The Psychology of Visualization

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Introduction

The overall goal of a visualization is to see patterns and understand any underlying relationships in the data. Whether the purpose of the visualization is for analysis or communication, the better the mapping between the data and the visual form reflects the capabilities of the human visual system, the better the chance the information will be detected and understood. To make certain aspects of the data explicit, it is necessary to know how information is encode in a visualization, as well as the implications of the choices made in representing those data.

The visual system can decode information in several dimensions, including spatial, chromatic, and temporal. By designing visualizations with human strengths and weakness in mind, it is possible to exploit the visual system's ability to recognize structure and patterns and circumvent human limitations in memory and attention. The fields of perception, psychophysics, and cognitive psychology have much to offer towards understanding the subtle workings of the eye-brain system. However, not all the work is these areas is equally applicable. There are no hard and fast rules for applying these results to the visualization problem, since there are often complex interactions among the representation methods depending on the task. Nonetheless, some researchers have been rather over zealous in drawing conclusions about the applicability of these findings, leading to misunderstandings regarding the difficulty of accurately portraying visual information.

This panel will discuss the specific application of the principles of psychology to the perception of graphic displays. All the participants are involved in research that directly addresses the problems of graphical perception and are well aware of the inherent limitations and task specific nature of visualization design. The audience will learn what elements of perception and cognition are important, the instances under which these principles can be effectively applied, and how this information can improve the effectiveness and efficiency of visualization designs.

Panelists Statements

A Model for Studying Display Methods
William S. Cleveland

A graphical method for visualizing statistical data consists of two parts: a selection of quantitative information to be displayed, and a selection of a visual display method to encode the information. Some display methods lead to efficient, accurate graphical perception --- the visual decoding of the encoded information --- and others lead to inefficient, inaccurate decoding. It is only through rigorous studies of graphical perception that informed judgments can be made about how to chose display methods that lead to efficient decoding. A model has been developed to provide a framework for the study of graphical perception. The model includes a partition of

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information encoded on displays, a partition of graphical tasks that are performed when a graph is viewed, and a specification of visual operations that are employed to carry out the tasks. Display methods are assessed by studying the visual operations to which they lead. Studies of the operations use the theory and experimental technique of various areas of vision research including psychophysics, cognitive psychology, and computational vision. Examples of display methods that have benefited from the study of visual operations are visual reference grids for graphs with juxtaposed panels and common scales, encoding a categorical variable on a scatterplot by plotting symbol type, and choosing the aspect ratio of a factor-response graph.

The Effects of Mapping Choices on Data Perception and Interpretation
Bernice E. Rogowitz

Visualization is the process of mapping numerical values onto perceptual dimensions. Every time we color the values of a variable according to a particular color map, or represent a variable as a translucent volume, we are affecting how these data will be perceived and interpreted. Moreover, representations which are identical mathematically may not be identical perceptually.

For example, a deformed surface map of an array of temperature values may show significant fluctuations which are not perceived in a rainbow colormap of the same data.

Although modern visualization systems offer us a wide range of visual dimensions, they typically offer no guidance on how these different visual dimensions are perceived. In this panel, I would like to demonstrate how mapping choices can affect whether or not structures in the data are faithfully represented in the image, and how easy it is to interpret perceptual artifacts as data features. I would also like to present the visualization architecture Lloyd Treinish are developing which explicitly incorporates rules for improving the mapping of variables onto perceptual dimensions. These rules are based on principles of human vision, visual perception and cognition.

Cognitive Task Analysis in Visualization Display Design
Christopher D. Wickens

The capabilities of scientific visualization graphics tools have generally outstripped the availability of human performance data on the perceptual/cognitive limitations of the visualizing scientist, particularly as these tools incorporate more and more of the features of "virtual reality" interfaces. (For example, giving the scientist the opportunity to "walk through" his or her data). One reason for this disparity may be the limited appreciation of the tools' designer of the need for good cognitive task analysis of the scientist's needs when dealing with complex data bases. This analysis should guide the choice of different technological features, for different applications.

The current presentation explores three kinds of features, relevant to the representation of multidimensional data bases: coding of data levels, integrating dimensions, and the nature of interactive capabilities (inside-out versus outside-in). We consider how what is known about these features can couple with task analysis, to create effective "user centered" visualization displays.

Perceptual Effectiveness of Visualization Techniques
Frank M. Marchak

Despite the plethora of visualization techniques, there are little data showing the perceptual effectiveness or efficiency of different representation methods, such as which definable and recognizable visual attributes are most useful for conveying specific information. The ability to objectively measure the perceptual effectiveness of a graphic requires knowing what information in the visualization is relevant, and how it contributes to the overall information being conveyed.

However, the problem is complicated by the complex interactions that arise between the visualization technique and the requirements of the task performed on the visualization. The effectiveness and relevance of any perceptual feature must be determined within the context of the task to be performed, whether that task is identification, comparison, categorization, or segmentation.

During this panel, I will discuss an approach toward determining the optimal choice of a visualization technique based on the task and perceptual constraints. The findings of several experiments that investigate this problem will be presented, and some guidelines for determining the efficiency of various visualization schemes will be discussed.

Panel Participants

William S. Cleveland

William S. Cleveland has migrated from the very theoretical to the very applied, starting with an A.B. in math at Princeton, then on to a Ph.D. in statistics at Yale, and finally a job in the Math Research Center at AT&T Bell Laboratories. Today, he does research in statistical methods and data visualization, and participates in many data analysis projects. Cleveland has written three books on visualizing statistical data as well as numerous journal articles. One major thrust of this work is studies of graphical perception, the visual decoding of information from graphical displays. Occasionally, though, he pays homage to his roots and proves a theorem.

Bernice E. Rogowitz

Bernice E. Rogowitz manages the Exploratory Visualization Group at the IBM T.J. Watson Research Center, where her research focuses on how to represent digital information to take advantage of human perceptual and cognitive capabilities.

Dr. Rogowitz earned her Ph.D. at Columbia University in Experimental Psychology (human vision) then completed a postdoctoral fellowship in the Laboratory of Psychophysics at Harvard University.

At the IBM T.J. Watson Research Center, she established and managed the Vision Science Group which investigated various topics in vision related to display technology, including the development of a technique for measuring and predicting display flicker.

In 1989 she joined the Computer Sciences Department as Senior Technical Consultant to the VP for Systems and Software.

In 1988, Dr. Rogowitz originated the SPIE/IS&T Conference on Human Vision, Visual Processing and Digital Display, which will hold its seventh annual meeting in San Jose in February, 1994. The purpose of the meeting is to introduce experimental psychologists to the perceptual and cognitive challenges posed by the new image, display, visualization and virtual reality technologies and to encourage the use in these fields of the data, models and methodologies of research in human perception.

Christopher D. Wickens

Christopher D. Wickens is currently a professor of experimental psychology and head of the Aviation Research Laboratory at the University of Illinois at Urbana-Champaign. He received his A.B. degree from Harvard University in 1967 and his Ph.D. from the University of Michigan in 1974 and served as a commissioned officer in the U.S Navy from 1969 to 1972. He is currently involved in research at the Aviation Research Laboratory and the Engineering Psychology Research Laboratory concerning workload assessment, the effects of divided attention on manual control and information integration, and decision performance in aviation systems. Dr. Wickens is a member and Fellow of the Human Factors Society and received the Society's Jerome H. Ely Award in 1981 for the best article in the Human Factors Journal, and the Paul M. Fitts Award in 1985 for outstanding contributions to the education and training of human factors specialists by the Human Factors Society. He served as a Distinguished Visiting Professor at the Department of Behavioral Sciences and Leadership, U.S. Air Force Academy in 1983-84 and 1991-92. He also serves on the National Research Council Committee on Human Factors, and authored a college textbook titled Engineering Psychology and Human Performance (1992, 2nd ed.) co-authored a second college textbook titled, Psychology, and co-authored books titled, Display Technology and Workload Transition.

Frank M. Marchak

Frank M. Marchak manages the Data Fusion Systems Section at TASC. His area of expertise is the application of principles of visual perception and cognitive science to human-machine systems, with emphasis in the areas of usability engineering and display design, scientific visualization, and human performance. Dr. Marchak's research interests include graphical perception of multivariate data visualization displays, perceptual image quality mensuration, and development of a methodology for optimal selection of scientific visualization techniques based on perceptual constraints. He is currently providing expertise in the areas of perceptual psychology and psychophysics in the design of a metric to measure the perceptual effectiveness of camouflage patterns.

Dr. Marchak received the B.A. degree in Psychology from Muhlenberg College in 1982 and received the Ph.D. degree in 1988 from Dartmouth College in Experimental Psychology - Cognition and Perception. His doctoral dissertation involved investigation of fractal functions as a model of human texture perception, evaluating the implications for visual simulation of natural, unpatterned textures. He is a member of the Association for Computing Machines -SIGGRAPH & SIGCHI, IEEE Computer Society, The Human Factors and Ergonomics Society, The Society for Computers in Psychology, and the Psychonomic Society.

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