Atoms to astronomy: Computer graphics at the Jet Propulsion Laboratory

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Within the Jet Propulsion Laboratory in Pasadena, California, state of the art computer graphics animation is done in the Computer Graphics Laboratory. The topics of the animations cover many scientific disciplines. Specific features of the system developed there, both hardware and software, are discussed. The prime mover of the effort is Dr. James F. Blinn of Pasadena; his role and experiences are elaborated. Their current largest project is The Mechanical Universe; the system is used for its production.

Key words: Education – Animation – Computer graphics – Physics – Solar system

he computer graphic animations produced by the Computer Graphics Lab at Jet Propulsion Laboratory since 1977 have been a unique blend of scientific realism and artistic creativity, united for the purpose of teaching people about science. Painstaking attention is given to the accuracy of the presentation, as well as the attractiveness and the boldness of the animation. From looking at the replication process in DNA to flying through the rings of Saturn, viewing Jupiter's magnetosphere or illustrating the theory of relativity, computer generated animation can show aspects of science and technology which cannot be seen otherwise. With these animations, the viewer can feel what it is like to be in the realm of the atom, be in outer space, or see the invisible. The viewer can discover the ideas and patterns behind how things move and interact.

The system developed in the JPL Computer Graphics Lab, though general purpose in overall design, has several features specially designed to handle the accurate generation of scientific images, and the large amount of footage required by NASA, The Mechanical Universe and Cosmos projects.

## The computer graphics lab's animation system

The hardware system is regular 'off the shelf' components assembled to fit NASA's budget and needs.

The Computer Graphics Lab timeshares on a cluster of two Vax 8600s, two Vax 11/780s, and two Vax 11/750s. One of the Vax 11/780s is allocated for priority processing and the other machines are available for low priority computing during low demand time periods.

A vector display is used as a tool for designing the objects within a scene, and for designing and studying the animation action. Because of its ability to draw 40,000 vectors per second, the vector display is used for previewing action in real time.

The third component in the hardware system is the frame buffer (raster display device) with a resolution of 486 lines and 512 samples of 24 bits each. The device is compatible with video resolution and allows for the use of 16,777,216 colors for full color images. The raster device is used for viewing a fully rendered image on the color monitors and for recording 1" video tape. (The video equipment came with The Mechanical Universe Project in 1983. Previous animations were made to 16 mm film.) The computation of the final raster video frames

Visual Computer

takes 30 seconds to 1 hour per frame and 30 frames per second are required for video, so an animation may take several hours to several days to produce. The software to make the animations and the animations produced at the Computer Graphics Lab at JPL have been accomplished by a handful of people, but primarily by Dr. James F. Blinn. The lab has benefited from having one person responsible for most of the design and implementation of its graphics system over its history. The problems of interfacing components of a large system and of maintaining a system that has evolved over nearly sixteen years have been minimized. And, since Dr. Blinn has been the primary user of the system in creating the many animations, the lab has eliminated the problem of poor communications between the programmers and the users of the system.

The modeling software has a number of components. A paint program can be used for generating textures for objects or backgrounds. The pre-encounter texture maps for planet moons and Uranus and Neptune were painted by astronomical artists with this program. Using the 'model builder', one can interactively draw two dimensional line drawings of objects or 'build' three dimensional objects. Data is input manually using a mouse or pen and tablet, or by typing coordinates at a keyboard. Object motion is designed in two or three dimensional space similarly.

The general purpose rendering software includes the standard collection of rendering programs to deal with polygons, quadric surfaces and patches. In addition, special case programs were developed to model and render planets, rings, starfields, blobby molecules and other scene 'objects'. The special purpose modeling and rendering programs take advantage of the special properties of their specific objects to increase the rendering speed or improve the rendered appearance.

The simulation software is the prime mover of the animation. Two techniques are used to transform or move an object in a scene: (1) absolute moves or (2) incremental moves. With absolute moves the definition of the position or size of an object in a given frame is stored in a table and intermediate

frame positions are generated by some form of interpolation. In incremental moves the current position and size of an object is stored by the program and the succeeding frame positions are determined by rules which might be based on the movement characteristics of the object being animated.

For The Mechanical Universe the computer programs to generate the animation often use the mathematical functions associated with the physical phenomenon being shown in the scene. Special computer programs are used to simulate the incremental motion of waves, atoms and springs. The 'blobby' software originally implemented for showing the polymerase-DNA interaction for the COSMOS series is used to show the attraction of hydrogen molecules. Blinn also developed a method for putting mathematics in motion in the visual context of 'algebraic ballets' to help the observer master these concepts.

The Mechanical Universe Project, with its 52 episodes, presented the challenge of completing over five hours of animation based on scientific theory. To label, organize and track the tremendous amount of animation produced for the project over the three years, a language was devised for archiving single frames, whole scenes and software used to generate them. Each component, be it a single frame, the animation chart used to generate the frame, or the completed animation for an entire episode was labeled and stored.

Special purpose animation programs have also been devised to simulate accurately the Voyager encounters with Jupiter, Saturn, Uranus and Neptune for the NASA fly-by animations. In the SPACE program, the relevant astronomy was modeled as well as the trajectory of the two Voyager spacecraft. The animation was then designed by working with several variables: the time of observation; the location of the observer; the object looked 'at', or seen through the spacecraft 'camera'; or the observer's 'lens' (from wide angle through narrow angle ranges.) An unexpected benefit of the implementation of this program has been its use as a 'previewing' tool by the Voyager Mission Planners when considering changes in spacecraft trajectories or camera aimings.

Fig. 1 a, b, d, e, h by Computer Graphics Laboratory, Jet Propulsion Laboratory, NASA

Fig. 1a Saturnrise over Mimas. b Voyager at Saturn; c The rings of saturn; d Voyager at Uranus; e Jupiter's magnotosphere; f Quadrupole focussing magnet in a linear accelerator; g Precessions of tops and gyroscopes; h DNA.

Fig. 1c, f, g by California Institute of Technology, Corporation for community College Television Annenberg, CPB Project



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Fig. 2a-c a Joe and Nartuhi, b Chin Li, c Mar All figures © David Em 1986

Fig. 2d–f d Hills, e Egypt, f Ola

Fig. 2g–i g Jose, h Nubes, i Puro

Throughout the Computer Graphics Lab's existence, Blinn has worked with scientists in physics, astronomy, biology and chemistry to produce accurate representations and interest grabbing animations. With scientists working directly with him, sometimes learning to use parts of the system, the Computer Graphics Lab is an efficient operation for producing animations depicting the state of current scientific knowledge. A side effect of working cooperatively with scientists is the opportunity to refine the ideas being portrayed. In the animation of Jupiter's magnetic field, several iterations were needed to refine the theory so it would hold together in three dimensions and over time. Again, in animating electric fields for The Mechanical Universe, the common two dimensional representations found in most text books turned out to be inaccurate. Three dimensions were required to accurately show how electric fields work.

From the lesson on Kepler's Laws or the SPACE fly-bys to the scenes showing the motion of atoms, the special purpose programs developed by the Computer Graphics Lab at the Jet Propulsion Laboratory have reflected and used the functions in the lessons. While much of the design effort is concerned with scene composition, interesting points of view, 'camera' action and colors, the use of real scientific data makes for the most startling and exciting results. The result is all the more exciting for the knowledge that, in some ways, this DNA or planet or magnetic field, which you probably will never actually see as it is presented, is real.

Marjory and Tom Blinn, two art teachers from Greenville, Michigan raised one of the foremost theorists and practicians in the field of computer graphics. His experience in the area of animation goes back to his schoolboy days when he was producing short home-made animations. Dr. James F. Blinn has been developing computer graphics for over 15 years. He received a Bachelor of Science degree in physics from the University of Michigan and earned a Ph. D. in computer science from the University of Utah in 1978. Since then he has been at the Jet Propulsion Laboratory of the California Institute of Technology. Dr. Blinn has produced realistic animations depicting various space missions to Jupiter, Saturn, Uranus, Neptune and Halley's Comet. He has also produced computer graphic effects for the PBS series COSMOS. In 1983 Dr. Blinn received the NASA Exceptional Service Medal for his contribution to science and the space effort. In addition, in 1983

he was honored by the Association of Computing Machinery, Special Interest Group in Graphics (SIGGRAPH) with the first Computer Graphic Achievement Award for his many contributions to computer graphic technology in the areas of lighting and surface modeling.

Dr. Blinn is currently teaching Computer Graphics at Caltech and at The Pasadena Art Center College of Design. He is also involved in assisting in the planning, and producing computer animation for the 52 part telecourse The Mechanical Universe being produced by Caltech in cooperation with the Corporation for Community College Television and funded by the Annenberg/CPB Project. The series is designed to be used as a tool for teaching introductory physics. Dr. Blinn is currently using The Mechanical Universe in teaching physics at The Pasadena Art Center College of Design. The Mechanical Universe is being shown on PBS stations and is available for use in schools. As always, he is also working on computer graphic animations in support of the United States space effort.