Collaborative Coupling over Tabletop Displays

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ABSTRACT

Designing collaborative interfaces for tabletops remains difficult because we do not fully understand how groups coordinate their actions when working collaboratively over tables. We present two observational studies of pairs completing independent and shared tasks that investigate *collaborative coupling*, or the manner in which collaborators are involved and occupied with each other's work. Our results indicate that individuals frequently and fluidly engage and disengage with group activity through several distinct, recognizable states with unique characteristics. We describe these states and explore the consequences of these states for tabletop interface design.

Author Keywords

Collaborative tabletop displays, single display groupware, mixed focus collaboration, coordination, coupling

ACM Classification Keywords

H.5.3. Group and organizational interfaces: computer-supported cooperative work.

INTRODUCTION

Many group activities, such as brainstorming, designing, and planning, involve *mixed-focus collaboration*, where individuals frequently transition between individual and shared tasks within a group [4]. Traditional (non-interactive) tabletops have been used for these activities for a long time [15,16]. Thus, understanding the nature of mixed-focus collaboration is crucial to designing useful collaborative interfaces for digital tables. Mixed-focus collaboration presents many challenges for tabletop design because these interfaces must support both individual and group needs, which are often in opposition [4]. For instance, should individuals be able to control how parts of the workspace are viewed, or should the group be restricted to a singular view? While independent views of a shared workspace may support individual tasks, they may also negatively affect a group's ability to coordinate its activities and manage shared resources [4].

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To complicate matters, we do not have a systematic understanding of mixed-focus collaboration beyond recognizing the end points: individual work and shared work. Yet, individuals do not instantaneously shift between independent work and group work. Instead, a group's *collaborative coupling style* (henceforth *coupling*), or the manner in which collaborators are involved and occupied with each other's work, frequently changes [1,12]. For instance, an individual might work on an idea alone before presenting it to the group, and then later work with the group to jointly manipulate the idea [15,18]. These kinds of *transitions* between independent and shared tasks have not been studied in depth. Our goal is to understand coupling in the context of tabletop collaboration for the purpose of groupware design.

In the context of collaborative tasks on a shared visualization, we present two observational studies that examine how three viewing techniques, which offer different facilities for independent and group work, affect coupling: (1) *lenses*, which show information in spatially localized areas, (2) *filters*, which show information globally, and (3) *ShadowBoxes*, which allow spatially localized areas to be displaced [17,21]. As we will see, these different presentation techniques affect how groups manage and coordinate their use of the shared physical space. Consequently, their coupling style, or the way in which they work together, differs with each tool.

We begin by describing how coupling relates to mixed-focus collaboration and awareness. We show how related work in collaborative tabletop literature motivates our own observational work. Our first study provides insight into how groups coordinate themselves over a spatially fixed visualization. Our second study reveals six distinct styles of coupling and how they relate to factors such as task, physical location around a tabletop, and interference management. These results motivate several design implications for the design of fluid, collaborative tabletop interfaces supporting both shared and independent work.

COLLABORATIVE COUPLING

Mixed-focus collaboration is used to describe certain tasks: those that require switching between independent and shared activity [4]. Considerable evidence suggests that in both collocated and distributed shared workspaces, group activities cannot be neatly dichotomized into "independent" and "shared" activity. Researchers [1,4,8,16,20] have typically described tasks and group work as being "tightly" or "loosely" coupled (e.g. [3,4,12]). Very generally, coupling refers to the dependency of participants on one another—when participants cannot do much work before having to interact, the work is tightly coupled; conversely, when participants can work independently for long periods of time, the work is loosely coupled [12].

We use collaborative coupling to refer specifically to *the manner in which collaborators are involved and occupied with each other's work*. This focus implicates the extent to which collaborators' activities are linked to one another, and varies dynamically through the course of work from being very tight (e.g. one individual follows another's drawing activity by tracing simultaneously), to very loose (e.g. individuals independently drawing on a work surface) [3]. Coupling is related to workspace awareness [3,9], but in co-located scenarios (such as over a tabletop) where no awareness information is hidden, coupling is primarily a reflection of collaborators' need or desire to work closely or independently of one another, and in part depends on task semantics.

Collaborative coupling is a way of describing group activity. As we will see, coupling is related to a wide variety of work practices on tabletops, such as physical arrangement, tool use, and fluidity of work. When a pair's activity is highly coupled, their actions appear coordinated and fluid, likely because the goals and intentions of each individual are known to the other, thereby reducing interference. This implicit, unspoken coordination of activity is most evident when observing a loosely coupled group (e.g. individuals working independently, or at momentarily cross purposes), where groups must rely on social or explicit protocols to negotiate conflicting needs. This concept of coupling is used to describe the results of our observational studies of mixed-focus collaboration.

BACKGROUND

Because traditional tabletops are a ubiquitous and flexible setting for collaborative work [11], studying their use has been of interest to researchers in both the real-time groupware (e.g. [4]) and tabletop design communities (e.g. [7,16]). Early observational studies of group work over traditional tabletops (e.g. [18]) frame our existing understanding of mixed-focus collaboration. For example, Tang's studies [18] of group activities on traditional tables provided key insights into work practices on tabletops, including the role of gestures, the mediation of work through space, the fluidity of work activity, and the role of tabletop orientation in structuring activities. Current efforts have continued to understand tabletop work practices with the aim of supporting the fluid activity found on traditional tabletops [10,14,15].

Coordination has been studied at a conceptual level to understand how cooperative, interdependent activities can be individually conducted [13]. We use coordination to refer to *workspace coordination*: the management of access to and transfer of shared resources [9]. Recent efforts in developing coordination mechanisms for tabletop interfaces have recognized the importance of existing work practices and social protocols [7,10,11,14,15]. For example, early work on interactive tabletop displays automatically rotated objects, but this protocol disrupted the fundamental role that subtle rotation variations play in coordinating collaboration, namely that the orientation of objects helps define working areas [7,15].

Researchers have not solved the problem of supporting coordination: we still frequently observe instances of *interference* [8,11]. For instance, commands that re-arrange all objects on a table are often disruptive [8], and individuals may sometimes attempt to manipulate single-user objects simultaneously [9]. Morris et al. [8] articulate a typology of coordination strategies to resolve these interference problems, which are classified along two dimensions: first by the scope of the conflict (global, whole element, sub-element), and secondly by the resolution mechanism (owner-controlled, mixed-initiative, reactive).

Another approach to supporting coordination is to understand and support the work practice of *territoriality*: how groups spatially partition a work surface to organize and coordinate activity [14,15,20]. This approach suggests that three kinds of territories are established organically through the placement and orientation of objects in the workspace [15]: *personal territories*, in easy reach, are used for fine manipulation and reservation of resources; *group territories* provide context for the "group" task, and used to hold shared artifacts, finally, *storage territories* provide temporary areas for artifact placement. This approach is compelling because it largely offloads coordination of workspace artifacts and table space to the group by providing mobile objects for interaction [14]. Yet, many tabletop activities do not involve small mobile objects. Thus, it is not clear how tabletop coordination and territoriality are supported in the presence of fixed data objects.

Collaborative Exploration of Fixed Spatial Data

In some mixed-focus collaboration tasks, groups cannot delineate territories using objects, potentially requiring computational assistance in coordinating view and access to the space. To understand collaborative mechanics in these contexts, we explored visualization tasks with spatially fixed data such as maps. In such tasks, the visualized data set takes up the entire display and cannot be moved from its location, potentially introducing physical and visual interference issues when individuals need to work independently in the same area. For example, in a

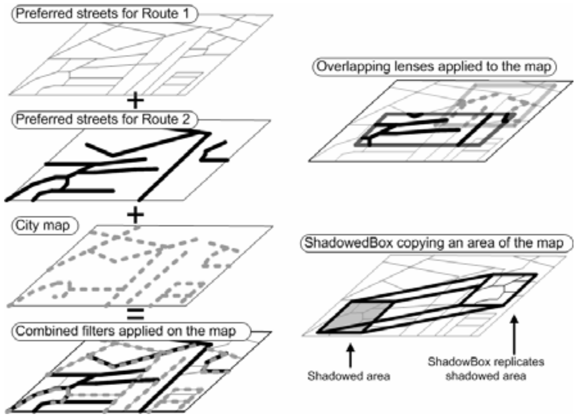

Figure 1. Three display techniques for coordinating space: filters being applied to a map (left); lenses being applied to the same map (top right), and a ShadowBox relocating a region of the map (bottom right).

meteorology application, one person may need to examine wind patterns while another studies temperature and pressure, both in the same geographic location.

Figure 1 shows three techniques for exploring fixed spatial data that potentially support different working styles by providing view-based partitioning of the data: *filters* (left), *lenses* (top right), and *ShadowBoxes* (bottom right). Filters are common in commercial mapping applications (e.g. Google Earth [1]), allowing users to selectively view multiple "layers" of visual information by simply stacking them atop each other. This global approach provides a single view of the workspace. In our studies, filters could be displayed or hidden using a set of graphical buttons. Lenses are mobile, resizable windows providing the same set of data visualizations as the filters, except in a localized view [17]. Several data layers can be shown simultaneously by overlapping multiple lenses. Lenses facilitate local view changes without affecting the global space. In our studies, lenses were created by using a set of graphical buttons, and were moved and resized by dragging their borders or corners, respectively. ShadowBoxes allow users to select an area of the display and copy the underlying information to a moveable viewing window, similar to the DragMag visualization technique [21]. Interactions in the viewing window are "shadowed" in both regions, meaning that drawing and erasing activities in either location is immediately reflected in the other. This displacement allows multiple individuals to work on the same part of the data simultaneously.

In our observational studies, we were interested in determining how these tools supported mixed-focus collaboration and coupling. By providing a single view, filters were expected to ease communication by facilitating gestural and deictic references [4]. Independent work was expected to be disadvantaged because view changes were global. Lenses were expected to support spatially distinct, local views of the data, allowing individuals to view and

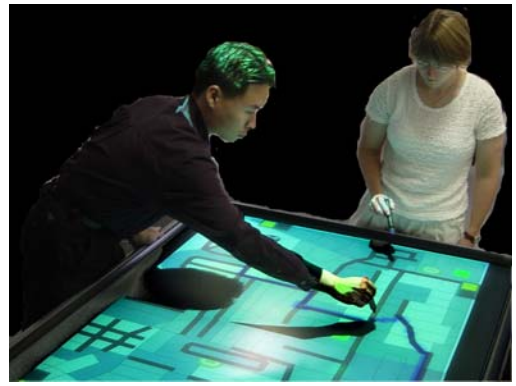

Figure 2. Tabletop users completing the task from Study 1.

work on parts of the workspace independently. Lenses were not expected to solve the problem of physical interference that might occur when two individuals want to work in the same physical space. We believed ShadowBoxes would provide a solution to this problem by allowing individuals to work in the same part of the data in physically distinct locations.

OVERVIEW OF OBSERVATIONAL STUDIES

We conducted two observational studies to better understand mixed-focus collaboration. In the context of a collaborative visualization task, we wanted to understand how tools such as filters, lenses, and ShadowBoxes would be used for both the independent and shared work aspects of mixed-focus collaboration and how these affected coupling.

In our first study, participant groups created routes by connecting multiple end points on a fictitious city map using our three tools to reveal data on the underlying map. This exploratory study was designed to understand how participants would use the tools to coordinate their activities over the workspace.

In our second study, participant groups created routes connecting multiple end points on a fully connected graph. The purpose of this second study was to confirm the presence of certain coupling patterns observed in the first study and to characterize the role of coupling in these activities. We included specific roles for individuals within a group, and created independent and shared tasks to tease out the transitions between individual and group work.

STUDY 1: EXPLORING GROUP WORK

To explore how groups work over spatially fixed data sets, we designed a map-based route creation task requiring collaborative visualization. Pairs created two separate bus routes in a map of a fictitious city (Figure 3, left). Beyond simply creating routes to connect designated end points, participants were to optimize their routes based on a set of constraints, ensuring that created routes: (1) were reasonably direct, (2) traveled along preferred streets, (3) passed through residential and commercial zones while

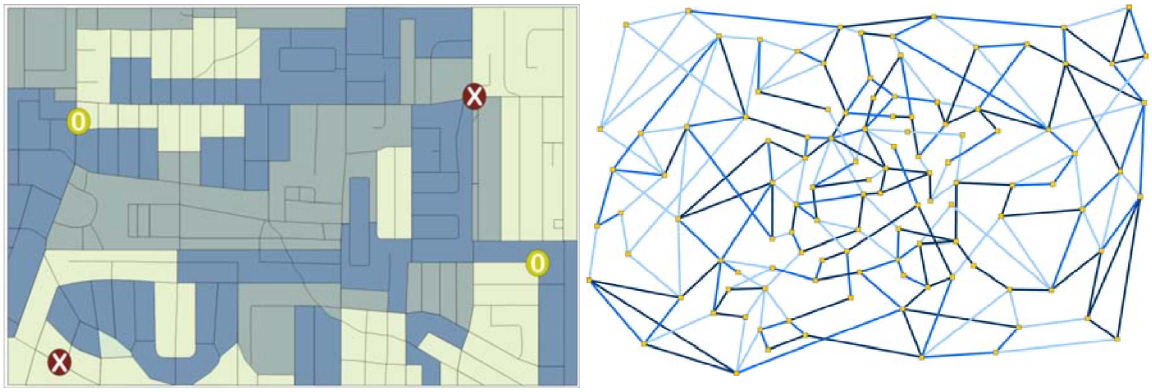

Figure 3. The street map provided to participants in Study 1 (left) and one of the fully connected graphs provided to participants in Study 2 (right).

avoiding industrial zones, and (4) avoided overlapping with each other. Various data layers including the street map, “preferred streets,” and locations of residential, industrial, and commercial zones were provided to groups to help them construct routes (Figure 3, left). These data layers were accessible to participants via combinations of filters, lenses and ShadowBoxes, depending on the study condition they were completing (see Design).

Based on prior work, we expected groups to exhibit certain kinds of behaviour:

- *Divide-and-conquer.* We expected participants to use a divide-and-conquer approach to the task, with each individual working on a separate route (e.g. [4]).
- *Individual work would be better supported by lenses and ShadowBoxes*. We expected participants to prefer lenses and ShadowBoxes for individual work because these tools would allow individuals to work independently without disturbing the view of others. We also expected filters to induce interference because one person’s view of the space would affect the entire group’s view.
- *Group work would be better supported by filters*. We expected participants to prefer filters when engaged in group work because we believed the single view provided a shared context for discussion, and interference would not be an issue.

Design

Our exploratory study used a 2 (filters vs. lenses) × 2 (with ShadowBoxes vs. without ShadowBoxes) within-subjects design. The presentation order of the conditions was counterbalanced across groups using a balanced Latin square because pilot testing suggested presentation order affected work strategy. Thus, every group participated in four different conditions: (1) filters with ShadowBoxes, (2) filters without ShadowBoxes, (3) lenses with ShadowBoxes, and (4) lenses without ShadowBoxes. Every group received a unique presentation order of these conditions.

Participants

Eight paid participants (four pairs: five males, three females) with normal or corrected-to-normal vision were recruited from the general university population. Each participant group was made up of two people who knew each other well. All participants reported being right handed. Four had previous experience with large displays, two of those had experience with tabletop setups, and five had experience with Web-based mapping software. Mean age of the participants was 29 years.

Apparatus

We used a large front-projected tabletop display (5 × 4 feet) with high resolution (1534 × 1024 pixels) supporting simultaneous two-touch interaction via SMART Technologies’ DViT. Participants could interact with the table by directly touching the table with pens or their fingers, though most participants only used pens. We placed two chairs within easy reach of the tabletop display and told participants that they could use them, but no participants chose to use the chairs in this study.

Our custom-build groupware application was built with C#, and Direct3D using the Trans2D library [19]. This software ran on a dual-Xenon 2.8 GHz Windows XP PC. Dragging a pen or a finger over the tabletop display would draw routes on the custom-made map while dragging a digital eraser widget would erase drawn routes. The application also provided widgets to control the display of additional data based on the study condition. Because our tabletop display supported two touch interactions simultaneously, both participants in a group could draw, erase, or manipulate widgets on the tabletop at the same time.

Method

Participants first filled out a questionnaire to collect demographic information and to assess their experience with mapping applications. They were then given a short tutorial on how to use the table display and general instructions on the task. Prior to each of the four conditions, participants practiced with the tools they would be using for that condition. Participant groups generally felt comfortable about using the various tools with less than five minutes of practice before each condition.

During the conditions, we instructed the participants to use a "talk aloud" protocol, and videotaped their interactions with each other and the tabletop for later analysis. On average, groups completed individual conditions in approximately 15 minutes. Once all four conditions were complete, participants took part in a semi-structured feedback session, which allowed us to gain valuable insight into their impressions of the task, the different interaction techniques, and their own performance during the study.

Three observers were always present during study sessions with groups, though only one directly interacted with the participants; the remaining two were passive observers during conditions. Observers collected field notes of group behaviours as they worked, which were later combined with the video recordings for a full analysis.

Results

Collected field notes and video were analyzed using an open coding approach similar to that used in other research [7,15,18]. Field notes were used to inform initial coding categories, such as whether participants were working independently or together at a given point in time. A video analysis was supplemented by a descriptive statistical analysis. We present our most salient findings below.

Tendency to work together

Contrary to our expectations, pairs worked together across all conditions, visibly working independently for only 24% of the total time. This was surprising because we had predicted that participants would prefer to work independently in the presence of lenses or ShadowBoxes. In only 6 out of the total 16 study conditions (4 groups × 4 conditions each) did pairs even attempt to divide up tasks. Groups generally worked together to find one route before finding the other route. Groups were highly mobile, with individuals frequently moving around the table to gain a shared perspective of the area of interest. Groups also worked in tandem. Often, one person would control the widget (either lenses or filter buttons) while the other would draw the route on the display. In some sense, this division of labour could be considered as divide-and-conquer; however, the pairs were working closely together on the same problem as opposed to working independently on different aspects of a problem.

Group 3 was a notable exception. In the filter conditions, this pair worked in parallel on different routes. To facilitate this parallel operation, they used the filters in a "time sharing" mode: when one needed to see a given data layer, he would tap and view his layer for as long as he needed while the other worked from memory. Group 3's working style suggests that some groups may desire to work independently. Group 3 found an awkward way to support their independent working style since the interaction widgets we provided did not provide fluid support for them.

Maintaining context

In addition to working together most of the time, pairs did not use the data widgets in the ways we had expected. Most strikingly, participants overwhelmingly preferred global filters. In lens conditions, users essentially mimicked the functionality of the filters (even when the filters had not yet been presented) by creating table-sized global lenses, moving them in and out of the workspace to cover the working area. ShadowBoxes were simply moved out of the way; widgets that affected the global space were preferred.

Participants reported that the lens widgets suffered from several usability problems. First, they were somewhat cumbersome—resizing and moving the lenses required a switch from the route planning activity to a widget manipulation activity. Second, lenses did not support the way in which participants worked (i.e. as a group rather than independently). Finally, lenses could not meaningfully partition the space because each lens needed to be larger than half of the table to provide enough information to plan each route. Since the task involved planning global routes, participants preferred global filters, which provided global rather than simply local information.

Discussion

Pairs were mobile and *non-territorial* when working over the spatially fixed data. For the most part, they moved together, worked together on the same route, and did not work independently. The entire workspace was therefore group territory and the tools for establishing personal territories (i.e. ShadowBoxes and lenses) were not used. Groups preferred visual mechanisms (i.e. filters) that allowed them to view the space together, even frequently standing in close proximity with one another, which was surprising since the workspace had no orientation cues.

From Study 1, we began to think about how to describe the group activity. For instance, many groups spent time working very tightly coupled, but in different ways: at times, they would draw routes together, and at other times, they would simply point alternatives out where one individual was more active than the other. Group 3 exhibited loose coupling, and often worked in parallel. To understand this issue of coupling further, we expanded the scope of the task to explicitly include independent, individual activity in Study 2.

STUDY 2: TRANSITIONS IN GROUP WORK

Based on the outcomes of Study 1, the following objectives were established for Study 2:

- *Giving participants independent roles.* Participants often worked in tightly coupled fashion in Study 1, but this may have been because they were not given independent roles.

- *Explicitly introducing independent and group tasks.* By imposing activity at the extremes of mixed-focus collaboration (independent work and shared work), we hoped to observe a range of group activity.
- *Multiple sub-problems.* Study 2 had three sub-problems that could be spatially partitioned (i.e. a person could work on each sub-problem without requiring the entire work surface). To induce instances of interference, one of these sub-problems slightly overlapped with the other two. Study 1's sub-problems covered the entire space, so spatial interference may have precluded independent work.
- *Completely conflicting data layers.* Data layers in Study 1 overlapped only in certain regions, so participants could often work with all filters turned on. In Study 2, we used completely occluding data layers to preclude this strategy, and to simulate situations where there are so many data layers that displaying all the information needed by one person will necessarily interfere with the other.
- *Redesigned lens widget.* Based on Study 1 feedback, we redesigned the lens to include filter buttons that could selectively apply layers in a local space.
- *Removal of the ShadowBox condition.* To focus our efforts on the effects of local and global views on independent and group tasks, we removed the ShadowBox condition. Including a ShadowBox condition in this study would have prevented us from practically using a within-subjects design.

Pairs found routes in a fully connected graph (114 nodes, 218 edges; Figure 3, right) covering the entire workspace. This task represented an abstract route planning task (such as airline routes). Two independent data overlays provided edge weight information ("travel time" and "financial cost"), where the weights could be 1, 2 or 3. Participants generated routes to connect four specific nodes on the graph. Depending on the condition, each participant was responsible for generating one of two *independent routes* (one for travel time, one for financial cost), or the pair was responsible for a single, group *compromise route* (taking into account both travel time and financial cost). We also varied the visual tool pairs used: global filters, or the redesigned lenses.

Design
Study 2 used a 2 (filters *vs*. lenses) × 2 (individual routes *vs*. compromise route) within-subjects design. The presentation order of the conditions was counter-balanced across groups using a balanced Latin square.

Hypotheses
Based on the results from Study 1, we had two major hypotheses.

- *Individuals will work independently with lenses.* Since lenses allow people to work in different parts of the table and some sub-problems were spatially distinct, we expected independent work to occur for those independent sub-problems. We expected this to occur even when participants were working on a compromise route, since participants could use lenses to work on different areas of the route at the same time.
- *Perspective sharing during tightly coupled work.* When working together on the same sub-problem, we expected groups to stand in close proximity to each other, thereby allowing groups to share the same perspective view of the problem space.

Participants
We recruited eight paid participants (four pairs: four males, four females), different from those in Study 1, with normal or corrected-to-normal vision from the general university population. Seven were right handed, two had previous experience with large displays, none had experience with tabletop setups, and six had experience with mapping software. Mean age of the participants was 28 years.

Apparatus and Method
We used the same apparatus and setup as Study 1, except that we replaced the map with a custom-made, fully connected graph, and that participants used the global filter and redesigned lens widgets. Study 2 used an identical protocol to Study 1.

Results
Video was analyzed using a multi-pass, open coding approach similar to [7,15,18]. Field notes were used to inform initial coding categories, such as individuals' positions around the table and which sub-problem each was working on at a given point in time. Subsequent coding passes were driven by iteratively refined coding schemes based on further study of the videos. This methodology facilitates an intimate familiarity with the intricate, subtle mechanics occurring in the sessions, providing a very rich understanding of the underlying collaborative processes.

This study imposed a variety of activities ranging from independent to group tasks, allowing us to explore a range of collaborative behaviour. Our analysis revealed six different types of collaborative coupling. These coupling styles were related to a range of other factors, including the experimental condition (i.e. task type and tools being used), collaborators' physical positioning around the table, and how interference was handled, providing strong support for our coding scheme. We begin by describing the six coupling styles we saw, and then describe other factors and how these related the coupling style.

Styles of coupling
Based on field notes, we iteratively refined a coding scheme for the videos in Study 2 to describe and capture the dynamic styles of coupling for each group. Individuals fluidly transitioned between styles, for example, moving from tight coupling, actively working together, to "medium

coupling," where they worked somewhat independently on the same task. We identified six coupling styles in Study 2; of these, we consider the first three (identified with round parentheses) to be "working together."

(SPSA)*: (Same problem same area):* Collaborators are actively working together to evaluate, trace, or draw a route (e.g. one person points at landmarks while the other connects them with a pen). Often, this is accompanied by conversation.

(VE)*: (View engaged: One working, another viewing in an engaged manner):* The pair is working together, but only one is actively manipulating the display. For instance, one may be showing a route to the other, or one may just be watching the other's actions very carefully. In the latter case, the individual is watching closely enough to suggest corrections. Conversation often accompanies this style.

(SPDA)*: (Same problem, different area):* Collaborators are working simultaneously on the same sub-problem, but are focused on different parts of the table. For instance, participants may be evaluating alternate solutions of the same sub-problem. This style is not accompanied by conversation. Instead, conversation and gestures often transition groups to more tightly coupled work.

[V]*: (View: One working, another viewing):* One collaborator is working on the task, and the other is watching, but is not sufficiently involved to help or offer suggestions. The person watching only reacts to high-level activities, such as when the active person stops working or needs resources (e.g. a widget).

[D]*: (Disengaged: One working, another disengaged):* One collaborator is completely disengaged from the task, not paying any attention to the task or partner.

[DP]*: (Different problems):* Collaborators are working completely independently on separate sub-problems at the same time. Each person's interactions with the workspace are not related to the other in any way. In this style, participants often peeked at one another to maintain an awareness of the other's activities.

After coding each of the 16 sessions (4 groups × 4 conditions), we ran a set of statistical analyses to understand how coupling related to the study conditions. Total time spent working in a particular coupling style was broken down by study condition. These coupling styles were subjected to a two-way, within-subjects ANOVA with repeated measures (filters and lenses × individual and compromise routes).

Relationship between coupling styles and tool/task type

Consistent with our hypotheses, when creating compromise routes, pairs' were more tightly coupled than when creating individual routes. They also worked more tightly with global filters than with lenses. Figure 4 shows the mean proportion of time participants spent working in particular coupling styles as broken down by condition.

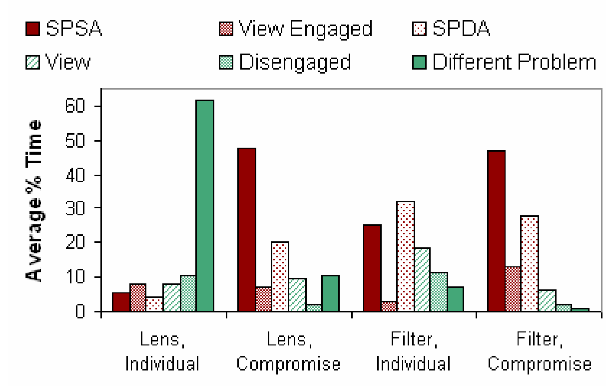

Figure 4. Observed coupling styles in each study condition.

The ANOVA revealed a borderline significant interaction between interaction technique (filters and lenses) and route type (individual and compromise) in the amount of time participants spent working on different problems (DP) [$F(1, 3) = 9.5$, $p = .054$, $\eta^2 = .76$]. Additional main effects for interaction technique [$F(1, 3) = 14.3$, $p = .032$, $\eta^2 = .827$] and route type [$F(1, 3) = 14.9$, $p = .031$, $\eta^2 = .833$] were also present for different problems (DP). These effects collectively suggested that participants spent the most time working on different problems in the lens+individual route condition.

A main effect was also present for route type and the amount of time participants spent working on the same problem and same area (SPSA) [$F(1, 3) = 159.6$, $p = .001$, $\eta^2 = .982$]. This indicated that participants spent more time working together on compromise routes than they did when working on individual routes. This was unsurprising given the differences between the two task types.

In all groups, we observed that participants worked independently and loosely coupled on the two problems that could be spatially separated, and then transitioned into more tightly coupled work, working closely on the problem that overlapped in the lens+individual condition. We were surprised by the activity in the lens+compromise condition, where we expected all participants to work in parallel on separate sub-problems. Instead, we found that three groups worked together in this condition about 96% of the time. Group 2 was an exception: they worked in a parallel, independent manner to generate the best individual routes, and later worked in a more tightly coupled manner to find the best compromise based on the individual solutions. They only worked together about 51% of the time.

Conversely, we found that participants usually worked together when using global filters. They worked together 79% of the time on individual routes and 94% of the time on compromise routes.

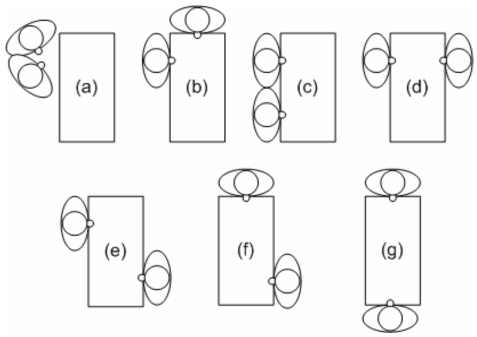

Figure 5. We coded seven position arrangements around the table (based on relative positions): (a) together, (b) kitty corner, (c) side by side, (d) straight across, (e) angle across, (f) end side, and (g) opposite ends.

White: < 1%
Light grey: 1-4 %
Dark grey: > 4%

	SPSA	VE	SPDA	V	D	DP
(a)Together	7.8	1.6	3.4	0.5	0.2	0.5
(b)Kitty corner	9.4	1.9	5.2	2.4	0.9	1.9
(c)Side by side	2.5	1.0	2.3	0.9	0.9	3.1
(d)Straight across	9.2	2.3	8.7	3.3	2.3	1.0
(e)Angle across	3.8	1.4	2.4	2.3	1.4	6.2
(f)End side	0.5	0.1	0.1	0.3	0.3	4.9
(g)Opposite ends	0.0	0.0	0.0	0.1	0.0	3.1

Table 1: Percent time working in each coupling style and physical arrangement. Arrangement categories are in increasing order of average distance between participants. Coupling styles range from working closely together (left) to working independently (right).

Arrangement

We suspected that with tighter coupling, participants stood physically closer to one another. To examine this relationship, we first video coded participants' location changes, thereby providing arrangement information, and then cross-tabulated this data with coupling style. Our coding scheme (Figure 5) considered the relative positions of participants and not their absolute positions.

As we expected, when collaborators worked more closely together, they stood physically closer, and when they worked independently, they stood further apart. This can be seen as a dark diagonal trend from the top left to bottom right of Table 1. Although this effect is complicated by the fact that participants were physically closer when working on the same sub-problem, it corresponds with results from our first study, which did not have spatially separated sub-problems.

A notable exception to this observation is that Side by Side arrangements were physically closer than Straight Across, yet Straight Across was a very common arrangement for group work. This result is likely the consequence of the particular collaborative ergonomics of our table: working Straight Across the table yielded a good position to work on the same problem while providing smooth face-to-face communication. Similarly, when working independently, standing Side By Side rather than Straight Across may have reduced visual distraction.

Consistent with prior work [15,20], physical positioning appeared to be related to territorial behaviour. Individuals tended to explicitly interact only with areas physically close to them, and avoided interacting with areas physically close to their partner (an exception is shown in Figure 6). Yet, these "territories" were transient. As individuals moved, others were no longer restricted from operating in those areas. Similarly, when a pair worked closely together on the same problem, we often observed one person taking on the other's perspective. In these instances, the second person would never displace the first: even if the second person was to gesture toward the table, he would move to a different location around the table before doing so.

Handling interference

We also saw many instances of interference, where one collaborator either blocked another's view or ability to physically interact with the workspace (Figure 6). When more tightly coupled, interference was less frequent, and was handled more gracefully, with one person moving out of the way just as another moved into the space. When collaborators worked in a loosely coupled fashion, we saw more frequent instances of one participant waving the other away, and in some cases, physically pushing or grabbing each other.

Not all interference was detrimental. While interference often interrupted independent work, interference (intentional or otherwise) often signaled or aided groups to transition to more tightly coupled working styles. For instance, any activity covering workspace (e.g. one person counting or drawing) often signaled that one collaborator "had a good solution." Since many pairs liked to validate their routes together, this activity would act as an invitation to closer collaboration (i.e. tighter coupling).

Discussion

The original observations we made in Study 1 were largely consistent with the results of Study 2. Participants preferred tools that supported their particular working style. Despite explicit independent and group tasks in Study 2, participants generally preferred to work together when they had joint responsibility for the outcome of the task, as was true when they were constructing compromise routes.

From Study 2, we identified six collaborative coupling styles to describe the workspace activity. These styles were closely related to other factors such as physical arrangement, the task and tool being used, and the incidence of interference. The coupling descriptors are useful in that they contribute to the description of significant aspects of group activity by characterizing the

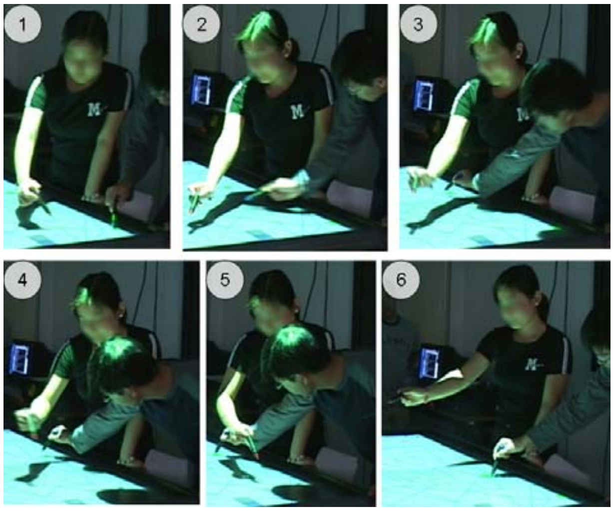

Figure 6. A series of frames representing a particular instance of interference with a loosely coupled pair (note how they are focused on different areas of the workspace in frame 1).

nature of mixed-focus collaboration: namely, that groups frequently and fluidly transition between several stages of working closely and working independently.

GENERAL DISCUSSION

In studying participants as they work over tabletops, and in attempting to communicate those observations to a wider audience, we have come to appreciate that collaboration is a highly complex and multifaceted construct—even when we constrain the investigation to real-time tabletop collaboration within a task in a study. The term "coupling," and associated terms "tightly coupled" (that entities work closely together), and "loosely coupled" (that entities work fairly independently), for example, have been used to describe one dimension of collaboration. Yet we have found that there exist many points along the spectrum between the two endpoints, and suspect that the nature of collaboration may vary in other orthogonal dimensions.

We describe six collaborative coupling styles, though do not believe this is an exhaustive list. The styles we observed were likely limited by the specific parameters of our study. For instance, if we had limited ourselves to the methodology of Study 1, we would not have seen the extent of varied styles of independent work that we described above. We expect that additional styles may be uncovered through studies with different user groups, tools, and tasks.

Although we attempted to order the coupling styles from tightest to loosest, the detailed ordering of all pairs is not necessarily obvious or finalized. We are unsure whether these coupling styles even fall along a single dimension. For instance, same-problem-same-area, view-engaged, and same-problem-different area appear to fall along a continuum of "degree of involvement in the other's task." However, it is not clear whether coupling is tighter when working on different problems or when one person is disengaged. To account for these observations, a promising approach may be to consider how collaboration might be described as a dynamic and fluid stateless system [6].

Implications for Tabletop Design

Groups move frequently and fluidly between many styles of coupling. Each style is accompanied by different behavioural mechanics. For example, in tight coupling, individuals work in close proximity even when the workspace has no implicit orientation. Furthermore, different display techniques support different styles: independent views support individual work because they reduce interference, and global views support group work because they provide common ground.

1. Support a flexible variety of coupling styles.

Mixed-focus collaboration encompasses many coupling styles: even in our own studies, there was a wide variance in the approach groups took. Most systems fail to provide support for multiple coupling styles, falling back on social protocols to effect different coupling styles (e.g. [7,10,15]). Since tabletop displays are dynamic, we can provide a variety of tools to support different coupling styles. A promising future direction may be the convergence of physical and digital media on tables as an alternative means for providing individual and group views.

2. Provide fluid transitions between coupling styles.

Supporting mixed-focus collaboration requires supporting the *transitions* between loosely coupled independent work and tightly coupled group work [1]. Providing only a single view of the workspace limits individuals' abilities to work independently [4], yet using separate copied workspaces may prevent many group collaborative dynamics, such as being able to see what others are doing, from emerging [16]. Our results do not suggest mitigating interference altogether since some forms of interference signal transitions between coupling styles and benefit group coordination. Furthermore, the recognition of interference can be used as a means to fluidly transition between coupling styles. For instance, the act of rotating an object toward a fellow collaborator temporarily signals the desire for attention [7]: the system may also use this cue to transition the workspace to match the tighter coupling.

3. Provide mobile high resolution personal territories.

The interference we observed was a direct result of individuals' desired working areas overlapping. Creating usable and useful personal territories could take several avenues, including a higher resolution workspace, or mobile regions of high resolution, or even using distinct displays for personal work (such as Tablet PCs or PDAs).

4. Support lightweight annotations.

Tabletop task spaces should support mobile, unobtrusive, and transient annotations. One of the affordances of the tabletop form factor is the ability to conduct independent work unobtrusively [18]. Annotations help to generate and track independent work, and may be moved to be shared with the group [7]. In our studies, participants surprised us by frequently annotating the map space with both spatially-relevant and spatially-invariant annotations. These annotations sometimes helped and other times hindered the other participant. We recommend supporting the easy creation, mobility and modification of annotations.

CONCLUSIONS

We presented two observational studies of mixed-focus collaboration, exploring the transitions groups make in their coupling styles. These coupling styles are descriptions of group activity and behaviour, allowing us to characterize the activity of groups. The two studies have demonstrated that different coupling styles are related to other variables such as preferred tools, physical arrangement, and the incidence and handling of interference. For example, groups use tighter coupling styles when working together closely, preferring common, global views. By providing a preliminary characterization of these coupling styles, we have identified design opportunities for tabletop researchers to support collaborative work. A flexible set of tools allowing fluid transitions between views is required to fully support the dynamics of mixed-focus collaboration.

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