Integration of Inter-Personal Space and Shared Workspace: ClearBoard Design and Experiments

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ABSTRACT
This paper describes the evolution of a novel shared drawing medium that permits co-workers in two different locations to draw with color markers or with electronic pens and software tools while maintaining direct eye contact and the ability to employ natural gestures. We describe the evolution from ClearBoard-1 (based on a video drawing technique) to ClearBoard-2 (which incorporates TeamPaint, a multi-user paint editor). Initial observations based on use and experimentation are reported. Further experiments are conducted with ClearBoard-0 (a simple mockup), with ClearBoard-1, and with an actual desktop as a control. These experiments verify the increase of eye contact and awareness of collaborator's gaze direction in ClearBoard environments where workspace and co-worker images compete for attention.

KEYWORDS
ClearBoard, TeamPaint, shared drawing, groupware, video conference, eye contact, gaze awareness

INTRODUCTION

One major focus of groupware development has been the creation of virtual *"shared workspaces (SWS)"* in distributed computer environments. Some groupware definitions take this workspace-oriented view, such as:

> *"Groupware... the computer-based systems that support groups of people engaged in a common task (or goal) and that provide an interface to a shared environment."* (Ellis et al. [7])

Whiteboards and overhead projections of transparencies are examples of shared workspaces in face-to-face meetings. Participants can see, point to, or draw on a whiteboard simultaneously. An overhead projector makes hand-written or computer-generated documents visible to all participants in a room, while permitting the speaker to point or draw. SWS activities include sharing information, pointing to specific items, marking, annotating, and editing. In a distributed, real-time collaboration, these activities can be supported by computer-based groupware, including shared screen systems such as Timbuktu [8], shared window system [20], and multi-user editors such as Cognoter [10], GROVE [7], Commune [3], CaveDraw [21], Aspects [14], GroupSketch [13], GroupDraw [13], and TeamPaint (described later). Use of hand gestures in a SWS can be supported by shared video drawing media such as VideoDraw [27] and TeamWorkStation [16, 18].

In face-to-face meetings, we speak, make eye contact, and observe each other's facial expressions and gestures. These verbal and non-verbal channels are important in building confidence and establishing trust [2, 5, 22]. A focus of tele-communication technologies such as the videophone and the video conferencing has been the creation of *"inter-personal spaces (IPS)"* that maintain a sense of "tele-presence" through the visibility of gestures and facial expressions of distributed group members. Media Space [26, 15], CRUISER [25], and VideoWindow [9] are examples of such technologies. Figure 1 illustrates these concepts and identifies relevant technical support[1].

LIMITATIONS OF EXISTING SUPPORT TECHNOLOGIES

Both SWS and IPS are present in ordinary face-to-face meetings and may be essential for remote, real-time collaboration. Several media space[2] technologies support both SWS and IPS.

1 This framework was developed through a discussion with William Buxton who pointed out the importance of a smooth transition between what he calls "shared task space" and "person space" [5].

2 "Media space," originally the name of a specific system [26, 15], is used here in the sense of Mantei et al. [22] as a general term to represent computer-controlled video environments.

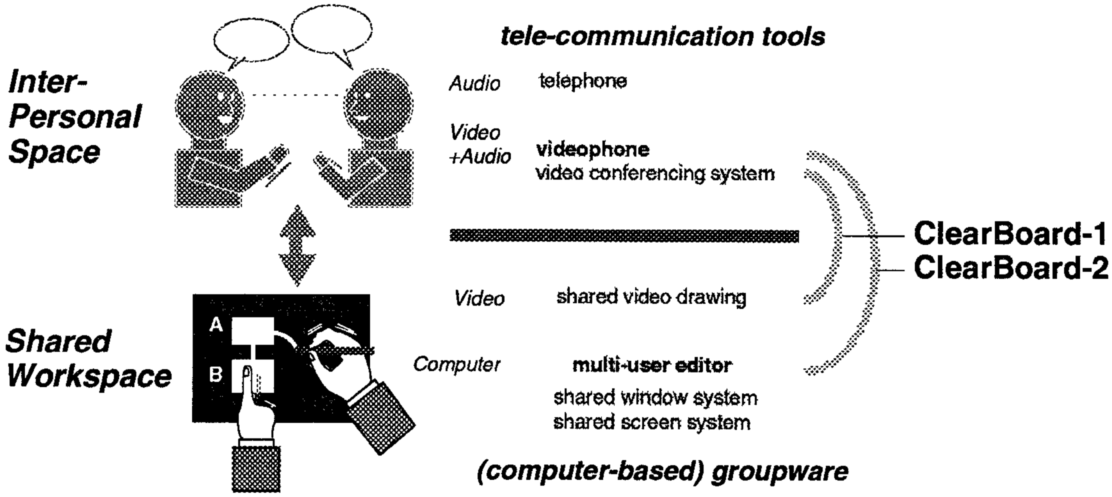

Figure 1. Inter-Personal Space, Shared Workspace, and Support Technologies in Real-Time, Remote Collaboration

Figure 2 illustrates three typical display arrangements of media spaces. In (a), a display providing a live video image of the partner's face is alongside a display for shared work. The ARKola simulation [11] in the IIIF environment [4], and some nodes of CAVECAT [22] adopted this arrangement. In (b), the displays are repositioned to resemble the situation of interacting across a table. VideoDraw [27] and Commune [3, 23] experiments adopted this arrangement. In (c), the live video images and the shared workspaces are incorporated into different windows of a single screen. TeamWorkStation [16-18], PMTC [29], MERMAID [30] and some CAVECAT nodes employed this desktop-video technology.

Although positive steps, these designs share a major limitation, an arbitrary *seam* between SWS and IPS. Experiments on TeamWorkStation proved that the problem is not entirely the superficial physical discontinuity between spatially separated windows. Users experience an undesirable *seam*, a gap between the two functional spaces, SWS and IPS. Absent are the *cues* that would enable a smooth shift of focus between these two spaces. Camera positioning prevents one person from knowing the direction of the other's gaze: It could be directed toward the face image, toward objects in the shared workspace window, or elsewhere. A shift in focus is not apparent until accompanied by a visible gesture, a mouse movement, or an audible remark. Mutual eye contact is impossible.

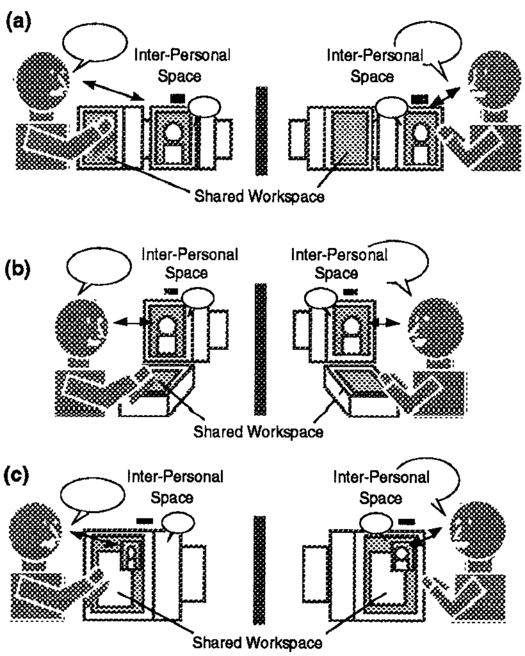

Figure 2. Typical Screen Arrangements in Media Space

In a face-to-face design meeting, while using a whiteboard or drawing surface we frequently switch our focus between IPS and SWS. Even when drawing, we briefly glance at our partner's face to attract attention or to gauge comprehension. Similarly, our partner's head turning, eye movement and gestures also attract our attention and trigger our focus shift. This dynamic and interactive focus switching between SWS and IPS is made possible by the presence of a variety of *non-verbal cues*.

Current media space technologies do not provide these cues. Spaces created by these technologies are discontinuous and arbitrary [12]. Users cannot switch their focus between the two spaces *naturally* and *smoothly*. ClearBoard is designed for pairs of users and overcomes these limitations by seamlessly connecting IPS and SWS (Figure 1). ClearBoard allows users to shift easily between IPS and SWS using familiar everyday cues such as the partner's gestures, head movements, eye contact, and gaze direction.

In the next section of this paper, we introduce the metaphor of ClearBoard: *looking through and drawing on a glass board.* We then introduce the architecture of ClearBoard-1, a prototype that supports remote collaboration through shared video drawing. Next we describe ClearBoard-2, which utilizes computer-based shared drawing to overcome the limitations of ClearBoard-1. Finally, we outline the experimental use of these prototypes[3]. These consist of both informal use and formal experiments, the latter designed to explore the feature of "gaze-awareness."

GLASS BOARD METAPHOR OF CLEARBOARD

Our first step was to consider metaphors that might allow us to create a medium that allows people to use everyday skills without requiring a special training.

In September 1990, Kobayashi and Ishii came up with the metaphor of "looking *through* and drawing *on* a big glass board" and gave it the name "ClearBoard" [19]. Figure 3 shows "ClearBoard-0" which is the simple mockup of this ClearBoard concept for co-located pair of users. ClearBoard-0 consists of a glass board positioned between the partners on which they draw or post objects. This prototype represents the best possible case for visual clarity. In addition to reinforcing the actual physical separation of the partners, ClearBoard requires *less eye and head movement* to switch focus between the drawing surface and the partner's face than would a whiteboard or desktop surface. A real glass board has the problem that written text appears reversed to one's partner; we were able to solve this problem by mirror-reversing a video image in ClearBoard-1 and 2 as described below.

Figure 3. ClearBoard-0: A Simple Mockup

The existing systems most similar to ClearBoard are VideoWhiteboard [28] and LookingGlass [6]. VideoWhiteboard utilizes the users' shadows to convey their gestures during shared drawing activity. VideoWhiteboard looks like a *frosted* glass board, in contrast to the *transparent* glass board that ClearBoard represents conceptually. VideoWhiteboard merges elements of IPS and SWS; however, the shadow images do not convey facial expressions, eye movement, or eye contact, all of which are present with ClearBoard.

LookingGlass displays the full-screen window of ROCOCO sketchpad (shared drawing software) over a full-screen video image of a remote partner. Using the the half mirror, LookingGlass supports eye-contact. However, the use of indirect drawing devices (mouse, digitizer) separates hand movements on a desktop from cursor movement on the computer screens, and users can not see the actual hand gesture behind the cursor movement. Another drawback is users can not place their hands close to marks on the computer screen surface because of the half mirror angled backwards at 45 degrees in front of the vertical screen surface. ClearBoard overcomes these limitations by allowing users to draw and gesture directly on the screen surface.

THE DESIGN OF CLEARBOARD-1

In order to implement the remote version of ClearBoard, we identified the following three design requirements.

(1) direct drawing on the display screen surface must be supported,
(2) the video image of user must be taken through the screen surface to achieve eye contact, and
(3) a common drawing orientation must be provided.

We devised the system architecture illustrated in Figure 4 to satisfy all these three requirements with simple technologies. We call this architecture "drafter-mirror" because it looks like a "drafter" (a desk for architectural drawing) and it uses a half mirror technique to satisfy requirement (2).

Kobayashi implemented the first prototype of ClearBoard-1 in November, 1990. Each terminal is equipped with a tilted screen, a video projector, and a video camera. The screen is angled backwards at about 45 degrees, and is composed of a projection screen, a polarizing film, and a half-silvered mirror. Video feedback between the two cameras and screen pairs is prevented by the polarizing filter placed over each camera lens and a nearly orthogonal polarizing filter that covers the surface of each screen. Users can write and draw on the surface of the screen using color paint markers and cloth erasers.

The video camera located above the screen captures the drawing marks on the screen surface and the image of the user reflected by the half mirror as a continuous video image. This image is sent to the other terminal through a video network, and projected onto the partner's screen from the rear. The partner can draw directly over this transmitted video image[4]. The image of the partner and his or her drawing is mirror-reversed so that ClearBoard-1 provides both users with a common drawing orientation on their screens. Since the user's image is also mirror-reversed, a right-handed partner will appear to be left-handed.

Results of ClearBoard-1 Experiments

Figure 5 shows snapshots of the ClearBoard-1 prototype in an experimental session described later. In summary, we observed effortless focus switching between the task and the partner. Users could read their partner's facial expression, achieve eye contact, and utilize their awareness of the direction of their partner's gaze (we call it "gaze awareness"

[3] Jonathan Grudin participated in this experimental and observational phase of the ClearBoard research.

[4] This shared video drawing technique, which allows remote partners to draw directly over the video image of their coworkers' drawing surface, was originally demonstrated in VideoDraw [27].

[19]). These last two features are novel aspects of ClearBoard prototypes and their importance is discussed later.

The drafter-mirror architecture results in the video camera capturing two images of the hand as it draws—one directly and the other reflected by the half-mirror, as shown in Figure 5. Most users did not notice this. Some users, however, reported an initial period of discomfort. No subjects reported difficulty with the mirror-reversal of the partner. This may be because our own images are reversed in mirrors.

An interesting and less critical confusion manifested itself when users directly drew over their partner's image, playfully adding a crown or mustache, for example. Clearly they had a "WYSIWIS" (what you see is what I see) expectation, not realizing that although the drawing is shared, the facial images are not, with each person seeing only the other's image. Thus, the metaphor of the ClearBoard is not always entirely assimilated.

We also encountered problems in using ClearBoard-1: The most serious problem of ClearBoard-1 was that video images on the screen are darker and less clear than is desirable. This is because i) the brightness of the projected video image is reduced by the use of half-mirrors and polarizing films, with more than half of the light lost; ii) the tilt of the screen places the bottom edge about 40 cm further from the camera than the top, making it hard to keep the entire drawing surface (and user's face) in sharp focus; iii) the video resolution was limited to the liquid crystal video projector's 90,000 pixels (in contrast to the approximately 400,000 pixels of the CCD camera).

The lack of video resolution forced the use of thick color paint markers; drawing with them is not precise and quickly uses up the available display space (50 cm x 55 cm). This problem is exacerbated by the difficulty of recording the resulting drawings. (We mainly used Polaroid™ cameras or video printers.) In addition, an inherent limitation of shared video drawing is that a user cannot erase the partner's drawing [27]. Marks drawn by each user exist only on their respective screen surfaces, and users often hesitate to ask each other to erase marks or are embarrassed by requests to erase their own marks. Moreover, the cloth eraser is somewhat ineffective, especially after the color paint has dried.

These problems were a major motivation to develop our next prototype, ClearBoard-2, with its pen-based computer input technology which permits the direct recording of work. It would be desirable to be able to bring both (a) computer files and (b) printed materials directly into the ClearBoard shared drawing space, much as was accomplished in TeamWorkStation. The first limitation is addressed by ClearBoard-2; the second is not easy to solve if we stick to direct drawing. If user A puts a sheet of paper on his/her ClearBoard surface and marks it, user B can see it, but subsequent marks by B will not be seen by A because the paper blocks the rear-projected image.

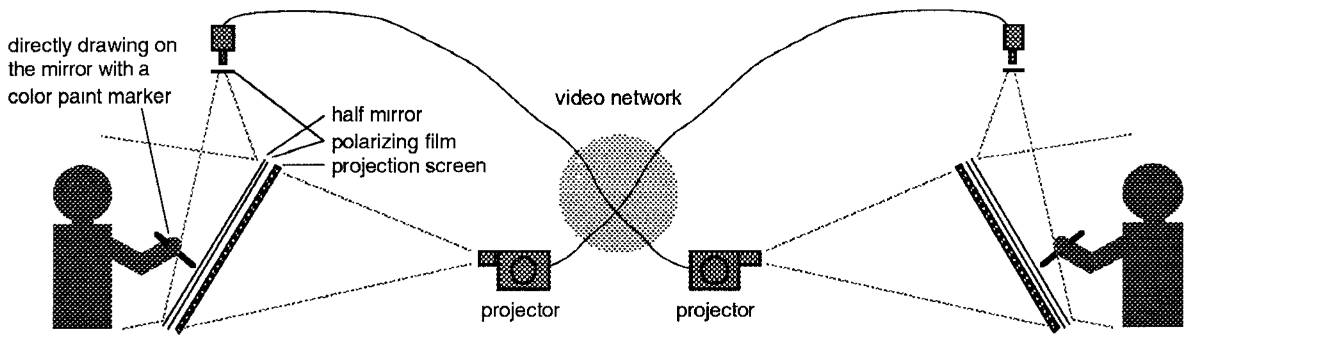

Figure 4. System Architecture of ClearBoard-1

Figure 5. ClearBoard-1 in Use

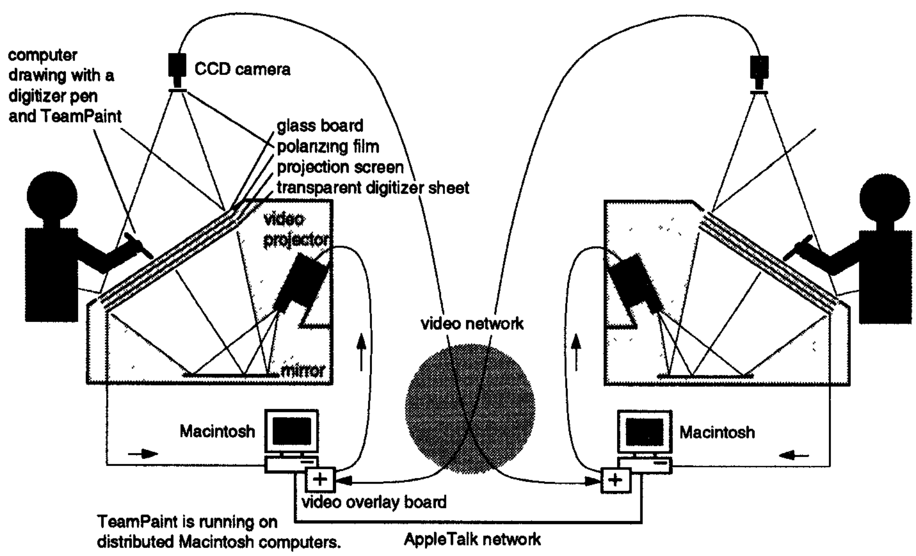

Figure 6. System Architecture of ClearBoard-2

THE DESIGN OF CLEARBOARD-2 WITH TEAMPAINT

To overcome many of the problems of ClearBoard-1, we designed a new computer-based prototype, ClearBoard-2. Instead of video drawing with color paint markers, ClearBoard-2 provides users with TeamPaint, a multiuser computer-based paint editor running on networked Macintosh™ computers, and digitizer pens. To improve the clarity of the screen image, we used a CRT-based rear projection display with a transparent digitizer sheet. The digitizer is mounted to the surface of a flat panel display. The screen size is 80 cm x 60 cm, 1.7 times bigger than that of ClearBoard-1.

Figure 6 illustrates the system architecture of ClearBoard-2. Although ClearBoard-2 is based on the same "drafter-mirror" architecture as ClearBoard-1, the digitizer pen and TeamPaint added the following new functions: (a) collaboratively created drawings can be saved in computer files and re-accessed later; (b) documents created with other editors can be imported, and (c) editing and erasing marks are easy. The shared drawing image (RGB video) is overlaid onto the video image of the partner (NTSC) using a special video overlay board and the mixed RGB video image is projected onto the screen by a video projector. Chroma-keying in the overlay sharpens the drawing image against the image of the co-worker.

TeamPaint: A Multiuser Paint Editor

TeamPaint is not a special component of ClearBoard-2, it is a groupware application that runs on AppleTalk™-networked Macintosh™ computers without any special hardware. It can be used by any number of users simultaneously, with some drop-off in performance. A mouse or tablet can be used for indirect drawing; the digitizer-screen supports direct drawing. Figure 7 shows an example of a TeamPaint screen. TeamPaint was designed based on the following principles.

(1) *A simple human interface .*
TeamPaint provides an intuitive interface based on the metaphor of drawing on a sketch pad with a color pencil and an eraser. Scissors provide the functions of cutting, copying and moving marks. To maximize transparency, it is a simple bit-map paint editor, not an object-oriented draw editor.

(2) *Replicated architecture.*
To be usable in time-pressured design sessions, TeamPaint was implemented so as to maximize run-time performance by employing replicated architecture [20]. It does not require a central server.

(3) *Multi-layer structure.*
Each user is provided with *individual layers* and can, by default, draw on only their own layers. All members see the composite of all layers. It is also possible to share one's layer, allowing another user or all other users to draw and erase the layer's image. Members normally use different colors to distinguish the ownership of marks. Because each layer is isolated from the others, *no access control* is necessary. *No floor control* mechanisms are needed to enable simultaneous gesturing and drawing by multiple users.

(4) *Gesture and process awareness.*
Gestures, in the form of cursor movements, and through them the drawing process, are visually shared by all members. This feature is important in enhancing the sense of a distributed group process[5].

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[5] Awareness based on such a tele-pointer may have limitations. Actual hand gestures have much more power of expression, and with ClearBoard-2, the real hand and pen gesture images that lie behind the tele-pointer augment the awareness provided by TeamPaint. This video-augmented computer-drawing technique was originally demonstrated in VideoCom presented by Minneman and Bly at CHI '91. In VideoCom, however, partner's hand image and face image are separated in different displays (see (b) of Figure 2).

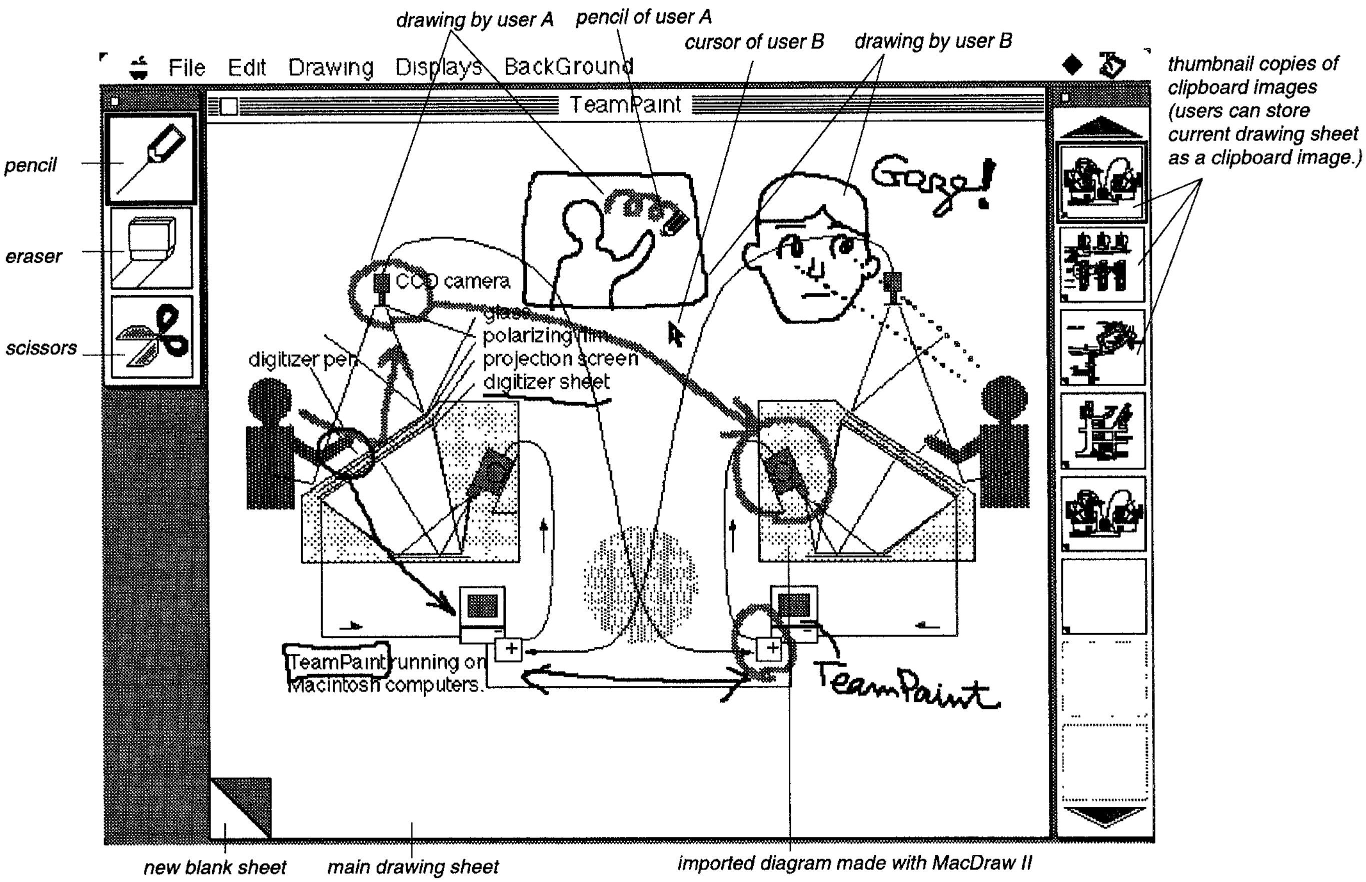

Figure 7. An Example of TeamPaint Screen

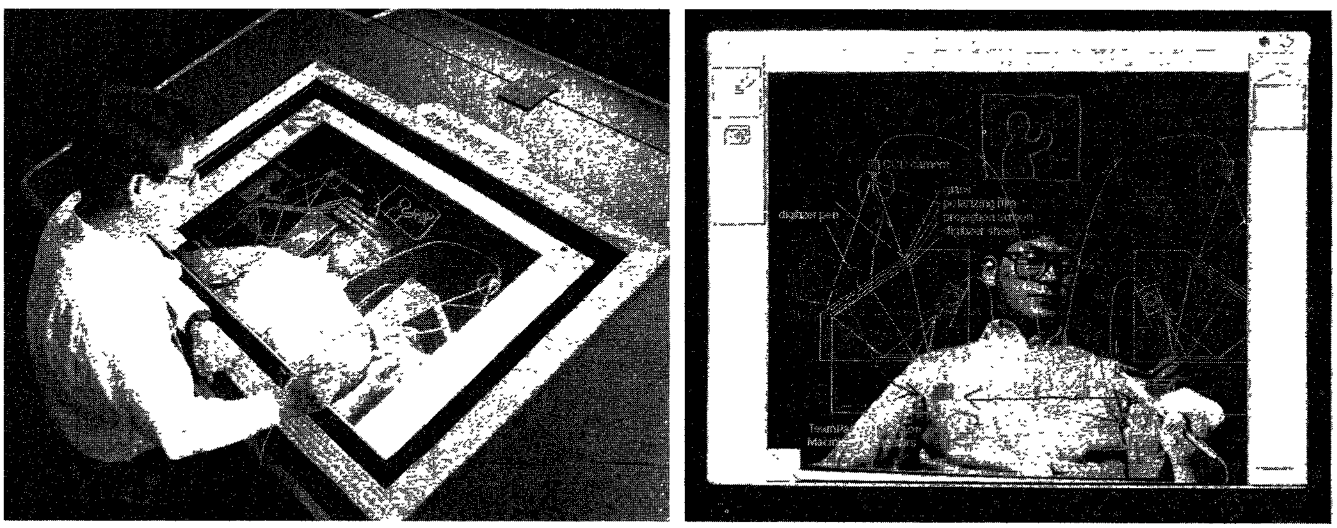

Figure 8. ClearBoard-2 in Use

(5) *Data exchange via standard format file.*
TeamPaint can store the results of shared drawing in the PICT file format which can be read by standard Macintosh™ programs. TeamPaint can also read PICT files created by other editors.

Initial ClearBoard-2 Experience
We finished an implementation of ClearBoard-2 in February 1992 and have used it for several sessions. The capability of recording results and reusing the data made in previous sessions or any other application programs promises to add tremendous value to an already practical tool. The use of

RGB video and the chroma-keying overlay technique do increase the clarity. Since the partner's video image is seen in the background of the TeamPaint groupware running in a Macintosh™ window, one has the feeling of interacting with one's partner through a window instead of through a big glass board.

The change of screen angle (45 degrees in ClearBoard-1, and 35 degrees in ClearBoard-2) decreased arm fatigue, but created more of an impression that the partner is *under* the screen, rather than *behind* it as in ClearBoard-1. Furthermore, it prevents users from covering the screen with their body and hindering the camera view.

Since ClearBoard-2 provides a precise shared drawing surface through the use of TeamPaint software, we found its video calibration need not be as strict as that required by ClearBoard-1.

It was often observed that the user's gaze follows the partner's pen movements. We confirmed that *gaze awareness* is as well supported as it is in ClearBoard-1. A user can know what object in the TeamPaint screen the partner is looking at.

The most serious problem of the current prototype is that drawing is sometimes halted because of the poor sensitivity of the switch at the digitizer pen tip. Users complained about the situation using the expression "out of ink".

EMPIRICAL RESEARCH USING CLEARBOARD PROTOTYPES

We have used the ClearBoard prototypes in work or work-like situations and in tasks constructed to explore certain aspects of the technology. In some cases we ourselves have been the users, in others the users were people not involved in the development of the technology. This section outlines some of the purposes of these studies and gives examples of the results.

One purpose was to obtain a quick first impression of the usability of the prototypes and of any obvious technical or behavioral problems. Many of the ClearBoard-1 problems and resulting ClearBoard-2 requirements described earlier were discovered through such use.

A second purpose of our experiments was to explore in more detail the way that users react to the new aspects and capabilities of the technology. More careful study is needed to see how people react to overlaid images and to collaborating remotely yet with eye contact and awareness of gaze direction, for example.

A third purpose was to gain increased understanding of how people work together and how technology might ideally support this. There are basic research questions that must be addressed before we can understand how our technologies affect or could affect collaboration.

Results from informal studies of use

The authors and six colleagues not involved in this research used the ClearBoard-1 prototype in conceptual design exercises (the limited marker resolution prevented the detail required by complicated electronic circuit diagrams, for example).

We found that users easily and frequently glanced at each other's face and achieved eye-contact both while conversing and while drawing. Switching focus from the drawing to the partner's face required almost no head movement. The effect seemed to be an increased feeling of intimacy and co-presence. These impressions were addressed more quantitatively in experiments described later.

Ishii and Arita found that users of ClearFace [17] hesitated to draw over the image of the partner's face, where the partner's image was in a translucent small window that appeared to be superimposed on a larger drawing image. In ClearBoard, users did seem to see the partner as *behind* the drawing and thus were not reticent in drawing on the board *in front of* the partner. This may be attributable to the transparent glass metaphor and to the relatively large size of the partner's image and head movements. Even with overlapping images, users did not report having trouble distinguishing drawing marks from the video background.

The importance of eye-contact is often discussed in the context of communication tools [1]. However, we found that even more important may be the more general capability that we call "gaze awareness," the ability to monitor the direction of a partner's gaze and thus his or her focus of attention [19]. More easily than is possible in an ordinary meeting environment with a whiteboard, a ClearBoard user can tell what screen objects the partner is gazing at during a conversation.

Experimental tasks

Further observations were carried out on ClearBoard-1 using a collaborative problem solving paradigm with a sharply delineated spatial element, the "river crossing problem." Through these experiments, described in [19], we confirmed the ability of users to recognize the direction of their partner's gaze and the utility of this information in understanding and guiding the partner.

More extensive experiments were carried out by videotaping "backgammon instruction" on a modified game board using ClearBoard-0, ClearBoard-1, and an ordinary table top as a control. The backgammon positions were laid out in a square as shown in the photographs from a ClearBoard-0 session in Figure 9. By confining the instructional activity to the periphery, we could differentiate patterns of visual attention to the workspace and to the partner, as seen in Figure 9. The backgammon game succeeded in engaging the subjects, and motivated them to focus on the task.

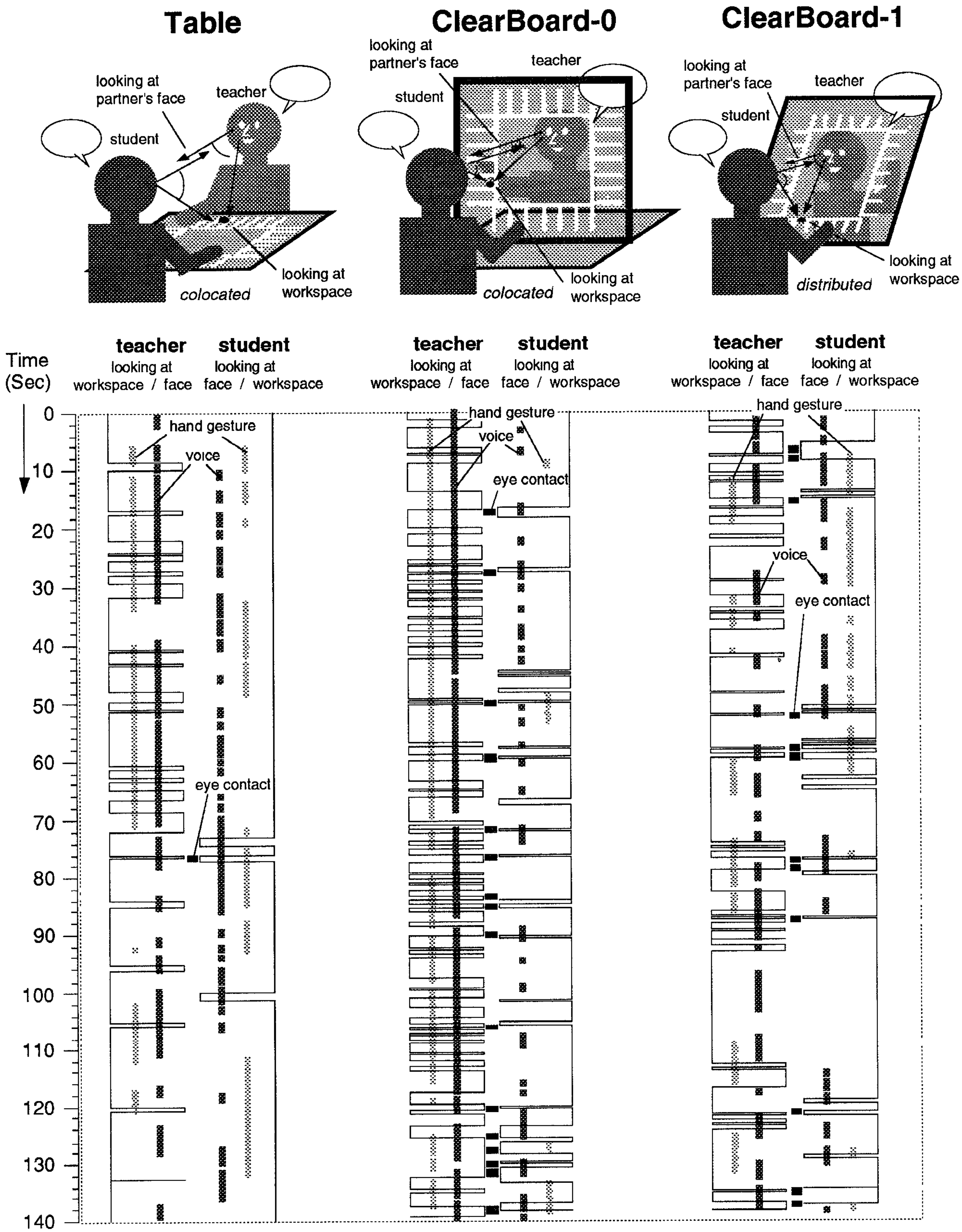

Figure 10. Time Chart of Gaze, Gesture and Speaking Pattern in Teaching Phase

Figure 9. Gaze awareness in backgammon instruction with ClearBoard-0

We used the same student-teacher pair (neither of them involved in the research effort) in three settings. The teacher, a backgammon expert, instructed the student in different backgammon tactics in three settings (table, ClearBoard-0, and ClearBoard-1). Each session took about 20 minutes, with the first half mainly being used for teaching the rules and tactics and the latter half spent playing a game using the knowledge that the student acquired. In the game playing phase, both teacher and student were often absorbed in the game, and rarely looked at each other's face in any of the settings. In the teaching phase, however, we found a big difference in the patterns of focus shifting. We analyzed the patterns of gaze, gesture and speaking in 140 second segments from the middle of each of the three teaching phases. As can be seen in the coded transcript of the patterns of conversation, gesture and gaze shown in Figure 10, there was considerably more shifting of focus between shared workspace and inter-personal space in ClearBoard-0 and 1 settings than when using the table.

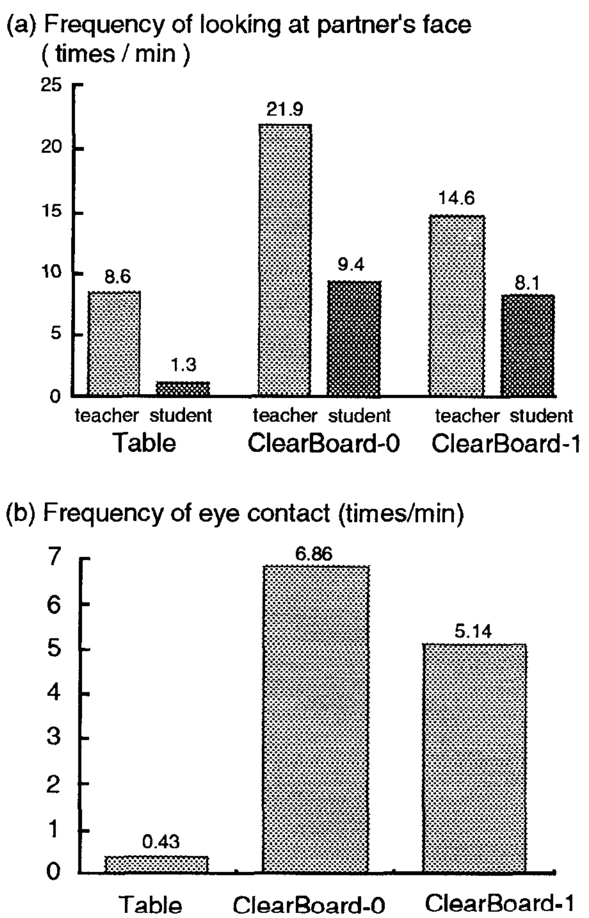

Figure 11. Frequency of Looking At Partner's Face and Eye Contact

The results of these experiments are summarized in Figure 11. They provide evidence that the participants do have a greater incidence of eye contact and focus shifts between SWS and IPS with the ClearBoard technologies. There is a decrease with ClearBoard-1 because of its lower resolution video, but the incidence is still considerably greater than the tabletop, where the separation of workspace and inter-personal space is greater.

CONCLUSION

We have described the designs of shared drawing media ClearBoard-1 and 2 which permit smooth transitions between shared workspace and inter-personal space. ClearBoard-2, in particular, can be seen as a bridge between two different technology streams: groupware technology and video conferencing technology. We expect that the seamless integration of computer-based groupware and video communication will realize the next generation of collaboration media.

Our studies suggest that users can make effective use of the ability to shift focus, making eye contact and monitoring a partner's direction of gaze. *Gaze awareness* may be crucial to the next generation of shared drawing media, a potentially useful capability that CSCW technology can greatly enhance. ClearBoard is the first system to provide distributed users with this capability.

In addition to refining the prototype systems, we plan to study visual behavior further in the context of overlaid images. Existing work on the roles of visual attention and eye contact (e.g., [2], [24]) will have to be supplemented with further research to explore the effects of the facilitated eye contact and gaze awareness provided by these technologies. We expect ClearBoard to be useful both as a collaboration medium and as a vehicle to investigate the nature of dynamic human interaction.

ACKNOWLEDGMENT

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