Linking Public Spaces: Technical and Social Issues

Gavin Jancke, Gina Danielle Venolia, Jonathan Grudin, JJ Cadiz, Anoop Gupta
Microsoft Research
One Microsoft Way
Redmond, WA 98052-6399
{gavinj|ginav|jgrudin|jjcadiz|anoop}@microsoft.com

ABSTRACT
Three public spaces frequently used by members of a single organization who are distributed across different floors of two buildings were linked by constantly-running video and audio connections. We discuss the design of the system, including issues in providing low-latency, full-duplex audio-video connectivity, ways to increase possibilities for interaction while addressing privacy concerns, and the introduction of the system to the community. We report on responses to the system and lessons learned, including unexpected issues, such as creative decorations of the spaces and assertions by a vocal minority of employees about the private nature of "public space."

Keywords
Informal communication, videoconferencing, privacy

INTRODUCTION

The value of informal interaction in workplaces is widely recognized and was convincingly demonstrated by studies of workplace collaboration at Bellcore in the 1980s (Kraut et al., 1990). As distributed work has become more widespread, it was natural to determine whether some of the digital technologies that make work distribution possible might not also facilitate informal interaction on a scale beyond casual email. Accordingly, the use of audio and video to support informal workplace interaction has been a strong focus of human-computer interaction research since the late 1980s.

Before reviewing relevant prior research, we will illustrate the appeal of the technology by describing the motivation for our system. Our organization of approximately 400 researchers and support staff moved from a single building of three floors with a central open atrium and stairway to two adjacent buildings with four floors each and a number of peripheral stairwells. We had overcome crowding, but casual encounters were far fewer.

To promote informal social interaction, four activities are in place, all centered around free food. They are an annual picnic, a monthly Friday afternoon social event, a weekly Wednesday mid-afternoon break with snack food, and our experimental system, a continuously running audio and video link between three of several "kitchens" where employees have always been able to help themselves to free soft drinks, coffee, and tea.

The previous building had three kitchens, each serving over 100 people. Now there are seven on different floors of the two buildings, each serving about half that many people. This reduces the number of chance encounters. We hope to improve the odds by linking them with audio-video connections, starting with three as a trial.

After reviewing prior research, we will describe our system, report on usage data and a survey, and identify a range of technical, behavioral, and social issues that were encountered. We conclude with lessons learned and directions for further inquiry.

OVERVIEW OF PAST RESEARCH

Many early studies of video support for informal interaction focused on desktop systems (e.g., Root, 1988; Dourish and Bly, 1992; Fish et al., 1992; Gaver et al., 1992; Tang and Rua, 1994). Computers were appearing on desks but were generally considered too expensive to be devoted to purely informal interaction. Some systems that were primarily for desktop videoconferencing included one or two views of public spaces such as a coffee kitchen, lecture room, or outdoor scene. These public spaces did not include displays – lack of reciprocity was occasionally noted but not considered a major issue.

In an unusual experiment, two pairs of researchers maintained constantly running video connections with a partner's office for a few years (Dourish et al., 1996). These "office-shares" led to considerable informal interaction, as when a visitor to one office found the other person present via the audio-video link.

Two early experiments linked common rooms in research organizations. Continuously running audio and video connected Xerox researchers in Portland, Oregon and Palo Alto, California (Goodman and Abel, 1986; Olson and Bly, 1991). The other site was viewed on monitors. It resembled a standard conference room videoconferencing arrangement apart from its use: Instead of being used strictly for formal meetings, it was available around the clock and about one-third of interactions were informal or social. Video links to offices were present on additional monitors. It was mostly

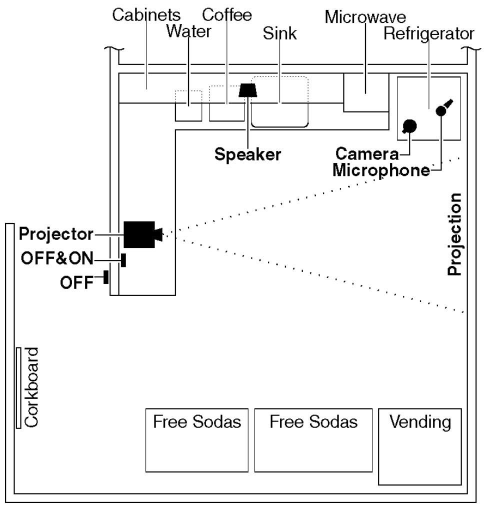

Figure 1. Plan view of a typical kitchen.

used for design discussions, notably design of enhancements of the system and environment.

The study most similar to ours was the Bellcore VideoWindow (Fish et al., 1990). Multi-channel audio and high resolution video displays, eight feet wide and three feet high, connected two common areas on different floors of a building. Free coffee was provided to draw people to the room and fifty people volunteered to have their mailboxes in the areas to further increase chance interaction. Images were life-size, somewhat as if seen through a window through which audio passed clearly. All interactions over three months were videotaped.

Fish et al. found that people who met in the same room face to face were about three times as likely to converse as those who met across the VideoWindow (although even the former conversed in fewer than half of all meetings). A contributing factor beyond the technology may be that people from the same floor who meet face to face know one another better. They noted a number of technical problems: due to camera placement, people could not accurately gauge each other's gaze direction; it was possible to stand outside the camera range yet see the other room; and the head of a person who walked up to the camera disappeared from the field of view.

Although these (and other) early experiments with video support for informal interaction were deployed at considerable cost and effort, none survived. Many factors contributed to abandonment. The infrastructures were expensive to maintain. The users were primarily researchers, who often work relatively independently. In addition, with the exception of the Portland-Palo Alto experiment, most involved people in the same building, often the same floor, who had other opportunities for informal interaction and could easily visit face to face.

Several papers in the book *Video-Mediated Communication* (Finn et al., 1997) discuss limitations of 'talking heads' video. A video connection alone does not provide the context of co-presence – objects cannot be shared, for example – and with the lack of awareness of gaze direction, gestural information, and other cues, it is not the same as being there. On the other hand, people often report liking video, and as it becomes more easily and inexpensively integrated into workplaces, its role is likely to grow.

Figure 2. The projected display (retouched for clarity).

DESIGN OF THE 'VIRTUAL KITCHEN'

Technology support for informal interaction occurs in the form of internal newsgroups, distribution lists, public folders, desktop videoconferencing, and so forth, but none of these are as spontaneous as the chance encounters that we hope to restore. The idea was deceptively simple, the design issues complex.

Choice of Public Location

The public places most frequented are elevator lobbies, inside elevators, printer/photocopier rooms, and kitchens. We decided on an initial deployment to three of the kitchens, two on different floors of one building and one in the other building. Each kitchen has a general-purpose refrigerator, two refrigerators of free sodas, a vending machine, coffee and hot water dispensers, and a microwave (see Figure 1).

We originally planned to determine the traffic level by installing a camera to record kitchen activity. Although kitchen areas have no doors and thus are very public places, we made it clear that audio would not be captured, that video would be seen and logged only by the project researchers, and that the logs would be anonymous, the plan drew a few strong objections. We abandoned preliminary data collection in response to the objections.

Visual and Auditory Connectivity

A camera, microphone, speaker, and projector were installed in each of three kitchens (see Figure 1). We chose projection rather than direct view displays to maximize image size. As shown in Figure 2, each projected image has four parts: the image in the upper left corner shows the view from the camera in this kitchen, two images are from other kitchens, and lower right is devoted to attracting the attention of kitchen visitors.

The attractor was included for two reasons: it might lengthen kitchen visits, increasing opportunities for conversation, and it could give a common topic for conversation. After considering several alternatives, we chose to show a television cable news channel, CNN.

The design called for placing cameras at the center of the display, to maximize gaze direction awareness and impression of eye contact. However, difficulty in mounting and shielding it from glare led to temporarily positioning it on the refrigerator near the projection wall.

As was noted in the VideoWindow project, people often have semi-private conversations in public spaces. We did not find technologies to enable this at reasonable cost and ease of use, so we deployed a full duplex system that broadcast sound uniformly.

Privacy Issues

Following the reaction to our planned logging of kitchen activity, we carefully alerted the organization to the research system prior to its arrival through an email broadcast and explanatory mockups displayed well in advance of deployment. The mockup is visible below the projected display in Figure 2. A public discussion list was created for issues related to the project.

Responses to our announcements made it clear that some people felt strongly that their kitchen activity, although it could be interrupted at any time by someone walking in, would be compromised by being observed.

It was apparent that we needed to allow people to opt out of participation easily. An OFF button positioned prominently outside the kitchen interrupted AV transmission; normal operation resumed after a fixed time elapsed. During this interval the display for the disabled kitchen showed drawn blinds and counted down the seconds to resumption. Inside the kitchen are large ON and OFF buttons, the former overriding the block and the latter enabling people in the kitchen to block (or re-block) the view.

Someone approaching from outside might not be aware of a conversation in progress, so heat and motion sensors detected presence in the room and disabled the outside OFF button when someone was in the kitchen. A person approaching would presumably not wish to interrupt a colleague's conversation inside. The sensors could support other features if they appear necessary: a notification sound to other sites when someone enters; after an OFF button is pressed, privacy can be extended until the kitchen is unoccupied.

Although audio and video were not recorded, we anonymously recorded kitchen occupation using the sensors. We also logged use of the OFF and ON buttons.

INITIAL ADJUSTMENTS

In the first hours and days of use we received feedback that led to some quick changes.

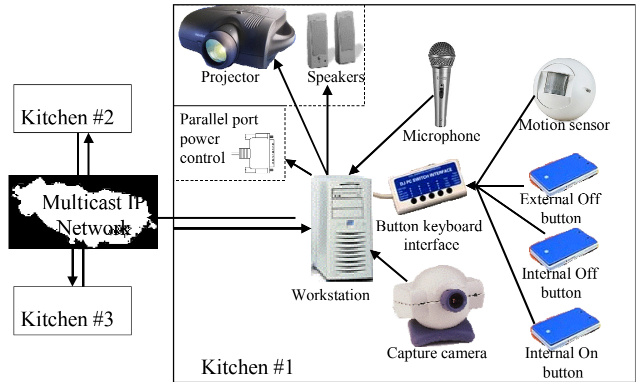

Figure 3. Hardware infrastructure.

The OFF duration of 20 seconds was deemed inadequate and extended to 180 seconds.

We made fine control of audio a priority to enable the automatic lowering of CNN audio when people spoke, but some felt the presence of CNN audio inhibited conversation initiation and complained of 'noise pollution' in general. We switched to CNN's closed captioning text alternative.

TECHNICAL SYSTEM DESCRIPTION

Each kitchen is required to:

- Capture and stream video,
- Capture, filter, and stream audio,
- Render all four video panes,
- Play audio from the two other kitchens and (initially) for the CNN channel,
- Provide privacy features, and
- Support system administration.

A primary goal is to run reliably on readily available hardware. Considering the video size and processing requirements we based each kitchen on a single networked Pentium III 550Mhz workstation running Windows 2000.

Our goal of leveraging existing audio/video streaming technologies succumbed to the exacting requirements of our real-time system. We needed point-to-point AV latency of under one half second. Tight processor and network usage, frame rate and compression algorithm control were also required.

Several off-the-shelf technologies were considered. Microsoft Windows Media is aimed towards one-way Internet streaming and introduces 10 seconds of buffering latency between the capture device and player. Microsoft NetMeeting video conferencing has sub-second latency but is a non-multicast peer to peer solution lacking interfaces for tight control of frame rate and compression. TAPI streaming technology, despite sub-second latency and multicast capabilities, doesn't provide the other tight controls we required.

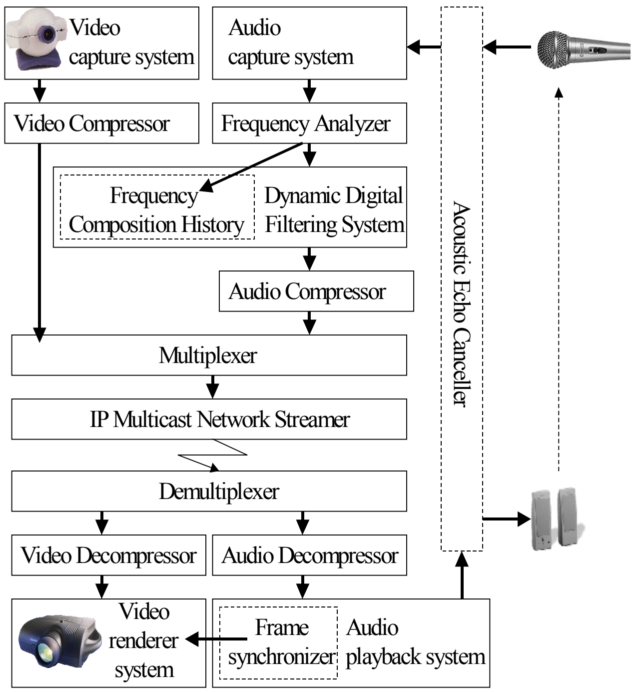

Figure 4. Software infrastructure.

Video

Considering CPU processing and network bandwidth requirements to compress, decompress, and stream video using existing compression algorithms at an acceptable frame rate, we chose CIF frame size (352 x 288 pixels). Given the proposed interface's grid layout of video frames within the display we chose 800 x 600 projector resolution, producing acceptably viewable video frames. For the video capture device we selected the Winnov Videum.

The capture frame rate, compression algorithm, and bandwidth control algorithm were determined by monitoring processor and network usage during full laboratory runs of the system. Ten frames per second consumed only 41% of the 550Mhz processor. Each of the four streams consumed 300Kbps of network bandwidth. We kept the frame rate to 10 per second as a safety margin given other network traffic on the LAN.

Audio

Audio was, and still is, the greatest challenge. Given the goal of casual and natural interaction, an open speaker/open microphone full duplex system was the only solution. The signal that is played by the speakers is picked up by the microphone, hence a there is an echo. Typical video-conferencing applications avoid this by a combination of half duplex operation, headphones, low speaker volume, reduced microphone sensitivity, and controlled acoustic environment. Our design requirements–multiple end points, full duplex operation, reasonably loud speaker volumes, sensitive microphones, and a noisy, acoustically reflective environment–combined to intensify the echo problem.

We tried to address echo cancellation by using an inexpensive product that combined speaker and microphone into a single unit. We found that the device often responded to a strong signal by switching briefly to half-duplex operation, which would disrupt conversation in our noisy environment. Also the device produced insufficient volume in our environment. Another product with a full DSP processor was prohibitively expensive. The final solution was a software-based echo canceling algorithm, which works well but not flawlessly, being still under development. The unusual composition of frequencies produced by the kitchen appliances created problems beyond the scope of the canceller. The refrigerators and vending machine produced sinusoidal tones that were hard for the echo canceller to cross-correlate; hence, it had difficulty removing them, resulting in feedback. This was solved by developing a frequency analyzer and dynamic filter that identified these tones and removed them from captured audio samples.

The acoustical characteristics of available microphones forced tradeoffs. Array microphones offer excellent noise removal and speech response, but their integrated automatic gain control interferes with the software echo canceller. Regular single condenser microphones have varying frequency response characteristics, each accentuating undesirable effects.

Privacy Controls and Presence Monitors

Large paddle buttons from Don Johnston Inc. were connected to the computer using their Switch Interface product, cleanly mapping button events to easily-intercepted keypress events. Radio Shack security motion sensors were connected to the Switch Interface, triggering a keypress each time presence was sensed.

Software responds to the OFF buttons by controlling the outgoing audio and video data stream. A static image of closed window blinds is streamed and the audio samples are zeroed out, producing silence. It was necessary to stream blank data to maintain synchronization and consistent audio mixing in the other kitchens.

System Administration

Considering the expense of video projector light bulbs it was decided that the projector was to run only during work hours, so the projectors and speakers in three locations needed to be turned on and off each day. Custom electronics were developed to safely interface the workstation's parallel port to control a power relay, so the workstations can perform this task autonomously.

550Mhz Pentium III workstation with Ethernet, high performance video card, 16-bit full duplex audio, camera, microphone	~$850
Video projector, mount	~$5000
Motion sensor, buttons, keyboard interface	$300
Cabling, connectors, custom power control	~$250
Total	**~$6400**

Table 1. System cost per installation.

Cost
Table 1 details the cost, assuming availability of a high speed local area network.

PATTERNS OF USE
We have three sources of information gauging use of the system. Observations, discussions, and email provided informal feedback. Logs of sensor data and button use provided detailed quantitative records of occupancy and privacy activity. And after about four weeks of use, an invitation to take a 25-question web survey was sent to the 220 people on the three floors involved, worded carefully to encourage participation regardless of use or opinion. Ninety-one (41%) people filled out the survey, with many contributing to the three open-ended questions.

General Observations
Use is limited. People often glance over and observe that others are present. Sustained conversations are rare, with a simple greeting or query ("Is there coffee available in your machine?") more common. An open question is whether simply seeing colleagues moving about is beneficial.

Decorations and Spoofs
The most unexpected consequences were creative responses to the system and the controversy that it generated. Soon after deployment, those entering a kitchen saw a green lizard staring at them from one of the kitchens. In fact, someone had moved back the camera slightly and taped a lizard to the refrigerator in front of it. Looking closely at Figure 2 you will see the lizard and its image in the upper left pane. The lizard does not entirely block the view of people and was treated as a humorous system extension. A silhouette cut-out appeared in front of a different camera.

Although minor, these decorations were noticed and frequently remarked upon. They helped to humanize the system. We did not place them there, but were grateful to the inventors. A drawback was that moving back the camera brought the white refrigerator top into the camera field, which increased the glare in the transmitted image.

Not long after deployment, a meticulously executed "Virtual Men's Room" spoof appeared outside and inside a nearby restroom. Organized around the notion that this was another place where people spent time in isolation that might afford opportunities for informal interaction through the placement of cameras and microphones, this funny, PG-rated parody mocked our explanatory notices and the potentially intrusive aspects of the project.

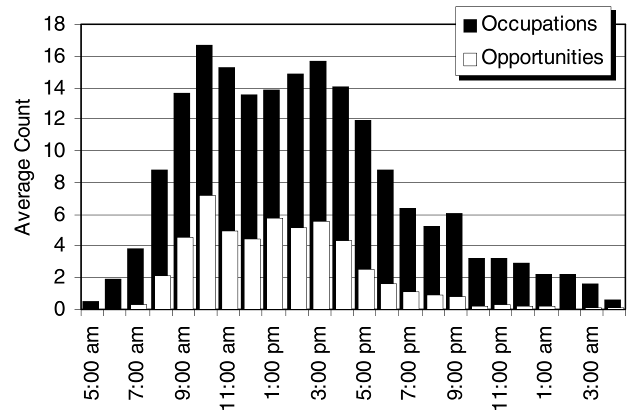

Figure 5. Average number of occupations and opportunities for interaction per kitchen for each hour of each day.

Sabotage and Controversy
The mildest forms of sabotage were written images and messages (for example, a rough pen drawing of two people talking in the kitchen) placed in front of the camera that entirely blocked the view of the room. More extreme, several times the system in one kitchen was disconnected. This occurred despite our efforts to allow kitchen visitors to temporarily disable the audiovisual transmission.

Privacy was the topic of considerable discussion and email traffic. A person with disabilities described avoiding using the kitchen when others were present; others said that they did not mind if those who worked nearby saw them live but were uneasy about relative strangers in another building. The lack of reciprocity was noted: someone can stand outside the camera range in another kitchen and see.

Some people did not trust that video was not being recorded. Some incorrectly believed that the OFF button would block the camera but not the sound. Others worried that they would forget or that visitors accompanying them would not realize they were being viewed.

Such feelings had effects. At least once, a person entered a kitchen where a colleague was conversing with someone in another kitchen. The second arrival walked over and pressed the OFF button, terminating the conversation.

Patterns of Occupation
The sensor data for two workweeks (August 7-11 and 14-18, 2000) were classified into "occupations" – times that the motion detector sensed continuous activity. An occupation is a series of motion detections separated by less than 30 seconds. It may represent one or more individual visits, as the detector cannot differentiate between individuals or the number of individuals present. Each occupation was recorded with kitchen number, start time and duration, and the interval (if any) that the system was disabled by the button. We recorded 5611 occupations.

The median occupation duration was 23 seconds. The distribution was highly skewed, with the mode being 6

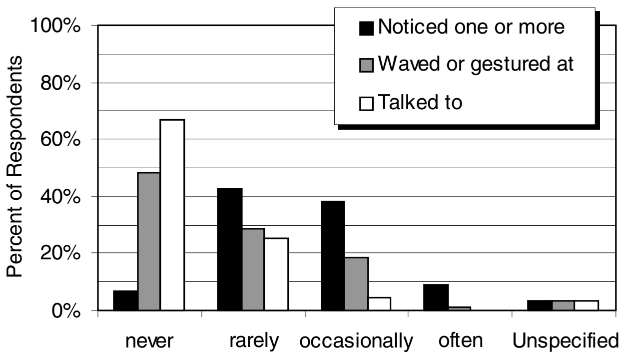

Figure 6. Responses to survey questions about interaction with people in other kitchens.

seconds, the time needed to grab a drink. Overall there was an average of 7.8 occupations per hour in each kitchen. The number varied by hour of the day, as would be expected (see Figure 5).

Patterns of Opportunities

Times when pairs of kitchens were occupied represent "opportunities" for interaction. An opportunity was recorded with start time, duration, and the kitchens involved. Opportunities are pair-wise – all three kitchens being occupied represents three distinct opportunities. We recorded 1577 opportunities.

The median opportunity duration is 13 seconds. The distribution is highly skewed, with the mode being 3 seconds. Overall, one or more opportunities for communication occurred during 41% of the occupations. The number of opportunities varied with the square of the number of occupations (see Figure 5)

Opportunities were indeed recognized by visitors to the kitchens: 81% responded to the question, "How often have you noticed one or more people in the other kitchens?" with a response "occasionally" or "often" (see Figure 6). However opportunities rarely turn into communication. Only 21% had those same responses to "How often have you waved or gestured at someone in another kitchen?" Fewer still (4%) had those same responses to "How often have you spoken to someone in another kitchen?"

Privacy

Most people felt that the privacy solution as implemented addressed their privacy concerns (71% agree or strongly agree with the statement "The OFF switch effectively addresses your privacy concerns," or indicated that privacy for them is not a concern). The OFF button was used infrequently: for 90% of the occupations, the system was enabled for the entire occupation.

Privacy remained a concern for a minority. A "privacy concern" score was calculated by tallying one point for each of these survey responses:

- The 7% responding "100%" to "For what percent of kitchen visits have your turned off the camera using the red OFF button as you entered?" (This matches the OFF button sensor data.)
- The 15% who rated "How serious do you think privacy issues are for VK?" as "very important."
- The 7% who strongly disagreed and 7% who disagreed that "The OFF switch effectively addresses your privacy concerns."
- The 9% saying "VK affects your privacy" "a lot."

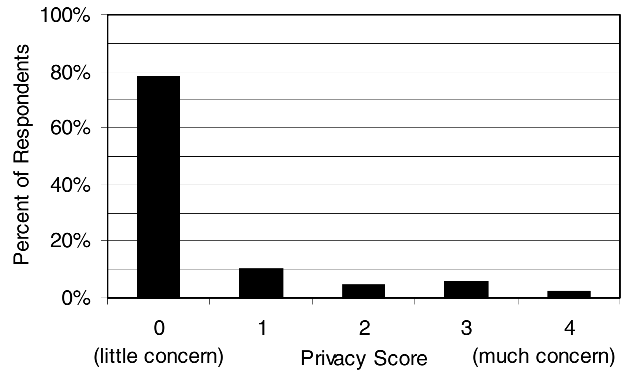

Figure 7. Survey respondents classified by privacy score.

With this scoring, 78% of survey respondents had a score of zero, indicating little remaining concern for privacy (see Figure 7). The remaining 22% had a score of one or more.

Audio and Video Quality

People perceived the audio quality to be too low but considered the video quality adequate. To the question, "On your most recent visit, the quality of the video was," 62% responded "acceptable" or "very good" (see Figure 8). To a similar question for audio, only 16% had those replies.

Although audio quality was perceived inadequate, it was considered a minor problem in the larger picture of usability. When asked "Would improved audio and video quality change your experience?" 30% replied "not at all," 42% responded "somewhat," and 21% replied "a lot."

We pushed the limit of today's inexpensive audio hardware,

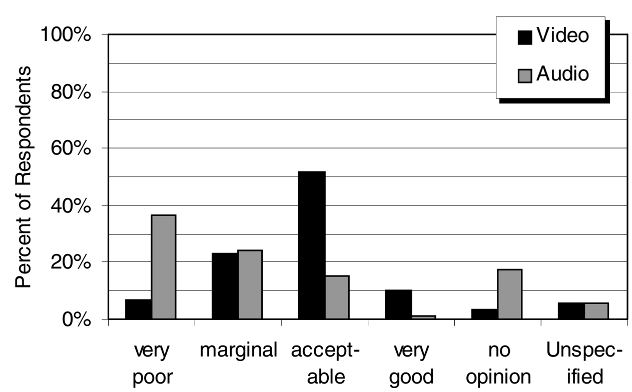

Figure 8. Responses to survey questions about audio and video quality.

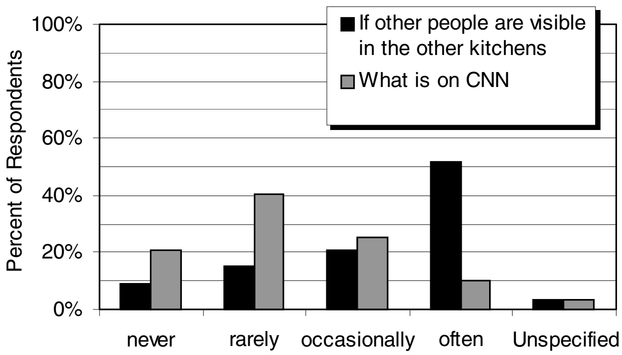

Figure 9. Responses to survey questions about glances at the display.

but audio quality was the most common complaint. It was being worked on continually, so negative first impressions could be a factor, but even good microphones are not as capable as the ear. To cleanly filter out noise requires better technology and algorithms than are affordable now.

Video presents similar challenges. Room lighting and glare was amplified by the creative repositioning of cameras. A glare-reducing surface around the camera could help. In general, video quality may be more important than survey respondents indicated in creating the desired sense of warmth and positive regard. Survey respondents also suggested (and we originally planned) that cameras be positioned within or closer to the projection areas to increase the perception of eye contact.

The Fourth Pane

While most visitors reported glancing at the other kitchens, a relatively small number glanced at the CNN feed. To the question, "How often do you glance to see if other people are visible in the other kitchens?" 73% answered "occasionally" or "often" (see Figure 9). To the same question regarding CNN, only 35% had those responses.

Closed captioning is preferred strongly over playing the CNN audio track. When asked "We have tried CNN with sound and with closed captioning (scrolling subtitles). Your preference is:" 43% responded "closed captioning over sound" and 19% preferred "sound over closed captioning." It is unclear whether the merits of closed captioning or the faults of audio in a public space explain this preference.

Was CNN the best choice for the fourth-frame attractor? Many alternatives were suggested. Some involve interactive games, such as an ongoing chess game to which visitors could contribute a move. Other displays are possible, such as a biographical or work sketch of a member of the organization selected randomly (from those willing to be included), traffic web-cams, news headlines, etc.

A Need for Informal Interaction

The survey results indicate that there is an opportunity for some kind of informal interaction. Survey respondents showed strong support for the problem that we're trying to solve: fostering informal interaction amongst researchers.

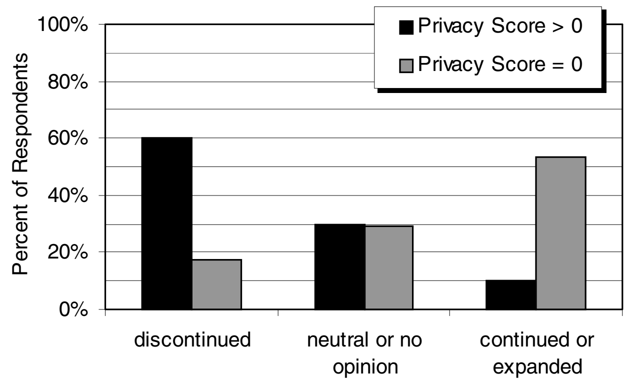

Figure 10. Responses to "should the project be continued?", segmented by privacy score.

To the question, "I think the level of informal interaction in MSR is," 78% responded "much lower than it should be" or "somewhat lower than it should be." No respondent indicated that there was too much informal interaction.

The survey showed support for some level of technological mediation of informal communication. To the question "What role do you think technology could have in facilitating informal interaction if implemented appropriately?" 53% responded "moderate" or "strong," 34% responded "weak," and 5% responded "none."

As reported above, 73% of respondents reported glancing at the display at least some of the time.

There was substantial support for continuing the experiment. When asked "The VK experiment should be" 46% responded "continued" or "expanded," and 26% answered "discontinued." To gauge which of the "discontinued" responses were due to privacy concerns and which were votes of no confidence, we segmented the responses by the privacy score described above (see Figure 7). The respondents who scored one or more were considered separately from those who scored zero. Of the privacy-concerned group (n=20), 60% responded "discontinued" and 10% responded "continued" or "expanded" (see Figure 10). Of the group expressing no privacy concerns (n=71), 17% favored project termination and 56% favored continuation or expansion.

Thus we believe that we are addressing a real problem, and that there is an acceptable level of support for this type of solution, particularly if we can address privacy concerns. But not everyone can be satisfied: A few survey respondents recommended removing the OFF buttons!

On the other hand, respondents feel that the potential for a technological solution to foster informal communication is inherently limited. When asked "What role do you think technology could have in facilitating informal interaction if implemented appropriately?" 53% responded "moderate role" or "strong role," 34% responded "weak role," and 5% indicated "no role." When asked, "How do you assess the potential for the Virtual Kitchen project to facilitate informal interaction?" 22% responded "moderate" or "substantial." The non-technical solutions enjoy more support: To a similar question regarding the weekly mid-afternoon snack break, 70% had those same responses. To a third question regarding the monthly social event, 79% had those same responses.

DISCUSSION

The Choice of 'Public Spaces'

As noted earlier, kitchens were not the only possibility. At this point it seems a reasonable choice, but it is possible that it led to some of the sensitivity. Some people may be uneasy about putting their consumption of junk food or caffeine on public display, others about the number of trips they could be detected making.

Potentially, we have four more kitchens upon which to draw, which would substantially increase opportunities for interaction. It might be oppressive to have seven displays, and showing only those with activity could lead to difficulty maintaining reciprocity. The display first active could perhaps be shown larger than subsequent ones.

Privacy and Controversy

Why didn't the literature on video support for informal interaction prepare us for the controversy over privacy and public space? It may be due in part to changing times – technological encroachments on personal information and space are more widely discussed today. With widespread security cameras, 'reality TV,' and webcams that enable parents to monitor children in daycare, we as a society are sorting out our attitudes to video technologies. Particular individuals or organizational cultures may play a role.

In retrospect, however, other factors are compelling. Most previous experiments involved smaller groups of more tightly-knit researchers. Some papers argued that one's colleagues should feel fine about allowing unannounced *one-way* video visits to their offices, indicative of a level of trust that is usually confined to small groups.

Consider the Bellcore VideoWindow experiment. Fifty of the participants volunteered to move their mailboxes to the common areas. Others who wandered in were rewarded by free coffee that was otherwise unavailable – being viewed was a price they agreed to pay. The free drinks in our kitchens were available before, so there was no *quid pro quo* for employees who did not value the possibility of interacting through the system.

One conclusion is to introduce a system especially carefully when it brings no obvious new benefit to everyone. Our use of a distribution list for airing grievances seemed useful, although it led us to believe there were more dissatisfied people than the survey and sensor data suggest.

CONCLUSION

It is too early to tell whether this technology is significantly enhancing informal interaction in our organization. It may never be possible to measure it with confidence. The experiment has generated discussion and raised technical and social issues. We partially succeeded in a technical implementation based on relatively inexpensive hardware. The cost of the hardware will fall, its quality will rise, and similar efforts will be easier. Attitudes are likely to change with experience and generational change – children who grow up surrounded by cameras and camcorders may respond differently than previous generations.

Lessons from this trial, not predictable from the prior literature, could motivate and inform future experiments.

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