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Video-as-Data: Technical and Social Aspects of a Collaborative Multimedia Application

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Abstract. We studied the use of a collaborative multimedia system for coordinating teamwork among members of a neurosurgical team. We analyze the use of video within the operating room and the use of broadcast audio and video to other locations in the hospital to enable remote neurophysiological monitoring. We describe how the multimedia system was used in a real world work context, including its benefits and problems. We argue that video can be useful as more than just pictures of people talking to one another; video can be a rich tool to enable analysis and problem solving. We discuss privacy problems inherent in collaborative multimedia technology and describe how they played out in the hospital during the course of our study.

Key words: audio, collaborative work, computers and medicine, multimedia, privacy, shared workspace, task coordination, video

1. Introduction

The rich information throughput afforded by multimedia makes it a logical extension to the computer-supported collaborative work technologies that have been under development during the last decade (Mantei *et al.*, 1991; Buxton, 1992; Ishii and Kobayashi, 1992; Kuzuoka, 1992; Sellen, 1992; Baecker, 1993; Bly *et al.*, 1993). To date, collaborative multimedia systems have tended to focus on the use of audio and video to enable synchronous interpersonal communication between remote participants. Video is used to communicate visual aspects of interaction such as eye gaze, gesture, facial expression (Chapanis, 1972; 1977; Sellen, 1992; O'Conaill *et al.*, 1993; Tang and Isaacs, 1993), or information about the presence or absence of a remote collaborator (Fish *et al.*, 1990; Dourish and Bly, 1992; Fish *et al.*, 1993; Bly *et al.*, 1993; Tang and Rua, 1994). Where such "talking heads" systems have been evaluated, the effects have been both subtle and task specific. Few benefits have been observed for collaborative problem solving tasks (Chapanis, 1972; 1975, 1977; Fish *et al.*, 1992), although tasks such as negotiation that require access to the motivations of others do show outcome differences when video information is provided (Short *et al.*, 1976). Commercial multimedia systems using talking heads video for supporting interpersonal communication have not been greatly successful (Noll, 1976; 1992; Egido, 1990). One consistent result, however, is a subjective preference by users for video over audio only interaction (Tang and Isaacs, 1993; Sellen, 1992). More research is needed in this area.

While multimedia offers many new and enticing technical possibilities in areas such as electronic publishing, interactive learning, and video on demand, such applications have not been explored to the same extent as those for talking heads. The few systems that do tackle the new applications have tended to be research prototypes, so we lack detailed information about their potential utility in real work settings.

The study we report in this paper attempts to redress the balance. We describe and analyze a multimedia system used to coordinate work among members of a neurosurgical team in a teaching hospital. Though the system we studied was experimental in the sense that it was still under development, it was actually being used in the hospital for everyday work, and we conducted our study by observing its use in the real work setting.

The paper focuses on four key issues: (1) the importance of video-as-data in contrast to talking heads video; (2) the need to develop new tools to make video a richer medium; (3) the differing uses of information in audio vs video channels; and (4) privacy problems associated with collaborative multimedia technology. Video-as-data contrasts with the traditional "talking heads" approach. In applications such as videophone and videoconference, video is used to show the head and upper body of remote interactants. By contrast, we focus here on using the video image to display *shared dynamic work objects* that are critical to the task being carried out by a distributed team.* We will investigate the importance of these shared objects in mediating collaboration in distributed teams.

2. The multimedia system in the hospital

In the hospital where we conducted the study, live color video is used in the operating room to coordinate team activity during neurosurgery and both live and recorded video are used for training in neurosurgery. During the critical parts of an operation, such as the removal of a tumor, the neurosurgeon looks through a stereoscopic microscope to view the brain or spine as he** works. A camera co-mounted with the optics of the microscope captures a video image of what the surgeon sees. The image is then displayed on a cable TV link. The entire neurosurgical team – anesthesiologist, neurophysiologist, neurotechnician, resident or fellow neurosurgeon(s), surgical technician, scrub nurse, circulating nurse, nurse-anesthetist, and

* The stance of recent media spaces applications is less clear about the role of video: while media spaces work mainly emphasizes "talking heads" video, there is some discussion of using video to focus on objects or artifacts (Bly *et al.*, 1993; Fish *et al.*, 1993).

** Our use of the pronoun "he" here is for convenience' sake; any other construction would make it awkward to describe individual roles in the operating room. We alternate he and she as generics.

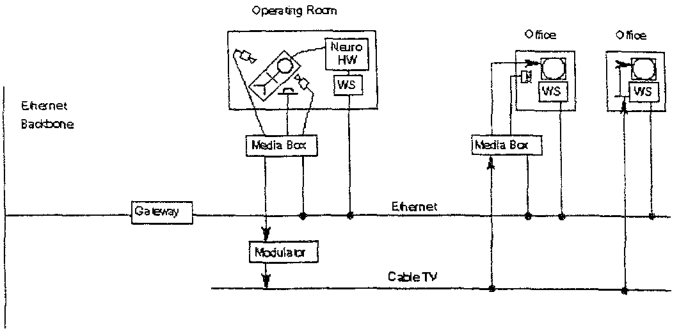

Fig. 1. The multimedia medical network. (Neuro HW = neurophysiological monitoring hardware, WS = computer workstation).

sometimes an anesthesiology resident – can see what the surgeon sees. The video image is 2D and is a somewhat smaller view of the surgical field than the surgeon's view. This technology has been in existence (though not universally available) for over twenty years, and is now an indispensable part of operating room activity in many hospitals.

The multimedia system in the hospital also has a new and very innovative facility for remote broadcast of video, audio, and quantitative data from the operating room instrumentation. The multimedia system includes MediaBox, an appliance for the control of media peripherals and analog signals (Sclabassi *et al.*, 1991). The MediaBox provides control, configuration, and integration with the workstation and network environment for multiple media sources. Figure 1 shows a schematic view of the multimedia medical network in the hospital.

The multimedia facility was developed by neurophysiologists who are interested in establishing how much of their job can be done from locations away from the operating room. Remote performance of their tasks would allow them to service a greater patient population, spreading their scarce expertise over a larger number of operations. Before describing how the neurophysiologists use the multimedia system for remote monitoring, we will briefly sketch their role in the neurosurgery team.

Neurophysiologists monitor the patient's neurophysiological responses during an operation and feed information back to the neurosurgeon and anesthesiologist if they suspect a problem. Neurophysiological monitoring has been successful in reducing patient morbidity by constantly tracking central nervous system activity to see that it is maintained within acceptable parameters. During many neurosurgical operations there is a high risk of damage due to the anesthesia or surgery itself; for example, cutting, stretching, or compressing a nerve, or cutting off the blood supply to parts of the brain. Neurophysiological monitoring helps prevent such events. It has enabled neurosurgeons to perform more difficult and daring operations (especially going deeper into the brain) and is available only in some hospitals. It is used during operations in which the patient is at high risk.

But the neurophysiologist does not need to actually be in the operating room at all times in order to monitor effectively. His main source of information is the instrument data showing neurophysiological measures displayed as plotted line graphs on a computer screen. This information is routinely broadcast to remote network nodes, outside the operating room, enabling remote monitoring. The new multimedia system feeds the *audio, video,* as well as the *instrument data* to nodes in a networked system allowing remote monitoring from other operating rooms, conference rooms and offices (Sclabassi *et al.*, 1991). The video and audio information supplement the neurophysiologist's view of the operation, supplying additional information for interpreting the instrument data (as we will discuss in detail). During routine parts of an operation, neurophysiologists can be in their offices answering patient calls, reading mail, editing papers, and tending to other duties while monitoring the operation as a background activity. In the future, the facilities for remote broadcast will also be used by remotely located neurosurgeons acting in an advisory role. Using the remote monitoring, neurophysiologists and neurosurgeons should be able to simultaneously monitor a larger number of operations, spreading scarce expertise over a greater area and making more efficient use of their time. Only a handful of nodes have operable video and audio capabilities at the present time, so our discussion of their use reports preliminary findings.

3. Methodology

To learn about the use of the multimedia system, we conducted an ethnographic study comprised of observations in the operating room; audio-taped, semi-structured interviews; informal interaction (such as going to lunch with informants and casual conversation in hallways and offices); and "shadowing." The shadowing technique involved following around a single individual for several days to track and record activity in as much detail as possible. We used this technique with the neurophysiologists to study their use of the remote video and audio. We had originally hoped to quantify this information in terms of times-per-task, but because of the complexities of hospital life we would have needed at least 3–6 months of shadowing to iron out anomalies and make statistically valid statements. The shadowing was nevertheless very informative as we learned a great deal about the daily activities of neurophysiologists and had many opportunities for informal conversation. A total of 14 person-weeks of fieldwork was conducted. Over 500 pages of interview transcripts resulted from interviews with about 35 informants.

Our observations were conducted in the operating room during a series of brain and spine surgeries. In some cases we observed complete surgeries, and in others we spent a period of hours in the operating room (neurosurgeries can last from about 5 to 24 hours). While it might seem odd that we were allowed in the operating room, the staff was accustomed to visitors because we were at a teaching hospital. We donned "scrubs" (soft, loose, cotton clothing) and masks, exactly the same as that worn by all operating room personnel, and our presence was not conspicuous.

Fig. 2. The neurosurgical team at work. The neurotechnician is seated by the neurophysiological workstation display at the left of the photography. The scrub nurse is shown in the center, while the surgeon, on the right, works on the patient. The anesthesia team is situated behind the hanging drape at the right of the photograph. In the foreground is the surgical table which contains instruments and supplies used by the surgeon.

We had opportunities to ask questions of all operating room personnel during operations (except the attending neurosurgeon) as there are always times when a particular team member is not busy. The scrub nurse was only briefly accessible, but because circulating nurses are also trained and work as scrub nurses, we had good opportunities to talk to them in the operating room about both roles. The semi-structured interviews were used to fill in gaps in our knowledge and to pose specific queries about many aspects of the use of the multimedia technology, especially the privacy concerns.

4. The operating room: roles and procedures

It is necessary to provide some background on work flow and work roles in the operating room during surgery to be able to make sense of the discussion in the following sections of the paper in which we analyze the use of the multimedia system in detail. Figure 2 is a photograph of the neurosurgical team at work. Figure 3 diagrams the work roles in the operating room.

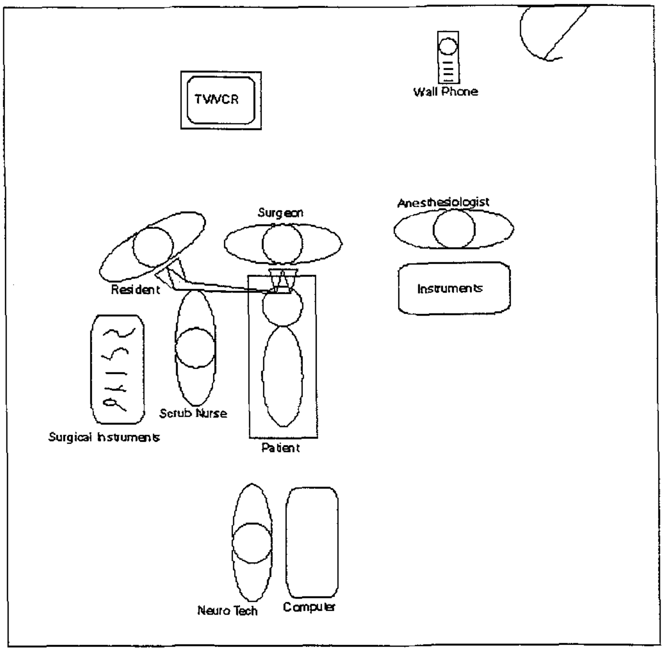

Fig. 3. The neurosurgical team.

4.1. PREPARING THE PATIENT

At the beginning of an operation the patient is tranquilized, anesthetized, and connected to a variety of monitors and drips. The attending anesthesiologist plans the general course of the anesthesia to be used for the operation, and is usually present during the "prep" period. The attending anesthesiologist works with the nurse-anesthetist and/or resident anesthesiologist to administer the anesthesia and insert the appropriate intravenous lines for blood and a catheter for urine. After the initial set-up, the attending anesthesiologist generally leaves the operating room to attend to another operation or to take care of other tasks. The resident and/or nurse-anesthetist then monitors the patient's basic physiological functions: heart rate, blood gases, blood pressure, breathing, urine concentration, and so forth. The attending anesthesiologist returns to the operating room when necessary. He can be reached by phone via his pager, and he makes "check-in" visits to see how things are going.

At this time, the nurses are busy setting up the operating room: arranging instruments on the sterile table that will be placed near the operating table, checking supplies, putting the patient's X-rays up on the wall.

The beginning of the operation is also the time when the patient, after being anesthetized, is connected to the electrodes that will be used to monitor muscle and nerve activity. The neurophysiologist and neurotechnician apply the electrodes which provide "evoked potential" data. Throughout the course of the operation the patient is given electrical stimulation (electrical potential for activity is actually evoked by stimulation) to make sure that muscles and nerves are responding appropriately, and are not being damaged by the surgery. The neurophysiologist supervises the neurotechnician and all on-going cases, and is ultimately responsible for the interpretation of the neurophysiological data. The neurotechnician does the more routine monitoring, sitting in front of the computer screen watching the plotted line graphs.

As mentioned, the neurophysiological data can also be viewed in other locations outside the operating room because the graphs can be displayed on remote nodes on the networked computer system. The system can display all of the neurophysiological data for any operating room to which the system is connected. A neurophysiologist, when on call, thus usually spends a part of the day in the various operating rooms and a part of the day in his office, monitoring the evoked potentials via the computer displays. Neurophysiologists may monitor as many as six operations concurrently (they have a back up person assigned to help in case of overload). When not in the operating room, they communicate with the neurotechnician in the operating room via telephone and they carry pagers. If during the course of the operation, the neurotechnician suspects a problem, she reports it to the surgeon, and she may also telephone the neurophysiologist if he is not in the operating room at the time. The neurophysiologist then returns to the operating room to evaluate the data and possibly communicate with other members of the surgical team such as the attending neurosurgeon or anesthesiologist.

4.2. "OPENING" AND "CLOSING" THE PATIENT

After the prep, the patient is "opened" – that is, the incision made – by the resident or neurosurgical fellow. The resident or fellow then continues to cut and drill until he is down to the point in the brain or spine where the most delicate surgery is required; for example, the brain tissue that must be "picked through" to reach a tumor, aneurysm, or blood vessel compressing a nerve. At this point the attending neurosurgeon arrives in the operating room to take over. Often the procedures used by the neurosurgeon are "micro-procedures," i.e., those requiring the use of the microscope. The resident or fellow neurosurgeon watches the operation through a second (2D) lens on the microscope, while the attending neurosurgeon views the surgical field through the main stereoscopic optics. When the microscope is being used, the video is on as well, so those in the operating room can watch a two-dimensional view of the surgery on the TV monitor. The audio portion of the system is on as soon as the microscope and VCR are turned on, often at the beginning of the operation, long before the microscope is needed.

Via the networked multimedia system, the neurophysiologist, if not in the operating room, can see the microscope video and hear a great deal of what is said and done in the operating room. The broadcast video image enables the remote neurophysiologist to see what the surgeon is currently doing. The broadcast audio also allows the neurophysiologist to hear what the surgeon is saying in the operating room as he calls for instruments, explains what he is doing, and describes the patient's state to students and others in the operating room. The neurophysiologist also hears other ambient sounds of interest such as the equipment noise, which often provides (whether by design or not) auditory cues to the progress of the operation or the patient's state. For example, the sounds from the suction device tell everyone in the operating room how much blood is being suctioned; a lot of blood might indicate a problem. The audio broadcast to remote locations transmits such sounds and many others: the Doppler ultrasound emits the noise of the heart pumping, the noise of the drill reveals the kind of drill being used, and hammers, saws, and chisels have their characteristic sounds. Oscilloscopes used by the neurophysiologists and neurotechnicians have audio output that tracks responses produced by stimulation, responses that may go by so quickly they cannot be seen visually on the display, but can be detected aurally.

The operation may be recorded on videotape, at the discretion of the attending neurosurgeon.

Throughout the surgery the scrub nurse hands the surgeon the instruments and supplies that he requests. The circulating nurse makes sure that the scrub nurse has everything she needs; the circulating nurse is a bridge between the sterile operating area and non-sterile areas of the operating room. When the attending neurosurgeon has finished his work, the patient is "closed" – that is, the incision is repaired – by the resident or fellow. The patient is revived from the anesthesia in the operating room and asked to wiggle his toes and say something. He is then wheeled to recovery.

5. Video-as-data

To date, most research on video has focused on talking heads video in which the video images are of remote participants conferring, or checking on each other's presence in a particular location, or performing some task together (Chapanis, 1972; 1977; Egido, 1990; Fish *et al.*, 1990; Mantei, 1991; Dourish and Bly, 1992; Fish *et al.*, 1992; Sellen, 1992; Baecker, 1993; O'Conaill *et al.*, 1993; Tang and Isaacs, 1993). In the operating room, video images of the workspace and work objects – i.e., *the data* – are the focus of interest. We describe the central role of video-as-data in *coordinating team work* and *educating medical personnel* in the teaching hospital setting.

In the operating room, the live video is used to coordinate activity during the most critical part of the surgery when the neurosurgeon is working deep in the brain or spine on very small structures that he sees only through the microscope. In a sense, even though operating room personnel are colocated, the video provides "remote" access; the surgical field is invisible, without the intervening video technology, to all but the surgeons. The video is used by the scrub nurse, anesthesiologist, nurse-anesthetist, circulating nurse, neurophysiologist, and neurotechnician, to see more precisely what the surgeon is doing.

The most important function of the live video in the operating room is to allow the scrub nurse to anticipate which instruments and supplies the surgeon will need. As one scrub nurse said, the video is "the only indication we have of what's going on in the [patient's] head." The TV monitor is on a movable cart, and its position changes depending on the orientation and position of the patient, which depends on the kind of operation being performed. The circulating nurse positions the monitor so that the scrub nurse has an unimpeded view, clearly revealing the importance of the video to the scrub nurse.

During the critical parts of the surgery, events move very quickly, and the surgeon must be able to work steadily and without interruption. He changes instruments as often as every few seconds, and he needs to work in tight coordination with the scrub nurse who is selecting an instrument from over one hundred instruments arrayed on the sterile table near the operating table. The scrub nurse may also need to hand the surgeon one of hundreds of types of supplies (sutures, sponges, teflon pads, etc.) brought to her by the circulating nurse. The work of a neurosurgical operation is extremely detailed and fast-paced, and the better idea the scrub nurse has of the surgeon's needs, the more smoothly the operation proceeds. Even with the video, the surgeon calls out the instrument or supply he needs next, but the ability of the nurse to anticipate what the neurosurgeon will want is considered very important by operating room personnel. One neurosurgeon used a sports metaphor to explain how the video supports neurosurgeon-scrub nurse coordination:

> **Neurosurgeon**: . . . an operation is like team work, [for example], ice hockey – the center brings the puck around, and the forward goes to the appropriate position, and the puck is coming in and he hits it . . . Surgeon and scrub nurse . . . it's mutual team work . . . So a good scrub nurse looks at the video and knows what's coming next – instrument in and out, instrument giving and taking. It's all team work, [like] sports activity . . . So if you don't have the video, there's no way to do so [coordinate activity quickly].So [with the video] it's uniform, harmonious work.

As she watches the video, the scrub nurse is tracking the course of the operation and looking for unusual events to which she must respond with the correct instrument or supply. For example, she may know that the surgeon is approaching a time in the operation when a clip will be needed. Or she may see the surgeon nick some tissue, in which case a cautery device will likely be called for to repair the nick.

The scrub nurse's effective use of the video depends on her own knowledge and understanding of what she is seeing; the presence of the video image is not a guarantee that she will be able to anticipate the surgeon's needs and respond quickly. There is an interaction between her level of expertise and understanding and the presence of the video in the environment. As one neurosurgeon explained:

Neurosurgeon: Some scrub nurses are excellent when they look at the video, they know what's next and they are very good. But other scrub nurses are not at that level yet, so [I] have to tell her what I need and even if she's looking, [she] is not at level yet, so it is more time consuming.

Because the scrub nurse is listening to the surgeon, selecting instruments and supplies and handing them to the surgeon, her use of the video involves very quick glances at the monitor to see what is happening. All the more reason she must instantly understand what she is seeing. In contrast to the scrub nurse's quick glances at the monitor, the others in the operating room who watch the video may watch it intently for long stretches of time. Their use of the video helps them keep track of the progress of the surgery, but generally they do not rely on the video for split-second reactions as does the scrub nurse. Anesthesiologists, nurse-anesthetists, circulating nurses, and neurotechnicians watch the video in part to remain attentive to the surgery, to maintain interest and concentration at times when they may have very little to do. For example:

Interviewer: What does [the video] tell you about what you have to do?

Anesthesiologist: In the neurosurgical procedure, the microscopic part actually is quite long and boring usually for us because once we get to that part of it . . . the patient usually is very stable . . . It's nice to see where they are, how much longer are they going to be. Is he [the surgeon] still dissecting or is he [finishing] up? I don't have to ask the surgeon that.

Many anesthesiologists, nurse-anesthetists, circulating nurses, and neurotechnicians commented that watching the video was "interesting" and that it was much better than just sitting there with nothing to do. The video thus alleviates boredom and provides a focal point of attention that helps maintain shared awareness of the work being done by the surgeon.

This is critical because events can change very quickly during an operation. Suddenly what is seen on the video monitor can dictate that someone take action or that a new interpretation of an event applies. Operating room personnel look for a variety of events such as the placement of a retractor or clip, where the surgeon is drilling, if there is bleeding, how close to a tumor the surgeon is. For example, a nurse-anesthetist explained that

Nurse-anesthetist: The anesthetic requirements [for] drilling through bone are different from the anesthetic requirements when they are working inside the head, where there are not pain fibers.

In this example, the actions of anesthesia personnel must be coordinated with those of the surgeon, and depend critically on what he is doing at a given moment in the surgical field. The video provides this information to anesthesia personnel.

Neurophysiologists and neurotechnicians interpret the graphs they watch on the computer display in concert with events shown on the video. One neurotechnician explained that they can "decipher the responses better" when they know what the surgeon is doing. For example, when a retractor is placed, a delayed response may result which should not necessarily be attributed to nerve damage, but may have been caused by the retractor itself. Interpreting the neurophysiological data is difficult because its meaning can be affected by signal noise, the type and amount of anesthesia used, surgical events, and random variation. The video provides an important source of information for making better inferences in a highly interpretive task. Again, the use of the video allows tasks to be coordinated appropriately by supplying neurophysiologists and neurotechnicians with critical information about the neurosurgeon's actions.

At a teaching hospital, education is of critical importance. Anesthesiology and neurosurgical residents and fellows, student nurses, and neurophysiologists- and neurotechnicians-in-training observe and/or take part in operations as a critical part of their education. While the neurosurgical resident or fellow uses the second 2D lens on the microscope to view the operation when the attending neurosurgeon is operating, others in the room watch the video. We observed students, residents, and fellows training at the hospital watching the video, and also visiting students, residents, and fellows from other hospitals. On several occasions they entered the operating room, parked themselves in front of the video monitor and watched for the duration of the microprocedures (which may go on for several hours).

Because of the innovative and experimental character of the operations performed at the hospital, the operating room accommodates visiting neurosurgeons, anesthesiologists, and neurophysiologists from institutions around the world who come to learn about the new procedures. One of their main activities in the operating room is to watch the video.

5.1. Implications of Video-as-Data

The use of the video in the operating room is very different from the typical uses to which we imagine putting video. The neurosurgical team needs to view the *workspace* – i.e., *the data* – on the video, rather than an image of a person talking. Video images of the workspace and work objects convey critical information about the work that enables tight coordination between members of the neurosurgical team and facilitates education. Team members, students, and visitors see lifelike images of the work objects and how they are changing and being manipulated. Video-as-data enhances task performance, rather than providing telepresence.

We were struck by the extent to which the use of video-as-data in the neurosurgical context serves a number of highly varied functions. The overall goal of the video is to provide a window into the unseeable world of the surgical field, but the uses to which the surgical information is put, and the way the information is gathered, vary greatly depending on the specific tasks associated with the differing roles on the neurosurgical team. As we have seen, the video image can coordinate fast-paced exchanges of instruments and supplies between neurosurgeon and scrub nurse; it can serve as a means of maintaining attention and focus over long stretches of time during which some team members are relatively inactive; it helps team members choose the correct action or interpretation depending on the event portrayed in the video; it educates a variety of medical personnel. The use of video-as-data in neurosurgery thus coordinates many activities all working toward a common goal.

Our study shows that the use of video in the neurosurgical context is quite different than standard notions of what it means to support collaborative work. Rather than facilitating direct interpersonal communication (as CSCW systems are often intended to do), in many crucial instances, the video in the operating room permits individuals to work *independently*, actually obviating or reducing the need for interpersonal communication. The video supplies enough information so that the need for interpersonal communication is reduced or eliminated, and individuals can figure out what they need to know based on the video itself, circumventing the need to talk to or gesture at someone. In the operating room, the provision of visual information at key moments provides a different channel of communication than that which would be provided through verbal, gestural or written communication. Rather than facilitating collaboration through interpersonal interaction, the video itself informs operating room personnel of the collaboration – in the sense of tasks that need to be performed to advance the work – that is needed. Collaboration and coordination are enabled as each member of the neurosurgery team interprets the visual information, and proceeds to do his or her job based upon an interpretation of that information. The video data, plus individual knowledge and understanding, combine to produce an interpretation that leads to the desired collaboration, with little or no interpersonal interaction.

There are parallels here to recent work on shared workspaces (Whittaker *et al.*, 1993). This work examined two-person telephone communication with and without the presence of a shared workspace, and two-person synchronous communication using shared drawing surfaces and documents for editing and design tasks (Whittaker *et al.*, 1993). A key function of the workspaces in these investigations was that they served as a record of progress through the tasks, so that both participants could directly observe modifications and annotations to the document or design as changes were made. As with video-as-data in the operating room, this sometimes obviated the need for verbal interaction, because both participants could jointly see the changes made by the other. In addition, the other participant's actions such as turning a page in the shared document could be directly observed, without the need for verbal communication, so that people could always "see where they were" in the editing task. In contrast, for interaction using telephone only, participants were forced to make such actions explicit verbally.

Although the video image in the operating room sometimes obviates the need for interpersonal interaction, at other times the content of the video image becomes the basis for discussion and interaction, another aspect of its use as a shared workspace. For example, we observed a nurse-anesthetist in the operating room watching the video with a student nurse-anesthetist and describing to her the progress of the operation. Indeed, we ourselves profited from explanations in which the video was a key point of reference as operating room personnel educated us about many aspects of neurosurgery. Visitors, residents, fellows, and students also discussed what was being shown on the video monitor.

Video-as-data may change our sense of what it means to be "remote" or "colocated." In the operating room, even though people are colocated, the surgical field is remote, because it is invisible to anyone not looking directly through the microscope. The surgical field is accessible only through the video to most operating room personnel. Thus it is not necessarily the location of *people* that is important in the video-as-data situation, but rather of the *workspace*. Aural information in the operating room, on the other hand, is not remote, so we have a situation in which the aural and visual have different values in terms of colocation. We can imagine other such situations; for example the repair of a delicate piece of machinery with many small parts might be a situation in which a view of the workspace is remote, while aural information is not.

6. Tools for video

Our observations in the operating room persuaded us of the importance of video-as-data in contrast to an exclusive focus on talking heads video. Video-as-data has been used for many years in medical and industrial settings and has become indispensable in many applications. For example, in power plants, live video of remote locations is used to monitor plant operations (Tani *et al.*, 1992). Video is used in telerobotics and remote surveillance (Milgram *et al.*, 1990).

There are many exciting possibilities for extensions and enhancements to basic video capabilities. Milgram *et al.* (1990) developed a system that combines stereoscopic video and stereoscopic computer graphics so that users can point to, measure, and annotate objects within the video. Tani *et al.* (1992) have proposed "object-oriented video" in which the real-world objects in the video become computer-based objects that can be manipulated so that users will be able to reference, overlay, highlight, and annotate them, as well as use the objects for control and information browsing. In Tani's prototype system for power plants, users can, for example, point to a burner on a boiler in the live video and bring up a document that explains how the ignition system of the boiler works. By pointing to a pipe on a live video they can view a graph that shows the amount of fuel running through the pipe. Users can get a more detailed video or related video of an object by pointing to the object, obviating the need to directly control remote cameras. Users can control remote devices through direct manipulation techniques such as clicking and dragging; for example, "pushing" a button on the video image engages a real button on the remote device (Tani *et al.*, 1992).

Lieberman (1994) developed a system in which digitized video is used to allow domain experts to select and graphically annotate frames containing objects of interest in the operation of machinery, the assembly and disassembly of circuit boards, and so forth. Using programming by demonstration techniques, users describe the actions that represent transitions between frames. The video then runs to show the objects and procedures of interest. These techniques provide a way for experts to document operational and maintenance procedures for complex systems (Lieberman, 1994).

Work on interactive iconic annotation and visual parsing of video sequences is underway (Davis, 1993; Weitzman and Wittenburg, 1993), and such work is essential for making video-as-data an accessible and usable technology.

The application of iconic and object-oriented video would be especially useful for educational applications where students need to learn to analyze and not just passively view video images. If video-based educational software is to be more than just educational television, students need tools that will help them to actively engage the material they are working with. Once we see that video goes well beyond talking heads, we can begin to supply the kinds of tools that will take advantage of video-as-data, and that will make video into an interactive medium supporting analysis and problem solving.

For the medical application we studied, we found that recorded video is already used for classroom teaching and to review events in past operations. Integration of video with other computerized time-based data is the next critical step. Uniform storage, access, and presentation methods for data are needed. Means of visualizing complex relationships between datasets of varying types will support research and teaching. Medical personnel in our study underscored the need for future tools that will allow for the synchronization of video with other data sources, in particular the instrument data relevant to a particular specialty. Anesthesiologists, for example, want to see the video images synchronized with the physiological data they monitor such as blood pressure, blood gases, heart rate, pulse, temperature. Such observations could be done during an operation, with video and instrument data they had just recorded. The synchronized datasets could also then be used for post hoc analysis, and for training purposes. Neurophysiologists want to see video synchronized with the many measures of nerve and muscle response that they monitor. Useful capabilities will include: (1) "scrolling through" a video/instrument dataset, (2) finding a particular video event, or instrument event, or a particular time, so that users can then view all related contemporaneous data for the event or time.

Users would also like to be able to scroll through different datasets at different rates to capture latency in cause and effect relations between variables. For example, a neurophysiologist might want to scroll back through a videotape to find an event that took place a minute or two ago, such as the placement of a clip, which might just now be causing a reaction in the patient which would show up in the neurophysiological data seen in the plotted line graphs. Scrolling at different rates in different datasets might also be done in studying the recorded operation and related data, after the fact, to try to ascertain delayed effects of surgical events.

Again, it is easy to see how the provision of such analytical capabilities will have wide educational applicability in many domains. Students trying to understand complex relationships among many variables would have a vivid graphic image with which to visualize events. At the same time, the more abstract quantitative measures would be made more intelligible, giving students help with difficult concepts. Animation would be an interesting substitute for actual video in some applications where a video image is not available and a simulation is needed, such as a collapsing bridge. The idea of seeing the image as data to be analyzed against other variables is the same in both cases and similar tools would be appropriate. It would also be possible to compare animated simulation information with actual video test data, i.e., testing the data of the real object against the simulations run during the design phase. There are many exciting possibilities then, for using video to analyze data and to support complex problem solving activities. The integration of video-as-data with other data sources will be useful in many applications for analysis, training, legal, and archival purposes (Whittaker *et al.*, 1994). Users of such technology will want to be able to edit, browse, search, annotate, overlay, highlight, timestamp, and display video data.

Of course, such manipulation of large amounts of relatively unstructured information presents a novel set of problems, particularly those related to indexing, search, and retrieval of video information. The user must be able to specify in a clear way what he or she is looking for. Unlike text systems and conventional database systems, where keywords to aid search may be generated automatically, keywords used today to describe the contents of video must be generated manually (but see Russell, 1994). This is labor intensive and error prone and may also introduce sources of bias as the description of content is subject to interpretation. For dynamically changing stores of video data, this task becomes particularly complex.

The alternative of content-based search and retrieval is promising, but remains an open research area. One needs to consider which features of the video information are represented, how these features are extracted, and how an index and search structure based on these features is computed. Often some level of user involvement is needed in the indexing; the effectiveness of the indexing mechanism, and the resulting level of ease with which a user can browse and navigate through the video information, may be thus dependent upon the level of sophistication of the user.

One partial solution to the indexing problem for multimedia data is to analyze user activities during audio or video recording to automatically generate event-based retrieval cues. Research prototypes have been built to co-index audio or video with handwritten notes. Pen-based computer applications allow users to gesture at their original handwritten notes of a meeting, and have the system access video or audio recordings of exactly what was happening when that note was taken (Minneman and Harrison, 1993; Whittaker *et al.*, 1994). Other techniques involve the construction of retrieval cues based on the intonational properties of the speech signal (Hindus and Schmandt, 1992; Arons, 1993).

Our findings about the importance of the on-going use of video-as-data in a real work setting with demanding requirements (as opposed to brief experiments or testing within research labs) should encourage us to pursue our understanding of how video-as-data can be extended and used in other work settings. Within medicine, video is used in many kinds of surgery including orthopedic surgery, plastic surgery and general surgery that employs micro-procedures. Non-medical applications of video-as-data could include monitoring and diagnostic tasks in complex mechanical or electrical systems such as the Space Station, power plants, or automated factories; and training for many aspects of using, designing, monitoring, and repairing such systems. Many companies, such as Xerox, use video to train people in the use of their equipment (Egido, 1990), and it is easy to imagine many training applications for video-as-data. Real estate agents might show properties remotely. Attorneys are making increasing use of video data in courtroom presentations. There are many potential applications for video-as-data.

7. Audio vs video

We have described the function of the live video in the operating room. The broadcast video served the same purposes in the remote situation for the neurophysiologists. Now we would like to describe the use of the remote audio facility and compare video vs audio.

The audio channel provided additional information to the remotely located neurophysiologist trying to interpret the situation in the operating room. This information came from two sources: (1) what was being said in the operating room, and (2) the overall affective atmosphere in the operating room, as revealed by the audio. We look at each of these in turn.

There is often important conversation taking place in the operating room that is of direct utility to the neurophysiologist. As the neurosurgeon works, he often explains what he is doing or discusses his anticipated actions with the other neurosurgeon(s). Anesthesia personnel discuss the patient's physiological function. The neurophysiologist is better able to interpret the instrument data he is looking at by hearing the comments of the neurosurgeons which reveal the progress of and plans for the operation. The comments of the anesthesia team can also describe physiological information and help the neurophysiologist to anticipate what will happen next in the operation.

In many cases, the neurophysiologist actually has better access to what is being said when he is in a remote location than when he is in the operating room. Within the operating room, it is sometimes difficult to hear some of what is said because of the noise of equipment and conversations. In contrast, when listening to the audio in a remote location, one gets a clear transmission of what the neurosurgeons and the anesthesia personnel are saying, as they are positioned closest to the microscope (on which the microphone is mounted). One neurophysiologist explained:

> **Neurophysiologist:** In fact, the audio is better over the network than it is in the operating room because you can't hear what the surgeons are saying in the operating room. So if you don't know the case, you kind of guess what they're doing. With the audio, you know exactly what they are doing. Because they talk to each other about the steps they are going to take. So you can really anticipate what potentially might happen.

This is an example of "beyond being there" (Hollan and Stornetta, 1992), where at least one aspect of being remote is preferable to being colocated.

The audio also allows the remotely located neurophysiologist to hear what the neurotechnician is telling the surgeon, and how the surgeon responds to that information. The neurophysiologist can see for himself what the neurotechnician sees on the graphs, but the response of the neurosurgeon is very important. The neurosurgeon may say that he's not doing anything that might be causing a problem, or that he doesn't understand the neurophysiological response, or that he will change an action he is taking. He may say nothing. These responses are of interest to the neurophysiologist.

The neurophysiologist may not agree with what he hears the neurotechnician tell the surgeon:

> **Neurophysiologist:** In that case, I heard the technician say something to the surgeon that I didn't agree with ... [He] said there was a change in the response. There wasn't.
>
> **Interviewer**: ... So what did you do, you called?
>
> **Neurophysiologist**: Called right away ... Told the surgeon there was no change.

Here the audio information directly influenced the neurophysiologist's behavior: he telephoned the operating room to provide a different interpretation of the neurophysiological data than that given by the neurotechnician.

Other audio information provides an overall impression of the atmosphere in the operating room, information on how the operation is progressing. This information is of an emotive, affective type; the neurophysiologist infers a general sense of the conditions in the operating room. As one neurophysiologist said:

> **Neurophysiologist**: ... What's the feeling in the room? The microphone is very close to the surgeon so I can really get a good feeling for whether he feels like the case is going well or not.
>
> **Interviewer**: When he is saying something.

Neurophysiologist: Yeah, you can hear it from his voice. You can [also] hear how much activity there is in the room, whether the people are scrambling.

Here the neurophysiologist was listening for the emotional tone of the room as evinced in people's voices and the quality of their activity ("whether the people are scrambling"). Again, this information influenced his behavior, in this case his decision as to whether to go to the operating room from his office:

Neurophysiologist: Well, if people are agitating, there's a lot going on. I probably would have a much lower threshold for going to the room because I'm alerted then that there's something going on in the room, and that's maybe an opportunity for me to make a significant contribution.

The neurophysiologists listened for situations such as a dead silence or nervousness in the surgeon's voice which would indicate a problematic situation. On the other hand, what the neurophysiologist might hear was the radio playing and people telling jokes and having relaxed conversations. This would indicate that things were moving along nicely, according to plan.

Our preliminary findings suggest that the information from the remote audio concerning the course of the surgery, the surgeon's observed and anticipated actions, the content of key comments made by personnel such as the neurotechnician, and the overall atmosphere in the operating room allow the remotely located neurophysiologist to perform his job more efficiently and effectively. He can better plan and coordinate his visits to the operating room because he has richer information with which to decide when he needs to visit a particular operating room, or whether he wants to place a telephone call. If he does need to go to the operating room, he arrives with better information about the status of the operation. If the neurophysiologist is communicating with the neurotechnician via the telephone, the neurophysiologist has a better idea of what is happening in the operation because of the presence of the audio data.

One of the biggest differences we found between the remote audio and remote video was that the audio conveyed the emotive, affective side of the operation. This finding is in contrast to studies of videoconferencing such as those of Short *et al.* (1976) in which the visual images conveyed the more subtle emotional clues. In a sense this is not surprising since the video image of a brain or spine could hardly convey emotion, but it does show that we cannot assume a priori that any given communication channel will serve a particular purpose. During videoconferencing, participants read each other's facial expressions, gestures, and posture to gain additional clues to the information conveyed in the audio channel. People are making a conscious effort to use the expensive videoconferencing time to say what needs to be said, but there is more information that can be gleaned from an interpretation of faces and bodies. In the operating room we have almost a mirror image of this situation: the video channel conveys the "hard data" while the audio channel picks up on tension, humor, nervousness, and so forth, as conveyed in people's voices and activity patterns.

Taken together, we found that the audio and video in the broadcast facilities provided a much more complete picture of operating room activity than the neurophysiological data in the plotted line graphs alone:

> **Neurophysiologist:** When you look at the computer data by itself [from a remote location], it seems to be one dimensional. When you add the rest of it [audio and video], you get a very rich picture of what's going on [in the operating room].

The use of remote multimedia facilities does not eliminate the need for neurophysiologists to be physically present in the operating room for at least part of the operation. Rather, it allows a reallocation of their time across operating rooms, offices, and conference rooms. The use of multimedia appears to give neurophysiologists more flexibility to move about the hospital on an as-needed basis, rather than to stay tied exclusively to a small number of operating rooms.

In the next section of the paper we continue our contrast of audio and video, but in the context of the privacy issues concerning the use of the multimedia system that arose during the period of our research.

8. Privacy in collaborative multimedia systems

Our assessment of the multimedia technology in the hospital is overall very positive but there is a problematic side to it which cannot go unmentioned. While many have pointed out the potential invasion of privacy inherent in the use of video (Mantei, 1991; Fish *et al.*, 1992; see also Clement 1994 on privacy in multimedia systems), in the hospital this became more than a possibility, as a situation of confusion and tension over the multimedia technology developed in which many misunderstandings and bad feelings arose. We describe the incidents related to the problem and suggest some potential remedies. We attempt to understand the nature of privacy concerns raised in the hospital, including concern over possible changes in the nature of communication within the operating room, fear of workplace video monitoring, and resentment over the way the multimedia technology was introduced.

Multimedia technology can facilitate collaboration in situations where people are not colocated, as we have described. This happens via a process in which information is taken out of its original context and presented in a different context. This very process reduces individual control over the kinds of information that people may consider private or personal. The context of information presentation and dissemination is suddenly radically altered; what was once an ephemeral event in a small, well-defined, visible space, with known participants, has now become a situation in which speech and action can be permanently recorded and/or broadcast live to remote, unseen and possibly unknown viewers and/or listeners.

During the course of our research, we encountered a growing discussion about privacy in relation to the multimedia technology in the hospital. Early in the second phase of the data collection we attended a meeting which was convened to discuss the rising tensions over the multimedia technology. In attendance were anesthesiologists, nurses, neurophysiologists, and some members of our research team. Anesthesiologists and nurses aired grievances about the recording and live broadcast of audio to remote locations outside the operating room. The concerns expressed were varied, ranging from concern over malpractice suits to fear of "Big Brother" (a term we heard on several occasions) monitoring job performance. There was a great deal of confusion over which technologies were actually in use or about to be installed. It was felt by some that the design and installation of the remote audio facilities had taken place in bad faith, without considering the impact on those who did not benefit directly from the technology. As observers, we felt that some of the concerns were justified and some reflected political maneuvering and political cleavages from past hospital history.

As designers of technology we were concerned about the criticism of the technology articulated at the meeting and we scheduled a series of interviews with anesthesiologists, nurses, neurotechnicians, and neurophysiologists to discuss the issues in detail. An advantage of the ethnographic method is that unexpected but clearly important events can be followed up without feeling that a rigid study design is being violated. The privacy concerns inherent in collaborative multimedia technology are certainly not unique to the hospital setting and we were able to take the opportunity to find out exactly what concerned people in this environment. The most subtle, and to us, most worrisome concern expressed at the meeting, in remarks we heard in the operating room, and in the extensive interviews we conducted, was that the free and unfettered atmosphere in the operating room was being compromised by the remote audio broadcast. It was pointed out that both tension and boredom in the operating room are relieved by the relaxed talk and joking that often go on during an operation. During an operation the radio may be playing, the neurosurgeon may be making casual conversation and informal side conversations are taking place. During one of our observations at a very routine part of an operation when everything was going exactly according to plan and the atmosphere was very relaxed, the resident asked, "Do you remember dead baby jokes?" It was not unusual for people to discuss topics such as movies they had recently seen, or to poke fun at some of the high status doctors in the hospital not present in the room at the time. Such lightheartedness might seem quite inappropriate to those outside the immediate situation – such as a prosecuting attorney or the patient's relatives – but to the staff in the operating room it is a way to cope with an extremely demanding job and a rigid professional hierarchy. The banter and fun in the operating room provide social cohesion in a situation that is often stressful and which requires meticulous teamwork, as we have tried to document. A remote audio broadcast is surely a hindrance to establishing and maintaining an atmosphere in which people do not feel that they must censor themselves lest their comments be misunderstood or overheard by the wrong ears. By opening up the operating room to those beyond its four walls, the remote broadcast changes the nature of communication within the operating room in significant ways. We heard many statements of concern that the multimedia technology would suppress valuable communication in the operating room.

A related concern expressed by the anesthesiologists and nurses was that because students are in the operating room as part of their training, both they and their instructors might feel inhibited if unseen and possibly unknown listeners had access to their conversation. Students are already nervous enough when learning the difficult skills of neurosurgery, and comments such as an instructor remarking, "I can't believe you did that," might be open to significant misinterpretation on the part of those not present.

We tend to think of the visual part of video as being most revealing and hence potentially most intrusive, but in the hospital the broadcast audio was perceived to carry the most risk. One reason was that people felt that audio information could so easily be misinterpreted. Taking the information out of context was seen as being potentially damaging:

> **Anesthesiologist:** You can't distinguish between those two [a true problem and something that just sounds bad] on the audio . . . It can sound terrible and not be, or the opposite. It can sound trivial and be horrible. And you get an incomplete picture without . . . an observer to fill in gaps . . . What you have is something that could be misconstrued. People are concerned about many things – that real information can be misconstrued, that artifacts and abnormal information can get interpreted as truth, and that truth gets blown out of proportion. So it can be on all those kinds of levels.

There was much discussion of the legal implications of recording video within the operating room. These concerns are valid; recent court cases show that doctors and hospitals can and do lose cases because of interpretation (or misinterpretation) of the audio portion of video recordings. (The visuals on these videotapes of course show the operation itself, e.g., some portion of the patient's brain or spine, and attorneys do not attempt to interpret these images in court). The hospital has been recording videotapes of operations for years, and the tapes go into a library maintained by the neurosurgery department. What drastically changes in the new situation with remote multimedia is that anyone at a remote node can record an operation (with the current low level of security in the analog CATV system) so it is no longer at the discretion of the attending neurosurgeon.

We found these concerns – communication style, student impact, and malpractice suits – to be well-motivated and reasonable in light of the kind of work performed in the operating room. Other concerns seemed to us to be more an expression of resentment over the way the remote audio and video facilities were installed, without consultation or buy-in from nurses and anesthesiologists. While the neurophysiologists and neurosurgeons were in line to have the technology installed in their offices and conference areas so that they could remotely monitor several operations at once (neurosurgeons in an advisory role), the nurses and anesthesiologists were not. So they felt that not only did the technology not benefit them, it was to be used at their expense, and without their agreement. There were also issues concerning the manner in which the technology was introduced (see Grudin, 1988). While those installing the system felt that they had informed the nurses and anesthesiologists, the nurses and anesthesiologists felt they had not. It is impossible to unravel the exact train of events now, but what is interesting is that some of the arguments advanced by the nurses and anesthesiologists against the multimedia technology seemed to stem from ill will aroused by their perception that they were being left out of the process.

We found that those in favor of *vs* those against the multimedia system (in its current configuration) were divided pretty neatly along professional lines. The nurses and anesthesiologists were against; the neurophysiologists and neurosurgeons for. The neurotechnicians who are closely allied with the neurophysiologists expressed some mild annoyance over the broadcast facilities in private interviews, but on the whole supported the technology. Some spoke out in favor of it in informal exchanges with the study team.

In the case of the nurses, because of the nature of their jobs, they do not stand to benefit from the remote broadcast facilities. They are at the lower end of the status hierarchy in the operating room, thus they perhaps feel most threatened by the possibilities of the system. It was the nurses who worried about the multimedia system (or a future version) being used in a "Big Brother" capacity to monitor their job performance.

The anesthesiologists were an interesting case because they would like to have remote facilities for monitoring physiological responses, but they were not as far along in a separate development effort to create such a system, and they did not stand to gain directly from the current system. We noticed that they seemed to accept the utility of the technology, even though complaining about legal dangers and other issues, and they offered ideas for privacy safeguards (which we discuss in a moment).

Another argument that we heard against the use of the remote broadcast was that it would invade the patient's privacy. However, patients essentially sign away all of their rights to privacy in this setting so this concern seemed somewhat manufactured. Individual doctors may go to great lengths to assure patient privacy, but legally, consent forms that patients sign remove rights. The recording of the video which has been going on for years in the operating room reduces patient privacy, yet patient privacy did not become an issue until the installation of the remote facilities.

We elaborate on the delicate political issues of these incidents not to dismiss the nurses' and anesthesiologists' complaints as politically motivated, but rather to suggest some possible remedies for future systems. We believe that the way the multimedia system was introduced in the hospital was less than optimal in two ways. First, it did not contain simple privacy safeguards such as an indicator showing when the video was being recorded. Second, and more important in our estimation, a serious, systematic, and thorough effort to inform staff of the benefits and features of the technology was not made. Many team members were genuinely puzzled about the utility of the remote audio broadcast. There was confusion about when the remote facilities were active, who might be listening at a remote node, when a recording would be made, whether both audio and video were recorded, and when new facilities would be installed and what they would be. Some of the nurses were not aware that their voices had been recorded on the videotape within the operating room as the tapes had been made over the years. The installation of the new multimedia system significantly raised awareness of, and concern over, not only the new system itself, but media capabilities that been in the hospital for some time.

In addition to the installed multimedia system, the neurosurgeons were considering the use of a wide angle or "environmental" camera that would show the operating room itself and the staff as they worked. This bit of knowledge came out as gossip, not a formal statement to the staff. At the meeting on privacy issues it was stated that, "No one assumed an environmental camera would be a problem." The rationale for a wide angle camera was given, vaguely, as "understanding the gestalt of the case." But an environmental camera is easily seen by almost any worker as a potential threat and the idea of installing a camera with the ability to watch and record people as they work is clearly one that needs to be openly discussed. The offhand rationale invoking the "gestalt of the case" failed to explain the potential value of a wide angle camera; rather, such a rationale suggested that staff input into decisions about the use of such cameras was not valued.

Of course to a large extent we are looking at this problem with 20/20 hindsight and we see in retrospect that privacy concerns might be an issue with recorded and broadcast multimedia. But we present this case in detail because we believe we can learn from this experience for future projects. Thus we recommend that collaborative multimedia projects instigate some form of participatory design (Muller, 1993) in which those who are to be affected by the technology are systematically informed of, and contribute to, the design of relevant parts of the technology. Through a series of careful interventions with a skilled facilitator, those affected by a technology learn about, and to some extent help to design the technology. Indeed, we saw this very process happen informally in the privacy meeting. Several suggestions for privacy safeguards were offered, such as a light showing when an operation is being recorded and an "on-air" light showing when the remote audio is being broadcast. It was suggested that the lights be placed not only in the operating room itself, but in the two hallways which have entrances into the operating room, so that people could mentally prepare themselves before entering the operating room. This is the kind of suggestion that can make a big difference to the success of a project, and which can only come from knowing the details of a particular situation, such as the layout of the operating room and the need to be prepared before beginning demanding work. This kind of site- and task-specific information is what participatory design techniques are good at discovering. In addition, through the process of negotiating the design of a system people come to understand it more fully and feel less threatened by it. Participatory design allows concerns to be taken into account *before* they lead to the kind of tense situation we encountered in the hospital. An important lesson from our research is that for inherently social technologies such as collaborative multimedia systems, social and technical solutions must play together to utilize technology to its best advantage (see also Nardi, 1993).

There are other technical privacy safeguards that can be built into collaborative multimedia systems. In particular, it will be valuable for people to know which remote nodes are active at a particular time so that they will have some sense of who may be viewing or listening. This is an inexact solution, but certainly preferable to having no idea at all of who is part of the current context. A unidirectional microphone picking up only the surgeon's comments might also be appropriate. This solution does lose some data of interest to neurophysiologists, i.e., picking up on the general atmosphere in the operating room and the sounds of the machinery, but it affords more privacy to the rest of the operating room staff. Such a trade-off might be appropriate in some situations. Alternatively, audio could be accessed via specific nodes for which access would be controlled by passwords or other security measures.

We have noted that reactions to the multimedia system split out along professional lines. There was an important exception: one of the neurosurgeons expressed grave concerns about the technology. The neurosurgeon felt that its utility had not been justified while its legal ramifications were extremely serious. Like the anesthesiologists and nurses, he felt strongly that the technology had not been explained or introduced formally or appropriately. He expressed a sense of a loss of control because of the ability of those at remote nodes to record an operation without a neurosurgeon's authorization. He suggested the implementation of security measures such as passwords and locks on equipment at remote nodes. While these solutions might seem obvious to computer experts, in the situation in which the system was being developed in the hospital it was not thought necessary to include such safeguards in the early phases of the project, even those as simple as "on-air" lights. Participatory design efforts might have channeled development energy into the security issues from the outset, showing good faith effort and allaying at least some concerns.

Because the audio portion of the multimedia system in the hospital was implicated much more than the video in notions of "public" and "private" during an operation, social solutions to privacy problems which allocate "public" and "private" times for audio broadcast and recording during an operation might be of use. (In another setting the video might be treated similarly.) In the hospital there seemed to be a fairly consistent view that certain phases of the operation – the critical phases – were appropriate for gathering and distributing audio information. Informal, personal conversation would not be taking place at these times and the spoken words of those in the operating room might be important for patient care. For example, a nurse-anesthetist observed,

> **Nurse-Anesthetist:** Anything that is directly related to the patient would be helpful. [Patient information is] more likely to be helpful to [the neurophysiologist] than us talking about, is it raining outside now? Or, what did they have for lunch today? Those kinds of things have very little to do with patient care whatsoever. What the surgeon is saying, what the neurophysiology technician is recording, seeing, and how he is communicating that to the surgeon, and how I am in between those two, and what dialogue takes place pertaining to a specific neurophysiological [event] – those things are pertinent and those things could be recorded without infringing upon anyone's rights.

These critical stages in the operation might well be viewed as *public* stages where all information was open to inspection and broadcast. Times before and after the critical stages in the operation, where personal conversation might take place, could be viewed as *private* times during which it would be appropriate to restrict distribution of audio information. It is possible that the agreement on conventions concerning public and private stages of the operation might be as effective as technologically-based solutions to privacy concerns. Again, participatory design techniques exist which can help people to sort through such issues (Muller, 1993).

We must also face the fact that collaborative multimedia systems will in many cases reduce privacy and change the nature of communication. The possibility of being remotely monitored at all times while you are at your job is indeed a very serious one. It is unavoidable that we must accept the disadvantages as well as the advantages of the technology, if we choose to use it. People should understand that choices are being made; the use of any given technology is not inevitable. Through the application of participatory design techniques we hope that people can arrive at collective solutions with which the majority feels comfortable.

9. Summary

We have described the use of *video-as-data* in a collaborative multimedia application. The promise of this approach is indicated by the application we studied in which the video image of a shared workspace served multiple but distinct functions in supporting complex teamwork. Many other activities, such as concurrent engineering and design which require distributed teams to coordinate, modify, and manipulate complex work objects, are likely candidates for the continued use of video-as-data. Future work should identify and refine these different applications of video-as-data.

Once we begin to view video as data, new analytic and display tools are required. We need techniques to directly manipulate video, in order to change the state of remote real world objects(Tani *et al.*, 1992). We also need techniques for annotating, indexing and manipulating multiple streams of synchronized data. We can use these tools in educational settings to explain and depict relations between complex variables represented in different media streams and in research settings to analyze and discover underlying causal relations between variables.

Our study results suggest that we should broaden our view of audio beyond the simple transmission of verbal communications. In contrast to previous claims about the functions of audio vs video (Short *et al.*, 1976), we found that remote audio was often used to judge the emotional state of the operating team, and video to supply hard data about the surgeon's actions and current state of the patient. We also found that provision of the video image often obviated the need for verbal interpersonal communication. Ambient audio proved of value in affording both local and remote team members access to gross aspects of patient functioning, such as heart rate, without having to read instruments directly. Thus audio is a rich and varied communication medium whose potential goes far beyond simply carrying words.

Finally, care must be taken to preserve privacy in settings where audio, video, and data from real work settings are broadcast to remote locations or recorded for future analysis. Study participants were concerned about the possibility of their work activity being broadcast to unseen and unknown observers. Fear of eavesdropping and/or unwished-for video recording may reduce the effectiveness of a collaborative multimedia system, impair interpersonal communication, and increase stress levels in the workplace. Steps should be taken to provide staff with feedback about precisely which data are being recorded or broadcast, when data are recorded or broadcast, and who is viewing or recording the data. The system should have appropriate security controlling who can view, listen to, or record data from, remote nodes. Our experience indicated the potential value of the use of participatory design techniques for the development and installation of collaborative multimedia systems. The use of such techniques can serve to reduce participants' fears that they are being inappropriately observed and evaluated, and also to solicit their suggestions about how to better design such systems.

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