

Understanding and Characterizing Insights: How Do People Gain Insights Using Information Visualization?

Ji Soo Yi

H. Milton Stewart School of
Industrial and Systems Engineering,
Georgia Institute of Technology

313 Ferst Drive
Atlanta, GA 30339
+1-404-385-6751

jisoo.yi@hsi.gatech.edu

Youn-ah Kang & John T. Stasko

School of Interactive Computing
& GVU Center
Georgia Institute of Technology

85 5th St., NW
Atlanta, GA 30332
+1-404-894-5617

ykang3@mail.gatech.edu &
stasko@cc.gatech.edu

Julie A. Jacko

The Institute for Health Informatics

University of Minnesota
308 Harvard Street SE
Minneapolis, MN 55455
+1-612-625-4912

jacko@umn.edu

ABSTRACT

Even though “providing insight” has been considered one of the main purposes of information visualization (InfoVis), we feel that insight is still a not-well-understood concept in this context. Inspired by research in sensemaking, we realized the importance of the procedural aspects in understanding insight. Thus, rather than asking “What is insight?” we instead focus on “How do people gain insights?” In an effort to better understand and characterize insight, we reviewed previous literature in InfoVis, seeking other researchers’ comments and views on this concept. We found that: 1) Insights are often regarded as end results of using InfoVis and the procedures to gain insight have been largely veiled; 2) Four largely distinctive processes of gaining insight (*Provide Overview, Adjust, Detect Pattern, and Match Mental Model*) have been discussed in the InfoVis literature; and 3) These different processes provide some hints to understand the procedures in which insight can be gained from InfoVis. We hope that our findings help researchers and practitioners evaluate InfoVis systems and technologies in a more insight-oriented way.

Categories and Subject Descriptors

H5.2 [INFORMATION INTERFACES AND PRESENTATION (e.g., HCI)]: User Interfaces – Evaluation/methodology.

General Terms

Measurement, Performance

Keywords

Insight, information visualization, evaluation, sensemaking, categorization

1. INTRODUCTION

Gaining insight about data has been considered one of the major purposes of information visualization (InfoVis). Card, Mackinlay, and Shneiderman declare, “The purpose of visualization is insight, not pictures” (p. 6) [4]. Even though InfoVis often involves complex and sophisticated data transformation, representation, and interaction techniques, ultimately InfoVis is about harnessing human’s remarkable visual perception capabilities to help identify trends, patterns, and unusual occurrences in datasets. By understanding better how these processes lead to insight, we will better be able to articulate and communicate the value of InfoVis.

The recent growth of visual analytics [29] and the emergence of insight-based evaluation [23,24] elevated the level of interest in insight as a proper evaluation measure of InfoVis. We anticipate that even more InfoVis evaluation studies will use insight-based evaluation or longitudinal case study techniques in the future (e.g., [21,27]). This growing body of studies should help us to better understand the nature of insight and eventually facilitate the creation of InfoVis technologies in a more insight-oriented way.

However, we believe that the concept of insight is still not well defined and understood. Even though a few definitions of insight exist, no commonly accepted definition has emerged in the InfoVis community. North acknowledges that defining insight is challenging, although he does provide an insightful characterization of insight [16]. Furthermore, it appears that different kinds of insights exist [19], and researchers are still seeking ways to help make their InfoVis technologies promote greater insight.

In this paper, we seek a better understanding of what insight is about and how InfoVis systems can help promote insight. We hope that our findings and ideas will stimulate discussion among other InfoVis researchers, and eventually increase the awareness of insight in the InfoVis community.

2. BACKGROUND

2.1 Insight

There are a few definitions of insight available in the InfoVis community. Saraiya et al. [23] have conducted insight-based evaluation studies in the domain of biology (analyzing biological pathways and microarray data), and they define insight as “an individual observation about the data by the participant, a unit of

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee.

BELIV '08, April 5, 2008, Florence, Italy.

Copyright 2008 ACM 978-1-60558-016-6...\$5.00.

discovery” (p. 444). They also elaborated the notion of insight by saying “arriving at an insight often sparks the critical breakthrough that leads to discovery: suddenly seeing something that previously passed unnoticed or seeing something familiar in a new light” (p. 443). They further group insights found in the context of bioinformatics into four different categories: overview (overall distributions of gene expression), patterns (identification or comparison across data attributes), groups (identification or comparison of groups of genes), and details (focused information about specific genes). (p. 445).

However, as North acknowledges, defining insight is very challenging [16], and no commonly accepted definition of insight exists in InfoVis. Instead of a definition, North describes characteristics of insight as follows (p. 6):

- **Complex.** Insight is complex, involving all or large amounts of the given data in a synergistic way, not simply individual data values.
- **Deep.** Insight builds up over time, accumulating and building on itself to create depth. Insight often generates further questions and, hence, further insight.
- **Qualitative.** Insight is not exact, can be uncertain and subjective, and can have multiple levels of resolution.
- **Unexpected.** Insight is often unpredictable, serendipitous, and creative.
- **Relevant.** Insight is deeply embedded in the data domain, connecting the data to existing domain knowledge and giving it relevant meaning. It goes beyond dry data analysis, to relevant domain impact.

Others have adopted North’s characterization as a definition of insight (“a non-trivial discovery about the data or, as a complex, deep, qualitative, unexpected, and relevant assertion”) [18], but we wonder if these characteristics are sufficient to clarify what is and what is not an insight or to measure the quality of different insights, two requirements for conducting evaluations of this type.

One characteristic we observed in some insight-based evaluation studies is that they seem to consider insight as the countable end results of an insight gaining process, as illustrated through the term “a unit of discovery.” Clearly, this may be appropriate in the context of evaluation studies since they eventually require some quantifiable measures. However, in a general context, this notion of “end results” could be problematic. We agree with North that some insights are not only end results, but also sources or stimuli of other insights. We also believe that insight is often not an achievable goal of a predefined task or procedure, but more likely a by-product of exploration without an initial destination. Thus, we think that the most important question to be asked in this context is not “What is insight?” but “How do people gain insight?” This changes our goal from one of defining insight to one of identifying the processes through which insight is gained.

2.2 Sensemaking

In order to understand the procedural aspects of insights, we found that understanding sensemaking is critical. Sensemaking clearly begets insights as shown in the model of sensemaking (Information → Scheme → Insight → Product) proposed by Pirolli and Card [17]. Though sensemaking might not be a necessary or the only procedure to gain insights, we believe that sensemaking plays a major role nonetheless.

Since the term “sensemaking” is used in numerous contexts (e.g., organizational research, educational research, and decision

science), definitions of sensemaking vary. Sensemaking simply can be defined as “making sense of things” or, drawing from Klein et al. (p.71) [11], more comprehensively described as “a motivated, continuous effort to understand connections (which can be among people, places, and events) in order to anticipate their trajectories and act effectively.” These different nuances of sensemaking bring out different aspects of the process.

Among the many characteristics of sensemaking, we found the following three to be most interesting and informative in the context of our paper. First, sensemaking procedures are cyclic and iterative. Russell et al. [22] describe the sensemaking procedure using Learning Loop Complex theory, which consists of 1) search for representations (generation loop), 2) instantiate representations (data coverage loop), 3) shift representations. As the name of their theory illustrates, the process of sensemaking is iterative in collecting data and re-generating a representation or scheme.

Second, sensemaking is not only a discovery procedure, but also a creation procedure. Weick [32], an organizational theorist, emphasized this notion of creation by providing a very clear distinction between interpretation and sensemaking. Weick argues that interpretation is a component of sensemaking, and states “the act of interpreting implies that something is there, a text in the world, waiting to be discovered or approximated. Sensemaking, however, is less about discovery than it is about invention” (p.13).

Third, sensemaking is retrospective. Literature in various contexts (e.g., [7,32]) supports that people often do *not* make sense of things after collecting information first. Instead, people often construct a framework first and retrospectively collect the relevant information and place it into the framework. If the collected information fits well with the framework, the framework is confirmed. However, if it does not, people become puzzled, and the framework could be discarded, updated, or replaced to explain the new information.

These characteristics are well summarized by the Data/Frame Theory of sensemaking of Klein et al. [12]. They argue that sensemaking involves two cycles: 1) elaborating a frame and 2) reframing. As shown in Figure 1, the three previously mentioned characteristics are well described visually here.

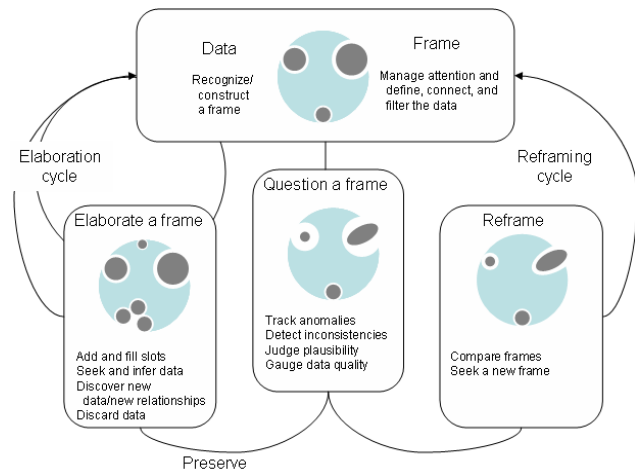


Figure 1. The Data/Frame Theory of sensemaking (adapted from [12])

Given this characterization of sensemaking, viewing insight as a mere end result might provide an incomplete picture. Insight is not only an end result or simple discovery of hidden truth, but also an intermediate state in the iterative and cyclic procedure of sensemaking and invention. Insight could be a framework that needs to be created first in a person's mind to draw the boundary of a problem and collect and understand information. Please note, however, that sensemaking might not be the only way to gain insight. We need to step back to see the broad picture of insight to have a balanced view though the discussed aspects of sensemaking provide a hint about important aspects of insight gaining processes.

3. METHODS

To develop a better understanding of the notion of insight and how insight is gained, we felt that it would be valuable to examine how other researchers in our community have characterized the goals and benefits of their InfoVis techniques and systems. By examining the variety of language and descriptions used by others to motivate their goals, we hoped to gain a more comprehensive picture of how this topic is viewed throughout the community.

Hence, we conducted an extensive InfoVis literature review, specifically focusing on the following question: "How do people gain insight through InfoVis?" We reviewed 4 books, 2 book chapters, and 34 papers published in major venues in InfoVis. In order to consider the bigger picture, we initially focused on books and articles that survey the benefits of InfoVis, and latter reviewed case studies and evaluation studies to find some procedural aspects of insight. However, we avoided papers about new InfoVis techniques without any user evaluation, which might fail to capture real users' perspectives. We gathered and categorized relevant quotes from this body of research, and we present our findings below. Hopefully, this small initial step leads us to a better understanding of the notion of insight in the context of InfoVis.

4. PRELIMINARY RESULTS

Earlier, we speculated that an insight does not appear suddenly "out of the blue," but instead there are paths or procedures leading to the insight. In this section, we introduce four largely distinctive processes through which people gain insight while using an InfoVis system. These processes emerged from reviewing the existing literature in InfoVis. As we gathered a variety of quotes from articles, different themes began to arise. The processes we have identified are: 1) *Provide Overview*, 2) *Adjust*, 3) *Detect Pattern*, and 4) *Match Mental Model*. Note that these are not categories of interaction or presentation techniques provided by InfoVis systems, but instead different processes through which InfoVis users gain insights.

4.1 Provide Overview

Provide Overview characterizes processes through which a person comes to understand the big picture of a dataset of interest. Even though observing an overview may not directly help a person gain insight, it appears to play an important role by helping people make sense of and find which areas they need to investigate more, thereby promoting further exploration of the dataset. That is, *Provide Overview* allows people to grasp what they know and do not know, which areas are available for further investigation, and to what extent they could gain new knowledge from the dataset. In many cases, this step precedes an actual exploration step and

serves as a key, leading to a further inquiry. Below are quotes that have a notion of *Provide Overview* as a benefit of InfoVis.

"InfoZoom allows data analysts to obtain a clear picture of their complete data, and to be able to see the wealth of information that lies in this data." (González and Kobsa, [10], p. 334)

"Our tool allows the biologist to interactively visualize and explore the whole set of trees, providing insight into the overall distribution and possible conflicting hypotheses." (Amenta and Klingner, [2], p. 71)

"The TreeMap of the stock market allows monitoring and exploration of many equities." (Card, [3], p.551)

4.2 Adjust

Adjust refers to a process through which people explore a dataset by adjusting the level of abstraction and/or the range of selection. Being able to flexibly change perspective on the dataset allows people to make sense of various aspects and test different hypotheses they have generated.

"Visualizations simplify and organize information, supplying higher centers with aggregated forms of information through abstraction and selective omission." (Card et al, [4], p. 16 discussing [20])

Selecting the range of a dataset to display by using a filtering interaction technique is a way to help explore a large amount of data. An entire dataset may contain uninteresting parts, so people often gain insight simply by filtering out some of unnecessary data.

"Data analysts appreciated being able to quickly include or exclude data for visualization, so they could concentrate on certain portion of data." (González and Kobsa, [10], p. 334)

"...Most important, the method of instantly responding in the display to the dynamic movement of the sliders allowed users rapidly to explore the multidimensional space of films." (Card, [3], p.551).

Grouping is also an effective way to explore data by abstracting huge datasets into more manageable pieces. It is difficult to gain meaningful knowledge from a large, unorganized dataset, particularly when the amount of data is enormous. Through the process of grouping and aggregating, relevant information is gathered, simplified, organized, and labeled. This greatly reduces people's search and working memory load, thereby allowing them to use their attention to find higher-level facts and ask new questions.

"Visualizations group information used together reducing search." (Card et al, [4], p. 16 discussing [13])

"By grouping data about an object, visualizations can avoid symbolic labels." (Card et al, [4], p. 16 discussing [13])

"Diagrams helped in three ways: (1) by grouping together information that is used together, large amounts of search are avoided. (2) By using location to group information about a single element, the need to match symbolic labels is avoided, leading to reductions in search and working memory." (Card et al, [4], p. 16)

4.3 Detect Pattern

Detect Pattern means to find specific distributions, trends, frequencies, outliers, or structure in the dataset. Through this procedure, people may not only find what they have been looking for but also discover new knowledge that they did not expect to find. We include the detection of relationships, tradeoffs, and anomalies (or outliers) in this category because they are things that could be uncovered while identifying patterns. A pattern itself could be an insight and further a person can cast a new questions and hypotheses by understanding patterns.

“The sight of a graphical encoding of data causes an ‘Ah Ha!’ reaction in the viewer in the sense that a useful discovery has been made.” (Spence, [28], p.5)

“Visually organizing data by structural relationships (e.g., by time) enhances patterns.” (Card et al, [4], p. 16)

“Visualizations can allow for the monitoring of a large number of potential events if the display is organized so that these stand out by appearance or motion.” (Card et al, [4], p. 16)

“In this visualization, the fact that the pockmarks appear in lines is immediately evident. The perception of a pattern can often be the basis of a new insight.” (Ware, [30], p.3)

“Visualization facilitates understanding of both large-scale and small-scale features of the data. It can be especially valuable in allowing the perception of patterns linking local features.” (Ware, [30], p.3)

“These benefits were achieved when subjects visually explored their data to discover new relationships, trends, and outliers.” (González and Kobsa, [10], p. 331)

4.4 Match Mental Model

One of the benefits of InfoVis is that a visual representation of data can decrease the gap between the data and user’s mental model of it, thereby reducing cognitive load in understanding, amplifying human recognition of familiar presences, and linking the presented visual information with real-world knowledge. Simple representation itself helps people explore data by mapping the data into a physical space. Further, metaphors facilitate more effective mapping of data and enable people to match a dataset to their mental model by visual representation.

“Information, then, need not be inherently spatial. But because we live and perceive in a physical world, it is easier to convey the information to the observer if the information is represented by being mapped to the familiar physical space.”(Gershon and Eick, [8], p. 39)

“Simple representations of risk can help professionals and patients move from innumeracy to insight and make consultations more time efficient.” (Gigerenzer & Edwards, [9], p. 744)

“Some cognitive inferences done symbolically can be recoded into inferences done with simple perceptual operations.” (Card et al, [4], p. 16 discussing [13])

“...solving a problem simply means representing it so as to make the solution transparent.” (Spence, [28] , p. 6)

“A picture is often cited to be worth a thousand words and, for some (but not all) tasks, it is clear that a visual presentation-such as a map or photograph-is dramatically easier to use than is a textual description or a spoken report.” (Shneiderman, [26], p.336)

“The display conveys the look of a 3-D pipe and is a geometric metaphor for a blood vessel... An improvement in intuitiveness, for example, should show in a reliable increase in correct judgments about the anatomical features and the physiologic structures in the display.”(Agutter et al, [1], p. 165)

“We present three new visual metaphors to help track activity within the VC market and help uncover trends or strategies that can help VC firms make more effective investment decisions.”(Chuah, [5], p.161)

5. DISCUSSION

Through review, we identified four categories of insight gaining processes (actually, the categorization itself was an insight gaining process.) We think that this categorization provides us with a relatively clearer picture of how the InfoVis community collectively perceives the insight gaining process.

However, this categorization should NOT deliver any false impression that there are four separate and independent procedures to gain insight. Instead, these four different processes are intertwined and often used together to generate insights. For example, *Provide Overview*, as mentioned previously, often precedes further *Adjust*, and *Adjust* and *Detect Pattern* are often used together to gain deeper insight. This aspect clearly mirrors the cyclic and iterative characteristic of sensemaking.

The creative and retrospective nature of sensemaking is also well reflected in the categories we found. *Adjust* and *Detect Pattern* are ways to create hypotheses and test them through various interaction techniques. Many quotes show that users appreciate the ability to interact with datasets and representation to make sense of data and test their hypotheses.

While these different processes serve to capture many of the ways InfoVis systems help people gain insights, our literature review also uncovered other comments that are difficult to resolve under this system. More specifically, some of insights found in the literature are somewhat abstract and higher level, so that linking them with any of the categories is questionable. For example, some insights found in the study of Saraiya et al. are summaries of other insights about the data or suggestions of future research which emerged after finishing data analysis [25]. These high-level insights must be built on top of other relatively low-level insights, and it is unclear how those insights were gained.

Additionally, one of most important factors to help users gain insight might be the degree of users’ engagement into the dataset. Simply providing an interactive system (e.g., NameVoyager [31]) helps users become engaged in the system, and helps them gain more insights. The nature of data and users’ interests and background knowledge can also heavily affect the insight gaining procedure.

“...Perhaps more important is that evidence suggests many people are engaging deeply with the visualization, spending considerable time and discovering for themselves facts and insights about name trends...” “...In hundreds of

spontaneous comments, users are seen to be engaged in extended exploratory data analysis, identifying trends and anomalies and forming conjectures."(Wattenberg, [31], p.1)

"... creative discovery processes are almost never structured, and require lots of interaction with the data before one can make sense of them and discover interesting facts..." (González and Kobsa, [10], p. 335)

Usability seems to be another important aspect to promote the insight gaining process. The following quote shows that a minor usability problem could be a major road block for users.

"Thus, these seemingly minor usability problems that developers might not have considered important had a major effect on these bioinformaticians when they had to repeat arduous operations 72 times." (Saraiya et al., [25], p.110)

Obviously, there exist other design aspects that hinder insight acquisition as well. For example, visual encodings that do not properly match with a user's mental model impose more cognitive load on the user, thereby impeding the insight gaining process. Norman [14] gives an example where an inappropriate use of substitutive shading to represent additive information makes a comparison difficult. Clutter and occlusion are also examples of barriers for insight acquisition that need to be addressed. Sometimes too much data on a limited screen results in visual clutter and occlusion, which in turn diminishes the possibility of uncovering patterns and trends. Consequently, researchers have sought to reduce clutters in various ways [6].

6. CONCLUSIONS AND FUTURE WORK

As an initial step toward answering the question "How do people gain insight through an InfoVis system?", we reviewed an extensive body of InfoVis literature to discover how other researchers have answered this question over the years. Our research uncovered many comments relevant to this question and led to the identification of four types of processes through which people gain insight using InfoVis: *Provide Overview*, *Adjust*, *Detect Pattern*, and *Match Mental Model*.

Identifying these insight-gaining procedures may not directly inform researchers of how to evaluate an InfoVis system. However, if we can clearly understand how insights are gained and what aspects of an InfoVis system promote and impede insight acquisition, we might be able to come up with recommendations and guidelines for InfoVis systems to promote insights. Further, we might be able to create an insight-oriented heuristic evaluation method as Nielson [15] did for usability of software or websites.

Finally, we hope that our research, the synthesis of the relevant quotes, and the identification of the four insight-gaining processes intrigues other fellow researchers and practitioners and encourages further investigation into these topics. There are still many more questions left to explore: for example, "Is there something unique about visualization in the way it produces insight that is different from other ways of producing insight?" and "What are the implications of analytics and reasoning processes in gaining insight?" We believe that such investigations hold promise in ultimately informing both the design and evaluation of InfoVis systems.

7. ACKNOWLEDGEMENTS

This research is supported in part by the National Science Foundation via Award IIS-0414667 and the National Visualization and Analytics Center (NVAC™), a U.S. Department of Homeland Security Program, under the auspices of the SouthEast Regional Visualization and Analytics Center. We thank Zachary Pousman for his insightful comments and help in literature review, especially regarding sense making. We also thank the anonymous reviewers for their advice and insightful questions.

8. REFERENCES

- [1] Agutter, J., Syroid, N., Drews, F., Westenskow, D., Bermudez, J., and Strayer, D. 2001. Graphic data display for cardiovascular system. In Proceedings of IEEE Symposium on Information Visualization (InfoVis '01), San Diego, CA, USA2001.
- [2] Amenta, N. and Klingner, J. 2002. Case study: visualizing sets of evolutionary trees. In Proceedings of IEEE Symposium on Information Visualization (InfoVis '02), Boston, MA, USA, 28-29 Oct 2002.
- [3] Card, S.K. 2003. Information Visualization. In The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications, J.A. Jacko and A. Sears Eds. Lawrence Erlbaum Associates, Inc., Mahwah, NJ, USA, 544-582.
- [4] Card, S.K., Mackinlay, J.D., and Shneiderman, B. 1999. Readings in Information Visualization: Using Vision to Think. Morgan Kaufmann, San Diego, USA.
- [5] Chuah, M. 2002. Demystifying venture capital investing. In Proceedings of IEEE Symposium on Information Visualization (InfoVis '02), Boston, MA, USA2002.
- [6] Ellis, G.P. and Dix, A. 2007. A Taxonomy of Clutter Reduction for Information Visualisation. IEEE Transaction on Visualization and Computer Graphics 13, 6, 1216-1223
- [7] Garfinkel, H. 1984. Studies in ethnomethodology. Cambridge, UK: Polity Press.
- [8] Gershon, N. and Eick, S.G. 1995. Visualization's new tack: making sense of information. IEEE Spectrum 32, 11, 38-40.
- [9] Gigerenzer, G. and Edwards, A. 2003. Simple tools for understanding risks: from innumeracy to insight. British Medical Journal 327, 7417, 741-744.
- [10] González, V. and Kobsa, A. 2003. Benefits of information visualization systems for administrative data analysts. In Proceedings of International Conference on Information Visualization, 2003 (IV '03), London, United Kingdom, 16 - 18 July 2003.
- [11] Klein, G., Moon, B., and Hoffman, R.R. 2006. Making Sense of Sensemaking 1: Alternative Perspectives. IEEE Intelligent Systems 21, 4, 70-73.
- [12] Klein, G., Moon, B., and Hoffman, R.R. 2006. Making Sense of Sensemaking 2: A Macrocognitive Model. IEEE Intelligent Systems 21, 5, 88-92.
- [13] Larkin, J.H. and Simon, H.A. 1987. Why a Diagram is (Sometimes) Worth Ten Thousand Words. Cognitive Science 11, 1, 65-100.

- [14] Norman, D. 1993. *Things That Make Us Smart*. Addison-Wesley, Reading, MA.
- [15] Norman, D.A. and Draper, S.W. 1986. *User-Centered System Design: New Perspectives on Human-Computer Interaction*. Erlbaum, Hillsdale, NJ.
- [16] North, C. 2006. Toward measuring visualization insight. *IEEE Computer Graphics and Applications* 26, 3, 6-9.
- [17] Pirolli, P. and Card, S. 2005. The sensemaking process and leverage points for analyst technology as identified through cognitive task analysis. In *Proceedings of International Conference on Intelligence*, McLean, VA, USA, 2-4 May 2005 2005.
- [18] Plaisant, C., Fekete, J.-D., and Grinstein, G. in press. Promoting Insight Based Evaluation of Visualizations: From Contest to Benchmark Repository *IEEE Transactions on Visualization and Computer Graphics*.
- [19] Pousman, Z., Stasko, J.T., and Mateas, M. 2007. *Casual Information Visualization: Depictions of Data in Everyday Life*. *IEEE Transactions on Visualization and Computer Graphics* 13, 6, 1145-1152.
- [20] Resnikoff, H.L. 1989. *The illusion of reality*. Springer-Verlag New York, Inc. New York, NY, USA.
- [21] Rester, M. and Pohl, M. 2006. Methods for the evaluation of an interactive InfoVis tool supporting exploratory reasoning processes. In *Proceedings of AVI workshop on BEYond time and errors: novel evaluation methods for information visualization*, Venice, Italy 2006 ACM Press New York, NY, USA.
- [22] Russell, D.M., Stefik, M.J., Pirolli, P., and Card, S.K. 1993. The cost structure of sensemaking. In *Proceedings of Conference on Human Factors in Computing Systems (ACM INTERCHI '93)* 1993.
- [23] Saraiya, P., North, C., and Duca, K. 2005. An insight-based methodology for evaluating bioinformatics visualizations. *IEEE Transactions on Visualization and Computer Graphics* 11, 4, 443-456.
- [24] Saraiya, P., North, C., Lam, V., and Duca, K.A. 2006. An Insight-Based Longitudinal Study of Visual Analytics. *IEEE Transactions on Visualization and Computer Graphics* 12, 6, 1511-1522.
- [25] Saraiya, P.B. 2006. *Insight-Based Studies for Pathway and Microarray Visualization Tools*. Doctoral Thesis. Computer Science and Applications, Virginia Polytechnic Institute and State University. pp. 198.
- [26] Shneiderman, B. 1996. The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations. In *Proceedings of IEEE Symposium on Visual Languages (VL '96)*, Boulder, CO, USA 1996 IEEE.
- [27] Shneiderman, B. and Plaisant, C. 2006. Strategies for evaluating information visualization tools: multi-dimensional in-depth long-term case studies. In *Proceedings of AVI workshop on BEYond time and errors: novel evaluation methods for information visualization*, Venice, Italy 2006 ACM Press New York, NY, USA.
- [28] Spence, R. 2007. *Information Visualization: Design for Interaction*. Prentice Hall.
- [29] Thomas, J.J. and Cook, K.A. 2005. *Illuminating the Path* IEEE, Los Alamitos, CA, USA.
- [30] Ware, C. 2000. *Information Visualization: Perception for Design*. Academic Press, San Diego, CA, USA.
- [31] Wattenberg, M. 2005. Baby Names, Visualization, and Social Data Analysis. In *Proceedings of IEEE Symposium on Information Visualization (InfoVis '05)*, Minneapolis, MN, USA, 23-25 October 2005.
- [32] Weick, K.E. 1995. *Sensemaking in Organizations*. Sage Publications.