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Managing Complexity in a Networked Learning Environment

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Abstract: As more universities and research institutions develop *digital classrooms*, a common theme is arising: the need to manage complexity. As more technology is added to a classroom in order to facilitate the presentation, transmission and recording of digital media, the complexity of the environment increases dramatically. By planning the design and implementation of a digital classroom with a strong focus on managing complexity from the beginning, it should be possible to deploy a highly functional classroom environment that employs advanced technology while at the same time managing the inherent complexity in such a way as to reduce the barriers to use. In this paper, we will examine how complexity arises within four specific areas: audio engineering, video production, encoding/decoding, and administration. We then present a list of solutions and conclude with an overview of what we have learned in the deployment of our own digital classroom, the Collaborative Technology Laboratory (CTL).

1. Introduction

Advances in technology do not always increase at the same pace as advances in the *use* of technology. In deploying the *digital classroom architecture* in the UCSB Collaborative Technology Laboratory (CTL) our initial goal was to put as much media technology into a classroom as possible (Rollins, 2001). The ideal outcome of this exercise was anticipated to be a learning environment in which digital presentation, distance learning, multi-group videoconferencing, wireless device interaction, electronic whiteboards, and more, would all coexist comfortably. In reality, every attempt to provide additional functionality in our digital classroom has increased the *complexity* of the room.

Complexity refers to the difficulty in managing and using the collection of hardware, software, and other media devices installed in the room. More formally, we define complexity as the multiplication of processes that must be simultaneously controlled, interdependence among processes, knowledge required to complete processes, and large-scale sensitivity of system performance to small changes in individual components.

Because the CTL is so complex, most professors and presenters cannot be expected to manage, or even use the simpler functions of the room. This in turn leads to an increased reliance on “expert” managers for both maintenance and operation of the space. The ideal scenario would be to have a presenter walk into the room, flip a switch, and seamlessly be able to use any and all functions the room provides. However, we have discovered that this scenario is nearly impossible to achieve. The consequence is that complexity has become a deterrent to effective use of the room.

In our initial deployment, the CTL was equipped with basic display and video switching equipment, two video cameras, and computers for encoding. Audio consisted of one presenter lapel microphone (Rollins, 2001). The early use of the room was primarily for recording courses and events. The primary format used for encoding was

Real Media, though we also experimented with Microsoft Media and NetMeeting. At this early stage, archived materials were not actually made available to students, but were used mainly for research purposes

Our second deployment added a number of new components to the system. These include an audio solution with multiple room microphones and monitors, better quality lighting for the presenter and for the whiteboards, a third camera, and a real-time video editing system. Figure 1 shows three views of the CTL. We have also recently made a server available in the room and have begun streaming content from a monthly seminar, and from a weekly teaching assistant seminar. This added functionality has come at a price. It has greatly increased the amount of equipment and the number of physical connections within the room. The increased number of devices and connections between them makes it difficult to understand the system and to troubleshoot, particularly if a person is new to the system.

(a) (b) (c)

Figure 1: The Collaborative Technologies Lab: front view, Access Grid participants, and "control room".

The additional hardware and software added in our second deployment enabled participation in the Access Grid (www.accessgrid.org). The Access Grid is described as, "...the ensemble of resources that can be used to support human interaction across the grid. It consists of multimedia display, presentation, and interactive environments. Te Access Grid will support large-scale distributed meetings, collaborative work sessions, seminars, lectures, tutorials and training." (Access Grid web site, 2002). The Access Grid functionality has allowed presentations in the CTL to be made to both local and remote audiences with robust audio/video interaction.

Based on our experiences deploying and using the CTL, we believe that complexity can be managed such that it does not become a deterrent to effectively using a digital classroom. By understanding the main sources of complexity from the initial planning and deployment stages, its effects can be greatly mitigated. The first goal of this paper is to identify the four primary sources of complexity. Our second goal is to recommend, based on our experience, a set of solutions to minimize the complexity of deploying and managing a digital classroom.

The remainder of this paper is organized as follows. Section 2 discusses the four major sources of complexity in the CTL. Section 3 provides a top ten list of solutions that will help minimize the complexity for both administrators and users. Section 4 concludes the paper.

2. Creating Functionality *and* Complexity

There are four major areas of complexity that must be managed in order to develop a functional digital classroom environment.

- **Audio Engineering**: Audio is considered the most important component of communication. Echo cancellation and proper audio mixing are key quality issues. Audio engineering is complex because there are many parameters that must be controlled in order to capture quality audio.
- **Video Production**: Video is also very important to effective communication. It introduces complexity because of the need for camera control, image quality, and real-time editing. Video is probably the biggest challenge to creating a fully functional system.
- **Encoding/Decoding**: Encoding/decoding includes the encoding and decoding of all audio and video signals, transmission, and archiving of all media content in the room, as well as quality issues related to the network. It creates complexity because multiple encoding formats may be used, and because problems can take place both within the local system and the network.

- **Administration**: Administration includes all of the other tasks associated with the facility including scheduling, ensuring regular maintenance and supplies, organization and labeling, and helping to facilitate publications and research. Administration includes maintaining the stability and use of the system and is of particular importance to effectively managing the complexity of the room.

None of the components are independent of any of the others. Everything is connected in a number of different ways. A major part of the complexity lies in these dependencies. The sheer number of dependencies, although mundane, is a serious management challenge. Understanding the complexity of the system is key to troubleshooting and teaching others how to use it.

2.1 Audio Engineering

Good quality sound is perhaps the most important element in the digital classroom environment. Studies have shown that audio cues are more important than visual cues for effective communication. Audio capture, mixing, transmission, encoding and archiving are all issues that have to be addressed effectively to achieve a high quality production. However capturing high quality audio is a non-trivial issue that involves a significant amount of complexity.

There are two kinds of audio in the CTL. The first is "local audio" and the second is "remote audio". Local audio includes all the audio originating in the CTL. This includes the presenter, the audience, and any devices such as computers, VCRs, CDs or DVDs. We do several things with local audio including local sound reinforcement (amplifying the presenter's audio), archiving, and transmission. Local audio is somewhat easier to deal with than remote audio. Remote audio is more complex and more expensive to deal with effectively primarily because of the need for "echo cancellation". The use of full duplex (or two way) audio means that we have to implement echo cancellation to prevent the audio from remote sites from being re-encoded in the CTL and sent back to them as "echo". Echo cancellation works by storing a digital copy of audio for a number of milliseconds after it is transmitted. If a similar audio signal appears during that time it is removed from the output signal.

There are a number of different ways to address echo cancellation including both software and hardware. In the CTL we utilize the Gentner XAP 800, an 8 channel digital mixer with distributed echo cancellation (meaning each channel of audio has its own independent echo canceller). While the Gentner is one of the highest quality and most effective echo cancellation solutions available, it is also quite complex. For example every microphone must have an Acoustic Echo Cancellation (AEC) reference, so that it knows what to look for and remove. By specifying in the Gentner which audio channel to use as a reference it is possible to remove the remote site's audio from the local audio even though it is being picked up by local microphones. However, if local sound reinforcement is used to amplify the speaker's voice, it is necessary to set up a virtual reference. Otherwise the echo cancellation will actually try to remove the presenter audio as well. Finer details of the setup depend on the audio configuration in the room. If the AEC is not set up properly for the room configuration a number of problems may emerge. Problems can range from ineffective echo cancellation (meaning remote sites will hear echo), to feedback within the room, to the accidental cancellation of audio that is supposed to be heard within the room or at remote sites.

In addition to echo cancellation, there are a number of other issues that must be resolved in order to have good audio. Any audio that is encoded must be part of a mix. It is possible to create a number of different mixes for different audio outputs. For instance, the audio that is sent to remote sites includes all of the audio being generated within the room, but it would not include audio from necessarily all remote sites. The mix that is used for archiving may include all audio including that generated locally and remotely. And the mix that is being sent to the speakers includes the remote sites' audio and may include the presenter and other sources, but not the audience. All of these mixes are affected by the audio quality coming from the audio inputs. For instance the audio generated in the room has much more background noise in it when the audience microphones are on. We often turn them off during the presentation and then turn them on when the audience asks questions. However, if there is some unexpected dialogue it may not be captured or transmitted. This can make it difficult for remote participants and people viewing archived material to comprehend what is being discussed. Having strategies in place for determining what is and is not included within the various mixes is important to generating good quality content.

Managing the complexity of the audio system can be quite difficult. It is necessary to find a balance between echo cancellation, local sound reinforcement, coverage of room microphones, and other parameters. Just as a sound engineer has to do in a recording studio, all of the levels must be adjusted properly in order to get quality sound reproduction. The software interface of the Gentner is a reflection of the complexity of the mixer. It includes an enormous amount of functionality, which is a good thing but can also intimidate an inexperienced user. Figure 2 shows the Gentner and its top level software interface. Furthermore, the complexity is not just in the mixer. For example volume must be adjusted throughout the system. The wireless lapel microphone's base has a volume control, there are also gain controls that effect volume on both inputs and outputs in the Gentner, and the computer doing the encoding has its own volume parameters. All of these must be set correctly to get a quality audio signal encoded. Using the system requires understanding some basic concepts of audio engineering as well as an understanding the specifics of the system itself.

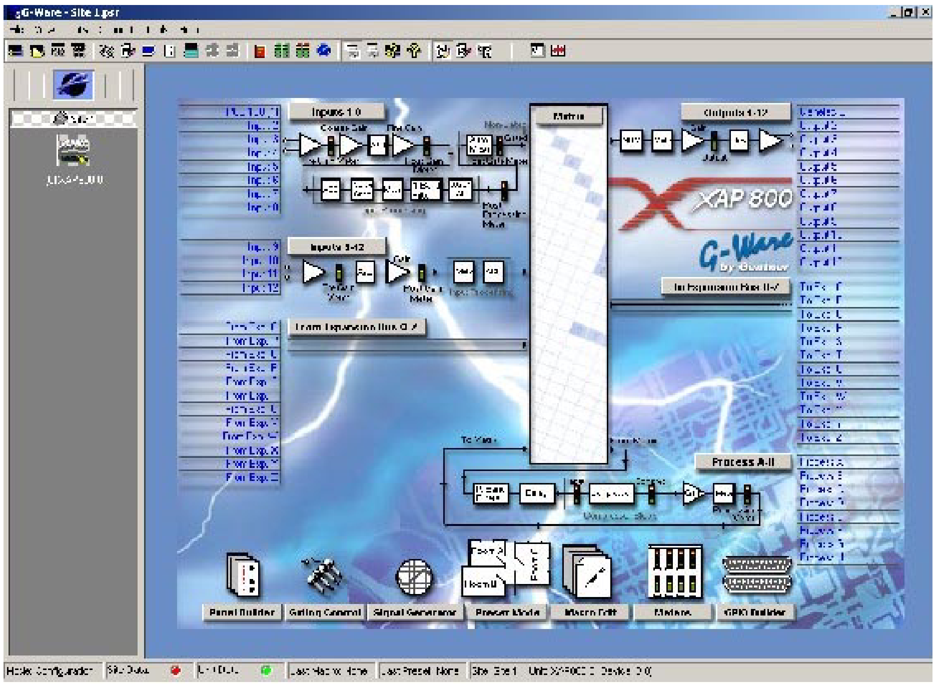

Figure 2: Gentner audio mixer interface.

2.2 Video Production

The video equipment is more straightforward to understand and use than the audio equipment. But, complexity is still added, it just comes in different forms. First of all, although there are 3 cameras in the CTL, there are other sources of visual content that must be captured for effective archiving, webcasting, and communication with remote sites. Presenters need to be able to use PowerPoint, demonstrate computer programs, browse the web and play DVDs. Capturing all of the presentation material is another level of complexity beyond the simple video capture of interactions in the room. At this time we primarily, use the cameras to capture what is being projected on the screens. This requires that we control the cameras to get a shot of the screen that is being used. The Access Grid has developed an effective tool for running Distributed PowerPoint (DPPT) but its use is limited to the Access Grid. We have also attempted to use an inexpensive scan converter with poor results. We are attempting to find a better quality version.

Generating good quality, live content for commercial media players (such as QuickTime, Real Player, and Media Player) requires switching between cameras and other input sources so that the video capture reflects the material being covered. We have implemented a real time editing system using a Sony Telemetrics controller for our three cameras, and a Videonics video mixer for switching between camera views. This system allows one person to control the editing in real time and can produce a fairly high quality video production. Although it is complicated, it is possible for one person to control all of the necessary equipment to produce a session while at the same time creating a high quality multi-camera webcast/archive. However, if something goes wrong, it is difficult for one person to both edit the video and troubleshoot. Although camera-tracking technology offers the possibility for automation, applications have both technological and physical limitations (Coen, 1998; Machniki 2001) and as long as there is a need for editing multiple cameras some labor will be necessary for production (Yu, 2001).

Another problem that originally caused poor video quality was that the CTL originally had all fluorescent lighting. This created problems at the front of the room where it was necessary to turn the lights off in order to use the

projectors. To solve this problem, we installed directional lighting with dimming controls. There are a number of small adjustable lights for illuminating the area where the presenter will be, as well as lamps for illuminating only one whiteboard at a time without washing out the one next to it. Good lighting is an important prerequisite for capturing good quality video. The lighting also introduced more complexity into the room because it uses a dimming system with 6 different adjustable zones and is yet another parameter to control.
The final component of video production involves media display within the room. The room has an Extron 12X8 (twelve by eight) video matrix switcher for switching between inputs from peripherals such as the presenter computer, DVDs, VHS and other media. It also is used for routing RGA signals from a display machine (used for Access Grid and other material originating at remote sites) to the projection screens. The display machine is a powerful computer which has three dual head display cards for sending an RGB signal to each projector in the room (as well as to the three cloned monitors at the production console), creating a power wall for presentation materials and viewing remote sites. Issues related to display also are affected by decoding issues as discussed in the next section.

Because of the large number of devices, including cameras, computers and hardware used for encoding, real time controllers and displays, as well as the associated connections, video production is a major source of complexity in the room. Managing this complexity requires some basic understanding of both video production and the setup of the specific system used in the CTL. The need to cut between and control cameras within the room requires a producer be present for real time editing. Managing the display equipment in the room is also quite complex requiring proper configuration of physical connections, the video switch, display settings on the projectors, and display settings on the presenter's computer.

2.3 Encoding and Decoding

Encoding consists of all of the issues relating to the capture, transmission and reception of audio and video signals. This includes overseeing the hardware and software systems and formats that are used for encoding, archiving, and distribution. Although in many ways, production elements in the CTL represent a scaled down version of a television studio, a fundamental difference between web-based content distribution and traditional television is that many different streams of audio and video can be sent simultaneously (Yu, 2001) Transmitting multiple video streams for the Access Grid while simultaneously webcasting and archiving through Real Player (and other formats) is an example of this flexibility, but it also demonstrates significantly increased complexity.

For general purpose recording and archiving of lecture material and presentations we have mainly used the Real Media format although we have experimented with other formats as well. For the most part, the consumer platforms that we have used are very stable. Actually setting up the software for encoding and starting it is fairly straightforward. Streaming live is somewhat more difficult partially because it includes both the production side of content encoding as well as the server side of content delivery. Although encoding and delivery for consumer media players involves some complexity, decoding consumer platform content is a fairly trivial issue.

Coordinating real time interaction is more difficult. We quickly learned that using consumer formats such as those mentioned above is not feasible due to latency problems caused by buffering [Rollins, 2001]. Although Microsoft NetMeeting is a viable format for more simple applications the quality is not very good and there is no flexibility. Our primary mechanism for real time interaction has been through the Access Grid. The Access Grid utilizes the Robust Audio Tool (RAT) and the Videoconferencing tool VIC. Both VIC and RAT are open source tools and can encode into a variety of formats. As specified by the Access Grid, they run on separate Linux machines. However, the display machine for projecting video onto classroom screens uses Microsoft Windows. This means that some understanding of both operating systems is necessary. Complexity also occurs because of demands on the network related to issues such as multicast routing, packet loss, and latency. Because real time applications generally employ the User Datagram Protocol (UDP) which does not retransmit lost packets, loss can become a serious problem that can make the quality of audio and video poor to unusable. This applies to audio and video sent from the room, and to that received from remote sites.

Encoding includes maintaining a server for storing and streaming content. This includes installing all of the necessary server software for the various formats that are being streamed. It may be necessary to use multiple servers or to allocate ports and other resources so that the server software used does not conflict. It is also necessary to ensure that the server has adequate storage space, that links to the data actually work, and that adequate data rates are supported for the number of users and quality of streaming desired.

Encoding and decoding are complex because there are many variables involved in the setup and operation of necessary devices. Although basic encoding and decoding related to consumer products such as Real Player have minimal complexity, real time applications are significantly more complex. Knowledge of the operating systems, hardware and software involved, and how to properly configure the systems depending on the required use is essential. Furthermore, encoding and decoding create additional complexity because they are so dependent on network operation, something that is generally beyond the control of those operating the facility. Managing complexity requires that people overseeing encoding and decoding have both the knowledge and the resources to address issues as they arise, and that they are able to interact effectively with network administrators. A final point is that quality of encoding and decoding is dependent on the quality of the original signal source. That means that audio and video signals from within the room must be good quality, and that the network must be operating well in order for good quality signals to be transmitted and received.

2.4 Administration

Administration covers virtually everything else, from organization and labeling of the system to maintaining the web site, facilitating research, to event scheduling. In many ways the focus on administration is an outcome of the process we have been through so far in the development of the CTL. Administration refers to the areas most essential to the setup of the room for ongoing use, and deals with many of the major issues of complexity. Proper administration will help to control complexity, and as a consequence, facilitate regular use of the room.

Scheduling of the room is important to basic use by faculty and researchers. It is also important for remote participation, where different time zones may also have to be taken into consideration. Scheduling use of the room and maintaining a calendar are also essential tasks for *promoting* use of the room. Upcoming events must be promoted ahead of time so that people are made aware of them, as opposed to classes which must be scheduled well in advance and have a fixed schedule.

Web site design is important for a number of reasons. The CTL is both a physical environment and a virtual environment. The online presence of the CTL can convey important information about the room to remote sites we are interacting with, to users of the room, and to other interested researchers. As a structured distribution point for publications about research in the CTL, it creates a forum for ongoing research and discussion of advanced uses of the facility. The web site can provide an online and easily updatable tutorial for users of the facility.

Documentation and tutorials are valuable tools to new users as well as “experts”. The information provided by manufacturers is important, but there are many aspects of the system that need to be explained on a general level for basic comprehension of the system. Developing easy-to-use tutorials makes it possible to have multiple users of the facility functioning at different levels of understanding. This is no small task either as it is not simple to put so much complexity into an easy-to-understand format. But if there are tutorials that will walk a more novice user through basic setup it can greatly reduce reliance on an expert managers to run the system.

Administration is the least technical area of focus, but may be the most important in terms of actually managing the complexity and providing a stable and understandable learning environment to faculty, staff, and students who utilize the room. We have found in the CTL that focusing on the mundane tasks relating to administration of the room greatly increases stability of the system and reduces the learning curve for new users. But we have learned this the hard way. It would be far better to start development of the room with a strong understanding of the need to manage complexity and initiate management guidelines early in the process. This can be difficult when the work being done is newer research and as more research is done into multimedia enhanced networked learning environments, people deploying new systems will be able to take advantage lessons learned about how to manage such facilities.

3. Solutions

We have alluded to some of the solutions for solving the complexity issue in networked learning environments. We now offer a top ten list of what we feel are the most important issues to address in the development and management of these facilities.

1. **Personnel is key**. It is of primary importance to have knowledgeable people. It would be ideal to have one person with intimate knowledge of the system who could oversee its operation. At the same time, it is difficult to find one person with all of the requisite skills. Budgetary constraints and/or the need to provide

research opportunities to student researchers may make having one person responsible for each area of focus listed above the best option. Whatever configuration of personnel is used it is important that all of the people involved in the management of the room have good communication skills and work together to establish and abide by guidelines for use.

2. **Organization, Cable Management, Labeling**. While this topic seems mundane, it is critical. Poor organization can be a poison pill for running a successful networked learning environment. In the absence of clear organization, the complexity will overwhelm most, if not all, potential users of the facility. Creating a clear system of labeling and cable management, along with support manuals and tutorials is essential for having multiple users and uses of the facility.

3. **Testing**. Rigorous testing helps to work out any bugs in the system. If this is not done during testing, problems are guaranteed to occur during more critical uses of the room. Testing offers an environment free from the pressures of a full presentation or class. Problems found during testing can be focused on and fixed immediately, while problems found during a scheduled use of the room may simply mean that the outcome will be a poor production or that the content generated will be unusable. Many things often need to be fine tuned including network settings, audio mixing, camera presets, display issues and more.

4. **Stability**. An important goal for managing a digital classroom environment is stability. Stability is essential if the room is going to be used regularly. Users need to be able to depend on a stable system in order to effectively use the facility. An unstable setup or one that changes too often will lead to frustration and subsequently the room will not be used to its full potential. The organization and testing mentioned above are key to maintaining a stable environment.

5. **Presets**. Presets also help to create stability by enabling users to adapt the room to their needs without permanently altering anything. Simple camera configurations, audio configurations, and settings for the video switch can make user interaction with the system much more seamless. Eventually, good quality presets may help to make the room automated so that a producer is not necessary in some situations.

6. **Scalability of technology based on resources and complexity**. It is important to make the technology in the room scalable based on what resources are actually needed and what amount of complexity can actually be handled. For instance many users of the room do not need to use the full Access Grid functionality. At the same time, even for many Access Grid events, full functionality may not be necessary. Obviously, it will be easier for someone to utilize a scaled-down ensemble of resources. Deploying technology should include a consideration of what is actually needed. In some situations it may make sense to have scaled-down audio with no audience microphone coverage, or fewer cameras, or no video switch. It depends on the resources available for installation, and ongoing staffing and maintenance.

7. **Tutorials**. Tutorials are necessary for providing new users with an understanding of the basic infrastructure and uses of the room. These tutorials should supplement equipment manuals and describe the system in both a general and comprehensive way, walking users through basic setups and configuration of the facility.

8. **User friendly interface**. Long term goals should be to provide a user friendly interface for interaction with the system, potentially allowing faculty and researchers to utilize the room without expert production support. In the short term, improvements to the system can provide a more user friendly interaction with the system for Teaching Assistants and other non-experts to control basic operation in the room without expert assistance.

9. **Ways to measure progress**. Another important long term goal must include a way to evaluate progress in the room. This means that feedback should be sought from all participants in the use of the room including the faculty, researchers and students. This feedback can be utilized to determine how useful various aspects of the system are and to determine problems in the system.

10. **Simplification**. Overall the trend with networked learning environments needs to be towards simplicity. Currently the complexity of the CTL is readily apparent by looking at all of the equipment used to run the system. Separate machines encode into different formats, some machines encode only audio while others encode only video. In the future it may be possible to consolidate more of this functionality into fewer machines.

4. Conclusions

Not until we deployed and started to use technology in the CTL did we begin to appreciate the complexity of managing such an infrastructure. Each new piece of equipment deployed in the room added additional functionality, and also additional complexity. As the infrastructure became more complex, we increased reliance on "expert" staff members to maintain the technology and to conduct events produced in the room. While it has become clear that the ultimate goal of having instructors enter the room, flip a switch, and start teaching is impossible to achieve (at least in the near term), it has also become clear that developing realistic solutions to managing the complexity in a networked learning environment is imperative.

The goal of our work has been to illustrate the four areas that introduce the most complexity in a networked learning environment and to suggest, based on our experience, potential solutions to dealing with these complexities. By having a full understanding of the limitations and challenges to managing a digital classroom space from the initial planning and deployment stages, the complexity management nightmare can be considerably reduced. While eliminating complexity entirely is an impossible task, by employing solutions outlined in this paper, complexity will not be a deterrent to effectively using an "improved" classroom.

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