Teaching Computer Science Using Hypermedia

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Abstract

A second-generation hypermedia system, Hyper-G, was used to present a senior undergraduate course in advanced computer architecture. This paper reports on experiences with course presentation using this technology.

1 Introduction

Hyper-G is a second-generation hypermedia system developed at the Technical University of Graz, Austria [1–3]. It is a client-server system supporting text, audio, images, and video, organised into a hierarchy of *collections* and cross-connected by links.

Hyper-G was used to teach a fourth year undergraduate course on computer architecture at Queen's University, Canada. This course is taken optionally by computer science major students and by electrical engineering students in their final year. The enrollment in the course was thirty-two.

As this was the first presentation of the course using hypermedia, traditional lectures were given for the first third of the term, decreasing in number and becoming more tutorial in nature as the term progressed. Students were required to do several assignments involving creation of their own hyperstructured material and to add their own comments to the on-line material. Students were asked to complete a detailed evaluation of Hyper-G and its usefulness in the context of the course.

I begin by discussing the properties of Hyper-G that make it interesting in an educational setting, and the plan that I formulated for using it in teaching. I then discuss the course for which it was used, and the way in which course material was organised. Finally, the lessons learned from this initial presentation are discussed. Overall the experience was positive for both instructor and students, although it will not be clear to what extent hypermedia instruction can replace more traditional teaching until after another presentation. There is at least potential to reduce or eliminate traditional lectures, perhaps in favour of face-to-face instruction of a more personal and tutorial kind.

2 Hyper-G – Properties and Use

Hypermedia systems contain material in multiple forms – textual, images, video, audio – internally connected by means of links. The material may be accessed in differing orders by following the link structure from document (in its most general sense) to document. The link structure is usually rich enough to allow for multiple paths through the material.

Here is a summary of the major properties of Hyper-G and their implications for its use as a pedagogical tool:

- Because the course material is on-line, it is always available, 24 hours per day. Students can access it in any order they wish, subject to the implicit structure built-in by the course designer. They can access it at any rate, and in any time frame. Night owls

can learn at night, early birds can learn first thing in the morning, and students whose personal or work commitments make normal lectures difficult to attend can learn whenever they have some time.

The system is distributed, so stored data can be placed at a variety of sites. There is no need for a central, dedicated server for the whole university with huge amounts of disk storage.

- Material is organised into a hierarchy of *collections*, which may contain other collections or documents. This hierarchy supplements and enriches the structure created by links between documents. Thus there are two different paradigms for navigation – one in which a user can move up or down in a hierarchy, and the other in which a user can move forward or backward along links. The availability of two different organising paradigms helps reduce the 'lost in hyperspace' sensation reported for many first-generation hypermedia system.

  The hierarchy of collections provides a natural way to organise course material. Each course can have its own place in the hierarchy, and can distinguish internally between core material, ancillary material, discussions, resources, and student-created material. Material can be organized into 'lectures', 'topics', or 'tours', or in any other suitable way.

- Links are stored independently of documents. When a link anchor is placed in a document, the system extracts it and stores it separately, together with its visibility status.

  The separate storage of links makes it possible to add a link *from* a document without corrupting it. In particular, any user of the system can use such links to point to some text that they have created and therefore annotate a document, either privately or publicly. The insertion of such a link does not alter the original document and can therefore be freely permitted. Private annotations allow users to make their own notes as they read, and structure these notes in any way that suits them. Public annotations provide a mechanism for public discussion and argument. This ability to interact with the community of those struggling to understand the same material is one of the most interesting novel features of this technology. There is the possibility of replacing the traditional seminar with an on-line, continuing discussion, moderated and possibly even assessed by the instructor.

  Computer-mediated class interaction makes it possible for students of visible minorities or with disabilities to make contributions with exactly the same status as those of any other student. Contributions can only be evaluated on their content.

  Objects can be added to the system piecemeal as they are constructed. Links for which only one end exists are added to the link database, but are not displayed until their other end has been added. Thus courseware can be developed incrementally while still

providing a consistent view of what has been put in place already. On-line material can be modified on the fly in the light of misunderstandings, errors, or material that turns out to be confusing or difficult. This permits the arduous business of course material construction to be spread over time, perhaps even over several years, making it more practical for instructors.

- There are access controls on a collection-by-collection basis. This provides privacy and security, making it easy to have material visible to a single student only, to student and instructor, to the other students in the course, or to the whole world.

  Semi-anonymous annotation, in which the identity of the contributor is known to the system but not associated with created documents, makes it possible for students who might otherwise be reluctant to contribute to discussions to do so anonymously. At the same time, those who misuse the system can be identified by the system manager.

  Student coursework can be assessed on-line. Instructors can use private annotations to give students feedback. Written work can also become the subject of public class discussion, and changing the visibility of an object requires only a change to collection permissions.

  On-line tutoring can be provided. Real-time help may be made available for some period of the day, so that students with questions can get them answered without delay. An important part of handling questions is that both the question and the answer are immediately visible to the whole class, so that other students with the same question get it answered without effort and perhaps before it even occurs to them.

- The system is gatewayed to other major software systems on the Internet, including the World Wide Web, Gopher, WAIS, Telnet, and ftp. There is also a generic interface that can be used to connect to arbitrary pieces of software.

  The system can invoke other programs, so that existing computerised packages of all kinds can be integrated into course material. For example, in the area of computer science, students can write programs and see them animated.

  The system can interface to CD-ROMs so that existing course material can be integrated, and high-volume data, such as video, can be made available, albeit with less flexibility.

  Links can be made seamlessly to any other site on the Internet. This can be used to ensure that material is up-to-date by linking to, for example, a manufacturer's home page and therefore being able to access new information as soon as it is placed on-line.

  An important resource is the growing number of sites on the Internet that provide indexing services. These include the Colorado Association of Research Libraries (CARL) UnCover service that provides indexes to journals in the sciences. In computer science,

a number of on-line services indexing technical reports and other bibliographies are also available.

There is a considerable advantage in being able to access the full resources of the Internet from within a single system. New users do not have to learn to use a variety of different interfaces such as ftp, Telnet, and web browsers.

- The system is client/server, with a wide variety of possible client systems using a range of hardware. Access to the course material can be made from anywhere that is sufficiently well connected, including from students' homes. The use of high speed modems makes it possible to access text, audio, and images at reasonable speeds, although video is still impractical.

  There is no need for the computers used by students to be all of the same kind, nor must they have large amounts of local storage or special devices. The main requirement of client computers is that they have sufficient bandwidth to communicate effectively with the server, and that they have enough processing power to compute at speeds compatible with the data delivery rate. This is particularly attractive in a setting in which students own their own computers, since different cohorts tend to own different configurations, but can still access the system in the same way. Furthermore, links can be followed without using a mouse, so that sessions to remote hosts can use the full power of the link structure.

  Since the interface to the system looks the same from anywhere on the Internet, the distinction between traditional on-campus students and students using distance education is blurred. Both interact with the course material in exactly the same way.

  Students can access the course material in their own time. This makes courses more accessible to single parents and other non-traditional students such as those tied to full-time day jobs.

- There are sophisticated search mechanisms, so that searches for the occurrence of particular phrases in particular contexts, or even fuzzy searches allowing some leeway in the exact phrase being searched for, can be made. This makes it possible for the course material to be much larger than material typically covered in lectures without leaving students lost in a maze of too much information.

- The system is multilingual, so that documents and the interface can use a variety of languages seamlessly. This makes the system useful for courses offered in other languages (French, German), but also makes it possible to use documents that are inherently multilingual with a consistent display and text entry interface (based on ISO-8859).

- The ability to deliver material using audio, or to display material in large fonts may help to make courses more accessible to students with hearing or visual disabilities.

A good deal of CD-ROM course material has been developed for post-secondary education. It provides some of the same features as systems such as Hyper-G: link structures, and non-textual objects, for example. However, it has a number of deficiencies:

- course material must be completely developed in advance, which is expensive, and then remains relatively static;
- the only interaction of student with material is a solitary one, and there is no natural way to interact with others learning the same material;

The World Wide Web is another obvious tool for education. It has many of the benefits of Hyper-G but has the following deficiencies, at least at the present:

- using only links as a structuring mechanism creates 'spaghetti' interconnections and requires more work to create;
- the lack of access control means that material is either isolated from the Web or visible to the entire world (although some other levels of restriction are becoming possible);
- annotations can only be private;
- there are no full search facilities (and it isn't even clear how to define them, let alone implement them);

3 The Course CISC441

CISC441 in the Department of Computing and Information Science at Queen's University is a course in advanced computer architecture, covering vector computers, pipelining, SIMD architectures, and MIMD architectures. A large part of the course is spent on programming models for such systems, especially for massively parallel computers. The course is taken in both the fourth year of the computer science major degree and the electrical engineering degree. Students have already taken a course in uniprocessor design, digital logic, and system software.

The course is offered in the final term of the degree program, in which almost all of the students are heavily involved in a final-year project. This consumes large amounts of their time. They are also typically having interviews for jobs, and have turned some of their attention to post-graduation life. Students are technically quite sophisticated, but have had little or no experience in writing or in finding information for themselves in a library or on

Property	*Use*
Continuous availability	Material always available
Remote availability	Distance education
Collection paradigm for navigation	Reduces 'lost in hyperspace'
Links stored independently	Annotation without corruption
	Public discussions
	Private summaries
	Piecemeal construction
Access controls per collection	Privacy
Gateways to standard Internet systems	Seamless access to Internet
	WWW accessible
	Always up to date
	Access CD-ROMS
Client/server system	Heterogeneous access h/w
	Local and remote access
Sophisticated search mechanisms	Large on-line material possible
Multilingual	Language teaching
	Mixed language environments

Figure 1: Hyper-G Properties

the Internet. They have had no exposure to hypermedia, except that many have used the World Wide Web.

The material that could potentially be covered in the course is very large and rapidly changing. The course is organised so that students learn the basics about all architecture types, but have the opportunity to go into greater depth in one or two areas. This is facilitated by the course assessment. Students select three of the four following assessment options, of equal weight:

1. A study of the architecture of a real parallel computer, about which they give a 25 minute presentation to the class and prepare a brief written summary which is placed on-line.

2. A 'hyperessay' summarising the state of the art in a topic selected from a given list. This gives students the chance to explore one of the newer areas of computer architecture that are not well-covered in textbooks. They are expected to use the research literature to gather material, both from the library and from the Internet.

3. An annotated bibliography on a topic selected from a given list. This gives students the opportunity to learn to find material on a particular topic, assess it critically, and present it in a useful way. This material was not placed on-line on the grounds that much of the work is in finding relevant papers.

4. An examination covering the full range of topics covered in the course, but allowing for considerable internal choice. The examination requires answers to four questions selected from a dozen.

Typically almost everyone chooses options 2 and 3, and the class divides evenly between options 1 and 4. Many students expressed appreciation for this ability to customise their work and assessment.

For this delivery of the course, students were given 10% for on-line participation.

4 Expected Use of the System

Looking at the properties of the Hyper-G system, I hypothesised that incremental course development could be effective. In this scenario, courses are adapted for hypermedia presentation in stages over a number of years. Initially, existing course material is placed on-line, together with ancillary material such as sample examinations, Internet links, handouts, and assignment questions.

During the first offering of such a course, questions and answers are collected and made permanent, alterations made to the course material in response to comments made by students, and student work added.

This then becomes the basis for a second offering, in which varied presentation approaches can be tried, the best examples of student assignment work preserved as examples, and perhaps edited video of some lectures added. During subsequent offerings of the course, on-line material is steadily improved and enriched.

The work for an initial offering appears to be only slightly greater than preparing to teach a course conventionally for the first time. The delivery work of subsequent offerings is lower, possibly making time to spend on enhancing the course material. Some enhancement comes as a side-effect of the delivery itself, partly from student interaction.

5 Actual Delivery

In line with my hypothesis about incremental course construction, the main material placed on line was based on the lectures given over the past two or three years. This was supplemented with other material, most of which was already on-line in one form or another. The course material was organised as follows:

- Introductory material which might have been traditionally included on course handouts. This included details of assessment, an outline of the course, a list of the topics for essays and bibliographies, an introduction to Hyper-G, and details of how to download clients for those with personal Internet access.
- Textual material based on lecture notes from previous offerings of the course. This material roughly corresponds to what might have been handed out as a detailed set of course notes. The material was organized by topic, rather than by lecture. Links were inserted to provide a sequential path through the material and to provide an opportunity to return to the top level at the end of each topic. Some additional link structure was used, to connect to versions of relevant papers for example, but otherwise the material was not heavily hyperstructured.
- A collection for public annotations. Since the normal way to access annotations is via links from the documents they annotate, this collection would not normally be accessed using the collection paradigm.
- Review material, including a collection of sample questions, to which the students were invited to annotate sample answers, and a copy of the previous year's final examination paper.

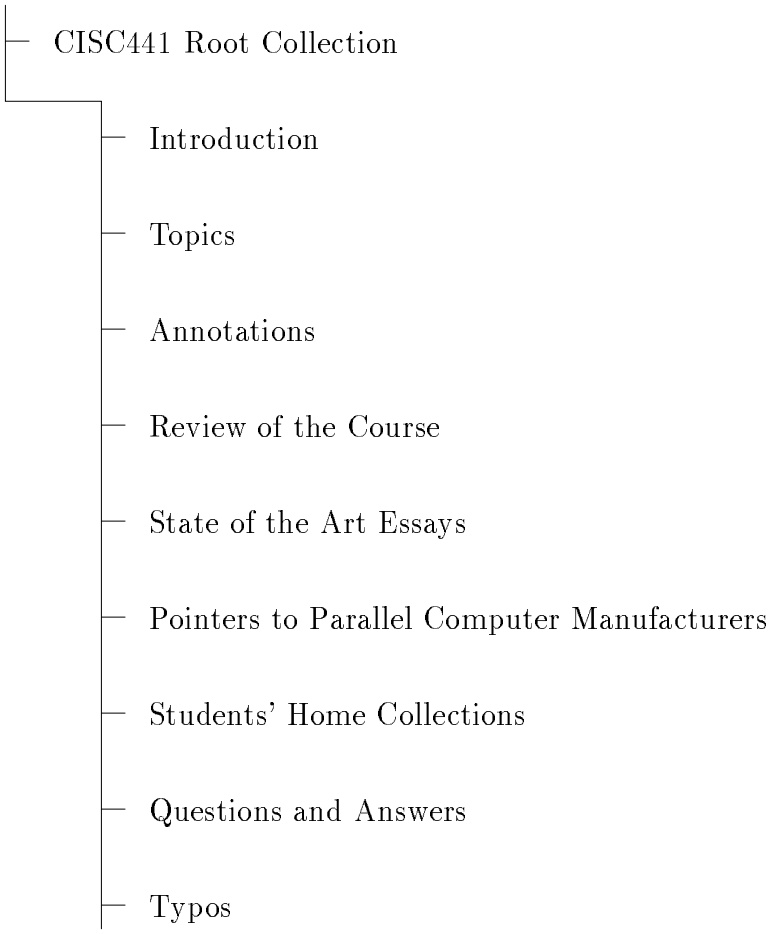

Figure 2: Course Collection Structure

- A collection into which the 'hyperessays' could be inserted as they were produced.
- A collection into which material on real computers could be inserted as it was produced.
- The home collections for each of the students, into which they could insert private material.
- A collection providing links to locations in the World Wide Web and other Internet sites. These included the home pages of most manufacturers of high-performance computer systems, several general pages on parallel and high-performance computation, a connection to the Colorado Association of Research Libraries UnCover system indexing journal publications in the sciences since 1988, and other useful locations. This enabled students to access the Internet seamlessly.
- A collection for asking questions and receiving answers. Questions were asked by creating text in this collection, and answered by the instructor or teaching assistant by annotating the question in the same collection. This made it possible to quickly scan answers directly, but also to find the answer to a particular question.
- A collection into which announcements were placed.
- A collection in which typographical errors could be described to help improve the on-line material.

The course began with the standard lectures being given (three times per week for twelve weeks) although presentations could be more discursive knowing that the necessary factual material was already available to students. The lectures were reduced to two per week by the fourth week of term, and continued in that way for the remainder of the term, except for the time when students were making presentations.

Students accessed the Hyper-G system primarily via a lab of workstations in the computer science building. Access was also made available via another workstation laboratory in an adjacent building to which the electrical engineering students were more accustomed. Access via dial-up lines and from other sites on campus was also possible. Using the system in a laboratory environment meant that audio capabilities of the system could not be utilised. The workstations were equipped with speakers, but these could not be used for more than brief demonstrations because the noise would have disturbed other users. Had the use of hypermedia been anticipated, workstations with headphone jacks could have been chosen.

6 Lessons Learned

Students has the opportunity to provide feedback in the following ways:

- by annotating a file called "What should be done differently next year"
- by written comments on the standard course assessment done by the Departmental Student Council at the end of term;
- by filling in a questionnaire asking specifically about experiences with Hyper-G;
- by verbal comments in class and in hallways

Because of the small class size the response data is anecdotal rather than statistical.

Most students were positive about the overall experience and slightly negative about some of the details. They found the experience of being able to access course material on-line helpful, while finding some of the idiosyncrasies of the system frustrating. There was general agreement that further supplementation of the material, particularly in the form of video, was necessary before a hypermedia course could be offered completely without human presentations. Several students indicated that they did not pick up ideas as quickly from a written presentation as from a description in a lecture. This suggests that video, even of a 'talking head', may be a valuable adjunct to more conventional material.

Basic Operation

The Hyper-G clients seemed quite unreliable running on DEC workstations. Students complained of crashes, often just as they were inserting new text. This, not surprisingly, was found to be very frustrating. No such problems have been encountered with clients running on other platforms.

Set-up

Setting up access accounts for students is a tedious process. A tool, *hgadmin*, is provided for this purpose but it is clearly designed for adding single users rather than adding many at a time.

Collection names are required to be unique within each server. Setting up home collections for students is similarly tedious, made doubly so when more than one collection per student is needed. A standard choice of collection name for a student Fred Nerk might be ~nerkf, but then what name should be used for the collection in which this student places a hyperessay? Having to invent consistent distinct names for this is difficult. Hyper-G is also rather coy about collection names once they are set up, so that it is non-obvious to discover the collection name of a location in the hierarchy, even when you are located at that node.

Use

A major potential problem with on-line course material is that its continuous availability means that there is little pressure to actually go and interact with it. Lectures create a series of minideadlines in the sense that missing a lecture makes it much harder to acquire that material. Since many students are largely deadline-driven, it has long been suspected that procrastination would be a major problem with on-line material. Some students did mention that they missed the pressure of lectures and found it easy to postpone learning material. Hyper-G has a feature by which documents can be made visible or invisible based on date. This feature could presumably be used to create some artificial deadlines, but it isn't clear whether or how this can best be used.

Weaker students were relatively disadvantaged by the use of on-line material because they did not make the effort to access the system until several weeks after the start of the course. Since the administrative material normally given in a class handout was all on-line, this meant that they did not really know what was expected of them. In some cases this led to missing sign-up deadlines. They also missed the tutorials on the use of the system that were presented early in the term. So early miscalculations led to extra difficulty using the system and completing term work. This may be a problem caused by the novelty of this kind of course offering.

The on-line annotations actually produced were metacomments on the course itself and comments on the work of other students. No comments were made directly on the course material. Many students commented that they enjoyed the chance to read the work of other students and they made surprisingly many detailed comments on it. They felt that it was beneficial to see other students' work. Presumably they felt slightly more intimidated commenting on material written by the instructor.

As expected, students found it hard to resist printing material and then taking the hard-copy away to read. This seems to be partly getting used to a new mode of learning, and partly the obviously lower quality of any screen-based presentation of text.

Many students commented that they liked the opportunity to work from home. All of the engineering students, and many of the Arts and Science students own their own computers, and could access the Hyper-G system via the campus backbone. Several had written most of the text they added to the system at home and uploaded it into the system.

Because the Hyper-G system is based on the international standard Standardized General Markup Language (SGML), it assumes that World Wide Web pages are SGML-compliant (as they are supposed to be). Unfortunately, many web pages are not compliant, and many web browsers do not insist on it, so some web pages are not viewable from Hyper-G. This is unfortunate, and Hyper-G may have to take a more forgiving attitude on this point if

Internet access is to be made as useful as possible.

Many students commented that they appreciated the exposure to hypermedia systems *per se* because they expect to see them in a variety of contexts in the workplace.

In a course in which attendance at lectures has always been erratic, it was pleasant as an instructor to be able to place announcements on-line and know that absent students could still see them.

The Hyper-G system assumes that annotations will normally take place in the same collection as the document being annotated. While possible, this is not very sensible in an interactive shared environment used for education because the documents themselves need to be protected from alteration. Students found it annoying at best and thoroughly confusing at worst that they had to figure out the collection name for the annotations collection and use it in place of the default whenever they wanted to annotate something.

The command name to insert a new piece of text under a collection is 'new text'. Unfortunately the command 'insert document', which actually creates a new collection under the present one, really does seem the logical choice and this created a great deal of confusion.

Use for Student Work

One unsuspected advantage of the annotation feature was the way it permitted students to sign up for topics. A list of fifteen topics was made available and students were asked to choose their topic, which was to be different from that chosen by others, by annotating this file. Since annotations are date and time stamped and owned by their author, this process was very easy.

I underestimated the amount of instruction that needed to be provided about both the mechanics of using a mark-up language, and issues of layout and style. Students who submitted work early in the term often produced simple text files with little use of mark-up and no use of hypertext. Work submitted later was generally more sophisticated, but even those students who used hypertext features extensively did not do so in ways that helped present their material. For example, essays were often presented as a 'table of contents' with a link from each section title to a text fragment, but no thread through the material was provided. Students clearly learned technique from seeing other students' work. Difficulties with style will be reduced in future years by leaving the best examples of previously-submitted course work as examples for new students.

There appears to be no simple mechanism to allow on-line marking of essays, that is the creation by an instructor of an annotation to a publicly readable text, where the annotation is visible only to the instructor and a particular student. The actual process of marking

on-line material was not particularly more difficult than marking hard-copy. This might be different if large amounts of work were handed in simultaneously and had to be marked quickly. In this course, work was handed in (that is, made visible) sporadically and it was easy to mark in short sessions.

Students seem to need more guidance about selection of material and how to use Internet tools to find resources such as journal papers.

7 Overall Assessment

The offering of this course using hypermedia can be judged a success. The amount of work required as instructor was about the same as preparing a new course. With some experience, this could be reduced slightly, but probably not by very much because of the sheer volume of material to be structured and entered. In return, the lecture time was reduced by six hours.

It remains to be seen how much time must be spent for subsequent offerings of the course. However, I will be surprised if this exceeds the normal time spent in preparation for the course that has already been taught; and it does seem likely that a more tutorial-oriented presentation will work for subsequent offerings. So if there is a net increase in instructor's time for the first offering, there is likely to be a net decrease for the second offering, and much larger decreases for subsequent offerings.

The student experience appears to have been positive. Most students seemed appreciative of the opportunity to listen in lectures rather than taking notes, and especially of the chance to see other students' work. They were also glad to have acquired some hypermedia experience, although this might weigh less for students in other disciplines.

There is clearly a need for more visual material to be included in the course material, and for better instructions to be provided for use of the system itself and for authoring within the system.

There is no evidence that students learned more or found it easier to learn using this kind of pedagogical setting. However, such an effect would have been difficult to detect in a course of this size and setting. A controlled comparison of an more junior undergraduate course is planned for the Winter Term of 1996.

The Hyper-G system has demonstrated its usefulness in an educational setting. Although there are problems with both reliability and with details of the interface, these are not unusual for the first production use of a new software tool, and no doubt most of them can be worked around with more experience and better documentation.

Students in the course gave permission for their written work to be made public. The course material used can be seen via Hyper-G or via the World Wide Web using URL `http://www.qucis.queensu.ca:1999/~skill`.

8 Future Plans

The Department of Computer Science plans to extend its use of Hyper-G to several other senior courses, to a first year course, sufficiently large to enable some statistical data to be gathered, and to parts of the graduate program. The obvious implications for distance education will also be investigated in small ways.

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