Educational Innovations in Multimedia Systems

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Abstract: *Multimedia systems have emerged as one of the fastest growing segments of computing systems and thus need to be well integrated into a computer engineering curriculum. Fortunately the teaching and learning of multimedia systems can be aided with novel instructional techniques based on multimedia. The DVD project at the University of Massachusetts Amherst is developing a unified set of instructional materials on the engineering techniques used in the design and test of hardware, software and networks for multimedia. This large project includes three facets: 1) multimedia instructional modules using web-linked Digital Video Disks, 2) multimedia communication utilities to facilitate student interaction and 3) multimedia component design projects. In this paper, we explain our approach to using multimedia as both content and instructional technology and briefly present preliminary results in each of the three facets.*

1.0 Why Multimedia Systems?

We define a multimedia system to be a computer-based communications system which delivers heterogeneous and compressed/coded/encrypted content (text, audio, video, graphics) from a source or storage device and transfers it over a heterogeneous channel (Internet, wireless network, local area network) to an end-user while maintaining perceptual integrity (Figure 1).

New multimedia systems have emerged in many forms in the last 5 years and are now a major driver in the design of computer hardware, networks, and both system and application software. Processors, RAM, cache, disk, display, sound card, graphics card, network card, operating system, browser and editors have all been modified to target multimedia systems. Multimedia presents a new class of applications in computing which is quite different than the business and scientific applications that drove previous generations of computing systems. It spans real-time computing, signal processing, and communications issues and thus requires a very wide range of technical background. Multimedia systems engineering is an opportunity to substantially update and invigorate undergraduate computer engineering curricula while providing exciting new content for exploring new instructional methods and technology.

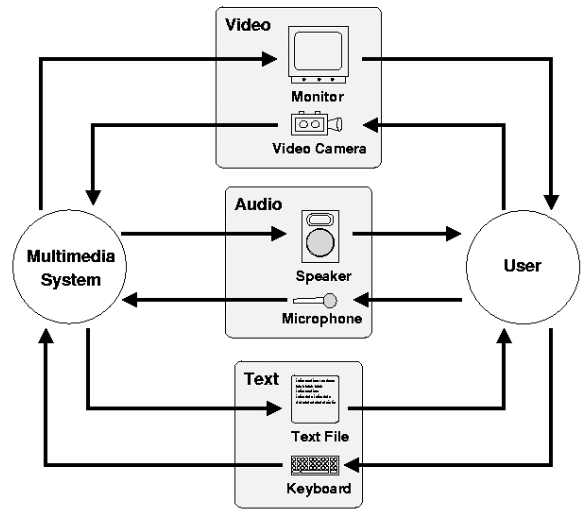

Figure 1: Multimedia Systems: The User's View

Multimedia systems also provide a motivating theme for integrating many of the fields of computer engineering thus encouraging multidisciplinary work.

- First, multimedia systems require **a systems approach** to design that covers the generation, transmission, storage and retrieval of widely varying content. Algorithm, hardware and software design problems can be unified in an integrated context, thus providing students with a ``big-picture'' view of computer engineering {DeMan}. We use this systems approach in design projects at all levels, requiring students to work in teams and deal with many design issues and constraints simultaneously.
- Secondly, multimedia systems designs involve a significant amount of **statistical and probabilistic analysis** for the estimation of performance and signal quality, thus substantially motivating math and signal processing courses in the curriculum. Simulation and visualization tools are used to show how system and algorithmic choices impact the resulting media product and result in variable run-times.
- Third, multimedia systems provide very **tangible functionality** (and misfunctionality!) to students, hopefully motivating them and showing real

applications without compromising engineering fundamentals.

2.0 The UMASS DVD project: "Using Multimedia to Learn Multimedia"

The UMASS DVD project is led by 7 faculty in the Computer Systems Engineering area within the Department of Electrical and Computer Engineering. Together, we are developing a set of integrated instructional tools and curricular innovations which are unified by the common theme of multimedia systems. Our approaches to this problem consist of:

- multimedia instructional modules using web-linked Digital Video Disks described in Section 3,
- multimedia communication utilities to facilitate student interaction described in Section 4, and
- multimedia component design projects described in Section 5.

Extensive multimedia archives, source code, demonstrations, modules, authoring materials and project details can be found at the DVD project web-site:

http://www.ecs.umass.edu/ece/dvd

3.0 Multimedia Instructional Modules

We are developing interactive DVD-based instructional modules in the following 6 areas related to multimedia systems.

- MODULE 1: Natural Content Coding (video, audio)
- MODULE 2: Synthetic Content Coding (graphics)
- MODULE 3: Multimedia Networks
- MODULE 4: Multimedia Architectures and Operating Systems
- MODULE 5: Design/CAD for Multimedia Hardware
- MODULE 6: Testing of Multimedia Systems

Together, the modules provide an integrated problem domain which cuts a wide swath through the field of computer engineering. With 7 different faculty developing 6 different modules in this project, we are able to amortize the module development infrastructure over a wide range of content and teaching styles. We believe that the overhead required to develop any re-usable instructional modules is significant enough that the infrastructure should be used by a variety of faculty in a variety of courses. We have developed a generic module template with utilities for novel functions (interactive video lectures, interactive video demonstrations, links to related design projects) , but we see significant variation in the individual modules due to the different topic areas and teaching styles.

These modules directly impact 6 undergraduate ECE courses as well as being used as short course tutorials for distance learning and self-paced instruction. The modules are based on a combination of interactive Digital Video Disks and Web technology, allowing a combination of high quality video and audio along with hot-links to the Web.

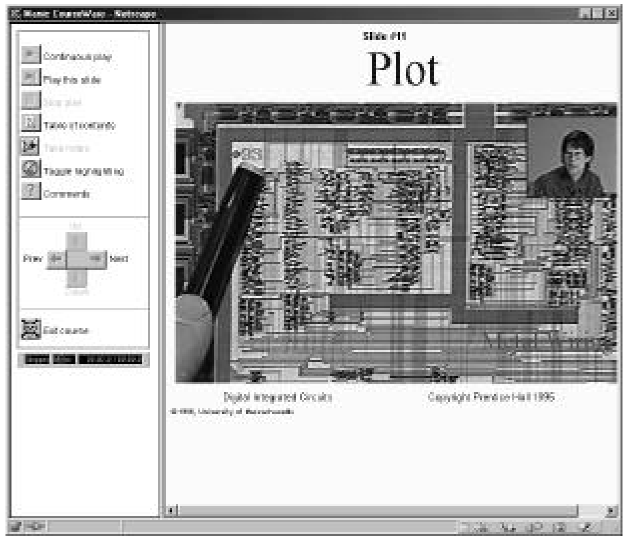

Figure 2: Clip from VLSI course using MANIC software for Internet-based slide show with synchronized audio

Figure 2 shows a screen shot from a module on VLSI design which illustrates many of the concepts in our multimedia modules. The video is captured in the professional studios of our Video Instructional Program just like any regular UMASS academic course or short course. We then digitize the video and integrate it with other course materials onto the DVD. Initially we use the MANIC system, developed in the UMASS Computer Science department {MANIC}, to integrate slides and video stills with synchronized audio into an Internet-based format that can be viewed by a standard browser (e.g. Explorer or Netscape) and media player (e.g. RealPlayer). The authoring process is quite efficient compared to tools like Macromedia Director, taking only about 2-3 hours for every hour of live lecture. This ratio depends on the amount of animation and annotation that is desired. UMASS undergrad Brendan English converted 31 hours of video lectures containing 528 slides to the MANIC format during a winter vacation week. The MANIC system allows easy navigation through the modules, either asynchronously by choosing the slides from a table of contents or search engine, or synchronously by just playing the audio and allowing the slides to be advanced automatically. At any point, the student can stop the presentation and interact. Current forms of interaction include:

1) navigation through slides via a hierarchical PDF-style table-of-contents,
2) following links to other slides, glossaries and external web-sites,
3) searching for key words that appear in the slides titles and text (search for keywords in video, audio or image is not currently supported).

Details on MANIC can be found at: http://manic.cs.umass.edu/

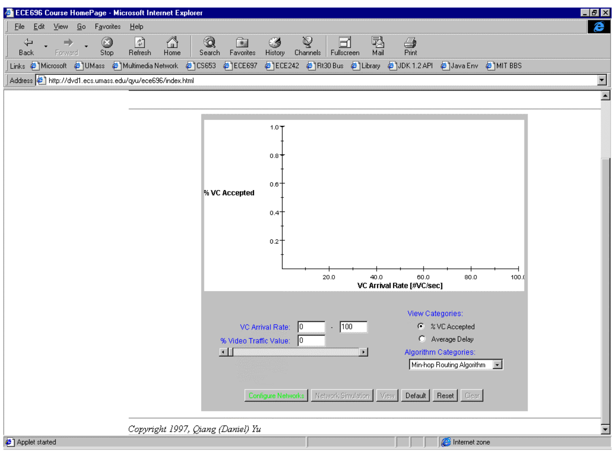

Figure 3: Applet for observing ATM performance on video traffic

Students can also interact with the lectures by requesting examples and demonstrations, which are written either as Java Applets run on the client or CGI programs run on the server. We have developed a number of Java applets that provide students with an interactive multimedia experience that enables them to grasp a number of networking concepts.

1. **Routing concepts**. The user can input any network layout (any number of nodes, links and link weights). Students can program their own routing algorithm and compare it to the classical shortest path. http://dvd1.ecs.umass.edu/kenny/j_spf.htm.
2. **ATM routing algorithms**. The user can input the network layout (nodes, links, links' weight, capacity and length), the routing algorithm (min-hop and min-delay) and the percentage of video traffic in the network. Figure 3 displays the delay versus virtual circuit (VC) arrival rate and also the percentage of accepted VCs versus the VC arrival rate. http://dvd1.ecs.umass.edu/qyu/ece696/index.html
3. **MAC and data link protocols** http://dvd1.ecs.umass.edu/qyu/ece796/index.html

An example of an interactive demonstration of the MPEG encoding algorithm is shown in Figure 4. In the first screen shot, the student chooses a number of parameters for the encoding algorithm and then submits them to the MPEG coder. In the second screen shot, the results of the student's parameters choices are shown, including the statistics of the MPEG-1 encoding program (run-time, compression ratio, file sizes, etc.) as well as the actual test video (in this case, the benchmark Table Tennis video which shows varying object motion (ball and paddle) and zooming). This work was done with UMASS PhD student Jeongseon Euh.

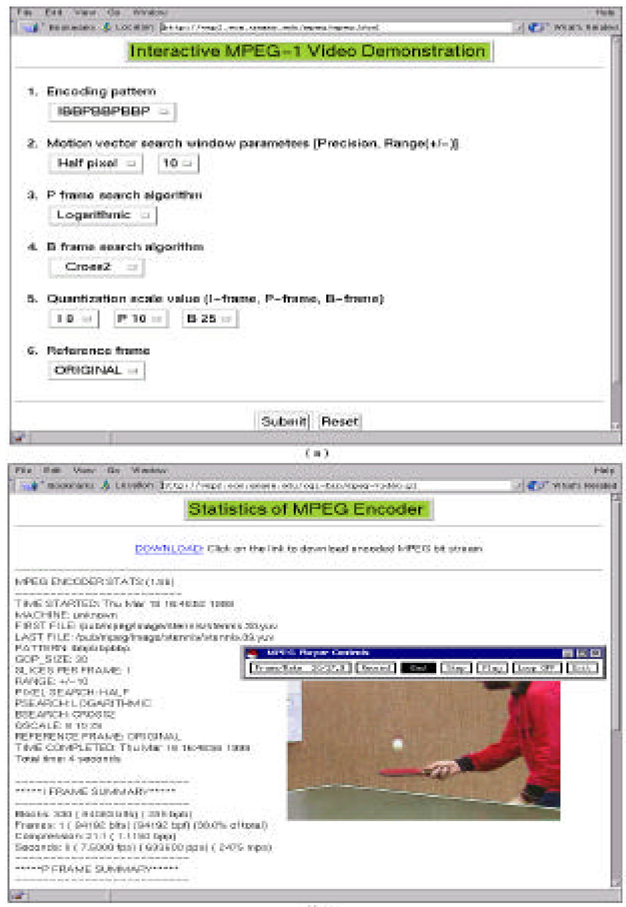

Figure 4: Interactive MPEG demo

Another form of student interaction is an on-line homework system. At any point during a module or outside of the module, students can choose a set of questions specified by topic and difficulty level. For example, after viewing 15 minutes of a lecture on Video coding algorithms, the student might request 3 intermediate-level questions on motion estimation techniques or, 2 questions drawn from the last *n* minutes of the presentation or *m* slides of the presentation. Another scenario is that a well-prepared student who already has some background in a particular area might request some questions **before** viewing the lecture. This allows students to make the best use of their time by "testing-out" of sections that they may already know. The homework can also be used to preview lectures and review material for exams, projects, job interviews, etc. Homework problems can also link to the interactive demos and applets thus providing continuity between the lectures and the homework. The software provides immediate feedback after the students submit answers. The feedback includes the score for each session, accumulated score for all sessions, how long students take to finish each session, right or wrong for each question (if an answer is wrong the program will present a correct answer to students). Details and a demo of the homework system can be found at http://tikva.ecs.umass.edu/quiz/index.html. The homework system was developed with Jianxin Wang, Xin Liu and Noel Llopis.

Our homework system is different than the many other on-line homework systems (see recent FIE proceedings) in the following ways:

- emphasis on multimedia in question and answers
- integration with modules (questions tagged by topic, time and difficulty)
- mixed-mode to support automated grading as well as human grading
- integrated with applets and demos

We have found that the modules are very useful as a review for students doing multimedia design projects. Students in a VLSI project course are designing a Huffman coding unit that uses a barrel shifter and a RAM. By searching for these keywords in the VLSI module, they can get a quick overview of the design issues for these blocks. Even for students that have never studied a particular topic, the modules can be used to give a quick introduction. For example, we have students designing a Lempel-Ziv compression chip who have never encountered the basic Lempel-Ziv algorithm. Rather than give them a journal article or textbook as background, or ask them to just “find it on the Web", or require a semester length Data compression course, the module allows a quick introduction to the topic from an instructor whose presentation style and reputation they already know.

4.0 Multimedia Communication Utilities

We have developed a variety of multimedia utilities to support communication and collaboration in conjuction with the instructional modules of Section 3 and the design projects of Section 5. Despite the promise of technology for the formal delivery of educational materials, we feel that some of the strongest benefits of technology are just to enable **informal human-to-human interaction**. Ideally each student could freely and frequently interact with the professor, the teaching assistant and their fellow students. However, the reality of time limitations and scheduling conflicts makes this difficult. One of the simplest, most general and most effective solutions has been the use of electronic mail and bulletin boards. We have developed several utilities that make it easier to discuss, critique, annotate, and revise multimedia objects. These are used in standard academic courses but are most important in design project courses.

One of the most fundamental utilities allows the student to **submit an arbitrary multimedia file into the on-line homework system**. Thus, a student can provide an audio file or a graphics file as a solution to a homework or quiz problem. This significantly expands the homework system beyond the limitations of automated multiple-choice question styles and also supports students with various communication and learning disabilities.

A **multimedia bulletin board** allows students to post their work and then view and comment on it. This is similar to students preparing their own Web pages except that commenting and interaction between students is better supported. Contributions can be listed either threaded by subject, or ordered by time of posting. Multimedia files such as figures, video and voice can be posted.

We have developed a **multimedia whiteboard** that allows students and the professor to actually collaborate on the design of a multimedia document. A document can be viewed with annotations in color and text added by the professor and students (Figure 5). A distributed client-server framework allows multiple documents from different courses and projects to be open at the same time, encouraging multidisciplinary collaboration. In addition to the whiteboard, we have also developed a **multimedia chat** program and a **multimedia forum** which are based on the same principles but have different modes of interaction. For example, chat and forum store a transcript of the interaction while whiteboard just stores the most current document. Chat is synchronous while the whiteboard and the forum are optionally asynchronous. In conclusion, all of these Internet-based communication systems can benefit from specific multimedia support. This work was done by UMASS undergraduate student Jeff Peden.

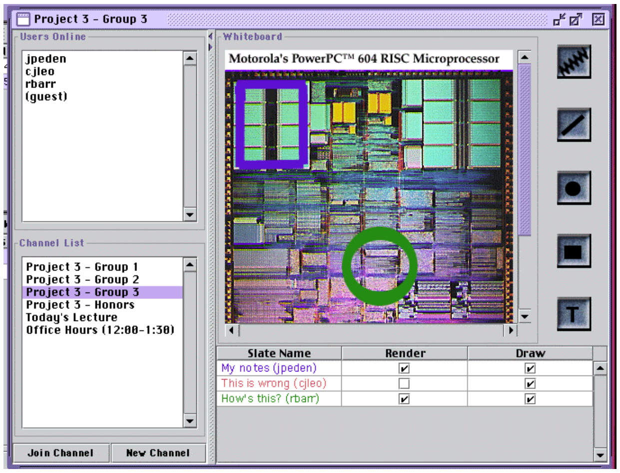

Figure 5: Multimedia Whiteboard

5.0 Multimedia Design Projects

Multimedia modules provide a good introduction to a topic area, but a more effective and realistic technique for learning computer engineering involves a team-based hands-on design project. To support this, we have developed an archive of hardware and software design projects related to multimedia systems and linked to the instructional modules at various levels. To facilitate these projects, we rely on the modules described in Section 3 as well as the utilities in Section 4. We have incorporated multimedia themes into several of our undergraduate design project courses. Projects vary from software and networking to architecture, microprocessor and VLSI design depending on the course. In the VLSI design course, we have projects in Audio Coding, Discrete Cosine and Wavelet Transforms, Image Filtering, LZ coding, Arithmetic coding, Huffman Coding, Cryptography and Video Motion Estimation. Although these are components or sub-systems, rather than complete multimedia systems, they all present significant challenges for the senior-level students since they have to thoroughly understand the correct functionality of the blocks before they can design the circuits and generate proper test vectors for simulations.

Expertise in the testing of multimedia systems is becoming required for system designers in industry and should therefore be introduced at the undergraduate level. Multimedia systems can be used to teach many concepts of testing in a very tangible way. Testing, in turn, forces students to carefully look at their design from an external viewpoint, addressing issues such as I/O, standards, and manufacturing defects. Several aspects of multimedia systems make their testing a unique problem:

Real-Time Systems: Multimedia systems are typified by a high bandwidth user interface which must meet real-time constraints. The high bandwidth required in many applications, such as video, can push design performance limits and necessitate **delay optimization** and **delay verification** {Sifakis92}.

Heterogeneous Systems: A typical multimedia application is built from many heterogeneous components which are required to interface the digital representation of multimedia data with the physical senses of the user, typically through audio and video. System components vary widely in terms of data throughput and implementation technology. Hierarchical design is well-known but a **hierarchical testing** {HierMurr90} approach is required to accomodate the various testing approaches required for each component.

Mixed-Signal Systems: The large majority of multimedia systems are based on digital components. However, because human senses are inherently analog, multimedia systems must include **analog** components as well. Mixed-signal design and testing present challenges beyond either digital or analog {MilorMixed98}.

Standards Implementation: Intense consumer demand for multimedia systems has driven standardization efforts in order to increase volume and reduce costs. The purpose of standardization is to create a common high-level functionality across different products, while giving a large degree of freedom in system implementation. Because different implementations of a standard will vary greatly, standards **compliance tests** {MpegComp95} must be designed which are independent of internal design.

We now present two VLSI senior design projects that have typical multimedia testing and verification issues. The scope of these projects has been limited to fit a typical senior-level digital VLSI design lab course. Each design is a single-chip, digital component of a larger multimedia system. By fully understanding the design and test of one of these designs, students get a glimpse of the design and test of multimedia systems in general.

Project: Montgomery Modular Exponentiation:
The Montgomery modular exponentiation algorithm is a central component of many cryptography systems. Since cryptography is important for a large class of internet-based secure multimedia applications, this design is a component in many multimedia systems. Since encryption/decryption are performed on the incoming/outgoing media data streams, modular exponentiation is part of the critical performance path and requires delay verification. Modular exponentiation is also a part of the RSA encryption standard. Although the implementation of the exponentiator is not defined in the RSA standard, the behavior of the exponentiator must be correct in order to guarantee the compliance of the larger RSA system.

Project: Video Motion Estimation Array:
Motion estimation is a part of the popular MPEG video compression standard, used in a wide range of multimedia equipment. Motion estimation is the most compute-intensive step of the MPEG encoding task. The high performance demands of digital video applications make delay verification essential in motion estimation. Developing test sequences to verify the estimation algorithm is very complex and best done in a high-level language.

The verification of these multimedia design projects requires the use of a structured, hierarchical approach to manage testing complexity. For the purposes of **functional testing**, the circuits are modeled by a C/C++ program which will be used as the golden simulation. Since delay verification is important for multimedia systems, a cycle-accurate model is required. The C/C++ program model is designed to be cycle-accurate to enable delay verification as well as functional testing.

6.0 Evaluation

This project is ongoing and presents numerous innovations that must be evaluated to determine their value in improved teaching and learning. We have just begun this large effort by piloting the various modules, utilities and projects into our own curriculum. After these pilot runs, we will also actively disseminate the materials to five other diverse institutions around the world (ENST Paris, Pusan Nat. Univ., Korea, National Technological Univ., Smith College, and the Springfield Technical Community College). Our evaluation strategy consists of four components:

1) **Student evaluation** of the teaching materials. Throughout the design of the modules, the utilities and the design projects we have incorporated numerous ideas from students. Undergraduates are heavily involved in the project. Early survey of the Networking module indicated 98% student satisfaction. We are currently administering a survey on video instructional techniques to both on-campus and off-campus students.
2) Assessment of student learning using **pre- and post-tests** for students using the modules versus a control group. Our homework system administration tools provide the course instructor the ability to edit and modify quiz files, and analyze quiz results. A more informal approach will be used for student projects due to the difficulty in formally assessing learning in design.
3) Feedback from the 5 **dissemination institutions** on the benefits of the modules, utilities and projects to students and faculty. The authoring tools and source code will be made available to these institutions as well as a module explaining how to develop your own modules.
4) Feedback from **industrial partners** who hire our students and use our courses for continuing education (e.g. Compaq, Sun, Samsung, Intel, Cadence, Cisco, Motorola.)

References:

{DeMan} H. DeMan, Keynote speech in ACM/IEEE Design Automation Conference, 1997.

{MANIC} M. Stern, J. Steinberg, H.I. Lee, J. Padhye, J. Kurose, "MANIC: Multimedia Asynchronous Networked Individualized Courseware," *Proc. of Educational Multimedia and Hypermedia*, 1997.

{MpegComp95}, P. Meehan and N. Hurst and M. Isnardi and P. Shah, MPEG Compliance Bitstream Design, *International Conference on Consumer Electronics*, June, 1995, pp.174-175.

{MilorMixed98},L. S. Milor, A Tutorial Introduction to Research on Analog and Mixed-Signal Circuit Testing, *IEEE Transactions on Circuits and Systems II: Analog and Digital Signal Processing*, vol. 45, no. 10, 1998.

{Sifakis92},J. Sifakis, Real-Time Systems Specification and Verification, *International Symposium on System Synthesis*, September,1995.

{HierMurr90}, B. T. Murray and J. P. Hayes, Hierarchical Test Generation Using Precomputed Tests for Modules, *IEEE Transactions on Computer Aided Design*, vol. 9, no.6, June, 1990, pp.=594-603.

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