Visualization Needs More Visual Design!

Organizer:
***J. Edward Swan II**, Naval Research Laboratory*

Panelists:
***Theresa-Marie Rhyne**, Lockheed Martin —*
United States Environmental Protection Agency's Scientific Visualization Center
***David Laidlaw**, Brown University*
***Tamara Munzner**, Stanford University*
***Victoria Interrante**, University of Minnesota*

INTRODUCTION

During the past decade, much work in the field of Visualization has resulted from the efforts of at least two groups of researchers. One group has focused on rendering techniques for visualization technologies (e.g. volume rendering), while another group has focused on designing visual elements for the purpose of visualizing a certain application domain (e.g. streamlines to visualize flow fields, as well as most applications in Information Visualization). This panel session brings together researchers from both groups. Together we will argue that utilizing visual design is difficult but important for visualization, and we need to work harder to tap into the many centuries of design knowledge that exists in fields such as art, music, theater, cartography, architecture, and so forth. Some of the issues we will explore include:

- Where do we get visual design knowledge? At least, we need more collaborations between computer scientists and practitioners from design fields.
- While many of us in the visualization field are trained in a scientific culture that values *objective* measurement, all of the fields listed above contain a significant *subjective* aspect. How can we best incorporate and measure subjective criteria?
- Is there a way that we can capture visual design knowledge into guidelines, in a manner similar to user interface guidelines? If we could do this, we could also incorporate the design knowledge into automated visualization systems.
- The general population in industrialized countries is becoming increasingly familiar with technology and computers in general, and with visualizations as well (e.g. atmospheric maps shown on the Weather Channel). Does this affect the sophistication of the visual designs we can incorporate?
- It is often said that Perceptual Psychology can supply us visual design knowledge — we just design in a manner that best fits human perception. However, perception studies often report "just noticeable differences" and similar measures of very low-level cognitive processes. Can we really generalize from these to create visual designs that support the higher-level cognitive processes of our application domains?
- We will illustrate our points with examples from a number of application domains, including battlefield visualization, environmental sciences visualization, biomedical visualization, fluid flow visualization, and information visualization.

POSITION STATEMENTS

J. Edward Swan II

Sensory Design Issues as a Driving Problem for Visualization Research

For the past 15 years or so most of Visualization's driving problems involved the rendering of different types of scientific data sets. Initially these driving problems—volume rendering, isosurface fitting, large data processing, etc.—were extremely challenging, and motivated fundamental research in new rendering techniques. Now, however, thanks to the development of clever algorithms and certainly also to Moore's Law, we can claim that many of these problems are at least partially (but not completely) solved. And even in cases where the problems are not solved (e.g. irregular grid volume rendering), we can at least state that the problems themselves are well understood (e.g. it is difficult to take advantage of coherence when rendering irregular grids).

Now it seems that Visualization's greatest challenges come not from rendering, but in the area of 'sensory design' — primarily visual design, but also the design of sound, haptics, and (one day) smell and taste. Many Visualization application areas contain 'design issues': problems that call for sensory designs and yet have few or no known design guidelines. As design issues frequently involve human perception or cognitive processing, the effectiveness of a sensory design is inherently difficult to quantify, measure, and model. Unlike rendering, with design issues it is difficult to even understand were the problems lie.

In Visualization we have at least one advantage over 'traditional' computer graphics (e.g. motivated by computer animation) — traditional graphics renders real, physical objects, and so the research thrust has been on accurate simulations of the interaction of light with the natural world. However, in Visualization we have no such motivation: often we are rendering images of abstract notions, or at least of items which have no 'natural' visual representation (e.g. fluid flow). Certainly, new and clever sensory abstractions are required. At the least, we should look at such fields as art, architecture, theater, and music, which (in great contrast to the entire computing field) contain many centuries of design experience.

Indeed, design issues are hard, very hard; and require the same degree of creativity and energy that it took to solve some of the rendering issues in the first place. To make this argument concrete I will briefly describe the problem domain of *battlefield visualization.* This is the science and art of depicting a large amount of battlefield data and friendly / enemy unit properties on a map, in such a manner that commanders can effectively execute military operations. Battlefield visualization is a very rich area for difficult design issues, and comes with a 2000-year-history of design knowledge that we would like to understand and apply. I will list and describe a number of difficult design issues in battlefield visualization, as well as some of our preliminary attempts at solutions.

Theresa-Marie Rhyne

Environmental Sciences Visualization: A Childhood Sense of Wonder

The significant factors that influence the visual representation of environmental sciences data and information include: type of data, relationships among different components of a data set, placement of data in spatial and temporal context and interpretation of the data. Since, frequently, earth sciences data is geographically registered, visualization experts can rely on the long history and many visual principles associated with the field of cartography. Perhaps the greatest challenge in using interactive computer graphics techniques for environmental sciences visualization is realizing and consistently remembering that chances are good someone else invented the basis of the visual metaphor long before computers existed. The notion of creating a flip book to depict hourly changes in weather patterns did not require the invention of a computer. The idea of a 3-D rotating texture mapped globe for depicting Planet Earth came long before we had computer graphics rendering techniques and interactive visualization systems. As a child, I remember having a 3-D globe that had a light bulb inside. Switching the light bulb "on" allowed for viewing the terrain of the oceans. Electricity was needed for that interactive concept!

It might even be safe to say that often-interactive computer graphics and visualization techniques benchmark their efforts against pre-existing cartographic visual metaphors. Ask a young person, does this map of pollutant concentrations look familiar to you. Chances are good they will say, "Yes, it looks like something on the Weather Channel". This should be taken as a high compliment because it is then possible to build on this familiarity to visually educate the general public about how air pollution is created. As a result, maybe an interactive Web-based Ozone map with red zones (indicating generally unhealthy air) will cause someone to limit their sunbathing at the local swimming pool for that day. Is that not localized decision making from publicly accessible environmental information?

After over ten years of working on 3-D visualizations at the United States Environmental Protection Agency, my driving sensory design concern is how to make the visualization experience simple enough to convey the environmental science issues under study. My goals continue to focus on stepping beyond the "wow, the computer can do that" stage to convey compelling messages about environmental sciences education and public health.

The abstract and mobile artist, Sandy Calder, is credited with having said: "There is nothing new under the sun, only more of it." I sincerely hope this is the case because, as the poet, Robert Frost, said: "I have miles to go before I sleep."

David Laidlaw

Visual Design for Science — Where Can We Look?

Of our five senses, vision is the highest bandwidth and, perhaps touch aside, the most parallel. Because vision is so important, I will focus on three approaches for addressing some of the issues of designing visual representations for scientific data.

The first approach is perception-based design. Perception studies have helped to quantify and compare visual representations, often by deconstructing the representations and answering quantitative questions about the pieces. An advantage of this approach is the rigor that can be applied to generate compelling quantitative results. One disadvantage is that it is difficult to ask questions about complex visualizations. "Does visualization A work better that visualization B for understanding fluid flow" is often difficult to evaluate because understanding is difficult to quantify. This is particularly true in the research community, where the "understanding" step can require a peer-review process.

The second approach to addressing visual design problems is to model the photographic process. In this case, advantages are that we can use the world around us to search for representations. I look out my window all the time to get visualization inspiration. Smoke, snowflakes, and dust can show us some of the structure of the wind, if we can just render them accurately. Photo-realism also gives us the advantage of a gold standard — we can compare our results with photographs and, if we are close enough, we have succeeded. On the downside, what does a photograph of a streamline look like? How accurate do we need to be? Can we practically model enough of the world with photorealistic accuracy?

A third approach to problems of visual design, and the one I'll spend the most time on, is how many artists operate. They use a broad context for presenting messages visually, not restricting results to look like photographs. They use visual shorthands for representing ideas while economizing on visual bandwidth. And they employ an analogue of computer programming "code re-use" by copying visual designs that have worked for other applications, frequently combining visual strategies from multiple sources. In some sense, their approach is very scientific: They hypothesize that some visual idea might work, they conduct an experiment to test the hypothesis by creating a work of art, and they evaluate the result. The process is iterative, and the evaluation of the hypotheses are often controversial.

Why would we bother with such a subjective process? There are many reasons. The potential to search hundreds of years of experience in producing visual representations is immense. Painters, illustrators, and sculptors can teach us much. We'll be able to encode more of the information that we want to transmit. We'll render faster. We'll create clearer representations — good maintenance manuals rarely use photographs because drawings are so much clearer. And we'll have more control over what we represent: we can emphasize what we feel is important and even control the order that a viewer will see different aspects of a visualization.

How can we adopt this approach? Talk to artists. As we find in any interdisciplinary project, learning to communicate in the language of another discipline is hard. But it pays off. Ask how an artist would "encode" information or deliver a message. They will ask you questions in return about your information and message. You probably won't even understand the question, but persevere. Explain what your visualization is intended to do and see what an artist says. Take art classes. Draw. Paint. Assemble renaissance teams of artists and scientists.

I'll discuss several specific examples where I feel that this approach has paid off: an application of line art to tensor visualization; an application of concepts from oil painting to displaying multi-valued images; and the metaphorical use of Trompe L'oeil that Pat Hanrahan presented in last years wonderful keynote address. As a final example, (in response to a Visualization '98 panel attendee's question) I'll explore Dadaism as a source for scientific visualization inspiration.

Tamara Munzner

In Search Of: Prescriptive Advice for Visualization

The visualization field could indeed benefit from knowledge gained in fields other than computer graphics, such as cognitive psychology, fine art, graphic design, cinematography, and so on. However, there is a caveat: effective use of such knowledge is contingent on arduous gleaning, not the easy harvesting of low-hanging fruit. It is highly nontrivial to distill an entire field with very different goals from our own into *prescriptive advice* that can help us design and evaluate visualization systems.

But it's absolutely worth doing! In fact, I argue that it's at the very heart of our right to exist as a self-described field of research, as opposed to a service profession. The standard argument for visualization is that exploiting visual processing, particularly preattentive processing, can help people explore or explain data. If it were trivial, then domain scientists could just take Graphic Design 101, Cognitive Psychology 101, and Computer Graphics 101 and be done with it. They'd provoke epiphanies by tossing exactly the right set of pixels onto the screen, and we'd be out of the loop.

We do have an active field of study because the design issues are significant and not fully understood. I think these issues are even more critical in information visualization than in scientific visualization. My current favorite definition of the distinction is whether the visualization strategy hinges on finding a spatial mapping of not inherently spatial data. Graphics research issues can arise in the creation of novel visual metaphors, especially as we scale up to large datasets, but algorithms for rendering are usually not the main stumbling block in the visualization field.

Instead, one of the biggest problems is judging the effectiveness and applicability of visualization systems: how do we know when we have succeeded? A paper about photorealism in graphics can simply state that it is an improvement over previous methods because it is faster or a quantitatively better match to a photograph of a real scene. The decision criteria for the success of a visualization system are not nearly as clear-cut. Many papers simply describe a technique without much comment on when that technique is effective. Some papers have anecdotal testimonials from users who attribute discoveries to the visualization system, others mention the size of the user community, and a few actually refer to user studies in the main body of the paper instead of in the future work section.

User testing uses methodology borrowed from cognitive psychology. An idea that we may be able to borrow from art and design is a methodology for discussing the worth of something when the criteria are not purely objective. Even though the merit of a painting is a mostly subjective judgement, the long tradition of aesthetic criticism offers a framework for shared discourse on the subject. While I doubt that any of the existing aesthetic frameworks are themselves completely suitable for the visualization field, constructing an appropriate such framework for ourselves may add another tool to our arsenal.

Victoria Interrante

Searching for Insight Into the Science Behind the Art of Effective Visual Representation

Effectively designed visual representations facilitate the understanding of complex phenomena by selectively emphasizing the most important features and relationships while minimizing the distracting effects of extraneous details. The fundamental challenges facing the visualization designer are: to carefully choose what to show and to carefully choose how to show it. When used appropriately, aural, haptic, and other sensory inputs have the potential to reinforce, or to expand the range of, the information that is visually conveyed. Objective measures for evaluating the effectiveness of particular approaches can facilitate the refinement of the design and offer insight into the strategies that have the greatest potential for success.

I will argue that there is both an art and a science to the design of effective visualizations, and that the greatest potential for significant advances lies in an interdisciplinary approach that combines insights and experience from computer vision and image processing (for feature extraction), computer graphics (for rendering), graphic design, art and illustration (for inspiration) and visual perception (for insight into what works, what doesn't, and why).

The critical first step, choosing what to show, can rely upon feature extraction to pare down the quantity of data that needs to be displayed and to establish a hierarchy of importance relationships between the multiple elements. For example, numerical simulations of combustion, turbulent flow, and other complex phenomena can produce hundreds of gigabytes of data, too much information to even write out to disk, much less attempt to display. However, the parts of the data that the engineers believe hold the potential to provide critical, quantitative insights into the processes being studied are just a fraction of that total. Even if we could show "everything", they maintain that it wouldn't help them - they don't want to see it all, only the aspects of the computation that they care about. Defining exactly what the important information is for each application, deriving algorithms for quantifying and extracting it, and verifying that the extracted data accurately encompasses the features of interest, can be a difficult undertaking that requires close interdisciplinary collaboration and a tight coupling between the data generation, feature extraction and data display implementations. In other applications, feature extraction can take the form of edge detection, or curvature discontinuity enhancement, or even be less of an issue, with features for example arriving implicitly encoded as part of the data definition.

The second critical challenge — how to emphasize the important information while minimizing extraneous detail — is the classical historical challenge faced, in different forms, by artists, scientific illustrators, and graphic designers over the centuries. It requires not only an expert understanding of both the viewer and the subject but also an aesthetic finesse in the rendition. The fact that we are attempting to automate at least some aspects of the process adds an additional layer of complexity and difficulty to the task. The goal is to achieve a flexible, hierarchical representation in which visual cacophony is eliminated and attention is drawn first and most strongly to the features of greatest importance, while being free to wander and refocus, and with minor effort bring secondary aspects to the fore.

Significant advances in the conceptualization and design of effective visual representations promise to come less from a methodical search through the parameter space of known possibilities than to be inspired in new directions by our expanding vision of what we want to achieve, grounded in a fundamental understanding of the strengths and weaknesses and the processes of human visual perception. From an understanding of how our visual system interprets information, we have the potential to gain critical insights into how to portray information in an easily accessible way. I will briefly include in this talk glimpses of some of the recent progress that my students and I have been making in this area.

BIOGRAPHIES

J. Edward Swan II is a scientist with the Virtual Reality Lab at the Naval Research Laboratory, where he conducts research in computer graphics and human-computer interaction. He received his B.S. from Auburn University, and his M.S. and Ph.D. from Ohio State in 1997. At the Naval Research Laboratory he is primarily motivated by the problem domain of battlefield visualization; previous motivating problem domains include biomedical visualization, terrain rendering, and virtual reality. Currently he is studying effective virtual environment locomotion techniques for battlefield visualization, as well as new techniques in terrain rendering. He is active in the IEEE Visualization conference; he has served on the conference committee for the past five years. He is a member of ACM, SIGGRAPH, SIGCHI, IEEE, and the IEEE Computer Society.

Theresa-Marie Rhyne is a Lead Scientific Visualization Researcher for Lockheed Martin Technical Services at the United States Environmental Protection Agency (US EPA)'s Scientific Visualization Center. She was the founding visualization expert when the US EPA Scientific Visualization Center opened its doors in May 1990.

When she was twelve years old, Theresa-Marie dreamed of visualizing environmental, civil engineering, and public health concerns. So, she went to Stanford University to study Civil Engineering and received Bachelor of Science, two Masters of Science and Degree of Engineer diplomas in that field. In the late 1970's, she applied her education to problems associated with "Access for the Physically Handicapped" issues at Stanford University. In the early 1980's , Theresa-Marie began working at Stanford's Center for Information Technology on public access to electronic information concerns. In 1987, she came to the US EPA's Environmental Research Center in Research Triangle Park, North Carolina, as an employee of Unisys Corporation. She spent her initial years at the US EPA learning and assisting with Agency-wide computer support issues before contributing to the US EPA's High Performance Computing and Scientific Visualization efforts.

Today, she lives her childhood dream.

David Laidlaw applies computer graphics and computer science to problems in other scientific disciplines. He is an Assistant Professor of Computer Science at Brown University. He received his Sc.B. and Sc.M. from Brown, where he worked with mathematicians to understand 2– and 3–manifolds. He received his Ph.D. in Computer Science from Caltech in 1995. His thesis presented new methods for extracting geometric models from medical imaging data of biological specimens. He is currently investigating computational methods with applications in developmental neurobiology, anatomical modeling, diagnostic medical imaging, remote sensing, and fluid mechanics. Research interests include visual representation of data, particularly those motivated by art, modeling of imaging data, tissue classification, optimization of data acquisition, geometry, numerical methods, and statistics.

Tamara Munzner is a PhD candidate at Stanford University, where she received a BS in computer science in 1991. In the intervening years she was a member of the technical staff at the Geometry Center, a mathematical visualization research group at the University of Minnesota. She was one of the authors of Geomview, the Center's public domain interactive 3D visualization system. While at the Center she was codirector and one of the animators of two computer generated mathematical videos, *Outside In* and *The Shape of Space*. Her current research interest is information visualization, specifically interactive techniques for visualizing large graphs and networks. Her recent research work on interactive layout and drawing of large graphs in 3D hyperbolic space has been commercialized through Silicon Graphics in the *Site Manager* application for webmasters.

Victoria Interrante is an assistant professor of computer science at the University of Minnesota and a faculty associate member in the Center for Cognitive Sciences. She received her PhD in 1996 from the University of North Carolina at Chapel Hill, where her dissertation research focused on the design of perceptually inspired artistic techniques for improving the comprehensibility of layered transparent surfaces in radiation therapy treatment planning data. Before coming to the University of Minnesota, she spent two years as a staff scientist at ICASE, a center of research in applied mathematics, numerical analysis and computer science operated by the Universities Space Research Association at the NASA Langley Research Center. Her broad research interests are in visualization, visual perception, computer graphics, image processing, and human-computer interaction. She is currently working on applying insights from visual perception, art and illustration to the design of methods for more effectively portraying surface shape and depth in computer-generated images.