

A Display Table for Strategic Collaboration Preserving Private and Public Information

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Abstract. We propose a new display table that allows multiple users to interact with both private and public information on a shared display in a face-to-face co-located setting. With this table users can create, manage and share information intuitively, strategically and cooperatively by naturally moving around the display. Users can interactively control private and public information space seamlessly according to their spatial location and motion. It enables users to dynamically choose negotiation partners, create cooperative relationships and strategically control the information they share and conceal. We see the proposed system as especially suited for strategic cooperative tasks in which participants collaborate while attempting to increase individual benefits, such as various trading floor-like and auction scenarios.

1 Introduction

Personal equipments such as PDAs and cellular phones are widely spread in our daily lives. Although this trend provides us efficiency in our business situation, a harmful influence is also recently pointed out; there is increasing number of people in younger generation who lacks social sense. One of the solutions for this problem is to facilitate face-to-face co-located environment for collaboration or negotiation with others which requires multimodal interactions with a variety information channels.

When working in groups, we often conduct face-to-face meetings to accelerate the exchange of ideas or opinions, or to complete a cooperative task. Collaboration, a natural and efficient approach to problem solving, has been one of the most challenging topics in HCI studies. Many studies and systems have been presented to facilitate face-to-face collaboration during group meetings or discussions [e.g. 1-6]. Collaborative table displays are designed to enhance functions of ordinary meeting tables to support small-group collaborative activities and have lately considerable attention [7].

One of the most important research topics of collaborative table displays is to develop techniques to support transitions between personal and group work. For example, many systems typically use multiple displays to share information among participants in a meeting, and use one or several large wall displays to show public information. However, a special framework is often required to allow multiple users to deal with private information in addition to the public one [8-11]. Many of the current

solutions to sharing public and private information between multiple users still suffer from ambiguities.

In this paper, we propose a collaborative, public and private, interactive display. It seamlessly presents the private and the public information and allows users to change the public information space and the private information space dynamically according to their spatial location and motion. With this system users can dynamically select collaborative partners and strategically control the information they share or hide during negotiation or cooperation. Our preliminary observations suggest great promise to the proposed system in tasks that require collaboration side-by-side with maintaining personal gain. We believe the proposed system can be useful in several trading floor, market-like, and auction scenarios where people need to meet and collaborate in order to exchange goods or information in an ad-hoc manner.

2 Private and Public Information

When we collaborate or negotiate with others while sharing information, we often have to be careful about which parts of the information can and cannot be shared [12]. These pieces of information can be classified into different categories [13]. The roughest classification is to divide it into private (that is not sharable) and public (that is sharable) information, a classification that can sometimes be static and sometimes dynamic. This section overviews display systems that support classification of information into public and private categories.

2.1 Related work

Let us assume that a piece of information has an attribute that can be either private or public. When two or more people are handling information items, some of these can be private and others public. One of the most common configurations is to present private information and public information on separate displays. For example, several systems use one or several large wall displays to show public information with small displays, PDAs, or notebook PCs to show private information [8-10]. In these cases, if people want to share personal information with others electronically, they have to explicitly place these pieces of information on a display surface that can be seen by others. When one has multiple information items that can be shared with other people, putting these pieces on the shared display surface becomes cumbersome and difficult to manage. Moreover, if the physical locations of public display and the private information are separated, people tend to concentrate mostly on their personal displays rather than attending to a number of other, less handy surrounding displays. In order to avoid this forced and potentially damaging display separation we need a more intuitive way that will seamlessly handle two different types of information displayed in the same spatial locality.

One possible solution for sharing information in multiple user environments is to directly make individual private display available to another particular user with whom we wish to share information. An example is to connect personal displays together on an ad-hoc basis [11]. Although this method is simple and intuitive, all information shown on the display is shared, and it is difficult to share and hide only a part of the information on the display. One may consider temporally hiding information that is not to be shared; however, a system or mechanism that handles both pri-

vate and public information equally and displays both of them simultaneously is required for the owner of that information.

Another solution is to use a technique for stereoscopic display, which provides two different peoples with a pair of images that are ordinarily provided to the left and right eye as stereoscopic images. For example, liquid crystal device shuttered glasses (LCD glasses) are used to separate private and public information displayed on a single display [14]. However, the number of users is limited to two because of the reason originating in its principle. In addition, the private information would be exposed to a non-participant who just happens to pass by the collaborative site without glasses, a fact that substantially limits the type of private data that can be displayed on the screen.

Another possible solution for such a system is to employ an automatic software filter that copies shared pieces of information on a public display [15, 16]. In these cases, information sharing forces a user of the system to be constantly alert to whether the information displayed on the user's personal display is also being displayed on the public display. The user should also remain watchful over other users accessing copies of the private information or trying to modify or copy it. This can be an important issue as such undesirable conducts may not be explicitly highlighted on the legitimate user's personal display. In such situations, users should maintain careful observation of the information being displayed on the public display area and carefully monitor other users' interest in their private information. We assume that these special attention requirements will make copying of pieces of information onto a public display much less desirable.

2.2 Collocation using Private and Public Information

Based on the considerations outlined in the previous subsection, in this subsection we discuss a display system that allows multiple users to deal with both private information and public information seamlessly in a face-to-face environment.

If shared pieces of information were still to be displayed in proximity to the user's personal display, the user would feel that these pieces of information are owned by her and are under her control. The others, who are interested in the user's public information, would physically look into the user's own personal display. This explicit motion of other users would increase the user's awareness of the environment and the collaboration state, that is, "if she stands next to me, she can see my private information". Moreover, a user is able to know whether someone is interested in the information he or she has. These considerations lead us thinking of using a part of the user's personal display as a shared display that is visible to the other participants.

Even in this configuration, when individual shared displays are located apart from each other, a user has to visit the participants' personal displays one-by-one to seek any public information being displayed. A user has to continually visit other user displays to look for updated information when public information changes dynamically. If multiple personal displays could be integrated into a single display, the display would turn into a single working surface on which users could focus their attention at one place and time. The single display surface becomes the only reference space where users act upon or view information.

The advantage of using a single shared display for displaying both private and public information is that a relatively small number of people can work more inti-

mately, with more productive and effective interaction. In particular, by using a tabletop-type display configuration, the display surface can also be used as a table to hold documents, stationery or coffee cups. However, how could we display private information on a tabletop-type of display without it being seen by other people? The following section describes the implementation of our display system.

3 Method

3.1 Principle

The display system consists of a normal display and a display mask, which has a hole in its center (Fig. 1(a)). The display mask is placed over the display surface at a suitable distance. Each user observes the display system through the hole. By controlling the position of the information display area for each user according to his/her viewpoint (measured by a suitable tracker), each user can always see his/her own individual area of the display. Figure 1(b) shows an example in which three users simultaneously observe information on different display areas. The information display area P in Fig. 1(b), which is derived from user P's viewpoint, is an area for showing the information for user P alone. The other users (Q and R), standing at their positions in this figure, are unable to see the P's individual information display area because the display mask adequately occludes this area. Therefore, this area can be used to show the private information of P.

On the other hand, the Q and R's information display areas overlap; therefore this overlapping area can be used to show the public information shared by Q and R. The areas other than the overlapping area are areas where only one of them can observe information; as a result, these areas can be used to show the private information of Q or of R.

If a user moves his/her head, the information display area corresponding to the user also moves according to the motion of the viewpoint. This feature enables users to dynamically determine—by simply moving around the display—which display areas are used for private information and which display areas are used for public information that might be shared with a particular user.

The configuration of the display and the mask is along the same lines as the IllusionHole, a stereoscopic display system for multiple users [17], although stereoscopic images are not shown in this configuration. In IllusionHole the overlapping of image drawing areas among adjacent users was a weakness, which the design tried to avoid. In our current display system this weakness is turned into a key design feature.

3.2 Position and Size of Information Display Area

The position of the information display area for each user is derived from two pa-

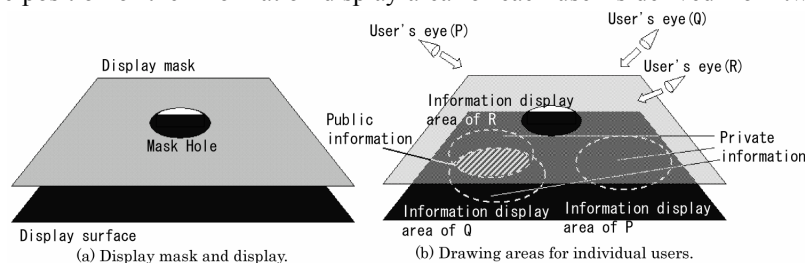


Figure 1: Configuration of the display system.

rameters: the user's viewpoint in the display coordinate system $(x_{eye}, y_{eye}, z_{eye})$, and the distance between the display surface and the mask D . By using the display coordinate system where the center of the display surface is the origin of the coordinate, the center of the image drawing area is given by $(-x_{eye}D/(z_{eye}-D), -y_{eye}D/(z_{eye}-D), 0)$. The radius of the information display area r is determined by three parameters: the height of the user's viewpoint z_{eye} , the distance between the display surface and the mask D , and the hole radius of the mask R , as $r = R z_{eye} / (z_{eye} - D)$. These values dynamically determine the information display area for each user, which expands/shrinks as the user approaches/retreats to/from the mask hole.

If a larger hole is used, a user is expected to observe a larger area on the display. The area increases with the distance between the display surface and the mask D and the radius of the mask hole R . On the other hand, the number of users decreases according to the radius of the mask hole R or as the distance between the display surface and the mask D increases.

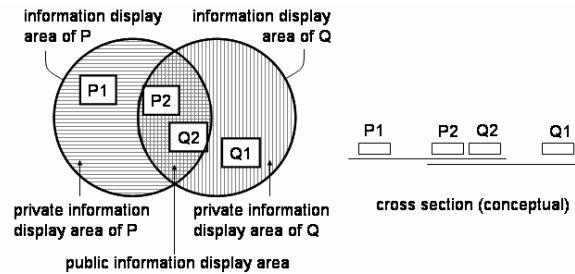
4 Displaying Information

In this section we detail the method of showing and handling information on our proposed display system. As representations of the virtual information items we use graphical icons and similar virtual objects to assist in the explanation.

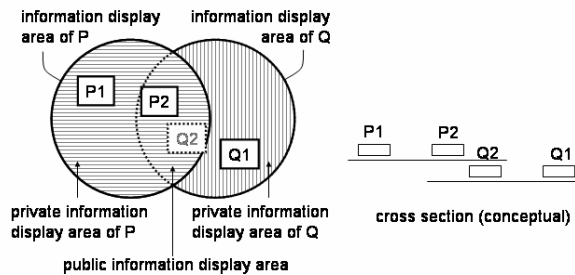
4.1 Priority Levels of Users

The display system provides several methods for presenting the information in overlapping areas, according to the priority levels of corresponding users. When two users with equal priority levels have an overlapping area, the objects owned by these two users are shown as equals in the public information display (Fig. 2(a)). In this case, user P can see object Q2 owned by user Q in the public information display area, and user Q can see object P2 owned by user P in the same area.

On the other hand, when two users who have different priority levels share an overlapping area, the objects will not be shown in the public information display area (Fig. 2(b)). In this example, user Q has a higher priority level than user P. Therefore, user Q can see object P2 owned by user P in the public information display area, but user P



(a) Example of two users with same priority level.



(b) Example of two users with different priority levels.

Figure 2: Examples of objects in the public information display area according to the users' priority levels.

cannot see object Q2 owned by user Q.

Here, the priority of users can be determined statically in advance or dynamically according to the users' conditions during the task. Examples of such conditions can be users' motion speed, direction, finger pointing or other behavioral patterns.

4.2 Permission Levels of Objects

Users possess and handle their own objects in their private information display area, in an association that can be considered as "ownership," allowing them to freely manipulate the objects. Here, "manipulate" means to execute, delete, copy, or edit the file identified by the object. For each object, the levels of permission can be classified as follows:

Level-1: no user other than the object's owner can either see or manipulate this object.

Level-2: the other users (non-owners) can see, but cannot manipulate this object.

Level-3: all users can both see and manipulate this object.

Here, the level-3 objects can be placed either in the private information display area or the public information display area, and every user can see and manipulate level-3 objects. The level-2 objects can also be placed either in the private information display area or public information display area. They can be seen but not manipulated by the users other than the owner if this object is placed in the public information display area. Finally, no other user besides the owner can see the level-1 objects, even if the objects are placed in the public information display area.

However, these level designations are not static and can be dynamically modified in correspondence to changes in the collaboration environment. Therefore, the visibilities of the level-1 objects have to be controlled in order for them not to be seen by any other user besides the owner (we describe these control mechanisms in the following section which describes our prototype). For example, if an adjacent user approaches the user closely enough, the public information display area expands as the approached user's private information display area shrinks. In this case, the visibility of objects displayed in the user's private display area has to be changed.

Let us examine the scenario presented in Fig. 3, describing interaction between users P and Q. In Fig. 3(a) two objects one classified into level-1 and the other into level-2, are shown in the information display area of user P. If user Q approaches closely enough toward user P as shown in Fig. 3(b), the public information display area expands as user P's private information display area shrinks. In this case, the level-2 objects can remain in their original positions; however, the visibilities of the level-1 objects must change. For this purpose, a possible method would be to use the priority levels of users shown in Fig. 2(b). Another possible solution would be to change the display positions of the level-1 objects and move them outside the bound-

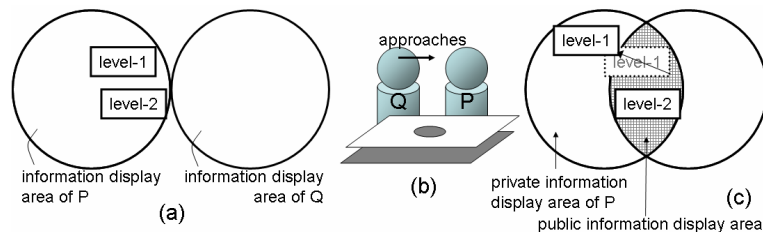


Figure 3: A visibility change.

ary of the expanding public information display area, as shown in Fig. 3(c). After user Q moves a sufficient distance from user P, the objects can be replaced to their previous visibility positions. This method is useful especially in an application where users' priority levels are not introduced.

5 Prototype

In order to examine our design approach we developed a fully operational prototype display system. The prototype display system enables participation and interaction of multiple users, who can all participate in collaborative tasks by manipulating displayed objects cooperatively or strategically.

5.1 Hardware

The proposed method is implemented by using a 68-inch conventional display system, i.e., BARON (Barco), to show the effectiveness of the method. The display system used in the trial system has a 1,360-mm-wide and 1,020-mm-deep display surface, and the height of the display surface from the floor is 1,000 mm. The display mask is placed over the display surface at a distance of 150 mm. The radius of the display mask hole is 200 mm. Each user's head position is tracked by an Intersense IS-600 Mark 2 SoniDisc, which is an acoustic 3D positional tracker. The system configuration is shown in Fig. 4. Here, a variety of interaction devices can be considered for manipulating objects. In this prototype, a game controller (SONY Dualshock2) is used for each user to manipulate objects.

5.2 Object Manipulation Interface

Following our proposed design principles, we implemented an object manipulation interface on the prototype system.

5.2.1 Object Sharing

Users can change the priority levels of their own objects at any time. In the prototype system, clicking an object with the controller changes its priority level. Users also can change whether the object should be in the private information display area or in the public information display area to be shared with other users. If a user moves (drags and drops) an object from the private information display area into the public information display area, this object can be instantly shared with other users. In this case, if the user moves a level-1 object from the private information area to the public information display area, it is assumed that the permission level of this object changes to level-2. The permission levels of objects are shown by color changes of their borders.

5.2.2 Copying and Moving Objects

Users can change the position of an object by simple drag-and-drop actions. If a user moves a level-3 object shown in the public information display area to her own private information display area, she will become the owner of the object. Users can exchange objects between their own pri-

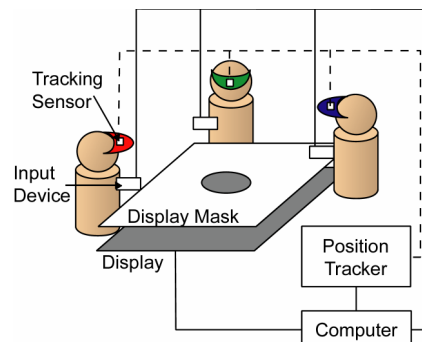


Figure 4: System configuration.

vate information display areas through the public information area. A user can also provide a copy of an object by dragging it from her private information display area to the public information display area, and then changing its priority level by clicking it.

5.3 Application Example

Figure 5 shows an example of applying the proposed system to a goods-barter task. Three users (named Red, Green, and Blue, from left to right) are exchanging miscellaneous goods (such as used watches, televisions, jeans, and so on) by using their private and public display areas effectively. In this example, each user has his own miscellaneous goods to be exchanged in his private display area, and move the appropriate ones to the area shared with a particular person who is interested in the exchange. The level of each displayed object is level-1 at the beginning, and it is automatically changed to level-2 when the object is moved to the public information display area. Each user can see the other participants' faces, and the negotiations progress through eye contact and hand/body gestures, which provides subtle communication cues. A user determines the best partner with whom to exchange information by changing his standing position and face-to-face communication using oral conversation. Figure 5 shows a the green user standing at the center, considering with which partner to exchange by comparing offered goods displayed on the overlapping areas with left user (Red) and right user (Blue). The top three images in Fig. 5 are user's views for Red, Green, and Blue (right, middle and left, respectively).

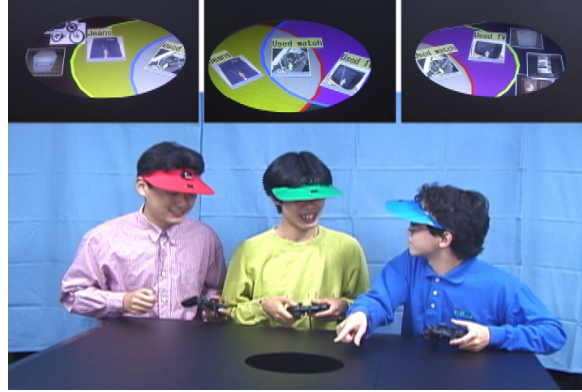


Figure 5: An example of application.

5.4 Analyzing User's Movements

We analyzed how the private information display area and public information display area are used by preliminary testing multiple users in a strategic cooperative task that requires handling of both private and public spaces. Three volunteers participated in a task which required assembly of a puzzle with nine pieces made from a picture divided into 3x3 areas. Three such puzzles, each having different pictures, are used in the task, so in total there are 27 pieces in the workspace, and each user owns nine of them at the beginning of the experiment. Users are asked to complete any one of the puzzles as soon as possible before the other users do, in their own private information areas, by exchanging the pieces among users through negotiation. The level of each piece is level-1 at the beginning. When an owner of a piece moves it to a shared information display area to show it to another user, he or she changes the permission to level-2 using the controller button. After the negotiation of exchange is concluded, he or she again changes the permission to level-3.

Behaviors and utterances of users during the experimental session were video recorded, and the head position of each user measured by a tracker was also recorded. Figure 6 shows a typical part of a transition (4 minutes of a 7 minute-22 second-session) of each user's position represented by the directional angles. The vertical axis of Fig. 6 represents the time transition (seconds). The time and positions where users exchanged the pieces of the puzzles are marked with circles. In this figure, ellipses mark the time and positions where users exchanged the pieces of the puzzles. Figure 7 shows snapshots taken during an experimental session: Figure 7(a) shows the display system shared by three users (named R, G, while B), and Fig. 7(b) shows the corresponding image display areas on the proposed system.

Preliminary observations revealed that some typical behaviors of users could be found throughout the session. For example, we found that, for the purpose of negotiation or exchange of pieces, a user actively approaches with his body to another particular user in order to share the information display area. The wedges marked a1 to a10 in Fig. 7 show the time and positions where these types of behaviors occurred.

Each user puts together pieces in order to complete the puzzle within his private information display area. If the adjacent user approaches too close to him, it becomes difficult for him to place the puzzle pieces to complete the task. When a user's private information display area became too small due to the adjacent user's approaching too near, we found that he naturally tries to expand his private information display area by moving away from the adjacent, approaching user. The arrows in Fig. 6 labeled by

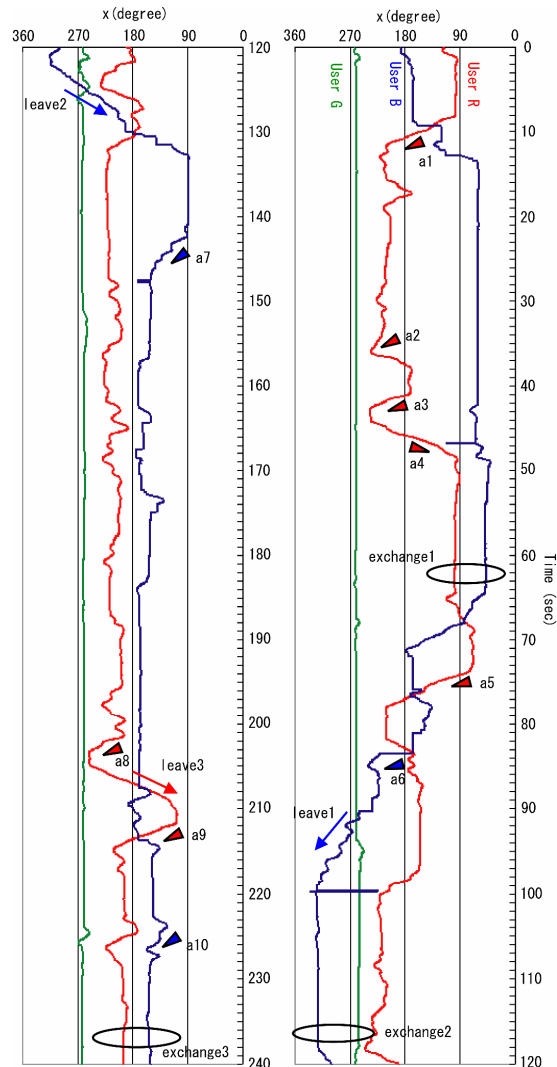
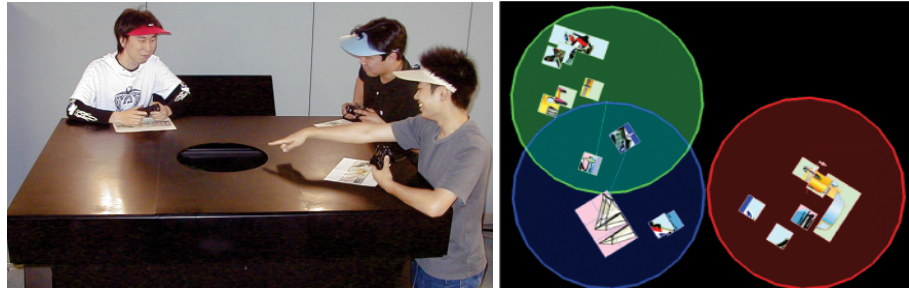


Figure 6: A time-position graph.



(a) Display system shared by three users. (b) Information display areas of three users.

Figure 7: Snapshots taken during experimental work.

leave1, leave2, and leave3 designate periods when the user moved away from an approaching adjacent user, under these conditions.

User's intentional actions aiming at disturbing other user private information display area and public information display area could be found in other situations. For example, at the 116th second labeled by exchange2 in Fig. 6, when two of the users (G and B) were preparing to exchange their pieces by using their public information area, the third user (R) came to disturb this exchange by approaching them and thus making their public information area shrink. Although no explanation was given to the users in advance as to how their movements around the display provide breakthroughs in their mutual situations, we found that users strategically altered both the public information display area and the private information display area by using their own body motions in order to fulfill their purposes.

Because each user could see the other participants' faces, the negotiations among users (regardless of whether they are friendly or strategic) were naturally and intuitively advanced through eye contact, which provided an intuitive and natural communication channel. It was also helpful for users to understand the state of the task by simply monitoring the location of the other users along the round display. This seems to be an advantage of a single display that can provide public screen space as well as private screen space.

6 Discussions

The proposed system provides a face-to-face environment by using a single display in which a user can smoothly negotiate with particular partners through showing his/her public pieces of information on the area adjacent to his/her private information display area. The public information display area naturally expands when two adjacent users approach each other closely enough. Furthermore, the system design promotes intuitive collaboration through the dynamic size of overlapping areas caused by the change of distance between users. This feature cannot be obtained by other systems such as those that use multiple displays. We believe that physical distances between adjacent users, and in accordance the distribution of public and private information on the display, might change according to the intimacy level, or other psychological parameters which influence interpersonal distances [18]. Since both public and private information are presented on the same display, users do not need to divide attention between several spatially separated displays and can easily

grasp the status of their private and public information. Users can communicate by using eye contact and/or face-to-face conversations; consequently, they can negotiate with each other naturally and intuitively. This is an important advantage of the proposed method using a single, round display.

Exploiting these features, our method can be applied to various collaborative tasks that incorporate strategic aspects. One example is to use it in a meeting on reshuffling of personnel in a company or an organization. At a meeting where managers or directors of some sections gather, the sharable information is general personnel matters such as careers or work experiences of the persons who are shuffled. On the other hand, some background information that does not necessarily have to be shared with all participants might be held as private by a manager. She can decide at some point that it is profitable to show the secret information to a particular participant, according to the situation. By using our proposed system, the participants can proceed through their negotiations by exchanging or sharing information with particular partners. One application example of this type is where sport team managers conduct a meeting on trading baseball players. Another possible example of this type is when negotiating the barter of goods among several participants, similar to the example shown in Fig. 5.

One of the drawbacks of our display system is the resolution of the information display areas; that is, only a part of the display surface is used for each user. A higher resolution image display will help alleviate this drawback, and it should even be possible to enlarge each user's display area by using different design parameters, e.g., employing a larger mask hole if the number of users can be limited to two. In the application example of Fig. 5, implementation was made more sophisticated, mainly to display pictures or portraits and accompanying text data of sufficiently large size by switching one after another by using the buttons of controllers.

7 Conclusion

In this paper, we proposed a round display system that enables multiple users to share private and public information following an intuitive collaboration mechanism. Through prototype implementation and preliminary evaluation, we found that the proposed system displays private and the public information seamlessly and that users can interactively control public and private information spaces by naturally changing their relative spatial location. Users can dynamically choose their collaboration partners, perform tasks which involve cooperation and negotiation, and intuitively control the information they kept private or shared publicly with their collaboration partners.

In the proposed system each user can see the other participants' faces. This support for natural eye contact provides subtle cues for communication between users. The users can proceed through their collaborative work naturally via conversation and hand and body gestures. Corresponding to the dynamically changing user locations the single display can provide public screen space as well as private screen space. The proposed method supports natural interpersonal interaction with a technique of seamless transitions between personal and group work. In addition, it provides users with a face-to-face collaborative work environment in which physical objects can also be used in the same environment.

We believe that the collaborative interaction paradigm the proposed system suggests can be easily extended to support a wide range of activities. We see the main

usefulness of this interaction paradigm in human activities that combine the need to collaborate and share information on one hand, with a necessity to strategically and dynamically conceal some knowledge on the other hand. Potential applications can range from stock market and trading floor-related tasks, barter of goods, auctions, cooperative human resources meetings and many others.

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