Investigating research issues in ubiquitous computing: The capture, integration, and access problem

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Project Summary

The interest in ubiquitous computing has surged over the past few years. The defining characteristic of ubiquitous computing is the attempt to break away from the traditional desktop interaction paradigm and move computational power into the environment that surrounds the user. As Mark Weiser has observed, "Applications are of course the whole point of ubiquitous computing." The Future Computing Environments Group at Georgia Tech, under the guidance of the PI, is taking this applications perspective to guide the discovery of fundamental research challenges in ubiquitous computing.

In this proposal, we focus on automating the capture of individual and group experiences in order to facilitate access to a richly integrated record of events. We refer to this as the automated *capture, integration and access* problem for ubiquitous computing. We take an applications focus in approaching this problem. Natural candidates for the capture, integration and access tools are collaborative activities —meetings, education, design. Whereas previous research in ubiquitous computing has focused on support for a single individual in the midst of a collaborative exchange, we will apply capture, integration and access tools to support many simultaneous collaborators.

We will initiate a large-scale ubiquitous computing effort at Georgia Tech —entitled Classroom 2000— to provide automated environments and tools to capture, integrate and access the rich interaction of the classroom experience. This effort will grow to support a wide variety of classes and assist students throughout their educational career and beyond. We will investigate open issues, such as the effect of granularity of capture, support for revision during access, and how interaction between collaborators affects capture and integration. We will plan and carry out an evaluation plan to determine the impact of capture, access, and integration on educational goals. We are specifically interested in determining if this technology supports note-taking practices that contribute to near- and long-term retention of knowledge. We hope that our work will provide a standard of evaluation for the experimental ubiquitous computing community as well as provide insight into more effective and modern teaching and learning methods. Finally, we will further demonstrate the generality of the capture, access, and integration problem through its application to other domains beyond education.

Much of the research focus in this proposal has an immediate relevance toward education. We expect to make a significant impact on educational practices by evaluating the effectiveness of ubiquitous computing technology —handheld devices, pen-based interfaces and cross-platform software delivery. As students and teachers experiment with the tools and new modes of interaction that are enabled by our technology, we expect new forms of education to emerge if we can show that they provide ways to motivate and energize both teacher and student.

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1 Introduction

The interest in ubiquitous computing has surged over the past few years [29, 30]. The defining characteristic of ubiquitous computing is the attempt to break away from the traditional desktop interaction paradigm and move computational power into the environment that surrounds the user. The focus of the proposed research is to use ubiquitous computing technology to automate the capture of individual and group experiences in order to facilitate access to a richly integrated record of events. We refer to this as the automated *capture, integration and access* problem for ubiquitous computing.

We take an applications focus in approaching this problem. Natural candidates for the capture, integration and access tools are collaborative activities —meetings, education, design. Previous work in this area has focussed on support for a single individual in the midst of some collaborative exchange. Supporting a scribe at a business meetings is a good example of this. We are interested in supporting many different "scribes", a model which is possible in a business or design meeting and also very suitable to a classroom situation, in which the teacher and the students all share some of the responsibility for recording relevant activities for later use.

1.1 Objectives

We have initiated an investigation of how ubiquitous computing can affect education. Specifically, we are interested to see how tools to automate capture, integration and access can support the mission of a teacher and student to enhance the learning experience. Our initial investigations have been very small-scale, but the results are encouraging. With this experience as a foundation, the objectives for the research in this proposal are as follows.

- We will initiate a large-scale ubiquitous computing effort at Georgia Tech —entitled Classroom 2000— to provide automated environments and tools to capture, integrate and access the rich interaction of education. This effort will grow to support a wide variety of classes and assist students throughout their educational career and beyond.
- We will investigate open issues in capture, access, and integration through prolonged experience in a real and complex application domain. These issues are:
  - determining the correct level of granularity for capturing collaborative interaction;
  - support for revision of material during access; and
  - supporting interaction between participants in situations in which anonymity may or may not be a concern.
- We will plan and carry out an evaluation plan to determine the impact of capture, access, and integration on educational goals. We are specifically interested in determining if this technology supports note-taking practices that contribute to near- and long-term retention of knowledge. We hope that our work will stand as a standard of evaluation for the experimental ubiquitous computing community as well as provide insight into more effective and modern teaching and learning methods.
- We will further demonstrate the generality of the capture, access, and integration problem through its application to other domains beyond education. Specifically, we are interested in support for the individual tourist and for a software design team wanting to preserve knowledge of high-level design rationale.

1.2 Defining the capture, access, and integration theme

Much of our time in business and academia is spent listening to and recording, more or less accurately, the events that surround us, and then trying to remember the one important event that eludes us. There is a value to using computational resources to augment the inefficiency of human record-taking, especially when there are multiple streams of related information that are virtually impossible to capture as a whole. Computational support can also automate explicit and implicit links between related but separately generated streams of information. Finally, a rich record of a group interaction can support later access to aid in recalling the meaning or significance of past events. Together, these automated tools to support capture, access, and integration can remove the burden of doing something we are not good at (recording) so that we can focus attention on things we are good at (indicating relationships, summarizing, and interpreting).

Though capture, integration, and access is a general theme in ubiquitous computing, we will make progress by focusing on well-defined domains. The first domain of focus is education, and we will initiate the Classroom 2000 project to explore the effect of ubiquitous computing in higher education. We have experimented with environments and tools to support capture, integration and access in a variety of classes, and our preliminary results have helped us to form a long-term vision of how ubiquitous computing can improve the educational experience [3, 4, 20]. Our goals are in alignment with those expressed in a recent NSF workshop report on the role of Computer Science in educational technology [11]. That reports notes that "education researchers are well aware of the dramatic changes that technologies are bringing to traditoinal educational systems." Though the effect of ubiquitous computing is not explicitly mentioned in that report, there are clear suggestions that the kind of technology we are bringing to the classroom (handheld devices, cross-platform software delivery, use of Internet-based resources and protocols for inter-personal communication and computation) are in harmony with important technical areas raised in that report.

Though education is the main application focus of this proposal, we are also principally concerned with the ubiquitous computing problem of capture, integration and access of rich multimedia information. To demonstrate the the generality of the capture, integration, and access theme, we will also explore two other domains of interest. In the domain of tourism, automated capture, integration, and access tools can be applied to generate travel diaries, or support for a roaming reporter. In collaborative software design, discussions about high-level design options reveal the rationale behind important architectural decisions but are often poorly documented.

In the education domain, our hypothesis is that capture, integration, and access support will provide students the means to take notes more efficiently and effectively, and thus contribute to a more positive and long-lasting learning experience. By efficiency we mean taking less time during a class to write notes, thus allowing more time to understand and engage in discussion. Effectiveness is a measure of how good the notes are for supporting recall of important concepts after a lecture. We also suspect that the effect of ubiquitous computing technology will be suitable for certain kinds of teaching styles and not other. It may also foster newer styles of teaching and learning. Rather than try to predict how teaching will change, we instead are taking an evolutionary approach to inventing new modes of instruction and learning.

1.3 Outline of research plan

The Classroom 2000 project will provide a very rich research area for both ubiquitous computing and educational technology problems. The main research focus of the PI is in applications of ubiquitous computing. Having a positive impact on education is also a goal of this work and to better judge that impact, we will enlist the aid of researchers from Georgia Tech's EduTech Institute who are well-positioned to aid in the evaluation plan.

Our specific research plan is summarized below.

1. We will build a single physical environment —the Classroom 2000 prototype classroom— to support automated capture of classroom interaction. This physical environment will include different scales of ubiquitous computing technology, ranging from large-scale electronic whiteboards for public display of information and medium scale electronic tablets or desks for use by students in class. This environment will also be equipped to capture audio and video streams of classroom activity and will be aware of the location of individuals in the room and their mood.

2. We will build software tools to support the capture of individual and group activity and automatically integrate different streams of activity into a form that is accessible to all participants in the class.
3. We will produce a long-term evaluation plan in cooperation with researchers from Georgia Tech's EduTech Institute to assess the impact that the capture, integration, and access tools have on teaching and learning goals. This plan will be executed across a number of classes that vary in terms of subject matter, class size and teaching style.
4. We will extend our efforts to develop cost-effective solutions for providing Classroom 2000 environments across the Georgia Tech campus.
5. We will generalize our capture, integration, and access tools to two different domains, tourism and system design rationale.

The first two activities will begin in Year 1 and continue to be the main focus of our work for the first three years. The evaluation plan will begin in Year 2 and continue for the duration of the project in collaboration with the EduTech Institute. Extending the single Classroom 2000 environment across Georgia Tech's campus will begin in earnest in Year 3 and will involve a multi-disciplinary effort with several engineering and design departments across campus and will work in conjunction with interested industrial partners. The final task will also begin in Year 4 and continue for the final two years of the proposal. Year 4 will involve understanding the two domains and determining how to adapt our capture, integration, and access tools accordingly with initial prototypes available within one year. Year 5 will involve deploying the prototypes in a realistic setting (such as a museum or metropolitan area, or within a software development company) to begin to assess the utility and observe how interaction patterns change.

2 Scientific background

2.1 Ubiquitous computing and the capture, integration, and access problem

Rather than force the user to search out and find the computer's interface, ubiquitous computing suggests a different paradigm in which the interface itself can take on the responsibility of locating and serving the user. The history of computing is filled with examples of radical paradigm shifts in the way humans interact with and perceive technology (see [19] or [7, Ch. 4] for more complete historical accounts). The vision of ubiquitous computing —first expressed by Weiser [29] and grounded in experimental work done at Xerox PARC— holds the promise of yet another interaction paradigm shift.

Our work on automated capture, integration, and access has been greatly influenced by the work at Xerox PARC in ubiquitous computing [29, 30] and tools to support electronic capture and access of collaborative activities [17, 18]. We want to capture information provided by the teacher during a lecture, so electronic whiteboard capabilities provided by the Xerox LiveWorks LiveBoard [8] are inviting. We also want to provide the students with an electronic notebook with the capability to take notes during the class that could be the basis for review after class. The Marquee note-taking prototype developed at PARC [28], the Filochat prototype developed at Hewlett-Packard Labs [31], and the Dynomite personal note-taking environment from FX-PAL [32] come close to what we wanted to have in the hands of the students. Paper-based solutions to note-taking, similar to the work done by Stifelman [25], are also attractive. The implicit connection between the note-taking device and alternate information streams (audio and/or video) is a common theme that has also been explored at MIT's Media Lab [12] and at Apple [6].

2.2 Applying technology in the classroom

Our technology-driven approach to educational technology contrasts with a more education-driven focus, as demonstrated by Wan and Johnson [27] or by Guzdial *et al.* [10], in which the purpose of the research is to understand and inform theories on learning. In the wider arena of educational technology, there must be both forms of research.

Shneiderman *et al.* [23] discuss the effects of introducing technology into the classroom in terms of the paradigm shifts that result. All of the existing systems they discuss, and all of the attempts we know of, have one common feature that we are trying to avoid. Technology in the hands of the student usually translates into a workstation at each desk. This is appropriate in some cases, but we want to investigate the usefulness of alternative pen-based interfaces that are less intrusive and allow natural handwritten note-taking.

We view the whole classroom experience as a multimedia Web authoring task. This more active use of the Web infrastructure is in tune with some recent applications of WWW technology in education [14, 22, 9]. Our major contribution beyond this existing work is the concentration on in-class capture of information that is to be augmented through coordination with other classroom information via the Web.

Several of the research prototypes cited above have been subjected to some form of evaluation to determine both usability and usefulness. The two most substantial evaluation studies have been conducted at PARC and Hewlett-Packard. For a two-year period at PARC, a suite of tools for capture, automated indexing and integration, and access [17] was used to support a process of intellectual property management [18]. At Hewlett-Packard, the Filochat system was evaluated in field and laboratory studies, generating both qualitative information on the reaction of users to the technology and also quantitative information comparing the accuracy, efficiency and confidence of Filochat with paper-based and dictophone systems [31].

3 Initial prototypes for Classroom 2000

We adopted a rapid prototyping approach to the development of the initial classroom prototypes. A common architectural approach was inspired by the movie industry, in which the development of a single movie is divided into distinct phases —pre-production, live recording and post-production and user access.

3.1 Pre-production phase

We assume that the teacher does some preparation for each lecture. The purpose of the pre-production phase is to transform this prepared material into the desired form for use during the lecture. Any prepared materials that the teacher wishes to display during the lecture or make available to students in class must be transformed into a format that can reside on the available technology (e.g., the electronic whiteboard or the student's electronic notebook).

Teachers are already overworked, so were very concerned with minimizing the impact the technology had on the preparation of lecture materials. Most teachers already have some form of lecture material that they will want to reuse. The more we require a lecturer to recreate that information, the less likely they are to adopt the Classroom 2000 technology. To minimize preparation effort, we use PostScript as the representation for material prepared by the teacher. Public domain utilities can be adapted to transform the PostScript lecture materials into whatever image format is necessary for use in the class.

3.2 Live recording phase

The live recording phase consists of the actual classroom lecture. The most important task to support in this phase is the capture of all relevant activity that will be useful for later review. We initially identified several relevant streams of activity in the classroom — what is heard (audio);what is seen (video); and teacher and student annotations. The classroom must capture these different streams of information as a natural by-product of classroom interaction.

Tools for the teacher

Most classrooms have a whiteboard or overhead projector for public display. A computerized display, such as the LiveBoard or equivalent, makes capture relatively simple. The electronic whiteboard can be instrumented to capture significant classroom activity. For various reasons, we had to write our own electronic whiteboard application, a Visual Basic prototype called ClassPad, whose interface is shown in Figure 1. We used ClassPad to present prepared slides and allow for public annotation by the teacher. ClassPad creates a time-stamped log of when the teacher navigates between slides.

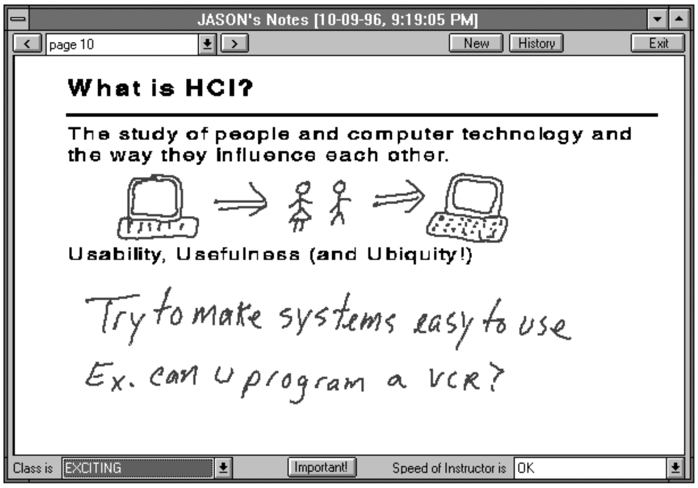

Figure 1: The ClassPad note-taking interface used by both lecturer and students.

Tools for the student

Support for the capture of student notes is also important. We have made a conscious decision to provide only pen-like interfaces for student notes. The main advantage of pen input is that it is much easier to draw arbitrary symbols. The advantages of keyboard input are faster input rates, increased legibility and easier search capabilities. However, we did not want the distraction in class of a cacophony of keyclicks. Future prototypes will likely include a combination of pen and keyboard input.

The ClassPad application runs on any pen-based PC, resulting in the electronic student notebook. The student sees the same information that the teacher put up on the electronic whiteboard and can annotate it with personal comments to make certain points clearer. Students could flip though the class notes the same way the lecturer did (though the units were not synchronized so the student was free to browse the slides at their own pace) and write whatever notes they wanted on top of the slides. The navigation between slides is logged by ClassPad.

3.3 Post-production phase

Once the lecture is completed, we enter the post-production phase. The purpose of post-production is to automatically integrate the different streams of activity captured during the live recording phase. Audio and video records of what happened in the classroom should be automatically linked to the appropriate points in the annotated notes.

Recall that the ClassPad application generates a log of when the teacher or student advances from one slide to the next. When reconstructing the annotated views for later review, these logged events are used to tie the static information (prepared slides with student/teacher annotations) to the audio or video stream associated with that class. Figure 2 shows an example of an automatically-generated Web presentation from a single lecture. The top frame shows thumbnail sketches of all slides from the lecture. The selected thumbnail image is magnified in the lower right frame. The lower left frame is divided into three main sections: a keywords sections shows words associated with the file to facilitate a content-based search; an audio section lists automatically-generated audio links indicating times in the lecture when that slide was visited; and a search link provides access to a search form for simple keyword search across all lecture notes. When an audio link is selected, an audio client is launched and begins playing the recorded lecture from that point in the lecture.

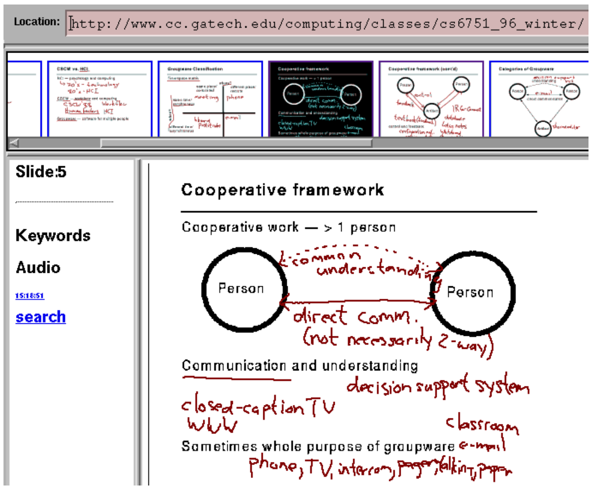

Figure 2: Frame-based Web presentation of non-editable lecture notes (made by student or teacher) with annotations and audio links.

3.4 Access

The final phase involves accessing the integrated material after class. In our initial prototypes, students could view all slides for a given lecture or pull up a set of slides from various lectures that matched some keyword phrase. Keywords match the prepared material on a slide, but could match the audio transcript or handwritten notes (using handwriting recognition to convert notes to text or by use of image matching algorithms. We are eager to investigate searching across material from more than one course, both in response to user demand or automatic system inference based on current activity. At the beginning of a course, a teacher could even find out what topics had already been covered by students in the class and tailor the course content accordingly.

To begin a fair assessment of how capture, integration, and access affects note-taking practices and learning, we need to provide a way for students to revise notes as well as review them during the access phase. Our initial prototypes did not provide this capability, so we will have to extend them accordingly.

4 Evaluation plan

One of the major contributions of this work will be the large-scale application and subsequent evaluation of ubiquitous computing in a significant domain. Specifically, we want measures of usability and usefulness of capture, integration, and access support in an educational setting. Usability tests will answer whether our preconceived notions of how students would interact with the technology are correct. Usefulness measures will test a more significant hypothesis.

The principal hypothesis we are trying to test is whether automated support for capture, integration, and access in the classroom reduces the amount of notes that students take, makes them more effective note-takers and improves their performance in the class. This is a very hard hypothesis to test, but one that needs to be taken seriously. We will describe in this section some quantitative and qualitative evaluation techniques that we have conducted with our initial prototypes and how those techniques will be improved to provide more substantive answers related to our general hypothesis.

We also want to observe trends in how educational behavior changes in reaction to effective use of this technology. Studies at Xerox PARC [18] that spanned two years of use by the same person revealed important note-taking habits of the single scribe. We would like to be able to discover similar habits developing for both teacher and student using Classroom 2000. For example, when all students, or even a significant number of the students, take electronic notes, will student participation in class change in character?

4.1 Quantitative evaluation performed

One of the initial prototypes was used in a graduate HCI course, and the quantitative and qualitative results presented refer to that class. The 10-week class met twice a week for 90 minute lectures [1]. There were 25 graduate students in the class representing a wide variety of disciplines across the Georgia Tech campus. We were unable to supply enough units to provide each student with a pen-based electronic notebook. The number of units varied throughout the course from a minimum of 6 to a maximum of 12 working units. The technology in the class was phased in incrementally, beginning with the LiveBoard, followed by audio recording and, finally, student electronic notebooks. By the third week of class, students were taking electronic notes. Four students (the "Regulars") were selected to take notes using ClassPad on the electronic notebook for the remainder of the quarter, a total of 10 lectures. Four students (the "Reluctants") chose not to take notes electronically the entire class. The remaining students (the "Occasionals") used the other units on a first-come, first-served basis, averaging 2.9 times each.

Students kept a journal of their notes and reactions to the technology throughout the course. At the end of the course, 24 of the 25 students filled out a questionnaire that investigated their reactions to the use of the technology in the class. The objective questions asked about overall impressions of the use of technology in the class and then specifically about the ClassPad note-taking application and the use of the LiveBoard with Web-based review notes. These questions were rated on the following scale: 1 (strongly disagree); 2 (disagree); 3 (neutral); 4 (agree); and 5 (strongly agree). We asked questions about overall impression, ease of use, whether the technology made aspects of the class more effective, how the technology affected class participation and whether the technology contributed to learning the particular subject matter of the course (in this case HCI). Table 1 summarizes the results of the objective portion of the questionnaire.

	Topic (# of questions)	**Avg.(σ)**
O	Was desirable technology (11)	3.67 (.98)
	Was easy to use (2)	3.02 (1.23)
	Increased effectiveness of class (9)	3.62 (.99)
	Improved class participation (2)	3.40 (.88)
	Contributed to learning subject (2)	3.94 (.86)
N	Was desirable technology (1)	3.13 (1.03)
	Was easy to use (3)	3.13 (1.14)
	Increased effectiveness of class (1)	2.88 (.90)
	Helped me take fewer notes (2)	2.85 (.87)
L	Was desirable technology (2)	3.87 (.82)
	Was easy to use (3)	3.68 (1.09)
	Increased effectiveness of class (1)	3.29 (1.04)
	Helped me take fewer notes (2)	2.88 (1.00)

Table 1: Reaction of students to overall technology (**O**), electronic notebook (**N**) and LiveBoard with Web notes (**L**).

The results show an overall positive reaction to the prototype. The strongest positive reaction is in how the prototype was perceived to contribute to learning the particular subject matter, and this is not surprising. The course was on HCI and the students were themselves experiencing a new interface in the classroom. In addition, the project work was based on developing and evaluating ideas for new prototypes, and the students appreciated the authenticity of redesigning a system they were currently using.

Of all technology involved in the class, our initial observations show that the students were most negative toward the personal electronic notebooks (see the presentation on qualitative evaluation for justification). The LiveBoard and Web notes together comprised the most desirable technology from the students' perspective.

The results of the survey questions indicate that the Reluctants had the most positive overall impression of the effectiveness of the technology and the Regulars had the least positive (though still favorable) reaction.[1] One reason for this, as discovered in follow-up interviews, was that the Reluctants received a lot of benefit without any additional effort in class. In fact, many students noted that simply having the lecturer's notes available after class relieved them of the burden of taking any notes at all. The Regulars, on the other hand, reported that they spent much more time writing notes in the electronic notebooks even if those same notes were available from the lecturer's notes. Though we can think of some arguments to justify these results, the truth is that we need to be more thorough in our own observations before we can draw any conclusions.

4.2 Further quantitative evaluation plan

Comparisons across frequency groups (Regulars, Occasionals, and Reluctants), provide a good opportunity for a more controlled experiment.[2] Our division into the frequency groups can be done less arbitrarily if we first determine note-taking practices of the students prior to exposure to the Classroom 2000 technology.

Use of audio in our original prototype was limited because we did not provide cross-platform access. This has been solved, and we can now generate per student logs of access to Web notes and use of the audio. Any conclusions about improved student performance can now be evaluated against use of the capture, integration, and access technology.

We can generate quantitative information on use of the technology to determine trends in note-taking. We can count the number of annotations (letters/words or symbols) that appear on each slide for a student and see if the annotations per slide average changes with extended use. We can also determine if there is any relationship between a changing average and access to the Web notes after class. We can compare student notes to the lecturer's notes to determine the level of redundancy between the two. Since the lecturer's notes are available to everyone after class, in theory students need not copy that information during class in their own notes. By comparing a student's annotations to the lecturer's annotations, and marking each slide on a scale of similarity (from no similarity to identical), we can track whether students begin to treat the lecturer's notes as an available resource that minimizes their own note-taking. [3]

To evaluate the impact on learning, we need to be able to measure how well students learn the material for the course. In the case of the graduate HCI course, there are typically two examinations during the quarter. The mid-term exam is a closed book, mainly objective test of accumulated knowledge on several areas in HCI. We will give a pre-test at the beginning of the class that is similar in content to the actual mid-term exam. This will allow us to determine how much student's increase their knowledge in the subject matter. We can then compare knowledge increase to use of the technology to note any trends.

For more long-term trends, we will trace student access to notes after a class has completed. For example, since the introductory HCI course at Georgia Tech is a prerequisite for another course on usability evaluation, we can track how much students who used Classroom 2000 technology accessed notes from prior classes.

4.3 Qualitative evaluation performed

The post-course questionnaire used in our preliminary studies also asked for subjective input on a number of topics concerning the use of technology in the class.

Use of the LiveBoard for several in-class usability evaluation exercises and the group presentations at the end of the class were both very popular. Both of these activities involved more than just the teacher

[1] These results based on frequency groups are not statistically significant because the sample sizes for the Regulars and the Reluctants was too small).

[2] This is a fortunate consequence of not having enough funds to put a unit in every student's hands.

[3] We recognize, however, that for some students it is the act of writing the notes in class that reinforces the memory, so we don't expect to reduce notes for all students. Our note-taking strategies questionnaire will identify that class of students.

interacting with the LiveBoard. Many students did not feel the LiveBoard was any better than an overhead or chalkboard when used exclusively by the teacher in a lecture mode.

The majority of the electronic notebooks used in the class were palmtop PCs (specifically, Dauphin DTR-1s with a 7-inch diagonal screen) and while the students found them good for drawing pictures, in general the screens were too small for writing legible notes. In addition, the response time of the units was slow relative to the LiveBoard. This made it difficult for students to navigate between slides as easily as the teacher.

Students found the Web-based review notes interesting in their novelty and useful for examining their own notes and the teacher's notes, especially on occasion when they missed class or did not pay close enough attention to some point during class. Despite the relative ubiquity of Web browsers on campus and in student rooms, several students still desired to have a printed copy of their notes.

Quantitative analysis of the electronic notes revealed that that initially most students would copy what the teacher was writing on the LiveBoard. When questioned about this afterwards, several students who used the electronic notebook throughout the class noted that they felt their note-taking became more economical as the course progressed. This is in spite of an apparent lack of use of the audio features. Upon further investigation, these students revealed that even without audio services, merely having the teacher's notes available after class saved them from the sometimes mundane task of copying. We will look in the future to see if the use of audio causes even more dramatic changes to the notes.

From the instructor's perspective, there were several advantages and disadvantages. The ClassPad application running on the LiveBoard was easy to use and was responsive enough to allow for a natural level of interaction. All of the lecture material for this class was available from a previous section of the course, but as the quarter progressed, it was judged necessary to modify the format of the slides. At the request of several people, the slides were redone to increase the amount of whitespace available for making annotations and the ability to insert a new blank page for notes after a current slide. On several occasions, there were no prepared lecture slides and we used ClassPad to provide a normal blank whiteboard capability.

4.4 Further qualitative evaluation plan

One improvement over our previous evaluation plan is to monitor more closely the students in the Regulars group. We will conduct longer interviews with each of these students before, during and after the course to gain a clearer insight into their views on the use of technology. We will pay particular attention to how those students perceive a change in their own note-taking and review habits. We will study the notes that they do take in class and how they are modified after class. Students who take follow-on courses will be interviewed during the follow-on course to see what their reactions are to the usefulness of the notes from the previous course and if they ever felt the need to modify the old notes to create links to later classes. Of particular interest here is whether they found searching techniques useful at all.

Another gauge of note-taking trends is to see how note-taking practices differ between those using the electronic notebooks and those annotating paper copies of the lecture slides. At least twice during a course, once near the beginning of the course and once near the end, we can collect notes from students annotating on paper and compare them against the electronic notes. We will be looking for characteristic differences in the electronic notes from the paper notes, particularly as the course progresses.

In later stages of this project, when we are able to provide support for a series of courses, we will be able to track how student note-taking practices evolve. We will also look to uncover how teaching practices change to suit the new technology. Though we can suggest a number of more serious evaluation measures, a very good measure of the impact of Classroom 2000 will be in how many different classes we will be able to continually support over the span of 5 years.

5 Extending capabilities in Classroom 2000

There are a number of ways in which we intend to improve the technology of our initial prototypes as we develop the Classroom 2000 concept. We will briefly outline a number of them here.

The static nature of slides in the presentation teaching style makes it easy to automatically generate audio links. For other teaching styles, it is not always a simple matter to attach the audio links to parts of the prepared material (see the discussion of the registration problem in Section 3.2).

Different student notebooks

We have investigated the use of smaller PDA-style electronic notebooks, such as the Apple MessagePad. Resolution and physical size of the screen are important, especially if we are going to mimic students annotating on top of prepared slides. There are several very interesting pen-based platforms that will soon be available and we will experiment with most of them. From our initial studies with the MessagePad, it is likely that different note-taking styles will have to be supported. We will need to be able to simultaneously support these different pen-based devices in the same class and different note-taking style.

Support for dynamic information

We provide good support for the display and annotation of static information. What if the teacher wants to show a video or run a computer simulation? During the presentation of this dynamic information, the teacher may indicate some important activity and the student would want to index the video image, perhaps even annotating a static frame as well. The Marquee system at Xerox PARC provides suggestions for how to do this integration between audio and video, and the approach is very similar to how we currently associate static notes to the audio stream [28]. But annotation of the dynamic information itself is not supported by any existing system.

Providing a larger electronic whiteboard

The LiveBoard is an excellent electronic whiteboard, but it has been designed for small meeting groups. Many lecturers typically use larger whiteboards that are at least three times wider than the LiveBoard and provide greater resolution. A larger whiteboard surface provides more persistent information for students and teachers to refer to. It is currently too expensive to suggest using multiple LiveBoards, but there are more cost-effective techniques for proving a larger electronic whiteboard. We will experiment with hybrid approaches that involve using a LiveBoard as the main interaction surface and multiple low interaction projection surfaces to extend the visible persistent display. In coordination with LiveWorks, Inc., the manufacturer of the LiveBoard, we have organized a multi-disciplinary project team across campus to help them better position their product for use in higher education. The larger surface area is one of the critical decisions we will explore.

Support for varying teaching and learning styles

Widespread use of capture, integration, and access in education requires that we expand the Classroom 2000 prototype into a family of system to support a wide variety of teaching and learning styles. We have examined several common teaching styles with respect to the challenges they present for capture, integration, and access. One of the main distinguishing features of a teaching style is the form of materials, if any, that are made available to students, either before or after the lecture. If material is made public, then we can augment it (using audio or video links, for example) with information captured during the lecture. If no material is made public, then we can only augment information that is produced as part of the lecture itself. We have suggested a number of prototypes for different teaching styles [4].

Just as teachers have different styles for teaching, so too students have different styles for learning. We have identified several different recording, or note-taking, styles that a student could employ (verbatim, highlighting and none), distinguished by the amount of recording that goes on. There are other distinguishing dimensions for note-taking, such as whether students use non-textual symbols or other graphics, and whether students modify their notes or otherwise use notes as a means of review.

Increased network capability

Networked interaction between users in a collaborative environment has been specifically explored in the DOLPHIN project, in which a LiveBoard is connected to remote information sources [26]. All of our prototype student notebooks have not had any network capabilities. The lecturer's whiteboard has often had network capabilities and this has been very useful for investigating information available on the Web during class. We strongly suspect that networked capabilities would be advantageous for the student as well, and would allow for much more interaction in class, both for information foraging and for exchanging information in class. To test this hypothesis out, we are building a special classroom with Ethernet capabilities to all student seats. The most recent pen-based technology will allow us to easily network all units in the classroom. We have built a prototype Java-based alternative to the ClassPad application which runs inside a Web browser.

Capturing context

Providing context-aware functionality is another important issue in ubiquitous computing [21]. Most context aware applications focus on location of the user (for example, our own work with the Cyberguide tour assistant [15, 16]. There are other notions of user context that can be useful in the classroom. The student could be affected by the pace of the lecture (either it is too slow or too fast) or by the content (too boring or very exciting). The ClassPad interface in Figure 1 provides the capability for the student to explicitly provide this context. Capturing this information can help a teacher better understand how students are reacting to the delivery and content of a lecture. In a networked situation, this might result in anonymous feedback to the lecturer to change pace or switch topics. As a summary across a number of classes, it might indicate trends in a class (e.g., everyone thinks the pace is too fast after about 20 minutes into the lecture, regardless of topic) that can be improved or highlighted. Simple histograms of pace and content indicators can also be linked to the material in the class, so the teacher could uncover exactly what was going on when the pace was inappropriate.

6 Open issues in capture, integration, and access

Apart from the educational impact of the ubiquitous computing technology proposed in Classroom 2000, we can see some issues of more general concern to the capture, integration, and access problem in ubiquitous computing.

Granularity of integration

We currently provide were only able to provide audio links at the level of granularity of an individual slide. Every time a slide was visited by the student (or teacher) the log file was updated and an audio link with the associated time would appear in the Web notes. Other capture, integration, and access systems provide a finer level of granularity, ultimately allowing any gesture (pen-down to pen-up) to produce an index into the audio or video stream. The reason we did not provide such functionality was technical (the Visual Basic ink object would not provide the information necessary), but it is not clear that the fine-grained indexing is optimal. Typically, the sound most closely relating to some annotation precedes the timestamp of the annotation itself, so there needs to be some intelligence in generating the link between annotation and audio. In our homegrown audio server, we took a first approximation at this intelligence by detecting the first pause in the audio track prior to the index point and beginning the audio stream from there. This was to simulate the beginning of a phrase or sentence by the speaker. Other researchers do not directly address how effective the fine-grained indexing was for the users during the access phase, though one report does note conventions in note-taking adopted to allow the user to be reminded how to adjust the system's timestamp to a more relevant audio index [18]. There will also be links generated that are not time related, one example of which we address next.

Support for revision during access

In our prototype, the Web notes were static, meaning that no additional information could be added to them after class. Upon reflection, this was obviously a bad choice, since it is common for some students to revise and rewrite their notes. In fact, the whole purpose of the audio-enhanced notes is to support this revision. Our later prototypes now support the ability to modify notes during review.

This additional capability introduces a subtle problem related to the granularity. How should notes referring to the past be integrated with streams captured in the past? This problem already appears during the classroom or meeting session, especially when each gesture provides a time-index into audio. If a student goes back to some notes during class to modify them (perhaps adding some more words for clarity), should a new timestamp be generated that now points to a different part of the lecture, a part that may in no way be relevant to the revised notes? When modifying notes after class, what if the student simply wants to rephrase some of their notes but retain the link to the audio from the original gesture? In this case, static slide-level audio links might be preferred, or assigning timestamps to gestures that approximate the nearest neighbors. There are certainly some strategies that can be adopted, but how is this done in a way that predicts but does not interfere with the intention of the user? That is a very difficult question, complicated by our lack of experience as users of audio-enhanced notes.

Supporting networked interaction

In a multi-user situation such as the classroom, there are many people taking notes. If we network all of the note-taking units, then a lot of interaction modes are possible, but which are useful? For example, we could allow students to "copy" the teacher's notes. Our analysis of student notes showed that a large number of them merely copied on their slides what was written by the teacher. This makes sense in a situation where the teachers notes are completely lost after the class. An electronic whiteboard solves that persistence problem, and some students (but not all) explicitly requested this copying service to allow them to pay more attention in class.

Students in the class also suggested the possibility of providing anonymous feedback during the lecture, to indicate whether the pace of the lecture was satisfactory or whether the material was boring or interesting, or to post questions that they might not otherwise ask. Real-time feedback during a lecture, if used properly, could actually improve a class. Even disregarding the real-time feedback, logging student reactions to lecture pace and content can be used to modify lectures later on, providing a service to the teacher that would otherwise be difficult to obtain.

7 Existing support and collaboration for Classroom 2000

Financial and collaborative support for this proposal comes from both inside and outside of Georgia Tech. Inside Georgia Tech, collaboration and financial support comes from the GVU Center (initial seed grant for work that contributed to this proposal), the EduTech Institute (personnel to assist in developing and executing evaluation plan) and the Office of Information Technology (funding from the State of Georgia to renovate classroom).

Outside of Georgia Tech, support for this proposal comes from NEC (funding for Visiting Scientist and student to work on initial prototypes), Xerox PARC (research collaboration with Tom Moran's group), FX Palo Alto Laborator (collaboration with Bill Schilit's group and $25,000 support), LiveWorks, Inc. (collaboration and potential seeding of equipment from John Knights, VP Customer Operations), and Nortel (proposed collaboration for investigation of design capture with Steve Ornburn).

8 Previous accomplishments

As Weiser points out, "Applications are of course the whole point of ubiquitous computing." [30] Fueled by this statement, and somewhat perplexed by research in mobile computing that is lacking any strong applications focus, [4] the PI established the Future Computing Environments (FCE) Group at Georgia Tech to investigate and invent applications of ubiquitous and mobile computing technology.

In addition to the capture, integration, and access problem, we have also identified two other principal research themes for ubiquitous computing that have emerged from our applications perspective: [2]

- customizing computational services based on knowledge of the user's physical context; and
- providing ubiquitous software services that are available on many different physical devices and integrated with a changing set of other services.

[4] peruse recent proceedings and edited texts on mobile computing that are mostly dominated by network and operating systems researchers [5, 13]

The Cyberguide project is an example of a context-aware application, using positioning and history to deliver better tour guide services [16, 15]. The CyberDesk project is an example of the automated integration of desktop and network services provided through a Web/Java interface [33].

Education Plan

9 Educational Objectives

A large part of the educational plan is intimately tied into the research plan involving the Classroom 2000 proposal. My additional educational objectives are to contribute to a global culture of excellence within the undergraduate community through my own local teaching efforts in the areas of Software Engineering and Human-Computer Interaction.

Educational philosophy

The Graphics, Visualization and Usability (GVU) Center that I belong to has recently been recognized as having the top graduate program in the Graphics: User Interaction category,[5] yet there is the perception that this exciting research culture has not included one of our greatest resources —an undergraduate population that is by some measures one of the most talented of any public institution in the country. The State of Georgia is undergoing a transition from the quarter system to the semester system, so the College of Computing is in the midst of rethinking its entire curriculum to prepare for the transition. The faculty has taken the opportunity to open up a discussion on why our current curriculum does not lead to an undergraduate culture of excellence and how it can be changed.

The titles and content of the courses we teach do affect the quality of students we produce. However, a more important factor is how we as individual faculty approach the way we teach. Education should be an engaging experience, both for the student *and* the teacher [11]. Rather than thinking mechanically about which topics in computation appear as course titles and (more seriously) in the content of various undergraduate courses, a faculty needs to think about how to take any course and engage teacher and student in the subject matter. If, for example I believe that aspects of Graphics, Visualization and Usability crop up in a lot of subjects, then I should be able to demonstrate the link to students through the courses I teach.

The most important aspect of a curriculum is relevance and variety. By relevance, I mean having students apply the foundational knowledge in one course to problems that are justifiably real. By variety, I mean that students have to have freedom in deciding what problems to work on. I believe in project-based learning, as do most of my colleagues. I do not like the idea of defining single projects for an entire course, as is often the practice, because that takes away student freedom. Give students the freedom to choose projects and I believe they will choose relevant ones, and most likely they will be more committed to doing a good job.

Relevance and variety do not represent a shirking of the responsibility to teach foundational topics in computation. If a topic is fundamental, then it will appear in just about any project a student would choose to do properly. Our mission as educators is to help students see how the the fundamental problems appear in many different problems. Also, relevance and variety means a *lot* of effort on the part of the faculty. You can not assume the projects you did in a previous version of a course will suffice for the next iteration of the same course. It takes time to help students pick different project topics and even more time to assess a wide variety of project deliverables, and that is time that comes away from research. To reconcile this apparent conflict, the solution is to encourage students to do projects that are relevant to my research goals. This philosophy has served me well over the past few years. I am a better educator as a result and a more productive researcher.

[5] Refer to recent U.S. News and World Report rankings for America's Best Graduate Schools, www.usnews.com/usnews/fair/gbcomspe.htm.

10 Educational Experience

Teaching

From October 1992 until August 1994, I was a non-tenure track faculty member with the Master of Software Engineering Program at Carnegie Mellon University. In my second year, I developed and taught a new course on comparative software development methods with David Garlan and Daniel Jackson. In collaboration with colleagues at the Software Engineering Institute, I developed a scenario-based method for software architecture evaluation that has been very well-received by industrial collaborators and been delivered as tutorials at several industrial symposia.

As a result of my postdoctoral experience with the Human-Computer Interaction Group at the University of York, I have coauthored a textbook on Human-Computer Interaction, published by Prentice Hall, International in 1993. This textbook is now one of the leading textbooks in the United Kingdom, having sold in excess of 7000 copies with a second edition in the works. Complete teaching materials are included with the book, and it is the basis for the undergraduate and graduate HCI courses taught at Georgia Tech.

I teach courses on object-oriented programming (Smalltalk and Java), Software Engineering and Human-Computer Interaction at both the undergraduate and graduate levels. All of my courses have significant group project components and nearly all projects involve some aspect of research related to the FCE effort I direct. I have experimented with prototypes of Classroom 2000 technology in both the programming course and the HCI course.

Student supervision

I supervise two Ph.D. candidates and one Masters thesis all in the general area of ubiquitous computing. My activities leading the Future Computing Environments Group provides me the opportunity to supervise many different graduate and undergraduate directed research topics. Each quarter, I supervise an average of 4 different graduate or undergraduate students projects. At the undergraduate level, there are 2-quarter design projects. Many of the Cyberguide prototypes have resulted from these projects and some of the initial Classroom 2000 prototypes were developed under this context.

Personal educational development

I recognize the importance of the Java programming model for the Internet and have taken steps to educate myself and my students in the fundamentals and possibilities. I will continue to keep myself current on emerging Internet technologies because that area provides a lot of material to help me address my personal educational philosophy of providing relevance and variety to students in my classes.

Industrial involvement

I am Associate Director for External Relations for the GVU Center, with primary responsibilities to provide access to and information on the GVU Center to prospective industrial collaborators. I am a representative on the Broadband Telecommunications Center (BTC) on campus, a statewide center of excellence for the promotion of broadband applications to the home environment. The BTC also has a large industrial sponsorship and I have specifically nurtured relationships with Intel, Kodak and Wink Communications based on projects from the Future Computing Environments Group that are relevant to the BTC vision of the home environment and education.

11 Summary of planned activities

Courses

I will contribute to the definition of the Software Engineering and HCI curriculum as we transition from a quarter to semester system. The semester transition is to be proposed by mid-1997 and implemented starting Fall semester 1999.

Student supervision

I will take on no more than one new Ph.D. student per year, but expect to begin co-supervising students with a number of faculty members over the next five years. Within three years, I expect to begin graduating Ph.D. students in the area of ubiquitous computing with emphasis on both software engineering and HCI topics.

I will continue to engage in research activities with a number of masters and undergraduate students. The FCE Group will begin to sponsor weekly software and hardware design sessions at night in addition to the weekly seminar series that has been going strong for 18 months.

Personal educational development

In addition to keeping myself abreast of emerging Internet and ubiquitous technology, I am committed to providing a wider systems development perspective to students in my project classes. This wider perspective includes aspects of marketing and business planning, industrial design, hardware design, group dynamics and communication in addition to software engineering principles. The Manufacturing Research Center at Georgia Tech is a leader on campus in developing such interdisciplinary design teams for real world projects. There is relatively little software development expertise in these design teams and I will be working over the next few years to incorporate these design group projects with our own software engineering projects at both the graduate and undergraduate levels.

Industrial involvement

We are currently negotiating with Motorola Corporation to set up a future computing design lab at Georgia Tech. This is a collaborative effort joint with Motorola and the University of Maryland, the University of Virginia and Michigan State University. Georgia Tech will provide the venue for rapid prototyping of advanced concept products that are in the commercial interest of Motorola.

We have also initiated a relationship with LiveWorks, Inc. to provide research and development work to advise them on how to make a greater impact with products such as the LiveBoard in the higher education arena.

Research on teaching effects

This has already been extensively discussed in the research portion of this proposal.

Departmental Endorsement

It gives me great pleasure to support the application of one of our most outstanding junior faculty members, Dr. Gregory Abowd, for a NSF Career award. Dr. Abowd is beginning his third year of a faculty appointment in the College of Computing, and in the short time he has been here, this former Rhodes Scholar has made outstanding progress in establishing his own research program as well as helping to shape the research directions within the College as a whole. He had a significant research record in applications of formal methods and software architecture upon arriving at Georgia Tech, and has since demonstrated tremendous promise in ubiquitous computing research.

Gregory serves as founder and leader of the campus Future Computing Environments Group. Modest seed funding from me resulted in the Cyberguide system, a mobile, location-aware tour guide to assist visitors to our monthly demonstration days within the GVU Center. Inspired by the success of Cyberguide, Gregory's group then commenced an even more ambitious project to incorporate advanced technology in education, and that work has lead to his very bold and exciting proposal of Classroom 2000. We have decided to renovate one of our own classroom's using state and university funds to directly support the research and teaching efforts of Classroom 2000. This work has excited a lot of people on campus and is an excellent example of how research excellence can lead to educational innovation.

Gregory has identified three major research issues in ubiquitous computing emerging from an applications perspective. While many other researchers in mobile computing worry about systems issues associated with wireless IP, for example, Gregory leads a group that is concerned with how wireless capabilities transform interaction capabilities.

Gregory's outstanding publication record is evidence of another important characteristic; he is an extremely effective collaborator, often times with researchers and students from rather varied academic backgrounds. On a recent visit to a number of Silicon Valley companies and labs, I discovered that Gregory's work was known to and respected by a large number of leading researchers.

As further evidence of the high regard we have for Gregory's work and his clear potential for success, the College has made the following commitments to him. We shall fund his academic salary in each year of his appointment, and provide three months of summer support at the end of this first year. The Institute committed close to $40,000 in "start up" funding to Gregory to help him advance his research agenda. Should this proposal be funded, the Institute has committed an additional $50,000 in equipment matching funds, in addition to the funds already allocated for classroom renovation. Our faculty enjoy a relatively light teaching load of four courses per academic year. This is designed to permit them time to devote to research. The College will be allocating up to $1,250 per year to him to support travel and other discretionary expenses. In addition, I have shown my personal support for Gregory's work by taking out of my own discretionary funds to provide him with occasional grants to bootstrap new efforts. I firmly believe that these small grants to Gregory have been some of the wisest investments of my professional career.

The College is committed to supporting the research career development plan outlined in Gregory's statement. His research efforts have already made an impact on the HCI and software engineering communities and I expect that the career of this exceptional young scientist will be marked by major scientific contributions. Your serious consideration of this proposal would be most appreciated, as I am convinced Gregory has the profile of a successful Career Award recipient.

The effective date of appointment for Gregory Abowd was September 15, 1994.
I have read and endorse this Career Development Plan.

Peter A. Freeman   Date
Dean, College of Computing

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Biographical Sketch

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October 1996

Professional Information

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Education

1991 D. Phil. in Computation, Programming Research Group, University of Oxford.
Thesis: *Formal Aspects of Human-Computer Interaction*. Mr. Bernard A. Sufrin, supervisor.

1987 M. Sc. in Computation, Programming Research Group, University of Oxford.
Thesis: *Arabic Word Processing*. Dr. J. M. Spivey, supervisor.

1986 B. S. (*summa cum laude*) in Honors Mathematics and Physics, University of Notre Dame.

Positions

Georgia Institute of Technology
Assistant Professor, College of Computing, September 1994–present.

Carnegie Mellon University
Visiting Scientist, Software Engineering Institute, September 1994–present.

Carnegie Mellon University
Joint Postdoctoral Research Associate, Computer Science Department and Software Engineering Institute, October 1992–August 1994.

University of York, England
Research Associate, Human-Computer Interaction Group, Department of Computer Science, October 1989 – September 1992.

Honors and Fellowships

1994 Georgia Tech nomination for NSF Presidential Faculty Fellowship and Packard Fellow.

1986 Rhodes Scholarship, Marshall Scholarship (declined in favor of Rhodes), NSF Graduate Fellowship (declined in favor of Rhodes).

1985-6 University of Notre Dame Department of Mathematics Prize for outstanding Mathematics Student in the College of Science.

1985 Phi Beta Kappa.

Publications most relevant to this proposal

Gregory D. Abowd, Christopher G. Atkeson, Ami Feinstein, Cindy Hmelo, Rob Kooper, Sue Long, Nick Sawhney and Mikiya Tan, Teaching and learning as multimedia authoring: The Classroom 2000 project. *Proceedings of Multimedia'96*. To appear.

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Gregory D. Abowd and Alan J. Dix. Integrating status and event phenomena in formal specifications of interactive systems. To appear in proceedings of *SIGSOFT'94 Symposium on the Foundations of Software Engineering*, New Orleans, LA, December 1994.

Recent collaborations

Larry Howard and Linda Northrop, Software Engineering Institute, Carnegie Mellon University.

Budget Justifications

Salaries

PI salary and postdoctoral and graduate student stipends are based on 1996 rates and projected increases of 5% for each of the five years of the proposal. Fringe benefits are charged at the rate of 24.7% on faculty salaries.

The yearly budget for this proposal contains one month of summer faculty support for the PI and support for one graduate student to work on all parts of the technical proposal in each of the five years.

The EduTech Institute at Georgia Tech is a separate unit that sprung out of research on educational technology in the College of Computing. EduTech postdoctoral students provide tremendous experience in evaluating the impact of technology in the classroom. In recognition of this valuable campus resource, and following the guidelines of a recent NSF report on evaluation in education to provide 5-10% of a project budget for serious evaluation [24], we have included one month's postdoctoral stipend per year beginning in the second year of the proposal to assist our evaluation efforts.

Travel

Travel funds are requested for the PI and graduate student to attend one conference apiece for each year of the project. These conferences include the annual SIGCHI conference, the ACM Multimedia conference, and the bi-annual CSCW conference. Estimated expenses for these trips is $1500 dollars which will cover airfare, conference registration, hotel accommodation and a per diem for food.

Computing Charge

Support for computer services is charged at a rate of $2,220/full-time equivalent for 1995, with projected increases of 5% per year.

Equipment

We have requested an equipment budget in this proposal for necessary equipment in the Classroom 2000 project. The total amount requested from NSF is $97,000 over the course of the five year proposal with a majority of this money front-loaded in the first two years. The University and College of Computing will provide matching funds for the amount of $50,000. The total equipment budget of $147,000 will be used to provide ubiquitous computing infrastructure to the Classroom 2000 project. Specifically, in the first year of this proposal, we intend to purchase a LiveBoard. The retail price for this unit is currently $47,000. The remainder of the equipment money requested is to purchase pen-based units for the individual seats in the classroom. The classroom is equipped to seat 40 students with full Ethernet connectivity. We intend to experiment with different pen-based platforms, specifically a Windows 95 platform and an Apple Newton OS platform. The pen-based unit with adequate memory and performance characteristics is the Fujitsu Stylistic 1000, the only general purpose pen-based unit that supports Windows 95. Each unit retails at $3440. We are budgeting for 20 of these units. In addition, we anticipate the arrival of the latest Newton-based product within the coming year, targeted for an educational market and priced at $800. We have budgeted to purchase 39 of these units to nearly fill the classroom.

In addition to providing the necessary infrastructure for the research and educational objectives of the PI, this equipment money will provide the University with a resource in the form of a fully-enabled Classroom

2000 prototype environment.

Facilities, Equipment and Other Resources

The College of Computing at the Georgia Institute of Technology provides an ideal environment for the proposed research because of the extensive computational facilities available and the concentration of colleagues working in Software Engineering and Human-Computer Interaction. Two research centers within the Institute — the Graphics, Visualization and Usability Center (GVU) and the Software Research Center (SRC) — provide strong evidence of the major commitment the Institute has made towards furthering research and education in both Software Engineering and Human-Computer Interaction.

The GVU Center, headed by Professor Jarek Rossignac, is unique in its interdisciplinary focus, bringing together roughly 30 faculty and researchers and nearly 100 graduate students from the College of Architecture, School of Civil Engineering, College of Computing, School of Industrial and Systems Engineering, Office of Information Technology, School of Literature, Communication and Culture, School of Mathematics, Multimedia Technology Lab, and School of Psychology. The GVU Center runs a lab which houses a variety of graphics and multimedia equipment, including high-performance systems from Silicon Graphics, Pixar, Sun, Hewlett-Packard, Digital, Apple, and Intel, as well as extensive video and audio facilities for recording and editing.

The Software Research Center (SRC) within the College of Computing serves as a focal point of research designed to enhance both the state-or-the-art and the state-of-the-practice of software engineering through industrial liaisons, education and research. Its staff includes nine faculty and eight graduate research assistants. One of the principal research areas is in Human-Computer Interaction which is manifest in several jointly appointed faculty in SRC and GVU (including the PI). The SRC runs the Open systems Lab which was established in 1993 to study problems in technology and systems transfer. The mission of the lab is to identify, track and participate in the development of relevant Department of Defense and industry standards and to assess the availability and maturity of open systems software. Areas of current research include standardized operating systems, open systems communications and networking, user interface migration, business process reengineering, reverse engineering and tool support, and distributed databases.

The College of Computing maintains a variety of computer systems in support of academic and research activities. These include Sun systems used as file and compute servers, eight of which are quad-processor machines, and an Epoch file server with a read-write optical library unit. In addition, there are more than 200 workstation class machines from Sun, Digital, Hewlett-Packard, Silicon Graphics, and IBM, as well as numerous smaller systems and over 125 X Window terminals.

A number of specialized facilities augment the College's general-purpose computing capabilities. These include the GVU and Open Systems labs, as well as the High-Performance and Parallel Computation Experimentation Laboratory (HPPCEL) All of the College's facilities are connected via local area networks which, in turn, are linked to a campus-wide network, providing access to systems throughout the Georgia Tech community. As a NSFNET and SURAnet backbone site, the campus networking facilities provide a direct connection to the Internet, offering a means of high-speed communication with the scientific community worldwide.

Additional computing facilities are provided to the Georgia Tech campus by the Office of Information Technology, including several public-access clusters of Apple, IBM, Dell, and Sun workstations, a Sun SPARCcenter 2000 with 12 superscalar RISC processors, CDC Cyber 990 and IBM ES9000 mainframes, and public-access interactive terminals. All are connected to the campus network, which provides direct communication with the Internet, as well as BITNET and Usenet.

The Office of Information Technology has provided funding from the State of Georgia to renovate a classroom in the College of Computing to directly support the efforts of the proposed Classroom 2000 initiative. This classroom provides state-of-the-art presentation equipment, audio and video recording facilities, full networking for 40 students seated in conventional lecture-style rows, as well as 10 design stations around the periphery of the room to support project-based work.

Current and Pending Support

Current support

1. Software Architectures for global information systems
   Sponsor: Motorola PI: Gregory Abowd
   Amount awarded: $27,389
   Award date: September 1996
   Duration: one year, with renewable yearly

2. MORALE: Mission Oriented Architectural Legacy Evolution
   Sponsor: DARPA (EDCS program)
   PIs: G. Abowd, A. Goel, W. M. McCracken, M. Moore, C. Potts, S. Rugaber and L. Wills
   Amount awarded: $1,226,108
   Award date: July 1996
   Duration: 40 months

3. Ubiquitous Computing Research
   Sponsor: FX-PAL (part of GVU Center Industrial Affiliates Program
   PIs: G. Abowd and C. Atkeson
   Amount awarded: $25,000
   Award date: September 1996
   Duration: 1 year

4. Support for Classroom innovation
   Sponsor: NEC (part of GVU Center Industrial Affiliates Program
   PIs: G. Abowd and C. Atkeson
   Amount awarded: $30,000
   Award date: December 1995
   Duration: 1 year

Pending support

1. Voice intensive applications for the mobile user
   Sponsor: Motorola, Cellular Infrastructure Group
   PIs: G. Abowd and C. Potts
   Amount proposed: $99,869.15 (plus equipment)
   Duration: 1 year

2. Use of automated capture and access tools to support design recovery
   Sponsor: Nortel
   PIs: G. Abowd and S. Ornburn
   Amount proposed: $354,123
   Duration: 3 years

3. Collaboration Technologies MetaCenter proposal for NCSA NSF bid
   Sponsor: NSF
   PIs: G. Abowd, J. Hardy (NCSA) D. Mittelman (Arizona), B. O'Keefe (Illinois) and G. Olson (Michigan)
   Amount proposed: $506,000 (Georgia Tech portion)
   Duration: 5 years

Special Information and Supplementary Documentation

Attached are letters of support from Xerox PARC and FX-PAL.