TeamWorkStation: Towards a Seamless Shared Workspace

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ABSTRACT

This paper introduces TeamWorkStation (TWS), a new desktop real-time shared workspace characterized by reduced cognitive seams. TWS integrates two existing kinds of individual workspaces, computers and desktops, to create a virtual shared workspace. The key ideas are the overlay of individual workspace images in a virtual shared workspace and the creation of a shared drawing surface. Because each co-worker can continue to use his/her favorite application programs or manual tools in the virtual shared workspace, the cognitive discontinuity (seam) between the individual and shared workspaces is greatly reduced, and users can shuttle smoothly between these two workspaces.

This paper discusses where the seams exist in the current CSCW environment to clarify the issue of shared workspace design. The new technique of fusing individual workspaces is introduced. The application of TWS to the remote teaching of calligraphy is presented to show its potential. The prototype system is described and compared with other comparable approaches.

INTRODUCTION

Groupware is being designed to create shared workspace that can overcome space and time constraints, and support dynamic collaboration in a work group. In order to realize productive shared workspaces, *continuity* with existing individual work environments is the key design issue because users work in either individual or collaborative modes and frequently move back and forth.

Mark Stefik pointed out that the key idea for the next generation collaboration technology is the *seamlessness* between individual and group work [Fost88]. He insisted that group tools (groupware) must merge with individual tools. Jonathan Grudin pointed out that if the tools force users to change the way they work, then the tools are generally rejected [Grud88].

Therefore, when designing real-time shared workspaces, the existing individual workspaces must be integrated so that users can shuttle smoothly between their individual workspaces and the virtual shared workspace. Even in the shared workspace, user should be able to retain his/her customary work practice such as drawing by pencil on a paper, or writing by a favorite word processor.

There have been two types of approaches proposed to realize real-time shared workspaces for distributed groups.

(1) Multi-user software such as shared-window-systems [Lant86, Suzu86, Lauw90A, Lauw90B, Ahuj90] and special purpose applications [Fost86, Elli90] running on networked workstations.

(2) Video and audio communication-based virtual shared work spaces, such as Media Space [Stul88, Harr90], CRUISER [Root88], VideoDraw [Tang90].

(1) is a computer-based approach to handle information stored in computers within a group. (2) is a tele-communication-based approach (like a video-conference) that can handle information external to computers (faces, drawing surfaces, etc.). Both approaches suffer from a lack of

flexibility in that data within computers and information outside the computers or outside of computer are treated separately and can never be fused. Users are still stuck with a rather large discontinuity (seam) between the computer and the actual desktop.

This paper introduces "TeamWorkStation" (TWS), which overcomes this discontinuity problem by a video overlay technique that permits the fusion of computer screens and actual desktop images. TWS allows users to keep using their favorite individual tools (in whatever form) while collaborating in a desktop virtual shared workspace.

"Media Space" [Stul88, Harr90] pioneered the use of video technology for the support of remote collaborations. Our work was motivated by their Office Design Project [Webe87]. "VideoDraw" [Tang90] provided the stimulus for this research. Tang and Minneman showed a new way to design shared workspaces by overlaying images of individual drawing surfaces. However, VideoDraw restricted the targets to be overlaid to hand-drawn images and hand gestures on a special transparent sheet attached to the surface of a TV monitor. TWS overcomes this restriction by fusing computer screens with general desktop images.

First, this paper discusses where the seams exist in the current CSCW environment to clarify the issue of shared workspace design. Then, the new technique of real-time shared workspace design in TWS is introduced. The application of TWS to the remote teaching of calligraphy is presented to show the potential of the computer and desktop fusion realized in TWS. The prototype system is described and compared with other comparable approaches. A multi-user interface design strategy for layout of windows with live face images is also described.

WHERE ARE THE SEAMS?

The world is full of seams. However, where are the seams that must be overcome using groupware technologies? "Between individual and group work" sounds too obscure to identify the technical problems that should be tackled.

During the development of personal computers, the *seams* among various applications were overcome by data exchange functions (e.g. copy and paste operation via clip board) and consistent user interfaces (e.g. consistent pull down menus) among the application programs.

Figure 1 illustrates the seams that exist in current CSCW environments.

There are three major seams:

(1) The seam between individual work modes and cooperative work modes.

(2) The seam between the computer-supported work (e.g. word processing) and the non-computer-supported work (e.g. writing with pen on a paper).

(3) The seam between asynchronous communication (e.g. E-mail), and real-time communication (e.g. telephone, video conference).

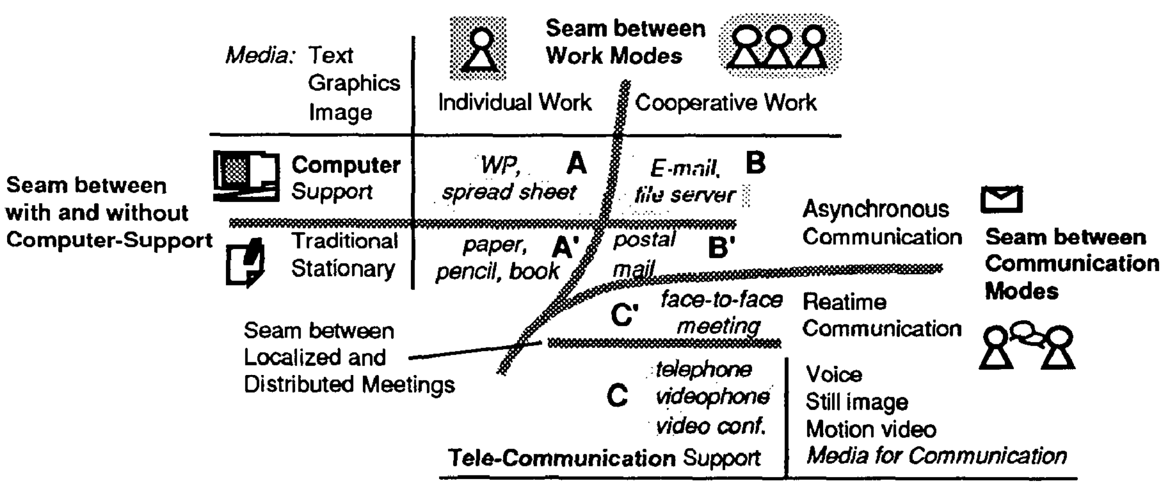


Fig.1 Seams in Current CSCW Environment

At first glance, the three seams appear to be orthogonal. However, as shown in Fig. 1, they divide the work environment into several worlds: (A) individual work supported by computers, (A') individual work with no computer support, (B) asynchronous communication supported by computers, (B') traditional asynchronous communication, (C') face-to-face meetings, and (C) real-time communication supported by telecommunication technologies.

Personal computers (PCs) have a wide variety of functions to support world A tasks such as preparation of composite documents. These documents can be easily shared among distributed group members using E-mail or remote file sharing functions (i.e. world B functions). The spread of LAN/WAN enables geographically distributed group members to share and exchange information in personal computers asynchronously. Therefore the gap between world A and B (A/B gap) is not a large obstacle compared to the other gaps, because both sides (A and B) are consistently supported by networked computers.

In the context of real-time collaboration, on the other hand, the gap between world A and C (A/C gap) is very serious. This is the gap between computer-supported individual work (world A) and real-time teleconferencing supported by the devices such as videophone (world C). Because of the differences in time characteristics (store&read vs. real-time), media (text and graphics vs. live video and sound) and support technologies (computer and LAN vs. telephone and PBX), this gap is difficult to overcome.

One approach to bridge world A and C is the shared-window-based groupware that extends an existing single-user application program so that it can be used by a group in a real-time mode. However, this type of system demands that the data be held by computers, and all group members must use the same single-user application at the same time. On the other hand, the other approach, video-based desktop conference system (in world C), cannot easily handle the information in computers.

An important fact is that in the individual work mode users work both with *computers* (world A) and on the physical *desktop* (world A'), and frequently move back and forth. Neither of them can replace the other. Depending on the task and the location of information (paper or computer file) to be shared, users should be able to choose either A or A' and to switch between them freely, and *independently of the other members' choices.* This means that group members must be able to use heterogeneous tools (computer-based and manual tools) in the virtual shared workspace simultaneously.

We believe the next generation collaboration technology must overcome both the A/C and A'/C gap. Information in the computer (world A) should be shared smoothly in real-time as well as information in hard-copy papers or books (world A'). Collaborators' facial expressions and gestures that can be conveyed by live video also play a very important role in real-time cooperation. These requirements suggest that the *fusion* of worlds A, A' and C is necessary to establish *seamless* collaboration technology, but existing groupware has not effectively supported this concept.

Therefore, the goal of TWS design is the fusion of worlds A, A' and C so that users can *keep their favorite individual work practice* such as pencil drawings on paper or writing by a word processor even in the virtual shared workspace.

Another focus of TWS design is "Shared drawing surface" that every member can see, point to and draw on *simultaneously*. One important feature of face-to-face collaborations is the role of the "shared drawing surface" such as a white board. Bly, Tang, Leifer and Minneman pointed out that the shared drawing surface plays a very crucial role not only to store information and convey ideas, but also to develop ideas and mediate interaction, especially in design sessions [Bly88, Tang88, Tang90].

Figure 2 illustrates the design requirements of TWS: "smooth transition " and a "shared drawing surface".

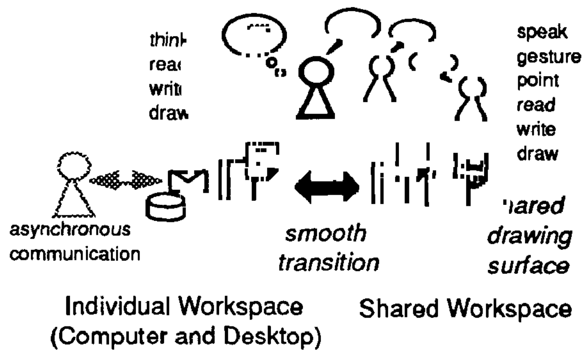
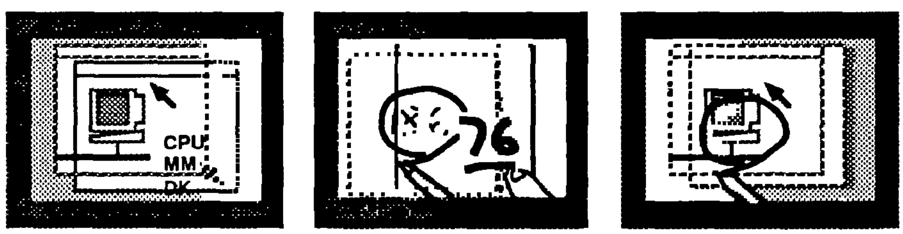


Fig. 2 Design Requirements of TWS

Key Design Concept: Overlay of Individual Workspace Images

We devised the key TWS design idea, *"overlay of individual workspace images"* in order to satisfy these requirements. The "overlay" function created with a live-video image synthesis technique allows users to combine individual workspaces, and to point to and draw on the overlaid images "simultaneously". Figure 3 shows the variations of overlay supported by TWS. The "overlay" function is so flexible that it can be applied to the desktop images captured by a CCD camera as well as computer screens. Therefore, collaborators can keep using their manual tools on desktop (e.g. papers, pencils, and hand gestures) as well as computer tools (e.g. word processors).

"Overlay" is a very simple and intuitive concept but powerful because it has much more flexibility than the existing task-specific groupware approaches. Although the medium of video is machine-unreadable, overlaid video images provide users with rich semantics that they can easily interpret.



(1) Screen Overlay (2) Desk Overlay (3) Screen and Desk Overlay

Figure 3 Variations in Overlay of Individual Workspace Images

Figure 4 shows the configuration of the TWS prototype and examples of shared screen images. TWS provides users with the following major components integrated on a desktop workstation that supports multiple displays:

(1) a shareable computer screen for concurrent pointing, writing and drawing, and

(2) live video and audio communication links for face-to-face conversation.

An auto-focus video camera to capture face image (Fig. 4 (2)), wireless microphone and headphone, and small (4") liquid crystal display with speaker (Fig. 4 (1)) are used for face-to-face conversations. Face images can be displayed also in windows on the shared screen as shown in Fig. 4 (3). A CCD camera is provided to capture the actual desktop image and handwriting. For ease of use, the CCD camera is mounted on a desk lamp with flexible arm as shown in Fig. 4 (2).

The present prototype is based on Macintosh™ computers. The workspace displays, individual and shared, are contiguous in video memory as shown in Fig. 5. Therefore, just by moving the window of any application program from the individual to shared display, a user can transmit the application's window to all participants for remote collaboration.

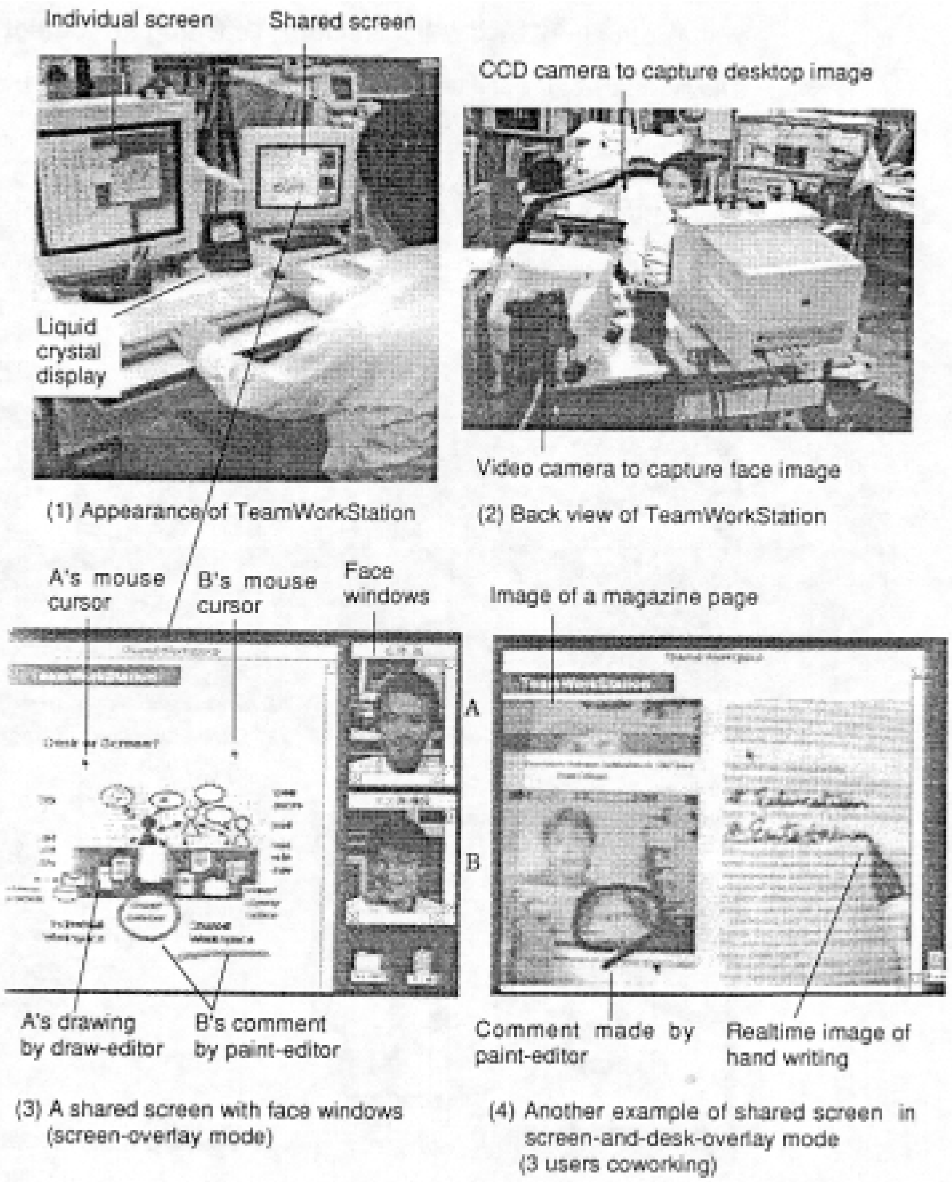


Fig. 4 Standard Configuration of TeamWorkStation Prototype

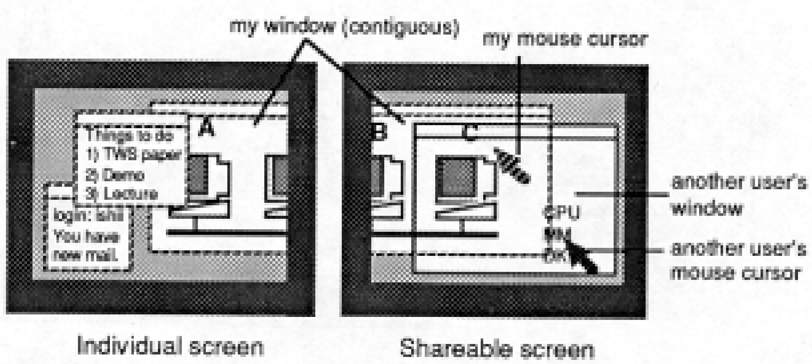


Fig. 5 Use of Contiguous Multiple Displays for Smooth Transition

An Application of TWS: Remote Teaching of Calligraphy

The most interesting and unique usage of TWS is the "screen-and-desk-overlay" mode. This mode allows a computer generated image to be overlaid with the real-time image of the desktop. When the images are "overlaid" their densities are adjusted so that details of both images are clear.

The most common usage of the "screen-and-desk-overlay" mode is to manually annotate computer-generated documents or drawings. One application that demonstrates the power of TWS is the teaching of calligraphy. Figure 6 shows the snapshots of the calligraphy application.

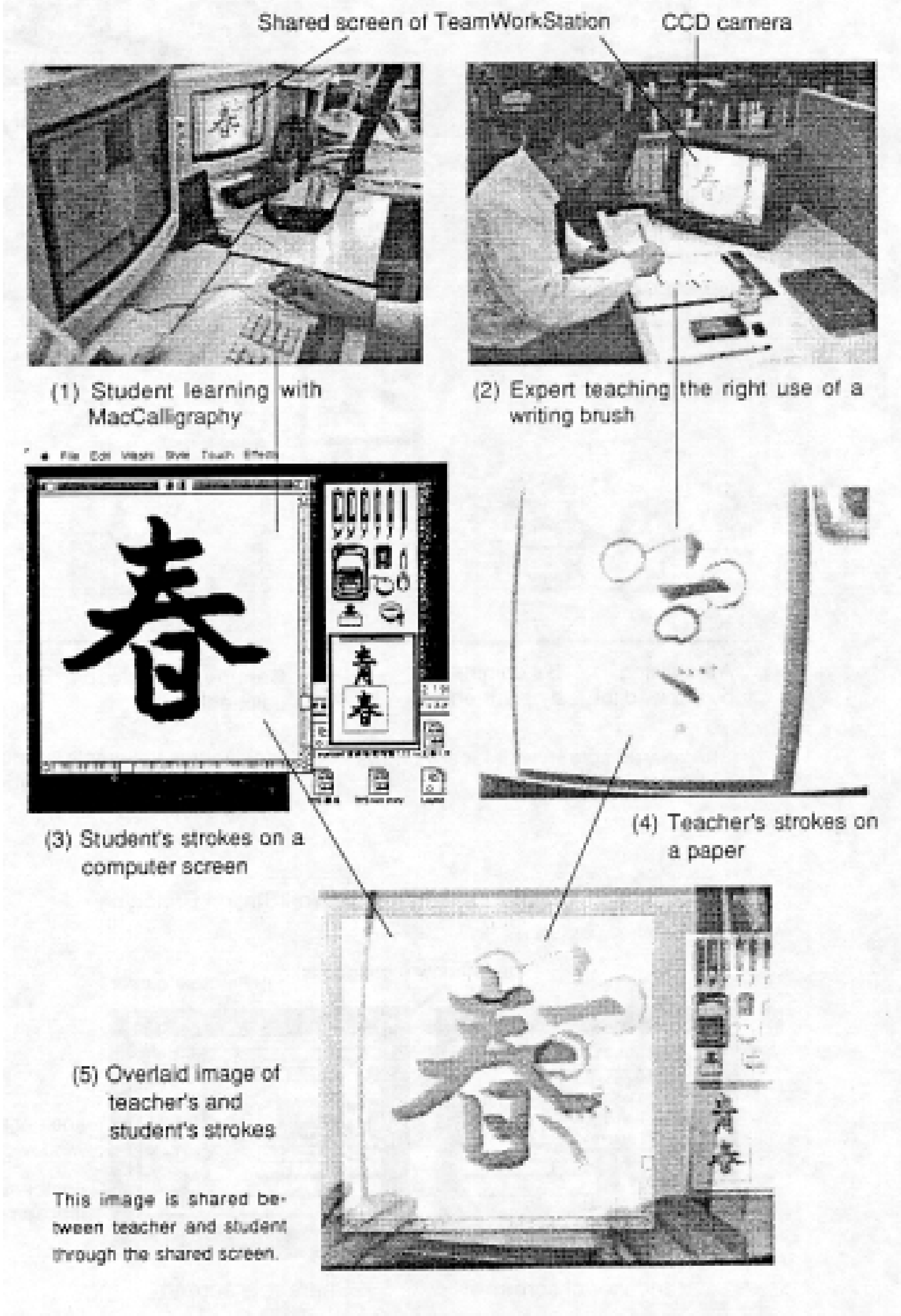


Fig. 6 Remote Teaching of Calligraphy using TeamWorkStation

First, the student uses MacCalligraphy™* and his computer to generate a Japanese character on the shared screen. The teacher watches the student's strokes via the shared screen and makes necessary comments by using an actual brush and paper. Here the real-time nature of the collaboration is extremely important. The teacher can make his comments when the student deviates from the suggested forms, and the student gains the immediate feedback from the teacher. We realized that the dynamic and three-dimensional gesture of drawing, which are conveyed by live video, 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 knowledge or skill between remote experts and trainees. The fusion of computer screens and actual live video images in combination with voice communication is expected to enhance the quality and efficiency of remote consulting and training.

SIX COLLABORATION MODES IN TEAMWORKSTATION

"Overlay" is just one of several TWS functions. In addition to the three overlay modes illustrated in Fig. 3, TWS also provides other collaboration modes as shown in Fig. 7. This diagram shows the three levels of collaborations and six collaboration modes supported by the current TWS prototype system.

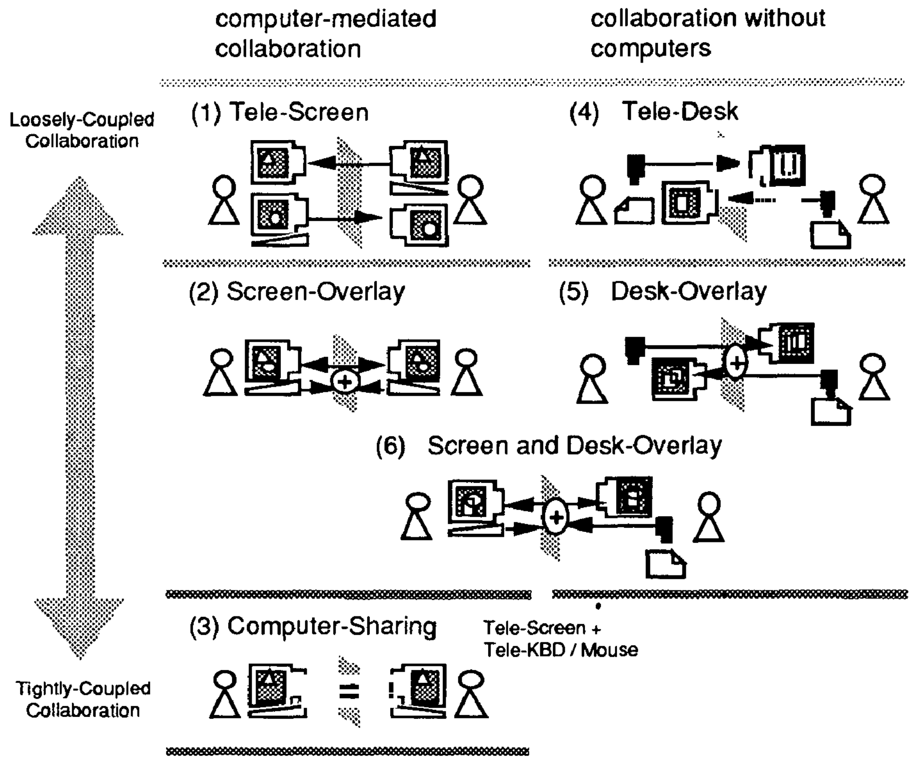


Fig. 7 Three Levels and Six Collaborations Modes in TWS Environment

"Tele-screen" (1) and "tele-desk" (4) modes are for the non-overlaid remote display of individual screens and desktop respectively. These modes are used to just show information within computer or on a desktop to remote users in a loosely-coupled collaboration. "Computer-sharing" mode (3) (by tele-screen + tele-keyboard + tele-mouse) is for tightly-coupled collaborations such as coauthoring.

In the "tele-desk" (4), "desk-overlay" (5), and "screen and desk-overlay" (6) modes, the images of member's documents and pointing/drawing gesture on desktop can be shared. Since users

* MacCalligraphy is the trade mark of Enzan Hoshigumi Co., Japan.

can use pencil and paper for writing, drawing and pointing, it is very close to the actual "shared drawing surface" common in face-to-face meetings.

An important feature of TWS is that users can choose the most suitable mode and move to from one mode to another according to task contents and roles played by the co-workers. For example, suppose user A starts to explain his plan by showing a diagram to user B using the "tele-screen" mode. (If his diagram was written or printed on a paper, the "tele-desk" mode was used instead of "tele-screen" mode.) If B wants to "point" to a part of the diagram to ask a question, they 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. The "computer-sharing" mode allows collaborators to operate one computer by connecting their keyboards and mice to the computer whose screen is shared in the "tele-screen" mode.

In order to connect distributed workstations, the current prototype system uses the following five different communication networks:
(1) RGB video network,
(2) NTSC video network,
(3) Voice network,
(4) Input device network, and
(5) Data network (LAN).

Networks (1), (2), (3) and (4) were newly developed and added to an existing Macintosh Local Area Network (5).

The video networks gather and distribute the computer screen images, desk images, and face images. These networks are based on a computer-controllable video switching system. Overlay of video images is done by the "video composite equipment" attached to the NTSC video network and the "desktop video card" installed in each workstation. The results of overlaying are redistributed to the shared screens or liquid crystal displays via the video networks. Liquid crystal displays are used as supplementary monitors to display collaborators' live face images to save the space of shared screen.

The voice network is for voice communication among collaborators who use wireless microphones and wireless headphones. We use stereo sound because the voice orientation helps users to identify speakers. Existing telephones can be used as an alternative.

The input device network is designed for the "computer-sharing" mode. The "computer-sharing" mode is a variation of the "shared hardware approach" taken by "Capture Lab" [Mant88, Halo90]. The same function has been implemented in software such as Timbuktu™ [Fara88]. However, the software solution creates excessive response delays.

In this "computer-sharing" mode, simple floor control is needed to pass the input control among collaborators. The current TWS prototype provides no special software or hardware embedded protocol for floor control, but relies on the informal social protocol agreed by the collaborators via the face-to-face communication links.

The data network (LAN) is used for remote control of video and voice switches, in addition to ordinary file and printer sharing.

At the moment,the TWS prototype utilizes five different networks. In the future, we will integrate them into a multimedia LAN and B-ISDN that are being developed by NTT.

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 linked Macintosh computers.

COMPARISON WITH OTHER SHARED WORKSPACE DESIGN APPROACHES

A comparison of TWS with other real-time shared workspace design approaches is shown in Fig. 8.

There are four basic approaches to building a realtime shared workspace.

(1) Single-user application in a shared window or computer

This is the approach that allows users to execute existing single-user applications in a shared window or shared computer. The advantage of this approach is that there is no need to modify existing single-user application programs for group-use. Therefore, it is not necessary to learn the usage of a new multi-user application. However, usually only one user can have a control of the shared application program or computer at a time.

(2) Special purpose multi-user application

Another approach is to implement new multi-user (*collaboration-aware* [Lauw90A]) application programs for particular tasks (e.g. group editing). 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) is provided. Each user can also have a personalized view if the program supports this function.

The drawback of this approach is the significant programming effort needed to write the new multi-user application. Discontinuity with existing single user application, and response delays caused by updating collaborators' shared windows can be also problems.

(3) Overlay of individual workspace images

We take a different design approach, that is, the "overlay" of transparent individual workspace images. Instead of designing task and window-system specific groupware, we have designed and implemented a more general environment for remote collaboration based on the "overlay" concept. This approach allows multiple users to use the existing different tools (such as pointing cursors, single-user applications programs, papers, pencils, hand gestures) simultaneously in a shared workspace.

The "overlay" idea was originally demonstrated by Tang and Minneman in VideoDraw [Tang90]. VideoDraw showed a new way to create a shared drawing surface by overlaying images of individual drawing surfaces using sophisticated system architecture. However, VideoDraw restricted the targets to be overlaid to the images drawn by hand and the hand gestures on a special transparent sheet attached to the surface of a TV monitor. TWS overcomes this restriction by integrating the images on desktops and the images generated by computers because this wide range of media, papers, printed materials, and personal computers, play a crucial role in individual work practice.

The drawback of this overlay approach is that the results of collaboration can not be shared directly. Another drawback is the quality of overlaid video images is not as sharp as most computer displays. These problems are discussed in the following section in detail.

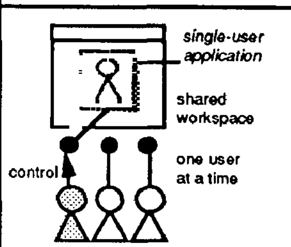
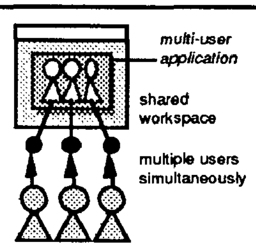
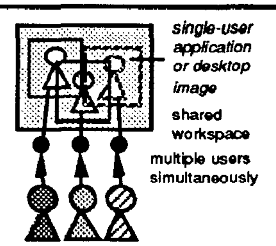
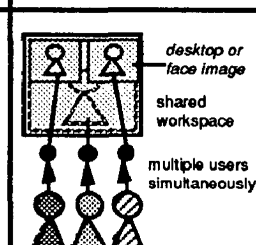
Approaches	Single-user-AP in a shared window or computer	Special purpose multi-user-AP	Overlaying of individual workspace images	Tiling of individual workspace images
Diagram				
Examples	• shared window system DPE [Suzu86], Rapport [Ahuj88], VConf [Lant86], Dialogo [Lauw90B • shared hardware system CaptureLab [Mant88, Halo89]	• group editor Cognoter [Fost86], Grove [Elli90]	• overlay by video synthesis **TeamWorkStation** [Ishii90] • overlay by special system architecture VideoDraw [Tang90]	• Media Space [Stul88, Harr90]

Fig. 8 Four Approaches for Real-time Shared Workspace Design

(4) Tiling of individual workspace images

Tiling is another approach to provide a multi-user interface for shared workspaces. Tiling (or use of multiple windows) is suitable to display multiple face images as shown in Fig. 4 (3). However, it can not provide the shared drawing surface because each member's individual workspace images are spatially separated on a monitor screen.

We feel that TWS has significant advantages over other approaches because i) it can support a broad range of *ill-structured* collaborations that can not be supported by *task-specific* groupware, and ii) it provides each collaborator with freedom in the choice of tools to use in the shared workspace.

EXPERIMENTAL USE OF TEAMWORKSTATION

Since July 1989, TWS has been used by the authors for daily work including refining the design of TWS itself, writing papers, and daily communication.

The major TWS usage has been discussion about the system configuration and the outline of issues to be investigated. These tasks are the so-called "upper-stream" tasks for idea development. The regular tools in our discussion were a drawing editor, an outline editor, and pencil and paper for handwriting. Comments were exchanged mainly by voice with pointing gestures in the overlay mode. Counter ideas were presented with the same type of editors (by screen-overlay mode) or papers (by "screen and desk-overlay" mode). However, in goal (output)-oriented collaborations such as making joint proposal, we mainly used the "computer sharing" mode.

Through the experimental use of TWS, we realized that the flexibility of movement among the various collaboration modes is very important. Since the pattern of collaboration changes dynamically according to the work content and roles played by group members, TWS's flexibility in shuttling between the six modes and between various application programs is very effective in supporting the dynamic collaboration process.

While using TWS, we noted that many common work practices such as printing, copying, and distributing paper documents became unnecessary. Information from printed materials, hand-written memos, or computer files can be shared with co-workers through TWS without hard-copying.

We also found that the face-to-face conversation link further increases system flexibility. The voice channel played an important role in the informal control of group interaction, especially for the use of limited workspace on the shared screen.

Problems in TeamWorkStation

Through the experimental use of the TWS prototype, we also found the following overlay problems.

• The results of collaboration can not 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 the video printer (to hard-copy), video digitizer (to store in a computer file) and video tape recorder to record the results and process of realtime collaboration. In the case in which both of the marks and marked documents are in Macintosh computer files, we used E-mail to exchange work results. We also tried to use a drawing editor with *multiple-layer function* (such as MacDraw II ™) to reproduce the overlaid documents, and found it works but it needs time and effort to adjust the spatial relationships among layers correctly.

• The quality of overlaid video images is not sharp or stable enough to support long-term viewing. In particular, the flicker of thin horizontal lines that comes from "interlacing" is intolerable. Although we tried to eliminate all thin lines with high contrast, the relief is only slight. We expect that this can be improved with HDTV technologies.

• Indirect drawing and pointing on desktop needs time and effort to get used to. Since the desktop images captured by TV camera is displayed on a shared screen after the image overlay operation, users must learn to use pencil or finger following the feedback from the screen. It is similar to the learning process needed by indirect pointing devices such as a mouse or tablet. VideoDraw [Tang90] solved this problem by letting users draw directly on the screen at the cost of less flexibility. Through the use of TWS, we found the advantages of flexibility created by the use of conventional desktop tools (such as papers and books) far outweighed this disadvantage.

• Identifying the owners of objects (such as cursor, draw object, window, icon, actual paper) on a overlaid screen is difficult especially when more than three screens are overlaid. 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 his/her CCD camera a little. However, we have not yet found the perfect solution to this problem.

• Since overlaid screen images are completely independent from each other, scrolling or moving of 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.

• Video is a *machine-unreadable* medium, and computers can not interpret and process the overlaid video images as it can text and graphic data. However, this is not a problem because human beings can understand the meanings of spatial relationships intended by the overlaid video images.

• The shared workspace of TWS is an strict implementation of the "WYSIWIS" (What You See Is What I See) design principle [Stef86]. Stefik pointed out that it is preferable to relax constraints of time, space, population, and congruence. The combination of individual and shared screen relax the space constraints. However, since overlay is done at the video signal level in TWS, it is difficult to relax all constraints. The following section describes an approach to overcome this strict WYSIWIS constraint in face-window layout.

FACE-WINDOW LAYOUT BASED ON THE SPATIAL RELATIONSHIPS OF COLLABORATORS IN A SHARED ROOM

Japanese companies prefer the workers in a department to share one large work space. This common work space is thought to enhance "group awareness" *1 and productivity.*2 Because Japanese emphasize the team rather than the individual, the physically shared room system is preferred to the private room system. Each worker has an assigned desk and develops an image of his spatial relationship to his collaborators. Figure 9 illustrates a typical room arrangement in our department. Although each person's work area is separated by low-partitions, they can see each other by standing up.

A Multi-User Interface Design based on the Floor Plan

The early version of TWS had the face windows arranged randomly on the shared screen. Each shared screen showed exactly the same arrangement as shown in Fig. 4 (3).

People who share a room create a mental map of the room's arrangement. Therefore, each member knows the physical orientation of the other collaborators. Through the experimental use of TWS by users within the same room, it was found that they preferred the arrangement to mirror the spatial relationship of collaborators. Thus we created the *floor-plan-based layout strategy* to replace the WYSIWIS principle.

Figure 10 shows how this new strategy makes the screen layout consistent with the orientation of the other collaborators. Both Example-1 and 2 are the face windows layouts for user D in the room described in Fig. 9. The differences between them are the location and orientation of the screen on which face windows appear. As illustrated in the figure, floor-plan-based layout strategy takes 1) physical orientation of collaborators, and 2) orientation of screen into

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*1 Awareness means the connection among collaborators during the times that they are not actively communicating with each other. [Stul88]

*2 High land and office rental costs are another strong reason for sharing rooms in Japan.

account. When we follow this strategy, collaborators do not necessarily share the "same" face-window layout on the "shared screen".

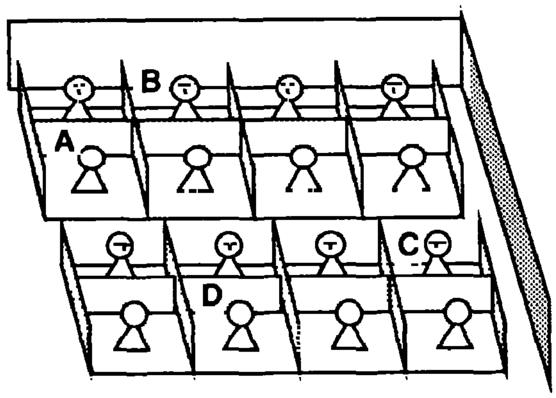

Fig. 9 A Typical Floor Plan in Our Labs

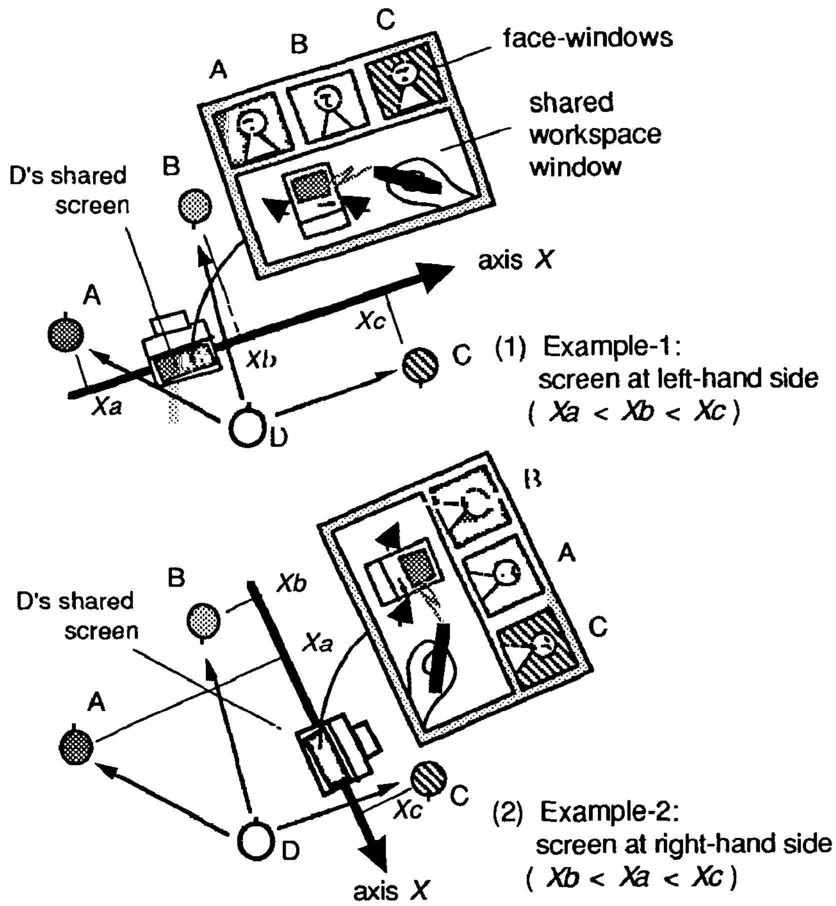

Fig. 10 Examples of Floor-Plan-Based Face-Window Layout

We confirmed the validity of this strategy by a questionnaire that asked people to arrange the photographs of their colleagues on a computer display. We are now redesigning the shared screen control system to relax the WYSIWIS constraint with additional video-tiling equipment for each workstation. We will allow the face-window layout to be customized depending on the spatial relationships among collaborators and displays.

CONCLUSION

TWS is a new human-human interaction media that approaches the *seamless* real-time shared workspace. It effectively integrates two kinds of individual workspaces: *computers* and *desktops*. Its key concept is the "overlay" of individual shared workspace images. Because each co-worker can continue to use his/her favorite application programs or desktop tools, there is only minor cognitive discontinuity (seam) between the individual and shared workspaces.

The additions of a simple CCD camera at each desktop and powerful video overlay functions significantly enhance the effectiveness of cooperative working. Real-time information such as hand gestures and hand-written comments can be shared between co-workers as well as information contained in printed materials and computer files. We believe the fusion of individual workspaces in computers with actual desktops leads to many synergistic effects.

TWS was not intended to replace existing groupware approaches. Rather, we designed TWS in order to support a broader range of ill-structured collaboration activities that range over several seams and can not be supported consistently by existing task-specific groupware. We expect that progress in video and HDTV technology will enhance the attractiveness of the TWS approach.

TWS is going to be tested with a larger variety of tasks and users to investigate the nature of collaboration, and to enhance computer support by reducing the seams. An expanded TWS system will be implemented on multimedia LAN and B-ISDN.

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