# Computer Supported Interaction in Distributed Design Teams

by

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Submitted to the Department of Civil and Environmental Engineering
in partial fulfillment of the requirements for the degree of

DOCTOR OF SCIENCE IN INFORMATION TECHNOLOGY

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

May 1998



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## Abstract

Modern industrial design processes require collaboration among several specialists in the realization of an artifact or product due to the large number of components and the hundreds of person-years of knowledge encompassed in large engineering systems. Coordinating the activities of design groups and supporting the generative design process requires significant interaction among the individuals in a design team. In the past, such collaborative processes required many face to face meetings to produce high quality efficient designs. The availability of high speed computing and communication networks provides an infrastructure alternative to physical meetings. Engineers can engage in design tasks while remaining in their ideal work environments and can collaborate with others without concern for geographical distance between them and their colleagues. This significantly reduces project life cycle time and costs due to the enhanced communication between design team members and the reduction of time and money spent in preparing presentations, going to meetings, and retrieving data.

This thesis presents the salient features of group interaction and a methodology for supporting interaction in distributed design teams. The approach presented in the thesis brings together research on meeting and negotiation processes with distributed artificial intelligence concepts to develop methodologies for intelligent facilitation of distributed computer-supported interaction. Models of meeting control structures, group dynamics, as well as conversation elements exchanged in the meeting setting have been developed from monitored design experiments. The characteristics of these design processes have been successfully mapped to a scalable computer-supported multimedia interaction tool that includes a communication infrastructure and an interaction management system.

Thesis Supervisor: Feniosky Peña-Mora
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Doctoral Committee:
Prof. Jerome Connor, Prof. John R. Williams and Prof. Feniosky Peña-Mora

# Acknowledgments

I would like to thank Professors Feniosky Peña-Mora, Jerome Connor and John Williams for their support and guidance throughout this study. I have particularly appreciated the latitude and guidance Prof. Peña-Mora has provided me in pursuit of my research. I would also like to thank Professor Madnick, Dr. Amar Gupta and Dr. Michael Siegel who have expanded my research horizons and provided me with financial support during part of my stay at MIT.

I would then like to thank all at the Department of Civil Engineering, the Sloan School, and at MIT at large who have contributed in making of my stay in the Institute a most enlightening experience. I have met here, among faculty and students, a special breed of dedicated people who will always remain a source of inspiration.

Our research group at the Intelligent Engineering Systems Lab has always been a great resource. I would like to thank Wissam Ali Ahmed, Sanjeev Vadhavkar, Lucio Soibelman, James Kennedy, and Peter Cocozza who have provided technical support and have always been there as true friends. I would particularly like to thank Kareem Benjamin who has assisted with significant portions of the code for the CAIRO system over the past two years.

Special thanks to Dalia Ali, Mona Fawaz, Jean-Pierre Hathout, Ziad Kanaan, Hisham Kassab, Ahmed Mitwalli (who's been a great help since the beginning of this PhD trip and who has been with me until the day we both defended our theses), Amr Mohammed, Amine Tazi Riffi, Hala Tayyara and Maha Yahya who were always there to assist me in difficult times. They have lived through my pains and my joys and have always remained the truist of friends. A sincere thanks to the members of the MIT Arab Students Organization for making my stay at MIT pleasant and exciting.

Finally, I would like to acknowledge the financial support of the National Science Foundation (NSF-CONACyT Grant No. IRI-9630021) and the MIT School of Engineering and the Department of Civil and Environmental Engineering under the James H. Ferry Jr. Fund for Innovation in Research Education. The research conducted was also supported by Kajima Corporation of Japan under the IESL-Kajima Program and Intel Corporation.

*This thesis is dedicated to my parents, Mohie El Din Hussein and Mervat Badawi, and my sister, Noha Hussein, thank you for all the support throughout my life. You have taught me the value of education and have provided me with the means and unconditional support I needed to achieve my goals.*

*They forever will be my inspiration.*

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# Chapter 1

# Introduction

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*For PC's, the "killer apps" were word processing and spreadsheets. For the internet until now, e-mail and the web.*

*In the long-term future, the internet's killer app is for when you can't afford to be at the right* **place** *at the right* **time**, *which is now already* **most** *places,* **most** *times. the internet's future killer app is telepresence, going places by sliding your bits, as Prof. Negroponte would say, through the internet instead of lugging your atoms through traffic, airports, hotels, office parks, and conference halls...*

*I'm talking about* **massive substitutions** *of* **communication** *for* **transportation**.

- Bob Metcalfe, MIT Enterprise Forum Lecture, Oct. xx 1997

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## 1.1 Motivation

"We are a meeting society" – a world made up of small groups that come together to share information, plan, solve problems, criticize or praise, make new decisions or find out what went wrong with old ones. All organizations are built up from groups of men and women. Regardless of their values or personal goals, individual members of these groups must coordinate activities and collaborate in order to achieve meaningful objectives and goals.

Coordination and collaboration are processes that are central to our livelihood. Self-sustenance is no longer a part of our society. Hence living stems from our ability to rely on and cooperate with others in order to fulfill the needs we are unable to sustain. Language and voice emerge as necessary components of such cooperation. They are mechanisms for representation, production and transportation of information among individuals. Furthermore, society was developed as a force that governs these interactions among individuals an organizational process that enforces norms on the group to produce orderly interaction. This is a mechanism for the organization and control of the flow of information.

Traditionally, the mechanisms for interaction were natural - namely vocal chords and air. Electronic communication provides a new sphere for human interaction. Within this new sphere there are opportunities as well as constraints. In order to cope effectively with this new "ether" of interaction, the representation and production processes as well as the normative flow control and organization mechanisms of natural interaction must be well understood. Since the transmission medium adds new dimensions to the interaction so should the representation, production, organization and control processes. As a society we are no longer constrained in communicating within the limits of geography since our interaction limits will only be determined by how far and how fast we can move our bits of information across the network. As Negroponte [61] has stated, we now live in a city of Bits rather than Atoms.

In the engineering domain, communication is an integral component of the design and problem-solving processes. Systems that are currently developed contain large numbers of components and encompass the knowledge of thousands of person-years. Clearly this is much more than one individual can retain in their limited mental storage capacity. Hence, the modern engineering process necessitates the engagement of several individuals in the realization of an artifact or product. Engineering meeting processes particularly highlight several issues in communication: representation - different standard terminologies and acronyms; transportation - in the form of symbolics, drawings, sketches, specifications and voice; organization and control - inter-linkages of system components and the need for diverse expertise in problem-solving, beyond the capacity of one individual.

Design teams and their interaction processes were chosen for this research since they provide a significant challenge to current communication technologies. Design processes require highly coordinated interaction to resolve design disputes and to align design goals within the team. Engineering design also typically involves ill-defined design problems that are composed of interrelated components designed by different individuals that must fit together to produce a working system. This adds another dimension of complexity to the coordination task, since access to the design artifact must be coordinated in order to avoid design failures. Finally, most engineering design requires multi-media interaction for product visualization and system architecture development.

The purpose of the research presented herein is to explore interaction paradigms for distributed interaction and to develop a system to support a coordinated distributed design process. The system developed, CAIRO (Collaborative **A**gent **I**nteraction control and synch**R**Onization system) allows individuals to hold meetings over the internet and work together in a coordinated fashion on shared design problems. The system provides automated facilitation services and supports a variety of meeting structures and floor control policies.

## 1.2 Objective

The objective of this research is to explore meeting environments in physical space and interpret them into a virtual environment as well as to exploit the unique characteristics of the new communication medium. This is accomplished through the deconstruction of group interaction into its core elements and the translation of these elements into computational representations. In addition, facilitation processes have been modeled in order to allow intelligent agent manipulation of the meeting process.

Traditional meetings impose physical and temporal constraints upon conferring individuals. These constraints are eliminated through a system that provides virtual meeting environments through distributed computer networks. The CAIRO project focuses on exploring mechanisms for automated facilitation of meetings to reduce overhead costs incurred by the coordination and facilitation of standard meetings.

In order to provide support for the relaxation of the *same place* constraint, a distributed conference architecture has been developed that provides synchronized multimedia communications among multiple participants over the internet. Mitigation of the temporal constraint is somewhat more complicated. In physical meetings, late participants disturb the progress of the conferring group by requiring that they recapitulate. In this virtual meeting setting, however, late participants can immediately catch up with meeting proceedings through an automated documentation system.

The general dynamics of group interaction can be analyzed on two levels, the semantic and the syntactic. At the semantic level, these dynamics involve the broader context of the meeting in terms of its goals and the process by which those goals are achieved. This includes providing flexible and dynamic floor control algorithms, automated facilitation services, group structuring and agenda structuring tools for distributed interaction. At the syntactic level, the group dynamics involve the transition of floor from one individual to another. Supporting these dynamics through computer representations involves providing mechanisms that enable requesting the floor, addressing individuals in the distributed interaction, and managing the transition from one individual to another.

## 1.3 Methodology

A multi-disciplinary approach was taken for the analysis, design and development of the CAIRO system to support interaction in distributed design teams. Preliminary analysis of the problem domain was conducted through an analysis of management and sociology literatures as well as computer science literature. In the management literature, three subject areas that are relevant to this research were examined: (a) discourse analysis and group dynamics; (b) high performance design teams and group design processes; and (c) negotiation and facilitation. From the technology perspective, the domains covered were distributed network systems, real time systems, agent-based systems and computer conferencing systems that are precursors to the CAIRO system.

The next phase of the research involved the modeling of group interaction, design processes, and facilitation. These models are necessary to allow for computer understanding of the human design process. After a review of the literature, gaps were determined in the modeling of group interaction. Several controlled experiments were conducted on groups in physical meeting settings. The data from these experiments was analyzed and models were developed for group interaction. These models in addition to facilitation models served as a basis for the design of the CAIRO system.

Once the models were derived, elements of these group interaction models were analyzed to determine the dependence of these social protocols on physical presence. Concepts that were not apparent in distributed interaction were re-mapped into the distributed domain through user input and output structures or through intelligent moderating systems. Mapping of these concepts involved a close examination of metaphors employed in the user interface since they are critical in the effectiveness of this human-centered communicative tool.

A set of tools was then developed that provided computer support for design interaction across distance. The tool was designed to provide for scalability in the number of users as well as in the multiple media used in the distributed interaction. Several prototypes were developed and tested among limited users and certain elements of the interface have been redesigned.

Finally, a "real world" test scenario was created through a distributed software engineering course taught simultaneously at MIT and at CICESE in Mexico. The course served as a test bed for several group interaction tools. Feedback from students as well as tool use patterns have provided this research effort with significant support for the CAIRO tool developed and outlined several important considerations for future interaction systems.

## 1.4 Terminology

The definition of terms in the computer meeting field are generally quite vague and contradictory in the literature. The following list provides a set of basic terminology that will be used consistently throughout this thesis.

**Agenda:** a set of guidelines for the topics of discussion in a particular meeting setting.

**Asynchronous:** asynchronous interaction is communication that is stored in some form before transmission to the receiver of the information.

**Collaboration:** to work jointly with others especially in an intellectual endeavor.

**Conferencing:** conferencing is the act of structured and formal group interaction, throughout this thesis it will refer exclusively to distributed group interchange.

**Facilitation:** providing process interventions in group discussion to enhance the efficiency and effectiveness of the interaction.

**Floor:** the right of one member of a group to communicate to other members within a group discussion or meeting.

**Interaction:** communication that engenders reciprocal communication or action.

**Knowledge:** the conceptual model of the environment and other information that a person is exposed to and assimilates.

**Learning:** the process by which knowledge is built, transferred and shared.

**Meeting:** individuals coming together for a common purpose.

**Negotiation:** the process of resolving conflicts or disputes among individuals.

**Synchronous:** happening, existing, or arising at the same time. Synchronous interaction refers to communications that are immediate and whose expected response is immediate. These include face to face meetings, telephone calls and video conference interactions.

**Telepresence:** the ability to provide a semblance of co-location of distributed individuals through the use of computer and communication technologies.

## 1.5 Thesis Overview

The following chapter presents an overview of current academic and commercial telepresence systems. Each system will be reviewed for their effectiveness in supporting distributed design processes based on criteria developed within the chapter. Chapter 3 discusses patterns in interaction and floor transition in groups based on experiments conducted during this research. The chapter concludes with a discussion of recommendations for the design of distributed group interaction systems. The design process is then discussed in detail in Chapter 4. This includes a discussion of generic engineering design models in addition to negotiation and facilitation support processes. An agent architecture is then proposed to provide the facilitating role within a distributed design support system. Based on the requirements of distributed communication and the necessary support for complex forms of interaction described in Chapters 3 & 4 a robust and scalable network infrastructure and system architecture are presented in Chapter 5. This is followed by a discussion of user interface considerations and a description of the final interface implementation in Chapter 6. Chapter

7 presents a distributed learning classroom experience which served as a test-bed for the CAIRO system. The chapter discusses the learning philosophy employed in the course and the variety of technologies used to support the distributed interaction within the classroom. The chapter concludes with an analysis of the effectiveness of various interaction technologies (including CAIRO) in supporting a distributed learning environment. A summary of the findings in this thesis as well as suggestions for future work are presented in the final chapter.

# Chapter 2

# Literature Review

## 2.1 Recent Work in Computer Mediated Communication

The emergence of high speed communication networks and improved visualization techniques has laid the foundation for computer based collaboration. Various collaboration tools have been developed by academic institutions, office system manufacturers and communication companies. In this chapter, the major conferencing systems that have been developed are reviewed.

The literature is rich with research in the area of computer mediated communication. The work spans multiple disciplines and hence there are three diverse focus areas in this research field[1]: Electronic Meeting Systems(EMS); Video Conferencing; and Shared social spaces. Each of these groups represents a different approach to computer mediated communication. EMS research focuses on the meeting process and decision support tools for the meeting process. Video conferencing research is concerned with transmitting multi-media data between participants (esp. audio

[1]This classification is based on the commonalities within the different subgroups. Researchers in all three different fields tend to use multiple vocabularies that can confuse the functionality of the systems

and video data). The shared social spaces perspective is concerned with enabling interaction and experience across distance and providing awareness and persistence within a virtual world. The following paragraphs will discuss the salient features of representative systems in each of these areas.

Electronic meeting systems encompasses a large body of research dedicated to the support of participants in traditional meeting settings. These systems arose from defense needs for efficient command and control centers. The GroupSystems EMS[63] and the Xerox Parc Collab project[91] are among the first such systems developed. Both systems have tools that structure brainstorming and problem solving processes and enforce interaction controls on the participants within the shared media. However, the control of floor in discussion is governed by regular meeting norms since all participants are co-located. Olson *et al.*[65] found that some of these additional process structuring constraints on the collaboration are not necessary and may decrease satisfaction within the workgroup. Further analysis of the use of these systems and their effect on group work are well documented[64, 39, 26].

Initial research on video conferencing focused on the technical aspects of transmitting video and audio data among individuals. Much of the initial work was constrained to two-person interactions and a large portion of the work utilized a telephony paradigm for the interaction. Further developments have occurred rapidly in this field and most modern systems such as Microsoft NetMeeting[55], Intel Proshare[43], PictureTel[75], and SGI Inperson[88] provide multi-person interaction and have extended audio and video services to include shared whiteboards, editors and browsers. However, these conferencing systems lack any appropriate concurrency control mechanisms and are cumbersome to use for group work.

The final area of research in tele-presence is devoted to the study of virtual communities and interaction in a virtual environment. Several tools have been developed to provide awareness, persistence, and interaction in cyberspace. The two leading research efforts in this field are TeamRooms[80] and Worlds[31]. The primary concern of these research efforts is in the representation of physical concepts of space and place in the virtual world. The environments developed provide richer interaction contexts, but are currently constrained by network bandwidth and display technology.

The research described in this thesis builds on earlier work in all these fields especially earlier work on electronic support for physical meetings. However, our aim is to extend support mechanisms to distributed meetings using commercial video conferencing technology. This necessitates the introduction flexible control and interaction support tools to compliment the decision support and conferencing infrastructures. The group interaction research described herein in addition to the recommendations presented are an initial step in providing such group support.

Telepresence is a term used to describe a variety of systems for interaction in distributed environments. This section will review the majority of seminal works in this field. This field includes a wide variety of devices and software systems that enable communication among groups of two or more individuals, including telephone systems. This review will be restricted to the class of systems that use general purpose computers connected via a network using any of a variety of communication protocols including TCP/IP (the Internet Protocols), ISDN (Integrated Services Digital Network) and ATM (Asynchronous Transfer Mode).

Descriptions of each system include:

- a brief overview of the architecture of the system,
- a description of the various media supported by the system (eg. X-window, audio, and video).
- Support for temporal dependence among various media channels, i.e. multime-

dia synchronization.

- support for higher level protocols to control meeting structure and floor control, i.e. collaboration and floor control.
- support for meeting logging and efficient retrieval mechanisms, i.e. process history support.
- effective transmission of information, i.e. addressability, reasonable delay times and minimal information loss (reliability).

## 2.2 Interaction Systems

The telepresence systems were analyzed based on the following critical system components:

**Communication Protocol** : A set of rules for information transmission across a network.

**Interaction Protocol** : A set of rules and algorithms that govern the accessibility of other participants in an interaction. These include definitions of proximity (proximity in a distributed sense has different implications than in the physical environment), addressability (controls over the ability to interact with others in the interaction environment) and presence (definitions of visibility of individuals to others).

**Interaction Environment** defines the interface between human and machine models of the interaction. These are typically exemplified by metaphors that represent protocol distinctions. For example a room metaphor is commonly used to denote presence of individuals and proximity.

**Interaction Modality** defines the variety of information structures and media available to the interaction. These may include audio transmission, video transmission, image transmission, text transmission and structured data (in the form of databases, schedules, CAD drawings, formatted text, etc...)

These components are combined to form an interaction system as shown in Figure 2-1. The interaction environment defines the space for the individual's interface to the machine and other networked individuals, while the interaction modality defines the input and output devices by which information is displayed within each individual's interaction environment. Communication protocols enable the transmission of information from one machine to another through the network. Finally, interaction protocols enforce order on the communication over the network collaboration by controlling the ability to address particular individuals..

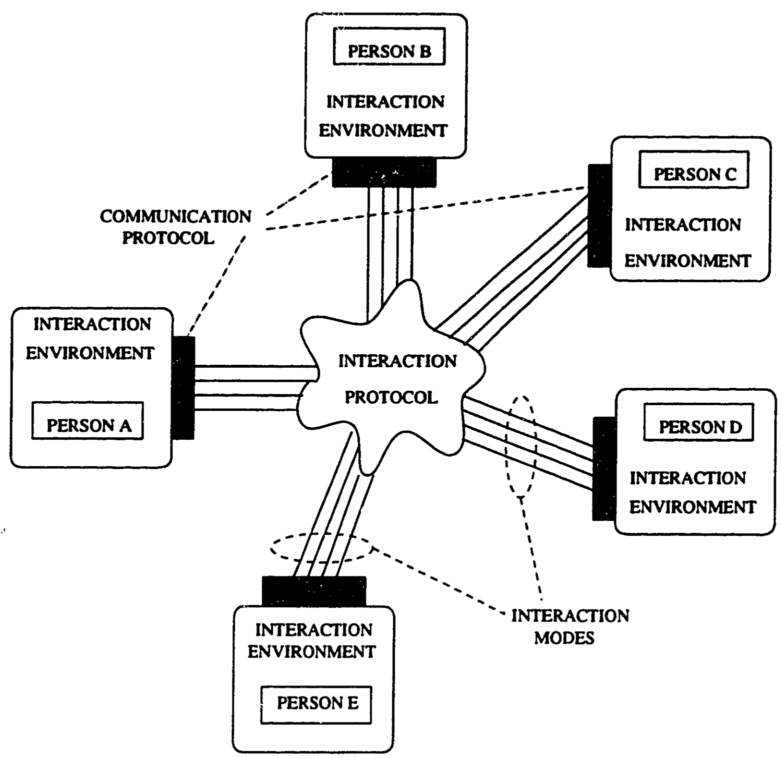



Figure 2-1: Interaction - a systems view

## 2.3 Electronic Meeting Systems

### 2.3.1 Xerox PARC Collab

The Xerox PARC Collab Project's [91] main emphasis is on collaboration control mechanisms for a shared board. Their work provides valuable insights into meeting cycles and social interaction during a group meeting. However, Collab is lacking in multimedia communication and assumes all participants are physically co-located.

**Architecture:** The Xerox Collab project is comprised of several tailor made shared applications for specific meeting functions (Board Noter, Cognoter etc...). There is no meeting or name server incorporated within the system

**Media Support:** The Collab system is a highly specialized system and therefore has only one shared application (i.e. a Whiteboard).

**Multimedia Synchronization:** None, since only one media is present.

**Collaboration and Floor Control:** Complex floor control mechanisms describe in detail in Section 3.1.3.

**Process History:** Personal notes and Snapshots of screens are allowed. Activity on the shared board is also continuously logged.

**Reliability:** Closed network (LAN) system with very high reliability.

### 2.3.2 GroupSystems EMS

The University of Arizona / IBM GroupSystems EMS (Electronic Meeting System) joint effort [63] extends the work undertaken in the Xerox Collab project. They provide mechanisms for retaining organizational memory, process support and structuring, task planning and structuring as well as control support for three basic meeting types (chauffeured, supported and interactive). As in Collab, GroupSystems EMS does not support multimedia communication and assumes a co-located meeting. Many of these EMS systems have been set up in convention centers to allow speedy issue resolution among top executives.

**Architecture:** GroupSystems EMS consists of a network of computers in a specialized meeting room with a large projection screen. Specialized software runs on each machine to provide support for process design and scheduling.

**Media Support:** Process support and structuring applications are provided (eg. Electronic Brainstorming, Electronic Discussion, Idea Organizer, Issue Analyzer, Vote Selection, Policy Formation).

**Multimedia Synchronization:** No synchronization is required since meetings are carried out face to face.

**Collaboration and Floor Control:** Three meeting types are supported:

1. Chauffeured - Single person enters group information.
2. Supported - All group members can enter comments, however, there is a central control on group memory access.
3. Interactive - All group comments and actions are logged in group memory.

**Process History:** Very detailed process support and structuring and extensive group memory maintenance (queuing and filtering).

**Reliability:** Closed network (LAN) system with very high reliability.

## 2.4 Distributed Conferencing Systems

### 2.4.1 WVU MONET

MONET (Meeting On the NETwork) [90], developed by CERC at West Virginia University, is among the first and most complex research efforts in conferencing systems. This project was supported by the DARPA DICE initiative.

**Architecture:** The MONET system is comprised of application sharing servers, conference servers, multimedia servers and a directory server. The application sharing server (COMIX [7]) intercepts XClient calls from any X application and broadcasts them to the members of a conference. The conference servers handle membership, invitation processing and archiving for an active conference. Multimedia servers' key function is inter-media synchronization, however, this portion of the MONET system has not been fully implemented. Finally, a directory server maintains lists of registered participants as well as characteristics associated with those participants. The MONET system has a simplistic user interface that is quite cumbersome to use.

**Media Support:** MONET provides support for audio, video and shared X applications. Audio and video capabilities are limited, however, and are comprised mainly of annotations to text rather than as an effective real time communication mechanism. The shared X system allows all participants access to any X application.

**Multimedia Synchronization:** Although multimedia synchronization is mentioned as a goal for MONET, no indication of synchronization was provided. Much of the effort has been focused on providing operating system and hardware support for synchronization.

**Collaboration and Floor Control:** MONET provides three basic floor control mechanisms: chairman control, time-limited FIFO, and a combination of the two.

There is no support for extension or design of more complex mechanisms.

**Process History:** MONET provides no conference logging facility.

**Reliability:** No information available.

### 2.4.2 NCSA Collage

NCSA's Collage [60] conferencing tool has a characteristically clean interface similar to NCSA Mosaic. NCSA Collage was designed with a focus on visualization applications and hence has complex image visualization and manipulation mechanisms incorporated within it.

**Architecture:** NCSA Collage is based on a strict client-server model. All participants initiate NCSA Collage sessions and NCSA Collage Servers are created as each conference is initiated. All future communication by participants in a conference are passed through the newly created NCSA Collage server. NCSA Collage lacks any form of directory service. NCSA Collage is also available on Macintosh and Windows platforms which greatly enhances its usefulness.

**Media Support:** Whiteboard, Text, Animation, and Image visualization tools are the core media supported by the NCSA Collage system. NCSA Collage also incorporates an effective screen capture mechanism. No support for audio and video is included in the current system.

**Multimedia Synchronization:** Due to the lack of audio or video media in NCSA Collage, no synchronization mechanism is incorporated within the system. All media drivers have no temporal dependence.

**Collaboration and Floor Control:** No floor control protocol is provided with the NCSA Collage system. All clients have access to the shared application and all interactions are broadcast to members of a conference.

**Process History:** No history of a conference session is maintained by the NCSA Collage Server. However, local snapshots of conference proceedings can be maintained by each client.

**Reliability:** No directory service provided.

### 2.4.3 SRI CECED

The Collaborative Environment for Concurrent Engineering Design (CECED), developed by SRI International, provides mechanisms for informal communication and history capture of informal stage in the specification and design process. The work undertaken has detailed the requirements for effective conferencing systems. SRI's approach has been to ensure that the conference system is non-intrusive and as natural as a standard meeting conversation.

**Architecture:** CECED builds on the MOSAIC platform (Multimedia Open System for Augmented Interactive Collaboration [18], [32]). As in the MONET and XTV systems, CECED distributes existing unmodified X applications. This is performed by specialized Collaboration Management Agents (CMA). A Shared Tool Event CMA provides broadcast capability to existing XClient applications. A connection CMA handles all underlying network protocol translations. A Session Manager acts as a user interface to the conference tool. An Information Store CMA provides archiving and data access control for the collaborative conference. CECED also incorporates Collaboration Aware Tools (CAT). These are specifically developed tools for the CECED system. The current prototype has an audio CAT to allow for audio communications in the collaborative environment.

**Media Support:** CECED supports any X-based application as well as limited audio capability through the audio CAT.

**Multimedia Synchronization:** Synchronization can be implemented as a CMA among various X-applications. However, the CECED prototype does not include any inter-media synchronization

**Collaboration and Floor Control:** CECED provides synchronous multi-user access. The access control protocol is similar to the Ethernet concept. It involves a listening process that waits till the line is free and then allows the participant to speak. This process known as COMET [33], is a distributed activity sensing floor control algorithm that guarantees a single stream of input to unmodified single-user applications.

**Process History:** CECED provides only a complete logging of conference proceedings. Furthermore, CECED provides logging of semantic changes in the conference as well as raw data.

**Reliability:** Completely distributed. No directory service is provided.

### 2.4.4 AT&T RAPPORT

The AT&T RAPPORT [4] system focuses on the network communication issues of conferencing and on effective user interface design for conferencing tools. It provides synchronized video, audio and data communication, however, RAPPORT uses heterogeneous networks for each mode of communication (PBX for audio, coax cable for video, LAN for data). RAPPORT also lacks effective support for conference control.

**Architecture:** Proprietary.

**Media Support:** Provides voice, video and shared X applications.

**Multimedia Synchronization:** Synchronization is not necessary since the system has virtually no communication latency. Currently, Rapport runs on three separate networks: a LAN for data transmission, a specialized coax video network for video, and an ISDN system for audio communication.

**Collaboration and Floor Control:** Chalk passing is the only control mechanism suggested.

**Process History:** No capture of process history is captured aside from screen snapshots and note-taking applications.

**Reliability:** Highly reliable communication with no data loss due to the nature of the network. However, the system is prohibitively expensive and not easily scalable.

### 2.4.5 XTV

The XTV [1](X Teleconferencing and Viewing) effort focuses primarily on providing reliable transfer of data among shared X systems. XTV incorporates a very simple floor control mechanism and does not provide support for non-X media communication.

**Architecture:** The XTV system is comprised of three key components: information daemons (ID), conference announcers (CA) and user interfaces (UI). ID's maintain communication among the UI's and the CA's. ID's are equivalent to meeting rooms in a physical conference. UI's are each individual participant in a conference. A UI is an

X-application used by a conference member that can be shared among all participants. CA's maintain conference membership lists and process conference invitations.

**Media Support:** XTV only supports X-based applications.

**Multimedia Synchronization:** No synchronization among X applications is provided by the XTV system.

**Collaboration and Floor Control:** Chalk passing protocol with a chairman override capability.

**Process History:** No explicit process history capture mechanism is provided by XTV.

**Reliability:** Provides redundant servers to insure fault tolerance and employs sophisticated protocols to insure reliable information transfer.

### 2.4.6 Microsoft Netmeeting

Microsoft Netmeeting [55] is the most prevalent video conferencing system currently in use. It provides the most effective support of video and audio on the internet. It provides no synchronization support among the multiple media channels. Netmeeting also does not support video and audio interaction among more than two people across the internet. However, windows applications and chats may be shared among more than two individualts. Netmeeting lacks any effective support for conference control. Any member of a meeting in Netmeeting can access a shared application by taking the speaker control from any other member. This is a very confusing concurrency control mechanism that can lead to a continuous tug of war for control of the floor.

**Architecture:** Based on Intel Proshare technology[43].

**Media Support:** Provides voice, video and shared Windows applications.

**Multimedia Synchronization:** Synchronization is not supported in current versions of Netmeeting. However, inter-media latency is limited and the media channels are presented almost synchronously.

**Collaboration and Floor Control:** Chalk "grabbing" is the only control mechanism provided.

**Process History:** No capture of process history is captured aside from the regular "save" commands of the shared applications.

**Reliability:** Semi-reliable communication with significant data loss across congested networks. However, a network monitor is provided to determine congestion on the network.

### 2.4.7 Intel Proshare

The Intel product is very similar to the system provided by Microsoft. In fact they share the same media transmission system. However, Proshare[43] provides some additional functionality yet requires Intel video hardware to work efficiently. Proshare provides communication over ISDN lines with multiple conferencing individuals. It is, however, limited to two conferring individuals in regular internet mode. Although, the Intel system provides an elegent interface using a room metaphor (switches to office and lecture hall depending on interaction mode), there is no individual addressibility in group ISDN mode.

**Architecture:** Based on Intel Proshare technology (Internet and ISDN support with Intel hardware)[43].

**Media Support:** Provides voice, video and shared Windows applications.

**Multimedia Synchronization:** Synchronization is not supported in Proshare. However, inter-media latency is limited (particularly in ISDN mode) and the media channels are presented almost synchronously.

**Collaboration and Floor Control:** Chalk passing and "grabbing" are the control mechanisms provided. Audio and video conferencing is uncontrolled, except in lecture mode where a single video and audio source is multicast.

**Process History:** No capture of process history is captured aside from the regular "save" commands of the shared applications and video snapshot capabilities.

**Reliability:** Semi-reliable to reliable communication with significant data loss across congested networks. In ISDN mode, communication is highly reliable and of very good quality due to Intel's hardware video and audio compression. Proshare also provides a network monitor to determine congestion on the network.

## 2.5 Shared Social Spaces

### 2.5.1 TeamRooms

The TeamRooms[80] research effort focuses primarily on the representation of interaction spaces. The room metaphor for a multi-user interface is used extensively within this system. It provides a highly consistent interface to interaction among group member using both asynchronous and synchronous media. Persistent objects may be placed within a room for later retrieval and participants in a single room may communicate in real time.

**Architecture:** Based on a MOO (Multi-User Dialogues extended with Object Oriented programming).

**Media Support:** Provides voice, and shared applications.

**Multimedia Synchronization:** Synchronization is not supported.

**Collaboration and Floor Control:** Object-based locking with permissions set by object owner. Complex control schemes may be incorporated but are cumbersome to program. Voice interaction based on co-location in a team room.

**Process History:** Process history is captured through persistent objects maintained in a team room.

**Reliability:** Reliable communication using MOO infrastructure.

### 2.5.2 CoNus

The CoNus[9] system is an extension of the TeamRooms concept (see previous section) without the use of a MOO infrastructure. The CoNus system provides video and audio conferencing and extends the room metaphor with floors and buildings (providing a room hierarchy). The system also supports persistent objects.

**Architecture:** The system is based on a combination of real time conferencing systems and a MOO-like system.

**Media Support:** Provides voice,video and shared applications.

**Multimedia Synchronization:** Synchronization is not supported.

**Collaboration and Floor Control:** No explicit floor control is provided by this system.

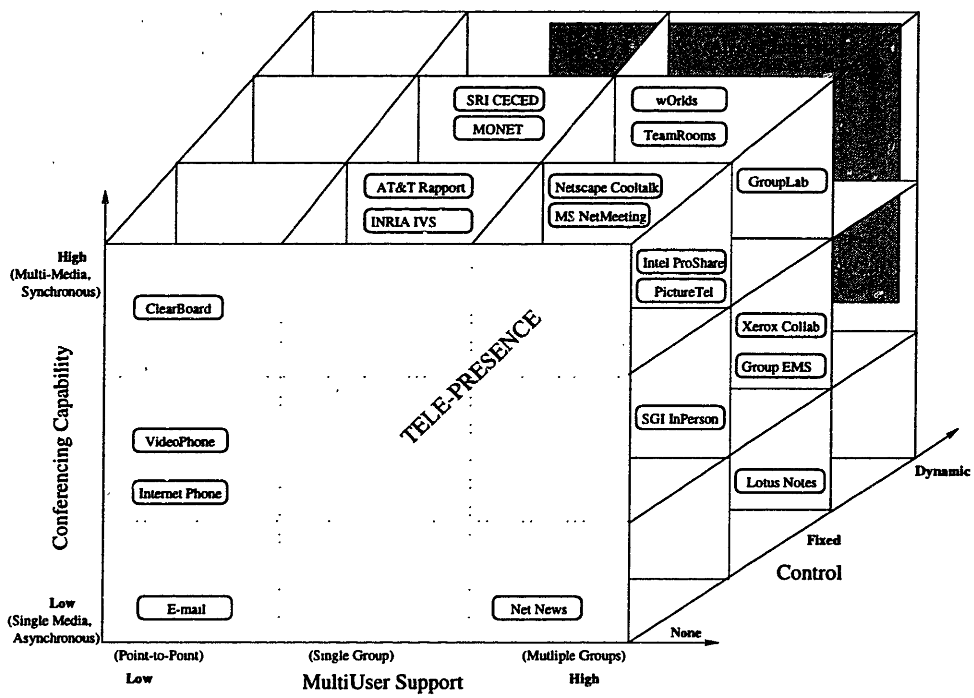
**Process History:** Process history is captured through persistent objects maintained in a room.

**Reliability:** Semi-reliable communication infrastructure that is highly reliant on network bandwidth. Tests have been primarily performed by the authors on high speed ATM (Asynchronous Transfer Mode) networks.

## 2.6 Concluding Remarks

The above systems provide an overview of the wide array of conferencing software available on the market. Three classes of conferencing software were discussed in the preceding sections: electronic meeting systems, distributed conferencing systems and shared social spaces. The electronic meeting systems (GroupSystems EMS and Xerox Parc Collab) are in general more focused on meeting organization and coordination, since the architecture of the system depends on the physical co-location of the group members. The distributed conferencing systems, on the other hand, ignore the coordination problem and concentrate primarily on co-location facilitators (i.e. multimedia information transmission). Finally, shared social spaces are designed primarily to support group gaming environments. They are occasionally used for distributed work, however, they have limited support for structured interaction although they have highly developed telepresence and addressing mechanisms. The approach taken in this thesis is to achieve an appropriate balance of distributed meeting co-location and coordination technologies.

Some of the current computer mediated communication systems (both academic and commercial) are classified in Figure 2-2. The figure delineates the multimedia capabilities of the systems on the y-axis. The x-axis describes the extent to which these systems support multiple participants in an interaction. Finally, the z-axis expresses the degree to which the systems allow effective control of the floor (concurrency control) in collaborative interaction. The core focus of this thesis is on the z-axis although the existence of multimedia and multi-user support are necessary prerequisites for the work described herein.

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Xerox Collab: Stefik et al. 1987
Group EMS: Nunamaker et al. 1991
Lotus Notes: Marshak 1990
TeamRooms: Roseman and Greenberg 1996

Figure 2-2: Overview of computer assisted communication

# Chapter 3

# Groups and their Dynamics

> We respond to gestures with an extreme alertness and, one might almost say, in accordance with an elaborate and secret code that is written nowhere, known to none, and understood by all.
> - (Edward Sapir, 1928)

Understanding design team interaction requires an understanding of the internal dynamics of groups. The following section provides the relevant background information on group dynamics and interaction. Section 3.3 provides a scenario from the AEC industry to illustrate the concepts discussed in this paper. This is followed by Section 3.4 that describes the methodology utilized to gather data to use as a basis for deriving the models of floor control which are described in Section 3.5. This is followed by a set of recommendations for any conferencing system that supports the group dynamics present in civil engineering interactions must satisfy. A prototype conferencing system and a floor control infrastructure are also presented in this section. Concluding remarks and future work are presented in the final section.

## 3.1 Understanding Groups

Group interaction patterns are an early indicator of a disfunctional group process. If users are aggravated and are starting sub-conversations then there is a clear deficiency in the control process. Patterns of interpersonal communication have often been used by social scientists to determine the effectiveness of team processes. We intend to have the computer agents analyze these communication patterns and hence determine the effectiveness of the team process.

### 3.1.1 Floor Transition

The key difficulties in providing automated facilitation of design meetings correspond to discourse transition decisions and group transition processes. Discourse transitions exist at two distinct levels. The first level is in turn taking transitions, and the second level consists of meeting process transitions. Due to the primitive state of natural language understanding these transitions must be realized from syntactic clues rather than from the semantic content of the interaction. Early analysis of data derived from various meeting forms as well as studies by Schiffrin [85] indicate that syntactic clues are a promising indicator of transition points.

Discourse analysis allows the extraction and interpretation of inflections in speech and a categorization of typical techniques employed by people in conversation to indicate relinquishing of floor control [85, 94]. The CAIRO research effort will build upon these studies and attempt to distinguish discourse markers in multiple media rather than just verbal communication.

Group interaction occurs within the context of a meeting process and a group life cycle. A description of meeting process is presented in Section 3.1.3. Group life cycles and their effect on group functioning is further discussed in Section 3.1.4.

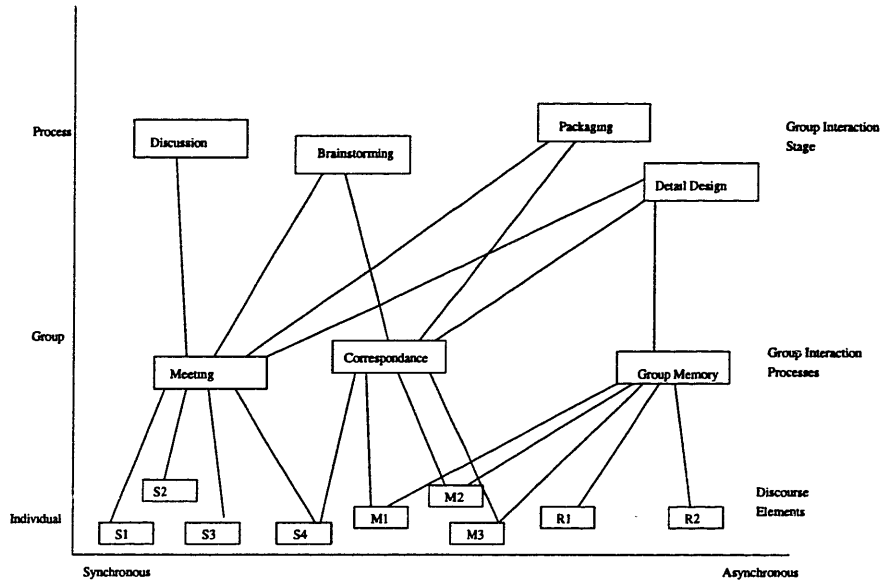



Figure 3-1: Structure of Design and Development Conversations

### 3.1.2 The Concept of Floor

This section presents a brief background on group communication with particular emphasis on the transition of the speaking state (the *floor*) from one participant to the other. Two key characteristics of efficient meeting (i.e., increased information flow and equal participation of individuals) greatly depend on efficient floor transfer policy. In fact, floor control policies are the principal concern of meeting facilitation strategies.[21]

The concept of *floor* represents the speaker state within a group discourse. *Floor*[1] commonly refers to the right of a member to communicate to a group (e.g., the project manager addressing contractors), alternatively, the term has also been used to refer to the topic of focus in a group discourse [Edelsky,1993]. For the purposes of this research, floor will refer to the right of a member to communicate to the group.

Several techniques have been proposed to enhance the floor transition process in

[1]floor(n.) (1) the part of a legislative chamber, auditorium etc. where the members sit and from which they speak; (2) the right of one member to speak from such a place in preference to other members. - *Random House College Dictionary, 1995 edition.*

task-oriented group work, including formal methodologies for facilitation [29, 92] and a fruitful business in group process consulting [84, 83]. The control of floor has been shown to affect power dynamics within a group and repressive floor control policies can stifle innovation and creativity in a group (see Patton *et al.* [67] and Walton and Hackman [96]). Furthermore, ineffective floor policies may lead to frustration, anxiety and conflict within the group.[58]

In order to enhance the floor transition process, there are two main issues in group dynamics that this paper addresses. The first is to investigate the possibility of extending current work on dyadic[2] turn-taking theories[23, 35, 95] and applying them to group floor control in a task-oriented setting, such as a change negotiation meeting in a civil engineering project, using discourse analysis. Most research on turn-taking does not take into consideration the situation when more than two persons are conversing. This paper argues that the two phenomena are different and use diverse modality and various discourse elements. In addition, a dyadic model will not work in large-scale engineering projects where a negotiation or design meeting rarely involves only two parties. However, the current work on dyadic turn-taking offers a good ground to pursue further analysis for group activities. The second problem addressed by this research is the derivation of a model for floor transition based on observed data and on the discourse analysis influenced by turn-taking. The model is based on a consistent description of the various states that a group will experience while exercising floor control. The validity of the derived model will be shown by mapping some of the concepts back to the actual data. This model will then become the basis for a set of requirements for computer conferencing systems to be used on problem solving distributed meetings in civil engineering projects.

[2]two-person interactions

### 3.1.3 Meeting Cycles

The most basic structure for group coordination and interaction is a meeting. Meetings among individuals involved in product design tend to follow a similar cycle. Researchers at Xerox PARC have isolated three stages in a meeting cycle to aid in the development of their groupware product Cognoter (a collective presentation preparation tool)[91]. The three stages consist of *brainstorming*, *organization* and *evaluation*. During the *brainstorming* stage various ideas generated by members of a team are laid out on a shared work-space (eg. a chalkboard). The second stage, *organization* consists of extracting the essential ideas and grouping and sequencing the various ideas presented. Finally, during *evaluation*, the ideas are further refined and tasks assigned to the members of the team. In the Cognoter model, brainstorming is carried out on a loosely controlled shared board (no erasing is allowed). During the *organization phase*, there is strict control on the meeting and only one person is allowed to access the board at any one time. At the final stage, when the tasks have been appropriated to the participants, each individual can refine his/her section and accept suggestions from the other participants. The Cognoter model in addition to the background research on meeting cycles suggest that interaction among members of a group or team varies as the meeting or project progresses. The control structure for a conference among these members must also evolve accordingly. Thus, a conference cannot have a static control structure but rather must be allowed to evolve as the needs of the participants evolve.

### 3.1.4 Group Life Cycles

Cole and Cole describe the cycle of group formation in [14]. This cycle consists of five stages: *forming*, *storming*, *norming*, *performing* and *adjourning*. Understanding the dynamics of each stage is critical for the realization of a distributed group interaction system since they each have a distinct form of conversational interaction.

Furthermore, each stage involves a distinct authority structure. In the *forming* stage, members get to know each other and the tasks assigned to them. *Storming* involves the definition of roles within the group. At this stage, significant tensions may arise between the members as authority is asserted by a few of them and subtasks are determined. At the *norming* stage all roles are settled and the group focuses more intensely on the priorities of subtasks as well as procedures and methods to tackle them. The *performing* stage is when real work gets done, goals are achieved and the group becomes productive, energetic and effective. The group finally loses its structure in the *adjourning* phase when the work is completed, the group is reorganized or the members are assigned a different mission. During this wrapping up stage, groups reflect on their learning experiences and document their work to retain it in corporate memory. It is clear from the above description that the form of the interaction among members varies significantly in the five stages. The conversation among the members varies from chaotic and informal (*forming* stage) to a more structured and focused form (*performing* stage). Furthermore, at each stage authority and control structures are reformulated. Therefore it is critical that a groupware tool provide the flexibility to adapt to the various situations.

## 3.2 Background on Interaction Dynamics

For the past three decades, linguistics research in discourse has analyzed inter-personal communication and conversation. Most of the literature focused on face-to-face dialogues or dyadic conversations [81, 23]. An overview of the research related to turn-taking is presented below, together with comments on relevant issues that have not yet been explored.

Thorisson[95] provides a comprehensive overview of research on dialog structures and their discourse elements. Thorisson argues that turn-taking is crucial for both negotiation and clarification, since it controls the flow of the conversation and hence restricts the amount of information exchanged in an encounter. Thorisson also shows that back channel is critical in conversations to signal auditor acknowledgment and understanding. According to McNeill and Goodwin, back channel helps in information exchange to support the interaction and assists in moving along the right path. Usually back channels are listener utterances that do not interrupt the speaker, when back channels interrupt the speaker's flow they may indicate a request for turn.

Furthermore, Thorisson shows that gaze is an important component of a conversation since it not only reflects the person's attention or mental activity, but also a person might look at an object or other person during a conversation which will provide some deictic[3] information[11]. Furthermore, gaze is used to signal the beginning (looking away from the auditor) and end of a turn (looking toward the auditor to pass the turn).

Duncan [23] offers a good structural analysis of human dialogues, but focuses mostly on the nature of the signals between the speaker and the auditor. Turn taking in Duncan's opinion (termed the "Speaker-turn system") includes signals from the speaker, back-channel signals (words such as "uhuh", or nodding the head) from the auditor, and some other state attributes (like the nature of utterances and body motion).

Speaker signals include turn signals, within-turn signals and continuation signals. The turn signals are signals that the speaker resort to in order to request a turn (such as raising a hand or interjecting). The speaker might use cues which can be intentional, content-based, syntax, paralanguage, and body motion. The latter include gestures that the speaker uses to take turn (e.g., gesturing at a blueprint of

[3]pointing or referential gestures - e.g., "place that object here" where "that" is accompanied by a pointing gesture towards a specific object and "here" is accompanied by another pointing gesture that directs the conversing partner to a particular location nearby.

the site while others are discussing it, thereby interrupting their field of vision). On the other hand, within-turn signals mark the ending of a turn or utterance, and consist of both paralingual or gesture cues (these include dropping off of speech volume or pitch as well as gazing at the other participant). Finally, the continuation signals can occur at the beginning of a speaker turn or at the beginning of a speech unit (these include looking away from the other participant and commencing of gesturing).

Goodwin [35] showed that gazing is crucial for the speaker during his/her turn of speech. There are several instances when the speaker resorts to gazing to either bring attention or to restart some phrases. It is believed that at the start of each turn, there is a high chance that the auditor will gaze at the turn-taker. At some point during the conversation, the person speaking uses several cues to bring the auditor's gaze towards him/herself. This effect of restarting is used to secure or request the gaze of a hearer. People do that by either lengthening some words, repeating or creating more pauses. Goodwin showed too that a speaker uses similar techniques to secure the gaze of multiple recipients.

Most of the current research has focused on turn-taking as a speaker or auditor state of dialogue, there has been little work on actually defining a good structure or framework on the characteristics of a turn (boundaries of when it starts, and how it starts, and how can one lose his/her turn). Furthermore, there has been limited work on the discourse analysis of group discourse which is crucial for this work to be useful in the AEC context. The work described above has been limited to dyadic conversation.

Further work has been conducted in the CSCW (Computer-Supported Cooperative Work) community in comparative studies of group activity with and without the use of computer mediation. Notably, Olson *et al.*[65] discusses the changes in group process related to the addition of a shared editor in a computer-augmented meeting room. This work found that the quality of group design improved with the addition of the shared tool, however, the group members were less satisfied with the process. Furthermore, the paper asserts that computer-based structuring for problem solving is not necessary and simpler groupware systems are more effective. Most of these early field studies [26, 63, 91, 39] used synchronous group tools that augmented traditional meeting rooms or used very low bandwidth communications. Our research argues that explicit computer coordination of group processes is necessary in a tele-presence environment with multimedia support. This is due to the synchronous form of the real-time communication and the overload caused by the high bandwidth interaction if all participants are equally engaged in the interaction. Furthermore, typical social protocols do not hold true in computer mediated communication where there is no physical interaction.

The author believes that understanding of group interaction and enhancing the process are critical in developing recommendations for the adoption of computer mediated communication technologies. This is especially critical in the AEC industry where there are many parties involved that are multi-disciplinary and do not usually work in close proximity.

## 3.3 A Sample Task Scenario

The following scenario is a fictitious description of a design task that was set by a state's Highway Department (HD) after a serious accident that damaged a bridge.

> On Monday morning, a freighter crashes into the support pier of a bridge crossing a major waterway in a large city. The pier is severely damaged and the bridge is no longer guaranteed to be structurally sound. This bridge lies on a major artery into the metropolitan area and a solution needed to be formulated quickly to restore a normal flow of traffic in the

city. The owner (HD) convenes a meeting with several experts in the field including a structural engineer, a traffic engineer, and a contractor to discuss possible solutions. The discussion involves an analysis of the situation and an initial investigation phase where all the parties involved collect data regarding the site, the extent of the damage, and the traffic flow patterns in the area. Several design alternatives are proposed by each of the individuals at the following meeting.

The design proposals were meant to address the four key concerns: public safety and the risk associated with the accident, cost of repair, time and space for repair, and traffic flow reduction or redirection. Given that the bridge could carry a minimal load several proposals were submitted by the parties to this design negotiation detailing construction alternatives and various traffic redirection patterns.

Throughout the second meeting the alternatives were discussed and the initial remedies are rejected due to their high cost, their effect on traffic flow in the area or their destruction of the aesthetics and symmetry of the bridge. After a heated discussion over three days involving significant compromise among all the parties involved, a preliminary design is ratified. The final design is presented by the structural engineer and minor adjustments are made in the final meeting. The design is then committed and the contractor begins the field work.

The scenario described above exemplifies some of the components in critical AEC design meetings. These meetings typically include the following key factors:

1. Urgency - Many design processes in the AEC industry have significant time pressures. Although most design sessions will not have the urgency of the emergency described above, almost any design task has some degree of urgency

and this becomes a critical factor in the design process.

2. Role Definition - each of the members of a design team brings in their own interests based on their professional experience or personal bias. The efficient combination of these experiences is necessary in the generation of an effective solution.

3. Discovery Phase - a stage in which all the meeting participants acquire and analyze all available data regarding the design situation.

4. Brainstorming - in the initial phases of design several proposals are generated by the participants.

5. Ranking / Refinement - given the initial set of proposals the engaged engineers will determine collectively the important components of the design options and prioritize the design factors.

6. Detailed Design - A final design is generated based on the earlier refinement process and is adjusted by all members of the group.

Having delineated the design process above, this research effort is interested in determining mechanisms to support this process and enable conducting such meetings with computer mediated communication and reduce design cycle time. Hence, an analysis of the standard physical meeting is necessary in order to determine the modes of communication among the participants. Further analysis of this communication scenario will determine requirements for the computer support of the design process described above. The experimental setup and the analysis process are described in the following section.

## 3.4 Experimental Methodology

Given the characteristics of AEC design meetings described above an appropriate experimental process was developed. The experimental meeting process needed to elicit the appearance of the following criteria: urgency, a discovery process, varying roles, a ranking and refinement process and a detailed design process. The experiment chosen was not particular to the AEC domain, however, it was a standard group dynamics simulation that magnifies the key factors described above in order to clearly identify the discourse characteristics in this setting.

Data was collected on several group meetings among 4 to 5 graduate civil engineering students with an average of 2 years field experience (using the simulation exercise described below), the data was transcribed and annotated followed by a discourse analysis of the annotations. A data-driven preliminary model (Sec. 3.5) was then generated and the model was verified with the available data.

The data set chosen for analysis was gathered from the following task-oriented group exercise:

> A group of students (4 to 5 persons) were given a simulated survival exercise. The exercise involved a crash of a plane in Northern Canada with the group being the sole survivors. The survivors managed to salvage 15 items from the wreckage and the members of the group were asked to rank the items according to their importance to their survival.

A preliminary analysis of the group process that naturally evolved from this exercise shows a direct correlation to typical engineering design processes. The situation is clearly urgent due to the life and death scenario posed. Although the roles of the group members are not predefined in the test scenario, clear roles emerged during the exercise. A group leader emerges and several advocates for particular solutions also evolve. Although survival is the goal of the exercise, each individual places a different weighting on the four core survival principles in this exercise: food, shelter, communication with rescuers and reaching the closest settlement. In each of the three groups tested a member in each of the groups emerged as a champion for one of those survival principles. These champions are similar to the different professionals in the AEC scenario above where each expert represents the interest of his/her field in the problem scenario.

The survival simulation in each of the three cases began with the examination of the map provided and the item list provided. The initial phase of the meeting consisted of each of the members checking each others' facts regarding the situation: their location, the weather conditions, the location of the closest settlement, the terrain and the use of each of the items on the list. This is synonymous with the discovery phase in the design discussion where all members of the design team review the extent of the bridge damage and the average daily traffic flow in the area.

Once the discovery process is complete, the group members then attempted to formulate a list. They typically began this process by attempting to brainstorm on the possible uses of all the items on their list (many of the items had multiple uses). They also began to brainstorm on an appropriate course of action given their situation. Similarly in the bridge emergency scenario the engineers developed several alternatives regarding construction methods and traffic redirection.

In all three groups the members then engaged in ranking the items. They typically chose a coarse ranking and throughout the meeting refined the list until it was agreeable to all those present (This is a ranking and refinement process as in the alternative negotiation phase in the bridge scenario). The final list was then drawn up and a course of action for survival was described. This constituted the final detailed solution design for the survival problem.

## 3.5 Modelling Group Discourse

The detailed discourse analysis of the conversations in the group exercise described above revealed two key physical discourse phenomena that govern speaker state transition and information flow in the group conversations. These phenomena are focus of attention and degree of engagement. These two concepts greatly affect the floor transition in group discourse and are described in detail in sections 3.5.1 and 3.5.2.

In addition, two models have been derived from this analysis to describe floor transitions in group discourse. The first model described in Sec. 3.5.3 describes the state of an individual within the group. For example, this model would characterize the structural engineer's state in a discussion concerning the effect of the accident on the load bearing limits of the bridge (presumably the structural engineer would either be speaking or engaged in such a discussion). The participant model is complemented with a model that indicates the state of the floor, which is a combined state derived from all participant states (described in Sec. 3.5.4). This model demonstrates the extent of confusion or simultaneous disruptive conversations in the group setting.

### 3.5.1 Focus of Attention

Individuals in a problem-solving group are by nature engaged in a shared task. This task is sometimes embodied by a shared blueprint, document or whiteboard. Qualitative analysis of the data from the survival exercise show that group members had attended to a distinct physical space throughout the interaction. This physical space has been termed the focus of attention. Focus of attention is proposed as an additional discourse element that is important in group discourse. This focus is sometimes explicitly determined (as in a parliamentary process where the podium is the main focal point), however, in most group discourse situations the focus emerges from the task discussed and from the particular meeting setting (e.g., A blue-print or physical model placed in the middle of the table in a civil engineering or architectural design meeting).

The focus of attention is a shared space whose manipulation greatly affects the transfer of speakers (floor transition) in a group meeting. Manipulation of the focus may be in the form of deictic and other forms of gestures used within the shared space. In other circumstances the manipulation consists of writing on, highlighting, or modifying the focus of attention.

The focus of attention varies greatly with the task at hand. When the task is not embodied in a physical space the focus of attention becomes the gesture space of the member currently controlling the floor (see Yerian[98] for a description of gesture spaces). In civil engineering meetings the tasks are typically embodied in a physical space and the identification of a focus of attention is generally simple.

### 3.5.2 Degree of Engagement

Participants in a meeting exhibit varying degrees of participation or engagement in the active discourse. The status of a participant in dyadic discourse is often classified as a speaker or auditor as in Duncan[23]. In group discourse this simple two state model is often complemented with a middle state referred to as a pending speaker. Observation of free form group discourse shows that participants can not simply be classified into these three rigid categories.

Participant state may more accurately be referred to simply as a *degree of engagement.* With respect to task-oriented group discourse *degree of engagement* is defined to be the relative attentiveness or interaction of a participant with the *focus of attention.* Several factors contribute to an increasing or decreasing degree of engagement with the discourse. These include: anxiety of the listener; patience threshold of the listener; interest in the discussed topic; and social and cultural norms of the participant. For example, in the bridge emergency scenario, the structural engineer may be discussing the stress calculations and the maximum load bearing capacity, in which case the contractor may not be engaged while the owner and traffic engineer is highly engaged in order to assess the traffic risks of the situation. The continuum of engagement can further be segmented, however, such segmentation does not necessarily provide any additional comprehension of the underlying phenomena. Section 3.5.3 attempts such a segmentation whose states are largely determined by basic discourse elements apparent in each state.

### 3.5.3 Participant Model

The model of each participant engaged in a group discourse is composed of several states ranging from observer to speaker (as opposed to dyadic conversation where participant roles are classified in a two state model of listener and speaker). An observer is defined as a member of a group discussion who is not directly engaged in the group discourse. This is generally physically represented by leaning back from the group discourse or by engaging in activities not directly related to the group activity. A speaker in this model is not necessarily engaged in vocal conversation, the speaker is merely the participant in the group discourse who holds the floor (e.g., a person may be demonstrating a traffic flow model without speaking, however, that person has the complete attention of the collaborating members - hence that person has the floor).

The intermediate states between observer and speaker consist of: engaged listener, focal interruption, and vocal interruption. These states define varying degrees of engagement (see Sec. 3.5.2) that are attempts to acquire the floor. An engaged listener is characterized by gaze direction, dorsal flexion and back-channel, he/she is gazing at the *focus of attention* and is leaning forward in the chair to attract attention. Focal interruption is a subsequent state of engagement in which the participant interrupts the *focus of attention* through manipulation of this shared space. Manipulation of this space varies in degrees, from simple deictic gestures in the space to physically moving, writing on, or tapping on the shared space. The final intermediate state is vocal interruption. This is the most disruptive form of engagement which involves the use of verbal techniques to acquire the floor. This involves use of interrupting repair sequences with increasing loudness and verbal interjections using discourse markers such as "oh", "but", "so", and "excuse me"..

It is important to note that these states are not clearly delineated and there is clearly a continuum of states from observer to speaker. The categorization described above is a first attempt at clustering degrees of participant engagement. As shown in Fig. 3-2 a particular participant may go through all stages in the model or alternatively may skip over several states, hence it is generally not a serial process. The dominant participant state transitions in the participant model are described in Section 3.5.5.

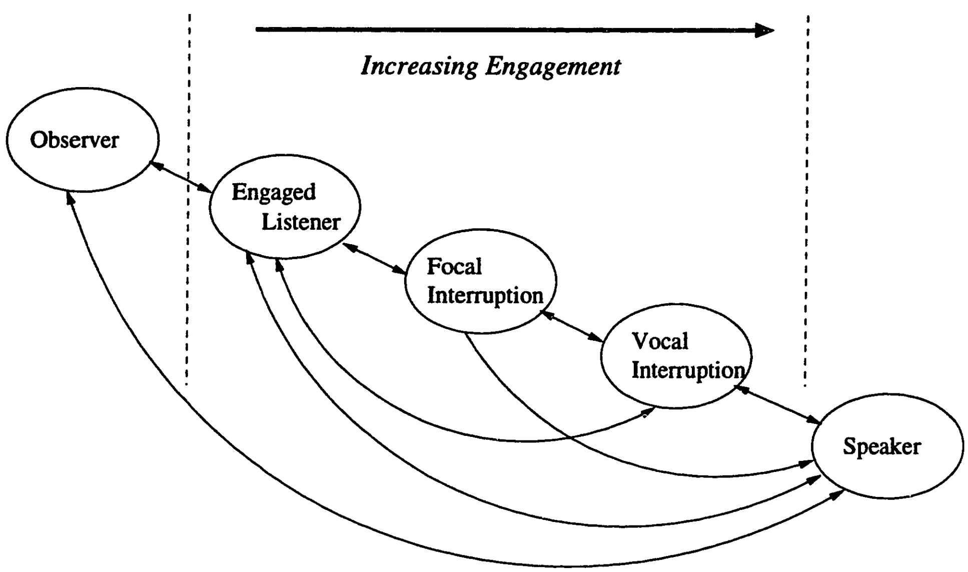



Figure 3-2: Participation states.

### 3.5.4 Floor Model

The model of floor is simpler than the participant model, however, the floor state transition matrix is significantly more complex. The floor, or active communicating role, is composed of three distinct states: empty, overlapping, and controlled. The empty state is characterized by the lack of intentional[4] communication between an individual and the group. The overlapping state is characterized by multiple participants in the interrupt or speaker state, thereby signalling a floor transition. Finally, the controlled state is defined to be the state at which there are no floor contentions and only a single participant is in speaker state.

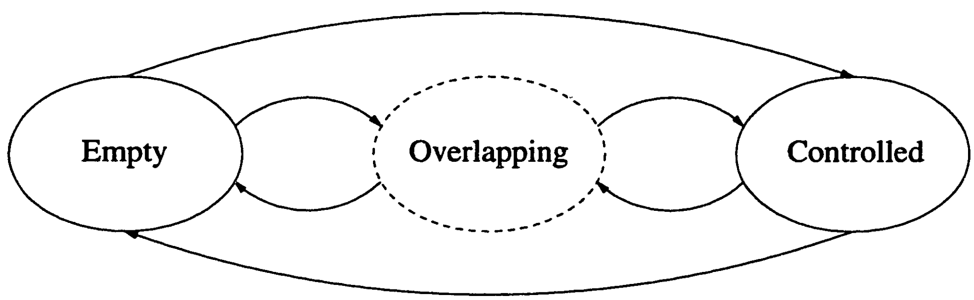



Figure 3-3: Floor states.

Table 3.1 shows the various state transitions and the conditions necessary for the transition that are derived from the participant model and the turn-taking discourse elements discussed in Sec. 3.2. The empty floor state is the most difficult to delineate and causes a large portion of the confusion in group meetings. The empty state is characterized by a pause and ceasing of gesturing. However, it is difficult to distinguish between intra-turn pause (breathing and thinking) and inter-turn pause (Empty floor). Hence, other discourse elements such as the lack of gesturing, falling pitch and questions posed by the speaker in combination with a speaker pause are better indicators of an empty floor.

[4]It is generally difficult to classify intentional communication. However, for the purposes of distributed conferencing applications, all communications are considered intentional.

| Initial State | Destination State Empty | Overlap | Controlled |
|---|---|---|---|
| **Empty** | (*null*) | Two or more participants reach speaker state simultaneously | One participant in Speaking State |
| **Overlap** | Pause, No gesture | (*null*) | Increased volume, repair sequences, spatial control of focus of attention by one of the overlapping participants. |
| **Controlled** | Falling Pitch, Feedback/Info Request, pause, no gesture | Back Channel, Focal Interrupt, Vocal Interrupt. | (*null*) |

Table 3.1: Floor state transition matrix.

### 3.5.5 Model Verification

The participant model hypothesized above was verified through an analysis of the experimental data. Transitions among the various states were tabulated for the group and then on an individual basis. The dynamics of the three groups studied were significantly different. The groups chosen for the exercise were culturally diverse and there were communication difficulties that significantly tainted the data. However, there are significant trends and similarities among all the individuals in the group exercise that allow the generalized model discussed above. The floor model was not verified since it is primarily derived from the turn-taking equivalent discussed and verified in Thorisson[95].

Table 3.2 shows the general state transitions of the participants in 20 minute segments extracted from each of the three groups. This data was used to test the validity of the degree of engagement hypothesis. The data shows that interruptions are used 49% of the time to signal floor transitions. Furthermore, the engaged participant state was a necessary prerequisite to floor control in 90% of the floor transitions.

To further classify the forms of interruption into focal and vocal categories a more

| Transition | Turns | (%) |
|---|---|---|
| Observer-Engaged | 27 | 7% |
| Observer-Controlled | 38 | 10% |
| Engaged-Controlled | 129 | 34% |
| Engaged-Interrupt-Controlled | 186 | 49% |

Table 3.2: Trends in floor transition for all three groups.

detailed analysis was performed on the data shown in Table 3.2. The second data gathering effort focused on determining the type and amount of interruptions used by each of the three groups A, B and C (shown in Table 3.3). The data varied widely among the three groups, which suggests that the dynamics of group interaction are highly dependent on the individuals involved in the group discourse. While the overall use of focal and vocal interruptions was 13% and 42% respectively, the use of focal interruptions by individuals in Group B was very limited (2%). The data suggests that vocal interruptions are clearly a valid intermediate state while focal interruptions occur with much less frequency. The data suggests that the degree of focal and vocal interruption is strongly dependent on the structure of the task performed by the group (e.g., engineers examining and modifying a blueprint have a clear focus of attention, while managers discussing corporate strategy may not have a clear focal point - with the possible exception of some graphs indicating market trends)

In this exercise, there was no explicit shared focus of attention, except for Group C which had the benefit of a blackboard. The seating arrangement of Group A and Group B also differed greatly. Group A was seated in a much tighter arrangement while the individuals in Group B were more spread out, this may partially explain the limited use of a focus of attention by Group B.

Finally, the data was sliced once more to determine the individual influence on group dynamics (it is important to note that the groups were composed of individuals from varying cultural and professional backgrounds). The interjection types were tabulated for each of the individuals in Group A (JR, SR, HC and YC) and are tab-

| Interjection | A | (%) | B | (%) | C | (%) | Total | (%) |
|---|---|---|---|---|---|---|---|---|
| Focal | 22 | 18% | 2 | 2% | 21 | 15% | 45 | 13% |
| Vocal | 48 | 39% | 50 | 53% | 50 | 37% | 148 | 42% |
| Neither | 52 | 43% | 43 | 45% | 66 | 48% | 161 | 45% |

Table 3.3: Use of focal and vocal interruptions in floor control in the three experimental groups.

ulated in Table 3.4. Two individuals dominated the floor in this group, JK and SR, however their use of focal and vocal interruptions varied. While JK's interruptions were spread evenly among focal and vocal, SR hardly used focal interruption. HC exhibited similar behavior to JK although they are from completely different backgrounds (native Chinese, and American). YC interacted minimally with the group. Both YC's and HC's limited interaction may be attributed to their inability to converse comfortably in English. The data is inconclusive regarding the reasons for the use of different mechanisms for interruption. Further controlled studies are required to determine inter and intra cultural use of interruption. This is particularly important given the increasing globalization of business especially in the AEC industry. However, the data confirms the validity of the focal and vocal interruption states in the participant model since they were present in over 50% of the floor transitions.

| Interjection | JK | (%) | SR | (%) | HC | (%) | YC | (%) | Total | (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Focal | 10 | 22% | 4 | 8% | 8 | 28.5% | 0 | 0% | 22 | 18% |
| Vocal | 15 | 33% | 21 | 54% | 12 | 43% | 0 | 0% | 48 | 39% |
| Neither | 20 | 45% | 16 | 38% | 8 | 28.5% | 8 | 100% | 52 | 43% |
| Total | 45 | 37% | 41 | 34% | 28 | 23% | 8 | 6.5% | 122 | 100% |
| Time(min) | 6.3 | 31% | 9.6 | 48% | 3.3 | 17% | .8 | 4% | 20 | 100% |

Table 3.4: Use of focal and vocal interruptions in floor control segmented by members of Group A.

### 3.5.6 Modeling Results

An analysis of interaction patterns in group design discourse was undertaken through an experimental setting described in Sec. 3.4 which directly mirrors the scenario described in Sec. 3.3. The preliminary hypothesis derived was verified through data accumulated from the experimental exercise. This data revealed the important dynamic characteristics of physical meetings. Discourse analysis was used to model the conversation flow (specifically the control of the floor) and the various signals that contributed to a change in the state of the floor. This allowed us to identify the weaknesses of current conferencing systems in supporting group problem-solving interactions such as design meetings and to generate a set of requirements for future systems that are delineated in Sec. 3.6. The key results of this exercise are outlined below:

- Participants exhibit multiple levels of engagement in the meeting setting. These engagement levels are critical to the floor transition process since they provide cues to all participants regarding the current state of the floor and the possibility for taking it.

- Interaction among designers is commonly governed by their physical proximity to each other and to the shared element in the meeting room (i.e., the focus of attention which can be a design specification, a site map or a simple blackboard). The participants gaze and manipulation for the physical space surrounding them contribute significantly to the efficient transfer of floor since they make the participants aware of an individual's intent to speak.

- Inefficient interaction patterns (e.g., long divergent conversation or multiple simultaneous discussions) are identifiable through syntactic cues (e.g., number of engaged individuals, number of individuals that are speaking, and increasing delays for individuals attempting to take the floor) in the interaction since floor state can be determined without semantic knowledge of the interaction.

## 3.6 Group Dynamics Aware Conferencing

The data accumulated in the experiment discussed above as well as previous work in group dynamics[6, 14, 65] provide a greater understanding of interactions in group discussion. Several elements of physical interaction are not directly replicable with simple audio and video communication. The elements of engagement and attention discussed in the previous section are critical in directing the flow of the conversation to facilitate the problem solving discussion. Given these deficiencies of current conferencing systems, a set of requirements and a core infrastructure for group dynamics aware conferencing tools has been developed. This section provides an overview of the state of the art in computer conferencing and discusses the mechanisms required to support an effective group discussion in an engineering problem-solving setting.

The analysis of the group interaction data discussed above can be performed on two levels. This analysis provides an understanding of the group process and the mechanisms necessary to support it. The lowest level examines the interaction dynamics among individuals in the group. The second more abstract level is a descriptive underlying floor control strategy (e.g., chairman controlled, democratic / free-form, or lecture) that is either formally acknowledged or dictated by the setting and norms of the interaction.

The models derived in Sec. 3.5 suggest several important implications for interaction dynamics in distributed synchronous communication. The models and experimental data outline the key aspects of group discourse that require a physical co-presence of the group members. Aspects of a participants degree of engagement cannot be realized by current conferencing technology[25] (assuming simple video and audio connections, not including some of the virtual reality systems under development[59] which are attempting to simulate the full physical embodiment of individuals in an interaction - unfortunately this technology is expensive, cumbersome and far from being applicable commercially). Motions and movements in engagement are subtle and assume a focus of attention that can be manipulated. Current conferencing systems have a limited notion of shared physical space that may be manipulated as in physical meetings. The experiments conducted have shown that this shared space along with the visual and physical indicators of participant engagement are necessary for effective floor transition in multi-person problem-solving meetings.

The following section provides a brief discussion of the user interface features necessary to satisfy the requirements outlined by the analysis performed in Section 3.5 in computer mediated communication tools. A sample implementation is also presented in this section. The final implementation is presented in Chapter 6.

### 3.6.1 Sample Multi-User Interface

The following sections outline recommendations for user interface design for synchronous distributed communication to support the collaboration process. Sample implementations in the conferencing system developed by this research group are also presented as a mechanism to satisfy these requirements. This conference system includes several extensions that enable voice, visual, textual, graphical interaction, as well as Web-based shared document browsing. Finally, a scheduling interface to Primavera is included for large scale collaborations (Figure 3-4 shows the various tools within the conferencing system).

Section 3.6.1 describes the general sense of space and the complementary concept of place. Section 3.6.1 outlines the support of spatial interaction among collaborators. This is followed by a mechanism to support varying degrees of engagement in distributed conferencing. Finally, Sec. 3.6.1 develops a macro view of floor transition and control to enable effective facilitation of distributed meetings.

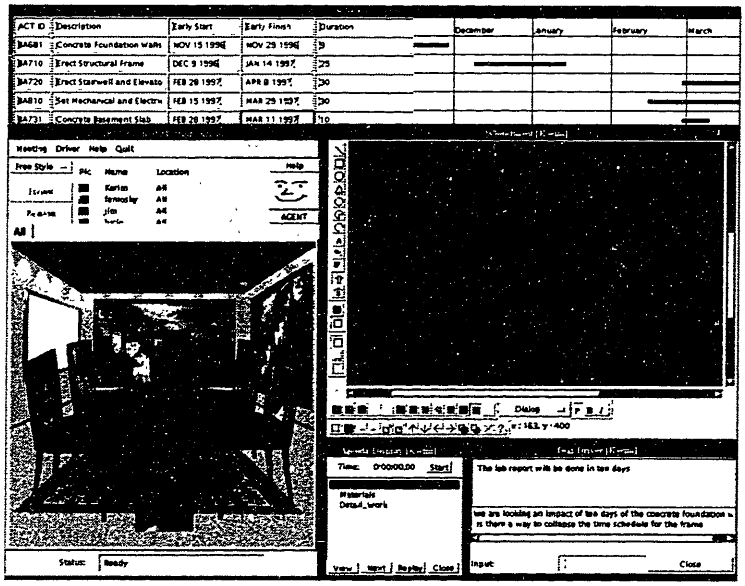


Figure 3-4: A complete view of the elements of the CAIRO research effort.

### A Sense of Place

The literature on computer supported work has been engaged in a fruitful discussion regarding the representation of awareness in synchronous group interaction. The notion of place where members meet and share persistent objects has become a growing influence in the CSCW (Computer-Supported Cooperative Work) community[30, 80]. It is critical to include mechanisms in the user interface that clearly portray entrance and egress of individuals as well as their relative stance to the others in the meeting. This provides a frame of reference for the collaborators that is essential for effective communication. The implementation chosen by this research group (shown in Figure 3-4 is one sample mechanism for promoting awareness (other efforts such as Xerox's Placeware[38] have more elaborate schemes for representing place that are necessary for casual interaction but are less important in formal meetings)).

### Spatial Interaction

A group aware conferencing tool must support deictic referencing in both gaze and pointing. Hence, the tool must have a pointing feature as well as a feature that clearly distinguishes between hearers of conversation and those to whom the conversation is addressed (as dictated by gaze in traditional meeting settings).

Conferencing systems typically provide a large set of interaction tools including whiteboards, text tools, audio, video and CAD or document sharing. These tools, although useful, can be distracting to the user since they do not provide a clear focus of attention. This does not suggest that the tools be reduced, instead it is necessary to include a mechanism for identifying the focal tool of the discourse. This tool becomes the center of floor transition engagement. This research approach is to bring the focal tool to the foreground of the screen or highlight the focal window to represent the focus of attention (see Figure 3-5).

### Degrees of Engagement

Since most conferencing tools adhere to a telephony paradigm, a person wishing to speak can only be in two states (dialing or engaged). The results of the research presented in Section 3.5.2 clearly indicates that the participant should have greater flexibility in defining his/her intent to take control of the floor. An initial interface that provides this functionality is shown in Figure 3-5. Furthermore, the pending speaker queue should be prioritized in order to allow for urgent commentary in an online meeting and the queue should allow simple dis-engagement from the conversation. Finally, the state of each participant should be visible to all those engaged in the on-line meeting. A threshold is then set for the value of engagement such that the floor changes from controlled to overlapping. This is necessary even during strictly chairperson control conferencing schemes.

### Floor Control Strategy

A final requirement for group aware conferencing is the notion of floor control strategies (e.g., chairman controlled, brainstorming, and lecture). In regular meetings a

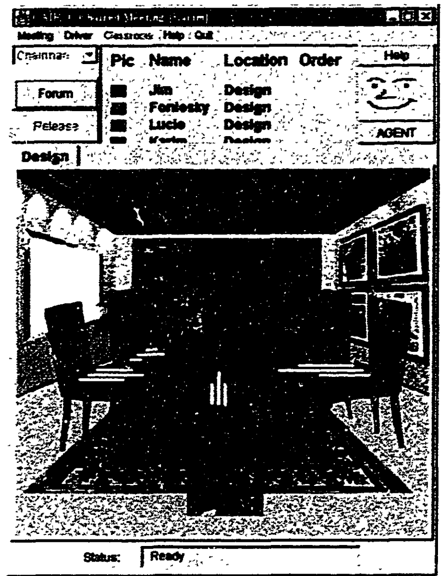



Figure 3-5: Metaphor for representing degree of engagement.

strategy is adopted either explicitly or implicitly due to group norms or due to particular meeting room arrangements. These strategies govern floor control on the macro level, they define a style for a group meeting. Effective choice of floor control strategy can improve the fluidity of the meeting process and enhance the collaborative effort. A toolkit of strategies has been developed by this research effort[41, 69] and have created a knowledge base that maps these strategies to various meeting situations. These strategies are specific to meetings or to individual agenda items. The user interface representation of three strategies is shown in Figure 3-6.

A more complex floor control strategy has also been developed based on the interaction inputs provided by the interfaces described above. The degree of attention was used to sort the queue of pending individuals. The sort function depended on both the level of engagement and the time that the individual was on the pending queue. The engagement level is given a value from 0 to 1 and the time on the queue was measured in seconds. An objective function for sorting the queue was derived by multiplying the two values. This provided a more natural floor transition process and was generally preferred by test users for brainstorming sessions.

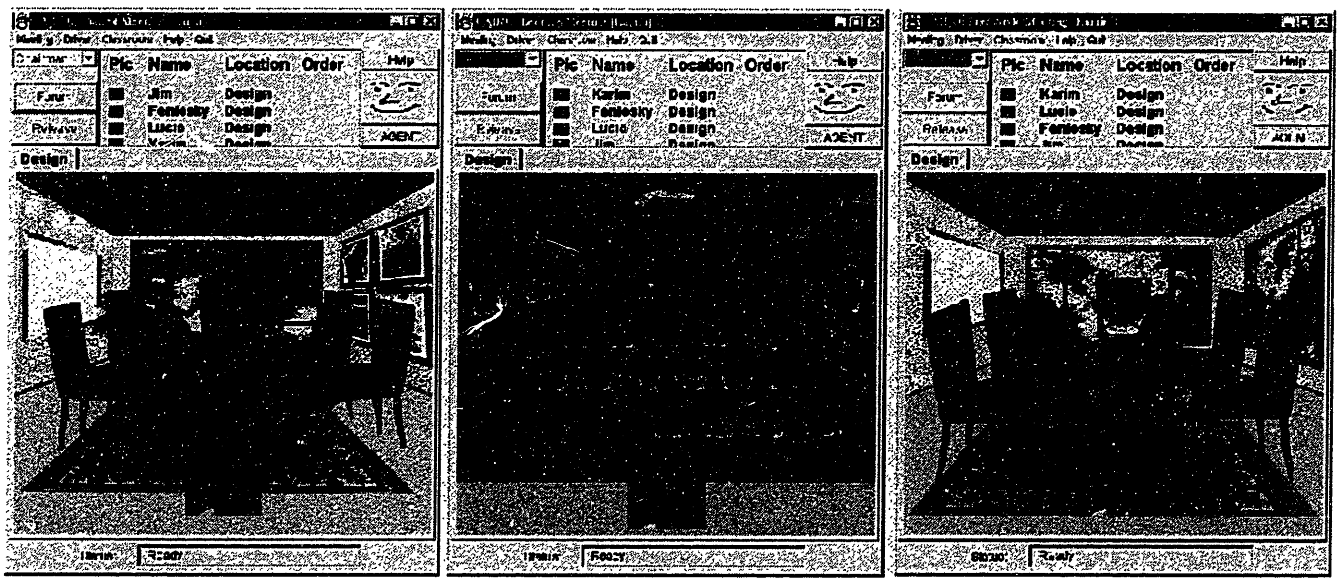


Figure 3-6: Representing multiple floor control strategies - (a) Chaired (b) Lecture and (c) Brainstorming

# Chapter 4

# Group Design Processes

Modern industrial design processes require collaboration among several specialists. These specialists have different perspectives, typically leading to many design conflicts. These conflicts, if not resolved early, create more expensive systems, delays in the development process, and compromises in the final product. Furthermore, current trends towards decentralization of operations and outsourcing components add to the complexity of the product design process. Thus, the decentralization and collaboration add the differentials of time, space and organizational dimensions to an already complicated product development process.

Effective collaboration involves efficient management of information flow and skillful coordination of design team activities. The advent of high speed networks and low cost computing provide a convenient tool for enhancing communication and coordination in design teams. Communication within a group or team involves asynchronous and synchronous exchange of information. Sophisticated workflow management tools have been developed to enhance asynchronous communication. However, limited research activity has been devoted to coordinated synchronous group communication. While the base technological infrastructure (video compression, low cost video acquisition, high speed networks, and computational capacity) has been significantly enhanced over the past decade, the software management layer has lagged behind.

Hence the research proposed herein is focused on improving the synchronous communication and coordination process with a distinct focus on the central coordination medium for group meetings.

Management of the interaction among collaborators in a design team is a critical factor in team success [58]. Ensuring participation of all individuals, encouraging innovative thought, knowledge sharing, focusing group activities, and enhancing commitment are all contributing factors in effective team process. The management and negotiation literatures are replete with methodologies and techniques for enhancing group coordination and communication. When applied these techniques have proven to be effective. However, most coordination methodologies require significant training and involve significant preparation for each group meeting.

Coordination involves two distinct intervention process, content intervention and process intervention. Content interventions include providing new information to a group or team, passing judgment on design proposals, as well as refinement of group ideas. Process interventions include maintaining order in group discussion and aligning discussions to the stated meeting agenda. Our research efforts focus on facilitation and process interventions due to their limited reliance on semantic knowledge in contrast to mediation which requires significant understanding of the discussed topic. Hence, the authors believe facilitation services can be addressed by current computing resources. As such the computer is envisioned as a compliment to the human designers and is essentially a facilitator of group activities.

Facilitating distributed meetings requires significant understanding of group dynamics and communication mechanisms. Hence, as a precursor to the proposed research the relevant social science literature in group collaboration/coordination dynamics [22, 47, 85, 94, 67, 96] has been analyzed as a basis for the development of a computer-facilitated group communication framework. This research on group dynamics has been combined with recent developments in intelligent agent technology and reinforcement learning [27, 99, 57, 89] have led to the approach and methodology discussed in this proposal. The authors intend to formulate methodologies for computer analysis of group dynamics and the automated synthesis of the appropriate corrective process to enhance collaboration within the design team.

The analysis of negotiation and facilitation theories is a prerequisite for providing appropriate computer support for facilitating design processes. This chapter presents two resulting computation models that support the distributed design process. The first model provides a language and mechanism for the specification of meeting collaboration control (i.e. coordination) with the aim of providing computer facilitators for distributed meetings. Within the scope of the research is the development of models for individual conversation elements that comprise meetings in order to provide more intelligent computer supported meeting documentation agents. This research builds on the discussions of group dynamics presented in Chapter 3 (particularly the work of Cole and Nast-Cole [14] and Ellis *et al.*[26]), coordination theory [51], and speech acts [86, 28, 6].

The second computational model identifies the various indicators of disfunctional meeting processes and provide automated facilitators to apply the appropriate corrective action. The key conversation features to be analyzed will be turn-taking points and patterns as well as floor control strategy transitions and group conversation patterns. Prior research in group behavior patterns [67, 96], discourse analysis [85, 94] intelligent agents [19, 87], and multi-agent systems (MAS) [27, 99, 57, 89] will be used as a basis for detecting and correcting such disfunctional meeting process.

The following section provides a description of standard design processes. It is followed by Section 4.2 which outlines the negotiation and facilitation processes in design. A preliminary list of requirements for a distributed meeting environment are also developed within section 4.2. In Section 4.3 an agent-based approach is presented to provide computer support for distributed design processes.

## 4.1 Design Process Models

There are numerous design methodologies proposed in the literature to enable large scale system engineering in large teams. They range from processes that necessitate minimal communication, minimal planning and limited structuring to highly interactive, thoroughly planned and structured processes. The following is a review of three of the more common design methodologies. The review is followed by a description of the most popular methodologies and their interaction and process structuring needs. These needs will be used as a basis for the design of the CAIRO system developed during this dissertation.

### 4.1.1 Waterfall Model

The waterfall model is the most straightforward engineering design process. It is also the most commonly used design process. The model provides simple communication boundaries between analysis, specification, design, construction and testing. This allows engineers to simply work on their predefined design role and pass the design document to the next design stage. Although this model is simple to implement is has serious shortcomings. It has been credited with causing many cost and schedule over-runs in engineering design due to the lack of accountability of the design team as a whole and the limited communication between the design stages.

### 4.1.2 Rapid Prototyping Model

A more commonly accepted modification of the waterfall model is the rapid prototyping model (see Figure 4-1). This allows for testing of preliminary specifications and design through prototype building. The model is not applicable to all engineering domains, since it may be impossible to prototype some engineering systems (e.g., an aircraft, although the Boeing 777 case is an illustration of advanced computer

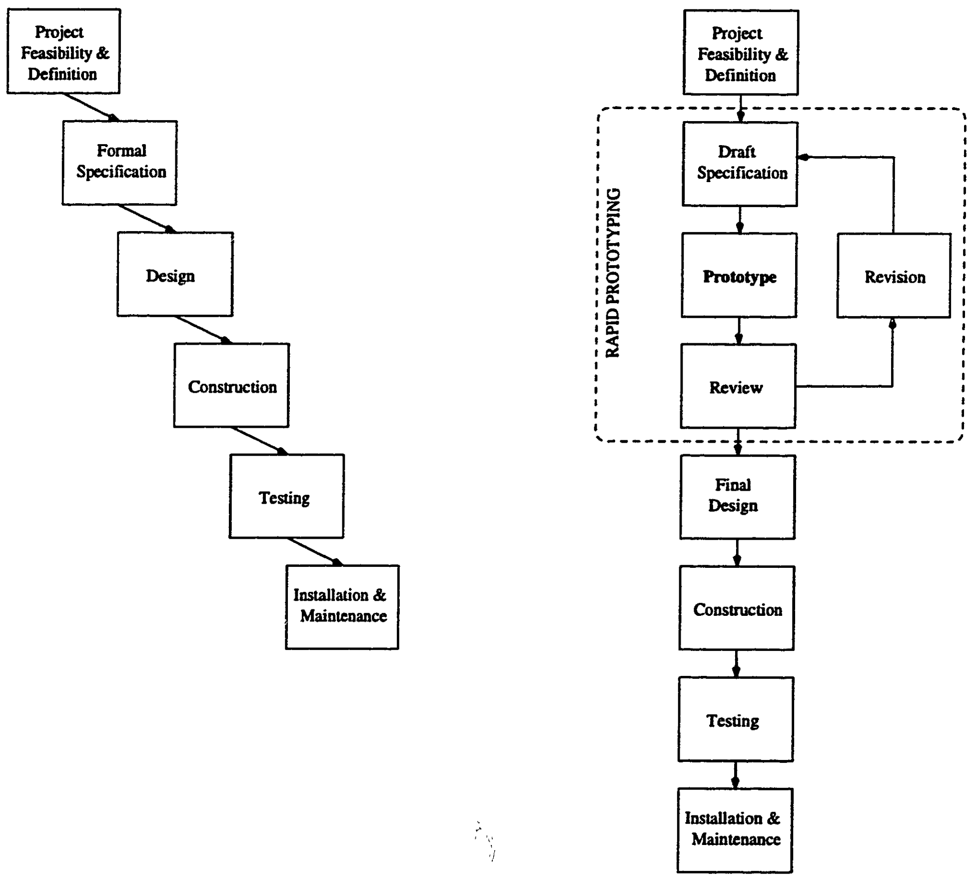



Figure 4-1: Waterfall and Rapid Prototyping models of System Engineering and Development

simulated prototyping of large and complex physical systems). However, current computer simulation techniques allow for prototyping of many engineering systems, although they are severely limited by the computational model utilized. This design process is primarily used in software system development where the final product can easily be prototyped and the prototypes can grow into actual systems. This model requires significant interaction among analysts, designers and builders in the early phases of project development. However, it follows a waterfall model in later stages of development as illustrated by Figure 4-1.

### 4.1.3 Spiral Model

The spiral model is a more complex system engineering design and development model (see Figure 4-2). Due to the inter-linkages among the design development stages, significant interaction is necessary among the system designers. This model was traditionally only applicable when the design teams were part of a single group in a single organization. It is among the most efficient and effective models for system engineering if the design teams are small and closely knit. Communication capability is the major bottleneck for this model. The aim of the design interaction support tools developed in this thesis is to support this model in teams that are not co-located within a physical or organizational unit. Furthermore, this model necessitates close interaction among designers and efficient design conflict resolution mechanisms which are discussed in the following section.

## 4.2 Conflict Management and Negotiation

Fundamentally, negotiation is a resolution of conflicting viewpoints which involves a conflict resolution process that ranges from fighting to adjudication [78, 48, 92]. Hence, design negotiation is a complex process requiring significant time, effort and

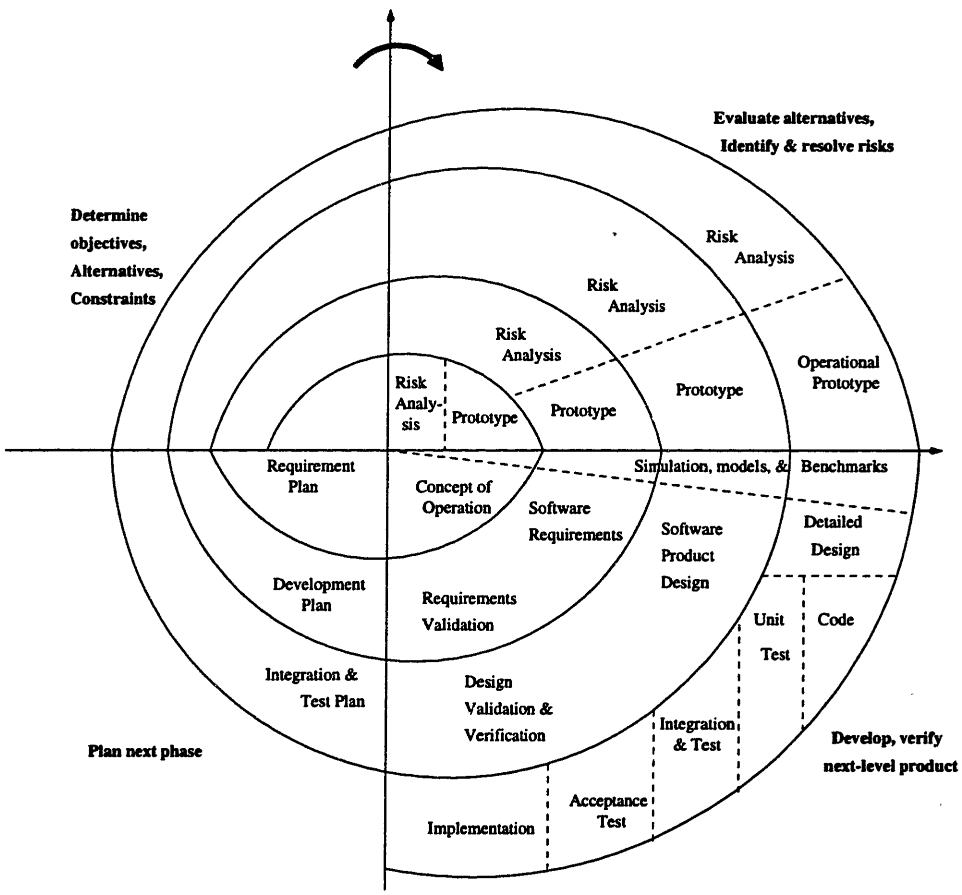



Figure 4-2: Spiral Model of System Engineering and Development

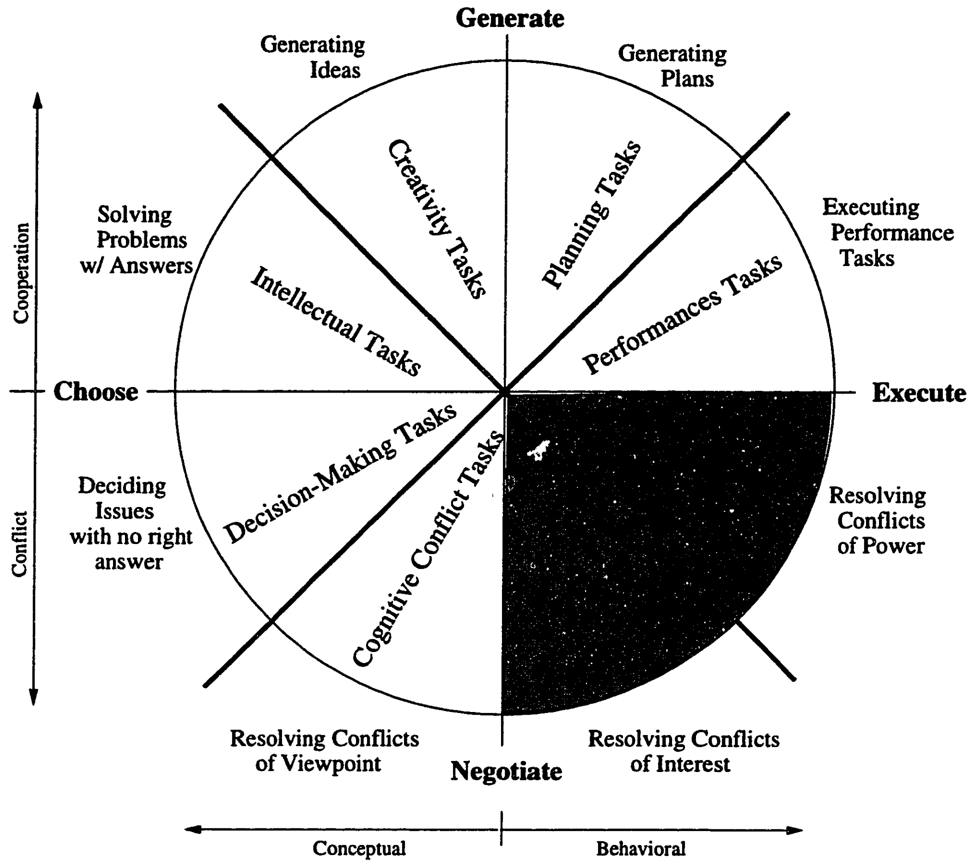



Figure 4-3: The Collaboration / Conflict Circumplex (Adapted from Easterbrook [25])

creativity on the part of human designers. The CAIRO tool is intended to support this negotiation process and reduce unnecessary conflict. The following statement from McMillan [54] summarizes the difficulties associated with computer-mediated negotiation.

> *Decision-making cannot be reduced to a computer program. There is more to most negotiations than can be encompassed in a mathematical formula. Negotiation is, as noted, art as well as science.*

Although the above quote may be conceived as discouraging for this research effort, it reinforces the authors' view that humans are central to the negotiation process (*art of negotiation*); however, the computer can play an active role in enabling and supporting the negotiation process (*science of negotiation*).

A large portion of negotiation effort revolves around resolving conflicts of perception and understanding rather than power or personality conflicts [24]. Figure 4-3 shows a a taxonomy of conflict – the shaded region delineates conflicts that can not be resolved through enhanced communication. Moore [56] suggests that:

> *Most communication theories propose that conflict is the result of poor communication in either* **quality**, **quantity**, *or* **form**. *The theory postulates that if* **quality** *of the information exchanged can be improved, the right* **quantity** *of the communication be attained, and if these data are put into the correct* **form**, *the causes of the dispute will be addressed and the participants will move toward resolution.*

This description of conflict suggests that a critical objective of a negotiation support tool is to enhance the communication links among individuals in a design negotiation meeting. CAIRO aims to provide information to the users in the appropriate quality, quantity and form through effective documentation of the design negotiation process. Furthermore, CAIRO provides access to software agents that support the analysis of civil engineering systems (the particular application domain chosen for the prototype) such as project scheduling, computer aided design (CAD), finite element analysis and computational fluid dynamics (CFD) tools.

Negotiation and conflict are closely related and the negotiation process necessarily involves significant human interaction in a tense setting. Various strategies have been used to deal with the tension and conflict including fighting, discussion, facilitation, mediation and adjudication [73]. Typical design negotiations can be resolved through direct discussion or through the use of assisted negotiation (facilitation and mediation). The CAIRO tool is intended to provide facilitation support to the designers since effective control of meeting process in a distributed environment is difficult and cumbersome for the system users.

## 4.3 Agent Approach

### 4.3.1 Agent Architectures

Behavior based learning agents[50] are being considered for the analysis of group and individual performance as well as to determine user preferences. These agents learn over time through interaction with the user and the conferencing application. The agent learns to represent the user and express his/her frustrations. All user representative agents can then agree on an appropriate process intervention to enhance the meeting process. Agents learn by being presented with situation-action pairs which are classified or structured in a rule-base. Future situations can then be proactively responded to without user intervention. The critical design decisions in agent implementation are feature selection and learning algorithm choice. Our research will explore the appropriate features and learning algorithms. In addition the following open questions will be addressed by this research effort:

1 *How do we build trust between the user and the computer agent providing facilitation?*

Current research is inconclusive with regards to the effectiveness of agent personification in building user acceptance. Furthermore, some researchers suggest building "dumb" agents that learn through interaction with the user in order to build a relationship between the agent and the user. This is the approach taken in this research effort.

2 *How much knowledge should be built into the agent representatives and how much should be learned through interactions with the user?*

As indicated earlier, "dumb" agents build trust incrementally with the user. On the other hand, "dumb" agents may also be very frustrating and ineffective in simplifying the user's tasks. They may require additional boot-strapping time before becoming effective in simplifying user tasks.

3 *What is the fastest yet most accurate machine learning technique for the agent representatives?*

Many different machine learning techniques have been developed. These techniques vary significantly in accuracy, the ability to generalize, the time required to learn, and the number of supervised situation-action pairs necessary for training. The choice of the appropriate methodology or methodologies is essential in the effective development of a conference facilitator agent. A simple clustering system is used in the current agent implementation with cluster boundaries set by the user.

### 4.3.2 Facilitator Agent

The meeting control process should help dissipate conflict elements among the participants during an engineering design negotiation. Negotiators often employ professional facilitators to invoke meeting process changes to ensure the focus of the negotiating group and to reduce conflict. Characteristics of effective facilitators are identified in [29] and are enumerated below:

1 Neutrality

2 Process expert

3 Maintains issue focus

4 Information resource

5 Trustworthy, non-authoritative

6 Not a decision maker.

In CAIRO, some of these requirements are satisfied through the use of computerized facilitator agents. These agents reduce the overhead required in the facilitation of change negotiation. The agents are:

1 inherently neutral since they are computer-based and have no emotions or agendas;

2 encoded with various process intervention heuristics and their reaction evolves with the use of the system;

3 trustworthy since they acquire the trust of the user by informing the user of all the agent's decisions and allowing the user to adjust agent control parameters as they evolve.

The facilitator agents are coupled to the control mechanisms described above. The agents establish the appropriate control mechanism for a given meeting setting.

The choice of conference control strategy at appropriate meeting milestones is critical in the effective coordination of group effort. The agent architecture developed in CAIRO is intended to automatically determine the strategy relevant to the current topic of discussion. The basis of the agents decision is an encoded meeting agenda as well as the meeting indices described in Section 5.1.3. Although the agenda and process representations are linear, typical design discussions involve a cyclical refining process. Hence, the agent must be able to traverse the agenda and process in accordance with the discussion patterns. The mapping of process and agenda stage to appropriate facilitation strategy are currently very simple and are based on several heuristics. The critical issue is the agent's responsibility to determine the transition between the stages outlined in the agenda and process model. The agent bases its behavior on the conversation graph and its relation to the design process and expressed agenda. Figure 4-4 shows the agenda tool developed for the CAIRO system.

The facilitator agent builds a rapport with the conferring individual through an interface technique that builds trust between user and agent as proposed in [50]. Initially the agent is encoded with very basic heuristics and will not make any independent decisions. The agent has a caricature representation that informs the user of its current process state (thinking, suggesting, gratified, disappointed, or confused).

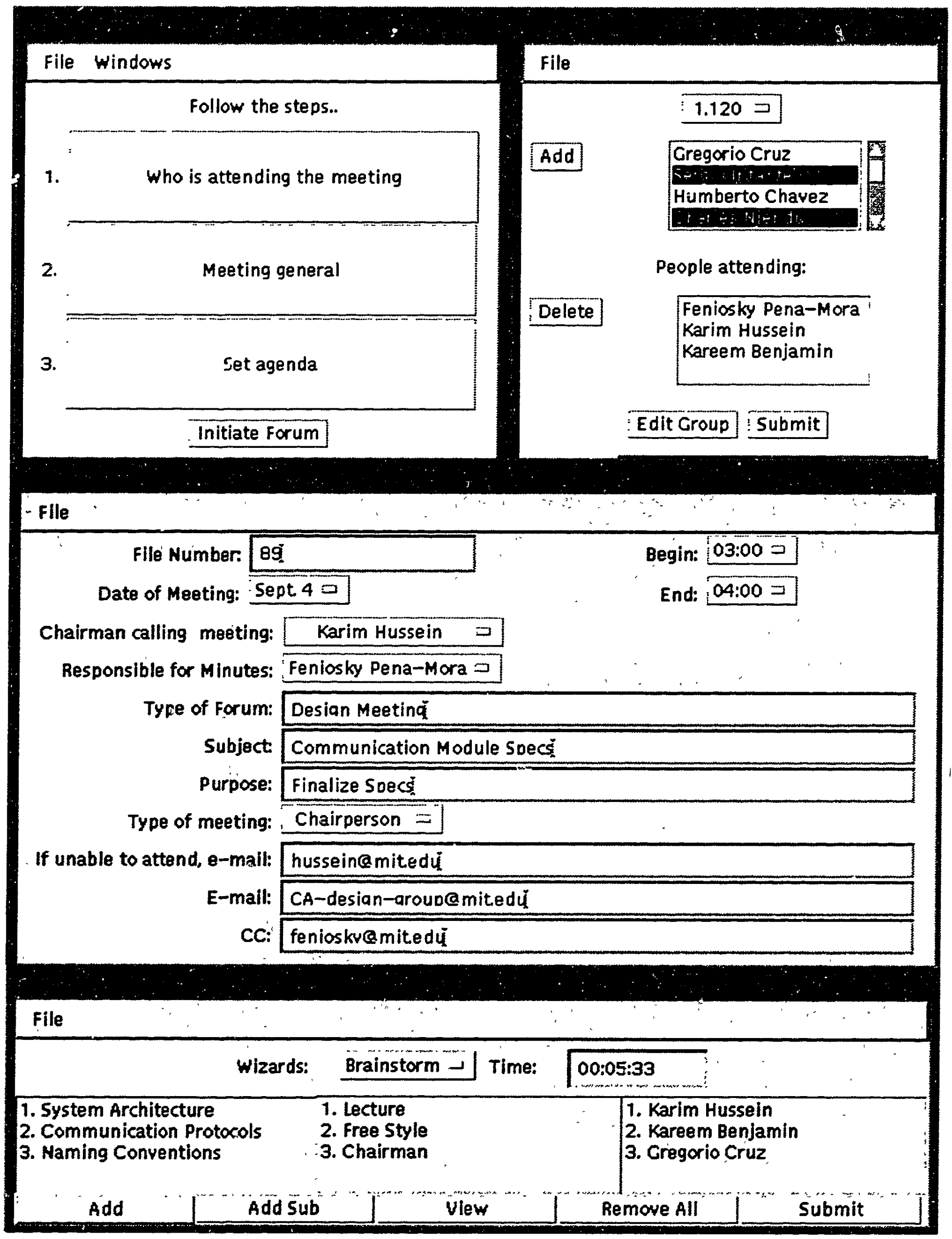



Figure 4-4: The Agenda Tool

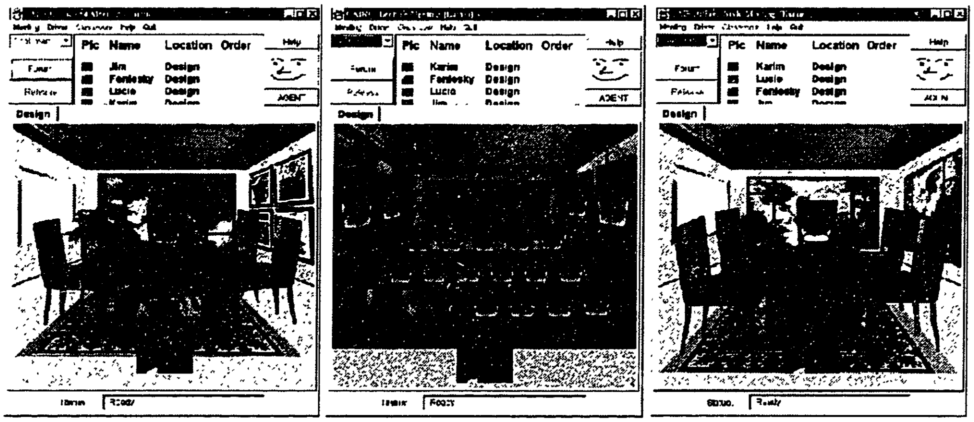


Figure 4-5: (a) Chairperson Mode, (b) Lecture Mode, (c) Brainstorming Mode

As decision points arise, the agent would make suggestions and show expressions of sadness or happiness dependent upon the reaction of the human user. As the agent suggests process interventions, the user may either reject or accept them. Eventually the agent builds thresholds for decisions that may be taken without user intervention. This interactive agent scheme ensures that a trusting relationship is built between agent and user. Figure 4-5 shows the prototype CAIRO user interface.

The following sections describe the agent environment, the agent's behavior vis-a-vis the environment as well as the cooperation of the agents to introduce control process changes.

### 4.3.3 Agent Environment

Each agent has access to information regarding the user as well as the negotiation process. This includes a thresholded encoding of user preferences for agent autonomy (i.e. an indication of what decisions the user is willing to delegate to the agent). The agent decisions on process interventions are based on the following aspects of the agent environment:

(a) The current topic's recommendation list.

(b) Threshold levels indicating user preferences.

(c) An averaged record of the participation of each participant in the negotiation process.

(d) The complete conversation model of the ongoing negotiation.

It is important to note that the agent has no direct understanding of the topic being discussed except for that provided by the meeting agenda. Although topic understanding is helpful in assessing the relative importance of certain individuals in the negotiation process, it is prohibitively difficult to realize with current knowledge understanding technology. This difficulty is addressed by specifying issue owners for various stages on the meeting agenda. This mapping should indicate the relative importance of the participant towards the resolution of a specific design conflict.

### 4.3.4 Agent Behavior

The current agent behavior is quite simplistic. It generates a vector representing:

1 The averages of the on-line time each individual has consumed.

2 The amount of recommendations generated regarding a specific intent.

3 The average time a pending speaker waits before he/she is given access to the floor.

4 The relevance of the topic to each speaker (as indicated in the meeting agenda).

At the present time, the facilitator agent only distinguishes between three control strategies: (1) Brainstorming/Free, (2) Lecture, (3) Chairperson. A weight is assigned to each of the components of the vector described above and the elements are summed. These weights are adjustable by the user. The resulting scalar is thresholded at three levels to indicate the appropriate meeting process that the agent should proceed to. These thresholds are adjusted by the computer as the agent interacts with the user and are also manually adjustable by the user.

This approach is not optimal at determining appropriate process intervention moments. However, controlled experiments have shown that the agent has made reasonable process intervention suggestions to the users.

### Social Agents

As has been previously indicated, each participant has an agent that monitors relevant components of the design environment and suggests appropriate actions to be taken by the participant. With continued interaction, the agent learns how to effectively represent each individual within the design environment.

As the agents become more familiar with their representees they can cooperate with the agents of the other conferees to decide upon the appropriate meeting control scheme. The agents reach consensus on a meeting process intervention through a simple majority rule mechanism.

# Chapter 5

# System Architecture and Network Infrastructure

This chapter presents the design of a tool to support distributed collaborative meetings. The tool provides an environment for structured information exchange across the internet in real-time. Critical design elements of the system are synchronous communication support, coordinated interaction support, system modularity and extensibility with a variety of media and tools, robust and reliable communication, and finally, a multi-user interface for collaboration (presented in Chapter 6).

Information exchanged in a shared environment is comprised of a variety of media (i.e., multi-media). Typical exchanges between members of a group involve speech, gestures, documents and sketches. Such interactions occur in real time, as in a meeting, or off-line, in the form of memos and more recently e-mail. This thesis focuses on the real time aspects of geographically distributed group interaction. Real time interaction is inherently taxing on both system and communication resources. Furthermore, the multimedia nature of human interaction necessitates a synchronization mechanism between the media channels to preserve the time dependence of the initial user input (see Section 5.1.1). For example, consider watching a movie where audio and video do not match (commonly referred to as "lip-sync"). The lack of synchronization can prove to be irritating as well as highly confusing if there is a significant delay between the two channels of communication.

A real time conferencing system is highly reliant on the available network infrastructure. Although, many advanced protocols such as ATM (Asynchronous Transfer Mode) and BISDN (Broadband Integrated Services Digital Network) have been proposed, the Internet remains the prevalent high bandwidth network today. The CAIRO system is based on the internet (see Section 5.1.1) and its underlying TCP/IP protocols. A major difference between current networks and future networks is the determinism of the network. Networks based on ATM will be deterministic (i.e. will have pre-specified packet delay times) which greatly simplifies the communication subsystem in the multimedia communication facilitator proposed in this thesis. However, CAIRO assumes that the underlying network is non-deterministic and methods have been developed to accommodate this inadequacy which are based on real time scheduling techniques (described in Section 5.1.1).

## 5.1 CAIRO System Services

In an effort to enhance group design and collaboration processes in a distributed environment, the following three objectives have been developed for the CAIRO system.

1 The relaxation of time and space constraints in traditional meeting settings;

2 The facilitation of distributed negotiation through the formalization of meeting control methodologies and the application of intelligent agent mechanisms to select the appropriate methodology;

3 The capture of process and rationale that generated a product design through the documentation of meetings.

To achieve these objectives a model of the distributed negotiation meeting process has been devised. This model is composed of four critical components: co-location, cooperation, coordination, and documentation. This model maps the necessary physical meeting elements into a general requirement list. These requirements are based on the fact that physical meetings require four key components in order to exist: (1) A physical meeting room in which the participant can meet (co-location); (2) A common language and a shared understanding of materials to be presented in the meeting (cooperation); (3) An agenda and an individual or set of individuals that ensures the agenda is maintained and the group is focused on resolving the issues outlined in the agenda (coordination); (4) Group memory which is comprised of each individual's memory and notes as well as the formally defined group memory incorporated in the minutes of the meeting (documentation).

The following provides a detailed description of the layers of a computer-based collaboration system required for an effective collaborative environment:

**Co-location** involves dealing with the network infrastructure to provide seamless communication among distributed clients in a conference. This layer should provide naming services to identify client locations as well as interaction with the network protocols to transmit data across the network between the clients.

**Cooperation** involves the sharing of information among clients in a team. Due to differences in software and capabilities of the various clients, translations need to be performed in order to provide a coherent view of the data among the clients.

**Coordination** involves control of the workflow and communication process. This allows for efficient control mechanisms to coordinate group effort. The coordination layer acts as a "virtual manager" of the conferring clients.

**Documentation** involves the capture and storage of conversation elements exchanged during a meeting. The documentation process provides a mechanism for the retention of group memory.

The first two layers of service are the preliminary infrastructure for the CAIRO project – they are discussed in detail in Section 5.1.1. Exploration of the coordination and documentation layers of service are the two key focus areas of the current research effort. Figure 5-1 provides an overview of the collaboration model developed for the CAIRO system.

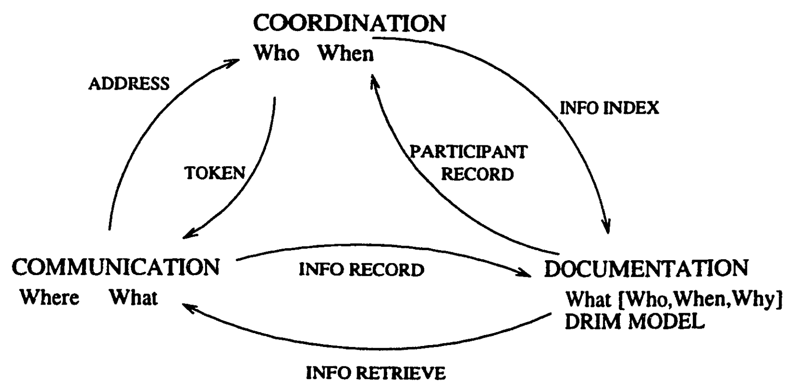



Figure 5-1: The Collaboration Mechanisms in CAIRO[1]

### 5.1.1 Communication Constraints

#### Distributed Networks - Internet

The Internet is a collection of interconnected nodes (machines) that interact via a common protocol that is TCP/IP [15]. Due to the nature of the protocol as well as the packet transmission and routing mechanisms prevalent on the internet, the internet is a non-deterministic network. Hence, inter-packet arrival time is unpredictable due to varying network traffic. In a real time application – an application with pre-specified time dependence – such random delay patterns can render the application useless. Insuring real time communication via the internet requires a series of delay compensation techniques discussed within this thesis. These heuristics reduce the amount of variability in the underlying network as well as provide the end user with near real time performance.

[1]The '[]' symbols indicate indexed by.

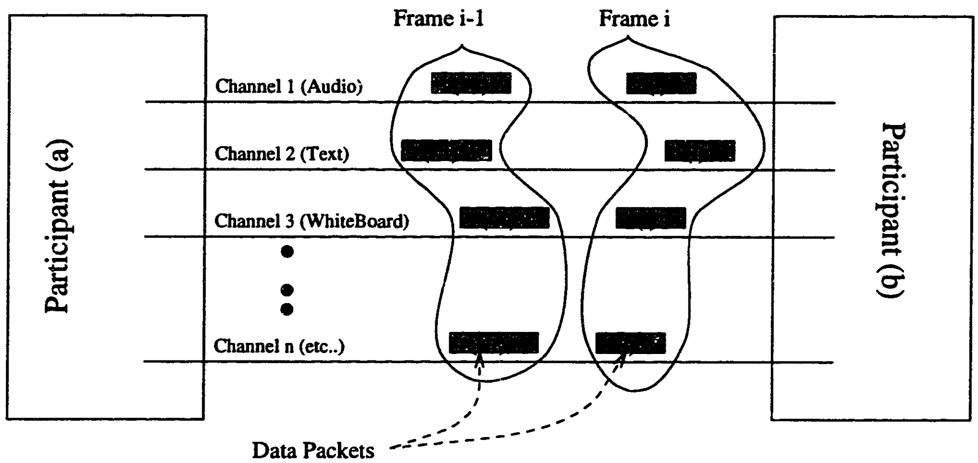



Figure 5-2: Synchronization issues between two conference participants

### Real Time Scheduling

Synchronization of the various media inherent in a multimedia conference requires real time scheduling support by the conference support tools. Most current operating systems[2] do not provide adequate support for real time scheduling. Real time system theory [13] addresses the scheduling of multiple independent channels or streams of data. These channels may have unpredictable arrival rates, although they must be subject to specific timing constraints (see Figure 5-2). Real time scheduling assures that all media channels are communicated within a given time period or frame, eliminating all "lip-sync" effects. Due to the possibility of losing packets or delays in packet transmission by the medium, a queuing mechanism is required to enforce the real time constraints.

Real time (RT) systems are commonly classified as hard or soft real time systems. Hard RT systems have critical deadlines that must be met, otherwise a catastrophic system failure would occur (eg. an aircraft control system). On the other hand, in soft RT systems, it is undesirable to miss a deadline. However, it is not catastrophic to system operation if some deadlines are missed. A conferencing system is a soft

[2]Notable exceptions are MACH RT and RTOS.

RT system since some video and audio frames may be dropped without significant consequences to the overall performance of the system.

### 5.1.2 Control Infrastructure for Group Conferencing

A communication control model has been developed in order to support both individual interaction as well as process control in group interactions. This model is centered around a forum server that acts as the communication control mechanism from the conferencing system. The forum server's primary function is the allocation of communication channels among individuals in the group. Communication among individuals is nneled through this server but is rather controlled by the forum process.

Forum processes are initiated by a forum manager tool that allows the definition of meeting membership, meeting control strategies, meeting agenda and meeting notification. The meeting may be defined as open (i.e., any person can enter the meeting room) or closed in which all participants in the meeting must be predefined in the agenda tool. Each meeting member is also assigned particular access rights that include: agenda editing, chairperson control, and control of the meeting proceedings. The agenda tool[8] is also used to define the meeting agenda items which are each assigned a floor control strategy by the meeting initiator. Once the agenda is complete, the system automatically sends notification messages to the participants and a forum server process is created with the appropriate membership and agenda.

The forum server model is shown in Figure 5-3. The forum class processes messages from the client systems which represent each participant in the meeting. The forum class is also responsible for maintaining meeting membership and temporal control of the meeting. This includes meeting notification, agenda traversal, and maintaining and traversing meeting logs. Communication requests received by the forum class from the clients are handled by one of the subclasses of the control class.

The Control classes contain functions to manipulate tokens[3] and manipulate the speaker queue. The queue is composed of all members that are interested in acquiring the floor. The ordering of the queue is based on the particular control strategy used. For example, the chairperson strategy would allow explicit ordering of the queue by the chairperson, the brainstorming queue would simply be a first-in first-out (FIFO) queue. Ordering of the queue can also be based on more complex inputs provided by the user interface mechanisms described in the following section. The token control mechanism and the forum processes are described in further detail in Section 5.3.3.

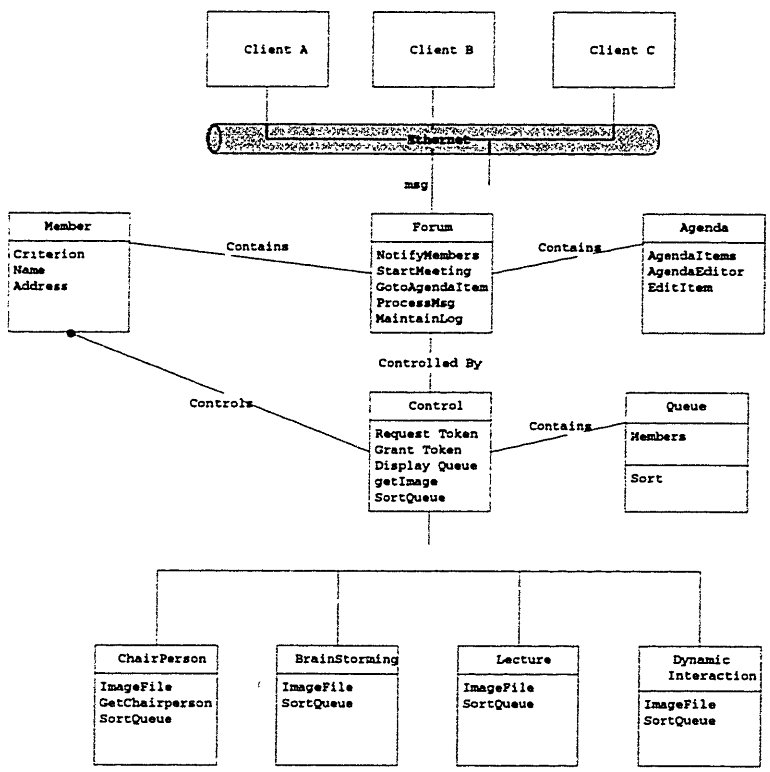



Figure 5-3: Control infrastructure model.

### 5.1.3 Documentation

Documentation of meeting proceeding serves two key purposes in the CAIRO environment: (1) Providing a convenient snapshot of negotiation proceedings for late

[3]Tokens are software keys that allow communication between two clients.

participants or for follow-up meetings; and (2) Retaining group memory by saving design rationale knowledge encoded in the speech exchange during a negotiation. There are two key mechanisms that have been designed to support negotiation documentation requirements: Conversation indexing mechanisms and Conversation browsing tools.

For the benefit of information retrieval and the retention of a meeting context for time-delayed participants a conversation model has been developed. The model is based on the four critical dimensions of design negotiation conversations; (1) Problem space / Product-Process model, (2) Information flow, (3) Authority and role of participant, (4) Absolute time and time dependence among conversation elements. The underlying conversation model provides a basis for indexing the free-form conversation occurring in a typical meeting event. The model is further refined by incorporating a semi-structured design rationale model [70] that includes designer intent, recommendations and justifications. This model supports both structured and unstructured design rationale data. More structured data is derived by refining the abstraction level according to the complete DRIM model shown in Fig. 5-5. Hence the documentation model provides support for multiple degrees of structure in contrast with other work performed in this area, such as the GDS System [12].

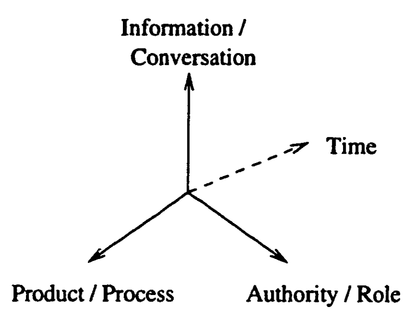



Figure 5-4: The four dimensions of conversation in CAIRO[4]

The DRIM (Design Recommendation and Intent Model) model represents multi-

[4]The dashed line for time indicates a fourth dimension.

ple designers who can be either human experts or specific computer programs (see Fig. 5-5). The designer after negotiating and collaborating with other designers, presents project proposals based on a design intent. The design intent refers to the objective of the project, the constraints involved, the function considered or the goal of the project. Each designer can present a number of different proposals satisfying a common design intent. A project proposal includes the designer's recommendation and the justification of why that particular proposal is recommended. The design recommendation can either introduce or modify a design intent, a plan or an artifact. When a design intent is recommended, it refers to more entities that need to be satisfied in order to achieve the design intent. Justification explains why the recommendation satisfies the proposed design intent. A justification can be either a rule, a case, a standard catalog, a principle, a tradeoff, or a pareto optimal surface. A justification reacts to other justifications by either supporting or contradicting their claims. For a more detailed discussion of DRIM refer to [70].

In CAIRO, a simplified DRIM model is used to represent conversations in design negotiation. The model includes an intent (shown as a rectangle), a recommendation (shown as a rounded rectangle) or a justification (shown as an elongated hexagon). Each of these boxes contain several words that describe the conversation clip. Clicking on the box will cause a multimedia presentation of the issue to appear on the CAIRO console (see Fig. 5-6).

The browser for a negotiation meeting is based on the DRIM indices described above. A combination of an index and a causal / temporal model of the interaction is used to generate a directed graph of the proceedings of the meeting. Such a graph forms the core of the user interface and allows quick visualization of the meeting proceedings. Users can then browse the conversation data based on a single graph or on the intersection of several graphs. For example the user may wish to look at all conversations regarding the functional specification phase (according to the process

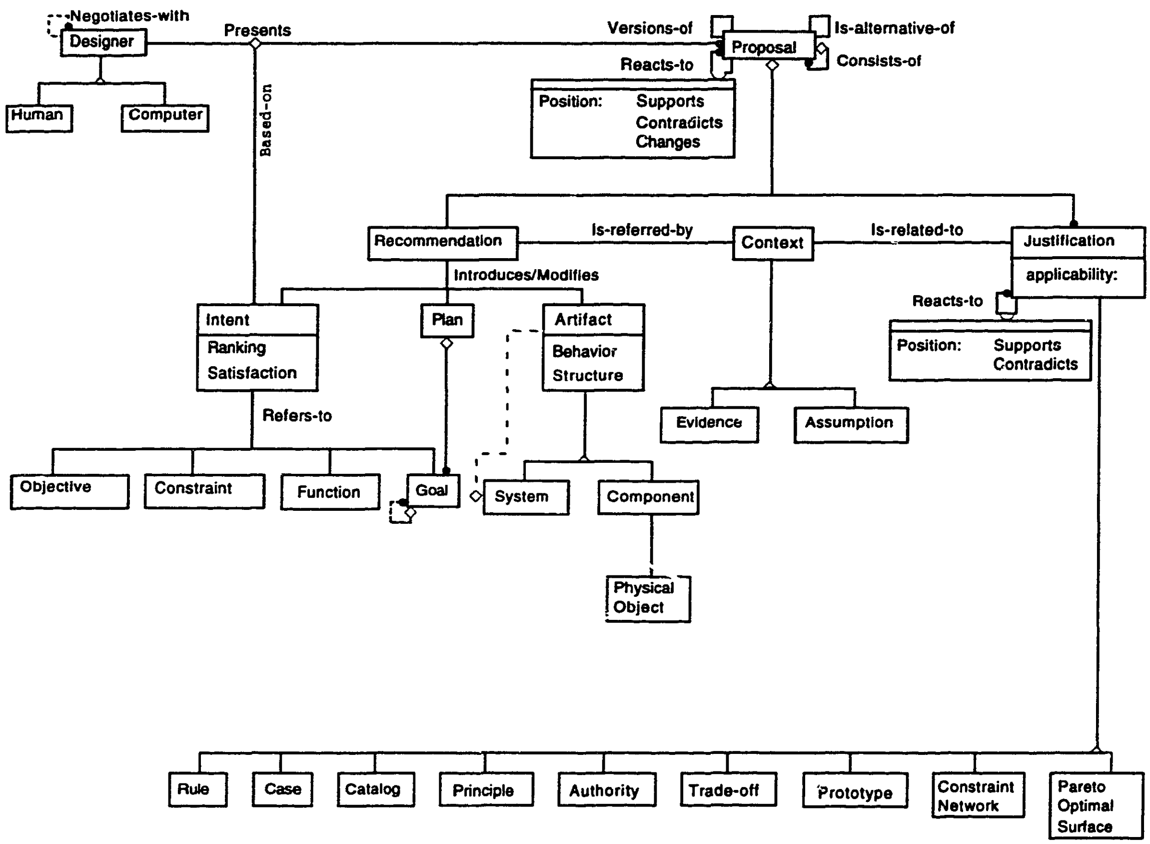



Figure 5-5: The DRIM object model.

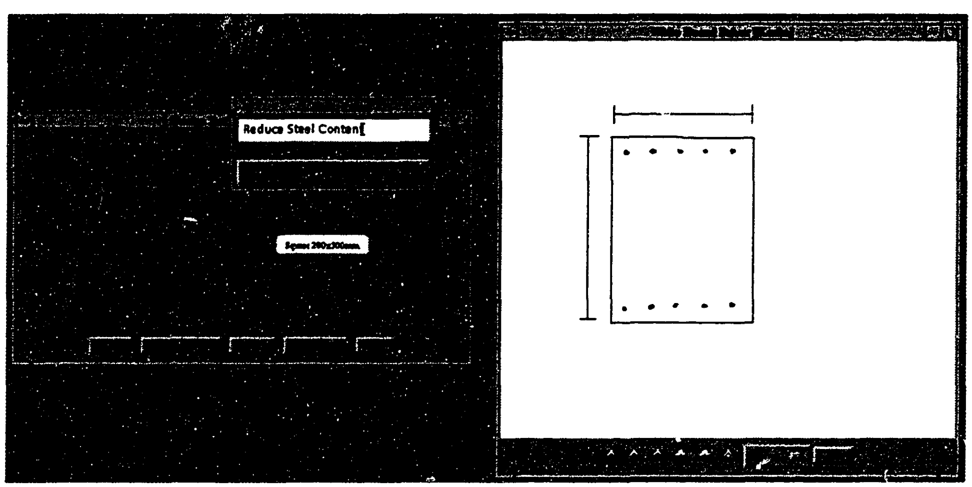


Figure 5-6: An example scenario of conversation structuring within CAIRO (intents are shown as rectangles, recommendations as rounded rectangles and justifications as elongated hexagons)

model) of a specific joint (from the product model) generated by the mechanical engineer (from the designer index). The scope of the graph can also be limited in accordance to user preferences derived by an intelligent user interface agent currently being developed.

## 5.2 Summary of Requirements

The social interaction models described in Chapter 3 and the meeting control strategies presented in Chapter 4 provide a sound basis for the development of an effective communication tool that would easily fit into the accepted social structure. The meeting cycle models provides an overview of typical engineering approaches to group problem solving. Finally, the group life cycle model provides insight into the organization of teams and their evolution. Furthermore, the previous section provided an overview of the technical constraints within which the communication tool must operate. Both the social and technical constraints contribute to the necessary list of requirements for an effective distributed informal communication tool enumerated below:

(i) Multiple media channels are required since group communication is generally comprised of audio, textual, and visual data.

(ii) Multimedia channel synchronization is essential due to random delays inherent in the underlying network.

(iii) A conference control mechanism is required to provide efficient group interaction.

(iv) The system must be adaptable to different conference styles (from informal, unstructured conversation to a stringent and formal conversation control mechanism).

(v) Ability to support groups in the various stages of formation, i.e. the ability to have hierarchically structured groups that are easily expandable.

(vi) Ability to retain group memory to build corporate experience as specified by the *adjourning* phase in the group life cycle.

## 5.3 System Components and Architecture

The CAIRO system is comprised of several interlinked modules and servers (see Figure 5-7). Each participant engaged in a CAIRO conference spawns a *Collaboration Manager* (shown as a dashed box) which is comprised of media drivers (shown as pictograms of the media – i.e. video camera, microphone and X display) and message servers (indicated by the acronym 'MSG'). The media drivers satisfy requirement (i) specified in Section 5.2. The message servers package data for transmission over the network and enforce synchronization constraints during media play-back thereby enforcing requirement (ii). *Forum servers* are processes that maintain control of a conference among several individuals (requirement (iii)) and enforces membership constraints (requirement (v)). Furthermore *forum servers* log all conference proceedings (requirement (vi)). *Forum servers* are spawned by *forum managers* (not shown) that define a specific control methodology. Forum managers also provide mechanisms for converting a *forum server's* control strategy thereby satisfying requirement (iv). Finally, the *name server* maintains a directory of all participants, forum managers and forum servers within the CAIRO system. It allows each participant to easily address any other member or forum in the CAIRO system.

The following sections describe the key components of the CAIRO system architecture. Section 5.3.1 defines terms that will be used throughout the architecture description. The collaboration manager module is then described in detail (Section 5.3.2). The functionality of forum servers and forum control are then detailed in Section 5.3.3. Finally, the functionality of the name server is illustrated in Sec-

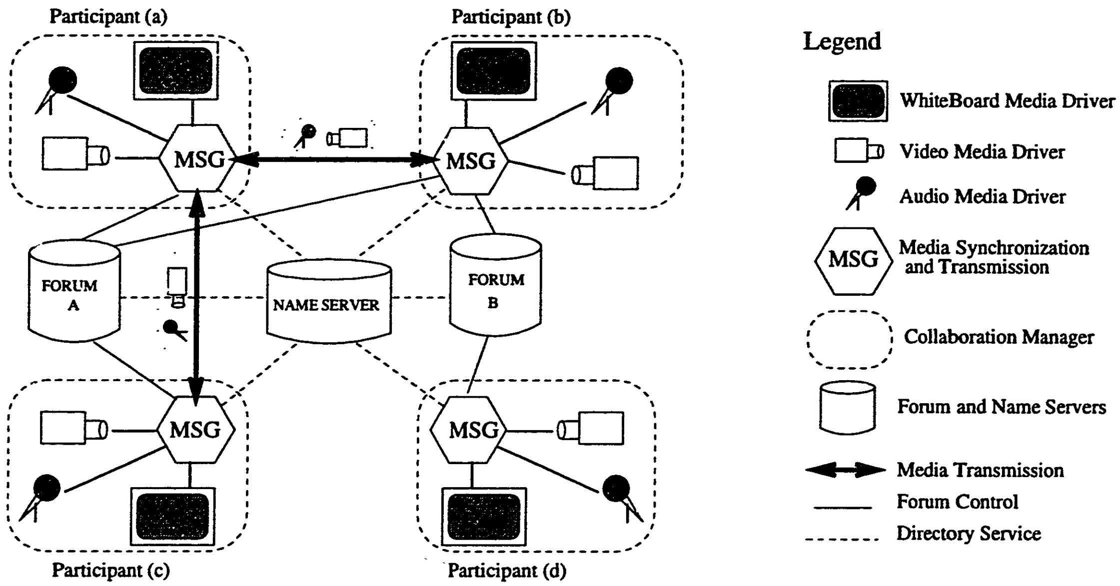



Figure 5-7: The CAIRO System: An overview.

tion 5.3.4.

### 5.3.1 Definitions

**Participant** a user who has the ability to participate in a multimedia session.

**Conversation** a multi-channel connection between two or more participants.

**Forum** a set comprised of participants and other forums. Associated with a forum are a variety of access control and collaboration control parameters. An atomic forum is a single participant.

**Media Source** a device or application that provides a channel in a multi-channel, multimedia conversation.

### 5.3.2 CAIRO Client

#### Collaboration Manager

The Collaboration Manager incorporates the CAIRO user interface and maintains lists of available media resources and forum servers (see Figure 5-8). The Collaboration

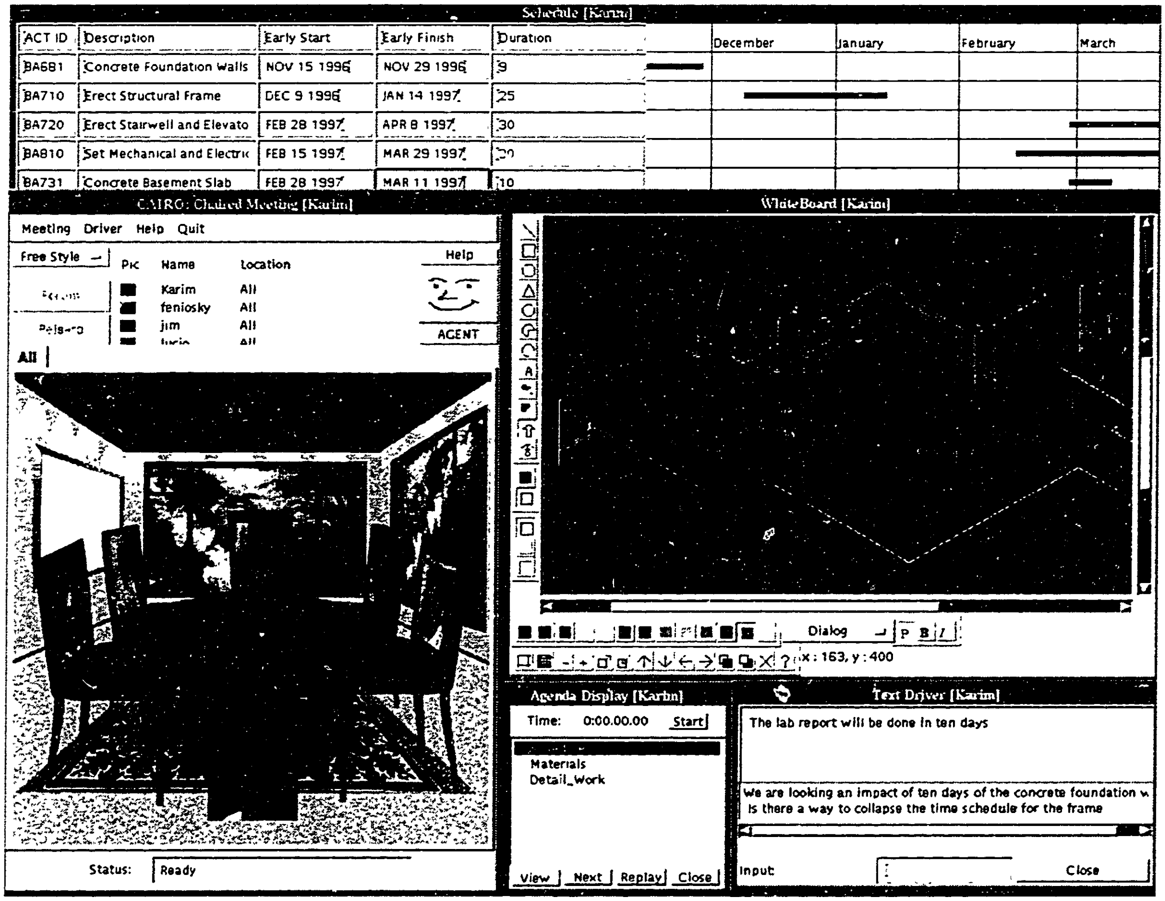



Figure 5-8: A Sample Session of CAIRO

Manager also has a snapshot facility that allows each participant to retain portions of the meeting for his/her own personal notes. It also enforces conference controls associated with the forums in which the user is participating. For example, a specific forum may not allow any conversations with users outside of the forum or may not permit any private side conversations with other members of the forum.

## Media Drivers

Media drivers handle all I/O between the Multimedia collaboration system and the underlying media channel. Each driver is tailored specifically to the underlying media represented. Each driver is responsible for data acquisition and frame compilation for transmission and replay. This module must also provide the multimedia server with synchronization information, frame size, and delay and error tolerances. Several media drivers have been implemented that enable distributed schedule coordination, shared whiteboards for sketching, a text tool for chatting, and audio and video drivers using Microsoft NetMeeting [55] technology.

**Audio Driver** This is a driver implemented using Microsoft NetMeeting SDK(Software Development Kit), a standardized API for teleconferencing on machines running Windows 95. This is the only portion of the code that is not portable across platforms due to the lack of standardization of telephony API's for the Java language.

**Text Driver** This is a driver that allows the exchange of short text messages among the participants. Lengthy text entries may also be pasted into the text entry input box for transmission to conference participants.

**Shared Whiteboard** This is a driver for an application that simulates a Blackboard in an office environment. It can be shared among the members of a forum to communicate visual information such as sketches of various product design ideas. It can also used to transfer bitmaps of images on the user's screen to the rest of the team.

**Shared Schedule** This is a driver for an application that interacts with a Primavera scheduling engine for large scale project scheduling. It can be shared among the members of a forum to allow for schedule modifications and additions .

### MultiMedia Message Server

Each user in the CAIRO collaborative environment is associated with at least one multimedia message server. This server (see Figure 5-9) handles all communication between users, schedules transmission and display of channel data, as well as main-

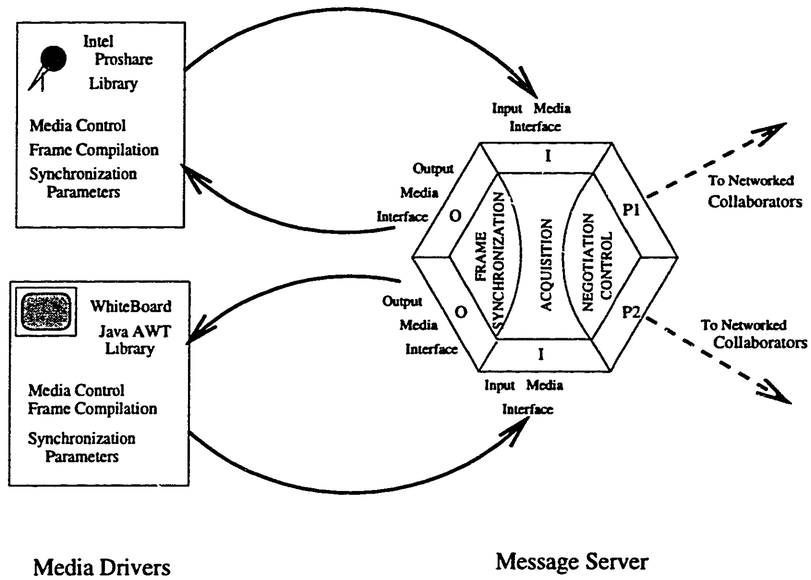



Figure 5-9: Message Server Overview: Media drivers for audio and whiteboard devices

tains membership on the various forums the user wishes to be associated with. The components of the multimedia server are described below:

### Media Synchronization

The CAIRO system is designed to support multiple media channels in a conversation. Due to delays in the transmission of the packets across the internet, packet arrival times are unpredictable (see Figure 5-2). Therefore, each multimedia frame does not arrive at the destination as one chunk. The receiver must then reassemble the frame and ensure that play-back of the frame is synchronized such that it reflects the initial input from the source. Figure 5-9 illustrates an overview of the media channel synchronization subsystem of CAIRO. Media synchronization is base on the synchronization parameters (Section 5.3.2) supplied by each media driver. Each media driver also supplies temporal relations with respect to the other media drivers in the system (Section 5.3.2). Given these parameters the system can compensate for skews in the delivery time of messages through the heuristics described in Section 5.3.2. A real time scheduler is then invoked to determine the schedulability of the input

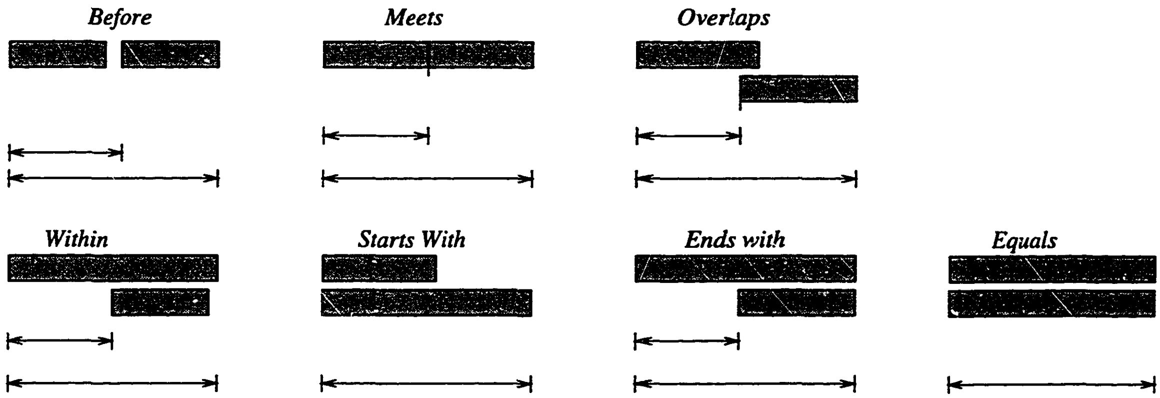



Figure 5-10: Various methods for combining channels. Adapted from [*Little and Ghafour*, 1993]

media streams (Section 5.3.2). A synchronization engine combines the synchronization heuristics and parameters to play-back the multimedia data to the receiver in as similar a form to the original data as possible (Section 5.3.2).

### Synchronization Parameters

The following are parameters that define the quality of service for a particular channel. These parameters are provided by each media driver involved in the CAIRO system and are required for scheduling of the media channel transmission by the message server.

**Frames per Second (FPS):** The average number of frames per second, along with average frame size, are critical for appropriate scheduling of media transmission and display. Example: Audio has been set at 40 FPS.

**Average Frame Size:** The size of each frame in bytes after all compression has been performed. Example: Audio is sent after $\mu$-law encoding at 200 bytes per frame.

**Inter-Glitch Spacing:** The maximum allowable spacing between missed or corrupted frames in the transmission stream. For audio this is typically 1 in 20.

Table 5.1: A subset of temporal relations between a channel $\alpha$ and a channel $\beta$.

| Relation | $T_\alpha$ | $T_\beta$ | $T_{TR}$ |
|---|---|---|---|
| *before* | $< T_\delta$ | $\neq 0$ | $T_\beta + T_\delta > T_\alpha + T_\beta$ |
| *meets* | $T_\delta$ | $T_\alpha$ | $T_\alpha + T_\beta$ |
| *overlaps* | $< T_\beta + T_\delta$ | $\neq 0$ | $T_\beta + T_\delta < T_\alpha + T_\beta$ |
| *overlaps* | $> T_\beta + T_\delta$ | $\neq 0$ | $T_\alpha$ |
| *starts* | $< T_\beta$ | 0 | $T_\beta$ |
| *equals* | $T_\beta$ | 0 | $T_\alpha$ |

**Delay Time:** The maximum amount of time a frame can be skewed with respect to the frame boundary.

**Temporal Relation to other Channels:** A listing of all other media driver channels with which this channel must be synchronized. Synchronization can occur in many forms which are discussed in Section 5.3.2.

### Temporal Relations between Channels

Each channel in a multimedia conference must include a parameter that describes its temporal relation to each of the other channels. Little and Ghafour have developed a conceptual model for capturing temporal relationships among various media channels [49]. Figure 5.3.2 provides a graphical overview of the temporal relations between channels. A subset of the temporal relations between two channels $\alpha$ and $\beta$ are described in Table 5.1.

$T_\alpha$ is the duration of a transmission on channel $\alpha$ and $T_\beta$ is the duration of a transmission on channel $\beta$. $T_\delta$ is the difference in time between the beginning of transmission on channel $\alpha$ and the beginning of transmission on channel $\beta$, and $T_{TR}$ is $max(T_\alpha, T_\beta + T_\delta)$.

### Delay Compensation Heuristics

All media channels are synchronized using the compensation heuristics described below as well as the real time scheduling algorithm described in the following section. The work undertaken is based to a large extent on [79][5].

**Frame Interpolation:** If a current missed frame time is greater than the inter-glitch spacing. Then replay the last frame and continue.

**Handling of Persistent Slippage:** If continuous loss of frames then switch to a lower resolution or lower frame rate (i.e. graceful degradation of a channel).

**Advance to Next Temporal Interval:** Retain frame until next frame arrives as long as the skew is not too far off the temporal interval boundary.

**Control of Frame Time-outs:** If packets on a channel are delayed by a specific amount then delay all subsequent packets, in order to try to only have one skew period.

**Output Queuing*:** Compile and store multiple frames prior to transmission on the ethernet until a pre-specified number(i.e. the queue length) of complete multi-channel frames are ready to for transmission.

**Input Queuing*:** Store incoming packets of data, until they can be compiled into a multimedia frame and there exists two subsequent multimedia frames that can continue the multimedia play-back.

**Variation in Queue Length*:** Increase the length of Input Queues of the various media channels to allow for enhanced scheduling of the multimedia frames.

[5]Extensions have been added in our implementation to enhance throughput on our network. Those that we have introduced will be indicated by an asterisk (*).

### Soft Real Time Scheduling

Real time scheduling is the scheduling of multiple concurrent tasks to be performed within a given temporal interval or frame. Each task $i$ has an associated computation time $C_i$ as well as a period $T_i$. The rate monotonic algorithm provides a conservative estimate as to the number and type of tasks schedulable on a system (see [34] for a more detailed discussion).

$$U(n) = \sum_{i=1}^{n} \frac{C_i}{T_i} \leq n(2^{\frac{1}{n}} - 1) \tag{5.1}$$

As each media device registers with the message server system $U(n)$ is checked for consistency with the above equation. Once all task computation times and deadlines are determined the scheduler operates on an earliest deadline first policy. That is within a given time unit the highest priority tasks to be scheduled are those that have the highest period.

### Synchronization Algorithm

The preceding sections provided a description of the necessary parameters and task constraints for multimedia synchronization in a distributed conference. Furthermore, Section 5.3.2 described the basic heuristics employed by the synchronization engine. This section describes in detail the synchronization mechanism implemented in CAIRO. The base data structures, multimedia frames and media device input queues, are discussed followed by the description of the synchronization mechanism.

### Frames

Multimedia frames transmitted by a source participant are encoded with a frame sequence number and a time stamp. Furthermore, the initial and final frames in a conversation are uniquely tagged to aid the synchronization and scheduling mechanism as discussed in Section 5.3.2. Temporal constraints described in Table 5.1 are encoded with respect to a single frame. Each frame is composed of multiple channels of media data for a given period of time. In order to ensure the arrival of all packets in a single frame, a delay in play-back at the destination must be introduced. CAIRO enforces a delay of .5 seconds although this may be varied as the network infrastructure changes.

The synchronization engine enforces three types of temporal constraints: before, after, and during. All three constraints are determined on the transmission side and the appropriate frame sequence numbers are chosen for each channel to reflect the constraint. For example, if text was required to appear after audio, and audio was sampled in frames $i$ to $i + 10$ then the text sequence number would be $i + 11$.

### Queues

All packets arriving on the receiving end are placed in input buffer queues by the media drivers (Appendix A provides a detailed diagram of object structures in CAIRO). The queues store up to $fmax$ frames ($fmax = 100$ in the CAIRO prototype). Incoming data is placed in the queue according to the frame sequence number. The queue index is equal to the frame sequence number modulo $fmax$. Each media channel has its own queue structure (eg. audio queues have 10 audio clips per queue element, text queues have 1 string per queue element) see Figure 5-11. The queue structure is a list of lists. The top-level list is indexed by sequence. For each sequence index in the top-level list a secondary list contains the media packets indexed by source (this allows a receiver to listen to data from multiple sources). Hence, a single sequence index can be associated with multiple elements. Each element in the queue is also tagged with a time-stamp and a source specification.

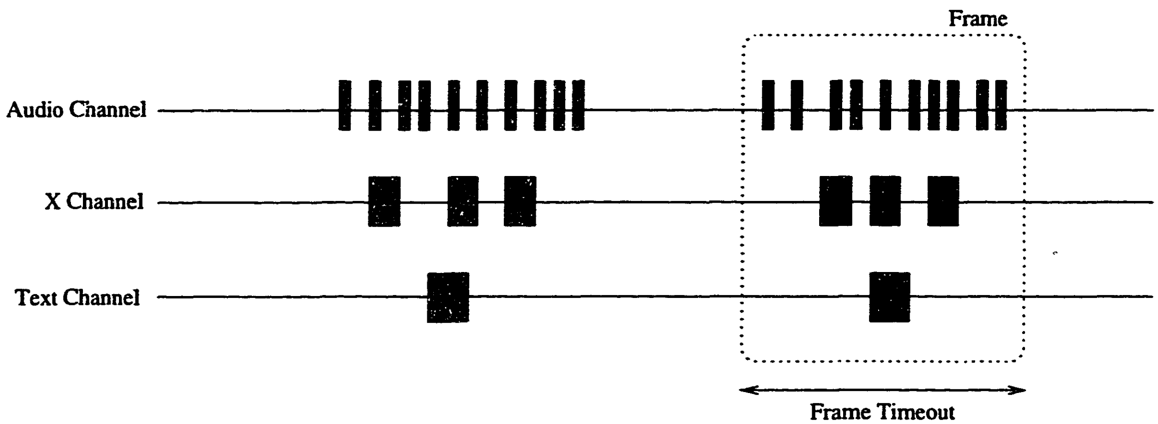



Figure 5-11: Multi-channel frames

### Scheduling

The scheduler operates on the basis of frames. The scheduler is invoked periodically based on the frame time-out period. The frame time-out period is arbitrarily set at a $\frac{1}{4}$ second. Each frame contains several packets on each media channel (see Figure 5-11). At each interval the scheduler polls each queue and retrieves a list of complete frames. If a complete frame exists and it is has the smallest sequence number the frame is scheduled for replay. However, if the frame with smallest sequence number is incomplete, the scheduler employs the delay compensation heuristic that is applicable. If none of the heuristics are applicable the user is notified that the communication channel can not support the quality of service requested and suggests decreases in the quality thresholds.

There are two exceptions to the behavior of the scheduler. As discussed earlier there are two special frame identifiers, initial and final. The scheduler should not replay a frame unless three frames are available for replay, unless the final frame is among the last three frames. This buffering of frames ensures that data will usually be available for replay at the frame time-out.

The synchronizer then takes a single frame and passes it on to the real time scheduler. The scheduler then posts the appropriate events to replay the frame.

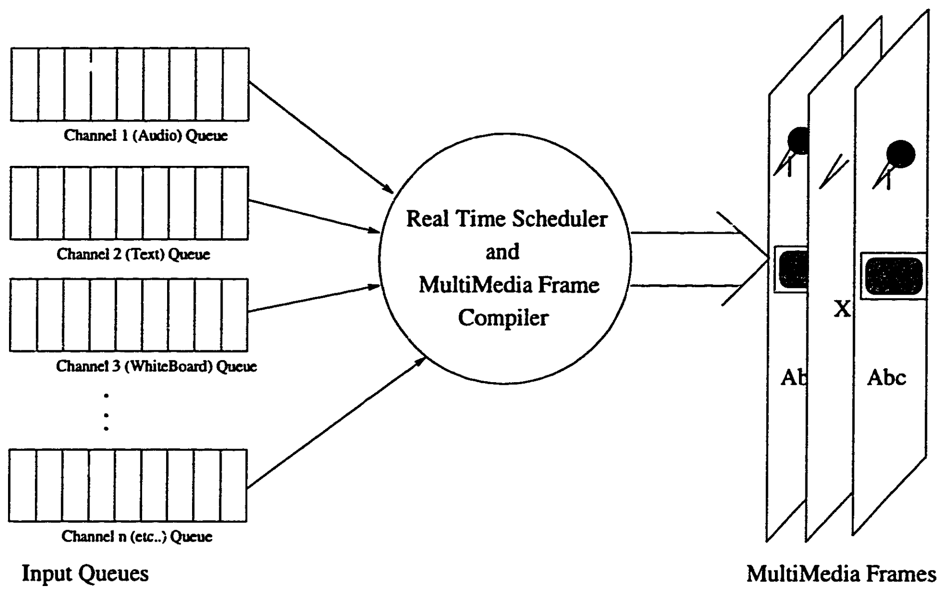



Figure 5-12: Multimedia Frame Assembly from Input Media Channel Queues.

The events are posted based on an earliest deadline first policy. The scheduler is implemented on top of the X event handler.

### Synchronization Engine

The engine maintains the input and output buffers and ensures that all channels are assembled before play-back by the media drivers. Figure 5-12 describes the essential functionality of the synchronization engine as well as its relation to the input queue and multimedia frame output queue.

**Multimedia Frame Output Queue:** Storage of multiple frames prior to transmission on the ethernet. This is required to allow for complete channel frame transmission.

**Input Media Channel Queue:** Storage of incoming data packets on each media channel. These are stored until they can be compiled into a multimedia frame.

**Connection Manager:** This object takes care of low level calls to the TCP/IP layer for maintaining socket connections and sending datagrams across the internet.

**Correspondence Cache:** A cache of addresses associated with all participants the user will broadcast to given that he/she is a member of a specific forum. Update requests are periodically transmitted to maintain cache coherence between the forum server and multimedia message server.

#### Message Protocol

Appendix B provides a complete listing of the messages exchanged between the various component of the CAIRO system. All messages are TCP/IP datagrams and are asynchronous. Each component of the system has an interrupt handler that manages incoming and outgoing messages and appropriately routes the messages to the appropriate objects.

### 5.3.3 Forum Server

Forum managers contain information on a particular type of meeting. They spawn off instances of forums that comply with the forum manager control mechanisms but with varying memberships. Currently, four such forum managers have been designed however the system is extensible and future systems need only comply to a predefined message protocol to enter into CAIRO. Chapter 5.3.3 describes the various control schemes and the underlying primitive control structures. Among the necessary provisions are membership request processing, membership grant, token request, token grant, as well as participant privilege explication. These parameters allow a forum manager to specify membership constraints as well as floor controls for a conference.

A forum is a structured group of participants involved in a collaborative effort. The forum server maintains a list of all participants in a specified forum as well as

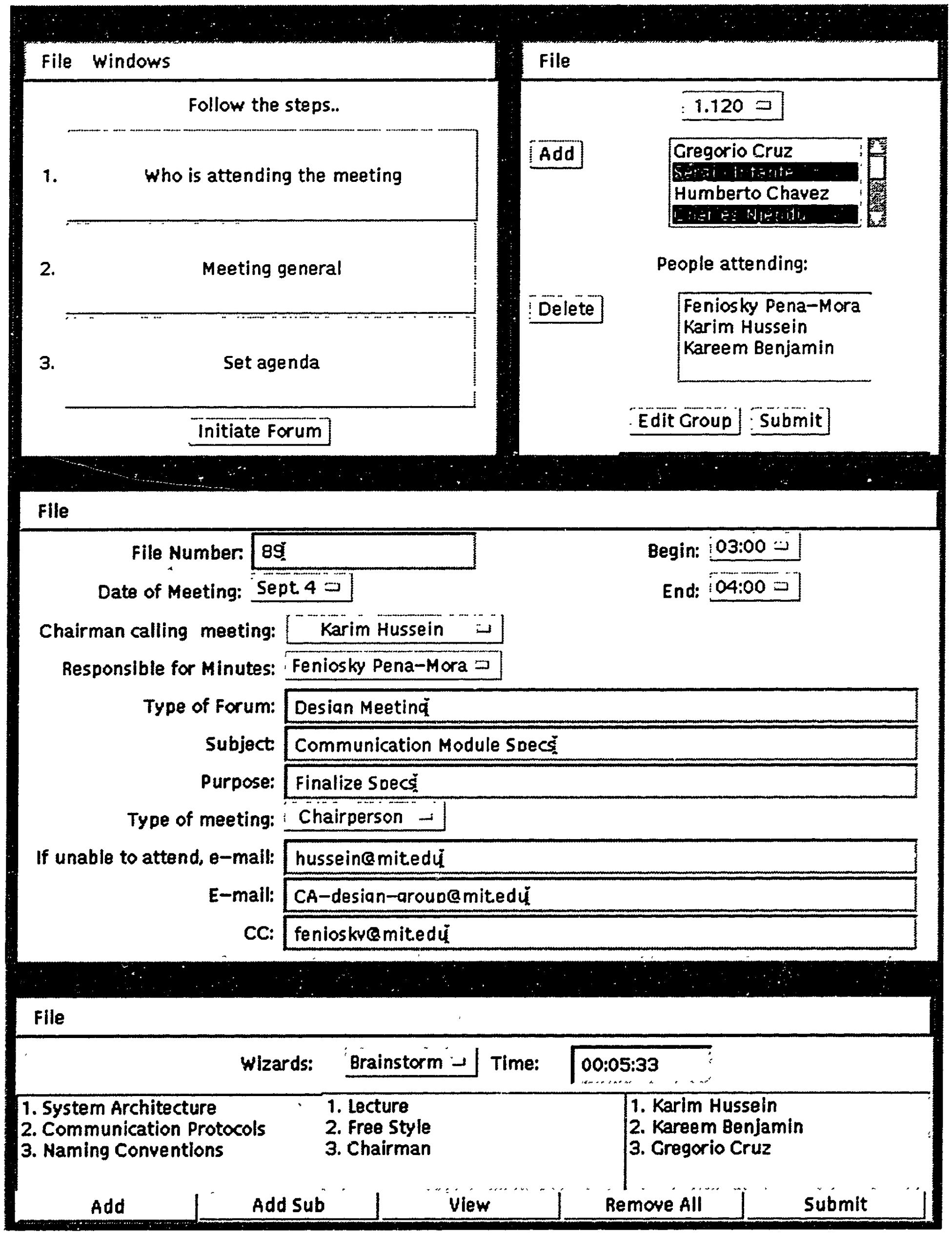



Figure 5-13: Forum Manager User Interface

the privileges associated with each participant. Each forum member is listed in one of three states in the forum: active (logged in and listening to conference), speaking (actively participating in conferencing, i.e. has control over the floor), or non-active (not logged in and not receiving any conference communications).

Forum servers have two key functions: subscription control and speaker control. Subscription control may be a predefined list of allowable conference participants or it could be through a vote by existing participants or it may be a forum maintainer with the right to revoke and grant membership to potential members. Speaker control is the process by which a forum server maintains an orderly conversation among the members of the forum. Speaker control or floor control of the forum is achieved through the granting and revoking of conversation tokens as described in the following Section.

### Token-Based Control

All restrictive controls on the participants in a forum are provided via token access. The Collaboration Manager cannot issue any communications without having received a token granting access privilege to that specific speaker. Token controllers on both the Collaboration Managers and Forum Servers must be secure and trusted code. Methods to enforce this abound, see [76, 97] for a more detailed discussion. Forum Servers issue two commands related to tokens: a Grant_Token command (specifying write or read rights to a communication channel with another participant) and a Retrieve_Token command (retracting read or write rights specified by a Grant_Token). Collaboration Managers respond with an Accept_Token or Reject_Token message depending on conflicts with other active forums on that user's workstation (eg. engagement in another forum that does not permit multiple parallel forums). Tokens have internal time-out counts after which tokens expire. Specialized tokens denote ability to participate in side conversations, external conversations, and interjection rights.

These side and external conversation tokens can be used to maintain confidentiality within a conference and to minimize group distractions. Interjection tokens allow for emergency situations.

Tokens are granted upon request submitted to the Forum Server by a Collaboration Manager. Such tokens can be granted automatically using a predetermined computer moderation scheme or can be granted manually by a moderator. Furthermore, conference logging is achieved via a specialized token requesting communication sent to the Forum server where all interactions are logged for future browsing and editing. This mechanism satisfies the process history support requirement (requirement (iv)) described in Section 5.2.

The token structure provides a centralized control yet distributed communication structure for conferencing. Hence, all high bandwidth communication is decentralized and direct, while all floor control requests are centralized by the forum server.

### Collaboration Control

Structuring and control of group meetings enhances the efficiency of a collaborative team. The following sections discuss the hierarchical meeting structure of CAIRO (Section 5.3.3 in addition to the collaboration primitives defined in the system (Sections 5.3.3 and 5.3.3) and the collaboration schemes built upon these primitives (Section 5.3.3).

### Hierarchical Forum Model

Forums maintain a conference among individuals. Each forum is associated with a *forum moderator* that defines the control behavior of the conference. The forum server processes requests for membership to the forum as well as requests to speak by participants within the forum. As shown in Figure 5-14, a forum is comprised of individuals and other forums. The forum `Management` that is a member of another

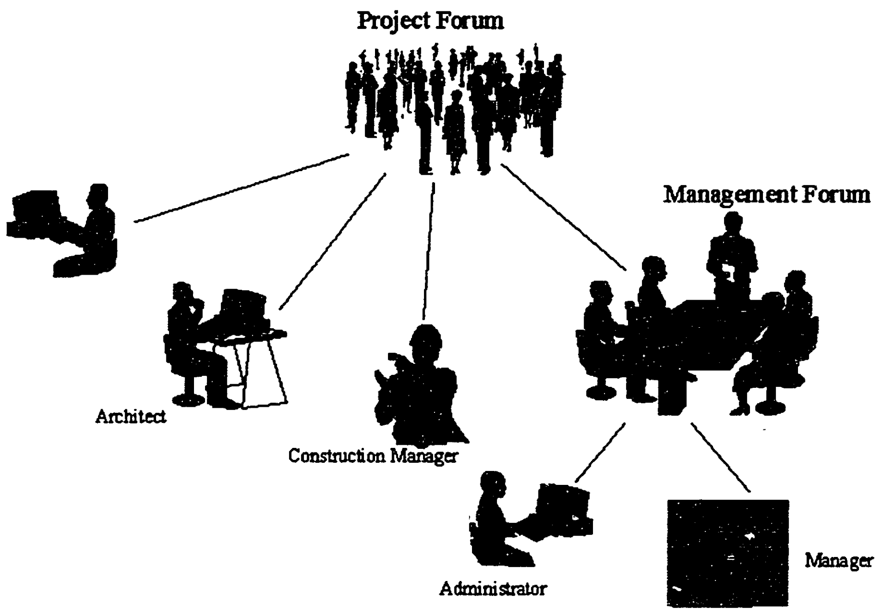



Figure 5-14: Hierarchical Forum Structure

forum `Project` must be at least as restrictive as the forum `Project`. Any restrictions on membership and communication must be upheld by the child forum, `Management`.

### Collaboration Primitives

During a meeting or conversation a particular participant can be in one of three states: *active* (i.e. speaking or demonstrating), *pending* (i.e. awaiting his/her turn to speak), or *inactive* (i.e. passive observer or listener). Each participant's state is relative to a specific forum and is stored in the forum server. The

**Speaker Request:** This is equivalent to a professional raising his/her hand in a meeting situation. It indicates to the forum moderator and to the other members of the forum the participant's intent to speak. A speaker request is accompanied by a qualification of the speech act the speaker intends to perform. The forum server would then place the participant on a list of *pending* speakers depending on his/her qualifications. In a democratic forum a participant becomes *active* if a majority agrees to his/her request to speak. Furthermore, the computer can automatically moderate (i.e. choose the *active* speakers from the *pending* queue) a forum based on pre-compiled speaker qualification data.

**Interjection:** This is a mode of conversation in which the participant can interrupt an ongoing conversation for a limited amount of time.

### Group Primitives

Group meetings can take on multiple characters and structures. As described in Chapter 3, group formation and meeting cycles require various group control procedures and paradigms. Below is a list of primitive controls on each forum from which a more complex collaboration control mechanism may be devised. The forum creator may choose to over-ride any of these primitives for a particular forum member.

**Chairperson:** A designation of a participant or group of participants who hold a privileged status within the forum. They may preempt speakers and arbitrarily choose active speakers.

**Interjection Duration:** Within the parameters specified for a forum is the length of time allowed for interjections. An interjection time of zero indicates no interjections are allowed. Conversely an infinite interjection time allows for complete unstructured free-form conversation.

**Maximum Speech Duration:** Within the parameters specified for a forum is the length of time allocated to a single member to hold the floor of the conference.

**Maximum Number of Active Speakers:** This parameter indicates the number of concurrent speakers allowable during the conference.

**Side Conversations:** Side conversations are two-way or multi-way conversations among a subset of the forum members. Forums may be created that do not allow such side conversations to exist.

**External Conversations:** External conversations are conversations between a member of a forum and other non-members while a forum is active. This form of conversation may also be restricted by the forum.

**Logging Mode:** Currently the system only provides either continuous logging or no logging at all of the ongoing conference.

**Speaker Evaluation:** A voting mechanism has been implemented to evaluate participant acceptance of a specific topic or to determine participant value to a conference. The results of this evaluation may be used to determine the order of speaker priority for a conference.

**Speaker Ordering:** The ordering of the *pending* speaker queue may be on a first come first serve basis or other evaluation criteria. These include: ordering of speakers based on value determined by the participants, as described in *Speaker Evaluation*; or ordering based on chairperson choice in a chairperson controlled conference. This control mechanism satisfies the requirement for free form and structured conferencing.

### Sample Collaboration Schemes

The collaboration primitives discussed above are combined to form a collaboration scheme or mechanism. The CAIRO system can easily be extended to provide many different collaboration schemes. Below are the list of schemes that have been implemented.

**Free:** All participants may talk at any time. Completely uncontrolled all speakers may speak at once. That is Chairperson='none', side conversation = ALL, external conversation = ALL, Speaker Ordering = 'first-come-first-serve'.

**Democracy:** Choice of the active speaker is based on a vote by all other participants. That is Chairperson='none', side conversation = ALL/NONE, external conversation = ALL/NONE, Speaker Ordering = 'highest vote'.

**Chalk-Passing:** Last active speaker chooses next person to be a designated active speaker. Each speaker may only speak for the time allotted by the *Maximum Speech Duration* parameter specified above. In this scheme: Chairperson='last speaker', side conversation = ALL/NONE, external conversation = ALL/NONE, Speaker Ordering = 'chosen by chairperson'.

**Chairperson Control:** A specific privileged participant (Mr. X) has the ability to choose the participant who should address the conference at any specific time. In this scheme: Chairperson='Mrs. Q', side conversation = ALL/NONE, external conversation = ALL/NONE, Speaker Ordering = 'chosen by chairperson'.

**Modified Delphi:** The system polls all participants in the collaboration on their views regarding a specific design problem. The results are compiled and presented to the conferring experts and the participants are then re-polled. This process is repeated by the questioner until the experts provide a consistent analysis. The Delphi method is used extensively in polling experts on directions in hi-tech industry. In this control strategy there exists a moderator as well as a questioner. A quicker more dynamic method using our collaboration methods is proposed. In this scheme:

Chairperson='moderator/questioner', side conversation = ALL/NONE, external conversation = ALL/NONE, Speaker Ordering = 'round robin'.

### 5.3.4 Name Server

The name server is an independent server that acts as a global directory for the CAIRO conference system. The following information is listed in the name server for each participant and each forum and may be queried by any participant or forum server.

1 Participant Name and Location: including media driver locations and media descriptors.

2 Participant Status: each participant is either in an active or non-active state. Active denotes that the user is logged into the conference system via a Collaboration Manager on his/her workstation. Non-active status is given to users who are subscribers to the CAIRO system but are not reachable.

3 Forum Manager Name and Location: including a brief description of control style.

4 Forum Name and Location: including a listing of shared media drivers.

5 Forum Status: each forum is either in an active or non-active state. Active forums imply a conversation is occurring among the participants of the forum. Non-active forums are structured meeting skeletons with membership lists for a meeting that is not currently in session.

## 5.4 Operational Description

The CAIRO collaboration control mechanism is composed of several interacting servers and modules. A brief description of the operations of these modules/servers is provided in this section. The operations are listed in the order in which they would naturally occur.

### 5.4.1 Forum Creation

A forum is initiated by invoking an Forum manager. The forum manager tool can be invoked by executing the appropriate forum manager program or by choosing the *New Forum* command from the CAIRO control panel (see Figure 5-15). menu. A series of dialog boxes and menus then guide the forum initiator through the creation process. Figure 5-13 shows the forum manager user interface. The forum creation process involves specifying the group primitives described in Section 5.3.3 as well as specifying the members of the forum and their associated privileges. The specified parameters are then stored in a forum specification file (see Appendix C) that is used by the forum server when instantiated.

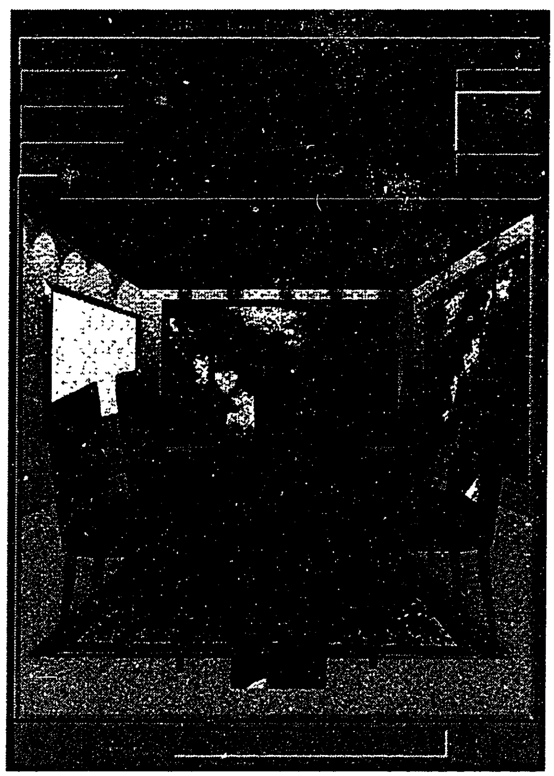


Figure 5-15: The CAIRO Control Panel

Forum managers can also be used to transfer an existing forum from one control scheme to another. The forum manager loads the forum specification file from the existing forum and prompts the user for any additional information required by the new forum control scheme.

### 5.4.2 Forum Startup

Forum Servers are instantiated by forum managers. As described earlier forum managers extract the necessary parameters for forum instantiation from the forum creator. The forum manager stores all parameters in a file according to the format described in Appendix C. The forum server is then started as an independent process. Upon startup the server reads the parameter file and initializes all internal objects accordingly. The server then registers itself with the name server. It is then ready to accept any login or membership requests from users of the CAIRO system.

The forum server maintains a membership list that includes an identification of each member's state. A forum member can be in any of the four states described below.

1. Member - the user has been specified as a person who is allowed to join the forum.

2. Logged In (active) - the user is actively engaged in a forum discussion.

3. Waiting to Speak - the user has requested the right to speak but has not yet acquired the enabling token.

4. Speaking - the user has the floor (i.e. the user possesses a speech token) and has the ability to transmit information to any number of forum members

Each state described above assumes that the user was in the preceding state before transition.

### 5.4.3 Participant Startup

Users of the CAIRO system must each start a collaboration manager (CM) process on their workstations. The manager provides an interface/control panel to the CAIRO distributed conferencing system. Upon startup, the CM registers with the nameserver. The CM then requests a list of the available forum managers and forum servers from the nameserver. Finally, the information is displayed in the first two list boxes in the CAIRO control panel. The control panel also provides the following functionality:

1. Local conference logging control (including recording and retrieval).
2. Screen capture.
3. Forum server creation via the forum managers.
4. Instantiation of media drivers according to the local workstation's capabilities.

### 5.4.4 Accessing Forums

Once the two key components (i.e. forum servers and collaboration managers) are running, conferences can be started on the CAIRO system. The initial step in entering a conference is accessing a specified forum. This can be done by simply clicking on the appropriate forum name in the forum list box in the CAIRO control panel. Once a forum is selected a login message is sent to the forum server, whose address has been supplied by the name server. The forum server then determines if the participant logging in has the appropriate access rights (i.e. the participant is on the membership list for a closed forum). An acknowledgment is returned to the collaboration manager if the user has been successfully logged in, otherwise a rejection message is transmitted to the user. Furthermore, if the login was successful, the forum server's *active* list is updated and all *active* members of the forum are informed of the addition to the community.

### 5.4.5 Retrieving Active/Pending List

The active member list box on the right side of the CAIRO control panel shows the currently logged in members of the forums highlighted in the forum list box. As described in the section above the forum server automatically updates all active members when any forum members have logged in or logged out (the messages involved are described in Appendix B).

### 5.4.6 Requesting to Speak

Speech requests on the CAIRO system involve two steps: selecting the audience and describing the speech intent. Audience selection simply involves selecting the appropriate recipients from the active member list box on the CAIRO control panel. Forums that do not allow side conversations will automatically have all items highlighted in the active member list box. A speech intent is indicated by pressing one of the speech request buttons.

As soon as a speech request button is depressed token requests are sent to the forum server. A token request is sent for each highlighted member in the active member list box. The forum server then processes the token requests. The server's response is dependent on the forum control scheme that is encoded in the forum server. According to the control scheme the forum server decides whether to place the speaker request on the pending queue or to automatically grant tokens to the requester. For example, in a chairperson controlled scheme, all requests are placed on the pending queue. When the chairperson allows a specific user to speak, his/her name is transferred from the pending queue to the speaking queue and tokens are granted to the user. Any changes in the contents of either the pending queue or speaker queue are automatically broadcast to all members of the forum.

### 5.4.7 Communicating with other Participants

Once the previous steps have been completed successfully (i.e. a participant logs onto an existing forum server and is granted one or more communication tokens) real time multimedia information can be shared with other members of the forum. The user can then use any of the media drivers available (i.e. audio, text, X whiteboard) at his/her workstation to send data via all connections for which the user has tokens (the tokens act as keys that unlock a point to point connection). The data generated by the drivers is transformed into TCP/IP packets and tagged with a time stamp and frame sequence number. The data receiver then replays the packet as per the algorithm described in Section 5.3.2.

## 5.5 Concluding Remarks

All conference communication and control mechanisms described above are generic and can be applied to any conference control scheme. Although only a limited set of control schemes has been implemented (see Section 5.3.3) simple tools are provided for control scheme extensions to the CAIRO system. Furthermore the tokenized control mechanism described in this chapter is highly efficient and eliminates any bottlenecks associated with a centralized communication and routing center.

# Chapter 6

# Multi-User Collaboration Interface

Developing a user interface for distributed collaboration requires a detailed study of the purpose and use of the system. The background developed on group dynamics and design processes provides an initial step in developing the user interface. The experiments conducted in group design processes provide us with a baseline to measure how closely the system developed conveys the information exchanged in a meeting (written, vocal, gesture and physical actions). A study by Salvador *et al.*[82] provides a detailed list of group support requirements for a distributed groupware system. These requirements, in addition to others developed from our experiments are presented in Section 6.1. This is followed by a discussion of the use of metaphors in user interfaces particularly for the purpose of creating interaction settings in Section 6.2. Finally, the user interface implementation chosen for the CAIRO system is presented with the rationale for each representation choice in Sectiontheui.

## 6.1 Interface Requirements

The primary function of an distributed interaction interface is to convey the actions of others engaged in the distributed conference. Awareness of the state of conferring individuals and their respective ownership or generation of shared objects is necessary to keep track of the interaction in a non-physical setting. Many conferencing systems significantly lack in supporting such awareness. Figure 6-1 shows a set of guidelines for necessary awareness elements in distributed interface design (adapted from Salvador *et al.*[82]):

| | |
|---|---|
| **Membership awareness**<br>Who has been there?<br>Who is there?<br>Who is coming?<br>Who is where?<br>Are you aware of what I am doing? | **Ownership**<br>Who owns artifacts?<br>Who can access artifact?<br>Who can change an artifact?<br>What artifacts are being worked on? |
| **Member actions**<br>Who is doing what?<br>Who is gesturing?<br>Who is pointing?<br>Who is signalling?<br>Who is working on an artifact?<br>Whose video image is this?<br>Whose cursor is this?<br>Whose voice is this?<br>Where in an artifact are people working?<br>What the emotional state of individuals? | **Speaker Awareness**<br>Who is interested?<br>Who wants to speak?<br>Who is speaking to whom?<br>What type of protocols exist?<br>What is the current protocol?<br>What roles are there?<br>Who is playing what role?<br>What are related roles? |

Figure 6-1: Four dimension of User Interface requirements for Distributed Collaboration

Representing all four dimensions of awareness is a formidable task to accomplish within limited screen real estate. The choice of metaphor for representation becomes critical to reduce the cognitive demand on the system users. The system presented does not address all the awareness questions presented above. However, a large portion of the critical questions are addressed in the interaction metaphors provided by CAIRO. The following section discusses the use of metaphor for the interaction setting.

## 6.2 Metaphor Methodology

The conferencing system implemented is constrained by available technologies, hence providing a simulated physical setting through virtual reality is impossible. Furthermore, replicating the physical setting in a distributed interaction setting would actually decrease the flexibility and benefits of interacting in a virtual space. The metaphors chosen combine elements from the physical setting (i.e., a meeting room) with standard "window" metaphors that are prevalent in modern operating systems. These metaphors were chosen to allow provide simple cognitive mappings between the intended use and the concept represented by the interface metaphor.

In determining the metaphors for group engagement several criteria were examined. These criteria are listed below along with a short explanation:

**Expressiveness** : The degree to which the metaphor embodies the action or control represented and does not project any unintended meaning.

**Naturalness** : The extent to which the metaphor complies to typical conferencing norms.

**Input mapping** : The degree to which the metaphor can be logically mapped to keyboard strokes, mouse movements or any other generic input device.

**Transparency** : The metaphor must not interfere with the task in which the conferees are engaged. Transparency in the interface also implies that the conference controls occupy a small section of valuable screen real estate.

**Dynamism** : The interface must represent the dynamic nature of the group interaction. The controls can not be binary since the speaker state is not binary.

The interface to the conferencing system separates control from the workspace. Several other conferencing systems have integrated control with the workspace. However, current display and input technologies do not provide an effective platform for the integration of control in the workspace due to the limited screen "real estate". Although this separation does not provide an adequate indication of presence, we feel that in task oriented discussion presence is not as critical as in other group interaction situations. Hence, the system adopted has separated control from the workspace.

A three dimensional interface was required to indicate the spatial relationship among the conferencing individuals. The initial interface was two dimensional, however, that system limited the representation of gaze and addressing in the control space.

## 6.3 User Interface Description

Metaphors were derived for the following concepts:

- Meeting entry and exit.
- Floor State
- Member State and Addressability.
- Focus of Attention
- Degree of Engagement.
- Gaze/Addressability

### 6.3.1 Meeting Entry/Exit

A hallway metaphor was chosen to represent the multiple meetings available on the cairo system. This provides a simple metaphor that maps virtual distributed meetings to physical doors and hallways well. This metaphor can be extended to include meeting hierarchies that include floors, buildings, blocks and cities. We have found no need to provide such a degree of hierarchy although if the system is scaled to a large organization such structures may be necessary.

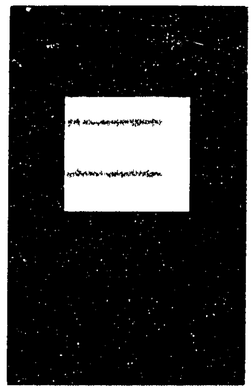


Figure 6-2: Door Controls

The doors in the hallway represent an individual distributed meeting. The door metaphor provides additional queues regarding meeting structure. A padlocked door indicates that the particular meeting has restricted membership. A red tab on the door indicates whether a meeting is currently active and the window at the top of the door indicates the number of people in the meeting (see Figure 6-2. Finally, a descriptive name for the meeting is placed above the door. The meeting entry and exit interface is shown in Figure 6-3.

### 6.3.2 Floor State

The floor state has multiple representation in the user interface. The item list at the top of the interface shows the current members of the conference and highlights pending and active speakers. Furthermore, the images of individuals in the interface

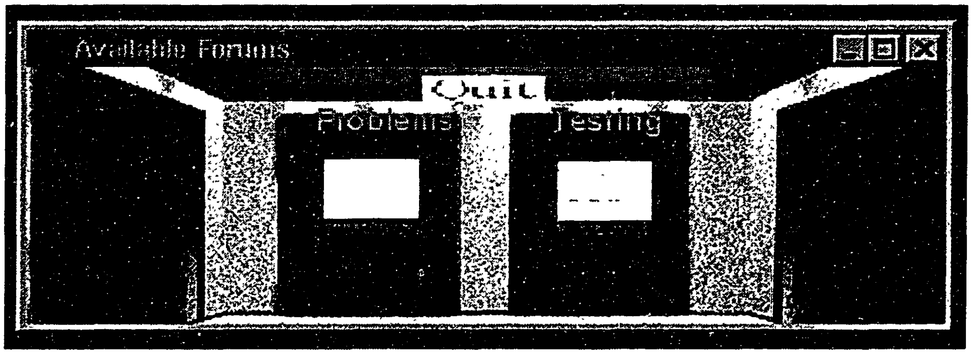



Figure 6-3: Meeting Entry / Exit Interface

are appropriately highlighted to show their different states. Finally, the floor can be split into multiple "virtual" rooms. This allows individuals to create sub-meetings or side chats within the main meeting. Side chats are shown as tabbed folders in the meeting interface (see Figure 6-4.

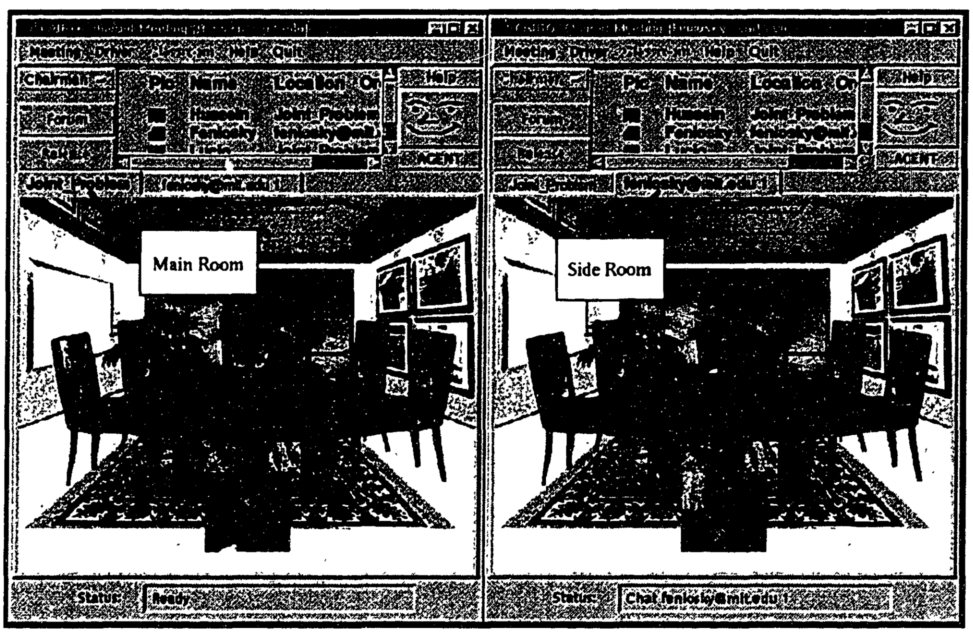



Figure 6-4: Meeting with Side Conversations

### 6.3.3 Member State and Addressability

Several mechanisms are employed to describe the distributed member state. Members choose the people they are to address by clicking on the appropriate members or clicking on the table to speak to everyone. Figure 6-5 shows Feniosky requesting to speak to the group. Once a speech request is made, the pending speaker is shown by red highlighting of the name and a red halo around the pending speakers image (see Figure 6-5). In a chairperson controlled forum, the chairperson can then allow a pending speaker to speak or leave him/her on the pending queue. Figure 6-7 shows the chairperson, Karim, accepting the speech request from Feniosky. Finally, Feniosky gains the floor and is able to address the group. The group members can determine the source of speaking by a green highlighting of the speakers name and a green halo around his/her image (see Figure 6-8 - left side). The speaker can determine his/her audience by bullet points that are displayed next to those that are listening to him/her (see Figure 6-8 - right side).

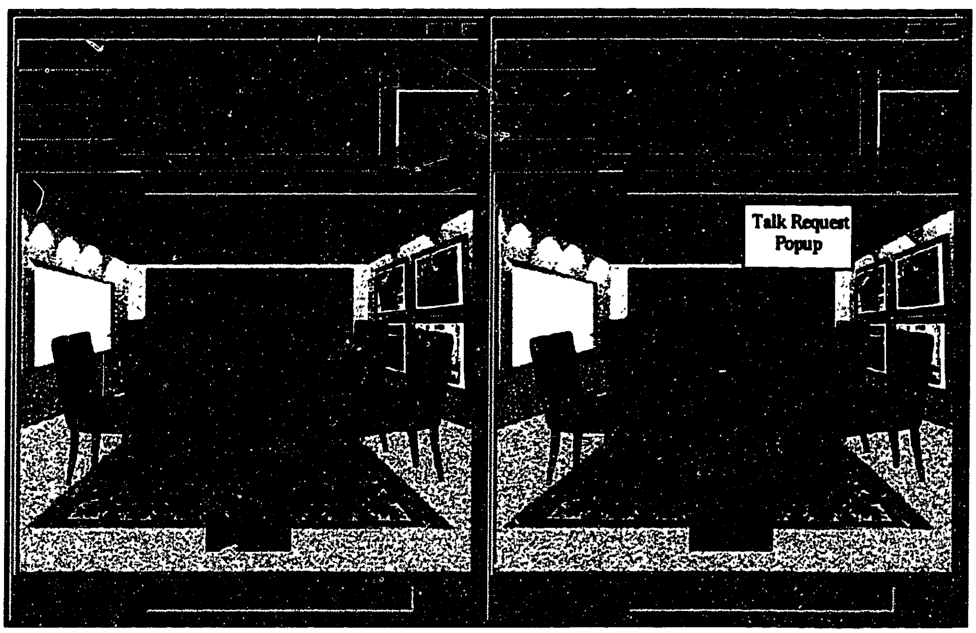



Figure 6-5: Speaking request - Feniosky is pending

### 6.3.4 Tool and Artifact Manipulation

Several tools are available for interaction and they can be accessed from the menu system or by clicking on their appropriate icon in the room (e.g., clicking on the

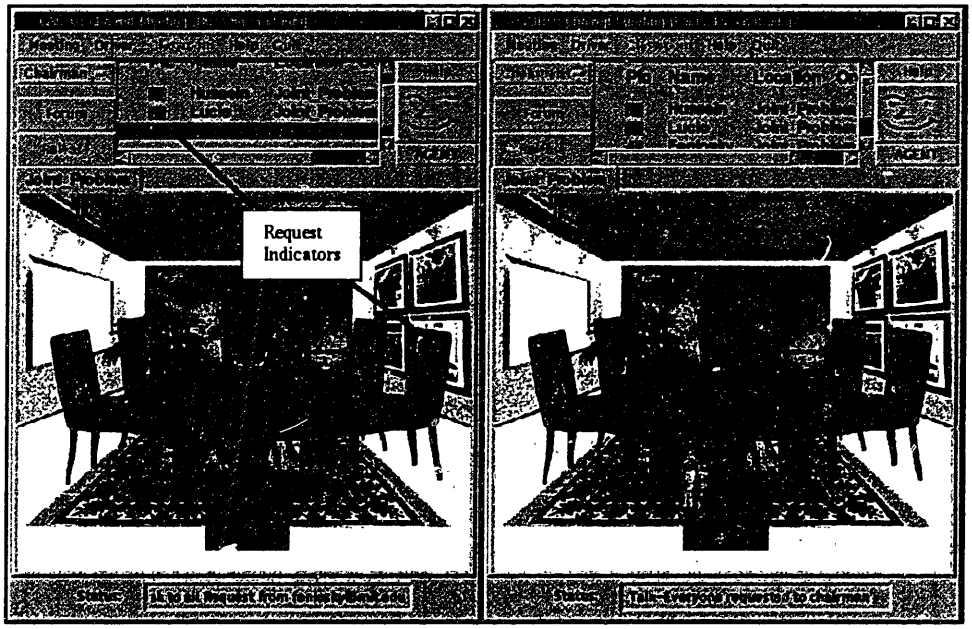



Figure 6-6: Request Indicator - Chairman's (Karim's) Screen

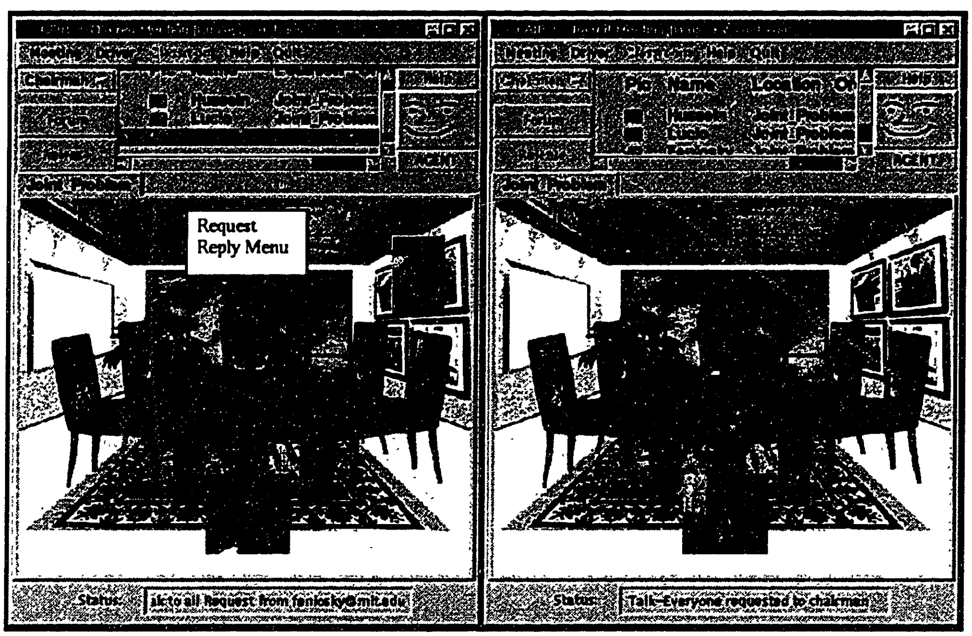



Figure 6-7: Chairperson grants request

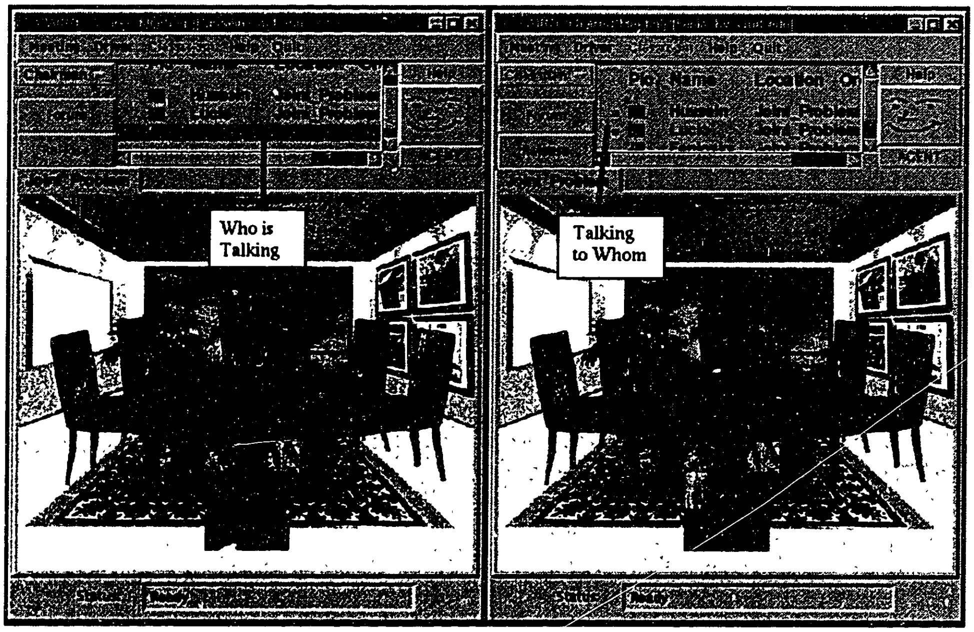



Figure 6-8: Feniosky is speaking

whiteboard will bring up a shared drawing tool). As users interact with objects in the different tools the owner of a particular object is highlighted. The interface with a variety of tools is shown in Figure 6-9.

### 6.3.5 Focus of Attention

The focus of attention concept is supported by highlighting the currently active interaction tool. Furthermore, the current person speaking is also highlighted in the control console of the CAIRO system. In the case where a tool is started by another individual in the conference, the tool will automatically be started on each distributed client to whom that individual is speaking. This creates an implicit focus of attention. More intrusive attention mechanisms were attempted (such as moving the focal window to the center of the screen), however, users resisted the loss of control over their environment that these automatic actions caused.

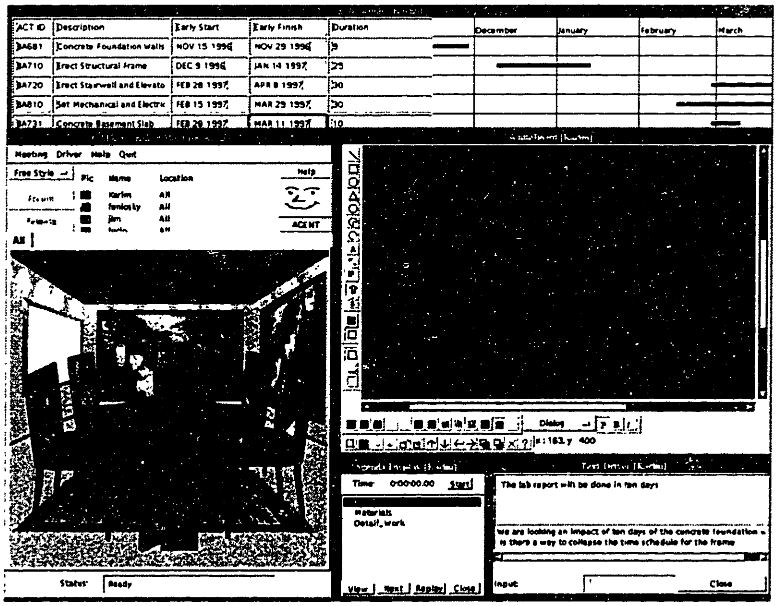


Figure 6-9: The CAIRO system user interface with several interaction tools

### 6.3.6 Degree of Engagement

#### Spring Metaphor

The Spring Metaphor reflects the tension and dynamism of the participants as they attempt to control the floor. The springs are attached to a central object on the table which acts as the focus of attention for the interaction. As a participant becomes increasingly engaged the springs tense up (coils are farther apart - see Figure 6-10) thereby indicating to the whole group the degree to which the participant is interested in addressing the group. Active speakers can be represented through color (e.g. active coils could be red) or they can be represented by the full stretch of the spring (i.e. the spring becomes a straight wire).

#### Heat Metaphor

The Heat Metaphor utilizes color to show degree of engagement of a participant in a conference. Control of the floor was difficult to indicate with color alone and the sample interface was found to be ineffective and aesthetically deficient. The

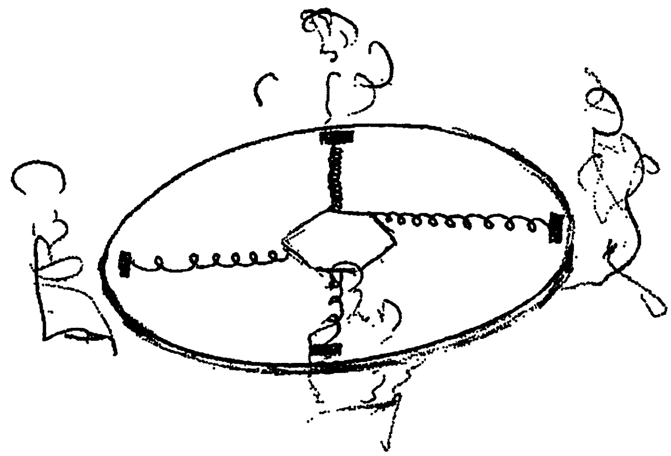


Figure 6-10: Sketch of spring metaphor

participant states are represented by a color variation in the table wedge in front of each participation. This metaphor was not chosen due to the difficulty in choosing a color scheme that would be meaningful to most users.

### Shadow Metaphor

A final metaphor that was examined was a shadow metaphor. This metaphor represented engagement as a shadow that emanates from each participant and shows their presence at the conference table. This metaphor may seem intimidating, however, its effectiveness can only be determined through user testing. The metaphor has important benefits in that it portrays a sense of physical presence. A sketch of the metaphor is shown in Figure 6-11.

## 6.4 Implementation Issues

The following classes were implemented in Java to facilitate the simple creation of flexible 3D interfaces. They extend the Java AWT to allow for events to apply to portions of an image in an efficient manner. The extension also provides animation features that enhance the dynamism of the interface.

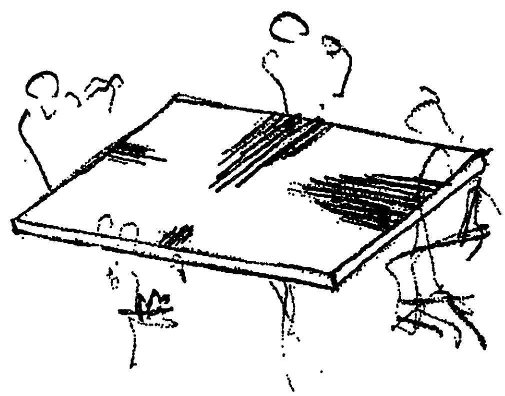


Figure 6-11: Sketch of spring metaphor

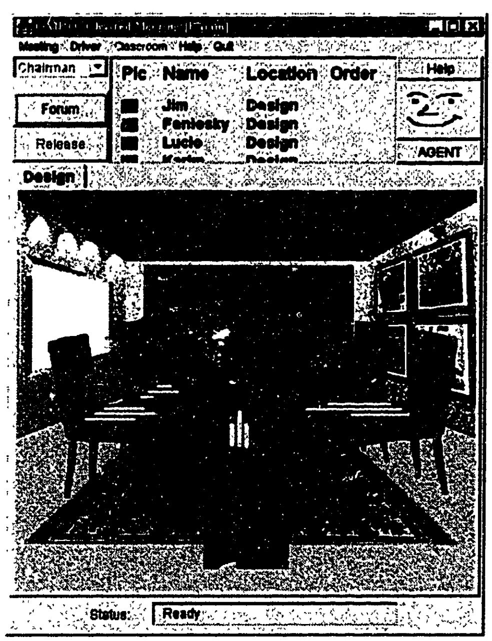



Figure 6-12: Implementation of shadow metaphor

**ImagePanel** : The image panel class is an extension of the Java AWT component class that allows nested active components. The class contains a vector of components and their locations. The event handler filters all mouse actions and passes them on to the appropriate components.

**ImageComponent** : A subclass of the Java AWT component class that provides button functionality without the rectangular limitations of the button class. The component also has an animation function that is can be activated by any of the standard AWT events. The ImageComponent class also provides multiple states for each component, thereby providing increased flexibility in the interface manipulation.

**MeetingPerson** : A special subclass of ImageComponent that provides additional functionality. It allows affine transformations to the image to provide directionality in the interface. It also provides several additional subcomponents that represent speaker state.

## 6.5 Conclusions

Through simple testing of the current interface several key problems arose. The use of color in the heat interface was not very effective since the different color tones signified different things to different people. Furthermore applying an affine transformation to each meeting person to show a direction of gaze provide a very awkward interface since it is not a complete three dimensional model of the person. Furthermore the affine transformation further slowed down the video throughput. Finally, the major difficulty in the current interface is the input mechanism. The mouse and keyboard have been found to be ineffective in presenting the degrees of participant engagement. During the course of this investigation very little attention was paid to the input interface.

However, limited user trials have confirmed that this interface is more effective at representing actual meeting proceedings and controls than a typical point and click interface such as the Intel ProShare system. A more extensive user testing with the multiple interfaces described above is necessary. During the fall semester an experimental software engineering course will be conducted simultaneously at MIT and CICESE in Mexico. Several different interface metaphors will be examined during this course and will be compared to our earlier interfaces and commercial packages.

# Chapter 7

# Interaction in Distributed Learning Environments

## 7.1 Introduction

This chapter describes the experiences of a distributed course taught simultaneously at the Massachusetts Institute of Technology and at Centro de Investigacion Cientifica y de Educacion Superior de Ensenada (CICESE) in Mexico. In addition, an analysis of the distributed learning process and a framework for effective distributed collaborative learning has been derived from this experience. The course curriculum has a strong emphasis on group work in large scale system management, design, and implementation. All work and assignments were expected to be conducted jointly by the MIT and CICESE students.

Significant research has been devoted to the area of distance and online learning over the past decade. The seminal work by Harasim et al. [36] provides excellent overviews of the technology and the implications of providing online "learning networks". The *Learning Networks* guide served as an important first element in designing and implementing this course. However, the advent of more advanced computer mediated communication technology and our initial goal of one student body

- two sites challenged many of the learning models presented in the book. Several other important research works were reviewed before embarking on this research and educational experience and they are discussed in Section 7.2.

Our core focus in this research and education experience was an analysis of the forms of interaction and their relations to activities in collaborative groups. We were particularly interested in the design of appropriate computer-mediated communication (CMC) environments to enable effective and efficient distributed project-based group learning.

**Chapter Outline** Online learning environments are analyzed throughout this chapter within the context of the course taught at MIT and CICESE. Several critical issues in online interaction have been highlighted by this experience. Preparation for the course included the study of various models of learning processes and educational evaluation which are highlighted in Section 7.2. The learning process chosen for the course necessitated multiple forms of group interaction. A discussion of interaction and its multiple online modes is presented in Section 7.3. This is followed by an abbreviated description and critique of our experience with the distributed classroom in Section 7.4. Section 7.5 provides guidelines for creating online collaborative group environments that have been derived from this experience as well as highlights of the most critical elements in online learning. Finally, concluding remarks on the effects of distribution on collaborative learning are presented in Section 7.6.

## 7.2 Educational Approach

The course described in this chapter is an initial stepping stone for a larger effort led by the Intelligent Engineering Systems Laboratory (IESL) at MIT. The objectives of IESL are three-fold: (1) studying major challenges in the civil engineering industry; (2) the conceptualization of solutions to those challenges; and (3) the use of information technology to implement those solutions with the support of organizational change and process redefinition. One of the current flagship projects of the laboratory, the Da Vinci Initiative [68], is the application of computer and communication technologies in support of distributed collaboration in engineering projects. To test some of the hypotheses developed in the Da Vinci Initiative, a classroom collaboration between MIT IESL and CICESE in Mexico was developed as an initial test environment. Several other research, educational and industrial institutions will participate in this collaboration consortium over the next five years. Currently, the following institutions are engaged in the collaboration: University of Sydney, Australia; Ecole Polytechnique Federale de Lausanne (EPFL), Switzerland; Pontificia Universidad Catolica de Chile (PUC), Chile; two corporate entities (Kajima and Shimizu Corporations, Japan); and one public agency (Massachusetts Highway Department, USA) (see Figure 7-1 for an overview of the collaboration effort).

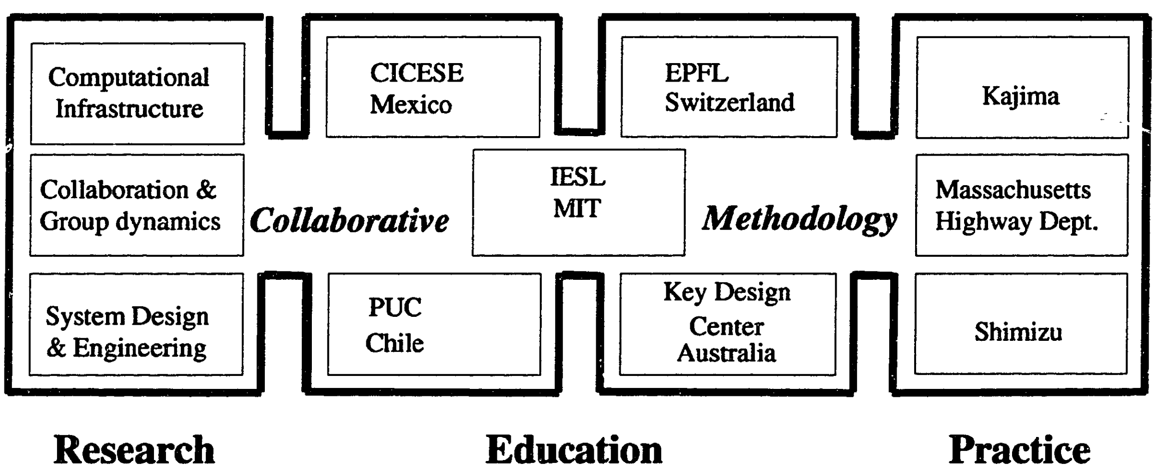



Figure 7-1: Multiple facets of the Distributed Collaborative Learning Consortium

In order to support this large collaborative effort, the course described in this chapter was designed to explore the interaction of collaborative methodologies with communication tools in a distance education experience as show in Figure 7-2. The course structure, discussed in Section 7.2.1, was designed to test the limits of computer-based collaboration. Furthermore, the learning process chosen, which is detailed in

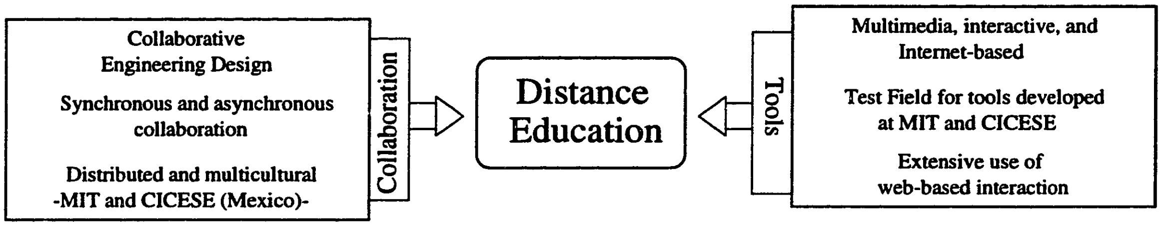



Figure 7-2: A summary of the distributed course objectives

Section 7.2.2, enforced significant distance interaction and provided a good platform for learning both the technical course material and the ability to work with large multi-cultural groups.

### 7.2.1 Course Design and Evaluation Methodology

The primary purpose of the course was to evaluate distance interaction and determine the most effective mechanisms for enabling distributed group learning. The class was structured to ensure that students had sufficient class and laboratory time to explore the system engineering concepts outlined in the syllabus. In order to complete a simulated "real world" project the course was conducted over two semesters (9 months) to allow the students enough time to grasp the complexities of large scale engineering.

Significant planning and development was undertaken before the beginning of the course to ensure that a multitude of interaction tools were available to the students. A large set of commercial and research tools were evaluated and several were incorporated in the class tool box. This provided the students with access to the "state of the art" in interaction tools so that the instructors could evaluate the effectiveness of these tools. An important result of the process was a clear understanding of the effectiveness of each of the tools tested in supporting distributed collaboration (see Section 7.3).

Furthermore, class evaluation was conducted through a variety of techniques. Skill surveys were conducted at the beginning and end of the course. Monthly evaluations of group dynamics, interaction technology effectiveness and course material understanding were conducted and analyzed. The students were also interviewed periodically to determine their reaction to the technology and the learning methodology. The instructors also created focus groups to concentrate on the evaluation of particular aspects of the course. Finally, the student learning process and the evaluation process were augmented by requiring students to critically document their process and discuss more efficient alternatives for the classroom setting and process. Results of all these evaluations are discussed in Section 7.4.

### 7.2.2 Learning Process

Several new forms of learning processes have been enabled or supported by computer and communication technologies. These processes include: (i) distance education - i.e., instruction using communication and computer technologies for remote presentation of course materials; (ii) simulation-based learning - i.e., learning through the use of computer models of physical system through a process of engineering hypothesis testing and experimentation; (iii) knowledge management - i.e., a variety of computer mechanisms for the support of knowledge acquisition and dissemination within an organization; and finally, (iv) distributed collaborative learning - i.e., learning through cooperative work among students and teachers across geographical distance.

The learning approach chosen for this engineering course can best be characterized as a constructionist distributed collaborative learning approach. Constructionism as espoused by Jean Piaget [74] and Seymour Papert [37, 66] is a process of learning by apprenticeship and shared manipulation of computer models and physical systems to grasp a particular concept. The students in the course were expected to "learn by doing" – building together a product, while collaborating with distributed team members in Mexico – with limited traditional instruction from the professors. The students also retained a fuller grasp of the material through reflective writing on the engineering process and their particular roles within that process. This additional learning tool reinforced their knowledge of the system engineering process. While the validity of this approach for teaching systems engineering may be argued – the approach best simulates a "real world" environment and is invaluable in evaluating interaction in distributed design teams.

The course was loosely structured and the students were permitted to explore the problem domain freely. Reading materials were only suggested references. The aim of the course was to allow students to learn the system engineering process by experiencing it with constraints that are similar to an actual environment. There was an additional constraint in the learning environment. Students needed to interact continuously with their Mexican counterparts in order to complete the engineering task. They used a variety of tools based on the internet and Web infrastructure to build knowledge together, to design a product, as well as to coordinate activities for the class project.

The course syllabus focused on the system engineering process, particularly in a distributed environment. Student feedback indicates that elements of the engineering process were the key lessons learned from the class. The students were also encouraged to reflect on the distributed interaction process through the class project assigned.

## 7.3 A Progression of Interaction

The distributed nature of the class imposes a major constraint on group interaction. Hence, providing computer support for distributed group processes required a detailed analysis of the interaction inherent in such processes. Interaction is discussed in this context based on the group activity it supports, its modality and the possible tools to support these various interaction forms.

It is critical in analyzing the various forms of interaction to make a clear distinction between acquiring information and developing knowledge. The two concepts are linked yet require distinct modalities of interaction to achieve the appropriate purpose of the communication. Section 7.3.1 provides a classification of collaboration activities. An outline of common modalities of interaction and their mapping to a typical group activity is presented in Section 7.3.2. Finally, Section 7.3.3 discusses the technical requirements for distributed online tools that support these interaction modalities.

### 7.3.1 Interaction Activities

Group activities engender different modes of interaction within the group. Understanding these group activities and the varied modalities they require is a prerequisite to creating an effective collaborative learning environment.

A classification of communication activities for distributed learning environments is presented below.

**Information dissemination** is transmitting information from an instructor to the students or from students to each other. The information may be in a variety of media formats. This is analogous to course handouts and readings distributed in traditional classroom settings.

**Knowledge Sharing/Building** is the process by which an instructor and students through discussions achieve a shared understanding of a particular concept. This is the core process in traditional class room settings that is embodied in lectures and discussions within the course. There is a wide degree of variance in abilities of instructors and students to relay their knowledge to each other. Various paradigms are applied within this context to achieve a better learning environment. These range from pedagogical instruction to mentorship relations between knowledge source (professor or student) and the knowledge sink (other students or professors). This is the activity generally associated with learning environments. However, the formal knowledge sharing interactions must necessarily be supported by the other interactions discussed below in order to provide an effective learning environment.

**Group Cohesion** is a prerequisite in supporting collaborative learning environments. Interactions among group members that are unintentional and unstructured provide a basis for such cohesion. These include informal social discussions over lunch, at a coffee break or in the hallway. They are crucial and defining interactions that provide a sense of group and create a shared motivation among members of a collaborative group.

**Group coordination** interactions are critical in the effective functioning of group work. These include notifications of meetings, agreements and responsibilities. These interaction forms comprise a large percentage of collaborative group interaction.

**Decision making** is another critical class of interaction that provide mechanisms for groups to reach a shared direction, goal or vision. These interactions include a large degree of conflict (which is healthy) and provide a critical mechanism for incorporating individual viewpoints within the group effort.

**"Building Networks"** is a broad category of interactions that encompass communications between members of the group and others outside the boundaries of the group. These interactions may be for the purpose of enlisting support, integrating additional members or seeking expert opinion or information.

### 7.3.2 Interaction Modes

Through analysis of group interactions in classical learning settings in addition to data generated from the experimental distributed learning environment described in Section 7.4, a taxonomy of interaction modes has been developed. None of these modes are binary in state, they all represent a continuum of modes. The following is a list of the four modes identified in addition to brief descriptions and examples:

**Synchronous/Asynchronous** Interactions can be classified according to the temporal relationship between the information source and sink. Synchronous interaction refers to communications that are immediate and whose expected response is immediate. These include face to face meetings, telephone calls and video conference interactions. Asynchronous interaction consists of exchanges of information through documents, videotapes or audio tapes - i.e. communication that is stored in some form before transmission to the receiver of the information.

**Structured/Unstructured** The degree of structure in an interaction is a more difficult concept to define. Structured interaction involves time critical discussions with explicit or implied agendas and explicit or implied facilitation processes. Unstructured interactions do not have an explicit or implied process associated with them. Examples of structured interactions are board meeting (synchronous) and change orders (asynchronous), while unstructured interactions are characteristic of lunch chats or FYI memos.

**Intentional/Unintentional** Intentional interactions are those that are planned beforehand and have an explicit objective. Unintentional interactions occur in coincidental meetings such as coffee breaks or hallway encounters.

**Committal/Non-committal** Interactions are meant to illicit a particular response or state of mind in the sender and receiver. The degree to which an explicit interaction response is expected defines the amount of commitment in the interaction form. The degree of commitment is generally defined by the environment of the interaction. For example, a purchase order implies a high degree of commitment to action by the receiving party, while a leaflet or flyers engenders no sense of commitment on the receiver to read or take action based on the information contained within it.

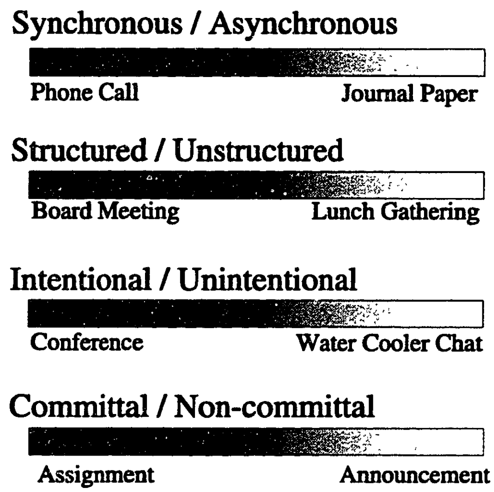



Figure 7-3: Range of Interaction Modes

An evaluation of the activities described in Section 7.3.1 in non-distributed classroom settings suggests that each activity has a typical set of modalities associated with it. Information dissemination typically exhibits asynchronous, unstructured, intentional and marginally committal interactions. Knowledge sharing and building, on the other hand, requires dynamic interaction among the group members which necessitates synchronous, structured, intentional and committal interaction processes. Interactions that are responsible for group cohesion activities are typically unintentional, non-committal and unstructured with varying degrees of synchronicity. Coordinating tasks requires clear definitions of process and hence is generally structured. The coordinating process is also intentional and requires a high degree of commitment from the receiving party. Synchronicity in coordinating process varies with purpose of the coordination activity. Decision making activities also require high degrees of communication among the group members and hence require synchronous, intentional and highly committal interaction. These activities are also typically structured. Finally "Building Networks" can take on any of wide range of modalities depending on the nature of the activity performed by the outside parties to the interaction.

### 7.3.3 Interaction Infrastructure

Several of the interaction modes described in the preceding section are easily supported in online environments. However, others have not been sufficiently explored (e.g., intention and commitment) or pose fundamental challenges to existing hardware (e.g., synchronicity), software (e.g., structure and commitment) and network (e.g., synchronicity) technologies. This research group has focused its research on synchronous, intentional and structured interaction although the classroom experiment was meant to elicit all modes of interaction. The following is a description of the technologies used and their support for the interaction modes and purposes described in Sections 7.3.1 and 7.3.2.

By far the most common interaction mechanism in distributed teams is e-mail. Hundreds of messages have been exchanged among members of the course team for a variety of purposes including information dissemination, coordination and knowledge sharing. Section 7.4.3 will discuss the effectiveness of e-mail in supporting these forms of interaction. E-mail is essentially an asynchronous, unstructured, intentional and relatively non-committal form of interaction. The students in the class developed particular group norms to relax the general constraints of the medium.

E-mail and online discussions were maintained through a threaded message presenter on the web. Two systems were used for this purpose: HyperMail (`http://www.hypermail.com`) and yawn (`http://kiliwa.cicese.mx/~cc/papers/yawn/indice.html`). They both support author, date and subject threading. More advanced document handling systems such as Lotus Notes [52] were avoided because they imposed a specific interaction and workflow process on the group. However, our lab has jointly developed educational templates with Lotus that will be applied in future distributed classroom settings (http://command.mit.edu).

Video and audio conferencing equipment is available to students in the lab. The primary tools used are Intel Proshare[43], Silicon Graphics InPerson [88] and Microsoft NetMeeting [55]. These systems are used for joint lab sessions and in additional group meetings. Furthermore some students have used the system to coordinate two and three person tasks. These systems support synchronous, unstructured, intentional and committal and non-committal interactions.

An additional synchronous communication system has been tested within the distributed laboratory context. The system, CAIRO [69, 72, 71], developed by this research group provides synchronous and asynchronous interaction with support for intentional and structured interaction. It provides a highly coordinated environment for synchronous group meetings.

Finally, the web is used as a document repository and acts as the primary information dissemination mechanism within the class (see http://kiliwa.cicese.mx/~disel). The class page contains background material, project schedule and milestones, project documents, and meeting agendas, minutes and agreements. This tool provides an effective mechanism for structured intentional asynchronous interaction. Figure 7-4 shows the structure of the course web.

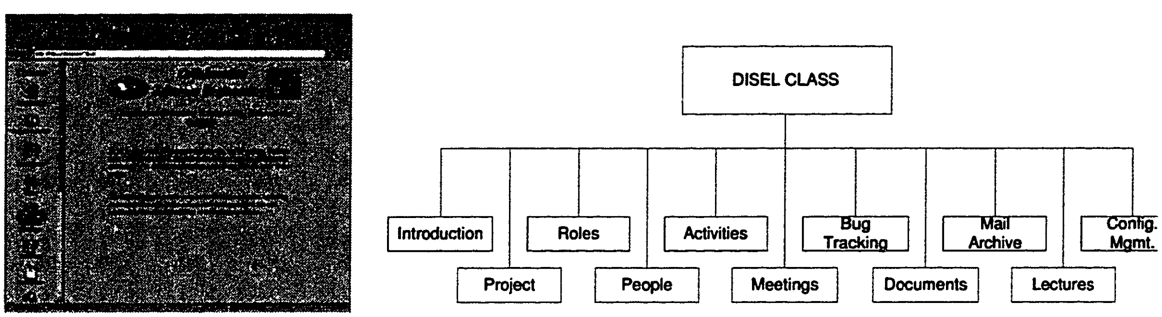



Figure 7-4: Main Course Web page and Web structure

Unintentional interaction modes are notably missing from the tools described above. Further research and application development needs to be performed in order to provide this important mode of interaction. Unintentional interactions are the primary mode with which individuals learn more about each other and assist in creating cohesive work groups through casual contact.

## 7.4 The DISEL Class

The pilot class that has been developed to test these interaction principles and the distributed collaborative learning methodology was named DISEL (Distributed Software Engineering Laboratory). The purpose of the DISEL course was twofold: (1) to engage the students in a realistic large scale software development process and thereby learn the managerial and technical aspects of the process; and (2) to test commercially available distributed interaction tools in addition to those developed by our research group. The class was composed of eight students at MIT, ten students at CICESE, an instructor from MIT and one from CICESE in addition to two lab facilitators (one at MIT and one at CICESE). Weekly classes included lectures and lab sessions. A software engineering model was delineated in the lectures [77, 45, 10]. This model included software development processes [40] (requirement analysis, design specification, coding and testing) in addition to role definitions (project manager, quality engineer, verification and validation engineer, programmer, analyst and configuration manager). The software engineering framework proposed by the instructors was modified dynamically by the students as they learned the constraints and shortcoming of these frameworks in their problem domain and distributed collaboration environment. A schedule of deliverables was set by the instructors and the lab sessions were intended to work towards the software engineering deliverables.

The subject matter in this course has many parallels in the large-scale Civil Engineering infrastructure domain. Both civil engineering and software engineering require the collaboration of large numbers of people, involve complex and highly interdependent complex systems and require similar development processes. Coding can be substituted by construction and the roles defined for software engineering can be considered analogous to engineers, architects, contractors and owners. In addition, this class has been a preliminary test-bed for a larger scale effort that will be developed over the following five years that includes collaboration among research, educational and industrial institutions on intelligent infrastructure systems. Software engineering was chosen as a preliminary course since it will permeate both the product and the process by which intelligent infrastructures are developed.

### 7.4.1 The Setting

The lectures and labs were conducted simultaneously in a classroom at MIT and one at CICESE. The room was especially designed for collaborative work including shared workspaces, large whiteboards, computer projection equipment, microphones, and individual workstations. The center of the room was a table for group discussion (Figure 7-5 shows a schematic diagram of the classroom settings at CICESE and MIT).

The software engineering team was deliberately designed to enable maximal interaction among students at MIT and CICESE (see Figure 7-6 for a description of the group organization). In each of the seven roles defined, there was at least one student at CICESE and one at MIT fulfilling the role (one as a lead and the other as an assistant). This was designed to foster significant communication in small functional groups. The whole team was engaged in a single software engineering assignment and most deliverables required the collaboration of all roles in the generation of the product.

The DISEL laboratory provided a variety of interaction tools to the students. These included:

- Online discussion groups (threaded online)
- E-mail lists and archival

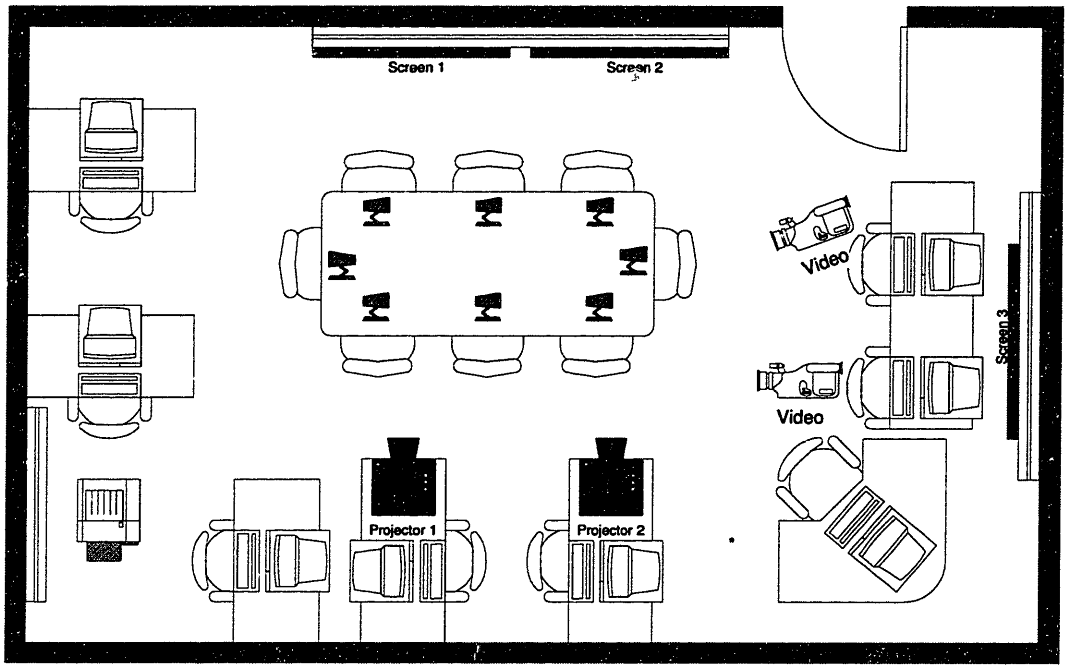



Figure 7-5: DISEL Room schematic

| MIT | CICESE |
|---|---|
| Project Manager (Lead) | Project Manager |
| Analys (Lead)<br>Designer | Analyst<br>Designer (Lead) |
| Programmer<br>Programmer | Programmer (Lead)<br>Programmer<br>Configuration Manager |
| V & V<br>Quality (Lead) | V & V (Lead)<br>Quality<br>Testing (Lead) |

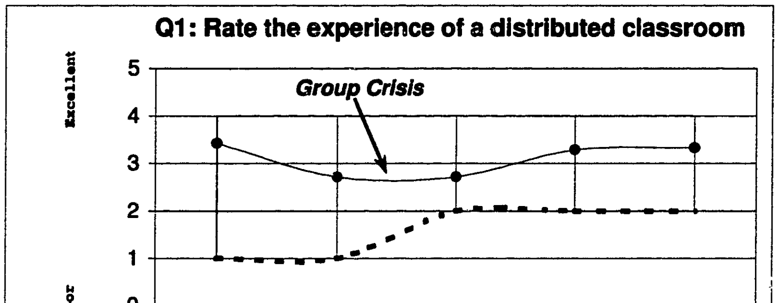
Figure 7-6: DISEL organizational structure

- Meeting related documentation (Agendas, minutes, agreements)
- Document repository (Analysis, Design, Code and Quality documents)
- Dynamic schedule (Primavera P3 and Microsoft Project used by Project Manager)
- Meeting Systems (Proshare[43], NetMeeting [55] and CAIRO [72] – a collaboration support tool developed by this research group)

The students were not provided with any guidelines on their expected use of these tools. Short projects which required the use of particular tools were assigned to provide familiarity with the systems available. Subsequently, the students were encouraged to use the tools that they deemed most valuable to the particular tasks. The intention was to determine the un-forced mix of interaction modalities used in a distributed learning setting. This may have been a misguided approach, since some students disengaged from the interactions, because of lack of comfort with the tools or lack of evaluative incentive to interact with the group. Since distributed interaction necessitates additional effort that is not enforced by standard classroom norms some students tended to interact a lot less in this environment. With time, as communication was necessitated by product delivery deadlines, student interactions increased significantly. However, their choice of interaction tools was limited primarily by those they had used in the past. There was limited willingness to experiment with additional interaction tools at this stage in the engineering process since the focus was really on production and timely delivery was crucial.

### 7.4.2 Development of Group and Team

The initial atmosphere in the project was intense and exciting due to the novelty of the classroom situation. Survey results from the first month (see Figure 7-7) show significant interest and eagerness on the part of the students. This initial enthusiasm quickly tapered off at the end of the first month. Conflicts due to cultural (both national differences and educational culture differences between CICESE and MIT) and language difference reached a climax in the middle of the second month.




| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Low | 1 | 1 | 2 | 2 | 2 |
| High | 4 | 4 | 4 | 4 | 4 |
| Mean | 3.428571429 | 2.714285714 | 2.714285714 | 3.285714286 | 3.333333333 |

Figure 7-7: Enthusiasm for Distributed Collaboration

Due to the lack of established group norms for interaction among the participants, expectations by the students of each other were not compatible. Exemplars of these conflicts are lack of responsiveness to e-mail, feelings of lack of appreciation, rigid formal structure for most interactions, and general dis-connectedness of the group. Since the interaction process is considerably different in a distributed environment, effective communication within the group broke down and the communication tools provided were ineffective at providing an appropriate collaboration environment.

The instructors then began a process of team training in group dynamics that involved the initial establishment of norms through a "team contract". The contract defined guidelines for communication, decision making, and conflict resolution in addition to a clear definition of the group's objective. The contract was formulated jointly during two lab sessions and in effect redefined the interaction modalities of the tools provided. E-mail messages would now contain an additional meta-header which defined its class ([Immediate Response], [Please Reply] and [FYI]). These meta-headers indicated the degree of responsiveness and commitment expected of the readers of the message. These ranged from response times of 24 hours and 48 hours to no response expected. Furthermore, norms were set for the frequency of interaction among the group members. A consensual decision making process was formulated to organize group lab sessions with appropriate mechanisms for supporting disagreements.

Several exercises in team decision making were then conducted to test the processes enacted. From that point onward the group members were more comfortable with their colleagues but technological limitations exacerbated additional conflict. Within the next three months the students began losing interest in the class since many processes were tedious and cumbersome. Discussions in the distributed classroom were less dynamic due to the quality of the video and audio transmissions, lack of awareness and feedback of the distributed party's activities, in addition to the language barriers which reduced the smoothness of the interaction.

Near the end of the semester, the relationships were significantly enhanced as the students became engaged in programming tasks. These tasks typically required much less decision making interaction in labs and the creation of an actual product was more fulfilling than writing specification documents. The students had also become accustomed to the communication technologies available and had more effective contact with their distributed counterparts. However, several students also expressed their anxiety over the course grading policy as the course neared its end. The students were only evaluated formally at the end of the semester and there were limited intermediate evaluations.

### 7.4.3 Use of Distributed Tools

In analyzing the e-mails, talk instances, conference logs and video tapes for the group interaction (from September 9, 1997 through April 1, 1998), several interaction patterns arose. An overwhelming proportion of the 500 e-mail interactions were notification related (i.e., informing other members of the group of the availability of a document, the scheduling of a meeting, or the agenda for a subsequent meeting). See

Table 7.1: Distribution of email-based activities

| *Information Dissemination* | *Knowledge Sharing* | *Group Cohesion* | *Group Coordination* | *Decision Making* | *Building Contacts* |
|---|---|---|---|---|---|
| 28% | 17% | 7% | **41%** | 3% | 4% |

Table 7.1 for a the distribution of e-mail archive messages by purpose:

Discussions on the class project primarily occurred on email, since it was the most readily available tool for interaction. Video conferencing equipment was only available in the DISEL lab. Thus, the video conferencing systems were primarily used for engendering social cohesion among members of the group and for general lab meetings.

A distributed structured meeting system (CAIRO) was used to facilitate the classroom discussion (see Figure 7-8). The system provided a unified classroom interface that showed the students whose hands were raised and who was talking at a particular time. These visual cues were lacking from the video image since the resolution was low and the camera was not always pointed in the appropriate direction. The system was also used for interactive design processes where students from both campuses needed to brainstorm, evaluate and come up with solutions to project problems jointly.

A synchronized web presentation tool was also used for class presentations. This tool provided a unified view of a web presentation in the distributed sites. This was primarily used to show agendas, lecture slides and design and specification documents.

Video and audio connectivity occurred primarily in the two hour lab sessions. A student assistant was needed to control the camera to provide the best view of the interacting individuals. However,this additional overhead can be eliminated through the use of more advanced motorized cameras. Use and placement of microphones within the room was also a critical issue. Initially one microphone was shared among

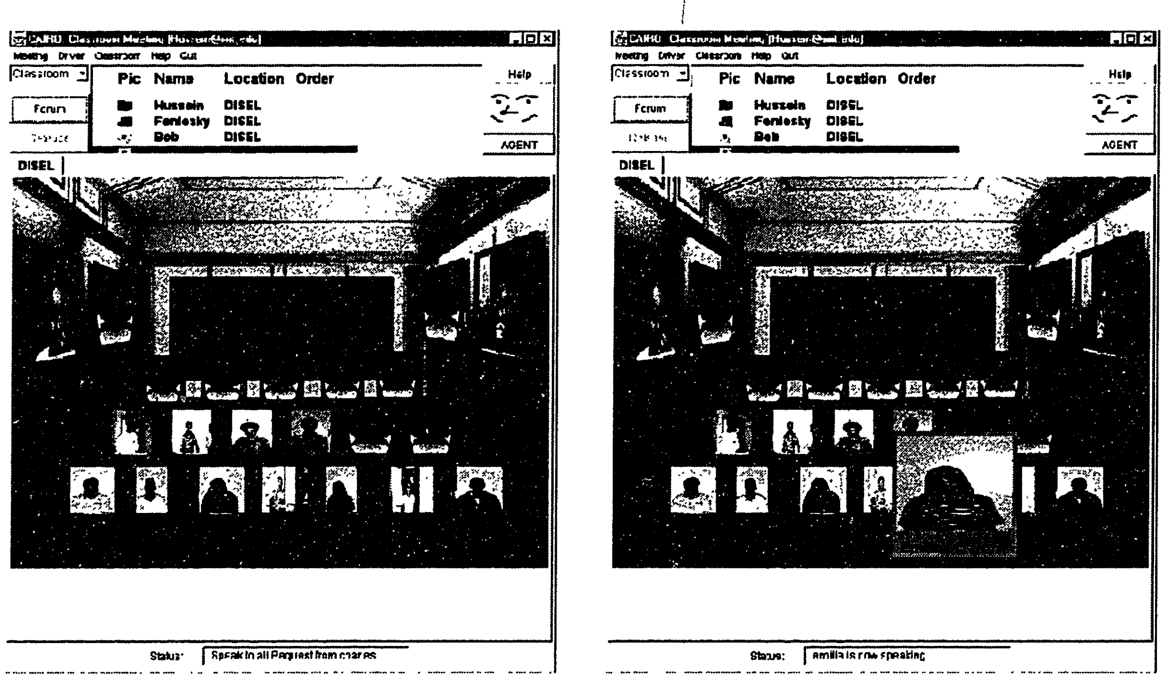


Figure 7-8: CAIRO Classroom Interface

the students forcing a chalk passing control process (i.e., the last person to talk becomes a de facto chairperson of the meeting until he/she passes the microphone) centered around the microphone. Additional table microphones were used with a mixer to allow multiple individuals to seamlessly engage in the distributed discussion. A breakdown of the activities performed in the formal classroom setting are presented in Figure 7-9.

Push-button switches were installed for each student to enhance their expressive abilities in the distributed setting. The switches were used to indicate a request to speak by each student and for voting purposes. When a student pressed one switch button a red halo was placed around their image in the shared CAIRO display (see Figure 7-8). The other button was used to tally votes on particular issues. The voting system was never used and is generally unnecessary given the size of the group in our experimental classroom, since verbal voting is equally efficient.

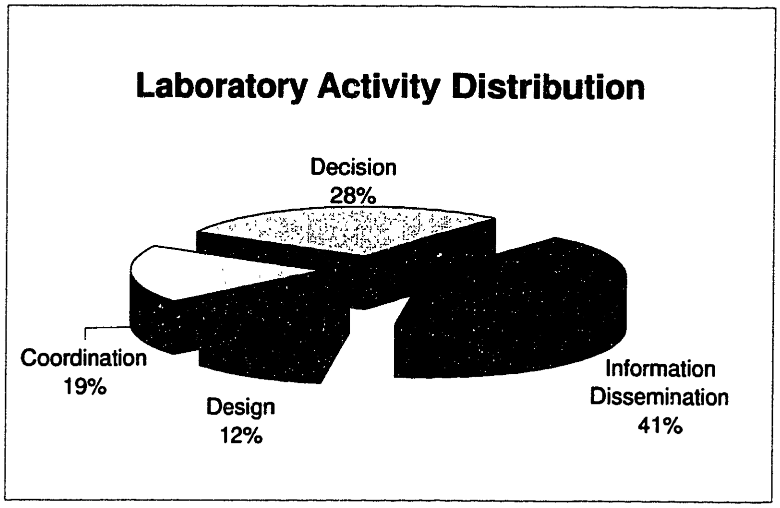



Figure 7-9: Distribution of activities in classroom settings

### 7.4.4 Student Surveys and Interviews

Questionnaires were administered to the students on a monthly basis throughout the course. An initial pre-skill questionnaire was given to evaluate the abilities of the students as they entered the class. The regular monthly questionnaires were geared toward the evaluation of three critical dimensions of this distance learning experience.

1 Understanding of course material.

2 Evaluation of the project based approach and the group process.

3 Effects of distance on learning.

4 Effectiveness of current distributed learning technology infrastructure.

Understanding of the lectures and the structured course material was initially very limited. The students found no correlation between the materials presented and the project requirements. Another important variable was achieving a balance between lecture time and laboratory time. Lectures provided summary information that introduced the student to the particular topic and the students were expected to explore the topic more deeply on their own through the laboratory sessions. On occasion, the laboratory and lecture sessions were not perfectly aligned in subject matter which would confuse the students. However, a critical intent of the class was to allow the students to formulate their own software engineering processes and to learn the roles and steps involved through the experience of software design. Figures 7-10 and 7-11 show the effects of distribution on understanding and learning with regards to software engineering.

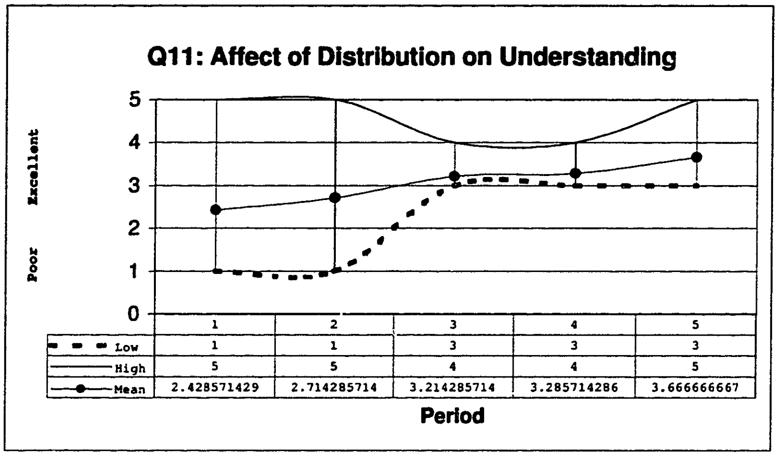



Figure 7-10: Understanding of Material

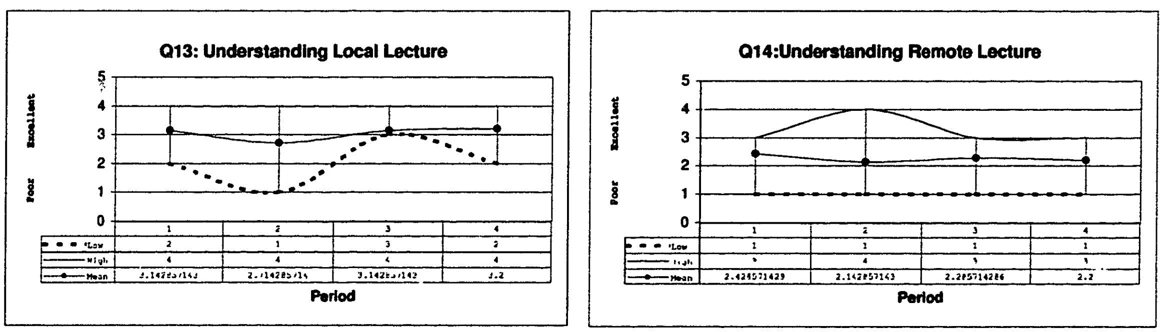



Figure 7-11: Understanding of Local/Remote Instructor

Results of the questionnaire showed an initial excitement and interest in the technology utilized for distance learning. However, as the limitations of the technology became apparent the students were increasingly frustrated with the available interaction systems. Figure 7-12 shows the averaged trends in the students perception of the technological infrastructure used for the classroom (particularly the conferencing equipment).

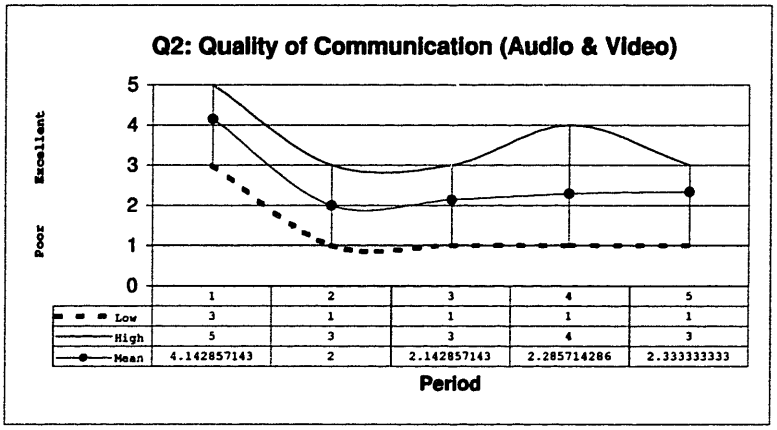
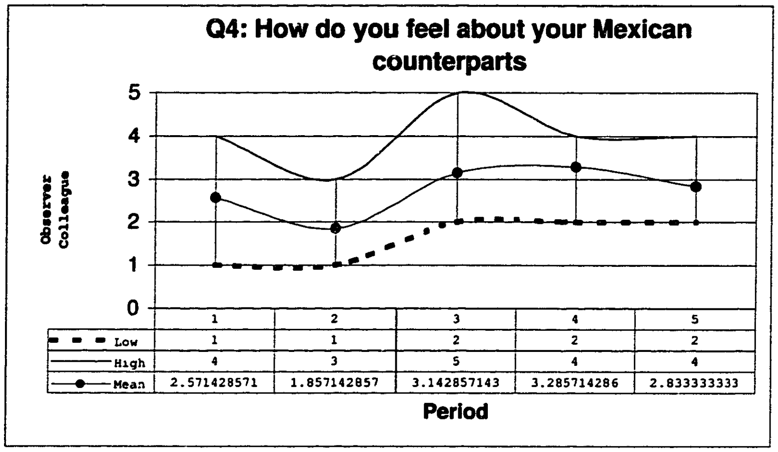



Figure 7-12: Perceptions of Distributed Technological Infrastructure

The distributed group process was evaluated through questions that related to the students' perception of their distributed counterparts. These perceptions varied greatly as each students' experience with the collaboration was different. However the general trend was a degradation of their relationship in the early phases and a gradual building of these relationships after the first 2 months. This coincides with two important events: (1) the establishment of a team contract [5] governing the interactions among the distributed members of the group; and (2) understanding and getting accustomed to the technological infrastructure. It is unclear which of these two variables had a more profound impact on the group process. Again the trends are exemplified by figures 7-13 and 7-14.

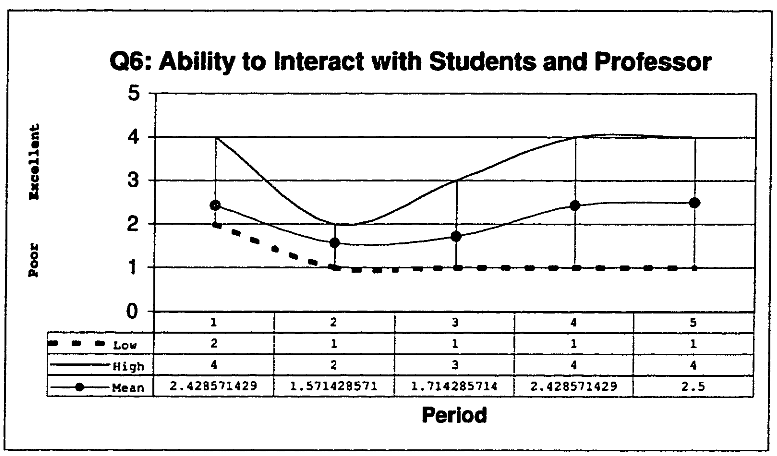
Finally, the affects of distance on learning were measured through a set of questions that evaluated the students' understanding of the distributed instructors and their own ability to express themselves and coordinate tasks. The results are show in Figure 7-15.

Through a beginning and end of term student interview process, the course supervisors were able to discern the students' impressions of the course and the learning process. The interviews were conducted by a fellow student and all results were anonymous. The interviewees were asked several questions regarding: the team process, both locally and in the distributed setting; knowledge gained from the class, both




| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Low | 1 | 1 | 2 | 2 | 2 |
| High | 4 | 3 | 5 | 4 | 4 |
| Mean | 2.571428571 | 1.857142857 | 3.142857143 | 3.285714286 | 2.833333333 |

Figure 7-13: Perception of Mexican Counterparts




| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Low | 2 | 1 | 1 | 1 | 1 |
| High | 4 | 2 | 3 | 4 | 4 |
| Mean | 2.428571429 | 1.571428571 | 1.714285714 | 2.428571429 | 2.5 |

Figure 7-14: Perception of group process

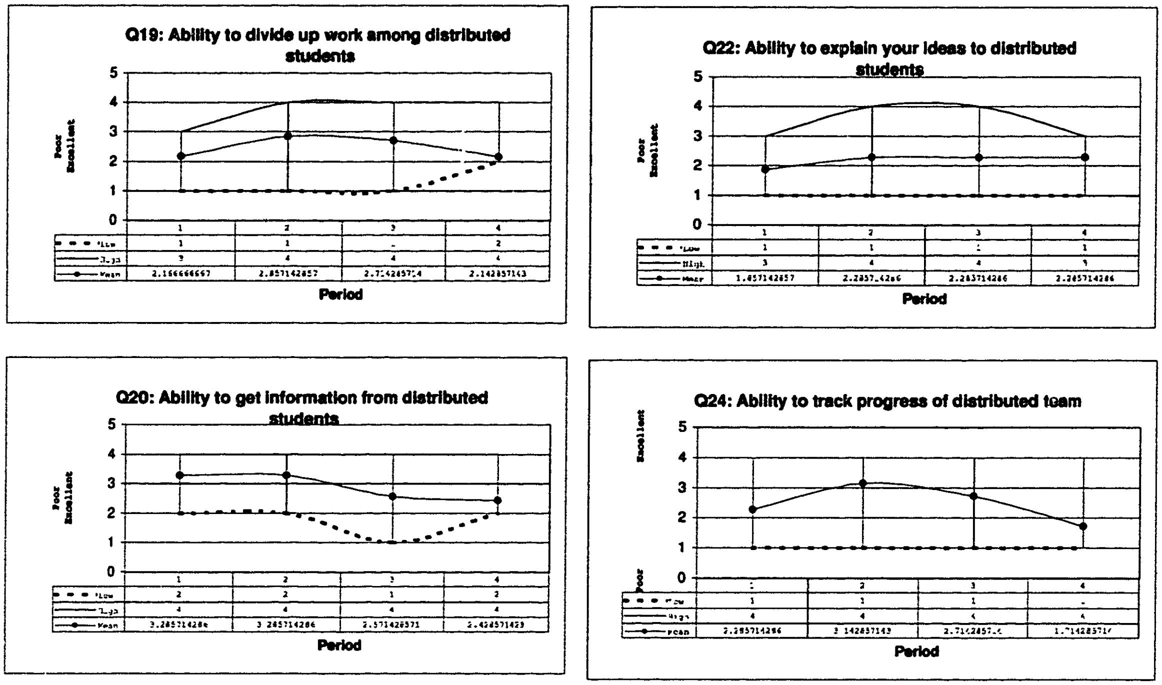



Figure 7-15: Affects of distance on collaborative learning

managerial and technical; and their recommendation for future distributed learning environments. Results of these interviews confirm the survey results presented above and are integrated into the distributed learning guidelines presented in Section 7.5.

Furthermore a structured skill survey was conducted in the first class and the last class. Mean results for the questionnaire are shown in Figure 7-16. They show significant increase in the ability to communicate in distributed environments (approx. 68%) and to program using object oriented methodology (approx. 45%). The survey also shows a modest increase (approx. 17%) in group skills (namely the ability to lead and work with multi-disciplinary teams - Question 4 & 5). The only skill that was lower (approx. -4%) in the final survey from the initial survey was communication skills with team members. This is probably due to the students realization of the difficulties of communication in the distributed setting. These skill survey results are only based on student self-evaluations. Additional studies need to be performed to verify the validity of the skill survey results presented in this section.

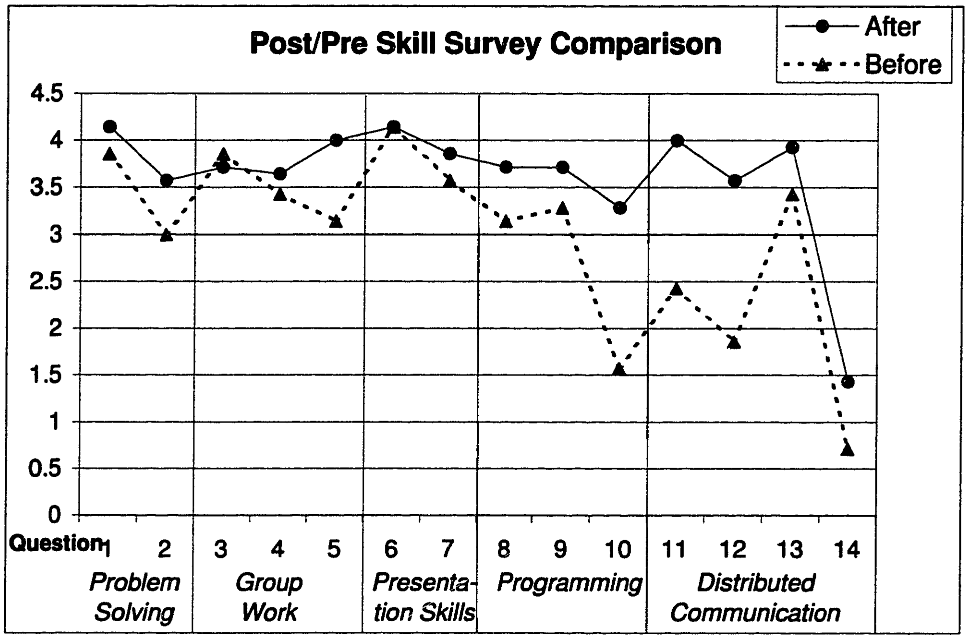



Figure 7-16: Results of Skill Surveys

## 7.5 Guidelines for Distributed Collaborative Education

This section serves as a brief guide to setting up a distributed collaborative learning environment. The experiences of the DISEL classroom have highlighted four major areas of concern in the development of collaborative learning environments. The first area is the technology infrastructure and its support for the learning activities. The second is the appropriate choice of group dynamics exercise to ensure project team cohesion. Third, the choice of appropriate learning incentives and evaluations through out the project-based collaboration experience. Finally, extensive feedback from instructors to the students is required to help ensure the appropriate learning path and reduce student anxiety.

### 7.5.1 Technology Infrastructure

As shown in Section 7.3, different computer tools are effective for different group interaction activities. It is necessary to predetermine the extent of each group activity in the learning environment and provide the appropriate computer-support tools for these activities during course preparation. The collaborative learning exercise has also shown that tool accessibility is very important in ensuring its effective use. Hence, email and web based interaction were more common due to their availability on all campus computers. Conferencing systems were only available in a limited number of labs. Furthermore, the interaction framework described in Section 7.3 provides effective guidelines for the design of future distributed group collaboration support tools. In summary, the choice of a technological infrastructure involves the following five steps:

1 Prioritize group activities required for distributed course. For example, structured information dissemination is a top priority for presenting course materials and assignments.
2 Given the results of Section 7.3 determine the interaction modes necessary to support the high priority activities. In this example supporting information dissemination requires asynchronous, unstructured, intentional and marginally committal interaction modes at a minimum. In addition since the instructor wishes to present course material, the designer should assume that this interaction process requires some structuring to present the material in a coherent manner.
3 Evaluate the available interaction tools for their support of the necessary modes. In this example, the Web, gopher and ftp provide sufficient support of all the interaction modes required for information dissemination.
4 Choose the tools that have the closest interaction modes to those desired for the activity. In this example, the more accessible and user friendly mechanism is the Web.
5 Make any modifications to the tools or their use to ensure their effectiveness in supporting the activities outlined in (1). In this example, the instructor may wish to provide a simple web structure to allow easy navigation through the course pages.

### 7.5.2 Group Dynamics

Unlike many traditional learning settings, group dynamics within a distributed environment must be more carefully engineered. Elements of the physical lab setting and the group cultural norms significantly affect the effectiveness of the distributed interaction. The physical lab environment must be structured to promote distance collaboration and to ensure that communication locally and remotely are on relatively equal footing. Otherwise, local interaction dominates and distributed communication is primarily used for notification of group discussion results rather than for actual group discussion. In the DISEL setting (see Figure 7-5), the group discussion table allows much easier access among the individuals at MIT. Hence, it gives the impression of one group communicating with another – this is exemplified by the students' choice to informally appoint a spokesperson for the group at MIT. A new setting has been designed to ensure a merging of the two groups by using a local crescent table, instead of a regular conference table, that is complimented by a mirror equivalent at the remote site (see Figure 7-17). Unfortunately this physical setting does not scale with more than two groups. More creative arrangements of the physical space will need to be engineered to incorporate the multiple groups envision in the Da Vinci Initiative.

Additional constraints on group process imposed by distance collaboration have been extracted from the survey and interview analysis described in Section 7.4.4. The main group process constraints experienced by the students were on creating a constructive discussion environment, achieving commitment from individuals across distance and getting to know their distributed counterparts (i.e., creating a sense of group cohesion). The instructors can provide several interventions to relieve some of these constraints. Constructive discussion can be enabled by designing small exercises that require significant discussion across distance and de-briefing the group members. This allows individuals to identify their limitations and to actively pursue enhancing

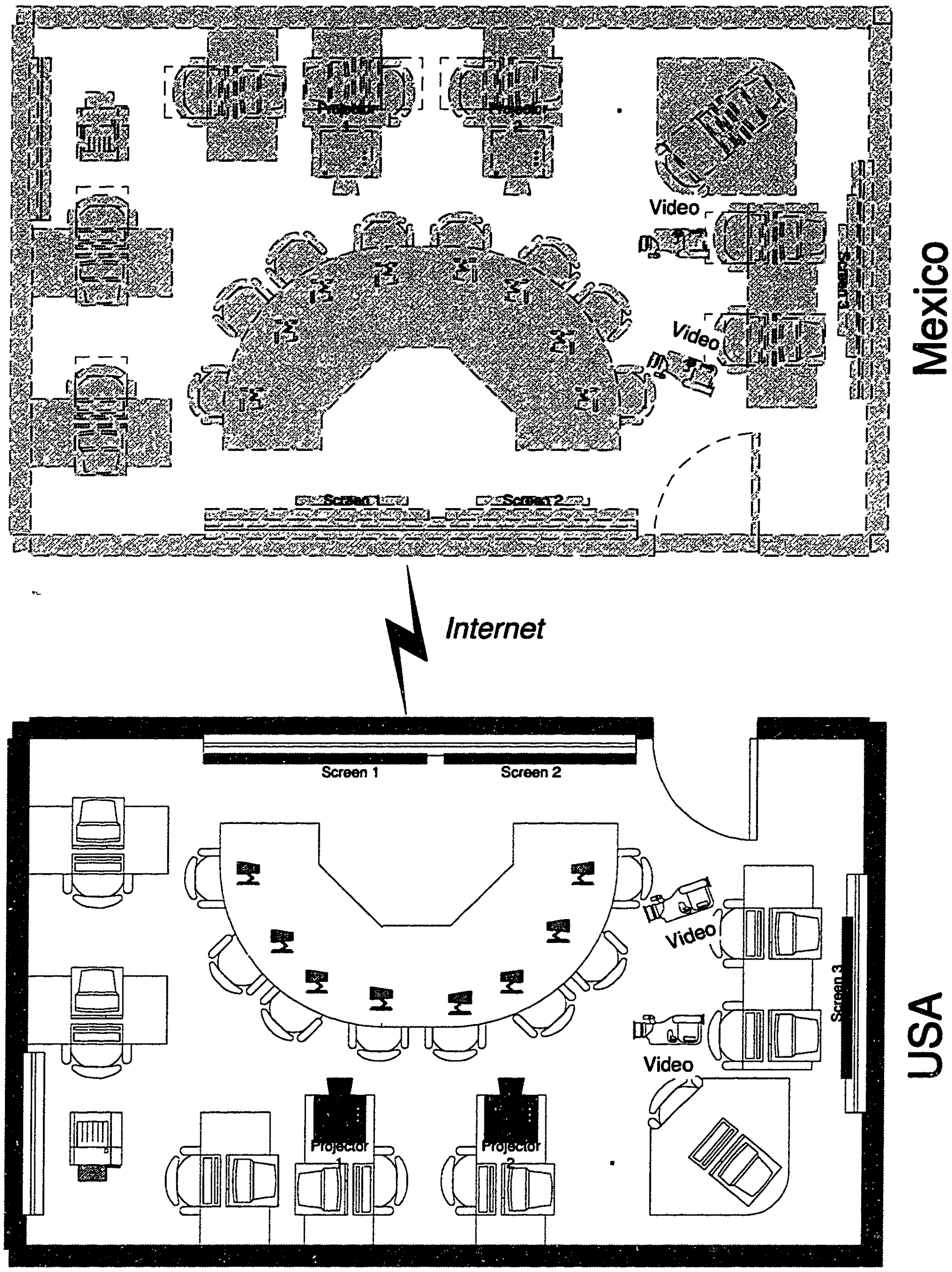



Figure 7-17: Modified DISEL classroom schematic

the group process. Further, commitment and enhanced discussion can be achieved through a consensual group process that develops a joint group objective and vision, defines a set of communication norms, establishes decision making criteria, and delineates mechanisms for conflict resolution within the group. An efficient mechanism for establishing this process is a team contract that is developed consensually among the group members that outlines the four components of the group process [5]. This contract should be developed before any significant work is performed by the group. A brief outline of the issues to be addressed by such a contract is provided in Figure 7-18.

Finally, the students on both sides of the collaboration should be educated on the basic conditions of their respective locales. Natural and social conditions can significantly alter the distributed interaction and should be transparent to the remote parties (e.g., adverse weather conditions due to El-Niño interrupted communication between MIT and Mexico on several occasions, creating several misunderstandings regarding deliverables).

### 7.5.3 Incentives and Evaluation

Having established an efficient group process, the instructors must ensure that the incentive and evaluation structure for the course be aligned with the group process and promote the learning of the material presented. In a project-based course, as in the case of DISEL, a large amount of the student's grade is based on the final project. However, the students should be receiving continuous evaluation on an individual as well as a group level. This evaluation can be performed on project milestones or on additional short term assignments administered throughout the semester. Further, incentives should also be developed to promote a cohesive group process. This can include graded exercises that require collaboration among the distributed participants and exercises that evaluate the students' ability to use the collaboration

**TEAM CONTRACT OUTLINE**

1 Objective/Mission

2 Meeting Procedures:

- How and when do you call for meetings?
- How much preparation is expected before each meeting?
- How do you excuse yourself from a meeting?
- What roles will people take during each meeting?

3 Communication Procedures:

- What tools to use for each type of communication?
- What is the maximum feedback time?
- How much information is expected in response to a query?
- What amount of commitment does each message imply?

4 Conflict Management:

- How will decisions be made (consensus, voting)?
- What happens in a decision deadlock situation?
- How do you expect people to discuss and argue with you?
- How do you deal with personal problems?
- To what degree are the instructors involved in conflict management?

Figure 7-18: Team contract outline

tools provided. If evaluation of group and individual activity is not immediate and continuous, students will tend to lose interest in the collaborative process and they will simultaneously become more anxious about the group process since they are unaware of their final grade until the course is almost completed. Finally, the incentives provided by the instructor should promote achieving commitment among the team members since individual commitment is difficult to provide without a possible consequence of foregoing that commitment. Since the team depends on commitments by all the members, the instructor should ensure that the incentives promote individual commitment to the group.

### 7.5.4 Feedback

Finally, it is important to remember that distributed collaboration is still an alien environment for the students and intensely alters their expectations of their colleagues and their instructors. Instructors must always effectively communicate the purpose of assignments and lectures to ensure that all student expectations are aligned. Furthermore, the instructor must maintain a pulse check on the group process to ensure that distributed interaction is effective and that the group has the sufficient tools and group processes for effective interaction in distributed teams.

## 7.6 Conclusions

Computer and communication technology provide new avenues for learning across geographical boundaries. The class conducted between MIT and CICESE is one in a series of a experimental classes to be conducted at MIT to test the boundaries of this new medium for collaboration. Through the experiences of this unique classroom setting this research has been able to identify some of the appropriate technological and social platforms for effective collaborative learning.

This chapter has laid out the foundation for providing appropriate tools to support collaboration in medium size group in a distributed environment. Interaction requirements for collaboration activities have been delineated and current examples of distributed collaboration tools have been discussed. The shortcomings of current tools have been identified to serve as a basis for future development of distributed collaborative learning tools.

Critical elements in maintaining effective group processes across distance have also been identified. Guidelines have been set for educators that wish to provide a distributed learning environment. There are many constraints and limitations of the distributed communication medium, however with careful attention to group dynamics many of these constraints can be eliminated. The frameworks devised can be successful in our experience and should serve to enhance any group effort in a distributed environment.

# Chapter 8

# Conclusions and Future Work

## 8.1 Thesis Summary

This thesis has presented models of design team interaction and their application to distributed collaborative environments. Furthermore, an experimental distributed learning experience is presented as an illustration of the use of a variety of interaction tools in a distributed learning setting.

Analysis of group interaction in physical settings has provided several important models of the rules that govern conversation in such settings. In Chapter 3, a model of floor transition is presented that describes the floor state based on individual discourse characteristics. This model in addition to a model of engagement in group discussions is used to analyze the critical differences between physical and online environment for design discussion. The concepts of focus of attention, degree of engagement, and address space (determined by gaze direction and speaker volume) have been derived and have subsequently translated from the physical group interaction to distributed group design. This is accomplished through the choice of appropriate user interface metaphors and the development of several interaction control algorithms for a distributed communication system.

On a higher level, group design processes were also reviewed to determine appropriate computer support for these processes. The structure of groups and meetings in addition to the norms that govern their discussion have been decomposed and computer support for group and meeting structuring as well as coordination have been developed. Meeting agenda structuring tools and group definition tools have been developed based on the criteria outlined in management literature to provide effective meeting support in an online environment. These tools enforce meeting membership, agenda flow, and floor control on distributed collaboration in design meetings. Additional intelligent agents have also been implemented to provide facilitating services in the online environment. These agents detect disfunctional meeting processes and meeting transition queues from user input. One agent senses the amount of time distributed users spend waiting to communicate with the group and changes the floor control process to provide an adequate forum for interaction. Another agent detects keywords that imply a shift in topic discussion or style of discussion to automatically change agenda stages or floor control strategies. Additionally, the online meeting environment provides simple "wizards" to generate standard meeting agenda templates[8].

The tool designed for distributed communication (CAIRO) provides the group support discussed above in addition to a robust multimedia communication infrastructure. CAIRO provides the ability to add arbitrary devices to be shared among the conferencing individuals. Devices may be added by adhering to the CAIRO application programming interface. The system provides synchronization of the multiple media devices and enforces group coordination control over each of the devices. Algorithms have been developed to maintain intra-media synchronization across a non-deterministic packet switched network (the internet) and to ensure limited communication bottlenecks. Furthermore, the system provides automated documentation of meeting interactions and browsing features for random-access retrieval of meeting proceedings. This is an effective mechanism for updating late or absent members on the activities and conclusions of the group.

The concepts derived from the experience of designing this design group support tool have been applied to a distributed classroom experience taught simultaneously at MIT and at CICESE in Mexico. The classroom was used as a test-bed for the system developed in addition to a wide variety of other distributed communication tools. A taxonomy of interaction activities and interaction modes was then developed from the classroom experience. This taxonomy is helpful in evaluating the effectiveness of distributed tools in supporting particular group activities. Further, the experiences of teaching one class in two sites using a distributed collaborative learning approach have been documented. These experiences served as guidelines for effectively creating and administering such a course are highlighted. These guidelines include methods for creating effective distributed teams, learning mechanisms for distributed settings, in addition to, an evaluation of necessary technological infrastructures for teaching in a distributed learning environment.

The CAIRO research effort has been primarily focused on the analysis of interaction in groups and the impacts of distributed communication on group process. Throughout this thesis, several models, methodologies and tools have been presented that provide more effective computer support for group design than is currently available through simple distributed communication tools. These support mechanism enable group work in distributed design teams and promises to significantly alter design processes in the future.

## 8.2 Future Work

Several areas of research can build on the work presented in this thesis. This section provides an outline of directions of future research on interaction in distributed design groups. These research areas are segmented in five categories: interface development, group process control, group dynamics analysis, meeting documentation and distributed education. The following sections provides a brief guide of open issues in each of these fields.

### 8.2.1 Interface Development

Multi-user interfaces stretch the current models of interface design. The approaches presented in this thesis are an initial attempt at providing appropriate feedback for distributed individuals. Further analysis of appropriate metaphors and representation for group interaction need to be explored.

Furthermore, the work discussed in the thesis has explored mechanisms for output representations, however, there is limited discussion of input user interfaces. In order to effectively enable group interaction in a distributed setting, input devices that can detect gaze direction and degree of engagement would be helpful. Inputing these parameters through keyboards and pointing devices is limiting and cumbersome when individuals are engaged in a group design task. Several devices have been developed that detect eye movement that can be useful in determining gaze direction. However, the resolution of current systems is inadequate to accurately provide meaningful gaze data. Unobtrusive detection of degree of engagement is a more difficult task since attention is represented by a multitude of physical characteristics that may not easily be detected by current sensing equipment. However, more direct engagement input mechanisms could be developed that rely on frequency of mouse, keyboard and other input device use to determine activity levels of the individual.

Finally, the representation of a focus of attention in the user interface can be provided through a multitude of interface mechanisms. These include highlighting the tool that is at the center of the focus of attention or bringing that tool to the center of the screen or using other more explicit attention grabbing elements. The degree of effectiveness and user acceptance of these tools needs to be evaluated in order to ascertain an appropriate representation of focus of attention in the user interface.

### 8.2.2 Group Process Control

Several aspects of the group process control methodologies presented can be enhanced in future distributed meeting environments. These include a refinement of floor control to object level control; more advanced automated facilitation mechanisms and enhanced degree of engagement detection and interpretation.

The floor control processes presented in Chapter 3 provide group access control on the complete design workspace. More refined concurrency control may be appropriate for particular applications were some components of a system design are independent and can be manipulated simultaneously. Control methodologies would need to be developed to enable multiple levels of control over the interaction among members of these groups in addition to the multi-level structuring of groups currently provided by CAIRO. Although these processes have been formalized in a physical sense through chains of command and group norms (e.g., formal addressing procedures in the military) they are not directly applicable to interaction through distributed communication systems. Tools that provide further segmentation of interaction control through spatially based or object based locking will need to be introduced into the system. This will allow multiple groups to be engaged in a single planning activity without "stepping on each others toes." The current group structuring system already allows multiple levels of communications within a group and within subgroups of that group through a simple communication interface that replicates standard physical meeting scenarios.

Facilitators in the current CAIRO system rely primarily on the syntactic queues of time on the pending queue, degree of engagement and degree of fragmentation of the conversation to determine floor control process transition. Enhancements to the facilitating mechanism can be provided by additional semantic interpretation of the meeting process - this would entail significant advances in natural language understanding. Furthermore, the system facilitators can be further guided by standard facilitation procedures available in the management literatures. Another constraint of the current facilitation strategy is its reliance on the honesty of the user in describing their interests. The system can currently be easily deceived by individuals interested in maintaining control over the floor.

Finally, a complete control wizard definition language needs to be developed to enable simple programming of relavant control methodologies within particular organizations. The current mechanism for control definition process is cumbersome and not user friendly. Additional primitive meeting control styles also need to be added as the needs arise. A handbook and generic classification of typical control styles and processes also need to be developed according to a rigorous academic analysis of current practice to enhance the extensibility of the control system.

### 8.2.3 Group Dynamics Analysis

In the area of group dynamics and group behavior, more expensive studies need to be conducted to verify the models presented for group interaction. The models have been derived from several group design experiments using multi-cultural subjects. More controlled experiments need to be conducted across and within cultural boundaries (national, corporate and professional). Form initial observation it is clear that the frequency of use of various interruption modes (focal and vocal interruption) is highly dependent on cultural background, meeting setting and familiarity within the group. These parameters are difficult to encode a computer support tool, however, the system could provide a range of intervention mechanisms that can be adjusted to a particular group's norms. Developing a taxonomy of group norms and behaviors would be a crucial enabler for providing such computer support.

### 8.2.4 Meeting Documentation

Meeting proceeding are currently documented in a flat file format in CAIRO. A structured interaction storage mechanism would provide greater flexibility and faster access times for information exchanged within a meeting. The current files are indexed by agenda item, time of interaction interaction origin and interaction destinations. Further integration with a design rationale model such as the one discussed in Section 5.1.3 would provide further dimensions of documentation access but would require additional user input. Although several models have been proposed for design process structuring [12, 70], additional models could be developed that aid in conversation structuring. These models need to be simple, requiring minimal user input, yet complete in recording design process and rationale for future reuse. Several efforts are currently being pursued by our research group in this field. Integration of the system with a product modeling language would further enhance the functionality of the system. However, product modeling languages are currently cumbersome and not widely used in engineering design. The benefits of such formal artifact description for future design efforts is great but the additional encoding overhead would be prohibitive and mechanisms must be formulated to reduce this overhead for these description languages to be universally adopted by designers.

The documentation browser currently employed is a simple meeting index. More complex search engines based on user preferences and previous search criterion can more intelligently retrieve relavent past meeting proceedings. The browser could also be more fully integrated into the current environment through appropriate metaphors for persistent meeting data within the meeting environment. This can include icons of documents generated within each setting that remain within the meeting room, such that the room represents a physical repository of information.

### 8.2.5 Distributed Education

The education experiments conducted were limited in scope due to the number of subjects available for this classroom. As additional classes are taught in this fashion more valid statistical analysis of interaction can be performed. Furthermore, structured controled experiments on design tasks conducted both remotely and locally would enhance the analysis of the effects of distance on the learning process. However, these experiments should be conducted over longer periods of time and more students to reduce the effects of random variation on the experimental results. Finally, the taxonomy of interaction activities and modalities derived should be reviewed periodically to ensure that it is comprehensive and complete.

# Appendix A

# UML Object Models

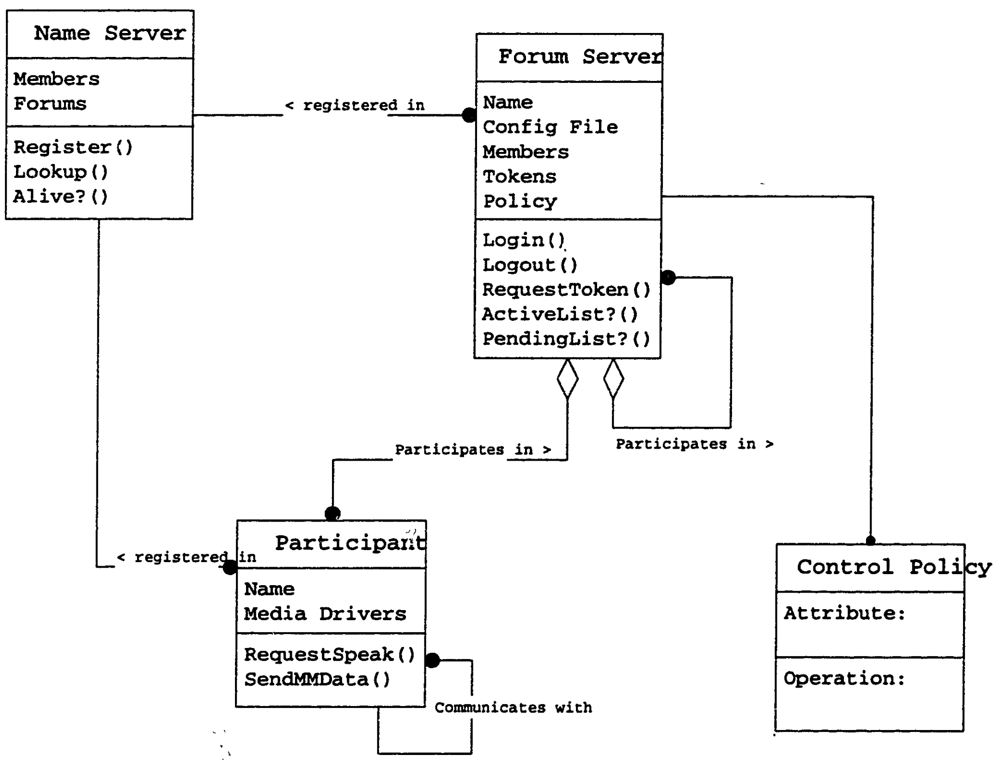



Figure A-1: Object Diagram: Overall Server Inter-connectivity

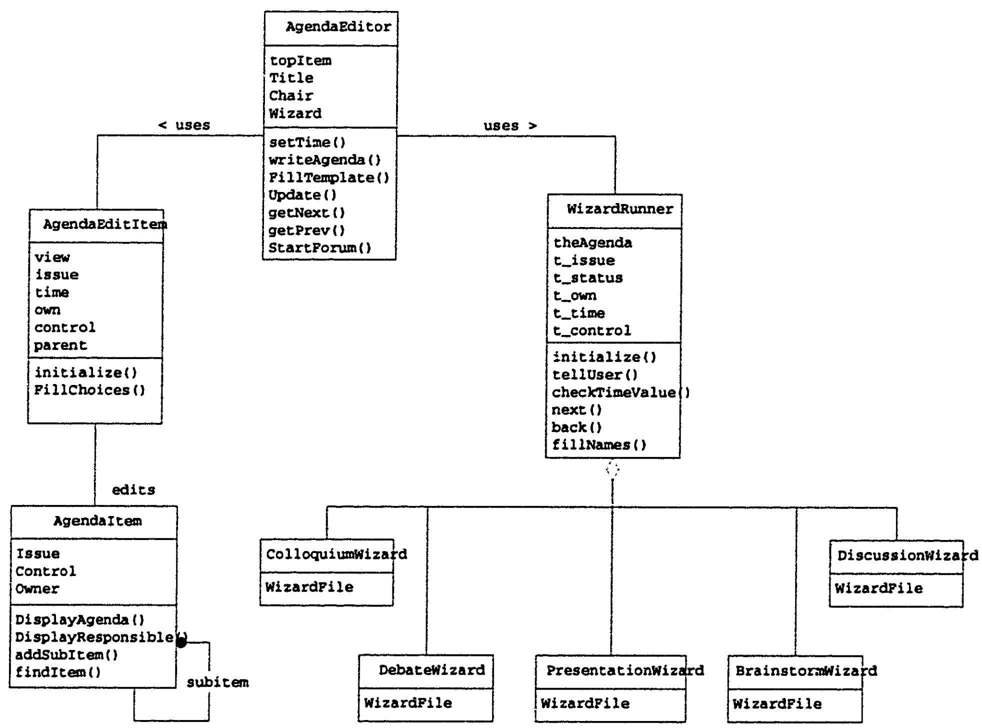



Figure A-2: Object Diagram: Agenda Editor and Wizzard Classes

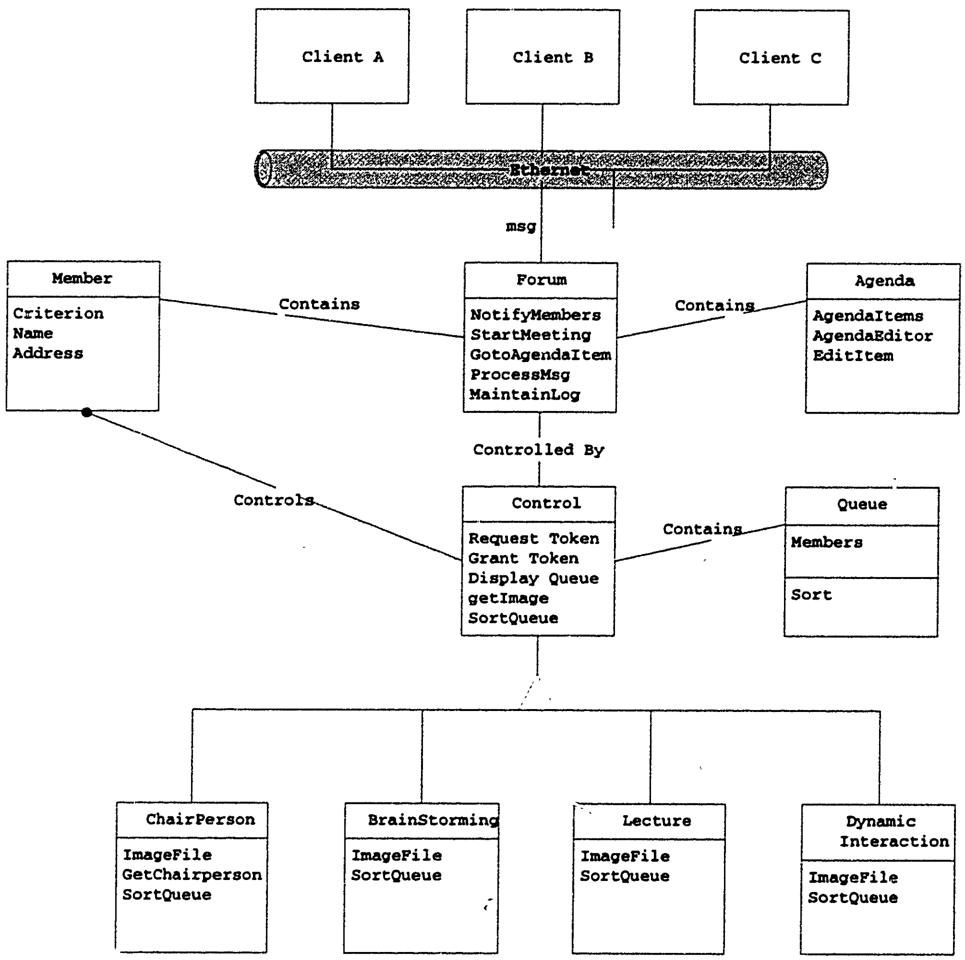



Figure A-3: Object Diagram: Forum Server Classes

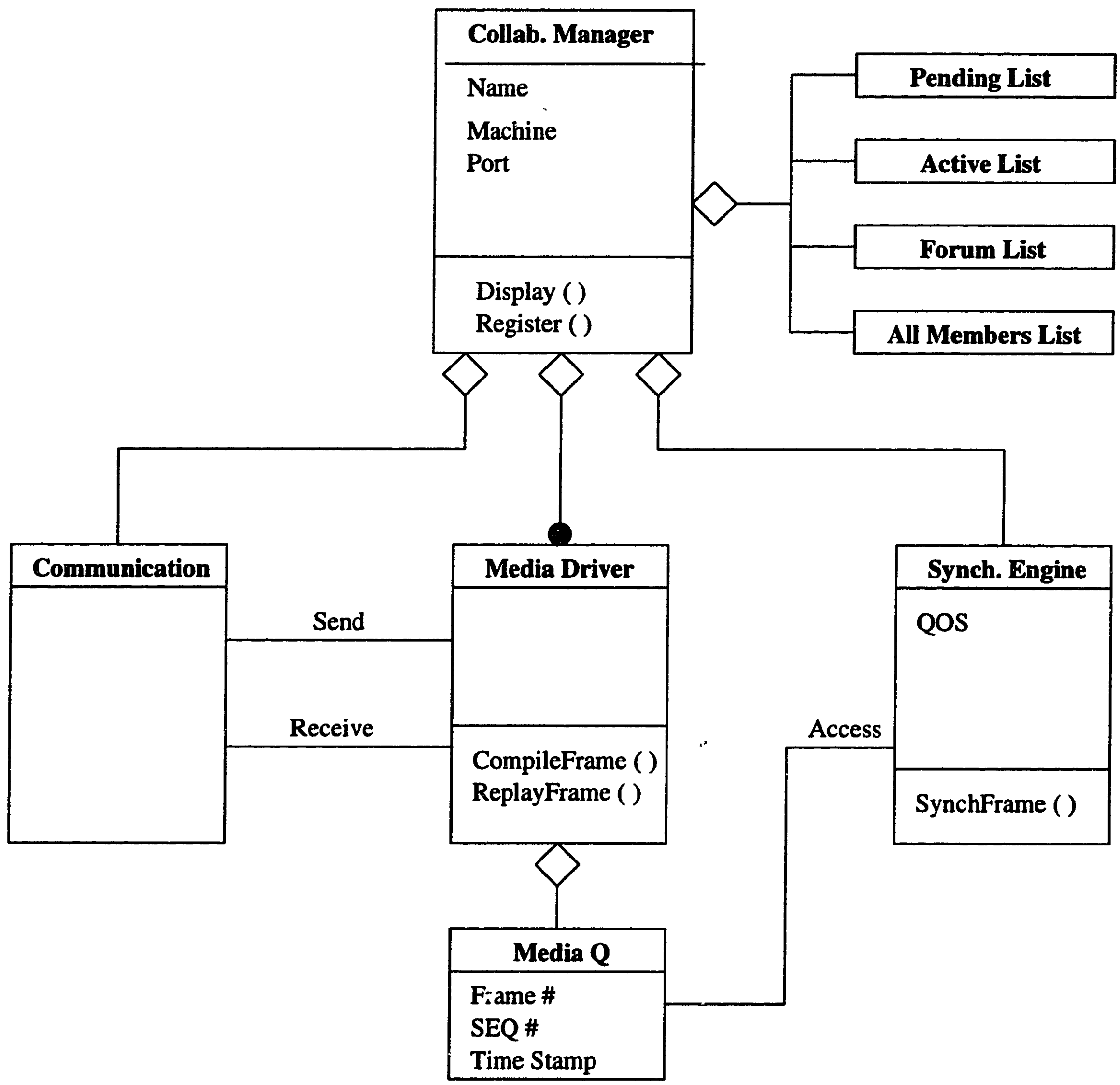



Figure A-4: Object Diagram: Components of a CAIRO participant

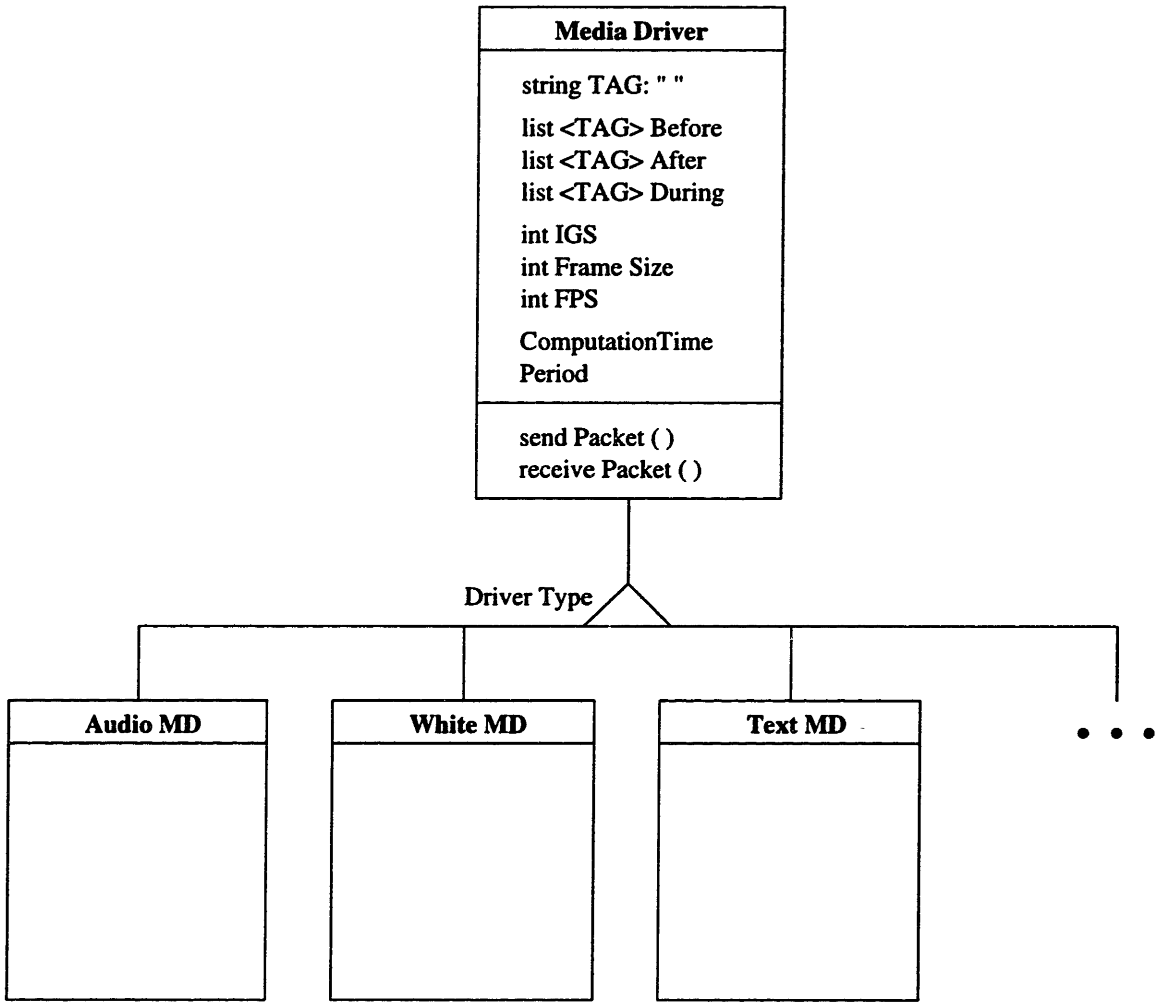



Figure A-5: Object Diagram: Media Driver classes

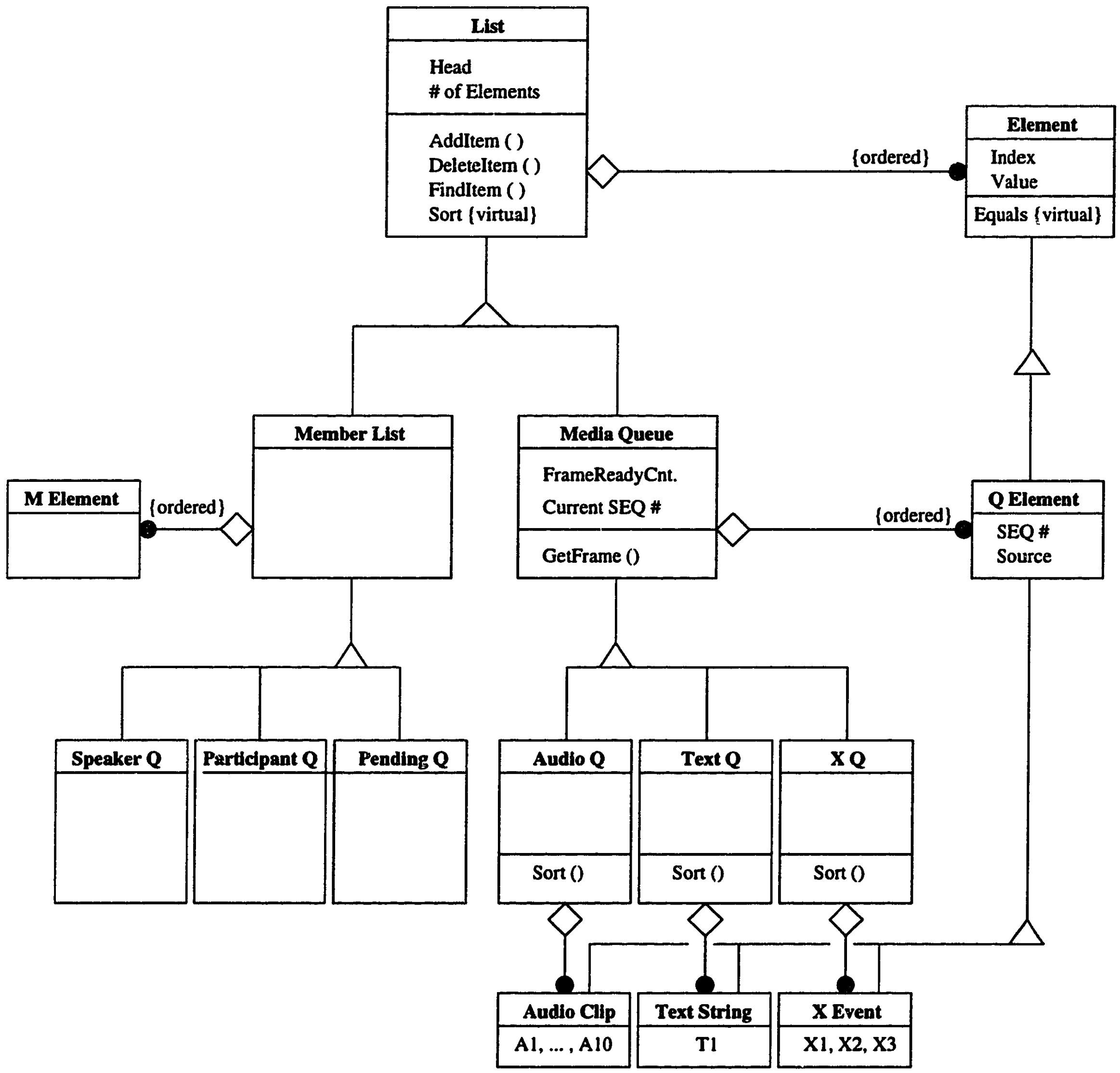



Figure A-6: Object Diagram: Queue Structure Hierarchy

# Appendix B

# Message Protocol

Table B.1: Forum Server Output Messages

| Prefix | ARG1 | ARG2 | ARG3 | ARG4 | Comment |
|---|---|---|---|---|---|
| RF | Name | Machine | Port | | Sends a forum registration message to the Name Server. |
| DF | Name | Machine | Port | | Sends a forum removal message to the Name Server. |
| AK | Name | Machine | Port | | Acknowledge a user login. |
| RE | Name | Machine | Port | Reference | Refuses a user login and sends a reference e-mail address to request membership in the forum. |
| UA | User # | Total # | Name | Machine, Port | Sends a list of all active users. |
| UR | User # | Total # | Name | Machine, Port | Sends a list of all pending speakers. |
| K | From | To | Expiry | Type | Provides a conversation token to a user. |
| L | From | To | Type | | Force a retrieve of a token from a CAIRO user. |

Table B.2: Forum Server Input Messages

| Prefix | ARG1 | ARG2 | ARG3 | Comment |
|---|---|---|---|---|
| A | User Name | Machine | Port | Registers a user with the Forum. |
| D | User Name | | | Removes a user from the Forum. |
| R | From Name | To Name | Token Type | Request a speech token from the Forum. Enforces collaboration control. |
| N | From Name | | | Releases a speech token from the Forum so that it can be re-used. |

Table B.3: NameServer Output Messages

| Prefix | ARG1 | ARG2 | ARG3 | ARG4 | Comment |
|---|---|---|---|---|---|
| FF | Name | Machine | Port | | Sends a forum's complete directory information in response to a CAIRO user query |
| FU | Name | Machine | Port | | Send a user's complete directory information in response to a CAIRO user query |
| GU | User # | Total # | Name | Machine, Port | Returns list of CAIRO users. |
| GF | Forum # | Total # | Name | Machine,Port | Returns list of active CAIRO forums. |

Table B.4: NameServer Input Messages

| Prefix | ARG1 | ARG2 | ARG3 | Comment |
|---|---|---|---|---|
| RU | User Name | Machine | Port | Registers a user with the nameserver. |
| RF | Forum Name | Machine | Port | Registers a forum with the nameserver. |
| DU | User Name | Machine | Port | Removes a user from the nameserver. |
| DF | Forum Name | Machine | Port | Removes a forum from the nameserver. |
| LU | User Name | | | Logs in a registered user with the nameserver, the user is now actively using CAIRO. |
| LF | Forum Name | | | Logs in a registered forum with the nameserver, the forum is now actively using CAIRO. |
| OU | User Name | | | Logs out a registered user from the nameserver, the user is no longer actively using CAIRO. |
| OF | Forum Name | | | Logs out a registered forum from the nameserver, the forum is no longer actively using CAIRO. |
| GU | Machine | Port | | Request List of all Active users from the Nameserver. |
| GF | Machine | Port | | Request List of all Active forums from the Nameserver. |
| FU | Search Name | Machine | Port | Request machine and port number of the user Search Name from the Nameserver. |
| FF | Search Name | Machine | Port | Request machine and port number of the forum Search Name from the Nameserver. |
| HU | UserName | | | Ping reply from a user. |
| HF | ForumName | | | Ping reply from a forum server. |

Table B.5: Collaboration Manager Output Messages

| Prefix | ARG1 | ARG2 | ARG3 | Comment |
|---|---|---|---|---|
| M? | Frame # | SEQ #, Time | Data | Transmits messages to another participant's media drivers where ?=T,D,A and T = Text Media Driver, D = Whiteboard Media Driver and A=Audio Media Driver |
| RU | User Name | Machine | Port | Registers the user with the nameserver. |
| DU | User Name | Machine | Port | Requests removal of a user from the nameserver. |
| LU | User Name | | | Logs in a registered user with the nameserver, the user is now actively using CAIRO. |
| OU | User Name | | | Logs out a registered user from the nameserver, the user is no longer actively using CAIRO. |
| GU | Machine | Port | | Request List of all Active users from the Nameserver. |
| GF | Machine | Port | | Request List of all Active forums from the Nameserver. |
| FU | Search Name | Machine | Port | Request machine and port number of the user Search Name from the Nameserver. |
| FF | Search Name | Machine | Port | Request machine and port number of the forum Search Name from the Nameserver. |
| A | User Name | Machine | Port | Registers a user with the Forum. |
| D | User Name | | | Requests the forum server to removes the collaboration manager from the Forum user list. |
| R | From Name | To Name | Token Type | Request a speech token from the Forum Server. Enforces collaboration control. |
| N | From Name | | | Returns a speech token to the Forum Server once the user has completed his speech. |

Table B.6: Collaboration Manager Input Messages

| Prefix | ARG1 | ARG2 | ARG3 | ARG4 | Comment |
|---|---|---|---|---|---|
| q | | | | | Move to the next step in the demonstration script |
| M? | Frame # | SEQ #, Time | Data | | Receives messages from another participant's media drivers where ?=T,D,A and T = Text Media Driver, D = Whiteboard Media Driver and A=Audio Media Driver |
| FF | Name | Machine | Port | | Sends a forum's complete directory information in response to a Find Forum request to the name server |
| FU | Name | Machine | Port | | Receive a user's complete directory information in response to a Find User request to the name server. |
| GU | User # | Total # | Name | Machine, Port | Receives a list of CAIRO users. |
| GF | Forum # | Total # | Name | Machine, Port | Receives a list of forums that are registered with the name server. |
| UA | User # | Total # | Name | Machine, Port | Receives a list of all active users. |
| UR | User # | Total # | Name | Machine, Port | Receives a list of all pending speakers. |
| AK | Name | Machine | Port | | Acknowledge a user login. |
| RE | Name | Machine | Port | Reference | Refuses a user login and sends a reference e-mail address to request membership in the forum. |
| K | From | To | Expiry | Type | A token is received that allows conversation between the users and the person specified by To. |
| L | From | To | Type | | Forces the collaboration manager to remove the conversation token associated with the (From,To) conversation. |

# Appendix C

# Forum File Format

Line 0:<FORUM NAME> [Name of Forum]

Line 1:[Number of Members]

Line 2:

Line 3:<NAME> [Name of Member1]

Line 4:<MACHINE> [Member1 Machine]

Line 5:<PORT> [Member1 Port]

Line 6:<NUM DRIVER> [Number of Drivers Supported]

Line 7:<DRIVER NAME> [Name of Driver1]

Line 8:<DRIVER NAME> [Name of Driver2]

.

.

.

Line M+1:<MEMBER TYPE> [Type of Member1]

Line M+2:

Line M+3:<NAME> [Name of Member2]

Line M+4:<MACHINE> [Member2 Machine]

Line M+5:<PORT> [Member1 Port]

Line M+6:<NUM DRIVER> [Number of Drivers Supported]

```
Line M+7:<DRIVER NAME> [Name of Driver1]

Line M+8:<DRIVER NAME> [Name of Driver2]

    .

    .

    .

Line   N:<FORUM TYPE> [Type of Forum]

Line N+1:<CHAIRMAN> [Name of Chairman]

Line N+3:<SPEECH DURATION> [Max. Speech Duration]

Line N+4:<INTER DURATION> [Max. Interjection Duration]

Line N+5:<NUM SPEAKER> [Max Number of Simultaneous Speakers]

Line N+6:<SIDE CONVERSE> [Side Conversations Allowed?]

Line N+7:<EXT CONVERSE> [External Conversations Allowed?]

Line N+8:<LOG MODE> [Logging Mode]

Line N+9:<LOG FILE> [Name of Forum Log File]

Line N+10:

Line N+11: Any additional parameters to be specified for a Forum ......
```

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