**Chapter 16**

**Computer Graphics and Entertainment: Movies, Games, and Virtual Communities**

**A Guide to this Instructor’s Manual:**

We have designed this Instructor’s Manual to supplement and enhance your teaching experience through classroom activities and a cohesive chapter summary.

This document is organized chronologically, using the same headings that you see in the textbook. Under the headings you will find: Lecture Notes that summarize the section, Teaching Tips, Class Discussion Topics, and Additional Projects and Resources. Pay special attention to teaching tips and activities geared toward quizzing your students and enhancing their critical thinking skills.

In addition to this Instructor’s Manual, our Instructor’s Resources also contain PowerPoint Presentations, Test Banks, and other supplements to aid in your teaching experience.

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| **At a Glance** |

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**Overview**

Chapter 16 explores the ways in which computing has become important in the development of movies, video games, and other computer-based entertainment. It describes traditional animation techniques, and the development of computer-generated animation methods. It describes the process of creating realistic images with computer graphics. The chapter introduces the differing challenges of generating images for dynamic video games, rather than static movies or still images. It explains how GPUs inside modern computers enable higher-quality rendering of dynamic images. The chapter examines the growing use of multiplayer online games, both competitive games like *World of Warcraft*, and online communities like *Second Life*.

# **Learning Objectives**

* Describe the changes in movie animation techniques caused by computer-generated imagery (CGI)
* List the steps in the graphics pipeline
* Explain how to create a computer model of a 3D object
* Understand how a transformation matrix can model the movement of an object
* Name three challenges involved in rendering a visual object
* Explain the purpose and function of a graphics processing unit (GPU)
* List and explain two techniques for achieving the real-time graphics required for video game animation as opposed to movie animation
* Describe how large virtual communities work, and the particular challenges they face

# **Teaching Tips**

**16.1 Introduction**

1. Briefly go over the early days of computing with price, size, and cost to operate.
2. Discuss the change in the 1960s with the advent of transistors.
3. Introduce Pong, Atari’s first product, which was a video game in which a “ball” was bounced back and forth between two “paddles” on a screen.
4. Talk about the growth of the video game industry in the 1980s, use Atari as an example.
5. Talk about how these early videogames began to pave the way for Computer Generated Imagery (CGI) in modern games and movies.

**16.2 Computer-Generated Imagery (CGI)**

1. Introduce the term **stop-motion animation**: physical figures are posed and photographed, and then moved slightly and photographed again.
2. A **frame** is a single photograph for a movie. Talk about how CGI creates movement in in the same way as stop motion, just in a digital space.
3. **Computer-generated imagery (CGI)** developed in the early 1990s as an alternative.
4. CGI can produce **photorealistic animation** and has become the standard for movie animation, largely displacing stop-motion and hand-drawn animation. Use Terminator 2 as an example.
5. Introduce the term **graphics pipeline**, and talk about its main steps:
   1. Object modeling
   2. Object motion
   3. Rendering and display.
6. Introduce the term **object modeling**, meaning the building of a three-dimensional computer model of an object being animated.
7. **Motion capture** is a popular method of object modeling. Use Golem from Lord of the Rings as an example of motion capture.
8. **Wireframe modeling** is the most common approach to object modeling, it builds a **tessellation**: a set of polygons that completely cover the surface of the object. Show Figure 16.4 for an example of tessellation. Objects are described by a **vertex list**, the corners of the polygons, described in 3D space.
9. Discuss the complexity of moving modeled objects in their virtual space. Introduce the terms **rigid motion**, **translation**, **rotation**, and **reflection**. These movements may be calculated using **transformation matrices** that capture, mathematically, the changes in an object’s location. Show students the application of a transformation matrix step by step, to clarify how it works. Animators use **keyframing**, where only the original and final positions are specified, and the computer fills in the remaining frames.
10. Moving portions of an object, or multiple objects in a space, requires the specification of **control points** or **animation variables**, places where some objects’ rotation is centered.

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| ***Teaching Tip*** | There are many videos available online that demonstrate computer animation in action. A nice example is at: <http://www.youtube.com/watch?v=IrRl_LgYE-c&feature=related> |

1. Introduce the term **rendering**, and the various aspects of rendering an object: lighting, color shading, shadows, texture mapping, and blurring. Introduce the term **rendering farm**.
2. **Ray tracing** is a common technique for rendering scenes. It models every ray of light and its path through the scene, using the results to decide on color and brightness for every surface in the scene.
3. Mention that the future of CGI is very bright, especially given the incredible advances in hardware.

**Quick Quiz 1**

1. \_\_\_\_\_\_\_\_ occurs when a human animator specifies the starting and ending positions for an object, and the computer fills in the rest of the motion.

Answer: Keyframing

1. Name the three steps in the graphics pipeline.

Answer: Object modeling, object motion, and rendering and display

1. What is the role of a tessellation in CGI?

Answer: A tessellation provides a model of an object in three-dimensional spaces, a set of polygons that completely cover the surface of the object, and that may be described as a set of vertices of the polygons.

1. What is a large group of computers used for rendering called?

Answer: Rendering farm

**16.3 Video Gaming**

1. Introduce the terms **static environment** and **dynamic environment** to contrast the generation of images for movies with that for video games.
2. Rendering images for video games must be done in real time to respond to players’ actions. Introduce the terms **real-time graphics** and **frame rate**, and the principle in the book: “If necessary, sacrifice image quality for speed of display.”
3. Introduce the term **GPU (Graphics Processing Unit)**, and its purpose in rendering real-time images to free up the main CPU. GPUs are specialized to optimize image processing. GPUs and specialized **image memory** or **video memory** are on a separate board, called a **video card** or **graphics card** or **graphics board**.
4. More speedups come from avoiding expensive algorithms like ray tracing, or simplifying color, shape, and shading. Introduce the terms **culling** and **cut-ins**. Culling refers to rendering only those parts of the objects that are currently visible. Cut-ins are pre-rendered objects that may be placed into the image as is.

**Quick Quiz 2**

1. Name two ways that video games simplify their task in order to be able to render images in real time.

Answer: Any two of the following: avoiding expensive algorithms, optimizing for the GPU, simplifying shapes, colors, and culling, or using cut-ins.

1. A(n) \_\_\_\_\_\_\_\_\_\_\_\_ environment is one in which user actions affect what is to be rendered next.

Answer: dynamic or interactive

1. (True or False) Culling is a technique where pre-rendered objects are placed into a dynamic image.

Answer: False

1. (True or False) A video adds additional memory for high-intensive tasks, but uses the CPU to render video.

Answer: False

**16.4 Multiplayer Games and Virtual Communities**

1. Introduce the term **massively multiplayer online games (MMOG)**. These multiplayer games involve thousands of players and continue indefinitely in real time.
2. Introduce the term **game server**: the computers that support the game on this scale. Remind students of the client/server model and note here that there are thousands of clients, and perhaps multiple game servers as well.
3. MMOGs have more complex issues than a typical video game: registration management, client/server protocols, security, and database design. The scale of operation makes these issues more difficult to resolve.

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| ***Teaching Tip*** | Take a virtual field trip to visit *World of Warcraft* with your class. Have them explore and discuss their experiences. |

1. Introduce the terms **noncompetitive MMOG**, and **metaverse**, for games where winning or earning points is not the main point. Instead, these are virtual worlds to explore, to interact with, and to meet other people in. *Second Life*is an example of a metaverse; it has several thousand game servers, 100 trillion bytes of data (1014), 1 million residents, with 50,000 logged on at any one time.

**16.5 Conclustion**

1. Computers have come a long way from purely textual input.
2. Graphics capabilities have grown tremendously over the past few decades.
3. Entire worlds have been created for users to explore through the use of the Internet and Web.
4. Graphics capabilities will only continue to improve, creating worlds that may seem virtually indistinguishable from the real world.

# **Class Discussion Topics**

1. After reading about the steps involved in computer-generated imagery, does it seem like more or less work than hand-drawn or stop-motion animation? What steps in the process are primarily technical, and where does the animator’s creativity fit in?
2. What are the pros and cons of online virtual communities and games like *World of Warcraft* and *Second Life*? Where do you think these virtual communities will be in 10 years?
3. Will it be possible in the next two decades to “plug in” to a virtual reality and have it seem as though it’s actually the real world? What kind of ramifications may this hold for the real world?

# **Additional Projects**

1. An alternative method for animating an object uses “motion capture,” where people or animals in the real world have their movements captured on film, and then those movements are tied to the movement of the animated object. Research motion capture and compare its results to the techniques described in the book.
2. Real-time ray tracing is a new approach for video game rendering. Explore online to discover what kind of computing equipment is required for real-time ray tracing, and how it reduces the computational load to a reasonable level for real-time graphics.
3. Using paper and pencil, lay out a three-dimensional cube or pyramid in a virtual space, choosing the vertices for the object. Then, apply the transformation matrices to move the object to a new location, rotating it around a horizontal control point (like a turning wheel) as it goes. Do all the calculations by hand.

# **Additional Resources**

1. Website about media production with good information about CGI: <http://www.creativecow.net/>
2. Real-time ray tracing demo of water and physics: <http://madebyevan.com/webgl-water/>
3. An article about “boutique,” smaller-scale MMOGs: <http://www.escapistmagazine.com/articles/view/issues/issue_75/431-Boutique-MMOGs>

**Key Terms**

* **Animation variable**: Another term for a control point.
* **Computer-generated imagery (CGI)**: Using computers to produce an image on a frame.
* **Control point**: A point or axis used to control the motion of an object.
* **Culling**: The process of only rendering those planes that will be visible in the next frame. This is done to speed up the rendering process.
* **Cut-ins**: The process of using pre-rendered objects in a frame.
* **Dynamic environment**: A visual environment in which input from the user determines the frames that will be shown.
* **Frame**: A single image used to produce the effect of animation.
* **Frame rate**: The rate with which a computer can produce individual frames.
* **Game server**: A computer that helps manage the operation of MMOGs.
* **Graphics board**: Another term for video card.
* **Graphics pipeline**: The sequence of steps that must be completed to produce a realistic computer-generated, three-dimensional image.
* **Graphics Processing Unit (GPU)**: A separate processor inside a computer which handles all of the fundamental graphics operations.
* **Image memory**: Another term for video memory.
* **Keyframing**: Using a computer to generate all necessary intermediate frames so that they do not have to be provided by a human animator.
* **Massively multiplayer online games (MMOGs)**: Online games that can be accessed via a network by thousands of players at the same time.
* **Motion capture**: Generally using a motion capture suit and a camera to capture the motion of an actor or animal then using those reference points to create a digital model around them.
* **Metaverse**: Short for "metauniverse"; another term for a noncompetitive MMOG such as *Second Life.*
* **Noncompetitive MMOG**:A simulated virtual world in which users can live, browse, shop, and play.
* **Object modeling**: The creation of a mathematical or algorithmic model of an object that can be stored in memory and manipulated by the computer.
* **Photorealistic animation**: Extremely high-quality lifelike images produced by computers.
* **Ray tracing**: One of the most widely used rendering algorithms. It is based on tracing each individual ray of light from a light source.
* **Real-time graphics**: The ability to create images at a rate that matches that of the real world.
* **Reflection**: Movement that produces a mirror image of an object such that every point in the reflecting image is the same distance from the mirror but on the opposite side.
* **Rendering**: The process of converting a mathematical model of an object in memory to a fully formed, visually pleasing image.
* **Rendering farm**: A large group of computers used to render highly complex computer graphics.
* **Rigid motion**: Motion that does not bend or deform an object.
* **Rotation**: Circular movement around a fixed axis of rotation.
* **Static environment**: A visual environment that does not interact with a viewer to decide what to do next.
* **Stop-motion animation**: A method of animation that involves building a small-scale mockup. You then take a picture, move the model, take another picture, and so on to create the illusion of motion.
* **Tessellation**: The algorithm used for building a wireframe model of an object.
* **Transformation matrix**: A mathematical structure used to implement the different types of rigid motion of an object.
* **Translation**: Movement of every point in an object by the same amount and in the same direction.
* **Vertex list**: The data structure that stores information about the polygons used to cover the structure of the object.
* **Video card (graphics card)**: A card containing a GPU and video memory.
* **Video memory**: Separate memory available to a GPU to store graphics related data, independent of the RAM on the computer.
* **Wireframe modeling**: A modeling technique that involves covering the surface of the object with non-overlapping polygons.

**Solutions to End-of-Chapter Exercises**

**1.** The text suggests Wikipedia as a starting point, but you should expect further research on the students' part. A good article to look at would be http://www.pcmag.com/encyclopedia\_term/0,2542,t=graphics+pipeline&i=43933,00.asp

**2**.  *vertex x y connected to*

(origin) v1 0 0 v2 v4 v5

v2 0.5 1.8 v1 v3 v5

v3 2.2 2.0 v2 v4 v5

v4 2.6 0.5 v1 v3 v5

v5 1 1 v1 v2 v3 v4

**3.** a. Since the motion takes place over 10 seconds, and the standard frame rate for

video is 30 frames per second, we must produce a total of 300 frames. To create

each new frame we must move 100,000 vertices, and each vertex requires a

matrix multiplication with 28 arithmetic operations per vertex. Thus, the total

number of operations required to carry out this operation is:

10 seconds × 30 frames/sec × 100,000 vertices/frame × 28 operations/vertex

= 840,000,000 arithmetic operations = 8.4 × 108 arithmetic operations

b. At 50 million operations/sec, 5 x 107, the time required to carry out this

translation operation will be:

= (8.4 × 108 / 5 × 107) = 16.8 seconds

**4**. In each second of real time we need to generate 30 frames, with each frame

containing 250,000 vertices. This will require the computation of

30 frames × 250,000 vertices/frame × 28 operations/vertex

= 2.1 × 108 operations in each second of real time

Thus we need a GPU that can execute at a rate of at least 210 Mflops

**5**. v2 v4

1

v5

v1

0 1 v3 2

**6**. We need to move the object three units in the x-direction, five units in the

y-direction, and zero units in the z-direction. Since the motion lasts for two

seconds, we need to have a total of 60 frames, which will require 59 separate

movements starting from the initial position in the first frame. Using the

translation matrix model shown in Figure 16.6, here is a matrix to

accomplish this motion:

1 0 0 3/59 1 0 0 0.05084

0 1 0 5/59 0 1 0 0.08475

=

0 0 1 0/59 0 0 1 0

0 0 0 1 0 0 0 1

**7**. The correct rotation matrix is:

cos Ø -sin Ø

sin Ø cos Ø

**8**. The correct reflection matrix to reflect an object around the y-axis is:

-1 0

0 1

**9**. Point A would be used to raise and/or lower the entire arm as a single unit. much

like raising a stick. This control point could be used to raise the arm high enough

so that the glass can reach the mouth. Point B would be used to bend the elbow,

while the rest of the arm, from elbow to shoulder remains motionless. So, once

the arm is in the correct position, this control point could be used to raise the glass

to the level of the mouth. Finally, Point C is used to bend the wrist and align the

angle of the hand. This control point could be used to align the glass to properly meet the mouth.

**10**. A flight simulation package must absolutely be a real-time graphics package if it is intended to train pilots. The response rate of the simulator display must be identical to the real-life response rate of the actual airplane controls, otherwise it would not be an effective learning and teaching tool. So, in many ways, the graphical software routines used in an airline simulator would be similar in structure to a video game software package, and a flight simulator would also potentially need to sacrifice realism to obtain the necessary display speed.

**11**. There are many different coloring algorithms. One popular approach to shading

in a triangular face is to color each pixel inside the face based on its normalized

distance from each of the three vertices of the triangle. For example, given the triangle shown in the question:

v2 (0,255,0) green

x'

p

x

v3 (0, 0, 255) blue

v1 (255, 0, 0) red

Point p is x units from vertex v1, while the total length of the line from vertex v1 to the line connecting vertices v2 and v3 is x'. Since the red contribution of vertex v1 is 255 we could simply multiply 255 times the normalized distance of p from v1, namely [1 - (x / x')]. When p is located on vertex v1 this term become 1 - 0 = 1, and the red contribution is 1 \* 255 = 255, the full amount. When p moves to the end of that line, point x', this term becomes 1 - 1 = 0, and the red contribution becomes 0 \* 255 = 0, or nil. Thus the red component of the color of

point p diminishes linearly with the distance of point p from vertex v1. We now do the same thing with point p and its distance from first v2 and then v3. The end result is a three-tuple

(i, j, k), which gives the red, green, and blue components, resulting in a single color, and that is the color we assign to pixel p.

**12**. Formal mathematical explanation is not called for, but students should be able to give an informal rule of thumb.

**13**. a. We would have a circle of radius 1 whose center is at (-6, 0)

b. We would have a circle of radius 1 whose center is at (-2, 0)

c. No change. Two reflections about the same mirror line will produce

the original image.

**Challenge Work**

While there is plenty of information available on these topics, the trick is to find explanations at a level suitable for students to understand.