Cognitive Engineering Research Methodology: A Proposed Study of Visualization Analysis Techniques

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ABSTRACT

The rapid development of new sensors and wide-band communications provides the capability to collect enormous amounts of data. An increasing challenge involves how to understand and interpret the data to yield knowledge about evolving situations or threats (e.g., of military situations, state of complex systems, etc.). New visualization tools and techniques are becoming available to support advanced visualization including three-dimensional, full immersion display environments and tools to support novel visualizations. Examples include network system display tools and evolving multi-sensory situation environments. Despite the emergence of such tools, there has been limited systematic test and evaluations to determine the efficacy of such tools for knowledge understanding and decision making. This paper provides an overview of this problem and argues for the need to conduct controlled experiments. A sample experiment is suggested.

1. INTRODUCTION

An evolving problem in intelligence gathering and military situation and threat assessment is the challenge of accessing and ingesting the enormous amount of collected data. The problem is due in part to the rapid increase in sensing capability via national resources, networks of nano- and micro-scale sensors (e.g., smart dust), unmanned aerial vehicles (UAVs), utilization of individual soldiers as data collectors and sensors, and utilization of web resources (e.g., open source information). The amount of collected data is increasing rapidly, with little regard to the actual ability to ingest or understand the data.

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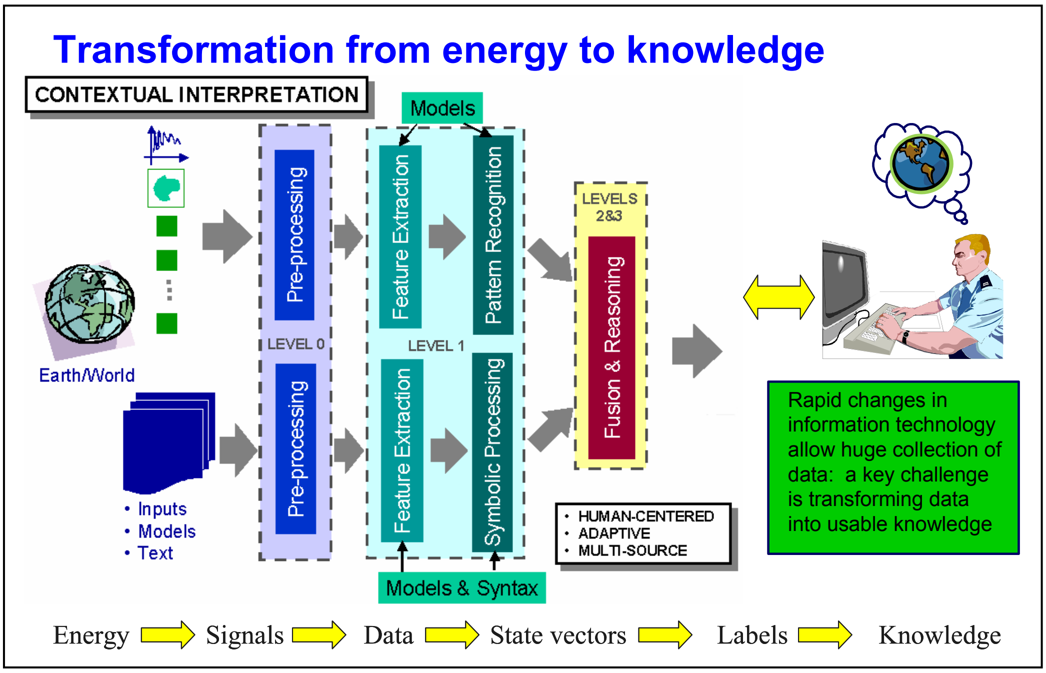

Figure 1: The Transformation from Data to Knowledge

Users are faced with a situation in which they are "drowning in a sea of data" but "thirsting for knowledge". In addition, multiple analysts may be working on parts of a particular issue and may not have direct interaction or any interaction at all. A traditional view is that automated systems must be developed to process all of the incoming data and somehow abstract or represent the data for human understanding. This concept is illustrated in Figure 1.

In this view, data collected from multiple sources are processed via multiple levels of data fusion (using the Joint Directors of Laboratories model) to provide results to be viewed or analyzed by users. Processing techniques are drawn from statistical estimation; pattern recognition, automated reasoning, and optimization for performing Level-1 through Level-3 fusion (see [1] and [2]).

Progress in data collection and Level-0 and Level-1 fusion processing has far outstripped the ability to support automated analyses. As a result, we face a situation in which a huge glut of data accumulates in a data base to be somehow analyzed by a limited number of analysts. Due to the structure of the intelligence community (IC), law-enforcement (in the areas of espionage and terrorism), and military intelligence organizations, collaboration is difficult at best. In a number of cases, analysts do not know who else may be working on similar issues related to their specific target. Additionally, all collected data does not reside in a single repository to be accessed. The overwhelming glut of available data becomes detrimental to the analysis and decision process. This has led some researchers to cite the need for data mining techniques. The claim is that the application of one or more algorithms such as pattern recognition techniques, machine learning methods, and advanced filtering techniques will allow knowledge to be gleaned from the data.

There are several difficulties with this suggestion.

1. First, there is an implicit assumption that the problem involves "finding the needle in the haystack" or "finding a nugget of wisdom among the data". In fact, no such needle or nugget actually exists. For example, no single source of data would have predicted the events of

September 11, 2001. Instead, multiple sources of data and information, combined with human imagination and analysis would have been required to foresee the actual events. Knowledge must be created and synthesized, rather than simply "mined".

2. Second, the process of creating such knowledge generally requires multiple humans to collaborate, each having different domains of expertise, rather than a single person. Data mining techniques tend to support an individual decision-maker or analyst.

3. Knowledge is inherently a human product, rather than the product or result of an algorithm or technique. It is important to consider the human analyst as a vital part of the inference/analysis process. We need to determine how to help the analyst do a better job at what they do best.

4. Finally, the approach has started "at the wrong end" of the data-to-knowledge chain. The process of improving the analysis process must start at the human side of the process (viz., the right hand side of Figure 1) rather than the data/sensor side. In short, we need to find ways to "cross the longest yard" to transition from data inside a computer (gathered via sensors and processed using level-0 and level-1 techniques) to knowledge inside a human analyst's head.

Figure 2: Example of 3-D Full Immersion Environment for Exploring Environmental Data

Thus, instead of attempting to completely automate data processing (e.g., via data mining techniques, machine learning, etc.) in order to understand data, we suggest that efforts be made to focus on visualization methods to assist analysts in creative interpretation and analysis. Indeed, this suggestion has been previously made by multiple authors (M. J. Hall et al (2000), Blasch and Plano (2002)), resulting in the creation of a new level of fusion (level 5) for the Joint Directors of Laboratories (JDL) data fusion process model. The new level introduced into the JDL model recognizes the need to explicitly consider the role of the "human in the loop" and develop methods to improve the link between the human part of a data fusion system and the automated part of the system.

Extensive work has been conducted in development of visualization techniques. It is beyond the scope of this paper to provide a review of such methods. However, an excellent tutorial is available by K. Andrews at http://www.iicm.edu/ivis/. A recent limited survey of visualization techniques to support decisions was conducted by J. Abraham (2006). Recent work involving 3-D environments are described by D. Shuping and W. Wright, and by Kapler and Wright (2005). An example of a full immersion, three-dimensional environment for displaying environmental data is shown in Figure 2. This work was conducted at the Pennsylvania State University by D. Hall et al (2005).

2. THE NEED FOR QUANTITATIVE RESEARCH

Over the past decade, network visualization tools are becoming a prominent method to aid in the analysis of data. Network visualization has the potential to become a powerful tool across a multitude of analysis disciplines. However, the drawback to this method is there is very little understanding about how these tools and their various components are perceived by the analysts. In addition, it is not clear whether efforts expended to develop advanced displays and interfaces quantitatively improves the analysis of data. Research specific to network visualization techniques could aid tool designers in understanding how color, shapes, line design, organization, and the cognitive characteristics of the user will impact the analysts' assessment of the presented data. Further, these issues must also be studied in relation to how a decision-maker perceives the presented data. The ultimate goal of near-term research should be aimed at building a comprehensive model to be used by network visualization tool designers in order to optimize the tool for use by the human.

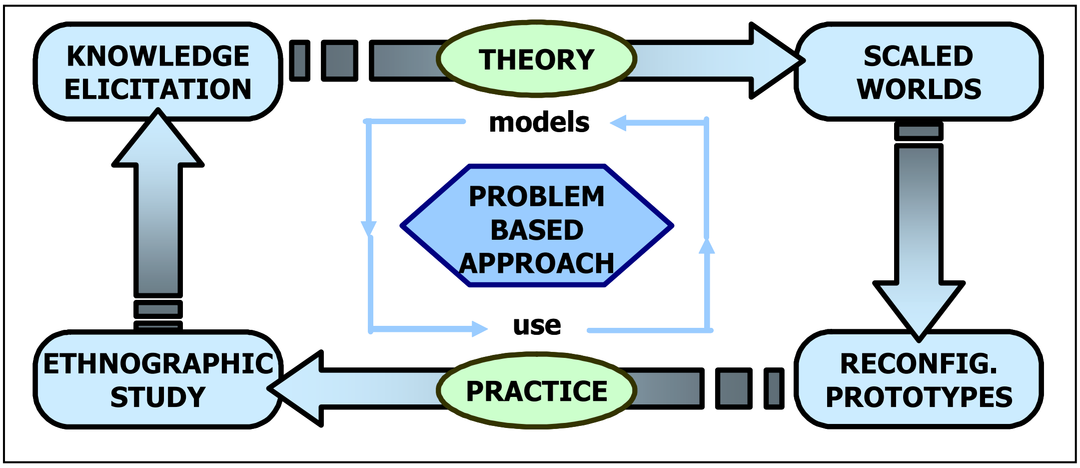

Figure 3: Systematic Evaluation Approach (McNeese (2003))

An excellent example of quantitative research in cognitive aids and visualization is the work by McNeese and his colleagues (McNeese (2003), McNeese and Vidulich (2001), Connors et al (2005)). McNeese has developed a systematic approach that links ethnography studies (direct observations of analysts/users in field environments), formal knowledge elicitation to develop cognitive maps of user analysis activity, creation of a scaled world environment, and evaluation of prototype cognitive aids and visualization tools using human subjects in a "living laboratory" approach. A conceptual view of this approach is shown in figure 3. Additional details on this approach are available at http://minds.ist.psu.edu. The site also provides information about a scaled world simulation tool called Neo Cities. Neo Cities provides the capability to allow teams to conduct analysis and decision making using a simulated terrorist attack on a small city. The tool allows experimenters to develop evolving scenarios (e.g., involving increasing activities), support data and reports to the team, introduce cognitive aids and visualization tools to support the decision making and analysis, and quantitatively evaluate the results of such tools and techniques. McNeese and his students have applied this methodology and conducted experiments for applications such as;

- Emergency Crisis Management Centers
- The TOPOFF Exercise, New York/NJ Port Authority
- Environmental Protection Agency: West Nile Virus Workers
- The WMD/Terrorist Readiness Exercise: Apollo, PA
- Police Operations, Centre County, Pennsylvania.

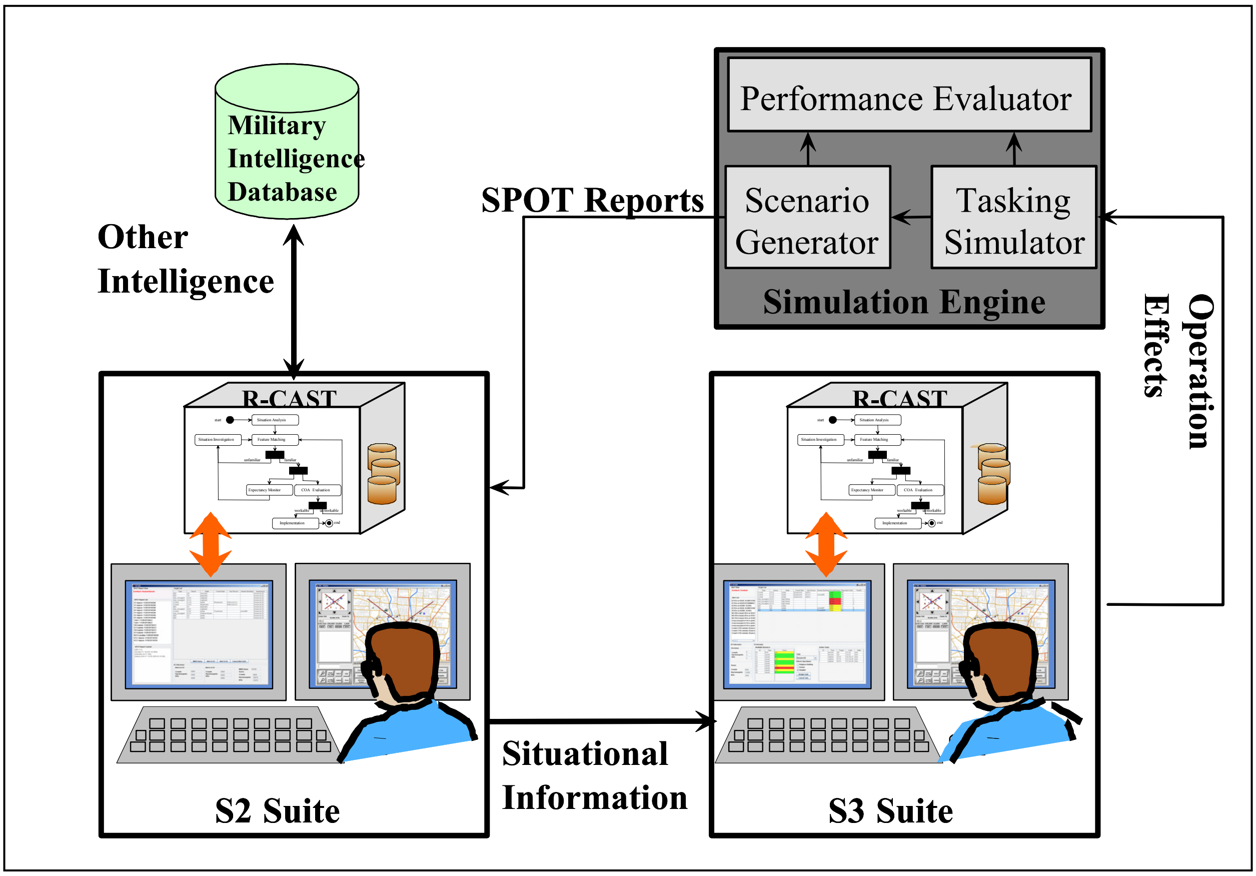

Figure 4: Concept of Experiments involving Team-Based Agents (Yen (2005))

Other types of experiments involving use of tools to support situation assessment and decision making have been conducted by J. Yen and his colleagues (Fan et al, 2005). Yen has developed an architecture and knowledge representation techniques to allow intelligent software agents to emulate how human teams interact. The concept involves allowing software agents to work as a virtual team, developing a shared computational "mental model" analogous to how human teams develop a shared mental model during team decision-making. Using this technique, Yen has developed cognitive aids to support military situation and threat assessment. His experiments have involved using human subjects to perform decision making in simulated environments evaluating whether or not agent assisted teams perform better than teams not provided with agent support (see Figure 4).

Thus, these are examples of the types of experiments that we argue should be performed to evaluate the use of visualization tools and techniques, especially for network visualization.

3. THE NEED FOR A COMPREHENSIVE COGNITIVE ENGINEERING MODEL FOR NETWORK VISUALIZATION

The ultimate goal of research in this area should be to build a comprehensive cognitive engineering model tailored for network visualization tools. This model would provide a basis for the designers of network visualization tools in order to standardize the use of color, shapes, and line design in order to build tools that can be quickly learned and utilized by a multitude of users. Additionally, these common visualization techniques would potentially maximize the usefulness and efficiency of these tools while minimizing potential errors induced in the analysis process due to the visualization tool.

Network Visualization is currently being incorporated into a number of critical analysis processes such as contagious disease monitoring, information system design, understanding machine learning, understanding social networks, etc. The techniques have the potential to be tailored to other critical disciplines such as intelligence analysis, environmental monitoring, decision support, and other areas.

It is important to consider the basic problems with human reasoning when creating a model to address such a critically important pool of data and information and the use of this information to make, in some cases, grave decisions. Research into the area of human reasoning has a long history and some classic studies can point to critical areas of concern for analysts. Cognitive psychologist Amos Tversky began looking at decision making and found some critical and potentially problematic tendencies in human reasoning. When humans are faced with more alternative than they feel that they can reasonably consider, as is in the case of an exploding data pool, individuals tend to take mental short-cuts that limit rational decision making and have difficulty predicting probabilities of events. A few biases that plague the human analyst are listed:

1. Humans judge the probability of an uncertain event according to the representativeness heuristic. Humans judge based on how obviously the uncertain event is similar to the population in which it was derived rather than considering actual base rates and the true likelihood of an occurrence (for example, airplane crashes being considered more likely than they actually are).
2. Humans also judge based on how easily one can recall relevant instances of a phenomenon and have particular trouble when it confirms a belief about the self and the world. For example, the vast media coverage of airplane accidents and minimal coverage of automobile accidents contributes to fear of flying even though statistically it is much safer. Media coverage however gives people dramatic incidences of airplane crashes to recall more than automobile accidents.
3. Even the order and context in which options are presented to people influences the selection of an option. People tend to engage in risk aversion behavior when faced with an option involving potential losses and risk seeking behavior when faced with potential gains.
4. People tend to have an inflated view of their actual skills, knowledge and reasoning abilities. Most individuals see themselves as “above average” in many traits including sense of humor, driving abilities, and other skills even though not everyone who reports this way could be.
5. Humans have a tendency to engage in confirmation biased thinking, in which analysts tend to believe a conclusion if it seems to be true (based on the context in which it is presented) even when the logic is actually flawed.

These considerations lead to a general need for considering research from the data fusion community and experimental psychology fields in order to bridge gaps in understanding about people and data.

4. AN EXAMPLE EXPERIMENT: THE EFFECT OF COLOR IN DISPLAYS

As an example of types of experiments that could be performed, we note that traditionally little regard has been given to the purposeful use of color, shape or design in node-link diagrams. Typically these elements are chosen for aesthetic purposes as opposed to aiding in the facilitation of better understanding. Research in the area of cognitive psychology has provided insight into the area of color perception of the individual that may have an impact on how knowledge is understood from this media. Generally speaking, color perception and its effect on mood has suggested that red is perceived by individuals as negative and tense, while blue has been identified as calm and cool. These perceptions may have a significant impact in the behavior of people. Studies in merchandising and consumer behavior (Bellizzi and Hite, 1992) have supported that blue shopping environments were associated with more purchases, fewer purchase postponements, and more browsing than red shopping environments. Further it has been suggested that this may be due to color-mood associations (i.e., how people self-report to identify with color) than to actual physiological arousal (i.e., increased heart rate, increased blood pressure and stress- hormone release) in the individual. `Other studies (Hemphill, 1996) support this by showing that when individuals are asked about color and reasons for choosing some colors over others, that bright colors were associated with positive emotional states and dark colors more negative emotional states. These self-report studies in addition to studies where color is manipulated suggest that colors have strong emotional, contextual and cultural implications. In this current project, color will be considered in a western culture framework in which color associations seem to be consistent.

When designing tools for use by analysts, it is important to consider other aspects of visual perception that may affect analysis. In the instance of considering color in the larger context of visual selection among other factors (i.e., location) it may not be the most salient factor in selection. There are several visual-attention theories that would argue that position, color, form and luminance are equivalent operations in attentional selection. However, Grabbe and Pratt (2004) in their study of competing top-down visual selection processes, found evidence to support visual attention theories that argue that spatial information plays a special role in the analysis of visual arrays. Hence in the proposed study position and structure of a node-link diagram may have a competing impact on judgment and perception in addition to color.

Although it may be possible that color and visual attention factors could be manipulated in the design of node-link diagrams and other visual displays to ensure better decision making and analysis, research on decision making processes suggest that biases and other human cognition characteristics may be difficult to counteract. It would be easy to assume that humans who are asked to perform tasks that involve precise and insightful decision-making would follow rules and maximization strategies to ensure success and accuracy. However, Schul and Mayo (2003) in examining binary signal prediction found that even when individuals were given a simple decision rule to maximize success individuals failed to use this rule. Individuals being required to plan were more likely to use rule-based decision-making (and thus optimize success), yet having to justify decisions afterward failed to increase rule-based decisions. Additionally, Tykocinski and Ruffle (2003) showed that individuals often wait for non-instrumental information before making a sure-thing decision. Further individuals who chose waiting behavior were overall less confident about committing to a decision.

So it seems that people, even when provided insight and “sure thing” decisions seem to have difficulty in understanding how to optimize and decide effectively. Presumably because of a need for power and control and wanting to create elaborate stories that justify actions. Social psychological study provides a broad research base that suggests that individuals are further affected by the mood of people around them and even how they interpret non-descript physiological arousal. These factors will be instrumental in understanding how collaboration of analysts and how materials are presented in a group setting have an effect on decision making.

4.1 Problem Statement

Network visualization is a rapidly evolving technique employed to assist in complex data analysis problems and as a decision-making tool. These new techniques, however, require an understanding how of how the human will interpret the data using the network visualization. From the analysts’ perspective, questions regarding the impact of the visualization tool on the analysis process include:

1. How does the use of color impact the comprehension of the presented data?
2. How does the organizational pattern of the network links and nodes impact the analysis?
3. How does the mood of the analyst prior to and after exposure to a network visualization impact interpretation of presented data?
4. How does color and organizational pattern of network links effect the analysts’ interpretation of presented data?

Further from the decision-makers' perspective, questions regarding the impact of the visualization tool on the decision process include:

1. How does the use of color impact the comprehension of the presented data?
2. How does the organizational pattern of the network links and nodes impact the final decision?
3. How does the mood of the individuals affect the decision-making process?
4. How does the behavior of the presenter influence the final decision and group process?
5. How does the behavior of others present in the meeting influence the final decision?

4.2 A Proposed Research Study

Phase I: Our research team will examine the effects of two classifications of colors (warm and cool) and three types of network organizational formats (hierarchical, radial, and random) on mood and threat assessment. Research participants will be screened for color-blindness and asked for informed consent to participate. Each research participant will be measured on mood before being presented with simulated data in order to create a base-line measure, in order to rule out extreme pre-existing mood as a confound. Upon completion of this and a short demographic questionnaire, research participants will simulate an analyst perspective as they will be presented with information at a computer screen individually and asked to make assessments and decisions based on what is presented. Mood and threat assessment will be measured using a questionnaire, Likert scale format (zero to seven scale, zero being "not at all" and seven being "very true") for continuous and more objective data. Interview data will not be used as interviews do not yield as reliable results. This data will be analyzed using a t-test to determine significant differences between group means. Our hypothesis is that warm colors will be associated with an increase in negative mood states and increased threat measures, whereas cool colors will not.

Phase II: After interpreting and analyzing data gathered from Phase I, the decision-makers' perspective will be investigated using the same variables and design, color and network organizational format. In order to simulate the decision-makers' perspective, research participants will engage in a group meeting in which a PowerPoint presentation, a presenter (trained by the research team for consistency and neutrality), and group discussion in a neutrally colored and decorated meeting room. After this process, research participants will be measured on mood and threat assessment as in Phase I. It is our intention to use a different group of research participants in this and Phase III as to not create effects based on repeated exposure to the stimuli. It is our hypothesis that the effects of color and organizational format will be consistent with that of Phase I results. It is our intention to examine any differences between mood and threat level for individual analysts and decision-makers.

Phase III: In the final phase, our research team will investigate the influence of the presenter on interpretation of data. We will use the results from Phases I and II to create a presentation of node-link diagrams that are associated with decreased anxiety and threat level. In a small group, meeting-room environment, research participants will be exposed to two versions of the same PowerPoint presentation, with the same presenter behaving in one of two ways: calm and reasonable or irritable and dramatic. Our research team will train an actor to play the two roles in order to create consistency and to control for variance. The use of deception and a confederate (a trained part of the research team who plays various roles) is common in social psychological study and helps to isolate social variables. After assessment of mood and threat level, research participants will be debriefed appropriately. In this study, our hypothesis is that in the condition in which the presenter was irritable and dramatic that there will be an increase in negative mood states and threat level.

5. SUMMARY

In this paper we argue that new visualization tools and devices provide the promise for significant improvements in the ability of analysts to understand data and make effective decisions. However, systematic research and evaluation will be required to determine the utility of visualization aids and cognitive aids. Human-based experiments are needed to quantify the effects of factors such as color, use of multiple dimensions, multi-sensory effects (e.g., sonification and haptic interactions), and individual versus team-based collaboration and analysis. Researchers such as McNeese and Yen's groups have developed effective approaches for conducting such research. We urge the continuation and further development of similar research.

REFERENCES

[1] Hall, D. and S. McMullen, *Mathematical Techniques in Multisensor Data Fusion*, 2nd edition, Artech House, Inc., 2004.

[2] Hall, D. and J. Llinas, editors, *Handbook of Multisensor Data Fusion*, CRC Press, 2001.

[3] Sternberg, Robert J., *Cognitive Psychology,* 2nd edition, Harcourt Brace College Publishers, 1999.

[4] Brehm, S. S., Kassin, S. M., Fein, S., Social Psychology, 4th ed. Houghton Mifflin Company, 1999.

[5] Bellizzi, Joseph A. and Hite, Robert E. "Environmental Color, Consumer Feelings, and Purchase Likelihood," *Psychology and Marketing*, September/ October 1992.

[6] Grabbe, Yvonne and Pratt, Jay. "Competing Top-Down Processes in Visual Selection: Evidence That Selection by Location Is Stronger Than Selection by Color," *The Journal of General Psychology,* April 2004.

[7] Hemphill, Michael. "A Note of Adults' Color-Emotion Associations," *The Journal of Genetic Psychology,* September 1996.

[8] Schul, Yaacov and Mayo, Ruth. "Searching for Certainty in an Uncertain World: The Difficulty of Giving UP the Experiential for the Rational Mode of Thinking," *Journal of Behavioral Decision Making*, April 2003.

[9] Tykocinski, Orit E. and Ruffle, Bradley J. "Reasonable Reasons for Waiting," *Journal of Behavioral Decision Making*, April 2003.

[10] Hall, M. J., S. A. Hall, and T. Tate, "Removing the HCI Bottleneck: How the Human Computer Interface (HCI) Affects the Performance of Data Fusion Systems," *Proceedings of the 2000 MSS National Symposium on Sensor and Data Fusion*, San Diego, CA, June 2000, pp. 89-104.

[11] Blasch, E. P. and S. Plano, "JDL Level 5 Fusion Model "User Refinement" Issues and Applications in Group Tracking," SPIE Volume 4729, Aerosense, 2002, pp. 270 – 279.

[12] Andrews, K. "Information Visualization", tutorial lecture, July 2002, see http://www.iicm.edu/ivis/