ABSTRACT

Theory is an increasingly hot topic in visualization, moving beyond definitions of low-level data mappings to bigger questions about how and why visualization works. In recent years, these questions have drawn visualization researchers into fields such as information theory, visual grammars, and cognitive science in search of better perspectives on their own field. While this search has begun to prove fruitful, it has also left those researchers interested in visualization theory somewhat isolated from one another in a loosely-connected set of subfields and special interests. Recent reviews of theoretical directions in information visualization show both the range of approaches and the difficulty of producing a solid theoretical foundation from these disconnected pieces [4, 5].

In other fields, theory plays a significant role for both advanced practitioners and researchers. Theory in the natural sciences seeks to explain, model, and predict reality. Theory in fields such as probability and statistics guides the development of tools like experiments and surveys which are often adopted by the practitioners of other fields. While in the long view, established theories will always be supplanted by newer ones in light of new evidence and understanding, fully developing established theories is necessary in order to steer significant research which advances knowledge and yields a new and more accurate theory.

Information visualization has a growing body of significant theoretical work from a wide range of perspectives. In order to significantly advance visualization theory, we need to start seriously synthesizing these different perspectives. The purpose of this panel is to encourage visualization theorists who have been exploring these far-flung fields to comment on each other’s work and, in the process, show how their theories fit together. Instead of directly presenting their own work, each panelist will review the work or commentary of the other panelists and discuss what they think are the important points of connection or contradiction from their perspective. Each panelist will also identify an important point or question which current theory has not addressed. The audience will then be encouraged to find additional points of overlap, as well as theoretical gaps and blind spots, when asking questions of the panel.

This format is intended to push the discussion towards a synthesis of perspectives, rather than simply presenting the state of the art in visualization theory.

By bringing together the perspectives of visualization theorists, we hope to answer not just individual theoretical questions, but the bigger meta-questions of visualization theory. What do we consider a successful theory, and why? What theoretical questions are settled, and which need to be addressed most urgently? And ultimately, what is visualization theory for? We hope that this panel will inspire the unification and continued development of these kinds of ideas which might make the field of information visualization as accessible to external researchers and practitioners as probability and statistics.

2 POSITION STATEMENTS

2.1 Robert Kosara

Most of what theoretical foundations we have in visualization comes from other fields. There’s perceptual research on colors, pre-attentive perception, gestalt laws, etc. There’s statistics, which tells us about correlations, clusters, etc., and also provides some of the most common and most useful techniques. There’s computer graphics, whose tools we use. There’s also the rather unlikely work of a French semiologist from the 1960’s [1].

This work has been extended, of course. Color research has been pushed forward by Bartram, Healey, Rogowitiz, and others. Perception research has been applied to visualization and extended by Laidlaw, Ware, and others. Mackinlay took Bertin’s work and applied it to a much broader range of visualizations than his original focus, maps.

The list goes on, but it is not very deep. Most of this work can be traced directly back to its origins in other fields. There is very little work that is purely motivated by visualization and entirely (or even largely) done with the tools and ideas in visualization.

Without such work, what are we? A coincidental overlap of all these other fields? A tiny sliver in a Venn diagram whose borders were drawn with too thick a brush stroke? I don’t believe that.

What we need is a new push towards visualization theory: to understand why and how this field works, to find out how it differs from statistics, psychology, computer graphics, etc.; to establish our own basics that we can build on more firmly than the largely ad-hoc approaches today; and to make the case that we do deserve to have our own community, our own conferences and journals, and our own slice of the funding cake.
I will talk about three aspects of current visualization theory:

1. Structural specification: A structural specification describes both the mapping of data to a visualization and the resulting layout. I will start with the algebra I developed in my Ph.D. Dissertation, which codified the semantics of graphics developed by the French cartographer Jacques Bertin. In particular, I developed algebraic operators that were used to automate the design of effective presentations of relational data using theoretical and practical knowledge about human perception. This algebra is also based on Stevens’ theory of scales of measurement. Using this algebra as a foundation, I will compare and contrast with some of the related work on structural specification of visualizations. In particular, I will describe how Pat Hanrahan and Chris Stolle extended my algebra in their Polaris system. I will point to open issues and opportunities.

2. Pipeline specification: A pipeline specification describes the process of going from raw data to an interactive view. I will describe, in particular, the reference model used in the readings book I co-authored with Stu Card and Ben Shneiderman. This reference model has been used to describe a wide range of visualization systems. Again, I will point to open issues and opportunities.

3. Knowledge crystallization: Stu Card is the major contributor of this aspect of visualization theory. The modern term for this area is “Visual Analytics.” As described in the book * Illuminating the Path* [5], there is extensive need in this area for additional development of visualization theory. I will focus in particular on the relationship of visualization and presentation with forward looking thoughts about using visualization for storytelling on the web, my current area of research.

**Bio:** Robert Kosara is Assistant Professor at the Department of Computer Science, College of Information Technology, at the University of North Carolina at Charlotte (UNCC), where he is also a member of the Charlotte Visualization Center. Kosara received both his Ph.D. (2001) and M.S. degrees from Vienna University of Technology (Vienna, Austria). Before coming to Charlotte, he worked at the VRVis Research Center and the in-silico pharmaceutical research company Inte:Ligand. Kosara’s research is in Information Visualization (InfoVis), with a special focus on perceptual issues and theoretical questions.

2.2 Jock Mackinlay

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**Bio:** Jock’s 1986 Ph.D. dissertation at Stanford University developed a formal algebraic approach for the automatic design of graphical presentations of relational information. After graduation, he joined Xerox PARC, where he focused on user interaction. In 1991, he co-presented three papers at the CHI conference that established the field of information visualization. Over the next decade, he developed many visual metaphors, some inspired by his dissertation formalism. In 2004, Jock joined Tableau Software, where he is working to broaden the adoption of information visualization. His 2007 IEEE InfoVis paper described how his dissertation work on automatic presentation finally became widely available when it was added as a core function to a commercial visual analysis application. In 2009, the IEEE VGTC presented Jock with their Visualization Technical Achievement Award for this work.

2.3 Bernice Rogowitz

A theory of visualization hinges on the question of semantics. In visualization, we map data onto visual elements in a way that we hope will help the user to perceive and reason about the structure in the data. We also develop interactive methodologies that we hope will allow the user to explore the data in a way that will help reveal structures that were previously hidden. To preserve the semantic structure of the data, we need to have a theory that will provide a mapping from data structures to perceptual structures. For example, experiments have shown that magnitude information is well-represented using color maps that have a monotonic luminance component. When equal steps in the data correspond to equal perceptual steps in the visualization, data magnitude information is directly available to the user, which can be very useful in revealing structure in the data. To pick another case, we have all seen examples of glyphs or textures that obfuscate the semantic meaning in the data. A theory of visualization needs to develop rules for characterizing which visual elements produce successful representations of different structures in the data.

In interactive visualization, the representation of the data is manipulated and transformed to reveal deeper structures in the underlying data. For example, the user may want to use color as a semantic marker, to highlight certain ranges in the data, or may want to peel away unselected regions in order to identify hidden structures. Or, the analyst may want to transform the data mathematically, or represent structures that have been revealed through algorithmic manipulations. The goal of a theory of visualization would be to predict how our perception of the meaning in the data depends on these various transformations, and how to match these different representations to our analysis goals and tasks. This work will require us to develop a deeper understanding of how higher-level human capabilities, such as attention, decision-making, and aesthetics, contribute to our ability to wrest meaning from our data.

In addition to developing a theory of visualization, we need methodologies that will integrate its rules into visualization software. In the same way a statistics or data mining program can guide the user in selecting an appropriate test or ensuring that the data fit the algorithm’s assumptions, we need to provide training wheels for visualization users. To do so will require extracting and providing guidance based on metadata about the data, the visual task, and the perceptual and cognitive capabilities of the user who will be interpreting it.

**Bio:** Bernice Rogowitz received her Ph.D. from Columbia University in human vision and perception. She has over 60 publications and patents in a wide range of areas, including representing meaning in data visualization, navigating more naturally through a digital archive of images, and conveying the sense of touch in 3-D virtual environments. Bernice founded the SPIE/IS&T Conference on Human Vision and Electronic Imaging, which she continues to co-chair. She is a Fellow of the SPIE and the IS&T and a Senior Member of the IEEE, and has been honored as the National IS&T Distinguished Lecturer and received the IS&T/SPfE Award in Recognition of Outstanding Achievement.

2.4 Ji Soo Yi

I believe that in order to build useful theories of information visualization, we should first collect reliable and comparable empirical evidence of how information visualization is used and work, so that researchers can identify patterns, propose hypotheses and theories, and test them. However, in the field of information visualization, we have not established a proper culture to collect comparable data, yet. Here are a few suggestions:

1. Taxonomies for more precisely defined cognitive tasks or activities would help researchers describe their experiences and evaluation results more precisely. When qualitative evaluation studies or scenarios are reported in an InfoVis paper, ways to describe the benefits of a proposed visualization technique widely vary and are sometimes vague. For example, one may write, “The main view provides a good overview.” However, it is not clear what specific cognitive tasks a potential user accomplished through the overview. It could be simply “seeing
all data points in a single screen” or “finding a linear trend in the given data set.” If we can establish and continuously evolve a precisely defined taxonomy for cognitive tasks in information visualization, we can make data more comparable and even searchable. The work of Chen et al. [3] could be an interesting start.

2. Standardization of measures would make collected data more comparable. For example, some have hypothesized that individual differences influence performance in visual analysis [6]. However, several studies concerning individual differences used different measures and different visualization tools, so it is very challenging to conduct meta-analysis over collected data. Proposing a standard set of measures and making the measures publicly available will not only save researchers’ efforts to find a proper set of measures, but also make collected data more comparable.

3. Quantitative and physiological measures might help data more comparable. Researchers in psychology and cognitive science have successfully design tasks to measure various psycho-physiological phenomenon, such as insight problem solving [2]. If the similar approach could be successfully adopted in information visualization, we may quantitatively evaluate proposed theories, which will drastically improve our understanding of information visualization.

Bio: Ji Soo Yi is an assistant professor in the School of Industrial Engineering at Purdue University. While pursuing his Ph.D. degree at Georgia Institute of Technology, he got interested in Information Visualization through Dr. John Stasko’s class, which led him to investigate various theoretical issues in information visualization (e.g., interaction and insight) and its applications in decision making (e.g., Dust & Magnet and SimulSort). More recently, he has been interested in the influences of individual differences (e.g., cognitive limitations and visualization literacy) on the performance of visual analysis and defining and measuring insights through brain imaging technologies (e.g., ERP).

References