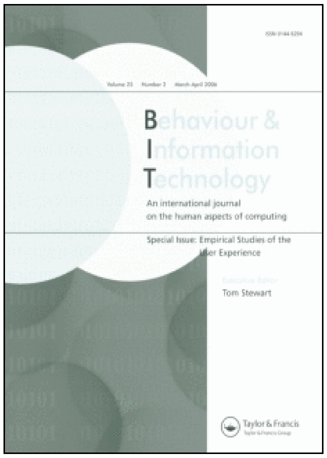

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Computer-supported co-operative work: research issues for the 90s

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Computer-supported co-operative work: research issues for the 90s

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1. Introduction

Much of today's work is not done individually, but rather in groups. Groups are here defined as sets of people who are knowingly collaborating on a common goal, who require communication and co-ordination among group members. Most real work is collaborative in nature, due to the complexity of the task, the severe time constraints, or the requirement for broad expertise. However, not all of it can or should be supported by computers. The focus of computer-supported co-operative work (CSCW) is the group work that potentially can be supported by some kind of technology, be it that for communication among group members or support of the conduct of the work itself.

Today's computers are woefully lacking in support for group work. We pass drafts of documents or designs among group members for comment and editing by sending paper mail or ascii conversions over email; groups huddle around one computer while they talk and gesture to create agendas, objects, or to-do lists and to make decisions; some use expensive video links and speaker phones to see and hear each other in meetings at a distance. Much more can be done. Researchers and designers are beginning to explore the special needs that groups have for technology support and to design systems that fit these needs.

Research issues for group technology echo many of the same issues listed in previous articles on human–computer interaction (HCI), but each with a special twist. Research in CSCW contains everything in HCI plus.

> There is need for **theories and models** of the users. With group work, theories must additionally encompass the conversations among the participants, the roles they adopt, and the organizational setting which guides many group actions implicitly, and the cultural practices. Simply stated, we need to understand the **nature of group work**. We need to know how the cognitive and communication abilities of individuals blend and progress in groups, both in the fast paced situation of face-to-face work and in the slower, constrained situations of asynchronous work. And, we need to understand how common knowledge from the organization and culture themselves implicitly guide activities.

Guidelines on **interaction styles** and **input/output devices** are incomplete when there are groups involved. That is, in addition to having devices that fit people's perceptual–motor and cognitive skills, group technology may also require a way to represent the intentions and actions of others who cannot be seen; entry and exchange of information may need to be very rapid so as not to interfere with the pacing of group interaction; in supporting remote group work, we may need to incorporate video and sound in such a way as to make the communication convey some of the richness afforded by face-to-face situations. When the interaction takes place over time, there may be an additional requirement to tell users what has changed or remind them about the previous context.

On the implementation side, there are needs for special **toolkits** and **user interface management systems** to manage the overhead that can be imposed by group work. This overhead includes facilities for tracking changes, keeping audit trails, presenting the myriad of views groups might demand, and allowing rapid simultaneous editing. Use of video for remote group work, both ana-

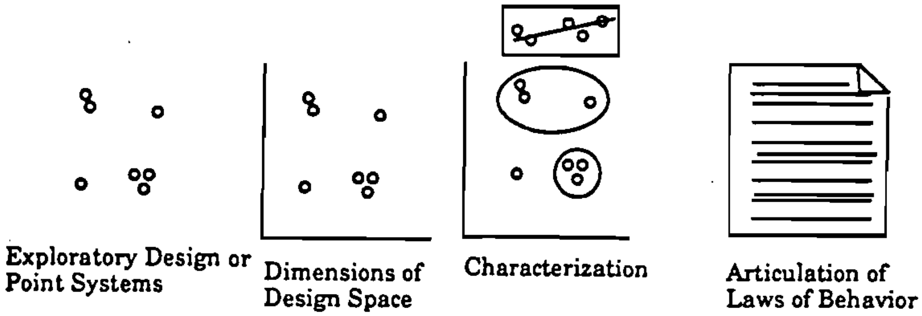

Figure 1. The four stages of the development of the field of HCI, from building example systems to articulating laws of behaviour.

logue and digital, poses special issues for the transport and display of large quantities of information at necessarily high rates of speed.

In addition, study of group technology generates two other important research areas.

> In group work, a salient feature is the **physical setting** in which it takes place. Eye contact and sound localization can affect the ease of communication, the perceived distance among the participants can determine the frequency of interaction, and noise, lighting, and the accessibility and clarity of the work object all play potentially important roles in the success of the work.
>
> Group work takes place in a very wide array of settings. To date, although there are some excellent anthropological accounts of group work, such as the work on SEALAB (Radloff and Helmreich 1968) and cockpit crews (Hackman 1986), most of the work under the rubric of CSCW is office work, design and engineering.[1] The design of technology for group work, broadly defined, would benefit from a better **characterization of the work and its organizational setting**.

This article presents a short review of the current state of research on CSCW, and then provides some look ahead as to outstanding important research needs.

2. Where we are in CSCW

CSCW is a younger field than HCI. Card (1991) has characterized the growth of the field of HCI as following four schematic stages typical of development of systems technologies in general. The four stages are illustrated in figure 1. According to this scheme, HCI has progressed from

—building illustrative **point systems**, or examples of what can be done to support work with computers;
—to evaluating, comparing, and reviewing systems so that we understand the **dimensions** (by which systems and work vary) that seem to affect the success of a system;
—to analysing the dimensions so that we can **characterize the relationships** in more detail;
—to finally **articulating** the models and laws that govern behaviour with systems.

CSCW is far behind HCI. It is mostly at the stage of building **point systems**. Many different systems have been built; only some have been evaluated; all show both the promise and the difficulties of computer support for group work. We are just beginning to understand the dimensions by which the systems and impacts vary, and have not yet characterized the relationships among them.

In fact, in this scheme, we have perhaps even missed an earlier prerequisite stage. We need to understand more about group behaviour itself, their strengths, weaknesses, preferences, and potentials. Social psychology informs us about the design of potential technology support less than cognitive psychology did at the advent of HCI. There are two reasons for this. Most of the research in social pscyhology focused less on the detailed process, and more on coarser grained observation of behaviour (e.g., Bales 1950, 1954), outcome measures, and retrospective reports. Furthermore, as was the style at the time, most work involved randomly assigned groups whose members were from the general undergraduate population, those who had no working history to guide their performance. Since then, we have recognized the importance of recording the detail of the behaviour during group performance (e.g., videotape that allows re-analysis of moment by moment behaviours and technology that allows automatic clocking of speaker utterances and extensive keystroke capture), and can analyse the behaviour in much more detail. We also recognize the importance of the group's organizational history, specific roles people adopt in a group

[1] But see Benson, Ciborra, and Proffitt (1990) and Engestrom, Engestrom and Saarelema (1990) for a recent look at computer support for non-office work.

they know well, and the hidden dictates from the organization's culture, telling individuals how to behave. All of these are critical to guiding the design and use of systems to support real work.

Although this four stage scheme describes well the progression of technology development, others have argued that it is not how systems *should* be developed. Rather, systems should be designed from consideration of the work situation, the group members, and the task specifics (e.g., Olson and Olson 1991). And, where appropriate, systems should be designed from theoretical considerations. Systems should be built for things that humans don't do well, and that fit the organizational practices. For example, asynchronous systems that do not support the maintenance of context are likely to fail because they lack support for known human limits in memory, and systems that capture data on worker performance can trigger outcries of Big Brother in a culture based on trust. Unfortunately, there are few theories that are ready for direct application to the design of systems in real organizational settings, and thus we have reverted to building systems and analyzing them in order to understand some of the basics of group work. In this sense, systems are informing theory just as theory can inform the design of systems.

In what follows, we first describe some current trends in CSCW in terms of major clusters of point systems, Stage 1, and then some early efforts to understand the dimensions of work and systems, the beginnings of Stage 2.

2.1. *The point systems, Stage* 1

2.1.1. *Group support systems*: A wide variety of systems have been developed to support different kinds of face-to-face group work. Because a lot of this work arose from Business Schools, in Management Information Systems departments, these systems pull together disparate prescriptions about how to help groups of managers solve business problems. First came Decision Support Systems (DSS), which were designed to allow a single business manager to retrieve information, display it in a variety of forms, and then make decisions about policy or practice. It was an easy migration to offer these systems to groups; thus the emergence of group decision support systems (GDSS).

Most GDSS structure the interaction among group members. For example, they require the group to separate their brainstorming activity from organizing the ideas and evaluating them. The systems allow groups not only to phase their work but to use various tools to help them in each phase (e.g., Nunamaker *et al.* 1991). Some GDSS require the services of a facilitator and someone to retrieve, run, and store results from one subtask to the other. Other group support systems, such as Colab (Stefik *et al.* 1987), ShrEdit (McGuffin and Olson 1992), and a commercial product, Aspects (Group Technologies 1990), are more free form, allowing groups to use a shared workspace as they wish.

Not surprisingly, these systems are evaluated as being variously facilitating and inhibiting in the decision making process and in the quality of the work product (McLeod 1992, Kraemer and Pinsoneault 1990). Generalization across all these GDSS is difficult, since they are designed to support very different aspects or phases of group work, to support groups of different sizes, and groups doing different kinds of tasks. They also have interfaces of various levels of quality, reside in different physical settings, and require various levels of skill in facilitation and technology manipulation (Hollingshead and McGrath, in press).

2.1.2. *Electronic mail and conferencing*: Email has been held up as the one groupware application that has seen wide success (Satzinger and Olfman 1992). For many, the ability to communicate with others in distant locations or at different times is greatly enhanced because of email. Corporations can broadcast messages to many at once without the time and cost of duplicating and distributing memos; communication can take place smoothly in spite of the fact that conversational partners are on different continents and dramatically different time zones. Voicemail additionally allows access to those who do not regularly use computers for communication, and transmits voice identification and intonation as well as the words themselves.

There has also been a fair amount of study of the use of electronic mail. Because of email's power to reach many subscribers quickly, it has changed the culture of the organizations in which it resides: it changes who talks to whom (Sproull and Kiesler 1991), what kind of person is heard from (Finholt, 1990), and the tone of what is said (Sproull and Kiesler, 1991). That is, some people, forgetting that there is a human reading the message at the other end, and in the absence of feedback from the recipient, tend to 'flame', to write asocial emotive messages that are either shocking, upsetting or offensive to the reader.

The fact that electronic mail is cheap and that sending a single message to a distribution list is easy, people send out a lot of it. Subscribing to bulletin boards or news lists can clog the email pipeline and make the task of examining and answering email aversive. Furthermore since mail arrives in chronological sequence, it can become difficult to follow the thread of a conversation; people do not fully explain referents (e.g., they say only 'OK. Friday' in the message as opposed to set the confirmation in context); readers get confused. And, email is currently severely limited to ascii text or Binhex encoded non-textual objects, mainly because we have no commonality across systems platforms.

In response to these problems, some email systems organize messages by topic. For example, Information LENS (Malone *et al.* 1987) and MagicMail (Borenstein 1992) allow users to generate rules by which the incoming mail will be sorted into folders that can be later examined by the reader in some priority order. Commercial products, such as Lotus Notes (Lotus Development Corporation 1989), organize both mail and various documents in a structured shared environment. Some email systems (e.g., the Michigan email system) allow readers to access the thread of a conversation by showing the preceding message as well as the current message which is its answer. The Co-ordinator (Winograd 1987) goes one step further in making the sender declare the action that the recipient is expected to make, by designating the message as a request, a commitment or promise, background information, etc. And, in response to the frustration of being limited to ascii text, a number of systems have been built: Slate (Thomas *et al.* 1985), and Andrew (Morris *et al.* 1986) are designed to send fully formatted, editable text, spreadsheets, and graphics. The NSF EXPRES project attempted to send multimedia through X-windows running on different platforms and sharing between systems through ODA[2] (Olson and Atkins 1990).

2.1.3. *Group authoring systems*: Much of group work currently consists of individuals writing documents (e.g., system requirements, policy proposals, project proposals) and then soliciting comments from many different people and making changes, iterating the comment/change cycle again. Today this activity involves a lot of paper drafts and a great deal of time simply entering edits previously decided upon. Some systems (e.g. For Comment, Edwards *et al.* 1986) support the commenting that people make, allowing marginal comments or electronic Post-its to be attached to the original document. Quilt (Leland *et al.* 1988) similarly allows marginalia-type annotation, but in addition helps with the co-ordination, planning, and information sharing with a notification system and a way of setting permissions of who can read and write various items. A new system, called the PrepEditor, allows readers to add comments in a side column, like a spreadsheet; the author then views readers' comments either individually or all at once, side by side. This supports the collating of suggested changes, which often come in the form of debates on various issues (e.g. Neuwirth *et al.* 1990).

In addition, there are more specialized systems to support groups whose tasks involve designing something, be it a computer system or architectural plan for a kitchen or building. Most of these systems are designed to capture the argumentation during the design process, linking the questions of consideration with the alternative solutions that were proposed as well as the evaluative discussion that accompanied it. The most well known of these is gIBIS (Conklin and Begeman 1988) which uses a hypertext linking structure to organize the various issues, alternatives and criteria in the design rationale. A great deal of interest has followed this early line because there is a strong belief that this kind of system would not only help designers design better by considering more alternatives and considering them more fully, but also help those other team members that later have to maintain and/or alter the system (Moran and Carroll, in press).

2.1.4. *Video for remote connectivity*: Ever since Picturephone (Wish 1975), designers have been exploring the use of video connections to support people working at a distance (Egido 1988). And, in spite of the commercial failure of Picturephone and the lack of evidence that video connectivity does anything to enhance simultaneous group work at a distance (Chapanis 1973), people persist in trying it. Video conferencing systems are commercially available (e.g., Pictel), intended to support distributed meetings where group members view their remote colleagues as well as a presentation outline, viewgraphs, or diagrams. Some experimental video systems are intended to support two or more co-workers while they engage in close work (Tang and Minneman 1991). The Video Whiteboard focuses the video only on the object under discussion and the hands drawing; others, like CAVECAT (Mantei *et al.* 1991) put the faces of the co-workers on the screen in small windows. Commune (Minneman and Bly 1991) show both user and drawing surface, whereas the ClearBoard (Ishii and Kobayashi 1992) blends the two by arranging people on either side of the object under discussion, as if looking through glass.

Other interesting systems have been developed to support the more casual interaction that people engage in over the course of long term group work: Cruiser (Fish *et al.* 1992) allows quick glances into people's offices to see if they are there and/or interruptible; the VideoWindow at Bellcore is intended to encourage both ordinary meeting and casual interactions from remote sites over coffee (Fish *et al.* 1990), and the RAVE suite of systems at Rank Xerox EuroPARC (Gaver *et al.* 1992) is intended to support awareness of

[2] ODA stands for Office Document Architecture.

global activity, glances into individuals' offices, and point-to-point contact for close intense work. Long-term use of video connectivity was analysed in the Portland Experiment (Minneman and Bly 1991).

In all of these point systems—group support systems, email, group authoring, and video systems—the question of evaluation emerges. In what way can technology be helpful to work? Can technology help overcome barriers of human communication (e.g., voting systems that allow even reticent participants to input their opinions, anonymous brainstorming that allows input without fear of reprisal)? Can it help us overcome the barriers of time and place of work (e.g., help reduce travel costs for meetings, help casual interaction among divisions that are not co-located, allow more consistent, timely interaction without formal initiation of meetings)? Since the field is still at the first stage, constructing point systems, and not yet at the point of discerning even the dimensions on which these systems differ, there is no simple answer. The question of whether technology helps is universally answered weakly by the phrase, 'it depends'. We now have to find out what it depends on.

2.2. *Beginning to understand the dimensions in the field, Stage* 2

Before we will fully understand the ways in which technology does and does not support group work, we need to better characterize the work situation, the players, their tasks, and the kinds of media used for supporting them.

2.2.1. *The global characterization of the group work situation*: CSCW covers a wide set of situations in which groups perform their work. Johansen (1988) nicely characterized the different sets of situations by separating the dimensions of time and location of work, noting whether they are the same or different.

		Time: Same	Time: Different
Place	Same	Face-to-face meetings	Project Rooms, shift work
	Different	Tele- and video-conferencing	Email, annotated drafts

That is, work can be in the *same place at the same time*, such as face-to-face meetings and informal project work. Electronic meeting rooms like Colab are intended to support this type of work. Group work also occurs in *different places but at the same time*. Systems, such as video and audio teleconferencing, fall into this category; they focus on remote work and attempt to help the individuals communicate effectively with a different set of channels and tools than those used in traditional face-to-face work. The third common situation is work that is *neither same place nor same time*; systems support it through email, conferencing, and group authoring tools. This kind of work requires not only the transfer of work objects and comments, but the overhead of coordinating the people. The fourth cell, work that takes place in the *same place but at different times* is less common, but is seen in shift work as in hospitals and factories, and in project rooms, places where all the material for a project resides, but individuals in the team come and go.

Although this characterization helps separate the different major modes of group work, one interesting offshoot of the development of certain technologies has been that these distinctions can be blurred to advantage. Currently, for example, in meetings, participants bring prepared material and take notes for work to do when they return to their offices. With in-room technology, which supports each person's ability to jot down ideas as they occur and can display one or more person's work, we see two changes. Work gets done *in* the meeting; and there is a smooth swing from silent, parallel thought and development of ideas, to a focused, one-at-a-time viewing of each person's shared ideas. Thus, technology has the power to blend synchronous and asynchronous work in new ways. Of course, whether this is beneficial or not remains to be seen.

2.2.2. *The kinds of tasks groups engage in*. Social psychologists have investigated aspects of the nature of group work for a number of years. Although the results are spotty and do not always generalize to the kinds of populations we are most concerned with, a taxonomy of kinds of group work has emerged. McGrath (1984) for example, has categorized eight types (see Table 1). In his original formulation, this list is drawn in a circle, with adjacent types sharing some features in common; the result is referred to as the task circumplex. This

Table 1. Task types, from McGrath (1984).

Planning tasks	(problem solving, generating plans)
Creative tasks	(generating ideas)
Intellective tasks	(solving problems with a correct answer)
Decision-making tasks	(solving for preferences)
Cognitive conflict tasks	(conflicts of view)
Mixed-motive tasks	(conflicts of motive/interest)
Contests/battles	(conflicts of power)
Performances	(psychomotor tasks)

taxonomy specifies whether the work involves co-operation or conflict, whether it involves conceptual work or motoric actions (as in a sport), and which stage of development the work is in, whether the work involves generating, choosing, negotiating, or executing.

This is not the only task typology possible, nor is it necessarily the most fitting for informing the building of group technology. Steiner (1972, 1976), for example, has examined in more detail how tasks require information from group members to be combined, which might lend itself to extension to inform us about how technology might support activity. But, both of these typologies miss the kinds of tasks groups engage in when they are trying to learn, to co-ordinate (as in giving a presentation so all participants can critique or buy in to the solution), or to get to know each other better.

It is very important for researchers in CSCW to develop or adopt some such categorization. When we understand the details of the tasks people are engaged in, the difficulties and obstacles they encounter in achieving their goals, and the successful techniques they use, we can better design systems to support the work. And, when we build systems and evaluate their effect on work, we may be able to generalize to the other kinds of work in the same class.

2.2.3. *The technology or media*: A variety of media have been used to support group work, and each medium supports different aspects of interaction. The primary differences have to do with whether the technology supports communication *about* the work, or whether it represents the work itself, similar to the content/process distinction made by Putnam (1981) and Poole and Hirokawa (1986). Thus, video connectivity typically supports conversation, including gestures and, sometimes, eye contact, as well as presenting actual artifacts (e.g., a model of a new landscape). On the other extreme, a real-time shared editor supports the work itself, presenting to all participants text, outlines, diagrams, etc. for both viewing and changing. Of course, chat boxes, bulletin boards, and email are a blend, supporting both the work and the conversation about the work, but by blending these roles, occasionally there is difficulty in understanding what a particular message means. Part of the progress in CSCW will come from delineating the dimensions on which the technology support differs.

Dimensionalizing the space of possible technology systems is difficult because in part it consists of generating a general theory of coordination or collaboration (e.g., Malone and Crowston, 1990). A key issue in the design of technology to support collaboration is which

Table 2. Seven media and their associated constraints from Clark and Brennan (1991).

Medium	Constraints
Face-to-face	Copresence, visibility, audibility, cotemporality, simultaneity, sequentiality
Telephone	Audibility, cotemporality, simultaneity, sequentiality
Video teleconference	Visibility, audibility, cotemporality, simultaneity, sequentiality
Terminal teleconference	Cotemporality, sequentiality, reviewability
Answering machines	Audibility, reviewability
Electronic mail	Reviewability, revisability
Letters	Reviewability, revisability

aspects of co-ordination should the technology explicitly handle, and which should be left to the social or organizational practices of the users. Of course, this depends on the task, on the nature of the group, on the specifics of the technology available, and other factors.

Attempts to dimensionalize the space of CSCW technologies are just beginning to appear (e.g., Ellis *et al.* 1991; Malone and Crowston, 1990, Olson *et al.* 1990, and Dewan and Choudhary, in press). These efforts are still quite preliminary, and there is no widely accepted framework. However, this is an extremely promising area of work, for it will help us to move beyond the early point systems of technology toward general theories of co-ordination that are needed for understanding how the technology can fit into human social, organizational, and cultural practices. These will be the key to developing effective technology tools in the future.

Other researchers are beginning to characterize the aspects of media that affect communication (e.g., Clark and Brennan 1991). They first note the features of communication that help one person easily understand the other, called 'grounding': Co-presence, visibility, audibility, cotemporality (receipt as it is produced), simultaneity (ability to send and receive simultaneously), sequentiality, reviewability, and revisability. They then evaluate various technology media for support of these features, as shown in Table 2.

These features variously support or disrupt a person's ability to understand the others and to move work forward. This analysis is then the foundation for evaluating the effects of degradation that technology sometimes produces on the quality of the work that the group is doing. Other candidates for such a feature or variable list might include delay times, ease of access to previous content, expressive quality, and quantity, etc.

2.2.4. *The group members*: Groups vary in both the characteristics of the individuals and how they interact with each other, their style and pattern of management. How do we characterize groups themselves in order to both discover appropriate technology support and generalize the findings of the success of one kind of technology from one group to the next?

First, there are characteristics of the individuals who comprise the group: their various expertise and talents, their attitudes, and personality characteristics. But equally important are features of the individuals' interactions with each other: how long they have known and worked with each other (how much they share a set of habits, expectations, and knowledge of each other) and what process they have adopted to manage themselves, including their roles for leading, playing devil's advocate, or following. These two factors are known as cohesiveness and structure; both of these additionally vary as a function of the size of the group (Forsyth 1990). Some of the relevant research comes under the rubric of team composition from organizational behavior, as reported in Hackman (1987) and previously by McGrath (1964).

There is an old literature on small group interaction (e.g., Bales 1954, Bavelas 1950) that focuses on the division of functions between participants that emerge either universally or in task and individual-dependent manners. For example, in almost all groups, 'process' and 'task' leaders emerge, and are rarely the same person. The smooth and effective working of groups can depend heavily on the proper division and exercise of leadership and participation roles which can be controlled or facilitated by the constraints or supports of the medium of interaction (Bales 1954, Fikes 1982). These studies were done before the availability of computer-mediated communication. They should be renewed and exploited as sources of suggestions for needed functionality for CSCW.

One can imagine how these characteristics of individuals and group structure interact with the embedded structure in technology. A group with one pattern of behaviour in unsupported work settings, e.g., democratic, cohesive but free-for-all, might react poorly to a technology that has embedded in it an autocratic method. The formal GDSS found in the Arizona lab, Plexys—where the group is expected to move first to brainstorming, then to structuring the ideas, and then to consensus forming or voting—might be a failure for this type of group, while the group might better fit free-for-all software such as the group editors of ShrEdit (McGuffin and Olson 1992) and Aspects (Group Technologies 1990).

2.2.5. *Integrating these dimensions*: Determining what type of group technology will be successful depends heavily on specifying all four of these aspects: the global situation (implied in asynchronous versus synchronous work), the task, the technology or media, and the group composition. These lists of aspects are just a first cut at understanding the dimensions on which computer supported cooperative work varies. We have yet to discover the relationships that hold among them, and the underlying causal explanation of why these relationships hold. That is the core of the research issues, outlined below.

3. Research issues

The foregoing review highlights some of the ongoing research dedicated to understanding how technology might support group work. In what follows, we outline a number of important additional research issues, essential for CSCW to move from a field of point systems to a higher stage.

We will need to:

(*a*) understand the fundamental nature of the group activity that we are attempting to support;
(*b*) extend our understanding of the dimensions by which the important aspects of the situation, the task, the technology and the group composition affect work;
(*c*) begin to build laws of group-technology behaviour.

We note on the immediate horizon special issues having to do with:

(*d*) the interface to both the object of work and the co-workers;
(*e*) the physical setting, whether virtual or real, in which work takes place;
(*f*) the underlying computer science to make new ways of work technically possible and economically feasible.

In addition, there are overriding issues of how we proceed in doing this work,

(*g*) our methods and analyses and theory building tools.

And, recognizing that the cost of research on groups is much greater than that for the support of individual work, we list a number of issues in the conduct of this endeavour that lead us to conclude that CSCW will require:

(*h*) a substantial effort, with a concomitant need for supporting infrastructure.

3.1. *Theory*

There are two contemporary approaches to the theory of group work. Simply stated, one approach is *top down*, from the view that the collective, the organization or group, is the object of study. It is the collective that has goals, methods of operations, and capabilities of its own including the ability to learn. In this view, individuals make up parts of the whole, but they are not necessarily equal subparts, each having a possible range of activities, either co-ordinated or not. The other approach is *bottom up*, from the view that the organization is a collection of individuals with strengths and weaknesses, interacting to produce a group outcome, not necessarily in concert. The first is the view of organizational behaviour and organizational psychology; the second of cognitive and social psychology. Their vocabularies, phenomena, and methods of study reflect their views.

In the view that the organization is the object, the relevant vocabulary often focuses on the global goals, the amount of shared view of those goals, and the agents who together perform those overall goals. Emphasis is on co-ordination of the individual agent activities, whether the co-ordination takes the form of expectations, norms, or internalized procedures. Focus here is often on how co-ordinating messages are passed from agent to agent, how agents perform their activities, and how certain kinds of organizational forms (e.g., hierarchies or markets) favour certain kinds of co-ordination over others (Levitt *et al.* 1992, Malone *et al.* 1987, Malone 1987).

Commonly, the technologies that are the focus of this line of research are those supporting asynchronous work. They include electronic mail, shared databases such as Lotus Notes, and various forms of hypertext including those incorporating Design Rationale notation, for such tasks as tracking change notices in engineering development or tracking of check procedures through a Shuttle launch.

Theories that go under the rubric of Co-ordination Theory (Malone and Crowston 1990), Organizational Learning (March 1988, Weick 1979), Situated Cognition (Lave 1988, Suchman 1987), and Distributed Cognition (Hutchins 1990, 1991) stem from this major view as to the nature and understanding of group work.

In contrast, the view that organizations are collections of individuals examines the task being accomplished by a set of individuals, each of whom has certain built-in strengths (e.g., ability to learn, make allowances for error, solve problems intelligently, etc.) and limits (e.g., slow to learn, inaccurate in communicating both sending and receiving messages, having conflicting motivations, etc.) In this view the emphasis is commonly micro: on the stage of problem-solving or activity the collection of individuals is in, how they blend their experiences and divide their attention, and how they move from individual to coordinated work and back. Additional emphasis is on the ways in which the individuals communicate their ideas, requests, and misunderstandings to each other, and the ways in which various technologies and media either help or hinder that co-ordination. Many of the work situations that are the focus of this approach are synchronous, either face-to-face or remote, with shared work objects and video or audio channels. The theoretical machinery is borrowed from cognitive psychology and communications. Some interplay of the roles people take and their interaction style (e.g., Bales 1950) are from social psychology, some (e.g., Fikes 1982) from cognitive science.

These are distinct lines of theorizing that are relevant to the global understanding of the nature of group work and the design and assessment of technology to support it. The field being so young, there is no need to encourage one over the other, nor to discourage entrants of other kinds.

Such theorizing has the potential of guiding our discovery of new ways of working. Technology removes some constraints and opens new possibilities. For example, having an electronic shared workspace with equal, parallel access to all participants allows behaviour we do not normally see in traditional meetings: people can *do work* in the room in parallel, moving freely from focused discussion to parallel work and back. This changes the character of the meeting from a situation in which we only talk about work (project management and planning) to a situation where we create and co-ordinate emerging work. We need better understanding of how groups fail to function optimally to suggest as yet untried supports (e.g., perhaps of new modes of record-keeping and access, or control of turn taking—but based on knowledge of what works). Such understanding will require a new generation of empirical work on the behaviour of groups and extended theory.

3.2. *Interface issues*

A number of the issues in the design of single-user interfaces apply to those for group interfaces. Two of those issues are especially highlighted: the core representation of the object of work and the simple ergonomics of presentation for making something readable and audible.

The group's topic can be either easy to communicate or obscure depending on the *representation* the group decides to use. For example, if the group is discussing the dependencies in time and resources between their various subtasks or projects, having the linked diagram of a Gantt chart helps communicate better than does an outline format of the subtasks and lists of dates due. Whatever research there is on representations for thought for use in single-user systems (e.g., Larkin and Simon 1987) needs to be extended to cover the communicative ability of those representations as well.

Participants in real-time group settings, either face-to-face or remote, today often have a great deal of difficulty simply receiving the intended information. In a computer-supported room, they are typically sitting further away from their screens than they do at their personal systems or are viewing the work object on a public projected screen. Variables of display contrast, background lighting and font size and kind can make the shared information either easily accessible or indiscernible. When working remotely, the simple presentation of the remote participants' voices is often unclear and uneven. These simple features, themselves, can have an enormous impact on the conduct of work, who will participate, and to what effect.

However, in addition to the interface issues that appear jointly in both group work and individual work, there are a number of issues that emerge uniquely because the work is done in a group (Olson *et al.* 1990). In some current systems, group members are no longer in full control of the changes to their system; co-workers are adding to the shared database (as in hypertext) perhaps without the knowledge of the individual, and things appear and disappear in real time in group editing systems. Users report that they are out of control and uncertain, far more than in single user systems, where the only active agent other than the user is the buggy software or crashing hardware. Furthermore, users ask for some indication of what the other members of the group are doing if they are working simultaneously (called having a 'sense of presence' of others). Also, if conversation is focused, they seek a way to co-ordinate their views, to be able to point to things in a short-hand style ('over here we need to . . .'). Clearly, various interface controls of the coordination of views and the 'telepointer' feature are important.

Also, to support the flow of work when the group members are not working simultaneously, there is a need for a way to convey the progress or changes made to the object since last time. There has to be smooth co-ordination between joint work and individual work, so that the shared document, or pieces of it, can be transferred to the single participants' workstations and back, and merged in a graceful fashion, both mechanically and in terms of the logic and expressive style of discourse. In a similar vein, people need to be able to control who sees what of their work, whether the annotations they are making are strictly private, shared among a subset of group members to read and or change, or whether they are for public viewing or editing. Both the control mechanism and the way the 'state' of a piece of information is conveyed to the user presents new interface research issues (Olson and Olson 1992, Madsen 1989).

3.3. *Design of physical space*

Group work has other aspects than electronic technology whose ergonomic features must be arranged or designed. Face-to-face group work takes place in meeting rooms, whose dimensions and placement of technology matter to the conduct of the work. As mentioned above, the participants typically sit further away from their technology support than in solo work, because their focus is on the conversation as well as the object (Mantei 1988). Our ability to understand conversation is often aided by seeing speakers as well as clearly hearing them, so individuals often migrate to a formation that allows them to see others. This potentially pushes them away from where the technology is housed (e.g., in the meeting table or a front screen), and thus, the information on the screen is less readable, unless it is purposefully made larger.

However, it is not just the distance of the people from the object they are discussing or the information presentation that matters, but also the ease of the communication among participants. We know from the field of proxemics (Hall 1966) that the distance and direction of regard between participants determines their attention and focus. Sitting further than 6–7 ft from a person across from you will encourage you to talk not to them but to the person next to you. Sitting at 90° to a participant is a more conducive angle of conversation than one either directly face-to-face or side-by-side (Sommer 1969). Thus, the spatial arrangement of a room can determine some of the conversational dynamics. Meeting rooms that house computers often alter these basic relationships. More of these effects need to be understood.

Things become even more complicated when people are not working face-to-face, but at a distance. We know that people who conduct remote meetings will choose high quality full-duplex audio over high quality video, because of the critical nature of timing to the conduct of human conversation (Clark and Brennan 1991). Furthermore, it disrupts one's normal learned responses of interpreting what others are doing when the video presentation of remote participants is not spatially sensible. That is, if the camera is placed in the upper corner instead of at eye level, or if two or more cameras' outputs are juxtaposed (so they look like bleachers full of meeting participants), the participants can no longer use their well-learned, 'natural' recognition processes to easily monitor the ambience of the group. Our ability to interpret the spatial location from sound is also potentially important to the design of the audio connection, to determine who is speaking, what background conversations might be taking place, and what sound distractions might be disrupting the remote participants (see, for example, Krauss *et al.* 1977).

Similarly, these ergonomic/proxemic considerations are important in the design of technology support for remote smaller groups of point-to-point co-workers. For example, the flow of work could be altered if video-links were positioned so that a participant couldn't tell where the others were looking, whether they were understanding the points discussed (by eye gaze) or referring by gesture to some unseen object, or attending to something going on in their background. How much work is altered and whether the resulting output is hindered or helped by these spatial features need research.

3.4. *Computer science issues*

New ways of using technology to support group work presents a number of challenges to the state of knowledge of computer systems themselves. On one end of the spectrum, synchronous group work with video connectivity pushes our network capacity and speed beyond its current capabilities. It is this capacity that is the goal of the National Research and Education Network (NREN), the national program for connecting the nation's research and educational institutions with high bandwidth, building on the Internet and NSFNET (Kahin 1992). At the other end, an organization that wants to keep an audit trail of all the changes made to various parts of interrelated documents has a nightmare of information on its hands that not only needs storing but managing and smart retrieval mechanisms. There are issues in shared database about how to maintain the integrity of the work; much of this focuses on solutions in the form of 'versioning' and locking various blocks of information from others' access while one person is working on it. We are pushing computer science for both speed and size.

Work is underway to provide the needs that group computing has generated. Algorithms are being explored that allow synchronous input and editing to a common document without 'locking', but rather smooth 'do what we mean' adjustments to conflicts (Ellis *et al.* 1988). Audio and video compression techniques are being explored so we can support the transport requirements of real-time interaction of people communicating across long distances (Le Gall 1991, Wallace 1991). Systems are built to store and retrieve large amounts of multimedia information linked in novel ways.

A separate line of research focuses on how to incorporate video into the workstation itself, so that the transport of video can be handled in much the same way as other digital information. Video on the workstation poses a number of interesting issues, both in its design, and in the interplay of the various kinds of degradation that occur because of bandwidth limits. These degradations will have effects on the work the users are trying to conduct. We need research on both the mechanisms for presentation of video and the relationship these have to the conversation/co-ordination that people are engaged in in real-time work. Issues about the kind, timing, and control over the degradation all are important for this kind of technology for group work.

Furthermore, there are a number of people investigating hypermedia, the design of systems to support organization of information, that allows meaningful relationships among information pieces to be captured and explored to suit many different work situations (Conklin 1987, Landow 1990). This type of system has a number of attractive features, allowing various users to explore different relationships, getting more from stored information than just one view. However, there are a number of outstanding issues having to do with the retrieval of this information, either by the user of information entered by another or by a group that allows others to add or modify the structure. Clearly there is a need for some guide to the content or change to a structure, as well as help in finding relevant pieces when doing work (Halasz 1988).

Group work, additionally, can benefit from allowing groups to have shared access to any of a number of single-user applications (e.g., Timbuktu, Farallon 1987). Because of the way these applications were built, this 'groupification' is not trivial. We need ways to easily specify what is shared, its read/write access, its linking of views, etc. to make something fit the task and the preferred style of group work (Patterson *et al.* 1990). Furthermore, we need UIMS to provide building blocks for network information exchange and monitoring to help developers to build entirely new group applications (Lantz 1986, Lauwers and Lantz 1988).

There are a myriad of possibilities that present-day computer systems can provide for groups of users. The design space is enormous. What is called for is the analysis of group work to guide or focus the research of computer scientists on the aspects of technology that seem to impact the group interaction the most. Thus, work on rapid transport of video and simultaneous work, the storage and retrieval of large amounts of structured, multimedia information, and the storage of audit/history information, are topics that can have immediate benefit to the building of systems to support group work.

CSCW offers an interesting trade-off between what is technically possible and what might be desirable. In fact, part of the art is knowing how little technology one can get away with and have an important benefit. Computer science either can't support brute force the sorts of interactions that one might imagine, or, if it could, there will still be advantage for more limited, but lower cost, smaller systems that could accomplish the important things. For example, satellite-based paging systems can have major impacts on business, even though the interactions they permit are extremely limited. Or workstation-based telepresence systems will probably have much larger effects than the larger videoconferencing centers despite inferior bandwidth, because people can integrate them with their offices and because they are much cheaper. New computer science technologies can be brought into existence, if CSCW analyses can identify pay-offs for them. CSCW applications can be brought into existence, if novel ways of using existing technologies can be found.

3.5. *Methods of investigation*

The design of technology to support groups takes its methods from both cognitive and social psychology as well as anthropology and sociology. It is understood that groups have shared understandings about how to do something and attitudes and roles that change from situation to situation. Thus, methods that allow observation of natural behaviour in the field are important to understanding groups at work and the impact technology has on them. From such studies, we have learned the importance of the artifacts people use in the conduct and co-ordination of their work, how 'institutional memory' dictates accepted modes of behaviour with organizational members, and how history with a particular group can dictate particular roles and contributions that individuals make. Since technology can change the frequency with which people meet casually, it can alter the nature of those roles and disrupt how they behave (Finholt *et al.* 1990). People who now can work at a distance are working in situations in which they do not know as much about each other; therefore it is much harder to fill in expectations and interpretations. Furthermore, technology in support of the objects/information in the work is itself an artifact, and has to be understood in the context of other artifacts that support work.

The methods used in this kind of study centre on careful observation. By either observing others at work or even participating in the work, one catalogues common behaviours and 'noticings', target events that seem to illuminate basic characteristics of work or its co-ordination.

There is controversy among researchers of CSCW whether understanding group work can or should be studied in more systematic settings in the laboratory. Since we know that the organizational history and the norms that specific groups build up are important, as well as a person's motivation to behave in certain ways depending on the long term reward structure, some argue that phenomena that rely on these aspects cannot be ported to the laboratory. Thus, case studies become the mode of data collection, and reviews of large numbers of cases for systematic aspects serve as the source of greater understanding.

Others hold that some aspects of group work can be studied in the laboratory (Weick 1965). The advantage of these studies is that one can give large numbers of groups the same thing to do, and study the process of the work they do as well as score the quality of the product. This kind of evaluation is impossible in the real world where many things besides group process determine the quality of the outcome. Acknowledging that habits from organizations and the motivational forces affect work, these researchers study more detailed, purportedly context-free aspects of group work. Saunders (1984) recommends running 'back to back' experiments: laboratory experiments to establish control linked directly to ecological studies that establish content validity. In one example in this line, intact groups are brought into a laboratory situation and they are given a small-scale, but genuine (not toy) problem to work on for a fixed amount of time. Researchers argue and then subsequently show that the constructed task elicits some of the relevant real-world behaviours that match a 'back to back' study of similar workers in the field (Olson *et al.* 1992a, 1992b).

The analysis of these studies uses methods and measures from a number of other fields. Although there are no standard measures of performance or process, researchers, for example, have borrowed measures of satisfaction from earlier research in social psychology, and have benefitted from research on questionnaire construction and statistical analysis. There are also somewhat standard methods to use to construct a measure of quality of outcome, by analyzing the components of quality, constructing an instrument for raters to use, and testing the validity and reliability of the instrument and raters (Olson *et al.* 1992b).

There are fewer established methods for analyzing group process. Traditional social psychology focused on concurrent observation; outcome measures and retrospective reports. Some researchers captured the dialogue of groups, some catalogued the messages passed between remote participants. Bales (1950) conducted the most detailed analysis of process, having teams of coders observe and mark the occurrence and timing of various social behaviours. Now that we can record the moment-by-moment behaviours of groups through videotape and re-view the behaviours, we must reopen the search for methods for describing and analysing that complex behaviour. Time is separated into task related vs process directed activities (Putnam 1981, Poole and Hirokawa 1986). Patterns of activity can be analysed using pattern recognition and grammar induction methods (Olson *et al.* 1992c). Content can be described using design rationale categories or domain specific topics along with judgements of levels of abstraction (Guindon 1990). Recently, some researchers have applied conversation analyses to the utterances in the group work (Novick 1988), some have catalogued and summarized the gestural interplay (Heath and Luff 1992). Clearly, more research is called for to establish widely applicable, reliable measures and analyses so we accumulate our results from situation to situation and from laboratory to laboratory.

3.6. *The field requires large scale efforts*

There are many factors that make this kind of research difficult. Group and organizational work is much more complex than individual work. Groups are expensive to run in the laboratory; one needs to find intact groups, confirm the similarity of the behaviour in the laboratory and the field, and test conclusions in the full field setting (Grudin 1988). Each data point requires many more hours to collect and an order of magnitude more to analyse. Recent estimates of a large study of group work in the laboratory (Olson *et al.* 1992) has found that it takes five hours per group to run (to include training, practice, and performance) and nearly 65 h each to analyse (including making transcripts, merging speech with keystrokes, and coding and summarizing the detailed behaviour). In doing this kind of laboratory work, one chooses the phenomena very carefully, since even with a team of researchers, each controlled comparison can require a minimum of two years elapsed time. We expect that as we learn more about what variables are the most reliable and revealing about technology's effects, we won't have to go to these extremes. In time, we will be able to better articulate the research so that we can focus on one telling issue, and run smaller, simpler controlled designs.

Work in the field is similarly difficult. It takes a researcher many hours on site to understand the culture, vocabulary, goals, and actions of the people they are observing. And, a single researcher may not be able to observe all the critical events, since at the critical moment, he/she may be located somewhere distant from the site where the event happens. Observation and careful recording of group/organizational work can take years per site.

Furthermore, in order for prototype technology to be tested in real group work, it has to not only be robust ('commercial grade') but it has to run on established platforms, compatible with systems that the people are getting other work done on. One cannot test a proof of concept for CSCW applications, nor just a single interesting module. The software has to support real work. This requires much longer development time. Again, as in the description of behavioural research, in time we may be able to test simpler modules in simpler settings, but at this point, where we are still exploring a wide design space and feeling our way, the efforts are large scale.

Clearly, for now, the scope of what we are doing is large and the development and concomitant data collection/analysis will be very slow. Progress will be slow and expensive. One way in which the results of this slow, costly work can be speeded up, however, is for the researchers themselves to share freely their methods and analyses, and for core sites that have particular expertises to be supported sufficiently so they can serve others as well as their own directed research.

A second way to enhance this work is to encourage research on understanding the basic dimensions of group work and technology, as mentioned above, advancing our field from one of merely inventing point systems toward understanding basic phenomena. The sooner we understand and agree on a vocabulary or taxonomy of dimensions, and describe fully the aspects of each research situation (task, group, technology, situation), the more easily we can compare results across laboratory or research sites and find trends and relationships.

Yet a third model could be adopted: the work can be divided across research sites, yet co-ordinated through technology itself to fit a long-term major plan of advancement. The 'Worm Project' is just such a collaboration, one that divides work among principal researchers in molecular biology at many sites and yet is connected via a large information system to both support the communication among researchers and allow flexible access to a myriad of scattered information sources (Schatz 1991). Research on collaboration technology could well be co-ordinated through collaboration technology.

3.7. *Infrastructure issues*

This work requires not only the co-ordination of concepts and sharing of methods and designs among researchers, but it also requires financial support on a scale much larger than seen in human–computer interaction. Laboratories doing this kind of work require high-end computing facilities: the prototype technology often sits on high end workstations, they need to be networked, and some require video channels and long distance video transport, all of which are very expensive. Once the studies are run, the mere collection and management of the mountain of data requires, again, high end computing facilities and teams of clerical as well as technical support. Furthermore, this kind of study often requires the commitment of time from researchers on the scale of years per endeavour rather than a few months for data collection and analysis. Results, done well, are slow to appear.

Training for this kind of work is highly multidisciplinary. Success in this field requires understanding of both behavioural, computer, and communication issues, not often found in one researcher. Teams are required in which not only all requisite expertise reside, but they also have appreciation and respect for the talents and work of the other. This is not a common occurrence. More Ph.D. level training in computer science should incorporate courses in behaviour, research, and statistics (to inform the direction of research toward problems that people will find relevant to their work), and courses in Psychology, Sociology, and Anthropology might include coursework on the possibilities of new technology so that they might guide the construction of systems that work for groups. The mix is critical to progress in this field. The mix need not be even in each researcher, but where there is heterogeneity, the critical ingredient is the appreciation and respect of the talents one gets from the other.

4. Conclusion

Collaborative work is the core of our society, wrought with both difficulties and benefits. It is clear that technology can change group work, and there is a good possibility that it can result in major enhancements to productivity. But, there is a lot of work to do before we understand fully how to accomplish that. Trial and error from creative system builders is too slow a discovery process. What is required is a better understanding of the nature of group work, the extent of the possibilities of the design space of technology features, and evaluation of systems in use that leads to a theory of computer-supported co-operative work, which in turn can help us direct subsequent invention of new ways to do group work.

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