VideoDraw: A Video Interface for Collaborative Drawing

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This paper describes VideoDraw, a shared drawing tool, and the process by which it is being designed and developed. VideoDraw is a video-based prototype tool that provides a shared "virtual sketchbook" among two or more collaborators. It not only allows the collaborators to see each others' drawings, but also conveys the accompanying hand gestures and the process of creating and using those drawings. Its design stems from studying how people collaborate using shared drawing spaces. Design implications raised by those studies were embodied in a prototype, which was subsequently observed in use situations. Further research studying the use of VideoDraw (in comparison with other collaborative media) will lead to a better understanding of collaborative drawing activity and inform the continued technical development of tools to support collaborative drawing.

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1. INTRODUCTION

As new technology is developed to support collaborative work, it is important to understand how that technology can best be applied to help the users accomplish their work. A working group of anthropologists, computer scientists and designers, known as the Designer Interaction Analysis Laboratory (DIAL)[1], was formed to study collaborative work activity. The aims of this

[1]DIAL is a working group within the System Sciences Laboratory at Xerox PARC. This paper expresses several insights that have arisen in DIAL meetings. The members of DIAL at the time of this work were Sara Bly, Francoise Brun-Cottan, Brigitte Jordan, Scott Minneman, Lucy Suchman, John Tang, Deborah Tatar and Randy Trigg

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interdisciplinary research are both to understand collaborative activity and to build tools to support that activity. Studying actual work activity leads to an understanding of how the participants accomplish their work. Based on that understanding, design implications for tools to support this activity can be identified and embodied into prototype tools. The use of these tools can in turn be studied, leading to a better understanding of the work activity and further design implications for improving the tool being developed. Tatar [20] describes the methodology emerging from this research of integrating work practice analysis with tool design.

One focus of DIAL's research has been the activity that occurs when two or more people work together using a shared drawing surface—what we refer to as shared drawing space activity. Much human collaboration involves a shared drawing surface (e.g., paper sheets, chalkboards, computer screens, cocktail napkins) and recent research explores computer support for such shared workspaces [6]. Our studies identified some important aspects of shared drawing activity that many computational collaborative tools do not support. It seems that most computational tools are primarily concerned with the resulting artifact (e.g., text, drawing, computer file) that the collaboration produces. We have come to view shared drawing space activity as encompassing the talking, writing, drawing and gesturing activity involved in creating and making use of the marks made on the paper, not just the resulting artifacts themselves.

The VideoDraw prototype embodies some of the design implications drawn from these studies of shared drawing activity. It uses video to enable two or more collaborators, who may be located remotely, to interactively share a common drawing surface. Each collaborator sees a composite image of all the marks made by the group. Furthermore, the hand gestures over those marks are also transmitted in real time to all the collaborators. By sharing a view of the marks and gestures that each collaborator makes, they can interact through VideoDraw much as they would if they were physically sharing a sketchpad.

This paper describes VideoDraw and illustrates how studying it in use has led to improvements in its design as well as new insights into shared drawing activity. We begin with some observations about shared drawing activity that have arisen in DIAL's studies. We describe VideoDraw and how it embodies some of the design implications raised by these observations. Based on preliminary observations of VideoDraw in use, we discuss some of its features and limitations and compare it with other collaborative media.

2. OBSERVATIONS ON SHARED DRAWING ACTIVITY

The DIAL working group has been studying videotapes of drawing space activity collected from a variety of situations, including sessions of

—pairs of collaborators specifying designs for a computer system, using a whiteboard [17];

—small teams (2-4 people) of designers working on human-machine interface design tasks, using large sheets of paper on a table [1, 18];

—a small team of researchers planning research programs and papers, using a collaborative software tool in a computer-augmented meeting room (Colab) [21]; and
—a team of architects conceptualizing a design for the office of the future, working remotely using audio-video links (Media Space) [16, 22].

Through these studies, three aspects of drawing space activity were identified that have design implications for tools to support that activity:

—hand gestures are used prominently and productively;
—timing relationships help the participants understand the drawings created; and
—timing relationships and spatial arrangement help the participants negotiate their use of the shared drawing surface.

Much of the collaborators' activity involves hand gestures and these gestures accomplish substantive work: to act out a sequence of events; to refer to a locus of attention; or to mediate their interaction (e.g., raising a hand to take a turn of talk). Furthermore, these gestures are often conducted in relation to a sketch or object in the drawing space (e.g., acting out a behavior over a sketch, pointing to a drawing). These observations indicate that it is important to convey hand gestures among collaborators and to do so in a way that maintains the relationship between the gestures and their referents in the drawing space.

The significance of shared drawing activity also extends beyond the resulting marks made in the drawing space. These marks often do not make much sense when viewed by themselves afterwards. It is through the interactive process of creating and referring to those marks that the group comes to understand what the marks mean. The coordination in time among drawing, gesturing and the explanatory talk is an important resource for interpreting the marks. The value of these timing relationships is further indicated by interactional difficulties observed in work settings where the timing was disrupted, as will be discussed later.

In face-to-face interaction, collaborators make use of a familiar sense of time and space to negotiate sharing a drawing surface. Although the collaborators may not be consciously aware of it, this negotiation often involves intricate relations in time (e.g., timing drawing activity with taking a turn of talk to get the group's attention) and space (e.g., coordinating hand motions to avoid collisions over the drawing surface). Often more than one participant is active in the drawing space at the same time, yet their ability to smoothly negotiate this activity in time and space avoids any confusion.

Another sense of spatial arrangement that influences the use of a shared drawing surface is the relationship between the collaborators and the drawing surface. For example, when using a wall-mounted chalkboard, the participants usually have to leave their seat and walk to the chalkboard to work at it. Alternatively, if the collaborators are working around a table with large paper sheets in their midst, everyone can easily reach the drawing surface. However, some drawings may appear upside down or at odd orientations to

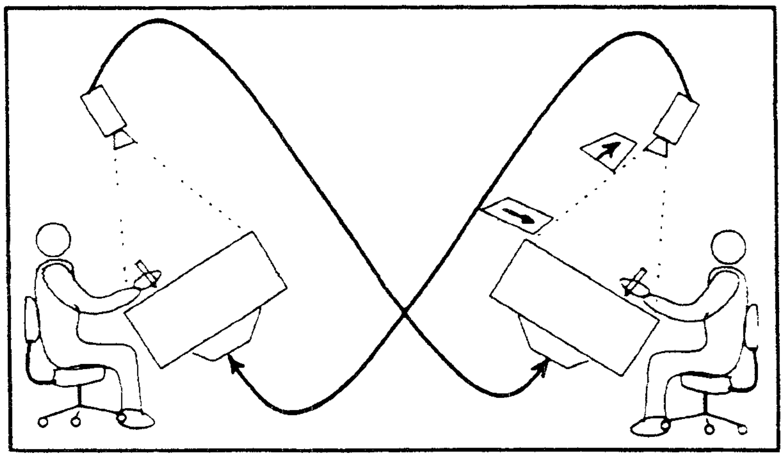

Fig. 1. Schematic diagram of two-person VideoDraw.

some of the participants that are working around a table, while viewing a chalkboard maintains a uniform, upright orientation for all the collaborators.

It is because these aspects of shared drawing activity occur without requiring any undue effort that sharing a drawing surface can be accomplished so smoothly. On the other hand, introducing technology to support shared drawing activity can disrupt these natural mechanisms. Computers, for example, can introduce delays that can disrupt real-time interaction. By beginning with some understanding of how people naturally accomplish shared drawing activity, we were able to design VideoDraw to afford many of the familiar mechanisms for accomplishing that activity.

3. VIDEODRAW: A COLLABORATIVE DRAWING PROTOTYPE

VideoDraw is a prototype to support collaborative drawing activity that embodies design implications based on observations from DIAL's studies. We designed and implemented a two-person VideoDraw prototype and studied how people used it in actual collaborative activity.

3.1. The Design of VideoDraw

A schematic diagram of VideoDraw is shown in Figure 1. In this configuration, VideoDraw allows two people to share a drawing surface. It consists of video cameras aimed at the display screens of video monitors, interconnected as shown. The participants use whiteboard markers (dry erase ink markers) to draw directly on the surface of the display screen. As each collaborator draws on the screen, the video camera transmits those marks *and* the accompanying hand gestures to the other collaborator. Each collaborator can add to a sketch that appears on the display screen and those additional marks and gestures are transmitted back to the other collaborator. At all times, a complete image consisting of real and "video" marks is visible on all the collaborators' screens. The collaborators can draw, erase, and gesture over the VideoDraw screens much as if they were sharing a pad of paper.

Figure 2 shows a picture of a two-person VideoDraw configuration within one room and Figure 3 shows a view of a VideoDraw screen as seen by the participant. Stations located in remote locations should be augmented by additional communication links (e.g., audio, video) between the collaborators. Although the utility of VideoDraw is most clearly demonstrated in the context of supporting the shared drawing activity of people in physically remote locations, the insights emerging from studying its use have implications for collaborative work in general.

Because a large part of the image that the video camera captures is eventually displayed on the video monitor that the camera is imaging, video feedback is a potential problem in this configuration. Video feedback between the two camera/display pairs is controlled by polarizing sheets covering the surface of each display screen and nearly orthogonal polarizing filters on the camera lenses.

3.2. Studying the Use of the Prototype

An initial prototype version of a two-person VideoDraw was operational for several months. During that period, several informal uses, some structured uses, and one extended use of the system were observed and videotaped for later analysis. In the observed informal uses, VideoDraw was set up within one room, as in Figure 2, and pairs of colleagues were invited to experience using it. The participants typically worked on a small problem of their own choosing for five to ten minutes.

In the structured uses of VideoDraw, the stations were placed in separate rooms and connected by an audio-video (Media Space) link, as shown in Figure 4. In addition to a VideoDraw station, each participant had a video camera and monitor conveying a frontal view of the collaborator's face and upper body. Telephone headsets or balanced audio channels provided a full-duplex audio connection. Fourteen pairs worked for 10-15 minutes on a conceptual problem solving task given to them.

In the extended use of VideoDraw, the participants were also located remotely. The pair of collaborators were familiar with working together from previous collaborations. They worked on a user interface design task of their own choosing for approximately 1-1/2 hours.

4. FEATURES OF THE USE OF VIDEODRAW

Based on our preliminary observation of VideoDraw in use, we have seen evidence that VideoDraw successfully embodies the design implications raised by DIAL's studies of shared drawing activity. We have observed that VideoDraw:

—conveys hand gestures among the participants;

—does not introduce problematic time delays into the interaction;

—affords a novel sense of spatial relationship among the collaborators and drawing space; and

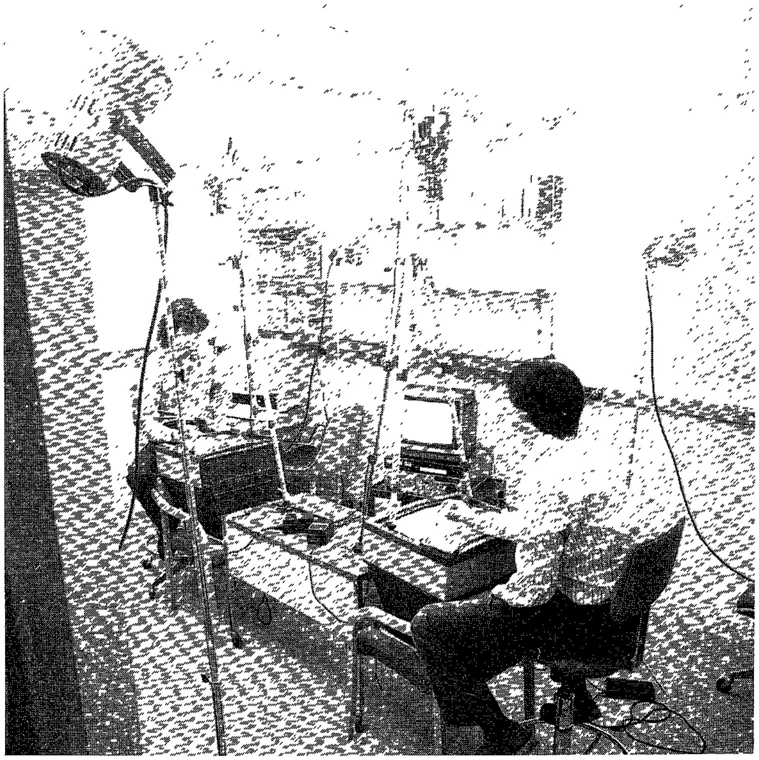

Fig. 2. Prototype setup of a two-person VideoDraw.

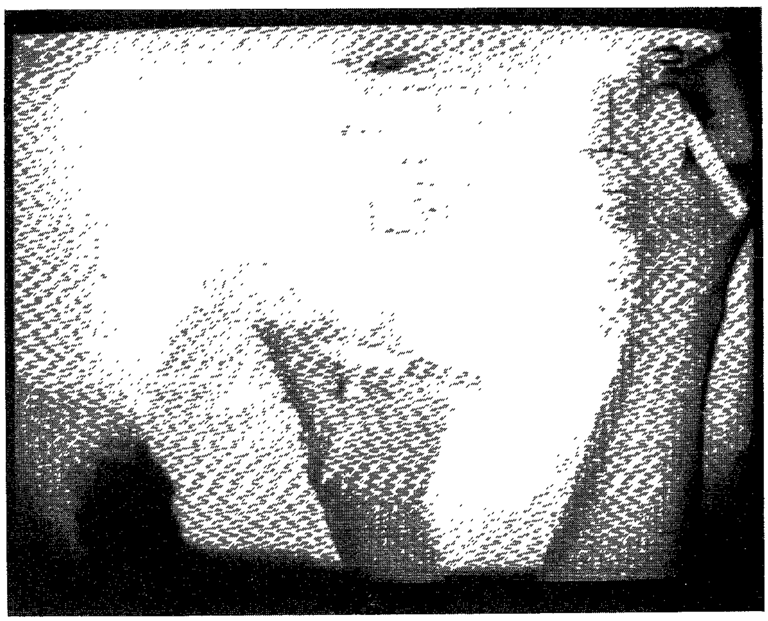

Fig. 3. Participant's view of a VideoDraw screen.

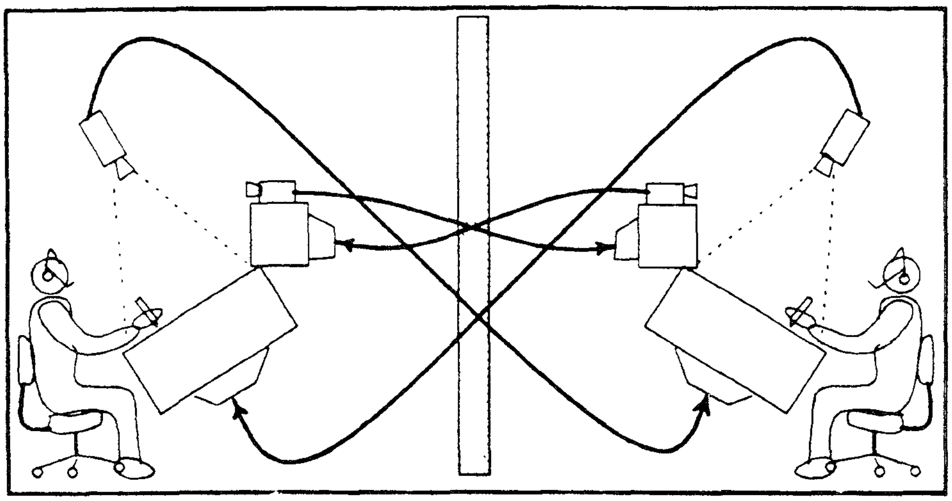

Fig. 4 Schematic diagram of VideoDraw connecting remote locations.

—allows multiple participants to have concurrent access to the drawing space.

These features are discussed individually and illustrated with examples from the observed uses of VideoDraw.

4.1. Conveying Hand Gestures

Although there is a long history of studying gesture as part of human interaction [8], we focused on the use of hand gestures in relation to drawing and other activity in the drawing space. DIAL's studies of drawing space activity indicated the importance of conveying hand gestures and their relationship to the drawing space. Hand gestures are often enacted with respect to sketches on the drawing surface to convey information. Figure 5 shows how these hand gestures are conveyed in VideoDraw; a participant is gesturing to indicate an operation on an object in a proposed user interface. The effectiveness of gestures of this type depends on maintaining the relationship between the hands and the sketches on the VideoDraw screen. A sequence of actions can be enacted with respect to a drawing on the screen or specific locations on the screen can be pointed at and those gestures and their referents are communicated to the other collaborators.

Furthermore, Figure 5 shows that VideoDraw conveys gestures that may involve two hands and/or multiple fingers. This communication of gesture is much richer than most computational systems afford (typically a cursor tracking a mouse that is operated by one hand). VideoDraw also conveys a sense of three-dimensional activity. Users can enact gestures in space, or even bring physical objects into the view of the camera, and a three-

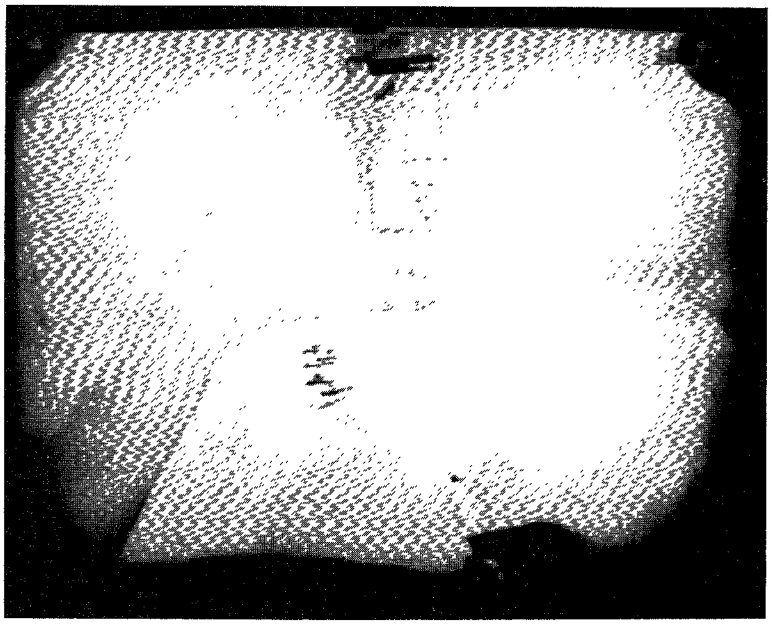

Fig. 5. Conveying gestures in VideoDraw.

dimensional sense of spatial relationship is conveyed to the other participants. We observed several uses of this sense of three-dimensionality.

4.2. Preserving Relationships in Time

DIAL's studies of drawing space activity showed that the collaborators rely on intricate relations in time among various activities. For example, one problem observed in Colab, a computer-based collaborative tool, was that the computer sometimes introduced time delays from processing and transmitting the data. These delays could disrupt the timing relations between the group's dialog and what was appearing on the computer screens [21]. In the current implementation of VideoDraw, using full-bandwidth video connection, there are virtually no transmission delays between the two screens. Figure 6 indicates how a collaborator can time a deictic reference with pointing at the object on the screen. The collaborators can coordinate the timing of their activities much as they would be able to in familiar face-to-face settings.

4.3. Offering a Novel Sense of Spatial Arrangement

In DIAL, we also observed that shared drawing activity is structured by the spatial relationships among the collaborators and the drawing surface. VideoDraw offers a novel sense of spatial arrangement that provides the advantages of being both side-by-side and face-to-face. Each collaborator can see the drawing surface in a proper, upright orientation, as if looking at a

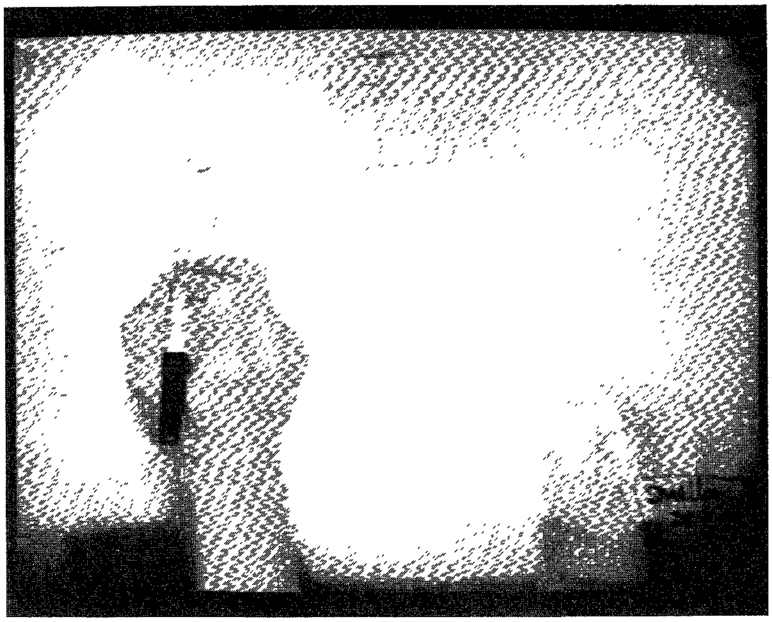

Fig. 6. Pointing, coordinated with saying "you've got this already?"

chalkboard or a sketchpad together side-by-side. Furthermore, anyone can also easily reach in to work on the drawing surface at any time, since each collaborator is positioned directly in front of a VideoDraw station. At the same time, they can look at each other's faces (either directly or through the frontal video cameras and monitors), as if they were sitting face-to-face. In our observed uses of VideoDraw, the collaborators were able to take advantage of being face-to-face and side-by-side without any confusion.

One feature of this sense of spatial arrangement that VideoDraw provides is that it allows both a common orientation to the shared drawing surface and easy access to it by multiple collaborators. The participants can collaboratively construct sketches and lists without having to crowd around the same physical surface. Figure 7 shows sketches and lists where both collaborators were involved in creating the marks, taking advantage of this common orientation and easy access.

In the uses of VideoDraw that we have observed, the users spend most of their time looking at the shared drawing surface rather than at each other's face. Users would occasionally glance up to look at each other during their interaction, much as they would if they were working together over a shared sketchpad. Extended face-to-face viewing was maintained when the topic of conversation did not refer to images in the workspace (e.g., metalevel discussions). Although looking at each other's faces was relatively infrequent, being able to do so is an important resource for effective interaction, especially during lengthy remote collaborations.

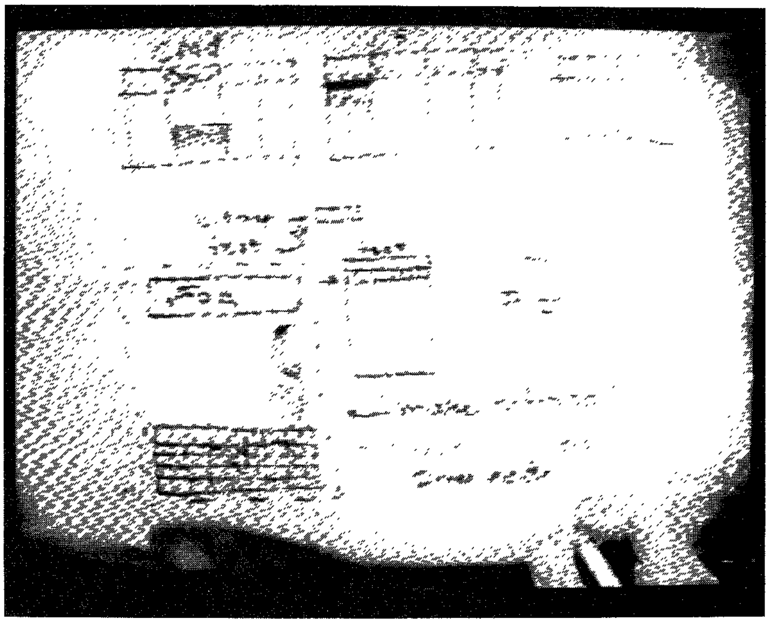

Fig. 7. Collaboratively constructed image (lighter marks are from one participant, darker marks are from the other)

4.4. Allowing Concurrent Access

DIAL's studies noted that drawing space activity often involves more than one person being active in the drawing space at the same time. While this concurrent activity might be considered to be a source of confusion for the collaborators, we found that being able to access the drawing space at the same time was actually helpful to their ability to smoothly negotiate their collaborative use of it. By analogy to sharing an audio channel, people usually avoid speaking over each other's talk for an extended period of time. However, having concurrent access to the audio channel (including overlapping or interrupting speech) is actually a valuable resource for accomplishing smooth turn-taking in talk [5]. The use of this resource is demonstrated by the problems encountered when using half-duplex audio connections, which only transmit one party's talk at a time. In overseas telephone lines and some video teleconferencing facilities, half-duplex connections contribute to making it difficult to achieve smooth turn transitions.

Similarly, concurrent access to the drawing space is an important resource in negotiating the use of a shared drawing surface. Figure 8 shows two participants' hands working over the screen at the same time. It also shows that their hands can actually be closer to each other in VideoDraw than if they were physically sharing the same drawing surface. We have observed several instances of the use of concurrent access in VideoDraw to help negotiate sharing the drawing surface.

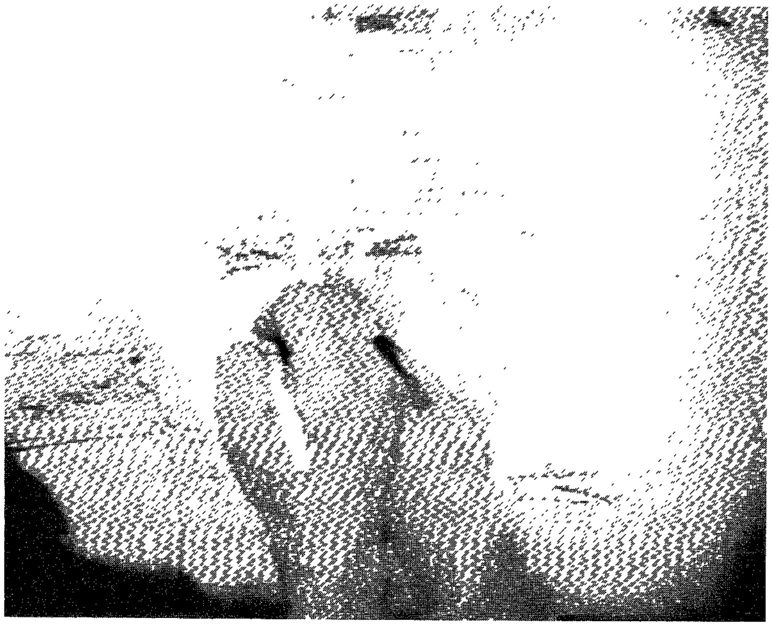

Fig. 8. Multiple hands active over a VideoDraw screen.

5. LIMITATIONS IN USING VIDEODRAW

Several limitations in the use of VideoDraw were also observed. A major constraint is the amount of legible information that can be effectively conveyed within the screen area of the twenty-inch diagonal video monitors used for the display screens. Due to the limited resolution of video in combination with the thickness of the dry erase whiteboard markers, the users' marks quickly filled up the screen, prompting them to erase and start again with a clean screen. Consequently, the users did not have convenient access to the images they created on previous screens. More recent research has been exploring the VideoDraw concept in a large area, chalkboard-sized prototype known as VideoWhiteboard [19].

In VideoDraw, each participant's marks are actually made and presented on different surfaces. Therefore, each participant can only erase marks made on his or her own screen and cannot edit the marks of the other collaborator. Several incidents where one collaborator requested that the other erase some marks were observed. Also, because of the thickness of the glass screens on the video displays, there is a noticeable amount of parallax between the marks drawn on the glass surface of the screen and the video image of the other participant's marks appearing on the phosphor layer of the screen. The parallax sometimes made it difficult to correctly align marks between the participants.

The marks drawn directly on the screen surface and the video marks appearing on the screen are of noticeably different intensity and resolution, as can be seen in Figures 7 and 8. This dissimilarity sometimes leads to problems in being able to view a collaboratively constructed VideoDraw sketch as a single image. However, in one of the observed sessions, where the participants were working on an architectural layout, the collaborators used this property to create two distinguishable drawing layers, much like separate sheets of tracing paper. One participant drew the lines representing a first floor plan, while the other added the plans for the second floor directly over the first. They were able to use this effect as a resource to permit viewing the floor plans superimposed in a single view.

The current VideoDraw prototype also has some rather uncomfortable human factors. Users must straddle the 20″ diagonal video displays in order to get close enough to the drawing surface. They must also keep their heads out of the way of the overhead video cameras. Viewing the display screen off axis in order to avoid blocking the camera view also exaggerates the parallax problem mentioned earlier. Because VideoDraw is constructed with only video equipment, it does not offer the familiar computational capabilities of printing, storing, retrieving, and editing images. We have been exploring ways of integrating the VideoDraw concept with our other research on computationally-based shared drawing spaces [12]. Ishii [7] also describes a shared workspace that merges video and computer technology.

6. OTHER COLLABORATIVE MEDIA

It is instructive to compare VideoDraw with other collaborative media. Computer-augmented meeting rooms [11, 15] and shared window systems [10] are computational systems that support collaborative work. These systems make available much of the computing power of personal workstations to participants in a collaborative context. However, as mentioned earlier, computers often introduce time delays that can disrupt group interaction. Computers also do not effectively transmit hand gestures (other than a cursor tracking hand motions). Furthermore, computational systems tend to dilute personal distinctions in drawing space activity (e.g., typed input versus handprinting, nondistinguishable cursors versus hands), diminishing the identification cues that are available to the collaborators. Smith et al. [14] explore how to provide some of these cues in a shared virtual world with a system known as SharedARK.

Video teleconferencing systems use video to support collaboration across remote distances [2]. However, most conventional video conferencing systems focus on providing views of the participants or presenting graphical images from one site to the other. They do not offer an interactively shared drawing surface that both sites can work on, limiting the kind of shared work that can be accomplished. More work is needed to explore how VideoDraw could be constructed with long distance transmission technologies, such as those used in video teleconferencing that have reduced bandwidth video and time delays due to transmission.

VIDEOPLACE [9] is a novel interactive computer system that converts a live video image of a participant into a computationally represented silhouette. Through this silhouette, features from the video signal can be detected as input to a variety of computational operations. One application enables participants to use the tips of their fingers to "draw" in space. At the CHI '89 conference [13], VIDEOPLACE was demonstrated in a collaborative configuration where users at two different sites could interact together. VideoDraw differs from VIDEOPLACE in that VideoDraw offers a sense of three-dimensionality by using the actual video image, not a computational silhouette of the image. Furthermore, in VideoDraw the drawing surface is overlaid directly on top of the display surface; in VIDEOPLACE the input focus (drawing in space) and output focus (watching a computer monitor) are separated, introducing a level of indirection in the drawing activity. VideoDraw offers a different perceptual experience among the collaborators than VIDEOPLACE.

More recently, virtual reality technologies enable users to perceive and interact with a computer-generated environment [3]. By wearing stereoscopic computer display goggles and gloves that translate hand and finger movements into input signals to a computer, users can experience a virtual world (that can include other collaborators) and manipulate objects in that world. However, the effectiveness of virtual reality depends on the ability to computationally simulate the perceptual cues and resources that people use to interact with the world. Current virtual reality technologies can graphically render only a limited amount of realism and require the user to wear goggles and gloves that are tethered to the computers. In contrast to using computers to try to *simulate* reality, VideoDraw *conveys* a view of reality through the rich media of video.

VideoDraw is not a replacement for these other collaborative systems. Rather, it is a research prototype for examining collaborative activity from a new perspective to identify what elements of shared activity are crucial to the interaction. At least two other research groups [4, 7] have built collaborative workspace systems largely based on the VideoDraw concept. By experimenting with VideoDraw, our intent is to raise issues for the designers of collaborative systems and provide a clearer sense of the impact of their design decisions on how their systems will be used.

7. CONCLUSION

VideoDraw is a novel prototype to support collaborative drawing activity. Its design incorporates studying collaborative work practice with developing the technology. The design of VideoDraw came as a direct result of noticing some important resources being used in collaborative work activity (e.g., hand gesture, timing relationships) that were not being supported by existing computational collaborative tools. Observing VideoDraw in use is helping us further probe collaborative work activity from a new perspective and reveal ways in which VideoDraw can be improved. The development of VideoDraw is itself a demonstration of the value of integrating studies of work practice in the design process.

Based on studies of shared drawing space activity, we constructed a VideoDraw prototype that conveyed hand gestures, did not disrupt timing relationships, offered a new sense of spatial relationships and allowed concurrent access to the drawing space. Preliminary observations of VideoDraw in use indicate that it provides collaborators with an enhanced sense of interaction not found in conventional computer-supported collaborative tools.

VideoDraw enables participants to do new things in familiar ways. It allows remote collaborators to share a drawing surface in much the same way that they would share a sketchpad if they were in the same room. It enables collaborators to be face-to-face and side-by-side at the same time without introducing any confusion in the interaction. It also allows the collaborators' hands to work more closely together than would be physically possible, without distracting the users. In part, this familiarity of use of VideoDraw stems from its grounding in DIAL's studies of how collaborators currently work in shared drawing spaces.

In studying collaborative activity, we have adopted the term "copresence" to describe a sense of awareness among collaborators that facilitates group interaction. We believe that remote collaborators will have more of a sense of copresence when they are able to draw upon the resources that are commonly used in face-to-face interaction. Based on our observations of VideoDraw in use, we believe that it affords a heightened sense of copresence compared to current computer-based collaborative tools. The video image superimposed on the drawing surface appears to provide participants with a greater sense of awareness of their collaborators. Seeing the marks on the drawing surface and the video image transmitting gestures and sense of space around those marks provides an awareness that helps the collaborators interpret those marks and negotiate using the shared drawing space.

Understanding what aspects of VideoDraw help create this sense of copresence will require further study. A better definition of what copresence is and how tools can provide or augment a sense of copresence among collaborators is needed. By studying copresence and how to provide it, we hope to understand collaborative activity better and to design new tools to support it more effectively.

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