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TOY STORY: A TRIUMPH OF ANIMATION

BY BARBARA ROBERTSON

Pixar's dream becomes reality as it puts the finishing touches on first full-length, all-digital movie

Walt Disney Feature Animation will make film history this fall when it releases the first full-length, all-digital movie; the first animation created entirely by artists using 3D computer graphics tools. The movie, *Toy Story*, produced and created by Pixar Animation Studios (Pt. Richmond, CA) and directed by Pixar's Academy-Award-winning John Lasseter, stars Tom Hanks as the voice of Woody, a pull-string cowboy doll, and Tim Allen as the voice of Buzz Lightyear, a space-ranger toy, with music by Grammy-award-winning Randy Newman.

Toy Story will be Disney's big Christmas movie for 1995, the linchpin for Disney's Thanksgiving and Christmas season. Already, the well-oiled Disney marketing machine is in motion: On the walls of a conference room at Pixar are designs for "Toy Story" shoes, chocolate bars with "fun movie scenes on every bar," "happy take-out meal" cartons, and of course, toys. Trailers for *Toy Story* are in theaters with *Pocahontas*, and in video stores with some copies of the live-action *Jungle Book*. And Pixar is already working on its CD-ROM version of *Toy Story*, using the same characters animated by the same animators who did the movie.

Barbara Robertson is CGW's West Coast senior editor.

"For a long time, we said to ourselves, 'this is our first film, don't expect too much,' " says Ed Catmull, Pixar president. "We'd hoped secretly that we'd do really well, but we were modest so we wouldn't get let down. Then we started showing it to people. We got glowing praise. And that took the lid off our expectations. We haven't heard from the reviewers yet, but we feel like we've got something special."

Peter Schneider, president of Feature Animation at Disney, agrees. "In my heart, I know it's a great movie. It is really, really, really funny. And it looks so different."

It *is* different. It's different from other feature animations because of the use of 3D tools, and it's different from other 3D animations because of its depth and breadth. *Toy Story* has a full cast of characters—humans, toys, and at least one dog—a total of about 76 in all, many with speaking parts. The characters move about in a wide variety of sets and locations just as actors might in a live-action movie. They're indoors, outdoors, at home, in cars; we see them at noon, at night, in a rainstorm, under neon lights. In all, *Toy Story* has about 1700 shots, and each shot has been modeled, animated, texture-mapped, shaded, lighted with a combination of proprietary and off-the-shelf computer graphics tools (running primarily on Silicon Graphics workstations), and rendered on rack after rack of Sun SPARCstation 20s—87 dual-processor and 30 quad-processor SPARCstations (294 processors in all) running 24 hours a day in a special room aptly named the "Sunfarm." It's just frame-by-frame animation, but Pixar has, somehow, imbued it with life.

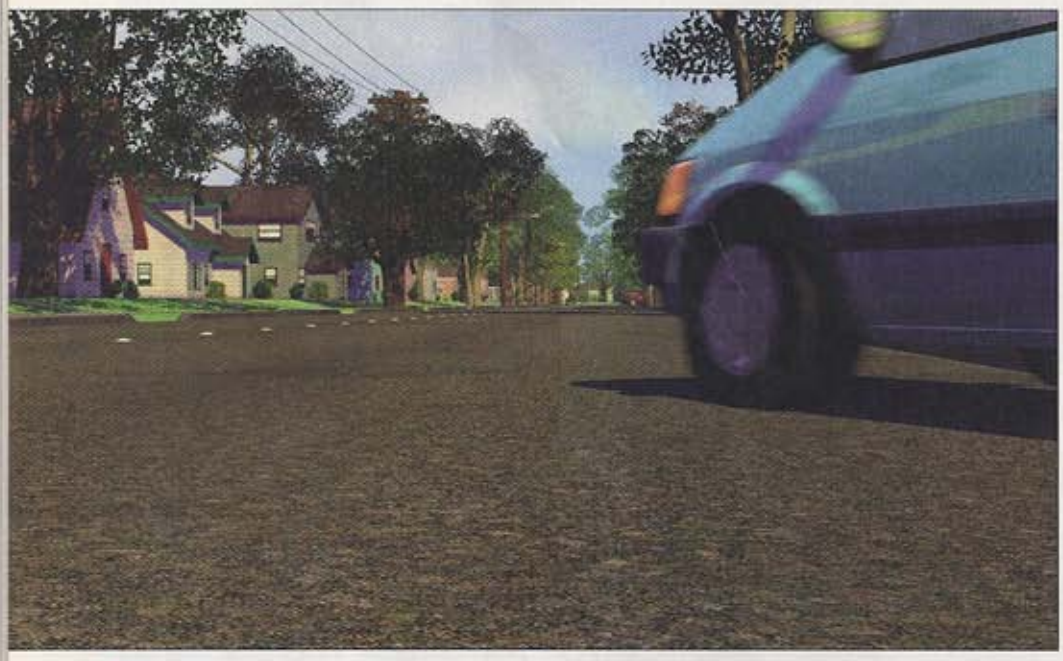
The length of the movie and its two-year-plus schedule have given Lasseter's remarkable creative team at Pixar and Pixar's brilliant computer graphics scientists room to stretch, to show what they can do given more than a 3-minute space to work in. The 110 people now working on the film (including 28 animators and 30 technical directors) have created a world of humans and living toys that's realistic in the way a children's book is realistic, believable in the way a good movie is believable. Andy's

room looks like a kid's room, not a drawing of a kid's room. There are laundry baskets filled with stuff. The bed bounces when Woody jumps on it. There are pictures on the walls and trees outside the window and books on the bookshelf and scuff marks on the doorjamb. And there are toys. Lots of toys.

Toy Story has a richness and level of detail never before seen in a long-format 3D animation. It will set a new standard for 3D animation as did Pixar's "Luxo, Jr." before it. "I'm not an optimistic person by nature, but I'm very proud of this," says Tom Porter, Shader technical director, who has been part of the Pixar team since the LucasFilm days.

For many people at Pixar, *Toy Story* represents the attainment of a goal they've worked toward, as a team, for well over a decade. "We could have gotten sidetracked," says

Surrounded by their supporting cast of toys are the Toy Story stars: space ranger Buzz Lightyear ("I come in peace"), and pull-string cowboy doll Woody ("I'd like to join the posse, boys, but first I'm gonna sing"). Buzz was modeled with Alias software. For Woody, Pixar used its own MenV software, which also provides animation controls, lights, and cameras. Rendering was accomplished via Pixar's RenderMan software running on Sun's multiprocessor SPARCstation 20s.



More than a pretty picture, this toy's-eye view of Andy's neighborhood shows an attention to detail, evidenced throughout the film, that helps draw the audience into the *Toy Story* world and make it believable. Notice, particularly, the hundreds of leaves on the trees, the gravel in the asphalt street, the motion blur on the car.

Catmull, "but through all the years we stuck to our goal, to make a feature-length film. And Steve [Jobs] was willing to fund us while we kept advancing the state of the art." Along the way, they collected numerous technical and artistic awards, including an Academy Award for the short animation "Tin Toy."

"In choosing the [*Toy Story*] story, we were interested in evolving from 'Tin Toy'," says Lasseter, "in exploring further the concept that toys are alive. That basic concept didn't change, but almost every other aspect did."

When you talk to people at Pixar and Disney about *Toy Story*, they quickly point out that no amount of technology will make up for a less-than-stellar story. "I think people don't understand the importance of storyboarding," says Lasseter. "If the storyline works and is entertaining, when it goes into animation it will get better. But if it doesn't work in story reel [the filmed storyboards], it isn't gonna work in final."

In fact, the group stopped production on the movie for two months to get the story right, to make the toys adult without being too harsh, to make the relationships among the characters richer. Pixar had help from Disney in getting the story right and in learning how to work on large-scale projects—notably, from Schneider and Tom Schumacher, vice president of development. And by all accounts, the story, basically a buddy picture, *is* right. "At the end of the day," says Schneider, "people will not review the technology, they'll review the quality of the story, the animation, how much people laugh. John [Lasseter] has a great eye."

We'll leave that to the film critics and ticket-buyers to evaluate. On these pages, we'll acknowledge that storyline is everything, but we'll celebrate the 3D computer graphics—the modeling, shading, animation, camera work, lighting, and rendering that bring the story to life. "The [*Toy Story*] world is a caricatured world," says Lasseter. "The audience knows it doesn't exist, but [with 3D] there is a sense of reality that's greater than with cel [animation].

"People will look at Buzz and believe," he adds. "He has rivets and embossing on his butt that says 'copyright Disney' that's there because my GI Joe had [embossing]. This collaboration of art and technology is absolutely vital. There is believability because of the technology."

First bit of technology, modeling.

Basically, the movie's 366-plus objects (Andy's bed, the minivan, Andy himself, Andy's sister's tea set, etc.) were modeled with Alias software (Toronto) or with Pixar's own procedural modeling environment, MenV (although the dog Scud was digitized from a clay model). MenV, now in its fourth generation, was originally built for Lasseter by technical directors Bill Reeves (who accepted the Academy Award for "Tin Toy" with Lasseter) and Eben Ostby. "I continue to be astonished that it's held up," says Ostby. "We've been pounding on it for close to 10 years."

Details

Today, eight weeks from their completion date in August, Ostby is using MenV to work on a five-block area of Andy's neighborhood. The sequence has already been animated, but the backgrounds aren't quite done. "We set up the neighborhood shot by shot," says Ostby. "If the camera is close to a lot, the lot is 3D. If the camera's further away, we use a simpler representation." Each lot in the neighborhood has its own house, with driveway, landscaping, cars, telephone poles,

Toy Story Teaser

When people aren't around toys, toys are alive. But you already know that.

It is always the toys' greatest fear that they will be replaced by newer toys, and now it's happening—this time to Woody (Tom Hanks), a traditional pull-string cowboy doll whose position as top toy in Andy's life is threatened by the arrival of Buzz Lightyear (Tim Allen), the great action figure with his push-button laser and digital voice and wrist communicator. Buzz not only gets Andy's attention, he's welcomed by Woody's friends, his dog Slinky (Jim Varney), the irascible Mr. Potato Head (Don Rickles), Rex the timid dinosaur (Wallace Shawn), the know-it-all piggy bank Hamm (John Ratzenberger), and his sweetheart Bo Peep (Annie Potts).

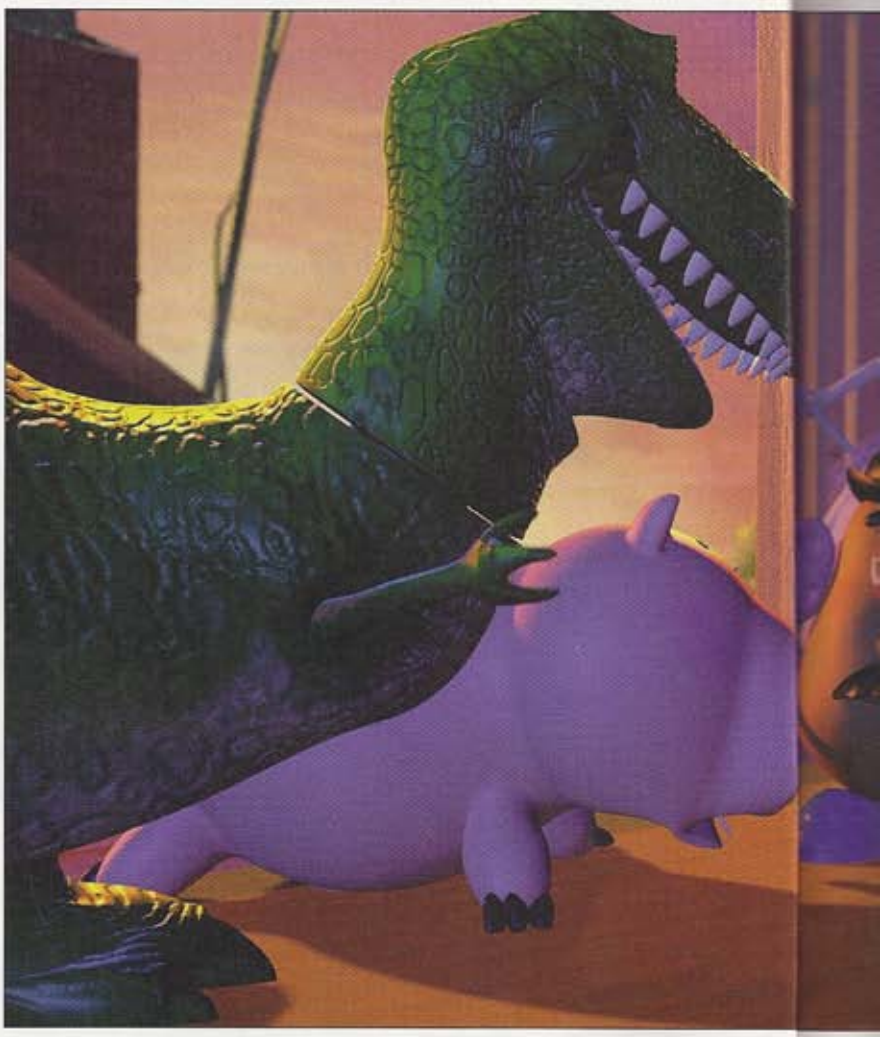
Woody plots to get rid of Buzz (who thinks he's really a fearless space ranger landed on an alien planet, not a toy). The plan backfires, and Buzz and Andy find themselves not only separated but in the hands of the viscious Sid, a sadistic neighborhood kid, and his dog, Scud, who torture toys for fun. And the plot thickens.—*BR*

A Hotbed of Invention

Pixar did not just take advantage of the technology that exists. The company was a major contributor to computer graphics and animation. There was a chain of development that went from the University of Utah, through New York Tech, Lucasfilm, and, finally, Pixar. Through the years, the group grew as it developed technology and invented the algorithms that made computer graphics useful for the film industry.

Among the contributions are:

- Z-Buffer: a technique for determining which surface is visible. This technique is now commonly implemented in hardware.
- Texture Mapping: the technique of placing textures, pictures, or paintings directly onto a surface to add visual complexity.
- RGB Painting: the first full-color paint system, and the first paint system to be offered commercially.
- The Alpha Channel: transparency was built into the image for compositing many images into one. Used in the graphic arts and film industries.
- The Matte Algebra: formalized mathematics for a variety of compositing operations. Used in the film industry.
- Two-Pass Warping: a fast method for rotating, warping, or transforming entire raster images.
- Volume Imaging: images are created from multiple 2D image slices. Used in the medical industry.
- Particle Systems: a method for generating large numbers of small primitives. Used to make pictures of fire, trees, grass, etc.
- The Shading Language: a language for describing the appearance of a surface and its interaction with light. This gives creative control to the special-effects houses.
- Stochastic Sampling: an anti-aliasing technique that has nice statistical properties which allow for solutions to a number of rendering problems.
- Motion Blur: a technique for generating images that are blurred in the direction of motion and is critical for mixing computer graphics with live action. This is the enabling technology for the current widespread use of computer graphics in special effects.
- RenderMan: many of the above techniques were put into a rendering system that is capable of handling extremely complex images. This made computer-graphics practical for motion-picture use.
- MenV: this is the animation system that was used to make "Luxo Jr." and subsequent Pixar animations. This system demonstrated to everyone the real potential of computer animation.

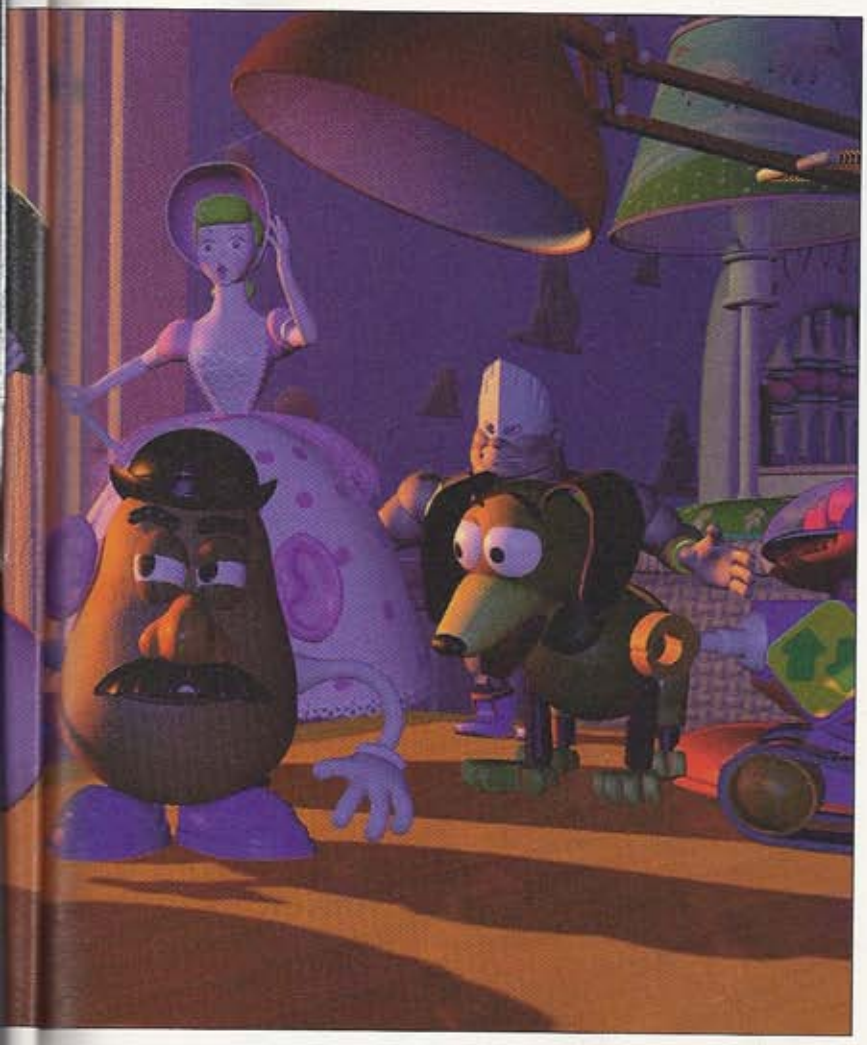


etc. The detail, for close-ups, is astonishing. To create the asphalt for the street, for example, Pixar scientist Loren Carpenter merged several photographs of gravel and sand in such a way that the texture looks random enough to be real. "We used a combination of techniques," says Carpenter. "It's semi-magic." Among them, the merging of color space coordinates using noise functions to perturb the coordinates so they wouldn't be coincident, and a scaling of the texture that changes as the pictures "swim downstream."

For characters, the modelers used Alias software and patch-editing tools in MenV—Alias for characters like Buzz that have a "manufactured" look, MenV for more organic models, like Woody and the humans. With every location, every stage set, every prop, every character in the movie needing to be modeled, the creative team became efficient recyclers—copying and reusing models. For example, they scaled down the dishes in Andy's dining room to create a tea set for a children's party (be sure to look for the teapot). They appropriated, appropriately, many of the mutant-toy parts from previously constructed parts of other toys. They copied body parts from some humans to make new people, changing sizes and proportions to add variety.

Sometimes they created models with incredibly complex detail—Andy and Sid's hair, for example. Other times, they reduced the number of models they might have needed by using shaders instead to add detail—scuff marks on the walls, for example. "It's amazing how big our shaders are," says Reeves. "They used to be a few lines of code. Now some of them are 10 to 12 pages."

"John has a working knowledge



One of the most difficult lighting techniques in computer graphics, backlighting helps separate characters from the background. When artists take CG lighting beyond the typical CG spotlights and diffuse lighting, they help a director establish mood, as this image of Bo Peep, Rex (the timid dinosaur), and other toys late in the day illustrates.

of everything. He well knows when you can do something better," says Porter, as a slow smile crosses his face. "He thinks nothing of putting a camera on a 3-inch-high toy on the run across a throw rug in Andy's room. Making shaders sufficiently complex to handle close-ups has been a challenge.

"One of the real differences in doing a movie rather than commercials is that there are a lot of approvals," he adds. "John and Ralph [Eggleston, the art director] approve the look of everything on a daily basis. If there's a decal on Buzz that has three colors, Ralph is ready, willing, and able to balance the colors."

Shaders, which describe surfaces and define how the surfaces react to light, were used for general "distressing" for splotches, stains, spills, cracks, divets—to "visually present the disparity between a manufactured look of the toys and a human look," says Porter. To add that "human look," they created a dozen different filth libraries. "It's unrealistic to have a plastic-looking baseboard when you know it's been kicked," says Porter.

"We have painters working here who were used to painting rich backgrounds like you see in cel animations," he adds. "Here they're painting splotches which get incorporated into shaders."

While the shaders help make the backgrounds believable, it's motion that makes the characters believable. First, the layout department places the characters in the background and positions the camera. For camera moves, Craig Good, layout supervisor, chose to use a live-action film grammar rather than computer graphics clichés such as "infinite tunnel shots" and "delirious fly-bys." "We tried to do what we could do on a set with real tripods and cranes," Good says. "We deliberately borrowed shots from live-action directors."

Once there's a sign-off on the layout, the animators begin to perform the characters, to give them life. "I guess we animated around 50 characters," says Pete Docter, directing animator for *Toy Story*. "There were three groups—the main characters and Andy's toys, the mutant toys, and the humans. We saved the humans for last."

Humans, as is expected, are turning out to be the hardest. While there's no attempt to create real people, the people must still be believable as humans and look different from the toys. What Pixar seems to have created is a Sunday-comics type of human. But, having saved this species for last, no one's sure how well they're working yet. "The clothes are really time-consuming," says Docter. "And some humans feel stiff at times. So we've tried to stage shots where we only see feet, hands—humans from a

Creating the illusion that toys are alive required sophisticated rendering as well as animation techniques. These army men are clearly manufactured toys in the process of carrying out a mission (they're going to spy on the humans; the baby monitor will be their communication device). Notice how the rendering of the floor and walls in the background helps you believe these toys live in Andy's house, not in a CG scene.

▲ **Since the mutant toys, which are made of a hodgepodge of parts from other toys, are unhappy, creepy creatures, the animators studied the movement of bugs like spiders and creepy animals like lizards and snakes for ideas.**

toy's point of view."

The animation for all the characters is accomplished within MenV, using animation controls built into the models. "A model builder can set up a model in ways that let animators concentrate on timing," says Ostby. Buzz, for example, has something like 800 animation controls.

"We're using inverse kinematics quite a bit," adds Reeves. "We have a really nice little toolset for walk cycles, for reaching and grabbing, that's simple but solves a lot of problems. We're also using a lot of deformation."

Rather than casting each character—that is, assigning a character to an animator—they tended to assign all the characters in a sequence to an animator. The "dailies" kept everybody aware of what everyone else was doing.

Before animating a toy, the animators looked first at what their toys were made of. "Buzz is rigid and tight," says Docter. "He's ball and socket, purposeful. Woody is a floppy, loose, limp rag doll. The humans are bigger creatures with more weight, so we slow down their movements."

Then, they watched videos of the voice talent reading the dialog and listened to the dialog track "over and over and over." They'd first animate the character's body before doing facial animation and lip sync. "If you can make it work in the body, you won't miss the lips," says Docter.

Finally, they created the facial animation and lip sync. To create the facial animation, each main character was modeled with "pull points" for facial muscles. The animator-performer could pull up Buzz's lips into a sneer, pull down

Woody's forehead into a frown. (Woody has eight controls for his eyebrows alone.)

Now, having had many months of work behind them, they're producing animation at a rate of 3 minutes per week. "At the end of a week, we've done two 'Luxo, Jr.s'," Lasseter points out, "which took us four and a half months to do [in 1986]."

Lighting, at least for this movie, is the final process (before rendering) and, it turns out, may be the most challenging.

"We've never done lighting like this before," says Reeves. "The typical computer graphics scene uses diffuse, office light or has spotlights bouncing everywhere. We have dramatic, moody lights in Sid's room, flashlight stuff, daylight, bright sun. We tried to create all sorts of environments."

In one sequence, for example, a rainstorm creates dark, gray skies with rain pelting a window. A few shots later, light streams through the window as the rain ebbs. "It's hard work," says Reeves.

"If you look at the history of computer graphics," says Porter, "this has been the most challenging. Modeling is not solved, but there are good tools; we're able to write shaders. But lighting continues to be a challenge."

"We hoped for more economy of scale than we got," says Galyn Susman, lighting technical director. "But we still have to light each and every shot."

In addition to defining time of day, lights create drama as they would in a live-action film. Andy's room, for example, has high-key, warm lights to create a happy, friendly, safe place.

"Lights add a lot of visual interest," says Sharon Calahan, lighting technical director. "As in

Toy Story Trivia

Characters: 76
Objects (including characters): 366
Lines of code describing the objects: 4.5 million

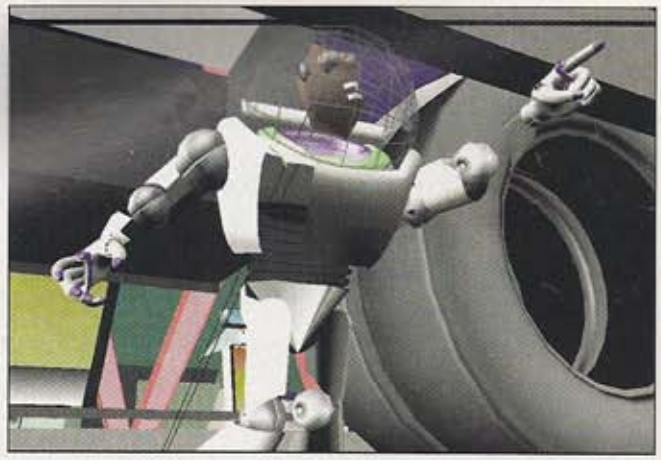
Hairs on Andy's head: 12,384
Hairs on Sid's head: 15,977
Animation controls on Sid's backpack: 128
Storyboard drawings: 25,000
Number of people at Pixar working on the film: 110
Number of animators: 28
Number of technical directors: 30

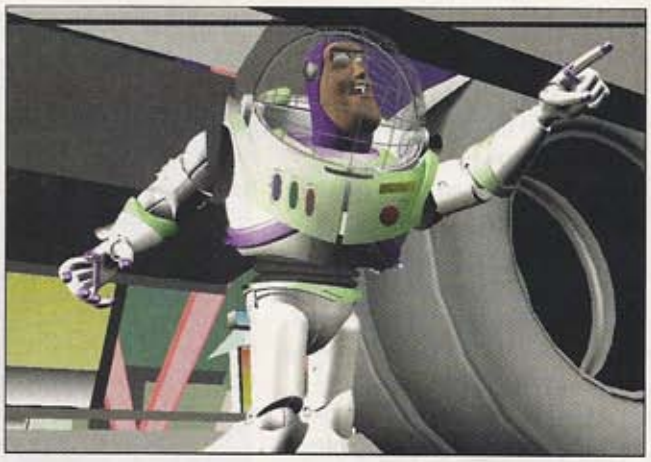
Leaves on a typical tree in Andy's neighborhood: 10,000
Trees on Andy's block: 100+
Leaves on Andy's block: 1.2 million

Number of basic arithmetic operations per pixel: 500,000

Painted texture maps: 2000+ (see "A Hotbed of Invention" sidebar)
RenderMan Shaders: 1300 (see "A Hotbed of Invention" sidebar)
Most complex shaders: human skin with as many as 10 separate texture maps applied to each patch of skin to control such detail as freckles, blushing, facial hair, oil, and wrinkles
Amount of RenderMan data files to be sent through the renderer: 34 terabytes

Total storage for final frames: over 500GB
Resolution per frame: 1526x922 pixels
Number of minutes: about 75





▲ **Obviously, Buzz is a complex model, as these images aptly show. The basic polygonal Buzz (left) is useful in the layout stage for character placement in a scene. This action scene places Buzz beneath a human-size vehicle. When his helmet is rendered, it will reflect the world around him, a requirement that caused the technical crew—notably, Rick Sayre—to incorporate a ray-tracing look in RenderMan. In all, there are more than 1500 RenderMan shaders and 2000 painted texture maps in *Toy Story*.**

live action, the director of photography lights faces to make them look their best. It's the same in our scenes."

The lights can also hide flaws. If, for example, Lasseter is not pleased with the final versions of the humans, you might see some humans in shadows, since the lighting crew can relatively easily place individual lights (including dark lights) on individual characters.

It's the inability to place lights interactively, however, that will drive the creation of a new set of tools for the next movie.

"We put a lot of energy into facial animation tools for *Toy Story*," says Susman. "For the next film, we've decided to put more into lighting tools."

"It's a great goal to do something not done before," says Lasseter. But because it has not been done before, we have to make it up as we go."

Thus, Pixar is inventing not only the art and technology of making a movie but also the process. "This is much bigger than 150 commercials," says Karen Robert, who worked with Heidi Stettner and Peter Nye to create a tracking system for the production. The system contains every bit of information about the movie, starting with the digitized storyboards—and everyone uses it.

"When we got started, we analyzed the process and found that it's somewhere in between cel animation and live action, but at any one aspect it is in a different space," Lasseter says. 3D is like live action in lighting. The story and design are like cel animation. "We found ourselves acting more like people doing an operating system," says Porter. "We had to consider the impact of changes and keep track of versions of things." Take that decal on Buzz, for example, with its colors carefully balanced. "There's no way you can write a surface that can handle any lighting," Porter explains. So, what happens if, after a couple dozen shots of Buzz-with-decal were approved three months ago and are on their way to film, you notice in a new scene the decal has a glossy highlight that's clearly incorrect? You keep track of the new version.

"The job of animators and technical directors hasn't changed much [compared to short animations], but production management has," says co-producer Ralph Guggenheim. "I have a brand-new appreciation of how little we know, compared to Disney, who really knows."

"Disney took a risk and it was a risk well worth taking," says Catmull.

"About five years ago," says Schneider, "we decided there's more than cel animation and started looking for animators who were the best in their business." The first collaboration, with Tim Burton, resulted in the feature-length stop-motion animation *Nightmare Before Christmas*.

It was Lasseter who attracted them to Pixar. "John's storytelling, his filming," says Schneider. "We trust him."

Says Porter: "It's definitely an overstatement to say this is John's movie, but the fact is, he's the only person in the universe who could have directed this movie. I can't imagine having someone who doesn't understand what a shader is all about direct a CG film."

"Everybody is talking about the integration of Hollywood and Silicon Valley," says Catmull. "We've pulled it off. Pixar Animation Studios is the merger. *Toy Story* is the first digital movie. While we were the ones who invented the technology, more significantly, at Pixar the computer scientists and the animators are peers. This is what the merger is all about. We've done it. And our next film looks even better." CGW