VISUALIZATION IN SCIENTIFIC COMPUTING[1]

Definition, Domain and Recommendations

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1. DEFINITION OF VISUALIZATION

Visualization is a method of computing. It transforms the symbolic into the geometric, enabling researchers to *observe* their simulations and computations. Visualization offers a method for seeing the unseen. It enriches the process of scientific discovery and fosters profound and unexpected insights. In many fields it is already revolutionizing the way scientists do science.

Visualization embraces both image understanding and image synthesis. That is, visualization is a tool both for interpreting image data fed into a computer, and for generating images from complex multi-dimensional data sets. It studies those mechanisms in humans and computers which allow them in concert to perceive, use and communicate visual information. Visualization unifies the largely independent but convergent fields of:

- Computer graphics
- Image processing
- Computer vision
- Computer-aided design
- Signal processing
- User interface studies

Richard Hamming observed many years ago that *"The purpose of [scientific] computing is insight, not numbers."* The goal of visualization is to leverage existing scientific methods by providing new scientific insight through visual methods.

An estimated 50 percent of the brain's neurons are associated with vision. Visualization in scientific computing aims to put that neurological machinery to work.

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2. DOMAIN OF VISUALIZATION

2.1. Problem: The *information-without-interpretation* dilemma

Today's data sources are such *fire hoses* of information that all we can do is gather and warehouse the numbers they generate. High-volume data sources include:

- Supercomputers
- Orbiting satellites returning earth resource, military intelligence, weather and astronomical data
- Spacecraft sending planetary and interplanetary data
- Earth-bound radio astronomy arrays
- Instrumental arrays recording geophysical entities, such as ocean temperatures, ocean floor features, tectonic plate and volcanic movements, and seismic reflections from geological strata
- Medical scanners employing various imaging modalities, such as computed transmission and emission tomography, and magnetic resonance imagery

2.1.1. The need to deal with too much data

There is every indication that the number of sources will multiply, as will the data density of these sources. For example, the definition of a supercomputer is changing from its former meaning of 0.1 - 1.0 gigaflops (billions of floating point operations per second) to 1 - 10 gigaflops. Also, current earth resource satellites have resolutions 10-100 times higher than satellites orbited just a few years ago.

Scientists involved in the computational sciences require these data sources in order to conduct significant research. Nonetheless, they are deluged by the flood of data generated. Using an exclusively numerical format, the human brain cannot interpret gigabytes of data each day, so much information now goes to waste.

Earth resource satellites sent up years ago are still transmitting data. All scientists can do is warehouse it. The technology does not exist for receiving, analyzing and presenting information in such a way that it is useful to scientists.

2.1.2. The need to communicate

Visualization by shared communication would be much easier if each of us had a CRT in the forehead. We speak — and for 5000 years have preserved our words. But, we cannot share vision. To this oversight of evolution we owe the retardation of visual communication compared to language. To overcome the bottleneck, scientists need improved visual interaction (1) with their data and (2) with each other.

1. The ability of medical doctors to diagnose ailments is dependent upon vision. Today, medical imaging is a computational science dependent upon visualization techniques. For example, in hip replacement operations, custom hips can now be fabricated in advance of surgical procedures. Accurate measurements can be made prior to surgery using non-invasive 3D imaging, reducing the number of post-operative body rejections from 30 percent to only 5 percent.

2. Scientists must learn to visually communicate with one another. Much of modern science cannot be expressed in print. DNA sequences, molecular models, medical imaging scans, brain maps, simulated flights through a terrain, simulations of fluid flow, and so on, all need to be communicated visually.

2.1.3. The need to steer calculations

Scientists not only want to analyze data that results from super-computations; they also want to interpret what is happening to the data during super-computations. Researchers want to *steer* calculations in close-to-real-time; they want to be able to change parameters, resolution or representation, and see the effects. They want to drive the scientific discovery process; they want to *interact* with their data.

The most common mode of visualization today at national supercomputer centers is batch. *Batch processing* defines a sequential process: compute, generate images and plots, and then record on paper, videotape or film.

Interactive visual computing is a process whereby scientists communicate with data by manipulating its visual representation during processing. The more sophisticated process of *navigation* allows scientists to *steer*, or dynamically modify, computations while they are occurring. These processes are invaluable tools for scientific discovery.

Immediate visual feedback can help researchers gain insight into scientific processes and anomalies, and can help them discover computational errors. For example, one astrophysicist found an erroneous boundary condition in his code after examining an image of a jet stream with an obvious reflection not apparent in the numbers.

2.2. Solution: Visualization technology

Scientists need an alternative to numbers. A technical reality today and a cognitive imperative tomorrow is the use of images. The ability of scientists to visualize complex computations and simulations is absolutely essential to insure the integrity of analyses, to provoke insights and to communicate those insights with others.

Several visually oriented computer-based technologies already exist today. Some have been exploited by the private sector, and off-the-shelf hardware and software can be purchased; others require new developments; and still others open up new research areas. Visualization technology, well integrated into today's workstation, has found practical application in such areas as product design, electronic publishing, media production and manufacturing automation. Management has found that visualization tools make their companies more productive, more competitive and more professional.

So far, however, scientists and academics have been largely untouched by this revolution in computing. Secretaries who prepare manuscripts for scientists have better interactive control and visual feedback with their word processors than scientists have over large computing resources which cost several thousand times as much.

Traditionally, scientific problems that required large-scale computing resources needed all the available computational power to perform the analyses or simulations. The ability to visualize results or guide the calculations themselves requires substantially more computing power. Where will this power come from? The following section considers these needs.

3. RECOMMENDATIONS FOR A ViSC INITIATIVE

3.1. The ViSC Initiative

This report supports the implementation of a federally funded ViSC (Visualization in Scientific Computing) initiative. It explores the developing synergy of science and visualization, and makes recommendations to nurture its successful growth and development. This initiative proposes to place high-quality visualization tools in the hands and minds of research scientists and engineers.

3.2. Areas of funding

The proposed ViSC initiative recommends the funding of both research and technology developments, immediately and in the long-term. Research developments are the responsibility of *tool users*, experts from engineering and the discipline sciences who depend on computations for their research. Technology developments are handled by *tool makers*, the visualization researchers who can develop the necessary hardware, software and systems.

Recommendations for a National ViSC Initiative

	VISUALIZATION Short-term Needs	VISUALIZATION Long-term Needs
TOOL USERS Computational Scientists and Engineers	Funding to incorporate visualization in current research	Funding to use model visualization environments
TOOL MAKERS Visualization Scientists and Engineers	No funding necessary	Funding to develop model visualization environments

3.2.1. Tool users, short-term visualization needs

Established user communities, funding realities and special needs felt by advanced scientific research facilities, primarily the national supercomputer centers, have encouraged a situation where resources have been devoted to raw megaflops for arithmetic computation, rather than to visualization.

Workstations, minicomputers and image computers are significantly more powerful and effective visualization tools than supercomputers. It is a waste of supercomputer cycles to use them to convert model data into new pictures. Specialized graphics processors are more cost-effective than supercomputers for specialized picture processing and/or generation. Workstations should be placed on the desks of each and every researcher to give them immediate access to local graphics capabilities. Every scientist and engineer should have a personal workstation, just as people who must drive for a living need access to cars. Workstations range in price from $5,000 to $100,000.

We must also provide concentrated visualization tools to advanced scientific research facilities. Every research center should provide on-site capabilities and facilities for high-end visualization. Visualization equipment and projects should be considered in competition with more memory, more disks, more networking, and so on, to provide a balanced response to user needs.

3.2.2. Tool users, long-term visualization needs

Commercially available visualization hardware and software are undergoing large-scale development akin to the growth of advanced scientific computing in general. Software is all development cost and no manufacturing cost, so its profitability and maintenance depend on its user base. Hardware does have manufacturing cost, typically 10 to 50 percent of the list price, but this drops with continued sales and the general decline in component prices. Workstations and image computers with impressive power fit on desktops and are well integrated into local networks. Advanced concepts of user interface are being developed and marketed. As long as one's science and engineering needs fit a product line developed for a commercial market niche, all is well.

If researchers only have access to instruments and software supported by pre-existing business demands, they will not be able to push the frontiers of science. Since many new companies are launched as a result of significant scientific discoveries made within research environments, the private sector itself may stagnate if researchers are deprived of adequate tools. Unfortunately, the universities, which have traditionally nurtured basic science without immediate market promise, do not themselves present a large enough market to stimulate the private sector development of leading-edge visualization tools[1].

To encourage the development of visualization tools for scientific and engineering research, interactions must be fostered between scientists, engineers and visualization experts. These interdisciplinary groups should be expected to develop, document, use, and publish both (1) useful results in their discipline, and (2) effective visualization software and documentation. Scientists and engineers need to rely on the experience and intuition of visualization experts to anticipate which representations best convey the information distilled from a cascade of numbers from a supercomputer; the visualization experts need to rely on scientists and engineers to point out the crucial information which flows from the underlying science of a problem.

Hence, we encourage the support of interdisciplinary research teams, rather than just facilities, to ensure that long-term visualization developments be grounded in *real* problems. Close interaction between scientific investigators and visualization technologists will foster better communication between researcher and computer, and between researcher and researcher. The resulting effective and reusable tools can then be shared with scientists and engineers in other research areas, and within the research community at large.

3.2.3. Tool makers, short-term visualization needs

At present, commercial industry supports visualization hardware and software. A pressing need is to bring the scientific and engineering communities up to speed using the commercial equipment available. Within this short time span, there is no immediate funding required to develop further tools.

3.2.4. Tool makers, long-term visualization needs

Raw computing power would be more effectively harnessed than it is today if calculations could be understood pictorially and their progress guided dynamically. Modern modes of computing involve interactive, extemporaneous generation of views from masses of data and models, and especially

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1: Academia supports only one product, MOVIE.BYU, distributed by Brigham Young University in Provo, UT, as a maintained set of visualization tools for scientists and engineers.

exploration of model spaces by interactive steering of computations. These visual modes offer significantly more usable answers per unit of computing power than symbolic computations alone.

The ability of scientists to comprehend the results of their computations will depend upon the effectiveness of available tools. All users of visualization have an interest in better hardware, software and systems, and much of what is developed can be shared by a number of scientific and engineering disciplines. We believe that future needs will be better served if potential barriers and bottlenecks are confronted now, in a sustained and programmatic way. We believe that the tool makers should be supported to address general visualization issues, such as:

- Interactive steering of simulations and calculations
- Workstation-driven use of supercomputers
- Graphics-oriented programming environments
- Higher-dimensional visualization of scalar, vector and tensor fields
- Dynamic visualization of fields and flows
- High-bandwidth picture networks and protocols
- Massive data-set handling, notably for signal and image processing applications
- Vectorized and parallelized algorithms for graphics and image processing
- Specialized architectures for graphics and image processing
- Establishing a framework for international visualization hardware and software standards

Essentially, funding agencies are being asked to support the development of visualization for the scientific marketplace. Funding would encourage the production of documented, maintained, upward-compatible software and hardware, would guarantee the publication and distribution of results on a variety of media, and would motivate manufacturers to solve bottleneck problems in interfacing and bandwidth.

3.3. Funding recommendations

According to Machover Associates Corporation, an international computer graphics consulting firm, the commercial/industrial market will grow from $7.61B in 1987 to $23.08B by 1992. A 1985 report by Frost & Sullivan, *Commercial Image Processing Systems in the U.S.*, claims that the world market for image processing (not including the machine vision market) will grow from $414.8M in 1985 to $1.58B in 1990, more than a three-fold increase in 5 years.

The Packard-Bromley *Report on the Health of the Universities* calls for doubling the annual federal support for basic research from its present level of about $7B or $8B, plus the commitment of another $5B for badly needed university facilities.

To foster a healthy basic research climate with integrated visualization tools, the United States' federal government should commit an amount equivalent to 1 percent of what industry is spending on visualization.

WORKSHOP ON METEOROLOGICAL OPERATIONS SYSTEMS
VIDEO PRESENTATIONS

DIGITAL PRODUCTIONS DEMO REEL '85

Created by Digital Productions, which is no longer in business.

Contact:

John Whitney, Jr.
Whitney/Demos Productions
300 Corporate Pointe
Culver City, CA 90232 USA

ANDRÉ & WALLY B

VOLUME VISUALIZATION WITH THE PIXAR IMAGE COMPUTER

André was created by the Computer Graphics Group at Lucasfilm, which is now Pixar.

Contact:

Alvy Ray Smith
Pixar
P.O. Box 13719
San Rafael, CA 94913 USA

L.A. — THE MOVIE

SCIENTIFIC VISUALIZATION — SCIENCE DATA SYSTEMS GROUP

Contact:

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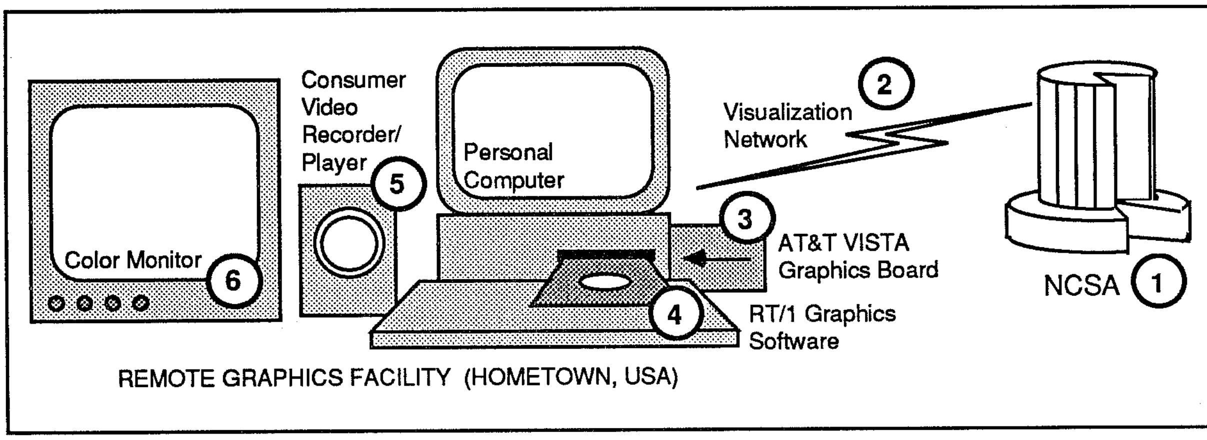

1. SUPERCOMPUTER ACCESS

We are currently developing a Remote Graphics Facility that will enable scientists to run graphic applications on the Cray X-MP at the National Center for Supercomputing Applications (NCSA) in Champaign, Illinois, while in their own office — at the university, the research lab or the computer center. To date, slow network speeds, centralized and expensive graphics equipment, lack of graphics software tools, and needs for specialists in film/video production have made this impossible.

The recent availability of low-cost graphics hardware and a good PC-based visualization toolkit, coupled with a growing awareness that scientists want to produce visuals for *personal* and *peer* use moreso than for *presentations*, is motivating this joint project between NCSA and the Electronic Visualization Laboratory (EVL) at the University of Illinois at Chicago.

Scientists can create ad hoc graphics, verify the integrity of their simulations, gain insights from their analyses, communicate their findings to others. Once they have discovered that for which they are searching, high-end graphics becomes important for technical presentations and publications. At that stage in their research, the experts at NCSA's Advanced Visualization Facility can help them create a quality production.

2. VISUALIZATION NETWORK

Televisualization, the application of networks to visualization, encompasses more than the transfer of text and gateway protocol decoding. It involves the transfer of images, which entails compression, decompression, rendering, recognizing and interpreting. With the availability of IMCOMP, an image compression and conversion system developed by EVL and running on NCSA's Cray, scientists can (1) compress color image files by over 90 percent without seriously compromising quality and (2) convert compressed picture files to different formats so they can be displayed on a variety of frame buffers. IMCOMP runs in less than 0.4 seconds on the Cray (about 10 cents of Cray time), and can reduce transmission time of an image at 1200 baud from 4 hours to 15 minutes.

To facilitate faster transmission speeds, EVL is investigating modifying TELNET. Currently, images shipped via TELNET go from Cray memory to workstation hard disk. Transmission speed would be improved if images went from the Cray directly to the workstation screen.

3. ANIMATION AND VIDEO

AT&T's VISTA board holds 16 full screens of graphics information, enabling scientists to compute 16 frames of animation on the Cray, store the images locally, and then play them back in real time. These cyclical animations are invaluable to the scientific discovery process; scientists may interact with them by single stepping, reversing the direction of motion, rocking, pausing indefinitely, or changing the speed of the display. This interaction is also necessary when selecting frames for subsequent videotaping. And, the VISTA is video compatible. It connects to any video camera so you can record a crisp, clear image directly from your computer's memory onto tape.

4. LOCAL VISUALIZATION ENVIRONMENT SYSTEM

Scientists need a set of visualization tools for convenience: picture compositing, picture saving/restoring, fonts and text, resizing, rotation, moving, copying, hand retouching (painting), color manipulation, etc. Together, these functions comprise a visualization environment system, which is to visualization what an operating system is to general computing.

RT/1, an easy-to-use interactive graphics programming language developed by EVL faculty and students, is available to interested people on a no charge (public domain) basis. RT/1 allows scientists to do local graphics enhancements to complex Cray-generated images. The software is written in C and runs under UNIX. It has been ported to the IBM PC and Sun workstations at NCSA, and runs on the TARGA-M8, TARGA-16, TARGA 24, TARGA-32 and Number Nine boards. Plans are to port it to the VISTA board.

5. CONSUMER VIDEO RECORDER/PLAYER

Low-cost consumer video recording and editing equipment now allows anyone to make their own videotape. And, this equipment comes with a built-in microphone so one can add narration or soundtrack to his/her recordings.

6. COLOR MONITOR

Today's consumer video systems not only record, but do playback. They can be hooked to any television monitor for immediate viewing of the material just recorded. But, the television doesn't have to be local. Scientists can take a small video unit to a conference and plug it into a television there to share findings with colleagues. And, should their peers have similar equipment in their offices in their hometowns, then colleagues can mail each other tapes for instant viewing.

How much does this configuration cost?
We are currently configuring the entire system for under $10,000. The software is either free or has a nominal licensing fee.

How can I get one?
We'll give you copies of the purchase orders. Just submit the equipment names and model numbers to your business office and *clone* the set-up we're designing.

When will it be available?
Some of the components already exist. Others will be developed within the next few months.