Research Issues in Scientific Visualization

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Visualizing data has ancient roots, and computer visualization has been with us almost since the first digital computers. Yet, in the 1980s, ever increasing data rates from supercomputers and sensors precipitated a fundamental change in both the need for and the complexity of visualizing data. Scientific visualization's birth as a discipline is generally associated with the 1987 report by the National Science Foundation's Advisory Panel on Graphics, Image Processing, and Workstations.[1] The report introduced the term "visualization in scientific computing," now generally shortened to "scientific visualization." It defined and justified the need for scientific visualization, while appendices examined the scientific and engineering research opportunities, the short-term potential and long-term goals of visualization environments, and the role of scientific visualization in industrial competitiveness. A companion video presented samples of the high-resolution, raster-based animations then used to examine scientific phenomena. This helped establish animation as an important technique for understanding time-varying data.

As an emerging research discipline, scientific visualization is developing those trappings that demonstrate growth. Started in 1990, the IEEE Visualization conference series became scientific visualization's primary conference, and the topic also became important within ACM's Siggraph conference. In Europe, the annual Eurographics Workshop on Visualization in Scientific Computing provides a gathering place for researchers and practitioners. Numerous other workshops and conferences worldwide now devote themselves, in part or in full, to the topic.

Similarly, journals and books have developed the theme. With articles from a 1989 special issue of *Computer*[2] plus nearly a dozen additional papers, the 1990 book *Visualization in Scientific Computing*[3] was perhaps the first to use the new name. *CG&A*'s annual scientific visualization issue has presented many key research results, drawing upon the IEEE Visualization conference's leading papers updated with new research. A full listing of computer science, physical science, and engineering journals devoting space to the topic would be extensive.

The marketplace for visualization products provides further evidence of the field's rapid growth. Visualization hardware expenditures were estimated at over $1 billion for 1990 and are projected to reach $3 billion by 1995.

Recent advances

A full progress report for the six years since the NSF report would be a lengthy, worthwhile contribution. Two articles within this special section of *CG&A* are devoted to topics where substantial growth has occurred: volume visualization and fluid dynamics visualization.

Volume visualization went from its initial applications in medical imaging to use across science. It portrayed clouds, water, molecules, and other phenomena from both empirical and simulated scientific data. Highly computational at first, it now takes place on a range of hardware platforms extending down to the Apple Macintosh, thanks to a variety of volume visualization tool sets. New algorithms are just beginning to effectively handle the recurring scientific problem of data collected at nonuniform intervals.

Volume visualization today is being extended from examining scientific data to reconstructing scattered data and representing geometrical objects without mathematically describing surfaces. Some now argue that this approach, called volume graphics, will replace raster graphics as the processing pipeline for graphics modeling and rendering.[4] Progress has been impressive, yet much research remains.

Fluid dynamics visualization affects numerous scientific and engineering disciplines. It has taken its place with molecular modeling, imaging remote-sensing data, and medical imaging as a domain-specific visualization research area. In 1987, 2D visualizations (with animation) were becoming commonplace. The problem of occlusion makes 3D fluid flow visualization more complex. Recently, much progress has come from using algorithms with roots in both computer graphics and machine vision.[5]

One important research thread has been the topological representation of important features.[6] Volume and hybrid visualization now produce 3D animations of complex flows. However, while impressive 3D visualizations have been generated for scalar parameters associated with fluid dynamics, vector and especially tensor portrayal has proven more difficult. Seminal methods have appeared, but much remains to do.

Great strides have also occurred in visualization systems. In 1987 visualization methods were largely inaccessible to the scientific community, demanding not only a visualization specialist but often teams of specialists. Commercial packages were limited in capability. For animations, direct video output from workstations using scan converters was just beginning to replace the difficult medium of film. Relatively simple visualization applications required months of programming using graphics languages such as PHIGS and Silicon Graphics' GL.

By 1989 products such as AVS and apE began to appear. These systems contained useful modules for creating a visualization, thus removing the need for each organization to produce its own sets of application modules. The major breakthrough that separated these systems from turnkey packages was the use of a visual programming interface that allowed users to easily assemble and connect modules into customized applications.

The area of automated selection of visualizations especially requires more work. Nonetheless, the situation has much improved, with these tools increasingly accessible to scientists and engineers.

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ONR Advisory Panel on Scientific Visualization

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Standing (from left): guest, guest, guest, guest, guest, Earnshaw, Hagen, Novak, Gallop, de Jung, Post, Höhne, Klimenko, guest, Bryson, Gagalowicz, van Wijk, Hesselink, Feiner, Rosenblum, Nielson; kneeling (from left): Shinagawa, guest, guest, Grave, Kaufman, Brunet, Göbel, Robertson, Kunii, Foley, Rossignac, Gershon, and Thalmann.

The ONR Visualization Workshop

The US Office of Naval Research (ONR) was the first US government organization given the responsibility after World War II to take the leadership in advancing scientific knowledge through basic and applied research. ONR remains one of the largest US funding agencies for university research. In September 1992 I began an 18-month assignment at the ONR European Office in London as Liaison Scientist for Computer Science. Part of this task is to meet with leading European scientists to evaluate new facts and ideas while supplying those visited with information on recent scientific and technological progress in the US. My position provided a unique opportunity to organize a workshop where European, American, and Asian experts could examine scientific visualization research issues. Participants wrote papers for presentation and organized roundtable discussions. These papers were also revised and improved for publication in a book.[7] The working groups' results were further developed to produce the "Research Issues in . . ." articles contained in this special section.

Some caveats are in order. The NSF Advisory Panel on Graphics, Image Processing, and Workstations was essentially a societal effort to give credibility to an emerging discipline. In addition to the technical issues involved, the new field was highly interdisciplinary, and a push was needed to promote academic credit for cross-disciplinary publications, video publications, and so forth, and to argue for funding.

The ONR workshop's goal was technical. We examined selected topics within the field to identify current and emerging research requirements. Readers may well feel their own specialty is underrepresented. This is inherent in the job we undertook and its associated limitations. Our 30 participants, chosen to cross-pollinate European, US, and Asian research directions as well as to blend senior and young researchers and multiple specialties, could not provide expertise in or coverage of all meritorious topics. We certainly do not claim completeness and encourage augmentation of our efforts by others.

The book[7] developed by the workshop's participants is a companion piece to these highly focused group articles on research directions. For the book each participant (often with coauthors) wrote a chapter that examines recent progress, current research, and state-of-the-art for their own research specialties. This allows both a broader view and more specialization than is possible within the limited pages of this special section. The book also provides a lot of the background and motivation for the workshop discussion of research issues. Some topics not covered here appear as chapters there.

The ONR workshop's participants are listed in the sidebar. Many hold advanced degrees in mathematics, engineering, or a physical science, and some remain active researchers in these fields. *CG&A* readers will be familiar with many of them.

Research issues in . . .

The seven short articles in this special section examine research issues, both ongoing (such as those discussed in "Recent advances" above) and emerging topics. Examples of the latter include volume graphics, multiresolution modeling, visualizing tensor fields, virtual reality interfaces for visualization, automating visualization designs and processing, validation tools, perceptual issues in visualization, and the relation between underlying mathematical models and the visualization process. The increased use of sophisticated mathematics in a trend seen in several of these articles. In most cases proposed research issues are clear-cut, but occasionally they are controversial. This is good, for the resulting discussions will contribute to a clearer vision of future directions.

As Fred Brooks noted in his Visualization 93 keynote address, scientific visualization is not yet a discipline, although it is emerging as one. Too often we still have a collection of ad-hoc techniques and rules of thumb. Perhaps by stepping back and taking a look at where we are going, these articles will assist the field's growth. ❑

Acknowledgments

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Special thanks are due to Andre van Tilborg (ONR Division Director for Mathematical, Computer, and Information Sciences) and Arthur Diness and John Silva (previous and current Technical Directors for ONR Europe) for their sponsorship and active encouragement of this project "from soup to nuts." The Liaison Scientist position has been an immensely enjoyable experience, and I appreciate ONR for providing the opportunity. The assistance and openness of numerous European colleagues, both with the workshop and in my daily tasks, is gratefully acknowledged.

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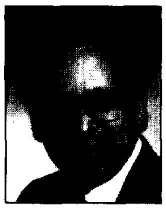

Lawrence J. Rosenblum is currently serving as Liaison Scientist for Computer Science at the US Office of Naval Research European Office in London while on leave from the Information Technology Division of the Naval Research Laboratory in Washington, DC. His research interests involve the application of scientific visualization, machine vision, and virtual reality to scientific data sets. He received his PhD from Ohio State University in mathematics.

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Research Issues in Volume Visualization

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Volume visualization is a method of extracting meaningful information from volumetric data sets through the use of interactive graphics and imaging. It addresses the representation, manipulation, and rendering of volumetric data sets, providing mechanisms for peering into structures and understanding their complexity and dynamics. Typically, the data set is represented as a 3D regular grid of volume elements (voxels) and stored in a volume buffer (also called a cubic frame buffer), which is a large 3D array of voxels. However, data is often defined at scattered or irregular locations that require using alternative representations and rendering algorithms.

The ONR Workshop on Data Visualization identified eight major research issues in volume visualization.

Volume graphics

Volume graphics is an emerging subfield of computer graphics concerned with the synthesis, manipulation, and rendering of 3D modeled objects, stored as a volume buffer of voxels.[1] Unlike volume visualization, which focuses on sampled and computed data sets, volume graphics primarily addresses modeled geometric scenes, particularly those represented in a regular volume buffer.

Volume graphics has advantages over surface graphics. It is viewpoint independent, insensitive to scene and object complexities, and suitable for representing sampled and simulated data sets and mixtures thereof with geometric objects (see Figure 1). It supports the visualization of internal structures and