Title: Theories of Visualization—Are There Any?

Introduction: A fundamental question in visualization is what constitutes a "good" visualization. A related question whether one visualization is better than another. In general, these hard questions are addressed by running user studies. However, evaluating visualizations with user studies a posteriori, in an inductive approach, is neither sufficient nor efficient. Ideally, we would like to have models that not only define what a good visualization is but also tell us how to construct them. Historically, general theories have been born from elimination and/or unification of competing and complementary theories that have emerged from specific domains. Clearly we need more theories of this kind in visualization. In this panel, we will discuss example theories of visualization and ponder how they relate to one another.

Organizers:

Çağatay Demiralp, *Brown University*

David H. Laidlaw, *Brown University*

Panelists:

Çağatay Demiralp, *Brown University*

David H. Laidlaw, *Brown University*

Jarke J. van Wijk, *Eindhoven University of Technology*

Colin Ware, *University of New Hampshire*

Position Statements & Biographies:

Çağatay Demiralp's Position Statement

Although a great many heuristics have been accumulated, how to measure and construct effective visualizations in general is an unsolved problem. While evaluating visualizations with user studies is and will remain important, this approach, analogous to attempting to reach the "truth" from observations, is inherently limited. In this context, we are expected to generate candidate theories (i.e., hypotheses) on visualization based on user studies or on our intuition. This is not done as often or as rigorously as it should be. There are several reasons for this. For one, the space of visualizations is large and visualizations work at several domains and scales in human perception and cognition. Another difficulty arises in separating (or not separating) the factors, such as interaction, that have significant effect on the success of visualizations. Thus coming up with general theories is difficult.

As it stands, the problem seems underconstrained. So, in my opinion, we need to build on specific and restricted theoretic models. These models should still provide explicit methods to create visualizations that are effective in their terms. One way of building such a model is to view every visualization as a function from data points to the space of visual primitives (or any other kind of primitives, for that matter). With this in mind, I would like to propose a visualization model based on structure-preserving maps and discuss how to construct good visualizations using this model.

Bio

Çağatay Demiralp is a PhD student in computer science at Brown University. His research interests are in characterizing the pattern and structure in data both qualitatively and quantitatively using topological, geometric, and statistical approaches. Computational brain connectivity using diffusion MRI is the current focus of his research. He has published more than 20 journal and conference papers on topics ranging from modeling and analysis of structural brain connectivity to line field visualization and surface deformations. He has received Brown University's Brain Sciences Research award, IEEE Visualization Best Poster award, and ASSH Best Layout and Best Scientific Presentation awards.

David H. Laidlaw's Position Statement

In 2008, at the end of the Vis conference, I sketched out a "theory" of visualization. There is controversy about what defines a theory of visualization -- I believe that I managed to clarify only one possible definition, providing limited insight into what might actually make up such a theory. In this panel session, I'll briefly review that definition and talk about some of my struggles since then to instantiate parts of it. A number of disciplines have worked toward predicting how users will perform when using computers. In explaining my struggles, I'll touch on some of this related work from the HCI and psychology domains that provide some hope for future success. I also look forward to hearing and discussing why this is the wrong approach, why it will never work, and what the right approaches are.

Bio

David H. Laidlaw is a professor of computer science at Brown University. He received his PhD from Caltech in computer science, where he also did postdoctoral work in the Division of Biology. His research interests revolve around visualization and modeling applications of computer graphics and computer science to other scientific disciplines. Dr. Laidlaw has published more than 90 peer-reviewed journal and conference papers; has served on or co-chaired dozens of conference committees; has been an associate editor of *IEEE Transactions on Visualization and Computer Graphics*; and has been a recipient of a number of best panel, poster, and visualization awards from IEEE Visualization, ACM SIGGRAPH, and NSF, and also of the 2008 IEEE VGTC Visualization Technical Achievement Award.

Jarke J. van Wijk's Position Statement

The discipline of visualization is not a science, it's technology. Our aim is not to develop theories about the world or the universe; we try to develop methods and techniques that enable people to do their job more effectively, efficiently and with greater satisfaction. Our community has been very successful in developing a wide variety of solutions for specific problems, but less in answering the question what to use when and why, which is the key question of our customers. And here's a strong need for more structure and theory.

To answer this question, in my opinion it is vital to consider development and use of visualization as a design process, with (a) definition of requirements, (b) generation of alternative solutions, and (c) evaluation of these as key ingredients. Translated to our field, we need (a) terminology and frameworks to describe the problem at stake, for instance taxonomies for types of use, users, tasks, data; (b) overviews of (partial) solutions and approaches; (c) methods to measure effectiveness, efficiency, and user satisfaction, as well as knowledge about the quality and scope of existing solutions.

Also, we need to distinguish here between different levels of scale and abstraction, and to understand the relations between these. End-users will be served best by providing suitable defaults for color scales, line characteristics, etc., at the other end of the scale we need cross-cutting insights that provide a foundation of our field, and guide us in our search for novel visualization solutions and understanding what works and what does not.

Bio

Jarke J. van Wijk is full professor of visualization in the department of Mathematics and Computer Science at Eindhoven University of Technology. He received a MSc degree in industrial design engineering in 1982 and a PhD degree in computer science in 1986, both from Delft University of Technology and both with honors. He joined Eindhoven University of Technology in 1998, where he became a full professor of visualization in 2001. His main research interests are information visualization, visual analytics, mathematical visualization, and flow visualization. He is cofounder and VP Scientific Affairs of MagnaView BV.

He has been paper cochair for IEEE Visualization (2003, 2004), IEEE InfoVis (2006, 2007), IEEE VAST 2009, IEEE PacificVis 2010 and EG/IEEE EuroVis 2011. He received the IEEE Visualization Technical Achievement Award in 2007 for his work on flow visualization, Best Paper awards at IEEE InfoVis 2003 and IEEE Visualization 2005, and the 2009 Henry Johns Award.

Colin Ware's Position Statement

Empirical studies of visualization have limited usefulness because each study only applies to a particular design and there is infinity of different designs. Theory is the means by which experimental results can be generalized and in the case of data visualization in large part this has to be the theory of perception. Visualizations work because transforming data into visual patterns enable us to apply our pattern perception skills to problem solving. A scientific understanding of human pattern perception can help provide theory-based guidelines for mapping data into visualizations. In addition to a theory of pattern perception we also need a theory of visual thinking algorithms to describe processes involving both perceptual/cognitive activities and computation activities. A visual thinking algorithm must incorporate perceptual activities involving visual working memory and pattern perception, together with epistemic actions, like mouse movements or eye movements, as well as computation activities, like brushing, dynamic queries using sliders, or generalized fisheye views. Analyzing the efficiency of these human/computer algorithms provides a way of deciding when to use a particular interactive process. Together distributed cognitive algorithms and applied perception provide most of the theory needed for a discipline of visualization design.

Bio

Colin Ware is director of the Data Visualization Research Lab in the Center for Coastal and Ocean Mapping at the University of New Hampshire. He has a PhD in perceptual psychology from the University of Toronto and a MMath in computer science from the University of Waterloo. His publications include two books*, Information Visualization: Perception for Design*, and *Visual Thinking for Design*, both devoted to applying the science of perception to problems in information display, as well as more than 130 articles on the same topic. He is currently working on describing a set of visual thinking algorithms, as well as designing and building visualizations of ocean-related data and networks.