DECISION MAKING AND INFORMATION VISUALIZATION: RESEARCH DIRECTIONS

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ABSTRACT

At first blush it might seem intuitively obvious that representing data visually ought to improve decision-making. Despite some work over the past two decades, the evidence to support this proposition is somewhat inconclusive and incomplete. Different disciplines have tackled this problem quite differently. Information visualization researchers, primarily out of the accounting or HCI disciplines have examined information visualization's affect on user satisfaction, the effort or time it takes to complete tasks aided with the technology, and to some extent, decision accuracy. In the economic and cognitive psychology disciplines, much has also been done to examine problem representation and errors in judgments and decisions -- the heuristics and biases track. Other threads in decision sciences and organizational development areas, strategic decision making and more recent forays into affect, emotion and imagery, have here or there hinted at the relationship between visualization and decision making. If, as the neurosciences indicate, human visualization processing is a foundation for higher-order cognitive processes, it could follow that representing problems visually would engage different cognitive mechanisms and thereby lead to different decision processes and decision outcomes. This paper evaluates some of the literature regarding information visualization and decision making, examines the issues that complicate research at the nexus of these two areas and offers suggestions for research directions.

DISCUSSION OF RELEVANT VISUALIZATION RESEARCH

Visualization techniques have been expanding in use over the past two decades and are finding their way to consumers via popular web sites (Peet's Coffee Selector, SmartMoney) and to business workers via popular applications such as SPSS, SAS, Microsoft Outlook and Adobe Photoshop (Plaisant, 2004). While commercial use has grown, in the academic community, several have commented on information visualization benefits. Citing several studies in the 1980s and the 1990s, Dull and Tegarden contend that visualization can improve problem-solving capabilities (1999, also Tegarden 1999). Card et al (1999) lists additional benefits:

1. Increasing the memory and processing resources available to the user
2. Reducing the search for information
3. Using visual representations to enhance the detection of patterns
4. Enabling perceptual inference operations
5. Using perceptual attention mechanisms for monitoring
6. Encoding information in a manipulable medium

Tufte (1997) provides a compelling argument for proper data visualization to support decision-making in his retrospective analysis of the documents NASA engineers used to unsuccessfully convince NASA managers to scrub the doomed Challenger launch in January 1986. On the day of the launch, managers and engineers discussed canceling the launch due to unusually cold weather. Engineers familiar with the problem had correctly anticipated the problem – the now infamous O-rings would fail in the cold weather – but did not make an appropriate visual presentation of the data to management.

Visualization researchers have described information visualization as a mix of higher level and lower level processing. Spence (2001) defines information visualization as a cyclical process by which the visual presentation of information leads to a mental model, or cognitive map. The four activities in the cycle include: a) browsing using lower-level visual processes, b) formation of an internal model, c) making a decision as to how and whether further browsing should continue d) development of a specific plan for browsing. Spence (2001) notes that the processes interplay between visualization and cognition are extremely complex and not fully understood. Ware (2000) points out that there are many subsystems in vision, but nonetheless describes a simple two-stage model of perceptual processing:

Stage 1. Parallel processing to extract low level properties from the visual scene, including contour, color, texture and spatial cues. Characteristics include rapid parallel processing, transitory nature of information which is held in an iconic store, bottom-up, data-driven model of processing,

Stage 2 Sequential goal-directed processing. Characteristics include: slow serial processing, involvement of both working and long-term memory, more emphasis on arbitrary aspects of symbols, top-down processing, different pathways for object recognition and visually guided motion.

Ware (2000) distinguishes between sensory versus arbitrary symbols. Sensory ones require no learning and are immediately apprehended by the user's perceptual processing capabilities. Arbitrary ones require learning, are often: hard to learn, easy to forget, embedded in culture and applications, formally powerful, capable of rapid changes. Most visualizations, Ware points out, are hybrids of both sensory and arbitrary symbols, complicating research. There is an intricate weaving of "learned conventions and hard-wired processing" going on (Ware, 2000).

Many current visualization research topics are dominated by typical human-computer interaction or systems concerns. These include perceptual psychology issues such as understanding change blindness, choosing color palettes, using color, size and shape properly; interface design research topics such as presenting information, using control widgets and animation effectively; computer science topics such as algorithms for rapid search, data structures for compact storage, software architectures, collaborative development; and commercial developer issues such as data import/integration, data cleansing (Bederson & Shneiderman, 2002). Missing from this list are empirical studies that assess the effectiveness of visualization, which are sorely needed (Mirel, 1998, Speier & Morris 2003).

Tables Versus Graphs

In the 1980s, with the introduction of the PC and popular spreadsheet applications, much research was conducted that examined the difference between graph and table representations of numeric data. Researchers conflicted on which representation was superior with some researchers citing numerous conflicts in studies (Coll, Coll & Thakur, 1994; Dickson, DeSanctis & McBride, 1986; Kaplan, 1988), while others, most noticeably Vessey (1991), providing an explanation for the apparent conflicts through the much cited cognitive fit theory. This theory views "problem solving as an outcome of the relationship between problem representation and problem solving task" (Vessey 1991). The problem representation must match the task at hand in order to produce improved decision-making performance. Graphs are a better fit for spatial (or sometimes referred to as relational) tasks where value interpolation or perceiving relationships in the data is important. Tables are a better fit for symbolic tasks that involve looking up or extracting a discrete value (Vessey, 1991). Vessey (1991) also points out that several studies included both spatial and symbolic representations, complicating the research and findings.

DISCUSSION OF RELEVANT DECISION RESEARCH

The fields of cognitive psychology and economics – including utility and prospect theory (Kahneman et al, 1988, and Kahneman & Tversky, 2000) and associated variations and reactions, which are much longer on research regarding judgment and decision problems – have proceeded somewhat unaware of information visualization's potential impact and theoretical linkages, except for a few studies (Keller 1985, Bisantz & Kirlik 1998, Cole 1989, Dull & Tegarden 1999).

Much of this research out of economics and cognitive psychology has focused on the gap between the correct answer to a decision making problem and the one given by subjects for problems, usually framed in probabilistic terms. In criticizing the penchant for probabilistic problem representation in the heuristics and biases track of decision making research, Gigerenzer (2000) argues forcefully that the human mind's processing of frequencies seems to be fairly automatic, like the encoding of time and space. Natural frequencies facilitate Bayesian reasoning, whereas probabilistic representations frustrate it. This begs for problems represented visually, especially as natural frequencies. In fact, some prior decision making and visualization studies have examined the common inability to properly integrate base-rate information or probability data have found that recasting the problem using frequency and 2-D representations can help in decision making (Cole, 1989, Burns, 2003[DU1], Gigerenzer & Edwards, 2003, Sedlmeier, 2000, Kurzenhauser & Hoffrage, 2002). The frequency versus probability problem format debate however does not have a conclusive answer (Sloman, et al, 2003). Could concepts from cognitive fit theory and lower-level information visualization research help explain some of the mixed results?

Judgment and decision making need not be thought of as best modeled using higher order cognitive mechanisms. Eisner (2003) argues that a connectionist approach can model complex, multi-attribute judgment tasks without the need for engaging higher-order processes involving rules or symbol manipulation. Gigerenzer (2000) points out that there exists within human beings lower order and higher order decision making equipment and that the modeling lower order perceptual and memory processes comes at a price to the researcher.

Other Applicable Research Directions

A strand of prior research has focused on personal vividness and its relationship to decision accuracy. (Pham et al, 2000). The influence of vivid information, compared to non-vivid information, on judgment and decision making has been the subject of a considerable amount of research. The relationship between imagery processes and imagery abilities and improved decision-making is more complex than once believed (Pham et al, 2000). Vivid imagers process decision information differently than non-vivid imagers. They tend to rely on more information that is less salient (less obvious) and less on information that is highly salient. Other researchers have attended to individual factors such as spatial abilities as possible factors explaining subject performance in decision tasks (Loy 1991).

Story telling may have a role to play in information visualization and decision making. Technology can combine film, television, radio, the internet and vast quantities of data transformed into easily understood images to a mass commercial audience. Information visualization designers could adopt a comic-bookstyle metaphor amplifying cognitive capabilities (Gershon & Page, 2001). Imagery and mental scenario rehearsal play a role in decision making. Bennet et al (1994) indicate that imagery shows promise for two key problem-solving and decision-making activities: distinguishing a problem from the symptom and deciding upon and implementing a course of action. Naturalistic Decision Making (Klein, 1998) also suggests scenario building and rehearsal strategies are at work for decision-making. Klein (1998) offers the recognition primed-decision model to explain how complex decisions are actually made in real life. These too seem to beg for information visualization applications.

Research Directions

At the junction of the two separate and large categories of decision-making and information visualization research lies little that integrates the two. This summary of prior research suggests four common concerns: a) should the research be done at lower levels or higher levels of processing? b) is the basis for decision quality normative or ecological? c) should the research be done in a laboratory or in a naturalistic setting? and d) should the scope of factors involved expand to include cultural, emotional, personal and other contextual attributes. Ripe categories of integration include:

- Examining the impact information visualization can have on a broader set of classic decision-making biases. Can information visualization serve as a debiasing technique?
- Exploring the relationship between preattentive visual processing and high-order decision making processes.
- More studies examining the role of emotions and affect in visualizations and decision making.
- Can the cognitive fit theory be expanded to cover other decision making problems, such as those explored by the heuristics and biases track?
- Most visualization tools are hybrid tools combining symbolic and spatial cues. How does combining cues improve decision making outcomes? Can research be effectively done combining elements?
- Narration, animation and mental rehearsal have some cognitive commonalities. What problem solving tasks are best suited for these problem representations?

These are some of the immediate directions that seem to suggest themselves. Since the common element in both areas lies in the workings of the brain and more specifically the relationship between visual processing and symbolic processing in decision-making, there is hope that the research in the different tracks can continue to inform each other.

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