TOWARD AN OPEN SHARED WORKSPACE: COMPUTER AND VIDEO FUSION APPROACH OF TEAMWORKSTATION

Groupware is intended to create a shared workspace that supports dynamic collaboration in a work group over space and time constraints. To gain the collective benefits of groupware use, the groupware must be accepted by a majority of workgroup members as a common tool. Groupware must overcome the hurdle of *critical mass.*

People do much of their work alone, without computers or with various tools on different computer systems, and have developed their own work practices for these situations. In order to get groupware accepted, *continuity* with existing individual work environments is the key issue because users work in either individual or collaborative modes and frequently move back and forth. Groupware that asks them to abandon their familiar tools, methods, and even computer hardware and software, and to learn a new system, just to gain benefits in communication or coordination, is likely to encounter strong resistance. Many case studies have shown that if the tools force users to change the way they work, then the tools are generally rejected [8].

Mark Stefik pointed out that the key idea for the next generation of collaboration technology is the *seamlessness* between individual and group work.[1] He insisted that group tools (groupware) must merge with individual tools. It is not easy, however, to develop a self-contained and wholly integrated environment over a variety of computer systems that support both individual and cooperative work, because each member may have very different preferences regarding individual tools and working methods. A member may like organizing his/her thoughts with an outline processor running on a book-size computer, and another member may prefer drawing on a sheet of paper with his/her favorite fountain pen to represent his/her idea.

Even in a heavily computerized individual work place, users often work both with *computers* and on the physical *desktop*, and frequently move back and forth. Neither can replace the other. For example, printed materials such as books and magazines are still indispensable sources of information. Therefore, when designing real-time shared workspaces, depending on the task and the media of the information to be shared (paper or computer file), co-

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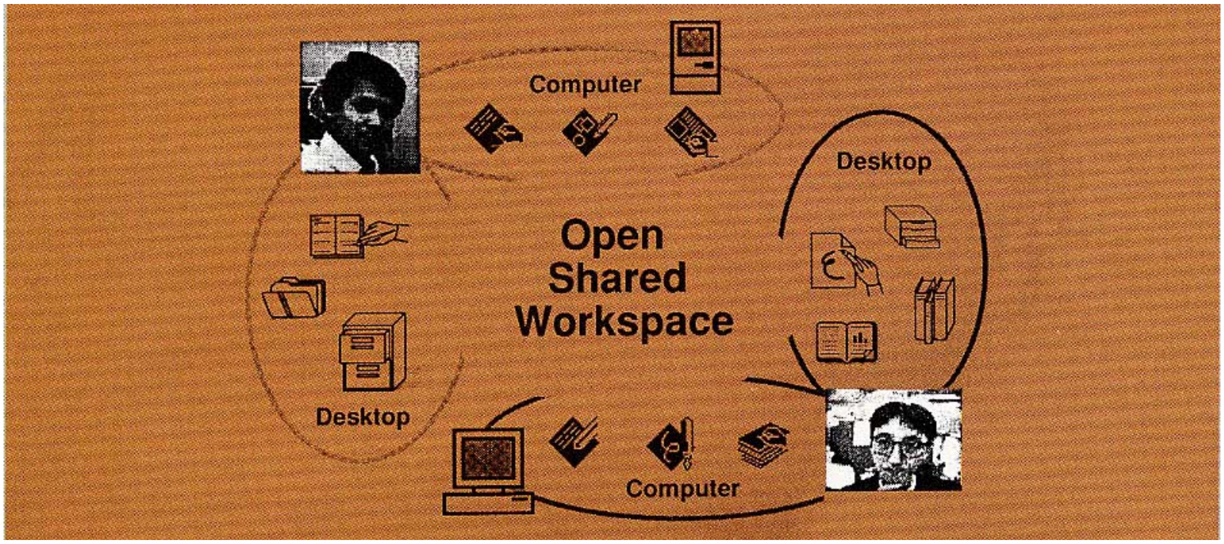
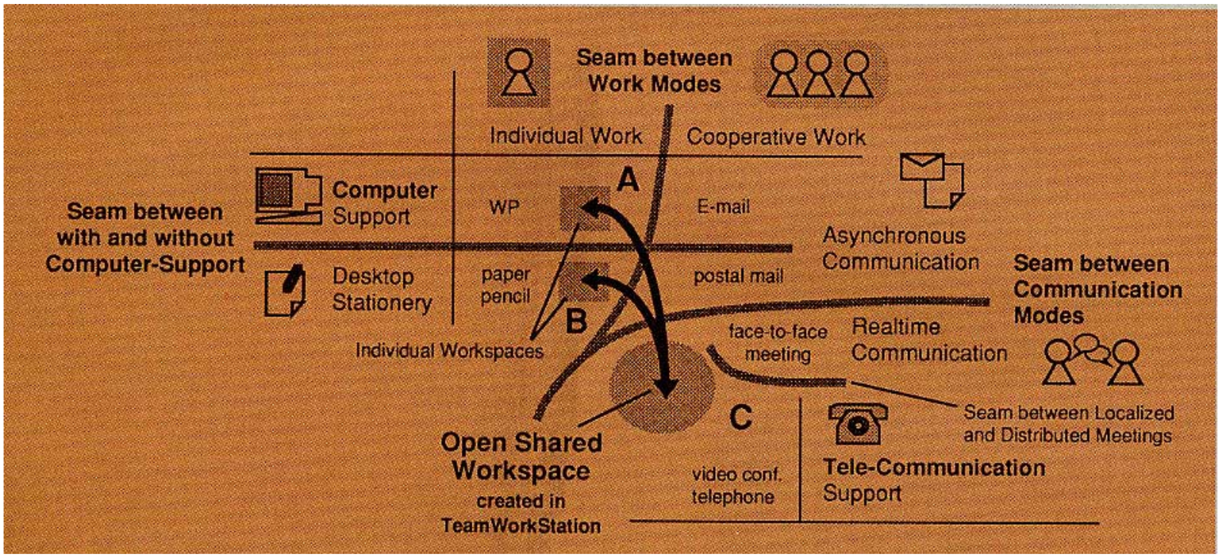




	Computer-Based Approach			Video-Based Approach	
Approaches	Computer sharing (a)	Shared window system (b)	Collaboration-aware multi-user application (c)	Computer-controlled video environment (d)	Direct drawing over the image of coworker's drawing surface (e)
Diagram	single-user application; shared computer; control; one user at a time	single-user application; shared window; control; one user at a time	multi-user application; multiple users simultaneously	desktop image; face image; multiple users simultaneously	image of coworker's drawing surface; multiple users simultaneously
Examples	• co-located meeting support CaptureLab [8, 9] • remote screen sharing Timbuktu [10]	• desktop conference system DPE [11], Rapport [12] • shared window system VConf [13], Dialogo [14]	• group editor Cognoter [16], Grove [17]	Media Space [18, 19] IIIF [20] CAVECAT [21] CRUISER [22]	VideoDraw [7] VideoWhiteboard [23]

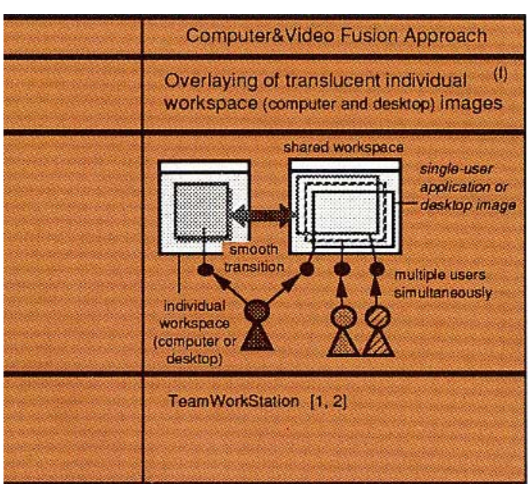
workers should be able to choose either computers or desktops, and to switch between them freely. This choice should be *independent* of the other members' choices. Group members should be able to use a variety of *heterogeneous* sets of tools (computer-based and manual tools) in the shared workspace *simultaneously.* We call such a space the "open shared workspace." Figure 1 illustrates this concept.

One important feature of face-to-face collaborations is the role of the "shared drawing space" such as a white board. Bly, Tang, Leifer and Minneman pointed out that it plays a very crucial role—not only in storing information and conveying ideas, but also in developing ideas and mediating interaction, especially in design sessions [2, 23, 24]. The open shared workspace should incorporate this shared drawing space concept and extend it by allowing the simultaneous use of both computer and manual tools. The shared workspace must support *direct interaction* among co-workers by allowing any member to directly point to and draw on other members' workspaces in real time.

FIGURE 1.
Concept of open shared workspace

FIGURE 2.
Seams in current CSCW environment

FIGURE 3.
Approaches to real-time shared workspace design



Current groupware has not effectively supported this concept of openness in shared workspaces. *TeamWorkStation* (TWS) solves this problem for real-time distributed collaboration. We chose *video* as the basic media of TWS because it is the most powerful media for fusing a variety of traditionally incompatible visual media such as papers and computer files.

The TeamWorkStation is designed to establish an open shared workspace by fusing distributed group members' workspaces, including both computers and desktops. We identify the role of open shared workspace in the support of a broad range of dynamic collaboration activities that cannot be supported consistently by existing task-specific highly structured groupware.

Seams and Design Approaches

The new shared workspace is required to be "open," in the sense that no new piece of technology should block the potential use of already existing tools and methods. A new piece of technology inevitably introduces with it the burden of learning. It is also often coupled with the introduction of seams and discontinuities from the old work practices. The world is filled with many seams. The current variety of application programs running on the same or different platforms creates seams of incompatible data formats and inconsistent human-computer interfaces. These seams increase the users' cognitive load.

Figure 2 illustrates a view of the major seams in current computer and communication-supported work environments. Some seams are easy to overcome, some are more difficult. For example, the seam between computer-supported work **A** (e.g., word processing) and the work supported by traditional desktop stationery **B** (e.g., writing with pen on a paper) is not easy to overcome because of the necessity of media conversion using special equipment such as image scanners, optical character readers, or printers.

The gap between computer-support **A** and telecommunication support **C** is also difficult to overcome because of the differences in time characteristics (store and read vs. real time), media (text and graphics vs. live video and sound), and the support technologies (computer and LAN vs. telephone and PBX).

Two major approaches, computer-based and video-based, have been proposed to realize real time shared workspaces for distributed groups. Figure 3 illustrates these previous approaches and the fusion approach of TWS.

Computer-Based Approaches

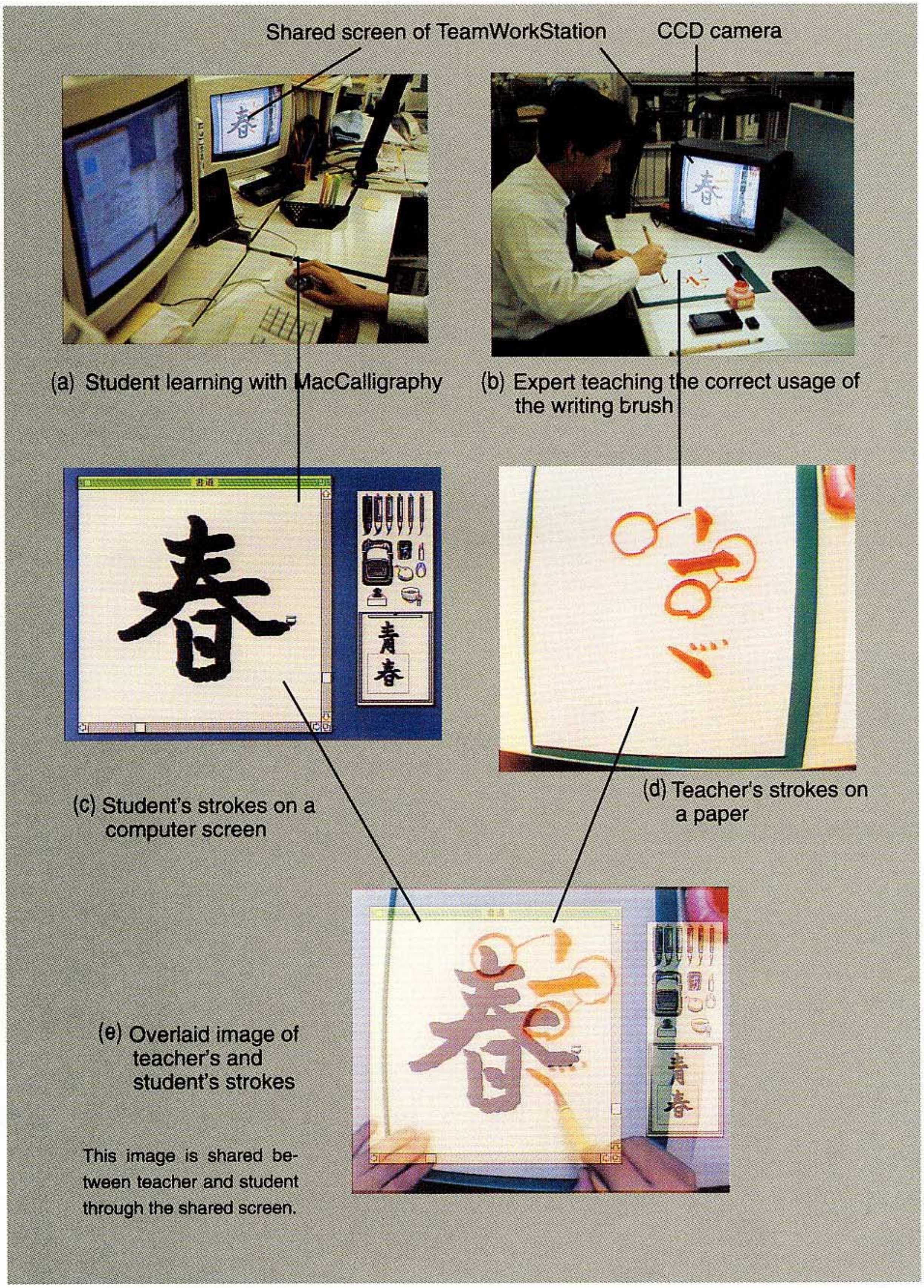
Computer-based approaches try to bridge **A** to **C** by enhancing computer programs so that data and programs can be used by a group in real-time collaboration.

Computer sharing (Figure 3 (a)), and the shared window system (Figure 3 (b)) allow users to execute existing single-user applications in a shared display or shared window. There is no need to modify existing single-user application programs for group use. All the users must use the same shared application programs, however, and usually only one user can control the shared application program or computer at a time.

Another approach is to implement new collaboration-aware[2] multiuser application programs for particular tasks (e.g., group editing) (Figure 3 (c)). In this type of system, multiple users can control the editing cursors independently, and an access control mechanism for smaller grain size objects (e.g., words on a screen) can be provided. Significant programming effort is

[1]Mark Stefik made this statement in the video that introduced Colab project of Xerox PARC [7].

[2]The word "collaboration-aware" was coined by Lauwers and Lantz [15].


Shared screen of TeamWorkStation
CCD camera
(a) Student learning with MacCalligraphy
(b) Expert teaching the correct usage of the writing brush
(c) Student's strokes on a computer screen
(d) Teacher's strokes on a paper
(e) Overlaid image of teacher's and student's strokes
This image is shared between teacher and student through the shared screen.

needed, however, to write new multiuser application programs. Discontinuity with existing single-user applications, and response delays caused by updating the collaborators' shared views can also be problems.

All three of these computer-based approaches can handle only information stored in computers of a specific architecture. These approaches suffer from a lack of flexibility in that information outside the computers cannot be utilized. Users are still stuck with a rather large seam between the computer **(A)** and the actual desktop **(B).**

Video-Based Approaches

The second type of approach utilizes video communication technology that belongs to area **C** in Figure 2.

The computer-controlled video environment, "Media Space" [10, 21] pioneered the use of video technology for the support of remote collaborations.[3] Media Space made video available as a work media, and the video was used to see coworkers' faces and drawing images (Figure 3 (d)). Recent development of computer-controlled video environments include CRUISER [19], IIIF [3], and CAVECAT [17]. In these systems, since each member's workspace images are spatially separated in multiple screens or windows on a screen, direct pointing and drawing over coworker's workspace image is hard to achieve.

Tang and Minneman showed a new way to design shared drawing space in their "VideoDraw" [24] by allowing users to draw directly over the image of coworker's drawing surface (Figure 3 (e)). VideoDraw allows users to draw on a shared surface simultaneously, and convey hand gestures without any time delay. VideoDraw, however, restricted the targets to be shared to the images (e.g., hand-drawn images and hand gestures) on a special transparent sheet attached to the surface of a TV monitor. No papers or printed materials can be used in the collaborative session.

These video-based approaches successfully mediate dynamic interactions, and a group can share information on physical desktops **(B)** if the system provides cameras to capture desktop surface images. However, they suffer from a lack of flexibility in that information stored in computers **(A)** cannot be utilized directly. Although these video-based systems can be used in conjunction with a shared computer application described in Figure 3 (a)-(c), video and computer are not integrated. Users still encounter a large seam between the video communication technologies **(C)** and computer technologies **(A).**

Fusion Approach of TeamWorkStation

TWS is designed to bridge gaps between personal computer **(A),** desktop **(B)** and telecommunication **(C)** as marked in Figure 2 and so realize the open shared workspace. The goal of TWS design is to provide distributed users with a real-time open shared workspace which every member can see, point to, and draw on *simultaneously* by using *heterogeneous* personal tools.

In order to satisfy the requirements of open shared workspace, the author devised the key TWS design idea, translucent overlay of individual workspace images[4] as illustrated in Figure 3 (f). This technique consists of superimposing two or more translucent live-video images of computer screens or physical desktop surfaces. The overlay function created with this video synthesis technique allows users to combine individual workspaces, and to point to and draw on the overlaid images simultaneously. Therefore, the entire task space is *open* to other members.

Figure 4 illustrates an overlay process in the remote teaching of calligraphy. The student uses MacCalligraphy™ (a calligraphy simulation program), while the teacher uses actual brush, ink and paper.

Figure 5 (a) shows the appearance of the TWS prototype. The individual screen and the shared screen are contiguous in video memory. Two CCD video cameras are provided at each workstation: one for capturing live images of the member, and the other for capturing the desktop surface images and hand gestures. For ease of use, the camera capturing the desktop image is mounted on a flexible desk lamp.

Figure 5 (b) shows an example of a shared screen image. Two users are discussing the system architecture by using a draw-editor, a hand-written diagram, pens, and hand gestures simultaneously. Face images can be displayed in windows on the shared screen. A speaker phone is used for hand-free face-to-face conversations in conjunction with these face windows.

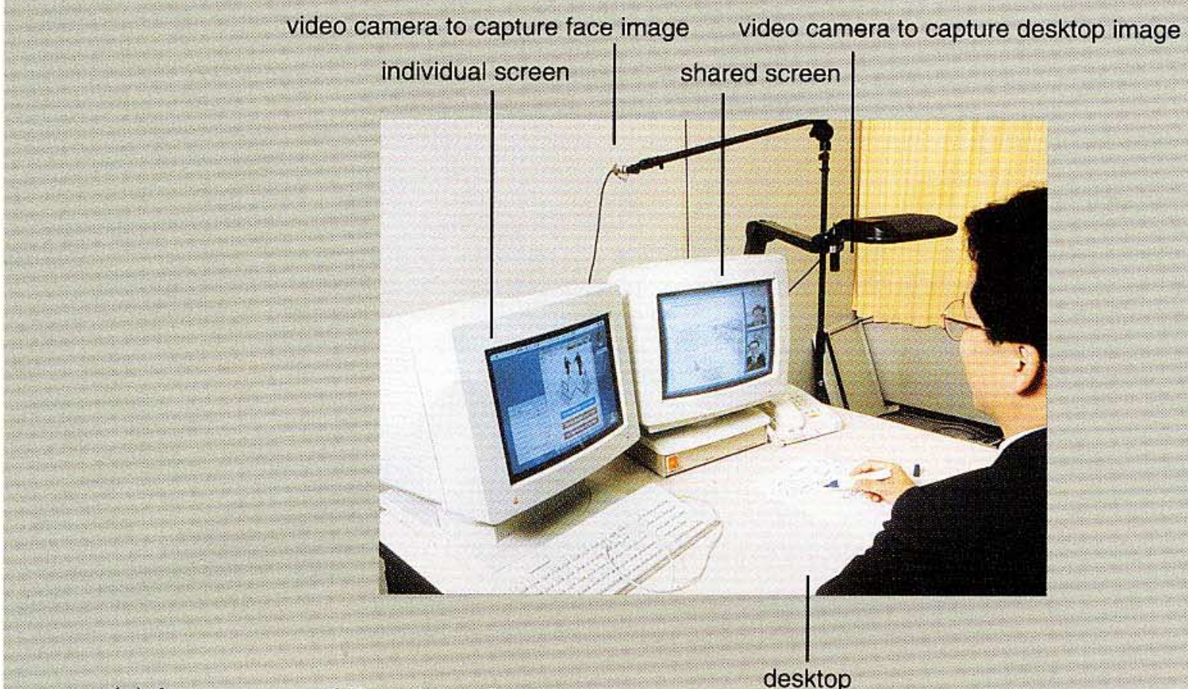
Translucent overlay is a very simple, intuitive, yet powerful concept because it has much more flexibility than the existing task and window-system specific groupware approaches. Overlaid video images provide users with rich semantics that they can easily interpret. We find that users can differentiate up to three overlaid video images without much difficulty. One drawback of this overlay approach is that the results of collaboration cannot be shared directly. Another drawback is that the quality of overlaid video images is not as sharp as most computer displays. These problems are discussed in the following section.

Shared workspace is taken by many computer people to mean data sharing.[5] We think, however, it is not necessary that all outcomes of the work-in-progress be directly "manipulatable" by all the participants. Psychological studies on collaboration highlight the important

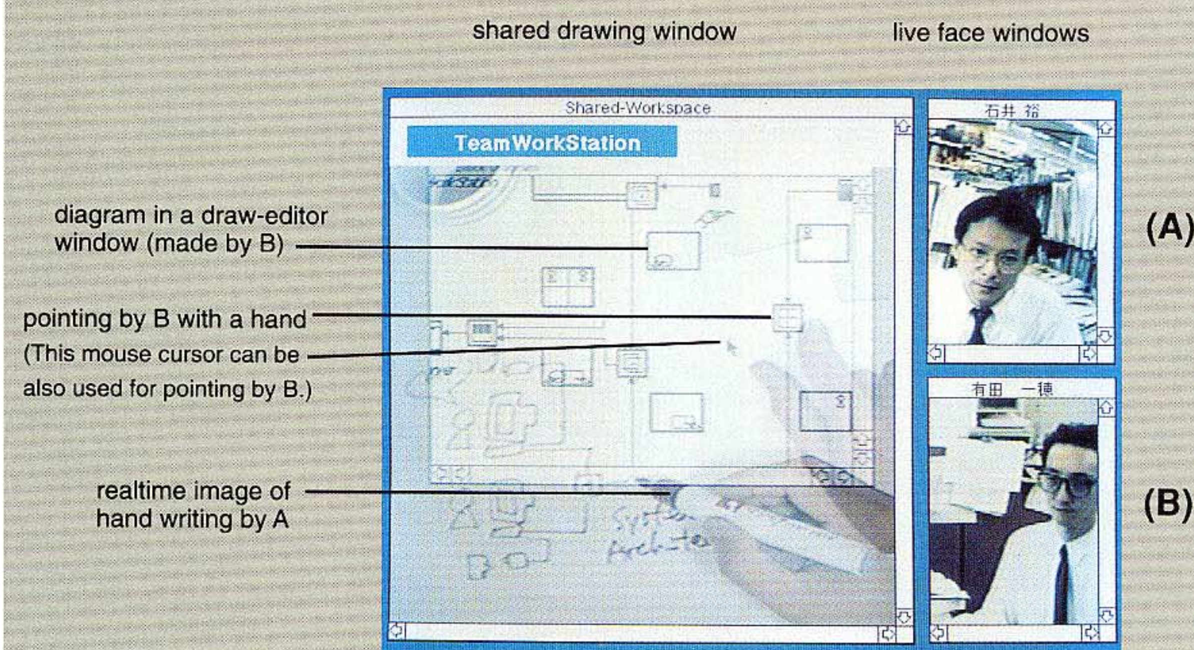
FIGURE 4.
Translucent overlay process in remote teaching of calligraphy

[3]Our work was motivated by their Office Design Project [26] that utilized Media Space for collaborative building design by geographically distributed architects.

[4]VideoDraw [24] led Ishii to come up with the *translucent* overlay idea.



(a) Appearance of TeamWorkStation



(b) A Shared Screen in Design Session

aspect of the shared task space. A detailed study of two-person joint problem solving indicates that the natural form of constructive collaboration is a type of *role division:* One member performs the complete task while the other monitors the progress [18]. The monitor does not get engaged directly in the work being done by the performer of the task. They work on different layers: The performer on the first layer, and the monitor on one layer above. It is important that the monitor and the performer share the entire visual space, open to both perspectives. These observations support the overlay approach to create real-time shared workspaces.

Cognitive Seamlessness Achieved in TeamWorkStation

TWS was designed to bridge the gaps between personal computer **(A),** desktop **(B)** and telecommunication **(C)** in Figure 2. Through the experimental use of TWS described next, however, we found Figure 2 shows just a superficial view of seams and TWS functions. We realized that the essence of TWS approach is not the functional seamlessness but the *cognitive seamlessness* that is achieved in the following two points.

(1) Since TWS allows users to keep using their favorite individual tools (in whatever form) while collaborating in a desktop shared workspace, there is no need to master the usage of new sophisticated groupware.

(2) Because TWS's multiscreen architecture allows users to move any application program window between the individual and shared screens just by dragging the mouse, it is easy to bring the data and tools in each personal computer to the shared workspace. The information on paper and books can also be easily shared just by bringing them under the CCD camera attached to the desk lamp.

FIGURE 5.

Appearance of TeamWorkStation and shared screen example

Architecture of TeamWorkStation

TWS is designed to provide small work groups (2–4 members) with the new media of dynamic interaction. TWS provides users with a shared screen as the open shared workspace, and live video and audio communication links for face-to-face conversation.

The present TWS prototype is based on Macintosh™ computers. The computer screens, individual and shared, are contiguous in video memory as shown in Figure 6. Therefore, just by moving the window of any application program from the individual to shared screen, a user can transmit the application's window to all participants for remote collaboration. The shared screen of TWS is a strict implementation of the What You See is What I See (WYSIWIS) design principle [20]. The combination of individual and shared screen, however, relaxes the space constraints of WYSIWIS.

The system architecture of the TWS prototype is illustrated in Figure 7. In order to connect distributed workstations, a video network (NTSC and RGB) and an input device network were developed, and integrated with an existing data network (LocalTalk™ network) and a voice (telephone) network. In the future, we will integrate these four networks into a multimedia LAN and B-ISDN that are being developed by NTT.

The video network is controlled by a *video server* that is based on a computer-controllable video switcher and video effector. The video server gathers, processes and distributes the shared computer screen images, desktop images, and face images. Overlay of video images is done by the video server. The results of overlaying are redistributed to the shared screens via the video network. The basic architecture of this video network is similar to that of EuroPARC's IIIF[6] (Integrated Interactive Intermedia Facility) [3] except for the overlay functions of TWS's video server.

Modes in TWS

In addition to the overlay mode, this video network also provides users with two other modes: *telescreen* and *tele-desk* modes. These modes are for the nonoverlaid remote display of individual screens and desktops respectively. These modes are designed to show just the information within a computer or on a desktop to remote users in a loosely coupled collaboration.

Another mode is computer-sharing (Figure 3 (a)), for tightly coupled collaborations such as co-editing. The input device network was implemented for the computer-sharing mode. The computer-sharing mode allows collaborators to operate one computer by connecting their keyboards and mice to the computer whose screen is shared. The computer-sharing approach was taken by Capture Lab for the support of face-to-face meetings [9, 16]. The same function has been implemented in software such as Timbuktu™ [5]. The software solution, however, creates greater response delays. In this computer-sharing mode, TWS provides no special software or hardware embedded-protocol for floor control, but relies on the informal social protocol agreed to by the collaborators via the face-to-face communication links.

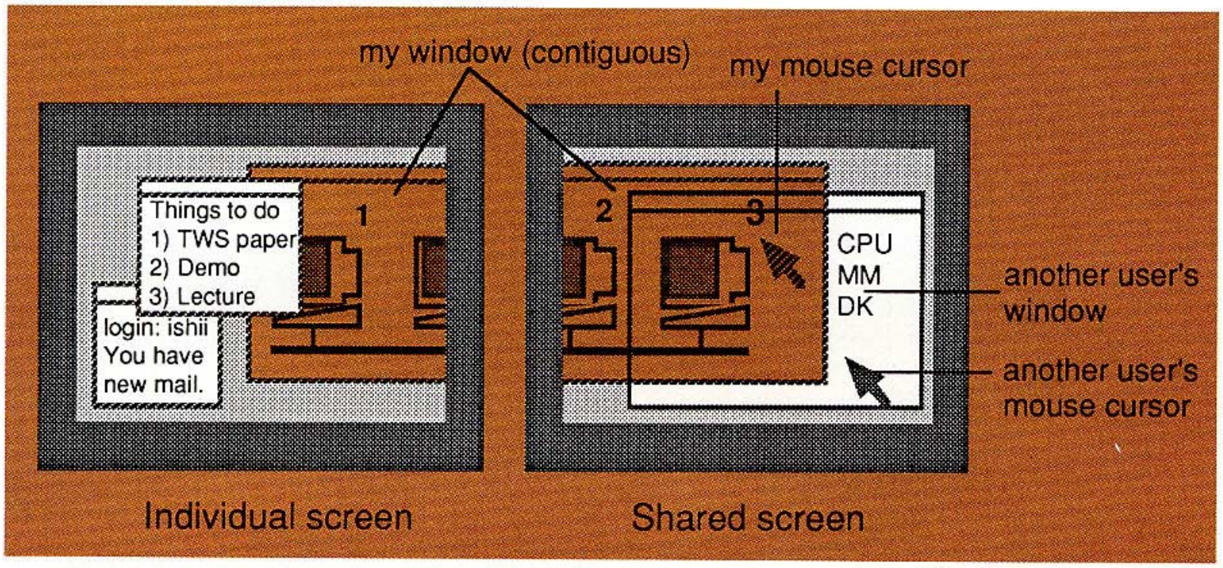
TWS is designed to allow users to

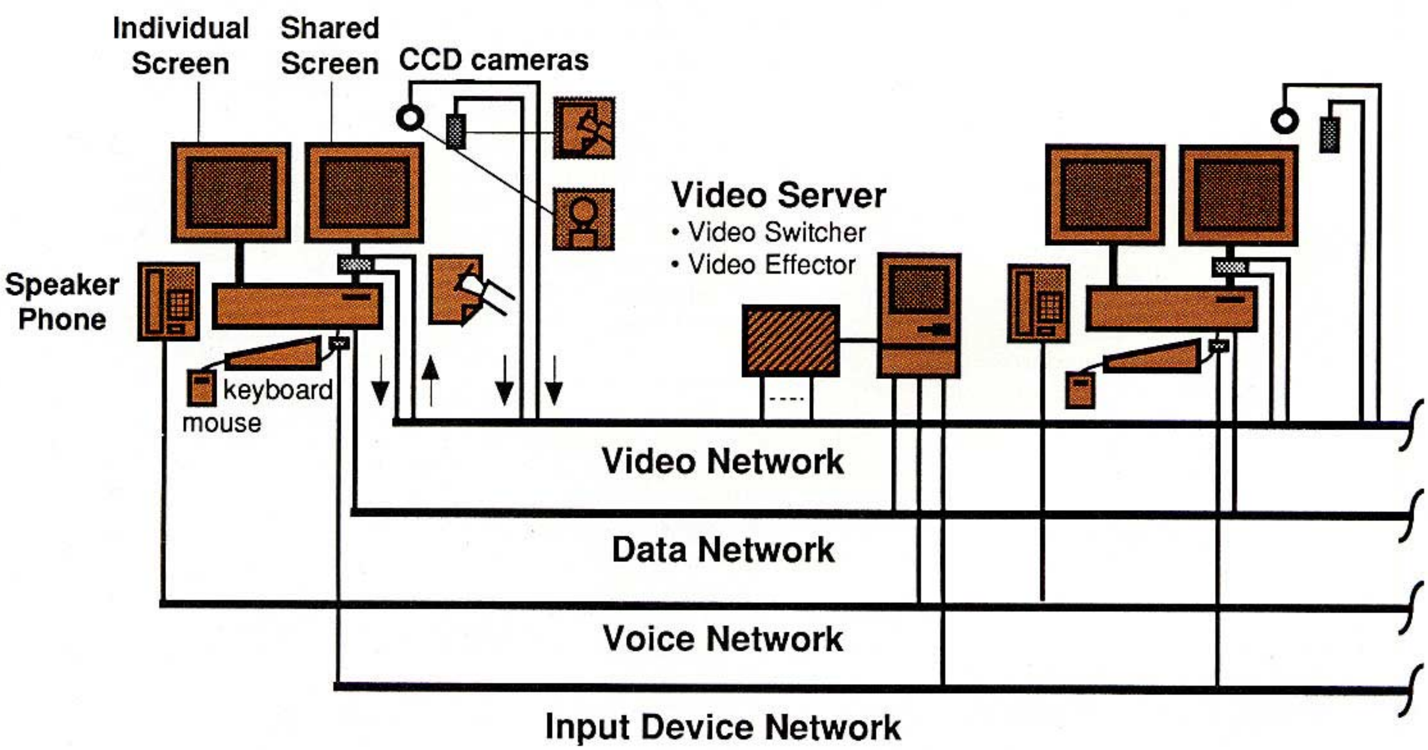
[5]Professor J. Nievergelt commented on TWS that the vast majority of the literature on collaboration uses the term "shared workspace" to designate *shared data,* in the sense that the actions of all participants affect the single *logical* version of the data. Instead of "shared workspace," he proposed to use the term "shared visual space" to explain the essence of TWS. The authors acknowledge his thought-provoking comment.

[6]In the invited lecture of IFIP WG8.4 conference at Crete in September 1990, Bill Buxton talked about his design principle: Let's do smart things with stupid technology today, rather than wait and do stupid things with smart technology tomorrow." Both IIIF [3] and TWS share the same principle. The authors believe this principle is essential in pursuing new groupware technologies.

choose the most suitable mode and move from one mode to another according to task contents and roles played by the coworkers. For example, suppose user A starts to explain his or her plan by showing a diagram to user B using the tele-screen mode. (If his or her diagram was written or printed on paper, the tele-desk mode would be used instead of the tele-screen mode.) If B wants to point to or mark a part of the diagram to ask a question, the users can move to the screen-overlay or screen-and-desk-overlay mode and user B can point to the part of A's diagram by B's own pointer (mouse or pencil). If B felt it was necessary to directly change a part of the diagram, and if A agreed, they could move to the computer-sharing mode.

Since the pattern of collaboration changes dynamically, TWS's flexibility in shuttling between these collaboration modes is important in supporting the dynamic collaboration process. The tele-screen and tele-desk modes, however, were seldom used in the experimental ses-





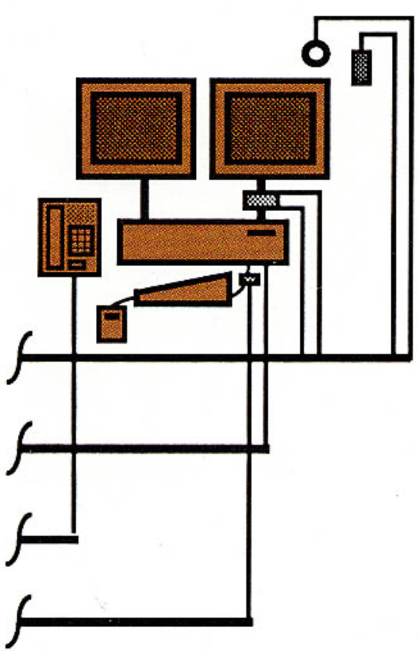
sions described next, because the overlay mode is more flexible and includes tele-desk and tele-screen functions. The overlay mode was used as the default mode in most collaborative sessions, and sometimes users moved to the computer-sharing mode when they needed to edit the same document or data stored in a computer.

Use of Heterogeneous Computers

Although the TWS prototype uses Macintosh workstations, heterogeneous computers can also be used since overlaying is done at a standard video signal level. Indeed, screen-overlay and tele-screen functions have been successfully implemented between an NEC PC-9800™ series computer running MS-DOS™ and the Macintosh computers.

FIGURE 6.
Contiguous multiple screens for smooth transition

FIGURE 7.
System architecture of Team-WorkStation prototype



Experimental Use of TeamWorkStation

Since July 1989, TWS has been used by one of the authors, Ishii, and two of his colleagues in NTT for daily work including refining the design of TWS itself.

Design Session

The major TWS usage has been discussion about the system architecture design. When Ishii and his colleague Arita redesigned and rebuilt the TWS prototype in July 1990, they used TWS to discuss the new architecture of video network for a total of approximately 10 hours. The photograph in Figure 5 (b) shows a typical shared screen image in our design session. The regular tools in our design sessions were drawing editors, an outline editor, a graphic computer,[7] and pen and paper.

Comments on the base diagram were exchanged mainly by using *voice* with pointing and marking by *hand* in the overlay mode. The capability of this direct hand pointing to the coworker's diagram gave us a strong sense of sharing common task space. We found the hand was preferred to the mouse as a means of pointing and marking because hand gestures are much more expressive, and because hand marking is generally quicker. Even in the situation in which a user presents a diagram made and stored in the computer, the user often overlaid his or her desktop over his computer screen image for explaining the points of the diagram by finger pointing and pen marking (Figure 5 (b) is an example of this situation).

While using TWS, we noted that the face-to-face conversation link played an important role in the informal control of group interaction, especially for the coordination of the use of this limited workspace on the shared screen.

Also, we rarely used the computer-sharing mode. Most of our comments and discussion on diagrams were performed in the overlay-mode. We seldom felt the necessity of editing the other's diagrams directly. If a diagram had to be changed, the originator would usually change it according to the comments made by the other. Thus, most of our collaboration was in the *role-division* mode, as observed and explicated in Miyake's joint problem-solving study [18]. On a few occasions we had to divide the entire task into subtasks and each had to be taken care of separately and in parallel. We used the computer-sharing mode only for such *subtask-division* modes.

One reason for this preference for *role-division* appears to come from the respect paid to the ownership of the diagrams. When a diagram is drawn, the artist owns it. When one person draws a diagram and someone else changes it, even with permission, that is a challenge to ownership. This is a very natural feeling, even in a close collaborative session. Through these design experiences, we recognized that the shared workspace does not always require the "direct data sharing and editing" function. The overlay solution provides us with a more comfortable environment, because the overlaid layers keep the person's own layer of work intact in the role-division mode.

Remote Teaching of Calligraphy

One of the important features of TWS is that all the collaborators can share not only the *results* of drawing or marking in the shared workspace, but also the dynamic *process* of drawing and pointing. One application that demonstrates the importance of process sharing is the teaching of calligraphy. The photograph in Figure 4 shows a snapshot of a calligraphy-teaching session we conducted using TWS, in which the student used MacCalligraphy™ and the teacher used an actual brush, ink and paper.

In these sessions, the student first uses MacCalligraphy (or a brush with black ink) to generate a Chinese character on the shared

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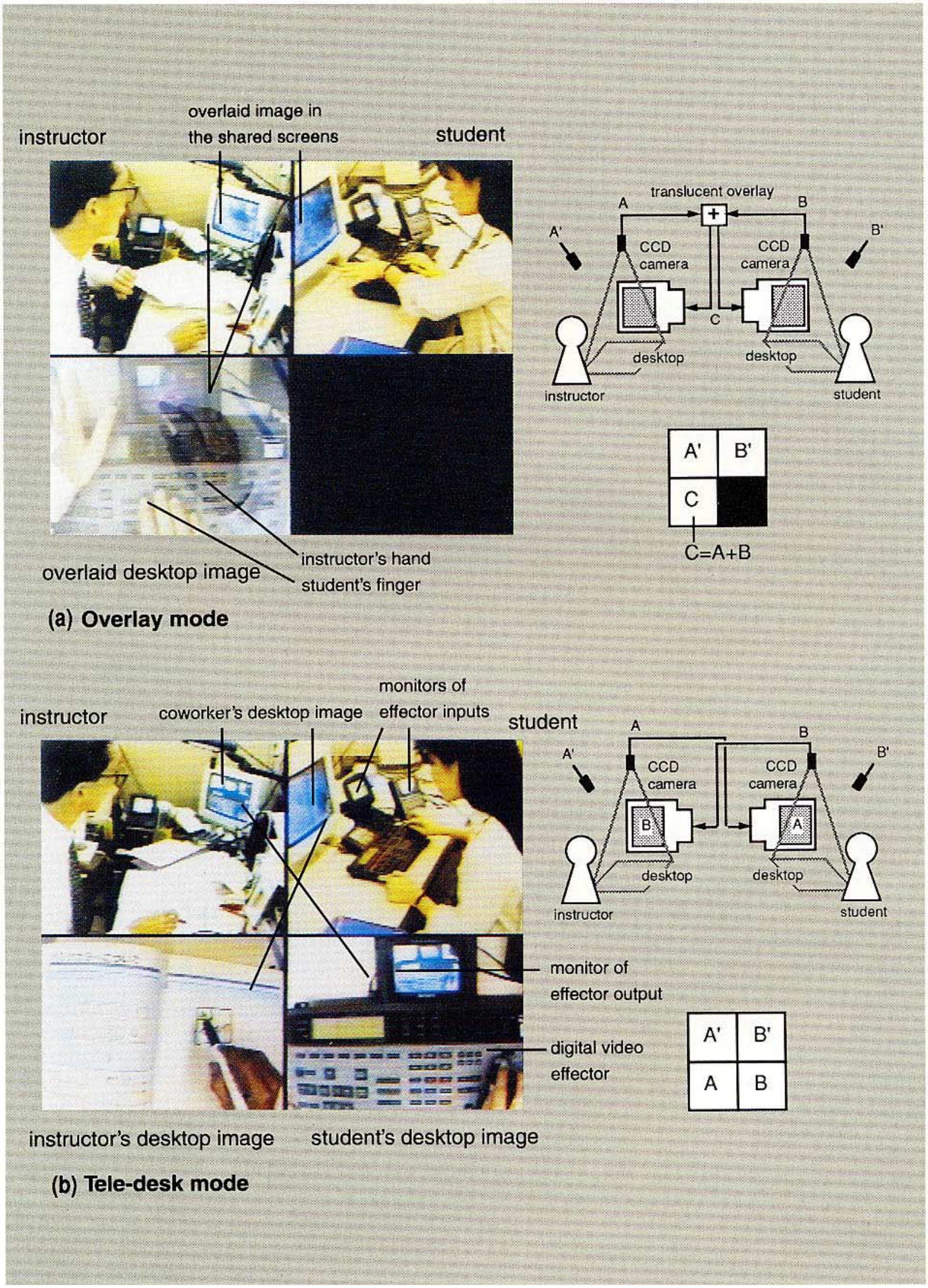
[7] "Graphic computer" is a painting tablet which generates the NTSC video output.


instructor
overlaid image in the shared screens
student
translucent overlay
A
B
A'
B'
CCD camera
CCD camera
C
desktop
desktop
instructor
student
A' B'
C
C=A+B
instructor's hand
overlaid desktop image
student's finger
(a) Overlay mode
monitors of effector inputs
instructor
coworker's desktop image
student
A
B
A'
B'
CCD camera
CCD camera
desktop
desktop
instructor
student
monitor of effector output
digital video effector
A' B'
A B
instructor's desktop image
student's desktop image
(b) Tele-desk mode

One of the important features of TWS is that all the collaborators can share not only the *results* of drawing or marking in the shared workspace, but also the dynamic *process* of drawing and pointing.

screen (or a sheet of paper on his or her desktop). The instructor watches the student's real-time strokes via the shared screen and makes necessary comments by using a brush with red ink on the paper on his desktop. Here the real-time nature of the collaboration is extremely important. The instructor can make comments directly over the student's strokes when the student deviates from the suggested forms, and the student gains the immediate feedback of the teacher (e.g., correct use of the wrist).

We also conducted other calligraphy sessions where both teacher and student used actual brushes on their physical desktops to evaluate the usability of TWS in teaching. Through these calligraphy experiments, we realized that the overlaid live video images of dynamic and three-dimensional gestures play a very important role in the teaching process.

We expect that TWS will be far superior to ordinary telephone or FAX communication systems for the sharing of *process-oriented knowledge or skill* between remote experts and trainees. The fusion of live video images of each workspace in combination with voice and face communication is expected to enhance the quality and efficiency of remote consulting and training.

Problems of Overlay Approach

Through the experimental use of the overlay mode in TWS, we also found the following problems of the overlay approach, based on the video synthesis technique.

- The results of collaboration cannot be shared directly. Since individual workspaces are overlaid as video images, the marks and the marked documents occupy different layers in the shared screens. They are actually stored separately in different places in different media (in computer files or on paper). We mainly used a video printer (to hardcopy), a video digitizer (to store in a computer file) and a video tape recorder (to record the results and the process of real-time collaboration). In cases where both the marks and marked documents were recorded in Macintosh computer files, we used email to exchange work results.
- The quality of overlaid video images is neither sharp nor stable enough to support sharing detailed documents. In particular, the flicker of thin horizontal lines that comes from "interlacing" is a problem. Although we tried to eliminate all thin lines with high contrast in the documents, the relief is slight. When we needed to discuss such detailed documents, we often distributed copies of the documents by email or Fax in advance.
- Indirect drawing and pointing on the desktop by hand needs time and effort to get used to. (This is similar to the learning process needed for indirect pointing devices such as a mouse or tablet.) Since the desktop images captured by CCD camera are displayed on a shared screen after the image overlay operation, users must learn to control their pencil or finger following the feedback from the screen. In contrast, VideoDraw [24] allows users to draw directly on the screen at the cost of less flexibility (unavailability of papers). Through the use of TWS in design sessions, we found that the advantages of using papers and books outweighed the disadvantage of indirect drawing.
- Especially when more than three users are coworking, identifying the owners of objects (such as cursor, draw object, window, marks on paper) on an overlaid screen is difficult. The use of a different color for each user's objects improves this problem slightly. To identify the objects, a user can also dim his/her video signal electrically, or move the CCD camera a little.
- Since overlaid screen images are completely independent of each other, scrolling or moving a document in one layer breaks the spatial relationships with the marks made on other layers. Users must pay some attention to retain the consistency of spatial relations among layers.

FIGURE 8.
Experiment of remote teaching of machine operation with and without overlay

Evaluation of Overlay in Remote Teaching of Machine Operation

The key design idea of TWS is the overlay of individual workspace images. In order to clarify the effects of overlay quantitatively, we conducted an experiment using the remote teaching of machine operation with and without overlay.

The Experiment

Task: Using a digital video effector, instructors, whose behavior was also the object of our observation, were to teach students how to achieve two desired results by combining two input video images into one, in two different layouts, Task 1 and Task 2. The difficulty of the tasks was set to be equal, by equating the number of steps required to achieve the outcomes.

Subjects: Two subjects, who were knowledgeable in the use of the video effector, served as instructors. Each instructor taught four students, two women and two men, who were all novices. There were thus eight students in all. They were recruited from adjacent labs for cooperative help, but none of them knew the experiment's objectives in advance.

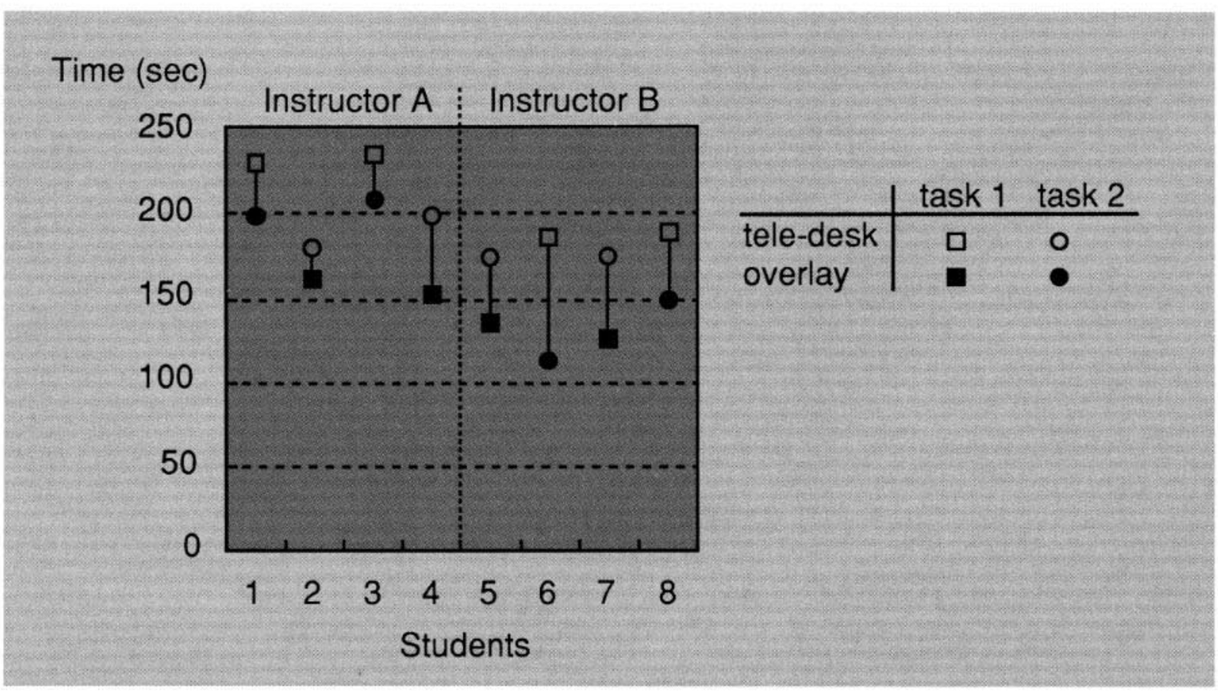
Design: Each student was to carry out first Task 1 and then Task 2, one in the overlay mode and the other in the tele-desk mode. To counter-balance the practice effect, half the subjects started with the overlay mode, while the other half started with the tele-desk mode. Figure 8 shows the snapshots and schematic diagrams of this experiment in overlay and tele-desk modes. After the tasks, both the instructors and the students were briefly interviewed, individually, about what they liked and disliked about the tasks and the task environment.

Results: For each task, the task-completion time was measured from the end of the explanation of the objective layout until the moment the instructor declared the expected outcome was obtained. The overall results are shown in Figure 9. Every student completed the task in the overlay mode faster than in the tele-desk mode, regardless of the order. The time difference was statistically significant ($F(1,5) = 58.40$, $p < .01$). F values were calculated from the 2 X 2 X 2 analysis of variance (mode difference as a within-subject variable, while instructor and mode-order type differences as between-subject variables). No other major effects, or interactions, were found to be statistically significant, although the instructor difference was almost statistically significant ($F(1,5) = 15.57$, $p = .01$). This difference appears to have come from the different teaching styles of the two. One, who spent more time teaching, tended to explain why some action would work, while the other limited himself to issuing procedures.

In the post-task interview, the students generally preferred the overlay mode to the tele-desk mode. They commented that seeing the teacher's hand actually move over the effector made it easier for them to follow. Two students commented that things (such as switches, buttons, images in a small monitor) had been difficult to see in the overlay mode.

Both of the instructors spontaneously commented quite favorably about the overlay mode. They often stated that the direct pointing, which was only possible in the overlay mode, had greatly relieved them of the extraneous burden of either verbalizing the locations of the buttons or pulling out the manual to indirectly point to the locations on the drawings. In the post-task inter-

FIGURE 9.
Results of experiment: Elapsed time for task completion in overlay and tele-desk modes by each pair



view, they both said they felt they had talked much less in the overlay mode. In fact, however, the actual numbers of units uttered in the two modes are roughly the same (on the average, 68.3 utterance units per minute for the overlay mode; 52.7 units for the tele-desk mode). This implies the relief felt by the instructors was not from less actual verbal "work"; it might have come from the ease of superimposing instructors' "monitoring" view onto the actual "task-doing" view of the student. The time efficiency and the teaching ease realized by the overlay mode are two good indicators of the gains that can be achieved in seam-reduced collaboration environments.

Conclusion

TWS is a novel collaboration media that approaches *seamless* CSCW. It effectively integrates two kinds of individual workspaces: *computers* and *desktops* and provides distributed users with an *open shared workspace*. Its key design idea is the translucent overlay of individual workspace images. Because each coworker can continue to use his/her favorite application programs or desktop tools, there is only a *minor cognitive seam* between individual and shared workspaces. Using translucent video overlay functions, real-time information such as hand gestures and handwritten comments can be shared between coworkers as well as information contained in printed materials and computer files.

TWS was not intended to replace existing groupware approaches. Rather, we designed TWS in order to support a broader range of dynamic collaboration activities that range over several seams and cannot be supported consistently by existing task-specific structured groupware.

TWS will be tested with a larger variety of tasks and users to investigate the dynamic nature of collaboration, and to enhance computer support by further reducing the seams. We expect that progress in B-ISDN and multimedia LAN technology will enhance the attractiveness of the TWS approach to realize the truly open shared workspace.

Acknowledgments

The authors thank Kazuho Arita, Minoru Kobayashi, and Masaaki Ohkubo at NTT for their contributions to building and testing the prototype of TWS. Thanks are also due to John Tang, Jonathan Grudin, Sara Bly, Keith Lantz, Marilyn Mantei, Saul Greenberg, Ellen Francik and Morton Kyng for insightful discussions and comments on this article.

Ishii also thanks Takahiko Kamae, Takaya Endo, and Gen Suzuki of NTT Human Interface Laboratories for their encouragement. C

References

1. Ahuja, S.R., Ensor, J.R. and Lucco, S.E. A comparison of application-sharing mechanisms in real-time desktop conferencing systems. In *Proceedings of COIS '90* (Apr. 1990), pp. 238–248.
2. Bly, S.A. A use of drawing surfaces in different collaborative settings. In *Proceedings of CSCW '88* (Portland, Ore., 1988), pp. 250–256.
3. Buxton, B. and Moran, T. EuroPARC's integrated interactive intermedia facility (IIIF): Early experiences. In *Proceedings of IFIP WG8.4 Conference on Multi-User Interfaces and Applications* (Crete, Sept. 1990), pp. 11–34.
4. Ellis, C.A., Gibbs, S.J. and Rein, G.L. Groupware: Some issues and experiences. *Commun. ACM 34*, 1 (Jan. 1991), 38–58.
5. Farallon Computing Inc. *Timbuktu User's Guide*, 1988.
6. Foster, G. and Stefik, M. Cognoter, theory and practice of a collaborative tool. In *Proceedings of CSCW '86* (Austin, 1986), pp. 7–15.
7. Foster, G. and Tatar, D. Experiments in computer support for teamwork—Colab (Video), Xerox PARC, 1988.
8. Grudin, J. Why CSCW applications fail: Problems in the design and evaluation of organizational interfaces. In *Proceedings of CSCW '88* (Portland, Ore., 1988), pp. 85–93.
9. Halonen, D., Horton, M., Kass, R. and Scott, P. Shared hardware: A novel technology for computer support of face to face meetings. In *Proceedings of COIS '90* (Apr. 1990), pp. 163–168.
10. Harrison, S., Minneman, S., Stults, B. and Weber, K. Video: A design medium. SIGCHI Bulletin, Jan. 1990, pp. 86–90.
11. Ishii, H. TeamWorkStation: Towards a seamless shared workspace. In *Proceedings of CSCW '90* (Los Angeles, Oct. 1990), pp. 13–26.
12. Ishii, H. and Ohkubo, M. Design of TeamWorkStation: A real-time shared workspace fusing desktops and computer screens. In *Proceedings of IFIP WG8.4 Conference on Multi-User Interfaces and Applications* (Crete, Sept. 1990), pp. 131–142.
13. Lantz, K.A. An experiment in integrated multimedia conferencing. In *Proceedings of CSCW '86* (Austin, 1986), pp. 267–275.
14. Lauwers, J.C., Joseph, T.A., Lantz, K.A. and Romanow, A.L. Replicated architectures for shared window systems: A Critique. In *Proceedings of COIS '90* (Apr. 1990), pp. 249–260.
15. Lauwers, J.C. and Lantz, K.A. Collaboration awareness in support of collaboration transparency: Requirements for the next generation of shared window systems. In *Proceedings of CHI '90* (Apr. 1990), pp. 303–311.
16. Mantei, M. Capturing the capture concepts: A case study in the design of computer-supported meeting environments. In *Proceedings of CSCW '88* (Portland, Ore., 1988), pp. 257–270.
17. Mantei, M., Baecker, R., Sellen, A., Buxton, W. and Milligan, T. Experiences in the use of a media space. In *Proceedings of CHI '91* (New Orleans, May 1991), pp. 203–208.
18. Miyake, N. Constructive interaction and the iterative process of understanding. *Cog. Sci. 10*, 2 (1986), 151–177.
19. Root, R.W. Design of a multi-media vehicle for social browsing. In *Proceedings of CSCW '88* (Portland, Ore., Sept. 1988), pp. 25–38.
20. Stefik, M., Bobrow, D.G., Lanning, S., Tatar, D. and Foster, G. WYSIWIS revised: Early experiences with multi-user interfaces. In *Proceedings of CSCW '86* (Austin, 1986), pp. 276–290.

21. Stults, R. Experimental Uses of Video to Support Design Activities. Xerox Palo Alto Research Center, 1988.

22. Suzuki, T., Taniguchi, H. and Takada, H. A real-time electronic conferencing system based on distributed UNIX. *USENIX Conference* (1986), pp. 189–199.

23. Tang, J.C. and Leifer, L.J. A framework for understanding the workspace activity of design teams. In *Proceedings of CSCW '88* (Portland, Ore., Sept. 1988), pp. 244–249.

24. Tang, J.C. and Minneman, S.L. VideoDraw: A video interface for collaborative drawing. In *Proceedings of CHI '90* (Seattle, Apr. 1990), pp. 313–320.

25. Tang, J.C. and Minneman, S.L. VideoWhiteboard: Video shadows to support remote collaboration. In *Proceedings of CHI '91* (New Orleans, May 1991), pp. 315–322.

26. Weber, K. and Minneman, S. The office design project (Video). Xerox PARC, 1987.

Categories and Subject Descriptors: H.4.3 [**Information Systems Applications**]: Communications Applications—*computer conferencing and teleconferencing;* H.5.1 [**Information Interfaces and Presentation**]: Multimedia Information Systems—*video;* H.5.3 [**Information Interfaces and Presentation**]: Group and Organization Interfaces—*evaluation/methodology, synchronous interaction*

Additional Key Words and Phrases: CSCW, desktop multimedia conference, real-time collaboration, shared workspace

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This article is a follow-up to the paper [11] presented at CSCW '90 in October 1990. Some of the technical descriptions and figures in the article, [12] published in the Proceedings of IFIP WG8.4 *Conference on Multi-User Interfaces and Applications,* were revised and included in this article with the permission of IFIP. Naomi Miyake participated in the experimental and observational phase of this research.