Computer-Supported Cooperative Work Challenges

Kevin L. Mills
National Institute of Standards and Technology, Gaithersburg, Maryland, U.S.A.

INTRODUCTION

In this article, we consider the main challenges that impede us from realizing the great promise of computer-supported cooperative work (CSCW). First, we discuss some of the key features that CSCW must provide in order to succeed with users. We follow this with a picture of the current state of the practice among CSCW users, and then we examine some technologies that hold promise for future application to CSCW. While considering these promising technologies, we suggest links between past CSCW research and related emerging commercial technologies, and we also identify some current research that holds great potential for future application to CSCW. We close with some speculation on the future of CSCW.

OVERVIEW

Robert Metcalf, the inventor of Ethernet local-area networking, observed that the value of a network increases nearly in proportion to the square of the number of users (see Ref. [1]). Similarly, economists discuss a concept called network externalities (see Ref. [1]), which embodies the idea that the value derived from adopting certain new technologies can increase as an exponential factor of the number of adopters. Metcalf's law and network externalities apply directly to CSCW technology. Since CSCW aims to improve the ability of groups to collaborate through the use of computers and networks, it stands to reason that the value derived from CSCW technology improves in an exponential proportion to the number of people who possess the technology. This fact looms as both a large opportunity and significant challenge for CSCW.

To derive the greatest benefit from CSCW, the supporting technology must infiltrate as widely as possible throughout the populace. Beyond abstract arguments related to Metcalf's law and network externalities, CSCW researchers have conducted studies that support this assertion. For example, Whittaker,[2] in a study of users of Lotus Notes, a technology intended to support asynchronous collaboration, found that both conversations and the creation of group archives proved more successful with large numbers of diverse participants, as compared against small, more homogeneous, project teams. Similarly, Whittaker reports that a large database of material was more likely to be used and extended than a small database. Further, the presence of a moderator was found to inhibit rather than enhance discussions. In other words, Whittaker's study suggests that the larger and more diverse the population of participants and the more free-flowing the conversations, the more effective the results from the use of Lotus Notes, a collaboration technology at the commercial state of the art.

What factors inhibit the widespread adoption of CSCW technology? First, CSCW technology generally relies on a big stack of computer and network technology, operating systems and protocols, data formats and user-interface devices. The dissemination of such capabilities, while growing at a rapid pace, is far from ubiquitous, and even where these technologies have penetrated, the systems, protocols, formats, and software are far from homogeneous. We can safely observe that the telephone handset appears to be ubiquitous, while the networked desktop computer is far less so. Some progress can be discerned regarding de facto standardization of desktop computer systems and software, as well as the adoption of standards associated with the World Wide Web. Even so, these technical underpinnings on which CSCW depends continue to evolve. Further, there exists little penetration of the systems and associated networking quality of service required to support effective videoconferencing. These facts suggest that, to some large degree, the pace of progress in CSCW depends upon, and must be tied directly to, those supporting technologies that achieve near ubiquitous adoption. On the other hand, as selected technologies evolve over time to become ubiquitous, the degrees of freedom available to CSCW researchers and designers also diminish.

Even assuming that the necessary networking and computing technologies achieve complete penetration throughout society, the deployment of CSCW may still be retarded by various administrative and policy decisions, which paradoxically may in part be taken in reaction to the depth of penetration of the technologies themselves. For example, as more people gain access to

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the Internet, the potential increases for various unwanted intrusions, eavesdropping, information theft, and denial-of-service attacks. To limit the effects of such incursions, network managers have deployed security fire walls. Such fire walls are typically configured to impede the free flow of communication among nodes on the Internet. These restrictions attempt to turn a phyically ubiquitous system of nodes into logically partitioned and protected enclaves of nodes and thus interfere with the ability of folks to collaborate—especially when the potential collaborators exist within separate administrative domains.

Beyond the need for widespread adoption of the necessary underlying technology, CSCW can suffer from Grudin's inequality,[3] which states that those who devote the time and effort to capture and record the articulation work associated with collaboration may not be the ones who benefit most from the results. This same issue appears again, but on a larger scale associated with knowledge management, in a panel discussion held at the 1998 conference on CSCW, where participants considered the question: ''Can an organization shape its culture so that people will network and share expertise, making knowledge explicit whenever possible, rather than just whenever convenient?'' In this case, an entire organization stands to benefit from the time invested by its individual members, while the members themselves might not gain directly from the time they invest. On an even larger scale, economists discuss a similar concept, known as the ''tragedy of the commons,''[4] which observes that some societal investments that serve the common good may prove too costly and yield too low an individual return for any one organization to invest. This situation sometimes appears with regard to the establishment of technical standards. For example, participants in the World Wide Web Consortium work together to set standards that can increase interoperability among the distributed computing software from numerous vendors, while also increasing the market for computer and communications equipment and related software. Likely, some participants in the process seek to slow the pace of standards setting so that they can attempt to set the relevant standards de facto by gaining ovewhelming market share, much as Microsoft has achieved greater than a 90% share of the market for desktop computer operating systems. In effect, each potential participant in a joint process must weigh the costs of participation against the likely benefits. Sometimes the costs may appear too high, or the benefits too low, to motivate individuals to participate constructively.

Another impediment to progress in CSCW concerns a general inability to measure progress within the field. In hardware-related fields, progress can be measured easily along many relevant dimensions, such as component density, execution speed, power consumption, and heat dissipation. To date, progress in software-related fields has proven less amenable to quantification. In human-computer interaction (HCI), which mainly involves the interaction of software and people, quantifying progress has proven even more elusive. By encompassing interactions among groups of people, including organizations, mediated through computers and networks, the scope of CSCW exceeds even that of HCI. A compounding factor, identified by Whittaker,[2] is that user perceptions about the effectiveness of CSCW technology often do not match the effectiveness as measured by an unbiased, outside observer. This finding implies that measuring progress in the field of CSCW cannot rely solely on surveying the experiences of users. For this reason, large companies often spend substantial resources to set up human-factors laboratories where users can be observed and recorded while using specific technologies and where the observations and recordings can be studied to glean information about the effectiveness and efficiency of various software features. Understandably, because CSCW encompasses such a complex and multifaceted research domain, measuring progress will remain difficult. Some researchers[5] have proposed a framework intended to encompass the important dimensions along which progress can be measured and to provide some examples[6,7] showing how to apply the framework. Still, the difficulty inherent in gauging progress in the research and application of tools and technology for CSCW remains a major impediment to progress in the field.

While conducting research and measuring progress in a field as wide-ranging and complex as CSCW appears challenging enough, we must also consider the fact that the underlying technology on which CSCW builds continues to change at an alarming rate. Because CSCW builds on a wide range of software and networking technologies, significant advances in those fields can challenge the assumptions on which CSCW applications are constructed. In fact, CSCW applications live at the end of a long food chain of technologies and so must adapt to any changes that arise. Further, several technologies within the food chain can change simultaneously, making it difficult for CSCW researchers and developers to track and understand the significance of the changes, let alone adapt to them. Even if CSCW researchers could adapt fast enough to technological changes, there still remains the problem of understanding and evaluating the effectiveness of the adaptations. By the time researchers gain an understanding, the underlying technologies have typically moved on again. This cycle poses quite a challenge to CSCW. Even worse, the adoption of new technologies and CSCW applications by people and organizations inevitably leads to changes in the way people work, as well as in the assumptions that people make

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about what should be possible or expected from CSCW in any given circumstance. For example, Olson and Teasley[8] discuss how working arrangements among a team changed to become more loosely coupled when the team was forced to work virtually at a distance. Similarly, Malone et al.[9] predicts a shift in the organizational structure of corporations as they come to depend on computer-mediated coordination technologies. This coevolution between CSCW technology and the reaction of people and organizations to the technology appears even more challenging when we consider the fact that evolution along each dimension operates on different timescales. While technology evolves quickly, people and organizations tend to resist change or to change fairly slowly, perhaps even at a generational pace. This mismatch in the pace of change adds to the difficulty CSCW researchers face when they attempt to assess progress in the field.

CSCW Success Factors

Given the challenges facing the field of CSCW, can we identify some keys to success? First, success depends on the degree to which CSCW technology becomes ubiquitously deployed throughout society. This implies that CSCW researchers must target their innovations and developments to ride on underlying technologies that appear poised for widespread adoption by a substantial portion of the population. Past examples of such technologies include telephones (in 1999, the Federal Communications Commission estimated that about 94% of Americans had telephones) and televisions (Nielsen Media Research-Nielson Television Index reported that sometime between 1980 and 1985, televisions penetrated 98% of U.S. households). Potential future examples include the World Wide Web, which connects millions of desktop computers together and to information and communication services. To date, World Wide Web technology has penetrated only to around 40% or so of the population in industrialized countries (as reported in the ''State of the Internet 2000,'' a study conducted jointly by the United States Internet Council and International Technology and Trade Associates, Inc.). A more recent study reported that the percentage of Americans with online access increased from about 67% in 2000 to about 72% in 2001.[10] While not certain, desktop computers and the Web seem likely candidates for near ubiquitous deployment.

Second, CSCW researchers must focus their efforts to understand and account for the characteristics of cooperative work. Some researchers have already contributed in this way. For example, Ehrlich[11] reports themes from research about group work. Communication among groups is generally ad hoc, informal, and unplanned, which implies that CSCW researchers should develop techniques that can support such interactions in the digital world. Group members also need to maintain awareness about the availability of others to communicate and about the state of joint work, which implies that CSCW researchers should seek to improve our ability to accomplish these tasks when working through computers and across networks. Further, issues related to sharing information often hinge on subtle notions of anonymity, which suggests the CSCW researchers should continue to experiment with mechanisms to manage the release of personal information in cooperative settings. In another contribution, Schmidt and Bannon[12] suggest some guidelines to consider when designing systems to support cooperative ensembles. Cooperative ensembles: 1) exist as large assemblies or as groups embedded within larger assemblies (which implies that CSCW researchers should focus on techniques that scale); 2) often emerge to handle a particular situation, then dissolve (which implies that CSCW researchers should explore techniques that ease the burden of establishing collaborative sessions); 3) exhibit continuously changing membership or membership that cannot be determined (which implies the CSCW researchers should investigate techniques for finding and forming effective subsets from larger populations); 4) often intersect (which implies that CSCW researchers should develop techniques to manage multiple collaborative contexts, including mechanisms to control the dissemination of information in accordance with policies that might conflict). MacKay[13] highlights another key to success when she identifies the importance for mechanisms that enable people to control who can see or hear them at any time and to know when someone is seeing or hearing them. MacKay also discusses a critical issue surrounding interaction and interruption. Specifically, individuals desire to determine the intention of any proposed connection or interaction and to avoid communications that might disturb their work. These observations imply that CSCW researchers could focus productively on mechanisms to automate the initiation and management of interactions.

A third key to success for CSCW relates to automated support for coordination of group activities. While CSCW researchers are now convinced that most workflow and coordination processes demand continuous negotiation among participants and entail liberal application of techniques to handle unanticipated exceptions, the work of coordination remains largely a domain where only people add value. While selected CSCW researchers investigate automated, language-based support for flexible workflow processes and for negotiation and coordination, this territory remains wide open. Will agent-based coordination systems really work effectively? Can

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constraint-based languages be applied to achieve flexible information and transaction flow? Can automated methods support coordination among people, or are the problems too hard? Finding the right balance between automated support and human responsibility could improve the prospects for CSCW technology to go beyond communication to include coordination.

Current Practice of CSCW

While some technologies appear promising as foundations for advances in CSCW, it should prove instructive to consider the current state of the practice. The typical collaborative session today consists of a telephone conference where collaborators discuss content, which might include faxed documents or perhaps some shared electronic documents, such as presentation slides or word-processing files that might be supported by change tracking capabilities. In some advanced situations, a collaborative activity that extends beyond particular real-time sessions might also be supported by a website, with one person elected as the editor. Typically, files to be added to the website would be sent by electronic mail to the editor. This typical collaborative session leverages a ubiquitous technology, the telephone network, which also happens to provide one of the most important channels, audio, for quickly conveying information among people and for conducting the real-time interactive dialog that helps to coordinate understanding and consensus building among participants. Typical collaborative sessions might also exploit the telephone network to distribute paper documents through facsimile machines. This permits discussions to center around shared documents, but relies on the use of the audio channel to ensure that all participants focus their attention on the same locations within a document. Increasingly, electronic mail is replacing the facsimile as a mechanism to distribute documents, and the documents usually adopt a widely available format, such as Adobe portable document format or Microsoft Word™ format, which also provides change-tracking capability, along with PowerPoint™ format for shared viewgraphs. These techniques help, particularly the change-tracking capability, which can be useful when several people wish to propose amendments to shared documents. Even in this case, either the document must be distributed serially to ensure all changes are recorded, or the collaborators are left to ponder changes independently proposed on various copies of the document. No clear advantage exists for either approach because it can be somewhat difficult to follow documents marked up with proposed changes. Notice that the use of electronic mail to distribute electronic documents still relies on the audio channel to coordinate the focus and attention of all participants during a collaborative session.

Some technologies aimed at improving the state of the practice have failed as yet to provide much help. For example, application-sharing systems exist, such as Microsoft's NetMeeting™, which can provide a means to visually indicate focus on electronic documents, can support simultaneous markup of electronic documents among a group of users, and can also include audio and video conferencing capabilities. Yet, these systems are not in widespread use. Why? Few widely agreed standards exist. The systems prove difficult to configure and use. They require support for a level of network quality of service that is not widely available. Videoconferencing systems, such as the roll-around stations and room-based systems available from PictureTel, have failed to catch on as well. Why? Such systems tend to be expensive; thus, they are deployed selectively and must be scheduled and shared. This limits their applicability for spontaneous collaboration. Further, such systems require specialized support for network quality of service, usually provided through dial-up integrated services digital network (ISDN) lines—such lines are not typically deployed ubiquitously. The Internet, while more widely deployed, does not provide the necessary quality of service. Systems (such as Lotus Notes) that support asynchronous collaboration can be used to disseminate documents and discussions and to trigger alerts when various events occur. Such systems have not achieved wide usage. Why? The litany of reasons should be familiar by now: lack of widely agreed standards; difficult to configure, deploy, and use; expensive to buy and maintain. A similar story can be told for collaboration servers, such as Collabra and TeamWare, another form of collaboration technology available today but not widely used.

While the current state of the practice in CSCW appears rather primitive and the landscape of more advanced technical solutions appears strewn with failures, some technologies promise to better support CSCW in practice. For example, the Web, with a growing infiltration in society and an increasing base of widely agreed technical standards, looms as a mass medium that can likely be exploited for collaborative purposes. In fact, as the Web's inventor, Tim Berners-Lee, has often observed, collaborative software development provided the original motivation behind the Web.[14] Of course, Berners-Lee has also rued the fact that at its current state of development the Web appears to be a mass medium more suited for television-like distribution of multimedia. Despite its current state, Berners-Lee and many other researchers and developers continue to seek mechanisms to improve the Web's support for collaboration. Great potential exists for CSCW on the Web because ubiquitous availability provides a crucial key to success. One company in particular has contributed to increase the ubiquity of the Web.

America On-Line (AOL) has grown to encompass more than 30 million users. Given the power of network externalities, the larger the user base becomes the more its value will grow and the larger still the user base will become, creating a powerful positive reinforcement. We might imagine that should this success continue AOL would become the de facto Web. What can we find among the AOL arsenal that might improve the effectiveness of CSCW? First, AOL encompasses newsgroups and chat rooms. To the degree that these aid collaboration, AOL will increase their value by increasing the number of participants. Second, AOL has pioneered the development of instant messaging, which provides user awareness services, including user-controllable privacy settings, and also provides the ability to initiate and accept invitations to engage in person-to-person text dialogs. Instant messaging technology is also available from others, such as ICQ (''I seek you'') and Microsoft. Future generations of instant messaging will likely support the exchange of documents, images, and other multimedia data as well. This technology supplies some of the essential features needed for successful collaboration. And the features will be available to the 100 million or more subscribers likely to use AOL at some future date. Perhaps CSCW researchers and developers should take a closer look at the technologies available through AOL.

Another significant development for CSCW appears to be the growing role of distributed, collaborative software development, as fostered by the ''Open Source'' movement.[15] Of particular interest is SourceForge (http://www.sourceforge.net), a website that provides services to open-source software development projects distributed around the globe. SourceForge provides hosted projects with Web-based tools for collaborative software development, a project Web server, tools for software maintenance and bug tracking, mailing lists and discussion forums, databases and compile farms, software release services, and advertising. SourceForge users have the option to mix-and-match these tools and are free to design and contribute tools that might enhance collaboration. As of February 2002, SourceForge hosted over 30,000 open-source development projects and more than 350,000 registered users. We might conclude that SourceForge employs Web technology in a form intended to realize the original motivation cited by Berners-Lee: collaborative software development.

What can we conclude from our examination of the current state of the practice in CSCW? The successful CSCW technologies appear to share some traits: ubiquitously available, easy to understand, easy to set up and use, few administrative constraints, reasonable technical requirements, and affordable prices. The unsuccessful CSCW technologies fail with respect to one or more of these traits. The expansion of users on the Web in general, and AOL in particular, seems likely to continue, perhaps achieving near ubiquity at some future date. Such ubiquity would provide a key foundation to improve computer-mediated collaboration at a distance. SourceForge provides an early glimpse of what might become possible. While current practice appears quite limited, growth in Internet-based communication suggests that we are living near the dawn of effective CSCW. A number of technologies seem particularly promising.

Promising CSCW Technologies

If we look a bit beyond the horizon of today's widely deployed systems, we can identify a few technologies that exhibit significant promise with regard to CSCW. One suite of technologies might enable us to divide the general Internet into enclaves inside which we can securely conduct collaborative sessions, both in real time and across time. Such technologies can replace the current fire walls, which divide the Internet up along administrative boundaries, with virtual private enclaves, which might divide the Internet, on demand, along the lines of function or context. Already, the elements of such technologies are commercially available. For example, Windows2000™ ships with networking technology that enables users to form virtual private networks, which use encryption to establish confidential, virtual Internets on top of the physical Internet. Other commercial products, such as VMware™, permit a single desktop computer to be divided into virtual operating systems, which provide multiple, separate contexts for the user. In a similar fashion, several vendors offer software that can divide Web servers into segregated enclaves so that a single physical Web server can appear as multiple, logically distinct Web servers. Desktop, network, Web server—these assets form the ingredients needed to support collaborative sessions among distributed users across organizations, and the ability to ''virtualize'' each of these assets in order to support multiple but separate contexts already exists in the commercial market. What remains to be developed are: 1) techniques for connecting these distinct virtual assets into unified virtual enclaves, each consisting of virtual desktops, a virtual network, and virtual servers and 2) mechanisms to quickly establish virtual enclaves and to support mobility among the virtual desktops and virtual servers. Some networking researchers[16] are already investigating techniques for composing virtual enclaves, while other networking researchers[17] are refining technology that can allow virtual networks to be established simply and on demand.

Above the networking and operating-system layers, technologies for the Web are evolving in interesting ways that also promise to support improved CSCW. In a companion article (see *Computer-Supported Cooperative*

Work), we mentioned the advantage of the extensible markup language (XML) for describing the syntax and content of information in a form both readable by people and interpretable by computers. The extensible markup language[18] seems likely to become the standard language for defining information objects exchanged among computers. Computer-supported cooperative work researchers and developers should be able to build safely on this base. The extensible markup language does not include a means to describe the behavior associated with various objects, except in the form of references to programs that can implement services associated with the object. The ability to express behavior directly in a form that can be transferred between computers seems to have an important place in future automated systems. At present, candidates for this role include portable scripting languages, such as TCL, Expect, Python, and interpreted programming languages, such as Java™ and Visual Basic. Some researchers,[19] have used Java to implement Habanero, a combined synchronous-asynchronous collaborative system that shows how the power of mobile programs can be applied to bring unprecedented interoperability, function, and performance to CSCW.

While XML and Java suggest how metadata and behavior can be described for dissemination among a network of computers, other technologies promise to provide new mechanisms to accomplish the distribution. Already, industry is busy working on notification services and publish-subscribe (pub-sub) technology that will facilitate the distribution of events and notifications to all people who have an interest. These pub-sub technologies, such as JavaSpaces™, build on research conducted by Gelertner,[20] who investigated the applicability of ''tuple spaces'' as a means for efficient, large-scale coordination among many distributed processes.

Gelertner, a creative and visionary computer scientist, also investigates techniques for organizing multimedia experiences, so-called lifestreams, into a readily accessible form.[21] Such technology would serve admirably to enhance the ability of collaborators to locate relevant information. Elsewhere (see *Computer-Supported Cooperative Work*), we discussed other research along these lines, such as Rough'n'Ready[22] and Informedia,[23] when we considered the importance of access to raw multimedia recordings of collaborative sessions. While this class of research has not yet matured to the point of widespread commercial availability, CSCW developers should be poised to make effective use of the technology. The same might not be true for pending advances in ''tele-immersion.''

As we outlined earlier, existing technology for videoconferencing has failed to achieve widespread acceptance, probably due to expense, configuration complexity, and requirements for guaranteed quality of service from the network. Despite the seeming failure of this technology, a few researchers[24] continue to investigate the possibility for radical advancements in tele-immersion, a technology that aims to facilitate live multimedia interaction. The goal of Lanier and his colleagues is to exploit computers, sensors, display technology, and networks to enable remotely distributed collaborators to hold virtual meetings with the same degree of quality as if they were collocated. Success along these lines would prove invaluable to enhance the power and effectiveness of CSCW. The challenges, however, remain daunting.

Technology for creating digital paper appears to be a bit more achievable at present. The ability to use paper-like devices to load and display information should provide significant improvements over current forms of visualization, freeing collaborators from reliance on bulky, expensive, power-hungry displays. As discussed earlier, companies such as E Ink are already developing some products along these lines. More work will be required to integrate input modalities along with digital-paper displays in order to provide collaborators with the ability to interact. Computer-supported cooperative work developers and researchers would be well advised to increase their investigation of techniques that can exploit familiar human interaction devices, such as whiteboards, walls, tape, paper pads, markers, and pens, while simultaneously crossing the boundary between the physical and digital worlds. Promising lines of research include the Easy Living[25] and Sentient Computing[26] projects. Finding effective methods to bridge the gap between people and computers promises to yield great improvement in the interaction of groups, leading to a boon for CSCW.

Outlook for CSCW

Computer-supported cooperative work has become a hot technology and seems likely to remain so for the foreseeable future. The information age, and related exigencies associated with increasing globalization and specialization in our modern society, impels an ongoing transformation in the organization of work. Work is becoming more information-based, relying on computers and communications and increasingly involves the activities of teams, often across organizations and time zones. Usually, people work on multiple teams, where the team composition changes depending upon the context, subject, and business arrangements. In this demanding environment, organizations and people naturally seek to employ any technology that can help get the job done better, faster, cheaper. These factors presage difficult, long-term problems whose solutions hold immense potential to benefit companies, individuals, nations, and society. Today, we stand only 20 years into what might be a 50-year endeavor to research, develop, deploy, and

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refine effective, efficient, and affordable technology for CSCW. Computer-supported cooperative work might encompass the greatest challenges facing information technology researchers and developers, but CSCW also promises to deliver the greatest benefits that computers, networks, and software technologies have to offer mankind. The central question guiding the CSCW field can be stated simply. How can computing systems enhance cooperative work without unduly constraining human collaborative processes? The question has no simple answer.

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