The Making of Toy Story

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Abstract

Toy Story is the first full length feature film produced entirely using the technology of computer animation. The main characters, Sheriff Woody and Space Ranger Buzz Lightyear, are toys that come to life when humans aren't around. Their story is one of rivalry, challenges, teamwork and redemption.

Making this film required four years of effort, from writing the story and script, to illustrated storyboards, through modeling, animation, lighting, rendering, and filming. This paper examines various processes involved in producing the film.

1. Introduction

Before *Toy Story* was made, the contribution of computer animation to feature films was measured in seconds or minutes. The challenge of this project was to produce an entire feature film showing a complete world created digitally, to populate it with characters seeming to act of their own volition and experience, and render it with the colors, shapes, and textures of a believable stylized reality.

The result is a film that couldn't have been made any other way. When Sheriff Woody and Buzz Lightyear come to life, they have a sense of three dimensional form that solidifies their existence, confirming our suspicions about the secret lives of toys. The techniques used can create motion so detailed and fluid that a character's emotion is clearly visible, all in an enticing world with the uncanny ability to appear simultaneously both real and unreal.

In the world of Andy's room, Buzz is the new kid on the block, blithely unaware of the the threat he poses to Woody's position in society as Andy's favorite toy. Their conflict causes a distraction at a dangerous time, when they are left behind at the gas station and faced with the prospect of being lost toys. Only through teamwork and friendship can they make it back home. Many elements were vital in making the film, including character and story development, unique software tools, the abilities of voice actors and animators, and the imaginations of artists and designers. Technical artists showed their ability to create beautiful models, lighting and surfaces, and managers kept the pipeline flowing. Lest we claim all the credit, much is owed to the Walt Disney Company, Pixar's partner and mentor.

2. History

Several core members of Pixar began work as part of Lucasfilm Ltd., starting with Ed Catmull in 1979. He attracted John Lasseter from Disney, and also collected Bill Reeves, Loren Carpenter, Tom Porter, Eben Ostby, and others to build the technical team. In 1986, Steven P. Jobs arranged for the team to split from Lucasfilm and form Pixar.

Numerous research papers have been produced by these researchers and others at Pixar, including advances in ray tracing and motion blur [2], rendering architecture [1], shadow casting [7], image compositing [4], particle systems [5], and animation [3] [6].

Through the years, Pixar's ventures into the graphics world have included the Pixar Image Computer, Renderman software rendering products, joint technical development of Disney's Computer Animated Production System (CAPS), several short films including *Tin Toy*, which won an Academy Award in 1988, and the production of various television commercials.

By 1991 the company felt ready to take on a larger animation project, and looked to Disney for support in creating a television special program. Instead of a TV project, the deal blossomed into talks of a full-length feature film, bringing to reality the long-time dream of Pixar's founders. In 1995, *Toy Story* came to market, providing the cornerstone for Pixar's future.

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3. Overview

Creating a fully computer-animated film requires borrowing techniques from both live action film production and traditionally animated filmmaking, as well as the invention of new techniques. In the new world, old-style cartoon character model sheets are expanded and merged with architectural designs to produce three dimensional models in the computer. Sets and props are constructed once and can be reused in any number of shots, and the time-tested methods of camera motion and real life film lighting are mimicked in the simulated world. Unlike the production of a live action film, both old and new animated films rely on a greater amount of pre-planning, as it is very expensive to create multiple takes or to cut out finished shots.

There are three main phases in the creation of a computeranimated film: creative development, production, and postproduction.

During creative development a story concept is built into a treatment, followed by a screenplay and story boards. Working with the editorial department, the story boards are recorded onto video as story reels and combined with voice recordings.

Once the creative development has sufficiently matured, production can begin. This includes art design, modeling, and shot layout, and continues with animation, lighting and rendering. As shots are approved in rendering, they are recorded onto film. The editorial department continues its work of inserting new material from various stages of production into the story reel, updating as more becomes available.

As significant sequences of rendered film become available, they can be sent on to the post-production phase. Here sound effects are added and mixed with a musical score, and color corrected copies of the finished print can be made.

Since the creation of an animated film is so sequential in nature, efficient management of the pipeline is crucial. A suitable inventory is required especially during the stages of the production phase, so that the order of attack can be optimized.

4. Creative Development

Before any film can be made, a story is needed. *Toy Story* was conceived and written at Pixar, and developed in a collaborative effort with a team from Walt Disney Feature Animation. It all starts with a story concept, the basic premise of the movie. This premise is expanded into what's called a treatment or outline, where the fundamental story points are identified and sequences are outlined.

Further refinement of the treatment produces a screenplay, complete with dialogue and scene descriptions. This is used to create a story board, where one or more illustrations are drawn in pencil for each shot of the film. A shot is a continuous camera take, which in *Toy Story* might last from a half second to almost thirty seconds. Story board drawings are scanned for use in an Avid Media Composer, where they are mixed with temporary dialogue and sound effects, producing story reels.

Once the story reels are created, an iterative loop is begun. The length of each shot is determined, and story pacing and camera angles can be judged. Weaknesses might mean the addition or deletion of a shot, a change in dialogue, or something more extensive. The creative development loop doesn't end until desired changes can no longer fit in the schedule. In order to gain some perspective, outside test audiences are shown work-in-progress reels at a point when the story is first considered to be "finished."

4.1. Artistic Design

The development of the story provides the locations and descriptions of the action, but ignores the details of color, lighting, and design. Character designs are explored early, and as the personalities from the story emerge changes are made in design. The selection of voice talent also influences this design.

The colors, shapes, and sizes of the various sets are chosen to emphasize the emotions and actions being portrayed. Andy's room is very bright, safe and with soothing colors. Lighting conditions vary to simulate times throughout the day, with the dramatic sunset lighting taking place as Woody schemes to knock Buzz behind the desk. In Sid's room, dank and hidden corners dominate a black lit prison. Notice however, that the lighting keeps pace with Buzz's reawakening. The rain falls during the night as he wallows in self-abasement, but morning light comes and the showers end as he realizes his worth and positive impact on others.

The artists also prepare design documents for every model created. Each item, from the hubcaps on the cars to the mailbox in Sid's yard, is thought out, sketched and dimensioned. The packet of model drawings is sent to a group of model builders, but when the time comes to add texture, dirt and scratches, the artists will once again be summoned.

Reference photos and magazine clippings may supplement illustrations in the model packet, and pointers to movie clips might be needed to clarify what is or is not wanted in some visual effects animation. For some models, especially faces, a clay sculpture is made to be used on a magnetic field digitizing table.

5. Production

The production phase of a film must wait until the creative development reaches an acceptable level of maturity. Because the creation of each shot will require so much work, it's important to have the story fleshed out as completely as possible beforehand. Occasionally a shot may get cut or changed after it has been produced in finished form, but that is rare given the total number of shots.

Models are produced from design packets created by the Art Department, and then placed in sets and dispersed into the proper shots by the Layout Department. Layout feeds the animators, who worry only about motion but not color or lighting. Before shots can progress from animation to lighting, shaders are written and assigned to models. Shaders are the surface textural description of an object, including its color, reflectivity, transparency, patterning, dirt, and scratches.

The Lighting Team is given shots that have been animated, and creates light sources, shadows, and reflections. Once the lighting is finalized for a shot, it is blessed for film rendering at a resolution of 1536 scan lines.

5.1. Modeling

The model builders translate the model packet designs directly into the computer. Some models are created using commercial design software from Alias, and then translated into the in-house *Model* language. Model is a module of *Marionette*, Pixar's proprietary production software environment.

Model builders are responsible for more than realizing the static description of an object. Taking into account the importance of the object, the builder must decide on the set of controls over its articulation. For example, both Slinky Dog and the Jack-in-the-Box mutant toy have a coil spring, but Slinky's has a more complex interface because it must do so much more. The controls of a model, known as *avars*, are described procedurally in the *Model* language.

Some models can be completed in hours, while others take weeks. Woody has 712 avars, counting 212 in his face alone. Muscular control is provided in detail over various parts of the lips, cheeks, and eyebrows. Special software tools exist to assist in the creation of flexible characters.

As models are constructed, review sessions are scheduled with the director, art director, and animation supervisors. Proportion, scale, detailing, and control sets are checked for propriety. Complex models may spend time in animation testing before being released widely.

5.2. Layout

As an inventory of models accumulates, the work of the Layout Department starts to grow. It is in Layout that the film takes its first step from the sketches of story boards to the three dimensional world of computer graphics. Working with Editorial, members of the Layout Department position and choreograph the camera movement relative to the objects in the shot. The transition from pencil to computer can often be difficult, as the realities of scale and perspective reveal liberties taken in the sketches. The overall motion of a character may also be blocked out during layout, especially if such motion must coordinate with a moving camera. Great care was taken to use established techniques governing the use of camera motion. Too many productions in computer animation move the camera simply because it's possible.

Members of the Layout group have many details to remember. *Toy Story* is composed of more than 1,500 shots, and logical consistency must be maintained. The collection of objects into sets is one way to maintain order, and a shot database assists in the task. The visual flow between shots is also a factor, and sometimes adjustments are necessary to make things work. The audience should never notice the camera cuts; they should always feel natural.

5.3. Animation

The role of the Modeling and Layout groups is to provide the animators with shots that are ready for animation. The sets are already provided, the camera view defined, and gross level motion blocked out. When an animator first visits a shot, they can even put on their headphones and hear the audio track as the shot plays on their computer.

Pixar employs an unusual strategy when it comes to the animation staff. Most other companys in the computer animation industry look for people with a certain level of computer graphics literacy, but the attitude at Pixar is to locate individuals who really know animation. They come from a variety of other media, including traditional cel animation, stop motion, clay, and even sand. Producing animation involves projecting personality, expressing nuance and emotion, using timing, staging, anticipation and follow-through. In short, animation is acting by proxy.

The traditional hand-drawn way of producing animation is for an animator to begin by drawing key poses for each character in a shot, roughing out the extremes and flow of the motion. The key poses derive from an *exposure sheet*, a breakdown of the action in the shot, and a *dope sheet*, a written indication of where the words and stress fall in the dialogue. A cleanup artist then inherits the shot, redrawing the key poses while making sure they conform to the established look of the characters. After adding some in-between drawings, they pass on the work to animation assistants, who complete drawings for each of 24 frames in a second of film. The process requires up to thirty people to complete a single shot; by contrast, all of *Toy Story* was completed by thirty animators.

Animation on computer is completed through a series of refinements. The rough motion inherited from Layout at the start is refined and adjusted to include broad gestures necessary to convey the intended message. Unlike traditional animation, where key poses are specified for an entire character, animators on a computer can structure overlapping key frames for different parts of the body at different frames in the shot. As the animation takes shape, more subtle secondary and tertiary motions can be layered above the primary action, which are then completed by facial gestures.

Another benefit of working on a computer is that the animators need not concern themselves with consistent drawing styles and proportions. At any point in time, an animator can see and hear their shot running in real time.

5.4. Shading

Models enter the shading department devoid of visual character. It is the shading department's job to settle on a look and realize it through the technology and capabilities of Renderman. Working from a shader packet assembled by the art department, the model is analyzed. What type of object is it? Is it old or new? Is the material reflective, or does it just carry a sheen? This process is straightforward, since the shader packet contains much of the information as written notes and photo reference. The first step is to assign basic surface colors for the object. Afterward, the shader author separates the surface details into layers, each layer a specialized procedure which adds to the final surface appearance.

The shader on Sid's window ledge is a prime example of layering. In order to provide the withered, old look that has been painted multiple times, it is divided into more than five layers: a layer for the wood grain, a hand painted layer to indicate where the base coat of paint lies, another painted layer to describe where this paint is chipped and scratched, more layers of paint for color, and finally, a layer of dirt and scratches to provide the aged affect.

In addition to describing the surface layers, the lighting model is encoded in the shader. The lighting model describes a surface's shininess and reaction to lights, and may be as simple as plastic or as complex as satin. At its completed stage, a shader will have anywhere from ten to two hundred lines of code to accurately describe its surface under a variety of lighting conditions.

The shaders in *Toy Story* also made extensive use of displacement shaders, which describe physical variations in the surface. Grass, for example, requires a massive amount of geometric detail and is ill suited to a polygonal or surface patch description. As a shader, however, it requires significantly less data to describe its shape, form, and variation. It also has the advantage of knowing how large the grass patches' projection becomes in screen space, and can automatically vary the amount of detail.

Another example of a displacement shader is the comforter on Andy's bed. For each step taken by a character, the shader determines how deeply the character intersects the bed and perturbs the surface downward matching the shape of the foot. This could have been done by animating physical deformations of the bed, but it would have required building a highly complex representation of the bedspread, especially to achieve the folds emanating from the footprint.

As more objects are given surface attributes, a library of useful shaders and functions begins to emerge. Special utilities are provided for projecting dirt and other texture paintings.

5.5. Lighting

When a sequence enters lighting, the placement of the camera and the animation are complete. The master lighter begins by meeting with the director and art director to discuss the sequence. Together they identify essential story points from the animation, color script, and story reels; they may also discuss relevant technical issues. With these as guides, the master lighter defines key lights in the set to establish the basic lighting environment for the sequence. Once this is in place, individual shots can be assigned to other members of the lighting team. Their job is to take the initial lighting scheme and refine it for their given areas.

The work done during lighting can be likened to ink and paint in traditional animation. Drawings done by the animators are painted on clear acetate cels and filled in with carefully chosen colors. Dark and light areas are defined to help lead the eye to the action. The difference is that in computer animation the visual complexity that can be achieved is so much higher than in traditional means.

Members of the lighting teams need to be concerned about lighting continuity, color, and brightness. Given the extreme freedom of altering lighting conditions on a pershot basis, it is tempting to beautify individual shots at the expense of consistency across a sequence.

Since *Toy Story* was produced in three dimensional computer graphics, setting up lights becomes very similar to the same task on a live filming stage. A key light provides the primary high-contrast contribution, added to a softer fill light, and with rim lights to help define the shape and produce additional highlights.

Even so, physical correctness in lighting is often less important than aesthetics. To achieve this, the behavior of light sources and surfaces are often cheated. Marionette and Renderman are very flexible in the kind of lighting they can provide. This includes the ability to alter the shape, softness and extent of a light, or to allow the light to shine only on specific objects. Shadows can be placed independently of their casting lights, or reflections can be altered to suit an artistic purpose. Throughout the lighting process, the challenge is to make the scenes look real, but with the visual richness that is not necessarily limited by realism. Since each shot is on-screen only briefly, its effectiveness depends on how quickly the viewer's eye is led to the key story elements. Lighting is one of our most effective tools for achieving this. By the use of lights, images are painted with areas of light and dark, cool and warmth, and hardness and softness. The interplay of these elements is indispensable in bringing out the focal points of the story.

5.6. Visual Effects

There were a relatively small number of shots in *Toy* Story that had requirements outside the normal pipeline. These shots had various visual effects animation on top of the other action, some examples of which are rain, sparks, smoke, exhaust and explosions.

The visual effects animation falls outside the expertise of the animators because achieving the proper look involves too much technical ability. Those producing the effects need to have a solid understanding of all phases of the pipeline, as everything from modeling to animation to shader writing to lighting must be addressed, often in an experimental loop.

The visual effects were often done after the main scene lighting, but just prior to submission for film rendering.

5.7. Production Software

Pixar uses mostly proprietary software for it's productions, with the exception of some modeling done in Alias and digital painting done with Amazon.

Marionette is Pixar's software system for modeling, animation and lighting for computer animation. Marionette is the primary software tool used by every animator and technical director at Pixar. In contrast to many commercially available animation systems which are designed to address product design, corporate logo graphics or cinematic special effects, Marionette has been designed and optimized for character modeling and animation.

The animation subsystem of Marionette is designed to be accessible to users with limited computer experience, allowing Pixar to hire an animator based entirely on artistic skill. At the same time, Marionette has powerful functional foundations that allow a more technically proficient user to take complete advantage of the system. In Marionette, models are programs in a specialized programming language. A technical artist can use the power and flexibility of this language to create models that move or deform in very complex ways, or can build control structures into the model that make it easier or faster to animate. Most animation systems represent models as sets of data separate from their animation controls. Changing the paradigm makes it easier to tackle a project as large as a feature film.

Pixar also has a data organization system in place called *Ringmaster*. Given the number of shots, models, and people

in a project the size of *Toy Story*, reliable data management is a must.

The first element of Ringmaster is its relational database, which is constantly updated with all aspects of production. It maintains inventories of models, textures, and images. Using this database, Ringmaster routes rendering requests to available machines on the *RenderFarm* and maintains appropriate status information. Once a rendering job is completed, Ringmaster continues the process by invoking the compositing of layers to produce a finished image.

Ringmaster also works with the Accom digital video recorders and the film recording software and hardware, helping to provide a more fully automated environment.

5.8. Production Hardware

Each animator and technical artist is provided with a Silicon Graphics workstation on their desk, typically an Indigo2 loaded with between 96 and 256 megabytes of memory and up to 2 gigabytes of local disk space. Every animator is also given a dedicated Bandit frame store device, and those producing high quality images can record them on one of four Accom digital video recorders. Two Solitaire film recorders transfer electronic images onto 35mm film. Film is viewed in the company screening room, complete with couches and the central command reclining lounge chair.

An arrangement with Sun Microsystems provided a *RenderFarm* of over 300 processors on the local network, combined with several Silicon Graphics *RenderFarm* machines. As personal workstations begin to sit idle, they are drawn into the pool of batch processors.

Disk resources are equally vast, with a *DiskFarm* of around 260 gigabytes of on-line storage containing approximately 140,000 digital image files.

6. Post-Production

The last phase of producing *Toy Story* occurred after the film left Pixar. At Skywalker Sound, sound effects were added and mixed with the final musical score. Final prints are made of the film after adjusting to get consistent color across all the prints. These are then distributed to the theaters.

Pixar's post-production is simpler than post-production of a live-action film, which requires more significant editing. In most live-action films, many hours of film are shot, and the film is then significantly edited and re-edited in the post-production phase to create a feature film. Pixar, like other animation studios, edits the film throughout the entire creative development and production process. Thus postprocessing involves only final editing.

7. Conclusions

The day is now here when it is feasible and cost effective to produce a feature length motion picture entirely on computers. The commercial success of *Toy Story* confirms the message long proclaimed by Pixar; that the important elements of filmmaking are story and character, and that people will come to see a quality film.

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