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14. ABSTRACT This project is focused on development of a research framework for dynamic integration of information from hard (electronic) and soft (human) sensors. This framework includes representation of 2nd order uncertainty. The overall approach is based on three pillars: (1) traditional sensing resources ("S-space"), (2) dynamic communities of observers ("H-space") and (3) resources such as archived sensor data, blogs, reports, dynamic news reports from citizen reporters via the internet ("I-space). During this project we have developed an overall framework,					
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## Report Title

Modeling and Mapping of Human Source Data (Final Report)

### ABSTRACT

This project is focused on development of a research framework for dynamic integration of information from hard (electronic) and soft (human) sensors. This framework includes representation of 2nd order uncertainty. The overall approach is based on three pillars: (1) traditional sensing resources (“S-space”), (2) dynamic communities of observers (“H-space”) and (3) resources such as archived sensor data, blogs, reports, dynamic news reports from citizen reporters via the internet (“I-space”). During this project we have developed an overall framework, implemented a distributed cyber infrastructure (an Extreme Events Laboratory) for conducting human in the loop experiments, performed literature reviews, and designed initial experiments related to focus of attention of human observers. In addition, we have developed some mathematical models for characterizing soft sensors and for knowledge representation.

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**List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:**

#### (a) Papers published in peer-reviewed journals (N/A for none)

Number of Papers published in peer-reviewed journals: 0.00

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#### (b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

- Alice Shapiro, “Humans as soft sensors in network centric cognition: a literature survey,” Technical Report published by the Pennsylvania State University Center for Network Centric Cognition and Information Fusion (NC2IF), July, 2008
- Participatory Sensing: A review of the literature and state of the art, technical report prepared for the Penn State Center for Network Centric Cognition and Information Fusion (NC2IF), November 20, 2009

Number of Papers published in non peer-reviewed journals: 2.00

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#### (c) Presentations

- D. L. Hall, “Issues in Hard and Soft Data Fusion,” presented at the Situation/Threat/Impact Awareness Workshop, sponsored by the Air Force Research Laboratory, 18-19 June, 2008

Number of Presentations: 1.00

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#### Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts): 0

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#### Peer-Reviewed Conference Proceeding publications (other than abstracts):

- D. L. Hall, M. McNeese, J. Llinas and T. Mullen, “A framework for dynamic hard/soft fusion”, in Proceedings of the 10th Annual International Conference on Information Fusion, Fusion 2008, Cologne, Germany, June 30 – July 3, 2008
- C. M. Hall, D. L. Hall, S. A. H. McMullen, M. J. McMullen and B. K. Pursel, “Perspectives of visualization and virtual world technologies for multi-sensor data fusion”, in Proceedings of the 10th Annual International Conference on Information Fusion, Fusion 2008, Cologne, Germany, June 30 – July 3, 2008
- K. Sambkhoos, J. Llinas and E. Little, “Graphical methods for real-time fusion and estimation with soft message data,” in Proceedings of the 10th Annual International Conference on Information Fusion, Fusion 2008, Cologne, Germany, June 30 – July 3, 2008
- D. Hall and S. Aungst, “The use of soft sensors and I-space for improved combat identification”, Air Force Research Laboratory Workshop on Human Factors – Issues in Combat Identification, May 13-14, 2008, Apache Junction, Arizona
- D. L. Hall, M. McNeese, B. Hellar, B. Panulla and W. Schumaker, “A cyber infrastructure for enhancing the performance of human centered fusion”, in Proceedings of the 12th International Conference on Information Fusion, Fusion 2009, Seattle, Washington, July 6-9, 2009
- K. Samboos and J. Llinas, “Evaluation methods for distributed multi-platform systems in electronic warfare and information warfare related missions,” in Proceedings of the 12th International Conference on Information Fusion, Fusion 2009, Seattle, Washington, July 6-9, 2009
- Hall, D., Hellar, B., and McNeese, M. D., (2009), “The Extreme Events Laboratory: A cyber infrastructure for performing experiments to quantify the effectiveness of human-centered information fusion,” submitted for presentation and publication in the Proceedings of the 2009 International Conference on Information Fusion (Fusion 2009), Seattle, Washington, July, 2009
- J. Llinas, R. Nagi, D. Hall and J. Lavery (2010), “A multidisciplinary university research initiative in hard and soft information fusion: overview, research strategies and initial results,” in Proceedings of the 13th International Conference on Information Fusion, Edinburgh, UK, July, 2010
- D. Hall, J. Graham, L. More and J. Rimland (2010), “Test and evaluation of soft/hard information fusion systems: an experimental environment, methodology and initial data sets” in Proceedings of the 13th International Conference on Information Fusion, Edinburgh, UK, July, 2010

**Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):**

9

#### **(d) Manuscripts**

- M. D. McNeese, N. J. Cooke and M. Champion, “Situating cyber situation awareness”, accepted for publication in the Proceedings of the Naturalistic Decision Making Conference, June, 2011, Orlando, FL
- J. Tang, M. Cebrian, N. Giacobe, Hyun-Woo Kim, T. Kim and D. Wickert, "Reflecting on the DARPA red balloon challenge", accepted for publication in the Communications of the ACM
- J. Rimland and D. Hall, "A multi-agent infrastructure for hard and soft information fusion," accepted for the proceedings of the SPIE Defense, Security and Sensing Symposium, 25-29 April, 2011, Orlando, FL

**Number of Manuscripts:** 3.00

#### **Patents Submitted**

#### **Patents Awarded**

#### **Awards**

- In 2009, David Hall was nominated by the Pennsylvania State University President, Dr. Graham Spanier, for a National Security Science and Engineering Faculty Fellowship
- An undergraduate student team from the Penn State University College of Information Sciences and Technology came in 10th (out of 3800 registered teams) in the DARPA red balloon challenge contest

#### **Graduate Students**

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
Alice Shapiro (phase II of project)	0.50
<b>FTE Equivalent:</b>	<b>0.50</b>
<b>Total Number:</b>	<b>1</b>

**Names of Post Doctorates**

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
<b>FTE Equivalent:</b>	
<b>Total Number:</b>	

**Names of Faculty Supported**

<u>NAME</u>	<u>PERCENT SUPPORTED</u>	National Academy Member
David Hall	0.05	No
Michael McNeese	0.06	No
<b>FTE Equivalent:</b>	<b>0.11</b>	
<b>Total Number:</b>	<b>2</b>	

**Names of Under Graduate students supported**

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
Jeffrey Vernon (phase II of the project)	0.20
David Reber (phase II of the project)	0.20
Leretta more (phase II of the project)	0.20
<b>FTE Equivalent:</b>	<b>0.60</b>
<b>Total Number:</b>	<b>3</b>

**Student Metrics**

This section only applies to graduating undergraduates supported by this agreement in this reporting period

- The number of undergraduates funded by this agreement who graduated during this period: ..... 3.00
- The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:..... 3.00
- The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:..... 1.00
- Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):..... 3.00
- Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:..... 0.00
- The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense ..... 1.00
- The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:..... 2.00

**Names of Personnel receiving masters degrees**

<u>NAME</u>
Alice Shapiro
<b>Total Number:</b>
<b>1</b>

---

**Names of personnel receiving PHDs**

NAME

**Total Number:**

---

**Names of other research staff**

NAME

PERCENT SUPPORTED

**FTE Equivalent:**

**Total Number:**

---

**Sub Contractors (DD882)**

1 a. Multisource

1 b. 62 Meadowview Lane

Williamsville NY 14221

**Sub Contractor Numbers (c):** 3385-MI-USA-0168

**Patent Clause Number (d-1):**

**Patent Date (d-2):**

**Work Description (e):** Provide research support for investigating hard and soft information fusion including characterizatic

**Sub Contract Award Date (f-1):** 4/14/2007 12:00:00AM

**Sub Contract Est Completion Date(f-2):** 10/14/2010 12:00:00AM

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**Sub Contract Est Completion Date(f-2):** 10/14/2010 12:00:00AM

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**Inventions (DD882)**

**Scientific Progress**

See attachment

**Technology Transfer**

Final Report for  
**Modeling and Mapping of Human Source Data**

David L. Hall  
College of Information Sciences and Technology  
The Pennsylvania State University  
and  
James Llinas  
Multisource

March 2011

### **Abstract and Summary**

The rapid proliferation of cell phones, new social network infrastructure such as Twitter and Facebook, and a new generation of “digital natives” who routinely collaborate in a distributed ad hoc manner, provide a major new source of input for situation assessment systems, namely humans acting as “soft” sensors. Human reports and observations augment traditional “hard” sensor systems such as radar, electro-optic and acoustic sensors. This project focused on understanding how to understand and model the role of human observers for the ultimate fusion of hard and soft data.

This project has provided the basis for establishing a new discipline of hard and soft information fusion. At the start of this project, only a limited amount of research had been conducted in this area. The concepts of “participatory sensing”, “human-centered information fusion” and “hard and soft information fusion” were just emerging in the research and application community. In part as a result of this project a research community is growing and regularly reporting their research results at conferences such as; (1) the annual International Conference on Information Fusion (ISIF) which has hosted special tracks on hard/soft fusion for the past 2 years, (2) the annual national symposium on sensor and data fusion (NSSDF), and (3) the annual Beaver Hollow Workshop hosted by the Center for Multisource Information Fusion. These concepts are also being utilized for studies such as an evaluation of operations at the Joint IED Defeat Organization (JIEDDO), evaluation of technologies for the National Geospatial Intelligence Agency (NGA), and other applications.

During this project a number of accomplishments are noted;

- (1) Development of the concept of human-centered information fusion (which encompasses the use of human observers and human in the loop fusion processing) (see [1], [2], and [3])
- (2) Conduct of an extensive literature review of participatory sensing [4],
- (3) Development of a theoretical framework for fusion of hard and soft data ([1], [5], [6], [17], [27], [28]),
- (4) Conduct of an extensive literature review of modeling techniques for representing human behavior [7],
- (5) Identification of algorithms for fusion of hard and soft data ([8], [9], [10]),
- (6) Development of an Extreme Events Laboratory to conduct human in the loop experiments ([11], [12]),
- (7) Development of methods for test and evaluation of hard and soft fusion systems ([13], [14], [30]),
- (8) Design and conduct of a human in the loop experiment focused on knowledge elicitation and direction of attention for a human observer [15], and
- (9) Initial demonstrations performed to illustrate the use of Twitter for data collection and reporting ([16], [26], [31]).

Technology transfer occurred via hosted workshops, special sessions in International Information Fusion conferences, meetings with government and industry personnel and technical reports for the Joint IED Defeat Organization (JIEDDO) and the National Geospatial Intelligence Agency.

## 1.0 Background

This report provides a summary of the activities, progress and approach for the *Modeling and Mapping of Human Source Data* project (contract no: W 911NF-07-1-0168) for the U. S. Department of the Army. The project was conducted by a research team led by the Pennsylvania State University College of Information Sciences and Technology (IST), with support from Dr. James Llinas of Multisource. This three phase project was aimed at developing concepts, algorithms and techniques to allow incorporation of human source data (e.g., human observations, comments and inferences) with traditional sensor data for improved situational awareness and decision-making. The premise is that the rapid evolution of web technology coupled with wide-band ubiquitous communications and personal devices such as cell phones, personal data assistants (PDAs) and laptop computers provides the opportunity to augment traditional sensor systems with humans acting as “soft” sensors in network centric operations. For military applications this provides a basis for “every soldier (acting as) a sensor”. For operations such as humanitarian relief and disaster recovery, in which military personnel must operate in conjunction with civilians and non-government organizations (NGOs), this concept becomes even more important to enable dynamic ad hoc communities of observers to assist in characterizing, analyzing and understanding evolving situations.

The objectives of this project were to: (1) develop a *methodology* by which a complete and robust approach to “source modeling” or “source characterization” of the human-based inputs can be carried out, (2) characterize a design approach to a data fusion process that accommodates the particular aspects of such human-based report inputs, (3) implement prototypes for data acquisition and knowledge extraction from human observers and techniques for fusing soft and hard sensor data, and (4) conduct limited human-in-the-loop experiments. One focus of the research was on the translation of human factors and uncertainties into probabilities or appropriate uncertainty representations that are judged necessary to deal with the idiosyncrasies of human observation under stress, etc. The overarching challenge is to develop an approach by which the errors through the observational and preprocessing chains can be characterized and then employed in the design of a fusion approach.

## 2.0 Summary of Results

During this project a number of accomplishments are noted;

- (1) Development of the concept of human-centered information fusion (which encompasses the use of human observers and human in the loop fusion processing) (see [1], [2], and [3])
- (2) Conduct of an extensive literature review of participatory sensing [4],
- (3) Development of a theoretical framework for fusion of hard and soft data ([1], [5], [6]),
- (4) Conduct of an extensive literature review of modeling techniques for representing human behavior [7],
- (5) Identification of algorithms for fusion of hard and soft data ([8], [9], [10], [17], [27], [28]),
- (6) Development of an Extreme Events Laboratory to conduct human in the loop experiments ([11], [12]),
- (7) Development of methods for test and evaluation of hard and soft fusion systems ([13], [14], [30]),
- (8) Design and conduct of a human in the loop experiment focused on knowledge elicitation and direction of attention for a human observer [15], and
- (9) Initial demonstrations to illustrate the use of Twitter for data collection and reporting ([16], [26], [31]).

Technology transfer occurred via hosted workshops, special sessions in International Information Fusion conferences, meetings with government and industry personnel and technical reports for the Joint IED Defeat Organization (JIEDDO) and the National Geospatial Intelligence Agency. A summary of these areas is presented below.

### 2.1 Human-Centered Information Fusion

The concept of hard and soft information fusion may be viewed as part of the larger concept of human-centered information fusion described by Hall and Jordan [1]. The conventional focus of the data fusion community has been the use physical sensor sources such as visual and infrared imagery, radar, satellite, and acoustic sensor data to observe physical entities like troops, vehicles, weapon systems, or other objects. Historically, this type of sensor activity has been very helpful for performing tracking, situation assessment, and threat assessment for military operations. Two recent factors have caused a major reassessment of this paradigm. First, military emphasis has

largely shifted from conventional warfare to the challenges of counterinsurgency and counterterrorism. Second, the emerging concept of human-centered information fusion [1] is causing the exploration of new ways in which humans and computer systems can work together to address challenges in a manner that optimally utilizes the capabilities of physical sensors, computer hardware and software, supporting cyber-infrastructure, and human beings ([2], [4]).

A particular focus of evolving fusion concepts involves counter insurgency (COIN) applications such as the detection and defeat of Improvised Explosive Devices (IEDs). While such tasks as defeating IEDs still rely on observation of physical entities (such as explosives, vehicles, and communication devices), it also requires an in-depth understanding of the social networks, intent, belief systems, connectivity, policies, and procedures that drive the process. Physical sensors can be useful in detecting some of the physical manifestations of these abstract concepts. However, they are largely unable to effectively classify their most important aspects without human intervention. In the past, the human role in the fusion process has largely been limited to analyzing the completed output of the fusion system. Unfortunately, when the human ability to observe and ascertain intent, beliefs, and cultural influences is critical to the sense-making process, any fusion system that withholds the role of the human until the end of the process is doomed to fail.

The concept of data fusion is evolving to integrate humans in a variety of roles [1]. First, there is the role of humans as observers (i.e., “soft sensors” or participatory sensing ([4], [5], [6])). Although humans are not able to compete with conventional hard sensors at many tasks, humans have an unparalleled ability to instinctively and intuitively make sense of complex situations and interactions that would leave the most advanced state-of-the-art computerized sense-making systems at a loss. With the assistance of ubiquitous smart phones and robust data networks, human observers have the capability to transmit annotated, geospatially and temporally stamped high-resolution imagery and video nearly instantly. Additionally, social networking tools such as Twitter facilitate crowd-sourced sensing that can be either tasked or opportunistic [7]. When tasked sensing is performed, the collection of desired data is requested of the human observer. Opportunistic sensing uses data that was gathered and annotated for other purposes and published to the open source community. The concept of human centric fusion is shown in Figure 1.

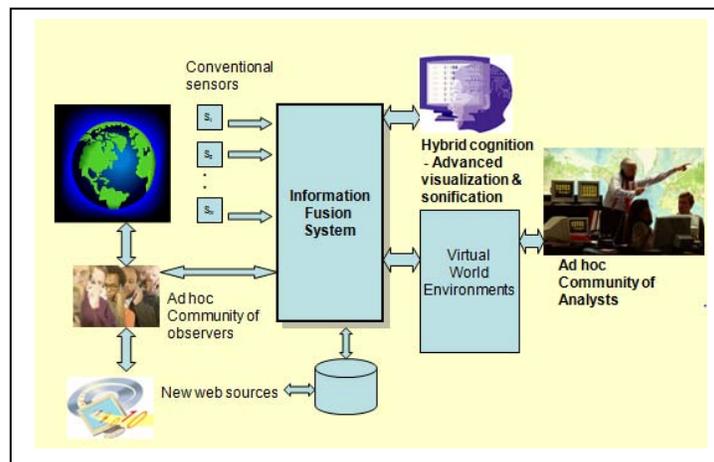


Figure 1: Concept of Human-Centric Information Fusion

Hall and Jordan [1] provide a detailed description of the concept of human centric information fusion and discuss issues related to all of the human roles identified above.

## 2.2 Hard and Soft Fusion Frameworks

Initial research in the area of hard and soft fusion was in part the result of this topic being addressed at the 2008 Critical Issues in Information Fusion Workshop<sup>1</sup>. At that workshop general processing strategies for combining and fusing observational data from hard and soft data inputs were discussed. These discussions ranged from low-level (L1) fusion processing operations to high-level (L2, L3) fusion processing. Some crucial issues in deciding on a process framework of course are how to both represent and quantify the confidence in the soft data but also how to incorporate the distinctive inputs that a human observer can provide, e.g. assessments of relationships, judgments of various type, and estimates of emotional states etc. It is important in exploring notions of processing frameworks not to consider human observational capabilities in the context of a “sensor surrogate” but rather to exploit these distinct human-only skills. The other major distinction in soft data/human observation is that the observational “content” is represented in natural language, imputing all of the complexities in processing and understanding natural language forms.

Upon consideration of these and many other factors that distinguish hard data from electronic/physics-based sensors and soft data from human observers and yet other data in linguistic form (e.g. much of contextual information, Web-service-based inputs, etc.), an approach was formulated as shown in Figure 2 (and used in a successful joint University at Buffalo-Penn State Army Research Office Multidisciplinary University Research Initiative (MURI) proposal on Hard-Soft Data Fusion).

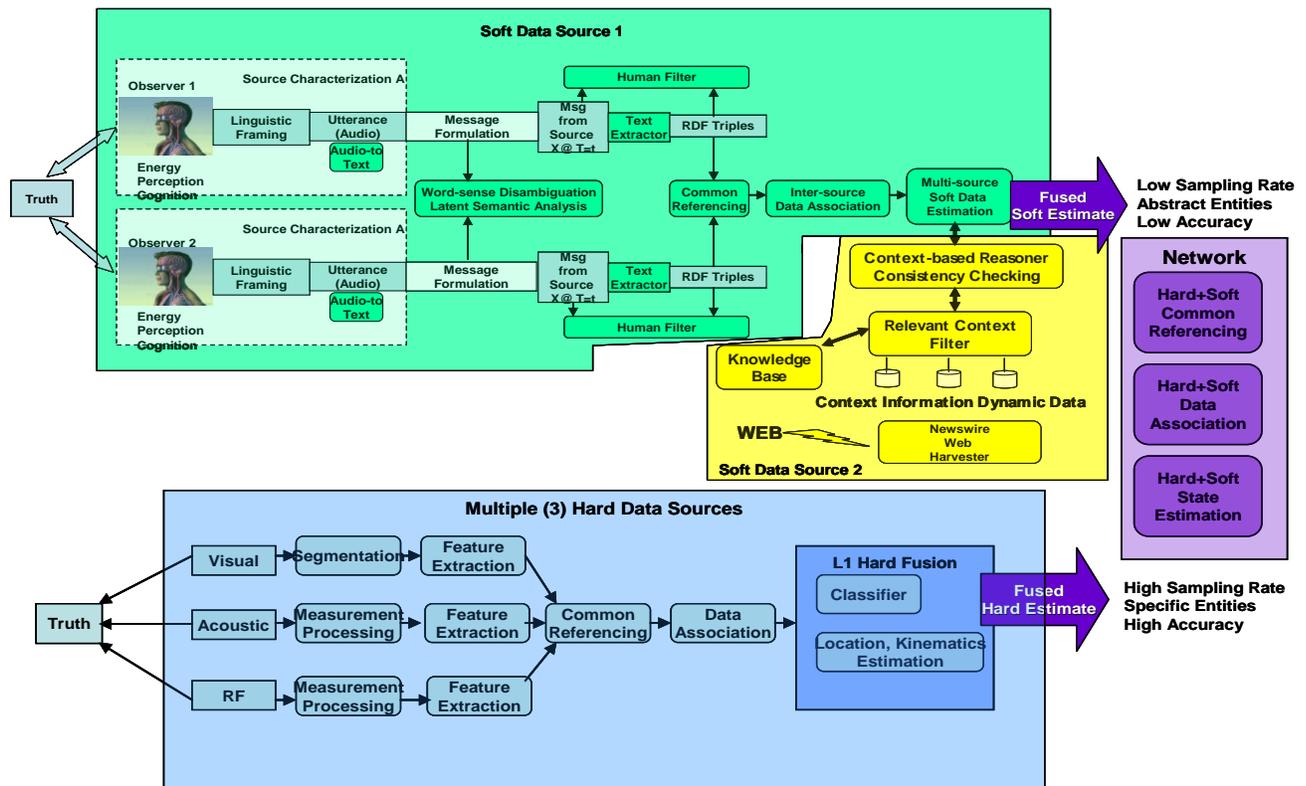


Figure 2: Hard and Soft Data Fusion Framework

The foundational arguments for this approach are as follows:

<sup>1</sup> 2008 Critical Issues in Information Fusion Workshop hosted by the Center for Multisource Information Fusion, University at Buffalo/CUBRC, October 2008

- The general idea is to conduct overall hard + soft fusion at the state/estimate level versus measurement level
  - Allows straightforward exploitation of existing, data-class-specific team algorithms and methods
  - Allows data-specific disparate algorithms to interoperate in a hybrid, multi-technique approach
    - Frame as services; analogs to existing legacy capabilities
    - Smooth porting to network environment
  - Avoids data association with disparate observational data
  - Fuses at the common-semantics level (~ Decision-level Fusion)
    - Lower computational load
    - Lower communication load (looking ahead to network-based studies)

The framework shown in figure 2 is conceptual. Additional levels of detail must be developed to provide a basis for algorithm selection, implementation and demonstration. An example of a further refinement of the framework is shown in figure 3. In that figure, three parallel processing flows are shown: (1) the top part of the figure shows the processing of human reports (with functions such as message formulation, word-sense disambiguation, automated filtering, soft source characterization, focus of attention/knowledge elicitation aids, etc.); (2) the central part of the figure illustrates the typical processes required for ingesting hard sensor data including common functions such as signal conditioning, feature extraction, common referencing, inter-source association, etc.; (3) Finally, the bottom part of the figure shows the type of processes required to address web-based information, using search engines in effect as “web-source observers”. A further refinement of this processing flow is introduced in section 2.4 of this report.

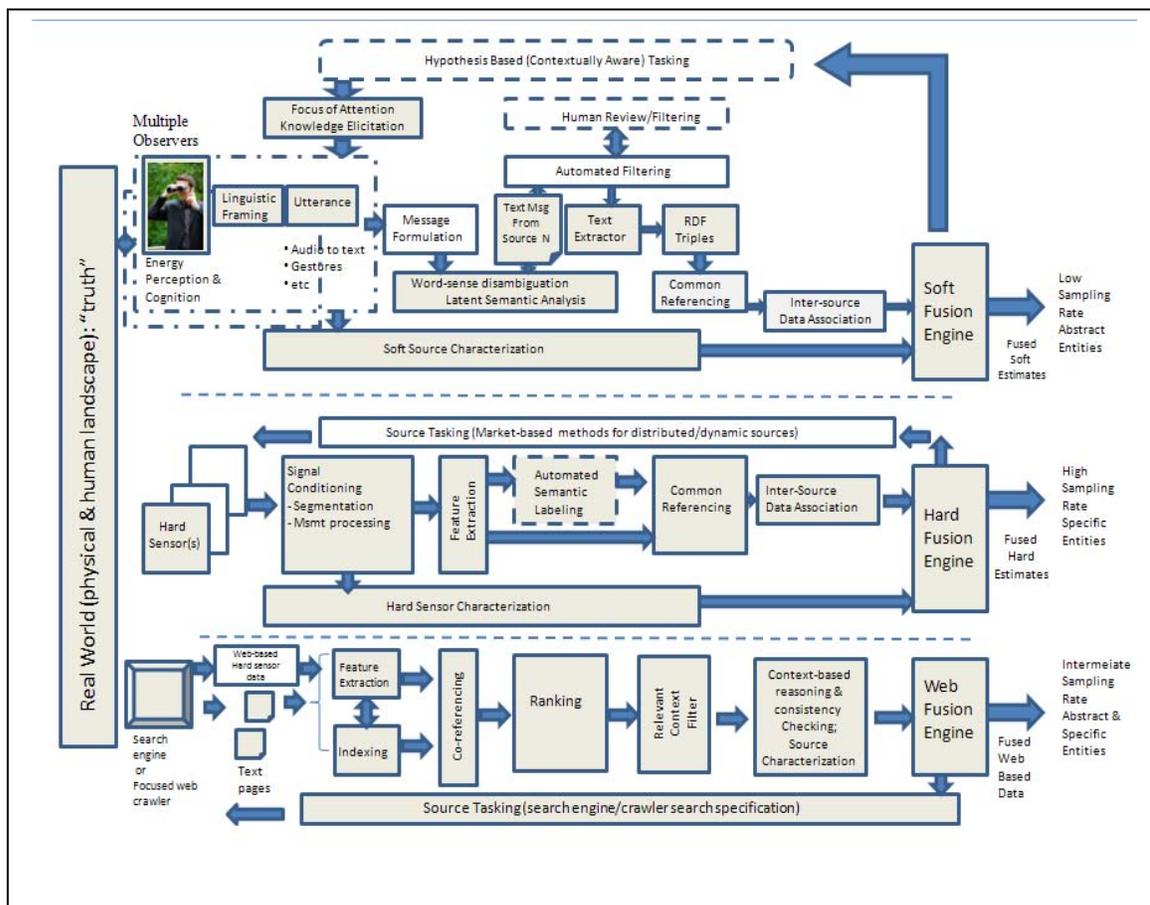


Figure 3: Example of Processing Flow for Hard/Soft Fusion

Another approach to developing a functional framework (and identifying relevant models and algorithms) is to follow the Joint Directors of Laboratories (JDL) data fusion process model ([32], [18]) and explore an analog between traditional fusion processing (at the JDL level 0 and level 1 sub-processes) for physical sensors observing physical targets, and creating similar sub-processes and functions for soft sensors observing the human landscape. Such an assessment is shown in figure 4. In that figure, the left hand side of the figure shows the level 0 and level 1 processes for translating traditional hard sensor data (e.g., signal and image data) about physical targets to state vectors that represent or characterize the targets (e.g., position, velocity, identity, attributes, etc.). The types of functions include data abstraction and representation, source characterization and meta-data generation, co-referencing, data association and correlation and finally state estimation. Types of algorithms and models are shown on the far left hand side of the figure. By contrast, the right hand side of the figure shows the parallel functions and algorithms for soft sensors observing the human landscape. In this case much of the data involves text-based information which still requires functions such as data abstraction, source characterization, co-referencing, data association and correlation and estimation. However, the specific types of algorithms shown on the far right hand side of the figure are different than those used for processing hard sensor data. This is to be expected. However, it should also be clear that, as in processing of hard sensor data for the physical landscape, there are no “magic algorithms” that address all aspects of modeling and prediction for the human landscape.

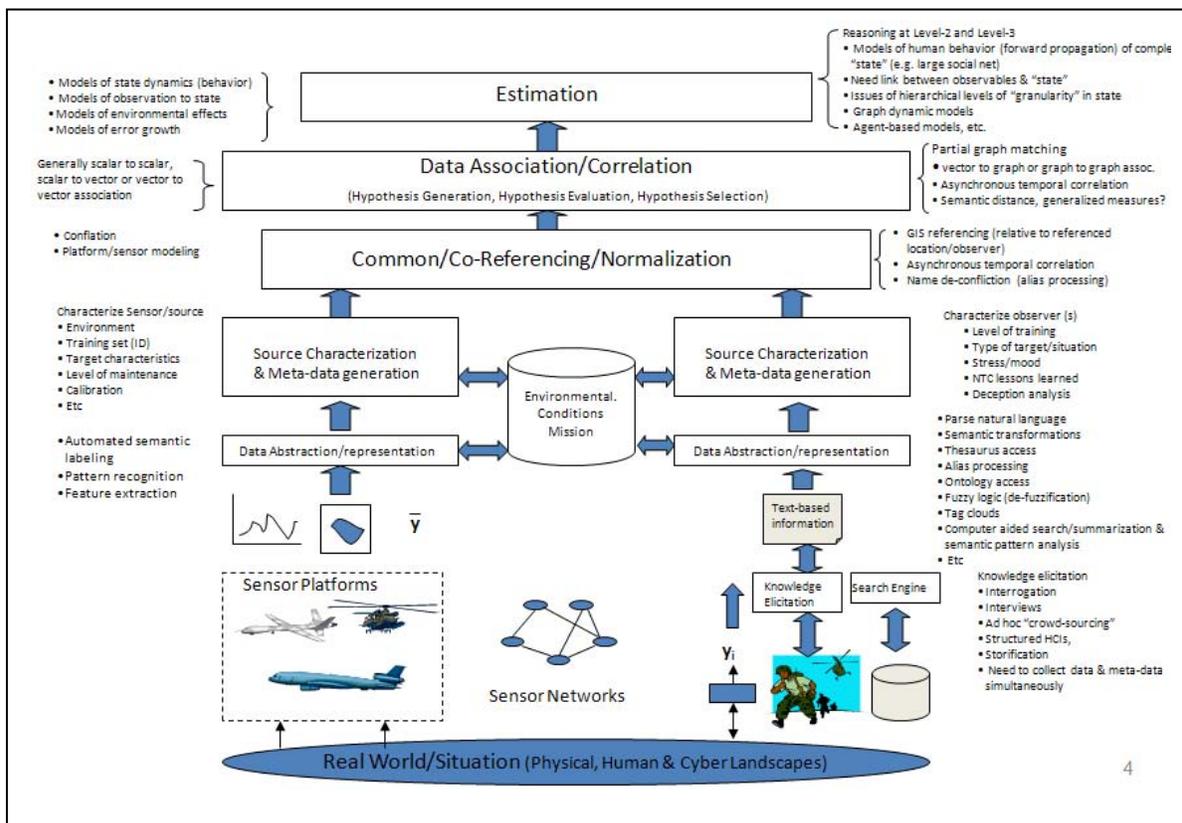


Figure 4: Information Fusion Hierarchy (JDL Levels 0 & 1) for Hard and Soft Data

### 2.3 Literature Review of Modeling Techniques for Representing Human Behavior

In conjunction with related tasking on a National Geospatial Intelligence Agency (NGA)-sponsored research task, efforts were combined to produce a literature survey report on “Understanding and modeling the New Domains”, meaning a survey of research on modeling adversarial human behaviors, typically in asymmetric, irregular-type warfare environments. It is these problem domains for which hard and soft data are most relevant.

The list of references analyzed in this work is shown below. A diagrammatic summary of the analysis is shown in Figures 5 and 6.

- Modeling of Social Dynamics
- Human Activity Modeling
- Human Performance Modeling
- Artificial Societies
- Virtual Humans
- Pattern Learning from Social Network Analysis
- Modeling Crowd Behavior, Dynamics
- Group Dynamics
- Computer-generated Forces/Modeling Terrorist Networks
- Modeling Terrorist Decision-patterns
- Terrorism and Game Theory

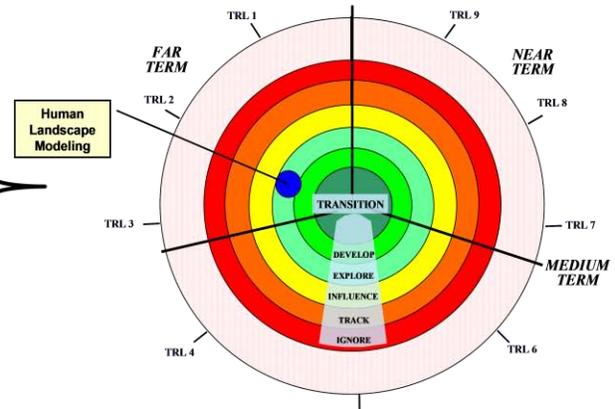


Figure 5: Surveyed Categories of Modeling and Overall Modeling Capability Assessment

The names of the many different modeling techniques found in the literature are shown on the left side of Figure 5. Each of these research areas in turn apply a variety of modeling paradigms in their work (see Figure 6 below) but in spite of these extensive efforts, the assessments conducted for example by the National Research Council (Ref Zacharias 2008 below) indicate that the state of the art is still at a very limited level of capability. This is why, in Figure 5 above, we judge the overall capability, in NASA TRL terms, as Level 2, requiring further exploration.

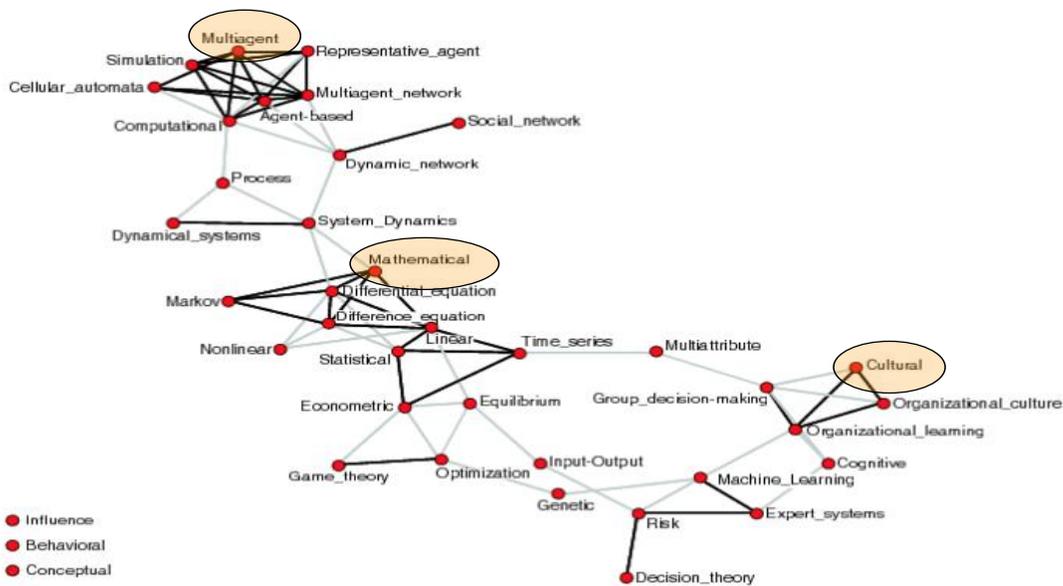


FIGURE II-1 Perceived similarities among types of models.

Figure 6: Variety of Mathematical Models Applied to Human Behavior Modeling (Ref Zacharias 2008 )

The following are key references for the Human Behavior Modeling Survey:

Wray, R.E., "Variability in Human Behavior Modeling for Military Simulations", Presented at: Behavior Representation in Modeling & Simulation Conference (BRIMS). May, 2003

Wise, B.P., et al, "Task Order (TO) 69 ATM Human Behavior Modeling Approach Study", Technical Research in Advanced Air Transportation Concepts & Technologies (AATT), SAIC Report Nov 2001 (for NASA)

WMD Terrorism Project, Center for Nonproliferation Studies, Monterey Institute of International Studies, CA., "Literature Review of Existing Terrorist Behavior Modeling", Final Report to the Defense Threat Reduction Agency, 14th August, 2002

Simulation Interoperability Standards Organization: Conference Proceedings: Computer-Generated Forces and Behavior Representation Conferences; there have been 11 of these through and including 2009; see the index at [www.sisostds.org/conference/index.cfm?conf=11cgf](http://www.sisostds.org/conference/index.cfm?conf=11cgf)

Zacharias, G.L., MacMillan, J., and Van Hemel, S.B., Editors, Committee on Organizational Modeling from Individuals to Societies, "Behavioral Modeling and Simulation: From Individuals to Societies", National Research Council, 2008

Pew, R.W. and Mavor, A.S., Editors, Panel on Modeling Human Behavior and Command Decision Making: Representations for Military Simulations, Committee on Human Factors, Commission on Behavioral and Social Sciences and Education, "Representing Human Behavior in Military Simulations", Interim Report, National Research Council NATIONAL ACADEMY PRESS, Washington, D.C., 1997

Pew, R.W. and Mavor, A.S., Editors, Panel on Modeling Human Behavior and Command Decision Making: Representations for Military Simulations, Committee on Human Factors, Commission on Behavioral and Social Sciences and Education, "Modeling Human and Organizational Behavior: Application to Military Simulations", NATIONAL ACADEMY PRESS, Washington, D.C. 1998

Silverman, B.G., et al, "Human Behavior Models for Agents in Simulators and Games", Presence: Teleoperators and Virtual Environments, Volume 15, Issue 2, April 2006

Weaver, R., et al, "Modeling and Simulating Terrorist Decision-making: A "Performance Moderator Function" Approach to Generating Virtual Opponents", Proceedings of the 10th Conference On Computer Generated Forces and Behavioral Representation, May 2001.

Goldstone, R.L. and Janssen, M.A., "Computational Models of Collective Behavior", TRENDS in Cognitive Sciences Vol.9 No.9 September 2005

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## 2.4 Theoretical Framework for Fusion of Hard and Soft Data

The definition and selection of algorithms for hard and soft fusion continues to evolve. A key aspect of the ongoing ARO MURI project on hard and soft fusion is focused on developing and refining such a framework. At this time, algorithms and techniques are being identified and prototyped ([6], [8], [13], [27], [28]). The initial strategy for fusion has been to separate the hard and soft information processing flows and to perform multi-source fusion for each information stream, with subsequent fusion of hard and soft processing results at the report level. That is, hard sensor data are fused to result in a series of reports or state vectors concerning observed activities, events, or entities. Hence, the hard fusion process transforms observed energy from physical sensors into a generalized state vector which may include semantic information (e.g., representing an assertion of entity identification based on pattern recognition techniques), scalar and vector data describing the characteristics, attributes and location/kinematics of observed entities. Similarly, soft data observations (which typically are asserted at the semantic level) are transformed into a general state vector characterizing an observed entity, activity or event. For soft data, semantic assertions of location (e.g., “the car is near the mosque”) may require translation to a scalar measure via de-fuzzification algorithms [33]. Subsequently these general state vectors or reports are fused using methods such as Bayesian Belief Nets, Generalized Logical Templates, or Graph Matching methods. The conceptual framework is illustrated in Figure 7.

We note that the standard requirements for source calibration/characterization, uncertainty representation, association and correlation and state estimation must be addressed for the hard fusion processing stream, the soft fusion processing stream and for the hard/soft fusion processing. It is conceivable that fusion can be performed at the feature or data level (viz. seeking to fuse the hard and soft data “closer” to the observations), although there are a number of potential modeling problems that would need to be addressed.

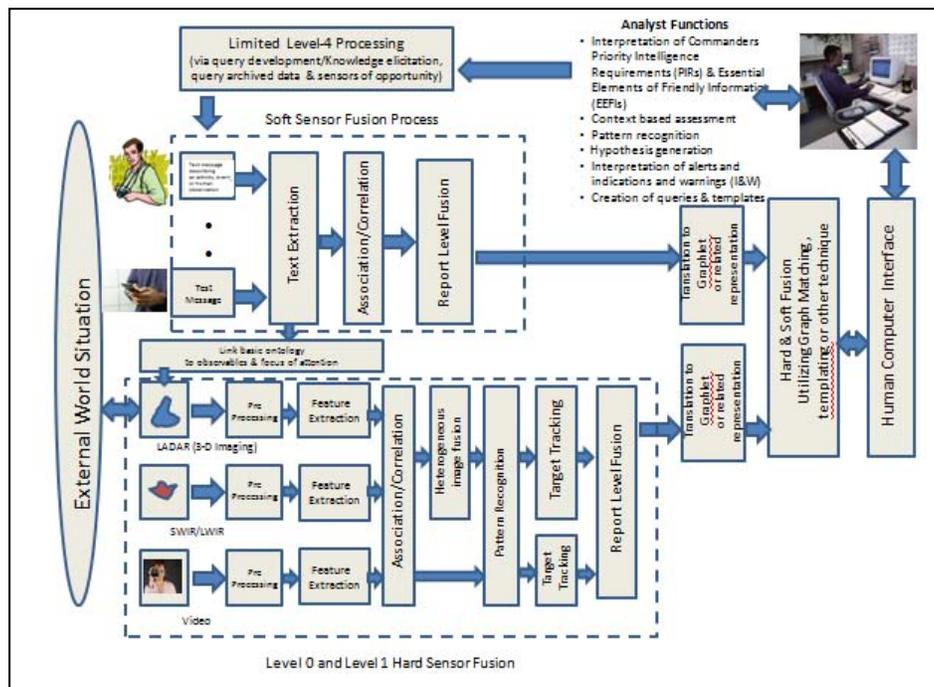


Figure 7: Evolving Architecture for Hard/Soft Data Fusion

## 2.5 Literature Review of Human Observational Capabilities

In this task, we leveraged NGA-sponsored tasking to produce a report for Penn State on Human Observational capabilities. The main result of this review shows that no general models seem to exist; many pointed studies regarding human observational capabilities have been done (to include Army-sponsored research) but all have been very directed, involving very specific observational conditions and observational goals. The works can be summarized in the following tables, which include the cited references.

Additional analysis and literature review is described by Hall and Jordan [1] in chapter 3. They use a conceptual framework as illustrated in Figure 8 as a basis for reviewing the literature on human observational capabilities and limitations.

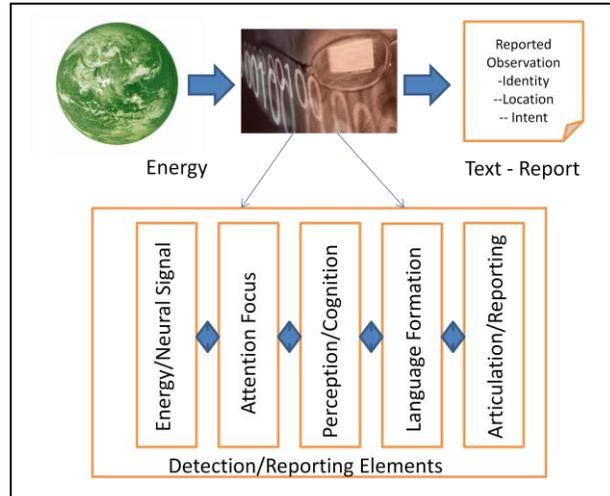


Figure 8: Conceptual Framework for Understanding Human Observations [1]

Human Observation Regarding	Sample Research Findings	Reference
Apparent size	Apparent size with distance depends on viewing mode and the angle subtended by the object; if the subtended angle is fixed, the apparent size is fixed.	Determinants of Apparent Visual Size with Distance Variant Author(s): Alfred H. Holway and Edwin G. Boring Source: The American Journal of Psychology, Vol. 54, No. 1 (Jan., 1941), pp. 21-37
Change blindness	At any instant, little visual information is retained, and, over time and across fixations the representation does not get more complete and complex. Instead, as attention shifts, so does the content of the mental representation (volatility of mental representations).	Volatile visual representations: Failing to detect changes in recently processed information M. W. Becker and H. Pashler, University of California, San Diego, La Jolla, California, Psychonomic Bulletin & Review, 2002, 9 (4), 744-750
Disinformation Detection	Tools seem to exist for helping to detect disinformation (in documents)—not perfectly but they reduce human workload. One example: the Linguistic Pattern Analyzer (LPA) compiles and scores information directly related to indicators of multiple computational social sciences models of various behaviors to include deception.	Models of Trust and Disinformation in the Open Press, from Model-Driven Linguistic Pattern Analysis, G. A. Mack, S. G. Eick, M. A. Clark, Aerospace Conference, 2007 IEEE March 2007

Distance Perception	People are good at estimating distance if the observational setting is static and level. When moving, the estimates can become better due to the continuing changes in perspective. But distance estimates are also affected by emotional and other factors. Range estimation in various settings show a power-law relationship between estimated and actual range with the exponent varying between about 0.8 and 1.25	Distance Perception D. R. Proffitt, Current Directions in Psychological Science, Volume 15, Number 3, 2006 Range estimates of distant visual stimuli, E. Galanter and P. Galanter, Perception & Psychophysics, 1973, Vol. 14, No. 2
Deception Detection	This and other papers substantiate that humans have poor ability to detect lies and deception; scores are typically in the 55-60% range.	Human ability to detect verbal and non-verbal deception, ivythesis.typepad.com/term_paper_topics/2008/02/the-human-abili.html
Training effects on distance perception	Effects of training do improve accuracy but only slightly	The Effect of Prior Training with a Scale of Distance on Absolute and Relative Judgments of Distance Over Ground, E. J. Gibson, R. Bergman, and J. Purdy, J Exp Psychol. 1955 Aug

Interobject Distances	Interobject distances are generally overestimated	Factors Affecting the Perception of Interobject Distances in Virtual Environments, D. Waller, Presence, Vol. 8, No.6, December 1999
Informant and rumor information	Various models exist, some quantitative ; in general there is a condensation to a few key factors that are reported reasonably consistently—details are lost however	Information Transmission Through Human Informants: Simulation I G. C. Lawson and C. T. Butts, Proceeding of NAACSO 2004, K. Carley (Ed.).
Velocity differences	Within an optimal velocity range humans can perform accurately in a speed discrimination task with a velocity difference as little as 7%. But for motion faster or slower than this the brain cannot discriminate the faster of two objects so accurately, even if the difference is quite large.	Illusions disrupting the accurate perception of velocity and position, L. Dartnell www.ucl.ac.uk/~ucbplrd/Lewis_Dartnell-MRes_project.pdf

## 2.6 Algorithms for Fusion of Hard and Soft Data

Many of the fusion algorithms applicable to traditional hard sensor fusion [18], [19] remain applicable to hard and soft information fusion. As illustrated in Figure 7, basic functions such as source characterization, association and correlation, hypothesis generation and selection, pattern recognition, etc. are requisite functions for hard and soft fusion. Initial work has been conducted by Sambhoos, Llinas and Little [8] and Sambhoos et al [13]. This work has focused on graph matching techniques. Other researchers at Penn State are developing methods for fusing hard sensor data involving the combination of information from 3-D active sensors (e.g., LIDAR) with 2-D image sensor data and with acoustic data [27]. Additional work is exploring the use of intelligent agent formulations [28].

Researchers at the University at Buffalo are focusing on soft sensor processing algorithms at the semantic and report level. A key component of the ARO MURI program on hard and soft fusion is to implement and explore such techniques. In this project, we established the basic framework and information architecture for selection and implementation of soft/hard fusion methods. A challenge in hard and soft fusion involves how to address issues of

the diversity of uncertainty representation (e.g., the use of probabilistic formulations for hard sensor processing and the use of fuzzy membership types of relationships for soft fusion processing).

## 2.7 Extreme Events Laboratory

The Extreme Events Lab (EEL) at the Pennsylvania State University was designed to facilitate research in hard and soft data fusion, visualization, and sonification [11]. The EEL features 4 large wall-mounted High Definition Liquid Crystal Display displays, 2D and true stereoscopic 3D projectors, a stereoscopic 3D Head-Mounted Display (HMD), haptic input devices, motion and acoustic sensors, various video and still cameras, several MacPro workstations, a conference area with a 54" HD LCD TV, and 8 professional-quality loudspeakers for experimentation with immersive 3D sonification.

The hardware can be easily switched between configurations optimized for maximum display capability (e.g. video-intensive multi-modal immersive visualizations) and maximum processing power (e.g. complex plume or geospatial modeling). The facility can be used to test Human Computer Interaction methods that optimize situational awareness through the use of non-conventional controller interfaces and immersive stereoscopic viewing of visualizations and geospatial situations. A view of the Extreme Events Lab data analysis centre is shown in Figure 9.

The stereoscopic HMD features semi-transmissive optics, which allows the computer-generated 3D images to be superimposed over the user's actual field of vision in order to function as a Heads-Up Display (HUD).



Figure 9: Interior of the Extreme Events Lab

## 2.8 Methods for Test and Evaluation of Hard/Soft Fusion

Waltz and Llinas initially described the challenges of test and evaluation of data fusion systems in their landmark text [22]. They describe a hierarchy of evaluation from measures of performance (MOP) (e.g., the receiver operating characteristics (ROC) curves for individual sensors) to measures of performance (MOP) (e.g., for target trackers), to measures of effectiveness (MOE) and ultimately measures of force effectiveness (MOFE). Evaluation of the hierarchy of fusion system performance from the individual physical sensor to support for decision making and action requires extensive data sets with known "ground truth". Throughout the fusion community enormous efforts have been made to collect data sets in laboratory environments, field test conditions, development of

simulators and data obtained during real operations [19]. Despite these efforts, no general purpose test bed exists to evaluate fusion algorithms for hard sensor processing, let alone for hard and soft fusion.

The need for calibrated data sets is exacerbated for human-centric information fusion and for soft and hard data fusion. For human-centric fusion we must consider several possible roles of humans (i.e., as observers, pattern recognizers/semantic level reasoners, and as collaborative decision makers). This involves all of the issues associated with hard sensor processing as well as involving how to evaluate the role and performance of humans in the various roles. Each role has its own challenges and issues. For example, the human as observer requires the development of an equivalent “ROC” curve for humans, while the role of pattern recognizer/semantic level reasoned involves issues of perception, attention, cognition, etc. Finally, collaborative decision making involves issues of team cognition and effective collaboration. Researchers such as Ensley [23] and McNeese et al ([24], [25]) have discussed such issues in detail and McNeese has developed a “living laboratory” approach illustrated in Figure 10.

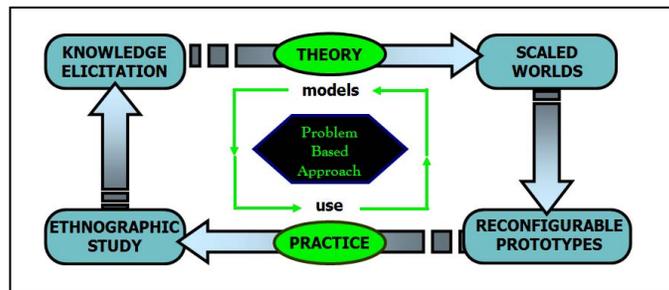


Figure 10: Living Laboratory Approach for Human in the Loop Experiments

An issue for hard and soft fusion test and evaluation is the need to obtain simultaneous and integrated hard data and soft data about a domain of interest. A general discussion of this problem for hard and soft fusion is provided by Hall et al [14]. Figure 11 shows the concept of a hierarchy of potential test data ranging from real operational data collected in field operations (in the upper left hand side of the figure), to data from training exercises [29], to synthetic hard and soft data created especially for test purposes [30], and finally the conduct of campus experiments to illustrate various issues such as tasking of human observers, dynamic knowledge elicitation, training of observers, etc. Beyond this project, we are developing such data sets and planning relevant campus experiments for COIN applications.

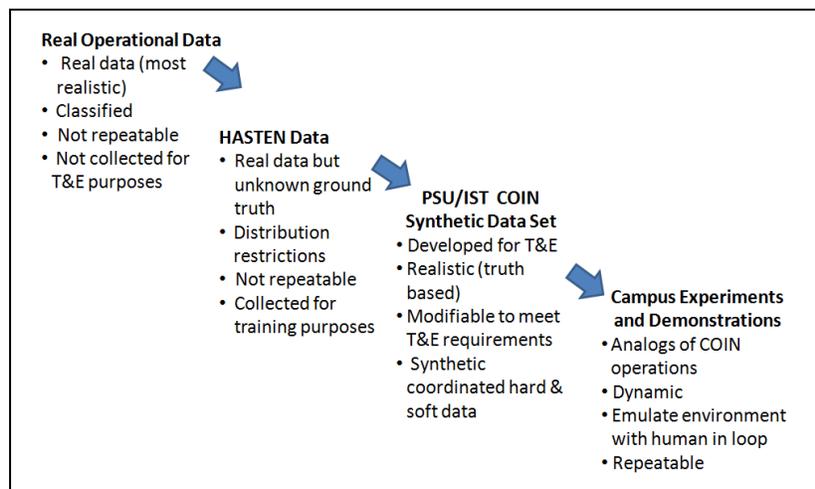


Figure 11: Hierarchy of Test Data for Soft/Hard Fusion

## 2.9 Human in the Loop Experiments

During this project some limited initial human in the loop experiments/demonstrations were performed.

Issues in the utilization of humans as soft sensors involves knowledge elicitation and focus of attention. Numerous examples are available of the failure of human observers to notice critical information, or conversely to report mistaken observations. An example of the former is the failure of students at Virginia Tech University to observe the precursors to the shooting spree in which a 23 year old student, Seung-Hui Cho killed 27 students, five teachers and himself. Observable precursors included Cho practicing locking a building with chains (to prevent police from entering and stopping his shootings), two days prior to the actual event. By contrast, Kaplan and Kaplan cite the following example (p 82) ; In 1978 the Rotterdam zoo reported the escape of one of its red pandas; hundreds of helpful people called in, having spotted it in places all over the Netherlands – when in fact it had been run over by a train just a few yards from the zoo fence.” Other examples of challenges in human observing and focus of attention include experiments involving the use of distractions. In an experiment conducted by D. Simmons and C. F. Chabris at the University of Illinois, for example, subjects were shown a video clip of two teams of people (in white and black uniforms) passing a basketball back and forth. The subjects were asked to count the number of passes by one team during a 60 second period. During the video, a person in a gorilla suit walks between the players, stops and waves and continues on. A surprisingly high number of subjects fail to notice the gorilla (<http://viscog.beckman.illinois.edu/flashmovie/15.php>). Thus, part of the effort associated with evaluating the use of humans as observers is to understand issues such as focus of attention, knowledge elicitation, observer bias and training and other effects.

During this project, a master’s degree student, Alice Shapiro, designed and conducted an experiment focused on how to guide an observer’s awareness for detecting an unusual person in a crowd [15]. Shapiro developed a spatial attention allocation guide to assist in directing an observer’s attention. The tool involved using a spatial guide (a circular area of focus) for observing video clips. Shapiro’s research; (1) designed a spatial visual attention guide, (2) created a test and evaluation video footage for a crowd near a building on the Penn State University Park campus, (3) conducted a statistically significant experiment involving requesting observers to find a specific person (carrying a bag) in a crowd during a several minute sequence, (4) evaluated the effectiveness of the attention aid (accuracy of observation *with* and *without* the aid), and (5) evaluated factors such as observer knowledge of the area, experience with video games and personal attributes. An example of the observer attention guide is shown in Figure 12.



Figure 12: Example of visual attention aid for observation

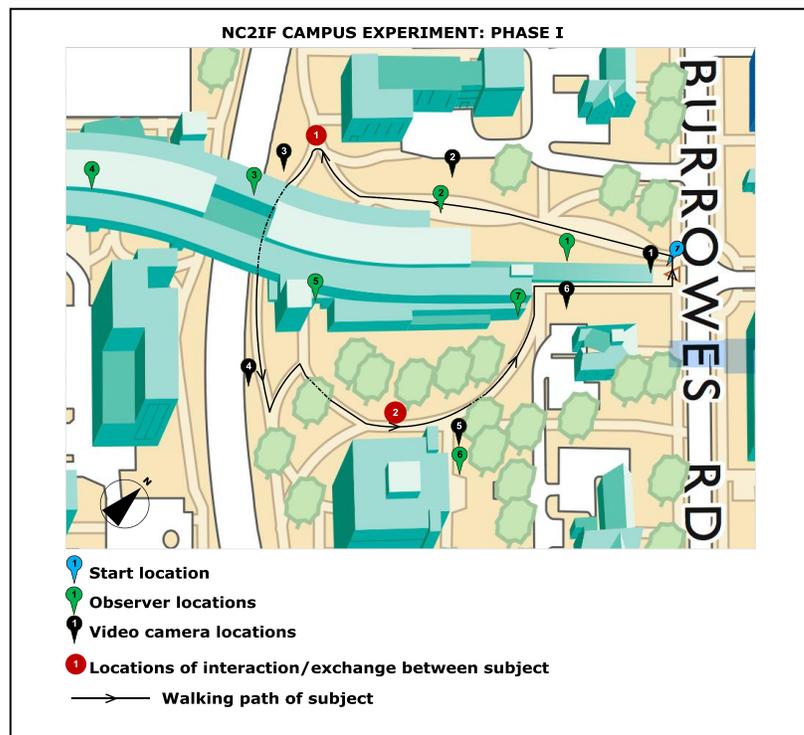


Figure 13: Penn State campus human in the loop experiment concept

A number of human in the loop experiments are planned at the Penn State University Park Campus later this year to illustrate issues such as tasking of observers, dynamic knowledge elicitation and other effects. Figure 13 illustrates the planned locations of physical sensors and use of student observers to simulate counter insurgency (COIN) activities and events. Data collected will include the “ground truth” of events, activities, entity locations, identities of scenario actors, timelines of unfolding events and data from physical sensors as well as human reports. Some initial activities have involved the development of special applications (APPs) for mobile phones and the use of group game playing motivation to stimulate competitive collection of information (e.g., about potential campus hazards). The concept of making a game-like environment to stimulate human interest is sometimes termed “gamification”. Initial experiments are described by McGill [26].

On a final note, it is possible to leverage other participatory sensing experiments and exercises to learn about issues and models for human observers. One example involved the DARPA Red Balloon contest (see <https://networkchallenge.darpa.mil/rules.aspx>). This contest sought teams to develop methods, using social network concepts, to locate and identify 10 red weather balloons placed around the United States during a weekend experiment. The prize for the first team to successfully verify the location of the 10 balloons was \$ 40,000. Over 3800 teams registered for this challenge problem, including a team of undergraduate students at the Penn State University College of Information Sciences and Technology. As might be imagined, there were a large number of false reports during the one-day exercise.

The Penn State team finished 10<sup>th</sup> out of 3800 teams. The Penn State team used two parallel strategies; (1) creation of a national social network of Penn State students and alumni to act as ad hoc observers, with web-based and mobile computing mechanisms for reporting observations, and (2) use of a strategy involving “watching the watchers” (viz., monitoring reports from other observers via Facebook, Twitter, etc), and seeking to verify or refute the dynamic reports faster than others could. This strategy of “watching the watchers” actually obtained more information than the use of social network based tasking and reporting. Such strategies might have implications for COIN applications. A description of the experiment and lessons learned is provided by [31].

### 3.0 Technology Transfer

A summary of technology transfer mechanisms and events is provided below.

- J. Llinas hosted the 2008 Critical Issues in Information Fusion Workshop (via the Center for Multisource Information Fusion, University at Buffalo/CUBRC) in October, 2008 at which 40 scientists from DoD and industry met to discuss concepts and issues in hard and soft information fusion
- J. Llinas and D. Hall assisted in organizing and hosting special sessions at the 11<sup>th</sup> and 12<sup>th</sup> International Conference on Information Fusion (in July, 2008 in Cologne, Germany and in July, 2009 in Seattle, Washington on the topics of hard and soft data fusion.
- D. Hall and J. Llinas co-hosted a 2-day data fusion technology workshop on December 6<sup>th</sup> and 7<sup>th</sup> held in State College, PA for government representatives from industry and the National Geospatial Intelligence Agency (NGA) to discuss technology issues in information fusion.
- D. Hall and J. Llinas co-hosted a 2-day information fusion working group on Future Roles of Fusion Technology to Support COIC Operations, for the Joint Improvised Explosive Device Defeat Organization (JIEDDO) in August 2010 and also contributed to a technical report entitled, *Future Roles of Fusion Technology to Support COIC Operations* for JIEDDO, Sept 17, 2010
- Special sessions on hard and soft data fusion are also planned at the International Conference on Information Fusion to be held in Chicago, Illinois in July, 2011.

### 4.0 Key Personnel

Key personnel on this project include Dr. David Hall and Dr. James Llinas. Brief bio-sketches are provided below.

*Dr. David Hall* is the principal investigator on this project. Dr. Hall is a Professor in the College of Information Sciences and Technology at the Pennsylvania State University. He also directs the Penn State Center for Network Centric Cognition and Information Fusion (NC2IF). He has more than 25 years of experience in research, research management, and systems development in both industrial and academic environments. Dr. Hall has performed research in a wide variety of areas including celestial mechanics, digital signal processing, software engineering, automated reasoning, and multisensor data fusion. During the past 15 years, his research has focused on multisensor data fusion. He is the author of over 175 technical papers, reports, book chapters, and books. Dr. Hall is a member of the Joint Directors of Laboratories (JDL) Data Fusion Working Group. He serves on the Advisory Board of the Data Fusion Center based at the State University of New York at Buffalo. In addition, he serves on the National Aeronautics and Space Administration (NASA) Aeronautics and Space Transportation Technology Advisory Committee. In 2001, Dr. Hall was awarded the Joe Mignona award to honor his contributions as a national leader in the Data Fusion Community. The Data Fusion Group instituted the award in 1994 to honor the memory of Joseph Mignona. Dr. Hall was named as an IEEE Fellow in 2003 for his research in data fusion.

*Dr. James Llinas* is the co-Principal Investigator on this project. Dr. Llinas brings over 30 years of experience in multi-source information processing and data fusion technology to his research, teaching, and business development activities. He is an internationally-recognized expert in sensor, data, and information fusion, co-authored the first integrated book on Multisensor Data Fusion, and has lectured internationally for about 20 years on this topic. He is co-editor of the recently-published *Handbook of Multisensor Data Fusion* (CRC Press). Dr. Llinas is a Technical Advisor to the Defense Department's Joint Directors of Laboratories Data Fusion Group, the only US DoD technology oversight group for Data Fusion, a position he has held for over 15 years. Dr. Llinas was awarded the definitive US defense community award from the Data Fusion community, the Joe Mignona Award, in 1999. In addition, reflecting his international interests and stature, Dr. Llinas was voted as the first President of the International Society for Information Fusion in 1998. Dr. Llinas created the concept for and is Executive Director for the "Center for Multisource Information Fusion" located at the State University of New York at Buffalo. This first-of-its-kind, University-based research has received sponsorship from a broad base of defense and industrial R&D organizations, and is conducting basic research in Distributed Situational Estimation, Distributed Learning, and in Correlation Science, among other programs.

## 5.0 Leveraged Projects

This project leveraged extensive previous and on-going research. A summary is provided in Table 3 below.

<b>Table 3: Examples of On-Going Research Projects related to Data Fusion</b>				
Project	Sponsor	Funding	Principal Investigator	Leveraged Technology
Multidisciplinary University Research Initiative (MURI) on hard and soft fusion	ARO	On-going	J. Llinas	Detailed investigation of fusion algorithms and development of appropriate test and evaluation data sets
Defense University Research Instrumentation Program (DURIP)	DoD	\$ 200 K	D. Hall	Infrastructure for Extreme Events Laboratory
Intelligent distributed group and team training systems	AFOSR	\$ 247 K	J. Yen	Development of new methods to support team decision-making using intelligent agents and collaboration
Distributed cyber-collaboration and information fusion	ONR	\$ 213 K	D. Hall	Modeling of distributed, dynamic sensor networks using advanced approximations for probabilistic graph methods
Integrated explanation and visualization of intelligent synthetic forces	Soar Technologies	\$ 109 K	F. Ritter	Cognitive models related to explanation and visualization of synthetic forces
Determine USMC anti-terrorism/force protection for resources and facilities planning and design	USMC	\$ 433 K	S. Haynes	Development of a decision model to support assessment and tradeoffs of potential threats to military resources and facilities & planning of protection mechanisms
Geo-Collaborative crisis management	NSF	\$ 400 K	M. McNeese G. Cai	New methods and techniques for improved crisis management via cognitive aids and collaboration tools for teams of decision-makers
Integrated framework for understanding integrated intelligence	SRI/NGA	\$ 213 K	D. Hall T. Shaw M. McNeese J. Wang	Development of cognitive aids for automatically processing image and non-image intelligence data to support a “whole-brain” analysis approach
NTR: Collaborative Research: testing and benchmarking methodologies for future network security mechanisms	NSF	\$ 720 K	P. Liu D. Miller G. Kesidis	Development of new testing methodologies for network defense mechanisms
Analyst Automation Task	Contractor	\$ 348 K	J. Yen M. McNeese L. Giles	Development of computer tools to support intelligence analysts including; multi-agent framework for analyst collaboration; adaptive search engines; problem-centered decomposition and analysis aids

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