How to Build a Planet

Imagine being called on not only to build a planet but to animate it for film. That happened to Digital Productions of Hollywood, and this is the story of how the computer graphics studio went about carrying out the assignment to build the planet Jupiter for the hit movie 2010. Digital Productions turned to the talents of its software engineer with a background in fluid dynamics and a long-standing enthusiasm for space-related research, Larry Yaeger. Yaeger had worked on flow-field solutions for the space shuttle, high-performance and experimental aircraft, laser cavities, and submarines. Then the studio hired Craig Upson, a mathematician who had been working in meteorology and atmospheric physics at the Lawrence Livermore National Laboratory for the preceding seven years. Upson had already begun to establish a reputation in his new-found interest, computer graphics.

Add to this talent a “snakeskin,” a “supreme artist” with an airbrush, Digital Scene Simulation (sm), and film know-how, and you come up with a Jupiter, not only in living color but in graphic motion, portrayed with techniques that didn’t exist when this project started but now have become the state of the art in this area.

This snakeskin and the one on the following pages are the “working papers” used by Larry Yaeger and Craig Upson to mark where vortices should be placed. They were provided by the Jet Propulsion Lab and are the composite photographs taken by Voyager of the planet Jupiter. If you look closely you can even see the place where somebody rested a coffee mug during the painstaking job of staking out the intricate pattern of vortices on the face of Jupiter.
Getting started

John Whitney, Jr., and Gary Demos, president and senior vice president and cofounders of Digital Productions, gathered together a team including Larry Yaeger and Walter Gish, a fractal consultant, and they convened at The Jet Propulsion Laboratory (JPL) with Peter Hyams, producer/director/writer and Richard Edlund, special effects supervisor, of Entertainment Effects Group. It was Richard Edlund who had decided that Jupiter needed computer graphics expertise if it were to be built to their satisfaction. At JPL Richard Terrile showed the group the Lab's footage of the real planet Jupiter from Voyager space shots. The group saw footage of the little-known and not understood planet, which showed heavy, swirling cloud action, an atmosphere apparently in constant motion, and fascinating patterns of color. But the films were not suitable for a feature film portrayal of the planet: They were too choppy and didn't have a high enough resolution or enough detail.

There were several suggestions of a way to handle the problem: They could take the JPL information available and interpolate those images, frame by frame. They could go the stochastic (fractals) route. Then Larry Yaeger proposed they use a flat two-dimensional image, the form the JPL pictures were already in, use realistic fluid dynamics to work all the details on that flat plane, and then wrap it around a sphere.

Yaeger says that from his work in fluid dynamics and computer graphics he felt it was possible to accomplish this, that sufficient resolution could be used in computing both the fluid flow and the graphic images to make the final result effective. He proposed a "pseudospectral" technique, which involves taking the fluid quantities of interest and doing a Fourier transformation into wave number space, multiplying by wave number, thus effectively differentiating these variables, to provide the terms in the governing fluid-dynamic equations. This would be a fast technique, computationally efficient, and the tools already existed at Digital Productions to map a two-dimensional image onto a spherical object. The final element needed would be a particle-to-image texture-map rendering tool. This was the route the group finally decided to take.
Snakeskin

To get started with the project, Upson and Yaeger secured a snake-skin from JPL. This is a long composite photo of Voyager’s shots of Jupiter, which you see a portion of in Figure 1. The snakeskin likeness was noticed and the picture so dubbed by scientists at JPL. The snakeskin appears to be almost pock-marked with little vortices. These oval structures served as the markers for placement of vortex structures in the simulation. At Yaeger’s suggestion the team made a large photo blowup of the snakeskin, and then, through Edlund’s Entertainment Effects Group, they got artist Ron Gress, who all parties agree is a master with an airbrush, to go to work right on the surface of the snakeskin. He enhanced every hint of detail in the rough snakeskin. He added detail to the red spot, built complex, realistic cloud swirls into separation and recirculation regions, and added contrast and color to delicate banded cloud structures and more obvious oval features. Overlapping close-up photographs of the retouched snakeskin were made in VistaVision 35mm format, and were then digitally scanned into the computer back at Digital. Individually scanned and remerged in the computer, for retention of maximum detail, these images served as the initial conditions, the start-up colors and positions, for the particles to be used in following the Jovian wind patterns. Meanwhile, on a large blowup of the entire new snakeskin, each area where a vortex appeared was marked in ink with a little angle or karat, which indicated both the rotational sense and the size of each vortex to be used to drive those wind patterns (see Figure 2).
Software

Now it was time for Yaeger, Upson, and Robert Myers (a consultant and former associate of Yaeger’s from his hydrodynamics days) to produce software that would put the selected vortices into motion. Together they wrote three programs collectively referred to as “Vortex”: “Trade,” which solved the 2-D plus time-stream function—vorticity; “Winds,” which took each particle and applied the wind field, moving the particles to their updated positions; and “Depict,” which took the particles through their paces one more time, averaging them into the proper pixels to produce a 2-D image. The result was a picture written out in a standard form appropriate for use with Digital Productions’ main rendering software “DP3D,” into which the Vortex software was fully integrated.

Upson and Yaeger also collaborated on software to produce the initial conditions for the simulation.

Pixel colors and locations in the snakeskin images were used to generate literally millions of particles, typically one to five per pixel. After encoding roughly a thousand individual little vortex markers, special software converted these into an initial distribution of vorticity.

The final effect is as if all the particles were cast into the winds of

Figure 2. Larry Yaeger (l) and Craig Upson (r) studying the snakeskins.

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Jupiter and then photographed, frame by frame, as they blew and swirled about in the greatest storms known to man.

**Extra special effects**

The product at this stage still did not exhibit quite high enough resolution for the large portion of the 65mm frame that the planet was to fill, so Yaeger applied a nonlinear texture mapping to the whole image. High resolution is saved for that part of the image that is broadly displayed. As the picture goes around the bend of the sphere, the resolution is lowered going toward the back, taking advantage of the effects of foreshortening.

Then it was time to to match the story line rather than reality, to show the monoliths compacting the planet. The simulated planet was dimpled, a velocity sink was placed at the center of the depression, and the image was forced to blacken with depth into the hole. Upson worked closely with Edlund and his associates to provide just the look being sought for the death and rebirth of Jupiter.

At this point some 1930's technology was needed. Several "hold-out mattes" were created. A hold-out matte is like a cutout. By skillfully using them, Edlund could create the effect of a haze around this now churning planet.

**Is it realistic?**

Nobody connected with this project will tell you that this is how Jupiter really looks. The fact is, Craig Upson explains, even with the *Voyager* pictures and measurements, nobody knows that much about Jupiter. Is it all made of gas? Liquids? Is there any solid surface at all? Is there only a collection of smaller structures (cylinders perhaps) that inhabit the same general area, appearing to be a mass? Nobody knows. What is known is precious little: that there is heavy radiation; that there is great turmoil of some kind; that some of the apparent vortices appear to go clockwise, while others go counterclockwise.

From there on Upson and Yaeger had to postulate. The use of nonlinear equations kept the complex instability part of the animation. Then they had to extrapolate from earth-bound natural occurrences to define admittedly ad hoc functional relationships between discernible Jovian features and the quantities of interest in their fluid dynamic models. The result is an acceptable version, fit for a feature motion picture, of what Jupiter might look like were any of us to view the planet with our own naked eyes.

**Aftermath**

With this labyrinth of scientific know-how and artistic talent putting Digital Productions' Cray XMP into overtime hours, over two minutes of Jupiter footage was produced. It was flatly lit, so the studio could do whatever lighting it wished to suggest distance, passage of time, etc., as the film's action drew near the planet. The same film—flipped, rotated, recropped, and differently lit—was used repeatedly throughout the final version of 2010.

What makes this the state of the art more than anything else is that Digital Productions has taken the initial steps into a higher level of marriage between computer graphics and other fields. The use of computer graphics in entertainment film features is obviously a combination of computer and art, but added to this is the weaving of scientists from other areas into this matrix of art and computer graphics. Will Craig Upson return to his work in meteorology alone? Upson was doing art back in his undergraduate days. Today he is using that background professionally, along with his meteorology and his computer expertise. Now director of software development at Digital Productions, Larry Yaeger was the first staff person Digital Productions brought in with a scientific background other than just computer graphics. He won’t be the last. Gary Demos has announced his intention to enlarge staff with an eye toward gaining other fields of expertise to broaden the base from which the firm operates. Jupiter was just the beginning.
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The Rings of Saturn is a 30-second TV commercial for Chevrolet, from which this image is taken.

The reflecting Coca-Cola cans in this image were done for the cover of Millimeter magazine.

This sequence from the SuperStation WTBS commercial for Turner Broadcasting Corporation is a Cleo award winner.
These Digital Productions images are from the Chevrolet Astro Orbit, a 30-second commercial for TV.