The Effect of View Techniques on Collaboration and Awareness in Tabletop Map-Based Tasks

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ABSTRACT

Digital tabletops have become a natural medium for collaborative planning activities involving maps. Such activities are typically mixed-focus, where users switch between high-level and detailed views of the map and between individual and collaborative work. A wide range of view-sharing techniques such as lenses, zooming and radar views provide both shared and individual access to the same workspace. However, it is not yet sufficiently clear how the choice of view techniques affects collaboration in mixed-focus scenarios. In this paper, we explore the effect of different view techniques on collaborative map-based tasks around tables. We report on two studies in the context of military planning, one in a controlled environment and one in an open-ended scenario carried out by domain experts. Our findings show how the success of different techniques is sensitive to the form of collaboration and to the proximity of work on the table.

Author Keywords

Digital tabletops; mixed-focus collaboration; digital maps.

ACM Classification Keywords

H.5.3 **[Information Interfaces and Presentation (e.g. HCI)]**: Collaborative Computing.

INTRODUCTION

Tables provide many benefits for co-located collaboration. One of their main strengths is their flexibility in supporting many different configurations of shared activity – they naturally allow people to maintain a strong group focus, to carry out individual tasks in different areas of the table, or to switch between these configurations simply and easily. Collaboration that involves these shifts between individual and group focus is called "mixed-focus collaboration" [10].

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However, a problem arises for mixed-focus collaboration when people work with a single large artifact that takes up the entire table, such as a map. This is a common occurrence in tabletop work and maps are used in many digital-table applications such as emergency response [17], utility grid management [23], geological exploration [4] and command and control [3, 22].

In situations where the table is used for a single large artifact, it becomes much more difficult for people to carry out individual tasks, because they cannot always re-configure their tabletop work area to provide a view that is appropriate for their work. For example, two people might need to carry out different tasks in the same area of a map, but only one person can have their hands and arms in the space at a time. Similarly, people may need different map zoom levels for their individual tasks, but only one level can be used.

Some digital surfaces attempt to solve this problem with augmented view mechanisms that provide multiple representations of the workspace (e.g. [8, 13, 25]). This can allow different people to have different views of the table, and can provide alternate external representations (such as overviews) that stay constant regardless of the zoom level or scroll location of the main table view. Where a traditional table would require that people accommodate the physical restrictions of artifact size, orientation, and layout, digital tables can create different views for different purposes – for example, allowing one person to zoom into a map while another person views their area at a high level.

Having different views on the same table can be very useful for individual work, since each person's view can be customized to the needs of the individual task. However, there is little understanding about whether having multiple views changes the ways in which people engage in mixed-focus collaboration. For example, we know little about whether individualized views can improve group performance, whether individual views compromise the shared focus that is possible on physical tabletops, and whether people are able to easily change their views to match the requirements of the mixed-focus collaboration. Without this knowledge, it is difficult for designers to know whether their tabletop systems will in fact support the collaboration styles and changes that will occur in real use.

We carried out two studies of augmented-view tabletop systems that provide new information on these issues. The first controlled study showed that group performance improves when the view configuration matches the spatial arrangement of the group's tasks. The second study showed that in a realistic task, people do not always choose the view configuration that best matches the demands of their current tasks. These results reveal potential contradictions and tradeoffs in the design of multiple-view tabletop systems.

Our work makes three main contributions. First, we quantify the performance benefits that can arise from choosing a view configuration that matches the spatial organization of a group task. Second, we show that despite these performance advantages, people often use a non-optimal configuration – suggesting that the overhead in managing views can reduce the benefits. Third, we provide new insights into why people use (or don't use) different views in different situations. Our results show that the use of flexible view configurations for tabletop systems is more complex than previously thought, and provide new design opportunities and research questions for future work.

BACKGROUND: MIXED-FOCUS MAP-BASED PLANNING

Digital tabletops have shown great promise for supporting collocated tasks. Wallace et al. [26] compared collaboration using a shared tabletop to the use of individual tablets, finding that the tabletop enhanced group performance. But mixed-focus collaboration requires more than simply the ability to view a shared artifact on a table. For example, Isenberg et al. have demonstrated the need to support different coupling styles in visual analytics tasks [14].

Planning around maps serves as an excellent example of why space-sharing mechanisms are required. Groups often need to work on different parts of the map at different levels of detail. Tang et al. were the first to analyze and compare the use of different space sharing techniques (filters, lenses and shadowboxes) for collaborative route planning tasks on maps [25]. They identified six different coupling styles and found these styles to be related to variables such as the preferred view technique, physical arrangement around the table, and the incidence and handling of interference.

Recently Jakobsen and Hornbaek [15] studied the use of a high resolution multitouch wall display for exploring a document collection. Their findings confirmed the validity of Isenberg's and Tang's previous work for vertical displays, showing that users had no difficulty in switching between coupling styles and that proximity and tight collaboration were correlated.

The research presented in this paper builds on this previous work with a focus on collaboration around a single, large shared artifact, such as a map. Collaborative work around large maps strongly differs from collaboration around multiple documents. The mechanisms used to manage the space and deal with interference raise several issues that need to be further explored, specifically the impact of space-sharing mechanisms on performance and collaboration. We seek to extend the work of Tang et al. by deeply examining the impact of choice of view sharing technique on task performance, and on how expert users choose to work when provided with a range of view sharing interaction techniques. As we discuss below, these aspects are particularly crucial in domains where there is time pressure on the collaboration.

We have explored space-sharing techniques in the domain of military map-based planning [3]. Typical tasks include deploying units in a defensive position, coordinating an attack using units under different peoples' control, and planning safe movement through a hostile area. Traditionally, military planners use a "bird table": a large physical table covered in a map. A small group of people can discuss the movement and disposition of units by pointing at the map, and drawing with markers on acetate sheets overlaying the map.

In map-based planning, people change focus in two dimensions: *Collaboration Coupling* and *Level of Detail*. In the *Coupling* dimension, planners move between *group work* (e.g. planning objectives, observing progress of others, and coordinating actions) and *individual work* (e.g. detailed planning for the units for which they are responsible). Planners may engage in **tightly-coupled coordination** (moving units at the same time while attending to others' work), **loosely-coupled coordination** (moving units at the same time, but not attending to others' work), and **turn-taking**, where one person moves units while others observe, possibly commenting on progress. Additionally, planners need to shift focus between different *Levels of Detail*. When developing a high-level course of action, planners may wish to see a map of the entire battlefield; when they are planning a detailed route or deployment, they may need to zoom the map to a scale where terrain details are available.

Digital maps can support movement within these two dimensions, but there are tensions to resolve. For example, if two people want to perform loosely-coupled unit movement requiring zooming at different points in the map, they may compete over which part of the map to zoom.

ORMIS: DIGITAL TABLETOP FOR MILITARY PLANNING

In order to investigate mixed-focus collaboration ranging over these two dimensions of coupling and level of detail, we enhanced the OrMiS tool for military planning [3] to provide representative view sharing techniques.

OrMiS shows a map on a 55" tabletop display. Military units are shown on the map using standard NATO symbols: a rectangle with an oval represents an armoured unit while a rectangle with a cross represents infantry. As with a traditional military bird table, OrMiS supports tightly-coupled discussion through the shared map, which planners can observe and reference via pointing and gesturing. The tabletop also provides group awareness during individually-focused work, as it is possible to see what others are doing on other parts of the table.

In OrMiS, plans can be enacted by the creation of routes. Routes are drawn using a touch-based polyline interaction technique (see Figure 1.3). To create a route, a user drags a finger from a unit to a destination. When their finger is lifted off the table a waypoint is created. The user then touches and drags from the waypoint symbol to create the next step in the route. The route can be edited by dragging or deleting waypoints.

In order to support detailed work, we added representative view sharing techniques to OrMiS. These provide *zooming* through table-level pinch and panning gestures, *overview+detail* through bi-focal lenses, and *focus+context* through radar views. These allow planners to work at and move between different forms of coordination and different levels of zoom. We now discuss these view sharing techniques in detail.

Global Zoom/Pan

Zooming is a common technique for providing more detail about a visual artifact such as a map. More precisely, zooming changes the user viewport magnification level [6, 27]. Zooming is typically combined with panning. OrMiS's *global zoom* is a traditional pinch-to-zoom technique as seen in most touch-based map applications.

We hypothesize that global zoom best supports discussion and tightly-coupled coordination around a focused area of the map. However, global zoom poorly supports collaboration around detailed views of non-proximate parts of the map. A zoom or pan operation by one user changes all other users' views, perhaps even removing from the display the part of the map others are working with. This can be a problem for users working separately on detailed views of different parts of the map.

Focus+Context

An alternative to global zooming is lenses, which provide *detailed focus* on one part of the map, while retaining *global context.* Lenses often rely on distortion of the visual space (e.g., "fisheye" lenses) to maintain visual continuity between different foci [9, 19, 20]. However, distortion can cause problems of interpretation [5] and focus targeting [9]. In contrast, magnification-only lenses [1, 2] are not subject to distortion issues but occlude the space adjacent to the magnified area. Despite these problems, lenses help users acquire a rapid overview of the data space through their peripheral vision while focusing visual attention on a specific area. Lenses have been proposed for supporting mutual awareness in interactive tabletop interfaces [8, 21].

We added a focus+context facility to OrMiS via bi-focal lenses (Figure 1.1) [1]. Users can place a lens on the table, and can zoom within the lens using a traditional pinch-to-zoom gesture. Lenses can be dragged to change the part of the map being magnified. Lenses support collaboration by allowing one user to focus on part of the map without disturbing the view of other users. Since the lens is visible on the main map, users can still view what others are working on, helping to maintain group awareness. Lenses may occlude part of the map, and if two users wish to zoom nearby parts of the map, their lenses may overlap. Originally, we used fisheye lenses [19] to maintain visual continuity. However, pilot testing revealed that distortion of the map interfered unacceptably with planning tasks. We hypothesize that bi-focal lenses are appropriate when users are performing loosely-coupled work at different levels of detail on non-proximate parts of the map.

Overview+Detail

Both global zoom and bi-focal lenses have the potential to hinder awareness of the broader context of work. Global zoom focuses on just part of the map, meaning that events on the other parts are no longer visible. Bi-focal lenses occlude parts of the underlying map, and when zoomed, can make it difficult for others to understand what part of the underlying map is being viewed.

Prior research suggests that this awareness problem can be addressed via an overview+detail interface, such as a radar view [6]. This approach provides two views: one that shows the entire workspace in miniature, and one that shows a zoomed-in view of a portion of the space. This approach is found in well-known interfaces such as Google Maps' mini view or StarCraft's mini map. Recent variants of overview+detail interfaces have added off-view

Figure 1. 1) The OrMiS tabletop interface showing lenses and the battlefield; 2) the OrMiS radar view; 3) Route planning

visualization techniques [13] and hierarchical links between overview and detail [16]. Overview+detail techniques are known to require additional mental and motor effort when the views' output spaces are physically separated [12]. Despite this, radar views have been shown to support awareness in collaborative situations [11].

As a representative implementation of an overview+detail technique, we added secondary displays to OrMiS (see Figure 1.2). These separate radar views display the entire map with all visible units and routes. A blue rectangle shows the area of the map currently visible on the table. Two concentric rings represent the lenses. The outer circle represents the size of the lens on the screen and the inner circle shows the lens's current focus. The filled orange area depicts the part of the map occluded by the lens. We hypothesized that these radar views would help planners to retain spatial context, and to view parts of the map occluded by a colleague's lens.

Route Planning as Mixed-Focus Collaboration

In order to evaluate how mixed-focus collaboration can be supported over a single large artifact, we focused on the problem of planning routes for military units. This task involves work at different levels of coupling. Different planners are typically responsible for different sets of units, but the movement of all the units must be coordinated, e.g., to ensure that units arrive at a location at the same time, or that traffic jams do not develop when units share a road.

Typically planners collaboratively develop high-level plans based on **discussion** using **high-level views**. Planners then work on routes for their own units, while maintaining awareness of the other planners' activities; this involves **loosely-coupled coordination** using **detailed views**. Some specific tasks may require **tightly-coupled** unit movement using **detailed views**, such as coordinating the shared use of a bridge. If problems arise, the group may return to discussion around a high-level view. Military route-planning therefore involves several points on the two axes of collaboration and level of detail, and thus serves as a strong example of mixed-focus collaboration over a large shared object.

We performed two studies, described in the next two sections, to examine how people worked in performing route planning tasks. The first study directly addresses the efficacy of the three basic techniques of global zooming/panning, bi-focal lenses, and radar views in supporting mixed-focus tasks. The second study presents domain experts with a realistic task, to see how well the techniques worked in combination, and to better understand peoples' choices around which technique to use under what circumstances.

STUDY 1: PERFORMANCE OF VIEW TECHNIQUES

Our first study sought to find out whether there is a difference in performance between view techniques in a mixed-focus task. The task involved both individual work at a detailed level of zoom and coordination between pairs of participants. Two variants of the task involved working at distant and proximate parts of the map.

System and Task

Participants were asked to collaboratively solve a maze on a digital tabletop using the global zoom, bifocal lens and radar view techniques described in the last section. Figure 2 shows an example of a maze. The goal for both participants was to draw a route for their unit through the green wall to the goal area, following one of a set of available paths. Two types of maze were used: Figure 2.1 shows two mazes at distant parts of the table, and Figure 2.2 shows two mazes located close together. Within the maze, participants needed to choose which route to take at a sequence of three forks. Each road exiting a fork was labeled with a blob shape. One of the two blobs appeared in both participants' paths; the participants needed to identify the common blob and ensure that they both followed the path labeled with that blob. All paths had the same length and the same number of forks. To avoid learning effects, blobs were randomly distributed. Blobs were designed to be abstract enough so users could not easily describe them verbally, thus requiring them to look at their partner's workspace. The task was completed when both units reached their goal.

Participants specified routes using the polyline technique shown in Figure 1.3. The map was covered in black at the beginning of each trial so users could not determine the path prior to drawing the route. The map was revealed as

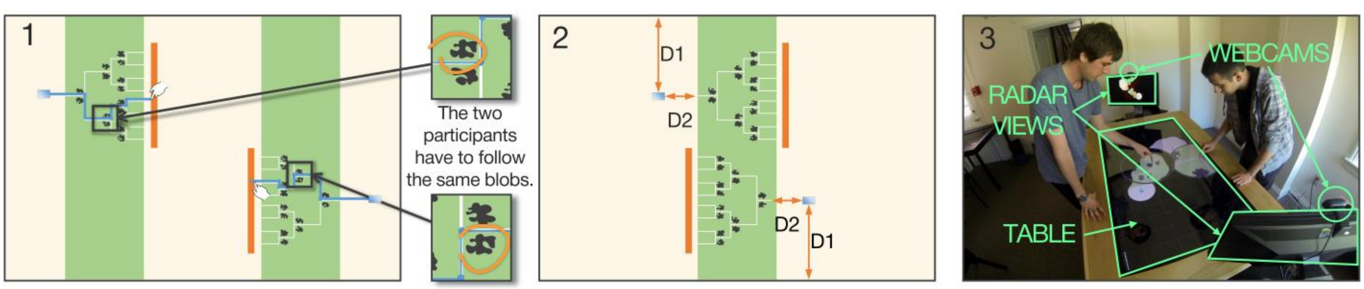

Figure 2. 1) Setting of the path on different regions. An example of the two paths following the same blobs on a turn is highlighted. 2) Setting the paths on the same region. The distances D1 and D2 are highlighted. 3) The study setup.

users drew a route. The intention of the task was to require participants to draw routes using a detailed view, and to coordinate their actions as they reached the fork points.

Procedure

20 participants (12 male, 8 female) were recruited from a local university. Since the task was abstract, it was not necessary to recruit military experts. All participants knew each other prior to the study, were between 19 and 30 years old and were daily users of touch-based devices. The experiment followed a 2×2×2 within-participant design:

	10	pairs of participants
×	2	**interaction techniques** {*Lens, Global Zoom*}
×	2	**radar conditions** {*Displayed, Not Displayed*}
×	2	**spatial arrangement** {*same region, different region*}
×	2	trials
	160	Total trials (16 per participant)

The trials were balanced for order using a Latin square. Participants performed each condition three times, with the first trial used for training. Sessions ended with a custom questionnaire and a semi-structured interview.

Apparatus and Measures

We used a 55” digital tabletop based on a PQ Labs G4S frame. As shown in Figure 2.3, two 1080p 23” screens were positioned on either side of the table to display radar views. The radar views were oriented consistently with the point of view of the participant. From pilot studies, we determined that paths should be 8 pixels wide, small enough to make it impossible to draw a route without zooming. The lenses were 14.5” in diameter, large enough for comfortable interaction and small enough to fit on the table.

We digitally logged all touches and associated positions, and video-taped the session. As shown in Figure 2.3, three cameras were used: a main camera focused on the tabletop surface while two webcams on the radar view screens showed when the participants looked at the radar views.

Hypotheses

This study tested the following assumptions about the suitability of view-techniques for different situations:

H1 *When participants are working on different regions of the map, lenses will be faster than global zoom*

H2 *When participants are working on the same region of the map, global zoom will be faster than lenses*

H3 *Conditions providing the radar view will be faster than equivalent conditions not providing it*

Results

We first report on performance for the different conditions, and then discuss the effectiveness of radar views.

Performance

Figure 3 shows the completion time of trials for each condition. We removed outlier trials where completion

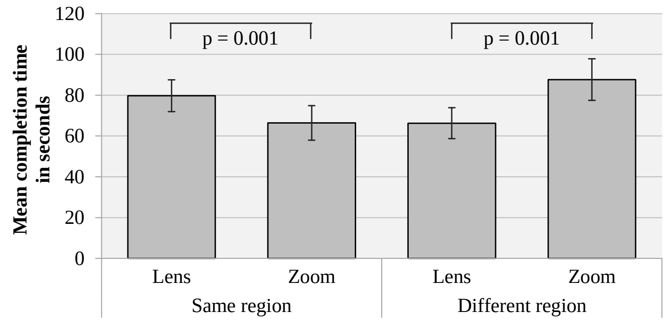

Figure 3. Mean Completion time per condition in seconds

times were two standard deviations from the average. An RM-ANOVA identified a significant main effect of technique on completion time ($F_{1,7}$=3.847, p=.002, η^2=.355). Post-hoc t-tests with a Bonferroni adjustment revealed that the difference between *lens* and *global zoom* was significant both when working on different regions ($F_{1,8}$=17.307, p=.001, η^2=.477) and on the same region ($F_{1,8}$=16.074, p=.001, η^2=.486).

As shown in Figure 3, users were faster with *lens* (M=66.28, SD=15.16) than *zoom* (M=87.65, SD=20.36) when working on different regions. Thus, hypothesis **H1** is supported by our data. Similarly, users were faster with *zoom* (M=66.43, SD=16.93) than with *lens* (M=79.72, SD=15.62) when working on the same region. Thus, hypothesis **H2** is supported by our data.

A post-hoc t-test revealed that the presence of radar had no significant impact on users performance ($F_{1,8}$=.615, p=.438, η^2=.016). The presence of an overview did not have an effect on group performance. Thus, **H3** is not supported.

Following the experiment, participants completed a questionnaire asking which interaction technique they preferred when they were working on the same or different regions. 19 of 20 participants preferred the lenses in the different region condition. However, surprisingly, only 11 of 20 participants preferred the global zoom in the same-region condition.

Role of Radar Views

We used the webcam video streams to count how many times participants looked at the radar view in each trial. Figure 4 illustrates this data. An RM-ANOVA revealed a significant main effect of condition on the number of times users looked at the radar view ($F_{1,9}$=4.023, p=.017, η^2=.309). Post-hoc t-tests with a Bonferroni adjustment revealed that on the condition *lens+radar*, the number of looks at the radar view between working on the same or different region was significant ($F_{1,9}$=10.321, p=.011, η^2=.534). Similarly, on the condition *zoom+radar* displayed the number of looks at the radar view between working on the same or different region was significant ($F_{1,9}$=8.800, p=.016, η^2=.494).

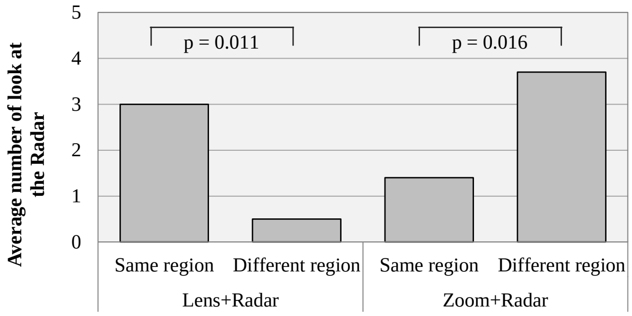

Figure 4. Average number of occurrences of looking at the radar view per trial

As shown in Figure 4, the radar was used significantly more in situations where the view technique performs poorly. We used an open coding process [24] to identify why participants looked at the radar view in these situations. This revealed that in the majority of cases, participants consulted the radar view while attempting to match blobs which were occluded by a lens or were off-screen (i.e., 76% of the time using *lens* in the *same region* condition and 58% of the time using *zoom* in the *different region* condition).

Discussion of Study 1

The first study confirms that there is a performance benefit to using particular view techniques for work on distant versus close regions of a map. Lenses were faster when users' actions took place in different regions of the map. We believe that this is because users could work separately and at a zoom level that was appropriate for moving their units. In contrast, the use of lenses on a proximate region of the map can lead to overlapping of lenses, making it difficult for users to work at the same time.

Conversely, the global zoom proved faster when users' actions took place on proximate regions of the map. The global zoom allowed users to share the same region without creating occlusion problems that could force turn-taking. However, when working on distant areas of the map, it was not possible for both users to zoom at the same time, effectively forcing the users to take turns.

Our radar views had no impact on user performance. This is inconsistent with previous studies of single user applications [12]. Our video analysis showed that the radar view is more watched in high-interference conditions – when using lenses proximately, or global zoom for non-proximate work. While the radar view does not increase performance, it may improve mutual awareness. As reported by one participant "*I think the easiest was when we were using the radar, and then one person could look in their thing, and then the other person would look ahead and then be like 'Okay, now go up, or down.'*"

Overall, these results suggest that people should use different view techniques depending on the proximity of their work areas on the map. This motivated our second study, which looked at whether people choose to use the most efficient technique in order to get those performance benefits in an open-ended and realistic scenario.

STUDY 2: REALISTIC MILITARY PLANNING TASK

Our second study looked at how people choose to configure and re-configure their view environment when working on a realistic mixed-focus task – and in particular, whether people choose the views that perform best for their current work focus. We asked officer candidates from a military university to perform a realistic planning scenario using OrMiS. Unlike the first study, participants were permitted to use any of the view sharing techniques.

System and Task Description

We used the version of OrMiS presented above, including all view techniques (*global zoom, lens,* and *radar view*). Lenses could be created on demand through a long-press menu; the global zoom was always active on the main table display, and the two radar views were always available.

Participants were asked to perform a simple but realistic planning scenario, shown in Figure 5. Each participant controlled different military units; one controlled armored units and the other infantry units. The scenario had two steps which the participants performed sequentially:

Part 1: Move units from A_1 and A_2 to rendezvous at B.

Part 2: Move units through hostile territory from B to the goal position at C. We instructed participants to use a standard military strategy in which armour drives slowly along the road while the infantry walks in the woods beside the road to flush out any ambushing enemies.

Procedure

Twelve male participants (18-30 years old) were recruited from a military university. All participants held the Basic Military Officer Qualification–Land (BMOQ-L), qualifying them as experts in topographical standards used in military maps and strategies used to deploy troops on land. Participants knew each other prior to the study. Participants were first trained with the system, and were given approximately 20 minutes to become familiar with the application and the interaction techniques. Participants were then asked to perform the scenario described above. There was no time limit to perform the task; on average, groups took just over nine minutes (*M*=9:12, *SD*=2:00). The

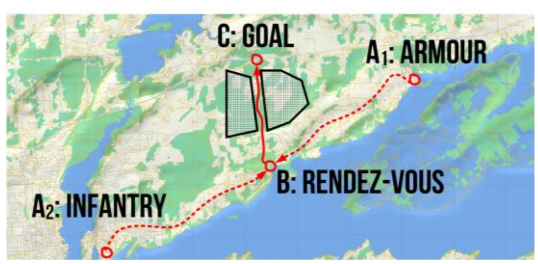

Figure 5. Scenario used in the second study.

exercise was followed by a semi-structured interview.

We used the same equipment as for the first study: a 55" tabletop and two 24" screens to display the radar views. As in the first study, and as shown in Figure 2.3, a main camera recorded the tabletop surface while two webcams recorded looks at the radar views.

Analysis

We used an open coding process [24] to identify behaviors and events of interest during the sessions. The videos for all 12 sessions were analyzed by two coders. All three points of view (i.e. the main camera and two web cams) were combined in one stream and analyzed simultaneously.

Fifty-five minutes of video were analyzed. Six specific situations were coded, either related to one user in particular (e.g., looking at the radar view) or related to the two users working collaboratively. Codes indicated which views and interaction techniques participants were using:

Lens: Period of time interacting inside a lens

Zoom: Period of time interacting on the zoomed map

Radar: Occurrence of a participant looking at the radar view

Single: Only one participant interacting on the table

Neither: Neither participant interacting on the table

Both: Participants interacting simultaneously on the table

Based on our observations during the first study, we assumed that lenses would be used when users needed to work on distant parts of the map (i.e., in part 1) and that global zoom would be used when participants needed to work closely together (i.e., part 2 of the task). We assumed that the radar view would support awareness overall.

Results

A summary of the coding results is shown in Table 1. In the next paragraphs, we use the coding data to answer our main research questions about the use of different views and the way the group coordinated their work.

Use of Views during the Parts of the Scenario

Groups had free choice of view sharing techniques at all times. In part 1 of the task, all six pairs created and used individual lenses to direct their units (see Figure 6.1). Coding data showed that participants interacted with lenses 56.5% of the time in the first part of the task (see Table 1).

	% of Duration		Occurrence	
	Part 1	Part 2	Part 1	Part 2
Lens	56.5%	19.1%	51	11
Zoom	19.6%	48.4%	32	29
Radar	-	-	14	38
Single	20.9%	46.9%	10	45
Both	21.5%	5.9%	47	146
Neither	2.3%	15.3%	78	49

Table 1. Summary of coding results

Participants also used the main table view in part 1 (20% of the time), which included time for setting up the lenses (since the global zoom view was the default view on the table). Participants did not zoom or pan the global view at all during this phase. The remaining 20% of time for part one of the task was taken up in simply waiting for the units to move to the rendezvous point after planning the routes.

At the rendezvous point, all six groups stopped to talk about what strategy to adopt for the second part of the scenario. However, contrary to our expectations, not all of the groups chose to use the global zoom for part two of the task. Four groups chose to use the global zoom, but two groups decided to continue using lenses – even though the group was now working in the same part of the map, and a single global view could show both participants' work areas.

In part two of the task, coding data showed that interaction with the zoom view accounted for 48.4% of the time, and interaction with lenses accounted for 19.1% of the time. However, these amounts reflect the fact that four groups only used the zoom view, and two only used the lenses.

Unexpected Use of Lenses in Part 2 of the Task

Two groups of the six decided to not use the main zoom in the second part of the task but instead shared a lens, thus forcing them to interact (sometimes awkwardly) inside a very small space (see Figure 6.4). These two groups, upon reaching the rendezvous point, destroyed their respective lenses and then created a new one to be shared. One group also shared a lens with one participant in charge of planning his units' route while the other was responsible for dragging the lens (see Figure 6.4). This led to awkward physical proximity in which participants had to move their bodies close together and cross their arms.

There are several reasons why participants may have chosen lenses in the second part of the task – for example,

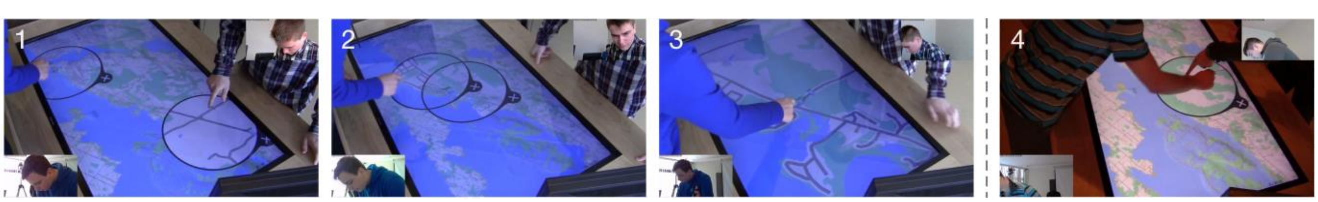

Figure 6. The sequential use of interaction techniques across the scenario: 1) In the part 1 of the scenario, participants worked with two lenses; 2) close to the rendezvous point, participants worked close together, but continued to use lenses; 3) In the part 2, participants had zoomed the map and started taking turns; 4) Participants shared a lens in the part 2 of the scenario.

interface inertia, reluctance to work in the same area, or interest in the novelty of the lens technique – and we discuss these further below. Regardless of the reason, however, our results show that a third of the groups decided to use the lens technique, rather than switching to the technique (i.e., zoom) that Study 1 showed to be significantly more efficient when working close together.

Coordination between Users with Global Zoom

In the second part of the scenario, planners needed to move their units in tightly-coordinated fashion from the rendezvous (point B in Figure 5) to the final objective (point C in Figure 5). Four of the six groups used the global zoom for this part of the task (see Figure 6.3).

Video coding revealed that participants interacted simultaneously only 5.9% of the time during the part 2 of the task. In Table 1, 146 occurrences of *Both* on Part 2 are reported. This corresponds to the very short periods of time where the switch form a user to another was performed. A qualitative analysis on the videos revealed that all four groups adopted a turn-taking strategy when using global zoom. The participant in charge of controlling the armored units always initiated the turn taking. This may have been because the scenario directed the armour to follow the road, and the infantry to flank the armour. Two strategies were used for turn-taking on the global zoom: 1) Two groups took long turns, each drawing the entire route from point B to C, one after the other; 2) two groups took short turns, drawing small parts of the route (usually one or two waypoints) and then permitting the other to continue.

As we discuss further below, these results suggest that global zoom views are not always used in parallel, even when there is room for both participants to operate.

The Role of the Radar View in Maintaining Awareness

Previous work suggests that radar views are extremely useful for maintaining overall awareness of a space [11]. We counted the number of times that participants looked at the radar view, shown in Figure 7. An ANOVA showed an overall effect of the number of people interacting with the table on the use of the radar view ($F_{1,2}$=12.428, p=.002, η^2=.699). Post-hoc tests revealed that when a single person is using the table, use of the radar is significantly higher than when both are interacting ($F_{1,2}$=12.428, p=.017, η^2=.713). Single-person use was also higher than when

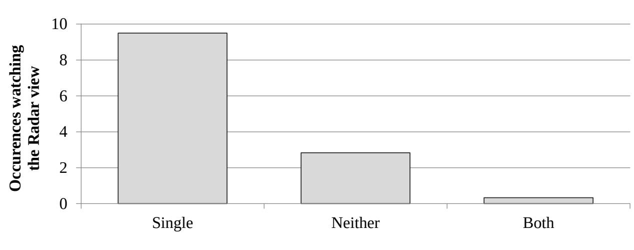

Figure 7. Average number of times radar view consulted per trial. Broken down by one/no/both people using table.

nobody was interacting – but this is not surprising since at the end of the task, both participants simply watched the units follow the planned route.

The radar view was mainly used in the second part of the scenario. 73% of radar view events occurred in the second part of the scenario (see Table 1: 38/(38+14) = 73%); 56% occurred while participants were working directly on a globally zoomed map, while only 36% of the radar view events occurred when participants were working with lenses. Video analysis showed that participants used the radar for awareness to monitor units while they moved along routes, thus providing a sense of the remaining time required to reach the destination point.

These results indicate that the radar was mostly used when people were waiting for their turn in the second part of the scenario. We further discuss the use of the radar view and its role in the task in the following sections.

DISCUSSION AND IMPLICATIONS FOR DESIGN

In the following sections, we discuss some of the surprising results uncovered by the study, propose explanations for these events, and highlight their underlying implications for the design of tabletop systems.

Users Don't Necessarily Pick the Performant Technique

Our first study showed that group performance significantly improves when the view configuration matches the spatial arrangement of the group's tasks. We were consequently expecting that planners in study 2 would choose the view configuration that best matched their current tasks.

However, observations showed that in practice users do not necessarily pick the most efficient technique. We observed that some planners continued to use lenses as they were getting closer together, even though switching to zoom would have led to more efficient work and better awareness. We do not believe that participants forgot the global zoom technique, since participants were trained with the techniques for about 20 minutes before the study. We can therefore assume that they were aware of the existence of both techniques.

The change of view technique (i.e., to zoom) typically happened only when users found a quiet moment in the task to communicate. Two groups of the six seemed to never find this quiet moment, and shared a lens until in the end of the task. We report this phenomenon as an *interface inertia* effect. Several reasons explain this behavior:

Politeness. Our observations suggest that switching from lens to global zoom requires verbal communication to negotiate a common agreement about which technique to use. In practice, participants do not necessarily pause to communicate, even if it is in their interests in terms of performance. The group may have difficulties in finding the right time to break the flow of the task to change the view technique, which may have led to inertia.

Task Structure. The structure of the task determined how participants used the techniques (rather than comfort or effectiveness). Participants were aware that the task was composed of two parts. They may have preferred to not interfere with the other person before the first part ended, anticipating that they would have to communicate and coordinate before starting the second part.

Overall our observations led us to reconsider and to extend previous findings. While Tang et al.'s work recommended providing "fluid transitions between coupling styles" [25] and Isenberg's et al. to "design for transient behavior" [14], we observed that transitions between techniques can be difficult to accomplish in practice. Social conventions may prevent users from choosing the most effective technique for a defined situation. It is therefore important that further work investigate the details of settings where switching occurs (e.g., in our case from loosely coupled to tightly coupled and vice-versa). In addition, although inertia has been observed in single-user settings, we are the first to look at it in collaborative settings where factors such as not wanting to interrupt the partner's task flow or politeness could increase the inertia.

Social Conventions May Override Space Constraints

Our first study showed that global zoom out-performed lens when participants worked on the same region of the map. Consistent with the observations of Tang et al. [25], most groups preferred the global zoom when the task required tightly-coupled coordination. However, we observed that in practice users chose to take turns for tightly-coupled tasks even when they had enough space to work simultaneously when using the zoom. This is a surprising result. Users had been working in parallel up to this point in the task and had ample room to work together without colliding.

Reluctance to Interfere. With our system, one participant could inadvertently pan the map and move the area where the other user person was working. In practice users were very cautious when touching the map and showed fear of panning the map while the other person was working. As one participant stated: *If you touch the map while the other is doing his thing, it moves!*" (Group1). Similarly, a participants Group 3 was explaining that they "*had to create a seniority of who was allowed and who was in control of the board, because at some points I would go touch something and it would screw him up*".

Touch Avoidance. Participants may have also opted for the strategy that would minimize physical contact. Previous research highlights peoples' tendency to avoid physical contact around a shared space [7]. In our study, turn-taking clearly minimized the risk of contact even at the cost of efficiency. For instance, one participant clearly stated that he would have preferred splitting the space rather than having to work simultaneously on the same map: *"When there are two people playing with it, we can zoom and I can do my waypoints so we can do both but I imagine that in a real scenario if there is two people touching* […] *I think we could crop one part of the map* […] *but not the rest of the map* […] *and something to lock it so it can't get zoomed in with a little icon on the side, because we tried to move our stuff and our fingers got close."* (Group 2)

Overall, these findings suggest that social conventions about turn-taking when working on the same artifact may override mechanical constraints such as available space. This has not been reported before in the tabletop literature. It strongly underlines the limitations of tabletops for working simultaneously around a shared artifact. This also emphasizes the need to make observations in realistic situations. Indeed, this result is quite counter-intuitive – the strategies that groups use in controlled studies may not carry over to realistic tasks.

Inactive Users Rely on Contextual Views

Our first study showed that while the radar view did not increase performance, it improved mutual awareness when parts of the map were not visible. We observed in our second study that users rely on the radar view when they are not interacting with the table during the second part of the scenario (i.e. the most tightly coupled part of the task). We wondered why users preferred to look at the vertical screen rather than the horizontal table when they are not interacting. Several reasons may explain this behavior:

Stable perception frame. When users are not interacting with the map, they may not understand which part of the map is currently visible on the table. Looking at the radar view provides a stable frame where the entire context can be seen. User comments suggest that this was useful to assess overall progress on the mission: "*I found [the radar] useful especially for the last part, I had an idea approximately where he was but just by looking at the map I don't know if it would have been possible… overall it is not very useful to add [the radar] but it gives an overall of the map*" (Group 1).

Comfort. Two participants reported ergonomic and orientation issues: "*The table should be higher or angled… there is clearly one side that's better*". One participant complained about pain in his neck at the end of the study, indicating the importance of making the height of the table comfortable for extended touch interaction. In fact, vertical surfaces are known to be more comfortable [18] than horizontal surfaces. This may explain users' preference for the radar view while waiting for the other planner.

These findings provided insight about the role of external overviews for mixed-focus collaborative tasks. We showed in study 1 that while the presence of overview displays does not significantly impact users' performance, it can improve awareness. Our second study emphasized the importance of an external overview to maintain awareness in a comfortable manner.

CONCLUSION

In this paper, we studied the combination of multiple view techniques to support collaborative map-based tasks on digital tabletops. We performed two studies to evaluate the performance and use of these techniques. Our results revealed that 1) view techniques do affect performance and awareness, 2) users do not necessarily pick the right technique, 3) social conventions may override space constraints, and 4) inactive users rely on contextual views.

These results show that there are several subtleties in the ways that view and collaboration interact. These subtleties have not been observed in previous work and can lead to new insights in the design of tabletop applications. Our observations in a realistic context provide new information about designing tabletop interfaces for collaborative activities.

Of course, future work is required to further investigate transitions in mixed-focus tabletop work, particularly in complex and realistic task settings and including complementary support to a digital tabletop for sharing space such as individual windows, personal devices (e.g. computers, tablets), and high resolution displays.

REFERENCES

1. Apperley, M.D., Tzavaras, I. and Spence, R. 1982. A bifocal display technique for data presentation. *EUROGRAPHICS'82*, 27–43.
2. Appert, C., Chapuis, O. and Pietriga, E. 2010. High-precision magnification lenses. *CHI '10*, 273–282.
3. Bortolaso, C., Oskamp, M., Graham, T.C.N. and Brown, D. 2013. OrMiS: A Tabletop Interface for Simulation-Based Training. *ITS '13*, 145–154.
4. Burns, C., Seyed, T., Bradley, K., Duncan, R., Balasch, A., Maurer, F. and Sousa, M.C. 2012. Multi-Surface Visualization of Fused Hydrocarbon Microseep and Reservoir Data. *GeoConvention*, 2–5.
5. Carpendale, S., Ligh, J., Pattison, E. and Light, J. 2004. Achieving higher magnification in context. *UIST '04*, 71–80.
6. Cockburn, A., Karlson, A. and Bederson, B.B. 2008. A review of overview+detail, zooming, and focus+context interfaces. *ACM Computing Surveys*. 41, 1, 1–31.
7. Doucette, A., Gutwin, C., Mandryk, R.L., Nacenta, M. and Sharma, S. 2013. Sometimes when we touch: how arm embodiments change reaching and collaboration on digital tables. *CSCW '13*, 193-202.
8. Forlines, C. and Shen, C. 2005. DTLens: multi-user tabletop spatial data exploration. *UIST '05*, 119–122.
9. Gutwin, C. 2002. Improving focus targeting in interactive fisheye views. *CHI '02*, 267–274.
10. Gutwin, C. and Greenberg, S. 1998. Design for individuals, design for groups. *CSCW '98*, 207–216.
11. Gutwin, C., Greenberg, S. and Roseman, M. 1996. Workspace awareness support with radar views. *CHI '96*, 210–211.
12. Hornbæk, K., Bederson, B.B. and Plaisant, C. 2002. Navigation patterns and usability of zoomable user interfaces with and without an overview. *TOCHI* 9, 4, 362–389.
13. Ion, A., Chang, Y.-L.B., Haller, M., Hancock, M., Scott, S.D. and Chang, B. 2013. Canyon: Providing Location Awareness of Multiple Moving Objects in a Detail View on Large Displays. *CHI 2013*, 3149–3158.
14. Isenberg, P., Fisher, D., Morris, M.R., Inkpen, K. and Czerwinski, M. 2010. An exploratory study of co-located collaborative visual analytics around a tabletop display. *IEEE VAST*, 179–186.
15. Jakobsen, M.R. and Hornbæk, K. 2014. Up close and personal: Collaborative work on a high-resolution multitouch wall display. *TOCHI. 21*, 2, 1–34.
16. Javed, W., Ghani, S., Elmqvist, N. and Lafayette, W. 2012. Polyzoom. *CHI '12*, 287–296.
17. Kobayashi, K., Narita, A., Hirano, M., Kase, I., Tsuchida, S., Omi, T., Kakizaki, T. and Hosokawa, T. 2006. Collaborative simulation interface for planning disaster measures. *CHI EA '06*, 977–982.
18. Pedersen, E.W. and Hornbæk, K. 2012. An experimental comparison of touch interaction on vertical and horizontal surfaces. *NordiCHI '12*, 370-379.
19. Pietriga, E. and Appert, C. 2008. Sigma lenses: focus-context transitions combining space, time and translucence. *CHI '08*, 1343–1352.
20. Pindat, C., Pietriga, E., Chapuis, O. and Puech, C. 2012. JellyLens. *UIST '12*, 261–270.
21. Schmidt, D., Chong, M.K. and Gellersen, H. 2010. IdLenses: dynamic personal areas on shared surfaces. *ITS '10*, 131–134.
22. Scott, S.D., Allavena, A., Cerar, K., Franck, G., Hazen, M., Shuter and T., Colliver, C. 2010. Investigating Tabletop Interfaces to Support Collaborative Decision-Making in Maritime Operations. *ICCRTS 2010*.
23. Selim, E. and Maurer, F. 2010. EGrid: supporting the control room operation of a utility company with multi-touch tables. *ITS '10*, 289-290.
24. Strauss, A. and Corbin, J.M. 1998. *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*. SAGE.
25. Tang, A., Tory, M., Po, B., Neumann, P. and Carpendale, S. 2006. Collaborative coupling over tabletop displays. *CHI '06*, 1181–1190.
26. Wallace, J.R., Scott, S.D. and MacGregor, C.G. 2013. Collaborative sensemaking on a digital tabletop and personal tablets. *CHI '13*, 3345.
27. Van Wijk, J.J. and Nuij, W.A.A. 2003. Smooth and efficient zooming and panning. *INFOVIS'03*, 15–22.