# Multimedia in the Workplace

# Media Spaces: Bringing People Together in a Video, Audio, and Computing Environment


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Coworkers sitting together over lunch discussing everything from the latest Super Bowl game to the knotty problems they encountered that day in their work is not particularly unusual—unless the workers are separated by 800 miles. The smooth integration of casual and task-specific interactions, combined with the ability to meet informally as well as formally, is a critical aspect of productive group work. Most tools in computer-supported cooperative work (CSCW) are devoted to the computational support of task-specific activities [7, 12], but support for cooperative work is not complete without considering all aspects of the work group process. When groups are geographically distributed, it is particularly important not to neglect the need for informal interactions, spontaneous conversations, and even general awareness of people and events at other sites [2, 13].

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Media space—a technologically created environment, emerged from a concern for both the social and technical practices of collaborative work and from an effort to support those practices. Our research is based on the premise that work is fundamentally social; it is constructed out of the activities of the participants and those activities depend on more than the explicit content of the work task [14, 24]. Technologies to support collaborative work are defined by the social setting and by the nature of the work, as well as by the features of the technology. Moreover, in the case of the media space, there has been an interdependent evolution of the technology and of the activity around the technology that could not have been set forth in advance.

Our media space was created at the Xerox Palo Alto Research Center (PARC) in the mid-1980s. For three years beginning in 1985, one of the research laboratories at Xerox PARC was geographically split between Palo Alto, California, and Portland, Oregon. The stated intent was to maintain a single group and explore technologies to support collaborative work. Such a cross-site working situation is, by its very nature, impoverished with respect to the usual ability to engage in joint activity of any sort. Yet it is precisely this joint activity that is essential to the creation and maintenance of a single lab or work group. Our research centered around finding a means of supporting that cross-site work including the necessary social connections. A media space of video, audio, and computing technologies allowed people at the two sites to work together and, perhaps more important, to "be" together (see Figure 1). The media space enabled a way of working that allowed social and task-specific activities to come together across time and space.

We define a *media space* as:

> An electronic setting in which groups of people can work together, even when they are not resident in the same place or present at the same time. In a media space, people can create real-time visual and acoustic environments that span physically separate areas. They can also control the recording, accessing and replaying of images and sounds from those environments [22].

We will look at three stages in the evolution of the media space. First we describe the social setting and the technological developments that led to the creation and evolution of the media space. Second, we discuss the media space in use, focusing on the Palo Alto-Portland link to gain a better understanding of both the technology and the work activity around the technology. Third, we look at the media space in its current forms and discuss what we have learned from the Palo Alto-Portland link. We suggest that research issues for media spaces concern the design of such systems, the use of such systems, the technology underlying such systems, and the ways in which work and technology are mutually interwoven.

## How Media Spaces Began

To understand the creation of the media space requires looking at its technological antecedents, its local roots, and its actual development. A variety of projects provided antecedents to influence the media space's initial form. In particular, in 1985 the availability of video technologies was growing and there were a range of explorations into the use of video for connecting people across distances. The local roots were in the Xerox PARC System Concepts Laboratory (SCL). SCL was established as a geographically split entity in 1984. Its mission was to consider interpersonal computing, the logical successor to personal computing which had dominated computing and communications research at PARC for several previous years.

### Antecedents

Outside the SCL research arena, the picturephone, video conferencing, and "Hole-in-Space" especially influenced the creation of the SCL media space. Since the early 1960s AT&T had been demonstrating various forms of prototype 'Picture Phones', telephones with video cameras and monitors that allowed callers to view each other. These prototypes had a unitary 'video follows audio' paradigm. The demonstrations, at such places as world's fairs and Disneyland, were set up in expanded telephone booths—special places where one would go to use the apparatus. The booths physically positioned the callers for optimum lighting and a semblance of eye contact, simulating in a crude way the one-on-one position of a face-to-face encounter. The 'callers' would not actually have the opportunity to place a call to someone they knew but would wait in line to talk with other callers who happened into the other booth.

More recently, the video conferencing industry has positioned itself primarily as an alternative to expensive and time-consuming air travel. Beginning in the mid-1980s, video conferencing has taken place in custom-built facilities using expensive and relatively scarce high-bandwidth satellite channels. The facilities are organized to provide balanced audio and video transmission; typically, to give the illusion of sitting across the table from the remote party. The equipment is complex and requires an operator to make connections, manage equipment and handle problems. The new generation of video compression technology developed for less expensive remote conferencing enabled the Palo Alto-Portland video link.

Of more direct lineage to the SCL media space was the 'Hole-in-Space' created by video artists Kit Galloway and Sherri Rabinowitz [5]. Hole-in-Space was a real-time video/audio connection between Century City (in Los Angeles) and Lincoln Center (in New York City). Set in outdoor public pedestrian spaces, each end projected approximately full-size images of people strolling by and encountering others across the continent. More similar to window shopping than a sidewalk encounter with friends, people would stop, stare for a while, hear the sound of the remote conversation, and then strike up a conversation with passersby at the other end. The apparatus was in suppport of the artists' agenda about the power

Figure 1.

Figure 2.

of casual social encounter to improve human relations.

### Roots

To trace the earliest roots of the SCL media space one must trace the way of working that the media space sought to enable. From the beginning, the Lab was a close group whose members collaborated on projects and management alike. Although there was a hierarchical management structure, lab members regularly attended staff meetings, and most decisions were made by consensus. In addition, weekly lab meetings ensured that there was not only frequent exchange of research progress but also social activity. The social orientation was an acknowledged part of SCL's agenda and way of working. To make the most of the diverse backgrounds and research interests within the Lab, communications (both social and technological) were a component of research and Lab discourse. With the move from personal to interpersonal computing, the lab initially took *computing* as the means to support this communication among people. Lab members saw it as a challenge to integrate access to large shared information sources and powerful computational services together with activities such as casual interrupting, gossiping, and brainstorming. A turning point for this group occurred when they recognized that high-bandwidth communications allowed them to talk about audio, video, and computing together [3].

The site in Portland was designed with a physical environment that closely matched the one in Palo Alto. Offices were on the periphery of a common area with a private conference room nearby. Each researcher was encouraged to make two trips a year to the other site. Initially, the two sites were linked by a 9.6 kilobit per second (Kb per sec) link between their computer networks for shared file access and electronic mail, as well as by telephone (speaker phones provided the support for group meetings). The data link soon grew to 56Kb per sec.

Although SCL was organized into groups which nominally carried responsibility for separate projects, project membership was fluid across these organizational boundaries. People would join and leave projects and discuss technical matters of other projects. It was not unusual to have project teams with members in both Palo Alto and Portland. Within this framework, two groups were particularly instrumental in the eventual formation of a media space: the Design Methodology group and the Collaborative Systems group. Tracking the development of the two groups is important because the media space did not result from a carefully structured design process. Rather, it grew out of the agenda of the Design Methodology group to support design as a social activity and evolved to become the research focus of the Collaborative Systems group.

The Design Methodology group was investigating tools to allow groups to keep records of significant project work. Records included mail, text files, code, project lists, and video recordings. An initial project was a video journal of the design of a house addition. One of the earliest uses of video in the group was a fixed, real-time, local area video/audio connection between three researchers' offices. The real-time connection, shown in Figure 2, provided a link among the group's offices which were separated by 50 to 100 feet. Building on ideas of Marshall McLuhan and Joshua Meyrowitz, video was used to increase the possibilities for keeping in touch by providing connections outside of physical space and extending the present time, place, and event [16, 17]. In parallel, the Collaborative Systems group concentrated on computationally based information and process management for group work. They wanted to understand and develop tools that would support an existing cross-site development project within the Laboratory.

For the various lab meetings, a fixed, two-way video link was established between Palo Alto and Portland in September 1985. A camera, monitor and speaker phone were positioned at each site in the common area, the shared area surrounded by offices. The link consisted of video compression equipment, a 56Kb per sec data line, an audio teleconferencing system, a standard phone line, and consumer-quality video cameras and monitors. The phone line providing audio link was left open all day. Thus, walking through the Commons provided an opportunity to see, hear, and speak with anyone in either Commons area. Although it had been intended as a cross-site meeting tool, the primary use of the link initially was for frequent chance encounters between researchers at the two sites. In part, this was a result of having a dedicated communications line, so there was no reason to turn off the link between meetings. Furthermore, because the equipment was relatively portable, researchers could and did move it into individual offices for private meetings.

Once the Commons-to-Commons audio/video link was established, the Collaborative Systems group included it as an extension of their agenda to understand and support group work. In fact, one project team took on the interactional problems of holding cross-site meetings. They addressed problems such as participation protocols and how it might be helpful to maintain a view of the entire group in order to participate effectively. Another team worked on technology as a way to provide a surrogate for physical presence. They proposed developing a robot to wander the hallways at the remote location, not only providing the 'seeing' aspect of remote presence, but, by displaying a video image of the person driving it, it would provide the 'showing' part as well. From all these early efforts, the audio/video system grew to provide manual, real-time control of visual and acoustic environments and simple, manual control of recording, accessing, and replaying.

### The Development of a Media Space

When the Design Methodology researchers brought together their audio/video network with the preexisting computing network, the first PARC media space emerged (see Figure 3). This initial prototype expanded and extended the fixed audio/video connection among their four offices. Through a crossbar switch that linked the cameras, monitors, and microphones in each office, the computer now gave switched access to persons in each office [22]. The video switch was critical in providing *modifiable* connections; participants could configure the electronic space to align with their current activity. The modification of electronic space had a physical component as well, since the placement and number of audio and video pick-ups and displays in each office were also the subject of constant change.

The four researchers in their individual offices worked with one another across the video connections—through the media space—while being physically separate from one another. Soon the four-office media space extended into the laboratory's shared work areas and incorporated the fixed video link between the two common areas in Portland and Palo Alto. Public-to-private connections were now added to the existing project-centric, peer-to-peer, office-to-office connections. The activities of people in the local Commons or one 800 miles away—passing through, chatting, assembling manuscripts, or whatever—were now occasionally part of the scene in the four offices. This served to connect the users of the four offices with other lab activities and represented an important link with the Collaborative Systems group. Lab members could move fluidly from using the public video/audio connection in the Commons to a more private use of media space in their individual offices. The media space could exist or not exist in a variety of places; the media space could be or not be a major focus in these locations.

> We changed connection by walking to the switch and pushing the buttons on its panel. We changed connection sometimes for reasons, sometimes for whim, never according to a schedule. We made changes many times a day, and we rarely went even for half a day without changes. We typically created a connection, lived with it for several hours, and then replaced it with another. Thus we moved irregularly through all the dyadic relationships in the group.
>
> We dealt with privacy directly, mostly by turning off the microphone in the office, perhaps once or twice turning off a camera. Conversely we dealt with disturbance just as directly, controlling the volume on the TV monitor [22].

The initial system of video, audio, and computing technologies used by members of the Design Methodology group demonstrated such potential for keeping members of a spatially distributed group in close, ongoing contact, that an improved media space became a research focus of the lab. The video/audio crossbar used in Palo Alto was extended to 20 × 20, and a 10 × 10 crossbar was installed in Portland. At this point, a complete media space could exist in and across the two sites. The initial media space of four offices in Palo Alto, several public areas, and the link to Portland was expanded to eight offices in Palo Alto, connections to various devices (such as video recorders and videodisc players), locations in other laboratories, six offices in Portland, several shared areas in Portland, and the cross-site link. Computer servers were implemented to control the media space's crossbar switches and other devices. Computer workstations could communicate with the servers to control the connectivity of the audio/video network as shown in Figure 4.

Many projects over the next 18 months focused on the SCL media space. These ranged from access to the media space (remote camera control, meeting protocols, and interfaces) to shared computational applications to augment the media space communications (for example, drawing tools and shared databases). Several issues emerged for research consideration: the impact of merging novel communication environments with existing social relations and work activities, the provision for privacy, and user-tailorable environments. A three-year study of the organizational and interpersonal dynamics of the distributed laboratory was started [20], and in 1987 a study of video-mediated interaction was begun [11].

In retrospect, it can be seen that where the antecedents took a fixed, physical space (e.g., a phone booth or a conference room) as a support apparatus for electronic communications, a media space uses electronic media (primarily video) to alter and augment physical space. Where the antecedents relied on technology to be constant and mostly outside user control, the Palo Alto-Portland media space was developed and was continually shaped by the people using it. At the same time, the roots provided by SCL pushed for support of a group, not individuals connecting only to do a particular task. The motivating problem was to recreate in a working group separated geographically the sense of embeddedness that we had found in working together locally. We tried a variety of devices (both social and technical) and we used those in a variety of ways, some anticipated and some not anticipated. As seen from the initial development of the media space, we iterated frequently and quickly; we kept the participants in control of the technology and of their work activity; we allowed the technology and the work activity to evolve together. The PARC media space began not with a single technological goal, but from the work of a diverse group of people exploring new ways of working and collaborating.

## The Use of a Media Space in the Palo Alto-Portland Link

The activity of using a media space is not a primary activity itself, but one enabling other activities. Unlike 'phone' or 'teleconference', 'media space' has not become a verb. As with its creation, the use of a media space requires understanding the continued evolution of the activities into which it is integrated as well as the technologies that constitute it. The Palo Alto-Portland link provides a particularly useful example, since colleagues who both needed and wanted to work together were distributed geographically; the link was often in use. Furthermore, much of the structure of the media space evolved through use of the link rather than through *a priori* hardware and software design.

As discussed earlier in this article,

the split lab was planned as an experiment in which the demands of the setting would drive the technological explorations. Anyone wanting an office node was provided with one, and audio and video were entirely separate both in the hardware and in the software. Since the switching interfaces included no access or connection restrictions, users determined their availability across the medium by directly controlling the technology. For example, the office camera was typically in one of three states; open and on—the user visible; open but focused on some nonuser location (a poster, outside the window, etc.—friendly but not personally visible); or closed (i.e., lens cap on and/or camera off–not available). While cameras were most often open on a user, microphones were often off but switched on quickly as needed. In the Commons areas, both the cameras and microphones were typically on but the camera was regularly moved as activities and participants in the area changed. There was not automatic notification when someone was watching, so the observed person was not responsible for responding in 'polite' ways. Similarly an observer took responsibility for changing his/her display if bothered by the image or audio. Individuals, not the technological system, evolved and maintained their own boundaries of personal and private space.

It is important to note that the Palo Alto-Portland media space was constantly in use, functioning like an extension of physical space. It was not something that was turned "off" or "on" during the day, but was continually available. The media space supported a sense of playfulness, the casual acceptance of one anothers' presence, and for people in Palo Alto, a closer sense of familiarity with those in Portland than with many in the same building.

### Kinds of Uses

From providing a background awareness of people and events to focused interactions among colleagues, a media space can be a part of many aspects of interaction. The following examples of uses from the Palo Alto-Portland media space indicate the range of possible activities and the ability of a media space to support colleagues moving among activities. This range of activities is an important component in the value of a media space. These particular examples have emerged from our own experiences, from videotaped data, from internal reports, and from anecdotal evidence [1, 11, 20].

***Awareness.*** Although seemingly the most invisible, the use of the media space for *peripheral awareness* was perhaps its most powerful use. The view frequently found in peoples' offices was the Commons at the other site. This view, at first glance, appeared to be nothing more than a view of an empty public space. On closer examination, however, there was rarely more than a minute or two in which there were not at least sounds from the other location giving clues about the ongoing activities there [11]. People walked through and were in and out of offices; conversations took place. Being aware of such activities required no response; it provided an overview of who was around and what was happening (and afforded the possibility of joining in). Of course, this background awareness was not constrained to the common areas. Lab members who were working closely together often had a colleague's office on the monitor as a background view. We have seen people casually share jokes, show a group of friends a new toy, or move cameras to unusual positions for interesting visual effects.

***Chance Encounters.*** *Chance encounters* occurred much as they do when people are in the same physical location. They were unintentional and provided an opportunity for interaction. Again, the common areas played a major role in the chance encounters, particularly since they provided live audio as well as video connection. As people walked through a Commons, they typically glanced at the screen, much as people look around them as they walk down a hallway. When people were also in the Commons of the other site, the opportunity for a chance encounter was at hand. Chance encounters also happened when people were using another office as a background. Thus, when someone wandered into an office at one site, he/she might find someone at the other site as well. Figure 5 illustrates such a chance encounter which started from a vacation discussion in Portland and went on to a lengthy conversation about configuring equipment to provide direct eye gaze.

***Locating Colleagues.*** Unlike chance encounters that occurred as a side effect of doing something else, *locating colleagues* was intentional, either to locate someone in particular or to find out who was around. Sometimes this was done by using the audio connection, for example, just calling to the other site "is John around?" or even "is anybody there?" Sometimes lab members located one another by specifically looking in the other common areas and/or offices using video switching. Asking, "have you seen John?," in the media space environment expanded the area in which one might have seen another to a space beyond the physical. These sorts of efforts to locate others all depend on the expanded awareness provided by a media space.

***PicturePhone Redux.*** *Video phone conversations* were often used cross-site between two colleagues who were focused on a particular technical matter or on cross-site supervision. In general, video phone conversations were less frequent than other uses of the media space. Still, the video helped colleagues to explain drawings to one another or to have added visual feedback as they discussed sensitive matters.

***Group Discussions.*** *Group discussions* in the media space most resembled the use of a video conferencing facility. However, the general availability of the Palo Alto-Portland media space throughout the areas of the lab led to great flexibility in the sponta-

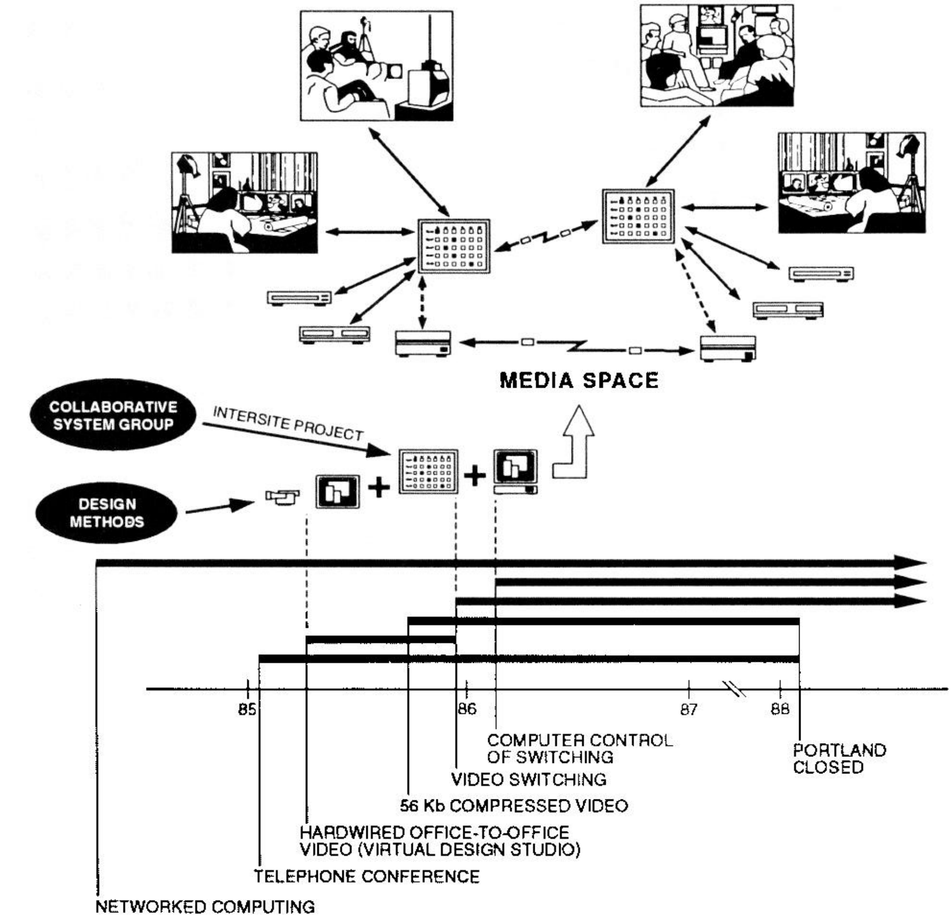



**Figure 3.** The PARC media space emerged from the interplay of different research projects and goals, as well as from the combination of technologies.

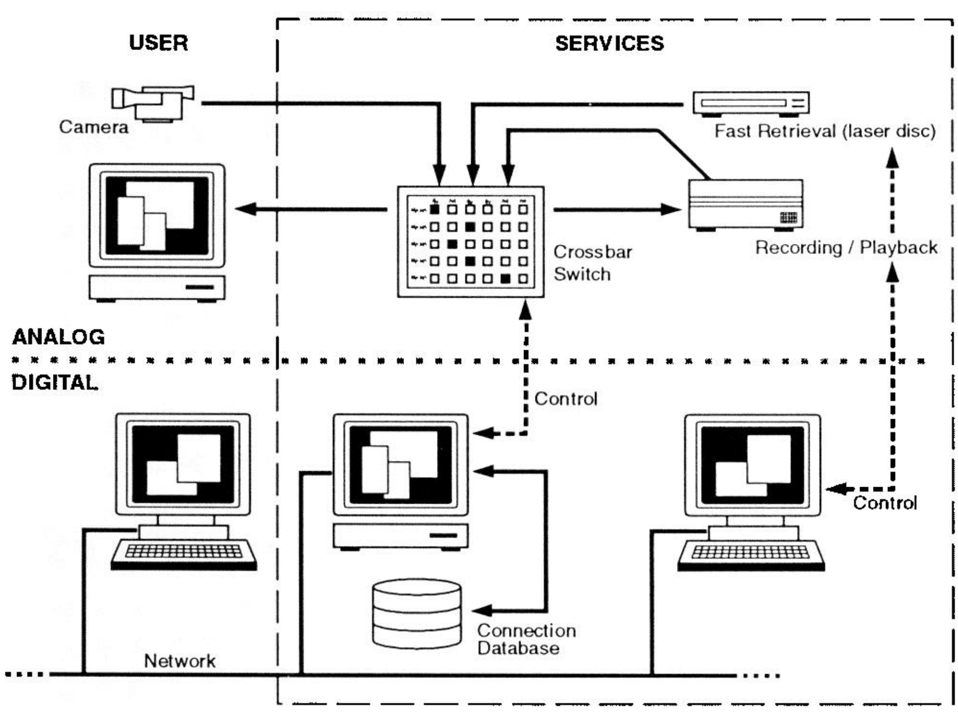



**Figure 4.** From its inception, it was a hybrid analog-digital system. Access control and the state of connection are available from workstations on the network. Additional computers control switching and other services on the analog audio/video network. Note that users may have multiple cameras and monitors. Also, images are sometimes displayed as windows on computer displays.

**Figure 5.** A sequence of images illustrates a chance encounter in the media space Commons areas. (Note: These images come directly from videotape recordings and thus don't have the high image quality of still photographs.) A) In Portland, Bob, Tim, and Beth are talking about their recent vacation. B) As they continue their discussion, Sam sees and hears them as he walks through the Palo Alto Commons. C) Sam walks up to the link, and Bob sees him and says hello. D) The group involves Sam in the remainder of the vacation story. Sam and Tim then proceed to have a lengthy technical discussion.

A)

B)

C)

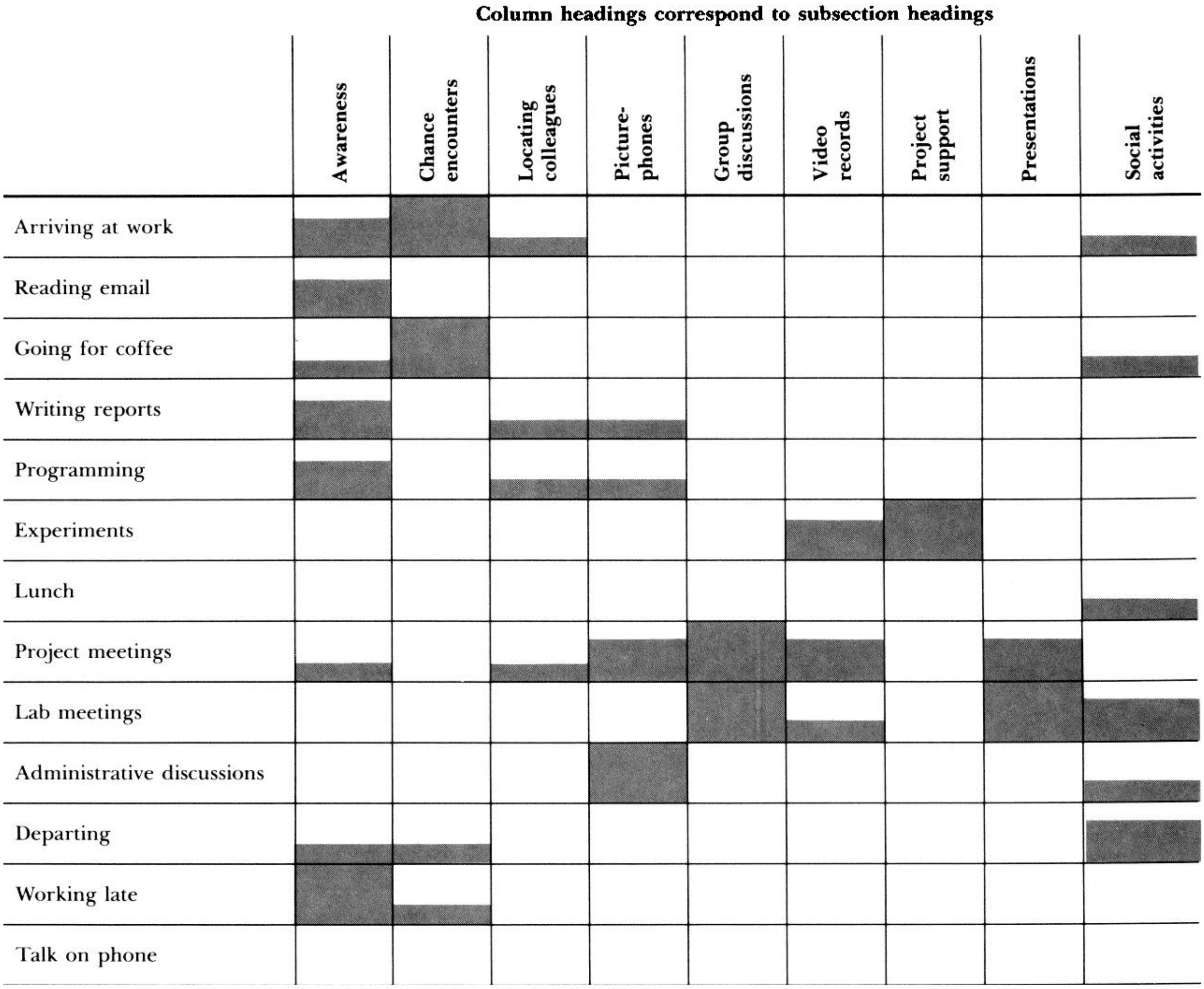
D)

neity and location of such meetings. Group discussions arose from casual conversations as well as from scheduled meetings. Small groups met in offices or the Commons, while larger meetings were frequently held in the Commons or the conference rooms. Work groups could meet on an as-needed basis with little need for special scheduling.

***Recording and Replaying Video Records.*** Although most attention was on real-time access, *recording and retrieving video records* were also available in the media space. Meetings were regularly recorded and made available to those participants who missed the meeting or who wanted to review the meeting after the fact (although this was not particularly easy cross-site). The notion of video memos or notes was used heavily in various design projects as well as within the Lab itself [23]. A later expanded version of video memos, called PARC-o-grams, were compilations of informal video interviews and events recorded on videotape and sent between the Palo Alto media space participants and their colleagues at EuroPARC in Cambridge, England.

***Project Support: Experimentation and Envisionment.*** As part of the working life of the lab, the Palo Alto-Portland media space was heavily used for *project support* [23]. In particular, a media space allows an easy way to set up envisionment exercises in which video/audio connections can simulate various means of support for distributed group work. The Office Design Project created an environment that allowed three architects who had never met face-to-face to participate in a design exercise, meeting and working in a media space [26]. In another project, equipment from the media space (i.e., cameras, monitors, and recorders) was taken to an actual mechanical design project to support the communications among groups

**Table 1.** Uses of a Media Space in Daily Activity. This table reflects the scenario of a typical work day in SCL. It is meant to suggest a framework for understanding how a media space was used by individuals. The thicker the box, the more significant the use.



[9]. In still another study, this equipment was used in simulations of the communication process between design and manufacturing [8, 18]. In prototyping and studying technologies for task-specific use, such as shared drawing tools, the media space has frequently provided video and audio connections for the interactions with these systems [19].

***Presentations.*** A media space can also be used as a means of augmenting *video presentations.* Again, because a variety of audio/video devices are connected to the network, it is straightforward to use videotapes or broadcast live video presentations to a particular place (i.e., the Commons or conference rooms or offices). In the Palo Alto-Portland media space, presentations held in the main PARC auditorium could be transmitted to nodes on the media space. This allowed Portland members to see and participate in PARC-wide meetings.

***Social Activities.*** A media space offers a medium for *shared social activity.* The background awareness creates a sense of what happens at other sites; the group meetings were occasions to work together. Both contributed to a sense of shared experience and culture. Other events that contribute to the cohesiveness of a working group also utilized the media space cross-site link. It was common for Palo Alto SCL colleagues once a week to eat lunch together in the common area. With the advent of the Palo Alto-Portland media space, the 'Commons lunch' often occurred at both sites. The Christmas party was held jointly, with at least a few activities planned to take advantage of the link and to minimize the properties of the link that were difficult to overcome (large cocktail group conversations were impossible, for example, but charades worked quite well).

### Media Space Use and Daily Activity

Given the various uses of a media space that we have observed, how might they appear across the activities of a typical day? SCL conducted its research in an office environment that is typical of so-called 'knowledge workers'. Table 1 shows one subjective view of the interaction between activities and uses across the work day in this environment.

- At the start of the day, people would arrive, some with briefcases in hand, walk across the Commons, glance at the large media space monitor to get some idea of who had already arrived in the other location, and say 'Good morning!' to whomever was within earshot.
- The morning might progress by reading and answering electronic mail (much of it from other SCL research staff) and writing code and reports. During this time, the monitor would very likely be showing a view of the local and remote common spaces. Occasionally, one might switch to the office of a specific colleague in order to ask a quick question or schedule a meeting. Others might notice this interaction on their own monitors and understand that this would be a poor time to interrupt.
- The morning would be broken by a stroll across the Commons to the coffee pot and the printer. Besides passing open office doors and crossing paths with other caffeine seekers, this meander encouraged electronic chance encounters as people's voices carried over the Commons' speakerphone and as colleagues would cross in front of the Commons' camera.
- In their offices, while engaged in the usually solitary enterprise of writing code and debugging, researchers might seek out the expertise of a colleague or catch a glimpse of others headed off to lunch together. The office could yo-yo from cloister to shared office in an instant, reflecting the moment-to-moment changes in focus.
- In contrast to the fluidity of a routine morning in the office, a project experiment could dictate a particular configuration of spaces and technologies. On these occasions, the media space became research apparatus by easily linking cameras and recorders in fixed connections.
- Some days were filled with meetings, many of which used the media space. Project meetings, held at regular and often frequent intervals, had small groups that would brainstorm ideas, review progress, assign tasks, refine understanding, gossip, and present work. This would be in a mix of formal agendas and casual discussion. The media space would be used to track down the tardy, to hold one-on-one and group conversations, and to make a videotape that those on vacation (or in other meetings) could later watch to keep current. Those not engaged in the project meetings might look in to remain aware of the group's progress.
- The entire Lab would hold much bigger meetings to deal with issues ranging from the assignment of office space to the formulation of a mission statement. Here the media space was a kind of cheap teleconferencing system supporting group-to-group connection. Lab meetings usually revolved around a set agenda but also included explicit social activities such as birthday parties.
- At the end of the day, the social ritual of 'Good night!' as people headed out the door would conclude with a sense of who was around based on the responses that were heard. Even this would not be the last use of the day, since one or two people could be found working late into the night. Most likely they would connect their offices, remaining aware of the other's presence even if they were not otherwise working together.

The scenario depicted in the preceding list illustrates a significant success of the Palo Alto-Portland media space: support for a broad range of working activities. The media space was not intended to replace face-to-face interactions, but it did provide an environment for a geographically distributed group that needed to work together. It was not a video conference system, though it was used for that purpose. It was not a video phone system, though it was used for that purpose. The value of the media space was that it was available and present across a range of activities. It accomplished this not by being neutral or 'all-purpose' but by affording appropriation to each of the particular groups and activities [21]. It offered a means of maintaining group working relationships and group work in a way not previously possible over an 800-mile separation.

## The Media Space Today

In January 1988, the Portland lab was closed, and SCL was merged with another PARC lab to form the System Sciences Laboratory (SSL). The media space in Palo Alto has expanded to include more switches, additional offices and new devices to support researchers engaged in the study of design process, collaborative systems and work practices. In addition, the group of researchers directly connected by the media space expanded to researchers in other groups at PARC, including people working on multimedia networks and on image manipulation and storage. Looking back over the creation and evolution of the media space, its use in the Palo Alto-Portland link, and its continued role in a variety of environments today, we can begin to characterize media space technologies and ways of working. These are relevant in the contexts we have studied but provide implications for other settings as well. The success of the Palo Alto-Portland link demonstrates the support of technologies for maintaining work and social activity across the two sites and demonstrates our method of interweaving technology advances and work activity. Perhaps most important, our continued use of the media space, as well as the success of related projects in other organizations (see sidebar, "Additional Media Space Research"), suggests the value of further evolution and iteration of connecting colleagues across space and/or time with video, audio, and computing technologies.

## Current Media Space Projects

In recent years several projects in other places have addressed issues of connecting colleagues across space and/or time with video, audio, and computing technologies (see "Additional Media Space Research"). In each of these, the user groups and the design decisions made for implementation of the technologies have differed from those in the Palo Alto-Portland link. These projects illustrate an even greater range of ways of working within a media space, provide additional experiences and observations, and raise new issues for study. The emergence of a media space at the EuroPARC lab in Cambridge, England, generated a number of new approaches to the use and study of media spaces and prompted consideration of connections over even longer distances and time differences [6].

The dissolution of our cross-site link led to a new instantiation of the media space at PARC, which also illustrates some different technologies and ways of working. The participants in the PARC media space are in the same building, often located in physically proximate offices. Now one finds that the view most often on monitors is that of the 4-input video display (the image consists of four separate feeds each shown in a different quadrant of the display). Although the four images do change from time-to-time, they are most often of a group of four researchers who work together regularly. Recently, an addition of two summer students to the project caused some renegotiation about which four images should appear. Different members of the group regularly reconfigured the four images for individual preferences. Over time, the member of the group who was least involved with the students was left out of the combination image; the students almost always appeared; and the other two images were updated as the other three researchers came and went throughout the day. The old pattern of use was changed as the group habits adjusted to different patterns in the communication.

The media space continues to play an important role in our work activity even though our offices are now close together. New participants particularly mention the value of having team members who are instantly accessible and interactions that can occur with relatively low effort. From this basis, the next steps in this research involve investigations of the implications of fully digital transmission and storage systems and the ways in which real objects and spaces can be shared at a distance. The media space continues to be ever-present and available but easily put in the background of conscious awareness.

## Research Findings

What does the media space development and use tell us about our premise that in creating technologies to support work, the technologies and work activities are intertwined and evolve together? First, the media demonstrates that we can develop technology to support social activity. Second, the Palo Alto-Portland link shows that with technological support a working group can collaborate effectively cross-site as a single entity. Third, we have identified considerations in the design of a media space. Fourth, we have demonstrated that design through an interweaving of technology and work activity is viable.

***Technologies in Support of Social Activity.*** Like video conferencing or video phones, the media space was concerned with supporting groups across distance. However, we were particularly concerned with the complex, multifaceted activities of work groups. Our experience with the Palo Alto-Portland link has demonstrated that technologies can support the social activity of work groups distributed across space. The frequent and regular use of the media space for awareness, for informal interactions, and for sharing culture are all indications that technologies are supporting more than task-specific communication.

***Group Maintenance Across Distance.*** A central demonstration of the Palo Alto-Portland link was not only that the technologies supported work activity, but that the group could and did maintain itself as a single community. People regularly referred to all members across sites as 'we'. People could and did move among projects and areas. People within the group depended on others, regardless of location, as resources in work and play.

***Considerations in the Design of a***

***Media Space.*** Although there is no easy formula for creating a media space, we can suggest some important considerations. The people participating in the media space have the greatest influence on the ways in which it will be used. The ways of working that people bring to a media space and create in that space can vary greatly. However, characteristics of the setting and the technology are also important in how a media space is used and what it becomes.

We consider the setting to include the individuals using the technology, the relationships among these individuals, and their activities. Factors affecting the shape of a media space include group size, the working relationships within the group, the physical proximity of members of the group to one another, the nature of the work, and the group's approach to work and social relationships. Different settings require different media space configurations. For example, *commonality of purpose* and the *degree of openness* about work are indicators that an open technological infrastructure can accommodate the group activity as in the Palo Alto-Portland case.

Likewise characteristics of the technologies impact use. The fact that the media space was easily accessible (often requiring no action on a participant's part except to participate) was critical as evidenced by the use of the Common's open audio/video channel. The interfaces to control the media space that persisted were easy to use and displayed the full possibilities for connections as well as who was connected to whom at a given time. Looking at the interface was like entering a room in which a party is going on and being able to see the various conversations under way at a glance.

The technologies of the media space include not only the objects of the system but also their placement, the access to them, the interfaces to them, and the connections among them. Several characteristics of the technological setup are influential in the resulting use of the system: access to real-time and recorded material, public and private links, additional shared tools, privacy protection, background views, reciprocity, audio and video separation, and connected open public areas. The placement of and access to the technologies, as well as their integration into the ongoing organizations of work life, is critical to the use and success of any media space.

***A Method of Creation by Evolution.*** We have found that our design and development based on the interdependence of work activity with technologies result in successful systems. (Not only did we demonstrate the use of the media space in the cross-site lab, but the media space continues to thrive within a colocated lab.)

The creation and evolution of the media space also led to development of other new technologies. One of the problems that became apparent early in the Palo Alto-Portland link was the need for a shared drawing surface. Users of the media space could easily point their cameras at drawing papers or whiteboards, and they did this relatively often. However, users were never satisfied with simply showing work to one another; they wanted and needed to collaborate on problems and solutions. In a manner similar to the creation of the media space, we used the work activity and the development of technologies in concert to explore a variety of shared drawing prototypes [19, 25].

Another impact of the work was on media literacy and the subsequent reliance on this media literacy by other projects in SCL. From Design Journal to Office Design Project, from Chinese Temple editors to Electronic Sketchbooks of Thangka Painting, from the mechanical design project to future engineering environments—each went from computing to computing augmented with audio and video, especially leveraging on the temporal characteristics of the media [8, 15, 18, 23, 26]. These projects illustrate steps in the evolution toward a unified field of audio, video, and computing.

Understanding the importance of awareness and open connection in SCL led us to consider whether awareness of people and activities in a working group had value independent of other mechanisms that might be available for collaboration. Tools were built to explore this notion of awareness. One such tool, Portholes, is regularly used today between PARC and EuroPARC [4].

## Practical Observations

While many issues in the media space have been addressed by the development of social convention, there have been recurring problems with several aspects of the media space which individual adaptation and social convention are not equipped to fix. Some of these problems may have technological fixes; some remain open issues.

***Scale.*** The Palo Alto-Portland media space involved about 20 participants in three groups (and a number of projects). We do not know how a media space extends to larger communities and organizations, and we do not have much experience across hierarchies. We expect that a group in which everyone knows everyone else will have a much different use of a media space than one in which members are less familiar with one another. We recommend that those interested in connections across time and space consider whether or not there is an ongoing group that works together closely. For interactions that do not depend on a day-to-day sense of community and a regular awareness of one anothers' activities, such as occasional task forces or information sharing, technologies other than media spaces may be more appropriate support.

Even in media spaces of 20 to 30 participants, each has been developed in a different organizational context to meet somewhat different needs. While the open, continuously available environment of the PARC media space is appropriate for a number of group settings, it is clearly not appropriate for all. One means of extending to larger organizations might involve connecting subgroups of media spaces. The opportunity and challenge of electronic connection is to support the variety of ways in which people can and might work together. With media spaces, one size does not fit all: To build systems that reflect the changing needs of user communities means they must fluidly be able to accommodate open styles of working as well as closed and private ones.

***Harmful Analogies.*** Mediated communication systems such as the media space are frequently compared to face-to-face interaction. It is important to reiterate that we did *not* try to replace face-to-face communication nor do we believe that mediated communication can replicate the face-to-face experience. The importance of the Palo Alto-Portland media space was that it provided an opportunity for communication not possible without 'being there' and that the support extended beyond communication on the explicit content of the work task. This is what made the media space a *sustainer* of working relationships.

It is also tempting to compare a media space with typical marketplace *technological* offerings: video conferencing, video phones, and desktop video. In fact, these systems have similarities to aspects of some media spaces, and most media spaces offer the capabilities of video conferencing, video phone calls, and desktop video. However, neither video conferencing nor video phones offer the flexibility provided by integrating those technologies into a computing environment. Most video conferencing requires that one 'go' someplace; it is not an integrated part of the office itself. The video phone model lacks the ability to maintain a peripheral awareness of activities in the space or to take advantage of spontaneous interactions; 'calling' requires a deliberate action and implies a beginning and an end. Desktop video, however, has potential for offering the same capabilities as a media space does, especially if the camera is not integrated into the workstation and is freely movable. It will be valuable to explore the possibilities for desktop video in supporting activities like peripheral awareness, chance encounters, distributed meetings and

## Additional Media Space Research

A number of research projects have sprung up over the last few years to look at media spaces [1, 3, 5, 7, 9, 12, 14]. While they all share a similar technological notion of a media space, each project has had a different mix of research agendas and use including telephony, computing, sociology, mediated communication, and user interfaces. In general, they share at least one methodological approach—to some degree each was built for use by the researchers as part of their work environment and a fundamental part of the evaluation included use of the system as part of routine work. Several are described briefly here.

**VideoWindow: Bellcore**
The VideoWindow system provided a large screen display with live audio between two public areas on different floors of a research lab building [3]. It was on 24 hours a day, 7 days a week, for approximately 3 months to support informal interactions among researchers and staff (about 50 people). The basic model is that of encountering others around the coffee pot; colleagues could interact or not as they chose. The VideoWindow did not require intentionality. People typically came to the area for some specific task (getting mail or coffee) and then could engage in conversation with others who happened to appear coincidentally either in the same space or in the space provided by the VideoWindow. Users could control their access by choosing to enter or not to enter the area.

**Cruiser: Bellcore**
Cruiser™ uses cameras, monitors, and computing to connect research offices for informal interactions [4, 14]. In contrast to the VideoWindow, Cruiser was based on the model of walking down a hallway and popping one's head into a doorway. Cruiser was always reciprocal in that one saw another 'popping in' (the monitor of the observed switched to show the person cruising through); users could control access to their images with status messages. During a cruise, either the observed or the observer had the option of changing the cruise activity to a two-way conversation activity. The expectation was that people would use Cruiser to look up others for a quick conversation and/or a chance to meet. In fact, it has been used in several ways, including office-to-office connections for long periods. The Cruiser system is described further in the material by Fish et al. appearing in this issue.

**RAVE: Rank Xerox EuroPARC**
At Rank Xerox EuroPARC, RAVE (Ravenscroft Audio/Visual Environment) supports about 20 people who form a single research lab spread across their three-floor building [2, 7, 8]. Every member of the lab has a RAVE node—managers, researchers, and administrative staff—with connections to offices, common areas, and audio/video devices. An important capability is the use of the media space audio for a variety of informational cues, from signaling that it is time for a meeting to greeting a new arrival in an office [6]. Software interfaces provide media space actions: glance, video phone calls, office-sharing, background viewing; there are no public areas connected with continually open audio/video links. Users control both the access to their individual views and the form of their responses to someone wishing to access them. Shared office situations are reciprocal; only public areas can be used as background. Thus, an observed person is always aware automatically that he or she is being watched, and an observer can be comfortable that the observed is aware (and has granted permission for that observation). The EuroPARC system has evolved into regular use for locating colleagues, for ongoing 'shared office' situations, and as a substructure for many other applications.

**CAVECAT/Telepresence: University of Toronto**
CAVECAT (Computer Audio Video Enhanced Collaboration And Telepresence) was a three-year project to investigate how the combination of computer groupware and audio/video technologies could be combined to enhance collaboration at a distance. The media space part of the project was based on EuroPARC's RAVE system (having been implemented by two of the same architects). The system supported a small group of 10 offices and laboratories in a single building [11, 12]. One focus of the project was combining computer mediated activities, such as shared writing or drawing, with shared personal presence through the media space [10, 13]. Another was on

means of supporting groups which are distributed over more than two sites [15, 16]. As with the Palo Alto-Portland media space and RAVE, the CAVECAT environment served both as part of the communications infrastructure of the group and as a platform on which to perform studies and experiments. The follow-on to CAVECAT, the Ontario Telepresence Project, is moving the technologies out of the research lab in order to study them in the context of extended geographical distance (including links with EuroPARC and PARC), as well in the context of arms-length workplace field studies.

**TeleCollaboration: US West Advanced Technologies**

Most like the Palo Alto-Portland link, the TeleCollaboration project supported a small group of people who were geographically distributed between Denver and Boulder, Colorado [1]. Within the relatively small research group at Boulder, there were two cross-site projects and the third project shared many interests with colleagues in Denver. The set-up included offices, a conference room, and a public area at both sites. The connection model was one of specific actions: "call" and "look around", video conferencing, and informal meetings. A *call* provided a private office-to-office connection with audio, video, remote camera control, and a possible shared data space. *Look around* was a video-only option. Video conferences of multiple participants were held in the conference rooms. The public areas were always connected and available for impromptu interactions.

**Kasmer: Xerox PARC**

Expanding the SCL media space, Kasmer connects several research laboratories within the single PARC building as well as offering media space links to external sites with codec connections. The underlying software is that used in CAVECAT, based on the system used in RAVE. The system is intended to support office-to-office connections and access to audio/video services and devices. There is a deliberate attempt to support a combination of frequent and accessible communications within research working groups and less frequent communication across groups and laboratories. Each working group of 10–25 participants has its own model of connection and resulting applications.

**POINTS OF REFERENCE**

One way to understand the differences between the various media spaces is to examine the particular language that is used to describe them. These "points of reference" come out in metaphors, paradigms, models, and other descriptive language that have a profound effect on the design of systems, the way their use is understood, the kinds of analysis that is applied to them, and how and to whom they are reported. Sometimes the point of reference predates the implementation and shapes its design; other times, it is postfacto or occasionally a personal overlay on some other model. Three major points of reference have emerged: spatial, object, and figural.

***Spatial:*** Many points of reference are spatial analogies, places with concrete immediate meaning. Stults, using a perspective derived from McLuhan, compares with abstract electronic space to abstract physical space [17]. From this observation, the term 'media space' was coined. More specifically, terms for different kinds of space—separate offices, hallways, conference rooms, design studios, villages, and tunnels—appear in a number of media space discussions.

***Object:*** There is a language of objects that refer to the system and its use—the 'coffee pot', 'desk', 'telephone', 'window', or 'village well'. Object terms, unlike spatial ones, tend to be used to describe activities of secondary legitimacy that shape the understanding of the space. One does not say a media space is a coffee pot, but that activity found around coffee pots occurs in media spaces.

***Figural (people):*** The delivered image (and less frequently the camera) is personified; it is a frequent occurrence for media space users to point at a monitor and say, 'There's Jim'. The system can become (in a limited way) the people and their activities. Looking at the image, people act toward it somewhat as if it were another person. This kind of reference occurs frequently in the midst of actual use where direct reference is made to an image as though it were the person.

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discussions, and envisionment exercises.

***Audio.*** One of the most noticeable problems in the Palo Alto-Portland media space was the difficulty in using the audio connection. Our half-duplex line meant that only one site could be heard at any one time. Seamless turn-taking and interruptions were not possible. We learned when and how to pantomime our intentions and mechanisms for controlling the microphones to minimize unintentional interrupts. Even with full-duplex audio, similar problems persist. There is not a general solution for feedback, line delay over distances, noise in rooms such as from cooling fans, uneven levels (one source may come booming out and another may be inaudibly low), user orientation, and audio cues.

These problems become more noticeable and more intractable when we try to discriminate among multiple speakers. In a group situation, not only is speaker discrimination difficult, but it is hard to get the attention of one member of a group without having separate audio and video channels to each of them. Furthermore, it is impossible to hold cross-site side conversations in situations of single audio and video channels between groups. These kinds of conversational moves—discriminating one of many speakers, gaining attention, and holding side conversations—are essential in fluid group activities, such as brainstorming.

***Access and Control.*** We have found several ways in which participants in a media space can increase their awareness of the system and their relation to it. Feedback monitors, displays that show whatever the local camera is sending, are frequently useful as a means of positioning oneself in relation to participants in other sites. These displays are also a visible alert to visitors that they are in a media space.

Having software interfaces that provide information about the state of a media space extends the feeling of control. For an individual to maintain a sense of the group, it is essential to maintain a sense of the members' connections to one another. Like walking into a room in which a meeting is about to begin, it is important to see who is talking to whom, who is listening in, and who is available. The user interface is part of the crucial continuum that not only allows switching one's own connections, it lets one know who is linked to any device, especially one's own camera. In turn, this lets participants know who may be aware of their actions. Knowing to whom someone else is linked offers awareness of their state. All this contributes to individual authority over equipment.

Often a simple mechanical widget provides the best interface for controlling the system. In RAVE [6], the microphones between two participants are turned on and off by foot pedals. In our current media space, we have on/off switches on our microphones making it simple to control access to the audio. Across the history of the PARC media space, all participants have been technological equals (i.e., one could not have a monitor without a camera); but more important, the media space was developed, owned and used by the same people. There was no external monitoring or control.

***Camera Control.*** There are some problems related to the difficulty of 'looking around'. People find it difficult to maintain spatial orientation in a media space. 'Where am I?' and 'What am I looking at?' are common questions, usually requiring the viewer to be familiar with the physical space containing the camera. While it is not technically difficult to control a camera remotely in order to look around, we have found the experience is not very useful. It is disturbing to see your camera move with no visible control. Not only do many feel 'watched' (more so than with static cameras), but it becomes very difficult to stay positioned on-camera. Another aspect of camera control is the trade-off between showing detail, such as writing on a whiteboard, and showing a wide field of view, such as all the people around a whiteboard. Focus on detail often results in people being off camera, a heightened spatial disorientation, and difficulty knowing who is present.

***Integration of Shared Technologies.*** Our experience with the software systems design project showed that having media space connections alone is not sufficient to support focused task activity. Although support for activities such as shared drawing and awareness of colleagues resulted in additional prototypes, we have not integrated these technologies with the media space environment. Similarly, it is important to provide continuity between tools for individual use and those for shared use [10].

***Experience, the Best Teacher.*** Consistently throughout the years, we have found the use of the technologies is best understood by experience rather than only by demonstration. While most new participants in the media space use it familiarly within a few days, some members of SCL chose not to become participants for several months or years. In one case, a member of SCL never had a media space node in his office. However, during a recent summer in which he supervised an intern whose office was several hallways away, he and his student asked to join the media space. He now continues to be a part of the media space although his student has been gone for over a year. Like a new taste, a media space can be described in familiar terms, but the actual effects occur only when technology and people interact.

## Conclusions

In the PARC media space, the way we work shapes the design and the media space shapes the way we work. This iterative molding of activity and technology is critical in allowing a media space to become the setting for work and not the locus of its own peculiar activity. This is also the key to developing technology that ultimately 'disappears' so that the life of the workplace is simply carried on through it. The Palo Alto-Portland media space was the result of a process that linked a particular group, a particular kind of work, and a particular set of technologies that evolved together. We believe such a process is necessary for the design of any media space.

We see our work with the media space as merely a beginning. Certainly there is still much to explore about media spaces and much to question. Many issues of privacy and group relationships are raised by such systems. Underlying architecture will play an increasingly important role as technologies make possible more digital audio and video transmission over long distances. (See associated sidebar, "Media Spaces and Broadband ISDN".) There are recurring problems that might be termed 'philosophical mismatch'. Some members of the media space believe that visual reciprocity (you can see me only if I see you) is a necessity and others believe that connection is not *a priori* symmetric so that unidirectional links can be made to anybody. Given that both want to use the same media space to work with each other, how can these positions be reconciled? We also need to know more about how to evaluate these systems and what constitutes success. Ultimately, we need to understand the design and use of such systems in broader contexts. Understanding more about the nature of the work activity and the ways in which people shape systems for their own uses is critical.

The media space offered something wonderful to those of us who experienced the Palo Alto-Portland link. We could be close to our colleagues who were, in fact, quite far away. The environment was always changing and always challenging. Sometimes unexpected actions made us realize anew how little we knew about the space we had created. Sometimes frustrations of not having the ability to interact as we would face-to-face caused us to embark on some new path. Sometimes the need to communicate more fully was answered by an airplane trip tempered by the realization that a media space, even when limited, offered a much richer environment than no cross-site connection. The PARC media space supported both the lab culture and the research activities. We were able to maintain an ongoing sense of being one group and of being 'present' to people geographically distant, as well as to those locally. Whatever else, the media space brought people together in a way that was not possible otherwise. Ultimately, a media space is a place in which people and events can expand experience in new ways.

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**CR Categories and Subject Descriptors:** B.4.1 [**Input/Output and Data Communications**]: Data Communications Devices—*Receivers (e.g., voice, data, image), transmitters*

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# Media Spaces and Broadband ISDN

*Bryan Lyles*

The Xerox media space is typical of early experiments with video in that, with the exception of the Portland link, the entire infrastructure is based on analog transmission and switching. These systems do not scale well because analog technologies are limited in the number of channels they can carry and the distance over which they can carry them. Digital video conferencing systems are useable over the wide area, but their designers have been more concerned with being able to transmit over low-speed links than with absolute video quality. The deployment of high-speed digital networks opens a new future for media spaces; one in which neither the quality of the media or the size of the media space are limited by the transmission system.

For media spaces, high-speed networks solve two of the current major limitations: relatively low video and audio quality, and limited capacity. Both video and audio quality are important if we are to concentrate on the substance of the collaboration rather than being constantly annoyed by the medium over which the collaboration takes place. Most of the current digital video encoders have been designed to run on inadequate networks and thus deliver low-quality images. They are acceptable only because better alternatives have not been available. The video quality available from modestly priced, consumer-grade video cameras is approaching levels previously associated with studio equipment, even though video conferencing codecs can reproduce only a fraction of the image. High-bandwidth networking allows us ask "What image quality is required?" rather than "What image quality can we get?" If the user needs studio quality video it should be available. The audio situation is similar: CD-quality, digital audio should be available as an option to the user.

The other limitation that high-bandwidth networking addresses is the number of simultaneous video/audio streams that can be supported, both to a single location, building or campus and between campuses. Since a single camera is usually incapable of covering even a single office, multiple cameras per media space node are likely. Likewise, monophonic sound fails to give the location clues which can facilitate collaboration. This analysis convinces us that network nodes supporting a media space will need to carry up to a half-dozen simultaneous, full-duplex video and audio streams. Each physical space in a building will need access to the media space, thus an organization will require hundreds or thousands of simultaneous audio/video streams.

It must be possible to interact with colleagues who are located either in the next office or thousands of miles away. Thus, universal availability within and between organizations is another requirement on the next generation of networks. This implies that the network must be highly scalable in the sense that the number of users can become very large both within the local organization and across organizations.

From the previous considerations and an estimated need for between 6 and 30Mb per sec for a single high-quality, video stream, we can estimate the bandwidth requirements of single nodes (e.g., offices or conference rooms). A single node must be capable of supporting full-duplex traffic in excess of 100Mb per sec. The aggregate of all the nodes in a building housing 100 workers is likely to be in excess of 10Gb per sec. These large aggregate numbers result from media space connections being left on for hours or days. This is in sharp contrast to the normal usage of the voice telephone system or conventional computer networks.

Current local area network technologies do not meet the aggregate requirements. Technologies such as the Fiber Distributed Data Interface (FDDI) lack the aggregate bandwidths necessary to support organization-wide connectivity. In a FDDI network the peak bandwidth available to any single user is the same as the aggregate bandwidth available to all users. Because network costs rise rapidly with increasing speeds, networks based on shared media will not be able to supply these large aggregate bandwidths economically. We have concluded that switch-based digital networks are the most appropriate technologies to meet these new challenges.

A new international telecommunications standard has the potential to provide both universal access and scalable bandwidths: the emerging Broadband Integrated Services Digital Network (B-ISDN), particularly the service known as Asynchronous Transfer Mode, (ATM). The ATM technology is important because its deployment will provide such features as public access to a commercial service, global connectivity, user-to-user bandwidths measured in the tens of Mb per sec or

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greater, and aggregate bandwidths measured in tens, hundreds or thousands of Gb per sec.

Because of its international standardization, ATM will ultimately be available on a worldwide basis and supported by the public telecommunications system. It is also a likely infrastructure for constant bitrate telecommunications services, including voice telephony, because it will provide significant flexibility in building on-demand virtual connections between voice switches. Much of the world's transmission capacity may ultimately be transmitted over ATM networks.

ATM defines a connection-oriented, fast packet-switched network service based on the transmission of small, fixed-size packets known as cells. The service provided by ATM differs from many previous telecommunications offerings in that each physical endpoint is potentially capable of supporting millions of connections. Each of these connections are lightweight in the sense that they do not provide reliable delivery of information, but instead only specify the route that cells will take when presented to the network.

ATM supports a range of link speeds. Because ATM is packet switched, links of different speeds can interoperate, an important aspect of system scaling. The slowest ATM physical interface currently defined in the U.S. uses the DS-3 rate, operating at approximately 45Mb per sec. The fastest interface runs at approximately 622Mb per sec. However, interfaces running at speeds of 2.4Gb per sec and higher are currently under study.

Traditionally, computer networks have employed fixed-speed links that were significantly slower than the telecommunication company's digital transmission facilities. The speed and capacity of the public network is increasing rapidly but computer networks are lagging behind in access to that bandwidth. By building on the public ATM infrastructure the computing community will get direct access to the evolving bandwidth of the public network.

The ATM standard is also applicable to local area, or private, networks. Current networking technologies present major technology discontinuities at the interface between the local area and the wide area. ATM switches for the local area are a cost-effective solution that will provide high-speed LANs while still seamlessly interconnecting with the public network. While it is ultimately desirable that small users be able to order 1, 2, or 20 ATM connections as though they were telephones, this will not happen any time soon because of the high capital cost of the large switches needed for universal public service. Local ATM is essential to the development of the public network, since it allows many users to be interconnected with relatively low capital investments on the part of the public carriers [*]. The combination of local ATM switches and lower-cost public deployment means that we will see wide area desktop-to-desktop ATM connectivity within a relatively short time frame.

Media spaces require changes to our conventional models of networks: their aggregate bandwidth requirements far exceed current practice. If we continue to build computer networks as overlays on the public communications network, it is unlikely that we will be able to provide universal network support for media spaces. Fortunately, the deployment of ATM technology by the public telecommunications providers will allow users direct access to the bandwidth of the communication infrastructure. ATM does not solve many of the difficult problems of networking, but, by harnessing the public telecommunications infrastructure, it does provide a proven process for usage-based growth.

The use of the ATM service does not come without cost to the computer community. To take maximum advantage of the public infrastructure, communications protocols must evolve beyond using the lightweight connections provided by the ATM service merely to interconnect routers. The need to directly leverage the public network means the computer networking community must forge strong links to the telecommunications community and be willing to work within the international telecommunications standards process. ATM is different from the system the computer community might wish to build, but different does not necessarily mean inferior. Likewise, the telecommunications community must be willing to accommodate the requirements of the computer community. The task of building a global network capable of supporting applications such as richly connected media spaces will require changes on the part of all parties. C

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