Group Coordination and Negotiation through Spatial Proximity Regions around Mobile Devices on Augmented Tabletops

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Abstract

Negotiation and coordination of activities involving a number of people can be a difficult and time-consuming process, even when all participants are collocated. We propose the use of spatial proximity regions around mobile devices on a table to significantly reduce the effort of proposing and exploring content within a group of collocated people. In order to determine the location of devices on ordinary tables, we developed a tracking mechanism for a camera-projector system that uses dynamic visual markers displayed on the screen of a device. We evaluated our spatial proximity region based approach using a photo-sharing application for people sat around a table. The tabletop provides a frame of reference in which the spatial arrangement of devices signals the coordination state to the users. The results from the study indicate that the proposed approach facilitates coordination in several ways, for example, by allowing for simultaneous user activity and by reducing the effort required to achieve a common goal. Our approach reduced the task completion time by 43% and was rated as superior in comparison to other established techniques.

1 Introduction

Mobile devices such as mobile phones, PDAs, laptops, or personal media players today have become ubiquitous both in business and leisure environments. It is hence only natural that many everyday activities now involve the use of these devices. In the context of this paper, we are particularly interested in group activities such as negotiations, games, or the exchange of data, which frequently occur while people sit around a table. For example, at the end of a meeting, participants may want to agree on a date for a follow-up meeting, which might involve group members exploring their personal calendar on their personal devices. Similarly, media such as ringtones or photographs might be casually shared in a group of partygoers by transmitting the files via Bluetooth from one mobile phone to the other. While it is possible to perform these activities with today's technology, the procedure users must follow can be quite difficult and cumbersome. They may face technical challenges (e. g. having to establish network connections) as well as problems resulting from limitations of the available technology (e. g. mapping device names to people or having to verbally synchronize with other group members).

In this paper, we present and evaluate a generic approach to support multi-party coordination through visuospatial interaction using mobile devices at augmented tables which has the potential to address some of these problems. In the following section, we will first discuss related work from a number of areas before introducing the basic concepts of our approach. We will then describe an example implementation, and present results from a user study in the context of a media-sharing application. The paper concludes with a brief summary and an outlook on future work.

2 Related Work

The approach we introduce in this paper combines ideas and results from several areas such as Artificial Intelligence, marker recognition, tabletop computing, computer-supported cooperative work (CSCW) and human-computer interaction (HCI). In the following, we discuss some relevant work from each of those areas.

Artificial Intelligence. Spatial reasoning is an active research area in artificial intelligence with strong links to computational theory and cognitive psychology. Spatial regions and their relationships have been investigated both on a theoretical level (e. g. [3]) and as means to detect and interpret human activities (e. g. [5]). Our approach relies on a simple region concept and containment relationships, rather than more complex relationships as discussed in [3, 5].

Marker recognition. Visual markers have been used in a number of different settings, which include augmented reality [2], location detection in smart environments [4], and tabletop interaction [10]. Ballagas et al. [1] provide a good overview how both marker-based and other vision-based approaches have been used in conjunction with camera-equipped mobile phones. The marker tracking mechanism we developed to implement our approach differs from previous work in two major ways. Firstly, we dynamically display markers on the screen of mobile devices in order to track their location on a table, rather than using static markers printed on paper. Secondly, our markers have been optimized for the use on mobile phones: they take up very little space at the bottom or top of the phone screen, and thus leave the majority of the display to the application itself.

Tabletop computing. Tabletop computing is an area in ubiquitous computing that has undergone rapid development in recent years. Early systems used custom hardware to detect user interaction [18] but more recently, marker-based mechanisms have become more popular [9]. A number of tabletop interfaces rely on physical artifacts for interaction (e. g., pens or tokens [9, 18]). Frequently, the user interfaces used to interact with tabletop systems incorporate region concepts to realize private and/or public workspaces [8, 18]. While our approach is not only applicable to a horizontal surface, the example implementation in our user study is realized as a tabletop system, which works with unmodified ordinary tables. Unlike most previous work, we use mobile phones for display and interaction, and our system can be used without an external display. The basic requirements are a camera monitoring the area of interaction, and a wireless link to the participating mobile phones.

BlueTable [19] is a vision-based system which enables the association of a mobile device with an interactive surface. A camera detects objects placed on the table as connected components of a certain size and shape. To check whether the connected component is a mobile device the system sends a request over Bluetooth to each device in range and waits for the device to blink its IRDA port. Wilson and Sarin [19] suggest that interactions with systems like BlueTable may positively impact collaborative interactions; a hypothesis which we investigate in this paper.

CSCW. Public displays (not just tabletop systems) can act as a hub for collaborative work (cf. [14] for an overview). A typical example of an activity involving coordination and negotiation among a group of (collocated) people is agreeing on a time for a meeting [15]. Tabletop systems in particular can serve as a hub for group activity. Scott et al. [17] propose a set of guidelines for such systems, e.g., dealing with orientation issues, supporting simultaneous interaction and providing shared access to physical and digital objects. In designing our example system, we tried to follow these guidelines except those referring to integration into a larger organizational context, which was beyond the scope of the prototypical implementation.

HCI. The benefits of fine-grained spatial interaction with handheld devices have been recognized in HCI for some time [6]. SyncTap [16] is a system that relies on proximity and simultaneous action to connect two devices. It makes use of proximity in two ways: implicitly (i.e., two devices must be within an arms reach of a user to allow for simultaneous interaction with both) and explicitly (e. g., using one device to knock on the other). The ReacTable [9] is an example of a tabletop system that uses proximity regions to trigger actions. It implements a musical instrument, and users control various aspects of the music by placing physical tokens on the table. If one token is placed near another one, they start to interact. Finally, Relate [7] is a system for the detection of spatial relationships between collocated mobile devices. It determines relative position and orientation via ultrasound sensing implemented on USB dongles. It has been used as a basis for a visuospatial interface toolkit [11]. In line with the aforementioned systems, our approach relies on spatial concepts for interaction as well. Our system also makes use of mobile devices but does not necessitate any hardware modifications. Unlike most of the cited systems, it can work without an external display; it does however require an external camera to track the devices.

3 Visuospatial Interaction

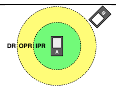
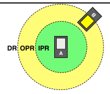
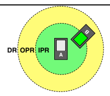
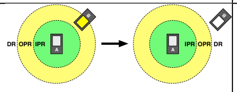
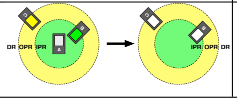
The basic idea underlying our approach is to use *spatial proximity regions* around mobile phones placed on an ordinary table to trigger particular actions in response to other devices entering these regions, leaving them, or staying within them for a certain amount of time. These actions (i.e., changes in the spatial configuration of mobile devices) can then be mapped to application-specific functions such as accepting a proposed date or transferring an image.

Although in theory any number, shape, and mapping of regions is possible, we initially explored a simple scenario consisting of three circular regions as shown in Figure 1. While it would have been possible to use just two regions (a proximal and a distal region) in combination with the device interface, preliminary studies showed that participants picked up the more expressive three-partite space quickly.

3.1 Terminology & Generic Semantics

We call the region furthest from a device its *distal region (DR)*. As long as devices are located in this region relative to another device, they operate independently. For example, in a meeting negotiation scenario, users could explore their own personal calendar while in the distal region. In the photo-sharing scenario described in Section 5, people

Table 1. Spatial actions involving devices A (offering, center) and B (exploring), associated generic semantics, and application specific mappings (for meeting negotiation and photo-sharing).

Spatial Action		Generic Semantics	Meeting Negotiation	Photo-Sharing
B in DR of A		no interaction, i. e. independent operation	browse personal calendar	browse local photos
B in OPR of A		explore item suggested by A in B's context	B's calendar shows time selected on A	B displays thumbnail of photo offered by A
B in IPR of A		accept item suggested by A	B accepts date/time selected on A	B downloads photo offered by A
moving B out of OPR		reject item suggested by A	B returns to browse personal calendar	B returns to browse local photos
removing A completely		cancel interaction, e. g. A stops offering item	B returns to browse personal calendar	B returns to browse local photos

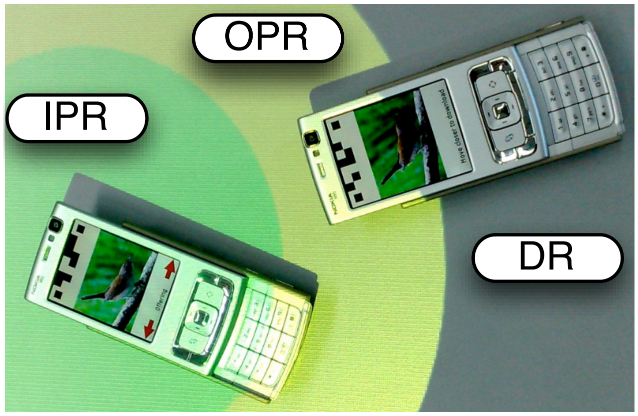


Figure 1. Proximity regions around a phone: inner proximity region (IPR), outer proximity region (OPR), and distal region (DR).

can browse photos that they have stored on their mobile device while in the DR.

The interaction between two devices is initiated once a device B enters the second region around another device A, which we call its *outer proximal region (OPR)* (see Figure 1). On an abstract level, we link the physical proximity of two devices to conceptual proximity: we associate it with the generic action of exploring the item that is currently selected on device A. On device B, this exploration takes place within its local context. For example, in meeting negotiation, we assume that the owner of the mobile phone A has selected a particular date and time and is proposing it to the group as a potential meeting time. Once a device B enters the OPR of device A, the calendar application on device B automatically jumps to the date and time that is selected on device A. The owner of device B can immediately see whether the meeting time suggested by A is still available in their own calendar. In the context of the photo-sharing application, moving device B into the OPR of A results in a preview of the selected photo device B.

Once device B enters into the region nearest to device A—its *inner proximal region (IPR)*—the interaction is taken one step further. On an abstract level we interpret this spatial action as B accepting the item suggested by A. In the context of the meeting negotiation application, B confirms the date suggested by A. In the photo-sharing scenario, moving a device into the IPR of another device initiates the download of the image selected on the latter.

By moving device B out of the OPR of A and into its DR, a user can reject the item suggested by device A. If this action is performed in the context of the meeting negotiation application, the calendar on device B reverts back to the state it was in before entering the OPR of A. Analogously, in the photo-sharing scenario this spatial action results in device B returning to browsing the local photo collection.

If a device A is taken out of its own IPR while offering an item, the item it was suggesting is retracted and all interactions with other devices are canceled. See Table 1 for a summary of all actions and their semantics.

3.2 Multi-Party Interaction

So far, we have focused on describing interactions involving two devices. A key benefit of using proximity regions to facilitate interaction and coordination is the ease of integrating multiple participants at the same time. Simultaneous multi-party interaction can take two basic forms.

The first realizes the regions and actions defined in Section 3.1 but allows for multiple devices to independently interact with the proposing device at the same time. For example, in the photo-sharing scenario, one person can offer a particular photo (by putting their device down on the table). All other members of the group can simultaneously explore or download the offered image by moving their device into the corresponding proximity region around the offering device. There are no interactions between non-proposing devices; they only interact with the device offering the photo. This approach is arguably well suited for the photo-sharing scenario, as multiple people can simultaneously explore a photo and decide whether they would like to download. This approach also solves the orientation problem [12]. When multiple persons sit around a table there are multiple perspectives onto the displayed item. If the item is replicated on each device display, then users can choose the orientation that is best for their own view. Current methods sequentialize this process, i.e., group members have to inspect and download an image one after the other by establishing individual connections to the offering device.

The second mode of interaction requires all devices to be in a particular spatial configuration with respect to the offering device. This approach is well suited for negotiating a meeting time as agreement is needed from all participants. Using this mode, once device B enters the IPR of device A, it confirms the suggested meeting time but only if there are no other devices involved in the negotiation. (User B can abort the confirmation by moving device B out of the IPR of A.) If there are more than two parties involved, all devices need to be in the IPR of A in order to confirm the suggested date and time.

3.3 Frames of Reference

Regions can be defined with respect to different frames of reference. So far, we have discussed frames defined by the position of a mobile device, i.e., by relative proximity to this device. This approach is well suited for small groups and small tables but can be inconvenient for larger groups or tables due to devices potentially having to be moved further than physically comfortable. Alternatively, we can define regions with respect to the physical position of the people involved. This frame of reference helps to increase scalability to larger tables and groups as users do not have to move devices over a long distance towards the offering device.

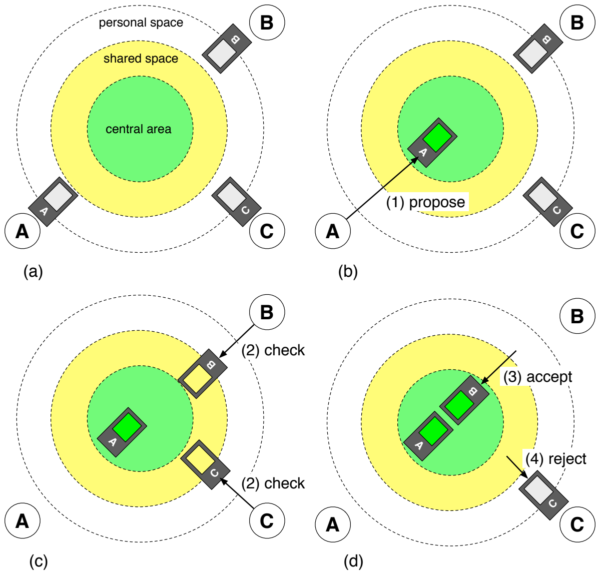


Figure 2. Alternative frame of reference: users A, B, C at a table. (a) independent use, (b) A proposes an item, (c) B and C explore proposed item on their devices, (d) B accepts proposed item, C rejects it.

Figure 2 illustrates this approach. The area closest to a user is defined as a personal space, in which devices operate independently. In our example applications, placing a device in this region enables users to browse their own calendar or photo collection. By moving a phone into the central offering region, a user can offer an item. Other participants can explore the suggested item by moving their devices into the exploration region, accept it by moving them into the central area, or reject it by moving their device back into the personal space. The actual shape of the regions may vary according to the geometry of the table. While the three regions defined in this way functionally correspond to the distal and inner/outer proximal regions, it is important to note that unlike the latter they remain static. The proximity regions discussed previously are relative to a device, and thus extend around its location on the table.

4 Implementation

In order to implement the presented visuospatial interactions, a camera connected to a PC tracks the phones on the table surface. Visual markers displayed on the phone screens (see Figure 1) help to identify the phones and to determine their positions and orientations. In our test applications, most of the application logic is implemented on the PC and only application-specific state changes are communicated to the phones.

The phone marker is designed in such a way that it occupies only a small amount of screen space. For a typical screen aspect ratio of 3:4 (as for the Nokia N95 used in the tests) the marker occupies only 15% of the screen area. The marker is bar-shaped and placed at the top of the screen. This decreases the probability that users inadvertently cover the marker with their hand. This design also ensures that marker recognition is resilient to perspective distortion when holding the phone in the hand. The layout of the marker is visible in Figure 1. It is delimited by two corner stones. The center is made up of a 7×2 element array containing a 12 bit data area and two direction indicators on the upper left (black) and lower right (white). Error detection is implemented with a simple linear code. The 12 bit code is decoded to an 8 bit value.

The recognition algorithm proceeds as follows: First, the corner stones are located by convolving the image with a 7×7 Gaussian kernel whose shape matches the shape of the corner stones and their surrounding whitespace. The kernel is separable in x- and y-components which allows for efficient convolution. The convolved image will have peaks at the locations of the corner stones. This approach is very robust against changes in brightness and is able to detect the corner stones on the device display even at low contrast. Based on geometrical constraints, pairs of matching corner stones are identified. In order to sample the data points of a potentially tilted marker, a homography is computed based on four points near the corner stones. For each detected marker the recognition algorithm provides the encoded value, the center position, rotation, and distance. In this way, the application can detect the device orientation and whether the device is lifted from the table.

In the study setup, we used a *Point Grey DragonFly2* with a Tamron lens with a focal length of 8 mm, facing downward onto a round table with a diameter of 79 cm and a height of 69 cm. The center of the lens was mounted at a height of 153 cm above the table surface. The camera view covered the whole table. The camera was operated at a resolution of 1024×768 pixels at 30 fps. The recognition system is implemented in Java. We wrote a Java Native Interface (JNI) wrapper for the *Point Grey FlyCapture* libraries to access the camera functionality in Java. The update rate of the tracker was about 10 Hz. Moreover, a projector for providing feedback about the spatial regions was mounted at 140 cm above the table surface.

All phones ran an identical JavaME application and were individually initialized by the PC on startup. In the Bluetooth condition the phones simulate the sequence of actions necessary to exchange images via Bluetooth, i.e., selecting a device from a list, waiting until the receiving side has accepted the connection, and waiting for the download. In our simplified procedure the list of devices only contained the four other devices and no discovery was necessary.

5 User Study

Sharing photos is an example of an activity, which requires coordination amongst collocated people. For certain groups it is common practice to share media files (e. g. ringtones, music, or photos) via Bluetooth. In the following, we present a study that investigates users' reaction to our visuospatial interaction approach in the context of this scenario.

5.1 Design

We designed the study to gather feedback from users with respect to usefulness, effectiveness, ease of learning, and satisfaction [13]. We also wanted to compare our approach to current practice. In a within-subject design, we had participants share photographs using three different techniques: via Bluetooth, using proximity regions alone and using proximity regions that were projected onto the table. We hypothesized that subjects would prefer proximity regions over the Bluetooth condition, and that they would prefer projected regions over invisible regions. We also assumed that they would be faster and would make fewer errors using our approach. We designed tasks and stimuli so that some images had to be shared with more than one person. One advantage of our approach is that multiple people can explore or obtain a shared photograph simultaneously, and we wanted to investigate whether this was of value to the participants.

5.2 Method

Subjects. We recruited 30 participants (aged 20 to 45; 16 male). All of them owned a mobile phone. No user owned the same model as we used in the study, 11 had a phone of the same brand. 19 had shared an image on their phone with someone else before and the majority of those did so once a month or less often, using either Bluetooth or MMS. All of the participants had used a computer before, rating themselves as “intermediate” or better. The subjects were split into six groups of five. We paid every participant a small amount of money to compensate them for their time.

Procedure. Every group of five subjects went through a number of steps. At the beginning of the experiment the investigator explained the goal of the study and handed out a brief questionnaire that was aimed at collecting demographic information. Then, the participants went through three rounds of sharing photos within the group, using a different photo-sharing technique for each round. We systematically varied the order in which the six groups were exposed to the three different techniques to counterbalance learning effects. We recorded all rounds on video. Each round followed the same procedure. The investigator first demonstrated the technique used in that round. Participants were then given a mobile phone each, and asked to get one photo from another member of the group and to share one of their own photos with one other participant. After completing this learning phase, the investigator handed out individual task cards to every participant and verbally instructed them to not tell the other members about their own task. A round ended once all subjects declared that they finished their assigned tasks. After three rounds, participants were given a final questionnaire and were finally asked for verbal comments.

Tasks and Stimuli. During every round, each participant had two tasks: (1) to share all eight photos originally stored on their phone with every other group member who wanted them, (2) to obtain all photos from other participants that met a given criterion. We used four sets of 40 photographs. Every phone was pre-loaded with eight photos at the beginning of the sharing phase; the pre-loaded photos on each phone were mutually different. One set was used for the learning phase and contained random photographs. The other three sets were structured so that on each phone there were three photos which met one criterion, four that met two, three that met three, and four that met none of the criteria. For every user, this distribution meant that they had to share their own eight photos, and that they had to obtain fourteen photos from other members of the group in total. Photo sets were rotated according to a Latin square design between groups and conditions to counterbalance any effects that might be caused by a particular set of images.

The objects the participants had to look for were one of the following: trees, cars, persons, dogs, clouds, birds, water, flowers, bikes, signs, fires, houses, roads, mountains, or snow. All images were scaled down to fit the device screen and three photographs were edited using an image processor to make them meet the set out criteria.

5.3 Results

In the following we summarize our observations, describe the main trends that we found from analyzing the video of the experiment, and report on the findings obtained from the questionnaires and the log data.

5.3.1 Quantitative results

The results in terms of task completion times are depicted in Figure 3. The error bars show 95% confidence intervals. The Bluetooth condition (BT) took on average 841 sec (14’01”), the regions only condition (RO) 566 sec (9’26”), and the projected regions condition (PR) 481 sec (8’01”). The BT results for two groups are omitted, as these groups prematurely exited this condition because of a failure in the phone application. A one-way repeated measures ANOVA reveals that there is a significant effect of the interaction method onto the completion times ($F_{2,8}$ = 26.87, p < 0.01). A Tukey HSD multiple comparison test shows that the completion time for BT is significantly different from the completion time for RO and PR, but the times for RO and PR are not significantly different from each other.

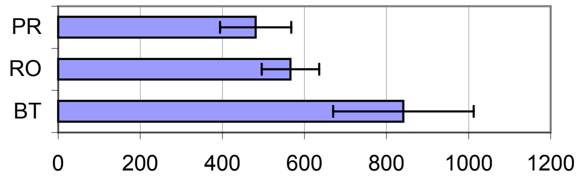


Figure 3. Mean completion times (seconds).

The overall error rate was very low. We split error rate in the number of images that a participant missed to download and the number of images that were falsely downloaded. The number of false downloads is lowest for BT (0.7), followed by PR (1.3), and highest for RO (2.8). A one-way repeated measures ANOVA shows that there is a significant effect of the interaction method on the number of errors ($F_{2,7}$ = 10.53, p < 0.01). A multiple comparison shows that the error rate for RO is significantly different from the other two conditions, which are not significantly different from each other. This outcome is plausible in that accidental downloads are easily triggered in the RO condition, in which there is now visual feedback about the boundaries of the regions. In contrast, triggering a download in the BT condition is a much more conscious and laborious process. The number of missing images at the end of the task was highest for BT (1.4), followed by RO (1.0), and lowest for PR (0.9). However, these differences are not statistically significant ($F_{2,7}$ = 0.62, p = 0.56).

In a questionnaire administered after the test (based on the *USE Questionnaire*[1], which uses a 7-point Likert scale), we asked users to rate the three different methods for photo exchange. We categorized the 12 questions into usefulness, satisfaction, learnability, and ease of use (Figure 4). PR was consistently rated best, RO was rated better than BT for usefulness and satisfaction, and BT was rated better than RO for learnability and ease of use. The latter may result from users a priori being more familiar with Bluetooth. We also asked users to rank the methods for each of these questions. Here, PR was consistently ranked best, whereas there was no clear difference between BT and RO.

5.3.2 Qualitative results

As part of the above questionnaire we also asked users to give free form positive, negative, and additional comments on each of the interaction methods. We categorized the comments and report here only the most frequent ones.

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[1] http://usesurvey.com

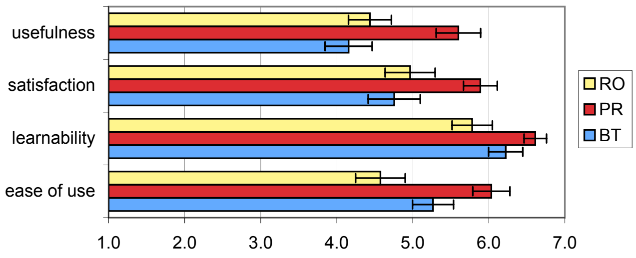

Figure 4. Ratings of the techniques (Likert).

Bluetooth. The most common positive comment about Bluetooth is its precise control over sending and receiving images to/from exactly the intended person. Bluetooth transmission was perceived as more secure and as resulting in less unwanted transmissions. As a standard method the subjects found it easy to learn and remember. It was also seen as positive that Bluetooth allowed to "work at a distance," i.e., at a leaned back position. On the negative side it was commented that an image can only be sent to one person at a time, that one has to wait until the receiver is ready, that multiple steps and button presses are required, that confirmation is required for each image, and that one has to remember which device belongs to whom. There were also negative comments about the absence of a preview and the need to show around the photo on one's own device or to hand around the device.

Regions only. RO received positive comments for the easy download of images, the preview on one's own device, the possibility of multiple concurrent downloads, the lower number of button presses, the intuitive and uncomplicated use, and increased fun. On the negative side users commented on unwanted downloads, lack of clarity about the current offering device, and unclear region boundaries. The lack of visual feedback on region boundaries made it difficult to know how close to go to start a download and to find the right place on the table. Another negative comment was that there was no control over who receives an image and that there was no way to cancel a download once started. The general feeling was that spatial regions without projection are less effective and secure than with projection.

Projected regions. The positive comments for PR were similar to the ones for RO. Seeing a preview of a photo on one's own device before downloading was perceived as fun and more controllable. Simultaneous transmission to multiple persons rather than waiting in turn to get a download was judged as positive as well. The visual definition of the preview and download areas and the quick orientation due to visual feedback were rated as very positive. On the negative side, users commented that unwanted downloads can happen, that there was sometimes confusion on who goes into offering mode next, that there is no control by the offering user over who receives the photo, and that there is no way to cancel a download. Two users commented that the projection negatively affects screen visibility.

5.3.3 Observations

The most striking observation was that the spatial region conditions led to a complete change in group dynamics compared to the Bluetooth condition. The latter inhibited the social process in that participants exhibited "heads down" focus on individual devices, whereas the spatial conditions naturally supported a more open and cooperative style of group work. On the other hand, some groups showed visual sharing behavior in the Bluetooth condition that could be naturally supported by the spatial system.

Behavior changed in two ways from the regions only to the projected regions condition. Participants used the OPR for preview more often and showed a two-phase download sequence (move into OPR, watch preview, move into IPR if preview matches criterion), possibly due to an increased confidence in the region locations. Moreover, they showed more flexibility in handling the phones. Some users did not place their phone on the table but rather hovered over, or tossed it into, the intended region.

Bluetooth. The main observation from the Bluetooth condition is the individually orientated nature of the group dynamic. Two groups dissected themselves into two distinct sub groups for the first half of the task. Users often had to twist their head and choose an awkward pose in order to view images on other phones. Occasionally the wrong target device was selected from the list.

Regions only. In the regions only condition participants worked together in a tightly coupled group towards a common goal of sharing their photos. There was a strong turn taking protocol evident, not only in the technical sharing of photos but also in the social offering protocol—e.g., people do not offer each other photos outside of the regions when the IPR is in use, they wait for it to become free and offer their photo to the whole group.

Projected regions. There do not seem to be any strong differences or trends in behavior between the projected and non projected regions conditions. Potential trends which can be highlighted are the increased use of the previewing function where regions are projected.

6 Conclusion

The goal of this work was to investigate how spatial regions around mobile devices located on a tabletop can help in group interaction tasks. We presented a generic mechanism that enables cooperative interaction within a collocated group using personal devices and spatial regions. We described an initial implementation of the approach using a tracking mechanism based on dynamic visual markers, which are optimized for mobile device screens. The implementation does not require a special table, but only a ceiling-mounted camera and projector. Moreover, we presented a user study, based around a simple media sharing task, which demonstrated the benefits of spatial regions with respect to group coordination and social processes. In comparison to a traditional technique the spatial regions approach was rated better and reduced the task completion time by 43% with visible projected regions and by 33% without. The observations and feedback from users gave valuable feedback on particular issues, such as control over who gets one's photos, how to stop accidental downloads, the required size of the preview and download regions, and the need for fluid change between offering phones.

Due to the overall positive results we plan to continue developing the presented approach. First of all, we intend to look into more complex spatio-temporal regions and relations. Secondly, we intend to enable spatial actions that are based on sensors integrated into the device and thus allowing for a wider range of movement gestures. In addition, an interesting alternative to a fixed infrastructure which we plan to explore is to use the cameras of the participants' devices to enable ad-hoc interaction.

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