Vision Science Meets Visualization

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Abstract

Vision science can explain what people see when looking at a visualization--what data features people attend to, what statistics they ascertain, and what they ultimately remember. These findings have significant relevance to visualization and can guide effective techniques and design practices. Intersections between visualization and vision science have traditionally built upon topics such as visual search, color perception, and pop-out. However, there is a broader space of vision science concepts that could inform and explain ideas in visualization but no dedicated venue for collaborative exchanges between the two communities. This panel provides a space for this exchange by bringing five vision science experts to IEEE VIS to survey the modern vision science landscape in order to foster new opportunities for collaboration between visualization and vision science.

Keywords: Vision Science, Visual Search, Peripheral Vision, Visual Perception, Visual Attention, Color Perception.

1 Introduction

Visualizations enable the human visual system to reliably and efficiently identify important features and trends in data. But how exactly does this cognitive pattern recognition work? How do people find the signal in the noise? Related questions have been studied extensively by vision scientists, but collaboration between vision science and visualization has historically been limited. In this panel, we will showcase recent results from vision science to expand our knowledge of vision science for visualization. This knowledge can help designers better understand and predict how people make sense of visualized data.

Many visualizations build on design practices grounded in a standard set of vision science concepts, such as pop-out, visual clutter, salience, and visual search. However, there is no dedicated venue for collaborative exchanges between the vision science and visualization communities. In vision science, the Vision Sciences Society (VSS) Annual Meeting alone hosts more than 1,400 presenters each year. Recent developments in these research topics (e.g., in visual attention, scene understanding, and quantity perception) can inform our understanding of how people interpret visualized information. However, historically, few VIS researchers have attended VSS, and few vision scientists have attended IEEE VIS. This limited overlap has stifled the exchange of information, ideas, and questions between the two communities.

Further, while crossover between vision science and visualization is not without precedent (e.g., work by Cleveland & McGill [2] and Healey & Enns [8]), these interactions can benefit from exposure to a broader set of vision science topics, such as object tracking, ensemble statistics, and visual crowding. Recent efforts that integrate newer concepts from vision science into visualization have generated significant excitement within the visualization community (e.g., work by Rensink & Baldridge [10, 11], Harrison et al. [6], Haroz & Whitney [7], and Borkin et al. [1]). These examples illustrate how drawing from current vision science phenomena and research can accelerate and broaden growth in visualization research while inspiring novel techniques and design practices.

The goal of this panel is to introduce a survey of modern results from vision science that may not have received sufficient visibility in the VIS community. We see this panel as a way to facilitate discussion between visualization and vision science experts, strengthening ongoing ties between both communities. Efforts in vision science have connected vision science topics to typical visualization tasks, exposing new research questions that span both communities. For example, visualization-focused meetings have been organized at the VSS Annual Meeting [3] and the upcoming Annual Workshop on Object Perception, Attention, and Memory [5]. Additionally, many vision scientists have incorporated visualization elements in their work, such as research on the perception of correlation in scatterplots [4], visual attention to redundant color/shape encodings [9], and how prior knowledge biases attention to different visual features in graphs [14]. A recent Journal of Vision publication surveyed crossovers between visualization and ensemble statistics research [12] and has already received over 4,700 views. These efforts are evidence of an increased interest in collaboration between these two fields.

This panel aims to build on this momentum by bringing vision science experts to VIS. The symposium will begin with an introduction to how visualization and vision science communities may interact, and the discussion of a specific example of the perception of correlations (Ronald Rensink). It will continue discussing quantity perception and summary statistics in communicating health risks (Todd Horowitz), how understanding fast and slow visual processing can inform visualization guidelines (Steven Franconeri), how perceptual features map onto semantic concepts (Karen Schloss), and modeling peripheral vision to evaluate usability (Ruth Rosenholtz). The discussion will provide further opportunities for innovation in these fields. Visualization researchers will have access to more information about when, how, and why designs work as they do, and vision scientists will have new questions and paradigms for investigating visual and cognitive mechanisms in a real-world context.

2 Panelists

2.1 *Visualization & Vision Science* Dr. Ronald Rensink, UBC

It is suggested that visualization and vision science can interact in three different (but compatible) ways. The first—more traditional—way is using knowledge of human vision to help design more effective visualizations. Many recent advances in vision science (e.g., what does or does not require attention) are counterintuitive and not well known outside of vision science; it is worth keeping up to date on the latest findings. The second way that vision science can help is via the set of techniques and measurements used to assess human performance on experimental tasks. Many of the concepts involved (e.g., just noticeable differences) can be readily applied to the evaluation of visualization designs. They can often shed new light on aspects of user performance, and reduce the likelihood that findings are artifacts. Finally, a relatively new form of interaction between the two fields is the controlled study of minimal versions of existing visualizations. This is akin to the use of fruit flies in biological research: such visualizations are deliberately simple, but when handled correctly can enable the discovery of many of the perceptual and cognitive mechanisms involved (e.g., studying the perception of correlation in simple scatterplots suggests that this is based not on the scatterplot dots directly, but on the entropy of the probability distributions derived from them). This talk will cover all three approaches, with a slight emphasis on the last.

Panelist Biography

Ronald Rensink is an Associate Professor in the departments of Computer Science and Psychology at the University of British Columbia (UBC). His research interests include visual perception (especially visual attention), information visualization and visual analytics. He obtained a PhD in Computer Science from UBC in 1992, followed by a postdoc in Psychology at Harvard University, and then several years as a scientist at Cambridge Basic Research, an MIT-Nissan lab in Cambridge MA. He is currently part of the UBC Cognitive Systems Program, an interdisciplinary program combining Computer Science, Linguistics, Philosophy, and Psychology.

2.2 *Quantity Perception, Summary Statistics, & Risk Perception in Cancer* Dr. Todd Horowitz[1][2], National Cancer Institute

Effectively preventing, identifying, diagnosing, and treating cancer depends on doctors and patients making good decisions under conditions of uncertainty and stress. In order to make these decisions, they need to understand probabilistic information about risk. How likely am I to get cancer if I stop smoking? Should I undergo cancer screening? What is the probability of cancer given these symptoms? Which treatment option is best? Research has shown that such information is often best communicated visually. However, most of the research on risk communication has been driven by the field of decision-making, with little input from specialists in visualization or visual perception. We suggest that better solutions for graphically conveying cancer-related risks would come from collaboration between visualization researchers and vision scientists. As an example, consider icon arrays, pictograms that illustrate proportions in order to convey risk. Work on the perception of numbers suggests that quantity perception depends on the interplay between the approximate and precise number systems. The precise number system applies to quantities below 4 or 5, so above this threshold, the effectiveness of icon arrays will depend on the precision of the approximate number system, which varies with age. More broadly, the design of graphics to communicate risk should take into account the visual system's ability to perceive quantities, and to extract "summary statistics" of visual features such as size and color in the periphery. Only once we take into account the capacities and limitations of the visual system can we develop effective methods of communicating health risks to doctors and patients.

Panelist Biography

Todd Horowitz is a cognitive psychologist, with a B.S. from Michigan State University (1990) and a Ph.D. from the University of California, Berkeley (1995). From 1995 to 2012, he worked at Brigham and Women's Hospital and Harvard Medical School, before moving to the National Cancer Institute, where he is now a Program Director in the Division Cancer Control and Population Sciences. He has published widely on visual perception and attention, including basic research as well as applications to the study of Parkinson's Disease, autism, driving, and airport baggage screening. Currently, he is working to engage cognitive psychologists and vision scientists with problems in cancer control, such as improving medical image interpretation, studying the cognitive effects of cancer and cancer treatments, and improving the effectiveness of visual health communications.

[1] Pending funding availability. Dr. Steve Haroz, who regularly attends both VSS and VIS, will be solicited as a speaker in the event Dr. Horowitz is unable to attend.

[2] Dr. Horowitz will present this work, though it is co-authored with Saira Umar. Saira is a Cancer Research Training Award Fellow in the Division Cancer Control and Population Sciences working on visually analyzing and displaying information for effective communication. Her educational background includes psychology and graphic design at American University. Her research interests include studying human interaction and how biological factors interact with developmental, social, and environmental factors to create personality and identity.

2.3 *Four Themes for Use-Inspired Basic Research in Perceptual Psychology* Dr. Steven Franconeri, Northwestern

Your visual system evolved and developed to process the scenes, faces, and objects of the natural world. Using that system to process the artificial world of data visualizations is an adaptation that can lead to fast and powerful – or slow and inefficient – visual processing. The fast processing tends to rely on a powerful system that quickly computes distributional information about various features (colors, sizes, orientations, etc) within 100ms. Based on this statistical snapshot of an image, the visual system iterates, several times per second, through a slower process of hypothesis testing, seeking meaningful patterns and relations across subsets of visual information. Understanding the power and limits of each of these types of visual processing produces guidelines for constructing effective visualizations for both visual analytics and visual communication of patterns in data, and explains how display designs and motivated cognition can bias interpretations of those patterns.

Panelist Biography

Steven Franconeri is Professor of Psychology at Northwestern University, and Director of the Northwestern Cognitive Science Program. His lab studies visual thinking, graph comprehension, and data visualization. He completed his Ph.D. in Experimental Psychology at Harvard University with a National Defense Science and Engineering Fellowship, followed by a Killam Postdoctoral Fellowship at UBC. He has received the Psychonomics Early Career Award and an NSF CAREER award, and his work is funded by the NSF, NIH, and the Department of Education. Franconeri conducts research on visual thinking, visual communication, and the psychology of data visualization. He is Principal Investigator of the Visual Thinking Laboratory, where a team of researchers explore how leveraging the visual system can help people think and communicate more efficiently.

2.4 *Color Inferences in Data Visualization* Dr. Karen Schloss, UW-Madison

A key aspect of interpreting information visualizations is determining how perceptual features map onto semantic concepts. For example, interpreting colormaps requires figuring out how dimensions of color correspond to quantities of a given measure (e.g., brain activity, correlation magnitude). This process should be easier when percept-concept assignments specified in visual displays match percept-concept assignments inferred in observers' minds (perceptual-cognitive fit). But, what are the inferred percept-concept assignments in observers' minds? My laboratory addresses this question in the domain of color. Our research on colormaps has revealed that observers infer that darker colors map onto larger quantities, regardless of contrast with the background, as long as colormaps are perceptually opaque (dark-is-more bias). However, if colormaps appear to vary in opacity, observers demonstrate an opaque-is-more bias that weakens or even overrides the dark-is-more bias. In a different study we found that observers form new color inferences, on-the-fly, while viewing a short series of lecture slides presenting bar graphs. Both studies reveal that perceptual-cognitive fit is relational, depending on perceptual relations among colors used to depict conceptual information and relations between those colors and other colors in the data visualization.

Panelist Biography

Karen Schloss is an Assistant Professor at the University of Wisconsin – Madison in the Department of Psychology and Wisconsin Institute for Discovery. She leads the Visual Perception and Cognition Lab, which studies color cognition, information visualization, and navigation in immersive virtual environments. She received her BA from Barnard College, Columbia University in 2005, with a major in Psychology and a minor in Architecture. She went on to study visual aesthetics and perceptual organization with Professor Stephen Palmer at the University of California, Berkeley, where she received her PhD in Psychology in 2011. She continued as a Postdoctoral Scholar with Professor Palmer from 2011-2013, before becoming Assistant Professor of Research at Brown University in the Department of Cognitive, Linguistic, and Psychological Sciences in 2013. Karen joined the faculty at UW-Madison in 2016.

2.5 *Peripheral Vision & Usability* Dr. Ruth Rosenholtz, MIT

Understanding and exploiting the abilities of the human visual system is an important part of the design of usable information visualizations. Designers traditionally learn qualitative rules-of-thumb for how to enable quick, easy and veridical perception. More recently, work in human and computer vision has produced more computational models of human perception, which take as input arbitrary, complex images of a design. Some of these models output quantitative predictions, but many models themselves output a "visualization": of what a user will readily perceive. These model visualizations can aid a designer in evaluating usability. My lab has worked on models of perceptual organization, saliency, visibility, and clutter. My talk will focus on our recent work on modeling peripheral vision, an important determinant of human perception that accounts for many perceptual phenomena.

Panelist Biography

Ruth Rosenholtz is a Principal Research Scientist in MIT's Department of Brain and Cognitive Sciences, and a member of CSAIL. She joined MIT in 2003 after 7 years at the Palo Alto Research Center (formerly Xerox PARC). Ruth's background is in electrical engineering, specifically computer vision. More recently, however, she has studied human vision, including visual search, perceptual organization, visual clutter, and peripheral vision. Her work focuses on developing predictive computational models of visual processing, and applying such models to design of user interfaces and information visualizations.

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