Collaboration and Workgroup Computing

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Abstract

Access to networked computing has transformed collaborative work, and so we expect the new capabilities coming with the Next Generation Internet to have an important impact on communication at work. This paper attempts to identify key issues for design and deployment of new solutions, including: coordination and shared meaning, knowledge networks, capture and recall of group process, decision-making, new organizational forms, and technology appropriation. Implications of these issues for high-performance digital environments are discussed.

1. Introduction

Collaborative work has been transformed over the last 5 years by the emergence of internet-based collaboration technologies. Groupware systems, sets of tools for exchanging messages and documents, have been available to workgroups for over thirty years. However, until recently most groupware systems have not been met with enthusiasm from users.

The emergence of the World Wide Web has changed this in significant ways. An accelerating percentage of homes and businesses have network connections, and a large fraction of the public have reasonably late-model web browsers on their desktops. While pre-web groupware systems required special client software, newer solutions, which work through the browser, are much more accessible and easy to adopt. This means that the full range of group tools from email to bulletin boards to chat rooms to voice/video conferencing are accessible to anyone with a browser.

This has created both a receptive audience for collaboration tools and an appetite for increasingly rich multimedia communication technologies. As the greater bandwidth and quality of service expected from Internet2 networking arrive, some of these more advanced collaboration tools will become practical. The purpose of this paper is to discuss the organizational and social context for such large-scale technology change. These changes, which are already underway, are not only influencing the ways people relate to each other, but also the very forms that human groups and organizations can take.

The paper will first discuss the background literatures that are relevant for a discussion of workgroup computing, then describe the key technologies currently being used and/or developed, and finally, outline a set of critical issues for the future of collaboration technology.

2. Background literatures

The research that is relevant for an understanding of this topic is both voluminous and highly dispersed. Some key literatures are:

- Human-computer interaction
- Computer-supported cooperative work and computer-supported cooperative learning
- Groupware and group decision support systems
- Organizational behavior and management information systems
- Collaboratories
- Computer-mediated communication
- Distributed cognition
- Cognitive engineering
- Social networks and network organizations
- Social presence and teleimmersion

Each of these areas is a large and diverse subfield, and it is far beyond the scope of this paper to summarize the work being done. What follows will be of necessity a highly abstracted representation of results and issues.

2.1. Human-computer interaction and cognitive engineering

Human-computer interaction (HCI) is concerned with the design, use, and impact of interactive computer systems. An excellent current overview of this field is provided in the final report of the ACM Human Computer Interaction Working Group (Myers, Hollan, and Cruz, 1996). Research and development in HCI focuses particularly on user interface issues, and has led to the development of direct manipulation of digital object (e.g., drag and drop), multiple tiled windows, hypertext, and integrated toolkits for user interface design. The foundation of HCI is application of theories of cognition, social behavior and human performance to the design of computing systems. The highly related field of cognitive engineering (e.g., Rasmussen, Pejtersen, & Goodstein, [9]) focuses on the application of theory and research to the design of the entire range of engineered systems (e.g., mechanical systems as well as computers).

The critical sources for HCI and cognitive engineering thus provide the interface between literatures in psychology, sociology, and other human sciences and the process of design. Some key contributors are Norman [7], Olson and Olson [8], and Kay [3].

2.2. Groupware, computer-supported cooperative work, and computer-supported cooperative learning

The area of computer-supported cooperative work involves the application of theories of social interaction, group decision-making, coordination science, and communication to understand the design, use, and impact of technology to support joint work. A special subfield, computer-supported cooperative learning, focuses more narrowly on the use of such technologies in educational contexts. The technologies that support cooperative work are known as "groupware." A representative overview of this area can be found in Baecker's collection of readings on groupware and CSCW [1]. A good review of the literature and technology survey is provided by McGrath and Hollingshead [5]. Important related topics are distributed cognition and distributed artificial intelligence, the coordination of multiple intelligences to perform complex tasks.

Study and design of *collaboratories*, distributed laboratories, is an important related area. For an introduction, see Finholt and Olson [2].

2.2.1. Organizational behavior and management information systems

The study of organizational behavior contributes to the design and analysis of management information systems, technologies that support coordination, data sharing, and communication within work communities. Key topics addressed within this literature include decision support systems, emergent communities, enterprise architecture, information systems design, and virtual organizations. An excellent gateway to work in this area is the ISWorld Net web site: http://www.isworld.org.

Emergence and characteristics of network organizations, organizations whose existence is dependent on networked computing technologies, is a topic of particular relevance. An excellent survey and framework for work in this area is provided by Monge and Contractor [6].

2.2.2. Computer-mediated communication, social presence, and teleimmersion

The study of computer-mediated communication focuses on the special challenges and opportunities involved in carrying on human dialogue via computer networks. A key resource for study in this area is John December's comprehensive survey of web resources (http://www.december.com /cmc/info/).

A significant topic within this area concerns social presence, the set of information resources

that are used in unmediated interaction and their translation into an online environment. This includes information about the other interactants, including their words, behavior, and physical/social characteristics; information about the setting and history of the interaction; and information about shared knowledge and culture. A useful review of research related to social presence is provided Lombard and Ditton [4].

3. Critical technologies

Advanced digital collaborative environments commonly integrate three kinds of applications: document management, conferencing/ communication tools, instrument/application sharing, and capture. In addition, these tools may be integrated within an immersive collaboration environment.

3.1. Document management

Document management technologies involve the application of digital library capabilities to support group work. Documents are shared digital work objects they can be videos, electronic forms, email messages, reports, or any other kind of documentary material. Document management systems coordinate the work done with such material, and in particular support coordinated use of documents. There are two key capabilities of a document management systems: *archiving* and *workflow management*.

3.1.1. Archiving

Archiving involves the storage and retrieval of documents, including such related issues as access management and data mining. Some critical drivers for future development of these technologies are:

- increasing diversity and amount of relevant information and databases;
- limitations of current indexing schemes and practices, combined with the need to support unanticipated uses of information in the future;
- increasing fluidity of organizational membership and boundaries, which complicates access control.

The arrival of high performance networking will enable new and expanded uses of such technologies. First, it will make sharing of rich media objects more practical by providing increased bandwidth. Second, as bandwidth increases, it will become more practical to conduct real —time analysis of complex databases from remote sites. Some of the more interesting I2 applications being shown this year, such as the Vanderbilt news archive, involve such remote search of large multimedia databases.

3.1.2. Workflow management

Workflow management involves coordination of the multiple contributions of individuals to a work process. The contribution of each individual is a subtask, a part of the whole to be achieved. A pair of related subtasks can be loosely coupled, capable of being carried out independently, with little communication between agents performing the work, or closely coupled, requiring ongoing sharing of information and results between agents. Support for workflow is designed to achieve smooth coordination among agents; particularly recognizing the different kinds of coupling that can exist between tasks. A primary goal is reduction in the costs of coordination (in time, money, errors, etc.), thereby realizing greater advantages from distributed, collaborative work processes.

Critical drivers for technology development in this area are:

- emergence of ad hoc teaming, including cross-organization teams in virtual organizations;
- reduction in acceptable lead time for decisions, increasingly rapid development of events, and increased pace of decision-making; and
- increased complexity of tasks and teams, requiring improved coordination. The drivers in this area are not bandwidth intensive, nor to they require significant improvements in quality of service. The most likely kinds of developments in this area that will be enabled by Internet2 capabilities involve synchronous conferencing or shared applications (see below).

3.2. Conferencing

Conferencing technologies provide workgroups with ways to exchange messages. Messaging involves directed communication among individuals in a workgroup. Early conferencing

tools were primarily text-based, and so messages generally took the form of email to individuals or lists, votes, document annotations, or postings on bulletin boards. As internet-based audio and video messaging become practical, these will provide enhanced capabilities for multimodal interaction.

Conferencing technologies are often classified in terms of their temporal and spatial positioning. In general, a conference can involve synchronous or asynchronous communication; it can involve copresent or geographically distributed participants (see Figure 1).

Figure 1. Types of interaction

Spatial position/ Temporal position	Same Place	Different Places (Telecom-munication)
Same Time (Synchronous)	Conversation, group meetings, briefings, lectures, rallies, etc.	Telephone, point-to-point audio and videoconference, text chat, etc.
Different Time (Asynchronous)	Written memos, bulletin boards, displays, etc.	Newspaper, book, sound or video recording, email, online BBS, etc.

The critical drivers for development in this area are derived from the desire to replicate the advantages of same time, same place communication in temporally and spatially distributed work processes. Same time communication offers the opportunity to seek and provide feedback, which is critical to mutual understanding. Different time communication makes the process of getting and giving feedback cumbersome, and the effort to create frameworks for organizing feedback effectively in asynchronous settings has led to the development of a number of interesting tools for threading discussion, annotating drafts of documents, organizing electronic bulletin boards, etc. Same place communication affords multimodal information about the shared environment as well as the thoughts and reactions of others. In same place communication, this rich multimodal information is available to inspection and can be selectively attended to; in different place communication (telecommunication) each type of information must be directly and intentionally encoded and transmitted via some medium. So, for example, in ordinary telephone communication, the conversational situation is reduced to the basics of voice exchange. By contrast, MUD and MOO environments generally use text to create an explicit sense of shared online space that can ground interaction.

Obviously, the more modalities available for communication, the more fully a sense of shared place can be created (a quality know sometimes as social presence or sometimes as media richness).

Communication that is distributed in both time and space faces challenges in that both richness and immediacy will be lacking unless considerable effort is expended to capture or encode multimodal messages and contextual information and deliver ongoing feedback in response to messages. The ultimate goal is to provide technology solutions for all types of collaborative situations that generate necessary levels of richness and immediacy for all types of group tasks.

Increases in bandwidth and quality of service guarantees are critical for attaining this goal. The richer the information being transmitted, the more critical it is to have sufficient bandwidth available. However, bandwidth alone is not the issue. To achieve adequate performance for synchronous communication, the key issue is latency. Same time, same place interaction is characterized by extremely low latencies, less than half a second. Longer latencies are highly disruptive of the normal flow of interaction. Voice communication via Internet requires relatively low bandwidth, yet Internet phone is still not viable due to the length of latencies between messages. This issue is expected o be addressed in significant ways via the quality of service improvements coming with Internet2.

3.3. Instrument and application sharing

Instrument and application sharing, the final technology area, is particularly significant for tightly coupled collaborative work. In addition to sharing documents and messages, agents often need to actually share tools. This requires the

capability to remotely read and control instruments, computer programs, and displays, and to share data and control with coworkers. This is particularly significant for enterprises that depend on coordinated observation using networks of sensors such as constellations of satellites or radar arrays.

Critical drivers for technology development in this area are:

- development of networks of sensors that are geographically distributed, often with distributed ownership and/or governance;
- tight coupling of observational and analytic work, which requires real-time collaboration;
- reduction in the cost of information via instrument sharing; and
- need to provide quicker and more open access to information.

In this area, as in the area of synchronous conferencing, bandwidth and quality of service are critical issues. Transmission of large datasets requires larger bandwidth. And the same stringent latency requirements that apply to synchronous conferencing apply to shared applications and remote instrumentation as well.

3.4. Capture and process support

One capability that is easier to achieve under conditions of telecommunication or asynchronous communication is capture of group processes. Indeed, the very tools that permit interaction to be shifted in space and time automatically generate digital records that can be archived, searched, retrieved, summarized, and fed back to participants to improved decision-making. The value of these capabilities has led to the use of groupware to support not simply distributed groups but also groups that are working together in the same place, at the same time. For example, many group decision support systems are actually intended to make it easier to capture ideas, opinions, votes, and other collective cognitions from copresent groups.

Drivers for developments in capture and group process technologies are:

- improvements in the ability to capture, transcribe, abstract, and index ongoing interaction, particularly advances in voice technologies;
- improvements in the ability to abstract content and re-present in useful forms; and
- development of network teams, in which collective memory will need to be constructed in new ways.

Internet2 technologies relate to these drivers via their connection to multimedia interaction capabilities and management of large databases. But as with conferencing, the ability to transmit rich multimodal, particularly synchronous, interaction data will help to make capture and recall technologies more practical.

3.5 Integrated environments

A natural development for collaboration technologies is toward their integration into seamless environments that afford multiple capabilities. While one can find and use individual tools (e.g., a chat tool, a discussion tool), many users prefer the convenience and psychological comfort of an integrated online environment.

Many early prototypes of online collaborative environments, such as the PLATO educational software system which incidentally formed the basis for later development of the Lotus Notes groupware product provided such a multifeatured, seamless integrated environment. Several capabilities for document management, conferencing, and application sharing will be provided through a common interface. It is now common to find collaboration environments that offer an extensive menu of options for online communication (e.g., Netscape Communicator).

An additional interesting development involves the creation of virtual spaces online using any of several immersive technologies to recreate a sense of shared place. Some of these experiments use simple graphics and text to create a sense of place, following the model of the MUD or MOO. Others build on more sophisticated three-dimensional visualizations and sonifications. Indeed, some of the most advanced experiments in this vein create a shared immersive environment and then integrate a set of collaboration tools of the standard sorts into that online world.

Key drivers for this integration are:

- user interest in having access to multiple tools via a simple, uniform interface;
- potential to increase group performance through appropriate visualization of the task and work setting; and

- need to provide some of the rich multimodal information about the interaction situation to aid in communication.

Obviously, as these integrative frameworks themselves become more elaborate and are used for synchronous interaction, Internet2 bandwidth and quality of service become critical to making them practical.

3.6 Summary

Parallel developments of networking capabilities, broad adoption of key infrastructure elements such as internet service and web browsers, and applications to support workgroup computing are creating a world in which the ability to collaborate fluently and securely with distributed communities is increasingly a reality. The task of social science researchers is to provide a base of information about the ways in which these new tools are co-evolving with the communities that use them, and particularly about the key processes in group communication with which collaboration technologies must engage.

4. Critical issues

This section identifies a set of fundamental issues related to workgroup communication and collaboration; they are grounded in discourse theory, group theory, and organizational communication theory. I believe that the best way to organize research and development efforts is to connect to such core issues. After briefly overviewing each core issue, I discuss the ways in which developments in networking will generate new questions for social scientific research and new opportunities for technology development.

4.1. Communication and common knowledge

A fundamental discovery has been made about human communication: messages never express everything that a speaker means, but rather index a larger meaning. This larger meaning is multilayered, and is constructed by message recipients, who interpret the message and make inferences that go beyond the message. Both in message interpretation and other inference processing, recipients rely on their knowledge of the message context.

Some components of the context are immediate: the activity in which participants are engaged, the immediately surrounding discourse, the physical setting, and so on. But other components of the context must be retrieved and constructed by interactants. They must make assumptions about what the intended context was and then use those assumptions to warrant inferences about what the communicator s intentions were. The context is thus constructed reciprocally based on what is assumed to be mutually known and taken for granted. Most theorists now recognize that reliance on mutual knowledge is a key enabling process in communication.

Obviously, the collaboration technologies that make it possible to engage in new types of relationships also circumvent the normal processes through which individuals become acquainted. With less shared experience and fewer opportunities for direct observation of the other, an individual is left with a sparse basis for reasoning about what the other knows or intends. In such a world of disembodied others, individuals may well need special support to develop common ground. Notice that when work is tightly rather than loosely coupled, the need for common ground the basis for mutual understanding is even more significant.

This points to the first key area for research and development: understanding how individuals operating in virtual environments come to know each other and their common knowledge. This is especially important since in conventional communication, common knowledge is tied very closely to activities and the settings in which they occur it is situated. Social situations conventionally are laminated with layers of cultural knowledge, group knowledge, and personal knowledge. They are rich in history and association. Virtual spaces, being constructed freshly, offer relatively little sustenance for interaction.

Just as there are clear needs for research on the way in which interactants situate online communication and construct mutual knowledge in online settings, so there is an opportunity to develop new kinds of technologies that substitute for, or perhaps even improve on, the information gathering strategies we use in face-to-face communication. A good example of this is the genre of collaborative filters: tools that allow a user to register his or her qualities or preferences, be matched with a group of others based on the preference profile, and then use this match to generate referrals to new products, people, or

services (the best known example of this is the online bookseller Amazon.com). Other solutions might be as simple as creating opportunities for informal social interaction in a distributed team or as complex as having an intelligent agent mine group archives and deliver background information at the moment it is needed during discussion.

Finally, both to design new tools and to understand the impact of technology on communication, we need to understand the contribution of rich, multimodal interaction on the achievement of mutual understanding. Early results have suggested that the type and amount of information required by interactants is very much a function of the task in which they are engaged, and as we design and deploy rich collaboration environments, it will be critical to know when and where to expect that they will succeed in helping groups work better.

4.2. Group discussion and decision-making

A very large literature on face-to-face group discussion and decision processes has established a set of generalizations about group work, including:

- identification of the factors influencing participation in discussion;
- identification of factors influencing group0 inquiry, particularly knowledge pooling, critical thinking, and conflict resolution;
- group facilitation effects, in which individual performance is shaped by influence from peers; and
- identification of factors influencing leadership emergence and social influence in groups.

Perhaps because the growth of this literature pre-dated widespread use of workgroup computing, there is a relative paucity of research on how these processes work in groupware environments, situations in which groups are interacting via software systems. A key priority for research is therefore reexamination of the established generalizations in the online environment. In many cases, we already have good reason to expect online interaction to be different. For example, individual participation rates tend to vary, with some individuals dominating conversation. But different individuals are frequent contributors in online and face-to-face media. Similarly, early reports noted a marked lack of inhibition in electronic messages

However, the existing literature does point to interesting directions for application development, particularly in the area of discussion protocols. A protocol is a standard operating procedure. Discussion protocols are often realized in group norms or even procedural rules (for example, a rule that everyone must have a chance to contribute before a topic can be changed). Discussion protocols can also be realized in software: for example, discussants might be required to contribute to a particular topic, with software agents tracking their contributions to ensure that they have contributed. Translating normative models derived from theory and research into software provides a new way to test old hypotheses as well as new.

4.3. Organizational communication and networks

Studies of organizational communication focus on patterns of human relationship, some formalized in organizational roles and reporting relationships; some realized in informal linkages based on communication. One of the paradoxes in the study of organizational behavior is that the formal structure, which is often the framework within which an organization understands itself, actually has relatively little value as a predictor of how the organization will behave. Instead, the web of messages and relationships the communication network appears to be the critical system governing organizational outcomes.

This has become even clearer as many organizations have evolved toward a new form, the network organization. In the network organization, enterprises are held together by relations of convenience, potentially temporary and sustained through flows of information. While the informal network is critical in every organization, it is even more central to understanding virtual organizations and other coalitions.

The emergence of network organizations has been enabled by web-based collaboration technologies. Support for collaboration has permitted cooperation and coordination of effort on a scale of geographic dispersion and group size never before possible. These network organizations, as well as informal networks in more conventional organizations, are relatively

poorly understood and insufficiently cognized by their members. Particularly as the links in the network are created via telecommunications rather than face-to-face communication, issues of trust and confidence take on central importance.

This is an area in which increasing the capability of networks may aid in delivering information that is critical for judgments about network partners. Research, which examines the effects of social presence on such judgments, is needed to provide a basis for evaluating the adoption and impact of new tools to support interaction.

Another critical priority for research and development is thus creation of tools for monitoring and visualizing social networks and the influence that flows through them. Individuals lack good tools for representing their networks; the Team Engineering Collaboratory, with which I am associated, is one of many labs that is currently developing tools for displaying networks for their members as well as researchers. Such tools could be used to support decisions about collaboration and affiliation and to help find resources in large and far-flung network communities.

5. An agenda for research

This brief overview of collaboration technologies and of the critical issues in workgroup computing can provide the basis for a heuristic to guide a program of research on collaboration in high performance computing environments. The strategy I want to suggest has two components.

First construct a grid in which the technology futures are laid out along the side and the key group process issues along the top. This creates a diagram with a set of cells, to be filled with items for a research agenda.

To fill the cell, ask a set of key questions about the combination of each core technology and group process: First, what are the major generalizations about that process, and how might individual or group performance vary as interaction takes place online? Second, related to that process, what are the things that groups and individuals currently do poorly? And third, how might technical advances related to bandwidth or quality of service help to overcome workgroup-computing problems?

This exercise generated Figure 2, which shows a set of sample research questions in each cell. Figure 2 is just a demonstration. If a researcher sees a different set of technology developments as being likely, or if a researcher sees a different set of themes as being critical for workgroup computing, then the grid can be reworked. But the general point remains: Previous work provides an excellent foundation for studies of the implications of high performance networking and computing on working groups, but there are a great many opportunities for important new research and technology development.

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Figure 2. Sample Research Agenda

Workgroup issues Technology forecast	Communication and coordination	Discussion and decision-making	Organizational network structure
Document management systems	1. How do ad hoc, distributed teams develop common vocabularies for working on a problem? 2. Where do groups experience difficulty in finding a common vocabulary? 3. Can automatic construction of a thesaurus help groups develop common vocabulary?	1. How do digital libraries influence use of other collective memory strategies? 2. Do groups effectively retrieve all the information they have? 3. Can a digital library assistant help a group more accurately construct its knowledge?	1. How do group members currently identify the possessor of knowledge or skills that they need? 2. Are individuals generally successful in finding the right people to help them? 3. Could patterns of connection in document collections be used to point to expertise?
Conferencing technologies	1. How do persons using conferencing determine where their common knowledge lies? 2. Where do they experience difficulty in finding common ground? 3. Does increasing social cues and activity information aid in constructing common knowledge?	1. How does the interactional medium influence patterns of participation? 2. Why does unequal participation occur? 3. Does increasing or decreasing richness and/or immediacy influence patterns of participation?	1. How does the media through which team members interact influence trust? 2. Why do they fail to develop trust? 3. Can use of richer or more immediate conferencing tools help to build trust?
Capture and retrieval technologies	1. Do individuals have less shared background knowledge when interacting online? 2. When do individuals fail to retrieve relevant knowledge? 3. Can a digital assistant help in establishing the context for communication by providing relevant background knowledge?	1. Do individuals recall fewer ideas from online discussions? 2. When individuals fail to recall discussion content, why does that occur? 3. Can a digital recorder provide an appropriate and accurate summary of content themes from a discussion?	1. Do members of network organizations have a comparable understanding of organizational influence to those in conventional organizations? 3. Can network visualizations influence the ways individuals understand their organizations and solve problems?
Remote instruments and application sharing	1. Is using two identical instruments comparable to sharing one, or is common ground increased by sharing? 2. Is cooperative work impeded by parallel problem solving rather than joining problem solving? 3. Can shared instruments improve joined work?	1. Does sharing an instrument lead to different kinds of discussions than parallel operation of instruments? 2. What problems arise in sharing an instrument? 3. Does instrument sharing improve decisions made about how to calibrate or use the instrument?	1. How does control of instruments shape patterns of citation and collaboration in science? 2. What problems of coordination occur in shared use? 3. Does providing remote instrumentation change patterns of interaction among scientists?
Integrated collaboration environments	1. Are individuals who meet on line as efficient as those meeting face-to-face in forming impressions? 2. Where are the discrepancies, if any? 3. Can rich personal displays increase the detail and accuracy of impressions?	1. Are groups who work online as effective at tracking and managing workflow? 2. Where are the discrepancies, if any? 3. Can a multimedia group work room, with displays of project plan, prototypes, and progress, aid in tracking and managing workflow?	1. Are network organizations as self-aware as other types of organizations? 2. Where are the discrepancies, if any? 3. Can a model of the organization aid in navigating their knowledge network?