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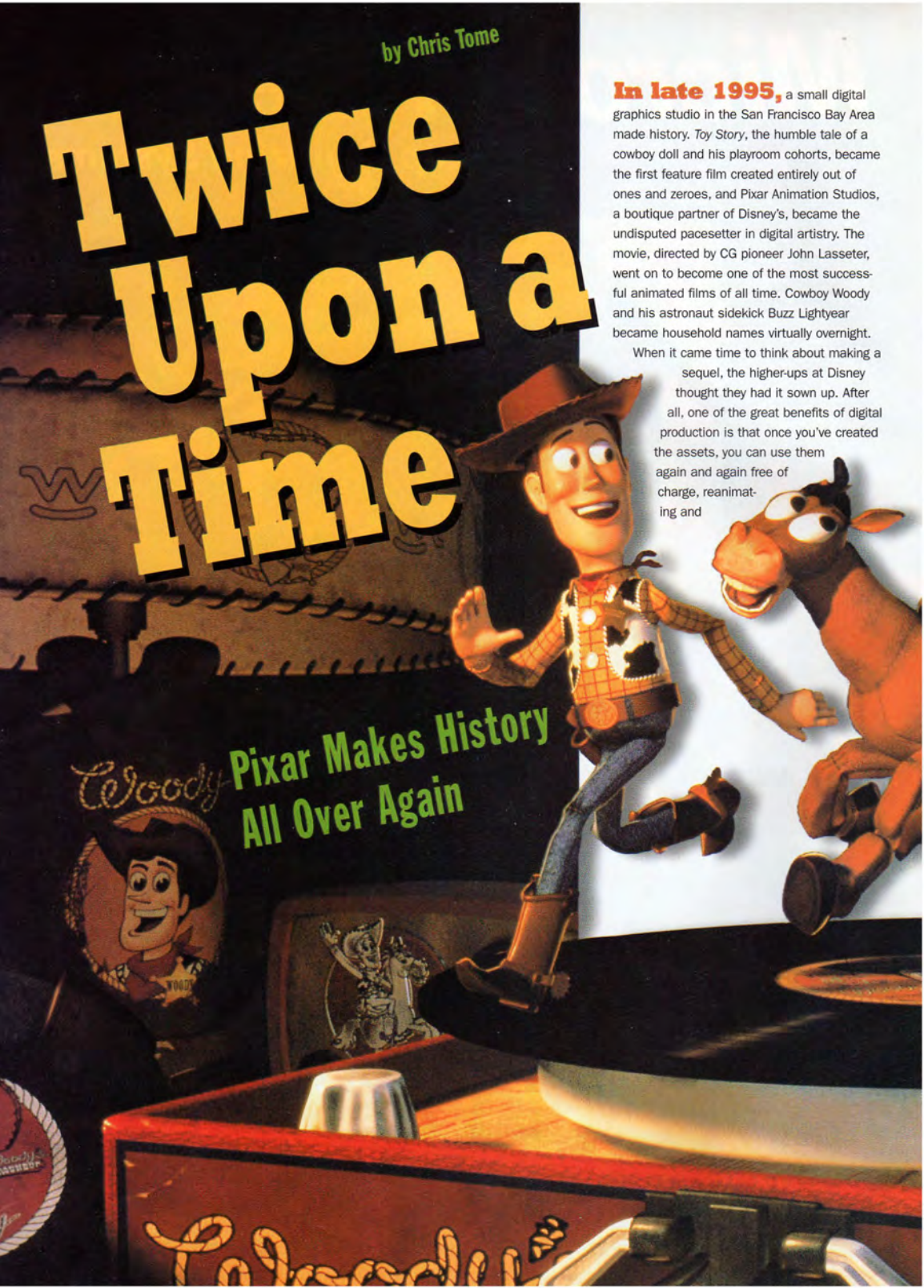
by Chris Tome

Twice Upon a Time

Pixar Makes History All Over Again



In late 1995, a small digital graphics studio in the San Francisco Bay Area made history. *Toy Story*, the humble tale of a cowboy doll and his playroom cohorts, became the first feature film created entirely out of ones and zeroes, and Pixar Animation Studios, a boutique partner of Disney's, became the undisputed pacesetter in digital artistry. The movie, directed by CG pioneer John Lasseter, went on to become one of the most successful animated films of all time. Cowboy Woody and his astronaut sidekick Buzz Lightyear became household names virtually overnight.

When it came time to think about making a sequel, the higher-ups at Disney thought they had it sown up. After all, one of the great benefits of digital production is that once you've created the assets, you can use them again and again free of charge, reanimating and

rerendering the models as many times as you want. To *Toy Story* Infinity and beyond!

The suits had another thing coming. During the intervening years, Pixar had poured its steadily advancing technology and experience into *A Bug's Life*, a second all-CG feature presentation whose imagery was a quantum jump beyond that of its predecessor. "They thought, 'We can approach the whole planning of the sequel as if it were *Toy Story*,'" recalls Galyn Susman, supervising technical director. "I said, 'We're coming out a year after *A Bug's Life*. That's not going to be good enough.'"

After endless rounds of meetings, Susman's point of view prevailed. When production began in earnest in early 1997, the central challenge became incorporating new technology and techniques while maintaining the look and feel of the original movie. As one artist involved in the project observed, "Inevitably we've gotten better at what we do, but on the other hand, we didn't want to create a completely different world no one would recognize."

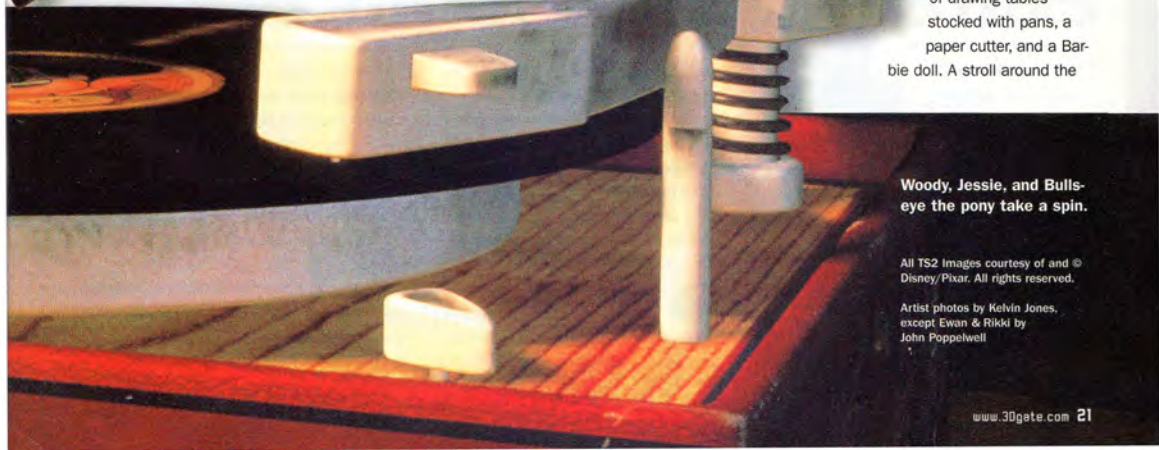
Today audiences the world over are revisiting Woody's world and seeing it anew. Once again directed by Lasseter, *Toy Story 2* presents a rich CG universe with believable characters, detailed textures, exquisite lighting, and stunning camerawork. All the original characters are back, along with original star voice talent such as Don Rickles and Tom Hanks. In addition, Pixar concocted a gaggle of new ones, among them Woody's trusty steed Bullseye; Al, a portly vendor of used toys; Wheezy, a rubber squeeze-toy penguin; and Jesse, a saucy cowgirl doll and love interest for Woody.

As described by coproducers Helene Plotkin and Karen Robert Jackson during the final stages of production, the story begins when, during a bit of roughhousing with young Andy, Woody's arm becomes torn. The damage relegates him to a dusty shelf with other broken toys such as Wheezy, whose squeaker emits only a dull wheeze. Bad turns to worse when the injured cowboy finds himself in a yard sale and becomes property of Al, who sells used toys to collectors - collectible status being the kiss of death for any playful toy. To his surprise, Woody learns that he is part of a designer collection, the other members of which he comes to recognize as his real family. A daring rescue brings the film to a fitting climax.

Toy Story 2's thematic underpinnings of mortality and belonging probe emotional territory rarely occupied by animation. Charting it was the work of Dan Jeup, who served as story supervisor. Storyboards created by Jeup and his team were assembled into animatics by layout supervisors Rikki Cleland-Hura and Ewan Johnson, who determined the role of shot composition and camera motion in telling the story. Meanwhile, associate technical director Larry Aupperle worked on modeling and rendering techniques, and directing animator Dylan Brown and his team brought it all to life. Then shading supervisor Brad West upgraded old textures and created new ones with help from associate technical director Oren Jacob and numerous others.

Tell Me a Story The halls of Pixar's main building are named like streets; walking from one office to another, you pass Rue de Pixar and NURBS Lane. The corridor walls, each painted in a different color, give the hallway a kaleidoscopic effect. They're covered with production artwork, including mattes and storyboards for *A Bug's Life* and other productions.

Even this feast for the eye pales compared to the Story Room. The walls surrounding this sizeable office are covered with bulletin boards to which are pinned a patchwork of storyboard panels. In the middle sits a cluster of drawing tables stocked with pans, a paper cutter, and a Barbie doll. A stroll around the



Woody, Jessie, and Bullseye the pony take a spin.

Artist photos by Kelvin Jones, except Ewan & Rikki by John Poppelwell

room's perimeter serves as a self-paced guided tour of *Toy Story 2*, and that's roughly how it functions for the artists, animators, and technicians throughout production.

When Dan Jeup first joined the project as story supervisor, the basic idea for the movie was in place, but not much else. A graduate of California Institute of the Arts, Jeup spent six years at Disney in various departments before being offered a position at Pixar by Joe Ranft, head of story for the original *Toy Story*.

Jeup's first task was to critique Lasseter's initial ideas. He wasn't alone in this role; all members of the story team contributed, pitching in ideas about story structure, defining characters, acting out scenarios, and so on. Ideas were revisited time and time again, refined until everyone was satisfied. The team averaged five members, but as the schedule grew more urgent, it swelled to 22. Fortunately, some among them had worked on the first movie, helping achieve the necessary continuity.

During his years at Disney, Jeup gained a keen appreciation of traditional story structure. "In any movie, story, or play, the main protagonist has some kind of problem, and he or she (or it) needs to overcome it," he explains. "As you go through the structure of the film, he faces obstacles and overcomes them, and he changes as a result. By the end of the movie, he overcomes his problem, and you wrap it all up with a happy ending. It comes down to what you're ultimately trying to say with that character."

What was the story team trying to say with Woody? "The film touches on Woody's feeling that he could possibly grow old one day, and what happens to a toy when that occurs," Jeup explains. "He has to face issues of abandonment and growing old."

Above: Ewan Johnson (left) and Rikki Cleland-Hura, layout supervisors. Right: Galyn Susman, supervising technical director.

One set of storyboards on the wall depicts the sequence in which Woody is put on the dusty shelf and meets Wheezy. While many of the boards were collaborative efforts, these were Jeup's own. It's rare to own a sequence, though. Almost every artist works on almost every sequence in the end. If a better idea comes along, it sticks. As Jeup puts it, "You kill your babies and move on."

Assembling Animatics The *Toy Story 2* storyboards moved on as well, landing on the desktops of layout supervisors Rikki Cleland-Hura and Ewan Johnson. "Layout is where the shots begin to exist," Cleland-Hura explains. "This is the first time a director sees the world that they've dreamed up." Her background is in computer engineering and game development. She came to Pixar in 1996 as a lead engineer on the product design team in the now-defunct interactive division.

"We figure out how to direct the viewer's eye," Johnson adds. Having studied photography and printmaking, he joined Pixar as a layout artist for *Toy Story* in 1994.

Once a minor step in the production pipeline, layout has flourished into a critical creative process at Pixar. In practical terms, it involves assembling the digitized storyboards into story reels, more commonly known as animatics, a moving representation of the still sketches. The layout team, which varied widely in number depending on the workload, met with Lasseter and the other directors to discuss each sequence in detail, including the overall goal, sets, blocking, and so on. Then they tackled each shot one by one, hammering out the details and delivering all the variations that were requested, along with a few of their own.

Once they were approved, the story reels were sent to the editorial department, where they were sequenced and dubbed with dialog and music to produce a mockup of the final product. Since the actual voiceovers frequently didn't match the timing of scratch tracks used during layout, this turned out to be a creative process as well. Editorial sent some shots back to be reworked, and they edited others extensively before the animatics were finished.

"In addition to that," Cleland-Hura adds, "because we're a computer animation studio, we set up all the shots as files. We get everything ready for the animators, putting the characters where they should be and adding the visual cues they need to understand what needs to happen in each shot." For example, for a shot in which Woody walked across a room, the layout team provided a file in which Woody slid from position to position, the first step in animation blocking.

Animatics and animation setup notwithstanding, the layout team's most apparent contribution to *Toy Story 2* was camera motion. The storyboards, Cleland-Hura points out, focused on conveying plot and emotion. "Our focus," she says, "was storytelling through the camera."

"It's akin to a live-action metaphor," Johnson continues. "You figure out what story you want to tell, then you design the shots you're going to use to tell it." He describes a scene in *The Silence of the Lambs* in which the psychiatrist Dr. Chilton inspects villain

Hannibal Lechter's room. "He's walking around and Hannibal is tied up and he has the mask on. Then Chilton looks at the bed and you see the pen. The camera cuts back to Hannibal, cuts back to the pen, and that's it—you know the pen is going to play a role in the story. This was not acting. This was just the camera."

One of the luxuries of using a virtual camera is the opportunity to execute moves no real-world camera could make, but this is discouraged at Pixar. "Our general philosophy is to use motion that feels like it could happen with a real-world camera," he explains. "Nonrealistic camera motion can really ruin a story for people. It makes them look at the movie instead of paying attention to the characters. But occasionally we'll resort to it to push home a point."

What if the point fails to get across? "There were times when what we thought would work didn't work at all," Cleland-Hura admits, "Then we'd hammer it out by trial and error, or by shooting a lot of coverage and giving it to editorial to see what they could come up with."

Nonetheless, she takes special pride in the subtlety of camera motion in *Toy Story 2*. "I think we did more in this film than we have in the past," she says. "We've got this really hard, fast, dynamic action stuff, and then we have beautiful slow moments. We did it all in one film, and we did it supporting the story."

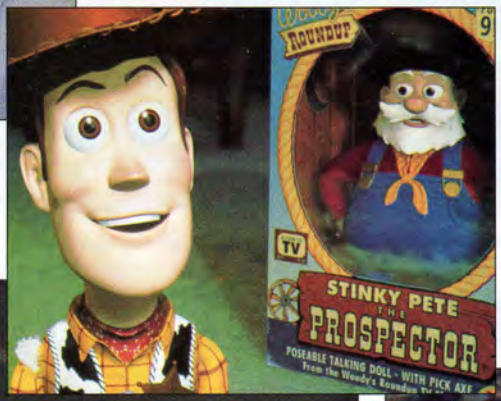
Character Design While Cleland-Hura, Johnson, and the rest of the layout team were piecing together the narrative, the modelers were busily assembling the cast. It seemed simple enough to reuse the original character models, so they assembled the new characters first.

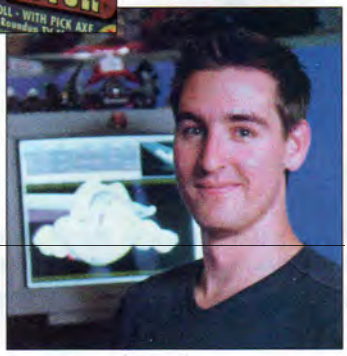
"The new characters looked fantastic," Susman recalls. "Then we looked at Woody, and he looked like old technology."

The difference became apparent with the completion of Stinky Pete the Prospector, one of the toys in Woody's designer collection. According to Larry Aupperle, associate technical director and self-described "third banana to the technical director," the cloth of Pete's shirt was rendered in such detail that Woody's clothing looked artificial in comparison. "We had to update Woody to a level that would be acceptable with the new stuff," he says, "but we couldn't go so far that people would think Woody's clothes had changed."

Aupperle's specialty is secondary motion. "Someone else will make a pant leg," he says, sitting in a small office festooned with cowboy lariats. "But what I'm interested in is how the pant leg folds up on itself." His goal was not physical accuracy, but the appearance of physical accuracy. "In many cases," he observes, "physical accuracy is not art-directable, and it just doesn't look right." Aupperle was bitten by the CG bug while attending his first SIGGRAPH meeting in 1989 as a Ph.D. candidate at Princeton; immediately he set about writing his own ray-tracer. He joined Pixar's commercial division five years ago just as *Toy Story* was entering the final stages of production.

The process of designing Al, over which he presided, was typical of Pixar's general approach to creative work. First the art department came up with sketches. Then Aupperle and his team watched footage of overweight people, paying special attention to secondary motion of jowls and the like. It was decided that Al would be more portly than fat, so they slimmed him down a bit based on photographs of Pixar's heavier employees. "We had to make it clear we weren't trying to insult them," Aupperle shrugs. Al's beard and balding head benefited from dramatic advances in hair rendering. "That's something we had lots of problems with in the original *Toy Story*," Aupperle recalls. The new technology, he says, is " basically a lot of little hairs. The cleverness is in being able to distribute them on a surface





Associate technical director Larry Aupperle (above) and directing animator Dylan Brown (far right). Big Al (bottom) is excited about his hand, and Woody (right) is wide-eyed next to Stinky Pete.

where they're artistically desired and keeping them so you can render in a reasonable amount of time. The rest," he adds, "was sweat."

Al's form made intensive use of subdivision surfaces, a Pixar technology that smoothes objects interactively and allows for adaptive level of detail (LOD). In fact, everything except his watch and glasses were built of subdiv surfaces. "We throttled back a bit on the dynamic nature of it," Aupperle says, in comparison with *Geri's Game*, a short film in which the technology made its debut, "simply because it's a matter of control."

The characters in *Toy Story 2* had many more control handles, or avars (animation variables), than their predecessors. Al, for example, had four avars just to control the movement of one eyebrow. But additional avars were only part of the difference. Equally important was the fact that they were organized in a more hierarchical fashion, which made the characters easier to control. "As an animator," Aupperle remarks, "you shouldn't need to know how it works—just that it does."

Unconstrained Motion The heart of Pixar is an area known as the Pit. The Pit looks like a cross between a corporate cubeland and an amusement park—the closest thing to the back lot, perhaps, in a studio where the sets reside in computers. A circus big top hangs overhead. Some cubicles are outfitted with castle walls built of styrofoam bricks, others with rattan roofs and potted palm trees. Inside the cubicles themselves, shelves packed with action figures complement SGI Octanes and Indigo 2 Extremes.

From his lair in the Pit, directing animator Dylan Brown oversaw *Toy Story 2*'s animation. Although he animated some shots, most of the job was managing the animation effort as a whole and putting out fires. His behind-the-scenes responsibilities included testing models and animation chains and making sure the animators got what they needed from the layout department.

Brown became obsessed with computer graphics while he was in college in the late 1980s. "I got all the information I could, which was pretty sparse at the time. Then I discovered Dennis Muren and said, 'I want to do what that guy does!'" Roughly a year and a half into San Francisco State's computer animation program, he signed on for an internship in Pixar's interactive division, from which he was plucked for a 10-week intensive training program in animation. Since then, Brown's education has been on the job, animating the bird in *A Bug's Life* and the "outtake" in which Flik stands on a dandelion and proclaims, "To infinity and beyond!"

The models for *Toy Story 2*, he says, were fairly lean and straightforward in comparison with those for *A Bug's Life*, which were much more complex due to the vagaries of insect anatomy. All the models from the first movie were converted into subdiv surfaces. "They didn't look any different," Brown observes, "but you can do a little more with them."

"It's a challenge to rework an established character," he continues. "Suddenly, you're able to rethink the controls. You have to decide how much of that to do and how much of the original structure to preserve, because you don't want the character to change in appearance and motion. It has to remain true to the original, so the audience has a sense of familiarity."

Generally, layout delivers simple animations that block out the scenes, which Brown modifies as needed. To view his work, he dumps frames to a Windows machine dubbed the Bandit that plays them back at full frame rate. Most shots arrive with the cameras locked off. Moving them

inside the toy chest: a peek at pixar's proprietary tools

One of the advantages of working at a large animation house like Pixar is access to tools tailor-made by staff programmers. Although off-the-shelf applications such as Adobe Photoshop, Amazon, Alias Studio, and Maya Unlimited are used, the core of Pixar's tool kit is a 3D animation package called Marionette.

Running on IRIX, Marionette encompasses virtually all animation functions. "The core system was designed by an animator for animators," Galyn Susman explains. "It allows us to bring in animators with little or no computer experience, and in a short period of time, they can use the system."

Marionette follows a traditional exposure-sheet paradigm. "You have control over every single moveable piece of a character in a timeline," Susman says, "every knuckle or whatever. You attach one hand to the other hand, and when you pull one, the other comes along for free."

Asked to compare Marionette to off-the-shelf 3D animation tools, Oren Jacob recalls an experience he had while teaching Softimage. "One day, a student said he wanted to make his character's belly jiggle when the hips move back and forth. In Softimage, you'd add an IK chain from the spine to the center of the belly button and maybe use a deformation lattice on the belly, but it's very difficult to connect that to the hip controls. In Marionette, you'd just add an avar (animation variable) to the character's belly. The entire model is linked with custom expressions, allowing the animators total control over how one part of a character influences another part."

Marionette disguises expressions as control handles, or avars, for the pieces of a character. "The other things you want to have happen just occur in the model," Jacob continues. "You can direct all the controls into a single important control, which is all you want to get your hands on."

"You don't have to be a programmer, either," Susman adds. "We have articulation tools that allow you to sweep out points and say, 'I want to control these points with this avar, and this is what I want them to do.' You can weight them to respond to the avar in a particular way. But it all looks like a general interactive user interface in any program."

Marionette's output is an executable program that's ready for the next stage of the production pipeline. "You run a script and it compiles everything and puts it into a real program that can be executed," Susman explains. "Once you've got that thing as code, a programmer can take it and write scripts for more functionality."

Dylan Brown sits down at his 300MHz SGI Octane to give a demo. At first glance, Marionette looks a lot like other IRIX applications. The GUI includes a control window, a camera window, and a perspective window. There are also function curve editors and a

isn't common, but the animators do have the ability to change camera placement if they feel it's necessary.

"When a shot comes to me," Brown explains, "it has been in story for a year or two, and in layout for at least two months. It has received a tremendous amount of thought, review, and scrutiny before it even hits my desk."

Problem solving is where Brown feels he had his biggest impact on *Toy Story 2*. One case involved the troll doll, which needed to nod her head to indicate yes and shake her head to say no. Unfortunately, her neck wasn't articulated for motion. Brown's solution was to build a separate model of the head with the necessary articulation and swap it in at render time when necessary.

I refer to this as a hack. "Exactly!" Brown replies. "People use the word cheat, but when you think about it, everything in CG is a cheat. You're faking things like gravity, contact, and all that. The only thing that matters is how the 2D image looks," Brown concludes. "It doesn't matter how you got there."

Painting Surfaces The final look of the 2D image was the responsibility of shading supervisor Brad West. Working with RenderMan, the renderer developed by Pixar and renowned as the best available for movie work, West and his team evaluated the texturing of the original characters one by one. In many cases, they retained the shaders and revised only the lighting. The sets, however, were another matter. "A lot more detail and experience shows through in the new environments," he observes.

Although West and his team used the same version of RenderMan that's available for sale, all the shaders were custom-coded, some by West's own hand. He had written his first shader as a student at the University of Washington. The University has close ties with Pixar, and after he graduated he attended Pixar University—onsite training for interns and new hires about being technical directors—where he learned the studio's production techniques and eventually landed a job.

RenderMan accommodates two main types of shader: bitmap and procedural. To conserve processor cycles—especially at render time—anything that can be done procedurally is. "We always try to make the choice that will get us where we need to go as fast as possible," West observes.

Even when a bitmap shader was used, a procedural component usually was layered on top of it. A bitmap looks like a bitmap, and a procedural map looks procedural. Mixing the two is the best way to get a believable surface.

Human characters such as Al presented

The progression of one shot (from top): storyboard, wireframe, smooth-shaded, and final render.

spreadsheet-style window that holds all of the character controls and keyframes for the current scene. Hotkeys toggle between them.

The spreadsheet's rows represent avars and the columns represent keyframes. Each cell contains the value of a given avar at a given keyframe. If you click on a cell and drag left or right, the number increases or decreases. Alternatively, you can move parts of a character in the perspective window. "I tend to block stuff out in the spreadsheet," Brown explains. "Then I go into the spline editor, where I actually animate."

Brown loads a Buzz Lightyear model. The head alone offers roughly 35 avars. "Including fingers, little facial stuff, and all that," Brown says, "you probably have to animate 300 avars for a shot, depending on the character. The challenge is knowing the right things to move and how to be efficient."

Surprisingly, Marionette doesn't typically use motion constraints. Brown pulls the avar that controls Buzz Lightyear's smile. As he pulls it to an extreme, the smile breaks.

Brown works in camera mode, which offers a low-res, Gouraud-shaded preview. Adaptive level of detail is inherent in the models, so he doesn't have to swap between low- and high-res versions while he's working. When he's ready to go home, he sends the shots to the render farm, which renders film-resolution frames.

Perhaps the best aspect of Marionette is the ability to request the features and alterations you need. If the animators run into a problem, the technical people code a fix quickly. "Improvements are being made constantly," Brown explains. "You'll hear somebody say, 'It would be great if it did this,' and you're like, 'Wow! I can't believe I never thought of that.'"

At the top of Brown's wish list is a real-time preview complete with shadows, motion blur, and all the other details that show up in a final render. Although he believes it will come in time, "I think it will never be fast enough," he adds. "If you can think and it takes a half second for your thought to appear onscreen, it's still not going to be fast enough."

the greatest challenge, and West worked closely with texture painters to achieve the stylized yet realistic look they were aiming for. "The painters looked at real skin," West explains. "Then they painted facial details such as blemishes, scars, and so on. Once we added things like procedural stubble, the combination looked very real."

In RenderMan, a light is just another shader. In fact, only one light shader is available, "but with a billion controls," many of which were added during the making of *A Bug's Life*. Some scenes look as though they utilized radiosity, but RenderMan doesn't do radiosity or even raytracing. Instead, the effect was created using environment maps. "If you have, say, reflective metal," West explains, "it will look like metal, but it's not nearly as processor-intensive as raycasting accurately."

Asked about the configuration of the Octane sitting under his desk, West had no idea. "We care more about the render farm," West said, "and I don't even know the stats on that. A lot of what we do here is write code using a text editor. As long as that works, I'm happy."

Rendering Challenges Even when everything works properly, the results aren't always as they were envisioned. When that happens, a production heads into the uncharted territory of trial and error. *Toy Story 2* had its share of such moments. One occurred during the rendering of the scene in which Woody meets Wheezy the broken squeeze-toy penguin on the dusty shelf where Andy's mother puts broken toys.

The shelf is a place that doesn't get much attention, and the dust has built up into a thick layer. Associate technical director Oren Jacob test-rendered the scene using dust algorithms cooked up by Pixar's technical crew. Unfortunately, it didn't look quite right. "John wasn't quite happy with the way it was going," recalls Jacob, who joined Pixar as an intern nine years ago while he was a student at the University of California's Berkeley campus. "I didn't know what to do about it."

The dust rendering software involved a RenderMan technique known as dynamically shared objects. In this case, the objects were minute hair primitives, the same ones used to make Al's beard. The hair primitives were mapped to spheres controlled by a particle system, but instead of drawing each sphere, the renderer substituted a number of hair primitives.

Jacob tried rendering with larger particles and particles of different characteristics, but nothing seem to improve the result. "Finally," he recalls, "somebody said, 'Why don't we use, like, 100 times the number of pieces of dust and see what happens?'

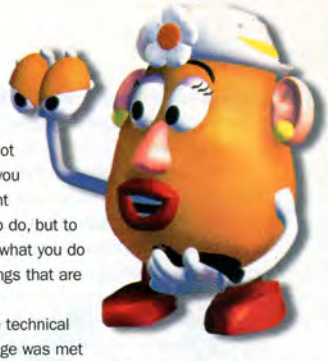
They went back to the computer and added more dust. First they rendered 10,000 particles, but it didn't make much of a difference. They bumped the number up to 100,000, and things seemed to improve. So they tried 500,000, then two million, then four million dust particles.

"We kept going until we found the look we wanted," Jacobs says. "It wound up being 2.4 million particles total. We spent a week figuring out how to do it, and in the end, it was just more of the same. It was a simple solution, but it took a week of very strained thinking."

For Jacob, this experience encapsulates both the best and the worst aspects of working on *Toy Story 2*. "When you try and don't get it right, and you're not seeing what the director is seeing, that's the worst part," he says. "When you go back and get it right, that's the best."

Life in a Playground In the broadest perspective, the challenge of making an all-CG feature film is twofold. One aspect is creative: imagining and creating every detail of a world. The other is technical: organizing a production pipeline in which, unlike a live-action production, changes can be made at every stage at any time.

The key to the creative challenge is in the hands of the director. Lasseter dealt with it by distributing responsibility throughout the entire team. As Rikki Cleland-Hura puts it, "John's philosophy as a director is that he's there not to tell you the right thing to do, but to find in what you do the things that are right."

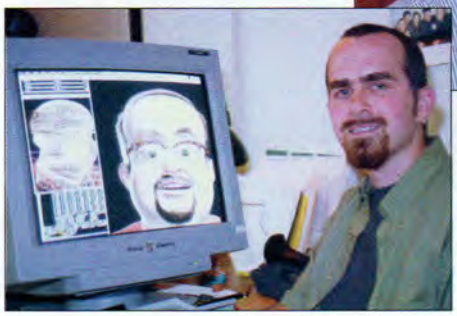


The technical challenge was met through an emphasis on communication, which Oren Jacob refers to as "one of the prime keys and motivators" at Pixar. The approach was thorough but flexible. Meetings between departments took place frequently, but the schedule was irregular. Meanwhile, everyone's work was evaluated daily by a supervisor or director.

"It's an evolutionary thing," Jacob observes. "As new issues come up, you devise new systems to deal with them. There's never one way or one production hierarchy. It changes constantly."

What makes Pixar unique? "Everything!" Dan Jeup pipes up without a moment's hesitation. "It's like the original Disney studio. There's great art and great technology, and a need to make great movies. Also, there's a priority not to put the technology over the story. Story is everything. If you don't have that, everything else falls apart."

Chris Tome is technical editor for *3D*. Email him at ctome@mfi.com.



Above: Associate technical director Oren Jacob.

Left: Shading supervisor Brad West (no relation to Big Al).