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How James Cameron's Innovative New 3D Tech Created *Avatar*

Director James Cameron is known for his innovations in movie technology and ambitions to make CG look and feel real. *Avatar* put his reputation to the test. How did Cameron make blue, alien creature look real on the big screen?

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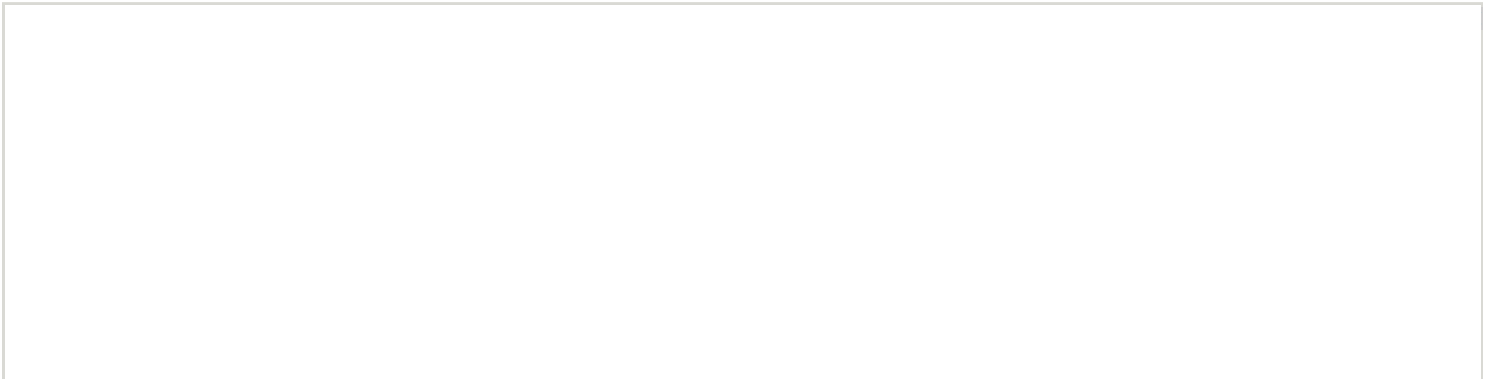
The 280,000-square-foot studio in Playa Vista, Calif., has a curious history as a launching pad for big, risky ideas. In the 1940s, Howard Hughes used the huge wooden airplane hangar to construct the massive plywood H-4 Hercules seaplane—famously known as the Spruce Goose. Two years ago, movie director James Cameron

Exhibit 2105

was in the Playa Vista studio at a crucial stage in his own big, risky project. He was viewing early footage from *Avatar*, the sci-fi epic he had been dreaming about since his early 20s. Cameron's studio partner, Twentieth Century Fox, had already committed to a budget of \$200 million (the final cost is reportedly closer to \$300 million) on what promised to be the most technologically advanced work of cinema ever undertaken. But as Cameron looked into his computer monitor, he knew something had gone terribly wrong.

The film—although "film" seems to be an anachronistic term for such a digitally intense production—takes place on a moon called Pandora, which circles a distant planet. Jake Sully, a former Marine paralyzed from the waist down during battle on Earth, has traveled to this lush, green world teeming with exotic, bioluminescent life to take part in the military's *Avatar* program. The human settlers are interested in mining Pandora's resources but can't breathe its toxic atmosphere, so to help explore the moon and meet with the native Na'vi who live there, Sully has his consciousness linked with a genetically engineered 9-foot-tall human–alien hybrid.

Cameron wrote his first treatment for the movie in 1995 with the intention of pushing the boundaries of what was possible with cinematic digital effects. In his view, making *Avatar* would require blending live-action sequences and digitally captured performances in a three-dimensional, computer-generated world. Part action–adventure, part interstellar love story, the project was so ambitious that it took 10 more years before Cameron felt cinema technology had advanced to the point where *Avatar* was even possible.



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The scene on Cameron's screen at Playa Vista—an important turning point in the movie's plot—showed Na'vi princess Neytiri, played by Zoë Saldana, as she first encounters Sully's *Avatar* in the jungles of Pandora. Everything in the forest is luminous. Glowing sprites float through Pandora's atmosphere, landing on Sully as Neytiri determines if he can be trusted. Playing Sully is Sam Worthington, an Australian actor whom Cameron had plucked from obscurity to play the movie's hero. Cameron was staring directly into Worthington's face—or, rather, he was looking into the face of a digitally rendered Worthington as a creature with blue skin and large yellow eyes—but he might as well have been staring into a Kabuki mask.

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The onscreen rendering of Worthington was supposed to be a sort of digital sleight of hand—a human character inhabiting an alien body so that he could blend into an alien world, played by a human actor inhabiting a digital body in a digital world. To make the whole thing work, Worthington's performance, those subtle expressions that sell a character to the audience, had to come through the face of his *Avatar*. But after millions of dollars of research and development, the *Avatar*'s face was not only lifeless, it was downright creepy. It "scared the crap out of me," Cameron recalls. "Horrible! It was dead, it was awful, it wasn't Sam. God, I thought. We've done everything right and this is what it looks like?"

The reaction Cameron was feeling has a name. It's called the uncanny valley, and it's a problem for roboticists and animators alike. Audiences are especially sensitive to renderings of the human face, and the closer a digital creation gets to a photorealistic human, the higher expectations get. If you map human movements and expression to cute furry creatures that dance and sing like people, then audiences willingly suspend disbelief and go along with it. (Think of the penguins in *Happy Feet*.) But if you try to give a digital character a humanoid

face, anything short of perfection can be uncanny—thus the term. Sometimes audience unease is to a character's advantage; in *The Lord of the Rings* the creature Gollum was supposed to be unsettling. But Cameron was looking for empathy, and in the first footage, that's not what he got.

Why is the computer-generated face of a blue, cat-eyed human–alien hybrid so important? Well, for one thing, lots of money is riding on it. But so, to an extent, is James Cameron's stature as an unstoppable force in Hollywood. Cameron has built up enormous fame and power based on his reputation as a technical innovator—pushing the science and technology of modelmaking, digital animation and camera engineering. But Cameron is perhaps even more famous as the industry's biggest risk-taker, which might have made him a lot of enemies if his risks hadn't been so spectacularly rewarded in the past. In 1997, the film *Titanic* taught Hollywood a powerful lesson in Cameronomics: The director's unquenchable thirst for authenticity and technological perfection required deep-sea exploratory filming, expensive scale models and pioneering computer graphics that ballooned the film's budget to \$200 million. This upped the ante for everyone involved and frightened the heck out of the studio bean counters, but the bet paid off—*Titanic* went on to make \$1.8 billion and win 11 Academy Awards.

A unique hybrid of scientist, explorer, inventor and artist, Cameron has made testing the limits of what is possible part of his standard operating procedure. He dreams almost impossibly big, and then invents ways to bring those dreams into reality. The technology of moviemaking is a personal mission to him, inextricably linked with the art. Each new film is an opportunity to advance the science of cinema, and if *Avatar* succeeds, it will change the way movies are captured, edited and even acted.

Filmmakers, especially those with a technical bent, admire Cameron for "his willingness to incorporate new technologies in his films without waiting for them to be perfected," says Bruce Davis, the executive director of the Academy of Motion Picture Arts and Sciences. It adds to the risky nature of Cameron's projects, but his

storytelling has reaped enormous benefits. There's a term in Hollywood for Cameron's style of directing, Davis says: "They call this 'building the parachute on the way down.'"

But repeatedly pulling off these feats of derring-do requires both the drive of an ambitious egomaniac and an engineer's plodding patience. "You have to eat pressure for breakfast if you are going to do this job," Cameron says. "On the one hand, pressure is a good thing. It makes you think about what you're doing, your audience. You're not making a personal statement, like a novel. But you can't make a movie for everybody—that's the kiss of death. You have to make it for yourself."

Gonzo Effects

Cameron's dual-sided personality has roots in his upbringing—the brainy sci-fi geek from Chippewa, Ontario, was raised by a painter mother and an engineer father. "It was always a parallel push between art and technology," he says. "My approach to filmmaking was always very technical. I started off imagining not that I would be a director, but a special-effects practitioner."

Unable to afford to go to film school in Los Angeles, Cameron supported himself as a truck driver and studied visual effects on weekends at the University of Southern California library, photocopying dissertations on optical printing and the sensitometry of film stocks. "This is not bull," he says. "I gave myself a great course on film FX for the cost of the copying."

Cameron eventually landed a job on the effects crew of Roger Corman's low-budget 1980 film *Battle Beyond the Stars*, but he didn't tell anyone that he was an autodidact with no practical experience. When he was exposed to the reality of film production, it was very different from what he had imagined, he recalls: "It was totally gonzo problem solving. What do you do when Plans A, B and C have all crashed and burned by 9 am? That was my start. It wasn't as a creative filmmaker—it was as a tech dude."

Over the years, Cameron's budgets have increased to become the biggest in the business, and digital technology has changed the realm of the possible in Hollywood, but Cameron is still very much the gonzo engineer. He helped found the special-effects company Digital Domain in the early 1990s, and he surrounds himself with Hollywood inventors such as Vince Pace, who developed special underwater lighting for Cameron's 1989 undersea sci-fi thriller, *The Abyss*. Pace also worked with Cameron on *Ghosts of the Abyss*, a 2003 undersea 3D documentary that explored the wreck of the *Titanic*. For that movie, Pace and Cameron designed a unique hi-def 3D camera system that fused two Sony HDC-F950 HD cameras 2½ inches apart to mimic the stereoscopic separation of human eyes. The Fusion Camera System has since been used for 3D movies such as *Journey to the Center of the Earth* and the upcoming *Tron Legacy*, and at sporting events such as the 2007 NBA finals.

The 3D experience is at the heart of *Avatar*. (In fact, some suspect that Cameron cannily delayed the movie's release to wait for more theaters to install 3D screens—there will be more than 3000 for the launch.) Stereoscopic moviemaking has historically been the novelty act of cinema. But Cameron sees 3D as a subtler experience. To film the live-action sequences of *Avatar*, he used a modified version of the Fusion camera. The new 3D camera creates an augmented-reality view for Cameron as he shoots, sensing its position on a motion-capture stage, then integrating the live actors into CG environments on the viewfinder. "It's a unique way of shooting stereo movies," says visual-effects supervisor Stephen Rosenbaum. "Cameron uses it to look into the environment; it's not about beating people over the head with visual spectacle." This immersive 3D brings a heightened believability to *Avatar*'s live-action sequences—gradually bringing viewers deeper into the exotic world of Pandora. In an early scene, Sully looks out the window as he flies over the giant trees and waterfalls of the jungle moon, and the depth afforded by the 3D perspective gives the planet mass and scale, making it as dizzyingly real for viewers as it is for him.

Shooting the Virtual World

Yet live-action 3D was hardly the biggest technical challenge. Only about 25 percent of the movie was created using traditional live performances on sets. The rest takes place in an entirely computer-generated world—combining performance capture with virtual environments that have never before been realized on film. Conjuring up this exotic world allowed Cameron to engage in "big-time design," he says, with six-legged hammerhead thanators, armored direhorses, pterodactyl-like banshees, hundreds of trees and plants, floating mountains and incredible landscapes, all created from scratch. He drew upon his experience with deep-sea biology and plant life for inspiration. Sigourney Weaver, who plays botanist Grace Augustine, calls it "the most ambitious movie I've ever been in. Every single plant and creature has come out of this crazy person's head. This is what Cameron's inner 14-year-old wanted to see."

To bring his actors into this world, Cameron collaborated with Weta Digital, an effects house founded by *The Lord of the Rings* director Peter Jackson. Weta has created some of the most groundbreaking characters in recent years, using human performances to animate digital creatures such as Gollum in the *Rings* series and the great ape in Jackson's 2005 version of *King Kong*. By now, the process of basic motion capture is well-established. Actors are dressed in "mocap" suits studded with reflective reference markers and stripes, then cameras capture the basic movements of a performance, which are later mapped to digital characters in a computer.

For actors, the process of performing within an imaginary world, squeezed into a leotard while pretending to inhabit an alien body, is a challenge. Motion-capture technology is capable of recording a 360-degree view of

performances, so actors must play scenes with no idea where the "camera" will eventually be. Weaver found the experience liberating. "It's simpler," she says. "You just act. There's no hair or makeup, nothing. It's just you and the material. You forget everything but the story you're telling." Directing within a virtual set is more difficult. Most directors choose their angles and shots on a computer screen in postproduction. But by then, most of the immediacy of the performance is lost. Cameron wanted to be able to see his actors moving within the virtual environments while still on the motion-capture stage (called the volume). So he challenged his virtual-production supervisor Glenn Derry to come up with a virtual camera that could show him a low-resolution view of Pandora as he shot the performances.

The resulting swing camera (so called because its screen could swing to any angle to give Cameron greater freedom of movement) is another of *Avatar*'s breakthrough technologies. The swing camera has no lens at all, only an LCD screen and markers that record its position and orientation within the volume relative to the actors. That position information is then run through an effects switcher, which feeds back low-resolution CG versions of both the actors and the environment of Pandora to the swing cam's screen in real time.

This virtual camera allowed Cameron to shoot a scene simply by moving through the volume. Cameron could pick up the camera and shoot his actors photographically, as the performance occurred, or he could reshoot any scene by walking through the empty soundstage with the device after the actors were gone, capturing different camera angles as the scene replayed.

But all of this technology can lead right back into the uncanny valley, because capturing an actor's movements is only a small step toward creating a believable digital character. Without the subtle expressions of the face, Cameron might as well be playing with marionettes. Getting this crucial element right required him to push Weta's technology far beyond anything the company had done before.

In fact, Cameron doesn't even like the term "motion capture" for the process used on *Avatar*. He prefers to call it "performance capture." This may seem like semantics, but to Cameron, the subtle facial expressions that define an actor's performance had been lost for many of the digital characters that have come before. In those films, the process of motion capture served only as a starting point for animators, who would finish the job with digital brush strokes. "Gollum's face was entirely animated by hand," says Weta Digital effects master Joe Letteri. "King Kong was a third or so straight performance capture. It was never automatic." This time, Cameron wanted to keep the embellishment by animators to a minimum and let the actors drive their own performances.

In order to pull more data from the actors' faces, Cameron reworked an old idea he had sketched on a napkin back in 1995: fasten a tiny camera to the front of a helmet to track every facial movement, from darting eyes and twitching noses to furrowing eyebrows and the tricky interaction of jaw, lips, teeth and tongue. "I knew I could not fail if I had a 100 percent closeup of the actor 100 percent of the time that traveled with them wherever they went," he says. "That really makes a closeup come alive."

The information from the cameras produced a digital framework, or rig, of an actor's face. The rig was then given a set of rules that applied the muscle movements of each actor's face to that of the *Avatar* or the Na'vi that he or she was playing. To make a CG character express the same emotion as a human actor, the rig had to translate every arch of a human eyebrow directly to the digital character's face.

But it turns out there is no magic formula that can supplant hard work and lots of trial and error. After Cameron complained about the uncanny-valley effect, Weta spent another year perfecting the rig on Worthington's *Avatar* by tweaking the algorithms that guided its movements and expressions until he came alive enough to meet Cameron's sky-high standards. "It was torturous," Letteri admits. But when Weta was finished, you could pour the motion-capture data into the rig and it would come out the other side right.

With all the attention focused on *Avatar*, anything short of perfection may not be good enough. Cameron is asking moviegoers to believe in a deep new universe of his own design and to buy the concept that 9-foot-tall blue aliens can communicate human emotions. If Cameron is wrong, then *Avatar* may be remembered as the moment when the battle for the uncanny valley was lost. If he is right, the technology will disappear behind the story line, and audiences will lose themselves in *Avatar*'s world.

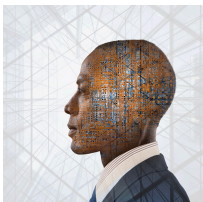
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