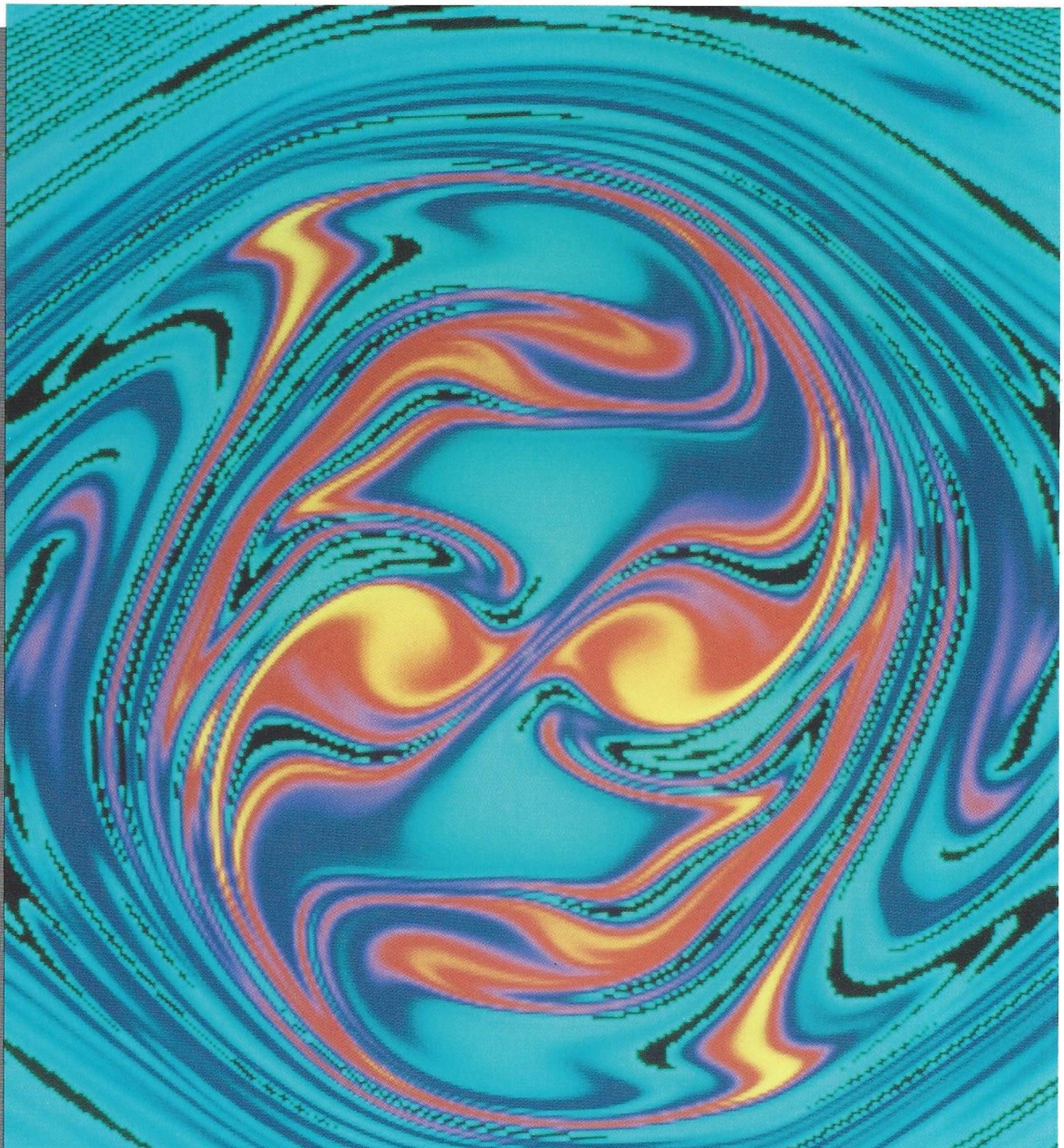
Supercomputer applications



CRAY

The computational laboratory

Cray Research computer systems are acknowledged widely as the world's most powerful general-purpose computing systems. Their speed and memory size enable researchers to model large and complex physical structures and processes mathematically. Scientists and engineers use computer modeling to study phenomena that are too small, large, quick, slow, or dangerous to observe directly. Using this method, scientists acquire greater insight into the complex inner workings of the world around us. Engineers using this method acquire greater freedom to explore novel designs and to test new designs carefully before they are committed to production. In addition to performing large-scale simulations cost-effectively, Cray systems frequently are used to translate the resulting data into graphic form for easier interpretation. In government, academic, and industrial laboratories, Cray systems provide users with the most accurate, detailed, and profitable results possible.

This brochure describes established uses of Cray computer systems. Along with these, new applications are evolving continually. Newer applications include genetic sequence analysis, linear programming for resource management, economic and financial modeling, discrete event simulation for factory management, and coupled symbolic/numeric processing that integrates the expertise of the scientist or engineer into the simulation process.

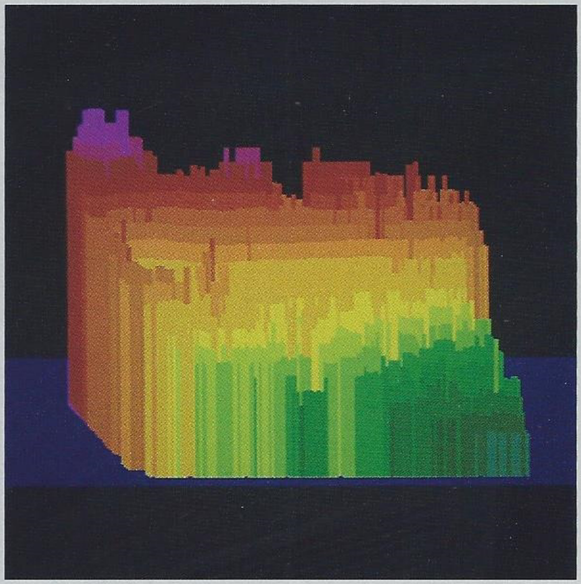
Petroleum exploration

Oil companies and geophysical contractors use Cray systems to process the large quantities of seismic data produced by reflection seismology, a method of geological exploration. The method involves first inducing a shock into the ground, usually with specially designed hydraulic devices. The resulting sound waves travel down through layers of rock and are reflected back to the surface from various geologic structures. Analyzing the reflected data can reveal underground features that may indicate the presence or absence of petroleum and natural gas.

The quantity of data needed to accurately profile a large volume of earth can be immense, and the required analyses are staggeringly complex. Only large-scale computers such as Cray systems can perform the necessary calculations in a timely and cost-effective manner.

Furthermore, Cray systems have allowed geophysicists to regularly perform three-dimensional processing and modeling, a more complex and more accurate process than traditional two-dimensional processing and modeling.

By making the processing of these large quantities of seismic data practical, Cray systems increase a geophysicist's understanding of a prospect area and maximize the opportunities for productive drilling. In this way, Cray systems are helping to find new oil and gas reserves while preserving the resources of petroleum companies and the environment.



Three-dimensional representation of processed seismic data courtesy ARCO Oil and Gas Company.

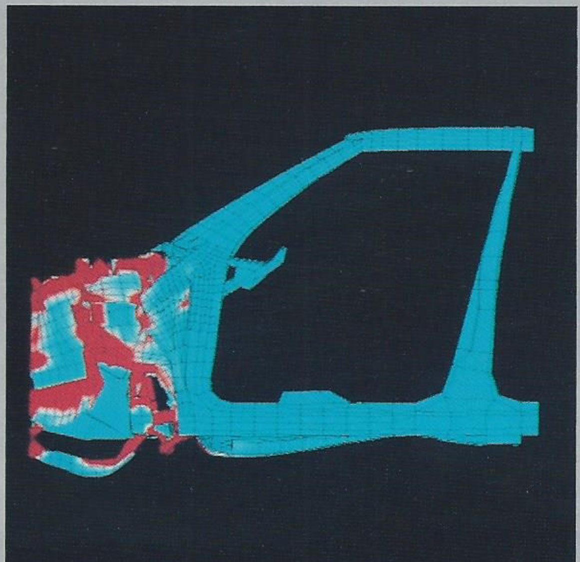
Petroleum production

The first Cray computer system installed in the petroleum industry was ordered by the Atlantic Richfield Company (ARCO) in 1981. ARCO obtained the system to run models of the complex flow phenomena that characterize petroleum recovery. Recovery operations often involve injecting a pressurized gas, water, or water plus a detergent-like chemical into an oil reservoir. This procedure mobilizes trapped oil and pushes it to the surface. To determine the best recovery strategy for a particular reservoir, engineers must consider the underground temperature and pressure, the chemical makeup of the petroleum, and the reservoir's geology. Cray systems offer an opportunity to model the interactions among these variables for large and complex petroleum reservoirs. Because an increase in reservoir output of only a few percent can translate into millions of dollars, Cray systems are among the petroleum industry's most valuable and cost-effective production engineering tools.

Varying concentration of underground oxygen from simulated hydrocarbon biodegradation experiment courtesy C. Dawson, M. Wheeler, Rice University.

Structural analysis

Finite element analysis is a mathematical method of studying the integrity of mechanical structures; it is a tool applied widely in the aerospace, automotive, and civil engineering industries. Engineers use this method by describing a proposed aircraft wing, automobile frame, bridge, or other structure with a two- or three-dimensional grid that divides the structure into a number of well-defined elements. This allows the engineer to simulate the response of the structure to a variety of load and constraint conditions as part of the design process. Cray systems enable engineers to conduct rapid finite element analyses, thus improving engineering efficiency and resulting in more structurally sound and lightweight components.



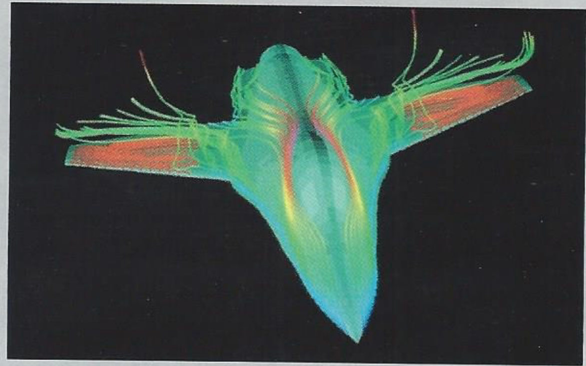
Computed crashworthiness test of BX car model courtesy Peugeot S. A.

Computational fluid dynamics

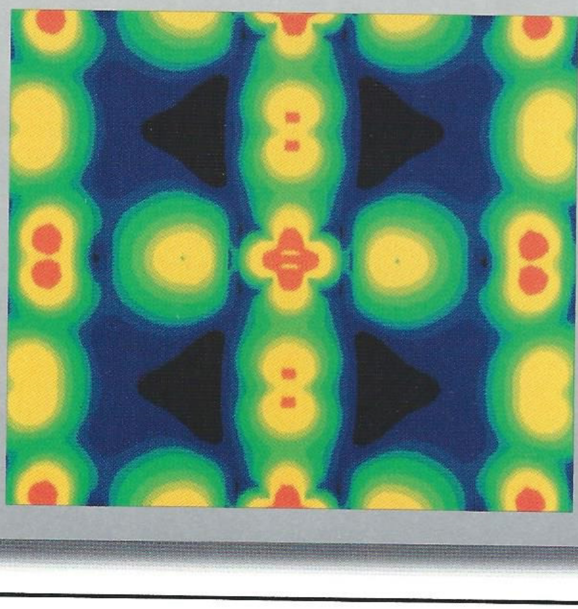
Aircraft designers long have relied on wind tunnels to evaluate the aerodynamics of airplanes and airplane sections. But wind tunnel tests require the time-consuming and costly construction of physical models. Wind tunnels also are expensive to maintain and cannot reliably detect certain airflow phenomena. Cray systems enable designers of airplanes, helicopters, automobiles, and ships to compute the fluid flow around proposed shapes quickly and then modify designs accordingly.

Streamlining designs computationally can provide a decisive advantage, as it did for *Stars & Stripes*, the winning yacht in the 1987 America's Cup competition. Designers used a Cray computer system to modify the yacht's design and shave critical seconds from its racing time. The ease with which designs can be modified on a computer encourages designers to experiment. In the case of *Stars & Stripes*, designers evaluated more than 300 designs on a Cray system before selecting the final hull design.

Grumman Aerospace Corporation, Cray Research's first commercial aerospace industry customer, purchased a Cray system in 1981 to model fluid dynamics for aircraft design. Today, research using Cray systems is conducted at many of the world's major aerospace companies. In addition, the U.S. National Aeronautics and Space Administration (NASA) is using Cray systems extensively to explore design alternatives for the national aerospace plane project. The processing power of Cray systems enables researchers to model aerospace plane performance at speeds up to Mach 25. Tests using conventional wind tunnels typically are limited to evaluating performance at speeds of Mach 8 or less. Consequently, development of the national aerospace plane would be impossible without Cray systems.



Streamlines over a modified F-16 configuration courtesy NASA Ames Research Center.

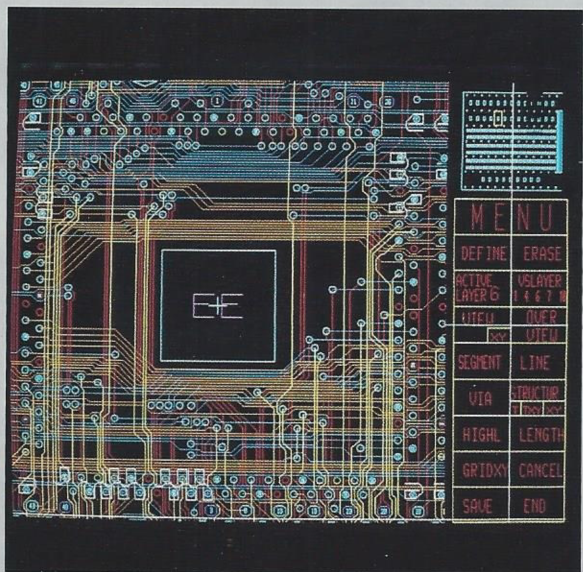


Computational physics

In some fields of physics, including branches of quantum physics and condensed matter physics, experimentation is difficult if not impossible. The subatomic world of quantum events is too small for direct observation and some modern theories can be tested only at high temperatures unobtainable in typical laboratory settings. However, where the mathematics is understood, computer modeling is a practical alternative to experimentation. Cray systems enable physicists to experiment on mathematical models of atomic and subatomic structures and so test and refine their theories faster than would be possible otherwise. Government laboratories rely on Cray systems extensively to model the complex interactions among atomic particles in magnetic and laser fusion research.

Contour map of the electronic charge around copper and oxygen atoms in the superconductor $YBa_2Cu_30_7$ courtesy S. Massidda, Jaejun Yu, A. J. Freeman, Northwestern University; and D. D. Koelling, Argonne National Laboratory.

Electronic design



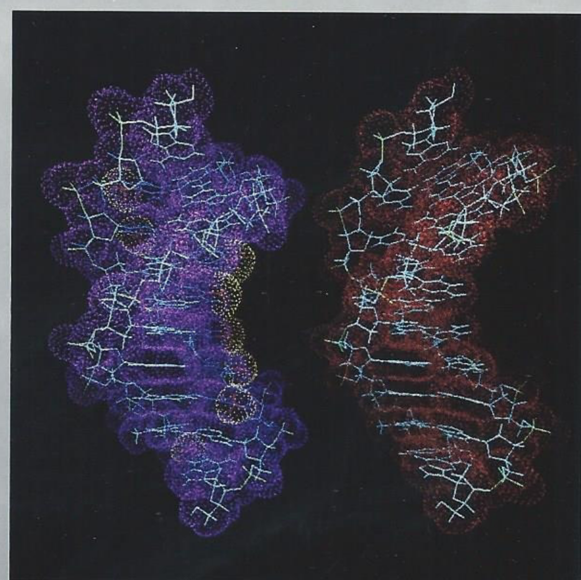
Designers of electronic components increasingly are using computer-aided design (CAD) methods that enable them to design and test components by modeling rather than by building and testing actual parts at each step in the design process. The complexity of today's electronic components and competitive pressures for faster design turnaround make Cray systems invaluable tools for CAD. Cray systems are used in the electronics industry to model logic circuit layout, system architecture, timing, design-rule checking, and other applications.

The payoff from applying Cray systems to electronic CAD can be extraordinary. Fairchild Semiconductor Corporation, for example, acquired a Cray system to design application-specific integrated circuits and has used the system to reduce by two-thirds the turnaround time needed for new circuit design. Cray Research itself uses Cray systems to design electronic components for use in future Cray products.

Routing display of a printed circuit board being designed for a future Cray computer system.

Computational chemistry

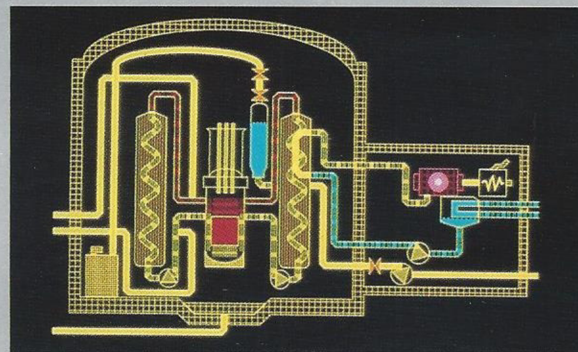
Computer modeling is an invaluable tool for studying molecular interactions, which can occur in a matter of picoseconds (trillionths of a second). Computer models of atomic and molecular systems can provide information about chemical reaction rates, properties of synthetic polymers, and the shapes of macromolecules containing thousands of atoms. Chemists use computer models to study the fundamental physics underlying molecular behavior, paving the way for new discoveries in materials science, medicine, and agriculture. The detailed and highly iterative mathematics involved in such modeling demands the computational capacities of a supercomputer. The DuPont Company became the first customer to install a Cray system for computational chemistry research. In laboratories around the world, researchers are using Cray systems to help design pharmaceuticals and polymers; to study combustion, catalysis, and atmospheric chemistry; and to model genetic material for biotechnology applications.



Model of human DNA sequence courtesy National Cancer Institute.

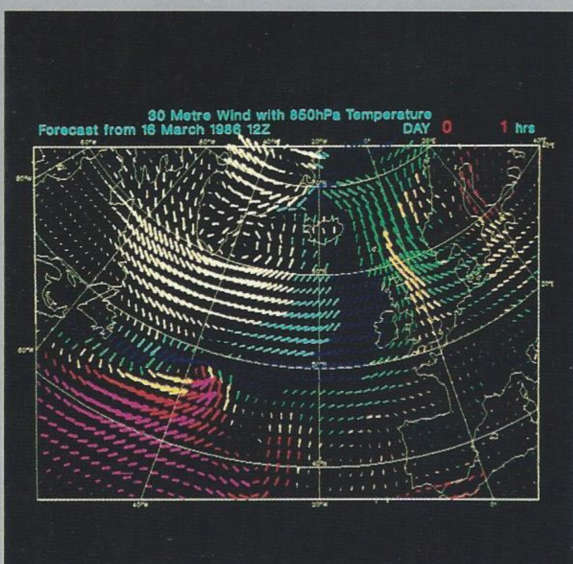
Nuclear energy research

As nuclear reactors grow in complexity (and safety concerns grow as well), proposed reactor designs must be evaluated on the most advanced computer systems available. Computer models of power plants are used extensively in the design and licensing of reactors in several countries. Only Cray systems provide the computing power needed to simulate in detail the intricate fluid flow, heat transfer, and neutronics phenomena that characterize nuclear power plants. Cray systems are used in the energy industry to help design reactors, implement automatic process control, analyze reactor conditions, and determine accident mitigation procedures. Running accident experiments on full-scale reactors is often impractical. However, computer modeling on Cray systems provides an opportunity to evaluate many safety issues related to reactor design and operation.



Pressurized water nuclear reactor model courtesy Patrick Hodson, Los Alamos National Laboratory.

Meteorology



Representation of a ten-day forecast for the North Atlantic courtesy ECMWF.

Laboratories for the study of weather and climate in the United States, Canada, and Europe rely on Cray systems to run large numerical models of the Earth's atmosphere. Such models typically must account for phenomena such as evaporation and condensation, solar heating, cloud movement, and thermal and fluid dynamics. Computing the interactions among these variables for enormous spatial volumes over long durations is a task for which Cray systems are ideally suited. The computing speed and storage capacity of Cray systems enable meteorologists to generate accurate forecasts quickly. The European Centre for Medium-range Weather Forecasts (ECMWF), recently shown to have the most accurate forecasts in the world, uses Cray systems to run production weather models and to conduct meteorological research. The cost savings from improved forecasts can be enormous in agriculture, transportation, and other areas.

The U.S. Air Force Global Weather Center, for example, estimates an aircraft fuel savings of $13-40 million annually thanks to improved forecasts derived from large atmospheric models executed on the center's Cray computer system. The improved predictions allow the Air Force to direct aircraft around storms and turbulence more effectively.

Meteorological researchers also use Cray systems to study a variety of weather-related phenomena, such as pollutant transport and wind shear, a hazard to low-flying aircraft.

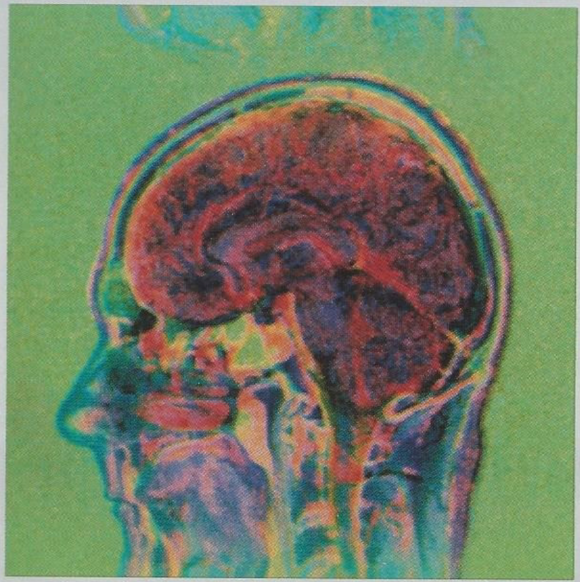


Image processing

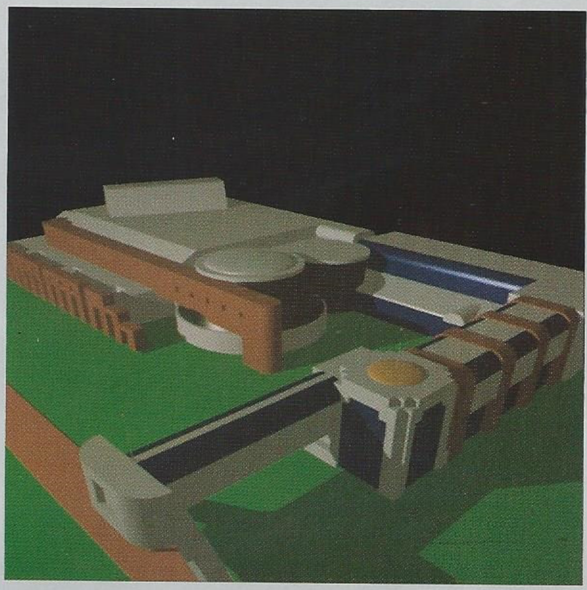
Earth-imaging satellites, space probes, and medical imaging devices generate tremendous amounts of data that need to be processed extensively to yield useful images. The images produced by these technologies often must be enhanced to make significant features more identifiable, or corrected geometrically to remove distortions imposed by the imaging device itself. Processing large, complex images can be computationally demanding because such images may comprise millions of tiny dots, called picture elements or pixels, each of which may be defined by many variables relating to color and intensity. Processing such large quantities of data in a practical timeframe requires the processing speed of Cray systems. Whether used to scan the Earth for resources, to analyze light from a supernova, or to track down deadly tumors, Cray systems meet the challenge of the most demanding image processing applications.

Processed magnetic resonance image courtesy M. Mixel, University of Minnesota.

Graphics

The need to analyze and understand the results of simulations performed on Cray systems has made computer graphics itself an important application. Researchers use many techniques and programs and many graphics hardware systems to display and study the results of their calculations. Increasingly, the processing capabilities of Cray systems are enabling scientists and engineers to simulate dynamic processes. Generating movies of results rather than still images is therefore becoming standard practice. Often the creation of such a movie is as computationally intensive as the simulation itself, but movies provide an opportunity to understand simulation results in much greater detail than still images do.

Cray systems also are used to generate commercial imagery for motion pictures and advertisements. In addition, Cray systems have been used to compute "fly-through" films of architectural models, enabling architects and clients to view a proposed structure from any angle or elevation.



Model of a performing arts theater generated with a Cray computer system.

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Cover: Star density in a two-dimensional phase space for a gravitational two-stream instability courtesy P. Woodward and M. Ondrechen, University of Minnesota.