Supporting Distance Education over the Internet

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Abstract

Distance education has been the topic of much research in the past years. However, much of this research has been aimed at constructing distance education environments that require high-bandwidth network connections and specialized equipment. Use of these systems has so far been largely limited to a few well-funded research groups, while many educational institutions, particularly in less developed countries, have been deprived of this possibility altogether. The advent of the Internet, however, has brought an affordable medium to these organizations and enabled distance education without the need for costly equipment and networks. Due to the inherent bandwidth limitations, systems that work over the Internet are necessarily more limited in their possibilities for delivering distance learning to students, and are unable to produce the same rich educational experience of the more costly systems. To alleviate these problems, we have developed a distance learning system that makes use of replicated databases and speech synthesis to overcome some of the limitations of Internet-based systems and to deliver a richer and more acceptable learning experience.

Keywords: Distance education, Internet, speech synthesis, replicated databases, groupware.

1 Introduction

Research in distance education has been going on for several years. Distance education is perceived to bring benefits to both schools and students—schools, because an entire school can run out of a small building and thus save costs; and students, because those who lack the time to travel to a campus, or who are geographically too far away, have the opportunity to take a course of study nonetheless [4, 9]. Various technical solutions for supporting distance education have been devised, ranging from television broadcast—the open university approach—to sophisticated two-way interactive virtual classroom systems. Interactive real-time systems have a special appeal as they enable a more active and stimulating learning environment than traditional one-way remote lecturing systems. However, most of the systems developed require special hardware and high-speed communication networks and are thus affordable only to a small fraction of educational institutions and research groups.

While traditional teleconferencing systems, such as the PictureTel group video-conferencing system [13] for example, can be used for distance education, they require costly equipment and software to be installed. Other systems use ordinary computer workstations, equipped with video cameras, but their operational cost is high due to the expensive high-bandwidth network connections they require. Examples include the IRI system [7] and the DooRae-EDUS system [12], which run over ATM intranet networks with 10 Mbits per second capacity per workstation. This enables continuous multicasting of audio and video streams between all users, besides other less bandwidth-demanding applications such as shared whiteboards, slide viewers, etc. Distance education using such systems offers a rich educational experience that comes close to, or in some aspects even surpasses, that of an actual classroom.

On the other hand, the advent in recent years of widespread use of the Internet as a relatively affordable network has led to the development of Internet-based distance education systems. Especially the World Wide Web is being favoured as the substrate upon which distance education systems are built, such as the HBLE system [10]. Even streaming audio and video, shared whiteboards and other group support tools are being integrated into the Web, in systems such as NetMeeting [8], CUSeeMe [18], CineVideo/Direct [3], and others. However, the quality is dependent on network bandwidth and saturation and can at times be completely unacceptable. Video images may only be updated once every few seconds, resulting in jerky motion, and voice streams may only be received in short, interrupted segments. Dependent on a site’s Internet connection, quality differences can be significant. The University of Macau, for example, has
a 192 Kbit per second connection, costing approximately MOP 1.5 million (about US$ 187,500) annually. This serves a community of nearly 4000 students and staff, however during peak hours transmission can come to a near standstill. Under such conditions, the value of audio and video transmissions over the Internet becomes at best questionable. Larger bandwidth can overcome this problem, but will of course increase cost\(^1\).

Several improvements to the current situation are either planned or already underway, such as adopting ATM technology [16] and upgrading the Internet protocols and backbones (the Internet 2 initiative) [5, 19]. However, these solutions take time to develop, standardize, deploy and gain widespread use. They are also certain to come at a significant expense. If we wish to take advantage of the possibilities that distance education can offer even less well-funded institutions, at this time, we should seek ways to use the limited network resources more effectively and efficiently. Naturally, this will come at the expense of some of the rich educational support that high-bandwidth systems offer. Nonetheless, it is possible to provide certain features that resemble those of more costly systems even on a low-bandwidth network. We have developed a prototype system here at the University of Macau that utilizes common (slow) Internet connections to conduct interactive, synchronous distance education while trying to maximize student and teacher support under the constraints of the network.

The remainder of this paper is organized as follows: the next section will introduce DESI, our prototype distance education system. In section 3 we discuss the design and implementation of DESI, and section 4 presents some conclusions.

2 Overview of DESI

DESI (Distance Education System for the Internet) provides virtual classrooms on the Internet in which teachers and students can have synchronous distance education sessions. Before going into details of DESI’s features, we should explain the class model that DESI supports. In distance education with DESI, as in conventional classroom-based education, students are enrolled in a number of courses. They have (typically) one teacher per class, although more than one teacher may be present in a classroom at any time, and have a number of classmates. Classes are scheduled to take place at certain dates and times and have certain durations. Students and teachers, from their own respective locations, “arrive” at class in time for the scheduled commencement time and enter the virtual classroom. They then remain in class until the class is dismissed by the teacher, usually when the time is up. During this time, they interact with each other and with the teacher(s) in the usual way, receiving lectures, watching slides shown by the teacher, asking questions and receiving answers, having discussions with the whole class, drawing on whiteboards, and even chatting individually with other students (an all too “usual” phenomenon in conventional classrooms).

DESI also supports the three main phases of a class:

**Pre-session phase.** During this phase the teacher prepares instructional material and stores it in a database for later use. The teacher may also notify students about an upcoming class.

**During-session phase.** When the distance education session is in progress, the teacher uses the previously prepared materials to conduct the class and communicates with students.

**Post-session phase.** After the session is finished, the teacher may wish to archive the materials used, together with a transcript of the session, for later review by the students, including those who were not able to “attend” the session.

Using DESI, each student and teacher has a client application on their computer, which communicates with servers and other clients. When launching their client application, users are presented with a class selection window that lists all upcoming classes (see figure 1). Upon clicking the “Enter Class” button, users are asked to indicate whether they wish to enter as teacher (authenticated with userid and password), or as student. The difference between students and teachers is that teachers have a few more functions and privileges than students, which are reflected in a slightly different user interface (having several more tool buttons). Tools for the other two phases of a class, i.e. the pre-session and post-session phases, are also accessible from the same window. On the **Pre-Session Tools** tab, two tools are provided: one tool to insert previously prepared material into the DESI database, and one tool to automatically notify every student about an upcoming class through email. On the **Past Classes Archive** tab, archives of classes that were stored by teachers at the end of a class are shown and can be viewed by students at their own pace.

\(^{1}\)It should be noted that the Internet cost in Macau is untypically high; in neighbouring Hong Kong, Internet charges for a 128Kbps leased line with unlimited throughput are, depending on access provider, in the range of 8.3% to 21.7% of the cost that Macau’s telecommunications monopoly charges [2].
Upon entering a class, DESI's slide browser window appears which shows the teacher’s currently presented slide2 and a text-based comments area. From this window, several tools are available, all of which can be launched concurrently. An example of a student’s screen, including the slide browser window and several tool windows, is shown in figure 2.

### 2.1 Main functions

As mentioned in the previous section, our goal in developing DESI was to utilize the limited networking resource as effectively and efficiently as possible. We have therefore ruled out any use of streaming audio and video between classroom participants. 

**DESI's main tools**, as shown in figure 2 are discussed below:

**Slide browser**: This is the tool that appears upon application launch. It consists of four parts: a menubar, a toolbar, a slide viewer, and a comments area. Users can launch other tools from both the menubar and the toolbar. While the teacher shows slides, the current slide is always displayed in the slide viewer. It implements a relaxed WYSIWIS3 shared view in which the teacher’s currently selected slide is displayed in all students’ windows. A comments area allows the teacher to type additional comments about the slide, or to display previously saved comments.

**Discussion tool**: During class, students may ask questions or the teacher may initiate a discussion, which are shown in the discussion tree window, visible to all students and teachers. This tool is similar to a newsgroup application, as followups to postings are threaded at the appropriate position, and the entire collection of threads is organized in a tree structure. Two forms of floor control are available and can be dynamically set by the teacher at any time: (1) open floor, where anyone may make postings at any time, and (2) moderated floor, where students’ postings are first received by the teacher who can decide whether or not to release them to the class.

**Whiteboard**: This is a typical shared whiteboard, allowing images to be drawn that are displayed on each participant’s screen. Like the slide browser, it also implements a relaxed WYSIWIS shared view. The whiteboard can be in shared mode, meaning that anyone can draw on it, or in locked mode, in which only the teacher(s) can draw on it. The whiteboard has multiple pages that can be kept for later use.

**Chat tool**: Class participants who wish to talk privately with each other can make use of this tool. It is similar to the Unix `talk` utility, allowing other users to be called and providing a split screen that shows the text typed by oneself and the other party. Separate chatting with several other people is possible, and distinct chat channels can be merged into a group chat conference if desired.

**Post-it note**: Short messages can be sent to other users using this tool. Notes received are shown as small yellow windows, resembling the well-known sticky yellow paper notes, and can be kept on the screen for later reference.

Besides these tools that are visible in figure 2, DESI provides a few other tools which are briefly mentioned below:

**History viewer**: Allows past slides to be reviewed, especially useful for students who joined a class late.

**Gestalt viewer**: Provides an overview of the current number of users (and their names) for each of the past slides.

**User information viewer**: A window showing pictures of all teachers and students who are currently in class. Clicking on a picture brings up a “namecard” with information about the person.

**Transcript saver**: This tool creates a transcript of a class, including a summary of general information, a transcript of the teacher’s com-
ments accompanying each slide, and a transcript of all discussions taking place through the discussion tool. The transcript is saved into a text file for students’ later use and is useful in reliving students from having to take notes.

As mentioned earlier, teachers have several more tools that are not available to students. The main ones are:

**Slide controller:** The teacher uses this to bring up any of the previously prepared slides.

**Speech dialog tool:** Text accompanying a slide, which may have been previously prepared, can be output as spoken text on students’ computers using speech synthesis.

**Highlighting pens:** Highlighting pens of several colours are available to the teacher to highlight portions of text shown in the slide browser window for extra emphasis.

2.2 Awareness support

A challenge that every distance education system faces is compensating for the absence of the cues that a face-to-face interaction in a real classroom provides. It may be difficult to know who is present, what these people are doing, which other people and objects they are interacting with, and even why they are doing what they are doing. Such awareness [6], however, is crucial for the success of any distributed cooperation, and a virtual classroom is no exception. Teachers will want to know whether any students are paying attention to what they are currently showing or “saying”, and indeed whether
any students are present at all; and likewise students want to know what the teacher is doing. The DESI system supports awareness in a number of ways:

**Current user display:** As mentioned earlier, the user information window shows all students and teachers currently present in the virtual classroom (an example is shown in figure 3). Moreover, the window is automatically updated whenever someone enters or leaves the class. In this way, users get an up-to-the-minute status of the presence of other class participants.

**Telepointers:** Each teacher has a telepointer with its own configurable colour. This enables students to trace the movement of the teacher’s mouse pointer in the browser window as the teacher presents a slide and writes comments, and to distinguish between different teachers in the case that more than one is present.

**Past slide viewers:** Using the Gestalt Viewer mentioned above, teachers can find out who is watching past slides, which slide they are watching, and how many students are watching each slide. This can provide useful information about who is paying attention to the currently shown slide and may be an indicator for whether the teacher is proceeding too fast through the class material.

**Notification:** News about important events taking place in the system are broadcast to all users. This includes the arrival and departure of teachers, the change of floor control policies for the discussion tree, and change of the whiteboard’s lock status.

Awareness is probably the area that is most difficult to support under the constraints of the network, and it is not easy to create adequate support without a full audio/video connection. We have considered, but discarded, ideas for other awareness tools, such as “activity meters” showing how much keyboard and mouse activity we can record from each user, which may indicate whether a user is paying close attention to the slides presented (low keyboard/mouse activity, as the user is watching the screen), or is busy with other tools (such as chatting, watching past slides, etc.). However, we felt that because of the complementary nature of the DESI toolset, it is difficult to interpret keyboard and mouse activity in this way, and that in general this measurement of activity would give rise to more misinterpretation than it would provide useful information.

### 3 Design of DESI

As mentioned in the introduction, our objective in creating DESI was to support distance education under unfavourable network conditions, such as when only slow and less reliable Internet connections are available. Our main design goal, therefore, was to make the most of the limited network resource by devising ways to reduce the amount of data to be transferred across the Internet. In the DESI system we have implemented three approaches that help reduce the data volume transmitted:

1. Replicated databases of instructional materials
2. Prefetching of materials for future use
3. Text-to-speech translation

These three approaches are explained in the following subsections.

#### 3.1 Replicated databases

If we observe how most traditional distance education systems are structured, we find that they use a centralized storage area for instructional material such as lecture slides used by teachers and students. Figure 4 shows a typical situation in this centralized architecture: a teacher and three students are located at four different sites A, B, C and D, and a server computer at the teacher’s site holds the instructional material used. Whenever the teacher wishes to share some material with the students, this is transmitted across the network to each student. While the transmission time may be negligible on a local area network or on a high-speed long-distance network, it can be quite significant on a public wide-area network such as the Internet, especially at times of high network saturation,
when data to be transmitted is large, and when locations A, B, C and D are located far away from each other.

Our first approach therefore, was to remove the need to transmit the material across the network to each student. In DESI we make use of replicated databases that store the instructional material used by teachers. Instead of using only one server machine, we use a group of interoperable servers, all of which are able to provide the material.

We intend for teachers to distribute the instructional material to the relevant participating servers in advance of the session, so that during the session this replicated material can be available to students at a server that is local or “nearby” (in terms of network distance). The DESI client’s pre-session tools support the replication of material onto a set of several servers. Now whenever the teacher shows some material, the student’s DESI client will retrieve a local replica, significantly reducing the data volume transmitted between teacher and student sites. Figure 5 shows the replicated architecture of the DESI database.

For the database server we use the HyperWave system\(^4\). The feature that is most relevant for our purposes, is replication. Copies of an object stored in a particular HyperWave server can be inserted as replicas into other HyperWave servers. A server can be queried for replicas of a particular object given a globally unique identifier, and if found can return the object. If not, it can retrieve the object from the server that stores the original.

In the current implementation, we assume that a replica exists at each site and that a local access will always yield the desired object. However, we plan to extend the replication support to automatically locate the nearest copy of a requested object. As shown in figure 5, all servers are connected to each other and are able to communicate with each other through a special server-to-server protocol. Fully utilizing replication, it would not matter if a student actually had access to a local replica of the teacher’s material, as the student would always be able to get the original from the teacher’s server. This whole process could be done transparently, although there would be a greater delay in retrieving a remote object. Naturally, it would still be preferable to install replicas at each student’s site in advance.

### 3.2 Prefetching

Another performance improvement that we have realized is to perform prefetching of instructional material. Typically, during an instructional session a teacher will go through a pre-defined sequence of lecture slides. We have taken advantage of this fact and perform prefetching of the next few items that the teacher is about to use. That is, when the teacher is currently showing item \(n\), the students’ client applications will already prefetch items \(n+1\) and \(n+2\) in the background and store them in a local cache (in the current configuration two items are prefetched, although this parameter is adjustable). As a result, when the teacher advances to item \(n+1\), the item is already found in the cache and can be displayed immediately. Safeguards are built into the DESI client that prevent the student from jumping ahead of the teacher and displaying these prefetched items before the teacher decides to use them.

Prefetching can also be helpful in cases where a student’s “local” server has to be accessed through the Internet, such as a server that serves a

\(^4\)Previously called Hyper-G; its main features are introduced in [1].
metropolitan area. Simple, on-demand retrieval of material could still result in an unacceptable delay in this situation. Using prefetching, however, the time which the teacher spends on one item may be longer than the time it takes to prefetch the following item, so that the fetching time may be hidden from the user.\footnote{5In fact, as two items are prefetched each time in the current configuration, the next item will be prefetched during the previous two items' use. Thus there is an even higher chance that the required item will have been prefetched by the time it is needed.}

### 3.3 Speech synthesis

As mentioned earlier, DESI does not provide full audio or video connections which other distance education systems operating on high-bandwidth networks offer. Instead, a text chat tool is used for communication among teacher and students, together with other tools that provide awareness about others' presence and actions. However, the full range of tools provided by DESI can easily cause the student to lose overview of the information presented in the various windows on the screen, as all the information has to be perceived visually. For example, a student may be too occupied with looking at the teacher's instructional materials and may not pay attention to the teacher's comments that are concurrently displayed in another window. To remedy this weakness it would be desirable to provide an audio channel carrying some of the information, so that students can listen to the teacher's comments while reading or watching some other information.

A fully-functional audio transmission, however, requires a high-bandwidth network connection with a guaranteed quality of service throughout the lifetime of the session, something which the Internet cannot offer. We decided therefore to transmit text streams with the teacher's comments to the students' client applications, where a text-to-speech synthesis software translates the text file into an audio stream of spoken English and plays it through the computer's sound subsystem. The effect is that the instruction is given in an audio-visual mode and the student's attention is eased compared with the visual-only situation. The use of speech-synthesis, however, can be selectively enabled or disabled by each student according to their preference.

### 3.4 Current implementation

The current implementation of DESI runs on Unix under the X Window system. It is built using the GroupKit groupware toolkit \cite{14} and is largely implemented in Tcl/Tk \cite{11}. The slide browser capable of displaying HTML slides is a heavily modified version of the WebTk HTML editor and browser \cite{17}, also written in Tcl/Tk. The Tix toolkit \cite{15} was used for many of the user interface widgets. As mentioned earlier, the networked database repository is HyperWave and some of the HyperWave access functions have been implemented in C, utilizing HyperWave's client API. The speech synthesis software used is the \texttt{tts} system from Bell Labs, running on Sun Solaris. All parts of the system, except \texttt{tts} should be able to run on any standard System V or BSD Unix system, and have been tested on Solaris and Linux.

In the future, we plan to port DESI to the MS Windows platform. As the main components are available on this platform (Tcl/Tk, GroupKit, Tix, HyperWave), it should not be too difficult to achieve the port.

Finally we should note that all the components from which the DESI system has been constructed are free of charge for educational institutions, which should make it attractive to low-funded institutions.

### 4 Conclusions

This paper has explored some issues facing distance education over slow, low-bandwidth Internet connections. Under such conditions, distance education systems cannot deliver the same high-quality, immersive learning experience of high-bandwidth systems. However, if the networking resource is used wisely, acceptable results may be obtained. We have used replicated object repositories, slide prefetching, and speech synthesis as methods that help reduce the volume of data which needs to be transmitted over the network, and can thus improve system performance. For educational institutions that lack the funds to acquire high-bandwidth network connections and the required hardware and software, systems such as the one presented here may be beneficial.

Thus far we have evaluated the DESI system only informally, confirming our assumptions regarding the expected performance improvements. We plan to carry out formal performance evaluations in the future to quantify the time savings that can be obtained from using DESI. In addition, a usability study should evaluate the effectiveness of the educational support provided by our system.

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