

An Evaluation of Coordination Techniques for Protecting Objects and Territories in Tabletop Groupware

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ABSTRACT

Indirect input techniques allow users to quickly access all parts of tabletop workspaces without the need for physical access; however, indirect techniques restrict the available social cues that are seen on direct touch tables. This reduced awareness results in impoverished coordination; for example, the number of conflicts might increase since users are more likely to interact with objects that another person is planning to use. Conflicts may also arise because indirect techniques reduce territorial behavior, expanding the interaction space of each collaborator. In this paper, we introduce three new tabletop coordination techniques designed to reduce conflicts arising from indirect input, while still allowing users the flexibility of distant object control. Two techniques were designed to promote territoriality and to allow users to protect objects when they work near their personal areas, and the third technique lets users set their protection levels dynamically. We present the results of an evaluation, which shows that people prefer techniques that automatically provide protection for personal territories, and that these techniques also increase territorial behavior.

Author Keywords

Tabletop, groupware, interaction techniques, territoriality, coordination techniques, awareness, collaboration.

ACM Classification Keywords

H.5.3 [Information Interfaces and Presentation]: CSCW

INTRODUCTION

Tables are a natural setting for collaboration, and provide many advantages for group work. In particular, tables allow for easy verbal and visual communication; simple awareness of presence, location, and activity; and a strong shared focus for the group. However, since people work

together around a common surface, they also must adopt coordination strategies to help manage access to space and resources.

One of the main mechanisms that people use to coordinate tabletop activities is to divide the table surface into territories, which are separate regions to support shared work and to support each person's individual tasks [20]. Territoriality is usually adopted automatically, and often with little thought on the part of group members. The area in front of each person acts as their personal territory, and the areas in the middle of the table are usually shared. Social protocols allow people to protect objects from others in their personal territories, and to make objects available to others by placing them in the shared territory.

Recent studies show that territoriality patterns seen on regular tables are usually adopted on direct touch tabletop systems [11,18]. Just as on regular tables, direct touch tables (e.g. [2]) require people to physically reach across the table to access digital objects; the access to others' personal territories is therefore regulated by the same social protocols that are found on regular tables. For example, people can protect digital objects by placing them in front of themselves, and they can physically prevent access by others by simply placing their arm across the table.

In spite of these advantages, direct touch interaction can be limiting on large tabletop surfaces because it is difficult and inconvenient to reach for distant objects. This is confirmed by several recent studies where users preferred indirect to direct input because indirect techniques allow them to access distant objects without the need for standing and physically reaching for them [11,12,14,16].

One of the side-effects of using indirect input is that territoriality patterns seen on regular and direct touch tables change dramatically. Given that reaching is accomplished using a digital pointer, the physical presence of users does not stop others from accessing anyone's objects or personal workspaces [11,14]. Nacenta et al. [11] found that territoriality patterns are different with indirect techniques and people work over most areas of the table instead of focusing their work around their personal territory.

The reduced sense of territoriality seen with indirect techniques makes it difficult for people to protect their

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work. They cannot physically shield objects because others can reach in and interact with them using their digital pointer. This can lead to serious coordination problems, where users interfere with each other [11,16], making it difficult for each person to succeed at their task. These conflicts can have a negative effect on the group's ability to work together effectively, and include situations where:

- People intentionally or unintentionally take items from others' personal territories,
- People inadvertently attempt to access the same item at the same time,
- People take objects that another person is interacting with, interrupting their current activity,
- People reorient objects when someone else was already using them,
- People begin working in an area of the table that overlaps another user's workspace.

We developed three new interaction techniques that preserve the benefits of indirect techniques (e.g. quick access to all areas of the table), and that address the problem of decreased coordination and territoriality. Each technique allows users to protect objects from being taken by others, but the protection is not absolute, and users can still grab other people's objects under some circumstances. All techniques operate using the concept of a control level that is either set dynamically by the system or directly through user input. A user can prevent others from taking an object when they have a higher control level. However, if the other user has a higher control level, they can steal the object. Each technique uses a slightly different approach:

- One technique *automatically* protects *selected objects* currently by the user by setting a higher control level when a user's cursor is closer to their personal territory.
- One technique *automatically* protects *objects in a user's personal territory* by affording higher control levels when the user's cursor is closer to their personal territory.
- One technique protects *selected objects* currently held by the user through real-time *user-specified control levels*, regardless of the location of their cursor.

In this paper, we present the results of a study where six groups used four techniques: our three techniques and an indirect technique that does not use a control level. The groups used the techniques while playing a competitive tabletop game that had both shared and personal objects, and encouraged users to steal both types of objects from each other. We found that users preferred techniques that automatically apply coordination policies, and that they disliked the technique that required them to specify their control level. Most users preferred the technique that applied automatic protection to the objects in their personal territory, and our results showed that it led to increased territoriality and that fewer objects were stolen by others.

RELATED WORK

Coordination is a fundamental part of all cooperative tasks; many groupware systems leave coordination to social

protocols, but others provide explicit support for coordination using interaction techniques or global policies to help users divide work and manage access. In this section we discuss several topics related to tabletop coordination, all of which played a major role in motivating the techniques and concepts that we cover in this paper.

Social protocols and tabletop coordination

Working in close proximity at a table allows people to directly observe others and to maintain an up-to-date awareness of everyone's activities. This close proximity makes it relatively easy for users to coordinate their actions—each person can adjust their activities based on observations of others, and they can explicitly negotiate their actions when more intense coordination is needed.

In tabletop tasks, as in other types of collaborative work, people rely on social protocols when coordinating their actions. Scott et al. [20] found that one of the main ways that people coordinate tabletop work is by informally partitioning the space into separate areas that support shared and individual work. Groups automatically divide the space on the tabletop into three territories: personal, group, and storage. The territories are not necessarily mutually exclusive, and they are partially based on users' positions around the table. Personal territories are used to support individual work, and each individual's personal territory is usually located directly in front of them. Group and storage territories are both shared spaces, which are located outside of personal territories, often at the center of the table.

Several researchers have considered the efficacy of social protocols for providing protection of people's personal territories. In a study where participants used direct touch input techniques, Ryall et al. [18] found that people maintained a private territory, and that it seemed rude for others to take objects directly from this space, even with the owner's permission. Participants were also reluctant to take objects that were near their partner, even when these objects were within reach. Nacenta et al. [11] and Pinelle et al. [14] also found high levels of territoriality when direct touch techniques were used and found that people spent most of their time working in their personal territories, with few visits to others' territories.

Other researchers have found that territoriality and social protocols are not sufficient for coordinating work in all tabletop contexts. For example, Pinelle et al. [15] found that when people carry out tightly-coupled tasks with high levels of interdependence, people are much more likely to take items from others' personal territories. Tang et al. [25] found that the coupling level used in group tasks affects coordination on tables; they found that pairs of people interfered with each other more often when working in a loosely coupled fashion than they did when working in a tightly coupled fashion. This discrepancy may be due to differences in group size used in the studies: Pinelle et al. observed tightly coupled tasks with 3-4 participants, making it more challenging to coordinate access, and Tang

et al. studied pairs of people who closely coordinated their actions, often working side-by-side.

Morris et al. [10] conclude that social protocols are often not enough to enable people to coordinate their actions in tabletop groupware, and they have found that people often have both “accidental and intentional conflicts.” They describe instances where users stole resources from others, and where people reoriented documents so that they faced themselves, making it difficult for others to access them.

Direct vs. indirect techniques

Direct touch techniques— where people manipulate objects by touching them with a pen or a fingertip – use a similar interaction style to that seen on regular tables (e.g., [2]). This allows people to coordinate their actions based on direct observations of others’ physical movements and interactions with the table. As previously noted, many social protocols seen on regular tables have been observed in direct touch systems [11,18]. However, direct touch also has disadvantages: it can be difficult for people to reach objects that are far away; arms and bodies can get in the way of each other, preventing people from working in the same space at the same time; and it can be awkward or uncomfortable to work close to another person.

In contrast, indirect input techniques (techniques where the action point is controlled remotely by the user) allow reaching to any part of the table and allow people to work in the same place without physical collisions. There are several tabletop techniques that support indirect input, including standard mouse-based drag-and-drop [1], hyperdrag [17], cursor-extension techniques [4,6], portal approaches [24], and laser-pointers [12].

Recent studies show that indirect techniques have several advantages over direct touch, such as improved access, less fatigue, and fewer occlusion problems [3,5]. Studies have also shown that people have a strong preference for indirect techniques in some tasks [11,14], and that this preference may be associated with working on large tables and in groups of several people [14]. In addition, territoriality patterns change when using indirect techniques, in that people work over all parts of the table, and that they often reach into others’ personal territories [11,14]. These studies also show that, in spite of the advantages seen with indirect techniques, there are usually higher rates of conflicts, where people interfere with each other or try to access the same object at the same time [5,11].

Explicit coordination mechanisms for tables

Several researchers have concluded that tabletop collaboration, regardless of whether direct or indirect input techniques are used, can be improved by providing more explicit support for coordination. For example, in an evaluation of two prototype systems, Pinelle and Gutwin [13] found that tabletop designers need to do more than support simple group interactions: they also need to help users avoid control conflicts, where they inadvertently interfere with each other.

Morris et al. [10] concluded that global coordination policies may need to be added to tabletop systems to minimize conflicts between users. They also hypothesized that conflicts will become more common on tables as the number of users increases because it becomes harder to monitor the actions of all users. They proposed several global coordination mechanisms. Notable among these are: 1) making all elements accessible to everyone and relying on social protocols, 2) allowing users to lock objects so that others cannot access them, 3) giving each user a ranking, and allowing higher ranking users to take objects from lower ranking users, and 4) allowing physical measurements, including speed and force applied by the user, to determine who is able to retrieve a contested object.

Several researchers have developed techniques for supporting improved coordination in tabletop systems. Scott et al. [20] suggest that territoriality can be used to design techniques that improve collaboration, for example by tying specific functionality to certain regions of the table; Interface Currents [7] and Storage Bins [19] explore this idea. Tang et al. [25] also suggest that techniques that allow users to create personal and mobile territories can help mitigate negative interference where people access others’ personal artifacts, while still allowing for positive awareness-related interference over shared artifacts.

Other techniques focus on improving specific aspects of coordination. For example, Jun et al. [8] developed a technique to improve handoffs, where one user transfers an object to another, and Pinelle et al. [14] developed embodiments for indirect techniques with a goal of improving user awareness of others’ actions and locations.

COORDINATION TECHNIQUES

We developed three new coordination techniques for tabletop groupware systems. Our goal was to reduce the control conflicts typical of indirect techniques, while still allowing people to quickly access items from all areas of the table. The design space for possible tabletop coordination mechanisms is vast (e.g. Morris et al. [10]), and our techniques provide partial coverage of that space. We developed the techniques through iterative prototyping, and the general approach (using variable control levels) was selected because it is lightweight and offers users significant flexibility in accessing and protecting objects. Through the prototyping process, we identified two main design dimensions that needed to be explored further. First, we wanted to evaluate tradeoffs between coordination policies that are controlled by users and those that are automatically applied, and second, we wanted to assess the differences between policies that protect selected objects and those that protect objects in users’ personal territories.

Our techniques were implemented using a mouse as the input device, although they would also work with other input devices, such as a stylus. We added a pressure sensor on the left side of each mouse (thumb side for a right-handed user) to support one of the techniques.

All techniques use policies based on a numeric control variable that determines which user can take control of an object over another user. The control variable is linked to a different parameter depending on the technique. In general, a user can only take an object from another person if they have a higher control level. We briefly summarize the coordination rules used for each technique below:

Automatic object. Users' control levels are determined by the distance between their cursor and their personal territory (i.e. the distance of the cursor to a control point that approximates the users' physical position - Figure 1A). The user's control level increases when their cursor is close to their territory, and decreases the farther they move away from it. Control levels do not provide protection for items that are not currently held by a user's mouse cursor (e.g. objects in their personal territories).

Automatic territory. Users' control levels are determined by the distance between their cursor and their personal territory (using the same approach described for the last technique). Protection is also applied to objects within a user's personal territory (see Figure 1B). A user can only take an item from another user's personal territory when they have a higher control level than the owner of the territory. For example, when a user reaches a distant part of the table, their control level will decrease significantly. Another user can take their items if they have a higher control level when accessing their territory.

User control. Control levels are determined by the force they apply to their pressure sensor, with more pressure resulting in a higher control level. Control levels do not provide protection for items that are not held by a user.

When we designed the input for the user-controlled technique, our goal was to allow users to specify control levels in a lightweight manner. We piloted a mouse wheel implementation that allowed users to set control levels by scrolling the wheel, but users strongly disliked it and reported that it interfered with their ability to manipulate the mouse. We chose the pressure sensor because it was a lightweight method, and people understood the mapping instantly.

We used the same embodiment for all three techniques. Embodiments are virtual placeholders for users in shared workspaces [23]. Pinelle et al. [14] found that tabletop users are able to track large noticeable embodiments more easily than small embodiments, so we use an augmented embodiment to help users stay aware of others' actions. The cursor position is shown using a small circle, and a line is drawn from the circle to a control point positioned at the edge of the table immediately in front of the user controlling it (see Figure 1A). Each user has a unique embodiment color. We also wanted to provide visual feedback on each user's current control level. Control level is shown using the thickness of the line embodiment (thicker lines, shown in Figure 1D, correspond to higher control levels).

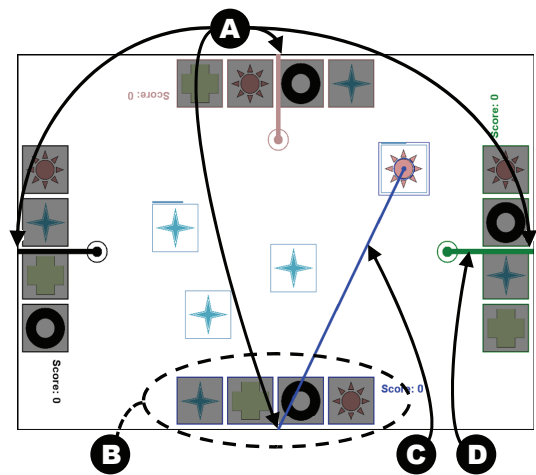


Figure 1: Screenshot from the game application. A: control points, B: personal territory for bottom user, C: embodiment low control level, D: embodiment high control level.

EVALUATION

We carried out an evaluation of the interaction techniques where six groups used the three techniques as well as a baseline technique with a constant control level. Each group used all techniques while playing a competitive tabletop game designed to foster a high level of interaction between the players, and to encourage players to take objects from each other. The main goal was to evaluate the effect that the different coordination policies would have on several aspects of group interaction, including conflicts, territoriality practices, and access patterns. We also assessed subjective reaction to the techniques, including users' preferences and their opinions on how the techniques affect their ability to protect objects from others. Our ultimate goal was to understand the tradeoffs used in each technique so that we could understand how indirect techniques can be designed to improve coordination and decrease conflicts on tabletop groupware systems.

Each group consisted of three participants that already knew each other, and also included a fourth person, called a confederate. Before the other participants arrived, the confederate was instructed to play the game, but to steal items from others when it would help him win. Other participants were not aware of the role the confederate played in the experiment. We added the confederate because we were interested in the effects the techniques would have on conflicts in the group, and early pilots led us to believe that group behavior would evolve over the course of a session before it stabilized. Using the confederate allowed us to promote consistency across groups and within the same group over time, and to introduce the idea of stealing early in the session.

Participants

18 paid participants, 4 female and 14 male, were recruited from a local university and organized into groups of three (for a total of six groups). Each group also included a confederate who is not considered a participant. All data from the confederate were excluded from our analyses.

Participants were regular computer users (at least 1-2 hours per week) of ages ranging from 19 to 33 (mean 24.6). Five participants reported that they had previous experience using tabletop systems, and two had previous experience with systems that use multiple mice.

Method

The experiment followed a within-group design, with each group using all four techniques: no control, automatic territory, automatic object, and user control. All groups used the no control technique during the first experimental trial, and order was balanced between groups for the remaining three techniques.

Each experiment session lasted approximately 45 minutes. Participants were provided with an initial orientation to the experiment, the tabletop system, the game, and the input devices (mouse with pressure sensor). Participants completed a four minute training trial using the no control technique, and then they completed an eight minute experiment trial using the same technique. After the first trial, we introduced participants to the control level concept. Participants completed a one minute training trial with each technique, followed immediately by an eight minute experiment trial for the same technique. If a participant won the game during a trial, the game automatically restarted, and participants continued to play until the time period expired. At the end of the trial, participants were asked to complete a questionnaire which asked them to rank the techniques according to their preference, and according to how well each technique allowed them to protect objects and territories. We also asked them to provide us with open-ended responses on each question, and we asked them to describe how each technique affected their perceptions of territoriality.

System and apparatus

We implemented a simple competitive tabletop game that supports four concurrent users. The goal of the game is for players to gather a set of four cards and to place them in the appropriate location in their personal territory. There are four different cards (see Figure 2), each of which displays a different symbol, and players have to put one in the corresponding bin in their territory (see Figure 1B). The bins in each user's territory are randomly ordered. The player that collects all four cards first wins the game.

Every eight seconds the shared workspace is refreshed and four random cards appear at random locations on the table (see Figure 1). Players can click on cards and drag them into the bins in their territories. As players need a specific set of cards to win, they can either wait for the card they need to appear on the table (and hope they can take it before another user gets there first) or they can try to steal it from another player. Cards can be stolen directly from another user's cursor, or they can be taken from the bins located in another user's personal territory. As discussed previously, the success of an attempted theft is determined by users' control levels (except in the no control technique).

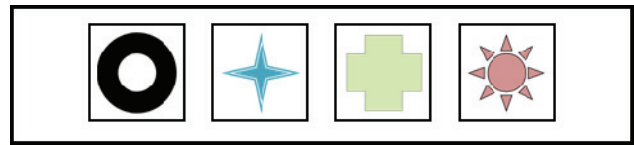


Figure 2: Four cards used in the game.

When a card is selected by a player, a border, with a color that matches the player's cursor color, appears around it indicating selection and ownership (see Figure 3A). Additionally, a timer, represented by a growing line, appears along one of the card edges (see Figure 3B). The timer line keeps growing until it spans the edge of the card. This process takes 16 seconds to complete. When a card is present on the table and its timer is running, it will not be replaced when the table is refreshed during the next eight second round. When a card is placed in a corresponding bin, its timer stops. If a card is stolen from a bin, a new timer will start for the card. The timer was added to encourage players to fight for control of a card.

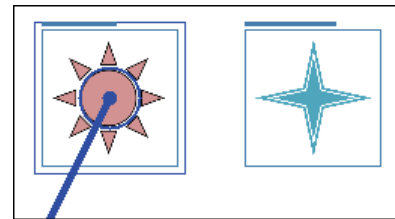


Figure 3: Cards. A: selected card, B: card with timer.

All four techniques were implemented in the game application. The user control technique and automatic object technique allow users to protect the card that they are holding with their cursor. The automatic territory technique provides protection for cards located in users' bins, and also provides protection to a card held with the cursor.

We developed the application using C# and the Single Display Groupware toolkit [22], which was used to handle four concurrent input devices. The game was deployed on a top-projected tabletop system with a display size of 1024x1536 pixels. The table surface measured 125x185cm with a display area of 118x178cm. Input was provided by four mice with pressure sensors on the left side.

Data Analyses

We designed the system to log data from events generated by users' actions: mouse movement, mouse clicks, holding and releasing cards, putting cards in bins, stealing cards from bins, stealing cards held by other players, failed stealing attempts, pressure sensor values, winning/losing, and new game events. Data gathered from the confederate were removed in all analyses.

Quantitative data were analyzed with the repeated measures analysis of variance (RM-ANOVA). All main effects were tested at $\alpha=.05$, and the Least Significant Difference adjustments were used for all pairwise comparisons. In cases where the sphericity assumption was violated, the degrees of freedom were adjusted using the Huynh-Feldt method. Questionnaire data were analyzed using non-

parametric statistical techniques appropriate for rankings. Main effects were tested with Friedman's two way analysis of variance of ranks for related samples, while pairwise comparisons were made with the Wilcoxon matched-pairs signed ranks test.

RESULTS

We begin by describing the performance results followed by the questionnaire results.

Performance results

Performance results were generated with data from the log files, from which we extracted a number of measures.

Pick distance

Cursor locations (x,y) for every object picked up from the table were recorded, not including stolen objects. These locations were used to calculate the average Euclidean distance to each user's control point (the point at the centre-edge of their side of the table).

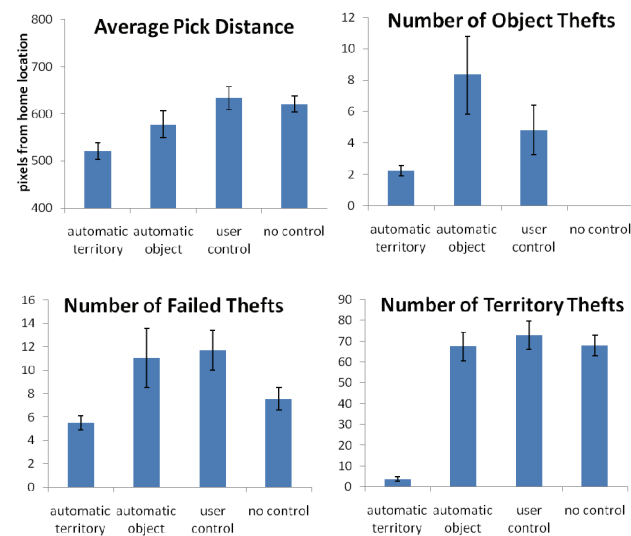


Figure 4: Means (± SE) for measures extracted from log files.

The average pick distance for each technique is shown in Figure 4. A repeated measures ANOVA showed a main effect of coordination technique ($F_{3,51}=5.42$, $p=.003$, $\eta^2=0.24$), with post-hoc analysis revealing that the average pick distance was lower with the automatic territory technique than with the user control technique ($p\approx .000$) or in the no control condition ($p=.002$).

Successful object thefts

The number of objects stolen from another user's mouse cursor was tabulated for each user with each technique. In the no control condition, objects could not be stolen from users' cursors; only the remaining three techniques were included in the statistical analysis.

Figure 4 shows the average number of successful thefts for each condition. There was a main effect of coordination technique ($F_{2,34}=4.2$, $p=.024$, $\eta^2=.19$), with post-hoc analysis revealing that the number of thefts was lower with

the automatic territory technique than with the automatic object technique ($p=.022$).

Failed object thefts

The number of unsuccessful thefts of objects from another user's mouse cursor was tabulated for each user with each technique. Although users were not able to steal objects from other users' cursors in the no control condition, they still attempted to do so. Thus the no control condition has been included in the statistical analysis.

Coordination technique significantly affected the number of failed thefts ($F_{2,0,34,7}=3.4$, $p=.045$, $\eta^2=0.17$). Post-hoc tests revealed that there were more failed theft attempts with the user control technique than with the automatic territory technique ($p=.001$) or in the no control condition ($p=.029$). The difference between the automatic territory and object techniques was marginally significant ($p=.055$) (Figure 4).

Territory thefts

The number of objects stolen from another user's territory was tabulated for each user in each condition. This action was possible using all four techniques.

There was a significant effect of coordination technique ($F_{3,51}=65.6$, $p\approx .000$, $\eta^2=0.79$). Post-hoc tests showed that users stole fewer objects from other users' territories with the automatic territory technique than the other three techniques (all $p\approx .000$, see Figure 4).

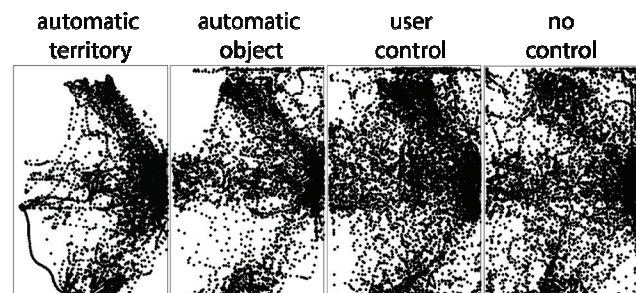


Figure 5: Mouse movements for one user with each of the techniques. The user sat at the right side of the table.

Mouse movements

To further investigate territorial behavior, we examined users' mouse movements. The location of the mouse cursor was recorded every time a mouse movement event was detected by the application.

Data for one representative participant, using all four coordination techniques, is shown in Figure 5. The mouse movement data echoes the results from the average pick distance. Visual inspection of the movement maps shows that users were more territorial with the automatic techniques. The user control and no control techniques show movement over the entire table and less territoriality.

Questionnaire results

Preference

We asked participants to rank the techniques according to their personal preferences (see Figure 6). People preferred the automatic territory technique, and 12/18 gave it the

highest rank. This was followed by automatic object and no control, both of which had very similar scores. The user-controlled technique had the lowest ranking, with 11/18 giving it the lowest rank.

Friedman's test revealed that the differences in rankings were statistically significant ($\chi^2(3)=9.0$, $p \approx .000$). Pairwise comparisons using Wilcoxon's test showed that users ranked the automatic territory technique higher than the automatic object technique ($p=.015$) and the user control technique ($p=.001$), but not the no control technique ($p=.063$). Also, users ranked the user control technique lower than the automatic object technique ($p=.003$) and the no control technique ($p=.050$).

In open-ended responses, people explained the reasons that they preferred the automatic territory technique. Most stated that they liked being able to protect the items in their local space, and that they did not have to worry about objects being stolen. For example, one user commented that, "I really like the protection function of the game because it can make all the players focus on the game instead of stealing items from others." People also stated that they found the user-controlled technique difficult to use. They indicated that it took considerable extra mental and physical effort to provide ongoing input to set their control level, for example: "the pressure was hard to remember to use..." and "extra effort on mouse causes distraction."

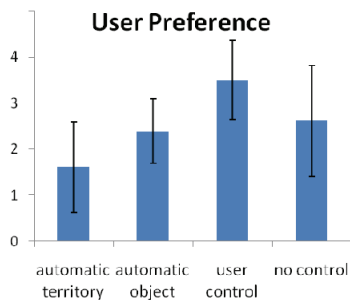


Figure 6: Average rankings for user preference. Error bars show std. deviation. Shorter bars indicate better ranking.

Protection

We asked participants to rank the techniques according to how well they allowed them to protect their personal territory (see Figure 7). Automatic territory was ranked the highest, with 14/18 giving it the best ranking. Automatic object was ranked second, followed by user control. No control received the lowest average ranking, with 14/18 users ranking it as the worst technique. These differences were statistically significant ($\chi^2(3)=35.0$, $p \approx .000$), and pairwise comparisons showed that all differences were significantly different (all $p < .05$).

People pointed out that automatic territory was effective at safeguarding their local workspace: "local protection beats everything, so much easier to protect area." Participant comments suggest that user control received a relatively low ranking because people found the technique difficult to use, and that automatic object was ranked more highly

because they found it more usable as they did not have to provide additional input. No control received the lowest ranking as it does not provide any type of protection. For example, users stated that, "with no control, no area was safe", and that it "has no protection at all."

Participants also ranked the techniques according to how well they allowed them to protect individual objects (see Figure 7). Surprisingly, a similar pattern was seen in the results, where the automatic territory technique again had the best ranking (ranked best by 15/18 participants), followed by automatic object, user control, and no control (ranked worst by 13/18 participants). These differences in ranking were significant ($\chi^2(3)=33.5$, $p \approx .000$), with all pairwise tests showing significant differences (all $p < .05$).

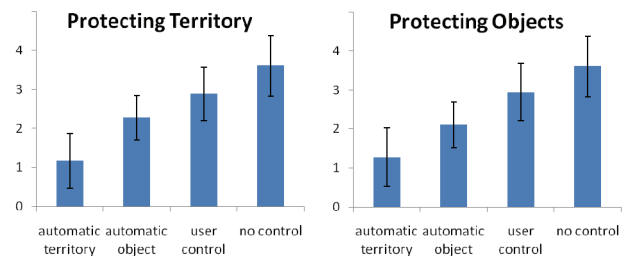


Figure 7: Average rankings for protecting personal territory and objects (\pm SD). Shorter bars indicate better ranking.

People indicated that they felt that automatic territory was also the most useful for protecting individual items. Several people stated that they could pick up items and quickly move them to their territory, making it difficult for others to take them. "I found most pieces were stolen from the collection [area] in front of me, and not necessarily from the pieces I was chasing after. Automatic control with local protection was easiest to keep pieces in your base/collection." Automatic object was ranked the second highest, and people indicated that it allowed them to protect objects, but "without the distraction" or "strain" seen in the user-controlled technique. Again, no control had the lowest ranking as it did not let people protect objects.

Perceptions of territoriality

We asked participants whether using control levels (seen in both automatic and user-controlled settings) changed their perceptions of their personal territories. The majority of participants (10/18) indicated that the control techniques changed their perceptions, but all open-ended responses focus on the automatic techniques, and several people describe how they changed their approach based on the settings. One person wrote: "I became more aware of the region/limits of my personal effectiveness." Four people pointed out that the automatic modes made them focus on protecting game pieces, and made them pay attention to their cursor position. One person wrote: "Made me more conscious of defending myself." Another participant compares the automatic techniques to the user-controlled technique: "I was less conscious of the area in front of me with the user controlled mode."

We also asked participants whether using control levels changed their perceptions of others' personal territories. Only half (9/18) indicated that their perceptions changed with the control techniques, but responses focused on the automatic control techniques rather than on user control. For example, one person indicated that when automatic techniques were used, they "...became more aware of others' regions of effectiveness and their limits." Most of the positive respondents indicated that the automatic techniques made it "harder to attack their [others'] areas." One person indicated that the user-controlled technique did not contribute to a sense of territoriality, but the automatic techniques did: "[the] Personal area [is] most vulnerable with user control and no control because [it is] easy to play/toy with pieces at [the] base and quickly pull them off."

Determining control levels

Regardless of the technique used, users had several ways to compare their current control level to others'. We asked people to rate the difficulty of determining whether someone else has a higher control level. Participants responded using a 5-point scale, with 1 indicating that it is "very easy" and 5 indicating that it is "very difficult." The average rating was 2.61, with a standard deviation of 1.29. People described three approaches they used to determine whether someone had a higher control level. First, people used the line embodiment, which has a width that increases and decreases with changes in control levels. Four people stated that they did not have problems interpreting the embodiment, but three others felt the embodiments moved too quickly, making it difficult to interpret line size: "...mice moved fast anyway, so the thickness changed rapidly, making it tough." Second, two people made judgments about others' control in the automatic techniques based on the distance between each user's cursor and their local territory. For example: "your brain knows well enough how the outcome will turn out given the distance." Third, three people stated that they did not have prior knowledge on who had the highest control level, and that they relied on feedback from attempted thefts: "we could tell right away when trying to grab pieces away from more powerful players and we were unable to."

DISCUSSION

Summary of results

One of the main benefits of indirect techniques is that they allow people to quickly access all areas of the table. In our study, when people used the no control and user control techniques, they accessed most areas of the table, and did not spend the majority of their time working in their personal territories. However, log results and movement maps show that when people used automatic coordination techniques—which gave them protection advantages when they worked in close physical proximity to themselves—they spent more time near their personal territory.

In spite of the movement limitations seen with automatic techniques, people preferred them. People had a strong

preference for the automatic territory technique since it helped them to avoid having objects stolen by others, and since they did not have to expend extra effort to use the technique, contrary to the user-controlled mode. Log results confirm that the average number of thefts was significantly lower when the automatic territory technique was used. Our results suggest that people are willing to accept restrictions in how much of the table they routinely access in favor of having more protection over the objects they are using.

Even though more territoriality is seen with the automatic techniques, people still exhibited the ability to access distant areas of the table. The movement maps shown in Figure 5 show that all people accessed all areas of the table, including those areas that would be outside of their physical reach, even though frequency varied by technique. Therefore, automatic techniques did not nullify the access benefits of indirect techniques; instead, participants changed the organization and coordination strategies so that they closely resembled those seen on direct touch tables.

Most people indicated that the automatic techniques fostered an increased awareness of territoriality on the table. People stated that they were more aware of their personal territories, and half of the participants indicated that they were more aware of others' territories as well. Several participants' pointed out that with user control, they did not pay as much attention to territoriality.

Limitations and generalizability

Our research was motivated by real problems encountered with indirect techniques on tables. Indirect techniques are flexible and users' access is not restricted by their physical reach, but conflicts occur due to reduced awareness and territorial behavior. Conflict resolution can be costly, forcing additional negotiation, which takes users away from their primary task. Our goal was not to only study the stealing of objects from another user's cursor, but to investigate conflicts that occur with indirect techniques due to decreased feedback on others' actions and due to changes in territoriality.

Our study used a controlled experiment to explore the effects our coordination techniques have on group behavior. Our approach was to make the best decisions to answer our questions, but tradeoffs in study design leave some aspects of the work open to critique. We decided to use the game and a controlled experiment because we were equally interested in quantifiable performance measures (impact of techniques on territoriality and conflicts) and qualitative aspects of using the techniques (user feedback). Choosing a more naturalistic task would leave us unable to use differential statistics to answer our questions because of group and individual variations in task execution, while a controlled experiment would increase precision but decrease real-world impact.

The use of the game application allowed us to study the coordination techniques in an environment where conflicts were common, and where people could choose to access a

variety of locations on the table. The game did not directly demonstrate applicability to real-world scenarios; however, our study addresses a real-world problem (i.e. conflicts in indirect techniques), and we believe our results will transfer to other tabletop tasks. The game applications strips coordination and conflict down to basic mechanical components, so it is useful for informing the broader design space, as fundamental interactions (e.g., pointing and clicking) are seen in most tabletop groupware applications.

In other tabletop applications, conflicts are not as common as they are in the game used in our study. However, interference still occurs in many tabletop tasks [10,11,25], leading to several types of conflicts that can have a negative effect on the group process [10]. In most group situations, behavior is dependent on the task and the group dynamics, and can affect the frequency of conflicts. For example, Tang et al. [25] and Pinelle et al. [15] have both shown that conflicts vary with task coupling levels. However, it is usually difficult for designers to anticipate how groupware applications will be used, and when conflicts will cause serious problems in groups. Therefore, providing support for avoiding conflicts can be important, even though the frequency varies during group activities.

Our study results show that the automatic techniques promote territoriality, and that they allow users to protect items more effectively than they can with standard indirect input techniques (e.g., the no control technique). We believe that these findings have implications for the design of other tabletop applications that rely on indirect techniques. In the study, we directly observed decreases in thefts from users and from their territories.

The territoriality and protection benefits seen in our study have the potential to help overcome many of the conflict types described in the introduction. Other problems, such as people working in others' territories, are less likely since it is more difficult to take items from others when working far from the home position. Further, the territoriality policies also prevent other disruptive behavior, such as reorienting objects when others are using them, because access policies can extend to all types of interactions that can be carried out with an object.

Adapting the coordination techniques to other types of applications raises several new design questions. In the next section, we consider the implications that our findings have for the design of other tabletop applications, and we discuss issues that need to be explored in future research.

Design implications

In the next sections, we discuss three issues that must be considered when transferring coordination techniques to other applications: control levels versus locking, specifying territories, and switching coordination techniques.

Control levels versus locking

We used multiple control levels rather than a binary “on” and “off” locking approach because we wanted to try to

facilitate some of the flexibility seen on regular and direct touch tables. In these settings, people can take items from others' personal areas, but this is usually infrequent because it brings people into close physical proximity, which can be socially uncomfortable [21]. The automatic territory technique, in particular, was designed to promote a similar style of work, by making objects difficult to take when a user is working in their territory, and by making them more accessible when they are working elsewhere on the table.

Locking techniques would allow users to guarantee that they are the only ones who are able to access objects in their territory, or to access objects that they have created. However, using object-level locking based on who created an object would not necessarily help to promote territoriality on tables, and could create other control problems, where people need to access an object, but cannot because it is owned by someone else. Similarly, allowing users to lock all objects in their territory could potentially lead to other conflicts, where people hoard all objects that they think they will need, making them unavailable to others. Further work is needed to investigate the use of control levels in other types of applications, to determine whether the benefits seen in our study will fully translate to other systems.

Specifying territories

The game that we used to implement the territoriality-based coordination techniques offered one advantage not seen in other applications: each user's personal territory was well defined, and did not change during the game. This made it easy to determine which area should be protected from others when implementing the technique; however, in most groupware tasks, territory size and location change [20], so coordination mechanisms must be able to adapt as the task evolves. Coordination policies based on territory will need to allow users to specify their territory, raising the question of whether users will be willing to take extra time to reconfigure their coordination policies.

Other approaches to setting users' personal territories should be explored. It may be possible to automatically determine each user's personal territory by applying simple algorithms based on proximity, clustering, and orientation. For example, Kruger et al. [9] found that people usually rotate objects that they are working with so that they are oriented toward them. Making use of orientation information, as well as information about object proximity to the user, may allow automatic coordination policies to be applied without the need to add significant user overhead. Future work will be conducted on the effectiveness of system-determined, mobile and fluid territories.

Switching coordination techniques

Group tasks often involve mixed-focus work, where people switch between shared and individual work [21]. There may be advantages to protecting personal territories during part of an activity, but there also may be times when users want to grant others access to the objects located in their personal

territories. Our user-controlled technique implicitly allows this behavior, but was tiring for users and assumes that by default (no pressure), objects are not protected. With our current automatic territory technique, users would not be able to access another person's territory unless the owner's cursor was moved across the table. This suggests that tabletop systems should either support a variety of coordination techniques, or should allow users to turn a coordination policy off for parts of an activity. To determine how users deal with coordination techniques in mixed-focus work, we plan to investigate the use of our techniques in ecologically-valid productivity tasks.

CONCLUSIONS

In this paper, we introduced three coordination techniques for tabletop groupware systems that were designed to reduce conflicts seen with indirect techniques, but to still allow users some flexibility in how they access objects. Two techniques were designed to promote territoriality, and allow users to protect objects when they are working near their personal territory. The third technique allows users to protect items by providing ongoing input through a pressure sensor. All techniques calculate the differences between users' control levels to mitigate conflicts.

We evaluated the techniques during a study where six groups used them while playing a competitive game that encouraged users to steal objects from each other. Users preferred a technique that allows them to protect objects in their personal territories when their cursor is nearby. Our results showed that users demonstrated increased territoriality with this technique, and there were fewer thefts. We believe our findings have implications for the design of other tabletop systems, and that they can be used to improve coordination when indirect input is used.

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