Perceptual Measures for Effective Visualizations

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INTRODUCTION

How do we measure the effectiveness of visualizations? Clearly any metric has to be based on perceptual models, since we are measuring how a display is perceived and interpreted by a human being. Can we build useful metrics to evaluate the value of image content? Can we build metrics for user interaction that can feed back into our visualization systems to improve their effectiveness? Is it impossible to have real metrics for visualization? Are rules of thumb all we have? Can better rules be developed for effectiveness? We will consider imagery used both for photorealistic visualization and scientific visualization. Metrics for static images and dynamic displays will be discussed. The goal of this panel is to promote discussion of research or development that is needed for improving the measurement of visualization effectiveness. We also hope to promote debate on whether general measurements are possible, or whether all visualization is case specific.

STATEMENTS

Holly Rushmeier

In the book "Graphical Methods for Data Analysis" the authors answer the question "why graphics?" with "Our eye-brain system is the most sophisticated information processor ever developed, and through graphical displays we can put this system to good use to obtain deep insight into the structure of data." This is what those of us working in the field of visualization believe. However many of us, myself as much or more than anyone, work with a fairly rudimentary understanding of what our eye-brain system is doing. We work with simple ideas such as brightness perception is non-linear, slope discontinuities in luminance can cause Mach bands, different spectral distributions of radiance can have the same perceived color, motion and shadows help us perceive depth. We rarely evaluate the value of the visualizations we produce even in terms of these simple concepts.

The most obvious area where we can apply perceptual measures to our results is in the area of realistic image synthesis. However, relatively little has been done even in this area. There have been a few attempts to have viewers compare real and synthetic imagery – both by some formal testing and by informally presenting side by side images. While the results of such tests offer reassurance that the simulation methods can work, they give no way of quantifying how well they will work on the next problem.

I was part of a group that worked on a project simulating a simple room under various lighting conditions, and comparing the results to images of the physical room captured with a calibrated camera.

When we looked at the simulated and captured images for a particular lighting set up, they looked relatively the same to us. For example, our simulation of the room with incandescent wall washers looked a lot more like the physical room with incandescent wall washers than the physical room with flourescent down lighting. A basic pixel by pixel RMS measure of the images didn't capture this sort of similarity. After some experimentation, we found some metrics that crudely accounted for adaptation, perceived brightness non-linearity and spatial frequency variations that better measured our impression of the images. These metrics suggested some new approaches to efficiently computing simulated images.

There is some potential for applying similar simple metrics to other areas of visualization. For example, can we get a better perception of the shape of an isosurface by incorporating perceptual metrics in the selection of light position, surface finish, color and level of surface decimation? Even if we can, are these issues at all important relative to other factors in building a visualization?

Penny Rheingans

An awareness of the mechanisms and characteristics of human visual perception can improve visualization effectiveness by guiding the selection and enhancement of new and existing techniques. Since the information contained in visualizations must pass through the perceptual system, careful attention to the system's characteristics can greatly improve the effectiveness of visualizations. Perceptually-based visualization strives to avoid distortions caused by perceptual anomalies, exploit cognitive and cultural expectations, and accurately convey the features of the data displayed. A number of interesting questions arise: which characteristics of vision are most relevant to the evaluation of visualizations?, how can knowledge about vision be transformed into principles for visualization?, when should perceptual principles be overridden by application-specific concerns?, and how can meaningful assessments of adherence to principles be made?

Experimental validation of effectiveness is a critical step in the development of new visualization systems and techniques. In the early days of visualization, the benefit of a new visual representation, especially where no visual representation had been available before, tended to be striking. While this is still sometimes true, the advantages of recently developed techniques, even those which offer significant advantages, are usually smaller and more subtle than in the early days of the field. Formal evaluation of the effectiveness of a visualization, through carefully controlled user studies, can substantiate claims made about the value of a new technique. Despite a growing awareness of the importance of objective evaluation, formal user studies of visualization effectiveness remain relatively rare. Unfortunately, performing good user studies is time-consuming and requires substantial expertise in experiment design and data analysis. How can we balance the importance of experimental validation with the time, effort, and expertise required? What should a visualization researcher thinking of performing user studies know? And finally, what should the consumer look for in a report of user study results?

Sam Uselton

The benefits of good metrics for the quality of visualizations are many, with a large potential impact. But bad metrics are worse than none at all. Quality is a slippery concept; it is hard to quantify. We teach children to distinguish whether a description is "Qualitative OR Quantitative?" because the concepts seem mutually exclusive.

Most writing about what makes a good visualization (eg Tufte's books) are prescriptions for communicating known information. These guidelines for expository visualization don't generalize to exploratory visualization. And recommending bar charts over pie charts is answering the wrong question for a scientist exploring his most recent forty-gigabyte simulation dataset.

Testing the performance of a specific population on a specific task using specific visualizations can yield reliable information about which visualization provides better performance of the task. The tests are time consuming, and quite expensive, especially if the population being tested is composed of highly trained professionals. Even then, these results don't generalize across populations, tasks, visualization methods or even data sets. *And exploratory visualization means continually using new data!*

My definition of a GOOD visualization metric is one that correlates well with the effectiveness that would be measured if the appropriate testing were done. Of course such metrics are hard to create, design or discover and even harder to verify. I would be happy to begin with metrics for comparing very similar visualization images. This would allow me to decide how much the error introduced by my shortcut for speed hurts the resulting image.

Visualization is a useful data exploration method because people are good at finding visual patterns (sometimes even when there are none in the data). Interactive control of visualization parameters can lead to finding local optima rapidly. The metrics must measure these visual patterns. Different metrics will be appropriate for different applications because different kinds of visual patterns are of interest.

Perceptual difference metrics are a good start, but just a start. If two images are perceptually indistinguishable, then "we're done" – they have the same quality for whatever task. BUT, if they are NOT perceptually indistinguishable, then visualization specific metrics are needed.

However, metrics for visualization images should not be based on automatically detected features. If the relevant features can be automatically identified or extracted, if the data can be classified automatically for a particular application purpose, then why is a person looking at images?

Or maybe we should use image enhancement methods to make imperceptible differences more noticeable?

In addition to my long list of things that don't work for use as visualization metrics, I will present suggestions of things that may work.

BIOGRAPHIES

Holly Rushmeier

Holly Rushmeier is a Research Staff Member at the IBM Thomas J. Watson Research Center. She received the BS(1977), MS(1986) and PhD(1988) degrees in Mechanical Engineering from Cornell University. Since receiving the PhD, she has held positions at Georgia Tech, and at the National Institute of Standards and Technology. In 1990, she was selected as a National Science Foundation Presidential Young Investigator. In 1996, she served as the Papers chair for the ACM SIGGRAPH conference, and she is currently Editor-in-Chief of ACM Transactions in Graphics. She has published numerous papers in the areas of data visualization, computer graphics image synthesis and thermal sciences.

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Harrison Barrett

Harrison Barrett is a Regents Professor at the University of Arizona. Dr. Barrett received a bachelor's degree in physics from Virginia Polytechnic Institute, a master's degree in physics from MIT, and a Ph.D. in applied physics from Harvard. He worked for the Raytheon Company, Research Division, for 14 years, and he has been at the University of Arizona since 1974. He is a professor in both the College of Medicine and the Optical Sciences Center. He has served as acting director of the Optical Sciences Center. In the Spring of 1990 he was named a Regents' Professor at the university. His professional interests have included solid-state physics, ultrasonics, optical computing and medical imaging. His current research, supported by the National Cancer Institute, includes applications of image reconstruction, pattern recognition, digital detectors and parallel computing in nuclear medicine.

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Penny Rheingans

Penny Rheingans is an Assistant Professor of Computer Science at the University of Mississippi. She received a PhD in Computer Science from the University of North Carolina, Chapel Hill and a BA in Computer Science from Harvard University.

Before coming to the University of Mississippi, Dr. Rheingans was a Visualization Specialist for Martin Marietta at the US Environmental Protection Agency Scientific Visualization Center. While there she developed visualization tools and techniques for the more effective display of environmental data to scientists, policy-makers, and citizens. As a research assistant at the University of North Carolina, she developed tools for the visualization of molecular surfaces, the design and manipulation of color mappings for bivariate information, the display of high-dimensional statistical data, and the utilization of virtual reality technology to conduct interactive walkthroughs of very large architectural databases.

Dr. Rheingans has taught in short courses entitled *Visualization of Environmental Data* (for EPA scientists), *Perception-Based Visualization* (SIGGRAPH 94 and 95), *From Perceptual Psychophysics to Graphic Design* (IEEE Visualization '96), and *Principles of Visual Perception and Its Applications in Computer Graphics* (SIGGRAPH 97). She has developed and regularly teaches undergraduate and graduate courses in computer graphics and visualization. She also teaches courses in such computer science fundamentals as introductory programming and automata theory.

Her current research interests include uncertainty visualization, multivariate visualization, perceptual issues in visualization, dynamic representations, the application of color and texture to data visualization, and the experimental validation of visualization techniques.

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Sam Uselton

Sam Uselton is a researcher in visualization and computer graphics. He has been a contractor with the NAS Systems Division at NASA Ames Research Center since 1989. He received his BA in Math and Economics in 1973 from the University of Texas (Austin) and his MS in 1976 and PhD in 1981, both in Computer Science, from the University of Texas at Dallas. Before moving to NASA, he taught computer science full time and consulted in industry for ten years. Sam has worked with many scientists from industry and academia to visualize data from a variety of fields, with particular emphases in aeronautics, oil exploration and production, and medicine. He is a member of the IEEE Computer Society, the ACM and SIGGRAPH, and on the steering committee for the Parallel Rendering Symposium. His current research interests include visualization quality, multi-source data analysis, direct volume rendering, realistic image synthesis, visualization of very large data sets and parallel algorithms for visualization and graphics.

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Andrew Watson

Dr. Watson is currently a Senior Scientist for Vision Research and Director of the Vision Group at NASA Ames Research Center. He studied perceptual psychology and physiology at Columbia University and the University of Pennsylvania (Ph.D. 1977), and did postdoctoral research at Cambridge and Stanford Universities. Dr. Watson conducts research on visual perception and its application to coding, understanding, and display of visual information. Recent accomplishments include a computational model of human visual motion sensing, and technology for perceptual optimization of digital image compression technologies. He has served as a member of the National Research Council Committee on Vision, and on program committees for the Association for Research in Vision and Ophthalmology, the Society for Information Display, and the European Conference on Visual Perception. He is a Fellow of the Optical Society of America, and an editor of the journals Visual Neuroscience, Journal of Mathematical Psychology, and Displays: Technology and Applications. With Albert J. Ahumada, Jr, he was the recipient of the 1990 H. Julian Allen Award, and in 1994 was appointed Associate Fellow of Ames Research.

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