[BY W. DANIEL HILLIS]

THE POWER TO SHAPE THE WORLD

Computer graphics not only helps shape our artifacts but our understanding of what is true about the physical world.

I know it dates me, but the first time I attended the annual SIGGRAPH conference the hot topic was how to eliminate hidden lines in wire-frame renderings. Since then, every SIGGRAPH has had an unspoken theme, like the year everyone discovered texture maps, or the year of ray-traced images. In those early days, the driving force behind SIGGRAPH was the quest to capture reality. Each year, there would be a hot new technique, and the following year, everyone would be using it. A new level of realness would be achieved.

In my time-lapse memory of past conferences, I see Martin Newell's teapot, the E. coli of computer graphics, materializing before my eyes. In my mental replay, it begins as a wire-frame image; then the hidden lines disappear, polygons fill and then become shaded, smoothed, anti-aliased, and texture-mapped, with ray-traced reflections appearing on successively more accurate surface models until—like Captain Picard materializing onto the transporter deck—the teapot becomes real.

State-of-the-art computer graphics now render simple objects like teapots with such realism it is almost impossible to detect the difference between the synthesized image and a photograph of the object. We are even beginning to reach

Guggenheim Museum in Bilbao, Spain, designed by architect Frank O. Gehry using sophisticated computer-aided design software usually associated with the aerospace industry, opened 1998; inset: detail of titanium facade.

PHOTOGRAPHS: DAVID HEALD/THE SOLOMON R. GUGGENHEIM FOUNDATION, NEW YORK that point with many natural objects, such as trees and grass, and although there are still a few unfinished problems, like the human face, the battle to reproduce reality has essentially been won.

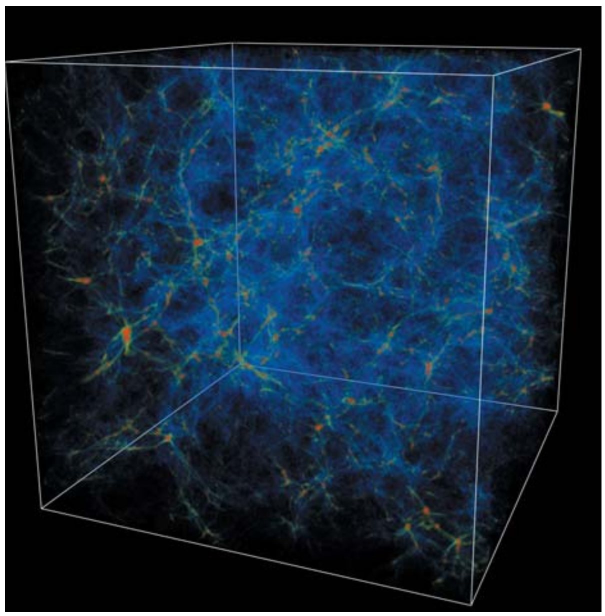
But there is an even more important sense in which the rendered teapot has become real: While computer graphics has increasingly approximated the real world, the real world has increasingly approximated computer graphics. In this way of looking at things, the notion of computer graphics capturing reality takes on a whole new meaning and importance.

I first noticed this trend when Silicon Graphics, Inc., moved into its new modernistic headquarters in Mountain View, CA. When I first visited the building, more than a decade ago, I remember thinking that it looked as if it had been rendered without enough polygons. As I began looking around the world I was living in, not just the buildings, but the cars, the furniture, and the coffeepots all started to look like they had fallen off a computer screen.

There was a time when the shapes of objects reflected the hands of the craftspeople who made them. The pot fit the shape of those hands, because it was shaped by the potter's hands in the integrated moment of design and manufacture. With industrialization, product design and manufacture became more disconnected. Objects were designed with compasses and T-squares and built on lathes and drill presses. They looked it, exhibiting the straight lines and circular forms naturally generated by these tools.

As computer-aided design tools replaced the drafting table, and numerically controlled milling machines replaced the drill press, the computer graphic rendering became the first instantiation of every new object. The computer rendering became a kind of way station on the path to reality where the design could be observed and refined. The design-build-refine cycle was replaced by a cycle of design-render-redesign, often with a computer simulation or analysis associated with the rendering. Once the design is refined in the computer, it can be sent directly for manufacture. It is no surprise that today's objects look as if they fell out of a screen—indeed they did.

Simulated cold and hot dark-matter universe 500 million light-years on a side, computed and visualized on a Connection Machine 5 using 512 processors and 16GB of RAM (Greg L. Bryan and Michael L. Norman while both were at the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign).



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Today, product manufacturing can be literally just another form of rendering. Objects are created directly from molds printed by some form of 3D printer driven directly from the computer file. (If you look closely you can sometimes see the artifacts, or voxels, of the printer's limited resolution, though most mold makers take care to anti-alias with a little sandpaper.) Increasingly, we are in a world full of objects that are printouts of a Platonic ideal that first existed within a computer.

This process of designing our reality through a computer is only beginning. Today our buildings and cars are designed this way. Tomorrow our ecosystems, our foods, even our bodies will be reformed from a model in a computer. Consider our bodies as an example. The Human Genome Project has given us the parts list of the proteins in our bodies, and the rapidly emerging field of proteonomics is beginning to give us the wiring diagram of how these parts interrelate. The computer gives us a tool to not only look at this vastly complex wiring diagram but a way of visualizing how we might effect it. Other types of graphic visualization allow us to imagine and design how the molecules interact. As frightening as the thought may be, computer graphics helps make the very fabric of our own bodies susceptible to modification and design.

It is not only our engineered reality that has been transformed. Even our most objective connection to reality—science—has become intermediated by computer graphics. Pick up any recent copy of *Nature* or *Science* and chances are the cover image will be a computer rendering. The objects of science—nanotubes, quantum wells, protein binding sites—cannot be viewed directly. They must be observed through the magic window of the computer screen. What science needs to see is sometimes so small it cannot, in principle, be seen with light; molecular bonds are a good example. And what science needs to see is sometimes too large to see, such as the foam-like structure of the universe on a scale of a hundred million light years (see the figure). There is absolutely no way to see such realities with any instrument other than a computer. As we have stretched the bounds of science, computer graphics has become our way of connecting to what is real.

When NASA's Cosmic Background Explorer satellite returned its first detailed measurements of the cosmic background radiation in 1989, the popular media hailed it as a "picture of the big bang." It was a picture, but it was not a photograph. Actually, it was more like an impressionist painting; the computer rendering program was a kind of Cosmic Renoir, communicating reality, but at the same time interpreting it. Just as the English scientist Robert Hooke saw a new reality through the lens of a microscope more than 300 years ago and the American astronomer Edwin Hubble saw it through a telescope 80 years ago, today's scientist sees reality through the screen of a computer. But unlike its predecessors, the computer is not a neutral reporter. The computer graphics programmer is not just a lens maker but an interpreter. Background radiation has no real color or shape. What is shown on the screen is not just a view of reality, but also a way of thinking about reality.

My conclusion from all this is that computer graphics has become important and powerful in both how it shapes our artifacts and how it shapes our understanding of what is true. With that power comes a responsibility. In a way we have lost our innocence. We are no longer just creators of beautiful illusions and charming teapots; we now have the power to shape our shared reality. With the power to shape the world comes the responsibility to shape it well. C

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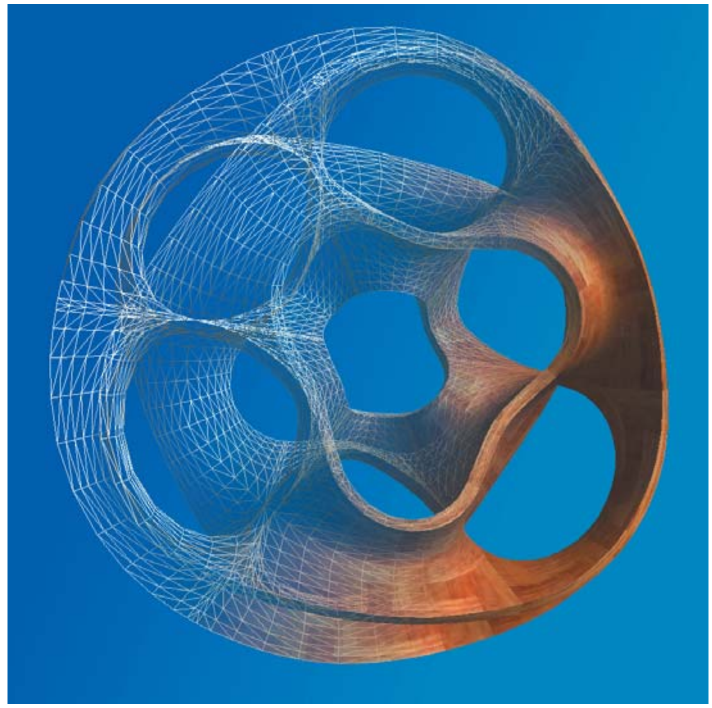

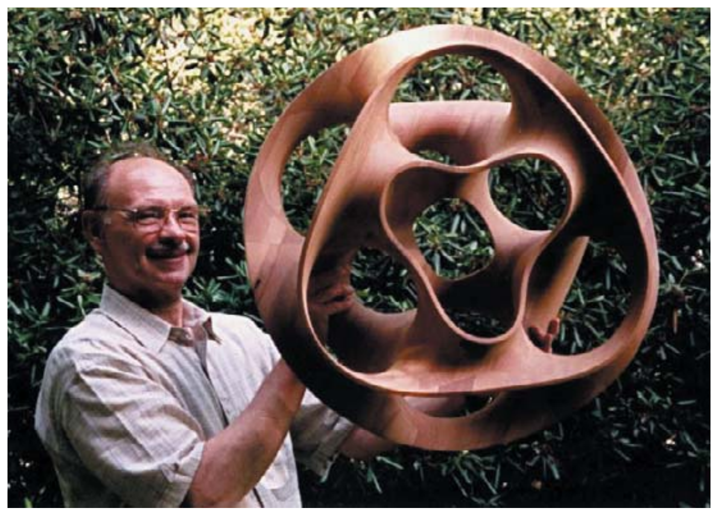

(top) How a virtual CAD model translates into a wood sculpture, using the example of "Hyperbolic Hexagon II" from Carlo Sequin's collaboration with Brent Collins, 1996.

(bottom) Brent Collins with "Hyperbolic Hexagon II" he carved from blueprints produced on Carlo Sequin's Sculpture Generator I, 1997 (Carlo Sequin, University of California, Berkeley).