CHAPTER 1

Introduction to Computer Graphics and 3D

This book is to introduce you to the workings of 3D animation (called computer graphics, or CG) with one of the most popular programs on the market, Autodesk's Maya. It will introduce you to a lot of the features and capabilities with the hopes of energizing you to further study. The best way to study for almost anything is to practice, so prepare yourself to go through exercises in this book, but also to think of exercises and projects that can take you further in the learning process. A book or class or video can take you only so far; the rest is up to you. Imagination and exploration will serve you well.

Throughout this book you'll learn how to work with Maya tools and techniques. This chapter will prepare you for the hands-on study that follows by introducing the most important CG concepts and the roles they will play in your Maya work. You'll begin with the most important concept that learning how to work with Maya is a process of learning how you work as an artist. Topics include:

- **Embrace the Art**
- **Computer Graphics**
- **The Stages of Production**
- **The CG Production Work Flow**
- **Core Concepts**
- **Basic Film Concepts**

Embrace the Art

Art, in many instances, requires transcendence of its medium; it speaks of its own accord. Learning to look past what you're working *with* and seeing what you're working *for* is key to learning CG art. So don't view this as learning a software package but as learning a way of working. As you begin learning 3D with Maya, you acquire a new language, a new communication. Keep in mind that the techniques you acquire should remain only a means to the end of expression. In short, relax and enjoy yourself.

Computer tools begin with logic and explicit numbers; your exploration of Maya, however, need not be limited to such a logical path. Your exploration is about learning what *you* can do and not what the *software* can do. Don't make this a lesson in how to make a software program work; make it about how you work with the software.

CG studios hiring professional 3D artists look primarily for a strong artistic sense, whether in a traditional portfolio or a CG reel. It is paramount, then, to fortify the artist in yourself and practice traditional art such as life drawings, photography, painting, sculpture, and so on as you learn CG, beginning with the core principles introduced in this first chapter. Keep in mind that the computer you'll be using for 3D work is nothing more than a tool. You run it; it does not run you.

In the past decade, interest in 3D has surged, partly as a result of the availability of powerful machines with lower costs. Since 3D can be resource intensive on the entire computer system, few machines have been powerful enough all around and accessible enough until relatively recently. Beginning with the late 1990s, production-level equipment has become available to the home market at reasonable prices, helping to spur interest in 3D.

With that emergence of powerful, cheap computing, a lot of artists are adding the language of CG to their skill set. And before embarking on learning a staple tool of CG, it's important to already grasp fundamental issues inherent to CG.

Computer Graphics

CG is simply the abbreviation for computer graphics imagery, also known as CGI. CG refers to any picture or series of pictures that is generated with the aid of a computer. By convention, CG and CGI generally refer to 3D graphics and not to images created using 2D image or paint programs such as Photoshop or Painter. Most 2D graphics software is bitmap based, and all 3D software is vector based. Bitmap software creates an image as a mosaic of pixels, filled in one at a time. Vector software creates an image as a series of mathematical instructions from one calculated or graphed point to another. This much more powerful method for creating graphics is behind all the impressive CG images you've seen—and the ones you'll soon create with Maya. You'll learn more about vectors and bitmaps in the section “Computer Graphics Concepts” later in this chapter.

If you're familiar with 2D graphics software such as Adobe Illustrator or Macromedia Flash, you already know something about vectors. What Maya and other 3D graphics tools add are calculations of depth. Instead of being drawn on a flat plane, objects are defined in three-dimensional space. This makes the artist's job fairly cerebral and very different than it is with 2D art; there is more of a cross chat between the left and right sides of the brain. When working in 3D, you get a better sense of working with and manipulating objects as opposed to working with lines, shapes, and colors used plainly to create images.

A Preview of the 3D Process

The process of creating in 3D requires that you model or shape objects in a scene, give them color and light, and render them through a virtual camera to make an image. In essence, you create a scene that tells the computer what objects are where, what colors and textures they have, what lighting there is, and what camera to use; it's a lot like directing an actual production, but without all the actor tantrums over bottled water.

Instead of a canvas on which to paint or copy and paste images, you have a 3D space—an open area in which you define your objects, set their colors and textures, and position lights as if you were setting up for a real photo shoot. CG is actually remarkably analogous to the art and practice of photography and filmmaking.

Photographers lay out their scene by placing the subjects to form the frame. They light the area for a specific mood and account for the film stock and lens they use and for the colors of the scene. They choose the camera, film, and lenses according to their desired result. They snap a picture, develop the negative, and print it to paper. Through this process, a photo is born.

Once you build your scene in 3D using models, lights, and a camera, the computer *renders* the scene, converting it to a 2D image. Through setup and rendering, CGI is born. And with a little luck, a CG artist is also born.

Rendering is the process of calculating lights and shadows, the placement of textures and colors on models, the movement of animated objects, and so on to give you a sequence of 2D pictures that effectively "shoot" your virtual scene. Instead of an envelope of 4×6 glossy prints, you get a sequence of 2D computer images (or a movie file like a QuickTime or AVI [Audio Video Interleave] file) that sit on your hard drive waiting to be seen, and invariably commented on by your know-it-all friends.

And that, in a nutshell, is the CG process. It requires planning and patience, as CG follows conventions that are so different than those for painting programs and image editors. Its work flow is entirely based in building, arrangement, and relationships. But it is an easy work flow to pick up and eventually master. And it can be done by anyone with the desire and the patience to give it a try.

Fairly soon, you will begin to see CG as a bigger part of the everyday computing environment, as we are seeing with image editors and digital-video editing software now. The more familiar you are with it, whether with Autodesk Maya or another package, the greater your part in the computing future. The day will soon be on us when we can custom-make our own environments for our 3D Windows desktops.

Animation

Although Maya can be used to produce remarkably lifelike 3D still images, most Maya artists also work with a fourth dimension, time. That is, most Maya art is animated. Simply put, *animation is change over time*. A solid foundation in animation involves understanding the simulation of something changing over a period of time. Underlying all animation, from paper flipbooks to film and on to Maya, is the following principle: when we see a series of rapidly changing images, we perceive the changing of the image as continuous motion.

In creating CG animation yourself, you have to create scene files with objects that exhibit some sort of change, whether through movement, color shift, growth, or other behavior. But just as with flipbooks and film animation, the change you are animating occurs between static images, called *frames,* an analogy with film. You define the object's animation using a "timeline" measured in these single frames.

You'll learn more in the section "Basic Animation Concepts" later in this chapter.

The Stages of Production

The CG animation industry has inherited from the film industry a work flow, or pipeline, a way of doing things that consists of three broad stages: preproduction, production, and postproduction. In film, *preproduction* is the process in which the script and storyboards are written, costumes and sets are designed and built, actors are cast and rehearsed, a crew is hired, and the equipment is rented and set up. In the *production* phase, scenes are taped or filmed in the most efficient order. *Postproduction* (simply called "post") describes everything that happens afterward: the scenes are edited into a story; a musical score, sound effects, and additional dialogue are added; special visual effects may also be added. (In a film that has special effects or animation, the actual CG creation is usually completed in post but may have started in the preproduction phases of the film or project itself.)

Although the work performed at each stage is radically different, this is a useful framework for understanding the process of creating CG as well.

Preproduction

Preproduction for a CG animation means gathering all reference materials, motion tests, layout drawings, model sketches, and such together to make the actual CG production as straightforward as possible.

Since the CG artist must define 3D scenes in the program, it is essential to have a succinct plan of attack for a well-organized production. The more time spent planning and organizing for CG, the better. Entering into production without a good plan of attack is not only going to cause you trouble, it will stunt the growth of your project.

In the real world, preproduction is part of every CG animation project. For the tutorial projects in this book, you'll work with sketches and other files supplied on the accompanying CD as your preproduction. Even for these tutorials, however, you're encouraged to gather as much information as you can about the objects you'll create, even more than what is presented to you. As with disappointing movies with terribly flawed preproduction stages, a poorly thought-out CG production will invariably end in headaches and wasted time.

The Script

To tell a story, CG or not, you need to put it in words. A story need not contain dialogue for it to benefit from a script. Even abstract animations can benefit from a highly detailed explanation of timings and colors laid out in a script. The script serves as the initial blueprint for the animation, to lay forth the all-important *intent*. It is then fleshed out.

The Storyboard

A storyboard is a further definition of the script. You break the script into scenes, and then you break those scenes into shots. You then sketch out each shot on a panel of a storyboard. The panels are laid out in order according to the script to give a visual and linear explanation of the story. Storyboards are useful for planning camera angles (framing a shot), position of characters, lighting, mood, and so on. Even rudimentary boards with stick figures on notebook paper are useful to a production.

The Conceptual Art

Conceptuals are the design elements that are needed for the CG production. Typically, characters are drawn into character sheets in three different neutral poses from the front, from the side, and from an angle called a 3⁄4 view. Some are even sculpted into clay for better reference. Color art can also be created of the various sets, props, and characters to better visualize the colors, textures, and, later on, the lighting that will be needed. Props and sets are identified from the script and boards and sketched out into model sheets. The better the conceptual art is visualized, the easier it will be to model, texture, and light everything in CG.

Production

Production begins when you start creating the models from the boards, model sheets, and concept art. You model the characters, the sets, and the props, and you assign textures (colors, patterns). The animators take the models and animate everything according to the boards and script. The sequences are rendered in low quality for dailies and checked for accuracy and content.

CG production itself has an involved number of steps that are usually defined by the needs of the production. We'll peer into 3D work flow in the next section, but to make a long story short, 3D scenes are created, lit, and animated in the production phase. Most of the CG techniques you'll learn in this book are part of the production phase.

Postproduction

Once all the scenes have been set up with props and characters and everything is animated, postproduction can begin. Postproduction for a CG project is similar to postproduction for a film. This is where all of a CG film's elements are brought together and assembled into final form.

Rendering

All CG scenes need to be rendered to their final image or movie files. Again, this is the process by which the computer calculates how everything in the scene should look and displays it. It is a process that makes great processing demands on your computer, usually requiring the full attention of your PC, and it can take a good amount of time. As you'll learn throughout this book, decisions you make in creating the objects in a scene can make a big difference in how the rest of the process goes.

You can render one scene while another scene is in production, but working on a system that is rendering is not advisable unless you're using a dual-processor machine with plenty of memory. When everything is rendered properly, the final images are sorted and the assembly of the CG project begins. Rendering is the subject of Chapter 11. Three more postproduction activities are advanced topics, beyond the scope of *Introducing Maya*: compositing, editing, and adding sound; you will find a multitude of books on these topics available for further study.

Compositing

Quite often, CG is rendered in different layers and segments and needs to be put back together. In a particular scene, for example, multiple characters interact. Each character is rendered separately from the others and from the backgrounds. They are then all put together in *compositing*, the process of bringing together scene elements that were created separately, to form the final scene. Maya makes this process easier with Render Layers, which you will experience in Chapter 11, "Maya Rendering."

Compositing programs such as Shake and After Effects not only allow you to compose CG elements together, they also give you some additional control over color, timing, and a host of other additions and alterations you can make to the scene. Compositing can greatly affect the look of a CG project; professionals consider it an integral part of CG creation.

One of the biggest problems students new to the CG process have is their need to generate their scene in one fell swoop. It is important to realize the component nature of CG and how you can use that to your advantage in rendering items separately and compositing them together in the finishing stage.

Editing

The rendered and composited CG footage is collected and edited together to conform to the script and boards. Some scenes are cut or moved around to heighten the story. This process is essentially the same as in film editing, with one big difference: the amount of footage.

Live-action filmmakers shoot much more footage than is needed for the film, to make sure they have adequate coverage for all their scenes and to leave extra room for creativity in the editing. The editor and the director sift through all the scenes and arrange them to assemble the film in a way that works best with what they have shot. A typical film uses a small fraction of all film or video that is shot.

Because CG creation and rendering is much more time-consuming and expensive to generate than shooting most live action, scenes and shots are often tightly arranged in preproduction boards so not much is wasted, if any. The entire production is edited with great care beforehand, and the scenes are built and animated to match the story, almost down to the frame. Consequently, the physical editing process consists mostly of assembling the scenes into the sequence of the story.

Sound

Sound design is important to CG. Viewers like to associate visuals with audio. A basic soundtrack can add a significant punch to a simple animation by helping provide realism, mood, narrative, and so on, adding a greater impact of gestalt to the CG.

Sound effects such as footsteps are added to match the action on the screen; this type of sound is also known in film as *foley sound*. Music is scored and added to match the film. Again, this is much the same procedure as in film, with one exception. In the event that a CG project requires dialogue, the dialogue must be recorded and edited *before* CG production can begin. Dialogue becomes a part of the preproduction phase as well as post. This is because animators need to hear the dialogue being spoken to match the lips of the characters speaking, known as *lip-synch*. Quite often, the dialogue or musical score inspires a character's actions or body language as well.

How It All Works Together

The process behind making a *South Park* episode makes for a perfect pipeline example. Although the show appears to be animated using paper cutouts, as was the original Christmas short, the actual production work is now done using Maya. In preproduction on a typical episode, the writers hammer out the script, and the voice talent records all the voices before the art department creates the visuals for the show. The script is storyboarded, and copies are distributed to all the animators and layout artists.

Beginning the production phase, each scene is set up with the proper backgrounds and characters in Maya and then handed off for lip-synch, the first step in the animation of the scene. The voices are digitized into computer files for lip-synch animators who animate the mouths of the characters. The lip-synched animation is then passed to character animators who use the storyboards and also the soundtrack to animate the characters in the Maya scene.

The animation is then rendered to start the post, edited together following the boards, and sent back to the sound department for any sound effects and such to round out the scene. The episode is assembled and then sent off on tape for a broadcast.

The CG Production Work Flow

Because of the nature of CG and how scenes must be built, a certain work flow works best. Modeling almost always begins the process, which then can lead into texturing and then animation (or animation and then texturing). Lighting should follow, with rendering pulling up the rear, as it must. (Of course, the process isn't completely linear; you'll often go back and forth adjusting models, lights, and textures throughout the process.) Chapters 4 through 12 follow this overall sequence, presenting the major Maya operations in the same order you'll use in real-world CG projects.

Modeling

Modeling, the topic of Chapters 4 through 6, is usually the first step in creating CG, and one that garners a lot of coverage in publications and tends to capture the interest of most budding CG artists. You most often start a CG scene by creating the objects you need to occupy your space. It can end up taking the majority of the time in your process.

There are many modeling techniques, and each could be the subject of its own series of books. The choice of which to use usually depends on the modeler's taste and preferred work flow. As you'll see, the choices are among NURBS modeling (Chapter 4), polygon modeling (Chapter 5), and a third method that combines elements of the first two, subdivision surface modeling (Chapter 6).

It helps a great deal in figuring out how to proceed with the modeling to have a good idea of your whole story via a storyboard. Knowing how an object is used in a scene gives you its criteria for modeling. You never want to spend more time on a model than needed. Beginning with a highly detailed model for a far-away shot will waste your time and expand rendering times. If a park bench is to be seen in a wide shot from far away, it does not need abundant detail or complicated surfacing. You can usually create any required details for it by just adding textures. However, a park bench that is featured prominently in a close-up needs as much detail as possible since viewers will see more of the bench. You'll learn more about this aspect of modeling in Chapter 4, but the more you use models in scenes, the better eye you will develop for knowing exactly how much detail to give them. As you begin your CG experience, however, it's a good idea to lavish as much attention on detail as you can. The detailing process will teach you perhaps 70 percent of what you can learn of modeling, which in turn will benefit your overall speed and technique. And with some more experience, you will be able to discern exactly how much detail to add to a scene and not go overboard.

Character Modeling

Character modeling usually involves organic forms such as animals, humans, aliens, and such. Practically anything that will be animated to be a character in a scene can be referred to as a character model. You need to create these with animation techniques in mind, as well as accuracy of form.

Some organic characters (as opposed to robots with mechanical parts and hard edges, for example) are built with patches of surfaces stitched together or as a single object that is stretched and pulled into shape. Character models need to look seamless since most character animation requires the model to deform in some way—to bend and warp at certain areas such as the joints.

A character modeler needs to keep the future of the character in mind to allow for particular character animation methods that will be used. Always try to build your characters with the proper amount of detail appropriate to the scene. Quite frequently, you will create several models for a character to account for different uses of that character and to keep the scene efficient and workable. You might create one character with fine facial detail for the close-up speaking scenes and another with hardly any details for walk cycles in distant shots. Listen to your mother: put only as much as you need on your plate.

Architectural and Environment Modeling

Architectural and environmental modeling includes architectural previsualization for the design of buildings as well as the generation of backgrounds for sets and environments. Typically, it involves modeling buildings or interiors as well as mountains or anything that is required for the scenery, such as benches, chairs, lampposts, and so on.

You should not create incredibly detailed environments if they are not featured in a shot, especially environments that use a lot of geometry. The greater the amount of geometry, the slower your computer will run and the longer rendering will take. You can create a good deal of the environment using clever textures on simple geometry. Detailed maps on bare surfaces are used frequently for game environments. The rule of thumb for all kinds of CG is "use whatever works."

> Since your computer stores everything in the scene as vector math, the term *geometry* refers to all the surfaces and models in a scene.

Props Modeling

Props modeling covers almost everything else needed in the scene. In theater and film terms, a *prop* is an object used by a character in the action; anything relegated to the scenery or background is a *scenic*. For example, a prop can be a purse a character is carrying, a leash on an animated dog, or a car a character is driving. If the car or purse were just sitting in the background, it would be considered a scenic.

Texturing

Once the models are complete, it's a good idea to begin *texturing* and *shading*, the process of applying colors and textures to an object to make it renderable. When you create an object in Maya, for example, a simple gray shader is automatically assigned to it that will let you see the object when you light and render the scene.

Because the textures may look different after animating and lighting the scene, it's wise to leave the final adjustments for later. Just as a painter will pencil in a sketch before adding details, you don't need to make all the shading adjustments right away since you can return to any part of your scene in Maya and adjust it to fine-tune the picture.

You'll learn more about texturing in Chapter 7.

Animation

Although modeling can take the biggest part of a CG artist's time, you can really make or break your scene with its animation.

We all have an innate sense of how things move. Culled from years of perception and observation, we understand how physics applies to things and how people and animals move around. Because of this, viewers tend to be much more critical of CG's motion than of anything else. Put bluntly, you know when something doesn't look right, and so will people watching your animation.

To animate something properly, though, you might need quite a lot of setup beyond just modeling. Depending on the kind of animating you'll be doing, you might need to set up the models for however you'll be animating them. For example, for character animation you will need to create and attach an armature, or skeleton, to manipulate to make the character move, like a puppet, and do your bidding.

Taking the models you've spent hours detailing and reworking and giving them life is thrilling and can make any detailed modeling and setup routine well worth the effort.

Chapters 8 and 9 cover animation techniques in Maya.

Lighting

Lighting can be the most important part of CG. During this step, you set up virtual lights in your scene to illuminate your objects and action. Lighting can drastically alter the look of your scene; it greatly affects the believability of your models and textures and creates and heightens mood.

Although you can set up some initial lights during the texturing of the scene, the serious lighting should be the last thing you do, aside from changes and tweaks.

The type and number of lights you use in a scene greatly affect not just the look of your scene, but also the amount of time the scene takes to render. Lighting becomes a careful dance between pragmatics and results. It is perhaps the subtlest part of CG to master.

Once you gain more experience with lighting, you'll notice it will affect every part of your CG creation. You'll find that you'll start modeling differently—modeling with the final lighting of the scene in mind. Texturing will change when you keep lighting techniques in mind. Even your animation and staging will change a bit to take better advantage of efficient, powerful lighting.

This is because *CG is fundamentally all about light*. Manipulating how light is created and reflected is what you're doing with CG. Without light we would not see anything, so it makes sense that simulating light is the most influential step in CG.

As you'll learn in Chapter 10, virtual lights in Maya are similar to lights used in the real world, from a single point of light such as a bulb to directed beams such as spotlights.

Rendering

At this stage, your computer takes your scene and does all the computations to create raster images for your movie. Rendering time depends on how much geometry is used in the scene, as well as on the number of lights, the size of your textures, and the quality and size of your output. The more efficient your scene, the better the render times.

A lot of people ask how long they should expect their renders to take or how long is too long for a frame to render. It's a subjective question with no answer. Your frames will take as long as they have to take for them to look the way you want. Of course, if you have tight time or budgetary constraints, you want simple scenes to keep the render resources and times to a minimum. But the general rule in production is, you're always out of time, so the most efficient pipeline will be your savior, and eventually your producer or boss will tire of hearing, "But I'm still rendering."

As you learn, use as many lights and as much geometry as you can handle for your scenes. The more experience you pick up, the better your eye will become for efficiency. It's important to understand *how* a scene is put together before you learn to *efficiently* put a scene together.

Core Concepts

3D animation draws from many disciplines. In learning Maya, you'll work with concepts derived not only from computer graphics but also from design, film and cinematography, and traditional animation. Here's a summary of the most important of those concepts as they apply to Maya.

Computer Graphics Concepts

Knowing a bit about the general terminology and methodology of computer graphics will help you understand how Maya works. Let's begin with the crucial distinction between raster (bitmapped) and vector graphics and how this distinction affects you as a Maya user.

Raster Images

Raster images (synonymous with bitmapped images) make up the world of computer images today. These images are displayed through the arrangements of colored pixels on screen or dots on a print to display an image. Everything you create in Maya will eventually be seen as a raster image, even though you create it using vectors.

Raster image programs such as Painter or Photoshop let you adjust existing settings such as color, size, and position for all or part of an image. They let you paint onto a scanned picture or a virtual canvas to adjust or create the pixels yourself. These programs essentially affect pixels directly, giving you the tools to change pixels to form images. For instance, you can use a scanned photo in Photoshop to paint the side of your house red to see what it might look like before you run down to the local paint store.

Recall from the beginning of this chapter that a raster or bitmap image is a mosaic of pixels, each pixel corresponding to a mosaic tile. The *resolution*—fineness of detail—of an image is defined by the number of pixels per inch (or other unit of measure) in the horizontal and vertical directions. Because they are based on a grid of a fixed size, raster images do not scale up well. The closer you get to a raster image, or the larger a raster image is scaled, the bigger the pixels become, making the image look blocky, or *pixelated*. To make large raster images, you need to use a higher resolution to begin with. The higher the resolution, the larger the file size. Figure 1.1 shows what happens when you blow up a raster image.

In light of this limitation, you might wonder why raster images are used. The answer lies in *how* these images are generated. Most common raster displays are television or computer screens. In fact, the term *raster* originally referred to the display area of a television or computer monitor. To form an image, the electronics in these devices essentially paint it as a grid of red, green, and blue pixels on a glowing screen. Every image generated by a computer, therefore, must either begin as a raster image or be rasterized as part of rendering for display.

Vector Images

Vector images are created in a wholly different way. Vector images are created using mathematical algorithms and geometric functions. Instead of defining the color of each and every pixel in a grid of a raster image, a vector image uses coordinates and geometric formulas to plot points that define *areas, volumes,* and *shapes*.

Popular vector-based image applications include Illustrator and Flash, as well as practically all computer-aided design (CAD) programs such as AutoCAD or SolidWorks. These programs let you define shapes and volumes and add color and texture to them through their toolsets.

They store the results in files containing coordinates and equations of points in space and the color values that have been assigned. This vector information is then converted into raster images (called *rasterization*) through rendering so you can view the final image or animation.

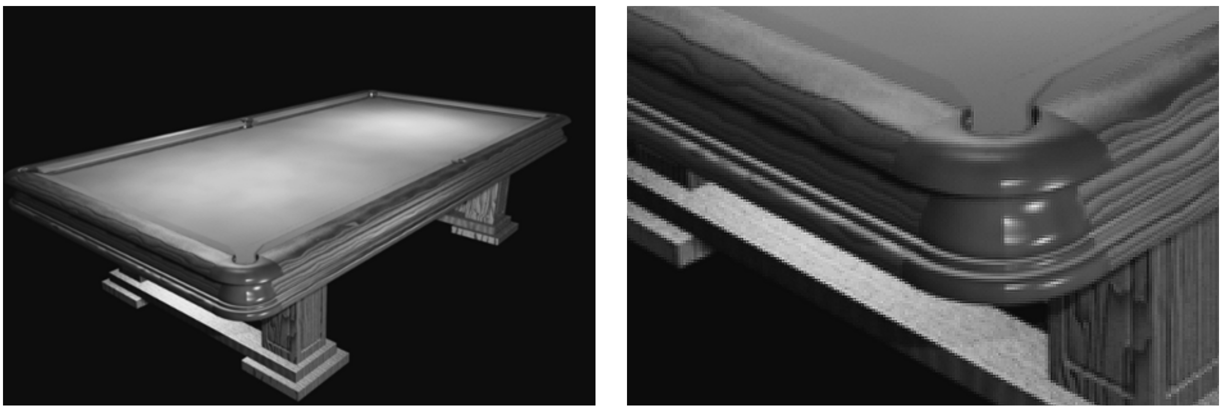


Figure 1.1
A raster image at its original size (left) and blown up two to three times (right)

When scaled, vector graphics do not suffer from the same limitations as raster images. As you can see in Figure 1.2, vectors can be scaled with no loss of quality; they will never pixelate.

Motion in vector programs is stored not by a long sequence of image files, but through changes in positions of the geometry and in the math that defines the shapes and volumes. When a Flash cartoon is played on a website, for example, the information downloaded and fed into your computer is in vector form. It contains the position, size, and shapes of all the characters and backgrounds of the animation. Your computer then renders this information on-the-fly, in real time, into a raster display that you can enjoy on your screen.

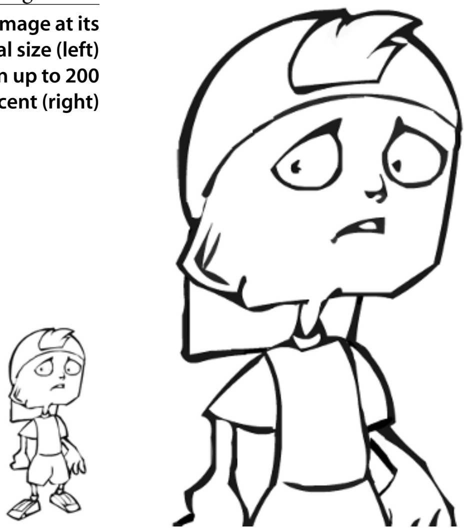


Figure 1.2
A vector image at its original size (left) and blown up to 200 percent (right)

In Maya, however, you work with vectors that are displayed as wireframes. When you finish your scene, Maya renders the image, converting the vector information into a sequence of raster images.

When a vector file is edited, its geometric information is altered through the tools of the vector program. This allows for easy manipulation and handling of changes and is perfect for design industries in which collaboration and efficiency in changes are a necessity. Only when the editing is finished will the vector file be rendered into a new sequence of raster images by the computer.

Image Output

When you're done with your animation, you'll want as many people as possible to see it; to make that happen, you have to render it out into a file sequence or a movie file. The file can be saved in any number of ways, depending on how you intend it to be viewed.

COLOR DEPTH

An image file stores the color of each pixel as three values, representing red, green, and blue. Image type depends on how much storage is allotted to each pixel (the *color depth*). These are the color depths common to image files in CG production:

Grayscale The image is black and white with varying degrees of gray in between, typically 256. Grayscale images are good for rendering out black-and-white subjects; no extraneous color information is stored in the image file.

16-Bit Color Display or High Color – 5-Bit Image File Each color channel (red, green, blue) gets 5 bits of space to store its value, resulting in an image that can display a maximum of 32,768 colors. Each color channel has a limited range of shades but still gives a nice color image. You might notice the gradation in the different shades of each color that can result in *color banding* in the image.

8-Bit Image File Commonly referred to as 24-bit color display or True Color, each color channel is given 8 bits for a range of 256 shades of each red, green, and blue channel for a total of 16 million colors in the image. This color depth gives the best color quality for an image and is widely used in most animation applications. It is said that the human eye cannot see quite as many shades of color as there are in a True Color image. Most of your renders from Maya will probably be as 24-bit color files.

16-Bit Image File Used primarily in film work using such file types as Cineon format or TIFF16, the image file holds 16 bits of information for each color channel, resulting in an astounding number of color levels and range. Each file can exceed several megabytes even at low resolutions. These files are primarily used in the professional workplace and are standard for film work since outputting CG to film can require high levels of color and brightness range in the image.

COLOR CHANNELS

As mentioned, each image file holds the color information in channels. All color images have a red, green, and blue color channel. Each channel is a measurement of how much red, green, or blue there is in areas of the image. A fourth channel, called the *alpha* channel, is used as a transparency channel. This channel, also know as the matte channel, defines which portions of the image are transparent or opaque. Not all image files have alpha channels. You can read more about alpha channels in Chapter 7.

FILE FORMATS

In addition to image type, several image file formats are available today. The most common perhaps is JPEG (Joint Photographic Experts Group), which is widely used on the Internet.

The main difference between file formats is how the image is stored. Some formats compress the file to reduce file size. However, the greater the compression, the poorer the image's color.

The popular formats to render into from Maya are TIFF (Tagged Image File Format), SGI (Silicon Graphics Inc.), Maya IFF (Maya Image File Format), and Targa. These file formats maintain a good 24-bit color depth using an 8-bit image file, are either uncompressed or hardly compressed (lossless compression), and are frequently used for broadcast or film work. These formats also have an alpha channel, giving you better control when you later composite images together. To see an animation rendered in a file sequence of TIFFs, for example, you must play them back using a frame player such as Fcheck or compile them into a movie file.

Ultimately, your final image format depends on the next step in your project. For example, if you plan to composite your CG, you'll need to output a format that can be imported by your compositing or editing program. TIFF files are perhaps the best format to use as they are widely compatible, store uncompressed color, and have an alpha channel.

MOVIE FILES

Animations can also be output to movie files such as AVI or QuickTime. These usually large files are self-contained and hold all the images necessary for the animation that they play back as frames. Like image files, movie files can be compressed to keep their sizes to a minimum, but they suffer from quality loss as well.

Maya can render directly to an uncompressed AVI movie format, saving you the seeming hassle of having to render out a large sequence of files as TIFFs or such. Although this might seem like a good idea, you shouldn't render directly to a movie file. It is best to render a sequence of files, which can easily be compiled into a movie file later using a program such as After Effects, Premiere, or even QuickTime Pro.

The reason is simple: nothing is perfect, and neither is rendering on your computer. At times, your render will crash or your machine will freeze. In such an event, you need to start your AVI render from the beginning, whereas with TIFFs you can pick up right after the last rendered frame. With a sequence, you also have the option of reordering the frames or easily adjusting a few individual frames' properties such as hue or saturation without affecting the entire movie file.

Color

Color is what we perceive as the differences in the frequency of light. The wide range of colors that we see (the visible spectrum) results when any of three *primary colors* of light—red, green, and blue—are "mixed" together. Color can be mixed in two ways, subtractive and additive. These color definitions are most often displayed in *color wheels*, which place primary colors equally spaced around a ring and place the resultant colors when primaries are mixed in between the appropriate primaries.

Knowing more about color will help you understand how your CG's color scheme will work and help you to design your shots with greater authority. (See the reading list at the end of this chapter for some books that expound on color theory and color's impact on composition.)

SUBTRACTIVE AND ADDITIVE COLOR

Subtractive color mixing is used when the image will be seen with an external light source. It's based on the way reflected light creates color. Light rays bounce off colored surfaces and are tinted by the different pigments on the surface. These pigments absorb and reflect only certain frequencies of the light hitting them, in essence *subtracting* certain colors from the light before it gets to your eyes. Pile up enough different colors of paint and you get black; all the color is absorbed by the pigment and only black is reflected.

With subtractive color mixing for painting, the traditional color wheel's primary colors are *red*, *blue*, and *green*. These three pigments can be mixed together to form any other color pigment. This is the basis for the color wheel most people are exposed to in art education. However, in the world of print production, a CMYK (Cyan, Magenta, Yellow, and blacK) color wheel is used, which places cyan, yellow, and magenta ink colors as the primary colors used to mix all the other ink colors for print work.

Projected light, however, is mixed as *additive color*. Each light's frequency adds upon another's to form color. The additive primary colors are *red*, *green*, and *blue*. These three colors, when mixed in certain ratios, form the entire range of color. When all are equally mixed together, they form a white light.

A computer monitor uses only additive color, mixing each color with amounts of red, green, and blue (RGB). Output for print is converted to a CMYK color model.

Warm colors are those in the magenta to red to yellow range, and *cool colors* are those in the green to cyan to blue range of the additive color wheel. Warm colors seem to advance from the frame, and cool colors seem to recede into the frame.

HOW A COMPUTER DEFINES COLOR

Computers represent all information, including color, as sets of numeric values made up of binary 0s and 1s (bits). In a 24-bit depth RGB color image, each pixel is represented by three 8-bit values corresponding to the red, green, and blue "channels" of the image. An 8-bit binary number can range from 0 to 255, so for each primary color you have 256 possible levels. With three channels you have $256 \times 256 \times 256$ (16.7 million) possible combinations of each primary color mixed to form the final color.

But color value can also be set on the hue, saturation, and value (HSV) channels of a color. Again, each channel holds a value from 0 to 255 (in a 24-bit image) that defines the final color. The hue value defines the actual tint (from red to green to violet) of the color. The saturation defines *how much* of that tint is present in the color. The higher the saturation value, the deeper the color. Finally, value defines the brightness of the color, from black to white. The higher the value, the brighter the color.

HSV and RGB give you different methods to control color, allowing you to use the method you prefer. All the colors available in Maya, from textures to lights, are defined as either RGB or HSV values for the best flexibility. You can switch from HSV to RGB definition in Maya at any time.

CMYK COLOR SPACE

A CMYK color wheel is used for print work, and this is referred to as the four-color process. Color inkjet printers produce color printouts by mixing the appropriate levels of these inks onto the paper.

All output from a computer, which is RGB based, to a printer goes through a CMYK conversion as it's printed. For professional print work, specially calibrated monitors are used to better preview the CMYK color of an RGB image before it is printed. Fortunately, only the print professionals need to worry about this conversion process because most of it is handled by our graphics software to a fairly accurate degree.

VIEWING COLOR

The broadcast standard for North America is called NTSC, as listed in the next section. One joke in the industry is that the acronym means Never The Same Color, referring to the fact that the color you see from one TV screen to another will be different. The same will hold true for computer monitors, especially flat panel displays. It's important to keep this in mind; all displays are calibrated differently, and what you see on one screen may not be exactly what you see on another screen. If it's important that the color matches on different screens, say between home and school, you can use traditional color bars downloaded from the Internet or your own custom-made color chart to adjust the settings of the monitors you work with so they match more closely.

Resolution, Aspect Ratio, Frame Rate

Resolution denotes the size of an image in the number of horizontal and vertical pixels, usually given as # × #, such as 640 × 480. The higher the resolution, the finer the image detail.

You will adjust your final render size to suit the final medium for which you are creating the animation. The following are some standard resolutions:

VGA (Video Graphics Array)	640 × 480	Formerly the standard computing resolution and still a popular television resolution for tape output.
NTSC D1 (National Television System Committee)	720 × 486	The standard resolution for broadcast television in North America.
NTSC DV	720 × 480	Close to the NTSC D1 resolution, this is the typical resolution of digital video cameras.
PAL (Phase Alternation Line)	720 × 586	The standard broadcast resolution for most European countries.
HDTV (High Definition TV)	1920 x 1080	The emerging television standard, sometimes also referred to as 1080i.
1K Academy (1K refers to 1000 pixels across)	1024 × 768	Typically the lowest allowable resolution for film production at Academy ratio. Since film is an optical format (whereas TV is a raster format), there is no real set defined resolution for film. Suffice it to say, the higher the better.
2K Academy (2K refers to 2000 pixels across)	2048 × 1556	Most studios output CG for film at this resolution, which gives the best size-to-performance ratio.
4K Academy (4K is 4000 pixels across)	4094 × 3072	A high resolution for film, used for highly detailed shots.

Any discussion of resolution must include the matter of *aspect ratio*. Aspect ratio is the ratio of the screen's *width* to its *height*, and of course, there are standards:

Academy Standard	1.33:1 or 4:3	The most common aspect ratio. The width is 1.33 times the length of the height. This is the NTSC (National Television Standards Committee) television aspect ratio as well as the aspect ratio of 16 mm films and some 35 mm films, especially classics such as *Gone with the Wind*.
Widescreen (a.k.a. Academy Flat)	1.85:1 or 16:9	The most often used 35 mm film aspect today. When it's displayed on a television, horizontal black bars appear above and below the picture so that the edges are not cropped off (letterbox).
Anamorphic Ratio	2.35:1	Using a lens (called an anamorphic lens), the image captured to 35 mm film is squeezed. When played back with a projector with an anamorphic lens, the image is projected with a width at 2.35 times its height. On a standard TV, the letterboxing would be more severe to avoid cropping the sides.

How many frames are played back per second determines the *frame rate* of the animation. This is denoted as *fps*, or frames per second. The following shows the three standard frame rates for media:

- NTSC: 30fps
- PAL: 25fps
- Film: 24fps

Knowing your output medium is important when beginning an animation project. Though not crucial, it can affect how you design your framing, create your movements, determine how to render, and so on. You can change the frame rate and render resolution at any time in Maya, but it's always better to know as best you can what the final resolution and fps will be before you begin.

Playing back a 24fps animation at 30fps will yield a slower-moving animation and will either necessitate the repetition of some frames to fill in the gaps or end the animation early. Conversely, playing a 30fps animation at 24fps will create a faster-moving animation that will either skip some frames or end later than it should.

3D Coordinate Space and Axes

It is essential with a 3D program to know where you are at all times. You can do so if you understand the toolset you're working with and the 3D space in which you're working. 3D space is merely the virtual area in which you create your models and execute your animation. It is based on the Cartesian coordinate system, a geometric map of sorts developed by René Descartes.

Space is defined in three axes—X, Y, and Z—representing width, height, and depth. The three axes form a numeric grid in which a particular point is defined by its *coordinates* set forth as (#,#,#) corresponding to (X,Y,Z).

At the zero point of these axes is the *origin*. This is at (0,0,0) and is the intersection of all three axes. The 3D space defined by these three axes is called the *World Axis,* in which the XYZ axes are a *fixed reference*. The axis in *World Space* is always fixed and is represented in Maya by the XYZ axis icon in the lower-left corner of the perspective windows.

But since objects can be oriented in all sorts of directions within the World Axis, it's necessary for each object to have its own width, height, and depth axis independent of the World Axis. This is called the *Local Axis*. The Local Axis is the XYZ coordinate space that is attached to every object in Maya. When that object rotates or moves, its Local Axis rotates and moves with it. This is necessary to make animating an object easier as it moves and orients about in the World Axis.

You'll get a hands-on introduction to Maya's Cartesian coordinate space in the tutorial in Chapter 3, where you'll re-create the solar system with the sun placed at the origin, the planets orbiting the World Axis and rotating on their own Local Axes, and moons orbiting the planets and also rotating (see Figure 1.3).

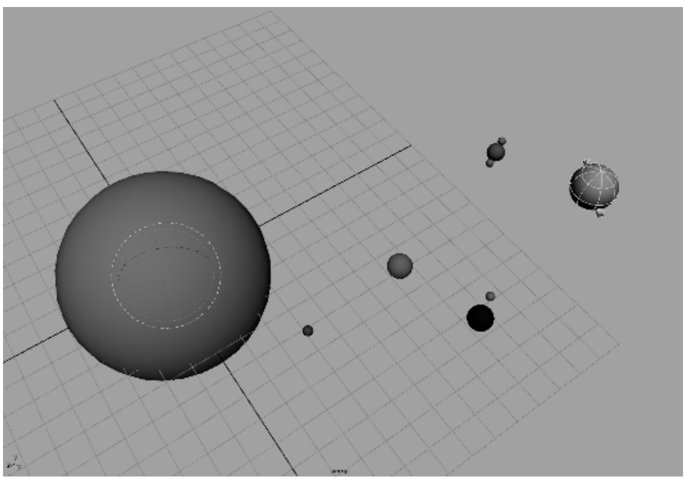
Basic Design Concepts

How you lay out your scene and design your colors is what composition is about. Creating a dynamic frame that not only catches the eye but informs and intrigues is itself an art form.

Some background in basic design is definitely helpful, and you'll want to look at some design books as you further your education in 3D. Understanding the fundamentals of layout and design makes for better-looking scenes and easier setup. The concepts presented here will get you started.

Figure 1.3

The sun at the origin, Earth and other planets orbiting the World Axis and also rotating on their own axes, and the moon orbiting Earth



Form, Space, and Composition

Space is defined as your canvas or frame. Since ultimately your canvas will be a rendered image, your design space becomes your image frame. Whether that frame falls into a tiny web window or a huge IMAX screen, the basics of design always apply: how you arrange your forms and divide your space says a lot.

A *form* in design is anything that can be seen; it has some sort of shape, color, or texture that distinguishes it from its frame. Basically any object you model or animate becomes a form in your frame when you render the scene. How these objects lie in the frame defines your composition. The space behind and between what is rendered out is the ground, or background plane. Objects become *positive space*, and the background becomes *negative space*.

To viewers, positive space tends to proceed forward from the frame, while negative space recedes. Playing with the position of positive and negative space greatly affects the dynamics of your frame. Add to that the element of motion and you have a terrific chance to play with your canvas.

Design a static frame in which the objects are all centered and evenly spaced and your viewer will wonder why they're looking at your composition. Arrange the composition so that your subjects occupy more interesting areas of the frame, in which they play with negative space and the eye can travel the frame, and you create a dynamic composition, with or without animation.

In the tutorial in Chapter 10, you'll use light and shadow to make a still life of fruit a dynamic and interestingly composed frame.

Balance and Symmetry

Balance in a frame suggests an even amount of positive space from one side of the frame to the other. A frame that is heavier on one side can create a more dynamic composition.

Symmetrical objects in a frame are mirrored from one side to another and create a certain static balance to the frame. An asymmetrical composition, therefore, denotes movement in the composition.

A popular technique used by painters, photographers, and cinematographers is called *framing in thirds*, in which the frame is divided into a grid of thirds vertically and horizontally. Interesting parts of the frame or focal points of the subjects are placed at strategic locations in the grid. Placing your subject in the lower third would make it seem small or insignificant. Placing it in the upper third would make the viewer look up to it, magnifying its perceived scale or importance. Figure 1.4 illustrates the difference between a static, symmetric frame and a frame based on thirds.

Contrast

Contrast in design describes how much your foreground subject "pops" from the background. As you can see in Figure 1.5, when you create an area in your frame that contains little variation in color and light, the image will seem flat and uneventful. Using dark shadows and light highlights increases the perceived depth in the image and helps pop out the subject from the background. Animating contrast can help increase or decrease the depth of your frame.

As you'll see in Chapter 10, light plays an important role in creating dynamic contrasts within your frame.

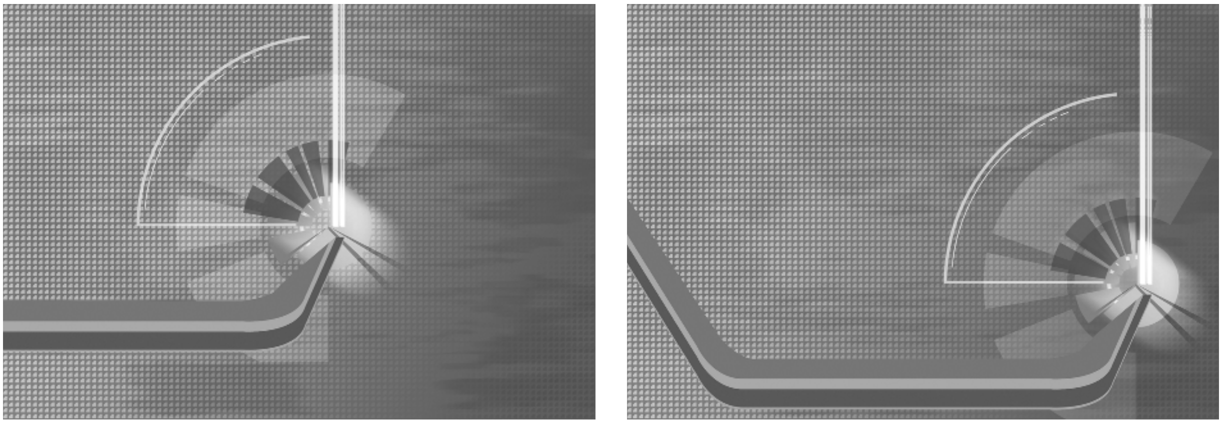


Figure 1.4

A purely symmetric frame looks static, but framing in thirds helps create a sense of motion.

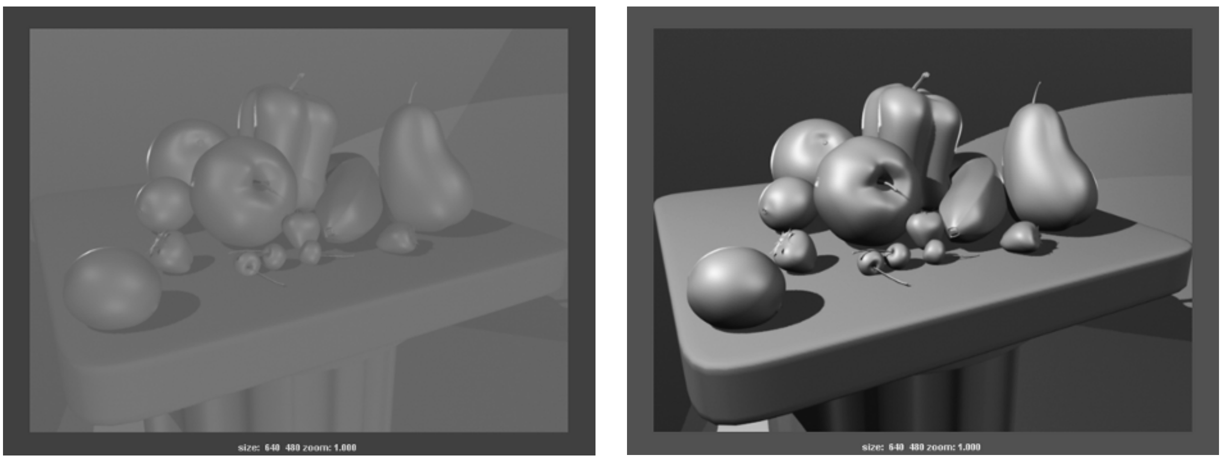


Figure 1.5

With low contrast, the subject seems to disappear into the background. Add shadows and highlights, and the subject will "pop out."

Color

Your use of color also plays a big part in creating impact in your frame. Warm colors tend to come out toward you, and cooler colors recede into the frame. Placing a warm color on a subject on a cool background creates a nice color contrast to help the dynamics of your frame.

Colors opposing each other on the color wheel are *complementary* colors and usually clash when put together. Using complementary colors can create a wide variation of contrast in your scene.

Design theory may not seem specifically pertinent to CG right now, but recognizing that there is indeed a way to quantify design elements of a pretty picture greatly helps the design student progress.

Basic Film Concepts

In addition to the design concepts used in framing a shot, you'll want to understand some other filmmaking concepts.

Planning a Production

Understanding the paradigm filmmakers use for their productions will make it easier to plan, create, and manage your own shorts. Most narrative films are broken into acts, which comprise sequences made up of scenes that are made up of shots.

> A *narrative film* is a film that tells a story of a hero called a *protagonist* and his or her struggle against an *antagonist*.

Narrative films are typically divided into three *acts*. The first act establishes the main characters and the conflict or struggle that will define the story. Act II covers most of the action of the story as the hero attempts to overcome this conflict. Act III concludes the film by resolving the action in the story and tying up all the loose ends.

Acts can be separated into *sequences*, which are groups of sequential scenes that unite around a particular dramatic or narrative point.

A *scene* is a part of a film that takes place in a specific place or time with specific characters to present that part of the story. Films are broken into scenes for organization purposes by their locations (that is, by where or when they take place). Don't confuse the scene in a film with the word *scene* in CG terms, which refers to the elements in the 3D file that make up the CG.

Scenes are then broken into *shots*, which correspond to a particular camera angle, or *framing*. Shots break up the monotony of a scene by giving different views of the scene and its characters. Shots are broken by *cuts* between the shots.

Shots are defined by angle of view, or the POV (point of view) of the camera. Shots change as soon as the camera's view is changed.

CG productions of even the simplest topics can follow this simple organization. By following a similar layout in the scripting and storyboarding of your own short, you will find the entire production process will become easier and the effect of your film stronger.

Lighting

Without lights, you can't capture anything on film. How you light your scene affects the contrast of the frame as well as the color balance and your overall design impact. For the most part, a typical lighting solution called the *three-point system* is the basis from which to at least begin when lighting a scene. This method places a *key* light in front of the scene as the primary illumination and to cast the shadows in the scene. The key light is typically placed behind the camera and off to one side to create a highlight on one side of the object for contrast's sake. The rest of the scene is given a *fill* light. The fill acts to illuminate the rest of the scene but is typically not as bright as the key light. The fill also helps soften harsh shadows from the key light. To pop the subject out from the background, a *back* light is used to illuminate the silhouette of the subject. This is also known as a *rim* light because it creates a slight halo or rim around the subject in the scene. It's a faint light compared with the key or fill lights.

Create lights in your scene that are too flat or even and you can greatly weaken your composition and abate your scene's impact. The more you understand how real lights affect your subjects in photography, the better equipped you will be in CG lighting. Although CG lighting techniques can vary wildly from real life, the desired results are often the same. You'll learn more about Maya lighting techniques in Chapter 10.

Basic Animation Concepts

As mentioned at the beginning of this chapter, animation is the representation of change over time. That's a simple view of an amazing art that has been practiced in one way or another for some time. Although this section cannot cover all of them, here are a few key terms you will come across numerous times on your journey into CG animation.

Frames, Keyframes, In-Betweens

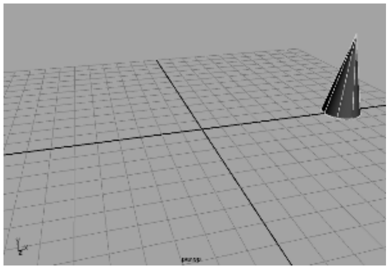
Each drawing of an animation, or in the case of CG, a single rendered image, is called a *frame*. A frame also refers to a unit of time in animation whose exact chronological length depends on how fast the animation will eventually play back (frame rate). For example, at film rate (24fps), a single frame will last 1⁄24 of a second. At NTSC video rate (30fps), that same frame will last 1⁄30 of a second.

Keyframes are key frames at which the animator creates a pose for a character (or whatever is being animated). In CG terms, a keyframe is a frame in which a pose, a position, or some other such value has been saved in time. Animation is created when an object travels or changes from one keyframe to another. You will see how creating poses for animation works firsthand in Chapter 9, when you create the poses for a simple walking human figure.

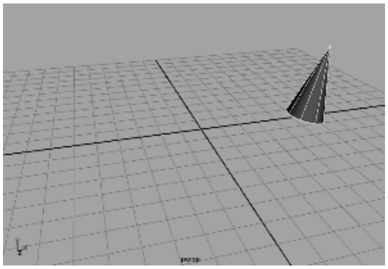
In CG, a keyframe can be set on almost *any* aspect of an object—its color, position, size, and so on. Maya will interpolate the *in-between* frames between the keyframes set by the animator. In reality, you can set several keyframes on any one frame in CG animation. Figure 1.6 illustrates a keyframe sequence in Maya.

Figure 1.6

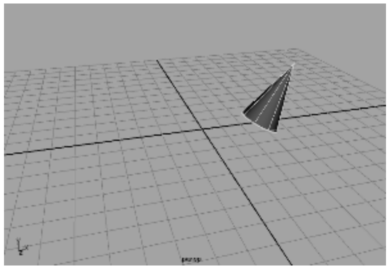
Keyframing. In the first frame of this sequence, a keyframe is set on the position, rotation, and scale of the cone. On frame 30, the same properties are again keyframed. Maya calculates all the movement in between.



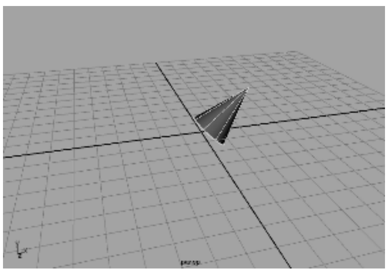
Keyframe at frame 1



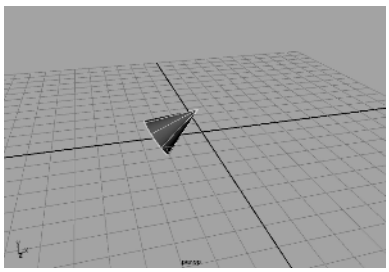
Frame 5



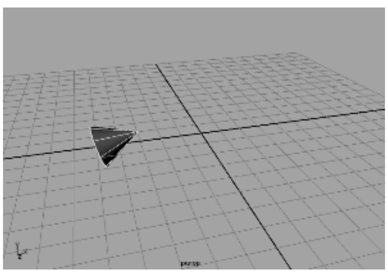
Frame 10



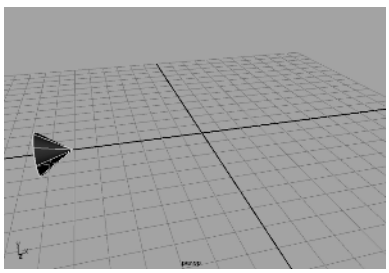
Frame 15



Frame 20



Frame 25



Keyframe at frame 30

Weight

Weight is an implied facet of design and animation. The weight of your subject in the frame rests on how it is colored and its contrast, shape, and location in the frame and the negative space around it. In animation, the idea of weight takes on a more important role. How you show an object's weight in motion greatly affects its believability. As you'll see in the axe tutorial in Chapter 8, creating proper motion to reflect the object's weight goes a long way toward creating believable animation.

Weight in animation is a perception of mass. An object's movement and how it reacts in motion and to other objects need to convey the feeling of weight. Otherwise the animation will look bogus, or as they say, "cartoonish."

Weight is created with any number of techniques developed by traditional animators over the years that in some ways distort the shape of the character to make it look as if it is moving. Although it may seem strange to distort an object's dimensions as with *squash and stretch*, it lends more realism of motion to the character. Chapter 8 will touch more on creating weight in animation; here's a quick preview.

SQUASH AND STRETCH

This technique makes a character responds to gravity, movement, and inertia by literally squashing down and stretching up when it moves. For example, a cartoon character will squeeze down when it is about to jump up, stretch out a bit while it is flying in the air, and squash back down when it lands to make the character look as if it is reacting to gravity.

EASE-IN AND EASE-OUT

Objects never really suddenly stop. Everything comes to some sort of rest in its own time, slowing before the complete stop in most cases. This is referred to as ease-out.

As objects don't suddenly stop, they also don't immediately start motion either. Most everything needs to speed up a bit before reaching its full speed. This is ease-in. The bouncing ball tutorial in Chapter 8 illustrates ease-in and ease-out.

FOLLOW-THROUGH AND ANTICIPATION

Sometimes exaggerating the weight of an object is necessary in animation. Objects ending an action typically have a follow-through in some way. For example, a cape on a jumping character will continue to move a bit even after the character lands and stops moving. This is similar to the movement of gymnasts. When they land, they need to bend a bit at the knees and waist to stabilize the landing.

Likewise, you can create a little bit of movement in your character or object *before* it moves. Anticipation is a technique in which a character or object winds up before it moves, like a spring that coils in a bit before it bounces. The axe tutorial in Chapter 8 will introduce you to these two concepts.

SUGGESTED READING

The more you know about all the arts that inform CG, the more confident you'll feel among your peers. To get started, check out the following excellent resources.

ART AND DESIGN

These books provide valuable insights into the mechanics and art of design. The more you understand design theory, the stronger your art.

Bowers, John. *Introduction to Two-Dimensional Design: Understanding Form and Function*. New York: John Wiley & Sons, 1999.

Itten, Johannes. *Design and Form: The Basic Course at the Bauhaus and Later*. New York: John Wiley & Sons, 1975.

Ocvirk, Otto G., and others. *Art Fundamentals: Theory and Practice*. New York: McGraw-Hill, 1997.

Wong, Wucius. *Principles of Form and Design*. New York: John Wiley & Sons, 1993.

CG

CG has an interesting history and is evolving at breakneck speeds. Acquiring a solid knowledge of this history and evolution is as important as keeping up with current trends.

Kerlow, Isaac Victor. *The Art of 3-D: Computer Animation and Imaging*. New York: John Wiley & Sons, 2000.

Kundert-Gibbs, John, Dariush Derakhshani, et al. *Mastering Maya 7*. San Francisco: Sybex, 2006.

Kuperberg, Marcia. *Guide to Computer Animation*. Burlington: Focal Press, 2002.

Masson, Terrence. *CG 101: A Computer Graphics Industry Reference*. Indianapolis: New Riders Publishing, 1999.

Periodicals

Computer Graphics World (free subscription for those who qualify) `cgw.pennnet.com`

cinefex `www.cinefex.com`

HDRI3D `www.hdri3d.com`

3D World `www.3dworldmag.com`

Websites

`www.animationartist.com`

`www.awn.com`

`www.highend3d.com`

`www.3dcafe.com`

`www.learning-maya.com`

Film

Block, Bruce. *The Visual Story: Seeing the Structure of Film, TV, and New Media*. Burlington: Focal Press, 2001.

Must Read

Myers, Dale K. *Computer Animation: Expert Advice on Breaking into the Business*. Milford: Oak Cliff Press, 1999.

Physics

You'll see in Chapter 12 that one of Maya's most powerful features is its ability to simulate the dynamics of moving objects. To use that capability effectively, you need a general awareness of the properties of physics—how objects behave in the physical world.

NEWTON'S LAWS OF MOTION

There are three basic laws of motion. Sir Isaac Newton set forth these three laws, summarized here:

- An object in motion will remain in motion, and an object at rest will remain at rest unless an external force acts upon the object. This is called inertia, and understanding it is critical to good animation. You'll find more on this in Chapters 8 and 9.
- The more massive an object is, the more force is needed to accelerate or decelerate its motion. This law deals with an object's momentum.
- Every action has an equal and opposite reaction. When you press on a brick wall, for example, the wall exerts an equal amount of force back to your hand. That way your hand doesn't smash through the wall.

Everyone in animation should and will definitely come to understand the first two laws to a good degree since they play a large part in how your animations should look.

MOMENTUM

In particular, it's important to understand what momentum is all about. When an object is in motion, it has momentum. The amount of momentum is calculated by multiplying the mass of the object by its velocity. The heavier something is, or the faster it is moving, the more momentum it has and the bigger the bruise it will leave if it hits you.

That's why a tiny bullet can cause such a great impact on a piece of wood, for example. Its sheer speed greatly increases its momentum. Likewise, a slow-moving garbage truck can bash your car, relying on its sheer mass for its tremendous momentum.

Basically, when one moving object meets another object that is moving or not, momentum is transferred between them. That means when something hits an object, that target is somehow moved if there is sufficient momentum transferred to it. For more on this notion, see the axe-throwing exercise in Chapter 8.

Summary

In this chapter, you learned the basic process of working in CG, called a *work flow* or *pipeline,* which is similar to the process of working on a typical production. In addition, this chapter covered the core concepts of CG creation and the fundamentals of digital images. Some important ideas in design foundation as well as traditional animation concepts were also covered.

Now that you have a foundation in CG and 3D terminology and core concepts, you are ready to tackle the software itself. Maya is a capable, intricate program. The more you understand how *you* work artistically, the better use you will make of this exceptional tool.

It seems as if there is a lot to think about before putting objects into a scene and rendering them out. With practice and some design tinkering, though, all this becomes intuitive to the artist. As you move forward in your animation education, stay diligent, be patient, and never pass up a chance to learn something new. And above all else, have fun with it.