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## Raytheon's University Relations Program

Collaborative Research to Advance State-of-the-Art Technologies for Our Customers

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# **Transforming Data Into Knowledge:** The Use of Advanced Visualization and Cognitive Aids to Support Improved Level 2 and Level 3 Data Fusion

In today's modern battlefield environment, commanders and warfighters have become inundated with vast amounts of unprocessed data from large arrays of sensors and remote data sources. This ever-increasing load of tactical and operational data creates a stressful operator environment that can significantly reduce effective decision making.

A comprehensive computational process is required for the management, processing, distribution and visualization of this information. This process is called data fusion — the integration of information from multiple sources, the management of information and knowledge derived from the aggregated data, and the visualization and presentation of the information to the end user.

Figure 1 depicts the data fusion process model and taxonomy for data fusion levels 0 through 4 which have been formally recognized by the Joint Director of Laboratories (JDL) Data Fusion Working Group. Only recently has level 5 fusion, *Cognitive Representation,* been considered as part of the formal process model. The six levels of fusion span the "sensor-to-screen" processing spectrum from the conversion of received energy from an active sensor (level 0: target detection process) to the visualization of all the processed information as displayed to the end user (level 5: visual representation).

Recently, Raytheon Joint Sensor Networks (JSN) in St. Petersburg, Fla., has teamed with leading data fusion academic research experts, including Penn State University's College of Information Sciences and Technology (IST), to apply PSU's level 2 (*Situation Assessment*) and level 3 (*Impact Assessment*) data fusion expertise for a global maritime domain awareness application.

The level 2 fusion process, *Situation Assessment*, is the process by which aggregations of detected objects are placed in context in their environment and relationships among objects and sets of objects are defined. Level 3 fusion, *Impact Assessment*, is the process where future operational impacts and situations are predicted based on the current estimated situation state. Level 3 fusion incorporates automated processes by which courses of action are recommended to the warfighter. These data fusion processes are key functions that bring actionable knowledge to the warfighter, as they estimate the contextual meaning of objects in their surrounding environment and the predicted intentions associated with these objects.

Led by Professor John Yen, the principle investigator for PSU's cognitive decision aid research with JSN, PSU's IST research efforts have included development of state-of-the-art level 2 and 3 data fusion processes — specifically, the development of collaborative agents to assist decision makers faced with intense operational tempos and large volumes of unprocessed data. PSU has applied their Recognition Primed Decision (RPD)–enabled Collaborative Agents Stimulating Teamwork (R-CAST) model to provide situational assessment and impact assessment aids to the warfighter.

The R-CAST technology research extends CAST agent architecture, which was initiated in 1998. The fundamental goal of PSU's R-CAST technology is the development of an information-sharing cognitive agent system that facilitates distributed understanding across multiple communities of interest, increasing situational awareness across multiple users, and reducing human-in-the-loop data processing load.

As shown in Figure 2, R-CAST is a complete level 2 and level 3 decision-making process and consists of several components. The main components of R-CAST consist of an active knowledge base, the RPD model, and several management functions that facilitate information processing, distribution and resource management tasking.

One of the main components of R-CAST is the active knowledge base. It is a forward-chaining rule-based system that facilitates the links between observations and information that can be deduced from them. Its primary feature is the representation of information dependency and relations — key for assessing situations as aggregates of observations of objects or events. This knowledge base is active in the sense that it keys on missing information and attempts to acquire needed information to fulfill the perceived knowledge gaps that would otherwise be facilitated by humans in the loop.

At the heart of R-CAST is the RPD model. It is a decision-making model that supports human-to-agent and agent-to-agent collaboration, enabling the end user to more effectively make tactical decisions collaboratively based on R-CAST's current assessment of the situation. This model uses a knowledge structure that represents knowledge about decision-making experiences based on RPD (refer to Figure 2, "experiences" process function). There are several functional areas associated with the RPD process including situational analysis, recognition, evaluation and execution (course of action implementation), and expectancy monitoring.

| Data Fusion Level | Data Association Process | State Estimation Process | Product |
|---|---|---|---|
| Level 0: Sub-object Data Association/Estimation | Assignment (observation-to-feature) | Detection | Estimated signal state |
| Level 1: Object Refinement | Assignment (observation-to-entity) | Kinematic/ attributive state | Estimated entity state (ID and track) |
| Level 2: Situation Assessment | Pattern recognition/ relationship (entity-to-entity) | Relation/identified pattern | Estimated situation state |
| Level 3: Impact Assessment | Evaluation (situation to actor's goals) | Prediction/estimate intent/COA analysis | Estimated situation utility |
| Level 4: Process Refinement | Resource management/ library refinement (task-to- resource) | Optimization/control/ a-priori state estimation (patterns, etc.) | Action/library update |
| Level 5: Cognitive Representation | Information discovery - multi-expert collaboration - (entity/situation/action-to-information representation) | | Shared understanding/ collaborative decision making |

*Figure 1. Six levels of data fusion*

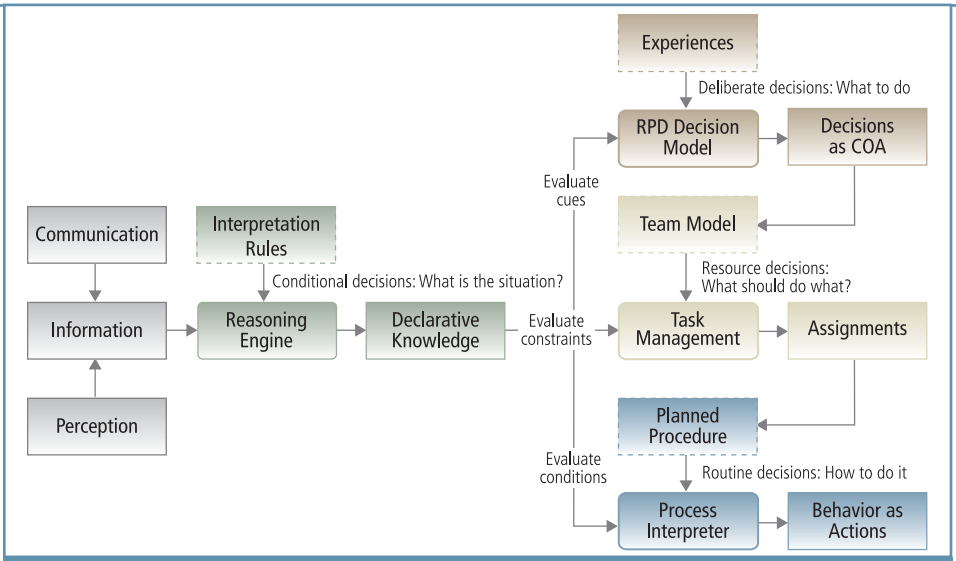


*Figure 2. R-CAST decision-making process model*

Without automating this processing capability, the warfighter would be challenged to consistently recognize (and remember patterns for) complex situations and could possibly by overloaded and misinterpret tactical situations.

There are several management functions associated with R-CAST that facilitate the end-to-end collaborative decision-making process. The process manager recommends courses of action and presents them to the end user based on R-CAST's situational assessment. The information manager manages supply and demand of information to and from multiple agents and has the ability to anticipate information needs. The communications manager facilitates information exchange and has the ability to handle heterogeneous message exchanges. The task manager facilitates and oversees the completion of assigned tasks (a resource management function). Finally, the configuration manager is responsible for making the R-CAST tool flexible enough to be used across many different applications and it enables the R-CAST tool to be reconfigurable both on and offline.

The R-CAST level 2 and 3 data fusion functionality provides state-of-the art situational assessment and course of action recommendation tools to the decision maker. To fully make use of these tools' products, the fused information must be presented to the end user in order for them to quickly comprehend and take action — a significant challenge for level 5 fusion (*Cognitive Representation*). Traditionally, two-dimensional displays with geographic reference overlays have been used to present situational data. Today, representation of other kinds of data such as situational context of threats, textual and time-sensitive data necessitate alternative visual presentations of this fused contextual data. PSU, under the leadership of Professor David Hall, is developing several state-of-the-art visualization technologies including three-dimensional immersive displays, as shown in Figure 3. These visualization technologies further enhance the end user's situational understanding and quickly facilitate the transformation of information to knowledge.

The complexity of the warfighter's information domain will undoubtedly increase as net-enabled technologies grow and mature. The combination of these state-of-the-art data fusion technologies ultimately enables the warfighter to collaborate more efficiently and effectively across many communities of interest, meaning higher mission success for the warfighter. The development and implementation of state-of-the-art data fusion technologies, such as those being developed collaboratively between Raytheon and academic research centers of excellence like PSU, is key for the transformation of information to actionable knowledge. ●

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*Dr. John Yen and Dr. David Hall are leading information fusion research scientists from PSU IST supporting this IRAD effort. They are contributing both their expertise and their data fusion products (R-CAST) for this IRAD. Dr. Yen is an IEEE fellow and his research focus is agent-based/team collaboration information fusion research and applications, including the agent-based system R-CAST currently being used in this IRAD. Dr. Hall is an internationally recognized research expert in multisensor data fusion. He is currently supporting this IRAD in several areas, including data fusion architecture and visualization.*

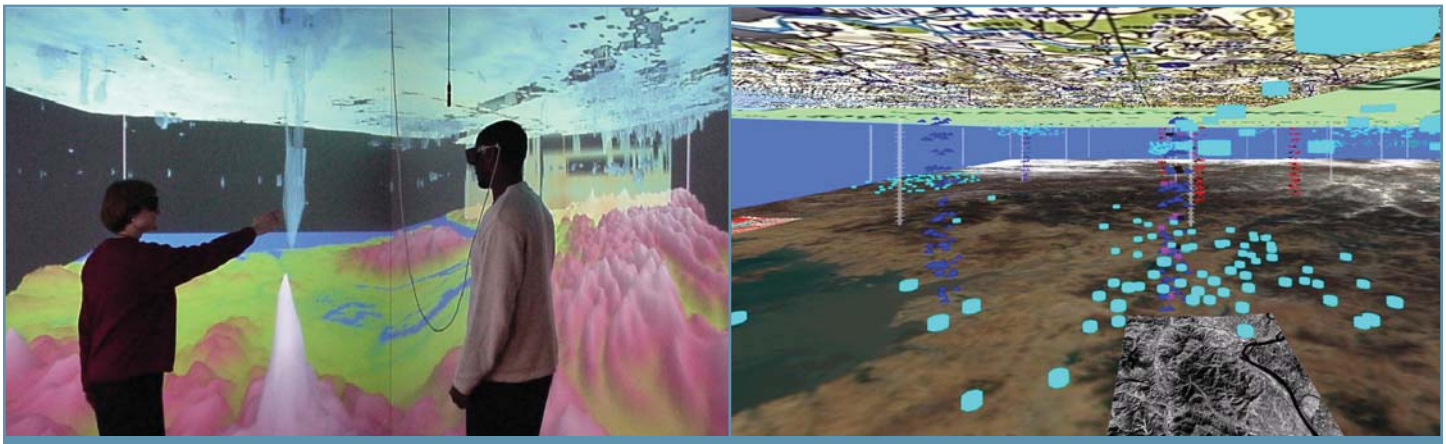

*Figure 3. Three-dimensional immersive and hierarchical displays*

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