Constructive, Inquiry-Based, Multimedia Learning in Computer Science Education

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Introduction

Interactive multimedia can facilitate diverse learning styles. A sensory-rich participatory design goes beyond the more abstract style typical of lectures or textbooks, helping students who learn by seeing, hearing or doing. Recently, PI Blank authored a textbook, *The Universal Machine*[1] with an accompanying multimedia CD-ROM, for a first semester course on computer science (CS1). In addition to C++ programming, *The Universal Machine* surveys the breadth of computer science, with chapters on the history of the idea of the universal machine, programming languages and their translators, the software life cycle, computer architecture, operating systems and networks, object-oriented software engineering (OOSE), social and ethical issues, and artificial intelligence (AI). Blank's experience with *The Universal Machine* has demonstrated that interactive multimedia courseware significantly improves final examination scores.[2] This proposal, building on an extensive body of multimedia material and lessons learned, seeks to provide a framework for multimedia-enhanced education throughout the computer science curriculum.

We envision an integrated, multi-track model of constructive, inquiry-based learning. *Constructive* learning goes beyond passively receiving knowledge, to learning by building systems, with immediate visual feedback. Moreover, *inquiry-based* learning guides the student into pursuing exploratory research in a community of students and scholars. A *multi-track* model will have two dimensions:

- The framework and its content will accommodate different learning styles, including visual, audile, kinesthetic (learn-by-doing) as well as abstract linear (Bonwell 1999).
- The framework and its content will be designed for use in both an introductory track as well as in more advanced tracks for upper-level undergraduate and introductory graduate level courses in computer science.

An important additional component of the learning environment is the range of assistance students will have available to them as they pursue their inquiry. We thus propose to design and implement a "reference librarian" avatar that will suggests research topics and help students extract content from dynamically mined material as well as traditional library resources, provide answers to typical questions and aid students in the construction of annotated bibliographies, reviews and research papers. To facilitate inquiry-based learning, we propose to give students access to an advanced text data-mining server based on PI Pottenger's research (Bouskila & Pottenger 2000). With the help of the reference librarian avatar, students will learn by exploring emerging trends in selected topic areas, using high-quality on-line databases such as Compendex and INSPEC. This component of our project will also advance and disseminate the results of new research in textual data mining

In terms of pedagogy, we believe that it is crucial that students perceive that their instructors are genuinely concerned about them as individuals. Since it is not possible for an avatar to meet the complete needs of human learners in this respect, we further propose to develop an interface in which avatars are seamlessly connected, via networking technologies, to real, human instructors. Students will be able to

[1] Glenn D. Blank and Robert F. Barnes, *The Universal Machine: A Multimedia Introduction to Computing* (WCB-McGraw-Hill, 1998). See http://www.eecs.lehigh.edu/~glennb/um for details.

[2] While developing *The Universal Machine,* Glenn Blank taught CS1 to 70-80 computer science majors and non-majors. From the first year, for which only the manuscript of the book was available, to the second, in which an incomplete version of the multimedia was introduced, mean final examination scores improved about six points. Knowledge of breadth topics showed notable improvement. In the third year, with the complete first edition, mean final examination scores improved another seven points.

reach beyond the instructor and librarian avatars to communicate directly with a live person—an expert that the avatar represents. Our goal is thus to provide a communication medium that allows an instructor or librarian to show how he or she would solve a problem, through a combination of audio, video-over-IP, and remote control. PI Kessler's research tackles network and systems issues for collaborative virtual environments. He has developed a network protocol (Kessler 1996) that addresses the low-latency and consistency needs of distributed and interactive applications. This protocol differentiates between unique event information and state update information. It communicates only that which the network requires and supports. We will design and implement a protocol for a collaborative desktop interface to communicate mouse pointer position, mouse actions and interface events. If the expert is not available, the avatar will be able to help the learner select from a library of "show me" tutorials.

Objectives

- To design a multimedia framework for constructive, inquiry-based learning, for introductory and upper level computer science courses, for students with diverse learning styles, gender and cultural backgrounds.
- To design, implement and evaluate content in three areas: a course introducing computer science (CS1) and two upper-level undergraduate/introductory graduate level courses in Object-Oriented Software Engineering (OOSE) and Artificial Intelligence with Applications in Textual Data Mining (AITDM).
- To design, implement and evaluate algorithms for textual data mining that will assist students and researchers in discovering emerging trends in topics germane to the OOSE and AITDM courses. A reference librarian avatar will guide learners using the technology.
- To design, implement and evaluate an interface in which avatars seamlessly connect via networking technologies to human instructors.

Our cost-share industrial sponsor, Allstate Insurance Company, will integrate the AITDM module and data-mining technologies into a workforce development module for dissemination by Allstate's Multimedia Education Group. (See the attached letter of cost-sharing commitment from Allstate in conjunction with the National Center for Supercomputing Applications, NCSA).

Approach

Our experiences confirm findings that Einstein and Sandom (quoted by Vaughan 1998) observe:

> If you're being driven somewhere in the bock seat of a car, you may not remember how you to your destination; but if you had been driving the car yourself, chances are you could get there again. Studies indicate that if you're stimulated with audio, you will have about a 20 percent retention rate, audio-visual is up to 30 percent, and in interactive multimedia presentations where you are really involved, the retention rate is as high as 60 percent.

Multimedia for Computer Science Education

The proposed framework will build on what high-end multimedia courseware currently facilitates: presenting expository material in text and audio, with follow-up point-and-click or drag-and-drop exercises. We propose to develop richer, more dynamic opportunities for constructive and inquiry-based learning. By *constructive*, we mean learning by building systems, visually, with immediate feedback. For example, after learning about the purpose and form of a class diagram in UML (Unified Modeling Language), learners will modify examples, then create new diagrams, with guidance and feedback from an online mentor. By *inquiry-based*, we mean learning by asking questions, solving problems and pursuing exploratory research in a community of students and scholars. For example, after learning about design patterns, a learner can investigate emerging trends in the literature on this topic. Our framework for inquiry-based learning will involve autonomous agents, networking technologies, dynamically generated resources, and multi-track learning structures.

Constructive, inquiry-based learning encourages students to view instructors as facilitators. We envision an avatar-based model of learning in which students interact with multimedia personae modeling a community of learners and instructors. *The Universal Machine* currently features a narrator, who speaks in a professional voice, but otherwise has no identifiable persona. It also has an animated character named "Knobby," who pops up from a pedestal to dialog with the narrator in the role of a learner, or prompts the learner to do interactive exercises. We have observed that novices enjoy interacting with Knobby, while more sophisticated students find him "juvenile" or "beneath" them. To address this issue, we will design a variety of characters with whom a wider range of students can identify, with respect to learning styles, gender or cultural background. Other avatars will include a professor, teaching assistant and a reference librarian. These avatars will model students and teachers studying material together, guide students though interactive and constructive exercises, and help students do exploratory research on relevant topics using online information.

The "reference librarian" avatar will suggest topics matched to student-centered preferences, help access high-quality collections of information, extract content from dynamically mined material and traditional library resources, guide researchers who want to keep abreast of the latest developments, answer typical questions and help construct annotated bibliographies, reviews and research proposals. As the OCLC Institute has noted, "to truly support education, solitary digital libraries of content must be transformed into social, exploratory digital libraries of learning" [OCLC]. We propose to create software that encourages students to research topics germane to specific computer science courses. (Narrowing the focus will facilitate our knowledge engineering and data mining tasks considerably. A student's learning context can provide a rich key for data mining search algorithms.)

To engage students, these avatars should be designed with compelling graphics and animation and also infused with intelligence and personality (Kiersey 2000). A reference librarian at Lehigh University (Sharon Siegler), who supports computer science and engineering research, has agreed to serve as a domain expert, for the purpose of knowledge engineering and systems testing. We will also investigate authoring tools for intelligent agents. Elliot and Brzezinski 1998 survey recent developments in the design of autonomous agents as synthetic characters. The Advanced Distance Education project at USC-ISE, for example, has created a synthetic agent, called ADELE, to help train medical and dental students. To quote their web site (www.isi.edu/isd/ADE/ade.html):

> Pedagogical software with personality - to assist students in working through course materials. The lead character, an agent named ADELE (Agent for Distance Learning Environments), interacts with students and tracks their learning as they work through course materials and simulation exercises. ADELE consists of a pedagogical agent and a 2D animated persona, which is implemented as a web-based Java applet. ADELE adapts the presentation of the material as needed, provides hints and rationales to guide student actions, and evaluates student performance.

Elliot, Rickel, and Lester (1997) have also explored maintaining believability in affective gesture. ADELE is a good starting point for the design of our reference librarian and instructor avatars.

A goal of this project is to develop an integrated, multi-track model of inquiry-based learning. We will use a collaborative interface in which instructors and students mutually share the screen. This collaborative interface will allow the instructor and reference librarian to interact with the student using a "show me" approach. In this context, students can demonstrate their problems or show that they understand a concept. The instructor can suggest solutions and acknowledge the student's progress. If live video connections are not available or desirable to the student, the avatar will offer chat or e-mail connections. Another "show me" approach will enable the avatars to offer a library of "show me" demonstrations as an alternative to corresponding with live instructors. Since students do not enter a course with the same prerequisite knowledge, background, interests and motivations, our approach will provide students with opportunities to explore content at their specific level and at their own pace. We will link multiple tracks of content within a single multimedia framework for delivery and exploration of computer science content throughout the curriculum.

We anticipate that integrating intelligent data-mining agents and networking technology in a pedagogically sound learning environment will increase interest in curriculum development and research in computer science and other disciplines. To demonstrate the application of our framework in a business environment, we will collaborate with Allstate Insurance to develop the AITDM module.

Detecting Trends in Textual Information

The reference librarian avatar will facilitate student inquiries by accessing collections of information matched to selected, student-centered topics. PI Pottenger's data mining algorithms trace topical knowledge domains over time to detect emerging trends in conceptual content. Technology forecasting, as an example application, has traditionally relied on human-expert analysis of sources (e.g., patent, trade, and technical literature) or bibliometric techniques that employ semi or fully automatic methods (White and McCain 1989). Automatic approaches have not focused on the actual content of the literature due to the complexity of dealing with large numbers of words and word relationships. With advances in computer communications, computation and storage infrastructure, we can explore complex relationships in content and links (e.g., citations) that detect time-sensitive patterns in large textual repositories.

Dr. Pottenger's data mining algorithms perform automatic analysis of textual information by partitioning collections of text into topical knowledge domains. The approach traces these topical domains over time to detect emerging trends in conceptual content. Examples of 'hot topics' detection include trends in warranty repair claims, technology forecasting and emerging interpretations in case law. 'Hot topics' detection employs collections of trade, technical, patent and other literature drawn from high quality collections, such as Compendex and INSPEC. The algorithms partition such collections into topical domains of knowledge that we refer to as regions of *semantic locality* (Bouskila 1999), (Bouskila & Pottenger 2000). The reference librarian avatar will guide researchers, especially student researchers, who wish to explore emerging topics, keeping abreast of the latest trends.

The process of detecting emerging conceptual content is analogous to the operation of a radar system. A radar system assists in the differentiation of stationary and mobile objects. It effectively screens out uninteresting reflections from stationary objects and preserves interesting reflections from moving objects. Similarly, our techniques identify regions of semantic locality in a set of collections and 'screen out' topic areas that are stationary. As with a radar screen, the user will query identified 'hot topic' regions of semantic locality, then determine their characteristics by studying the underlying literature automatically associated with each 'hot topic' region.

The five steps in the process, which we discuss in more detail below, are as follows:

1. Concept identification/extraction
2. Concept co-occurrence matrix formation
3. Knowledge base creation
4. Identification of regions of semantic locality
5. Detection of emerging conceptual content

1. Concept identification/extraction

Our approach to concept identification/extraction includes the following three steps: input item (document) parsing, parts of speech tagging and noun phrase identification. The parsing stage takes SGML, HTML or generalized XML tagged items as input. We have utilities to convert from a variety of input formats to XML, including proprietary airline safety data (from an NCSA industrial partner) and US government patent data. Based on AI techniques, parts of speech tagging include lexical and contextual rules for identifying various parts of speech. After identifying each word's part of speech, we invoke a finite-state machine that accepts an enhanced version of a regular expression of English language grammar (Karttunen 1996). Our enhanced grammar identifies and extracts concepts consisting of complex noun phrases composed of multiple modifiers, including gerund verb forms. The final result of these three steps is a reformulation of the original collection that includes a summation of the location and number of occurrences of each extracted concept. The next stage of the process then receives the reformulated collection.

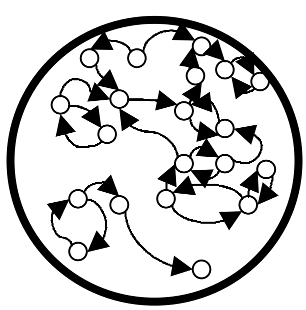
2. Concept co-occurrence matrix formation

"Co-occurring" defines concepts that occur within the same item. The co-occurrence relation is reflexive and symmetric but not transitive. Given concepts extracted by the above process, we compute concept frequency and co-occurrence matrices. We also compute the frequencies of co-occurrences of concept pairs among all items in the set. An item is an intelligently created logical unit of text that is cohesive semantically. Examples include abstracts, titles, web pages, airline safety incident reports, patents, etc.

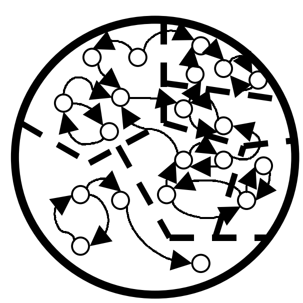
The literature discusses various definitions of co-occurrence (Baeza-Yates & Ribeiro-Neto 1999). Our approach will incorporate metric measures based on proximity as well as measures that dynamically define the extent of sub-items within a given item. Our preliminary results indicate that this latter approach is crucial in dealing with the full-text of items. PI Pottenger reports on research in parallelizing the computation of such semantic relations based on his theory of *coalescing loop operators* (Pottenger 1998). As part of this research, we will apply similar techniques to collections the information management algorithms develop.

3. Knowledge base creation

Knowledge base creation is a meta-level organizational process. For each concept in each matrix in each collection we rank co-occurring concepts. This one-to-many mapping associates each concept with a list of related concepts ranked by similarity. Co-occurring concepts rank in decreasing order of similarity. More general concepts occur lower in the list. Each concept pair (concept to ranked concept) gets a weight creating asymmetric measures of pairwise similarity between concepts. Chen and Lynch (1992) and Pottenger (1997) give quantitative definitions for similarity between concepts. It is a mapping from one concept to another that quantitatively determines how similar they are semantically. The resultant mapping is a *knowledge base* that represents an asymmetric illustration in which nodes are concepts and arc weights are similarity measures. One can visualize a knowledge base as the illustration on the left below. The vertices represent concepts and the edges represent the pairwise similarity between two concepts.



Knowledge Base



Knowledge Neighborhood

4. Identification of regions of semantic locality

The resulting weight assignments from knowledge base creation are context-sensitive. We use these weights to determine regions of semantic locality (i.e., conceptual density) within each repository. We then detect clusters of concepts within a knowledge base (Bouskila 1999), (Bouskila & Pottenger 2000), (Tarjan 1972). The result is a knowledge base consisting of regions of high-density clusters of concepts—subtopic regions of semantic locality. These regions consist of clusters of concepts that commonly appear together and collectively create a *knowledge neighborhood*. Our premise is that one may impute a constrained, *contextual transitivity* to a co-occurrence relation (Bouskila & Pottenger, 2000), thereby forming regions of semantic locality (see the illustration on the right above).

5. Detection of emerging conceptual content

Our fundamental premise is that algorithms can automatically detect emerging content by tracing changes over time in concept frequency and association. We have found at least two important features that an emerging concept should possess. First, in order to classify a concept as emerging, it should be semantically richer at a later time than it was at an earlier time. Second, an emerging concept should occur more frequently as an increasing number of items (documents) reference it. We can approximate the semantic richness of a concept by the number of other concepts that are in the same region of semantic locality. To be an emerging concept, the number of occurrences of a particular concept should exhibit an accelerating occurrence in a large corpus. In addition, if occurrences are artificially high they fall into a class of redundant concepts. Combining these constraints, we have automatically identified emerging content given a statistically significant sample of items from the domain of interest (Yang 2000). We use a cluster-based approach. Individual clusters of concepts represent regions of semantic locality that encompass portions of one or more items. Item-based approaches attempt to measure deltas in semantics between items. Based on our research in cluster-based retrieval mechanisms, we believe clusters more accurately capture the dynamics of the semantics between collections of similar items being compared across time. Our research will address each of the five steps above. Validation of the algorithms and prototype will apply standard metrics of precision and recall adapted to the detection of emerging content. We will study several test collections including both 'gold standard' (i.e., containing the appropriate pre-identified 'hot topics' in the OOSE and AITDM domains) and application-specific collections ranging in size and content in the evaluation of the prototype of our text data-mining server.

The "Show Me" Collaborative Interface

Through network connections, we will create a distributed system that provides shared communication environments for students and experts (instructors or librarians). Strategically embedded interaction commands within the application interface allow users to demonstrate their use of the interface to each other. Using this "show me" interface, a expert will have a replica of the student's application in its current state. In a "real time" live demonstration, an expert might guide a student through a lesson suggesting how to use the interface or clarifying steps that involve interacting with the application. Conversely, a student can demonstrate their problems or interpretations of material directly to an expert by manipulating remote interfaces. Complementing other modes of input (Oviatt 1997) that provide information, this design acknowledges research that shows people prefer to provide information spatially using spatial input. The system will also support "observation" styles for other students, such as a list of frequently or recently asked questions, which index demonstrations that replay the conversation and actions of an expert on a replication of the active interface.

The challenges we face include: defining interface components and actions that can concisely describe an interface demonstration, synchronizing communication channels between students and experts (voice, video, interaction manipulations, etc.), and providing different levels of group awareness to students and experts. Identifying semantic components of the interface such as search text boxes, document scroll bars and database lists provides a compact representation of demonstrations that the interface can communicate, store and replay easily. It can also use techniques, such as circling components to identify them, to enhance demonstrations. In addition, the program will have the capability of recording and archiving sessions. By replacing certain tagged actions by the original inquirer with points at which the session replay pauses to allow students to demonstrate their understanding, we can use recorded sessions as an instructional tool.

In converting demonstrations by users to such dialogues, the system will differentiate between updates. It will condense mouse movements to start and end points and a path approximation and differentiate between events, such as mouse clicks and component identification. The last update before an event will help define the context in which the event occurs. The system will maintain a causal (partial) ordering (Lamport 1978) for all events that participants observe and produce. In the context of the "show me" interface, this requirement will ensure that if a student's actions follow an expert's demonstration, other observing students will see the expert's demonstration before the first student responds.

Work in Progress

In April 2000, the first two principal investigators received "Ventures" funding ($6500) from Lehigh University to develop a preliminary prototype for the project. During the summer of 2000, we plan to redesign content from the *Universal Machine* for the introductory OOSE module and design a rapid prototype of the user interface featuring the reference librarian avatar. We will also develop surveys to determine learner characteristic styles and pre-tests and post-tests for the OOSE and AITDM courses. In the fall of 2000, we will gather control group data, a year before the alpha version of the advanced OOSE and AITDM modules.

Dr. Pottenger is currently PI of several industrial partner grants at the National Center for Supercomputing applications, an Army Research Lab grant and an NSF grant in the textual data mining area. He is working to develop solutions for distributed search and retrieval, technology forecasting, and other textual knowledge management applications as part of his research and development of HDDI, Hierarchical Distributed Dynamic Indexing (Pottenger, Callahan, & Padgett 2000; Bouskila & Pottenger 2000; Auvil, Hsu, Pottenger, Tcheng ms for 1999).

Sharing communication requires a distributed system that provides partial ordering guarantees of interactions so that the system maintains the correct order of steps given by the users. Simultaneously, the system must be interactive and allow for waiting students to "look in." The Remote Attribute Virtual Environment Library (RAVEL) (Kessler 1998) is a distributed system that addresses these issues for collaborative shared virtual environments. It builds on the network protocol and adds the enforcement of causal ordering of information communicated between distributed tasks. To maintain interactivity, the RAVEL system supports dynamic entrance and exit of distributed tasks and different communication needs of different tasks. The RAVEL system provides a starting point for implementing the network communication structure and needs of the learning environment.

Related Work

Instructional Design, Usability and Performance

To address the diverse needs of our audience, we will incorporate Kiersey's (2000) research on personality and emotion, Bonwell's (2000) research on learner characteristics as well as Nielsen's (2000) and Norman's (2000) research on human-computer interaction and usability. Since we plan to deliver the learning modules via the Web, it is germane to include research and techniques relevant to readability (Scharff 1999), integrated performance centered design (Winslow & Bramer 1997) and Web-based Performance Support Systems (WBPSS) (Kilby 1994). WBPSS describes practical applications of Web technologies to solve human performance problems. It builds on Kilby's professional experience in computer systems analysis, user interface design, media production, instructional systems design and classroom instruction. Incorporated within traditional instructional design (Clark 2000; Gagne 2000; Miller 2000; Piaget 2000), we will use storytelling (Schank 1990, 1995, 1998) as a technique to deliver instructional concepts with the expectation that learning through stories will be entertaining, enhance performance and improve retention and transfer.

Textual Data Mining

Several research projects are exploring solutions to the detection of changes in topics. The Topic Detection and Tracking Pilot Study (TDT) project, for example, segments streams of data into distinct stories and identifies new events occurring in news stories (Allan et al. 1998), (Yang et al. 1999). The TDT problem consists of three major tasks: (1) segmenting a stream of data, especially recognized speech, into distinct stories, (2) identifying those stories that are the first to discuss a new event occurring in the news, and (3) finding all stories in the stream given a small number of sample news stories about an event.

Major methods for new event detection in text data mining research come from work at Carnegie Mellon University (CMU), University of Massachusetts (UMass) and Dragon. The CMU approach clusters stories in a bottom-up fashion based on their lexical similarity and proximity in time. The UMass approach uses a variant of single-link clustering and builds up cluster groups of related stories to present events. The UMass method focuses on rapid changes by monitoring sudden changes in term distribution over time. The Dragon approach based on observations of term frequencies, uses adaptive language models from speech recognition. It hypothesizes a novel event when prediction accuracy of the adapted language models drops relative to the background models. The results show that the CMU incremental approach achieves 62%/67% in precision/recall, the CMU group average clustering top-level approach reaches 83%/43%, the Dragon approach reaches 61%/69%, UMass 100T approach reaches 34%/53% and the UMass 10T reaches 33%/16%.

Kumar and other researchers in the IBM Almaden Research Center use a graph-theoretic approach to identify emerging communities in cyberspace (Kumar et al. 1999). The concept is that competitive websites in the same emerging community do not reference one another. Additionally, they may choose not to reference each other because they do not share the same points of view. Noncompetitive sites and those with similar points of view do link to these non-mutual-referencing sites. Thus, websites in the same community become a strongly connected bipartite graph. Kumar et al. (1999) propose an efficient and effective algorithm to find the strongly connected cyberspace bipartite sub-graphs and cores. A core is a complete bipartite graph. An initial crawl found that 56% of the sampled communities were not in Yahoo! while a crawl 18 months later found 29% were not in Yahoo!. Kumar (Kumar et al. 1999) interprets this finding as a measure of reliability of the trawling process, namely, that many communities that they identified as emerging 18 months ago did later emerge. The average level of these communities in the Yahoo! hierarchy was 4.5.

The Envision system at Virginia Tech is a digital library of computer science literature. It allows users to explore trends in digital library metadata (Nowell et al. 1996). Envision visually displays information search results as a matrix of icons with layout semantics that users control. The system gives users access to complete bibliographic information, abstracts and full content. It graphically presents a variety of document characteristics and supports an extensive range of user tasks. By using the Envision system, users can browse topics and trends graphically to identify emerging contexts.

ThemeRiver is a prototype (mock-up) that visualizes thematic variations over time across a collection of documents (Havre, Hetzler & Nowell 1999). As it flows through time, the “river” changes width to depict changes in the thematic strength of temporally collocated documents. The “river” is within the context of a timeline and a corresponding textual representation of external events. This enables users to visualize trends and detect emerging themes. However, the ThemeRiver system and the Envision system rely on human expertise to identify contexts – they do not provide a fully automatic approach to identify emerging contexts in collections.

The goal of many of these research projects is essentially to detect changes in topics – disruptive events exhibiting discontinuities in semantics. Our research (Yang 2000; Bouskila & Pottenger 2000) focuses on integrative or non-disruptive emergence of topics that build on previously identified topics. There is a subtle but important difference between these two approaches, and based on our research to-date, we maintain that an integrative, cluster-based approach is necessary to correctly identify emerging conceptual content.

Collaborative Interfaces

The system support for providing demonstrations by a real domain expert to students is an example of computer-supported cooperative work (CSCW). When students access stored demonstrations, they interact asynchronously. The communication is one way, although tutorials provide students with opportunities to interact with demonstrations. When students interact with the experts, they interact synchronously. There are two approaches to synchronous CSCW: collaboration transparency and collaboration awareness (Begole 1998). Collaboration transparency (Microsoft's NetMeeting) software, replicates an application and allows multiple users to manipulate the application. This tightly coupled approach does not allow for interactions that involve loose coupling of actions, as supported by systems such as Flexible JAMM (Begole 1998). A loose coupling approach is desirable for our demonstration system. It allows us to provide extra annotation tools in the experts' interface and allows observing students to have different representations of the demonstration based on their interests and knowledge levels.

Sun (1998) has studied techniques for enforcing casual ordering of actions to collaborative interfaces, such as group editors. Systems that support group editing provide three properties for ordering actions on the interface by groups: convergence, causality preservation and intentional preservation. Convergence is where representations shown to all users will eventually agree with each other. Causality preservation is where the cause of an action will precede its effect. Intention-preservation is an action initiated by the users. Our distributed system will add the intention-preservation property to support our shared demonstration environment. We anticipate that the communication structure between experts and students will allow for optimizations not available to generic support for group work.

The Evaluation Process

Evaluation is the process of determining the value and effectiveness of learning. We will assemble a panel of students and instructors to evaluate the output of the analysis, design, and prototype stages of development. The purpose of evaluation is to determine the impact the program has on learners. To evaluate the program and the learners we will collect and document learner performance, link performance to objectives and provide quality control, determine the relationships between learning and the transfer of knowledge to practical applications and determine if multimedia, avatars, GUI and aesthetics have an effect on learner performance. The instruments to collect data will include questionnaires, interviews, observations, focus groups, tasks, term projects and tests. In order to determine if the instructional development accomplishes our goals, internal evaluations will focus on instructional process and measurement of learning gain. The evaluation component will address four levels of Kirkpatrick's Evaluation Model. Level 1 (Reaction) will measure how students react to the program and their perception of the course. Level 2 (Learning) will look at the extent students change attitudes, improve knowledge and increase skills as a result of the learning[3]. Level 3 (Behavior) focuses on the extent to which behavior changes as a result of the learners using the program and tests the

[3] A pre-test will determine entry level knowledge. A post-test will reveal what learners learned, what knowledge they acquired, what skills they developed or enhanced and what attitudes changed.

learners' application of the skills learned[4]. Level 4 (Results) measures learning effectiveness, the ability of learners to apply learning skills to new or unfamiliar situations[5].

The two major components of evaluation are evaluation of the program (software performance) and evaluation of learning (student performance). Over the three-year period of the grant we will conduct formative and summative evaluations on both components. The tables on the following page address the evaluation component and the methodology for collecting data. Table 1 "Evaluation of the Program" focuses on development of the software according to the criteria identified in the proposal. Table 2 "Evaluation of the Learning" focuses on the process and outcome of learning from the learners' perspective. Evaluators will assess the impact of the program on learners by correlating criterion-referenced achievement and performance with learner characteristics. Data gathering methods include electronic tracking, learner questionnaires, observations, interviews, focus groups and testing.

Evaluators (Dr. Morgan Jennings, Ph.D., and graduate student Harriet Jaffe, MFA) will analyze the data collected from each of these assessments using quantitative and qualitative methods. We will use Analysis of Variance to compare achievement on pre-test and post-test scores between the control group and the experimental group. We will correlate learner characteristics and demographics with achievement, quality of student work, learner preferences and learner paths. Expert analysis will assess quality of content and student work in order to determine the correlation. We will identify emerging trends and explore the interdependencies and relationships.

Data gathering and analysis will occur in three stages for the OOSE and AITDM modules: while teaching with introductory multimedia in the OOSE course and without multimedia in the AITDM course, while teaching with an alpha version of the software and while teaching with a beta version of the software.

Development Plan

Year 0

Summer 2000. "Ventures" funding from Lehigh University.

- Audience and task analysis of the OOSE module.
- Design prototype of OOSE module.
- Design prototype user interface for CS1, OOSE and AITDM modules.
- Design graphical representation of avatars.
- Specify requirements for implementation of "intelligent" avatar behavior
- Specify network interface for the reference librarian avatar.
- Develop surveys to determine demographic data, learner characteristics styles, pre-tests and post-tests for the OOSE and AITDM courses.
- Teach OOSE and AIDTM (Fall 2000) courses at Lehigh University with limited multimedia, assign and gather course related projects, administer surveys, gather pre-test and post-test data.
- Evaluate course related projects, surveys, pre-test and post-test data
- Write and submit proposals to publishers for dissemination.

[4]We expect behavior data to provide insight in to the transfer of learning form the class environment to real life applications.

[5]Level 4 (Results) addresses what impact the program has achieved. Is it working and yielding value.

Table 1: Evaluation of the Program (Software Performance)

Evaluation of the Program	
Evaluation Components	**Evaluation Methods**
1. Internal and external resources.	Count resources, assess quality analysis, questionnaires.
2. Media (audio, graphics, video, internet/www, videoconferencing).	Count resources, assess quality analysis, questionnaires, interviews.
3. Interactivity.	Record learner interaction and track paths.
4. Multi-level content to address diverse knowledge levels.	Analyze depth and breadth of material.
5. Inquiry-based learning environment and activities.	Record type of learner interaction and analyze quality of material.
6. Dynamically generated material.	Record updates of data-mined material.
7. Self-paced learning environment benefit students who learn at different rates and in different ways.	Record learner paths.
8. Appropriate material to maximize student learning.	Expert analysis of content and record learner paths.
9. Do avatars (autonomous agents) facilitate inquiry-based learning.	Learner questionnaire; interviews; focus groups; tracking.
10. Content quality and type of content included in program.	Expert analysis.
11. Effectiveness of the program for women.	Questionnaire; interviews; focus group, compare scores of males and females; expert analysis
12. Effectiveness of the program for a multicultural audience.	Questionnaire; interviews; focus group; compare scores of diverse ethnic/cultural groups; expert analysis
13. Effectiveness of the interface and ease of navigation.	Learner questionnaire, record paths and use of help menus
14. Visual display and its effect on human performance.	Learner questionnaires, interviews, compare scores of participants and control group, learner style correlated to pre-test and post test.
15. ‘Show Me’ tutorials: do learners use them and do they affect performance?	Record and track user steps after viewing the tutorials, expert analysis of performance.
16. Avatar suggestions: do learners follow suggestions of the avatars?	Track and record learner paths.

Table 2: Evaluation of the Learning (Student Performance)

Evaluation of the Learning	
Evaluation Components	**Evaluation Methods**
1. Do audio, visual and kinesthetic learners have higher exam scores than others because of the interactive multimedia presentation of material?	Learner Style correlated to pre-test and post test scores.
2. Do novice learners achieve higher scores than the control group?	Compare pre-test and post test scores.
3. Do novice learners achieve higher levels of learning than the control group?	Analyze student work and compare learner responses to particular exam questions.
4. Do advanced learners achieve higher scores than the control group?	Compare pre-test and post test scores.
5. Do advanced learners achieve higher levels of learning than the control group?	Analyze student work and compare learner responses to particular exam questions.
6. Do learners using the program have greater knowledge retention than control group?	Follow-up exam within a specified time period after the conclusion of the course.
7. Do individual learner characteristics determined avatar preferences.	Record avatar use and compare to demographics.
8. Do learner paths influence achievement scores?	Record and compare learner paths to post test scores.
9. Do learner characteristics determine learner paths?	Record and compare learner paths to demographics.
10. Does the dynamically mined material influence the quality of student performance?	Record use of dynamically mined material and analysis of student work.
11. How frequently do students choose to connect to human instructors?	Record contacts; record reasons for choosing human instructor.
12. What type of information do the learners obtain when using the human instructors?	Categorize and record communication.
13. Which communication methods do learners use to contact the human instructors?	Record communication methods.
14. Does multi-tracking encourage learners to work toward greater depth than expected?	Record learner paths.

Year 1

- Conduct interviews and focus groups of students in OOSE and AITDM classes for evaluation.
- Analyze surveys, pre-test and post-test data from OOSE and AITDM classes.
- Prepare evaluation report of control data from OOSE and AITDM courses for review.
- Assemble review panel to evaluate analysis and design.
- Implement prototype of OOSE module, user interface, avatar graphics and requirements for avatar behavior.
- Assess infrastructure for multimedia development at Allstate Insurance.
- Discuss results of review panel evaluation with Allstate and NCSA staff.
- Get Allstate input for text data mining server and AITDM module requirements, to be developed at NCSA and Lehigh with assistance from Allstate.
- Rework and complete analysis and design of OOSE module, user interface, avatar graphics and requirements for review panel feedback.
- Determine and specify data to track for evaluation of programs.
- Develop rubrics for analysis of performance-based assessments based on criteria from proposal and program analysis.
- Identify test and control groups at Lehigh, Allstate and other campuses, possibly with assistance of publisher or software vendor.
- Design and implement alpha version of reference librarian avatar behavior.
- Design alpha version of authoring language for describing specific avatar behaviors.
- Design and implement networking subsystem for remote reference avatar that maintains causal ordering of communication.
- Define semantic interface components for communication with the reference librarian avatar.
- Design and implement alpha version of interface support for "show me" interaction and integrate with networking subsystem.
- Design and implement alpha version of data mining server.
- Implement alpha version of OOSE multimedia module incorporating alpha version of reference librarian behaviors and networking capability.
- Teach OOSE and CS1 courses (fall 2001) at Lehigh using alpha version of OOSE module.
- Conduct surveys, pre-test and post-tests for CS1 and OOSE courses. Observe use of software, conduct interviews and focus groups, and assess programming projects.
- Gather electronically tracked data from OOSE module software in OOSE and CS1 courses.
- Track usage of advanced OOSE content and reference librarian avatar for CS1.
- Design and implement alpha version of AITDM multimedia module.

Year 2

- Analyze data from alpha version of OOSE and CS1 courses. Compare results with control data.
- Assemble review panel to evaluate results from OOSE and CS1 courses and assess alpha version of OOSE and AITDM modules to recommend improvements.
- Teach AITDM course (Spring 2002) at Lehigh using alpha version of AITDM module. Administer and gather surveys, tests, and electronically tracked data.
- Analyze data from AITDM courses using alpha version. Compare results from alpha version with control data.
- Fix bugs and make improvements to OOSE module to prepare for beta version.
- Teach OOSE and CS1 courses at Lehigh and other campuses (Fall 2002) using beta version. Administer and gathering surveys, tests and electronically tracked data.

- Implement beta version of AITDM module for use in upper lever undergraduate/introductory graduate classes.
- Implement beta version of AITDM module targeted at Allstate industrial applications.
- Develop beta version of "show me" interface, fix bugs and add needed features. Include tight integration among video, audio, chat, and email, and the dialog of semantic interactions with the interface.

Year 3

- Analyze data from beta version of OOSE and CS1.
- Compare results from alpha and beta versions.
- Assemble review panel to evaluate results from OOSE and CS1 courses and assess beta version of OOSE and AITDM modules in order to recommend improvements.
- Teach AITDM course (Spring 2003) at Lehigh and other campuses using beta version.
- Administer and gathering surveys, tests, and electronically tracked data.
- Fix bugs and make improvements to OOSE module.
- Analyze data from AITDM courses using beta version.
- Compare results from alpha version of AITDM with control data.
- Deploy beta version of AITDM module at Allstate and evaluate impact of framework in an industrial environment.
- Disseminate deliverable versions via publishers and demonstration versions via the web.
- Document methodology of analysis, design, implementation and evaluation of multimedia, "show me" networking and data mining algorithms.
- Begin authoring a textbook on multimedia design and development, incorporating the methodology developed for this project.

Dissemination Plan

We will make our deliverables available to the academic computer science community through dissertations, conferences, journal articles and textbooks.

1) Alpha, beta and demonstration versions of the OOSE and AITDM modules will be available via the Web.
2) Deliverable versions of the OOSE and AITDM modules will be available via CD-ROM. We will seek a vendor and/or publisher to help assemble external review panels, develop a marketing plan and handle distribution of either a stand-alone or packaged product.
3) We will seek a publisher for a new CS1 book, revising text and multimedia content from *The Universal Machine*.
4) We will document the methodology, design, development, multimedia and evaluation and present it in Ph.D. dissertations, technical conferences and journal publications.
5) Toward the end of the project cycle, we will author a textbook for an upper level course on multimedia design and development, based on our experiences and research, documenting how to create new modules using our framework.

We will ensure reasonable competition among vendors and/or publishers to disseminate our research material. Criteria for a vendor/publisher to disseminate our research include their market share of the target computer science audience, commitment and budget for external review and quality of marketing plan. It is our intent to retain intellectual property and reproduction rights to continue developing and distributing future versions of the software.

Project Management

PI Glenn D. Blank, Ph.D. is an Associate Professor of Computer Science at Lehigh University. He has a wide-ranging background in natural language processing (Blank et al. 1995; Blank 1989), and knowledge-based systems (Parson & Blank 1990; Blank et al. 1989). Blank developed most of the textbook and multimedia of *The Universal Machine*. He supervised the work of a joint author, multimedia art director, illustrator, cartoonist, researchers, three graduate and eight undergraduate students. He also coordinated the work of professional multimedia developers sub-contracted by the publishers Richard D. Irwin and WCB/McGraw-Hill[6]. Blank developed and produced the completed second version of the *Universal Machine*, which is available upon request (glenn.blank@lehigh.edu).

Co-PI William M. Pottenger, Ph.D., has an extensive background in knowledge management (Auvil, Hsu, Pottenger, Tcheng & Welge 1999; Bouskila & Pottenger 2000; Chung, Pinto, Pottenger & Thompkins 2000; Pottenger 1998; Pottenger, Callahan, & Padgett 2000; Pottenger & Schatz 1998; Pottenger & Zelenko 1998; Alper 1998). Pottenger holds a joint appointment as Assistant Professor of Computer Science at Lehigh University and Research Scientist at the National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign. He has supervised the thesis work of two Masters students in knowledge management (Bouskila 1999) and (Yang 2000) and is currently supervising the thesis and dissertation research of three Masters students and four Ph.D. students at Lehigh University and the University of Illinois. Dr. Pottenger also has an extensive background in the development of parallelization and scalability theories (Blume et al. 1996; Blume et al. 1994; Pottenger 1998; Pottenger 1997; Pottenger 1995; Pottenger & Eigenmann 1996; Pottenger & Eigenmann 1995; Alper 1998). He has experience on supercomputing platforms with a variety of languages and language extensions supporting parallel computation including C, Fortran, C++, and Java and has implemented high-performance knowledge management algorithms with linear speedups on supercomputers at NCSA (Pottenger 1998).

Co-PI G. Drew Kessler, Ph.D., is an Assistant Professor in the Electrical Engineering and Computer Science Department of Lehigh University. He will oversee the development and implementation of the distributed system and interface software for the "show me" demonstration component. His dissertation is in frameworks and support libraries for extensible, dynamic, and distributed virtual environment systems. While lecturing at the University of Pennsylvania, he served on three Ph.D. committees. The research involved an innovative design for large-scale virtual environments and defining compact semantic descriptions for actions of participants in a multi-user virtual environment.

Education and Workforce Development

The proposed project will incorporate an education and workforce development component. An essential element of this component will be an extensive summer internship program for undergraduate students working with the project's research faculty. The summer program will engage students in the research of this project to both advance the research and to provide an opportunity for undergraduate students to experience a research-programming environment. The purpose is to help students make decisions that will influence their professional development. We will recruit undergraduate and graduate students from Lehigh University to participate in summer internship programs at either Lehigh University or NCSA in Champaign, Illinois. Students at Lehigh and NCSA will work side-by-side with faculty researchers in a shared multiple workstations environment. Students will have full access to desktop workstations, computational servers, workstations for visualizing the results of computation, and high-speed networking to support their research projects. To support flexible work styles, they will be able to work in campus residences using campus workstation laboratories.

[6]Including a graphics designer, a script writer, a narrator, a sound editor and two multimedia programmers.

To share information technology issues and findings relevant to the project, students and faculty will meet for bi-weekly seminars. Faculty and students will lead discussion groups. We will invite guest lecturers, faculty and staff from Lehigh and NCSA/UIUC to provide students with a broad background in topics related to the research project. Culminating the summer program, students will present summaries of their work to discuss with fellow students and project faculty. Additionally, they will deliver a formal presentation on their research activities. We will post student projects on the project web site. If the NSF funds this project, we will solicit Research Experience for Undergraduates (REU) funding to support the undergraduate education and workforce development component of the research program described herein.

Expected Significance

We believe the research and curriculum development proposed herein will interest colleagues seeking to modernize computer science curricula, researchers in educational technology and industrial partners intent on leveraging such technology in workforce augmentation initiatives. The proposed general framework will feature a multi-track instructional design that accommodates diverse learners and learning styles. Avatars will represent a collaborative community of teachers and professionals who help students use dynamically mined materials, traditional research methods and networking to facilitate inquiry-based learning. The interface will focus on usability and performance enhancement. Our goal is to make the interface and content accessible to novices and challenging to advanced students. A long-term goal is develop new textbooks with accompanying multimedia for introductory and upper level courses.

As part of this project we will design, implement and evaluate material for senior/graduate level courses in Object-Oriented Software Engineering (OOSE) and Artificial Intelligence with applications in Textual Data-Mining (AITDM). These modules will build on the existing multimedia content that incorporates more advanced material in a multi-track multimedia environment. For example, the OOSE module will incorporate material on UML, design patterns, large-scale software architectures, and implementation issues, with references to implementation issues and example projects developed in Java and C++. Christine Hofmeister of Siemens Corporation, recently hired as a faculty member at Lehigh University, will contribute her expertise and real world experience in applied software architectures (Hofmeister, Nord and Soni 2000) to the development of the OOSE module. Our industrial sponsor, Allstate Insurance, will assist in the design, development and evaluation of the AITDM module.

The project seeks to advance the state of the art in automatic data mining of textual repositories with the help of NCSA industrial partners and Allstate Insurance. The detection of emerging conceptual content in textual collections is a significant area of research to industry and government.