Visualization Captures the Imagination of Physicists

Larry Smarr

Researchers are putting visualization techniques to work and experimenting with sound, advanced graphics, and "virtual reality"

During the four years since *Computers in Physics* was first published, scientific visualization has moved from being a novelty to being a routine tool of computational physics. This trend will continue, with additional capabilities coming from several emerging technologies, including sonification, high-definition technologies, and virtual reality, coupled with advanced forms of computer graphics, image processing, video, and multimedia. The result will be a "metavisualization" or "integrated sensory" environment of much greater power than is available today.

From 1D to 3D

Physicists have always used visualization techniques; however, these have largely been simple line graphs of one-dimensional data sets, which were as often done by hand on graph paper as they were done by computer. Today a variety of commercial products are available for personal computers and workstations (hereafter referred to as desktop computers) that allow for a wide range of graphing capabilities with automatic links to data tables. Scientists use visualization, even in this simple context, to ascertain trends and relationships graphically in a much better way than one can by reading tables of numbers. This basic characteristic of the human eye-brain system is part of the reason for using sophisticated techniques of scientific visualization on increasingly complex data sets.

During the past few years, with the advent of less expensive memory, desktop computers have become routinely capable of supporting two-dimensional color raster images. This enables physicists to visually represent functions of two variables, by using a color map to convert the function values into 256 color values. The shift from line graphs to 2D raster graphics has permitted new software tools to be brought to the desktop (such as NCSA Image for the Apple Macintosh), which use powerful techniques of image processing previously available only on expensive graphics workstations. Just as they did in specialized fields, such as radio astronomy and medical imaging, these tools have enabled physicists to change color maps easily, in order to bring out the dynamic range inherent in their data.

As a result, the researcher is able to shift from scanning one-dimensional information (slopes, discontinuities, relative values, etc.) to two-dimensional pattern analysis (identifying wave fronts, vortices, mixing layers, etc.). In addition to analyzing computer simulations, such visual approaches have become the standard tool for examining the structure of complex mathematical functions such as fractals.

Three-dimensional visualizations became possible in an interactive fashion on powerful graphics workstations. Specific fields that made heavy use of such 3D techniques, such as molecular biology, witnessed a move from vector graphics machines (such as that made by Evans and Sutherland) to raster graphics computers (such as those produced by Silicon Graphics, Inc.). However, outside these traditional scientific visualization subfields, the

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lack of application-specific software and the high entry price of the hardware resulted in few physicists using these devices.

Animation

During this same period, the frontier of scientific visualization was at first defined by teams of computer graphics experts and computer artists working with specialized graphics software that allowed for the creation of time-varying 3D representations of scientific data. These individual masterpieces were both computationally intensive and labor-intensive, but they gave us our first experience in visualizing realistic dynamic computational realities. Videotapes containing these animations of numerical simulations went from being a show-stopping oddity to becoming a normal part of scientific conferences. Unfortunately, the creation of these videotapes remained technically difficult and time-consuming; either they were done by central facilities at supercomputer centers or by leading-edge computational researchers with access to specialized animation recording systems.

Today, after a period of several years of assimilation of these new modes of research, we are once again encountering a flood of new technologies onto the desktop, many of which are removing these remaining problems. Analytical investigations are now amenable to visualization as a result of symbolic computing packages with visualization front ends (such as Mathematica from Wolfram Research, Inc.). There are now commercial software offerings (such as that from Spyglass, Inc.) for desktop 2D image processing and 3D volumetric analysis. Network-distributed volumetric-analysis software has become available in the public domain (e.g. NCSA Viewit). Surface-rendering packages for analyzing 3D data sets on the desktop are being developed by several sources (such as AVS from Stardent Computer, Explorer from Silicon Graphics, Inc., ApE from the Ohio Supercomputer Center, FAST from Sterling Software, and PolyView from NCSA). The development of desktop video production systems will soon make the creation of visualization research notebooks and presentations common among researchers, although at lower resolution than what is viewed on the desktop computer.

Finally, inexpensive desktop computers that combine interactive 3D graphics with high-quality digital sound have arrived. An example is the recently announced Indigo from Silicon Graphics, Inc. This development clearly calls for more sophisticated software with integrated use of sound and visual techniques for representing and analyzing data.

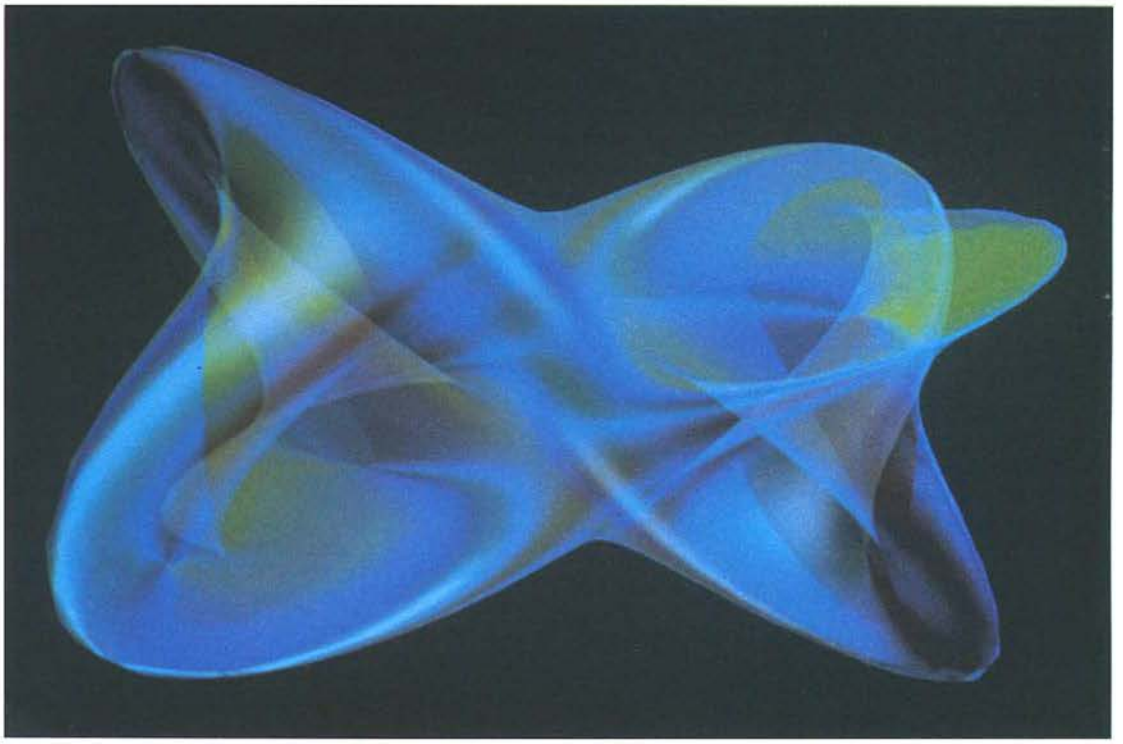


Fig. 1: High-resolution image visualizes the Romboy Homotopy, a complex deformation in four-dimensional space. The image was rendered with Wavefront, Inc. software using a Cray Research X-MP, an Alliant FX/80, and a Silicon Graphics IRIS 4D/70G. Work was done by computer artist Donna Cox, mathematician George Francis, and computer scientist Ray Idaszak at NCSA and at the University of Illinois at Urbana-Champaign.

The Power of Networking

What can we expect to be on our desktop by the mid-decade? One of the most important changes will be the higher bandwidth and universal connectivity brought about as the Internet evolves into the National Research and Education Network. This will allow for geographically dispersed researchers to hold simultaneous work sessions with new collaboration software, supporting multiple-windowed screens which will display the same information to each participant. These windows will hold text, graphics, computer code, numerical arrays, and other "live" data

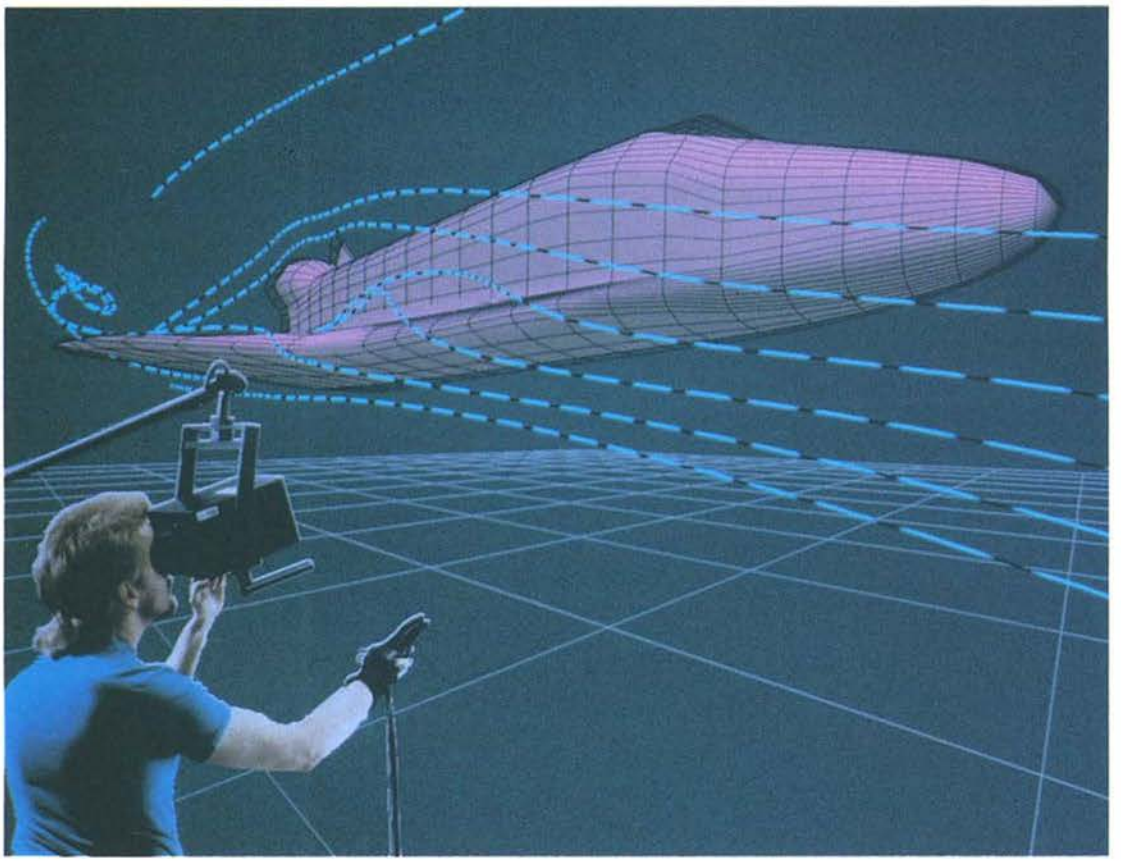


Fig. 2: Virtual Windtunnel, developed at NASA Ames by Steve Bryson and Creon Levit, immerses a researcher in a computer simulation of air flow around the Shuttle. The user sees the graphics in three-dimensional head-tracked wide-field stereo, using the Fake Space boom, and controls the position of the streamlines via the VPL Dataglove.

types. NCSA is developing a version of this software, built on its previous suite of imaging and analysis tools for Mac, X-UNIX, and Windows-DOS user interfaces, so that multiple-vendor machines can engage in the same scientific conversation with full data and scientific visualization support. Audio and video teleconferencing will merge with this scientific workspace by the mid-1990s to create a nationwide information space in which scientific colleagues can work with each other from their home offices.

Currently there is still a wide gap between the visual representation capabilities of the most sophisticated computer graphics software (such as that from Wavefront, Inc.) and the 3D rendering software for desktops mentioned above. Exploring three and four dimensions visually requires at least as big a conceptual jump as that which we experienced in going from 1D line graphs to 2D raster imaging. One has to consider a wide range of visual methodologies for representing the data (multiple light sources, frame of reference of the viewer, transparency, hidden lines, etc.). For these software tools to truly become tools of scientific inquiry, a great deal of this complication must be hidden from the researcher. This will probably require the development of artificial-intelligence software aids, which capture the expertise of computer graphics professionals and computer artists. We will also need a great deal more compute power and memory on the desktop to deal effectively with the data size and rendering complexities.

One of the most important applications of advanced image and signal processing will be in laboratory instrumentation. Almost any leading-edge instrument in the lab today comes equipped with a computer to handle the instrument control, data collection, and analysis. These computers are typically personal computers or low-end UNIX workstations. By coupling these smaller computers through the network into remote powerful computers, one can turn batch operation of the instrument into real-time operation. By computing the data stream in real time and then using scientific visualization to give an instant image of what is being observed, one can control the instrument while the experiment is going on. For instance, NCSA is utilizing advanced visualization techniques in a project with the Tunneling Microscopy Laboratory, in the Beckman Institute at the University of Illinois, to permit real-time instrument feedback, so that researchers can perform atomic-level modification of semiconductor surfaces and device structures. This is the digital version of the time-honored analog method of looking through a light microscope and turning the focus knobs or moving the slides with one's hands. All of this can be run, in principle, from a networked personal computer using distributed image- and volumetric-processing software.

Sound and HD Imaging

Digital sound is emerging in the workstation world, with the result that data sonification is rapidly becoming a serious application to com-

plement visualization. In sonification, one passes the user's data set through a sound map, rather than a color map. At NCSA we have experimented with mapping the transition to chaos, fractal mathematics, ecological data, and fluid dynamics to the sound domain. The ear seems to be much more quantitative than the eye in picking up Fourier components or small and growing differences between functions. Sonification options will soon be available in desktop software so that one can use a combined audiovisual map to analyze scientific data.

Although high-definition (HD) imaging technologies are discussed in the United States primarily as the standard for the next generation of consumer television, they will have a profound effect on computing. HD technologies have the potential to unify the currently separate video and computer-graphics environments, eventually emerging as the standard for image display, transmission, and storage for scientific visualization in the next decade. For instance, in the next year HD frame buffers of high resolution and gigabit/s transfer rates will become available to add "windows" into supercomputers. HD technologies are also well suited to be a domain for video recording at resolutions comparable to computer graphics formats. As mentioned above, current NTSC video formats are of low resolution and are not satisfactory as the "video hardcopy" for computer graphics imagery, since they cannot handle the 1280x1024 pixel 70-Hz resolution of modern color workstations. In contrast, HD formats as large as 2048x1280 pixels are currently being discussed. Thus, HD technologies can provide accurate video hardcopy, recording and storage for scientists' imagery—an important functionality not currently available.

Virtual Reality

Even with the above improvements, one is still trying to create a three-dimensional world on a two-dimensional screen. The viewer is unable to "go inside" the artificial reality which has been computed, and to interact with it in the way in which we are used to interacting with time-changing three-dimensional physical reality. A new generation of systems is rapidly changing this nonimmersive paradigm. Termed "virtual reality" (VR), these technologies involve replacing the computer screen either with small displays located close to the eye, or with enclosed environments such as those found in flight simulators. A combination of "multimodal" computer/human interfaces (such as stereo positional viewing and advanced input devices) transports the user into the computational space.

In VR, the user is "in" a simulation, directly manipulating its parts. Those who have been "in" a VR system report that the engagement is intense and greatly enhances the perceptual and cognitive connection to a computational simulation. VR technologies are maturing rapidly, and, despite media hype, cannot be ignored as a scientific visualization technology. In advanced computer laboratories, such as NASA Ames, NASA Goddard, NCSA, the Electronic Visualization Laboratory at the University of Illinois at Chicago, the MIT Media Lab, and the University of North Carolina, these technologies are currently being used to investigate biomolecules, engineering design, plasma physics, mathematical functions, and general relativity and cosmology. It would seem that there may be very useful applications of VR in electron structure of materials and in quantum chemistry.

Not only will these emerging technologies provide new capabilities by themselves, but there will be a synergistic effect as they begin to combine with each other into a metavisualization environment. Within the next several years, VR should benefit from work with HD technologies. Displays are being planned which will use small HD-format liquid crystals to deliver a high-resolution virtual display. Within a year, VR will use 3D sound beacons to add to the positional sense in the VR space. The compute engine most commonly used to do the visual rendering is a multiprocessor Silicon Graphics VGX, which couples all we have learned about advanced computer graphics rendering to the VR environment.

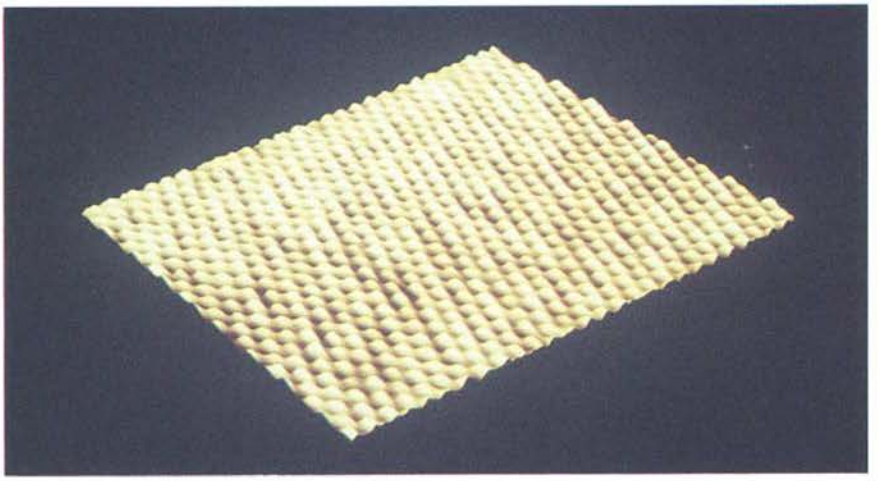


Fig. 3: Atomic-level image of a gold metal surface derived from data taken with a scanning tunneling microscope. The image was rendered by a Stardent Computer in the Tunneling Microscopy Laboratory of Joe Lyding and John Tucker, in the Beckman Institute of the University of Illinois at Urbana-Champaign.

Finally, the development of multimedia workstations will create a hardware platform for delivering these new technologies to the user's desktop, with the national network connecting all of these desktops to each other. The result will be an ever closer coupling of the human sensory system to the output of computers, thereby creating a more intuitive ability for us to study the complex solutions of the laws of physics.

Acknowledgments

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