Videoconferencing: Recent Experiments and Reassessment

Steven E. Poltrock
Boeing Phantom Works
Seattle, WA 98124
steven.poltrock@boeing.com

Jonathan Grudin
Microsoft Research
Redmond, WA 98052
jgrudin@microsoft.com

Abstract

We describe several recent videoconferencing experiments and deployments. An extensive literature has shown limited benefits from video in support of live meetings. However, technical, cost, and behavioral shifts suggest that new opportunities are emerging. To understand the prospects requires careful differentiation among videoconferencing configurations along dimensions such as point-to-point vs. multi-point, conference rooms vs. offices, and ISDN vs. IP. Behavior can be affected in ways that are not always intuitive. Still, declining costs, increasing ease of use, and growing use of personal video are having an impact. Will the new generation of IP-based videoconferencing overcome past obstacles to wider use of video? We review the challenges and opportunities and emerge with guarded optimism.

1. Introduction: Summary of a research thread

Countless experimental studies and deployments of consumer, desktop, conference room, and classroom videoconferencing have been published over the past half century. Studies encompassing technical and behavioral aspects of video use have been a mainstay of the literature in the computer supported cooperative work field. In 1986 Goodman and Abel [1] described a link between two conference rooms. The first session of CSCW '88 included a paper describing a desktop videoconferencing system [2] and an equally influential paper titled "Videoconferencing as a technology to support group work: A review of its failures" [3]. A torrent of studies was conducted in the late 1980s at PARC, Bell Labs, Toronto, EuroPARC, NTT and elsewhere [e.g., 5 – 9]. Many companies released products in the area, which did not do well. Interest subsided.

In the mid-1990s the pursuit of video continued with published research from Olivetti, Sun, Keio University, and elsewhere [e.g., 10 – 12]. Whereas many of the earlier studies had relied on computer-controlled analog video, networks and processors now supported digital video, albeit often with lags or lapses. When these experiments did not realize their promise, latency and jitter was often seen as a cause, despite similar results having been obtained earlier with latency-free analog video.

As these researchers grew discouraged, another set came along. Microsoft Research, Michigan, and others [e.g., 13 – 15] have continued the tradition of broad behavioral and technical research based on controlled experiments and deployments of prototype systems.

At the same time, products have continued to appear, some disappearing and some surviving. Many organizations have experimented internally, drawn by the same anticipation that motivated researchers. Microsoft has engaged in some long-term internal deployments of prototypes as well as commercial systems, Boeing has researched room designs and engaged in methodical studies of commercial systems.

In this paper we review these studies, not all of which have been published. Together with the work of others partly outlined above, they seem to offer a deeper understanding and suggest the course that may lie ahead. Recent advances in video and audio technology are inspiring renewed hope among champions of videoconferencing that it will soon be widely adopted. These changed conditions leave us with guarded optimism that modest but significant opportunities are finally here.

2. Different kinds of videoconferencing

Videoconferencing implementations can be characterized on at least three dimensions: (1) dedicated environments with continuous video versus short-lived conferences that require call set up; (2) theater, conference room, and personal video; and (3) video based on computer-controlled analog, ISDN, or IP protocols.

Continuous video is generally more expensive to install and operate. It has been an active area of research, used to link conference rooms in the aforementioned first CSCW video study [1], corporate mail rooms or refreshment areas [16, 17], pairs of offices for long durations [8, 18], and multiple offices [19]. In addition, some desktop conferencing systems provide an option to display the image from one camera continuously when the system is not in active use for conversation [6, 20]; people often use this capability to view a public space or outdoor image. Recently more playful use of continuous video in public places has been tried [21]. Continuous video remains fairly exotic in practice, but it is used—in the next section we describe continuous video among rapid-response teams at three Boeing sites across two states.

Theater video (video for a lecture, panel discussion, or performance) is most likely to have multiple cameras (for

speaker, slides, audience) and dedicated operators or videographers. Otherwise, many of the requirements of camera positioning and operation are similar to conference rooms [22]. Historically, managed videoconference centers were often used for distributed meetings that would have been held in unfacilitated conference rooms if people could have assembled. Such centers have long been in use and have been a less active research focus.

However, declining digital technology cost and greater ease of operation have led to more, unstaffed, video-equipped conference rooms. These present opportunities and challenges that in some cases resemble those of desktop video systems, which have been extensively researched by those envisioning video communication as a natural evolution of computer systems. The conference-room / desktop distinction is further blurred by their use together. Historically, video-equipped conference rooms connected just to other conference rooms, perhaps with an audio connection to those who lacked access to videoconferencing equipment. Now it is not uncommon for multiparty videoconferences to link people in a conference room with others using desktop or personal videoconference systems in offices.

Early videoconference centers were based on analog video. Many of the early desktop video deployments reported in the CSCW literature utilized computer-routed analog video. This provided major advantages: Latency and image quality problems were avoided and participants had separate monitors for video and for their computers. Difficulties encountered even with these favorable conditions must be considered carefully as we work to reduce digital latency and increase resolution even further.

The ISDN/IP technical distinction has capability and support infrastructure implications. Most production videoconferencing systems are built on an ISDN infrastructure, which is deployed and managed by telecommunications organizations. Establishing multiparty ISDN calls typically requires manual setup by the equivalent of a telephone operator. Configuration is slow and somewhat tedious, partly because the required information is generally not at hand. The person requesting the meeting may only know that the call will include people in Huntsville, for example. Someone has to find out what room in Huntsville, and then the ISDN number of the video equipment in that room. This information has to be entered into the bridge. Configuration often takes more than 30 minutes. Once configured, the operator essentially pushes a button to initiate all the calls.

Newer IP technologies use the same network used by computers and voice-over-IP telephones. Calls can be placed over an intranet or the Internet and managed by computer, reaching the ISDN and telephone networks as necessary via a gateway. This opens a range of new capabilities. Multiparty videoconferences are much more easily managed with IP technology.

In the next sections we review issues for different environments, focusing on those not restricted to research settings, as a prelude to considering the implications of the new technologies.

3. Rooms

3.1. Dedicated environments with continuous video

We observed a geographically distributed team staffing a rapid response center within Boeing that adopted a continuous three-way videoconference throughout their working hours to strengthen team cohesion. This group, distributed across three locations, supports Boeing commercial aircraft during nights, weekends, and holidays when the primary support organization is off duty. At each location a handful of people work in a single open-plan room with a large (60”) video display and camera at one end.

Initially two sites located about 45 miles apart were connected. The image from one site filled the display at the other. The support staff working in these rooms knew most of their colleagues at the other site and had the same supervisor who divided his time between sites. The videoconference simplified group discussions. People at one site frequently spoke to staff at the other site just as they would to someone at the far end of the same room. They simply called out the person’s name and initiated a discussion that everyone else could overhear. Sometimes small groups would gather in front of the two displays for a conversation about the best way to respond to a support problem. They could also remotely control the far camera. Sometimes a support engineer would use the remote control to zoom in on a particular colleague at the other site for an extended conversation with that one person, although it could be overheard by everyone.

The third site, hundreds of miles away, was added with the intent of building a stronger relationship with that group. The staff at that site did not seem to welcome this intervention, however. They typically aimed their camera toward an unoccupied part of the room and they rarely initiated or participated in any communication with the others. The addition of a third site also had some unfortunate consequences for the ongoing communication between the original two sites. To accommodate three sites, the video system divided the display into four regions and displayed the remote sites in two of the regions and the local site in the third region, leaving the fourth region blank. This significantly reduced the size of their view into the other sites, essentially moving them further away. It also prevented remote camera control.

In interviews the staff members from the first two sites reported enjoying the ability to talk to their colleagues at the other sites, and we observed many instances of its effective use. They had reservations about it, nonetheless.

They were careful not to say anything critical of management in front of this system because they suspected that management was, or at least could be, monitoring them via this video camera.

3.2. Staffed videoconference rooms

As noted above, managed videoconference rooms or theaters were used in large distributed enterprises prior to the digital era. The Boeing Company introduced videoconference theaters about four decades ago to support development of the 747 airplane and maintains a network of about 50 theaters today. Until recently each was supported by fulltime staff who scheduled and configured the videoconferences and controlled the equipment, including multiple cameras. Participants often traveled locally to reach one of the rooms.

The early rooms used an overhead video camera to capture and transmit the content of printed presentation materials. Today most theaters have scanners for this purpose. More commonly, however, information is on a computer and shared via a concurrent data conference. Executive management has been a primary user of many of these theaters. Their support staff generally establishes the videoconference and data conference in advance of the scheduled meeting time. A large Boeing project frequently holds well-planned videoconferences attended by customers, partners, and suppliers around the world.

Although expensive to operate, these rooms, like continuously running video connections, work in a reliable and timely manner. In the continuous connection a system breakdown is noticed immediately and fixed; here, the staff tests equipment and sets up connections prior to the meeting. With multi-point conferences this can require some expertise. Even the conceptually simple problem of scheduling across time zones requires care. The staff also facilitates document distribution, merging audio-only phone connections, and other complications.

3.3. Walk-in-and-use videoconference rooms?

Whereas executive management once monopolized the need for communication over distance, distributed teamwork has moved down in many organizations. Change in technology use has coincided. Determining causal relationships would be difficult. What we see, though, is that the communication needs of distributed teams are growing, funding for dedicated staff who manage videoconference centers is disappearing, and technology affordability and usability are increasing.

In addition to the theaters described above, Boeing now has hundreds of conference rooms with video conference technology. Many have two screens at the front of the room and two ceiling-mounted projectors—one for the video and one for data. Other conference rooms have large monitors and cameras on a mobile stand. People learn how to use the technology by observing others while attending a meeting and by following instructions posted near the equipment.

Early rooms of this kind were often not reliable. Rooms were not well engineered for lighting or audio. Infrequent use led to configurations not working or to instructions that were not current. A leading manufacturer of videoconferencing equipment found that it took 30 minutes on average to set up a meeting (Ross Cutler, personal communication). Today's rooms and equipment are better engineered and can be strikingly easy to use. At Boeing, it is always on and ready for use by any visitor. A clearly marked remote control makes it easy to answer an incoming call or initiate a call to anyone in an online directory. The manufacturer's estimate has been cut in half, and our observation is that it can be even easier.

3.4. Behavioral issues with rooms

Adding videoconferencing technology to a conference room can introduce some surprising behavioral issues. To illustrate these issues, a typical conference room arrangement is depicted schematically in Figure 1. If one person is presenting or leading the meeting, they are often at one end, facing the camera and display of the remote site at the other end. A microphone on the table is positioned to pick up conversation in the room.

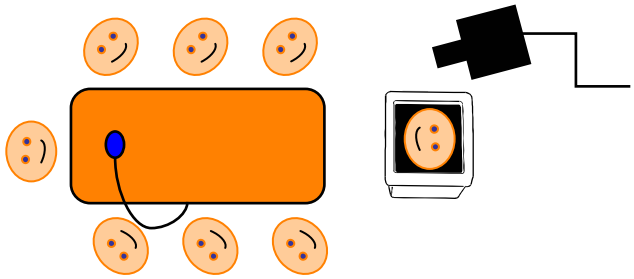

Figure 1. A typical videoconferencing arrangement.

This obvious and seemingly natural arrangement is subject to a multitude of subtle problems that often go unnoticed. People who are less interested in the meeting topic, who may engage quietly in other tasks or simply not participate, are more likely to sit farther from the meeting presenter. Given the camera placement, it is these bored individuals who loom largest in the view as seen remotely. The speaker at the head of the table is smallest, with reactions and emotions most difficult to make out.

If the remote viewers are not active participants, they may be ignored by those in the room, which is not good. If they do participate, attention of people in the room can be glued on the monitor (or on a microphone/speaker in the middle of the table). The person at the head of the

table may be accustomed to being the center of attention of face-to-face meetings and find this shift unsettling.

The people at the remote site appear as diminutive images on the distant screen, which is not flattering. Cameras placed high to view over seated participants look down on the speakers, which has been shown to detract from their impact [23]. If the speaker at the head of the table wishes to address these small, distant figures, it is natural to raise the voice. Given the microphone placement this comes across as shouting to the remote viewers.

Even with good microphone placement, audio has historically been a critical problem. Distorted audio can detract from a speaker's impact. A joke or casual remark intended for everyone in the room may not be transmitted clearly enough, leaving remote viewers unsure at whose expense the joke was made (as though it were a whispered joke intentionally withheld), or feeling left out of the discussion.

It is difficult to get room lighting right, so people in the room can appear shadowy or to have a washed-out, ill appearance. This perception can be magnified by audio distortions or by jerky or unsynchronized video. Even short transmission latency can lead to confusion over what a remark or reaction is in response to.

Participants may not single out any of these effects, but the net effect for remote viewers can be of an ill, jerky, uneasy speaker shouting at them past inattentive colleagues. Work can get done, but morale and enjoyment are affected.

3.5. Technical efforts to address issues

Ease of use and the current generation of dramatically better audio systems are a significant contribution. Room design and lighting are better understood, and digital video quality has improved.

In conference rooms, small cameras and microphone arrays can be placed on a table, with software identifying images and further adjusting them so that all participants appear the same size. With larger flat panel displays it may also be possible to bring displays of remote participants to the table.

As noted, videoconference rooms have been in successful use despite the subtle behavioral disruptions. These will never be eliminated, but a significant improvement has been realized, with a path forward.

4. Desktop videoconferencing

4.1. Cycles of optimism

Although the waves of research on desktop video noted in the introduction might have overlapped a little, Moore's Law and the trailing work on software and human-computer interfaces has led to a succession of distinct efforts over twenty years.

Motivations differed. Telecommunication companies anticipated higher consumption of bandwidth. Networking companies anticipated higher use of their products. Professions and cultures with a more oral or visual orientation anticipated benefits.

Although reports from experiments and field deployments appeared to show successes, the efforts were invariably abandoned. Research at Xerox, Bellcore, Toronto, NTT, NYNEX, US West, Olivetti, Sun, Keio University, Microsoft Research, and other laboratories produced literally hundreds of papers but no successful videoconferencing products. Few if any of those researchers continues to pursue videoconferencing.

In parallel with prototype building and testing came myriad social science studies examining the potential benefits of video for group performance. Over and over, these studies showed that audio – spoken conversation – is a major contributor to group accomplishment, but that video adds nothing. People often report liking video, but this did not show up in task outcome. The difficulty that researchers experienced when searching for a performance advantages of videoconferences led to a workshop and a book, *Video-Mediated Communication* [24], which reviewed this research and sought a path for future research. (See also [25 and 26].)

Exceptions to this pattern were reported by Williams [27], who found suggestions that video might be useful among people engaged in high-conflict tasks and among people using other than their native language to communicate. The latter was also reported in [28].

4.2. Behavioral issues with desktop video

4.2.1. Video and performance in group tasks. Why persist in looking for video solutions if studies show no performance benefit? Apart from the strong commercial interests in promoting the new technology, there are some encouraging behaviors. People say they like video. People say they want to be able to see the person they are talking with, especially when it is someone they do not know well. In some situations it seems to improve performance.

McGrath [29] identified four modes of group operation: formation, problem solving, conflict resolution, and execution. He also identified three functions of group activity: production, maintaining team well-being, and insuring support for team members. Together these produce 12 categories of group activity (Table 1).

The studies showing no benefit of video have generally focused on just one cell, team execution. Video may not contribute there. But it may contribute elsewhere. Williams [27] showed that it may help with conflict resolution. The fact that people like it suggests that it can help in member support. Wanting to see other people

suggests a belief that seeing them can contribute to team health.

	Production	Group Well-Being	Member Support
Inception	Production demand and opportunity	Interaction demand and opportunity	Inclusion demand and opportunity
Problem-Solving	Technical problem-solving	Role network definition	Position and status attainments
Conflict Resolution	Policy resolution	Power and payoff distribution	Contribution and payoff distribution
Execution	Performance	Interaction	Participation

Table 1. McGrath's typology of group activities.

It is a common failing of collaboration technology assessment to focus solely on performance measures [30, 31]. We need evidence that video will deliver in these other areas, but there are grounds for some optimism.

4.2.2. Challenges in desktop video adoption. A trial deployment of Polycom ViaVideo videoconferencing at Boeing pointed to several noteworthy disadvantages of desktop when compared with room systems. Offices are not engineered for video, and participants often position equipment inexpertly. The ViaVideo devices restricted the layout options; they were mounted on top of the managers' computer monitors, which served as the display devices. Lighting was frequently a problem: Many managers sat with their backs to a window and in a videoconference they appeared as black silhouettes in front of the view out their windows. They had to learn to monitor the image they were sending and adjust window blinds and lights to achieve acceptable lighting conditions. A technology that requires adjusting the window blinds whenever engaged in conversation does not encourage frequent use or rapid adoption.

The ViaVideo is among a handful of devices that performs video compression and echo cancellation in firmware, communicating with a PC via a USB connector. For these PC-based devices installation can be challenging and reliability uneven: Will the video software be running after rebooting, after a system upgrade, after installing another third party application? Some managers only launched the ViaVideo application when they wanted to make a video call, unlike a telephone that is always available for both outgoing and incoming calls. Video must also compete for display space on the computer monitor with the object one might wish to discuss or share over the network.

Other managers at Boeing use Tandberg 1000 video devices. Like ViaVideo, these are personal systems designed for use in an office with communication over the IP network, but the Tandberg is a standalone appliance with a built-in camera, monitor, and speaker. Like a telephone, it is always on and ready to make or receive a call. It can also be positioned more flexibly because it has no connection to the managers' computers except over the shared network.

Another behavioral challenge to video is that we are accustomed to privacy in our cubicle or office. Some people are reluctant to be viewed in this private or quasi-private space. A manager who often scanned email or documents while participating in telephone conferences felt required to watch the monitor during videoconferences because he would appear inattentive otherwise. His task sharing was made visible by the videoconference.

An MSR project tried to foster informal communication by establishing continuous video links among kitchens frequented for coffee and soft drinks [17]. We found that about 10% of our colleagues objected to the possibility of being observed in this openly accessible, door-less space. Providing an "OFF" button that could be easily pushed as one approached did not satisfy everyone.

Again, this stands in contrast to rooms: Because we are visible to others in the same room, adding a remote viewer is less of a change. The contrast is illustrated in a two-year deployment of a two-way system making a Microsoft Research lecture room available via the corporate intranet [32]. From the offices, the lecture could be viewed, including camera shots of the seated audience. We added a large projected display on the side wall of the lecture room so the lecturer and audience could see images of remote viewers. A remote viewer could choose to appear as an anonymous standard silhouette, a still photo or other bitmap of their choosing, or a live video feed if equipped with a desktop camera. Some tried the live video but discontinued, realizing that in the privacy of an office we put up our feet, slurp a drink, chat with people, and otherwise behave in a way we did not wish to display. In contrast no one in the lecture room ever objected to the outgoing video.

Participants in the ViaVideo experiment also noted that video was more useful for communicating with people they did not know. This suggests another advantage to room systems: There is greater likelihood of not knowing some participants at remote sites in larger group meetings.

Given that most use of desktop systems is among a small number of people, rooms have another advantage. For some purposes, the value of a room videoconference is simply in knowing who is present and what the environmental context is at the distant site, whether or not

individual reactions are visible. The uncertainty in an audio-only conference can lead to confusion or ill ease. With a desktop call, one generally knows to whom one is speaking and where they are.

Another behavioral challenge to desktop video use is that a call connects directly to the desktop of the person called. This may be fine for firmly scheduled meetings and for calls among individual contributors, but many managers and executives have administrators who screen their phone calls and even their email. Subordinates are unwilling to force an interrupt, so will avoid a video call to their manager. Conversely, managers who have their admins organize a phone call and bring them in when the connection is ready will not find the direct line useful.

4.3. Technical issues and desktop video

A major change in desktop video potential is in the shift in commercial videoconferencing systems from communication over ISDN switched networks to IP networks. ISDN never attained the ubiquity of telephone networks or IP networks. Participating in videoconferences required installing ISDN and paying both monthly and usage fees. ISDN networks were used because they provided the guaranteed bandwidth required for business-quality audio and video. Some systems used analog lines to achieve higher quality within a campus, reverting to ISDN lines when communicating with people off campus. Even some desktop systems, such as Intel's ProShare product, used ISDN because IP networks could not provide adequate performance.

The current generation of commercial videoconferencing systems communicates over IP networks instead of or in addition to an ISDN network, and provides excellent audio and video quality when matched with an up-to-date network infrastructure. The Boeing network has more than enough bandwidth to handle audio and video traffic over local area networks, and it employs Quality of Service (QoS) mechanisms in routers to give priority to time-sensitive audio and video data traveling over our wide-area networks. A persistent concern about IP networks is the potential that other people might eavesdrop by intercepting the packets. Boeing avoids this problem by using videoconferencing equipment with encryption integrated into the compression and decompression technology.

This ongoing evolution in technology promises some significant improvements. Because IP networks are ubiquitous, videoconference technology can be installed anywhere or transported from place to place without installation or usage fees. The low cost of an IP videoconference is an important consideration in the business world. The continuous connections of Boeing's rapid response center were conducted over an IP network, and the cost of continuous connection of an ISDN network would have been prohibitive. Video over IP can also leverage elements of the computing infrastructure sharing this same network, such as corporate directories and calendar services. A personal videoconference system may be part of a personal computer or a separate appliance that communicates with computers and other appliances over the network. Like a telephone, these systems can always be on and ready to make or accept a call. The actions involved in placing a call can be integrated into existing communication tools. If a conversation via instant messaging suggests the need for a face-to-face conversation, either participant could click a button to launch a videoconference.

The advantages stand out when establishing a multiparty conference. With the earlier generation of technology an operator typically established multiparty conferences. The operator had to determine the ISDN number of each participant, configure a bridge to call all the numbers, and handle late arrivals. More than 30 minutes was often required to arrange a multiparty call. Scheduling a conference with the new generation of technology is like scheduling a conference room, done through the corporate calendaring system or a website. All actions involved in configuring and initiating a conference can be performed automatically.

5. Hybrids: rooms and offices

As desktop systems spread, the use of conference room systems joined by participants in offices will increase. As noted in the case of the lecture room telepresentation system, this will lead to some differences. A remote viewer wishing to be actively involved may choose a bi-directional video presence; a viewer preferring to be a fly on the wall may feel it is sufficient to see and be heard.

6. Discussion: Looking Forward

This decade has seen impressive advances in digital multimedia. Digital photography is sweeping away film photography. As it does so, a host of powerful, easy to use tools for manipulating and displaying photos has appeared. Studies repeatedly pointed to the primacy of audio in real-time communication, and impressive advances in audio quality have emerged. With continued improvement in processing speed, networking, and storage capacity, video is clearly in range. Camcorders are now available that record video directly on mini-DVDs. Tools to handle digital video have long been a topic of research interest [e.g., 33] and are in line for concerted attention.

The question of utility and the tension with privacy remain issues in many contexts. Do people want to record and review meetings? Do they want their words and actions in meetings made available to unknown others during or after the fact? As we have seen with Rodney

King and Abu Ghraib, a visual record can have unexpected, life-altering effects.

Insofar as the utility of video is concerned, we have described studies that suggest that it does have value. Now that improvements in audio have addressed the barrier to performance, video is a reasonable focus for incremental improvement focused on team-building and member support aspects of group activity.

We have identified several areas for improvement in video systems. The susceptibility of video to lighting changes seems ripe for improvement, given that the technology for identifying people's images is quite robust. Provision of telephone-like screening and routing of calls, and integration with online scheduling tools, application-sharing, and other communication channels are natural extensions.

Video mail was the most popular use of video in two laboratories that experimented with a wide range of video technologies ten years ago, the University of Toronto [7] and Olivetti's Cambridge Labs [19]. As storage and network capacity make video mail feasible, it could be a hook that draws people to acquire video capability that will then be recruited for other purposes. Alternatively, just as cell phones now routinely have camera attachments, desktop IP phones may come with video cameras.

How privacy issues will evolve remains to be seen. A generation growing up with camcorders, with the continual availability provided by cell phones, and the unexceptional nature of open personal display seen in web pages and blogs will surely have different stances toward privacy than the generations that came before them.

7. Acknowledgments

Thanks to Mark Shearer for demonstrating and explaining the capabilities of next-generation commercial IP videoconferencing technology.

8. References

[1] G. Goodman and M. Abel, "Collaboration research in SCL," *Proceedings of Computer Supported Cooperative Work* (CSCW'86), Austin, TX, 1986. Revised version in *Office: Technology and People, 3,* 1987.

[2] R.W. Root, "Design of a Multi-Media Vehicle for Social Browsing," *Proceedings of Computer Supported Cooperative Work* (CSCW'88), Portland, OR, 1988.

[3] C. Egido, "Videoconferencing as a Technology to Support Group Work: A Review of Its Failures," *Proceedings of Computer Supported Cooperative Work* (CSCW'88), Portland, OR, 1988.

[5] S. Harrison, S. Bly, S. Anderson and S. Minneman, "The Media Space," in K.E. Finn, A.J. Sellen, & S.B. Wilbur (Eds.) *Video-mediated Communication,* Lawrence Erlbaum, New Jersey, 1997.

[6] R. Fish, R. Kraut, R. Root and R. Rice, "Video as a Technology for Informal Communication," *Communications of the Association of Computing Machinery, 36, 1993,* 48-61.

[7] M.M. Mantei, R.M. Baecker, A.J. Sellen, W.A.S. Buxton, T. Milligan, & B. Wellman, "Experiences in the Use of a Media Space," *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI 1991), New Orleans, LA, 1991.

[8] P. Dourish, A. Adler, V. Bellotti and A. Henderson, "Your Place or Mine? Learning from Long-term Use of Video Communication," *Computer-Supported Cooperative Work, an International Journal, 5,* 1993, 36-62.

[9] H. Ishii, M. Kobayashi and J. Grudin, "Integration of interpersonal space and shared workspace: ClearBoard Design and Experiments," *ACM Transactions on Information Systems (TOIS), 11*, 1993, 349-375.

[10] S. Wray, T. Glauert and A. Hopper, "Networked Multimedia: The Medusa Environment," *IEEE Multimedia, 1,* 1994, 54-63.

[11] A. Pearl, "System Support for Integrated Desktop Video Conferencing," *Sun Microsystems Technical Report TR-92-4,* 1992. Available in the ACM Digital Library.

[12] K. Okada, Y. Ichikawa, G. Jeong, S. Tanaka and Y. Matsushita, "Design and Evaluation of MAJIC Videoconferencing System," *Proceedings of INTERACT'95,* 1995, 289-294.

[13] Y. Rui, A. Gupta and J. Grudin, "Videography for Telepresentations," *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI 2003), Ft. Lauderdale, FL, 2003, 457-464.

[14] J.S. Olson, G.M. Olson and D. Meader, "Face-to-Face Group Work Compared to Remote Group Work with and without Video," in K.E. Finn, A.J. Sellen, & S.B. Wilbur (Eds.) *Video-mediated Communication,* Lawrence Erlbaum, New Jersey, 1997.

[15] O. Morikawa and T. Maesako, "HyperMirror: Toward Pleasant-to-use Video Mediated Communication System, *Proceedings CSCW 98,* 149-158, 1998.

[16] R.S. Fish, R.E. Kraut and B.L. Chalfonte, "The VideoWindow system in informal communication," *Proceedings of Computer Supported Cooperative Work* (CSCW'90), Los Angeles, CA, 1990.

[17] G. Jancke, G.D. Venolia, J. Grudin, J.J. Cadiz and A. Gupta, "Linking Public Spaces: Technical and Social Issues," *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI 2001), Seattle, WA, 2001, 530-537.

[18] A. Adler and A. Henderson, "A Room of our Own: Experiences from a Direct Office Share," *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI 1994), Boston, MA, 1994, 138-144.

[19] A. Hopper, "The Pandora Multimedia System," CSCW '92 Video Review. *SIGGRAPH Video Review Issue 87.* 1992.

[20] P. Dourish, "Culture and Control in a Media Space," *Proceedings of the Third European Conference on Computer-Supported Cooperative Work* (ECSCW'93), Milan, Italy, 1993, 125-137.

[21] K. Karahalios and J. Donath, "Telemurals: Linking Remote Spaces with Social Catalysts," *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI 2004), Vienna, Austria, 2004, 615-622.

[22] Y. Rui, A. Gupta, J. Grudin, and L. He, "Automating Lecture Capture and Broadcast: Technology and Videography," *Multimedia Systems*, *10*, 1, 2004, 3-15.

[23] W. Huang, J.S. Olson and G.M. Olson, "Camera Angle Affects Dominance in Video-Mediated Communication," *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI 2002), Minneapolis, MN, 2002, 716-717.

[24] K.E. Finn, A.J. Sellen and S.B. Wilbur (Eds.), *Video-Mediated Communication,* Lawrence Erlbaum, New Jersey, 1997.

[25] S. Whittaker, "Video as a technology for interpersonal communications: a new perspective," *Proceedings of SPIE Volume 2417 Multimedia Computing and Networking,* 1995, 294-304.

[26] J.C. Tang and E. Isaacs, "Why Do Users Like Video? Studies of Multimedia-Supported Collaboration," *Computer-Supported Cooperative Work: An International Journal, 1*, 3, 1993, 163-196.

[27] G. Williams, "Task conflict and language differences: Opportunities for videoconferencing?" *Proceedings of the Fifth European Conference on Computer-Supported Cooperative Work* (ECSCW'97), Lancaster, UK, 1997, 97-108.

[28] E.S. Veinott, J. Olson, G.M. Olson and X. Fu, "Video Helps Remote Work: Speakers Who Need to Negotiate Common Ground Benefit from Seeing Each Other," *Proceedings CHI 2001,* 2001, 302-309.

[29] J.E. McGrath, "Time, interaction, and performance," *Small group research, 22,* 2, 1991, 147-174.

[30] A.R. Dennis and B.A. Reinicke, "Beta versus VHS and the Acceptance of Electronic Brainstorming Technology," *MIS Quarterly, 28*, 2004, 1-20.

[31] J. Grudin, "Return on Investment and Organizational Adoption," *Proceedings CSCW 2004,* in press.

[32] G. Jancke, J. Grudin, and A. Gupta, "Presenting to Local and Remote Audiences: Design and Use of the TELEP System," *Proceedings CHI 2000,* 2000, *384*-391.

[33] L. Wilcox, and J. Boreczky, "Annotation and Segmentation for Multimedia Indexing and Retrieval," *Proc. HICSS 31*, 1998, Vol. II pp. 259-267.