

Theories in Information Visualization: What, Why and How

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ABSTRACT

In this paper we explore the perceived absence and greater need for theories in information visualization through the perspectives of what, why and how. We discuss five possible forms of theory: law, model, framework, taxonomy and interpretation (the “what”), the reasons and potential benefits of theories (the “why”) and possible ways to generate theories (the “how”).

KEYWORDS: Theory, information visualization.

1 INTRODUCTION

In the InfoVis community today, there is a general belief that the field lacks sufficient theoretical foundations and that we need more supportive theories to describe, validate and understand our design work [10]. But what does one mean by “theories” in InfoVis? The notion of mere “theory” or “theoretical work” is extremely vague and we argue more context and clarification are necessary. In this paper we explore and provoke ideas about what might constitute theories in InfoVis, why we need theories and how to develop theories. Since theoretical work in InfoVis is only nascent, our arguments here are often speculative, inviting discussions and debates.

2 WHAT

The term *theory* is used with different connotations in various disciplines. Most theorizing is inherently about generalization: people devise theories to capture regularities that generalize across seemingly diverse phenomena. Through experience and reflection, we have observed at least five forms of theory that are potentially relevant for InfoVis: law, model, framework, taxonomy and interpretation.

2.1 Law

Laws are propositions that state regularities across instances of phenomena under certain conditions, and are inherently descriptive. When laws are accurate and precise enough, they have predictive power. Famous examples are Newton’s three laws of motion and law of universal gravitation, which can be expressed in mathematical forms. Fitts’ law is a good example from HCI. In perception research, examples of law-like theories include the Gestalt principles of perceptual organizations.

The explanatory powers of laws are open to debate. Some might argue that description alone implies an explanation. But it seems justified to say laws often do not explain the phenomena they generalize in terms of causations. For example, many theorists including Newton himself attempted to provide a mechanistic explanation for the law of gravity. Similarly, some are not satisfied with Gestalt principles and criticize that they are merely descriptive and are too vague and imprecise.

Laws are often devised using scientific method by associating

data extracted from a sample of the population. Direct measurement and experimentation are the essential methodological tools used. As van Wijk has argued, visualization is a complex phenomenon and can be approached from different perspectives. Due to the context-sensitive nature of human perception and behavior, idealized law-like theories such as “Given D find V such that ΔK is optimal” seem next to impossible [11].

2.2 Model

Models differ from laws in that they are not primarily concerned with correlation and dependence between variables, but procedures and mechanisms. They posit formal logical abstractions about objects, events and processes and linking them with causal or operational mechanisms in a greater unit.

One type of model is often formulated as routines or stages where the steps are causally linked. Examples include the InfoVis reference model [1], the Model Human Processor [2], Norman’s seven stages of action [8] and Pinker’s computational model of graph comprehension [9].

Existing work in InfoVis such as that by Mackinlay [7] and Wilkinson [12] also presents models on the structure and formal descriptions of visualizations. In these models, different types of visualizations are analyzed and a fundamental set of graphical language elements is formulated. These elements can be combined by algebraic operations to generate visualizations with different semantics.

2.3 Framework

Models are abstract descriptions of the reality, and are often based on assumptions. The term “framework” has been used in many different ways. Our intended use here refers to theoretical work that is primarily concerned with assumptions: what are the central concepts and ideas that should be the focus of theorizing – something akin to a worldview. Frameworks hence are associated with more philosophical connotations. Since visualization is a multi-faceted phenomenon, there can be multiple relevant exemplary frameworks:

- the cognitive aspect: different worldviews or frameworks serve as the foundation of understanding visual perception and cognition. Perception and cognition can be assumed as computations performed by the brain or as emergent properties of interaction between an enactive agent situated in a material and cultural environment [6], for example. For the former, the central concepts are symbolic representation and algorithmic computations; for the latter, the central concepts are internal and external representations and their interaction.
- the specification aspect: The compositional algebraic model underlying APT, for example, is based on the assumption that visualizations are sentences of graphical languages, which are similar to other formal languages in that they have precise syntactic and semantic definitions [7].

Each worldview or framework determines the approach taken by the researchers to formulate more detailed theories.

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2.4 Taxonomy

Taxonomies of data, representation, task and interaction are abundant in InfoVis research. Some argue that classification and categorization are fundamental forms of human cognition, and much human understanding and knowledge is based on the ability to categorize. Taxonomies differ from models in that the relationships between the entries are not characterized in terms of mechanisms but conceptual classification; and they are certainly not as philosophical as frameworks. Sometimes it is not always clear-cut whether some theory is a taxonomy or model. For example, Lam's work on interaction costs [4] is based on Norman's model, but the discussion and enumeration of various instances of interaction issues seem to better suit the definition of taxonomy.

2.5 Interpretation

In fields like social sciences and humanities, some researchers believe that the human world is so dynamic and complex that it is not amenable to experimentation, and the expressive power of languages are fundamentally limited. As a result, it may not always be possible to make valid generalizations. Many of the theories hence are more interpretations than laws or models. Interpretations are useful when they defy conventional readings of a particular phenomenon and bring on a novel perspective. Many hypotheses for example have been posited to account for the origin and characteristics of the enormous difference between the modern scientific culture and the pre-science era, including changes in the structure of the brain, in social relations and economic infrastructure. Latour offers a different interpretation where he argues the production and circulation of visual inscriptions played a pivotal role [5].

3 WHY

Why do we need theories for InfoVis? After all, the field has matured over the years and many impressive systems and techniques have been developed without leveraging many theories. In addition, despite the seemingly great relevance, recent developments in theories about perception and cognition in cognitive science and cognitive psychology seem to have had little impact on our field. Perhaps many InfoVis researchers chose to work in InfoVis instead of cognitive science because of their inclination towards a practical approach towards research. Perhaps people are not excited about theories because theoretical work often requires long-term investigation and does not always yield immediately usable results. For those of us who believe in the value of theories, we need to formulate clearer goals and agenda and articulate how our work can be relevant.

An important question is that do we want to have an impact on practice, i.e. the design and implementation of visualizations? Some believe the ability to inform design and evaluation is a must for theories to be useful, but others might argue that a greater theoretical understanding is good enough. This question is inherently concerned with the value of theories and how to evaluate them. Making accurate predictions is a tangible indicator that can be assessed. Theories that allow systematic exploration of design spaces may be evaluated fairly easily as well. There are however more subjective and less tangible values of theories and these are difficult to evaluate. For example, one can claim that a theory deepens people's understanding of a particular issue, or allows easier introduction of visualization design to novice practitioners. Being able to evaluate claims like these and to differentiate good theories from the bad is a difficult yet crucial issue.

4 HOW

How can good theories be generated? An important question to be answered first, as we believe, is what phenomena we are trying to describe, explain, model, interpret and predict. What makes good theoretical research questions and what are not viable research questions? Here frameworks, as we have discussed earlier, seem to be relevant because they serve as foundational anchors that ground central concepts and questions.

It seems to be a conventional belief that the process of theory building is filled with rigor and formalism. The InfoVis community has been using scientific methods to conduct comparative and controlled studies for a long time. Yet so far these studies have produced data, not theories. As Carl Hempel, a renowned philosopher of science, pointed out, theories cannot be systematically constructed or deduced from facts [3]. Inspiration and creativity are indispensable ingredients for theory invention. The data and facts may always be there without an adequate theory accounting for them. Famous scientists often gave accounts of how they performed imaginary thought experiments and mental visualizations to arrive at genuinely novel theories.

Pure speculation may be needed for provoking theoretical ideas, but not sufficient for verifying and evaluating theories. Here we need more rigorous methods to test or disprove theories. The scientific method is useful, but has its limitations. Since visualization involves a multitude of factors interacting to produce an emergent outcome, we need more powerful methods. In addition, InfoVis is a multi-disciplinary field, different and even conflicting perspectives may co-exist. Some researchers may choose to adopt a humanities approach with interpretive ethnography as their main methods, while some others may insist the sole validity of scientific method. As a community we need to make sure that these different viewpoints can be reconciled and do not result in schisms.

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