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A Cyber Infrastructure for Evaluating the Performance of Human Centered Fusion

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Abstract – *Humans are becoming an increasing important component of information fusion systems including; (1) acting as observers or "soft sensors" to augment traditional sensor systems, (2) participating in data analysis by using semantic reasoning and pattern recognition to augment computer processing, and (3) collaborating in ad hoc teams for situational analyses. These roles are supported by emerging information technologies such as social networking tools, advanced visual displays and cognitive aids. This paper describes a cyber-infrastructure and associated research strategy developed at Penn State University to support human in the loop experiments to quantitatively evaluate concepts and tools for human centered information fusion. Examples of on-going experiments are also presented.*

Keywords: human experiments, test and evaluation, soft sensors, hybrid reasoning.

1 Introduction

Hall et al [1] introduced the concept of human in the loop information fusion, in which humans play new roles in information fusion systems including; (1) acting as observers or "soft sensors" to provide inputs to augment traditional hard sensors systems, (2) performing as hybrid "computers", supporting automated reasoning techniques via visual and aural pattern recognition and semantic reasoning, and (3) collaborating in ad hoc human teams in a "hive mind" concept to conduct distributed analysis and decision making. Examples of use of advanced visualization to support hybrid computing and distributed analysis are provided by Hall et al [2]. The concept of these new roles is illustrated in Figure 1.

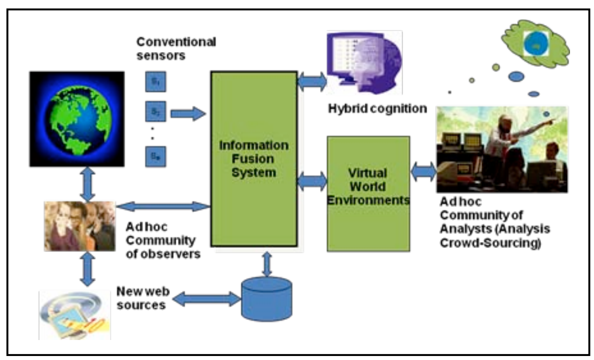

Figure 1: Concept of Human Centered Fusion [1]

Figure 1 illustrates an information fusion system which processes input about a domain of interest (e.g., situational awareness of a location on earth, environmental monitoring, etc.). Historically, fusion systems processed inputs from physical sensors such as radar, infra-red or ground-based acoustic sensors (shown on the top left portion of Figure 1). The traditional information fusion system processed these data using a data driven approach and sought to perform automated signal and image processing, state estimation, pattern recognition and limited automated context-based reasoning to result in a situation display or common operational picture. This display was viewed relatively passively by one or more user/analysts. Extensive amounts of research have been conducted in this area with numerous systems implemented, especially for military applications (see [3] for information about techniques, architectures, data structures, systems engineering, and surveys of applications).

However, new concepts are emerging as described by Hall et al [1] and illustrated in Figure 1. In this emerging approach, the traditional sensors are augmented by information from a community of ad hoc observers and from the internet via search engines (e.g. searching blogs, News to Me reports and on-line sensors such as web cameras). In addition, user/analysts are beginning to take a more active role in performing reasoning and pattern recognition using advanced interface environments. Finally, multiple, distributed people are collaborating for analysis and decision making.

For each of these roles, new tools and aids may be developed to enhance the overall performance of the combined human/computer/sensor fusion system. In order to support ad hoc observations, for example, knowledge elicitation aids for hand-held devices could be developed including information collection forms analogous to military S.A.L.U.T.E. reports, http://www.geocities.com/esm2nddiv/salute.html , advisory software agents to solicit information in an evolving situation, or visual guide tools (e.g., to assist in directing a person's gaze or attention [4]). Tools for supporting human aided pattern recognition include advanced visualization techniques such as full immersion, 3-D environments ([2], [5], [6]), the use of sound (sonification) to support recognition of patterns in data (see Ballora et al [7]), and semantic reasoning aids [8]. An example of a 3-D immersive display is shown in Figure 2. Finally, advances in virtual world technologies such as Second Life (www.secondlife.com) and *Protosphere* enable people to collaborate in a virtual distributed environment. Experiments are beginning to be developed to determine the utility of such environments for distributed learning and decision making ([2], [9], [19]).

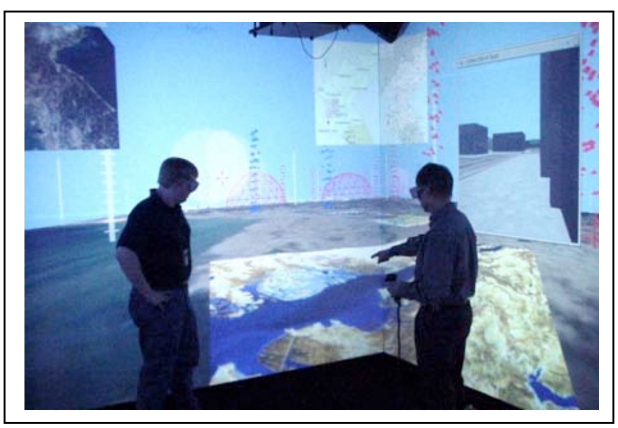

Figure 2: Example of 3-D Full Immersion Display [5]

While rapid changes in information technologies such as advanced displays, social network and collaboration tools, and automated reasoning tools that support human in the loop fusion, a challenge remains regarding how to determine if such tools and aids are effective. In particular, does the introduction of these artifacts improve the overall decision-making and analysis for a human/computer/sensing system or not? In some cases the use of collaboration methods such as instant messaging (IM) or twitter (http://twitter.com) might actually degrade the performance of a fusion system by distracting analysts or by encouraging "group think" rather than insightful analysis. Similarly, the use of human input data may lead to erroneous situation assessments due to human biases in observations, lack of expertise in given domain specifics, cognitive biases [10] or deliberate deception. Loescher, Schroeder and Thomas [11], suggest that a significant problem in the near future will be the creation of false information that emerges from multiple people interacting on the web – information that is not deliberately false, but that takes a life of its own and disrupts our view of reality.

A need exists to explore, test and evaluate tools, concepts, and cognitive aids to understand the utility of the techniques and to evaluate the complete integrative performance of the human/computer/sensing information fusion system. At the Pennsylvania State University Center for Network Centric Cognition and Information Fusion (NC2IF) we have developed a cyber-infrastructure and framework for conducting such tests and evaluations. The experimental concept and strategy is described in the next section, followed by a description of the components of our test and *extreme events laboratory*. Subsequently we provide examples of some on-going research and experiments.

2 Experimental Strategy

The basic strategy for evaluating human centered fusion artifacts (e.g., tools, visual aids, collaboration tools) involves recognizing the need to connect real-world problems with statistically significant experiments. On one hand, we need to obtain an understanding of real-world problem domains such as command and control centers, 911 emergency centers or emergency medical operations. On the other hand, we recognize the challenges of conducting research in such domains. It is often not feasible to introduce artifacts into critical operations and expect that; a) users will readily allow new concepts or artifacts to be introduced in "live" operations, b) that

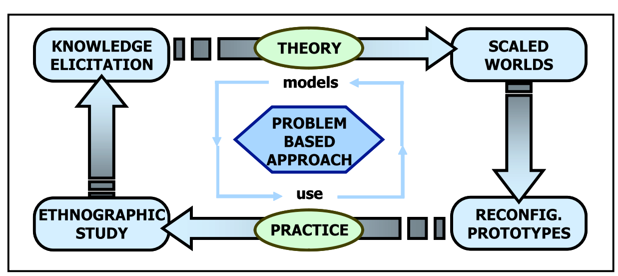

Figure 3: Experimental Strategy [12]

repeatable experiments could be performed "with" and "without" the use of introduced tools, or 3) that statistically significant experiments could be conducted in which, perhaps hundreds of test runs are conducted under controlled circumstances.

Thus, it is necessary to abstract a real operational environment or conduct miniature experiments and argue that the results can be scaled to a real-world environment.

An experimental strategy that links real-world environments with statistically significant experiments has been developed and implemented by McNeese et al [12]. The concept is illustrated in Figure 3. This approach involves four key processes. First, ethnography studies are conducted in real-world environments such as 911 centers, command and control centers and emergency room operations. These studies provide for controlled data collection using techniques such as observations by a psychologist, video recordings, interviews, tape recordings of conversations and self-reporting by participants. Second, the data are analyzed using formal knowledge elicitation techniques including the use of focus groups, one-on-one interviews, introduction of sample problems to field personnel, and interactive information discovery using methods such as fuzzy cognitive maps [13]. Third, theories are developed and implemented in a scaled world environment which allows for laboratory experiments to be conducted in a controlled environment. For example, one can evaluate the performance of a small team performing situational assessment and resource allocation based on different types of displays, cognitive aids and collaboration tools. These experiments can be conducted using multiple test subjects to achieve statistical significant (viz., evaluations of team performance with or without the use of an artifact). Finally, the experiments can result in recommendations for re-configured prototypes or for ultimate transition to a field environment.

The ethnographic studies allow information to be drawn from real-world operational environments, while the scaled world test environment allows controlled statistically significant experiments to be performed. A close connection between the operational and experimental environments ensures selection of relevant problems and transition of experimental results to fielded environments.

This overall research strategy is supported by a cyber infrastructure implemented at the Pennsylvania State University described in the next section.

3 Experimental Cyber Infrastructure

A special cyber infrastructure has been designed and implemented at the Pennsylvania State University College of Information Sciences and Technology. The infrastructure consists of three elements; (1) an *Extreme Events Laboratory* (EEL) which involves a central data analysis and display facility coupled with a campus wide wireless network system to allow secure communications between handheld devices (e.g., cell phones, laptop computers, Nokia 800 devices) and the central facility, (2) a scaled world simulation environment, called NeoCities, which drives simulation based experiments for individual and team performance, and (3) Virtual world tools for evaluation of distributed analysis. This framework provides the opportunity to demonstrate and conduct experiments involving humans as observers, humans performing pattern recognition and reasoning, and also distributed decision-making and analysis. The cyber infrastructure enables both quantitative experiments of the new human-centered fusion functions as well as demonstrations of the potential for scaling tools and aids to a real-world collection, processing and analysis environment. Each of these elements is described below.

3.1 Extreme Events Laboratory

The Extreme Events Laboratory (EEL) is illustrated in Figure 4. The EEL consists of a central data analysis and command facility housed in the Information Sciences and Technology (IST) building at University Park campus in central Pennsylvania. The central facility includes computer servers, several large screen displays for 2-D display and analysis and a one-wall, 3-D immersive visualization facility. The central facility can be dynamically connected to mobile devices such as a Nokia N810 internet tablet computer or the Neo 1973 device. A wireless mesh network around campus was implemented using Meraki portable nodes and the Penn State University public internet. The backend systems use an environment including RedHat Linux, OpenVPN, MySQL, and Flex. The network traffic is encrypted using Public Key encryption.

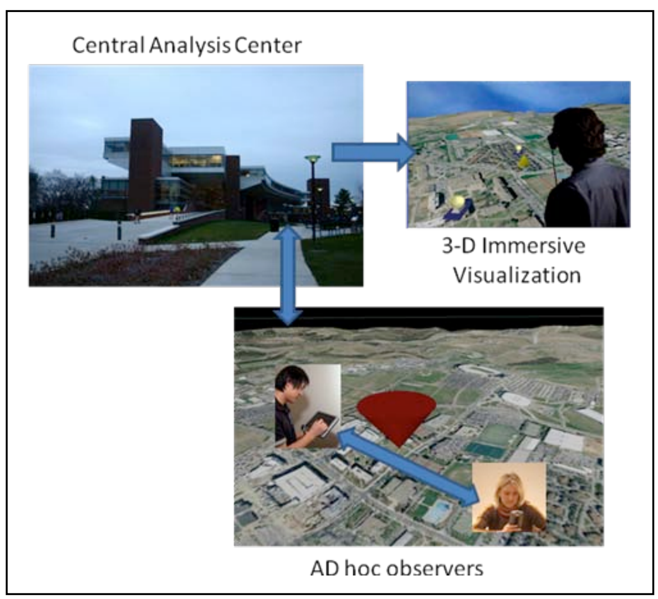

Figure 4: Extreme Events Laboratory

Additional details of the EEL are provided by [14]. The basic elements of the EEL were funded by a Department of Defense University Research Instrumentation Program (DURIP) grant.

Examples of the EEL capabilities for experimentation and demonstration include the following:

- Collection of human reports (both using humans as soft sensors and as sensor platforms) and display of these reports on both a 2-D Google Earth display as well as a 3-D, full immersion representation of the Penn State University Park campus and surrounding areas,
- Investigation and demonstration of soft sensor phenomena such as dynamic resource allocation, tasking of human observers, computer assisted knowledge elicitation and focus of attention,
- Exploration of distributed collaboration (e.g., combining users at a central data analysis facility and distributed user/observers) and decision making,
- Display of 3-D data including information related to models of the physical landscape, the human terrain/landscape, and cyber-networks,
- Combination of exploration of 3-D immersive displays and 3-D sound interfaces for pattern recognition,
- Utilization of advanced search engines and data mining tools,
- Modeling of physical phenomena (e.g., dispersion plumes for chemical/biological phenomena and nuclear related phenomena) and 3-D displays of advanced mathematical model results using *Mathematica,*
- Use of hybrid pattern recognition and information fusion combining human-centered processing with automated tools
- Exploration of fusion of human reports with traditional sensor data.

3.2 NeoCities

The second component of the cyber-infrastructure is a simulation tool called neoCITIES, which has evolved over a number of years at Penn State under the direction of M. McNeese [15]. NeoCITIES uses a scenario-based structure involving an emerging storyline related to an escalating terrorist plot at the Penn State University Park campus. Participants are provided with a situation display involving a map display, information about received reports, and information about available resources to deploy to respond to the emerging situation (Figure 5). Typically, a multi-participant team is tasked with assessing the evolving situation and responding to a series of emergencies or events. The participants take on the role of addressing fire conditions (FIRE), police conditions (POLICE), or hazardous materials (HAZMAT).

To address these events the response teams are required to meet the needs of their constituents and develop an awareness of the situation while responding to various problem constraints (e.g., related to constrained resources). The simulation presents the subjects with two different types of events; (1) "distracter" events involve routine procedures for the response teams such as addressing a domestic dispute or small trash fire, and (2) events that are concerned with the underlying storyline (e.g., actions of individuals associated with the emerging terrorist event).

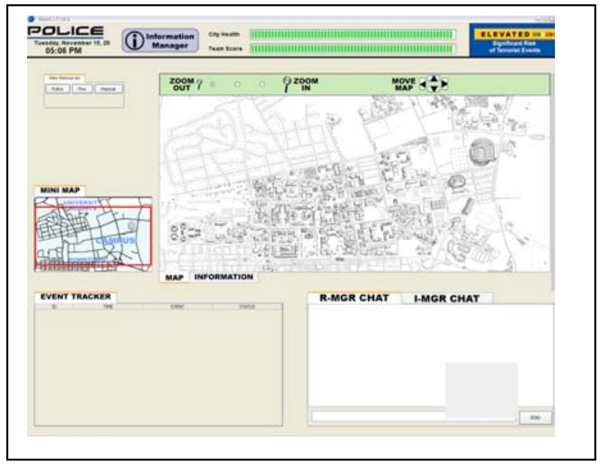

Figure 5: Sample NeoCITIES display

NeoCITIES provides extensive flexibility to construct a wide variety of experiments. Examples of variations supported by the tool include;

- *Number of participants* – the number of participants can range from a single participant to teams of two to six members,
- *Complexity of the scenario and underlying storyline* – the underlying storyline and events can be varied widely including growth and rate of events and interactions among and simultaneity of events,
- *Speed and rate of information presentation* – the timeline and rate of "real-time" can be modified,
- *Collaboration among participants* – various techniques such as instant messaging, e-mail, video conferencing, or direct interactions can be introduced to assist (or impede) communications among the participants
- *Information presentation* – The displays for NeoCITIES can be modified from simple map displays and use of icon overlays to more complex interactions,
- *Feedback provided to the participants* – Different levels and types of feedback can be provided to the participants to rate their performance, and
- *Cognitive aids* – Different types of cognitive aids can be introduced to support the subjects, ranging from semi-intelligent software advisory agents to simple template help files.

During a typical experiment, data gathered using NeoCITIES includes information about individual participants, interactions among participants (for team experiments), user preferences and individual and team member performance on situation assessment and resource allocation. Thus, NeoCITIES provides a key part of the human centered cyber infrastructure. It allows the design and conduct of relevant experiments to evaluate key aspects of individual and team cognition and collaboration. NeoCITIES has been used for a wide variety of experiments ranging from understanding the role of stress and mood on decision making [16] to assessing the effects of risk analysis models on time-stressed decision making [17].

The NeoCITIES simulation provides full-scale control of independent, control, and dependent measures associated with a fire-police-hazmat team involved with a crisis management scenarios that require 1) situation awareness of emerging events, 2) allocation of required resources from each team member, 3) executing decisions with limited resource and timeline bandwidths. Because NeoCITIES incorporates both an adaptable client-server architecture and interface structure (see below – Adobe Flex environment), the simulation can be orchestrated to look at individual, team, and team-of-teams performance. As a human-in-the-loop experimental testbed it is important to be able to assess and evaluate various levels and types of performance. For this reason, experiments involving the NeoCITIES simulation have utilized various embedded and external metrics.

Within the simulation there are various parameters that are available that lead directly to metric composition: 1) *event-related* (e.g., types of events, positioning and sequence of events, severity of events, event interdependence, timing and spacing of events, and information richness) and 2) *resources-related* (number of units required for an event, number of resources of available to a team, values assigned to each resource, and team-to-team contact communicating resources [18]. Metrics can be integrated to represent certain types of team performance measures. For example, we can track performance on *containment* (counting the number of events out of control), *resource allocation efficiency* (counting cumulative event intensities), as well as *team information sharing* (counting information screen use frequency; counting frequency of communication interface use). Furthermore, the *communication patterns* within and across teams can be analyzed to understand how various independent variables impact performance in the simulation. One should note that metrics could be tracked across different time windows of the simulation, thereby showing how a situation unfolds and impacts various parts of a scenario. In addition to the above metrics the simulation computes individual and team resource allocation scores that can be available to team players throughout the game. Individual questionnaires have also been used in the studies to assess and evaluate levels of situation awareness, stress, and other cognitive states while performing in the NeoCITIES simulation.

It should be noted, that while NeoCITIES was originally designed as a stand-alone simulation tool, it has been re-designed and implemented using an Adobe Flex software environment which allows deployment on a wide variety of computing platforms (including handheld mobile computers) and integration with other systems and services such as linking with the Extreme Events Laboratory and virtual world systems described in the next section.

3.3 Virtual World Environments

The final component of the cyber infrastructure involves the use of virtual world environments to conduct experiments with ad hoc groups of analysts [2]. There has been a very rapid evolution of massively multi-player, on-line games such as *World of Warcraft*, *EverQuest* and *Underlight*. In these games a huge number of simultaneous players (as many as 40,000 simultaneous players) involve a collaboration and competition to address a complex virtual world. The games have migrated to mobile phones and are beginning to incorporate real-world, real-time data. For example in the Madden NFL game, players can incorporate real weather data (or weather predictions from Accuweather) to affect the performance of their football teams in the home stadium.

Figure 6: Example of problem collaboration in a virtual world environment

At Penn State NC2IF, we have begun experiments with Second Life, OLIVE, and Protosphere. These virtual world environments are similar to games, but are simply graphic and symbolic representation environments to allow a user to construct avatars (e.g., to represent the user in the virtual world environment), construct collaborative portions of the virtual world, and interact in the virtual world with other people. For the second life environment, the host company, Linden Lab, rents space on a centralized server environment to allow a user to buy virtual real estate (called islands). Having purchased such space, a user can create a virtual world containing virtual buildings, avatars, interactive kiosks, etc. A number of companies and organizations have created very extensive environments. These range from recreations of physical environments such as virtual museums which emulate actual physical museums to the use of Second Life to support collaboration.

At the Penn State College of Information Sciences (IST), we have developed a virtual space, called ISTANIA, to explore education, collaboration, and team projects. The rapid acceptance of virtual world technologies by the digital natives [18] makes this a promising area of research. Our particular interest involves use of virtual world environments to support ad hoc collaboration and problem solving [19]. We have found (not surprisingly) that our undergraduate students are comfortable using such environments, but need specific tasking to use the technology effectively. Our plans will entail linking a virtual world environment for collaboration (using Protosphere) to the Extreme Events Lab and to NeoCITIES.

4 Examples of Experiments

Using components of this infrastructure, researchers at Penn State have conducted (and are currently conducting) a number of experiments. Examples of previous and on-going experiments are summarized below.

Characterization of human reports and observers - Research is being conducted to develop a framework for human observations and reporting ([20], [23]) including;

- Development and demonstration of mathematical models for fuzzy observations,
- Modeling second order uncertainty of human observations , and
- Exploring concepts of deception in virtual world environments.

Computer assisted knowledge elicitation - Techniques are being developed for eliciting knowledge from ad hoc observers, especially using hand-hold devices such as Nokia 800 systems. Examples include;

- Guided visual attention [4],
- Use of civilian equivalents to S.A.L.U.T.E reporting,
- Guided methods for uncertainty representation, and
- Understanding cultural biases for remediation using a "cultural lens" concept [21]

Dynamic resource allocation - Methods are being developed for dynamic allocation of system resources in a distributed fusion environment (e.g., use of sensors, communications bandwidth, computing resources, etc.). The methods focus on utilizing using market based methods [24] which treat resources such as sensor attention and communications bandwidth as market suppliers, while fusion algorithms and human analysts are treated as consumers seeking information. In this approach, a human can act as both a supplier of information or observations (acting as a soft sensor) as well as acting as a consumer of information (acting as an analyst or decision-maker).

Advanced visualization and sonification - New techniques are being implemented and evaluated to improve data understanding and situational awareness. Examples include;

- Cyber-situational monitoring [22],
- Methods for visualizing the human landscape, and
- 3-D visualization of situation and decision space [25]

Distributed ad hoc analysis and decision-making - Methods are also being developed to explore ad hoc, distributed decision making. Examples include;

- Decision support for emergency management,
- Decision aids to enhance emergency response decision-making [17],
- Decision support aids for situational awareness, and
- Use of Virtual World technologies for collaborative decision making [19].

The cyber infrastructure provides a useful toolkit and environment for designing and conducting these human in the loop experiments.

5 Conclusion

New information technologies are rapidly changing the community view of information fusion systems, from one in which physical sensors are used to observe physical objects in a data driven, semi-automated process, to a new view in which humans are active collaborators with the fusion system, acting as observers, human computers, and distributed analysts and collaborators. Technologies such as virtual worlds, social network software, advanced computer interfaces and cognitive aids provide the opportunity for a wide array of new tools to support these roles. However, it is necessary to develop new methods to test and evaluate how these tools affect the complete sensor/computer/human fusion system. At Penn State, we have developed a cyber infrastructure to support test and evaluation, linking real-world problem domains to laboratory-based statistically significant human in the loop experiments. On-going research and experiments involve exploring the use of humans as observers ("soft sensors"), humans as hybrid computers (performing pattern recognition and semantic reasoning), and distributed ad hoc collaboration (exercising "the hive mind") to address complex problems. This infrastructure provides a new capability for evaluating how humans can perform to support improved situation awareness and decision-making.

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