Toward Practical Information Visualization Theory: Lessons from the History of Decision Science

Ji Soo Yi, *IEEE Member*

School of Industrial Engineering
Purdue University

ABSTRACT

The goal of this position paper is to propose two-stage development of information visualization theories inspired by the history of decision science. Decision science, a sub-discipline of economics, investigating how people make decisions, has two distinctive schools of thoughts: normative decision theories and descriptive decision theories. Normative decision theories have evolved based on mathematical axioms and models, which entailed rapid development of unified theories, but these theories are sometimes unrealistic. In contrast, descriptive decision theories are based on close observation of human behaviors, which complement normative decision theories, but they are often fragmented. The author believes that adopting two-stage development of InfoVis theories alleviate some issues in InfoVis theory development. Potential issues and challenges were also discussed.

KEYWORDS: visualization theory, decision science, staged development of information visualization theory

INDEX TERMS: K.6.m [Management of Computing and Information Systems]: Miscellaneous

1 INTRODUCTION

One of difficulties that information visualization (InfoVis) community runs into is that we do not have sufficient theories to describe and predict important phenomena in InfoVis. Unfortunately, the following seemingly basic questions are largely remained unanswered: How a certain visualization technique works better than the other? How to make a visualization tool better? How do people gain insights? Existing theoretical work is far from sufficient to answer these questions. Why do not we have these InfoVis theories?

Aside from the fact that InfoVis is a still fledging discipline, the author believes that the biggest missing piece to build reasonable theories is a lack of collected empirical evidence. Though evaluation studies have been more emphasized in the InfoVis community (e.g., the BELIV workshops), it is often difficult to make sense of these data and make connections. In many cases, the main motivation of these evaluation studies is to prove the effectiveness of authors' own visualization tool. Thus, the evaluation results only tell that the proposed tool is superior to compared one, but they are seldom comparable with other studies. We may be able to standardize evaluation methods as some comprehensive evaluation methods have been proposed (e.g., [1]), but evaluated visualization tools will still remain different, and the outcomes will be hardly comparable.

Thus, I would like to make a suggestion to overcome this issue. Before presenting a suggestion, a brief history of decision science will be introduced. Though decision science sounds very remote from InfoVis, it shares some common aspect of research: dealing with delicate human cognition. From the way that decision science evolves, the author found an interesting hint for building InfoVis theory.

2 DECISION SCIENCE

Decision science is a sub-field of economics (or psychology) that investigate how people make decisions and how to improve decisions. Theories in decision science are often divided into two schools of thoughts: normative decision theories and descriptive decision theories [2]. Normative decision theories are based on several axioms, which help formulate mathematical model of decision problems. The mathematical model leads to an optimal choice of a given problem. For example, subjective expected utility theory [3], which is one of normative decision theories, is often described in the following mathematic model:

$$SEU(A_i) = \sum S_{ik} U(C_{ik})$$

, which describes the subjective expected utility (SEU) of an alternative A_i, given subjective probabilities S_{ik} and consequences C_{ik}. Here, function $U(C_{ik})$ represents a utility, or a structure of decision maker's preference. If one knows the values of these parameters and the utility function, one can calculate SEU's of all possible decision alternatives and choose the best alternative that maximizes SEU. Mathematical models developed in normative decision theories provide robust foundation for further development of exciting theories, such as game theory, and normative decision theories have been widely applied to various areas, such as business, public policy, and decision support systems [4].

However, the problems of normative decision theories were also noticed. Simon's bounded rationality [5] is one of the most famous attacks to normative decision theories. According to Simon, a human decision maker has a limited cognitive capability, so that computation required by normative decision models cannot be done. According to field studies and observation, people did not consider all possible options but relied on simpler heuristics to search for satisfying options. This notion of bounded rationality greatly influenced development of decision theories and entailed copious research in heuristics, bias, and decisions in naturalistic settings, which violate many of axioms of normative decision theories. These set of decision theories are called "descriptive decision theories."

Though results of descriptive decision theories largely corrected basic axioms of normative decision theories, descriptive decision theories did not totally replace normative decision theories as Einstein's theory of relativity did not totally replace Newton's law of universal gravitation. Instead, normative decision theories are still used in many cases to describe decision-making procedure, and descriptive decision theories provide partial adjustments in the normative model, such as adding additional parameters or adjust values [6]. In other words, the normative decision theories work as the rough approximation of decision-making phenomenon, and the descriptive decision theories refine the approximation. In contrast, it also should be noted that normative decision theories provide more elegant and unified theories, but descriptive decision theories provide more realistic and fragmented theories.

3 Implication to Information Visualization Theories

Inspired by the distinctive development of decision theories, the author proposes to develop InfoVis theories in two distinctive braches. The first branch will be normative InfoVis theories, and the second branch will be descriptive InfoVis theories.

In normative InfoVis theories, development of theories will be based on ideal human users as normative decision theories did. The ideal users have perfect vision, do not run into any usability issue, perfectly understand a context of given data, do not have various individual differences, and know how to interpret various visualization techniques. Normative InfoVis theorists should focus on what kinds of visualization techniques should used in order to present certain type of information. Normative InfoVis theorists do not need to consider whether human users actually can notice the given information or not. Based on this assumption, normative InfoVis theorists can focus on building blocks without too much worrying about variance caused by unpredictable human mind. Mathematical models using other theories (e.g., information theory [7] and theory of graph comprehension [8]) could be used to build mathematical models for normative InfoVis theories. As discussed in normative decision theories, a good set of axioms should be provided as foundation for normative InfoVis theories.

In contrast, descriptive InfoVis theories should focus on how realistic human users use InfoVis techniques. However, instead of evaluating different visualization techniques every time, descriptive InfoVis theorists should focus on commonly selected InfoVis techniques, which may survive the test of normative InfoVis evaluation. In this way, descriptive InfoVis theorists can have comparable empirical evidence to expand the knowledge of how human work with InfoVis techniques. Descriptive InfoVis theorists should focus on how human mind works while using InfoVis techniques, and they should pay less attention on creating new InfoVis techniques. Obviously, descriptive InfoVis theorists also questions axioms in normative InfoVis theories, so that normative InfoVis theories do not deviate too much from reality.

The main benefits of this division between normative and descriptive InfoVis theories would help researchers focus on their own problems and help build comparable empirical evidence at the same time. This division is not totally new to current InfoVis community. The InfoVis conference has accepted papers in five different types: technique, system, application/design study, evaluation, and theory/model. In technique papers, providing a use case or usage scenario often replace formal evaluation studies. In evaluation papers, proposing novel visualization techniques is not required. What makes the present proposal distinctive is that normative InfoVis theorists should provide a set of normative evaluation measure, which can replace currently practiced scenario-based evaluation. If possible, the normative evaluation measures should provide quantitative measures as well. Having these normative measures will provide a robust foundation for descriptive InfoVis theorists, who will verify these normative measures are actually valid in realistic settings.

Proposing these quantitative measures would be the first hurdle to this approach. These normative measures should be reasonable and convenient to use, so that many InfoVis researchers should be able to use easily without too much resistance from peer researchers. However, if these measures could be generated, and empirical studies using these measures are repeated, we will have a good set of empirical data, which help create more inclusive and robust theories of InfoVis. Some of work regarding insight categorization [9] and InfoVis taxonomies provide some hope to come up with these measures.

4 Conclusions

The proposal of this paper may be perceived rather radical and may run into lots of resistance from researchers. However, the author noticed that lots of efforts to conduct human subject studies were wasted, and theorists in InfoVis failed to make sense of these data. The author believes that the core idea of this proposal could provide a different perspective in solving issues of InfoVis theories. The author hopes that this position paper will induce healthy and constructive discussion among the InfoVis community.

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