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The Royal Treatment

By: Barbara Robertson

Pixars extraordinary run of successful films starring male characters took a courageous turn in June with the release of Disney/Pixar's 13th feature, Brave, the studio's first princess film. The conflict in this feature centers on the relationship between Merida, a young "don't wannabe a princess," and her mother, the elegant Queen Elinor. Merida inherited her father's fiery character along with his flaming red hair, rather than her mother's calm demeanor. She would rather be outdoors riding her horse, rock climbing, and practicing archery like Fergus, her father, than studying to be a princess and meeting her pre-ordained destiny—marriage to the son of a rival clan leader. With a fairy-tale setting in medieval Scotland amidst lush landscapes and kilt-wearing clans, and a fairy-tale plot that includes a tricky witch, a spell that must be undone, and plenty of action-adventure along the way, Brave enters new territory for the studio.

Behind the scenes, Pixar's toolmakers and artists entered new territory as well, by developing and implementing new technology and methods for the first time that affected everything from the landscape to the costumes, from animation to Merida's mop of curly hair.

Setting the Stage

During late summer of 2006 and again in October 2007, 12 members of the Brave production team—including directors Mark Andrews and Brenda Chapman, producer Katherine Sarafian, story lead Luis Gonzales, production designer Steve Pilcher, and shading art director Tia Kratter—traveled to Scotland to meet people, immerse themselves in the landscape, and scout locations. In the Scottish Highlands, the team felt the wind in their faces and pushed their hands down into the spongy moss that softened the rocks and draped the earth. They saw lichen dripping from trees shrouded in mist. They stretched out like snow angels in fields of heather.

"We knew the world of Brave was going to be really, really rich," Kratter says. Merida would race through the world surrounding her family castle, on Angus, her Clydesdale. She would run through it on foot, following little electric-blue will-o-wisps. It was a landscape beyond anything attempted before at Pixar. "The thing about the landscape is what it gives you in spirit," Pilcher says. "To do something without that power and magnificence would be a disservice. We built the ring of monolithic stones. The castle and the black houses covered with thatch. The beautiful sky with sunlight moving through mist. The forest, the highlands, the lochs. We had a full range of emotions to work with visually."

Although the castle and cottage were dense sets and artistic challenges, the technical challenges had their roots in the vegetation. "We prepared lots of set dressing, rocks, and trees, and put them into a curving landscape," says Pilcher. "But, the moss didn't look right." Nor did the lichen, bracken (ferns), or grass. Modelers formed the terrain, rocks, and tree trunks by hand, and set dressers placed the elements into scenes. But, these landscape elements had no texture.

Pixar implemented a completely new animation system to produce and perform Fergus, Elinor, Merida, and the other characters in Brave. Dubbed "Presto," the new system encompasses character rigging, animation, layout, and simulation.

Painting with Code

"If you just render the geometry, it's pretty, but it doesn't look lush and furry," says supervising technical director Bill Wise. "We wanted Spanish moss hanging from tree limbs, and clumps and hummocks of moss. The Highlands of Scotland were like another character in the film, a living backdrop for what was going on. We had never tackled as vast an outdoor landscape, but we were able to generate it using insane procedural geometry developed by Inigo Quilez. He's a magician."

Quilez describes the method he used to generate the 15 types of foliage, rocks, and even small flies as "painting with code." The code exists as a Pixar RenderMan plug-in written in C++; that is, a DSO. When Quilez started, he rendered with PRMan 15, then, as time passed, changed to Version 16.

"It was quite fun using a compiler to produce assets," Quilez says. "Going from the flat world into a super-dense 3D world was all my work. Moss with small clover leaves around it, bracken, hummocks, hanging moss, all the leaves and pine needles, lichen, grass and flowers, heather, birch trees, gorse, Scotch broom, the distant trees and rocks, the small dots that were flies, all were specific pieces of code; all the shapes, the colors, everything is in the code. We didn't write a tool that an artist would use; there's no user interface. Usually we use code to glue things together. In this case, we thought of code as assets."

At first, Quilez planned to hard-code only moss and grass, but the result was so successful he ended up writing specific code for many more types of vegetation. "I abstracted the code and found the parts they all had in common, but in principle, each is different," he says. "They share the logic, of course."

He treated the vegetation that grew on the rocks, trees, and up from the ground differently from that without supporting geometry. For the former: "We'd start with 3D models and go polygon by polygon in the mesh," Quilez explains. "For every quad, we would generate random points, and from those points we would grow flowers, leaves, and something else."

For the latter: "When we didn't have a mesh," Quilez explains, "we'd place cubes where we wanted things to grow. These weren't polygons; they were mathematical descriptions: This is the center, these are the sides, end of story. The code would use that to generate detail inside. We generated bushes out of nowhere."

Quilez didn't use typical plant-growing rules to produce the grass, moss, and other vegetation. "The problem with L-systems and other old-school techniques is that you have to encode the rules," he says. "If you want to change something, you have to change the rules, which isn't intuitive. When we wanted to change something, we'd go into the code and make the change."

The

Scottish landscape provided a living background for much of the action in the film. To coat the rocks and earth with moss and clover (above), technical director Inigo Quilez painted the landscape with code.

Master Gardener

To grow the moss, Quilez would use the orientation of the surface. If the normals pointed down or horizontally, which suggested more water and less sun, the moss would have more clover. If the normals pointed up or vertically, which suggested more sun and less humidity, no clover would grow. “So, the clover followed the shape of the tree or rock,” he says. “We used these little tricks to make everything organic. If you just drop flowers everywhere, it doesn’t look natural. You need driven randomness.”

All the code executed at render time. There were no physical versions of these plants, no files, no point clouds. As Quilez refined the look of the vegetation, he’d render the elements to screen for review, and then delete the render. He didn’t save images to disk. If a director or art director asked for a different look—wilder grass, perhaps—he’d change a number, then compile the code and render it again.

“Everything happened in the CPU when we rendered the frames for the final shots,” Quilez says. “If we had stored all this detail on disk, we would have had terabytes of data. We just had formulas and generated the shapes at render time.”

That meant, though, that animators could not see the shapes until the code rendered. “Luckily, it was quite quick,” Quilez says. “We could have the ground plane with grass growing on it within 20 or 30 seconds using 10 CPUs.”

Even so, about halfway through production, the crew developed a real-time preview version in OpenGL for the animators and layout artists. “We did a one-to-one match between RenderMan and OpenGL,” Quilez says. “Of course, the quality wasn’t the same, but every blade of grass was there in the real-time tool.”

Although lighting artists didn't have feedback until after rendering, that didn't seem to be a problem, according to Quilez. "They didn't have to worry too much because it was quite predictable," he says. "We didn't use raytracing or deep shadows for the grass. Instead, we faked the occlusion and shadowing. Instead of casting rays, I took the procedural signal, all the formulas and the fractals, and generated occlusion and shadows myself. That way, all the vegetation responded to lighting in a predictable way."

For example, when the code would create a clump of grass, Quilez darkened the blades in the center manually. Similarly, if a tree canopy had a key light on the left, rather than lighting the left side and darkening the right with shadow maps or deep shadows, he faked the lighting with instructions in the code.

Magician at Work

"The process would be like this," Quilez says. "A tree trunk gets rendered. It calls the code that grows the leaves. The leaves grow with a shader attached that generates the color, the same as for anything, and passes it to the lighting. But, some of the coloring and lighting decisions are in the code. The code doesn't apply them; the decision about what is dark and light just passes down the pipeline to the shader and lighting tool." When vegetation needed to interact with characters, Quilez hand-coded the animation, too. "Because we didn't have data on disk, there was nothing to simulate," he says. "So instead, I told the code where the interaction would happen by putting in spheres that defined a radius. Then we had parameters we could tweak to move the blades of grass inside the sphere."

The parameters would specify when the blades bent, by how much, and how long it would take to bend and bounce back. "It wasn't that difficult to hand-code the animation," Quilez says. "I had three or four numbers to change and everything happened automatically. Because things ran fast, we could iterate fast." Quilez also paid attention to level of detail. To reduce the computing load, grass and other vegetation far from camera would grow with fewer curves and less detail. "In the end, we could render all the sets, which are quite complex, in less than 2gb," he says.

When Quilez showed his idea to other people at Pixar, some told him he was, in effect, moving backward; that this was how people did things in the old days before artist-friendly tools, back when programmers had to write code to create images. Quilez disagrees with the notion that he's reverting to old-school days.
"You always think of CG as moving forward," Quilez says. "But, it's more like a spiral. We have faster computers now. And this was super fun. It was a dream. I love math, and to have a chance to use math to make images and beautiful movies was super cool."

For her part, Kratter, the shading art director, has her own opinion of Quilez and his work. "When I first came back from Scotland and said I wanted a dense layering of lichen, grass, and moss, I was told it would be too expensive. But, Inigo [Quilez] spent six months working on his code, maybe more, and it was like he gave us a secret present. We had moss blanketing everything. We called him the wizard."

Presto, Rig-o

This living backdrop, as Wise describes the landscape, is primarily Merida's world, a lush, green world. In the beginning of the story, we see her as a child picnicking with her parents in the woods, but usually when she's outdoors, she's alone. There are two exceptions—when she visits the witch and when her mother changes. But otherwise, when she's with other characters—her parents, her wild little triplet brothers, the three clan lords, the dozens and dozens of rowdy clan members—we see them in and around the castle.

All these characters were rigged, animated, and simulated through an entirely new proprietary system first implemented for Brave. Named Presto, the system replaces Pixar's previous character pipeline, which was known internally as MenV (2x), and which included the studio's proprietary animation system, Geppetto.

Modelers at Pixar work primarily in Autodesk's Maya. Presto takes over from there and encompasses character rigging, animation, layout, and character simulation. Cached scenes go from Presto to lighting and effects.

Character supervisor Bill Sheffler began working on the new system in 2007 when
Ratatouille wrapped. "A code base over 20 years old or so can reach an end of life," he says. "You can't make big changes and push yourself further. We kept the best workflows, but this is a first-rate new code base for us to expand on. The big benefit is that our IK systems are better, sculpting and weighting tools are better, and we can do better layering, referencing, and class structures within the rigs. And, it's more WYSIWYG."

Some of the major changes affected the way in which the technical directors rigged characters. "In the past, we would weight and sculpt by hand," Sheffler says. "Now we fill a new character full of a kind of jelly, put an armature inside, pose the armature via simulation, and use that to extract shapes for rigging. We can have a fully, nicely simulated, rigged character in a couple days."

The new system also automates the process of balancing blendshapes in faces and makes the process of rigging multiple characters easier. "You could think about a character as the sum of artistic opinions," Sheffler says, explaining that a character's rig file contains those artistic opinions, the decisions made as the rig evolves.

"It's like a painting or drawing, except with a lot of ones and zeros," Sheffler says. "If you were to look at it over time, like a time-lapse, you would see the artistic opinions in a particular syntax iterate and change slowly. You want to have a nice way to put those opinions in a global repository."

Presto provides that global repository, which gives character riggers flexibility and speed: They can move rigs in part or wholly from one character to another. "Say you want to see the work on master characters propagated into hundreds," Sheffler says. "This is a class system we couldn't do in the past—pushing work from one to multiple places in a dynamic fashion. Now, we can mix and match layers and define how one inherits another—the shape of a face, maybe, or a control within a face. We have a space in which the system can interpolate those artistic opinions."

To flex characters' muscles and jiggle skin, Presto integrates simulation—volumetric flesh and ballistic skin—more closely. This was particularly important in Brave for Merida's powerful horse Angus and the svelte mother bear. In addition, the new system provides inputs to external, proprietary cloth and hair simulation systems, each of which incorporated new methods and technology developed for Brave, and the various other simulation systems used at the studio, as well. All the departments, including simulation, shading, lighting, and effects, needed to redo workflows to connect with the new animation system. No question, a major undertaking.

"The characters in Brave are the most complex we've made," Sheffler says. "We're consistently upping the bar internally. And if that weren't hard enough, rebuilding the tools to do the film was an additional challenge. It was a large tax on the technical side in many ways."

At top,

tailors modeled the clothes using 3D tools for the Brave characters, rather than creating costumes from 2D patterns, as on previous films. At bottom, traditional articulation with volume and skin simulations, less-defined musculature, and thick fur helped give the bears mass and volume.

Bear-ly There

To move muscle and skin for those characters, Pixar used the PhysBam system (developed at Stanford) for the second time. "We had started working with muscle rigs for Bob in The Incredibles," Wise says. "But the first time we used the PhysBam volume simulator was to create big and jiggly humans in Wall-E, the Captain in particular. We wanted him to have believable mass, weight, and jiggliness. We also used it in the big final sequence with the humans sliding down and piling on top of each other. But, we hadn't used it since, until Brave. So, using PhysBam was not new, but we spent a lot of time experimenting with simulated muscle rigs."

To make Angus's muscles look as if they expand and contract as he gallops through the forest, the team ran volume simulations atop an articulated, underlying musculature. "We'd build a 3D volume out of the high-resolution skin mesh, fill it with tetrahedrals, and conform it to the shape of the final skin mesh," Wise says. "We ran the volume sim on that 3D tetrahedral mesh and warped the skin mesh to the results of the simulation." As a result, the skin looks as if it stretched over the muscles appropriately.

To jiggle the skin, the team used a second simulation. "We take the surface mesh, after it has been warped with the volume simulation, and then run a skin simulation," Wise says. "That simulation slides in the plane. It doesn't break the silhouette; it slides along the surface. We attach hair to the result of that simulation, and then run the hair simulator."

The bear was a different challenge. "The bear has looser skin and flesh," Wise says. "Having the bear feel alive, getting the feeling of mass and weight, meant feeling that flesh move. So, we used more traditional articulation with volume and skin simulations, less-defined musculature, and thicker fur."

Hair Brains

The studio estimates that 96 percent of the shots in Brave had some form of simulation. To handle hair and cloth simulation, Claudia Chung led a team of 16 simulation artists, five tailors and four groomers, and four simulation leads. In addition to work specifically on shots, the team handled changes to the pipeline caused by the switch to Presto.

"We have people with varied backgrounds," Chung says. "Artists and tailors, and one has a masters' degree in physics. Some have backgrounds in computer science and programming. We built our team to have a full gamut of backgrounds and to rely on one another. The cool thing is that as a simulation artist, you might understand how to program, to write a simulation, and understand physics, but you also have to understand the flow and dynamics of cloth and hair to make it realistic. That requires a different eye. The artists are the people who know when something looks wrong and can figure out how to make it right."

Three senior scientists at Pixar, Andrew Witkin, David Baraff, and Michael Kass, developed the studio's FizT (for cartoon physics tool) simulation system, originally developed for Monsters, Inc. to move the cloth in little Boo's T-shirt and the monster Sully's blue hair. The breakthrough came with unique methods they devised to trace and analyze intersections and solve problems caused when hair and cloth intersect, and especially when one part of a garment inadvertently finds itself stuck inside another and can't decide how to get back out. The three scientists published their findings in a SIGGRAPH 2003 paper, and received Scientific & Engineering Academy Awards in 2006 for the cloth system they developed.

After Monsters, Inc., Pixar's simulation artists continued using FizT to move hair and cloth, with only a few evolutionary changes along the way, for each film since. But, Merida's hair was too much.

"Around the fall of 2008, Lena Petrovitch, our hair lead on Brave, and Andy Witkin came together to work on a new system," Chung says, "Lena on the production side, Andy on the R&D side."

Petrovitch, who had responsibility for hair modeling and simulation for Brave, had identified a problem with FizT: To move the volume of hair in Merida's design without producing a tangled mess, every part of every curly strand had to see every other strand, which FizT could do, but not as fast as they would need. Merida's thick hair was too long and curly.

"At that time, Andy was really into multiprocessing," Chung says. "One of the solutions he came up with was that at the initial start of the simulation, the system could figure out which hairs cared more about each other and, depending on algorithms, could send groups of hairs to different processors. That way, we could run the simulations somewhat independently while keeping track of whether the groups cared about each other." The team discovered that Merida's hair ran best on eight processors. Beyond that, the overhead caused by having the groups talk to each other outweighed the advantages of multiprocessing.

Witkin also devised a solution to handle the volume of curls. "Before, we ran the simulation on every point of the hair, however many points were modeled," Chung says. "With the new method, we filter the curl to a core spring system, as if you had a core curve through the curl. That provided dynamics in a more stable way."

Chung suggests imagining a curly telephone cord to understand the concept. If you swing the cord, it stays curly. "But, the motion is almost as if a curve runs through the curl and that's what moves the curl," she explains. "So, what we created was a way to simplify a curl into a core curve, and simulated that. The motion was on this filtered core curve. The fun was taking that physical model and figuring out how to translate it into a point and spring system."

The core curve solved another problem, as well. Again using the phone cord example, if you were to fling a phone cord very fast, it would uncurl and then bounce back into place. With the system Witkin devised, the same thing happens with Merida's curls: They lengthen, but at a certain point, snap back into place.
"This was Andy's model," Chung says. "He was all about phone cords. His way of explaining things was the key to understanding what the problems were."

Sadly, the new system, named Taz, was moving into full production when Witkin died, September 12, 2010, in a scuba diving accident. "I remember about that time doing weekly walk-throughs with Andy," Chung says. "He would visit every technical artist and help us figure out whether a problem was a production problem or a core problem. He was very much like a teacher. The very fact that I can explain this to you now is because he was able to explain it to me."

The 

tailors created the kilts by stitching together 2D panels into an accordion shape, and then had the cloth simulator relax the accordion into soft folds.

Hair She Is

To create Merida's curly hair, Elinor's long braids, Angus's main and tail, or all the other characters' hair that Taz would move as the characters delivered their performances, groomers started with a bald model and then placed and defined key hairs. "Merida's hair was hardest," Chung says. "Angus's was the most complex."

Indeed, Merida's hair stylists spent months placing curves on her scalp that represented the curls—1,500 curves that became 111,000 curves in the final render. To create Angus the Clydesdale's hair, groomers hand-placed 111,000 curves that became 1.8 million in the final render. Wise describes the process: "We lay down a curve in 3D space in Maya, and click, click, click, put control points on the curve," he explains. "Then, we bend them. It's very interactive. We define the curl and sculpt how we want the curve to flow." Shapes designed around each key hair define a shell that fills with interpolated hair at render time.

"We spent months and months sculpting and tweaking to get the parameters just right," Wise says. "Merida's hair was directed to within an inch of its life. This forelock must go here. It must be this thick. It must curl that way."

The groomers attached the hairs to Merida's scalp starting with the innermost layers, working up her head to the outermost, positioning the key hairs with the simulator in mind.

"Merida's curly hair was so massive and interwoven together, the challenge for Lena [Petrovitch] was in keeping it from becoming a rat's nest," Chung says. "To have control over the artistic design, she decided to groom Merida's hair in an antigravity way, almost as if Merida had touched a light socket."

Once the groomers finished styling Merida's curly mop, they sent all the data to the simulator and turned on gravity. When the hair relaxed, the artists evaluated the look. Did it sag too much, as if she had just gotten out of the shower? Is it too stiff?

"We had a whole suite of calisthenic tests that we ran the characters through to see how the hair behaved," Wise says. "We turned their heads left and right, animated them jumping up and down, twisted their torsos with their arms out to the side. It's an iterative cycle that goes on until we have it just right. Later in production, we ran fast-motion and slow-motion shots to be sure the simulator could handle those situations and that the parameter settings were correct. People say, '[With simulation] you get the motion for free.' That's the funniest thing. Yeah, it's for free—after three years of development and months of iterations."

Once the crew untangled the challenges in creating Merida's curly hair, they moved on to Angus's straight hair. "Those were our test pieces," Chung says. "Once we figured those out, our other characters fell into place."

The groomers grew Angus's hair in exactly the way a horse's hair would grow, following the contour of his muscles. The challenge was in creating appropriate motion for his long, silky mane and tail. "We wanted it to move and hang luxuriously," Wise says. "It was less of a grooming challenge and more of a parameter-tweaking challenge. He has some of the most extreme motion in the film."

Angus might be swishing his tail in one frame, galloping through the forest in another at speeds no horse could achieve, and coming to a stop more quickly than would be possible in reality. However, the simulation engine uses the laws of physics, those for velocity and gravity, to move the digital hair, which sometimes resulted in hair moving in non-artistic ways. So, the artists essentially tricked the simulator, using various knobs, levers, and parameters to dampen the motion when necessary and move the hair with "cartoon physics" instead.

That was true for the other characters, as well. For example, Merida might turn her head quickly, causing her hair to cover an eye during an important emotional moment. Or, worse. "We had to get rid of hairs from
Angus's mane that ended up in Merida's nose," Wise says. "It isn't like every shot needed extra work. We put the simulation through such rigorous testing before production that the intervention was about artistic choices."

An early goal, according to simulation groom and asset lead Emron Grover, was to be able to send half the shots with Merida on through without tweaking. "We got to the point where Merida's hair wasn't a big deal, and that was huge," he says. "She wasn't easy. There were so many shots. And, with all those vertices and hair layers colliding, the simulation times were pretty high, but it was a huge help to use eight cores simultaneously for her hair. Her hair was faster than her cloth simulation."

Dresses and Tresses

For cloth simulation, the team used the latest version of FizT, the engine originally developed by Witkin, Baraff, and Kass for Monsters, Inc. The big change was in how the tailors modeled the costumes that FizT would move.

In the past, tailors created all the costumes for all the characters in Pixar films from flat panels in the same way tailors in the real world make clothes out of cloth cut from 2D patterns. The 2D planes fed the simulator pristine UV coordinates. The system worked.

“You can get garments that look like real clothes because you’re mimicking real life,” Baraff says. “The skill set needed to model clothes is pretty specific; you have to understand real tailoring.” There was only one problem: “The number of people who understand clothing design is fairly few and far between,” he adds. “We have a few of those, but we have a whole building full of 3D modelers.”

Thus, the R&D group developed a new system called C3D, for 3D cloth, that made it possible to create the costumes for the hundreds of characters in Brave by building the clothes on 3D models. They tested the system on Toy Story 3 to help Ken with his costume changes, and put it into full production on Brave. Even so, for some costumes in Brave, the tailors adopted a hybrid approach, using flat panels for ruffles and folds. “The 3D modeling system was a good way to do fast iterating,” Chung says. “But sometimes, when we modeled things on the organic bodies, the clothes didn’t look right.” For example, the cloth in Merida’s father Fergus’s kilt looked lumpy and sculpted when the simulator moved cloth modeled in 3D. Instead, the tailors created flat planes, seamed them together in an accordion shape, and let the simulator relax the pleated accordion into soft folds.

“We started with Merida and Fergus,” Grover says. “Merida because she’s a main character, and Fergus because we knew he’d be the most difficult. We had two tailors working on those two. And then we got another tailor and started on Elinor and the triplets.”

When characters wear more than one layer of clothing, the tailors would model each layer in 3D (or the 2D/3D hybrid) and then send the heaviest layers to the simulator first. Fergus had the most layers, usually 10 or more including a shirt, a chain mail tunic, a leather tunic with metal studs, the kilt, a leather strap, a belt around his waist, and a cloak with a bear pelt on it. They started with his belt, worked inward, and then put his cloak on top.

Although a cloth simulation could affect how the hair moved, the simulation artists tried to avoid those collisions. "We didn't want to wait an hour for the cloth simulation and then another half hour to 45 minutes to see the hair," Grover says. "So 95 percent of the time the hair doesn't collide with the clothes." Adding an offset outside Merida's dress helped, and the trick was not obvious. Otherwise, some shots would have been onerous.

In one sequence, for example, Merida rides Angus while holding a tapestry on her lap. "She's at full gallop," Chung says. "We had to simulate the horse's hair, Merida's hair, her dress, and the tapestry. That was a moment. Fortunately, we prepared for hard shots like that. It was the one-off's that were harder."

Chung singles out one shot in particular. "Merida takes off her hood in a dramatic moment that lasted 600 frames," she says. "Simulations are progressive, one frame after another. If the shot were short, we could have faked it. But, when it's over 600 frames, everything has to be stable."

Internal Forces

The relationship between mother and daughter is at the core of Brave's story, and during the film, Merida and Elinor learn to appreciate each other and discover how to work together to achieve a goal. Metaphorically, at Pixar, departments that typically work separately came together on this film and collaborated in new ways.

"We've gotten into a rhythm over the years, but sometimes we need to change the process slightly," Wise says. "For example, simulation and character articulation [rigging] used to be separate. First of all, because there wasn't much character simulation, and second, because simulation happened after a character was rigged and handed to animation. On Brave, the departments needed to be more tightly coupled, particularly in the case of the bear and the horse. The volumetric flesh and skin simulations, and how they affected hair simulation, were part of the rigging process. We had to have a lot of close collaboration and coordination."

The same was true of simulation and animation. Chung's background is as a simulation artist. She was the cloth lead for Up, and before that, a simulation artist and tailor on Ratatouille, and a simulation artist on the short film "Lifted." "Some of my most fulfilling moments were when I was working on something artistic and technically challenging with an artistic partner," she says. "I wanted to bring that experience to other people. I made sure the simulation and animation departments worked together."

To facilitate that collaboration, the simulation group, knowing that the animation department could not set up and run simulations, introduced an animation preview. "It gave them a fairly low-stress, low-effort way to run a fast representation of the hair and cloth simulation to judge animation," Chung says. "Animation really insisted that it be fast and reliable; that it wouldn't impact their creative cycle. If it blew up, they wouldn't use it, and simulation can be unstable. So it was a hefty technical project."

In addition, the animation supervisors and Chung agreed that they would lockstep the two departments. "When animation kicked off, I kicked off a technical artist, as well," Chung says, "so they could work together."

Thus, each animator had a geeky buddy; and each simulation artist had a thespian pal. "I think both sides were apprehensive," Chung says. “Animators want to be creative and not stifled by something technical. The technical artists don’t want to be directed. But in the end, I think both sides realized each had something different to offer.”

There are shots, for example, in which Merida picks up her skirt and sprints away while running her hand through her hair. Animators would know how to create the performance. Technical artists would understand the dynamics.

“An animator might say, ‘I want to hit this silhouette,’ ” Chung says. “And the technical artist would say, ‘If you want to hit that silhouette, you need to get her arm out of the way.’ It was pretty cool. It’s what the animation supervisors and I wanted to happen. Both sides realized that we are people who can work together.”

There’s another theme running through Brave, too, one embodied in the title. “This movie is about being brave enough to look inside and see who you really are,” says director Andrews. “About internal forces. All the characters in the movie go through being brave.”

So, too, the studio, which was brave enough to tell a story about a young girl who didn’t want to be a princess, yet would grow strong enough within herself to command a queenly presence. The tomboyish Merida learns to protect her family through collaboration and with soft power—dominance without relying on physical force. And, she does this without marrying a handsome prince.

Behind the scenes, making this story possible, was another form of bravery: A crew courageous enough to create this film using new simulation technology, an entirely new animation pipeline, and new forms of inter-departmental cooperation. Merida’s hair, the animals’ musculature. Fergus’s clothes, moss growing everywhere. A show in which 96 percent of the shots had simulation.

"Brave was the most challenging film I've ever worked on," says Wise, who joined Pixar in 1994. "It was a hard, hard, hard film. The sheer amount of new technology we had to implement made it hard. But, I like to think the result is there on the screen to see. It's probably the most beautiful film I've ever worked on. I'm really proud."

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Back to Top