The Cognition of Complex Visualizations

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Abstract

We explore current research on how complex visualizations are perceived, comprehended, used, and taught.

Introduction

How do people perceive, comprehend, and use complex visualizations, and when are they needed? Many domains (meteorology, scientific visualization, stock market analyses) deal with very complex data that must be displayed and used in novel ways. Unfortunately, very little is known about how these complex displays are used, how to best display complex graphical information, or how to design good complex visualizations for teaching purposes. This symposium will examine:

- how people understand and use complex visualizations;
- how people gain expertise in using complex visualizations;
- how to teach complex domains by using graphs and visualizations;
- how to visualize uncertainty across many variables;
- why a visualization is hard or easy to use; and
- how current models of graph comprehension scale up to more complexity.

Building Qualitative Mental Models

Greg Trafton

How do people use a complex visualization? Most current theories predict a straightforward process of reading off specific information, typically at the request of an experimenter. Many complex domains, however (many areas of scientific visualization, meteorology, etc.) need to deal with multi-dimensional data with complex interactions and anomalies.

I will present several recent studies that show that while experts mostly conform to the standard models of graph comprehension, there are some glaring holes in current theories. Specifically, experts do more than simply read off information. First, they extract primarily qualitative information from complex visualizations (e.g., "The wind is fast over San Diego") even when quantitative information is available and needed later. With this qualitative information, they build a complex mental representation (which we call a qualitative mental model, or QMM) to reason with.

I will present data that shows how experts build these complex mental structures by looking at complex visualizations. I will also present evidence from eye-tracking and protocol studies of experts and novices working in their own domain, showing how novices seem to conform to the standard graph comprehension models while experts do not.

The Role of Prior Knowledge in Complex Data Comprehension

Priti Shah & Eric G. Freedman

People are increasingly faced with the task of interpreting complex˚multivariate quantitative data sets. Unfortunately, much research on graph interpretation has focused on how novice (college undergraduate) viewers use common formats˚ (e.g., bar and line graphs) for simple tasks (e.g., read a data point or describe a trend) and sparse (2-3 variables and few data points) and meaningless (axes labeled x and y) data.˚ In our presentation, we argue that models based on this research may not scale up to account for more complex data interpretation, which differs in several key features. Complex data interpretation usually refers to tasks involving many variables, complex interactions between the variables, and a large number of data points. Complexity extends beyond simply data complexity, however. Dealing with complex data coincides with complex tasks (e.g., making decisions or explaining data) rather than fact retrieval.˚ Complex data also involves the extensive use of prior knowledge and viewers with data interpretation skills (experts use complex data, not novices).˚ Finally, complex data is often presented via

cognitive work do not have to follow them. In fact, we notice these laws through the consequences that have followed repeatedly when design breaks them in varying episodes of technology change. The statements are law-like in that they capture regularities of control and adaptation of cognitive work, and they determine the dynamic response, resilience, stability or instability of the distributed cognitive system in question. While developers may find following the laws optional, what is not optional is the consequences that accrue predictably from breaking these laws, consequences that block achieving the performance goals developers and paractitioners, technologists and stakeholders set.

Respect for the Laws is essential, for in the final analysis:

> in design, we either hobble or support people s natural ability to express forms of expertise.

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References

Ashby, W. R. (1957). *An Introduction to Cybernetics*. Chapman and Hall, London.

Billings, C. E. (1997). *Aviation Automation: The Search For A Human-Centered Approach*. Hillsdale, N.J.: Lawrence Erlbaum Associates.

Carroll, J.M. & Rosson, M. B. (1992). Getting around the task-artifact cycle: How to make claims and design by scenario. *ACM Transactions on Information Systems*. 10, 181-212.

Conant, R. C. (1976). Laws of information which govern systems. *IEEE Transactions on Systems, Man, and Cybernetics*, SMC-6, 240-255.

Cordesman, A. H. & Wagner, A. R. (1996). *The Lessons of Modern War, Vol.4: The Gulf War*, (Boulder, CO: Westview Press).

Craik, K. J. W. (1947) Theory of the operator in control systems: I. The operator as an engineering system. *British Journal of Psychology*, 38, 56-61.

Feltovich, P.J., Spiro, R.J., & Coulson, R.L (1997). Issues of expert flexibility in contexts characterized by complexity and change. In P.J. Feltovich, K.M. Ford, & R.R. Hoffman (eds.), *Expertise in context: Human and machine*. Menlo Park, CA. AAAI/Mit Press.

Flores, F., Graves, M., Hartfield, B. & Winograd, T. (1988). Computer systems and the design of organizational interaction. *ACM Transactions on Office Information Systems,* 6, 153-172.

Hirschhorn, L. (1997). Quoted in Cook, R. I., Woods, D. D. and Miller, C. (1998). *A Tale of Two Stories: Contrasting Views on Patient Safety.* National Patient Safety Foundation, Chicago IL, April 1998 (available at www.npsf.org).

NASA, Mars Climate Orbiter Mishap Investigation Board. (2000). Report on Project Management at NASA, March 13, 2000.

Rasmussen, J. (1986). Information processing and human-machine interaction: An approach to cognitive engineering. Amsterdam: North-Holland.

Rasmussen, J. & Lind M. (1981). *Coping with complexity* (Ris¿-M-2293). Ris¿ National Laboratory, Roskilde, Denmark: Electronics Department.

Roesler, A. Feil, M. & Woods, D.D. (2002). Design is Telling (Sharing) Stories about the Future. Draft Working MediaPaper at url: http://csel.eng.ohio-state.edu/animock

Sarter, N. & Amalberti, R., eds. (2000). *Cognitive Engineering in the Aviation Domain*, Erlbaum, Mahwah NJ.

Sarter, N., Woods, D.D. & Billings, C.E. (1997). Automation Surprises. In G. Salvendy, editor, *Handbook of Human Factors/Ergonomics*, second edition, Wiley, New York.

Wiener, N. *The Human Use of Human Beings: Cybernetics and Society*, Doubleday NY,1950.]

Winograd, T. and Flores, F. (1986). *Understanding computers and cognition.* Norwood, NJ, Ablex.

Woods, D.D. (1988). Coping with complexity: The psychology of human behavior in complex systems. In L.P. Goodstein, H.B. Andersen, and S.E. Olsen, editors, *Mental Models, Tasks and Errors*, Taylor & Francis, London, (p. 128-148).

Woods, D. D. (1998). Designs are hypotheses about how artifacts shape cognition and collaboration. *Ergonomics*, 41, 168-173.

Woods, D. D. & Christoffersen, K. (in press). Balancing Practice-Centered Research and Design. In M. McNeese and M. A. Vidulich (editors), *Cognitive Systems Engineering in Military Aviation Domains.* Wright-Patterson AFB, OH: Human Systems Information Analysis Center.

Woods, D. D. & Dekker, S. W. A. (2000). Anticipating the Effects of Technological Change: A New Era of Dynamics for Human Factors. *Theoretical Issues in Ergonomic Science*, 1(3), 2000.

Woods, D. D. & Tinapple, D. (1999). W^3: Watching Human Factors Watch People at Work. Presidential Address, 43rd Annual Meeting of the Human Factors and Ergonomics Society, September 28, 1999. Multimedia Production at http://csel.eng.ohio-state.edu/hf99/