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**Development and Understanding of Automated Capture  
Environments to Support Long-Term Use: Proposal**

**Maria da Graça C. Pimentel  
Gregory D. Abowd**

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**DEVELOPMENT AND UNDERSTANDING OF AUTOMATED CAPTURE  
ENVIRONMENTS TO SUPPORT LONG-TERM USE**

**Acronym: InCA-SERVE**

**Principal Investigator (Brazil — ProTeM-CC/CNPq Proposal)**

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**October 1999**

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### 3 Project Summary

The aim of the proposed research is to integrate flexible hypermedia infrastructures to automated capture environments in order to support long-term use. Previous work by the group at GATECH has aimed at making capture a ubiquitous service at any point in time and over a short period of time. The real use of the infrastructure has created the interesting problem of having too much information available. The objective of the proposed joint research is to find flexible and customizable information access solutions that scale over time, increasing the benefit of captured memories for the human as time passes and more information is captured. Our approach to this problem is to view capture as only one part of the information acquisition process in any given application. We introduce a spiral model for capture that stresses how the capture repository must be viewed as an ever-growing container for activities and knowledge that occurs before, during and after live capture sessions. As the repository grows over time, specialized automated services must be created that add structure by highlighting inter-relationships between the captured experiences and activities that occur outside of capture. Moreover, flexible services for structuring and accessing the information must be provided. Work that involved Abowd and Pimentel demonstrated how the digital media of the captured lecture can serve as an effective anchor for collaborative discussions and Web-based homework assignments — Abowd et al. (1999). The four main activities of the joint research plan are:

1. The definition of a spiral model to describe the research challenges of an automated capture service to support long-term activities.
2. A generic Infrastructure for Capture and Access — InCA. InCA provides not only the framework for a run-time environment to support the capture of many live activities, but also an extensible information model for captured experiences that will be used to link activities occurring during a live session to those that occur outside of the live session, as described by the spiral model.
3. The development of a generic and open infrastructure to Store, Extend, Retrieve, and Visualize Evolutionary information, or to SERVE captured information to humans. The SERVE infrastructure will support specialized services that occur outside of live capture and serve to augment the information contained in a capture repository and to generate automatic associations between related experiences.
4. The continued experimentation within the educational domain as well as the development of expertise in a new domain, distributed collaborative design meetings.

These activities will be split between researchers in the ICMC-USP, Brazil, and researchers in the Future Computing Environments Group at GATECH, U.S.A. These institutions are particularly well positioned to do meaningful research on automated capture environments. The FCE Group, lead by Dr. Gregory Abowd, invented the Classroom 2000 system, the foremost demonstration of a large-scale automated capture environment. The USP Group, with extensive experience in the modeling and design of hypermedia systems, is lead by Dr. Maria da Graça Pimentel, who has worked closely with the FCE Group to extend the capabilities of the Classroom 2000 system over the past year. This collaboration has involved 8 different graduate students, 3 from USP, and will continue at least for the next 15 months, with Dr. Pimentel and another faculty member from USP, Renata P.M. Fortes, working at Georgia Tech. This proposal, if funded, will continue to feed the momentum of this collaborative activity. In terms of the work proposed in this document and its companion proposal submitted by Dr. Abowd to the NSF in the U.S., the FCE Group will be responsible for the development of the InCA framework for developing capture applications for different domains. The group at USP will be responsible for the development of the SERVE infrastructure and will actively participate in the use of the revised Classroom 2000 educational capture system at ICMC-USP. Both groups will collaborate in the development of a new educational capture environment and one to support distributed design meetings. It should be evident from this proposal and the one submitted by Dr. Abowd to NSF that this research could not be carried out at this scale without effective collaboration between these particular partners.

The results of the research applied to the educational domain will benefit directly part of the teaching activities in both USP and GATECH, while the research applied to distributed collaborative design meetings could benefit any other software development teams.

**Duration:** 3 years. **Budget Requested:** R\$ 129,605.28 + US\$ 37,983.33. **Corresponding investment from ICMC-USP (payroll):** R\$ 400,000.00.

## RESUMO

O objetivo da pesquisa proposta é integrar infraestruturas hipermídia flexíveis a ambientes que realizam a captura automática das informações, de maneira a prolongar a vida útil da informação capturada. Trabalhos em andamento no grupo da GATECH têm investigado desafios associados à implementação de ambientes de captura ubíquos, utilizados por aplicações que manipulam informações por períodos de tempo relativamente curtos. Um problema enfrentado por ambientes desse tipo é o oferecimento de serviços quando a quantidade de informações capturadas se torna muito grande. A proposta do trabalho conjunto entre a USP e o GATECH é prover soluções flexíveis e "customizáveis" que sejam escaláveis em termos de tempo e que permitam aumentar o tempo de vida útil da informação capturada — podendo até tornar mais útil a informação capturada à medida em que ela vá se tornando mais antiga. A abordagem utilizada é considerar a captura apenas como um dos processos de aquisição de informação. Introduzimos um modelo espiral para captura que enfatiza que o repositório de informações capturadas deve ser visto como estando em constante crescimento, para acomodar informações produzidas antes, durante e depois de cada sessão de captura. Propomos que serviços automáticos especializados devem ser criados para permitir a adição de novas estruturas que reflitam os relacionamentos existentes entre as informações capturadas durante as sessões de captura e aquelas informações produzidas por atividades que ocorrem fora daquelas sessões. Além disso, serviços flexíveis para a estruturação e o acesso à informação resultante devem ser providos. As quatro atividades principais a serem realizadas no contexto da pesquisa a ser realizada pelos pesquisadores da USP e da GATECH são:

1. A definição do modelo espiral que descreve os desafios associados à implementação de um serviço de captura que suporta atividades de longo-prazo.
2. Uma *Infrastructure for Capture and Access (InCA)* genérica que pode ser especializada para vários domínios. A InCA provê, além de um framework para uma aplicação que suporta a captura de muitas atividades realizadas em sessões "ao vivo", um modelo de informação extensível para a captura de experiências que podem ser utilizado para integrar as atividades que ocorrem fora da sessão de captura, como descrito pelo modelo espiral.
3. O desenvolvimento de uma estrutura genérica para armazenar (Store), estender (Extend), recuperar (Retrieve) e visualizar (Visualize) informação evolucionária (Evolucionária) — ou seja, servir (SERVE) a informação capturada aos usuários da aplicação. A infraestrutura *SERVE* deve suportar serviços especializados oferecidos fora da sessão de captura e servir para estender a informação armazenada.
4. Dar continuidade à aplicação dos serviços implementados no domínio de educação, e a extensão dessa aplicação ao domínio de *distributed collaborative design meetings*.

As atividades serão divididas entre os pesquisadores do ICMC-USP, no Brasil, e do Future Computing Environments (FCE) Group da GATECH, U.S.A. Estas instituições estão bem capacitadas para realização da pesquisa ora proposta. O grupo do Dr. Abowd inventou o sistema Classroom 2000, uma bem sucedida implementação de sistema de captura em ambientes que utilizam computação ubíqua. O grupo da USP possui extensa experiência na modelagem e implementação de sistemas hipermídia. Dra. Maria da Graça Pimentel, que coordena esta proposta junto ao grupo da USP, está realizando um estágio de pós-doutorado junto ao grupo do Dr. Abowd de Outubro de 1998 a Fevereiro de 2000. A colaboração envolveu 8 alunos de pós-graduação, 3 dos quais são da USP, e deve continuar com o estágio de pós-doutorado a ser realizado no FCE-GATECH pela Dra. Renata P.M. Fortes, do ICMC-USP, por 12 meses a partir de janeiro de 2000.

De acordo com o trabalho proposto neste plano, e no plano correspondente apresentado pelo Dr. Abowd junto ao NSF, o grupo do FCE será responsável pelo desenvolvimento do InCA framework e o grupo da USP será responsável pelo desenvolvimento da *SERVE* infrastructure. Além disso, eles irão colaborar na desenvolvimento de uma nova versão do Classroom 2000 e um versão que suporte a captura de reuniões de projeto, as quais utilizem as infraestruturas construídas. Deve-se notar que o trabalho aqui proposto não poderia ser realizado nesta escala sem a efetiva colaboração dos dois grupos envolvidos. A nova versão do sistema Classroom 2000 poderá ser diretamente aproveitada em atividades de ensino da USP e do GATECH. O ambiente de captura de reuniões de projeto, além de utilizado pelo próprios grupos, também o poderá ser por outros grupos envolvidos na construção de software.

**Duração:** 3 anos. **Orçamento pleiteado:** R\$ 129,605.28 + US\$ 37.983.33. **Contrapartida do ICMC-USP** (salários): R\$ 400,000.00.

## 4 The Research Groups

The overall research will involve researchers from the ICMC-USP, Brazil, and researchers from the Future Computing Environments (FCE) Group at GATECH, U.S.A. The USP group is formed by Dr. Maria da Graça Pimentel (Assistant Prof.), Dr. Renata Fortes (Assistant Prof.) and Dr. Edson Moreira (Associate Prof.). Dr. Gregory Abowd (Assistant Prof.) is the principal investigator from Georgia Tech. These institutions are particularly well-positioned to do meaningful research on automated capture environments. The FCE Group, lead by Dr. Gregory Abowd, invented the Classroom 2000 system, the foremost demonstration of a large-scale automated capture environment. The USP Group, with extensive experience in the modeling and design of hypermedia systems, is lead by Dr. Maria da Graça Pimentel, who has worked closely with the FCE Group to extend the capabilities of the Classroom 2000 system over the past year.

### 4.1 Universidade de São Paulo

Dr. Pimentel is an Assistant Professor in the Departamento de Ciências de Computação e Estatística — ICMC-USP, where she has been working for eleven years. Her research interests involve issues associated to building distributed hypermedia systems in general, and those suited to be used in the World Wide Web in particular. Dr. Pimentel received the degree of B.S. in Computer Science in 1986 from the Universidade Federal de São Carlos, the degree of M.Sc. in Computer Science in 1989 from the Universidade de São Paulo, and the degree of Ph.D. in Computer Science in 1994 from the University of Kent at Canterbury - England (funded by CAPES-Brazil). Dr. Pimentel is a Visiting Scientist at the College of Computing at GATECH from October 1998 to February 2000, funded by FAPESP-Brazil.

Pimentel's previous work includes the modeling of tools for supporting the authoring, presentation and database storage of structured teaching material in the WWW, as well as their use in a collaborative environment (Pimentel, Kutova & Teixeira 1999) (Pimentel, Santos & Fortes 1998a,b) (Pimentel, Kutova, Macedo & Teixeira 1998). Dr. Pimentel has been developing research in hypertext systems both in terms of distributed hypermedia (Pimentel et al. 1997) (Macedo, Pimentel & Fortes 1999) and hyperdocument modeling (Pimentel, Scott & Teixeira 1998) (Scott & Pimentel 1999a,b). Work on the user-hypertext interaction area has also been developed, e.g. (Pimentel 1994) (Pimentel & Buford 1996) (Pimentel & Hagui 1996). Her work with graduate students has resulted in the development of prototypes to make complex hypertext structures available in the WWW environment (Trindade & Pimentel 97) (Pimentel, Baldochi, Fagundes & Teixeira 98). These results were part of an important participation of the candidate in two CNPq ProTeM-CC fase 2 Projects (HyperProp and SMmD). Three of her graduate students in the Master's Program at the ICMC-USP were involved in projects related to this proposal (Pires 98, Macedo 99, Kutova 99). Moreover, three of her Masters students spent a Summer Internship at Georgia Tech in 1999: Alessandra A. Macedo (3 months), Daniel F. Pires (2 months) and Fúlvio P. Parmejani (1 month). The researcher was a member of the organizing committee of two of the Brazilian Workshops on Hypermedia and Multimedia Systems (95 and 97) — she was the general chair in the third edition held in São Carlos in 1997. She was a member of the program committee of all five editions of this event which, in 1998 and 1999, were full conferences sponsored by the Brazilian Computing Society.

Dr. Fortes is an Assistant Professor in the Departamento de Ciências de Computação e Estatística - ICMC-USP, where she has been working since 1987. The main research interests includes the application of techniques and methods from Software Engineering in order to support the building and evaluations of hypermedia applications in the World Wide Web. Dr. Fortes work involves aspects of modeling and formalization of hypermedia structures (Fortes 1997) (Fortes & Nicoletti 1997a,b) as well as the modeling and implementation of hypermedia applications (Pimentel et al. 1998a,b) (Macedo et al. 1999). Dr. Fortes received the degree of B.S. in Computer Science in 1982 from the Universidade de São Paulo, the degree of M.Sc. in Computer Science in 1991 from the Universidade de São Paulo, and the degree of Ph.D. in Applied Science in 1996 from the Universidade de São Paulo. Dr. Fortes plans to be a Visiting Scientist at the College of Computing at GATECH from during 2000.

Dr. Moreira is an Associate Professor in the Departamento de Ciências de Computação e Estatística - ICMC-USP where he has been working since 1984. Dr. Moreira received the degree of B.S. in Electronic Engineer in 1982 from the Universidade de São Paulo, the degree of M.Sc. in Applied Science in 1991 from the Universidade de São Paulo, and the degree of Ph.D. in Computer Science in 1996 from the University of Manchester-UK. His interests are in the area of computer networks and distributed systems in general, and in the support to audio and video in particular (Soto et al 1999). His work deals both with the storage and processing of multimedia information (Moreira et al. 1995a,b) (Moreira et al. 1997)

(Hachisuca et al. 1998) and with the development of applications to exploit the infrastructure provided (Castro et al. 1998) (Goulart et al. 1998).

## 4.2 Georgia Institute of Technology

Dr. Abowd received the degree of B.S. in Mathematics and Physics in 1986 from the University of Notre Dame. He then attended the University of Oxford in the United Kingdom on a Rhodes Scholarship, earning the degrees of M.Sc. (1987) and D.Phil. (1991) in Computation from the Programming Research Group in the Computing Laboratory. From 1989-1992 he was a Research Associate/Post-doc with the Human-Computer Interaction Group in the Department of Computer Science at the University of York in England. From 1992-1994, he was a Postdoctoral Research Associate with the Software Engineering Institute and the Computer Science Department at Carnegie Mellon University.

Dr. Abowd's interests lie in the intersection between Software Engineering and Human-Computer Interaction. Specifically, Dr. Abowd is interested in the application of formal methods from Software Engineering to the design and analysis of interactive systems. Dr. Abowd's group is investigating the use of the Classroom 2000 by teachers and learners in a university environment. The research involves studying the impact of this use on the multimedia environment supported (Abowd 1999, Abowd et al. 1998), and to which extend the environment itself can be used as a seamless authoring tool (Abowd et al. 1996) (Abowd et al. 1997a). As a result, many issues regarding multimedia synchronization and presentation have been identified (Brotherton, Bhalodia & Abowd 1998). Moreover, the group has also addressed these challenges by using simple but effective techniques that approximate intelligence (Brotherton & Abowd 1998).

In the context of the Future Computing Environments Project, Dr. Abowd's research group has been also investigating the issues related to the development of software to support collaborative work in context-aware environments (Abowd et al. 1997b) (Dey, Abowd & Wood 1999) (Abowd & Mynatt 1999).

## 4.3 Ongoing Collaboration

Dr. Abowd and Dr. Pimentel have been collaborators on applications of automated capture services to the educational domain for the past year. Dr. Pimentel is the recipient of a 16-month fellowship from FAPESP-Brazil that began in October 1998 and she is spending her fellowship at Georgia Tech working with Dr. Abowd on the Classroom 2000 project. Their work has already resulted in one conference publication and several submitted journal and conference papers that are currently under review.

This collaboration has involved 8 different graduate students, including 3 from USP, and will continue at least for the next 15 months, with Dr. Pimentel and another faculty member from USP, Dr. Renata P.M. Fortes, as Visiting Scientists at Georgia Tech. This proposal, if funded, will continue to feed the momentum of this collaborative activity.

## 4.4 Other Current Funding Resources

Dr. Pimentel has a Post-Doc grant from FAPESP (PD) from October 1998 to February 2000, and a graduate grant from FAPESP (MSc) for Daniel F. Pires, from May 1998 to April 2000.

Dr. Fortes has a graduate grant from FAPESP (MSc) for June 1999 to May 2001 for Elisandra Aparecida Alves da Silva, and has applied for a Post-Doc grant from FAPESP from January 2000 to January 2001.

Dr. Moreira has two DSc graduate grants (FAPESP for Rudnei Goulart and UNIFENAS for João B. Santos Jr.) from 1999 to 2001. He is a collaborator with the Projeto PRONEX (FINEP): Integração da Manufatura (1997/1999). He is the ICMC-USP local Coordinator of the Projeto Infra-estrutura de Pesquisa: Rede Metropolitana de Alta Velocidade para Integração de Grupos de Pesquisa em Ensino à Distância, Redes de Computadores e Hipermidia Distribuída - FAPESP 1997/1999

## 5 Objectives

Authoring meaningful and useful multimedia documents — those that present effective integration between several media components — is a hard and expensive task. One approach to ease multimedia authoring is to process media streams in order to generate an associated multimedia document. Work reported in the literature has investigated problems associated to supporting the automatic generation of documents from existing streams. Chua and Ruan (1995) discuss a semi-automatic video processing system that includes support to indexing and retrieving the original presentation. Shahraray and Gibbon (1995) present a system that produces structuring and synchronization information from an original presentation by exploiting its associated closed-caption text and underlying structure. Similarly, Amir et al. (1999) report on the automatic production of summaries and indexes from an original video presentation. In such cases, the resulting information can be seen as a semi-automatically generated multimedia document.

Another approach is to instrument an environment so that live experiences can themselves be used to author multimedia records of those experiences. This approach assumes that the everyday experiences are rich in information which, if captured and made available as multimedia documents, may provide a valuable source of information. It also assumes that humans need support in capturing the salient memories from live experiences that they can then call upon at a later time. There are many situations in our everyday lives that satisfy both of these criteria.

One possible environment is the classroom. The GATECH group has spent the past four years developing tools and environments to automate the capture of live lectures to support the teaching and learning experience (Abowd 1999, Abowd et al. 1998, Brotherton et al. 1998, Abowd et al. 1996). The Classroom 2000 project exploits ubiquitous computing technology — electronic whiteboards, large projected displays, networked computers, and streaming digital audio/video — to create a room that automatically captures much of the rich detail of a lecture experience and provides effective multimedia-enhanced Web-based interfaces for both students and teachers to review the lecture. The result is twofold: the student is free to take on a different, more enriching role in the classroom while the instructor is provided with a tool to generate Web-based material at almost no cost (<http://www.cc.gatech.edu/fce/c2000>).

In the context of the Classroom 2000 project, evaluations have shown that over the course of an entire term, there is a clear value added for students in gaining access to captured lectures. They report being able to pay better attention during lecture, having less of an obligation to take stenographer-style notes, and generally being better able to learn effectively in classes that provide the automated capture service. Students have also indicated a desire to access captured classroom lectures in the future, after they have completed a given course. Logged access patterns reveal that within one calendar year more than half of the accesses to captured lectures have occurred outside of the term in which the lecture was given, indicating that long-term access is an important consideration in designing useful capture systems.

Leveraging off the positive experience with the Classroom 2000 project, the work in this proposal aims to address several important open problems in the area of automated capture environments:

- We wish to develop a better software infrastructure for capture and access that can be specialized for various domains. This includes a scalable infrastructure to support the capture of information in ubiquitous computing environments and an extensible information model for the captured data that can be applied to different domains.
- We must develop services that support the human activities that occur before, during and after captured experiences, for short-, medium- and long-term benefits.
- We will continue and increase our focus on developing living laboratories for long-term evaluation of the impact of automated capture, so as to demonstrate the value of this research methodology for ubiquitous computing research.

The aim of the proposed research is to integrate flexible hypermedia infrastructures to automated capture environments in order to support long-term use. Previous work by the group at GATECH has aimed at making capture a ubiquitous service at any point in time and over a short period of time. The real use of the infrastructure has created the interesting problem of having too much information available. The objective of the proposed joint research is to find flexible and customizable information access solutions that scale over time, increasing the benefit of captured memories for the human as time passes and more information is captured. Our approach to this problem is to view capture services as only one part of the information acquisition process in any given application. We introduce a spiral model for capture services that stresses how the capture repository must be viewed as an ever-growing container for activities and

knowledge that occurs before, during and after live capture sessions. As the repository grows over time, specialized automated services must be created that add structure by highlighting inter-relationships between the captured experiences and activities that occur outside of capture. Moreover, flexible services for structuring and accessing the information must be provided. Work that involved Abowd and Pimentel demonstrated how the digital media of a captured lecture can serve as an effective anchor for collaborative discussions and Web-based homework assignments — Abowd et al. (1999). In this proposal we will outline the four main activities of the joint research plan:

1. The definition of a spiral model to describe the research challenges of an automated capture service to support long-term activities.
2. A generic Infrastructure for Capture and Access — InCA. InCA provides not only the framework for a run-time environment to support the capture of many live activities, but also an extensible information model for captured experiences that will be used to link activities occurring during a live session to those that occur outside of the live session, as described by the spiral model.
3. The development of a generic and open infrastructure to Store, Extend, Retrieve, and Visualize Evolutionary information, or to SERVE captured information to humans. The SERVE infrastructure will support specialized services that occur outside of live capture and serve to augment the information contained in a capture repository and to generate automatic associations between related experiences.
4. The continued experimentation within the educational domain as well as the development of expertise in a new domain, distributed collaborative design meetings.

Since the time of Vannevar Bush (Bush, 1945), we have dreamed of being able to incorporate more of our physical everyday experiences into our electronic worlds in such a way that memories are not lost. This proposal is aiming to build a slice of that dream for two specific domains — education and software design teams.

Using the distributed nature of collaboration between the research teams in the U.S. and Brazil as a testing ground for the software design is another important example of building a living laboratory for ubiquitous computing research. Mark Weiser observed that the whole purpose of ubiquitous computing research is to support applications for human use of technology (Weiser, 1991). We are adding another maxim through demonstration — the only way to do valid ubiquitous computing research is to subject large-scale systems to extended and actual use. In the tradition of experimental research inspired by the success of the Classroom 2000 project — in which a capture system is built and then used and evaluated extensively by the researchers to support their everyday activities — the continued collaboration of FCE-GATECH and ICMC-USP will serve as one subject for our long-term capture experiments.

The FCE Group will develop the InCA framework for developing capture applications for different domains. The USP Group will develop the SERVE infrastructure that, interfacing with InCA, will support the development of flexible and customizable capture-based hypermedia long-term applications. Both groups will cooperate to develop a new educational capture environment and one to support distributed design meetings. The results of the research and its evaluation will be reported in appropriated Conferences and Journals.

The results of the research applied to the educational domain will benefit directly part of the teaching activities in both USP and GATECH, while the research applied to distributed collaborative design meetings could benefit any other software development teams.

It should be evident from this proposal and the one submitted by Dr. Abowd to NSF that this research could not be carried out at this scale without effective collaboration between these particular partners.

## 6 Research Issues and Planned Activities

The aim of the proposed research is to integrate flexible hypermedia infrastructures to automated capture environments in order to support long-term use. Previous work by GATECH group has aimed at making capture a ubiquitous service available at any point in time and over a short period of time (see section 6.1.2 on the Classroom 2000 project). The everyday use of the infrastructure has created the interesting problem of having too much information available. The objective of the proposed joint research is to find flexible and customizable information access solutions that scale over time, increasing the benefit of captured memories for the human as time passes and more information is captured. Our approach to this problem is to view capture as only one part of the information acquisition process in any given application. We introduce a spiral model for capture that stresses how the capture repository must be viewed as an ever-growing container for activities and knowledge that accrues before, during and after live capture sessions. As the repository grows over time, specialized automated services must be created that add structure by highlighting inter-relationships between the captured experiences and activities that occur outside of capture.

Our objective is to find solutions that scale over time in the educational domain and in a software engineering domain. This entails:

- understanding how groups who have live or synchronous meetings can benefit from this support so as to model the processes associated with information and knowledge generation in these groups;
- establishing a framework to guide the development of the proper software infrastructure to automate the generation of this information and knowledge augmentation support.

In order to focus our research, we will exploit our own background and other state-of-the-art related work. Specifically, we detail next the following planned activities:

1. The definition of a spiral model to describe the research challenges of an automated capture service to support long-term activities.
2. A generic Infrastructure for Capture and Access — InCA. InCA provides not only the framework for a run-time environment to support the capture of many live activities, but also an extensible information model for captured experiences that will be used to link activities occurring during a live session to those that occur outside of the live session, as described by the spiral model.
3. The development of a generic and open infrastructure to Store, Extend, Retrieve, and Visualize Evolutionary information, or to SERVE captured information to humans. The SERVE infrastructure will support specialized services that occur outside of live capture and serve to augment the information contained in a capture repository and to generate automatic associations between related experiences.
4. The continued experimentation within the educational domain as well as the development of expertise in a new domain, distributed collaborative design meetings.

### 6.1 Modeling Evolutionary Multimedia Derived from Captured Experiences

#### 6.1.1 A spiral model of the generation of evolutionary multimedia information

When a group of people have cause to meet on a regular basis, we argue that over an extended period of time, captured information from those live meetings may be important both on a short- and long-term basis. Moreover, many activities carried out before, during and after the regular meetings gain significance over time. Consider the classroom:

- Users (or students and teachers) meet regularly in live sessions
- The course usually runs for a certain period, or term, during which live lectures are presented on a regular basis, such as twice a week.
- From the instructors' perspective, many tasks have to be performed — preparing lectures, assignments and examinations, reviewing and assessing student work.
- Students are also engaged in many tasks — reading, participating in class discussions, completing assigned personal or group work, studying and taking exams.

In this context, the live meeting is the lecture itself. During the meeting, the instructor's activities include delivering the prepared presentation and holding discussions with students, while the students' tasks

include reflecting upon the contents presented by the instructor and participating in the discussion. In the timeframe of the application—in this case the course—users work on related tasks and are likely to interact with each other in order to clarify and evolve the understanding and joint knowledge first discussed in the live lectures.

The many associated activities associated with one course (lectures, homework, projects, exams, discussions and more) generate material that is in some way relevant to the educational goals of the course. These artifacts are all produced at different times, but can all be seen as anchored off the main activity of the group (instructor and students), that is, the live lecture. This educational experience or application is just one example of a group setting in which regular meetings occur over an extended period of time and serve as a focus point for gathering knowledge from a wide variety of activities of the individuals of the group. Another example would be a design group involved in developing some software artifact with regular status meetings of the whole group and various other meetings of subgroups of designers, both planned and unplanned.

The important point for any of these applications is that, in the timeframe between the regular meetings, many authoring and presentation tasks have to be performed by the users. This scenario illustrates the following features associated to the body of material generated within the context of these applications:

*Active growth:* The amount of associated material expands continuously throughout the timeframe of the application, as a result of the contribution of all participants, and these contributions occur before, during and after any live group session.

*Intrinsic referencing:* At any given point in time the information being discussed may refer to portions of material discussed at any previous time in the context of the application itself.

These characteristics explain why it is a challenge for users to keep up with the amount of information created by the group, which makes it difficult to process the information and store it for later retrieval. An automated capture system that is used as a multimedia authoring system can be exploited in these situations. The repository of captured information can be viewed as evolving over time, ever expanding as a spiral from its central origin, continuously creating new knowledge that can refer to any previously captured knowledge.

We now assume the general context of group situations which involve live or synchronous sessions—such as a live session, where the delivery of the prepared material generates information that is augmented by design meetings and presentations. Using a live session as a landmark in the context of group's activities, information can be categorized as to whether it is generated before, during or after a given live session. As time passes, a spiral of the underlying information is produced as follows:

- Before a live session, material is produced as a result of the activities of preparing for the session itself, such as preparing an agenda or formal presentation to be used during the session.
- During a live session, additional material produced as a result of the associated tasks.
- After a live session, users produce additional material as a result of the tasks defined during the session.

Each traversal of the spiral represents the activities associated with the information produced in three distinct but complementary phases: before, during and after a single live session. As each new session occurs, the body of information continues to grow. In addition, since many sessions build up information based on previously generated material, the repository of information generated by the users in the context of the application becomes more and more interrelated, with new information being built upon previous material.

The spiral concept is able to capture those two important features of the body of information being generated, active growth and intrinsic referencing. The active growth is indicated by the expansion of the spiral that, at each turn, covers a larger space reflecting the amount of information produced, and by the concentric organization of each turn of the spiral, reflecting that the information produced in each turn builds up over the previous existing information. The intrinsic referencing is illustrated by spiral traversing the three phases while expanding, therefore allowing the newly generated information to reference material produced "inside" at any prior time, independent of the activity that generated it.

### 6.1.2 The Classroom 2000 Project

The Classroom 2000 is an environment that exploits (Abowd et al., 1998; Brotherton, Abowd & Bhalodia, 1998; Abowd, 1999a):

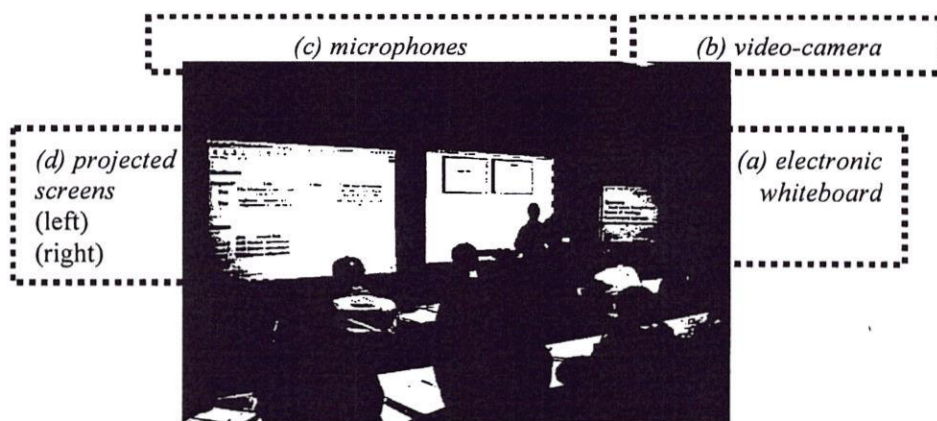
- Ubiquitous computing technology — electronic whiteboards, large projected displays, networked computers, streaming digital audio/video and appropriate software — in order to create a room that automatically captures much of the rich detail of a lecture experience.
- The Web as a platform to provide access interfaces for students and teachers to review the lecture as captured.

Given its application domain, the aim of the project is to allow students to take on a more active and enriching role in the classroom by capturing details of the session and making them widely available. Since accurate details are made available, students are free from taking detailed notes and have more time to create their own personalized notes and actively participate in the classroom. In this section we describe the infrastructure built by the group at GATECH.

### 6.1.2.1 Capturing classroom experiences

The Classroom 2000 software infrastructure has been used to support activities in several classrooms and meeting rooms presenting varied hardware infrastructure. The most comprehensive hardware installation is found in the original prototype classroom, presented in Figure 1 and in operation since January 1997. In this room, the hardware infrastructure includes an electronic whiteboard, two ceiling-mounted projectors, one camera and several microphones embedded in the ceiling, all operating in unison through a suite of networked computers.

The supporting software infrastructure, referred to as the Zen\* system, is a set of client/server modules that perform the tasks of capturing and synchronizing streams of information during each live session. These tasks include controlling the capture of the media streams (audio and video) and orchestrating the generation of the associated multimedia document when the session is finished. As a result, a few minutes after the instructor concludes a lecture, a multimedia-enhanced web document has been automatically authored and is available to students. We describe this document next.



**Figure 1:** The Classroom 2000 classroom provides automated capture of the information written or presented on the (a) electronic whiteboard, captured by a (b) video-camera in the back of the room and by (c) microphones embedded in the ceiling, as well as web navigation activities projected on screens (d-left). The information captured from the whiteboard can be accessed in real-time by any (remote or not) computer; in the classroom this is used for presenting several slides worth of information on a projected screen (d-right).

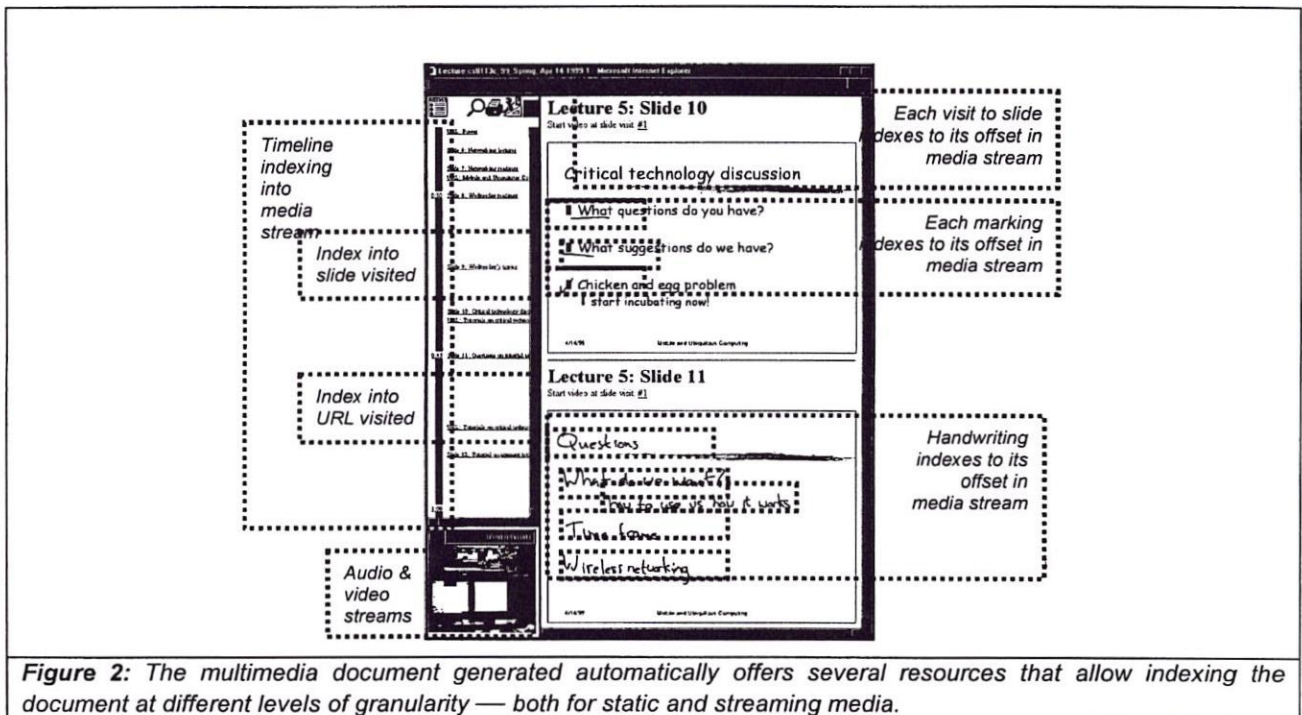
### 6.1.2.2 Automatically generating a multimedia-enhanced Web document for each session

The document presented in Figure 2 is an annotated sample of the multimedia documents automatically generated after the capture of a live session with the Classroom 2000 infrastructure. The frame on the right hand-side presents the lecture as a sequence of discrete slides as presented or created during the lecture. In this particular case the instructor used prepared slides. When a lecture does not use prepared slides, the instructor writes on a blank screen and generates as many slides as needed — each slide being associated to one screen's worth of information. The system provides different interfaces that allow accessing a given lecture with audio or video augmentation combined with single or multiple slides in a way that can accommodate either a fast or slow network connections. The streaming media — audio and video — is presented within a frame embedded on the bottom left-corner of the overall window, as shown in Figure 2, or as an external window.

The lecture is recorded as a single audio or video stream, and the access interface allows a student a number of ways to index into that continuous stream at various significant points in the lecture. The

simplest thing to do for a student is to begin playback of the lecture at the very beginning. However, there are often times when a student wants more random access to the lecture and the document provides a number of ways to index into other significant parts of the lecture. On top of each slide in Figure 2, there is a link into the continuous audio or video media corresponding to each time the slide was visited during the session, providing a slide-level granularity into the associated audio or video recording of the lecture, played back as a RealNetworks™ stream. An instructor can spend a long time presenting a single slide, and sometimes the student may want to jump directly to the discussion in the middle of a slide. The black timeline along the left edge allows the student to index into the audio or video in 20-30 second intervals. Decorations alongside the black timeline indicate what kind of activity was going on in the class at that time, such as a new slide or Web page being visited, and these provide cues to help a student pinpoint a specific segment of the lecture. Finally, the electronic ink —handwriting, drawing or markings created by the instructor on the electronic whiteboard during the lecture— is sensitive. Clicking on the ink will launch the audio or video at the point in the lecture when the instructor wrote that annotation.

As described above, the timeline is also decorated on its right-hand side with relevant activity as it happened during the lecture, either a new slide being visited on the electronic whiteboard or a Web page being visited on a separate display inside the classroom. Selecting the link corresponding to a visit to a Web page in the timeline causes the corresponding Web page to be presented in a separate new window; selecting the link corresponding to a visit to a slide causes the frame on the right to focus on that slide. In this timeline, visits to the slides and Web pages are marked with their title, when that information is known.



**Figure 2:** The multimedia document generated automatically offers several resources that allow indexing the document at different levels of granularity — both for static and streaming media.

### 6.1.2.3 Use of the Classroom 2000 infrastructure to support meetings

The Classroom 2000 infrastructure has been used in a regular basis to support weekly meetings of two FCE-GATECH groups. For the most part, these meetings are synchronous and collocated: the groups meet in a room equipped with an electronic whiteboard and projector attached to a single computer. A computer is used to run a Zen\* client (that presents prepared slides and capture handwriting and other session information) as well as capturing audio and allowing Web navigation. However, in a number of occasions the environment has been used in two distinct types of distributed meetings. In one type, participants from other universities (e.g., Brown University and Carnegie Mellon University in the U.S and McGill in Canada) have joined the meeting by running a program that allows them to see the same information presented in the electronic whiteboard in the meeting room at GATECH. In the other case, the group in the meeting room could see the information as shown by a remote presenter in his or hers own whiteboard. In both cases, the participants held an audio conference with professional full-duplex speakerphones attached to standard telephone lines.

### 6.1.3 Related Work

Though there has been a lot of research activity in the area of automated capture (see Abowd & Mynatt 1999 for a review), there has been no reported work that attempts to extend the use of capture beyond the

short-term. For example, the seminal work on the Tivoli system at Xerox PARC (Minneman et al. 1995 and Moran et al. 1997) was only used to support a single scribe summarizing the results of a single technical meeting. Though the system was used over an extensive period of time, its use only reflected very short-term needs. A capture system developed at Microsoft Research (Barger et al. 1998; White et al. 1998) attempts to provide support for annotations of captured presentations during and after the live event, but does not try to incorporate activities or comments that occur before the presentation. They also do not address implicit linking between different presentations.

A more comprehensive approach has been taken in the design of DOLPHIN, a groupware application designed to support co-located or distributed meetings (Streitz et al. 1994). The capture session allows users to extend a prepared agenda and to record handwritten information that, as in Tivoli, could be manipulated during the meeting by editing operations that included gesture recognition. Support to integrating information produced before the sessions is done by allowing the users to import text, images as well as prepared hypermedia information. Support to integrating information produced after the sessions is done by allowing the captured contents to be imported to a collaborative hypermedia system (Haake et al. 1994). Although providing potential support for activities before, during and after the capture session, the authors report only on short-term use of infrastructure.

Our own experience in Classroom 2000 comes closest to supporting long-term activities both inside and outside of the live experience. The Classroom 2000 system provides a primitive searching function across all captured lectures that students have found effective for pinpointing related parts of the same course and that teachers have used to find relevant portions of lectures taught previously by other instructors. Work that involved Abowd and Pimentel demonstrated how the digital media of the captured lecture can serve as an effective anchor for collaborative discussions and Web-based homework assignments (Abowd et al. 1999). But our own efforts are limited because they do not effectively allow the addition of relevant links between student and teacher notes and between current material and previous material. We also have scoped the "application" in terms of a single course, consisting of 20-30 lectures. The appropriate application has a much longer timeline, extending at least as far as an undergraduate career and probably longer.

#### **6.1.4 Planned Work**

To overcome the shortcomings of prior work in automated capture, we have to develop a software infrastructure and extensible information model. The first two activities to be carried out in the context of this plan, detailed in Table 1 in section 6.5, are:

- #1. Definition of a Spiral Model of Evolutionary Hypermedia/Multimedia Information
- #2. Definition of a Spiral Framework for applications exploiting InCA/SERVE infrastructures

Activity #1 will be carried out by both groups, involving particularly Dr. Pimentel, Dr. Abowd and Dr. Fortes. Dr. Pimentel will be in charge of leading a paper that describes the resulting model. Activity #2 will also be carried out by both groups, involving particularly Dr. Abowd and Dr. Pimentel. Dr. Abowd will be in charge of leading a paper that formalizes the InCA infrastructure, Dr. Pimentel will present the formalization of the SERVE infrastructure.

The InCA and SERVE infrastructures will be created as Application Programming Interfaces (APIs) in three levels — basic, intermediate or advanced. In each level the APIs will provide services that will emphasize support to evolutionary information — the services will support the growth and intrinsic referencing of information produced before, during and after the capture session.

## **6.2 An Infrastructure for Capture and Access (InCA)**

Our challenge is to create an information environment to support the spiral model of evolutionary multimedia. We need to provide a powerful and seamless environment for capturing multimedia information and turning it into meaningful documents, as well as providing interfaces that accurately reflect the change in material and the relationships between them.

### **6.2.1 Requirements for InCA**

Some of the requirements for this Infrastructure for Capture and Access (InCA) include:

- Multiple streams of information must be captured during the live sessions. We currently capture an electronic whiteboard for presentations, Web pages and audio and video of the entire group. We have experimented with distributed capture in the classroom, enabling students to personalize the lecture experience with their own notes (Truong & Abowd 1999; Truong, Abowd & Brotherton 1999). Our

current infrastructure does not scale appropriately to support this level of simultaneous capture, so we must redesign the client-server infrastructure. As we do this, we will generalize the capabilities to be able to capture a much greater number and variety of activity streams.

- To support implicit linking back to previous material, we need to define an extensible information model. The InCA system must define an API to support this information model. We have defined a preliminary information model for classroom lecture material, but this must be modified to allow for linking at different levels of granularity (references to a whole course, a lecture within a course, a particular live segment within a lecture, or to some other artifact produced outside of lecture). This information model will be defined as an XML data type definition, allowing InCA to define views of the data accessible through modern Web browsers. These access view present a visualization problem in and of themselves, which we address briefly below.
- Annotations to the capture repository can be made by any of a number of individuals and at many levels of granularity, as described above. However, we must also provide for annotations to refer to material outside of the repository itself. For example, captured lectures may provide links automatically to associated readings in a textbook or relevant Web pages. If these associations occur as part of the natural course of the live experience (such as Web browsing during a lecture), then they will be included as part of the capture repository. Otherwise, we will have to allow for them to be added as links to an external source. This is precisely the approach we took when associating segments of captured lectures as anchors for collaborative discussion spaces (Abowd et al. 1999).
- Annotations are a case of needing to capture activity that occurs outside of the synchronous and live experience. Many have noted the need for supporting this so-called modification during access problem for automated capture environments, but no system supports it as yet. The general InCA framework is intended to provide direct support for this type of modification as annotation of past captured material.
- At least in the educational domain, we see the need for captured material to be part of a reusable repository. For instance, teachers using Classroom 2000 have made use of previously captured lectures to prepare their future lectures. This simple example of reuse can be extended to the point at which the development and sharing of educational material is similar to the open source software development effort in which many people contribute to the development of a complex and robust software artifact.

### 6.2.2 Planned Work: physical installations

The InCA infrastructure will be validated through application to at least two very different domains — education and collaborative design. This demands that appropriate infrastructure in terms of equipment and physical installations exist in both institutions, as specified in Table 1.

#3. Implementation of classroom infrastructure for capturing multimedia documents using InCA

#4. Implementation of infrastructure for capturing multimedia documents for FCE/ICMC design team rationale capture using InCA

Activities #3 and #4 will be carried out by the group at ICMC-USP, where Dr. Moreira will be in charge of the supervising the installation of the necessary hardware infrastructure while Dr. Pimentel will manage the installation of the software. As far the software is concerned, all the infrastructure already developed at GATECH (including the work by Dr. Pimentel) will be made available at USP. Activity #3 will also be carried out by GATECH, and Dr. Abowd will be leading the task of setting up the already existing meeting environment to work collaboratively with the environment at ICMC-USP.

### 6.2.3 Planned Work: development of InCA

The development of the InCA framework will be the responsibility of the Georgia Tech researchers, and correspond to the following activities listed in Table 1:

#5. Definition of a basic API for capturing information — year 1

#6. Definition of a basic API for accessing information — year 1

#18. Definition of intermediate API for capturing information — year 2

#19. Definition of intermediate API for accessing information — year 2

#28. Definition of intermediate API for capturing information — year 3

#29. Definition of intermediate API for accessing information — year 3

Both groups will carry out all the design, implementation and evaluation of the overall system, including the InCA infrastructure, using an evolutionary approach in 3 phases: basic, intermediate and advanced —

where each phase will be completed in one year. This will allow us to tackle requirements with different complexity in separate levels, and to make the necessary adjustments in terms of research issues that will rise from the evaluation experiences.

Dr. Abowd will be supervising one graduate student that will be in charge of implementing InCA. Dr. Abowd will be in charge of leading a paper that describes research issues tackled during the implementation of the InCA infrastructure as a whole.

Satisfying these requirements for InCA will lead to the development of capture repositories that better support long-term group activities. InCA relies on an extensible, application-specific information model. The services associated with such an information model are the subject of another aspect of this collaborative research proposal: the SERVE infrastructure detailed next.

### **6.3 Developing Specialized Services to Support Long-Term Capture: SERVE**

There are many services that can be defined to enhance the usefulness of a large repository of captured experiences. In this part of the proposed research, we aim to define a generic and open infrastructure to Store, Extend, Retrieve and Visualize Evolutionary information. In short, we aim to SERVE information to groups of individuals to cater to their long-term needs. Therefore, it is a requirement that the SERVE infrastructure support the spiral model in general and the before and after capture phase in particular.

The work on developing the SERVE infrastructure will be done in Brazil by the group led by Dr. Pimentel, who has already developed some useful visualization and retrieval systems for Classroom 2000. SERVE will support specialized services that occur outside of live capture and serve to augment the information contained in a capture repository and to generate automatic associations between related experiences.

Information storage refers to an open definition of the content of information primarily captured in live sessions. Using definitions in an emerging standard representation language such as XML will enable us to extend the information model over time and still retain the ability to view information in browsing environments that all users will possess. Retrieval mechanisms include simple keyword search to more sophisticated information retrieval techniques and automatic associations between parts of a captured repository. We have already experimented with such automated linking in classes that have many content streams captured as well as external collaborative discussion spaces and we have found that automated techniques can create relevant links that humans don't already create manually. Another effective technique to retrieving relevant information is to provide adequate visualization techniques so that humans can see patterns of interest that might otherwise go undetected. For instance, it might be hard to search and present summary information about a collection of topics covered during 30 lectures of an introductory software engineering course. However, the same course can be visualized in a fairly small space and decorated with information to allow the user to find out what parts of the course related to project work and a discussion of requirements gathering. Large-scale visualization techniques can be used to provide efficient browsing strategies when explicit search does not work. Too many important results have been reported on those several areas; a few of the most relevant are commented next.

#### **6.3.1 Related Work**

Important research has been done in terms of storing and retrieving multimedia documents. A case in point is the Infromedia Project, which implements a database of digital media that allows media-based retrieval. The project implements a three-level architecture that includes a level of indexing into the media contents. The indexing is generated by two complementary methods: metadata is generated by automatic voice transcription of the audio streams and the segmentation of the audio and video streams is made by the identification of specific patterns such as silence in audio and scene transition in video (Wactlar et al 1999). The research issues tackled by the project include the identification of good enough processing of the media in order to provide appropriate results upon retrieval. Moreover, important visualization issues concern the provision of appropriate user interfaces for the user to perform queries and for the system to present relevant results (Christel & Martin 1999).

Mbase is a Media Management System that also exploits the generation of metadata from the transcription of audio and segmentation of video information. Additionally, Mbase includes a service for the identification of the speaker in audio streams (Wilcox & Boreczky 1998). The Mbase system has been integrated into a capture based system, Kumo Interactive, which corresponds to a media-enabled conference room where activity is captured, annotated, indexed, and stored on the Web — and includes the use of handwriting to index into video streams (Chiu et al. 1999a,b).

Information retrieval systems are designed to search terms in collections of information in order to retrieve certain items in response to queries — text-based systems being the most traditional systems. The effectiveness of a traditional retrieval system is usually evaluated in terms of a pair of measures, known as recall and precision. Recall is the proportion of relevant material that is actually retrieved, while precision is the proportion of the retrieved material that is found to be relevant to the users' needs (Salton 1981). Salton (1986) has proposed a basic process to create automatic indexing that include techniques such as term truncation, term weighting and addition of synonymous in order to reach the desired recall and precision levels. However, Salton (1981) observes that the homogeneity of the information can be more relevant than other characteristics usually considered in the context of information retrieval. The queries can be performed by users, as when interacting with search engines on the Web, or by programs. The latter has been exploited to provide the automatic generation of links (Salton et al 1994; Allan 1996) — a similar approach can be used to extend captured information in order to integrated it to information produced outside the live sessions. When the amount of information manipulated by an information retrieval system may correspond to the whole Web, Chakrabarti et al. (1999) recommend the use of special techniques that include analyzing the hyperlinks contained in the pages in order to better classify the Web pages.

Extension of information may also be achieved by supporting varied forms of synchronous or asynchronous collaborative work. Important work has been done in order to exploit the Internet as an environment for synchronous communication that supports collaborative work — a case in point is Habanero, a software suite designed to facilitate the development and integration of collaborative Internet applications (Chabert 1998). A pioneer in the area of computer supported collaborative work, Nunamaker's (1999) view is that collaborative computing applications should be tailored to users, easy to use and provide the appropriate amount of functionality.

In order to build SERVE as an open infrastructure, it is important to consider the current efforts from the Open Hypermedia Systems and the World Wide Web Consortium (W3C).

Hypermedia "system researchers" implement Open Hypermedia System that provide, via an open architecture, hypermedia services to client (third-part) applications. On the other hand, the architecture implemented in the systems built by hypermedia "domain researchers" tends to be monolithic. Open Hypermedia Systems usually implement a limited set of link services — usually navigational ones — while domain researchers present more varied and specialized abstractions in their monolithic systems (Nürnberg et al 1998). Most Open Hypermedia Systems reported in the literature were built independently of the Web, but many have ported their infrastructure to take advantage of the Web — e.g. (Anderson 1997). However, Nürnberg and Ashman (1999) discuss that both the Web and Open Hypermedia Systems may learn from each other: Open Hypermedia Systems should take into account the benefits of consistent and ease of use interfaces of the Web; the Web should be able to provide a more powerful middleware capable of serving structural hypertextual abstractions.

The W3C has been investing many efforts in order to guarantee the growth of the Web in an open and standardized way, for instance by defining recommendations regulating the formalization of the structure of documents and their presentation format. The Extensible Markup Language (XML) aims at helping domain application designers to provide a logical structure for the supported documents (W3C 1998). The Cascade Style Sheets (W3C 1996) and Extensible Style Sheet Language (W3C 1999) help those authors to standardize the presentation format and reuse of their document. Although XML aims at supporting intra-domain interoperability, there is still the problem of providing distinct domains a way to cross communicate. To solve the latter, the W3C has released the specification of the Resource Description Framework (RDF), a foundation for processing metadata and make information exchangeable across application domains on the Web. The structuring and storage of the information produced during a session using a standard markup language such as XML bring many advantages to XML based-applications (Connolly 1998) such as distributed processing, customized view, semantic attribution and independent searching.

### **6.3.2 Supporting Evolutionary Information**

While the InCA infrastructure will focus in capturing information during live sessions, the SERVE infrastructure will provide support for evolutionary information — providing services that integrate the information captured to information produced before and after the capture session. The infrastructure will be open since it will provide an interface for application designers to access its services in the three phases. SERVE will also provide services associated to the capture phase: an interface will be provided that uses the services of the InCA infrastructure and allow the captured information to be structured and manipulated.

In the context of the Classroom 2000 project, Abowd's and Pimentel's joint research in supporting the after capture phase session has demonstrated how the digital media of the captured lecture can serve as an effective anchor for collaborative discussions and Web-based homework assignments (Abowd et al. 1999). The group has also experimented with searching, automatic linking and visualization of search results over information of different granularity — such as single lecture, a whole course or a set of many unrelated courses. The goal of the implementing SERVE is to generalize and formalize such support, so that its services may be extended to employ new research results applicable to all three phases of the spiral model.

One possibility which can be exploited here is the use of MPEG-4 and MPEG-7 standards for video streams manipulation. MPEG-4 is a standard developed by MPEG (Moving Picture Experts Group) and ISO (International Organization for Standardization) that provides the standardized technological elements enabling the integration of the production, distribution and content access paradigms on interactive multimedia (eg. ITV and WWW) (MPEG-4, 1999). MPEG-7 is a standard created to represent information which can be used alongside MPEG-4 and adds flexibility to the XML capabilities.

### 6.3.3 Planned Work

The work on developing the SERVE infrastructure will be done in Brazil by the group at the ICMC-USP, and will include the following activities listed in Table 1:

- #7. Definition of a basic API for storing captured information — year 1
- #8. Definition of a basic API for retrieving the captured information — year 1
- #12. Definition of a basic API for extending the captured information — year 1
- #13. Definition of a basic API for visualizing the captured information — year 1

Sample STORE services include the definition of sessions (by allowing the structuring of information stored by the InCA infrastructure) and their capture (by requesting the InCA services). Sample RETRIEVE services include the generation of XML documents based on the structure of a session. Sample EXTEND services include the automatic generation of extended structuring information based on the structure of a session. Sample VISUALIZE services will allow the application to associate XSL specifications to the elements that correspond to the structure of a session.

- #20. Definition of intermediate API for storing captured information — year 2
- #21. Definition of intermediate API for retrieving the captured information — year 2
- #22. Definition of intermediate API for extending the captured information — year 2
- #23. Definition of intermediate API for visualizing the captured information — year 2

In this level we will emphasize services toward supporting flexible and customizable information. STORE services will support structuring of collaboratively information to be added to the repository. RETRIEVE services should allow information from distinct applications captured from different users to structured on the fly. EXTEND services would augment stored information and manage preferences users' preferences. VISUALIZE services would allow the application to offer users ways of personalizing the interfaces and contents they access.

- #30. Definition of advanced API for storing captured information — year 3
- #31. Definition of advanced API for retrieving the captured information — year 3
- #32. Definition of advanced API for extending the captured information — year 3
- #33. Definition of advanced API for visualizing the captured information — year 3

In this level we will emphasize services toward supporting long-term applications. STORE services should be able to refer to structure and contents of information stored in distributed databases. RETRIEVE services should allow information for distinct applications captured in separate period of times to be recovered and structured on the fly. EXTEND services would include the integration of information produced by third-part applications and to process the stored information in order to identify relevant relationships. VISUALIZE services would allow the application to offer users ways of visualizing non-uniform structured information produced during long periods of time.

The design and implementation of SERVE in the ICMC-USP will be carried out by three teams lead by Dr. Moreira, Dr. Fortes and Dr. Pimentel. Dr. Moreira's team will be in charge of modeling and implementing the APIs for the Store and Retrieve components of SERVE with respect to the manipulation of multimedia streams. Dr. Fortes' team will be in charge of modeling and implementing the APIs for the Store and Retrieve services of SERVE with respect to the hypertext components. Dr. Pimentel's team will be in

charge of modeling and implementing the APIs for the Extend and Visualize components of SERVE. These researchers will be responsible for leading papers on the issues tackled and the achieved results.

As detailed in the next section, during the whole duration of the project, the three levels of the infrastructure will be used to build three versions of applications called Classroom 2000 and Meeting 2000. The applications will be used in seminars and meetings of the researchers involved, as well as to support everyday courses at both USP and GATECH. The seminars will be supported by the Classroom 2000 infrastructure and the meetings will use the Meeting 2000 infrastructure. This will provide a unique opportunity to define the requirements of the basic, intermediate and advanced levels of the InCA and SERVE infrastructures, at the same time that will provide valuable data for evaluating the work as it evolves.

## **6.4 Applications Research and Evaluation**

The whole point of automated capture is to support human activities, so a significant portion of the work will be applications centered. While we are interested in general results of our research that can be repeated by others in different situations, we firmly believe that the true depth of understanding of the problems of automated capture can only be understood through real experience of these systems. Our two main application themes for this proposed research are in an educational and in a software engineering domain.

### **6.4.1 Classroom 2000 Continued: Long-term support**

The Classroom 2000 project provided the experience of instrumenting an environment to ease the capture of a lecture and producing a digitized and extensible artifact that represents what went on in the classroom. Automated support to the capture of audio and video of the live sessions in order to have the presentation available for later review is also the aim of the ADEPT Project at Stanford (Harris & DiPaolo, 1996) and of the AutoAuditorium Project (Bianchi, 1998). These two implementations, however, do not support integration of additional material used during the presentation. The Cornell Lecture Browser captures, besides the audio and video streams, images of electronic slides presented during the session and automatically generates table of contents that provides synchronized indexing into the slides and the video information. The Classroom 2000 infrastructure is more comprehensive both in terms of automated support to a course as whole (many lectures in several styles) and a more detailed record of each experience (capture of whiteboard information and Web activity).

It is the intent of research proposed in this plan — and in its companion submitted by Dr. Abowd to NSF — to add robustness and reliability to capture over a longer period of time: we can envision a student being able to have access to all of his or her educational experience. It is then that more significant long-term uses will be crucial as we aim toward building an intelligent student assistant able to summon up relevant knowledge from a student's past when and where it is needed. From the educational provider's perspective, our long-term goal is to enable more efficient reuse of educational material, building what we have earlier referred to as an open source model for the development and adaptation of educational material.

### **6.4.2 An Alternative Approach to Rationale Preservation for Design**

The second application is an attempt to resurrect a part of software engineering research, design rationale, that failed in the late 80's and early 90's not because it was not useful but rather because the techniques for extracting rationale were unusable and hence disregarded.

Design is a vital activity in software and systems development. The quality of a design greatly affects the quality of the final system. A designer's goal is to produce a specification of the system that will be built. However, many factors lead designers to that specification. These factors are often referred to as design rationale. Design rationale is the explanation behind the design —why the design is the way it is. Design rationale has been considered in several ways: as the history of alternatives considered and decisions made during the design (Conklin 1996; Fischer 1996), as the set of psychological claims embodied in the design (Carroll 1996; Singley 1996), and as a general description of the design space and the location of the design within it (MacLean 1996).

The challenge in applying ubiquitous technology to the rationale capture process is to provide an organization of multimedia streams that facilitates access to the rationale. This requires going beyond simple record and playback schemes to providing meaning to the various activities and records of a design meeting. Since design meetings often have a semi-structured process, the task is made simpler. There is a universal sense in software development that design rationale is important to document.

However, none of the traditional rationale techniques has been accepted into general software practice due to the high cost of capturing rationale. Research has suggested that rather than capturing full explanations of rationale, design knowledge should instead be captured. Thus, we propose capturing design knowledge by using ubiquitous capture and access technology to record everyday design meetings.

Gaining access to a test-bed for any software engineering research is difficult, for it is hard to gain access to the details of a project that is sufficiently complex and large-scale. In our case, we will focus our initial studies on our own design efforts. While this may at first seem too contrived to generate useful results, upon reflection, it is a wise choice for a number of reasons:

- Dr. Abowd's group has been working on capture systems for the past four years and will continue to do so for the foreseeable future. With the constant flux of development team members, there is a constant need to re-inform the whole team on important principles that guide the design and evolution of our various systems. Therefore, design rationale is constantly repeated, but not constantly enough.
- With the successful funding of this project, the GATECH and USP groups will become a more physically distributed development team with regular synchronous but remote meetings.
- Like any development team, a number of important meetings, encounters in which significant knowledge about the workings of the system is discussed occur at unplanned times and when not all relevant team members are around. These meetings are poorly recorded, resulting in an inefficient dissemination of relevant materials.
- Our capture systems are fairly complex software artifacts, using a collection of home-grown and third-party software. Though not the most complex of all possible software artifacts, they offer a more interesting case study for software engineering research than most problems studied as part of software engineering educational exercises.

Dr. Abowd will be supervising one graduate student that will be in charge of investigating the research issues in this domain — as well as performing the associated implementation and evaluation tasks.

#### 6.4.3 Planned Work

Since we will be applying our research to the educational and software engineering domains, we will experiment with applications in those domains in both research groups. These implementations will be depending upon the resources provided each year by the three phases of the development of the InCA and SERVE infrastructures, and the data collected will provide invaluable feedback to their design. Both research groups will implement, in a collaborative and complementary way, the following activities from Table 1:

- #9. Implementation of Classroom 2000-like application of static multimedia documents InCA-Store + Retrieval basic infrastructure — year 1
- #10. Testing and installation in classroom and meeting environments — year 1
- #11. Data collection and analysis of use of system in the environments — year 1
- #14. Implementation of basic Classroom 2000-like application of evolutionary multimedia documents using InCA-SERVE (adding Extending and Visualizing capabilities) basic infrastructure
- #15. Implementation of equivalent Meeting-2000 application — year 1
- #16. Testing and installation in classroom and meeting environments — year 1
- #17. Data collection and analysis of use of system in the environments — year 1
- #24. Implementation of extended Classroom 2000-like application of evolutionary multimedia documents using InCA-SERVE intermediate infrastructure — year 2
- #25. Implementation of equivalent Meeting-2000 application — year 2
- #26. Testing and installation in classroom and meeting environments — year 2
- #27. Data collection and analysis of use of system in the environments — year 2
- #34. Implementation of advanced Classroom 2000-like application of evolutionary multimedia documents using InCA-SERVE advanced infrastructure — year 3
- #35. Implementation of equivalent Meeting-2000 application — year 3
- #36. Testing and installation in classroom and meeting environments — year 3
- #37. Data collection and analysis of use of system in the environments — year 3

## 6.5 Plan of work at a glance

In this section, we describe how work will be split between the research teams at ICMC-USP and GATECH. Table 1 presents the plan of basic activities and assignment of responsibilities that has been agreed upon by the researchers from USP and GATECH. The basic idea is that GATECH will create run-time framework of the InCA infrastructure and continue its deployment and evaluation in the educational domain. USP will define the API's that comprise the SERVE open infrastructure and will assist in the application of these APIs to extend long-term capabilities in the educational domain. The two teams will collaborate on the development and use of the design team rational capture support system.

The activities to be performed by the USP group are organized in a calendar of macro-activities as presented in Table 2. This table also details which researcher of the group is responsible for the particular macro-activity, as well as indicates what results are expected to be achieved.

**Table 1: Calendar of Activities as Planned by both Groups**

ACTIVITIES TO BE CARRIED OUT AT GEORGIA TECH AND UNIVERSIDADE DE SÃO PAULO		GA TE CH	USP	Marco Activity at USP – as in Table 2
<b>YEAR 1</b>				
1.	Definition of a Spiral Model of Evolutionary Hypermedia/Multimedia Information	√	√	1
2.	Definition of a Spiral Framework for applications exploiting InCA/SERVE infrastructures	√	√	2
3.	Implementation of classroom infrastructure for capturing multimedia documents using InCA		√	3
4.	Implementation of infrastructure for capturing multimedia documents for FCE/ICMC design team rationale capture using InCA	√	√	3
5.	Definition of a basic API for capturing information	√		
6.	Definition of a basic API for accessing information	√		
7.	Definition of a basic API for storing captured information		√	4-5
8.	Definition of a basic API for retrieving the captured information		√	4-5
9.	Implementation of Classroom 2000-like application of static multimedia documents using APIs above	√	√	7
10.	Testing and installation in classroom and meeting environments	√	√	7
11.	Data collection and analysis of use of system in the environments	√	√	7
12.	Definition of a basic API for extending the captured information		√	6
13.	Definition of a basic API for visualizing the captured information	√	√	6
14.	Implementation of basic Classroom 2000-like application of evolutionary multimedia documents using APIs above	√	√	7
15.	Implementation of equivalent Meeting-2000 application	√	√	7
16.	Testing and installation in classroom and meeting environments	√	√	7
17.	Data collection and analysis of use of system in the environments	√	√	7
<b>YEAR 2</b>				
18.	Definition of intermediate API for capturing information	√		
19.	Definition of intermediate API for accessing information	√		
20.	Definition of intermediate API for storing captured information		√	9-10
21.	Definition of intermediate API for retrieving the captured information		√	9-10
22.	Definition of intermediate API for extending the captured information		√	11
23.	Definition of intermediate API for visualizing the captured information	√	√	11
24.	Implementation of extended Classroom 2000-like application of evolutionary multimedia documents using APIs above	√	√	12
25.	Implementation of equivalent Meeting-2000 application	√	√	13
26.	Testing and installation in classroom and meeting environments	√	√	12-13

27.	Data collection and analysis of use of system in the environments	√	√	12-13
<b>YEAR 3</b>				
28.	Definition of advanced API for <b>capturing</b> information	√		
29.	Definition of advanced API for <b>accessing</b> information	√		
30.	Definition of advanced API for <b>storing</b> captured information		√	14-15
31.	Definition of advanced API for <b>retrieving</b> the captured information		√	14-15
32.	Definition of advanced API for <b>extending</b> the captured information		√	16
33.	Definition of advanced API for <b>visualizing</b> the captured information	√	√	16
34.	Implementation of advanced Classroom 2000-like application of evolutionary multimedia documents using APIs above	√	√	17-18
35.	Implementation of advanced Meeting-2000 application	√	√	17-18
36.	Testing and installation in classroom and meeting environments	√	√	17-18
37.	Data collection and analysis of use of system in the environments	√	√	17-18

Table 2: Calendar of Macro Activities to be developed at USP

Macro Activity	Title	Summary	Month	Researcher in charge	Result to be achieved
1	Spiral Model	Definition of model describing issues and proposed approach	1 - 3	Pimentel & Abowd	Report + Full paper
2	Spiral Framework	Definition of framework of InCA and SERVE APIs	1 - 3	Pimentel, Fortes, & Moreira Abowd	Report + Full paper
3	Classroom 2000 + Meeting 2000 environments	Installation of Classroom 2000 and Meeting 2000 physical environments with current Classroom 2000 technology	1 - 3	Moreira & Pimentel	Classroom 2000 and Meeting 2000 environments installed + Report
4	Basic SERVE Store & Retrieve - multimedia	Design and implementation Store & Retrieve components of Basic SERVE API — for multimedia	4 - 6	Moreira	API & Report + Full paper
5	Basic SERVE Store & Retrieve - hypertext	Design and implementation Store & Retrieve components of Basic SERVE API — for hypertext	4 - 6	Fortes	API & Report + Full paper
6	Basic SERVE Extend & Visualize	Design and Extend & Visualize components of Basic SERVE API	4 - 6	Pimentel	API & Report + Full paper
7	Classroom 2000-Basic	Design and implementation of Classroom 2000 application using Basic Serve	6 - 12	Pimentel & Moreira	C2000 Application + Evaluation paper
8	Meeting 2000-Basic	Design and implementation of Meeting 2000 application using Basic Serve	6 - 12	Fortes & Moreira	Meeting Application & Evaluation paper
9	Intermediate SERVE Store & Retrieve - multimedia	Design and implementation Store & Retrieve components of Intermediate SERVE API — for multimedia	13 - 18	Moreira	API & Report + Full paper
10	Intermediate SERVE Store & Retrieve - hypertext	Design and implementation Store & Retrieve components of Intermediate SERVE API — for hypertext	13 - 18	Fortes	API & Report + Full paper
11	Intermediate SERVE Extend & Visualize	Design and Extend & Visualize components of Intermediate SERVE API	13 - 18	Pimentel	API & Report + Full paper
12	Classroom 2000-Intermediate	Design and implementation of Classroom 2000 application using Intermediate Serve	19 - 24	Pimentel & Moreira	C2000 Application + Evaluation paper
13	Meeting 2000-Intermediate	Design and implementation of Meeting 2000 application using Intermediate Serve	19 - 24	Fortes & Moreira	Meeting Application + Evaluation paper
14	Advanced SERVE Store & Retrieve - multimedia	Design and implementation Store & Retrieve components of Advanced SERVE API — for multimedia	25 - 30	Moreira	API & Report + Full paper
15	Advanced SERVE Store & Retrieve -	Design and implementation Store & Retrieve components of Advanced	25 - 30	Fortes	API & Report + Full paper

	hypertext	SERVE API — for hypertext			
16	Advanced SERVE Extend & Visualize	Design and Extend & Visualize components of Advanced SERVE API	25 - 30	Pimentel	API & Report + Full paper
17	Classroom 2000-Advanced	Design and implementation of Classroom 2000 application using Advanced Serve	30 - 36	Pimentel & Moreira	C2000 Application Evaluation paper +
18	Meeting 2000-Advanced	Design and implementation of Meeting 2000 application using Advanced Serve	30 - 36	Fortes & Moreira	Meeting Application Evaluation paper +

## 6.6 Planned Budget — ICMC-USP

Table 3 presents the planning for the use of the budget by the group at USP.

*Table 3: Planned Budget — ICMC-USP*

	Year 1	Year 2	Year 3
<p><b>Equipment for capture of audio, video and handwriting: R\$ 15,000.00</b>  <i>Equipment for the capture of audio(R\$ 3mil).</i>  <i>Equipment for the capture of video (R\$ 6mil)</i>  <i>Electronic whiteboard and computer (R\$ 6mil)</i>  <i>This capture equipment will be used to instrument one classroom and one meeting room.</i>  <i>Additional equipment needed — computers and projectors — will be using the resources already available at the ICMC-USP (computers and projectors).</i>  <i>Dr. Abowd will loan one touch-sensitive video-tablet for capturing handwriting information (US\$ 3mil) until the USP group receives their Electronic Whiteboards.</i></p>	√		
<p><b>6 grants DTI-G for 12 months</b>  <i>One DTI-G researcher will be in charge of implementing the Classroom 2000 environment using the InCA-SERVE basic and intermediate infrastructures in years 1 and 2. Other will be in charge of implementing the Meeting 2000 environment using the InCA-SERVE basic and intermediate infrastructure in years 1 e 3. A third, joining the teams in the 2<sup>nd</sup> and 3<sup>rd</sup> years, will be in charge of extending those implementations to use the InCA-SERVE advanced infrastructure. They will also be in charge of running the Classroom 2000 and Meeting 2000 physical environments.</i></p>	√	√	√
<p><b>10 grants ITI-A for 12 months</b>  <i>Five ITI-A students will give general support in terms of implementation and testing of the SERVE infrastructure and the Classroom 2000 and Meeting 2000 applications</i></p>	√	√	√
<p><b>2 grants SPE for 4 months @ GATECH</b>  <i>Two of the DSc students in the project will use the SPE grants in the 2<sup>nd</sup> and 3<sup>rd</sup> years, to carry out collaborative research.</i></p>	√	√	√
<p><b>2 grants BSP for 30 days @ GATECH</b>  <i>Dr. Pimentel will use one BSP 30-day grant to visit GATECH in years 2 and 3</i></p>	√	√	√
<p><b>4 grants BSP for 10 days @ GATECH</b>  <i>Dr. Moreira will use one BSP 10-day grant to visit GATECH each year. Dr. Fortes will use one BSP 10-day grant to visit GATECH in the 3<sup>rd</sup> year</i></p>	√	√	√
<p><b>5 grants BSP for 5 days</b></p>	√	√	√
<p><b>12 grants BEP for 4 days</b>  <i>The group will be able to use 5 BSP and 12 BEP grants to present their work in</i></p>	√	√	√

*international and Brazilian Conferences or visit other research groups developing related work.*

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## 7 Organization and Management

### 7.1 Distribution of tasks and resources

Dr. Pimentel will work with Dr. Abowd and Dr. Fortes in the formalization of the Spiral Model of Evolutionary Hypermedia/Multimedia Information and in the associated Spiral Framework for applications that exploit the InCA -SERVE infrastructures.

Dr. Pimentel will coordinate the activities at ICMC-USP. She will work closely with Dr. Moreira and Dr. Fortes, who will be in charge of running their respective teams.

- Dr. Moreira team includes two DSc and one MSc students working full time in the project each year. This team will be in charge of modeling and implementing the Store and Retrieve components of SERVE that deal with services related to the manipulation of multimedia streams. They will also collaborate with supporting the Classroom 2000 and Meeting 2000 physical environments.
- Dr. Fortes will be in a post-doctoral visit to GATECH for the first year of the project. She will be supervising two MSc students during that time, with the support of Dr. Pimentel in Brazil. During the following two years she will be supervising one DSc and two MSc working full time in the project. This team will be in charge of modeling and implementing the Store and Retrieve components of SERVE that deal with services related to the manipulation of hypertext structures.
- Dr. Pimentel's team includes one DSc and two MSc students working full time in the project each year. This team will be in charge of modeling and implementing the APIs for the Extend and Visualize components of SERVE.

Two DTI-G researchers will join the teams during the first two years. One of them will be responsible for the implementation of the new version of the Classroom 2000 system that will use the InCA-SERVE basic and intermediate infrastructures. The other will be in charge of implementing the Meeting 2000 environment using the InCA-SERVE basic and intermediate infrastructures. A third DTI-G researcher, joining the teams during the 2<sup>nd</sup> and 3<sup>rd</sup> years, will extend the work developed by the first two DTI-G researchers, now taking advantage of the InCA-SERVE advanced infrastructure.

Five ITI-A students will join the Brazilian group for a period of two years each, and will give broad support in terms of implementation and testing the SERVE infrastructure and the Classroom 2000 and Meeting 2000 applications.

Dr. Moreira will use three BSP 10-day grants to visit GATECH during each year of the project. Dr. Fortes will use one BSP 10-day grant to visit GATECH in the 3<sup>rd</sup> year. Dr. Pimentel will use two BSP 30-day grants to visit GATECH in years 2 and 3. Two of the DSc students in the project will use the SPE grants in the 2<sup>nd</sup> and 3<sup>rd</sup> years.

Dr. Abowd and other members of his team will be visiting the ICMC-USP in years 2 and 3, funded by NSF.

The ICMC-USP will be providing consumable resources (such as paper and mail), as well as the physical location for the Meeting 2000 and Classroom 2000 environments. Moreover, the ICMC-USP will also permit the use of equipment such as computers and projectors.

### 7.2 Inter-group (Brazil-U.S.) and intra-group (Brazil) work

A set of meetings and seminars will be used to support the collaborative work here proposed. These encounters will, at first, be supported by the audio-conference infrastructure as already provided by the Classroom 2000 environment (see section 6.1.2.3), and will make use of the new Classroom 2000 and Meeting 2000 infrastructures as they are made available during the life time of this project. In the meetings, one preliminary session will discuss issues related to the management of the project.

In a meeting run every-other-week, Dr. Abowd, Dr. Pimentel, Dr. Fortes and Dr. Moreira will collaborate in the design of the InCA-SERVE infrastructure and discuss the integration of their work. In a monthly seminar the researchers will present the results achieved by the groups in Brazil and in the U.S.

In Brazil, each of the three teams will run weekly meetings to discuss their overall work in general and the design and implementation of the SERVE infrastructure in particular. The whole group will run a seminar every-other-week, when the members will present the results of their work. Another seminar run every-

other-week will allow the participants to present reviews of the state-of-the art in areas related to the project.

Each year a Workshop held at the ICMC-USP will open partial results to a broad public consideration. The proceedings of the workshop will be produced in electronic media.

As far as asynchronous collaboration is concerned, the Classroom 2000 environment has already been integrated to the CoWeb — an informal and unstructured Web repository, which allows collaborative authoring of Web-based material — in a work that involved Dr. Abowd and Dr. Pimentel (Abowd et al. 1999). This collaborative infrastructure will be used to provide generate and provide easy access to both research and management information of the InCA-SERVE Project.

This setting will provide a unique opportunity to define the requirements of the basic, intermediate and advanced levels of the InCA and SERVE infrastructures, at the same time that it will provide valuable data for evaluating the work as it evolves. We believe that this will allow the overall work to be carried out as planned.

### 7.3 Management procedures

Dr. Pimentel was the Local Coordinator, at ICMC-USP, of the SMmD Project and was a collaborator in the HyperProp Project, both funded by CNPq/ProTeM-CC-fase II. She was the general chair of the III Workshop em Sistemas Hipermídia, held in São Carlos in 1997, which received funding from CNPq, CAPES, FAPESP and FINEP. She was a member of the organizing committee of the I Workshop em Sistemas Hipermídia held in São Carlos 1995 as part of the SMmD and HyperProp Projects, and of the organizing committee of the XV Simpósio Brasileiro de Redes de Computadores, held in São Carlos in 1997. During her visit to Georgia Tech, she leads the group responsible for modeling and implementing the current database infrastructure and the dynamic hyperdocument models for the Classroom 2000 Project. Each of these experiences has provided complementary skills we believe enough to coordinate the Brazilian portion of the InCA-SERVE Project

The following management procedures will be adopted:

- An integrated set of asynchronous electronic forums will support the intra and inter-group communication — the meetings and seminars detailed before. E-mail lists will also be integrated to a collaborative asynchronous authoring environment — the CoWeb used in the Classroom 2000 Project at GATECH — so as to support those forums. This infrastructure further allows the anchoring of the discussion held in the forums into information captured from the meetings and seminars.
- Each year the Brazilian group will promote a Workshop, at the ICMC-USP, opening the partial results and some project strategies to a broad public consideration. The proceedings of the workshop will be produced in electronic media.
- Dr. Pimentel will be coordinating the broader forums and associated meetings at the ICMC-USP, and Dr. Moreira and Dr. Fortes will be coordinating those of their teams.
- Dr. Pimentel, Dr. Moreira and Dr. Fortes will be analyzing the reports produced by the individual members of the their teams. They will also produce their own reports analyzing the overall work.
- All documents produced in the context of the project — research papers, design documents, reports, presentations, etc. — will be integrated in the CoWeb site of the project, so as to allow the whole group to collaboratively store, access and maintain the information.

The ICMC-USP has dedicated staff for supporting the researchers managing administrative tasks demanded by the project. Dr. Pimentel will be supported part-time by an administrative assistant.

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