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 extract, 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 color perception, pop-out, and salience. 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. The Psychonomics Annual Meeting hosts 1,300 presentations on wide ranging topics in cognition and vision science, and its co-located Workshop on Object Perception, Attention, and Memory (OPAM) hosts 100 presentations. 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 related venues, 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.

The 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 how visualization may provide a ripe testing ground for understanding the way we see the world (Ronald Rensink). It will continue by 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], 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] 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 *Perception of Data Visualizations, Fast & Slow* 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 expertise can guide interpretations of those patterns. The needs of the visualization community also demand new work from perceptual psychology, such as formal models of the types of 1D and 2D patterns that we can visually extract, remember, and compare, from depicted data.

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.

2.4 *A Color Inference Approach to Interpreting Colors in Information Visualization* Dr. Karen Schloss, UW-Madison

While looking at visual displays, people are capable of extracting complex messages from perceptual features. To do so, they must determine how perceptual features map onto abstract concepts. In many cases, there are legends or labels to specify this correspondence. However, the visual and temporal limitations can make it challenging for observers to discern these mappings while also devoting resources to understanding the information the displays were designed to convey. One way make this process easier is to anticipate observers' expectations of how concepts map onto visual features, and then design displays that match those expectations. The problem is, what are observers' expectations? My laboratory addresses this question in the domain of color. We developed a Color Inference Framework, which proposes that humans make inferences about how colors signal concepts by integrating information from two sources: (1) stored color-concept associations in the mind acquired through experiences in the world, and (2) perceptual/conceptual context relevant to the visual display. I will present studies guided by this framework to investigate how observers interpret colors used to depict different quantities or categories in visual displays.

Panelist Biography

Karen Schloss is an Assistant Professor at the University of Wisconsin – Madison in the Department of Psychology and Wisconsin Institute for Discovery. Her Visual Perception and Cognition Lab studies color cognition, information visualization, perceptual organization, and navigation in virtual environments. She received her BA from Barnard College, Columbia University in 2005, with a major in Psychology and a minor in Architecture. She completed her Ph.D. in Psychology at the University of California, Berkeley in 2011 and continued on as a Postdoctoral Scholar from 2011-2013. She spent three years as an Assistant Professor of Research in the Department of Cognitive, Linguistic, and Psychological Sciences at Brown University before joining 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. A fundamental constraint on performance in any visual task is the information available at a glance. Tasks that cannot be done at a glance require time-consuming shifts of the point of gaze. What one can do at a glance, in turn, hinges critically on the strengths and limitations of peripheral vision. Human vision research has recently made considerable progress in understanding peripheral vision. Many aspects of human vision of interest to information visualization appear to be subsumed by understanding visual processing in the periphery: items that "pop out" are those easily processed; peripheral vision facilitates getting the "gist" of a display; and tasks that have been thought to be "preattentive" may actually just be those that are easy to perform using peripheral vision. To get intuitions for information visualization, one only need to introspect on how a design looks out of the corner of one's eye (rather than the old advice to squint at the it). We have developed the state-of-the-art model of peripheral vision, and created a tool to aid intuitions by visualizing the information available in the periphery.

Panelist Biography

Ruth Rosenholtz is a Principal Research Scientist in MIT's Department of Brain and Cognitive Sciences, and a member of CSAIL. She has a B.S. in Engineering from Swarthmore College, and an M.S. and Ph.D. in EECS from UC Berkeley. Her lab studies human vision, including visual search, perceptual organization, visual clutter, and peripheral vision. Her work focusses on developing predictive computational models of visual processing, and applying such models to design of user interfaces and information visualizations. She joined MIT in 2003 after 7 years at the Palo Alto Research Center (formerly Xerox PARC).

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