DISTANCE LEARNING WITH HIGH-DEFINITION LOW LATENCY VIDEO AND MULTI-MEDIA INFRASTRUCTURE

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Abstract: Although distance learning has a history that spans many decades, the full opportunity that is implicit in its exploitation has not been fully realized due to combination of factors including disparate experience between it and its classroom counterpart. However current and emerging technologies are helping overcome this barrier by providing significantly better interaction among the individual participants, thereby opening new avenues for knowledge dissemination. LSU in collaboration with five other institutions has developed effective methods that greatly extend the educational opportunities through combination of advanced technologies and educational methodologies. LSU and its partners have tested these technologies in real-time over the last two years. While further improvements are needed, this activity represents the current state of the art in technologies utilized and the quality of content and experience delivered. The distance learning initiative undertaken by LSU and its partners is driven by a vision for education, which aims to deliver expert & top-quality educational content to locations irrespective of their economic or technological limitations.

1 INTRODUCTION

Distance learning is as effective as the means to emulate the local classroom experience is successful. The motivation to realize the potential of distance learning is to address critical challenges being imposed by the realities of economics, demographics, cultural diversity, and the rapidly increasing wealth of possible topics and specialties. Of particular importance to the work undertaken by the authors represented in this paper is the opportunity to dramatically increase the choice of educational pursuit by students independent of geography, financial circumstances, and stature of the educational facility. Only by aggressively addressing this challenge of choice can the full potential of every student be realized for the benefit of themselves and society as a whole.

Although distance learning has a history that spans many decades through continuing education programs and more than two decades through low grade video, the full opportunity that is implicit in its exploitation has not been fully realized because of disparate experience between it and its classroom counterpart. Recent advances in high definition digital video over Internet have opened new vistas in the quality of the distance learning experience with advances in both visual quality and narrowing of round trip latency for realistic dialog. As will be discussed in the next section of this paper, a transformative change in the future of higher education may be achieved through the effective use of a combination of these and other technologies for a synthesis of the distributed teaching and learning experience.

Louisiana State University in collaboration with five other institutions has undertaken an important experimental program in distance learning to develop effective methods greatly extending educational opportunity through the combination of

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advanced technologies and educational methodologies. Specifically, LSU has employed a range of real time video qualities including the use of uncompressed high definition for low latency over long distances in real time. It has combined this with an active web site for a multitude of material dissemination techniques including on-demand video download to provide a viable and effective educational experience that rivals that of local classroom teaching. To exercise these technologies and methods in a real world distance learning setting, LSU has developed a new first-year graduate course: "*High Performance Computing: Models, Methods, and Means*" which is intended as an introductory treatment of the multi-subdisciplinary area of high performance computing for the largest diversity of student interests. This course was also opened to advanced undergraduates as the prerequisites were minimized for maximum participation. This course was received in real time by four other campuses for each of two cycles in the Spring of 2007 and 2008.

The purpose of this paper is to present the methods employed, the resulting experiences, and the advances still required to fully achieve the dream of the promise of distance learning as a mainstream strategy. The next section of this paper discusses the details of this promise that provides the long-term motivation of our work and its importance to the future of college education in the US. Section 3 provides an overview of CSC-7600, the computer science course developed in part to develop the methods used in conjunction with the advanced distance learning technologies. Section 4 provides a comprehensive description of the array of technologies and their synthesis used for this experiment. Section 5 then describes the strengths and weaknesses experiences from the perspective of the educational process. Finally, Section 6 briefly discusses additional extensions to the techniques employed that are being pursued to improve the overall educational experience in response to our initial results. This work has been funded in part by the National Science Foundation (NSF) and by the LSU Center for Computation and Technology (LSU-CCT).

2 VISION FOR DISTANCE LEARNING

The role of distance learning combined with the advanced technologies and methodologies that enable it will have a transformative impact on how higher education is accomplished in the 21st Century. In the US diversity in demographics, geographical economics, and the effects of world competition is challenging effective delivery of quality education, especially in rapidly changing Science, Technology, Engineering, & Mathematics disciplines, including computer science and engineering. Such fields demand expertise and experience in a diversity of sub disciplines for effective education at the college level. These areas are in constant change and require faculty who are actively participating in related research to remain current. Unfortunately, these specialties are under-represented or entirely absent at many or even a majority of US universities and smaller colleges. As a consequence, students at these otherwise fine institutions are deprived the opportunity to benefit intellectually in these areas. While many such students may not ultimately undertake such studies in any case, they are deprived the fundamental opportunity of choice. At a time when many young students are still in a stage of personal development, being deprived of such choice predetermines that outcome of their potential evolution and overly constrains the promise of their professional potential.

A second critical factor is the cost of education. This cost includes the development of new courses as well as those advanced courses which must be constantly updated. In recent years, the cost of a student-seat-hour has skyrocketed in the US only partially offset by increased student tuition raises. Even these increased tuitions can prove a severe inhibitor to economically challenged students in their choice of college or even whether or not they undertake higher education at all. While many factors contributed to these escalating costs, one major factor is the significant increase in the salaries of faculty in fields for which there is a strong industrial competition. High technology and applied science fields are among these.

The application of advanced digital multimedia, communication, and computer technologies may alleviate and even transform higher education through distance learning. When combined with innovative methodologies of teaching, these emerging technologies may deliver:

- Higher quality education by making courses available from national experts in specialized fields, and investing more resources in to the development of each such course,

- Lower cost by amortizing the course development across a wider range of institutions and students,
- Greater choice for students in pursuit of the professional and personal growth through access of the widest possible number of excellent courses being delivered at their local institution, and
- Increase the number of highly specialized courses by amortizing such courses over an aggregate student body distributed across a large number of institutions.

This last opportunity is a subtle but important one. Often a course, which could be taught, is not because enrolment is too few. Although the material may important, the desire of the professor to teach it is high, and the interest of the few students who sign up also high the economics simply cannot permit the realization of such a course. The exploitation of distance learning may create a distributed student body of sufficient capacity to justify teaching a course and bringing new diversity and quality to education. Ultimately all of these factors provide unprecedented choice for students of the widest variation in circumstances. This may be true internationally as well with technologies spanning national boundaries and language barriers reduced through a worldwide community.

To achieve the promise of this vision for freedom of choice and opportunity in higher education, advanced technologies and pedagogical methodologies have to satisfy key requirements:

- Point to point high bandwidth digital communication that is real-time, reliable, stable, and bounded in cost for practical application,
- Broadcast capability n-way to n-way,
- High definition video streaming,
- Low latency video and audio for real-time dynamic interaction,
- Active web site for access to all course information and materials including but not limited to course slides, schedules, problem sets, reference materials, tutorial notes, homework solutions, and wikis for frequently asked questions,
- On-demand downloadable videos of lectures and recitation sections,
- Self-tests and quizzes for frequent evaluation of progress,
- Back channel communication for set up and management of networked sites, as well as continuation of lectures with degraded resources, and
- High quality course material crafted with the recognition of the strengths and limitations of the media being used.

The remainder of this paper describes the methods and experience of one consortium of universities to address these challenges for a new graduate course in high performance computing provided in high definition video among multiple campuses in the US and one in Europe.

3 HIGH PERFORMANCE COMPUTING COURSE MATERIAL

LSU has developed a new course with the express purpose of teaching it via distance learning using the advanced technologies described in the next section. CSC-7600 – High Performance Computing: *Models Methods and Means* – has been offered as a first year graduate course and advanced undergraduate course. It has been so structured to serve four key professional goals including:

1. Computational sciences – for students who wish to focus on other fields that require the use of high performance computing as a tool to achieve the goals of the science or engineering discipline being pursued,
2. Research in Computer Systems – for doctoral students in electrical engineering and computer science who wish to conduct research in this and related fields of study,
3. Hardware & Software Developers – for future engineers pursuing positions in industry involved in the design of hardware or software systems associated with HPC, and
4. Systems Operations – for future managers and administrators of supercomputers and their centers.

Because of the diversity of professional goals and disciplines from which participating students may come, this course required a minimum of prerequisites including: user familiarity with a Unix-like environment (e.g., Linux) and programming experience with the C programming language. Wavers were provided in most cases for those without C background but with experience with other comparable languages such as Fortran. No text book was used but reference material from a number of sources (Sterling, 2003; Gropp, 1994; Chandra, 2001; Hennessy & Patterson, 2003; Galvin, Gagne & Silberschatz, 2005) was made available through the course web site, some of which was developed expressly for the course. All lectures were taught using slides in electronic form. These were developed using Microsoft PowerPoint and disseminated via the web site in .ppt and .pdf formats. The availability of slides downloaded to remote sites early was a risk mitigation factor that allowed the lecture to proceed even if the video link was disrupted by using the back channel conference call channel. It also allowed a higher quality remote presentation of slides that was achieved through live video capture and distribution of the same visual material. Live demonstrations were done this way, however that was not always sufficient for the purpose.

The one-semester curriculum was taught over a fifteen week period including exams and holidays and comprised six major parts:

A. Introduction and Throughput Computing
B. Clusters and Message Passing
C. Shared Memory Processing
D. Parallel Algorithms and programming techniques
E. Operating Systems
F. Visualization and Advanced Tools

The course partitions the concept space for HPC into three classes of parallel processing, two of which are commonly referred to and a third essential to a correct representation as it relates to scalability, programming models, and system architectures. The cross cutting theme is performance and throughout the course performance implications are examined as well as skills are developed using tools for evaluating performance. The first part explores the simple but important form of capacity or throughput computing that exploits concurrent work stream of independent and unrelated user jobs. The class of architecture employed for this is a workstation farm and loosely couple clusters. Condor is taught as a framework for controlling this ultra coarse grain parallelism and simple means of measuring performance are introduced. Weak scalability is employed to increase performance by increasing the number of jobs as the system size is increased.

The second part provides in-depth coverage of the very important message-passing execution model used with commodity clusters and MPPs and programmed with MPI. Collaborative computing is offered the domain of weak scaling that applies multiple processing elements to a single parallel task. As the system scale is increased, so is the size of the application problem yielding more work to do and maintaining a constant level of granularity. The third part covers the most difficult form of HPC, capability computing in which a single problem of fixed size is able to reduce its time to execution through increased system scale. OpenMP is used on a shared memory system to represent capability computing and provide a programming model.

The fourth part is dedicated to reinforcing the lessons of the previous three by investing substantial time in additional programming experiences for different classes of problem algorithms. The use of instrumentation tools such as Tau and PAPI are developed to measure performance improvements and evaluate effective scalability. The course considers four sources of performance degradation including overhead, latency, contention, and starvation and shows how they may be addressed through different techniques.

The fifth and sixth parts focus on system software and methods for using supercomputers to practical advantage. This includes the important domain of scientific visualization for conveying the meaning of the resulting data to the end user. The course included hands-on experience through examples, exercises, and projects using a cluster of SMP nodes dedicated to the course.

4 ENABLING TECHNOLOGIES FOR DISTANCE LEARNING

Technology is the key component to enable teaching and distribution of course materials without any geographical barriers. The HPC course was distributed to different sites using different technology methods for each site. The technology method used were uncompressed HD streaming, compressed HD streaming using a Polycom HD device, Access Grid and SD streaming using Ncast stream engine. The type of technology used at each site was determined based on the available resources at that site.

Table 1: Distance learning technologies used by different participating sites.

Media Format	Sites
Uncompressed HD Video (Ultragrid)	Masaryk University, Brno, Czech Republic
Compressed HD Video (Polycom)	University of Arkansas – Fayetteville, Arkansas
Access Grid	Louisiana Tech University – Ruston University of Arkansas – Little Rock, Arkansas
Web streaming (NCast)	Back up option and also used for recording of lectures to enable post reviewing for students

- **Uncompressed HD video streaming:** This technology was used to stream uncompressed HD video of the HPC course to Masaryk University, Brno, Czech Republic over a private 10Gb optical network using a open source application called Ultra-grid. Each HD stream is 1.5Gbps. Multiple optical networks had to bridge connections and make allocations to make the communication happen between LSU and Masaryk University over 10Gb optical network. The network partners were Louisiana Optical Network Initiative (LONI), National Lamda Rail (NLR), StarLIght and CESNET.
  Two high-end workstations one to send and the other to receive video were deployed at both sites. The sender workstation consists of video capture components and a 10Gb network interface. The receiver workstation consists of an Nvidia graphics card with a DVI out that is capable of displaying HD resolution (1920x1080) and a 10Gb network interface. A HD camera and a HD display device (LCD or Plasma screen) were deployed at both locations to capture and display video respectively.
  The HD camera was used to capture the video at each location and fed the capture device on the sender workstation. Ultra-grid application then sent the captured video over 10Gb network to the recipient site. The receiver workstation at each site received network stream and Ultra-grid displayed the far site video on the HD display at each site. A different application called Robust Audio Tool (RAT) was used to send audio over the same network.

  Pros: The video quality was extremely sharp with almost no latency. The output resolution was 1080i. The interaction was very good in this technique.

  Cons: Deployment of this technique was very expensive, bandwidth intensive and involves lot of manual intervention throughout the session. The equipment costs a lot and the charges for the network bandwidth usage are extremely high. Not all sites have 10Gb network access to participate using such a technique and even then the site has to purchase the workstations, capture cards, etc, which are expensive. Even after making such an investment, they can only collaborate with another site that had all these and a 10Gb network, which is very uncommon.

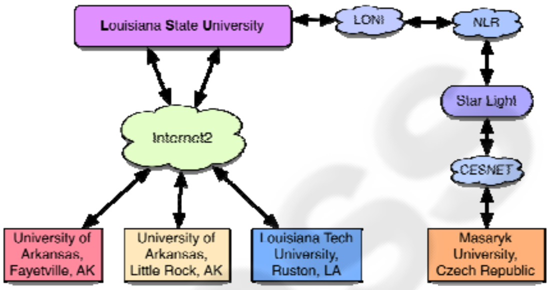

Figure 1: The different interconnection technologies used in the distance learning experience.

- **Compressed HD streaming:** This technique was used to stream compressed HD audio/video to University of Arkansas at Fayetteville. A Polycom HDX 9000 unit was deployed at both the locations. This is boxed product that works well and the stream is sent on commercial Internet. At LSU, the same video captured on the HD camera (used for the uncompressed technique) was fed in to the Polycom unit and the audio was picked from the room mixer/echo canceller. University of Arkansas has a HD video camera that fed the video to the Polycom unit and the audio from the room mixer. Both sites had HD LCD screens to display the far sites.

  Pros: Video quality was good with a little latency. The output resolution is 720p. Very low bandwidth utilization of less than 1Mbps, that is affordable at all sites. The device can talk to non-HD Polycom or any H323 unit.

  Cons: The unit is expensive as it is a commercial solution.

- **Access Grid:** Access Grid is an open source application developed to enable collaboration of research universities. This application is available at many universities and simply uses low cost capture cards, cameras and PCs to capture send and receive video to/from far sites. This technology was used to stream to University of Arkansas at Little Rock, Arkansas and Louisiana Tech University at Ruston, Louisiana.

Pros: Very easy to setup and the application is free. Anyone can install the AG on a PC and participate in the class

Cons: Video quality was not very good as the resolution is very low. There is a little latency. Students cannot feel the interaction as opposed to other techniques above. Application is very unreliable.

- **Webstreaming:** A boxed product called NCast was used to send the video stream live over the internet. Users can access it via a browser or quicktime video. Also the same video is recorded to enable on demand access to the lectures. This feature was very popular as students accessed the videos numerous times. This technique also served as backup plan if AG does not work

  Pros: On demand access and very basic requirements to access the video

  Cons: Huge latency. Not suitable for interactive sessions mainly due to latency factors.

5 EDUCATIONAL EXPERIENCE AND DISTANCE LEARNING

In its first offering, this course involved more students than any other computer science graduate course presented that semester. In its second offering, it received the highest student evaluations of any graduate course of the computer science depart in its semester. For this accomplishment, the professor was awarded the Graduate Teaching Award for his College in 2007.

Student and Faculty Perceptions. Technical application is only one facet explored in the presentation of the course. A study was conducted through the first iteration in order to ascertain student response to the various technical aspects that were used during the class. This study was designed to demonstrate both the strengths of using multiple technologies to foster interaction as well as the weaknesses proctored by trying to combine these technologies as well as human factors and have them mesh together seamlessly.

The study itself consisted of a combination of anonymous surveys, journal entries and discussions with the instructors as well as proctors from the various remote sites. In order to maintain continuity, only sites that made use of all of the various technical applications participated in the study. This included two remote sites: the University of Arkansas and a satellite location on the campus of Louisiana State University, as well as the local site at LSU. The overall population comprised 38 participants: 16 (42.10%) attending the class from a remote site and 22 (57.89%) attending from the local site.

Students who participated in the anonymous survey revealed correlations between three distinct areas of interaction and the technological aspects of the course. Dependent on the strength of the technology at the various sites, students demonstrated a greater sense of interaction between themselves and the other sites as well as with the host site. These correlations offer keys to the technical areas that need the most work to best engage every student.

Video Quality and Interaction. The technology that had the most positive impact on student interaction was the uncompressed video. Every student participating in the course either agreed or strongly agreed that they were able to clearly see the professor. Considering that current research suggests that video clarity is paramount in maintaining student attention as well as retention in a distance-based course the use of the uncompressed high definition video offered students the ability to engage the professor as well as the other sites visually (Coventry, 1998; Fillion, Limayem, & Bouchard, 1999; Pitcher, Davidson, & Napier, 2000).

According to journals kept by the proctors at the individual sites, while video quality offered a numerous amount of tweaks and readjusts throughout the course, it more often than not remained running and smooth once initiated. As a result, any problems that may have been encountered in regards to networking, camera issues, and the like were often not experienced by the student considering the amount of setup time allotted to the course before it was presented each class day.

Table 2: Remote Site Students Opinion of Interactivity Key: 1 – Strongly Disagree | 2 – Somewhat Disagree | 3 – Not sure | 4 – Somewhat Agree | 5- Strongly Agree.

	N	Min	Max	Mean	Std. Dev.
I could hear the professor clearly.	19	1	5	3.63	1.342
I could see the professor clearly.	19	4	5	4.63	.496
The audio/video quality did not distract me from the course material.	19	1	5	3.47	1.124
I made use of the video archives outside of class.	19	1	5	3.26	1.661
I felt comfortable asking questions during class.	19	1	5	2.47	1.389
I felt like I could interact with people from other institutions.	19	1	4	2.11	1.100

Audio Quality and Interaction. Where video problems were not perceived within the course, audio problems abounded and offered a significant deterrent to student interaction. According to Frater, Arnold, & Vahedian, (2001) as well as Tan & Tan (2006), audio quality stands out as the most important technology within a synchronous distance-learning environment to maintaining the ability of students to interact with the professor and remote sites (Frater, Arnold, & Vahedian, 2001; Tan & Tan, 2006). According to follow up comments offered by students the audio often distracted them from the material and was the technology that needed to improve the most. The survey also demonstrated a positive correlation between audio quality and the students' perception of their ability to interact with both the host site as well as the remote sites.

According to proctor journals, much of the audio problems stemmed from the varying types of equipment being used. While every site made use of the Robust Audio Tool to send and receive audio, each site used their own mixers, microphones, speakers, echo-cancelling equipment, etc. to process the audio being sent and received. In synchronous distance-learning situations, if one site is sending bad audio then it often propagates to all the sites. For example, there was often a problem when one site's echo cancelling was faulty. All other sites would then have to either mute the offending site or continue while hearing their own voices sent back to them often to the point of complete distraction.

Asyncronous Technologies. Asynchronous technologies were often called upon to provide a firm brace to class. Whenever there were issues in the live class offerings, online videos were provided to allow for the continuity of learning. One of the more interesting developments demonstrated from the student surveys was the fact that more local students regularly viewed the archived videos than the remote students. Those who did view the videos both locally as well as remotely commented that they used the videos for study guides and to assist in the assimilation of the entirety of knowledge given throughout class. More important to the idea of interactivity, there was a positive correlation demonstrated between students who viewed the videos and the perceived ability to interact and ask questions during class.

6 CONCLUSIONS

Table 3: Local Site Students Opinion of Interactivity Key: 1 – Strongly Disagree | 2 – Somewhat Disagree | 3 – Not sure | 4 – Somewhat Agree | 5- Strongly Agree.

	N	Min	Max	Mean	Std. Dev.
I could hear the professor clearly.	19	4	5	4.74	.452
I could see the professor clearly.	19	4	5	4.95	.229
The audio/video quality did not distract me from the course material.	19	2	5	3.89	1.05
I made use of the video archives outside of class.	19	4	5	4.68	.478
I felt comfortable asking questions during class.	19	1	5	3.16	1.39
I felt like I could interact with people from other institutions.	19	1	5	2.79	1.13

Distance Learning is fundamentally important in furthering knowledge across man-made limitations. Based on our experience, using the latest technologies it is possible to enable distance learning across wide range of partners irrespective of the local technological constraints. The tried and tested methodologies developed by LSU and its partners, verify the fact that using the technologies such as optical networking, compressed HD via polycom, live streaming via web, can be effectively utilized (measured by student experience surveys) to deliver highly involved – technical content across geographical boundaries. Furthermore through offline (non-live) mediums such as podcasts and on-demand web streaming (of recorded material), the educational content can be disseminated to a wider audience; more importantly reaching the end users who do not have access the state-of-the-art technologies. While a lot more needs and can be done, this work demonstrates the critical strides taken by LSU and its partners in developing the essential elements and methodologies to deliver expert content to remote sites irrespective of capability limitations.

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REFERENCES

Coventry, L. (1998). *Video conferencing in higher education.* Heriot Watt University, Edinburg.

Fillion, G., Limayem, M., & Bouchard, L. (1999). Videoconferencing in distance education: A study of student perceptions in the lecture context. *Innovations in Education & Training International, 36*(4), 302.

Frater, M. R., Arnold, J. F., & Vahedian, A. (2001). Impact of Audio on Subjective Assessment of Video Quality in Videoconferencing Applications. *IEEE Transactions on Circuits & Systems for Video Technology, 11*(9), 1059.

Pitcher, N., Davidson, K., & Napier, J. G. (2000). Videoconferencing in Higher Education. *Innovations in Education & Training International, 37*(3), 199-209.

Tan, S.-C., & Tan, A.-L. (2006). Conversational Analysis as an Analytical Tool for Face-to-Face and Online Conversations. *Educational Media International, 43*(4), 347.

T. Sterling, E. Lusk, and W. Gropp, Eds. 2003 *Beowulf Cluster Computing with Linux*. 2. MIT Press.

Gropp, W., Lusk, E., and Skjellum, A. 1994 *Using MPI: Portable Parallel Programming with the Message-Passing Interface*. MIT Press.

Chandra, R., Dagum, L., Kohr, D., Maydan, D., McDonald, J., and Menon, R. 2001 *Parallel Programming in OpenMP*. Morgan Kaufmann Publishers Inc.

Patterson, D. A. and Hennessy, J. L. 2003 *Computer Architecture: a Quantitative Approach*. Morgan Kaufmann Publishers Inc.

Silberschatz, A., Galvin, P., and Gagne, G. 2005 *Operating System Concepts*. 7th. Wiley Publishing.