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Understanding Effects of Proximity on Collaboration: Implications for Technologies to Support Remote Collaborative Work

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This chapter analyzes why computers and telecommunications have not created computer-mediated work environments for collaboration that are as successful as physically shared environments. Our goals are, first, to identify the mechanisms by which proximity makes collaboration easier, concentrating on the way it facilitates interpersonal interaction and awareness; and second, to evaluate how current computer-mediated communication technologies provide or fail to provide the key benefits of proximity. We use a decompositional framework that examines how visibility, copresence, mobility, cotemporality and other affordances of media affect the important collaborative tasks of initiating conversation, establishing common ground, and maintaining awareness of potentially relevant changes in the collaborative environment.

Increasingly, collaborating with other people is as likely to take place over distance or time as it is face-to-face. An abundance of new communication technologies has been developed to mediate remote collaboration: e-mail, bulletin boards, instant messaging, document sharing, videoconferencing, awareness services, and others. Yet collaboration at a distance remains substantially harder to accomplish than collaboration when members of a work group are collocated. For example, in collaboration at a distance, communication is typically less frequent, characterized by longer lags between messages, and more effortful.

In this chapter we consider why these computer-mediated work environments are not as successful as physically shared ones. Our goals are to identify the mechanisms by which proximity makes collaboration easier, concentrating on the way it helps interpersonal communication and awareness, and to evaluate how current computer-mediated communication technologies provide or fail to provide the key benefits of proximity. We extend a decompositional framework, first proposed by Clark and Brennan (1990), to analyze these technologies and their impact on collaboration in remote work groups. We illustrate our discussion with evidence and examples from the domain of scientific research, but believe that the principles here apply to almost all interpersonal collaborations involving communication and coordination of tasks.

An Example of the Effects of Proximity

Even in the age of telecommunication and the Internet, physical proximity increases the likelihood of collaboration. This phenomenon was demonstrated for scientific collaboration in the 1960s by Hagstrom (1965), and it is still true among scientists who have access to the Internet and are heavy users of telecommunications and computer-mediated communications. Consider, for example, a reanalysis of data originally reported in Kraut, Egido, and Galegher (1990), predicting the probability of successful collaboration among scientists and engineers in a large telecommunications company.[1] This company had been using Internet-based e-mail since its founding, and at the time of data collection, every member of the research division had an e-mail account and a personal workstation or computer, and most used e-mail heavily.

Kraut, Egido, and Galegher examined which of the 164 scientists and engineers in the sample actually collaborated as a function of the pairs' organizational proximity (an ordinal measure of how close they were in the organizational chart—same supervisory group, same department, same laboratory, or different laboratory), research similarity (an index of the semantic similarity of a pair's solo publications), and physical proximity (an ordinal measure of how close the office of potential collaborators were—same corridor, same floor, same building, different buildings). (See Kraut et al. 1990 for more details.)

Results showed that even in this environment, pairs of researchers were unlikely to complete a technical report together unless their offices were physically near each other, even if they had previously published on similar topics or worked in the same department in the company. As figure 6.1 shows, virtually all joint publications occurred among researchers with similar research interests. But researchers with the most similar interests were more than four times as likely to publish together if their offices were on the same corridor as they were if their offices were on different floors of the same building, and researchers whose offices were in different buildings almost never collaborated regardless of their research interests.

The association of organizational proximity with collaboration was similar. Most successful collaboration occurred among people who were in the same department. However, among researchers in the same department and those in different

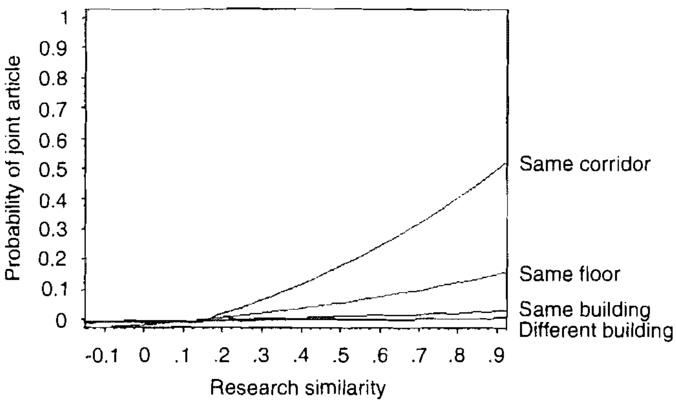

Figure 6.1
Association of research similarity and probability of collaboration at different levels of physical proximity.

departments, researchers physically close to each other were more likely to collaborate than those farther apart. The positive statistical interactions between physical proximity and both research similarity and organizational proximity suggest that physical proximity stimulates collaboration among people who might otherwise not work together. For example, if two people were in the same department, they were two-thirds more likely to collaborate if their offices were on the same corridor than if the offices were only on the same floor. If they were not in the same department, then being on the same corridor boosted their likelihood of collaborating over eight times.

Generic Collaborative Actions

The preceding analyses demonstrate that something about physical proximity encourages or enables collaboration among researchers with the right fit—common research interests or organizational membership—and may even compensate for poor fit. However, this demonstration tells us little about the mechanisms through which proximity works its magic. Collaborative projects are complex endeavors, often taking a year or more to move from an initial idea to a first paper submission (Garvey, Lin, and Nelson 1970) and involve overcoming many social and work-oriented hurdles (Kraut, Galegher, and Egido 1990). In particular, to be successful, potential collaborators must identify and form connections to others whom they believe are both competent and relevant with respect to a work project. They must move from the discussion of an often vague research topic to a detailed research plan. Finally, they must execute the plan. These processes are not linear and consist of many active subtasks as well as active and passive monitoring of information. During these processes, there are important ways in which proximity might facilitate collaboration.

In the remainder of this chapter, we look more closely at how relevant features of proximity affect interpersonal interaction and awareness in collaborative work. We focus on a small number of generic collaborative actions or subtasks that previous research and everyday observation lead us to believe are essential to all collaboration: initiating communication, conducting a conversation, and maintaining awareness of the state of the environment, task, and team.

We discuss how the features and affordances of physical proximity help or hinder accomplishing these tasks. We are mindful, however, that there are other important generic subtasks, and these may depend on the domain within which collaboration takes place. For example, the need to exchange physical objects is likely to differ among mathematicians and surgeons. Similarly, our discussion ignores the processes by which potential collaborators build liking and trust, even though this achievement may be a necessary precondition for many sorts of collaborations (see Nardi and Whittaker, chapter 4, this volume, for a discussion of such issues). Our approach builds on earlier more holistic research (Chapanis, Ochsman, Parrish, and Weeks 1972; Daft and Lengel 1984; Short, Williams, and Christy 1976; Sproull and Kiesler 1991), which examined how types of media influence the success of collaboration. It also aims to extend other recent decompositional analyses of media effects, including Daly-Jones, Monk, and Watts's (1998) analysis of the different functions of audio and visual information and Clark and Brennan's (1990) analysis of the affordances of communication media for grounding in conversation.

Initiating Communication

When people are collocated, it takes relatively little effort for them to start interacting. For this reason, physical collocation has consequences for the frequency of encounters, the likelihood that chance encounters lead to conversations, people's comembership in a community, and the common ground that they develop due to repeated encounters.

Frequency of Communication

Proximity increases frequency of communication. All else being equal, people communicate most with those who are physically close by. Researchers since Zipf (1949) have observed that physical proximity leads to communication. This occurs among potential friends (Festinger, Schacter, and Back 1950), potential work partners (Allen 1977), and people who are already working together (Kraut, Egido, and Galegher 1990).

Frequent communication with collaborators is useful both during the initiation phases of a collaboration, when people are sizing up potential partners and refining vague ideas, and during the execution phase, when they are actively carrying out a plan, performing joint actions, and coordinating individual ones. Each communication episode provides the potential for people to learn something new about their partners, make decisions, monitor the state of the work, take corrective action, and perform other joint activities. If the communication episode does not take place, then the information exchange and joint action will not occur.

Likelihood of Chance Encounters

In part, physical proximity increases the frequency of communication by putting people who have the prerequisites for conversation in each other's presence (Monge, Rothman, Elsenberg, Miller, and Kirste 1985). As a result, they have chance encounters with others inhabiting or visiting the same location, which provide opportunities for conversation. For example, Kraut, Fish, Root, and Chalfonte (1990) showed that in the university and research labs they examined, the majority of conversations were opportunistic, planned by neither party before they happened. Architectural features like common rooms and public events like seminars increase the likelihood that inhabiting a common location leads to opportunities for interaction (Allen 1977).

Proximity facilitates even planned meetings. Being in the same environment as another allows one to pick up information opportunistically about another's availability. One can learn, for example, whether someone keeps morning or afternoon hours, whether the light is on in an office, or whether a conference room is free. Because meetings at a distance incur higher time and transportation costs than local ones, rational actors are likely to ration in-person communication sessions with distant collaborators.

Transitions from Encounters to Communication

In addition to increasing the likelihood of chance encounters, physical proximity leads to more communication by increasing the likelihood that a chance encounter results in conversation. Physical space helps people engage in conversation because when two people encounter each other, they are reminded of each other's existence, can assess each other's availability for communication, have a channel to signal intent for communication, and have the resources to carry it out. Kendon and Ferber (1973) have described the choreography and precise timing that occurs as people make the transition from sighting others to engaging them in conversation. Both physical mobility and the visual channel are important. People frequently wait until the other is not engaged in other activity, catch the other's eye to signal intent to communicate, and then move to an appropriate interpersonal distance before actually speaking. Other media do not support this well-honed routine.

Community Comembership and Repeated Encounters

Merely being in the presence of another does not automatically lead to communication. People frequently ride on mass transit, go to public amusements, and sit in a doctor's waiting room without conversing with the strangers they meet there. The organization of encounters in universities, research labs, and another venues for collaboration helps to increase the likelihood that encounters lead to conversation and that conversation is conducive to collaboration.

Many universities and companies organize office space so that people who have the most need to communicate are collocated. The consequence is that people who are likely to encounter each other in these spaces are likely to have a common history and common purpose.

People inhabit space in a physical work environment such as an office building or laboratory for a relatively long period. As a result, a person one encounters at the coffee station or printer table on one day is likely to be encountered again in the future. Festinger and associates (1950) demonstrated how repeated encounters help relationships form among unacquainted individuals. Although chance conversations tend to be short (Kraut, Fish, Root, and Chalfonte 1990; Whittaker, Frohlich, and Daly-Jones 1994) they typically take place within a broader context of more enduring work or social relationships, with a history and a future. In addition, the inhabitants of these spaces are often mutually exposed to events such as fire drills, seminar speakers, and memos from administrators. The common ground established in prior interactions and from immersion in a shared environment may serve as the stimulus for informal conversations. The knowledge that one will likely encounter colleagues in the future may introduce an obligation to speak to them.

Disadvantages of Physical Proximity for Initiating Communication

Up to this point, we have stressed the mechanisms through which physical proximity facilitates communication and collaboration. But dependence on physical proximity imposes substantial costs as well and may undercut successful collaboration. At a mechanistic level, the most important problem is that when conversation is initiated in person, the people must be simultaneously present. The precise timing in greetings described by Kendon and Ferber (1973) is necessary only because participants must attend to the same thing at the same time. E-mail, telephone answering machines, and computer bulletin boards remove the requirement for synchrony and as a result may facilitate the initiating of communication among people whose schedules do not easily align. Of course, these media can be used by people working together whether their offices are distant or close by.

A second problem with physical proximity for initiating communication is that the opportunistic and spontaneous communication that it supports is not always welcomed. Physical proximity leads to interruptions and loss of privacy, when more disciplined communication might be less disruptive and more productive (Perlow 1999).

Finally, physical proximity by definition privileges communication with people who are nearby. But in many cases, these are the wrong people to communicate with to get productive work done. In particular, these may be people who have too much overlap in orientation and knowledge to support productive collaboration (Burt 1992). Ancona and Caldwell (1992), for example, demonstrated that problems can arise when people concentrate communication within a supervisory group and fail to exchange enough information with others outside the group.

Initiating Communication in Other Media

If people try to use the same strategies to initiate conversation in a remote medium as they do face-to-face, the probability that an encounter will lead to communication is reduced. For example, Fish, Kraut, and Chalftone (1990) evaluated videoconferencing systems that kept an open visual and auditory connection between separated physical environments. Although spontaneous conversations did occur across these video links, they occurred less frequently than communication among people who met spontaneously within a single location. In part, the low resolution of the video images and the asymmetries between what individuals on opposing sides of the video link could see and hear prevented conversational attempts from being consummated. A less exotic technology, the common telephone, is not as successful as physical proximity in supporting spontaneous communication because it severs an assessment of availability from the signaling channel. People place phone calls with no guarantee that the called party is available or amenable to interruption. As a result, the majority of office-to-office telephone calls are not completed on the first try.

Also, asymmetries in the information available to people who are not perceptually copresent may prevent mutual awareness and lead to difficulties with initiating communication. In the world of cellular phones, briefcases ring in inappropriate settings because the caller does not know the called party's state when placing the call. Caller ID is another interesting case: The called party can assess the identity of the caller and choose whether to take the call, but the caller does not know (for sure) whether he or she is being assessed. The result is that the caller is left to guess whether the called party is absent or unwilling to take the call. An analogous situation occurs when it is ambiguous to the sender of an e-mail message as to whether the message is yet unread or is being ignored. Although this asymmetry in knowledge is a disadvantage to the sender, it is quite an advantage to the recipient when privacy is a priority.

Chatrooms and MUDs (Curtis and Nichols 1993) are virtual places where people come together and exchange messages with each other. These are synchronous text services in which text typed at one terminal is displayed on another person's terminal, in close to real time. Almost all have mechanisms to show who is in attendance. For example, in the generic chat interface in figure 6.2, the list of recipients on the right side shows who is available; this list is updated as members enter or leave, although there is ambiguity when people walk away from their machines without logging out or fail to announce themselves when they return. Seeing that others are available stimulates communication with them.

The new generation of instant messaging services also fosters spontaneous and opportunistic communication. In these services, such as America Online's Instant Messenger and ICQ (a mnemonic for I Seek You; see figure 6.3), people agree to make information about themselves and their activities available to a set of others. When people subscribe to the service and run the instant messaging application, their personal computer sends a notification to a server announcing their

Today's Topic		Participants
Sue:	Hi folks :)	@chanserv machine@address
Sam:	Hey sue	@John-away
Peter:	((((((sue))))))	@Sue
Sally:	How are you?	Sam
Sue:	Fine, u?	Peter
		Sally
		Linda

Figure 6.2
Sample communication in internet relay chat (IRC).

availability. Others who subsequently run the instant messaging application are notified when people on their "buddy lists" go on-line.

Chatrooms also lead to chance encounters and the development of social and work relationships among the previously unacquainted because they lead to repeated interactions, which fosters common ground. Many chatrooms are organized around special topics, such as health, investments, politics, or games. In the most successful of these virtual environments, a subset of participants who are especially interested in these topics attend repeatedly. Together, such characteristics enable these virtual places to support spontaneous and opportunistic communication among the participants at the moment, much as physical proximity does. Like collocation, extended copresence in chatrooms and MUDs leads to the formation of personal relationships (Parks and Roberts 1998).

Conducting Conversation

Almost all collaborative work involves communication. People talk, write, gesture, and participate in multimodal interactive exchanges that serve both instrumental and social ends. For example, at the beginning of a scientific collaboration, people may have extended discussions to develop a common view of the research problem and approach. Later, they might argue the pros and cons of particular research decisions, evaluate and revise experimental protocols, instruct research assistants, apprise each other about the status of the work, or outline manuscripts.

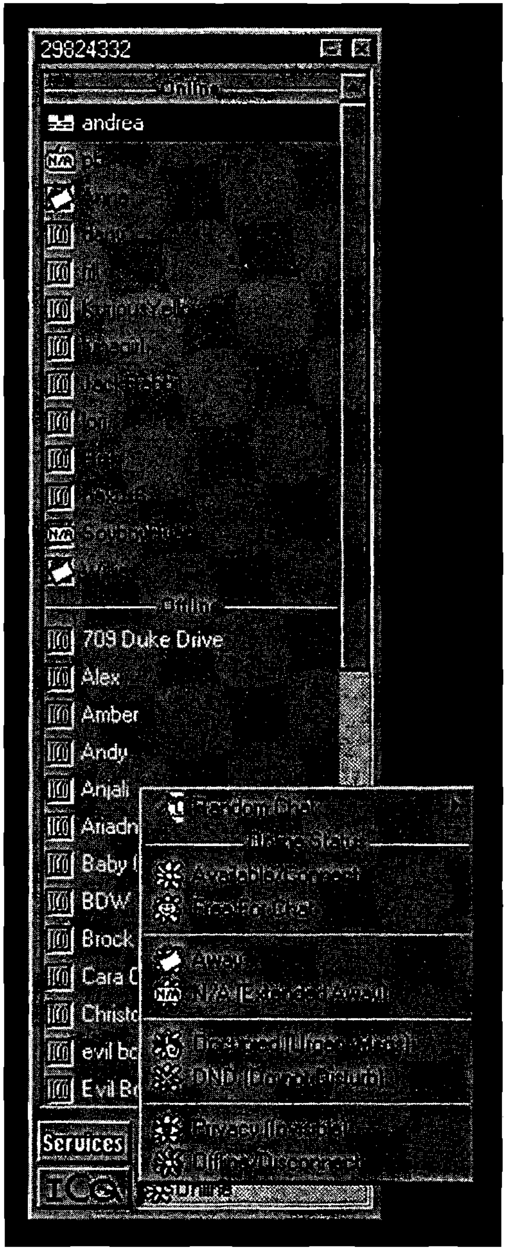

Figure 6.3
User interface for instant messaging.

Table 6.1
Affordances of communication media

Affordance	Definition
Audibility	Participants hear other people and sounds in the environment.
Visibility	Participants see other people and objects in the environment.
Tangibility	Participants can touch other people and objects in the environment.
Copresence	Participants are mutually aware that they share a physical environment.
Mobility	People can move around in a shared environment.
Cotemporality	Participants are present at the same time.
Simultaneity	Participants can send and receive messages at the same time.
Sequentiality	Participants take turns, and one turn's relevance to another is signaled by adjacency.
Reviewability	Messages do not fade over time but can be reviewed.
Revisability	Messages can be revised before being sent.

Source: Adapted from Clark and Brennan (1991).

All language use rests on a foundation of information of which participants are mutually aware, termed *mutual knowledge* or *common ground* (Clark and Wilkes-Gibbs 1986, Clark and Marshall 1981). People can assume common ground prior to an interaction if they know they are members of the same group or have experienced the same events. They also develop common ground by more active means. The term *grounding* refers to the interactive process by which communicators exchange evidence about what they do or do not understand over the course of a conversation as they accrue common ground (Clark and Wilkes-Gibbs 1986). As Clark and Brennan (1990) proposed, different media offer different resources or affordances that shape communication (see table 6.1). As a consequence, different media incur different grounding costs, including those of starting up a conversation, formulating and producing an utterance, receiving and understanding it, delaying in order to plan it more carefully, changing speakers, dealing with the inability to time the placement of a turn precisely, displaying or referring to something, and repairing misunderstandings.

While physical proximity does not preclude collaborators from conversing electronically, we focus here on the affordances of face-to-face conversation that make communication particularly efficient. Face-to-face conversation facilitates the process of grounding utterances in the following ways.

The Use of Common Ground

Whether communication is face-to-face or remote, speakers can rely on what common ground they have with addressees and side participants when they formulate utterances. To the extent that collocated collaborators may be more likely to be members of the same organization, they may have more common ground than remote collaborators. To the extent that speakers and listeners share a common work environment and culture, they can draw on this shared knowledge in planning and interpreting utterances. Experts, for example, can rely on specialized vocabulary in their domain of expertise that can lead to more efficient conversation (Isaacs and Clark 1987). Or collaborators might rely on their joint membership in a specific work culture (e.g., one in which the day ends at 6 P.M.) to clarify an utterance such as, "I'll have this to you by the end of the day."

When a speaker and listener are mutually aware that they are present in the same physical setting (copresence), the speaker generally has a good idea of what the listener can see or hear at any moment and uses these inferences in formulating an utterance. For example, speakers assume that elliptical references to salient objects and events in the environment will be understood (Clark, Schreuder, and Buttrick 1992). Hearing an unexpected noise, a speaker might ask, "What was that?" assuming that the listener had heard the same sound. In addition, the mobility of copresent speakers and listeners gives them greater flexibility in adapting each other's perspectives—for example, by moving closer to see what a partner is looking at.

When people are physically copresent, they can also use a full range of linguistic, paralinguistic, and nonverbal behaviors to communicate. They can use deictic gestures (pointing) to refer quickly and easily to people, locations, and objects. Although these nonverbal behaviors can be replaced with verbal substitutes, the substitutes take more time and effort (Brennan 1990). For example, when coauthors are jointly revising a manuscript, it is easier for one of them to say, "change this," while pointing to a specific sentence, rather than "Change the second to the last sentence in paragraph three on page 24." Of course, pointing can also be done effectively with a mouse and cursor during electronic communication. But sometimes the cursor may not be very salient, it may be delayed, or the person doing the pointing cannot easily monitor whether the remote partner is attending. Such visual evidence about joint attention is most important when speakers are discussing objects and activities that have a spatial character or that are changing. In addition, paralinguistic evidence such as facial expression, intonation, and timing are potentially helpful in detecting speakers' confidence in or attitudes toward what they are saying (Brennan and Williams 1995).

The Precise Timing of Cues

Because face-to-face communication is produced in real time and interpreted online and because it affords visual, auditory, and gestural cues, speakers have feedback on how a message is being understood as it is being delivered. Speakers often deliver utterances in installments, and listeners often precisely synchronize visual and verbal backchannels (e.g., head nods or "uh-huh") with these installments, providing evidence of understanding and interest. The features of face-to-face conversation that make it real-time (cotemporality, simultaneity, and sequentiality) are probably more important than its visual nature, since some information in visual and verbal backchannels may be redundant (Short, Williams, and Christie 1976). However, seeing others' actions can enable people to infer comprehension and clarify misunderstandings more efficiently. If a speaker says, "Adjust the red dial," but the addressee instead tries to turn a red screw, the speaker can see that the message was misunderstood and that the problem lies in the identification of the dial (Fussell, Kraut, and Siegel 2000).

The Coordination of Turn-Taking

When speakers are located in the same physical space, their contributions to conversation tend to be timed so that there is little overlap between speaking turns, and when such overlap does occur, it is usually resolved quickly, so that one person is speaking (Sacks, Schegloff, and Jefferson 1974). Although one turn can lead to another by explicit verbal means (e.g., when one person asks another for an opinion), gesture and eye gaze can facilitate the process, and these features are especially important in multiparty conversation. Speakers frequently direct their eye gaze to indicate whom they are addressing and whom they expect to respond (Duncan and Fiske 1977). Since spoken utterances are usually grounded in the order they are produced, adjacent utterances tend to be relevant to one another, and people strongly expect such relevance. This is not the case in chatroom conversations, where multiple threads typically emerge.

The Repair of Misunderstandings

The real-time nature of face-to-face conversation improves the prospects for repairing misunderstandings and other problems. Because speakers have moment-by-moment evidence of what addressees understand and accept, they can repair problems immediately, often in mid-utterance. The more quickly a problem is repaired, the less costly it is likely to be (Clark and Brennan 1990).

Disadvantages of Physical Proximity for Conducting Conversation

Just as the real-time character of face-to-face interaction makes grounding so efficient, it also places cognitive demands on both speaker and listener due to the fact that conversation must be done spontaneously. Speakers have to plan and execute their utterances simultaneously at multiple levels. They need to formulate a relatively long-term conversational strategy (e.g., stage an argument), design the substance and syntax of sentences, find particular words to fill slots in the sentences, and articulate the result; they may begin speaking while they are still planning (Levelt 1989). They need to do all this rather rapidly or risk losing their listeners' attention. Simultaneously, they must monitor what they are saying to ensure that it is consistent with their intentions. They must also monitor feedback from the listener and reformulate their speech accordingly. Not surprisingly, with all these cognitive demands, spoken conversation is littered with sentence fragments, pauses, sounds such as *um* or *uh*, imprecise word choices, and other departures from idealized language. However, because listeners can give feedback in real time about their comprehension and because speakers can quickly reclarify, these errors are often not consequential.

Listeners are also faced with cognitive burdens. Because spoken utterances are ephemeral, unlike messages on an answering machine or in a written document, the listener cannot pause or reread the message when some portion is difficult. Again, however, the ability to ask for clarification partially compensates for the ephemeral nature of speech. When there are many listeners, however, it is far more costly for a single one whose attention has wandered to stop the speaker for clarification.

Other Technologies for Conducting Conversation

People can conduct efficient, productive, and satisfying conversations other than face-to-face, but how they accomplish this varies across media. According to Clark and Wilkes-Gibbs's (1986) principle of least collaborative effort, people try to ground their conversations with as little combined effort as possible. In response to the costs imposed by different media, people adapt different strategies in grounding. In this section we consider the implications of conversing over media that do not support real-time communication (lacking cotemporality, simultaneity, or sequentiality), compared with those that enable physical and linguistic copresence.

As we have seen, spoken language can be filled with disfluencies and still be comprehensible because the costs of turn taking, feedback, and repair are relatively low. Listeners can indicate precisely where in an utterance they are confused, and speakers can repair just this section (Kraut, Lewis, and Swezey 1982). Communication media that introduce even small delays make grounding substantially more difficult to accomplish (Krauss and Bricker 1966). Research suggests that such disrupted conversations are less successful in the sense that participants communicate information less well, feel the conversations are less natural, and terminate them sooner (O'Conaill, Whittaker, and Wilbur 1993).

The telephone supports interactive grounding well, even though it lacks visual evidence and is used remotely. Indeed, early studies of media differences in communication found that full-duplex phone communication was indistinguishable from face-to-face communication for many referential communication tasks (Williams 1977). Speakers partially compensate for the lack of visual channels by producing more verbal backchannels than they would in face-to-face conversations.

Asynchronous text-based communication, such as e-mail, is neither cotemporal, simultaneous, nor necessarily sequential. Because writers of e-mail messages do not have feedback from an audience during the composition process, they need to be more explicit in forming a message. And the often long delays between sending a message and receiving a reply (not to mention the other messages that may arrive in between) often mean that linguistic context is not well preserved. Many of us have received an incomprehensible yes or no answer to a question asked days before by e-mail. For messages to be interpretable, writers may need to reintroduce quotations from previous messages into the body of the message itself. Indeed, many e-mail systems offer commands for this. Even so, it is more effortful to ground utterances in e-mail than in spoken conversation. Linguistic copresence accrues over hours or days by e-mail, as opposed to within minutes in person, by telephone, or in synchronous computer-mediated chats.

We believe that a difficulty in grounding is one reason that collaborators with a choice of communication media try to use face-to-face conversation for tasks that require consensus or negotiation, while using e-mail for coordination (Finholt, Sproull, and Kiesler 1990) and that teams forced to rely on e-mail tend to work more independently, especially in the early stages of a project when they are setting direction (Galegher and Kraut 1994). On the other hand, the fact that e-messages can be stored, consulted when they are replied to, and reviewed later makes linguistic copresence easier to achieve and maintain over longer time periods, compared to the imperfect memory or notes resulting from ephemeral face-to-face meetings. Having such a record can be a real advantage for long-term collaborations.

Because synchronous text services are by definition cotemporal, people ground utterances in chatrooms very differently than in e-mail. On the one hand, the relatively quick exchanges in chatrooms and instant messaging systems make feedback and repair much easier. The potential for rapid interaction has led to a style of communication more like spoken conversation, with short installments and frequent responses.

With respect to video teleconferencing, early research suggested that being able to see a conversational partner's face is surprisingly unimportant in communication. Subjects in problem-solving experiments rated video that simply provided a link to a communication partner as less valuable than video used to share data (Anderson, Smallwood, MacDonald, Mullin, and Fleming 1999). Having a shared visual environment (visual copresence) especially improves communication when it contains the objects being talked about (Karsenty 1999; Fussell et al. 2000; Whittaker and Geelhoed 1993). For some collaborative tasks, such as giving instruction about the operation of a software package, being able to share screens on a computer might provide sufficient shared visual space to improve communication (Karsenty 1999). For tasks where the objects are not computationally generated, higher-bandwidth video may be more important. However, because of quality problems, video may not be sufficient to achieve a shared visual space (Anderson et al. 1997, Fussell et al., 2000). For example, limitations in mobility and fields of view mean that not everything visible to one party in a conversation might be visible to others. Similarly, limitations on resolution and field of view often mean that one party in a conversation cannot easily assess the focus of attention of the other party.

Maintaining Task and Team Awareness

To achieve the coordination required for collaborative action, people maintain an ongoing awareness of events in their work environment and beyond. Many types of awareness may play a role in successful collaborations, varying by domain (e.g., environment, team, and task) and temporal granularity (with timescales ranging from months to fractions of a second; Cooke, Salas, Cannon-Bowers, and Stout

2000). People keep up with information about the demand for their work in the real world, how particular tasks are progressing, what fellow workers are doing, who is communicating with whom, what equipment is out of order, and many other details of the collaboration that concern them directly or tangentially. Here we distinguish between awareness of the task (e.g., what steps need to be taken next; Seifert and Hutchins 1992) and awareness of the collaborative team, (e.g., who knows what among the members; Liang, Moreland, and Argote 1995). Developing and maintaining this awareness is much more difficult in distributed teams than collocated ones (Cramton 2001).

Task awareness, which includes collaborators' beliefs about the overall project, including its history, current status, and future directions, is crucial for successful coordination. When collaborators divide work, they need to monitor their partners' activities for personnel management and to understand the impact of their partners' progress on their own work. This monitoring can help people determine when and which collaborative actions are required (e.g., whether it is time to nag someone to complete his or her section of the project). The granularity with which collaborators need to maintain task awareness differs depending on the nature of the task and the type of collaborative actions they wish to perform. For activities such as collaborative writing, which are characterized by periods of individual work followed by integration of efforts, it may suffice to know that a coauthor will be working on the article at some point during the week. However, under deadline pressure, the same task may require awareness that is more frequently updated. For other tasks, such as a medical team working together in an operating room, a much more finely grained awareness of the current state of the task is needed.

Team awareness, on the other hand, refers to collaborators' beliefs about both stable and changing attributes of their partners. Detailed and accurate models of each other's knowledge, skills, and motivation help collaborators assign tasks appropriately and solicit and offer appropriate help (Liang et al. 1995). Collaborators share beliefs about project roles and responsibilities, interdependencies among team members, the current status of each person's assigned tasks, their availability for interaction, and the like (Cannon-Bowers, Salas, and Converse 1993; Levine and Moreland 1991).

When teams members are collocated rather than distributed, they can provide and receive up-to-date information about the status of current tasks and each other's capabilities relatively easily. Proximity increases the frequency of communication, and each episode of communication provides a setting in which teammates can explicitly exchange information about task status, personal competence, and availability. Equally important, when teammates are collocated, they can passively monitor activities going on around them and pick up relevant information without explicit communication. In face-to-face settings, people display what they are doing simply by doing it, with no special communicative intent. When people share a physical and social work environment, for example, they can attend meetings where others are expressing views, pass by an ongoing activity en route to the printer, overhear a conversation, or view a diagram on a hallway whiteboard.

This passive monitoring of other's activities aids collaboration. For example, Liang and associates (1995) demonstrated that members of a team pick up information about each other while training side by side, which allows them to allocate tasks more effectively. Seifert and Hutchins (1992) demonstrated that team members can assess the competence of new recruits and correct their errors by overhearing conversations.

Not only do collocated teams pick up information implicitly, but they also share a context that helps them accurately interpret this information. Cramton's study of distributed project teams (2001) showed that the lack of shared context leads to misattributions for behavior, resulting in poorer coordination and distrust. For example, one member may send another mail asking for an update, but does not get a response because the recipient is on vacation. In a distributed team, the lack of shared context often led to ambiguity about interpreting silence, which in turn resulted in failures of coordination and distrust. In the teams Cramton (2001) studied, failure to respond to mail was attributed negatively to the person (that person is unreliable) rather than to the situation (the mail did not get through or the team was on vacation). By contrast, in a collocated setting, vacation schedules and availability would likely be known.

The Disadvantages of Physical Proximity for Maintaining Awareness

Because proximity supports frequent communication and passive information gathering, people in collocated teams are more aware of the shared environment, the team, and the tasks than are members of distributed teams. This information is necessary for internal communication but not sufficient. Success in research and development teams also depends on keeping up with changes in the broader social and technical environment (Allen 1977, Ancona and Caldwell 1992). When competing for the Nobel Prize, for example, Watson and Crick needed to know what was happening in Linus Pauling's lab as well what was happening in their own (Watson 1968). We hypothesize that the ease of local communication and information acquisition may bias the information tracked by a work group, causing them to overattend to local information at the expense of more remote, contextual information.

Maintaining Awareness Through Other Technologies

A long-standing goal for research in both information retrieval and computer-supported cooperative work (CSCW) has been to develop tools that aid passive awareness. The major design challenge is that the information needed to maintain awareness of team, task, and environment may overwhelm team members and prevent them from actually doing work. It is difficult, for example, to craft a document if one is continually checking on a teammate's progress. What is needed are automatic ways of detecting relevant changes to the collaborative state and then presenting these changes to interested parties without overwhelming them.

Automated techniques for selectively distributing information have existed for at least a quarter of a century (Salton and McGill 1979) and are designed to match changing information with a subscriber's interests. Using these techniques helps scientists keep aware of new publications in their research areas. Many e-mail systems apply analogous techniques to filter private and group correspondence, with the goal of highlighting the important messages.

Another stream of research builds tools to provide collaborators with knowledge of other team members. Many of the CSCW tools for passive awareness have used images and video to provide a view into the work environments of remote team members (Dourish and Bly 1992, Fish et al. 1992) to show availability and progress. Others use social network techniques to show someone's communication partners (Ackerman and Starr 1996).

Other approaches have concentrated on awareness of people's use of shared documents. For example the edit–read–wear systems (Hill and Hollan 1992) display which aspects of documents were more frequently read and changed. Similarly, the TeamSCOPE system (Yang, Steinfield, and Pfaff 2000) attempted to provide members of a distributed collaborative team up-to-date information about which project documents had changed, who had read them, and which team members had been active. One problem with these systems is that inferences about teammates activities are often fragmentary, ambiguous, or wrong. For example, just because software notices that someone has downloaded a document, there is no guarantee that he or she has read it. Moreover, even when users get detailed and accurate information about other teammates' work activities, this information may not improve their coordination. For example, Espinosa and others (2000) gave teams accurate information about documents their partners had read. As a response, individuals assumed, erroneously, that they did not need to read material their partners had read; this decision prevented them from deliberating over jointly read documents.

Details in design can strongly influence whether information for awareness will overload its users. Awareness systems differ on whether they broadcast information to users or require them to poll a database. Consider two techniques to allow a team member to monitor discussions among collaborators. These discussions could be delivered to recipients through distribution lists or listservs, a broadcast technology. Alternatively, they could be deposited in a Web site or electronic bulletin board, which users must poll to see if new material has arrived. The value and costs of these mechanisms are likely to depend on the granularity and frequency of updates. The broadcast technique is genuinely passive. In a listserv, for example, people see the awareness information whenever they check their personal e-mail. Broadcasting awareness information, however, can be highly intrusive. Butler (1999) showed that each message sent to a listserv drives some subscribers away, even as it attracts others, with more members lost than gained per message sent. To alleviate this problem, highly active listservs allow members to subscribe to a digest, which concatenates messages and delivers them once per day. Polling techniques are much less intrusive but require people to check whether new material has arrived. Because awareness techniques based on polling are not passive awareness mechanisms, they are likely to be ineffective at keeping people up to date unless polling is done frequently.

In addition to information delivery mechanisms, the success of passive awareness systems strongly depends on the details of the user interface. Interfaces to instant messaging systems, which support passive awareness of friends' and colleagues' availability, illustrate one way to announce new information without demanding excess attention. In figure 6.3, a user has entered more than twenty individuals in his "buddy list," of whom he wants to keep aware. When a buddy goes on-line, his screen name moves to the upper part of the window, alerting the user that he is online and hence potentially available for communication. When one of the buddies attempts a conversation, the icon representing the buddy flashes. Other icons allow users to indicate that they are on-line but not accepting calls, and other variations on their availability.

Conclusions

This chapter has explored how copresence, visibility, mobility, cotemporality, and other affordances of media affect the important collaborative tasks of initiating conversation, establishing common ground, and maintaining awareness of potentially relevant changes in the collaborative environment. Although not perfect, collocation and face-to-face communication bundle together affordances for these generic collaborative tasks, making collaboration easier to accomplish among people who are collocated than among those who are apart. People, however, can and do collaborate over distance, using whatever technologies they have available. In the nineteenth century, Darwin corresponded with naturists around the globe on the role of emotional expression in humans and animals (Darwin 1965). In such cases, people adapt, within limits, to the means of communication they have available. One can ask questions by letter and get explanations in response, but because of delays and the extra effort required to write text, using this method of communication changes the nature of the communication and the collaboration. For example, communication will be less social, more focused on the topic at hand, more planned, less ambiguous, and more likely to contain misunderstandings than communication conducted in person.

We discussed results in terms of media affordances, but it is difficult to differentiate physical attributes of the media from long-standing adaptations of social systems and individual behavior to media with specific features. For example, it is because media influence the probability of chance encounters that organizations collocate people who need to talk to each other. Because typing is more effortful and slower than speaking, people who interactively communicate in chats, MUDs, and instant messaging systems write in abbreviations that get their meaning across with less typing (see figure 6.2). Communities of users have developed conventions of abbreviations, where, for example, LOL means "laughing out loud," IMHO means "in my humble opinion," and BBFN means "bye bye for now."

E-mail and instant messaging are both text-based computer-mediated communication, but they differ from each other in the likely delay between a message's being sent and being received. We have treated the greater interactivity of the instant messaging systems as a matter of media. However, to some extent, these differences are a matter of convention. Although it is possible to use conventional e-mail so that a dyad rapidly exchanges messages as soon as they arrive, in practice most e-mail is exchanged with substantial delays between when a message is sent, when it is read, and when it is replied to.

This chapter has not been an exhaustive treatment of either collaboration or media differences. Rather, the goal has been to illustrate an approach that examines how the affordances of media influence important tasks within a larger social process such as collaboration. We have treated only several media affordances. We have skimmed only three generic collaborative subtasks, and there are numerous domain-specific tasks we have not discussed at all. Although our conclusions are limited, they illustrate the value of the decompositional approach.

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