THE NEW MEDIA - INTERACTIVE 3D

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ABSTRACT

3D media has emerged as a powerful capability for interactive courseware (ICW) development. Since the late 1970s, proven multimedia products for use in ICW programs have included full-motion and still-frame video, film, photographs and slides, 2D graphics and animation, audio, and text. The new media consists of real-time graphics and interactive 3D modeling.

Instructional content is often best conveyed and illustrated in three dimensions of space. Interactive 3D graphics and animation allow a designer to develop visual simulations and dynamic scenarios that enhance the student's conceptual understanding, resulting in faster knowledge acquisition. Instructional content areas in which the new media is an appropriate choice for presentation of visuals include electronic warfare concepts such as target angle aspect effects, countermeasure techniques, antenna beam-forming methods, integrated air defense operations, terrain masking, and coordinated air combat tactics methods for suppression of enemy air defenses.

This paper describes the new media and addresses the appropriateness of using it in ICW programs. Information on the hardware and software systems commonly used to develop and deliver the new media is provided. Because the process of designing and developing the new media for ICW is unique, the paper focuses on the specific tasks performed, the personnel required to produce 3D media, the ICW products produced at each phase of the process, and the amount of time required to develop various types of 3D graphics. The paper summarizes the advantages of using the new media in terms of instructional effectiveness and software reusability.

ABOUT THE AUTHORS

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DESCRIPTION OF THE NEW MEDIA

The evolution of 3D media is impacting the interactive courseware (ICW) training market by taking multimedia to another dimension. Representing a three-dimensional world in a computer requires the computer to do things that are easy for people but hard for machines. Information-processing theories of learning reveal that humans rapidly develop the geometry of objects through simple observation. For example, we naturally avoid bumping into real and solid objects, as information from our senses is registered in our brains and transformed into neural information. Computers do not naturally learn these rules, and to teach them, programmers have to express them mathematically. Even a simplified model of a scene can require a database of hundreds of thousands of megabytes.

We have seen dazzling examples of the application of computer-generated 3D special effects in movies like "Jurassic Park" and "The Lion King." A U.S. Army recruiting commercial released earlier this year uses 3D graphics to show an imaginary scene of a tank traversing a rugged terrain and dissolving into actual video of the same scene. The voice-over narration relays the message that training in the Army is so realistic that even high-tech job skills are easy to master.

Krum (1995) reported that while 3D is rapidly changing the face of media and entertainment industries, these fields make up only about 15% of the 3D graphics business. He notes that, like many advanced technologies, 3D technology got an early boost from the Department of Defense, as the armed services looked to infuse the technology into training simulators. The image generators (IGs) within these training simulators provide the most sophisticated real-time 3D graphics to be found. Once based almost entirely on proprietary architectures and databases, today's IGs are increasingly becoming more open, enabling user programming of the IG software and reuse of databases and models. This openness is due primarily to the decreasing price/performance ratio provided by Silicon Graphics workstations and the emergence of standardized 3D graphics application programming interfaces (APIs) and common database formats.

The same graphics APIs and database formats that are used to design high-end simulators may now be accommodated on the desktop. This new capability has significant implications for training system developers, since content may now be shared across media types within a training system. For instance, rather than developing stand-alone ICW, part-task trainer, and mission simulator software configurations, the new media capability supports the development of one software module which can be reused for each phase of training on phase-specific hardware.

As 3D becomes more affordable, it is likely to become a mass market technology that continues to change the way products are designed and built, including ICW multimedia and training systems. Now that new 3D modeling and rendering tools are available on a variety of low-cost computers, 3D is proving to be a versatile alternative to traditional ICW media such as motion and still-frame video and simple 2D graphics.

A unique capability of 3D media over traditional ICW media is that the student can completely control objects or models on the screen. The student can follow any eye pattern through the model space. With videotape, the student can only go where the camera went. With 3D, the student can view an object from the top, turn it around, view it from the bottom, look inside it, move it to see how it affects other objects, and so on. For example, in the electronic warfare ICW the Air Force is currently developing, the student can manipulate radar beams including main lobe, side lobes, and back lobes. Students can also view complex radar concepts in 3D such as Palmer-Helical scan patterns and cross-polarity effects.

This level of interactivity is not described in current ICW guidelines or specifications, such as Military Handbook 284-1—ICW Developer's Guide, or AF Handbook 36-2235, Volume 5—ICW Design, Development, and Management Guide. It is a unique level of interactivity now possible with 3D media.

HOW THE NEW MEDIA IS DEVELOPED

Content Databases

New media content databases are typically developed using a sophisticated modeling tool. New media content includes not only 3D objects but also object behavior, time, user interaction, conditional branching, answer judging, feedback, and audio/sound effects. These

functions are controlled by a run-time application program. Modeling tools are available to generate both real-time interactive 3D content and 2-_D content, which is prevalent in video games.

Interactive 3D - Interactive 3D content requires that objects and scene features be rendered in each frame according to an object specification. The object specification is created by the modeling tool according to the user's selections and includes the object's geometry, polygon arrangement, color, shading, transparency, surface material, texture, and lighting parameters. Interactive 3D enables the user to interact freely with the database without restriction. This type of content has traditionally been found in simulators but is now available on the desktop as well.

2-_D - 2-_D media, which is often developed for video games, adds some 3D effects to a primarily 2D engine. The main limitation of 2-_D media is that the user is forced to interact with the content in a pre-defined way since the images that make up the scene are for a fixed set of viewpoints. A 3D illusion is achieved by a process where a series of still images are sequenced in a predefined order. This series of frames is played one at a time at a rate that produces the motion illusion.

Interactive Rendering

Interactive 3D databases are rendered by a three-step process performed by a graphics pipeline under the control of a run time applications program. Depending on the computer system, some or all of the stages in the pipeline may be executed by specially designed hardware.
First, objects in the database are culled to include only objects that are visible in the field of view (FOV). Next, polygons that are visible on the in-FOV objects are determined, typically by a Z-buffer operation. Then the pixels that comprise these polygons are colored, lit, and filled in accordance with the object specification, and stored in a frame buffer which is then converted to video output for display.

The rate at which the graphics pipeline can process objects, polygons, and pixels determines the frame update rate of the graphics program. ICW applications in which the user is manipulating objects or controlling processes call for smooth update rates above 12-15 frames per second. Below this, the user may become distracted by the jerkiness of the presentation.

Game Rendering

Most video game databases are rendered simply by loading and layering 2D image elements into the frame buffer. An example of this is a player's sprite moving around on top of a background which also moves. This enables game rendering systems to be relatively simple and inexpensive.

Some games are marketed as 3D, but this claim is only partially true. While the game may contain pre-rendered 3D models, the game play is actually in two dimensions: the player's sprite is restricted to movement along the X and Y axes. Newer game rendering systems are beginning to implement versions of the interactive rendering processing steps described previously, along with subsequent increases in hardware costs.

Run Time Applications Program

The run time program handles user interaction, manages object behavior, performs time-critical operations, handles conditional branching, coordinates audio generation with graphics, and controls the rendering process. The run time program is typically developed in C/C++.

AFFORDABLE 3D DEVELOPMENT

Until recently, most 3D software resided on expensive UNIX workstations or proprietary image generators, and the hardware costs alone were beyond the reach of ICW multimedia developers or users. Today, upgraded CPUs, bus structure and plug-in graphics boards make Pentium and PowerPC systems the equal of entry-level UNIX workstations offered by SGI, Sun Microsystems, Hewlett-Packard and others (Krum, 1995).

The cost of 3D rendering hardware has fallen dramatically this year. A number of vendors at the 1994 Comdex exhibit in Las Vegas demonstrated 3D acceleration circuitry for both professional and consumer-level graphics boards. A variety of 3D graphics APIs are also now available, including SGI's 32-bit OpenGL, and several British-developed integer APIs. OpenGL is the de facto standard API for technical applications and is available for Microsoft Windows NT, DEC alpha, and MIPS platforms. The integer APIs such as RenderWare, Reality Lab, and BRender are targeted at game developers whose applications require less precision and must run on 486 class PCs or game consoles. Several APIs are also available for supporting run time application program development. These include SGI's Performer and OpenInventor libraries, as well as OpenGVS from Gemini.

The price of modeling tools has also dropped dramatically due to increased demand and competitive forces. Sophisticated content creation tools are available from Multigen, Coryphaeus, Alias/Wavefront (Silicon Graphics), and Soft Image (Microsoft).

TRAINING APPLICATIONS FOR 3D MEDIA

Three-dimensional media is an appropriate choice for training programs and interactive courseware in the following situations.

(1) The training program or courseware must provide a high degree of realism to help personnel learn their jobs without putting them, or their high-priced equipment, at risk.

An excellent example is firefighting training using 3D simulations in a virtual environment. For this task, the student needs to be presented with simulated emergency situations and fire conditions that are convincing and representative of real-world events. Actions that the student performs must result in outcomes that are faithful to actual circumstances. Much like the way flight simulators are used for training pilots, 3D media enables firefighting trainees to be immersed in a training situation such that they can assess time-critical problems, take actions, and observe the course of those actions.

(2) The tasks to be trained are of such a nature and complexity that the training program or courseware must incorporate dynamic spatial scenarios that are interactive.

An example of this requirement comes from the electronic warfare domain. Three-dimensional visual simulations are an appropriate and highly appealing method of enhancing the student's conceptual understanding of concepts such as target angle aspect effects, countermeasure techniques, antenna beam-forming methods, integrated air defense operations, terrain masking, and coordinated air combat tactics methods for suppression of enemy air defenses.

(3) Training must be developed for an emerging system and delivered prior to the new equipment coming on line.

For example, 3D systems are currently used in a training program to simulate manufacturing and assembly tasks for personnel at a major U.S. automobile manufacturer. Auto workers are trained to build complex mechanical and electrical products for a new automobile model prior to its complete fabrication.

(4) It is impossible to capture an object or scene for an ICW multimedia presentation on videotape or film.

A good example of this situation was encountered by NASA on a Space Shuttle training program. It was impractical to videotape all operational conditions and failure modes for the Shuttle's rendezvous radar system for training. Instead, a 3D media lesson was developed.

The student interacts with virtual control panels and keypads and views the rendezvous radar operation through simulated camera and CRT displays. A detailed 3D model of the antenna mechanical assembly coupled with simulation software enables the astronaut students to become familiar with failure modes and corrective procedures. For example, if the antenna assembly gimbals lock in place, then the payload doors cannot be closed and the shuttle cannot safely re-enter the atmosphere. A procedural option in this case is to initiate explosive charges that separate the antenna assembly from the payload bay.

(5) There is no other option for training except simulation, and the personnel being trained only get one chance to perform the task to 100% accuracy.

An example of this situation was the training conducted to prepare NASA Shuttle personnel to repair the Hubble Telescope. A virtual reality training system using 3D graphics was developed to allow astronauts to practice the repair tasks prior to their departure to fix the telescope. They only had one opportunity to make the fix, so they needed training that was highly realistic and performance-based.

SYSTEMS FOR 3D ICW

Hardware

A variety of low-cost hardware is available for hosting a 3D ICW system. Options include UNIX workstations, PCs and Macintosh platforms.

Workstations - Workstations are typically more expensive than PCs but offer the advantages of superior CPU, graphics, bandwidth, and multitasking support. UNIX workstations with graphics hardware are available from SGI, HP, Sun and DEC.

Pcs - PCs are progressing into low-cost 32-bit workstations that are capable of hosting 3D ICW applications. A growing number of graphics boards are now available to support interactive 3D applications using a variety of graphics APIs. *Real Time Graphics (April/May 1995)* provides a review of available graphics boards.

System Architectures

3D ICW systems require architectures that are low cost yet provide 12-15 fps frame rates (or greater) with good image quality and few distracting artifacts. Computer architectures for 3D ICW may be specified in terms of CPU processing power, graphics bandwidth, graphics API support, and special feature support.

Processing Power - CPU processing power is determined by the number of instructions per second that can be

performed and is further defined by the number of floating point operations per second that the CPU is capable of. Another consideration is the ability of the host operating system to perform multi-tasking. The host CPU has to concurrently respond to user interactions, control audio generation, execute the course content math models, and perform rendering functions. CPU performance is critical for 3D ICW since most low-cost graphics systems use the CPU to cull and sort content objects as well as perform Z-buffering to determine visible polygons. This approach allows flexibility in rendering, but requires large bandwidth between the host CPU and the graphics board since every polygon vertex, normal, and color must be transferred from the CPU for each rendered frame. Bandwidth. The amount of bandwidth available through the CPU and graphics board is an important determinant of interactive performance. For example, suppose a 90Mhz Pentium can transform 80,000 to 100,000 polygons per second, assuming that no other tasks are active. If each polygon has three vertices, a 24-bit color at each vertex, a transparency and a normal, then the bus between the CPU and the graphics board must provide a bandwidth of 1.2MB per second or the system will experience a bottleneck. This is why many systems use 8 bits per color which is then dithered to 24 bits by the graphics board, with subsequent reduction in image quality. Another key bandwidth specification is pixel fill rate. Fill rate represents the graphics board's ability to draw pixels that subtend polygons, and determines the window size that may be rendered into at a given frame rate. For instance, an NTSC sized window (640 x 480) requires a fill rate of 4.6M pixels per second to achieve a 15 fps update rate.

Graphics API Support - A key architecture parameter that must be assessed when specifying a system for 3D ICW is the graphics API, since not all graphics boards accommodate all APIs. Popular APIs include OpenGL, 3D Quickdraw, Reality Lab, BRender, and Intel 3DR.

Special Features - Special features such as lighting, texture mapping, transparency, fading, anti-aliasing, and gouraud shading may be important in conveying instructional content. Not all graphics boards provide these features. Because graphics APIs also may handle these features differently, a clear definition of which features are needed is required when specifying a system for 3D ICW.

DEVELOPMENT PROCESS USING 3D MEDIA

The instructional design and development process for 3D ICW as compared to traditional media is similar in the analysis and the evaluation phases, but different in the design and development phases.

Analysis Phase

Regardless of the media in an ICW application, a detailed front-end analysis in which learning objectives are identified is critical. A treatment plan should be developed to describe the media and instructional strategies in as much detail as possible.

Design Phase

Two types of design are performed: instructional design and software design.

In the instructional design tasks, the storyboards developed for 3D ICW should be more highly illustrated than for traditional media, including motion video, because the visual realism required to create a 3D illusion is more dominant than with traditional media. Handing a programmer a storyboard with a narrative description of the 3D graphic instead of even a crude line drawing is not recommended. A visual representation of the graphic, as well as a written description of how it functions, will help the programmer create the images more accurately and more quickly.

The software design task begins with an analysis of the storyboard content. This analysis should be conducted by a programmer who is experienced with real-time software development. Early in the software design task, the 3D ICW system should be specified in terms of hardware and software. This specification should include an identification of the software components as well as a description of the hardware configuration.

Identify Software Components - This is the key step in specifying an ICW system. The software configuration drives the hardware selection. The first task is to identify the graphics API that will be used to render the courseware content. Compatibility and reusability issues will affect the selection process; for example, will the models developed for the ICW be reused as content for another instructional delivery system such as a part-task trainer or simulator. Next, the database format and modeling tool for developing the course content is selected. The database format is the file format in which content is output from the database modeling tool. Options include .dxf (autocad), .flt (Multigen), .obj (Wavefront), etc. This format is dependent upon the graphics API previously selected. Finally, the run time applications software is selected. The run time application controls the rendering of the course content and provides for student interaction and model interfacing. The run time software may take advantage of run time APIs such as Performer or OpenInventor for controlling scene rendering operations.

Select Hardware Configuration - After the software is selected, the appropriate hardware platform is selected

to execute the courseware at the required frame rate at an acceptable price. Host CPUs and graphics boards must be selected with regard to compatibility with software configuration, processing power, bandwidth, and cost.

Development Phase

In the development phase, the system configuration specified above is used to develop an ICW shell and ICW content in accordance with the storyboards.

ICW shell development consists of configuring a set of run time templates and programming the ICW user interface. The run time template is a shell that is based on the run time applications software environment. The shell is linked with a system-specific user interface (e.g., Windows NT, Motif) and provides a content-independent means for managing content retrieval, controlling time-critical operations, handling conditional branching, and coordinating audio generation with rendering operations.

ICW content is developed by creating or modifying models through use of the database modeling tool and writing run time environment modules that control the behavior of the models in accordance with the storyboards for each lesson. Audio content, including voice-over narration, music, and content-specific sound effects, is recorded or generated, digitized, stored, and linked to the 3D graphics content.

Evaluation Phase

There are no differences between the evaluation of 3D and traditional media. Data should be collected from members of the target population, technical reviews should be performed, and the ICW should be revised to reflect changes.

COSTS

Hardware Costs

Hardware costs consist of the host platform cost and the graphics board cost. Hardware costs are directly proportional to frame rate and image quality. High frame rates with high image quality equals high-end hardware at a substantial cost. Desktop 3D systems available today provide low to moderate frame rates at low cost. Average retail prices for typical system configurations are:

PC
100MHz Pentium CPU	- $4,000
100K poly/sec Graphics	- $2,400

Workstation
133MHz R4600 CPU	- $6,500

Includes 100K poly/sec Graphics

Software Costs

Software license costs for 3D database modeling tools, APIs, and run time APIs are becoming increasingly attractive. Average retail prices for typical software configurations are:

Simple Modeling Tool (Medit class)	- $2500
Sophisticated Modeling Tool (Multigen, Coryphaeus class)	- $10-65K
Graphics API (OpenGL class. bundled with IRIX)	- $1,200
Run Time API (Performer class)	- $1,000

Development Costs

Development costs for 3D ICW vary depending on the complexity of the graphic in terms of the mathematical modeling, the complexity of the instructional design in terms of student data, feedback, and branching, and the overall quality expectations from a visual realism perspective.

Table 1 provides a description of various types of 3D graphics that can be produced and the number of labor hours and lines of code estimated for production of each. The estimate of lines of code is based on the existence of numerous subroutines that were generated at the beginning of the project or purchased from a third-party vendor. A call to a subroutine is counted as one line of code, and each subroutine consists of anywhere from three to one hundred lines of code. The levels are based on complexity of the object to be modeled, the behavior of the model(s), the amount of control the student has with the models, and the incorporation of audio.

The estimates shown in Table 1 are for production of graphics only, and do not include the time required to analyze the instructional content or design the storyboards. The estimates assume there are no existing models, where software is reusable. All the models are new, that is, developed from scratch. The estimates are based on use of SGI's OpenGL for Windows NT, OpenInventor Toolset, and C++. The develop-ment platform is a Pentium PC. These time estimates are based on data collected over the past two years from various 3D programs developed for the Air Force, NASA, and private industry.

The various types of 3D graphics shown in Table 1 are described below.

Simple Model/Simple Movement - The effort to produce a 3D graphic of one simple object which performs an easy and single behavior, with no associated audio. An example of a 3D simple model/simple movement is *a radar beam that rotates about a single axis.*

Simple Model/Complex Movement - The effort to produce a 3D graphic of a simple model which performs a difficult behavior, with no associated audio. An example of a 3D simple model/complex movement is *a radar beam that is performing a scan pattern.*

Two Simple Models: Interactive Movement/With Audio - The effort to produce 3D graphics consisting of two simple models interacting with each other, with associated audio. An example of this type of 3D graphic is *two functional radar beams, both pointed at the same object, where one beam is acting as the receiver and one beam is acting as the transmitter.* An audio recording, synched to the action on the screen, is describing the functioning of the two radars.

Complex Model/Simple Movement - The effort to produce a 3D graphic of a more complicated object which performs a very simple behavior, with no associated audio. An example of a 3D complex model/simple movement is *an aircraft that flies from one side of the screen to the other.*

TABLE1. DEVELOPMENT EFFORT FOR 3D GRAPHICS

3D Graphic	Lead Software Designer[1] Hours	Modeler[2] Hours	Sound Technician[3] Hours	Lines of Code
Simple Model/ Simple Movement	1-1/2	4	0	25
Simple Model/ Complex Movement	4	4	0	60
Two Simple Models Interactive Movement With Audio	10	8	1	130
Complex Model/ Simple Movement	1-1/2	12	0	25
Complex Model/ Complex Movement	4	12	0	60
One Simple and One Complex Model Interactive Movement With Audio/Student Control	11	16	1	150
Two Complex Models Interactive Movement With Audio With Student Control	60	24	1	300

[1]The lead software designer has a CS degree and five years of real-time programming experience.
[2]The modeler has a CS degree and six months of real-time programming experience.
[3]The sound technician is responsible for digitizing the audio; this is often accomplished by an entry-level student intern.

Complex Model/Complex Movement - The effort to produce a 3D graphic of one complicated object which performs an intricate behavior, with no associated audio. An example of a 3D complex model/complex movement is *an aircraft that flies onto the screen and makes a maneuver revealing another perspective of it.*

Two Models—One Simple, One Complex: Interactive Movement/With Audio/With Student Control - The effort to produce a 3D graphic of one simple model and one complex model interacting with each other, with associated audio. The student has control over one of the models. An example of a complex 3D graphic of this type is *a student-controlled aircraft on the screen and a radar beam tracking the aircraft's movement in real time.* An audio recording describes the activity as it takes place.

Two Complex Models: Interactive Movement/ With Audio/With Student Control - The effort to produce a 3D graphic consisting of two complex models, with interactive movement, audio, and student control over one of the models. An example of this type of 3D graphic is *two aircraft engaged in a dog fight, with the student controlling the actions of one of the planes.* Audio is synched to the action.

ADVANTAGES OF THE NEW MEDIA

The most important advantages of 3D media are its effectiveness in conveying instructional content through interaction, and the ability to reuse software for different training needs.

Instructional Effectiveness

Three-dimensional graphics are a highly effective method for conveying instructional content in three dimensions of space. For content such as electronic warfare, 3D visual simulations and dynamic scenarios have been shown to result in faster knowledge acquisition and conceptual understanding than traditional media. By viewing and interacting with 3D graphics and simulations, students form mental models of what is taking place. Many students find it difficult to formulate a correct image of what is happening from a two-dimensional graphic or from a written or verbal description. Only highly sophisticated learners seem to have this ability. When the correct mental model is formulated, the concepts become meaningful. The Air Force is currently using 3D modeling and simulation technologies to develop a new training system for Airborne Warning and Control Systems (AWACS) weapons directors (WDs). When students are learning to become AWACS WDs, it is important that they get a sense of what is taking place in a particular airspace. Aircraft 3D track data appears on the AWACS console as 2D symbology. This 2D symbology is converted into a realistic and dynamic 3D scene of the terrain and the movement of the aircraft through the airspace. The student can view a radar moving in three dimensions and watch as an aircraft enters the radar space and the

instruments react. Later, when the students actually perform the task, they will have a better feel for what is happening, even though they cannot see what is happening directly, because they will be able to recall the images from the 3D ICW.

Reusable Software

An advantage of the new media approach to ICW is that software modules and 3D models that have been previously developed for training platforms such as part-task trainers and mission simulators may be reused for ICW. This reusability is due to adherence to graphics standards such as OpenGL and common data formats such as Wavefront's .obj format. The ability to reuse software between training media types means that the cost to develop a total training system is much less with the new media than with traditional ICW media. Current approaches to developing total training systems utilize separate hardware platforms for each training phase. Typically, a PC is used for ICW, a workstation is used for part-task training, and a proprietary high-end system is used for mission training. This traditional heterogenous approach is expensive to implement and requires the student to re-learn procedures for each platform. A homogenous approach is provided by using 3D media across all three training platforms, and the student only needs to learn one set of procedures for the training system.

LIMITATIONS

One limitation to developing 3D media is that it is very difficult to find software designers and developers who have real-time programming experience. The rapid growth in 3D graphic development has caused the pool of talented programmers to become very small. Most computer science undergraduate degree programs provide little or no instruction in real-time graphics design and development, and training programmers to model and design 3D software is a time-consuming process. Krum (1995) reported that ultimately the development of 3D media is more of an art than a science, with many common situations requiring ad hoc programming tricks which are discovered only after years of trial and error.

A second limitation is lack of a standard program-ming interface. For example, a graphical user interface developed for an ICW application for delivery on a PC will not automatically run on an SGI machine because the PC version would be built for Windows NT and the SGI version would be built for UNIX x-windows. However, 3D models and the rendering software can be ported from one platform to another as long as the graphics API and programming languages are the same.

CONCLUSION

While this paper promotes the use of 3D media in ICW, an organization that is interested in developing 3D media for ICW or other training systems should analyze its training needs carefully prior to making this decision. 3D is still very new and can be very expensive to produce, depending on the hardware and software specification, the complexity of the simulation, and the quality expectations of the customer. Extra effort should be made to ensure that the instructional content is best conveyed using three dimensions. Care should also be taken in selection of the graphics API that will be used to render the courseware content. Two key concerns with 3D media are compatibility and reusability. A smart selection of the graphics API can give a developer a high return on investment dollars, as software can be reused from project to project.

BIBLIOGRAPHY

Real Time Graphics, Computer Graphics Systems Development Corp., April/May 1995.

SIGGRAPH '94, course lecture notes.

Lyn, Craig. "3D Game Authoring for the Rest of Us," *Multimedia Producer*, Vol. 1, No. 5, May 1995.

Krum, Ted. "3D: A Whole New Look in Multimedia," *NewMedia*, Vol. 5, No. 1, January 1995.