GRAPHICS PROFILE

Pixar Goes Commercial in a New Market

Selling the $125,000 image processor

By Barbara Robertson

Some companies, particularly start-ups and those with new products, spend a tremendous amount of time and money trying to generate media attention and public awareness.

Others seem born to center stage. Pixar is one of the others.

Pixar began as the graphics division of Lucasfilm, formed in 1979 by George Lucas to bring high tech to filmmaking. Staffed by computer graphics wizards, the division developed the Pixar Image Computer, which was used by Lucasfilm's special effects division, Industrial Light & Magic, to produce computer animation for a number of successful movies.

By 1985, attendees fought their way through rough-and-tumble crowds to see the Pixar Image Computer demonstrated at several industry shows. That same year, Lucasfilm began courting target markets such as medical imaging, scientific geophysics, and color pre-processing, where fast image processing is important.

By December, the company had five beta customers field-testing the product. But without funding for sales and marketing, the company couldn't take orders.

Enter Steven P. Jobs, co-founder and former chairman of Apple Computer and recent founder of Next, a Silicon Valley computer company. In February of this year, Jobs bought 57 percent of Pixar, and the money, magically, was there. Pixar employees own the remaining 43 percent of the company, leaving George Lucas to concentrate on filmmaking.

Who's going to buy a $125,000 image processor that requires a host computer and has software development tools but no applications software? Pixar hopes to attract OEMs and software developers who will, in turn, market products in several key areas: medical, seismic and energy, federal and military, color prepress, graphic arts, TV animation, and non-destructive testing. The first beta customer, a company that's had the machine for over six months now, has ordered two.

The Stained Glass Man from "The Young Sherlock Holmes" shows Pixar's roots in filmmaking.

"For us, it's a test bed," says Tom Stephenson, manager of the Image Processing and AI Lab at TASC (The Analytic Sciences Corp.), a Massachusetts company that does research and development work and provides analytic engineering services primarily for various government agencies.

"Applying AI and image processing to the problems of remote sensing and non-destructive testing led us to marry IP to AI and enter the general area of *image understanding*. And that led to graphic issues such as creating 3D geometries from 2D images," Stephenson continues.

"To create an image of Mars, for example, we can use stereo pairs, or we can use several images taken at different times of

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the day and infer the shape from the shading. The Pixar is a unique device. It spans image processing and graphics in a single box, and it's very easy to program," says Stephenson.

TASC has developed solid modeling, cloud generation, and color compression and decompression applications on the Pixar. The cloud generations (from satellite data) are used for weather products marketed to TV stations.

Modeling Nature

Cloud simulations are also important to the Department of Defense, which wants to know, for example, what the chances of seeing the ground are when there's a 50 percent cloud cover. Similarly, by modeling and visualizing smoke and dust, the Pixar can help the Forestry Department judge how far an airplane could see during a forest fire.

TASC often uses the Pixar's large frame buffer to hold images for animation. "We've generated 300 frames in the buffer for monochrome cloud animation at 256-by-256-by-8-bit resolution," Stephenson reports (that's a lot of frames in one buffer).

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"We also used the Pixar to do a space shuttle model with a full image of the earth. We compressed the Pixar's 48 bits per pixel to 12 bits, which enabled us to store about 80 images at 512-by-384 resolution. Then we re-expanded in real time the 12-bit image back to full Pixar resolution. The 80 images in the machine play back in an animation loop. The result shows a realistic lighting model of the tumbling spacecraft with a sharp source of light from the sun (harsh shadows) and diffuse light from the earth (no shadows)."

This ability to combine many detailed images quickly is also useful in non-destructive testing—probing the inside of anything from the human brain to the earth itself.

"There's no question the Pixar is the leading image display of its time," says Dr. Robert Livingston, professor of neurosciences at the University of California at San Diego. "It has a very fast bus system, displays lots of data, manages the data adroitly, and displays valuable medical images.

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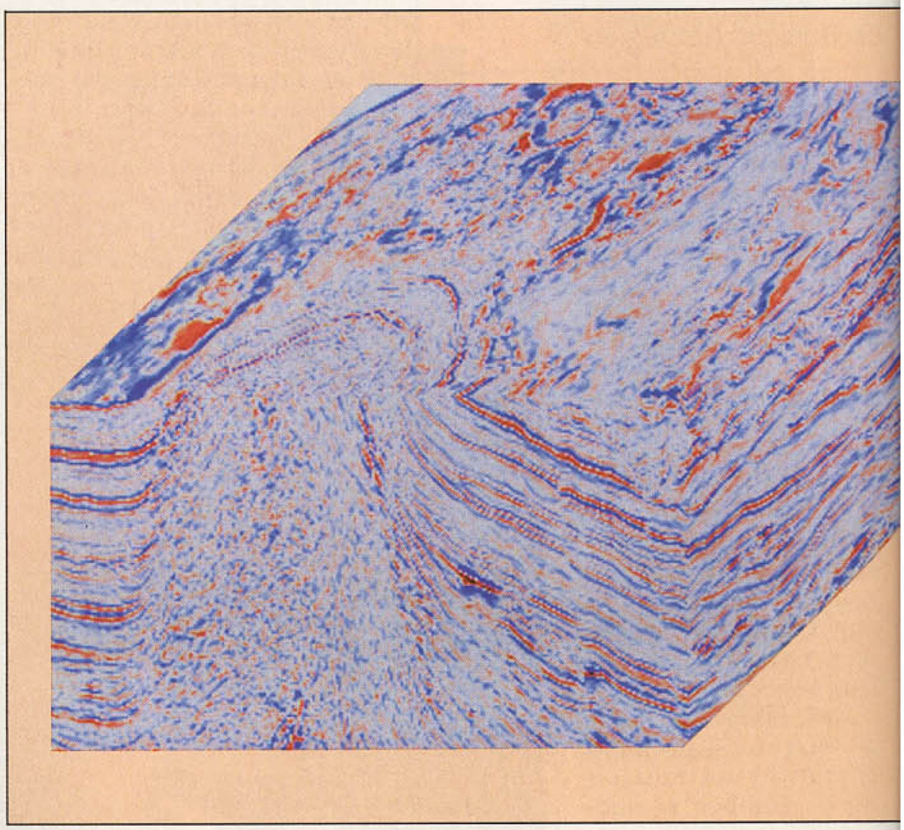
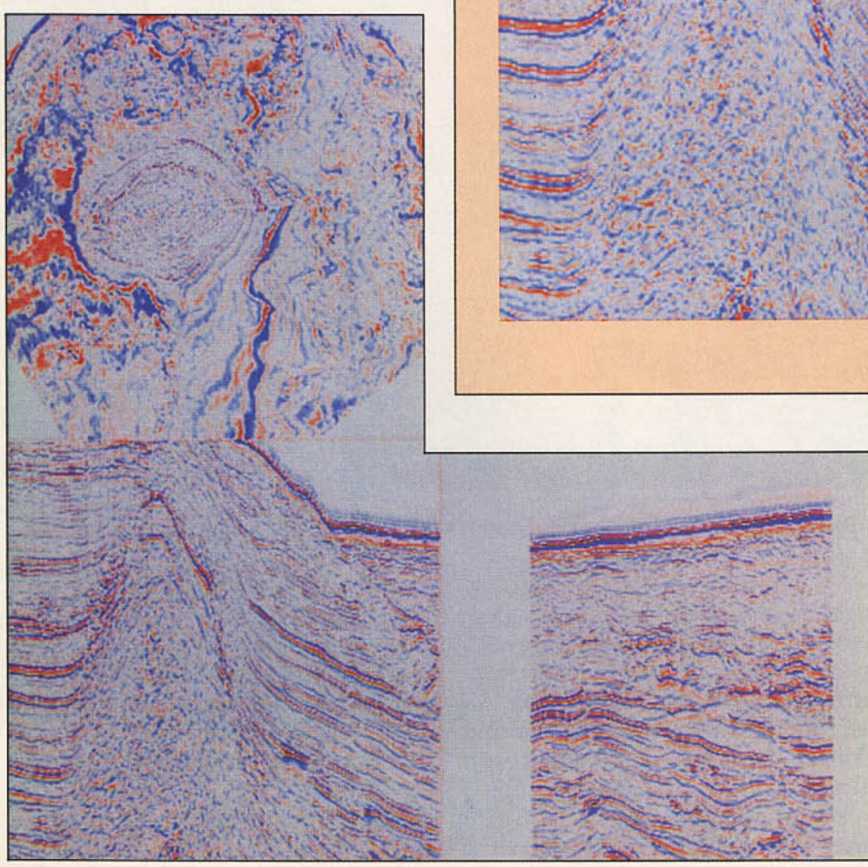




In seismic applications, the Pixar can assemble and manipulate 3D cubes of land (above) that can be viewed on any face (left).

Creating the General-Purpose Image Computer

By Alvy Ray Smith

How did a machine with roots in the movies come to have applications in medicine, energy, print, and government? I'd like to claim prescience, but here's the true story.

While part of Lucasfilm, our group was chartered to build a digital film printer. We used a laser scanner for film I/O and a special digital hardware box for matting and merging the digitized film images.

We didn't believe we could ever foresee all the problems of matting and merging sufficiently well to justify gambling on a special-purpose design. The techniques used by Industrial Light and Magic (the special-effects division of Lucasfilm) alerted us to a whole host of image-processing options that they might wish to use. So we built a programmable box. That was the key decision that gave us Pixar. Among many other consequences, it freed the machine from being just a 2D box and made 3D graphics possible on it.

Three other requirements of the digital film printer beneficially impacted the design that became the Pixar Image Computer. First, it had to work on film-resolution images. At the time, we didn't know this resolution and set the memory address space specification at a generous 8K by 8K pixels.

Second, it had to know the so-called matte of an image. That is, the shape or silhouette of the image would be as important as its contents for matting and merging. In computer graphics terms, the transparency of each pixel is as important as its color. So we decided that there would be a fourth component, or channel, at every pixel, in addition to the usual red, green, and blue channels.

And third, the dynamic range of film necessitates a bit more depth for each color component than video. Because nine bits is an awkward digital number, we selected 12 bits per channel, giving our design 48 bits per pixel. This provided sufficient dynamic range and several bits for accumulation of partial results.

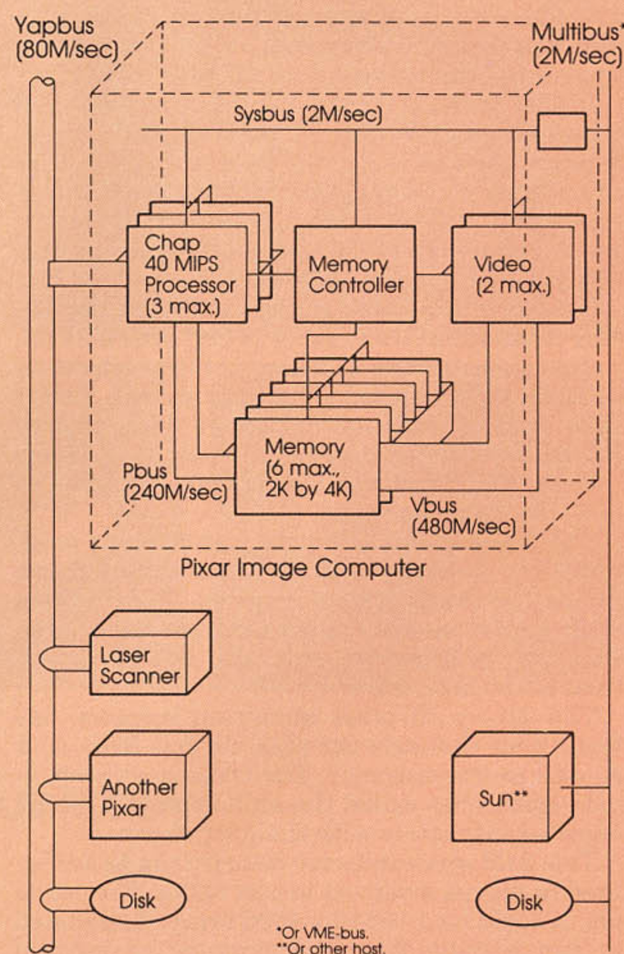
Of course, it didn't take long for us to figure out that the programmability of the box gave it great flexibility, and the full generality of what we had created began to dawn on us.

Currently vice president of Pixar, Alvy Ray Smith has been seriously involved with computer graphics for nearly 15 years. In the late '70s, he helped make the New York Institute of Technology's Computer Graphics Lab one of the premier facilities in the world. He joined Ed Catmull (now Pixar president) in the computer division of Lucasfilm in 1980, where he worked on projects including the Genesis sequence for "Star Trek II—The Wrath of Khan," an animation for "Return of the Jedi," and last year's NCGA award-winning "The Adventures of Andre and Wally B.," which features completely motion-blurred, full-character 3D animation. Most recently he and Ed Catmull formed Pixar.

The idea of an image computer is new, but it's based on the well-known principle that better price/performance is obtained when hardware is specialized to a given task. The image computer does not take this principle to the limit, however, but falls between the full generality of an ordinary general-purpose computer and the total specificity of, for example, a flight simulator.

The Pixar is general-purpose in the sense that it's fully programmable over computations on images. It's special-purpose to the extent that its hardware is optimized for this subclass of all computations. Such an image computer far outperforms a general-purpose computer on image computations, but its performance would be abysmal on accounting, high-energy physics, inventory control, or database management.

Various segments of the applications domain of image computation have been addressed by special-purpose computers. Machines like the Iris by Silicon Graphics and the Picture System by Evans & Sutherland are tuned to real-time vector graphics. A flight simulator such as the CT6 by Evans & Sutherland is an example of real-time simulation. Digital effects boxes such as the ADO



by Ampex, the Mirage by Quantel, and the FGS-4000 tiling engine from Bosch Fernseh represent another subclass: real-time video effects.

A general-purpose image computer performs all these functions (vectors, scene simulation, video image spins and folds, and polygon rendering), but swaps real-time performance for much higher image quality, resolution, and complexity.

Other image computations include those performed by what are usually called image processors and frame buffers (by Adage, Gould, and Raster Technologies, for example) as well as the sort of image synthesis typically done on general-purpose computers such as the Cray, VAX, or Ridge. An image computer can implement all these functions in one box at speeds often equal to or better than that of the special-purpose processors, while maintaining the capability for new functions with just a programming change.

Flexibility Outweighs Speed

Synthesis of highly complex (ideally approaching reality) 3D images is slow even on large machines. The Pixar can resolve visible surfaces and render them with textures, lighting, and transparency at supercomputer speeds—40 million instructions per second (MIPS).

Our experience shows it to be consistently 200 times faster than a popular minicomputer (VAX 11-780) on all image-computing tasks programmed on both machines, or 50 times faster than a superminicomputer (CCI Power 6/32).

Rather than design the Pixar for the display of a limited number—say 3000—of aliased, single-width vectors in real time, we've designed it for the rapid (but not real-time) display of an unlimited number of antialiased, full-color, arbitrary-width vectors. The color and width can even vary along the length of a single vector.

Similarly, the Pixar is more suited to the display of an unlimited number of polygons with antialiasing, arbitrary shading, arbitrary texture, transparency, and multiple light sources rather than for the real-time display of fewer aliased polygons of limited shading and texturing. Nonetheless, the Pixar can tile 100,000 polygons in just a few seconds.

The Pixar Image Computer achieves its capability and diversity with the architecture shown in the hardware system diagram. It features a large picture memory, a powerful processor to operate on the memory, and video display of portions of the memory.

The 2K-by-2K-pixel minimum memory has four 12-bit channels per pixel for full RGB color as well as transparency. The transparency channel—sometimes called the alpha channel—is integrated intimately with the color channels.

This 24M semiconductor memory can be configured in almost arbitrary aspect ratios. For example, it could be a 1024-by-4096 array. Tessellated to run equally fast in horizontal or vertical accesses, it resides on three Pixar boards, and three additional cards double the size of the memory.

The channel processor (Chap) provides 40 MIPS of image computation power. It's a fully programmable computer based on four bit-slice microprocessors and four multipliers running in parallel with an SIMD architecture. The four microprocessors can operate on either the RGB and transparency channels in parallel or on one channel of four adjacent pixels simultaneously for monochrome applications.

Up to three Chaps (12 microprocessors and 12 multipliers) can be accommodated on the current backplane, and Chaps on different Pixars can communicate via an 80M-per-second bus, the Yapbus, for high-speed picture passing.

The picture memory contents can be displayed via a video board that provides two video formats: standard 525-line interlaced or 1024-by-768 interlaced. Pan, zoom, scroll, hardware cursor, and genlock are provided. Up to two video boards can be accommodated for viewing two parts of memory.

The Pixar requires a host computer. Interfaces currently exist for popular hosts with the Multibus or the VME bus, and others will be added shortly. A one-rack turnkey system, called the Standard Pixar Development System, includes a Pixar, a Sun-3, a Fujitsu Eagle disk, and a Barco RGB monitor.

A software development package for the UNIX 4.2 BSD environment bundled with the Pixar consists of an assembler, preprocessor, loader, and debugger. Diagnostic software is also included, as are several libraries for basic graphics manipulations, window management, picture storage and retrieval, copying, channel shuffling, clamping, channel arithmetic, merging, convolution, histogram, warping, resizing, and rotation.

Surprising Imaging Interest

We showed the first Pixar prototype in a suite at SIGGRAPH two years ago, without knowing who would respond to it. Given our background, we expected the strong response we got from the graphic arts and video production markets.

Much to our surprise and gratification, though, we have found about a dozen markets (including oil, geophysics, medicine, military, and mapping) which, though diverse, can all be characterized as having data sets of ever-increasing volume and insufficiently powerful means of analyzing or manipulating them. That these are generic problems to many markets explains the wide applicability of Pixar and explains away the seemingly strange fact that it came from the movies. CGW

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"With the Pixar's ability to handle transparency," Livingston continues, "you can look deeply into the body of a living patient. It's as though the surgeon or radiologist had suddenly been given x-ray vision. You can look at the image in a way that reveals its relationship to other parts.

Unprecedented Potential

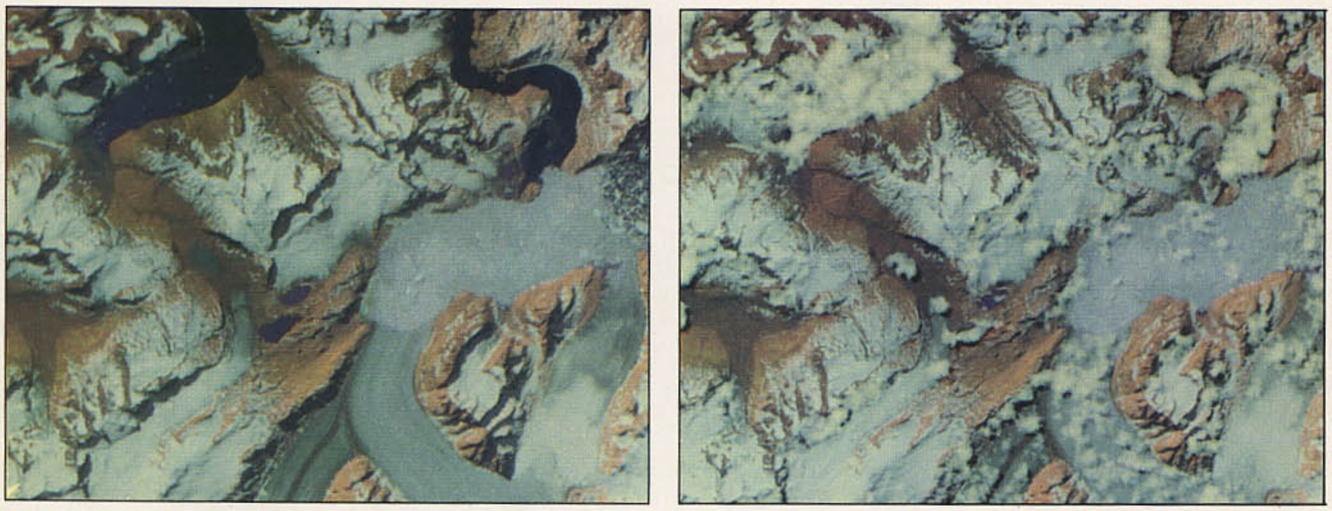
"Most machines don't do as good a job of taking all the data into account as the Pixar does," Livingston says. "Unless you have ways of displaying subtle differences in gradients in the CAT scan, you lose texture. I've

spent hundreds of hours on other machines that purport to do the same thing without being able to extract a complete image."

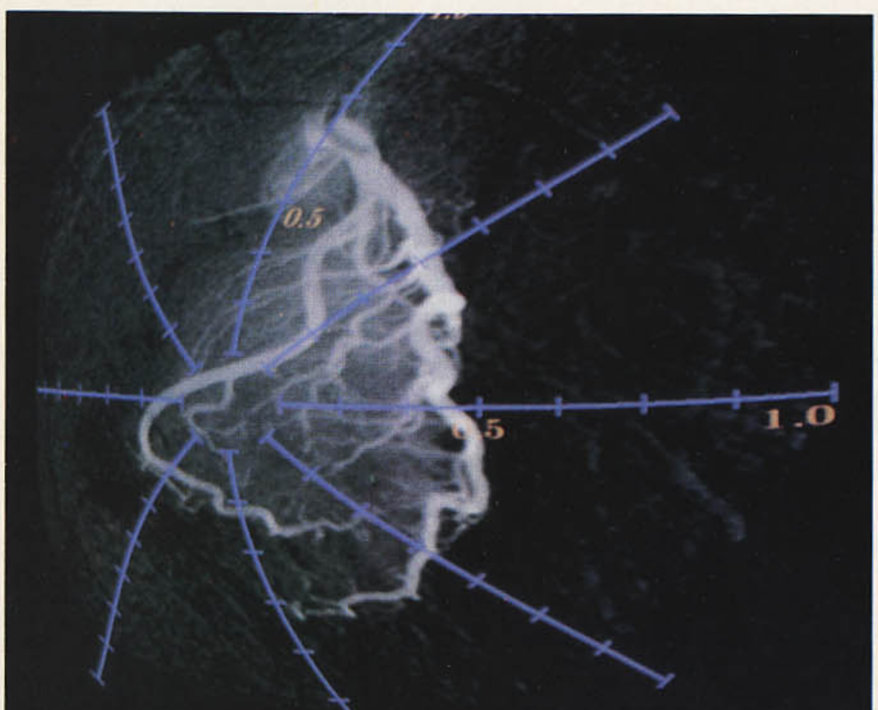
Livingston expects to use the Pixar as a research tool for projects that "otherwise couldn't be done at all." As principal investigator for a federally supported national program that plans to create a digital atlas of the human brain by assembling microscopic slices into a 3D model, Livingston and others will be collecting an enormous amount of data. "The human brain is a gigapuzzle. It's one of the most complex things known to man," he explains. "We'll have to create an entirely new graphics machine, and the Pixar provides a good learning environment."

The ability of the Pixar to generate 3D images from slices of the real world is also attracting attention in a second area where the amount of data being collected is increasing dramatically—seismic tomography.

"Scientists used to work with eight slices of data. They'd print contour maps on huge sheets and tack the maps to the wall. Now



Pixar's translucency channel makes it especially suited to modeling opacity, as in this cloud simulation (above) created at The Analytic Sciences Corp. The clouds visible on the right were modeled on the Pixar and matted into the original LANDSAT image of a section of Greenland. Note various degrees of translucency, shadows under cumulus clouds, and lack of shadows for low fog banks over bodies of water.



On the left, a monochrome medical application shows an image of a heart with overlaid grid that has intentionally been warped.

they work with cubes of data: 500 rows, 500 columns, and 2000 samples," says Pixar's Bob Drebin. "But people are drawing the contours of each line without using the information in front or in back, therefore treating the information as a 2D project.

"For image processing, the Pixar is as fast as a supercomputer. Seismologists and meteorologists can cut out a piece of an image, tilt it, and overlay it," Drebin continues. "They can work interactively on Pixar workstations with 3D contour maps of the world beneath the earth's surface. Because the Pixar can store large image sets, and because it's optimized for large pixel transfers, it can be used to roam through planes of data."

While the federal government and oil companies can cost-justify the Pixar, what about the price-sensitive medical community?

"It's an expensive instrument," Livingston admits. "But when you consider the cost of the CT machine and the immense flow of information, you can see it's

Four rotations of a color 3D image of a human pelvis.

unwise to be skimpy on the display and analysis when it can make a substantial difference in what you're able to do for the patient."

"I'm not sure there are alternatives to the Pixar in terms of its speed and ability to handle high-resolution images, but we can't afford to buy the machine and develop software applications ourselves," says Eric Hoffman, an associate consultant and assistant professor in physiology at the Mayo Clinic and Mayo Medical School who is working with 3D medical imaging (*CGW*, April 1986, p. 33).

"Steve Jobs makes things less expensive," Hoffman says. "One hopes he can do this for image analysis stations and they'll become inexpensive enough to be used in physicians' offices."

"All computers can get cheaper," claims Rodney Stock, who was project leader for the Pixar from May 1981 through August 1984 and is now director of graphics engineering for the Dana Group.

"There's a fair amount of overhead in the back panel of the Pixar that could be helped enormously by going to gate arrays," Stock continues. "The Pixar is presently designed exclusively with merchant chips. There's a clear opportunity for applying custom-designed ASICs (application-specific integrated circuits), a natural way to lower the costs. I think the technology is there to do it. The question is whether the market is large enough to justify the up-front engineering cost."

Pixar may be a new company, but it isn't exactly a start-up. Whether it can successfully leverage the technology through OEM channels probably won't become clear until 1987, when the majority of applications will begin to appear and the marketplace passes judgment. CGW

Suggested Reading

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Levinthal, Adam and Thomas Porter, "Chap—A SIMD Graphics Processor," *Computer Graphics*, Vol. 18, No. 3, July 1984, p. 77.

Porter, Thomas and Tom Duff, "Compositing Digital Images," *Computer Graphics*, Vol. 18, No. 3, July 1984, p. 253.

Smith, Alvy Ray, "Computer Power for Film and Flight, Supercomputers," Hearings before the Committee on Science and Technology, U.S. House of Representatives, Ninety-Eighth Congress, No. 47, U.S. Government Printing Office, November 15-16, 1983, p. 242.