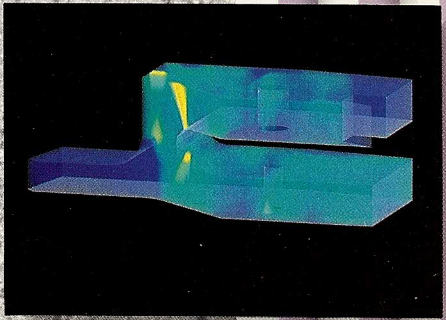
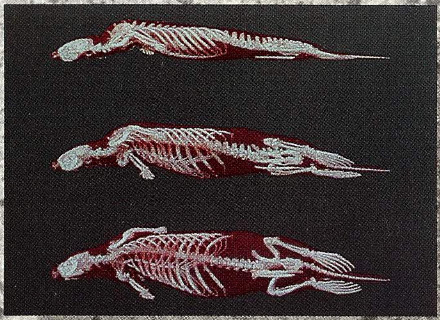
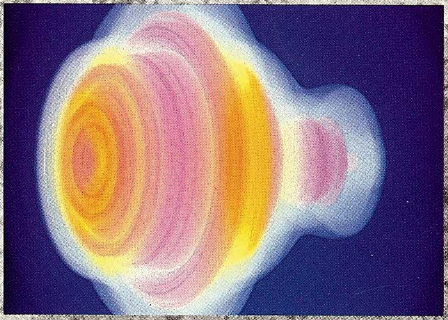
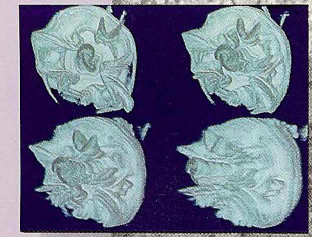
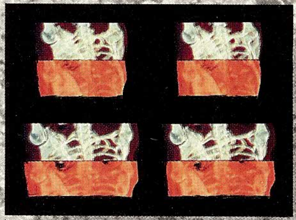
ChapVolumes











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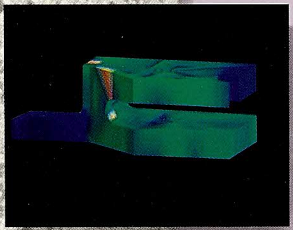
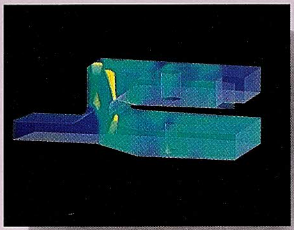
In the sciences, engineering, and medicine, we are looking for better ways to analyze and interpret both computer generated information and natural phenomena. We want to gain insights from simulations of physical behavior or illustrations of biological structures. Often the most effective way to analyze this information is visually—by examining graphical images of the information.

In many cases, the objects or phenomena being studied are actually *volumetric*. Volumetric data is a class of three-dimensional data that has essential information *internal* to the volume, not just at its surfaces or edges. Some examples of volumetric data are astrophysical and geophysical measurements, sections of the human body, computer simulations of finite element models, stress patterns in materials, and fluid flow. To represent volumetric data accurately, a new technique is needed that displays internal information of the volume.

Pixar has developed such a new technique—*volume rendering*.

Volume rendering preserves all of the visual characteristics of three-dimensional data as it becomes a computer image. Traditional computer graphics techniques for projecting volumes use lines or polygons to approximate the edges or surfaces of a volume. This approach is appropriate for rendering three-dimensional surface data, such as models of products, terrain data, or any object that is sufficiently described by a model of thin surfaces. Visualizing volumetric data, however, requires an image-rendering technique that captures the *contents* of each point in the data set. Volume rendering is available on the Pixar Image Computer™ with our new software package, known as *ChapVolumes*™. ChapVolumes will let you develop powerful volume rendering software for your particular application.

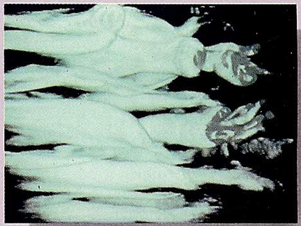




The results of a stress analysis performed on a mechanical part are displayed on the above left using "surface rendering." On the right the same results are displayed using "volume rendering." In the surface version, only the stresses on the surface can be seen, while in the volume version, internal stresses are now visible too. Notice that the spot of high stress in the fork of the part as seen in the surface version can be seen to extend into the part's interior in the volume version. Data courtesy of Harris Hunt, PDA Engineering.

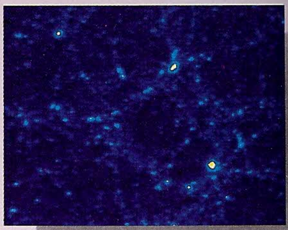
SOME EXAMPLES OF VOLUME RENDERED IMAGES

FLUID DYNAMICS RESEARCH. Applying ChapVolumes to fluid dynamics, researchers can study the formation of vortices and micro-vortices in turbulent fluid. Scientists are in the early stages of development of a mathematical background for vortex formation. By calculating and studying multiple views of turbulent fluid, scientists can gain a better understanding of the three-dimensional internal structure of fluid flow.

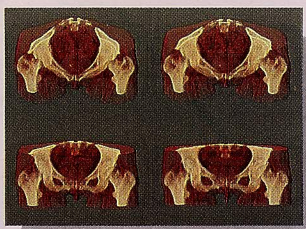


Dye is injected into a water flow and excited by a laser for imaging. Data courtesy of Gregory Russell, Department of Mechanical and Aerospace Engineering, Princeton University.

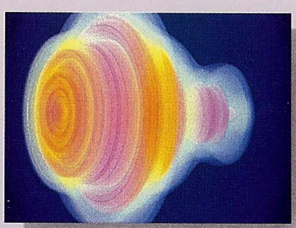
ASTROPHYSICAL SIMULATION. To study the formation of the galaxies, twenty hours of calculation on a Cray X-MP™ computer generated data simulating the structural formation of the universe. The results of the simulation were imaged using ChapVolumes, and a film loop was produced showing different views of the universe. Because the structures in the universe are so complex, rotation of the volume helps scientists better understand the data.



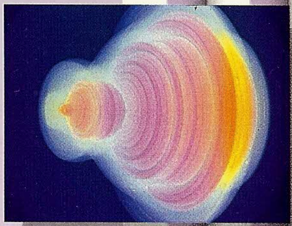
Simulation of the dispersal of matter after the Big Bang, showing galaxies and clusters of galaxies due to Newtonian gravitational effects. Data courtesy of Professor Mark Davis, Department of Astronomy, University of California at Berkeley.



Four views of the pelvis from a rotation sequence. Data courtesy of Philips Medical Systems, Inc.



Several views of a three-dimensional Mandelbrot set. Images generated by Pixar.



MEDICAL IMAGING. Applied to medical imaging, ChapVolumes can be used to project views of body sections to aid physicians in medical diagnosis and treatment. In this example, a pelvic bone reconstruction is made from 48 CT scan slices. The slices are assembled into a volume and realistically rendered.

VOLUME RENDERING: HOW IT WORKS

The volume rendering algorithm deals directly with the three-dimensional nature of the data. Instead of approximating the volume by its surfaces, volume rendering uses the three-dimensional array containing the original data to create the image. Each volume element, or building block, of the volume is treated as a mixture of materials. Materials may be the various metals that compose a component; the stress and temperature in a mechanical part; or the bone, muscle, and soft tissue within a section of the human body. Or, the volume may comprise a single material, for example, fluid in a fluid flow volume. The percentage of each type of material in the volume is used to determine the make-up of the volume elements, and the projection of the volume is made based upon these individual volume elements. Determining the material composition of each volume element is called classification and is performed by the developer, based on the properties of the data being studied.

To better illustrate the data, parameters are assigned to the materials that compose the volume. Color can be assigned to show classes of related materials (such as areas of constant stress in a component). Refractive index can be assigned to show transitions between materials within the volume (such as the transition between ice and water in a mixture of ice suspended in water). Opacity can be used to display information about the thickness of structures and the degree to which one structure obscures another. In addition, the relative contribution of reflected and emitted light can be factored into the projection.

WHY CHAPVOLUMES IS BETTER FOR VOLUME DATA

Viewing data with a ChapVolumes program will let users:

- *See a more accurate and realistic projection of volumetric data.*

Because ChapVolumes retains all of the volumetric characteristics and visual cues of volume data, users can view a true representation of the original volume, including internal make-up, spatial relationships, and thickness and depth. Since ChapVolumes treats the volume as a continuous function and doesn't use geometric approximations or other non-linear operations, a representation of the volume is reconstructed that looks smooth and realistic. In addition, the image is free from artifacts such as aliasing, which can interfere with the viewer's ability to interpret the data. Moreover, subtleties like small cracks in components or irregularities in material composition are retained.

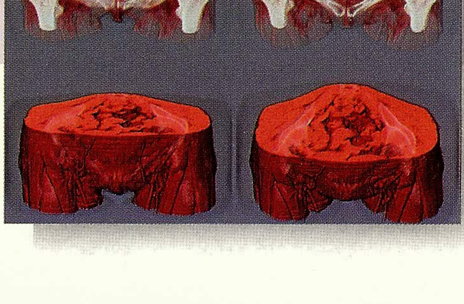
- *Rotate the image and view from different angles.*

ChapVolumes lets you rotate the image and examine the volume as it rotates. Viewing the volume from different angles shows features that may be obscured from another angle of view. In addition, motion produces visual cues not available from observing a series of static images, giving more definition to three-dimensional objects, helping the viewer perceive depth, and bringing out objects that might go unnoticed in a static image.

- *Isolate and highlight specific areas of interest.*

To view classes of related materials in the volume, the data can be classified according to the materials or parameters of interest. For example, areas of constant velocity in fluid flow can be identified, or muscle mass in a hip can be viewed separate from the fat tissue surrounding it. ChapVolumes uses color, opacity, and shading of material boundaries to isolate and highlight these areas.

Four views of the pelvis of a patient. Color is used to distinguish soft tissue and bone. In the bottom half, the fat tissue is made transparent, allowing visualization through to the muscle. In addition, surface texture such as muscle striations is brought out by assigning appropriate refractive indexes to the muscle and fat tissue. In the top half, the bone is isolated from the surrounding muscle by making the soft tissue as well as the fat transparent. Data courtesy of Philips Medical Systems, Inc.



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SOFTWARE DEVELOPMENT

ChapVolumes is a set of library routines that lets graphics developers program the Pixar Image Computer to produce volume rendering applications for specific data. ChapVolumes includes subroutine libraries for data transfer, image generation and processing, and image transformation.

Only available on the Pixar Image Computer, ChapVolumes takes advantage of the parallel processor, large display memory, and full-color pixel data structure of the Pixar Image Computer, which are essential for the computation- and memory-intensive operations of volume rendering.

ChapVolumes can be integrated with our other Pixar software, extending the usefulness of the product. ChapTools™, our toolkit for developers, provides the Chap™ C compiler, assembler, and dynamic loader. Pixar's ChapLibraries™ software features routines for arithmetic operations, image manipulation, line drawing and text display operations, and image processing functions. And, for surface rendering, ChapReyes™ generates very fast, high quality images of three-dimensional geometric models.

A GLOSSARY FOR VOLUME RENDERING

Because volume rendering is a new, advanced imaging technique, certain terms have evolved to define the volumetric concepts.

assignment — give values for color, opacity, and **refractive index** to each volume element. Example: in a medical image muscle might be assigned a rose color, 50% opacity value, and 85% refractive index, while bone might be assigned an ivory color, 70% opacity value, and 95% refractive index. The muscle would be partially opaque, allowing bone to be partially visible through the muscle. The bone surface would be very distinct (because of the difference in refractive index between the muscle and bone). Because of the slight transparency of the bone, we would be able to see into the bone but not much behind it.

classification — determine the percentages of each material present in a volume. Example: a component undergoing non-destructive testing might be classified into its percentages of steel, aluminum, and ceramic.

opacity — the capacity of a material to obstruct the viewing of objects which lie behind it. Opacity is the opposite of *transparency,* which is the ability to see through a material.

refractive index — the property assigned to a material to allow surfaces between materials to be defined. When two materials of different refractive indexes meet, a surface occurs. For example, in a mixture of ice suspended in water, the viewer can see a surface between the ice and water (even though both ice and water are transparent), because we assign different refractive indexes values to the ice and water.

surface rendering — the process of generating images of three-dimensional surface data from a set of mathematically defined surfaces.

volume element — a three-dimensional pixel. Each point in a volume is called a volume element. (A volume element is sometimes referred to as a *voxel.*)

volume rendering — the process of generating images of three-dimensional volumes from a set of volume data.

COVER IMAGES (left to right, top to bottom)
ENGINEERING ANALYSIS: Stress analysis results from a finite element model of a mechanical part. Data courtesy of Harris Hunt, PDA Engineering.
PHYSIOLOGY: Whole body reconstruction of the musculoskeletal system of a sea otter. Data courtesy of Dr. Michael Stoskopf, The Johns Hopkins Hospital.
MEDICAL IMAGING: Reconstruction of a human pelvis from 48 CT scans. Created by Pixar. Data courtesy of Philips Medical Systems, Inc.
FLUID DYNAMICS: Image shows how laminar flow breaks down and becomes a turbulent vortex. Data derived by scanning a puff of smoke with a laser and recording the particulate densities. Courtesy of Professors Juan Agüi' and Lambertus Hesselink, Department of Aeronautics and Astronautics, Stanford University.
MEDICAL IMAGING: Reconstruction of human chest and upper shoulders from 38 slices of CT data. Image courtesy of Dr. Elliot Fishman, The Johns Hopkins Hospital.

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