoff occurs in many different ways in real tasks;
- Designers should allow flexibility in defining public and private spaces to accommodate the variable construction of handoff;
- If possible, the system should make the sender and receiver aware of the final destination of the target, which allows users to better negotiate and share the overall workload of transferring objects.

8. Conclusion

In this paper we studied handoff both in the real world and in digital tabletop systems. We introduced a new handoff technique that uses force fields around objects to facilitate handoff negotiation. The technique is based on the observation that in existing handoff techniques, the negotiation of handoff takes a disproportionate amount of time. In the force-field technique, when the receiver's pointing device gets within a force-field zone of the object, the object drifts towards the receiver's input device to allow the receiver to acquire the object. A comparative study showed that users' performance was significantly better when using the force-field technique, and that they preferred this method.

In future work, we plan to study handoff in other situations and with other techniques. We will explore the differences in handoff location and time when handoff happens as an interruption to a collaborative activity, and when handoff happens as a critical part of a shared activity. We are particularly interested in seeing how handoff time is distributed between the sender and receiver. We also plan to study the effect of force-field handoff on co-located and distributed tabletops. It is possible that the use of distributed embodiment techniques can enhance remote handoff. We are also interested in whether our force-field technique is effective when the sender and receiver do not have visual contact with each other. Finally, in this study we only focused on tabletop systems; in the future we plan to consider handoff in shared wall displays where the dynamics of the interaction may be very different.

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