Top Research Questions for Empirical Studies in Visualization

Brian Fisher[*] Simon Fraser University
Petra Isenberg[†] Inria, Université Paris Saclay
David H. Laidlaw[‡] Brown University
Melanie Tory[§] Tableau Software
Daniel Weiskopf[¶] University of Stuttgart
Alfie Abdul-Rahman[‖] (Organizer) King's College London

ABSTRACT

Empirical studies are an indispensable component in visualization as they allow us not only to understand the interactions between humans and computers, but also to evaluate and confirm our results and experiments. In this panel, we ask five researchers – "What are the top research questions for empirical studies in visualization?" Our panelists cover a range of topics including:

- A focus on cognitive science as well as synthesizing theoretical perspectives;
- Causes of empirical studies focusing on narrow hypotheses vs. broad hypotheses as well as mechanisms for tracking them;
- Understanding human-computer interaction of visualization, what works best, and how we predict performance;
- The need for a great diversity of empirical studies and the gap between research and practice; and
- Quantitative measures of empirical studies as well as the role of eye-tracking.

1 INTRODUCTION

Empirical studies are essential for guiding the design of visualization and for demonstrating its effectiveness in applications. As graphical visualization matures, it becomes crucial for the field to define research perspectives, questions, and methods that generate meaningful research questions for empirical investigations. This will not only enable us to advance the science of visualization but most importantly will allow us to support newcomers to the field to transverse the sea of possible research questions.

Empirical studies can provide a structure for determining whether a specific research hypothesis holds true for a specific representation of information or a class of visualization styles. While empirical studies enable us to "test drive" a particular hypothesis, it is important for us to ask how to choose and test research questions that expand the scope of possible visualizations and extend the field of visualization to diverse applications. In this panel, our panelists discuss this topic: "What are the top research questions for empirical studies in visualization?"

2 WHY THIS PANEL AT IEEE VIS 2019?

Empirical studies play an important part in visualization as they allow us to understand the mechanisms and workings of a specific visualization. There are many ways that one can implement an empirical study, such as quantitative evaluation and qualitative evaluation, and we can see a steady presence of empirical study papers in the visualization community.

[*]e-mail: bfisher@sfu.ca
[†]e-mail: petra.isenberg@inria.fr
[‡]e-mail: dhl@cs.brown.edu
[§]e-mail: mtory@tableau.com
[¶]e-mail: weiskopf@visus.uni-stuttgart.de
[‖]e-mail: alfie.abdulrahman@kcl.ac.uk

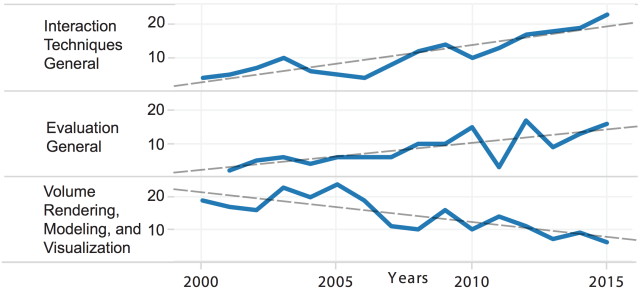

Figure 1: The trend of the *evaluation* keyword from the IEEE VIS conference from the years 1990 to 2015. [3].

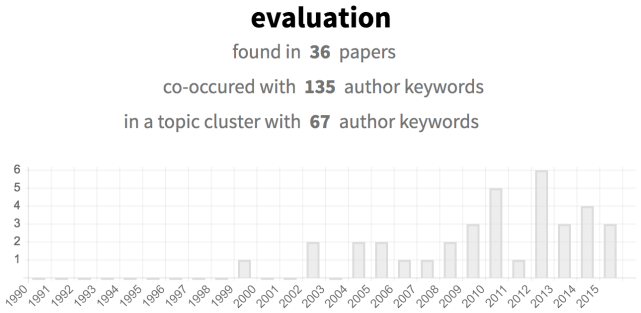

Figure 2: The trend of the *evaluation* keyword from the IEEE VIS conference from the years 1990 to 2015 [2].

Isenberg et al. [3] show an increasing trend of the *evaluation* keyword in the papers published in the IEEE Visualization conference series (now IEEE VIS) between the years from 1990 to 2015 (Figure 1). Similarly, we can also visualize this increasing trend on *KeyVis* [2] (Figure 2). In this year's InfoVis conference, 42% papers submitted to InfoVis selected a keyword from the precision conference system (PCS) *evaluation* category, and out of all keywords 24% chose *quantitative evaluation* and 15% selected *qualitative evaluation* (similarly with *HCI*). From these numbers, it is therefore important for us to understand more deeply the nature of empirical studies and their role in pushing the boundaries of visualization. This issue will generate a lively discussion to address these questions.

3 PANEL FORMAT AND LOGISTICS

The panelist will present their positions addressing the topic – "What are the top research questions for empirical studies in visualization?".

- The introductory remarks will be made by Alfie Abdul-Rahman. Her introduction will last for 5 minutes.
- She will chair the panel and she herself is not a panelist.
- Each panelist will be given 10 minutes (6 minutes presentation plus 4 minutes of Q&A) – for a total of 50 minutes. The purpose of including a short period of Q&A after each individual

presenter is for clarification purpose.
- This will provide approximately 30 minutes of audience participation in the discussion.
- All panelists will have the opportunity to offer a summary view at the end of the panel (2 minutes each).

The panel chair will solicit audience feedback after the position statements have been delivered. Prior to this, we will also be collating questions, feedback, comments, and suggestions from our visualization community before the start of IEEE VIS 2019 at `http://thisisalfie.com/top-research-questions.html`. The panel format will also be described in the panel opening.

4 Position Statements

Brian Fisher

Position statement: The set of events that make up IEEE VIS have always had a place for researchers who are interested in how people see, understand, and reason with visualization. Researchers with experience in vision sciences, cognitive sciences, and decision sciences have joined with their colleagues in computer graphics and graphical design to examine the use of visualizations in the lab and establish the effectiveness of visualization in application domains. I believe that recent developments in VIS organization– VIP, Diversity, application spotlights and others – reflect the growing maturity of an increasingly interdisciplinary field. What is needed now is to consolidate a somewhat disorganized set of theories and methods to a smaller set of theoretical perspectives and define a set of critical research questions from each of these perspectives. My background in cognitive science leads me to propose several from that perspective:

- Is there a stable cognitive architecture of visually enabled reasoning that we can explore and define in laboratory studies?
- How does visualization literacy and other forms of perceptual expertise interact with and build upon the cognitive architecture?
- How can we support acquisition of visually-enabled reasoning expertise in specific applications and for the general public? Can field experiments and crowdsourcing be better used to do this?
- How do diverse stakeholders use visualization to provide common ground for discussion, argumentation, and coordination of action in organizations and society? Can we develop field research approaches to measure this?

Biography: Brian is a Professor in SIAT, an interdisciplinary technology design program at Simon Fraser University and Affiliate Professor in Computer Science at the University of British Columbia. His research takes a cognitive science perspective on the design and evaluation of technology to support human understanding, decision-making, and collaboration in applications that include personalized health, aircraft safety analysis, and command, control, and interoperability for emergency management. Brian is a Fellow of the Psychonomics Society, and serves on the Natural Sciences and Engineering Research Council of Canada, the IEEE VAST Steering and VIS Executive Committees. He is a co-Chair for VIS 2019.

Petra Isenberg

Position statement: Research questions in visualization range from narrow, testable hypotheses to broad and general research questions that may take many studies and years of research to answer. All have in common that they try to assess the *value* that interaction techniques, algorithms, visual encodings, or systems (might) add — possibly compared to existing techniques. Past discussions, such as van Wijk's [6] value model or Stasko's I-C-E-T model [5] have focused on visualizations' analytic and knowledge-generating value combined with cost-factors such as effectiveness and efficiency. Yet, several new directions in visualization show us that value metrics need to be expanded and cover a broader set of values, such as hedonic qualities, creativity, or affective, physical, intellectual, or social engagement [7]. For example, data physicalizations may help people to establish a personal connection to the data either through construction or physical touch and personal data visualizations may carry deep emotional value that is essential to a person's understanding of the data, self-reflection, or decision making. I argue that the community needs to work considerably more on establishing a comprehensive understanding of visualization values and that these values need to be the basis of new empirical research questions.

Biography: Petra Isenberg is a research scientist at Inria, Saclay, France in the Aviz research group. Prior to joining Inria, she received her PhD from the University of Calgary in 2010 working with Sheelagh Carpendale on collaborative information visualization. Petra also holds a Diplom-engineer degree in Computational Visualistics from the University of Magdeburg in Germany. Her main research areas are information visualization and visual analytics with a focus on off-desktop data analysis, interaction, and evaluation. She is particularly interested in exploring how people can most effectively work together when analyzing large and complex data sets on novel display technology such as small touch-screens, wall displays, or tabletops. Petra is associate editor-in-chief at IEEE CG&A, associate editor of the IEEE Transactions on Visualization and Computer Graphics, has served on many organizing committee roles at IEEE VIS including as papers co-chair for Information Visualization (InfoVis), and has been the co-chair of the biennial Beliv workshop since 2012.

David H. Laidlaw

Position statement: Empirical studies are a way to understand how humans and computers interact. They are experiments that involve observing, sometimes quantitatively and sometimes qualitatively, something about humans as experimenters vary characteristics of what they are perceiving from a computer-based visualization.

There are three main research questions that I will discuss.

A first research question is "How do humans see and think when using visual tools?" This encompasses a lot. In some cases, simple reporting on observations of user behavior in the wild or in laboratory conditions contributes new knowledge that advances our understanding. For example, a paper about a visualization system might report what users were able to describe about something they were visualizing. Or it might describe their activities during the course of using the software. Of course, in order to be a contribution to our understanding, such observations must be analyzed and compared with what is already in the literature. It must be clear how the observations advance our understanding of how humans see and think.

Contributions addressing this first research question may also come from qualitative, subjective, or objective measures of performance or behavior. These cases are somewhat more satisfying, because they are often easier to directly compare to related work.

A second research question is "What visualizations work best and why?" This is intentionally a broad question. Left implicit are the task, which almost certainly needs to be specified in any particular experiment. This research question is almost always explored by varying the visualization and measuring user performance or behavior. Experiments addressing one of the research questions can often be quite similar to experiments addressing the other. Sometimes one experiment addresses both.

A third question is "What models predict human performance or behavior using different visualization?" Asking such questions usually involves assembling answers to both of the first two questions above. Such models are very hard to create. Human behavior is not

easy to predict. Often, only the very lowest level of predictions can be made. For example, there are quantitative models for how fast and how accurate humans are at moving a mouse, cursor, or tracker to a target. These are quite useful for designing some aspects of a human-computer interface, but are far from a full model of human behavior.

In addition to these direct research questions, I would add some research challenges that I think are worth considering. A first challenge is in adopting and adapting research methods from other domains. A number of other domains study human behavior. These include sociology, psychology, anthropology, and behavioral economics. While it is probably too hard for any one researcher to span so many disciplines, there is clear value to building on research methods that are already developed. Collaborative research projects can be particularly fruitful here. It is important to keep in mind the questions that our field wants to answer, since the methods from other fields are not asking the same questions. Adopted methods almost always need to be adapted.

A second research challenge is educating our field to better recognize, describe, and value different kinds of research contributions. As I described above, contributions from different kinds of experiments can range from anecdotal observations to quantitative evaluations of specific visualization methods to quantitative evaluations of quantitative models. All potentially have value, but new knowledge does not always fit into a particular pre-defined category. While it is certainly helpful to have exemplars of paper categories, slavish categorization can be harmful. Educating our field to recognize a wider range of research contributions will move us forward more quickly. Educating our field to more clearly articulate research contributions will, as well.

Biography: 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. He has worked with researchers in, for example, archeology, developmental neurobiology, evolutionary biology, medical imaging, neuropathology, orthopedics, art, cognitive science, remote sensing, and fluid mechanics to develop new computational applications and to understand their strengths and weaknesses. Dr. Laidlaw has published more than 100 peer-reviewed journal and conference papers, is an IEEE Fellow, has served on or co-chaired dozens of conference committees, has been an associate editor of IEEE Transactions on Visualization and Computer Graphics, was awarded the 2008 IEEE VGTC Visualization Technical Achievement Award, and has been the recipient of a number of other research related awards from IEEE Visualization, ACM SIGGRAPH, and NSF.

Melanie Tory

Position statement: Empirical studies have become an established practice in visualization, but the diversity of contribution types in empirical study papers at VIS is currently quite limited. Many of the big open questions in our field are exploratory and open-ended in nature. How do visual analytics tools fit into the data ecosystems and practices of organizations? How do people with different backgrounds and roles work together with data within those organizations? Which user needs are not being met by VA tools? What are the barriers to wider adoption? Answering these types of exploratory questions demands a different approach from our existing practice of quantitative hypothesis-driven research. We need a greater diversity of empirical studies at VIS, most notably greater adoption and acceptance of qualitative methods.

Examples of the types of empirical work I'd like to see more of include pre-design studies that attempt to understand user populations, problem domains, existing practices, and user needs [1] and long term case studies of real deployed systems [4]. Applied user researchers do a lot of this work to inform product development, but those studies are rarely published. In contrast, academic research in VIS seems heavily biased towards quantitative experimental paradigms. As a result, there is a growing gulf between academic research and practice, not to mention a missed opportunity. Visualization research is most impactful when it makes its way into the world and changes the way everyone uses data in their work or daily lives. Let's work together to understand the analytics challenges people are facing every day so we can change the way the world works with data.

Biography: Melanie Tory manages Tableau Software's user research in the area of visual analytics. Many of her recent empirical studies have explored how non-expert users interact with visual analytics, especially through natural language. She employs both qualitative and quantitative approaches in her research and has co-delivered VIS tutorials on qualitative methods. Before joining Tableau, Melanie was an Associate Professor in visualization at the University of Victoria. She earned her PhD in Computer Science from Simon Fraser University and her BSc from the University of British Columbia. Melanie co-edits the People in Practice department of IEEE Computer Graphics and Applications and has served as Papers Co-chair for the IEEE Information Visualization and ACM Interactive Surfaces and Spaces conferences.

Daniel Weiskopf

Position statement: Empirical research plays a highly relevant role in visualization, as the basis for manifold research findings and confirmation of results. I take a broad perspective on empirical research: while it certainly includes a wide spectrum of user studies, I would like our community to also embrace studies of different flavors, for example, including the quantitative evaluation of the technical performance of computing systems for visualization (such as scalability experiments of large-scale data visualization) or the application of image metrics to assess visualization quality. I want to emphasize this breadth of empirical research because our community often restricts the notion of empirical studies to those involving users.

Another part of my position statement is concerned with the integration of user studies as part of techniques papers. There is an ongoing discussion about the need of evaluation in techniques papers; in fact, many reviewers ask for user studies in such papers, and use the lack of user studies as a reason to reject papers. I argue that this reviewing practice might hurt progress in our community and degrade the quality of empirical research because there is the imminent danger of (unconscious) bias in studies conducted to "sell" a visualization technique. Therefore, our reviewing standards should be adapted to ask for other kinds of validation in techniques papers instead. One of our top challenges is to establish ways of evaluating and validating visualization techniques without the immediate need for user studies; these ways could still include empirical studies, yet based on metrics or other quantitative characterizations of visualizations. On the other end of the spectrum, I would like to see even more user study papers that focus on bias-free studies but without an accompanying technical contribution.

Finally, from the perspective of my own research interests, I think that understanding the role of eye tracking for visualization is a highly relevant research question that needs to be addressed in empirical visualization research. While eye tracking has a long history in many areas, including psychology or marketing, we are still not in a position to make full use of its power for visualization. In particular, I see the specific need for best practices of user studies with uncontrolled settings, such as in-the-wild studies with realistic visualization or visual analytics applications.

Biography: Daniel Weiskopf is a full professor at of computer science, one of the two directors of the Visualization Research

Center (VISUS), and acting director of the Institute of Visualization and Interactive Systems (VIS) at the University of Stuttgart, Germany. His research interests cover all areas of visualization (information visualization, scientific visualization, and visual analytics), including research on evaluation methods and conduction of empirical studies alike. In particular, he is interested in the role of eye tracking in the context of visualization research; in this context, he co-initiated the series of Workshops on Eye Tracking and Visualization (ETVIS), co-organized several of these, and co-organized a Dagstuhl seminar on "Ubiquitous Gaze Sensing and Interaction". He has served numerous roles at visualization conferences and related scientific conference, for example, as papers co-chair for ACM ETRA 2020, IEEE SciVis 2019 and 2018, IEEE PacificVis 2017, SIGGRAPH Asia Symposium on Visualization 2016, Biovis 2016 and 2015, Eurovis 2010, and Eurographics Symposium on Parallel Graphics and Visualization 2009.

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