24 Collaboration Technologies

Gary M. Olson and Judith S. Olson

CONTENTS

24.1 INTRODUCTION

Computing and communication technologies have provided us with useful and powerful information resources, remote instruments, and tools for interacting with each other. These possibilities have also led to numerous social and organizational effects. These tools are of course just the latest in a long line of modern technologies that have changed human experience. Television and radio long ago broadened our awareness of and interest in activities all over the world. The telegraph and telephone enabled new forms of organization to emerge. The new technologies of computer-supported cooperative work (CSCW) are giving us greater geographical and temporal flexibility in carrying out our activities. They have also given us new modes of socializing.

In this chapter, we will review software designed to run over a network in support of the activities of a group or organization. These activities can occupy any of several combinations of same/different places and same/different times. Software has been designed for all four of these combinations. Early applications tended to focus on only one of these cells, but more recently, software that supports several cells and the transitions among them has emerged. These technologies support collaborative activities at many levels of social aggregation. Both the individual members of groups and the organizations in which they are embedded affect and are affected by collaborative technologies.

A brief note on terminology: in the several decades since networked computing made possible the kinds of software functions we review in this chapter, terms have changed. It was quite popular in the 1990s, for example, to refer to such software as "groupware." However, as Grudin and Poltrock (2011) point out in their excellent historical review of trends in CSCW, this term has largely been supplanted by terms more neutral as to the level of social aggregation involved. Hence, in this chapter we will use the term collaboration technology. All of the technologies we review have some bearing on how people collaborate with each other. And, again as Grudin and Poltrock point out, the field has moved beyond the focus on work only (see also Crabtree, Rodden, and Benford [2005]), though in some quarters this has been lamented (Schmidt [2010] sets forth the view that the focus on work is significant enough to merit an undiluted field of study).

CSCW emerged as a formal field of study in the mid-1980s, with conferences, journals, books, and university courses appearing that used this name. There were a number of important antecedents. The earliest efforts to create groupware used time-shared systems but were closely linked to the development of key ideas that propelled the personal computer revolution. Bush (1945) described a vision of something similar to today's World Wide Web in an influential essay published shortly after the end of World War II. Doug Engelbart's famous demonstration at the 1968 International Federation of Information Processing Societies meeting in San Francisco included a number of key groupware components (see Engelbart and English [1968]). These components included support for real-time face-to-face (FTF) meetings, audio and video conferencing, discussion databases, information repositories, and workflow support. Group decision-support systems and computer-supported meeting rooms were explored in a number of business schools (see McLeod [1992]; Kraemer and Pinsonneault [1990]). Work on office automation included many groupware elements, such as group workflow management, calendaring, e-mail, and document sharing (Ellis and Nutt 1980). A good summary of early historical trends as well as reprints of key early articles appear in three early anthologies: Greif (1988), Marca and Bock (1992), and Baecker (1993).

Today, there are a large number of commercial collaboration products. In addition, collaboration functions are now appearing as options in operating systems or specific applications (e.g., Windows, Mac, and Linux operating systems, suites of tools by Microsoft, Google, Yahoo!, and many others). Collaborative functionality has become widespread and familiar. However, there are still many research issues about how to design such systems and what effects they have on the individuals, groups, and organizations that use them.

Let us clarify what this chapter is about. It is not a general review of the field of CSCW—that would be an enormously larger task than we can take on here. Rather, we are going to focus on the kinds of collaborative applications that have emerged and achieved wide adoption. We will describe their characteristics, in terms of what functions they serve, and we will mention *some* of the studies done to evaluate them. These studies are a mix of controlled laboratory studies and studies of the technologies in real organizations. For many of the technologies we review, entire chapters could be written about the work that has been done with them. So we will, of necessity, have to be selective in our coverage. Our goal is to be *representative*, not exhaustive.

24.2 ADOPTING GROUPWARE IN CONTEXT

Collaborative systems are often intended to support groups, which are usually embedded in an organization. As a result, there are a number of issues that bear on the success of such systems. In a justly famous set of papers, Grudin (1988, 1994) pointed out a number of problems that such systems have (see also Markus and Connolly [1990]). In brief, he pointed out that developers of such systems need to be concerned with the following issues (Grudin 1994, p. 97; we here use the groupware terminology that he used in these original articles):

1. Disparity in work and benefit. Groupware applications often require additional work from individuals who do not perceive a direct benefit from the use of the application.
2. Critical mass and Prisoner's dilemma problems. Groupware may not enlist the "critical mass" of users required to be useful, or can fail because it is never in any one individual's advantage to use it.
3. Disruption of social processes. Groupware can lead to activity that violates social taboos, threatens existing political structures, or otherwise de-motivates users crucial to its success.
4. Exception handling. Groupware may not accommodate the wide range of exception handling and improvisation that characterizes much group activity.
5. Unobtrusive accessibility. Features that support group processes are used relatively infrequently, requiring unobtrusive accessibility and integration with more heavily used features.
6. Difficulty of evaluation. The almost insurmountable obstacles to meaningful, generalizable analysis and evaluation of groupware prevent us from learning from experience.
7. Failure of intuition. Intuitions in product development environments are especially poor for multiuser applications, resulting in bad management decisions and error-prone design processes.
8. The adoption process. Groupware requires more careful implementation (introduction) in the workplace than product developers have confronted.

There are reasons, however, for optimism. One specific example is Palen and Grudin's (2002) follow-up study of the adoption of group calendars. They found that organizational conditions in the 1990s were much more favorable for the adoption of group tools than they were in the 1980s. Further, the tools themselves had improved in reliability, functionality, and usability. There is increased "collaboration readiness" and "collaboration technology readiness" (Olson and Olson 2000) that has made for increased success of such applications. Indeed, the very rapid take-up of technologies like Wikipedia, Facebook, Twitter, and multiplayer games (and many other examples) is testament to the changed circumstances in current times. Certainly items 5 and 6 in Grudin's list are not as much of a challenge at present. But many of the others persist as serious challenges.

24.3 TECHNICAL INFRASTRUCTURE

Collaborative technology requires networks, and network infrastructure is a key enabler as well as a constraint on such systems. High-quality broadband networking has emerged across most parts of the developed world. Good access to the Internet is now common in many places other than the office, such as homes, hotels, coffee shops, airports, and even in many open spaces like parks. It is also the case that networking infrastructure is spreading throughout the world. However, heterogeneity in network conditions remains a major technical challenge. For instance, doing web conferencing when some participants are on slow dial-up lines and others are on fast advanced networks requires special coordination. Some good resources on the latest developments in networking are Comer (2008) and Kurose and Ross (2009).

The World Wide Web and its associated tools and standards have had a major impact on the possibilities for collaboration (Schatz and Hardin 1994; Berners-Lee 1999). Early collaboration technologies mostly consisted of standalone applications that had to be downloaded and run on each client machine. Increasingly, collaborative tools are written for the web, requiring only a web browser and perhaps some plug-ins. This makes it much easier for the user and also helps with matters such as version control. It also enables better interoperability across hardware and operating systems. The emergence of Web 2.0 has helped create a plethora of interesting applications in a wide variety of areas. For example, many conferencing tools are now accessed through a web browser. See Bell (2009) and Campasoto and Nilson (2011) for a variety of examples and details.

Another major technical advancement has been the explosion of collaborative functions on mobile devices. Laptops, personal digital assistants, wearables, pads, and cell phones provide access to information and people from almost anywhere. More and more applications are being written to operate across these diverse environments (e.g., Tang et al. 2001; Starner and Rhodes 2004; Wiltse and Nichols 2009; Gunaratne and Brush 2010). These devices vary in computational power, display size and characteristics, network bandwidth, and connection reliability, providing interesting technical challenges to make them all interoperate smoothly. For instance, accessing websites from a cell phone requires special user interface methods to make the tiny displays usable (Jones and Marsden 2006). More information about these advances is available in Ling and Donner (2009), and an interesting analysis of the implications of these advances in mobile communication is in Rheingold (2002).

Security on the Internet continues to be a major challenge for collaboration technologies. In some sense, the design of Internet protocols are to blame, since the Internet grew up in a culture of openness and sharing (Longstaff et al. 1997; Abbate 1999; Tanenbaum 2011). E-commerce and sensitive application domains like medicine have been a driver for advances in security, but there is still much progress to be made (Longstaff et al. 1997; Camp 2000). Coping with firewalls that block access to certain organizations can limit the flexibility of web conferencing. A good recent discussion of these issues is in Wong and Yeung (2009).

Additional flexibility is being provided by the development of infrastructure that lies between the network itself and the applications that run on client workstations, called "middleware." This infrastructure makes it easier to link together diverse resources to accomplish collaborative goals. For instance, the emerging Grid technologies allow the marshalling of powerful, scattered computational resources (Foster and Kesselman 2004). Middleware provides such services as identification, authentication, authorization, directories, and security in uniform ways that facilitate the interoperability of diverse applications. All of these technical elements are components of cyber infrastructure (Atkins et al. 2003). There is considerable interest in the development of this infrastructure because of its large impact on research, education, and commerce.

24.3.1 Communication Tools

We now turn to a review of specific kinds of collaboration technologies, highlighting their various properties and uses. We have grouped this review under several broad headings. We do not aim to be exhaustive, but rather seek to illustrate the variety of kinds of tools that have emerged to support human collaborative activities over networked systems. We also highlight various research issues pertaining to these tools.

24.3.2 E-mail

E-mail has become a ubiquitous communication tool. The early adoption of standards made it possible for messages to be exchanged across networks and different base machines and software applications. E-mail is now also done from cell phones, personal digital assistants (PDAs), television sets, and kiosks in public sites. Documents of many types can be easily exchanged. Because of its widespread use, it has often been called the first successful collaboration technology (Sproull and Kiesler 1991; Satzinger and Olfman 1992; O'Hara-Devereaux and Johnson 1994; Anderson et al. 1995). Indeed, it has become so successful that e-mail overload has become a major problem (Whittaker and Sidner 1996). And of course, it has become a vector for viruses, worms, and other malware.

Researchers have shown that this widespread use has had a number of effects on how people behave. It has had large effects on communication in organizations: it changes the social network of who talks to whom (Sproull and Kiesler 1991; DeSanctis, et al. 1996), the power of people who formerly had little voice in decisions (Finholt, Sproull, and Kiesler 1990), and the tone of what is said and how it is interpreted (Sproull and Kiesler 1991). For example, with e-mail, people who were shy found a voice; they could overcome their reluctance to speak to other people by composing text, not speech to another face. This invisibility, however, also has a more general effect—without the social cues in the recipient's face being visible to the sender, people will "flame," send harsh or extremely emotive (usually negative) messages (Arrow et al. 1996; Hollingshead, McGrath, and O'Connor 1993).

As with a number of other "designed" technologies, people use e-mail for things other than the original intent. People use it for managing time, reminding them of things to do, and keeping track of steps in a workflow (Mackay 1989; Carley and Wendt 1991; Whittaker and Sidner 1996). But because e-mail was not designed to support these tasks, it does not do it very well; people struggle with reading signals about whether they have replied or not (and to whom it was cc'd); they manage folders poorly for reminding them to do things, and so forth.

In addition, because e-mail is so widespread, and it is easy and free to distribute a single message to many people, people experience information overload. Many people get hundreds of e-mail messages each day, many of them mere broadcasts of things for sale or events about to happen, much like "classifieds" in the newspaper. Several early efforts to use artificial intelligence techniques to block and/or sort incoming e-mail were tried, and this has continued to be a very active area of work (Malone et al. 1989; Winograd 1988). There are two broad classes of uses of e-mail filters. One use is to automatically sort incoming mail into useful categories. This is relatively easy for mail that has simple properties, such as a person's name. It is more difficult for subtle properties. The other major use is to weed out unwanted mail, such as spam. The state-of-the-art in spam filtering was in the range of 80%–90% effectiveness in 2005 (e.g., Federal Trade Commission 2005). Such filters are so good that many institutions automatically filter mail as it comes in to the organization's gateway, sparing users the need to do it in their own clients. Similarly, many clients now come with built-in spam filters that can be tuned by the user (e.g., Google's Gmail).

These problems have led to the "reinvention" of e-mail (Whittaker, Bellotti, and Moody 2005). For example, given that e-mail is often used in the context of managing projects, systems have been explored that have a more explicit scheme for task management (Whittaker 2005; Bellotti et al. 2005). To deal with problems of e-mail overload, new schemes for filtering e-mail have been explored, such as routing messages differently to different kinds of clients (e.g., cell phone vs. desktop machine; see Schmandt and Marti [2005]). Another approach has been to explore pricing mechanisms for e-mail that are analogous to pricing for regular mail (Kraut et al. 2005). In such schemes one would pay to send e-mail, with higher prices presumably indicating higher priority, analogous to the difference between first class postage and bulk rates. These schemes are exploratory, but are likely to result in new options in future e-mail clients.

Kraut et al. (1998) reported that greater Internet use, which in their sample was mostly e-mail, led to declines in social interactions with family members and an increase in depression and loneliness. Not surprising, these results triggered widespread discussion and debate, both over the substance of the results and the methods used to obtain them. Kraut, Gergle, and Fussell (2002) reported new results that suggested these initial negative effects may not persist. Interpersonal communication is one of the principal uses of the Internet, and the possible implications of this kind of communication for social life are important to understand (see reviews by Bargh and McKenna [2004] and Benkler [2006]). Indeed, Putnam (2000) has wondered whether the Internet can be a source of social cohesiveness. These kinds of questions need to be addressed by additional large-scale studies of the kind carried out by Kraut and his colleagues (see review by Resnick [2002]).

24.3.3 Conferencing Tools: Voice, Video, Text

There are many options available today for on-line conferencing among geographically dispersed members of a group. So-called computer-mediated communication (CMC) has become widespread. There are three principal modes of interaction, but each has numerous subtypes:

- Video + Audio
  - Full-scale video conferencing room; many options for specific design
  - Individual desktop video; many options for quality, interface
  - Conferencing options on mobile devices
- Audio
  - Phone conference
  - Voice over IP (Skype being a very popular application)
- Text
  - Instant messaging, chat, SMS on mobile phones

CMC was an early research focus for CSCW, and much of what we know dates from the early studies. To be sure, there have been some recent refinements of this literature, for which we will mention a few examples.

There are many studies that compare FTF with various forms of CMC. There are some clear generalizations from such work. The main one is that CMC is more difficult to do than FTF and requires more preparation and care (Hollingshead, McGrath, and O'Connor 1993; McLeod 1992; Olson, Olson, and Meader 1995; Siegel et al. 1986; Straus 1996, 1997; Straus and McGrath 1994). A variety of things that come for free in FTF are either difficult to support or outright missing in CMC (Kiesler and Cummings 2002). Backchannel communication, which is important for modulating conversation, is either weak or nonexistent in CMC, although it has become common to keep an instant messaging (IM) chat going during audio or video conferences (e.g., Kellogg et al. 2006). Paralinguistic cues that can soften communication are often missing. Participants in CMC tend to have an informational focus, which means there is usually less socializing, less small talk. Over time, this can lead to poorer social integration and organizational effectiveness (Nohria and Eccles 1992).

CMC often introduces delay. This is well known to be very disruptive to communication (Egido 1988; Krauss and Bricker 1966; O'Conaill, Whittaker, and Wilbur 1993; Ruhleder and Jordan 2001; Tang and Isaacs 1993). Participants will communicate less information, be more frustrated with the communication, and actually terminate communication sessions sooner. Delay can be managed, but it takes special care among the participants and turn-taking widgets in the interface of the tools being used. For instance, if there is delay, then full-duplex open communication will not work, since participants will step all over each other's communication. Either the participants must use a social protocol (e.g., like that used in radio communications with spacecraft), or they must employ a mike-passing procedure with interface indications of who wants to talk next.

Although it might seem desirable to always have the maximum communication and tool support possible, it is not always possible or even necessary to do so. Research shows that effective real-time collaboration can take place under a number of different arrangements, depending on the task, the characteristics of the participants, the specific geographical dispersion of the participants, and the processes employed to manage the interactions. There are also organizational effects, especially when the real-time collaborations are embedded in ongoing activities, as they almost always are.

For instance, early work (Williams 1977) showed that, in referential communication tasks, full-duplex audio is just as effective as FTF. Subsequent research comparing audio and video conferencing (see summaries in Finn, Sellen, and Wilbur [1997]; Cadiz et al. [2000] found similar results for a tutored video-instruction task) showed that for many tasks audio is sufficient and that video adds nothing to task effectiveness, though participants usually report they are more satisfied with video. There are important exceptions, however. Negotiation tasks are more effective with video (Short, Williams, and Christie 1976). This is probably because the more subtle visual cues to the participants' intentions are important in this kind of task. Further, Veinott et al. (1999) found that when participants have less common ground, video helps. In their case, participants were nonnative speakers of English who were doing the task in English. For native speakers, video was no better than audio, but nonnative speakers did better when they had video. Again, visual cues to comprehension and meaning likely played an important role. Recently, an experimental study by Daly-Jones, Monk, and Watts (1998) showed that high-quality video resulted in greater conversational fluency over just high-quality audio, especially as group size increased. There was also a higher rated sense of presence in the video conditions.

An important lesson to draw from this literature is that there are two broad classes by which we might assess whether video is important in real-time collaboration. On the one hand, except for tasks like negotiation or achieving common ground, groups are able to get their work done effectively with high-quality audio. However, for things like satisfaction, conversational fluency, and a sense of presence, video adds value. These kinds of factors might be very important for long-term organizational consequences like employee satisfaction. As of yet, no long-term studies have been done to examine this conjecture.

Audio quality is critical. Ever since early literature review (Egido 1988), it has been reported over and over again that if the audio is of poor quality participants will develop a workaround. For instance, if the audio in a video conferencing system or in a web conferencing system is poor quality, participants will turn to a phone conference.

The social ergonomics of audio and video are also keys to their success. Many of the failures of audio conferencing, especially over the Internet, result from poor-quality microphones, poor microphone placement, poor speakers, and interfering noises like air conditioning. Getting these details right is essential. Similarly, for video, camera placement can matter a lot. For instance, Huang, Olson, and Olson (2002) found that a camera angle that makes a person seem tall (as opposed to actually being tall) affects how influential a person is in a negotiation task. Apparent height matters a lot. Other aspects of camera placement or arrangement of video displays make a big difference as well but are not well known.

An exception is eye contact or gaze awareness, where studies of FTF communication show that these are key linguistic and social mediators of communication (Argyle and Cook 1976; Kendon 1967). It is very difficult to achieve eye contact in CMC systems. Many attempts have been made (Gale and Monk 2000; Grayson and Monk 2003; Monk and Gale 2002; Okada et al. 1994; Vertegaal 1999; Vertegaal et al. 2001), and at least the subjective reports are that these can be effective. But these all require special equipment or setups. And they do not scale very well to multiparty sessions. A recent study by Nguyen and Canny (2007) showed that a relatively simple and inexpensive setup that supports gaze awareness (being able to tell who is looking at whom) had a clear effect on a task that assessed the formation of interpersonal trust.

While for most situations having at least high-quality audio is essential, there are some special cases where a text-based channel, like chat or instant messaging, can work fine. For instance, in the Upper Atmospheric Research Collaboratory (UARC, later known as the "Space Physics and Aeronomy Research Collaboratory" or SPARC), a chat system worked very well for carrying out geographically distributed observational campaigns, since the flow of events in these campaigns were relatively slow (campaigns went on for several days, key events would take many minutes to unfold). McDaniel, Olson, and Magee (1996) compared chat logs with earlier FTF conversations at a remote site and found many elements of them very similar, including informal socializing. But this kind of ongoing scientific campaign is very unlike the interactions that take place in a typical meeting.

Instant messaging is a new communication modality that is making substantial inroads into organizations. Muller et al. (2003) found in a survey study of three organizations that the introduction of instant messaging led to significantly less use of such communication channels as e-mail, voice-mail, telephone, teleconference, pager, and FTF. They also found that instant messaging was used for "substantive business purposes." Furthermore, in one of the organizations where they surveyed users after 24 months of usage they found that the substantive reasons for using IM increased. In a study of IM logs in an organization, Isaacs et al. (2002) found that a large proportion of IM conversations involved "complex work discussions." They found that IM users seldom switched to another communication channel once they were engaged in

IM. Nardi, Whittaker, and Bradner (2000) observed in a field study that workers used IM for a variety of purposes, not just for information exchange. Such matters as quick questions, scheduling, organizing social interactions, and keeping in touch with others were common uses of IM. Thus, IM has emerged as a significant communication medium in the workplace and is used even when other, richer communication channels were available.

Although IM is a relatively new phenomenon in the workplace, it is clearly established as a useful and widely used tool outside the workplace. This will undoubtedly assist in the development of more sophisticated versions of the tool, as well as its integration into on-line conferencing systems. There is clearly much promise here. We have noticed, for example, that during online conferences IM or chat serves as a backchannel for side conversations or debugging, an extremely useful adjunct to the core audio or video communication taking place in such conferences.

The other key feature of successful remote meetings is the ability to share the objects they are talking about, such as the agenda, the to-do list, the latest draft of a proposal, a view of an object to be repaired, and so on. Many researchers (Fussell, Kraut, and Siegel 2000; Karsenty 1999; Kraut, Fussell, and Siegel 2003; Kraut et al. 2002; Luff et al. 2003; Nardi et al. 1993; Whittaker, Geelhoed, and Robinson 1993) have provided experimental evidence of the value of a shared workspace for synchronous audio-supported collaboration. More traditional video conferencing technologies often offer an "object camera," onto which the participants can put a paper agenda, Powerpoint slides, or a manufactured part. More generally, any form of video can also be used to share work objects (Fussell, Kraut, and Siegel 2000; Nardi et al. 1993). For digital objects, there are now a number of products that will allow meeting participants to share the screen or, in some cases, the remote operation of an application. Some companies are using electronic whiteboards, both in a collocated meeting and in remote meetings to mimic the choreography of people using a physical whiteboard. In some "collaboratories," scientists can even operate remote physical instruments from a distance and jointly discuss the results.

There are a growing number of studies that have looked at cultural issues in CMC. For example, Setlock, Fussell, and Neuwirth (2004) studied the differences in conversational content between Chinese and American pairs while engaged in a decision-making task, either in a FTF situation or using instant messaging, and found a series of differences in how they conversed. On the basis of analyses of agreement and efficiency, along with some specific text analyses, they characterized pairs of Americans as viewing the task as one of working out a mutually acceptable joint rating, whereas the Chinese pairs worked to reach agreement on the relative worth of the specific items to be rated. Fussell and her colleagues have carried out a series of studies comparing CMC behaviors across Asian and American cultures (e.g., Diamant, Fussell, and Lo 2009; Wang, Fussell, and Setlock 2009). A recent review of work on multicultural teams is by Connaughton and Shuffler (2007). The emergence of a new conference series on Intercultural Collaboration (e.g., International Conference on Intercultural Collaboration or ICIC 2010) provides a focused venue for work like this.

24.3.4 Blogs

Weblogs, or more commonly called "blogs," have burst upon the Internet scene in recent years. Blogging software that makes it easy to put up multimedia content has led people to set up sites for all manner of purposes. A site can contain text, pictures, movies, and audio clips. A common social purpose is to keep an on-line diary. Another is to provide commentary on a topic of interest. For instance, blogs played a major role in the 2004 election (Adamic and Glance 2005). Nardi et al. (2004) studied why people blog, as it is sometimes puzzling that people would essentially share personal or private information about themselves through the web. Blogging has emerged as a major research topic in this area, and the literature is growing apace.

A special topic related to blogging is the emergence of microblogging, best instantiated by Twitter. Twitter limits contributions to 140 characters, so of necessity "tweets," as they are called, are concise. Yet Twitter has emerged as a major social phenomenon, and of course is also receiving significant scholarly attention. A couple of recent examples of such studies include Huberman, Romero, and Wu (2009) and Zhao and Rosson (2009).

24.3.5 Disaster Response

Within the past decade the kinds of CMC tools we have been reviewing have emerged as major resources for dealing with disasters. There are now a number of studies of these phenomena. For example, Vieweg et al. (2010) studied the use of Twitter in two natural emergencies, the 2009 grass fires in Oklahoma and the 2009 flooding of the Red River. They found that the use of Twitter made major contributions to situational awareness in both cases. Palen et al. (2009) studied the role of CMC in the 2007 mass shooting at Virginia Tech. Mark, Al-Ani, and Semaan (2009) looked at the role of CMC in maintaining resilience in a war zone, particularly Iraq. Schafer, Ganoe, and Carroll (2007) looked at emergency management planning in a community, focusing on what kind of software architecture would support the kinds of needs faced there. These examples are just the tip of the iceberg of recent work in the area, all of which is showing that the wide variety of collaboration technologies now available can have a substantial impact on the handling of emergencies.

24.4 COORDINATION SUPPORT

24.4.1 Meeting Support

An early and popular topic in CSCW was the support of FTF meetings. A number of systems were developed and tested. While of late the focus has shifted to the support of geographically distributed meetings, the early work on meeting support led to some important and useful conclusions.

Some meeting-support software imposed structure on the process of the meeting, embodying various brainstorming and voting procedures. Group decision-support systems (GDSSs) arose from a number of business schools, focusing on large meetings of stakeholders' intent on going through a set series of decisions, such as prioritizing projects for future funding (Nunamaker et al. 1991). With the help of a facilitator and some technical support, the group was led through a series of stages: brainstorming without evaluating, evaluating alternatives from a variety of positions, prioritizing alternatives, and so on. These meetings were held in specialized rooms in which individual computers were embedded in the tables, networked to central services, and summary displays shown "center stage." A typical scenario involved individuals silently entering ideas into a central repository, and after a certain amount of time, they were shown ideas one at a time from others and asked to respond with a new idea triggered by that one. Later, these same ideas were presented to the individuals who were then asked to rank or rate them according to some fixed criterion, like cost. Aggregates of individuals' opinions were computed, discussed further and presented for vote. The system applied computational power (for voting and rating mechanisms), and networking control (for parallel input) to support typically weak aspects of meetings. These systems were intended to gather more ideas from participants, since one did not have to wait for another to stop speaking in order to get a turn. And, anonymous voting and rating was intended to insure equal participation, not dominated by those in power.

Evaluations of these GDSSs have been reviewed producing some generalizations about their value (McLeod 1992; Kraemer and Pinsoneault 1990; Hollingshead, McGrath, and O'Connor 1993). The systems indeed fulfill their intentions of producing more ideas in brainstorming and having more evaluative comments because of anonymity. Decisions are rated as higher in quality, but the meetings take longer and the participants are less satisfied than those in traditional meetings.

A second class of technologies to support real-time meetings is less structured, more similar to individual workstation support. In these systems, groups are allowed access to a single document or drawing, and can enter and edit into them simultaneously at will. Different systems enforce different "locking" mechanisms (e.g., paragraph or selection locking) so that one person does not enter while another deletes the same thing (Ellis, Gibbs, and Rein 1991). Some also allow parallel individual work, where participants view and edit different parts of the same document, but can also view and discuss the same part as well. This kind of unstructured shared editor has been shown to be very effective for certain kinds of free-flowing meetings, like design or requirements meetings (Olson et al. 1993). The rated quality of the meeting products (e.g., a requirements document or plan) was higher when using these technologies than with traditional whiteboard or paper-and-pencil support, but like working in GDSSs, people were slightly less satisfied. The lower satisfaction here and with GDSSs may reflect the newness of the technologies; people may not have yet learned how to persuade, negotiate, or influence each other in comfortable ways, to harness the powers inherent in the new technologies.

These new technologies did indeed change the way in which people worked. They talked less and wrote more, building on each other's ideas instead of generating far-reaching other ideas. The tool seemed to focus the groups on the core ideas, and keep them from going off on tangents. Many participants reported really liking doing work in the meetings rather than spending time only talking about the work (Olson et al. 1993).

A third class of meeting room support appears in electronic whiteboards. For example, the LiveBoard (Elrod et al. 1992), SoftBoard and SmartBoard are rear projection surfaces that allow pen input, much the way a whiteboard or flip chart does. People at Xerox PARC (Palo Alto Research Center Incorporated) and Boeing have evaluated the use of these boards in meetings in extended case studies. In both cases, the board was highly valued because of its computational power and the fact that all could see the changes as they were made. At both sites, successful use required a facilitator who was familiar with the applications running to support the meeting. At Xerox, suggestions made in the meeting about additional functionality were built into the system so that it eventually was finely tuned support for their particular needs (Moran et al. 1996). For example, they did a lot of list making of freehand text items. Eventually, the board software recognized the nature of a list and an outline, with simple gestures changing things sensibly. For example, if a freehand text item was moved higher in a list, the other items adjusted their positions to make room for it. The end product was not only a set of useful meeting tools, but also a toolkit to allow people to build new meeting widgets to support their particular tasks.

As technological developments have enabled the creation of large, affordable displays, research has picked up on the utility of large displays for small team collaboration. An obvious application of large displays is for complex, high-resolution data, such as maps, medical images, and a variety of complex scientific visualizations. There are of course interesting issues in dealing with such large displays, such as how to navigate them when they are extraordinarily rich in detailed information (Ball, North, and Bowman 2007), how to distribute control among users (e.g., single selection device vs. one per person; see Birnholtz et al. [2007]), and how to deal with sensitive or private information, as in the context of shift changes in a hospital (Wilson, Galliers, and Fone 2006). Robertson et al. (2005) have a good discussion of the many usability issues that arise with large displays. There is a large and growing literature on this topic.

Tabletop displays constitute another way of presenting lots of information for collaborators. This too is a rapidly growing area of research that we do not have space to cover in any detail. But some recent, representative studies that would help one get into the literature include Isenberg et al. (2010), Morris, Lombardo, and Wigdor (2010), Hartmann et al. (2009) and Tang et al. (2006).

Meetings are important, though often despised, organizational activities. Research of the kind just reviewed has shown quite clearly that well-designed tools can improve both work outcomes and participant satisfaction. However, meetings in organizations seldom use such tools. Inexpensive mobile computing and projection equipment combined with many commercial products mean that such tools are within reach of most organizations. But not having these elements readily available in an integrated way probably inhibits their widespread adoption.

While traditional meetings are often viewed as wasteful and frustrating, there can be huge benefits to working together in collocated environments. Kiesler and Cummings (2002) reviewed a number of the characteristics of physical collocation that can benefit performance. In a detailed study of one such situation, Teasley et al. (2002) found that "radical collocation," in which software development teams worked together in a dedicated project room for many weeks, dramatically improved their productivity. Reasons for this included the constant awareness of each other's work status, the associated ability to instantly work on an impasse as a group, and the availability of rich shared artifacts generated by the project.

24.4.2 Workflow

Workflow systems lend technology support to coordinated asynchronous (usually sequential) steps of activities among team members working on a particular task. For example, a workflow system might route a travel reimbursement voucher from the traveler to the approving party to the accounts payable to the bank. The electronic form would be edited and sent to the various parties, their individual to-do-lists updated as they received and/or completed the tasks, and permissions and approval granted automatically as appropriate (e.g., allowing small charges to an account if the charges had been budgeted previously or simply if there was enough money in the account). Not only is the transaction flow supported, but also records are often kept about who did what and when they did it. It is this later feature that has potentially large consequences for the people involved, discussed in the last paragraph in this section.

These workflow systems were often the result of work reengineering efforts, focusing on making the task take less time and to eliminate the work that could be automated. Not only do workflow systems therefore have a bad reputation in that they often are part of workforce reduction plans, but also for those left, their work is able to be monitored much more closely. The systems are often very rigid, requiring, for example, all of a form to be filled in before it can be handed off to the next in the chain. They often require a great deal of rework because of this inflexibility. It is because of the inflexibility and the potential monitoring that the systems fall into disuse (e.g., Abbott and Sarin 1994). However, Grinter (2000) examined several cases of successful deployment of workflow systems, and drew some helpful conclusions about what is required for these to work. Klein, Dellarocas, and Bernstein (2000) introduced a special double issue of *Computer Supported Cooperative Work* on adaptive workflow systems that deal with some of the exception-handling that can be such an important feature for success.

The fact that workflow can be monitored is a major source of user resistance. In Europe, such monitoring is illegal, and powerful groups of organized workers have made sure that such capabilities are not in workflow systems (Prinz and Kovenbach 1996). In the United States, it is not illegal, but many employees complain about its inappropriate use. For example, in one software engineering team where workflow had just been introduced to track bug reports and fixes, people in the chain were sloppy about noting who they had handed a piece of work off to. When it was discovered that the manager had been monitoring the timing of the handoffs to assign praise or blame, the team members were justifiably upset (Olson and Teasley 1996). In general, managerial monitoring is a feature that is not well received by people being monitored (Markus 1983). If such monitoring is mandated, workers' behavior will conform to the specifics of what is being monitored (e.g., time to pass an item off to the next in the chain) rather than perhaps to what the real goal is (e.g., quality as well as timely completion of the whole process).

24.4.3 Group Calendars

A number of organizations have now adopted online calendars, mainly in order to view people's schedules to arrange meetings. The calendars also allow a form of awareness, allowing people to see if a person who is not present is expected back soon. Individuals benefit only insofar as they offload scheduling meetings to others, like to an administrative assistant, who can write as well as read the calendar. And, in some systems the individual can schedule private time, blocking the time but not revealing to others his or her whereabouts. By this description, on-line calendaring is a classic case of what Grudin (1988) warned against, a misalignment of costs and benefits; the individual puts in the effort to record his/her appointments so that another, in this case a manager or coworker, can benefit from ease of scheduling. However, since the early introduction of electronic calendaring systems, many organizations have found successful adoption (Mosier and Tammaro 1997; Grudin and Palen 1995; Palen and Grudin 2002). Apparently such success requires a culture of sharing and accessibility, something that exists in some organizations and not others (Lange 1992; Ehrlich 1987). But today group calendars are a common piece of infrastructure in many settings (Miller 2009).

24.4.4 Awareness

In normal work, there are numerous occasions in which people find out casually whether others are in and, in some cases, what they are doing. A simple walk down the hall to a printer offers numerous glances into people's offices, noting where their coats are, whether others are talking, whether there is intense work at a computer, and so on. This kind of awareness is unavailable to workers who are remote. Some researchers have offered various technology solutions; some have allowed one to visually walk down the hall at the remote location, taking a 5-second glance into each passing office (Bellotti and Dourish 1997; Fish et al. 1993). Another similar system, called "Portholes," provides periodic snapshots instead of full-motion video (Dourish and Bly 1992). Because of privacy implications, these systems have had mixed success. The places in which this succeeds are those in which the individuals seem to have a reciprocal need to be aware of each other's presence, and a sense of cooperation and coordination. A contrasting case is the IM system in which the user has control as to what state they wish to advertise to their partners about their availability. The video systems are much more lightweight to the user but more intrusive; the IM ones give the user more control but require intention in action. Another approach investigated by Ackerman et al. (1997) looked at shared audio as an awareness tool, though this too has privacy implications.

As mentioned earlier, instant messaging systems provide an awareness capability. Most systems display a list of "buddies" and whether they are currently on-line or not. Nardi, Whittaker, and Bradner (2000) found that people liked this aspect of IM (see also Muller et al. [2003]; Isaacs et al. [2002]). And, since wireless has allowed constant connectivity of mobile devices like PDAs, this use of tracking others is likely to grow. But again, there are issues of monitoring for useful or insidious purposes, and the issues of trust and privacy loom large (see Godefroid et al. [2000]).

Another approach to signaling what one is doing occurs at the more micro level. And again, one captures what is easy to capture. When people are closely aligned in their work, there are applications that allow each to see exactly where in the shared document the other is working and what they are doing (Gutwin and Greenberg 1999). If one is working nearby the other, this signals perhaps a need to converse about the directions each is taking. Empirical evaluations have shown that such workspace awareness can facilitate task performance (Gutwin and Greenberg 1999).

Studies of attempts to carry out difficult intellectual work within geographically distributed organizations show that one of the larger costs of geographical distribution is the lack of awareness of what others are doing or whether they are even around (Herbsleb et al. 2000). Thus, useful and usable awareness tools that mesh well with trust and privacy concerns could be of enormous organizational importance. This is a rich research area for CSCW.

An important body of material on this topic appeared in a special issue of *Computer Supported Cooperative Work* in 2002. We do not have the space to engage the nine important articles published in this special issue, but anyone wanting to delve more deeply into this topic of necessity needs to digest this special issue. Schmidt's (2002) article exploring the very concept of awareness itself certainly deserves attention.

A related problem that has recently received much attention is the matter of interruptions. Interruptions have the property that there is an asymmetry between the interrupter and the interrupted, in that the former seemingly has more control over the occasions of interruptions than the latter (Nardi and Whittaker 2002).* These issues become even more acute in distributed work, especially with weak awareness support. Given this, several investigators have explored with some success whether techniques drawn from statistical decision theory or machine learning could be used to figure out from sensor data whether a person is interruptible (e.g., Horvitz and Apacible 2003; Fogerty et al. 2005).

24.5 INFORMATION REPOSITORIES

24.5.1 Repositories of Shared Knowledge

In addition to sharing information generally on the web, in both public and intranet settings, there are applications that are explicitly built for knowledge sharing. The goal in most systems is to capture knowledge that can be reused by others, like instruction manuals, office procedures, training, and "boilerplates," or templates of commonly constructed genres, like proposals or bids. Experience shows, however, that these systems are not easy wins. Again, similar to the case of the on-line calendaring systems described in Section 24.4.3, the person entering information into the system is not necessarily the one benefiting from it. In a large consulting firm, where consultants were quite competitive in their bid for advancement, there was indeed negative incentive for giving away one's best secrets and insights (Orlikowski and Gash 1994).

Sometimes subtle design features are at work in the incentive structure. In another adoption of Lotus Notes, in this case to track open issues in software engineering, the engineers slowly lost interest in the system because they assumed that their manager was not paying attention to their contributions and use of the system. The system design, unfortunately, made the manager's actual use invisible to the team. Had they known that he was reading daily what they wrote (though he never wrote anything himself), they would likely have continued to use the system (Olson and Teasley 1996). A simple design change that would make the manager's reading activity visible to the team would likely have significantly altered their adoption.

The web of course provides marvelous infrastructure for the creation and sharing of information repositories. A variety of tools are appearing to support this. Of particular interest are open source tools that allow for a wider, more flexible infrastructure for supporting information sharing (see www.sakai.org). The major types of collaboratory (see Section 24.7.3) are those that provide shared data repositories for a community of scientists. The topic of "knowledge management" has received extensive treatment over the past decade or more and is far beyond the scope of what we can review here.†

* Though one interesting finding is that in the normal course of activity, many interruptions are self-administered (Mark, Gonzalez, and Harris 2005).

† A Google search in August 2010 under "knowledge management" yielded over 70 million hits!

24.5.2 Wikis

A wiki is a shared web space that can be edited by anyone who has access to it. They were first introduced by Ward Cunningham in 1995, but have recently become very popular. These can be used in a variety of ways, both for work and for fun. The most famous wiki is Wikipedia (www.wikipedia.org), an online encyclopedia where anyone can generate and edit content. It has grown to have millions of entries, and has versions in at least ten languages. A recent study carried out by *Nature* found that for science articles Wikipedia and the Encyclopedia Britannica were about equally accurate (Giles 2005). Bryant, Forte, and Bruckman (2005) studied the contributors to Wikipedia, and suggested that a new publishing paradigm was emerging. Viegas, Wattenberg, and Dave (2004) developed imaginative visualizations of Wikipedia authoring and editing behavior over time. While an extensive literature on Wikipedia has developed in recent years, an interesting paper by Kittur and Kraut (2010) studies nearly 7000 other wikis, noting both similarities and differences with the findings that have emerged from studies of Wikipedia. For instance, coordination mechanisms across a wide range of wikis tended to be similar to Wikipedia. But a wide range of policies, procedures, and other mechanisms for managing a wiki appeared in the larger sample.

24.5.3 Capture and Replay

Tools that support collaborative activity can create traces of that activity that later can be replayed and reflected upon. The UARC explored the replay of earlier scientific campaign sessions (Olson et al. 2001), so that scientists could reflect upon their reactions to real-time observations of earlier phenomena. Using a video cassette recording metaphor, they could pause where needed, and fast forward past uninteresting parts. This reflective activity could also engage new players who had not been part of the original session. Abowd (1999) has explored such capture phenomena in an educational experiment called Classroom 2000. Initial experiments focused on reusing educational sessions during the term in college courses. Lipford and Abowd (2008) report on the long-term deployment of such a system, noting a number of challenges in making such systems effective. We do net yet fully understand the impact of such promising ideas.

24.6 SOCIAL COMPUTING

24.6.1 Social Filtering, Recommender Systems

We often find the information we want by contacting others. Social networks embody rich repositories of useful information on a variety of topics. A number of investigators have looked at whether the process of finding information through others can be automated. The kinds of recommender systems that we find on websites like Amazon.com are examples of the result of such research. The basic principle of such systems is that an individual will tend to like or prefer the kinds of things (e.g., movies and books) that someone who is similar to him/her likes. They find similar people by matching their previous choices. Such systems use a variety of algorithms to match preferences with those of others, and then recommend new items. Resnick and Varian (1997) edited a special issue of the *Communication of the ACM* on recommender systems that included a representative set of examples. Herlocker, Konstan, and Riedl (2000) used empirical methods to explicate the factors that led users to accept the advice of recommender systems. In short, providing access to explanations for why items were recommended seems to be the key. Cosley et al. (2005) studied factors that influence people to contribute data to recommender systems. Recommender systems are emerging as a key element of e-commerce (Schafer, Konstan, and Riedl 2001). Accepting the output of recommender systems is an example of how people come to trust technical systems. This is a complex topic, and relates to issues like security that we briefly described in Section 24.3.

24.6.2 Trust of People via the Technology

It has been said that "trust needs touch," and indeed in survey studies, coworkers report that they trust those who are collocated more than those who are remote (Rocco et al. 2000). Interestingly, those who spend the most time on the phone chatting about non-work-related topics with their remote coworkers show higher trust than those they communicate with using only fax and e-mail. But lab studies show that telephone interaction is not as good as FTF. People using just the telephone behave in more self-serving, less-trusting ways than they do when they meet face to face (Drolet and Morris 2000).

What can be done to counteract the mistrust that comes from the impoverished media? Rocco (1998) had people meet and do a team-building exercise the day before they engaged in the social dilemma game with only e-mail to communicate with. These people, happily, showed as much cooperation and trust as those who discussed things face to face during the game. This is important. It suggests that if remote teams can do some FTF teambuilding before launching on their project, they will act in a trusting/trustworthy manner.

Since it is not always possible to have everyone on a project meet face to face before they launch into the work, what else will work? Researchers have tried some options, but with mixed success. Zheng et al. (2001) found that using chat for socializing and sharing pictures of each other also led to trustful relations. Merely sharing a resume did not. When the text is translated into voice, it has no effect on trust, and when it is translated into voice and presented in a moving human-like face, it is even worse than text-chat. (Jensen et al. 2000; Kiesler, Sproull, and Waters 1996). However, Bos et al. (2001) found that interactions over video and audio led to trust, albeit of a seemingly more fragile form.

If we can find a way to establish trust without expensive travel, we are likely to see important productivity gains. Clearly the story is not over. However, we must not be too optimistic. In other tasks, video does not produce "being there." There is an overhead to the conversation through video; it requires more effort than working face to face

(Olson, Olson, and Meader 1995). And, today's videos over the Internet are both delayed and choppy, producing cues that people often associate with lying. One does not trust someone who appears to be lying. Trust is a delicate emotion; today's video might not just do it in a robust enough fashion, though the Nguyen and Canny (2007) study mentioned in Section 24.3.3 presented some encouraging results.

24.7 INTEGRATED SYSTEMS

24.7.1 Media Spaces

As an extension of video conferencing and awareness systems, some people have experimented with open, continuous audio and video connections between remote locations. In a number of cases, these experiments have been called "Media Spaces," and these were very popular experiments in industry in the late 1980s and early 1990s. For example, at Xerox, two labs were linked with an open video link between two commons areas (Olson and Bly 1991), the two locations being Palo Alto, California, and Portland, Oregon. Evaluation of these experiments showed that maintaining organizational cohesiveness at a distance was much more difficult than when members are collocated (Finn, Sellen, and Wilbur 1997). However, some connectedness was maintained. Where many of these early systems were plagued with technical difficulties, human factors limitations, or very large communication costs, in today's situation it might actually be possible to overcome these difficulties, making media a possibility for connecting global organizations. A new round of experimental deployments with new tools is needed.

24.7.2 Collaborative Virtual Environments

Collaborative virtual environments are 3D embodiments of multiuser domains (MUDs). The space in which people interact is an analog of physical space, with dimensions, directions, rooms, and objects of various kinds. People are represented as avatars—simplified, geometric, digital representations of people, who move about in the 3D space (Singhal and Zyda 1999). Similar to MUDs, the users in a meeting situation might interact over some object that is digitally represented, like a mock up of a real thing (e.g., an automobile engine, an airplane hinge, a piece of industrial equipment) or with visualizations of abstract data (e.g., a 3D visualization of atmospheric data). In these spaces, one can have a sense as to where others are and what they are doing, similar to the simplified awareness systems described earlier. In use, it is difficult to establish mutual awareness or orientation in such spaces (Hindmarsh et al. 1998; Park, Kapoor, and Leigh 2000; Yang and Olson 2002). There have even been some attempts to merge collaborative virtual environments with real ones, though with limited success so far (Benford et al. 1998).

The emergence of multiplayer games with rich virtual environments has literally exploded in the past decade. There is a growing literature on the characteristics of play and collaboration in these games. Ducheneaut and Moore (2005) described the learning of social skills in such games. Brown and Thomas (2006) speculated that achieving mastery in such collaborative games might become an important entry on a resume. Bainbridge (2007) discussed the scientific research potential of such worlds. Nardi (2010) summarized her extensive experience in playing World of Warcraft. This is just the briefest sample of what is available.

Another recent development is the emergence of virtual environments like Second Life. These are not game environments, but a platform in which a wide range of social phenomena are supported in a virtual world. Participants have an avatar, whose visual appearance and clothing can be designed. People in Second Life engage in commerce, buying and selling real estate, making things like clothing or furniture, and a variety of other imports from real life (or RL as it is known in Second Life). Many colleges and universities have a presence in Second Life, and have experimented with offering classes and discussion forums. A number of corporations have a presence in Second Life, and have engaged in creative activities such as prototyping future places (e.g., hotel designs) or software. The first author of this chapter recently participated in a usability evaluation of software developed by IBM Research.

24.7.3 Collaboratories

A collaboratory is a laboratory without walls (Finholt and Olson 1997). From a National Research Council report, a collaboratory is supposed to allow "the nation's researchers [to] perform their research without regard to geographical location—interacting with colleagues, accessing instrumentation, sharing data and computational resources [and] accessing information in digital libraries" (National Research Council 1993, p. 7). Starting in the early 1990s, these capabilities have been configured into support packages for a number of specific sciences (see Finholt [2002]). The Science of Collaboratories project (www.science of collaboratories.org) has identified more than 200 existing collaboratories and has drawn lessons about why some succeed and others do not (Olson, Zimmerman, and Bos 2008).

A number of companies have also experimented with similar concepts, calling them "virtual collocation." The goal there is to support geographically dispersed teams as they carry out product design, software engineering, financial reporting, and almost any business function. In these cases, suites of off-the-shelf groupware tools have been particularly important and have been used to support round-the-clock software development among overlapping teams of engineers in time zones around the world. (Carmel 1999). There have been a number of such efforts, and it is still unclear as to their success or what features make their success more likely, though Olson et al. (2008) have summarized a rich variety of possible factors.

24.8 CONCLUSIONS

Many of the functions we have described in this chapter are becoming ordinary elements of infrastructure in networked computing systems. Prognosticators looking at the emergence of collaborative technologies and the convergence of computing and communication media have forecast that distance will diminish as a factor in human interactions (e.g., Cairncross 1997). However, to paraphrase Mark Twain, the reports of distance's death are greatly exaggerated. Even with all our emerging information and communications technologies, distance and its associated attributes of culture, time zones, geography, and language will continue to affect how humans interact with each other. Emerging distance technologies will allow greater flexibility for those whose work must be done at a distance, but we believe (see Olson and Olson [2000]) that distance will continue to be a factor in understanding these work relationships.

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