Caretta: A System for Supporting Face-to-Face Collaboration by Integrating Personal and Shared Spaces

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ABSTRACT
In this paper, a system called *Caretta* that integrates personal and shared spaces to support face-to-face collaboration is described. We use PDAs and a multiple-input sensing board for personal and shared spaces, respectively. Users of *Caretta* can discuss and negotiate with each other in the shared space by manipulating physical objects, while they individually examine their ideas in their own personal spaces. *Caretta* allows users to participate in group activities interchangeably and seamlessly using both these spaces. *Caretta* is applicable to various collaborative tasks. In this paper, it supports users in urban planning tasks. User studies of *Caretta* demonstrated that it allowed users to collaborate in a flexible fashion: users could work individually in their personal spaces at their own pace, cooperatively work together in the shared space, and smoothly transition between both of the spaces.

Categories and Subject Descriptors: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems -- Artificial, augmented, and virtual reality; H5.2 [Information Interfaces and Presentation]: User Interfaces -- Input devices and strategies; Interaction styles, Screen design; H.5.3 [Information Interfaces and Presentation]: Group and Organization Interfaces -- Computer-supported cooperative work;

General Terms: Design, Human Factors

Keywords: Personal and shared spaces, Face-to-face collaboration, PDA, Sensing board

INTRODUCTION
In the field of CSCW (Computer Supported Cooperative Work) research, many systems supporting collaboration between people in distributed locations have been developed. However, when we think of our daily activities, at schools or offices, we find that collaboration frequently occurs in co-located, or face-to-face, situations, and supporting such collaboration is still an important issue.

Research on Single Display Groupware (SDG) [15] has investigated the best means to support group collaboration in face-to-face or co-present situations. Several SDG applications accept simultaneous inputs by multiple users through their graphical user interface (GUI). Making the users' behavior more visible and increasing their level of awareness is more effectively achieved if the constraints of a conventional two-dimensional display are overcome. Systems with tangible interfaces [5] or augmented reality technologies are examples of overcoming these constraints. These systems, however, have the following problems:

- When a group of users simultaneously use a system that accepts multiple inputs but has a single output, such as a display, it is often difficult for individual users to recognize the results of their own operations, because all the results are visible to all the users.
- Several studies have shown that supporting individual activities as well as group activities to support collaboration is important—but there is a tradeoff between the two [4]. In most systems of SDG or with augmented reality, a visible workspace is shared among all the users, and therefore, it is difficult to support fully each user in his or her personal work within the collaborative work.

To solve the problems described above, we propose a system called *Caretta*, which integrates personal and shared spaces for supporting face-to-face collaboration. In *Caretta*, a sensing board is used for the shared space, and a personal digital assistant (PDA) is used for each personal space, as shown in Figure 1. *Caretta* is applicable to support various collaborative tasks. In this paper, it supports users in urban planning tasks: users of *Caretta* surrounding a table manipulate physical objects to redesign a town, and evaluate it through computer simulations. The following functions are requirements for *Caretta*.

- The system can rapidly recognize locations and types of hundreds of objects manipulated by multiple users in a physical world (for example, 500 objects within 0.1 second).
- Based on the arrangement of objects, the system executes computer simulations and visualizes the simulation results using an overlay on the physical objects. Using augmented reality technologies, the system not only increases the level of visibility of the users' actions, but also creates an immersive environment for collaboration.
- The system allows users to work on their own PDA: users can arrange objects on their own display and execute personal simulations without being disturbed by other users.
- The shared space and personal spaces are linked together: users can easily display results of their work conducted in the shared space on their own PDA, and project their personal work from their own PDA into the shared space. This allows users to work seamlessly in both personal and shared spaces.

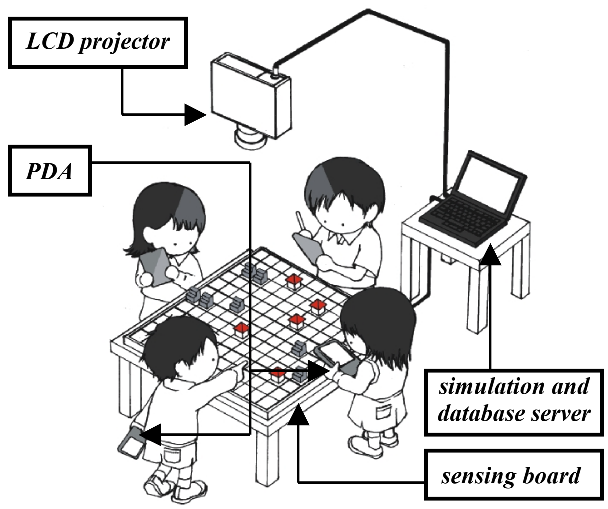

Figure 1. An overview of *Caretta*

For object recognition in the shared space, we use the RFID technology by embedding an RFID tag in each physical object and RFID readers in the sensing board [8]. In order to support users' seamless use of the shared and personal spaces, an intuitive method for supporting users' smooth transition between the spaces has been developed.

User studies of *Caretta* were conducted to investigate how it could support users' collaboration and affect their activities. Through the studies, *Caretta* was demonstrated to support users in their collaboration in a flexible fashion, and its functions worked effectively for users' seamless use and work in both shared and personal spaces.

RELATED WORK

There have been many systems that use augmented reality to support collaboration. Designer's Outpost [7] is a system to support designers in collaborative web page design. It uses a camera and a touch-sensitive display to recognize the locations of real Post-it™ notes placed by a group of designers, and projects links between the notes on the display. Augmented Surface [12] allows users to drag files, such as documents, images, or icons, to be shown on a computer desktop, a table or a wall. Users can easily share these files with other users and bring them into their own personal computer. InteracTable [14] allows a group of users to collaboratively create and edit information objects. InteracTable could rotate and shuffle information objects on its display to accommodate easy viewing from all perspectives. Senseboard [6] is used for supporting collaborative tasks of organizing conference papers into sessions. Luminous Room [19], EDC [1], and BUILD-IT [2] are systems for urban planning simulation that integrate physical and virtual spaces. These systems do not have personal spaces for each user, and all the users' activities occur in the shared space.

Greenberg et al. describe a system that displays a personal and a public space in a PDA [3]. Users can create documents in their own personal space and move them to the public space, or bring documents from the public space to their own personal space for editing.

Caretta is related to systems categorized as SDG. One critical issue in SDG is that concurrent operations of multiple users in a single display interfere with each other. [20] proposes a transparent menu which avoid interrupting users working in a shared display. Another issue in SDG is that a user has no way of concealing their activities from the other users because any information or activity in a shared space is visible to all users. Single Display Privacyware [13] proposes a solution by making private information visible only to the corresponding user through a head-mounted display (HMD). Another approach is to give each user a mobile device. Pick-and-drop [11] allows users to use a special stylus pen with which they can "pick up" and "drop" information between the shared space (whiteboard) and a personal space (PDA). Pebbles [10] is a system that supports group activities by connecting PDAs and a PC. In Pebbles, PDAs are used as input devices for the shared display of the PC, but not as personal workspaces. ConnecTable [18] is a table that has a display embedded in its surface. ConnecTable is used for a personal display. When multiple ConnecTables are connected, their displays become one display for a group of users, and a support for them in their data sharing.

INTEGRATION OF SHARED AND PERSONAL SPACES

Shared Space

Figure 2 shows the shared space of *Caretta*. A group of users (three to eight people), with PDAs in their hands, surrounds the shared space. They manipulate physical objects such as houses, stores, or office buildings, to redesign a town. When *Caretta* identifies changes to the object arrangement in the shared space, it starts computer simulations, and updates the simulation parameters and the visualization overlaid onto the space. Some simulation parameters shown in the upper right corner of Figure 2 are related to the status of the whole town, such as the town's revenue and expenditure, population, etc.

Figure 2. A shared space in *Caretta*. In the upper right of the figure, some simulation parameters are displayed.

Personal Space

A personal space in *Caretta*, to support a user's individual work, is depicted in Figure 3. The arrangement of objects in this figure is the same as that in the shared space shown in Figure 2. By themselves, users can freely redesign the town and test their plan in their personal space—for example, by adding new objects, or removing or moving existing objects. When a user changes the arrangement in his or her personal space, the visualization and values of simulation parameters in the space are immediately updated by computer simulation. Results of the simulations given to the user relate to both the whole town and the users' residential area (for example, the level of convenience to the user based on the distance from, and the number of, public facilities). By viewing these simulation parameters, users can evaluate their own plans.

Supporting Users in Shared and Personal Spaces

To support a group of users working collaboratively in a shared space, and individually in a personal space, *Caretta* has the following functions:

Personal mode and shared mode

Users can select the personal mode or the shared mode when they use their PDA. In the personal mode, changes in the shared space are not reflected on the user's PDA, and the user's personal work on his or her PDA is therefore not disturbed by other users' manipulations of objects in the shared space. On the other hand, in the shared mode, the shared space and the user's personal space are synchronously updated: the object arrangement and simulation parameters displayed in the user's PDA change when the other users have changed the arrangement in the shared space.

Visual indication to attract users' attention

When users work in the personal mode on their PDA, they may not be aware of what has happened in the shared space. If the changes in the shared space are not related to certain users' interest, such changes should not be reported to them. On the other hand, if the changes are related to certain users' work in their personal space, some indication should appear on their PDA to notify them, even though they do not want to be disturbed by others. *Caretta* therefore implements a function to attract users' attention by comparing the object manipulation log between each user's personal space and the shared space. When a user working in a personal space has changed the arrangement of objects in the area where the other users have changed the shared space, or when the users in the shared space have changed the area where the user has changes, a visual indication to notify the changes appears on the user's PDA, as shown in Figure 4.

Figure 3. A personal space in *Caretta*. A user can freely add, move, or remove virtual objects for personal simulation.

In *Caretta*, users can freely select and change their working modes—that is, whether to work individually or collaboratively. When we carried out informal user studies with a prototype of *Caretta*, we found that users often concentrated on working in the personal space only, and ignored the shared space. This sometimes caused a situation where users did not join their group activities, and discussions or negotiations among users did not happen. In [9], functions given to users in the private spaces (handheld devices) are limited, in order to enhance users' interactions in the shared space. In *Caretta*, we use another approach:

agreement buttons are set on the shared space. After a group of users has evaluated a plan proposed by one of them (for example, where to place a police office) through discussions in the shared space, each of them votes for or against the plan by placing a special object (on which an image of a seal is printed) on the agreement buttons (Figure 5). If all or more than half of the users agree to the plan, it is adopted, and the arrangement of the objects and vote results are stored in a database with a timestamp. If not, the plan is discarded, and *Caretta* returns to the status before it was evaluated.

Although the agreement buttons may work effectively, they require users to collaborate in a (tightly) controlled manner. To let all users show their agreement or disagreement may hinder their flexible collaboration. Therefore, in the user studies of *Caretta*, it was left to users whether they used the buttons.

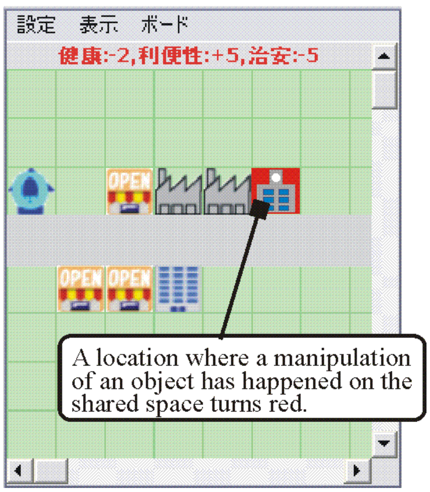

Figure 4. Visual indication that appears in a personal space to attract user's attention

Manipulations of the shared space through a personal space

Users' PDAs can be used to manipulate objects in the shared space. For example, when users discuss where a highway should be constructed, they can draw it on the shared space using their own PDAs. This function is useful for placing virtual objects, which are as difficult to place as physical objects (for example, a bus service route, or physical items that are easier to draw than place physically, such as a railway).

Transition from the shared space to users' personal spaces

When users working in the shared space want to test their own ideas personally, it is necessary to display the working area in the shared space on their personal spaces. Users have to scroll through a small screen of their PDAs, and feel difficulties in finding the corresponding area of the shared space. *Caretta*, therefore provides users with an intuitive transition method from the shared space to their personal space. When users brings their PDAs close to an area of interest on the shared space (Figure 6), the corresponding area immediately appears on screens of their PDAs. By using this method, users are liberated from the irritating task (scrolling through a small display to find an area of interest), and smoothly transition to their personal spaces in an intuitive manner.

Copying a user's personal space to the shared space

When users want to propose a plan that has been examined individually in their own personal space, they can copy their personal space to the shared space. When users copy their plan, the differences between their personal space and the shared space (such as object arrangement, remarkably changed simulation parameters) are highlighted on the shared space. This function helps users to propose their plan to other users easily, and helps them understand what will happen if their plan is adopted.

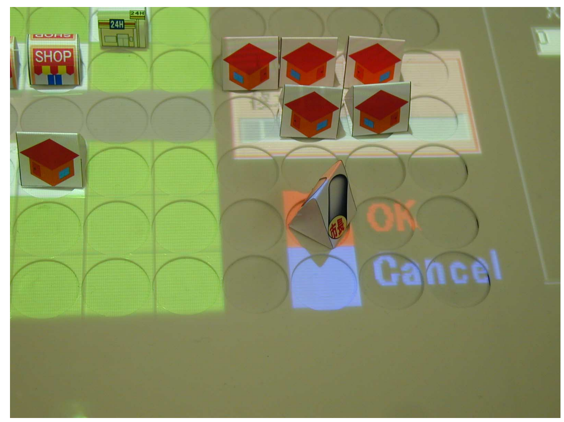

Figure 5. The agreement buttons ("OK" and "Cancel")

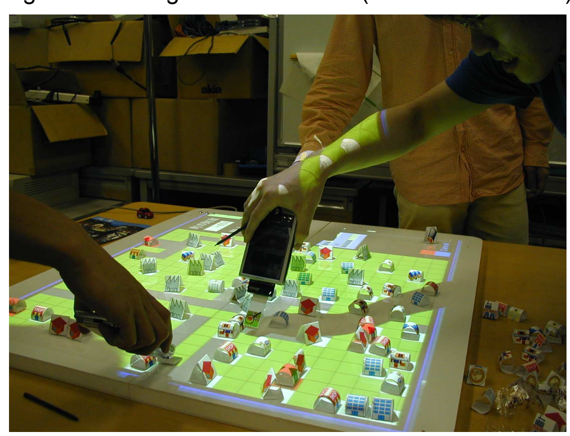

Figure 6. Displaying an area of interest in the shared space on users' PDAs for smooth transition to their personal spaces

Backtracking

Caretta allows users to return to a discussion and change design plans previously decided in the shared space, or to look back over their design processes after they have completed their collaborative work. While backtracking, *Caretta* lets users know where objects were placed, causing their corresponding locations to blink. Using this function, users can restart their work from any point of their design process.

User interface for a personal space

The screen of a PDA is too small to display all the information related to a user's work. Therefore, we designed a user interface for a personal space that enables a user to zoom in and out and scroll up and down. When not all the information is displayed, a small map that supports a user's navigation in the personal space appears, as shown in Figure 7.

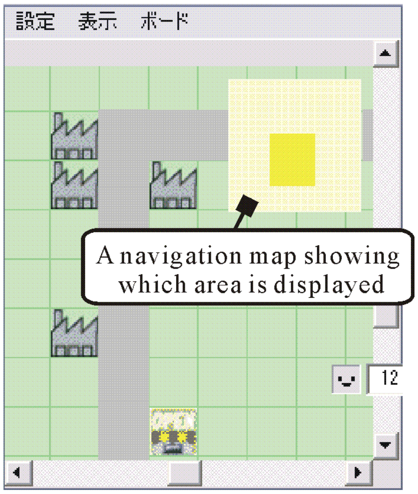

Figure 7. A map to support a user's navigation, shown at the upper left of the figure.

IMPLEMENTATION

Caretta is composed of a sensing board, a simulation and database server, an LCD projector, and PDAs as shown in Figure 1. The sensing board and the server are connected through RS232C interfaces. Data communication between the PDAs and the server is through a wireless LAN.

Sensing Board

We have devised a sensing board that can rapidly recognize locations and types of objects [8][17]. We have utilized RFID technology (Omron, V720 series) for object recognition. A grid frame is laid out like a checkerboard on the surface of the sensing board. An RFID tag embedded in an object is placed inside a grid, and an RFID reader is embedded in the board under each grid, as shown in Figure 8. In this board, there are 20 × 24 grids with sides of three centimeters. The time taken to acquire the arrangement of objects on the board is less than 0.05 second.

When we started our project in 1998, we tried a touch-sensitive display and image-processing methods for object recognition. However, at that time, touch-sensitive displays accepted only a single input and could not recognize hundreds of simultaneous inputs. Recognizing objects by image-processing methods using cameras was not sufficient, because users often cover some objects with their hands or heads, and a camera above the objects cannot always generate an image where all the objects appear whole. This causes a problem when *Caretta* tries to synchronize the object arrangement in a user's personal space with that in the shared space for their personal simulations in their PDA. More detailed implementation issues of the sensing board are described in [16].

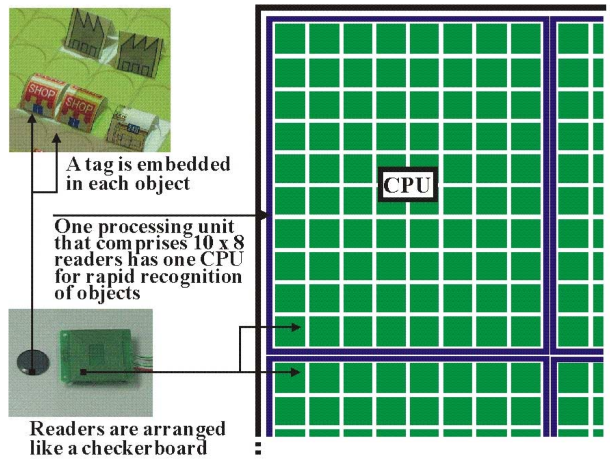

Figure 8. How the RFID technology is used in the sensing board

PDA Augmented with RFID

In order to support users' smooth transition from the shared space to their personal spaces, an RFID tag is attached to each user's PDA. When a PDA is brought close to the surface of the sensing board, its user and location on the board are identified. Then, the visualization of the PDA is updated and the corresponding area of the shared space appears on its screen.

Software Architecture

Figure 9 shows the software architecture of *Caretta*. It comprises several modules that allow users to work seamlessly in the shared and personal spaces.

The *Board Control Module* periodically (every 0.1 second in the current version) accesses the sensing board, controls it (activates or inactivates its RFID readers) and updates its object arrangement information.

The *Simulation Module* accepts an event (*ObjectArrangementChangeEvent*) from the board control module or requests from the users' PDAs. If the event has occurred because users brought their PDA close to the sensing board, the module sends a command to the PDAs so that the corresponding areas of the shared space appear on the screens of the PDAs. If the event has occurred due to users' manipulations of physical objects on the board, the module starts computer simulations. The module accesses a database, retrieves the values of the simulation parameters and then calculates the financial and environmental changes of the town on the sensing board, based on the current object arrangement information given by the board control module. The updated values of the simulation parameters and the object arrangement information are stored in the database.

Recent PDA models have considerable computational capabilities. It is, however, still insufficient to complete computer simulations rapidly. Therefore, we implemented *Caretta* so that the simulations for each PDA are executed on the server: when a PDA receives a request for a simulation from a user, the request is sent to the server. The server generates a thread for the simulation, and returns the simulation results to the PDA. However, from the viewpoint of users, the simulation seems to be executed on their PDA. *Data communication modules* in the server and PDAs exchange messages, such as requests from the PDAs or replies from the server.

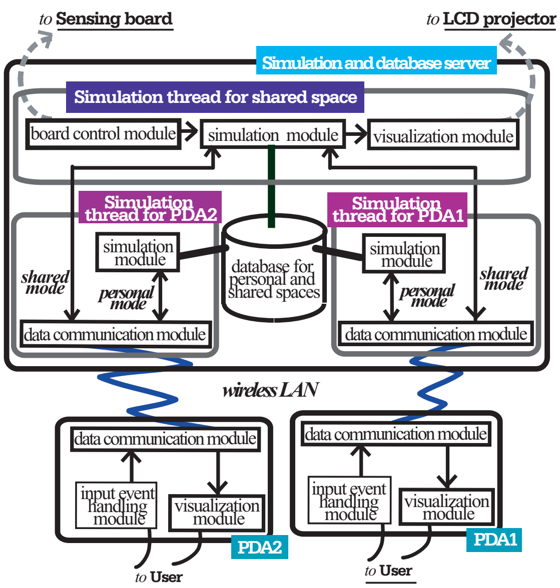

Figure 9. Software architecture of *Caretta*

The software of *Caretta* was developed with Microsoft Visual Studio .NET and is executable on Windows XP (server) and PocketPC 2002 (PDA). In order to support collaborative work in various domains, *Caretta* was designed so that the simulation module and visualization module were developed for specific applications, and other modules were reusable. Therefore, we prepared Application Program Interfaces (APIs) for these two modules to allow developers to easily construct different applications.

USER STUDIES

22 students from our university participated in the user studies with *Caretta*, as shown in Figure 10. They were divided into six groups (two groups of three and four groups of four). They use PCs in their everyday life, but do not always use PDAs. The user studies with *Caretta* for each group lasted approximately one hour. To make the participants' work concrete and raise the level of their engagement, each group was given an existing Japanese town in the shared space, and was asked to do the following urban planning tasks: decide (1) locations of public facilities and (2) where to construct highways, railway stations and bus service routes, by considering the town's finance, the environment, and the convenience of their own residential areas.

Figure 10. *Caretta* in use

How *Caretta* was used

Figure 11 shows the usage log of *Caretta* by one of the groups. Dots on this graph mean users' manipulations: placing, moving, and removing objects on the shared and personal spaces, respectively. From this figure, we see that the users first used their PDA to devise and examine their own plan through personal simulations. When User3 devised a new plan for constructing a highway (2:19), he presented it to the other users by drawing the highway on the shared space using his PDA with a stylus pen. User2 and User3 discussed the plan by viewing the simulation results and changing the locations of objects. On the other hand, User1 and User4 updated their personal spaces by bringing their PDAs close to the corresponding locations on the shared space, and examined User3's plan personally with their PDAs. User4 then proposed his idea by modifying User3's plan (3:40). It was noteworthy at this point that users' activities in *Caretta* happened in parallel: some users collaboratively worked in the shared space and, at the same time, other users worked in their personal spaces.

Both User3's and User4's plans were rejected, and all users returned to their personal spaces to find more acceptable plans. User4 again proposed a different plan (4:19), and all users joined the discussion in the shared space—and finally, User4's plan was accepted.

The user studies proved that all groups of users used personal and shared spaces interchangeably to devise and examine their own plans, and to discuss and negotiate with other users. For issues related to the design of *Caretta*, we received the following feedback from the users.

- The shared space could support users' discussions and negotiations, because they could easily participate in their collaborative design by manipulating physical objects, and could easily recognize what happened through the visualization of simulations.

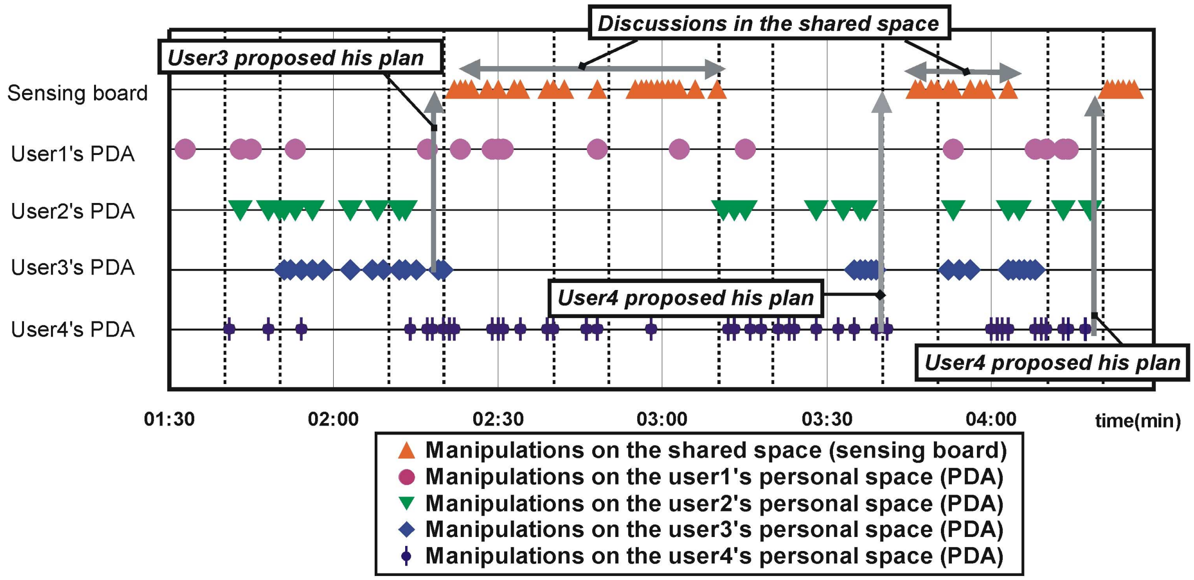

Figure 11. An example usage of *Caretta*

- The users were not confused with the integrated utilization of the personal and shared spaces. In particular, some users told us that drawing an object on the shared space through a PDA was useful, because it was much easier for users than drawing directly on the shared space with a special object (e.g. a pen-like object embedding an RFID tag), and made a user's plan more intelligible than copying his or her own personal space. Users also told us that the intuitive method for supporting their smooth transition from the shared space to their personal spaces was extremely helpful and inevitable for them to work effectively and seamlessly in both these spaces.
- Visual indication was effective in attracting users' attention to the shared space. However, users also complained that it was often obtrusive, because they could not easily understand why such indication appeared (although *Caretta* evaluated the relevance between users' activities in their personal space and group activities in the shared space).
- Effects of the agreement buttons seemed controversial and questionable. Users of three groups preferred the buttons because they made all users verify proposed plans as a group and try to obtain their agreement through discussion. Conversely, users of the other three groups told us that when they did not join the discussions in the shared space, but worked personally on matters unrelated to the discussion, they felt interrupted and could not understand why, and what agreement was required. This result indicates that more intensive user studies are required in order to design a collaborative environment that integrates shared and personal spaces: for instance, a user study to investigate relations among types of tasks, characteristics of users, styles of collaboration, and functions of systems.
- The backtracking function was useful, when users who checked a previous group decision in their personal space could find a more suitable plan. Actually, a user in one group asked the other users to go back to a previous design decision, and they restarted their collaborative design from that point. We assume this happened because users could work in the shared and personal spaces in parallel at their own pace.

An interesting finding from the observations of the user studies was that the group of four users often formed two subgroups of two, and used their PDAs for collaboration: One user of each subgroup showed a plan on his or her PDA to another user, and discussed it. We did not expect such a usage of the PDAs, but the users regarded them as a tool not only for supporting personal work, but also for enhancing subgroup collaboration. In other words, in this case, the shared space was used publicly and not for private communication within subgroups. Therefore, the PDAs were used as private spaces for subgroups that shared the same objectives or interests.

CONCLUSIONS AND FUTURE WORK

In this paper, *Caretta*—a system for supporting face-to-face collaboration—was described. The function of *Caretta* is to integrate personal and shared spaces. The multiple-input sensing board with augmented-reality technologies is used for the shared space, and a PDA is used for each user's personal space. In this paper, *Caretta* is used to support collaboration in urban planning tasks. Users' studies of *Caretta* demonstrated that users used personal spaces interchangeably for individually examining their own plans, and used the shared space for discussing and negotiating with others by manipulating physical objects. Although the user studies with *Caretta* might be informal, several issues were clarified. We therefore plan to carry out more intensive user studies to evaluate and improve it.

Currently we have been developing systems for supporting collaborative musical composition and brainstorming, as applications of *Carreta* in different domains. In our future work, we will extend the functions of *Caretta*, so that it can automatically recognize different types of devices (for example, a tablet PC or a mobile phone), and provide an appropriate user interface to them. We will use *Caretta* in school education to support children's collaborative learning.

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