Bayesian-Game Modeling of C2 Decision Making in Submarine Battle-Space Situation Awareness

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First Some Context

- **Who we are.**
- **What Intelligent S/W Agents are.**
- **Bayesian-Game Modeling.**

About 21CSI

- 21st Century Systems, Inc.® (21CSI®) is a pioneer in agent-based decision support systems for time- and mission-critical military applications
  - Woman-owned, founded in 1996
- Decision support tools across the spectrum of missions
  - Individual Soldier Situational Awareness
  - Distributed Warship Command and Control
  - Decision Under Uncertainty
  - Homeland Security/Force Protection Situational Awareness
  - Secure R&D Collaboration…*and others*
- Our applications run on all types of hardware…
  - Wireless PDAs
  - Laptops, desktops, to massive parallel computers

  …*and are Operating System independent*
- Military Small Business Contractor Success Story
  - 100% Commercialization Achievement Index
- Offices in : NE, MO, HI, WA, RI
  - Top Secret Facility Clearance

Software Agents Are:

Software that:

- **Maps *precepts* into *actions*, or**

Software that:

- **Is *autonomous*, *reactive*, *proactive*, *rational*, and *socially adept*, or**

Software that:

- **Is a proxy contractually bound to Humans**
- **Is capable of *observing* and *acting* toward a set of goals**
  - **Belief, Desire, Intention (BDI)**
  - **Knowledge representation (KR)**
- **Executes ‘autonomously’ and (inter-)acts ‘rationally’**
- **Transforms data into knowledge within the semantics of a domain**

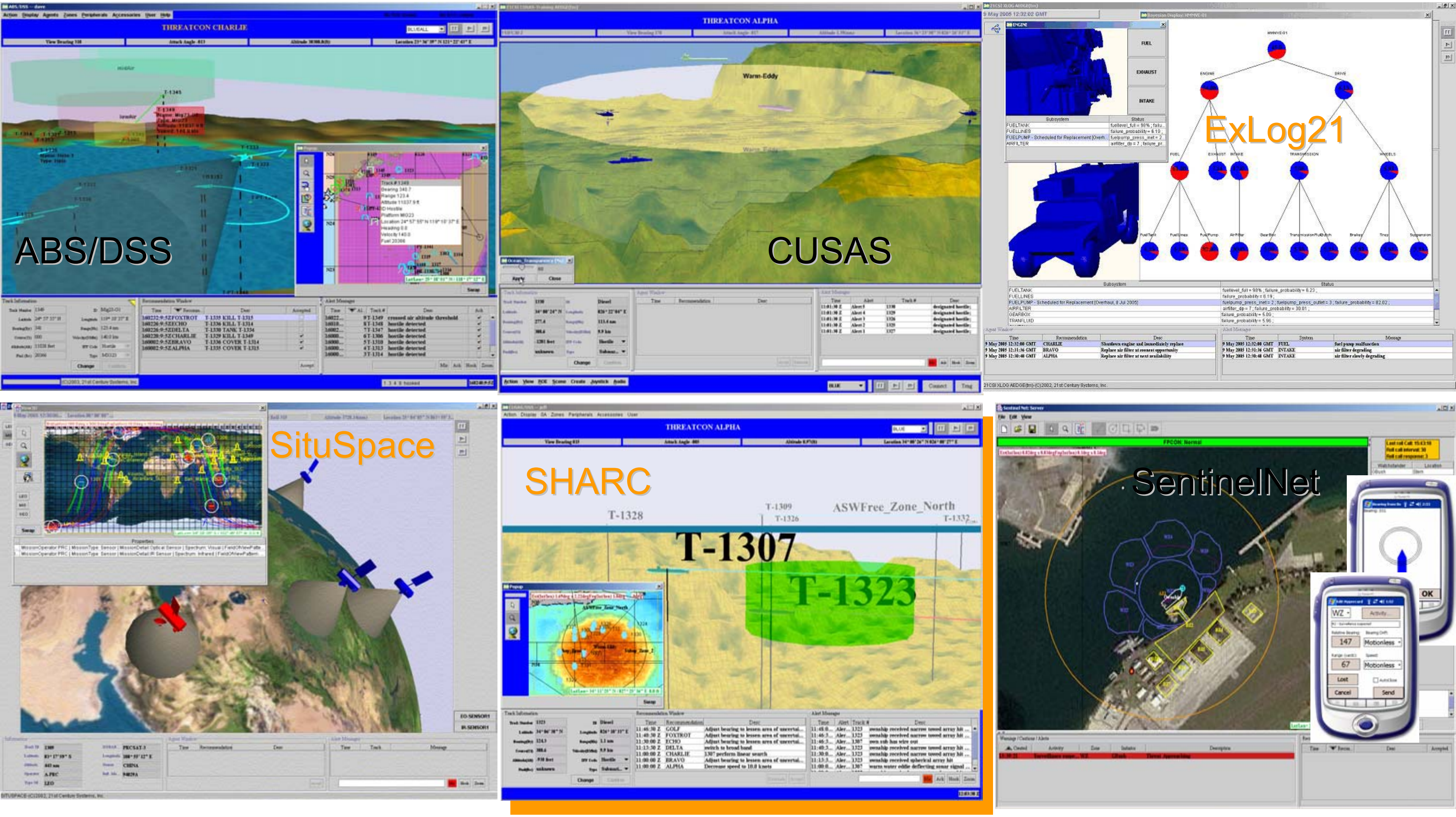
Agents Can:

- Monitor and Alert
- Perform repetitive, time-consuming tasks
- Consider and evaluate alternatives
- Coach and Advise
- Mimic and Learn
- Act as the ‘glue’ for legacy systems
- Provide a trusted environment
  - Information integrity
  - Contract enforceability
  - Flexibility, Scalability

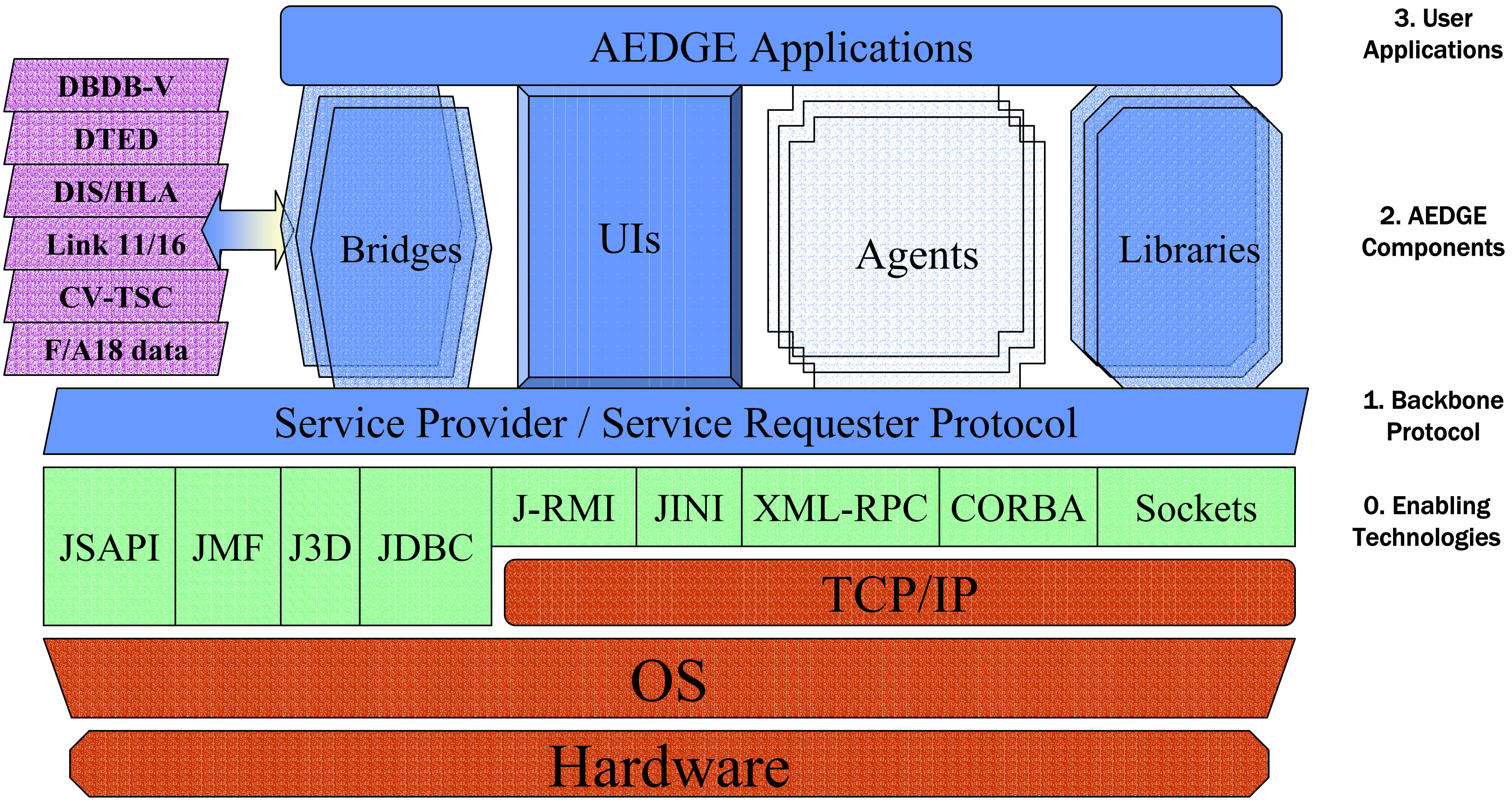
Agents in AEDGE

- AEDGE (Agent Enhanced Decision Guide Environment)
- AEDGE is an architecture that lets Agents ‘plug’ into a complete computational framework
- AEDGE has several diverse agent applications
- AEDGE 1.0 is current version, AEDGE 2.0 is in development

Some AEDGE1.0 Applications



AEDGE1.0 Tiers



Outline

Problem statement

I. Introduction
II. System Overview
III. Technique Description
IV. System Implementation
V. Conclusion

Problem Statement

1. **Applying a Bayesian-Game-theoretic approach to multi-source data fusion**
   - **Achieve situational awareness**
   - **Support C2 decision making in time and mission stressed settings with significant amount of information uncertainty and inaccuracy**.

2. **Consolidated Undersea Situation Awareness System (CUSAS)** – To provide:
   - Information management and integration
   - Bayesian evaluation of sensory and environmental inputs
   - Mapping from combat space data sets to situation states
   - Quantitative ranks of situation states and hypotheses
   - C2 State determination and conflict resolution

3. Asynchronous and intelligent agents

- to support:

- prioritization, management, coordination of data fusion process,
- modeling adversarial and friendly behavior
- providing advices to decision makers (or software agents playing human roles).

The agents with data fusion ability are to learn and cooperate to process overwhelming combat information more accurately, systematically, and in a well-prioritized manner.

I. INTRODUCTION

I. INTRODUCTION (1)

Situation Awareness

An SSN may at times find it very difficult to maintain informational, electronic and general combat superiority over enemy boats and other hostile assets, due to

- **Uncertain** information of enemy and environment ,
- **Partially inaccurate** information of enemy and environment
- **Partially unavailable** information of enemy and environment
- **Complexity** of counter threats.

to assist the SSN team (CO, XO, OOD, sonar-men and others) in their exceptionally hard jobs of acquiring accurate situation awareness in complex combat settings

I. INTRODUCTION (2)

Situation Awareness (Cont.)

A well crafted computer system integrating knowledge acquisition tools and proper decision support models can assist military planners in their tactical decision-making in many different ways,

Particularly with respect to quickly identifying responses and counter-responses to enemy action or inaction

- **To determine the best allocation of tactical resources,**
- **To accomplish the unit's assigned mission,**
- **To satisfy the commander's strategic intent.**

When the unit staff uses a suitably automated "war gaming" tool to support Course of Action (COA) analysis, the commander can quickly gain a comprehensive understanding of the action-counteraction dynamics between the opposite units, thus increasing the assurance factor of the mission success.

I. INTRODUCTION (3)

Relationships between the evolutionary game model and the Bayesian probability network:

- The evolutionary games theoretic model (GT)

  In charge of state determinations and solutions to the mappings between the data sets and the situational state hypotheses.

- The Bayesian probabilistic network (BN)

  Evaluates sensory and environmental data and quantitatively ranks the information entities (packages, blocks) in terms of certainty functions.

II. SYSTEM OVERVIEW

II. SYSTEM OVERVIEW (1)

The demand

Good decision-making requires an accurate or at least a plausible "degree of certainty" situational assessment and awareness through

- a vigilant and timely information processing, and
- an effective management of
  - stress,
  - pressure,
  - overload,
  - fatigue,
  - emotional states, and
  - other distractions.

Information overload can be equally bad and often dangerous as is in the lack of useful information.

II. System Overview (2)

The issues

- Much of the situation awareness (SA) task aboard submarines is made very difficult by incomplete, confusing and partially correct (and partially incorrect!) information from the various resources.

- To model friends, foes and the environment, and to provide functional, timely and relevant advice to CO, XO, OOD, Sonar Supervisor and others, we need to make use of theories suitable for modeling information and structuring information in the presence of incomplete, partially correct data and under conditions of time and mission stress.

II. System Overview (3)

The issues (Cont.)

Situation Awareness (SA) Under Uncertainty

Uncertainty can mean several degrees of things

(1) lack of good probabilistic knowledge,
(2) lack of information, and
(3) lack of awareness.

II. System Overview (4)

The issues (Cont.)

SA Under Uncertainty

- Requires assumptions about
  - the **condition of nature**, and
  - the **intentions and methods of adversary**.

- One usual assumption:

  all parties will behave rationally,

seek to maximize their gain and/or minimize their losses depending on the conditions and point of view from which each party is operating.

II. System Overview (5)

Human Factors and SA

- **Human decision making performance is in part**
  - **dependent on personality and motivation,**
  - **dependent on level of knowledge, training, and natural abilities**.
- **Good performance requires**
  - strategic thinking and planning and
  - effective use of short and long term memory,
  - avoid natural biasing tendencies

    recent effects, premature closure, anchoring, etc.

Intelligent technologies can provide valuable assistance at many levels to an individual information analyst or collaborative group.

II. System Overview (6)

Human Factors and SA (Cont.)

Factors that bias reasoning :

- Ignorance
- Conjunctive Fallacy
- Gambler's Fallacy
- Availability heuristic
- Hindsight Bias
- Anchoring and Adjustment
- Attentive Bias
- Illusory Correlation
- Primacy Effect
- Premature Closure

II. System Overview (7)

Human Factors and SA (Cont.)

- **Bias of perception and reasoning appear from:**
  - transient or long held beliefs
  - human intuitions.
  - stress and pressure situations,
  - long working hours
  - etc.

Computerized automatic information processing system must account for these deficiencies and provide assistance to complement for the human thinking and judgment.

III. TECHNIQUE DESCRIPTION

III. Technique Description (1)

Game Theoretic SA

- **Strike an appropriate balance**
  between
  - **Representing game pertinent aspects of data sets**
    and
  - **Abstracting away irrelevant detail**

  in order to
  achieve the efficiencies required to appropriately sample the action-reaction game space.

Can’t have a computer model that is so detailed - only models a few scenarios - when thousands of scenarios may need to be sampled. Likewise, the model must be designed in sufficient detail to provide useful insight to the allocation of resources.

III. Technique Description (2)

Game Theoretic SA (Cont.)

- **Identifying and prioritizing "gaps" in a unit's knowledge about enemy disposition and intent**

  Collection assets can be concentrated on enemy indicators that "tell" or "give away" tactically significant actions.

- **Assisting the analysis of uncertain intelligence**

- **Reducing the probability of tactically "stupid" enemy actions and increasing the probability assigned to savvy opposition moves.**

III. Technique Description (3)

Game Theoretic SA (Cont.)

Three basic perceptions to consider：

- ***States of Nature***:
  - data, information, knowledge, and beliefs about the internal and external operational environments.
- ***Acts:***
  - objects of choice, the courses of action that are available to the decision maker.
- ***Consequences:***
  - possible results of an action, what are the likely results, what new difficulties or benefits may arise.

III. Technique Description (4)

Bayesian Evaluative SA

- When under uncertainty and incompleteness of the information sources and counter actions, the game model needs to take account of how easy it is to switch between actions,

  i.e., how swiftly can the unit commander response to new information, to retract actions, and to regain control points in a non-monotonic course.

- if the consequence function is stochastic and known to the decision-maker, then the decision maker is assumed to behave as if he maximizes the expected value of a (utility) function that attaches a number to each consequence.

III. Technique Description (5)

Bayesian Evaluative SA (Cont.)

The basic idea of Bayesian game is **to construct, for any information-incomplete game G, some information-complete game G*** that are game-theoretically equivalent to G.

- The approach involves introducing some random events (variables), assumed to occur before the players choose their strategies.
- The random events will determine player's cost function and other resources; and so will completely determine the payoff function.

III. Technique Description (6)

Bayesian Evaluative SA (Cont.)

In Bayesian game

- Both players
  - will be assumed to know the joint probability distribution.
- Each player
  - know only his own cost functions and resources
  - not know those of his opponent;
  - know how much information himself has about the opponent
  - not know exactly how much information the opponent has about him.

IV. SYSTEM IMPLEMENTATION

IV. SYSTEM IMPLEMENTATION (1)

Hierarchical Information Integration

- Four abilities:
  - to process overwhelming combat information more accurately, systematically and in a well-prioritized manner,
  - to solicit and routinely benefit from intelligent software advice,
  - to systematically filter, correlate, and analyze large amount of data inflow, and perform state prediction and other tasks, and
  - to hierarchically project relevant information and systematically measure (heuristically) the quality of past and present decisions, and to project the like measures of the quality of future decisions.

IV. SYSTEM IMPLEMENTATION (2)

Hierarchical Information Integration (Cont.)

Methods to **compensate** for data ambiguity, uncertainty and imprecision **by the information fusion agents**

- Information annotated with ranked expectation attributes
- Information linked to typical, previously observed cases of similar suspected, verified-positive, verified-negative and unknown contacts.
- Information provided by one sensor associated with (possibly correlated) information provided by other sensors.
- Information refined, re-ranked, and re-annotated.
- Qualitative and quantitative triggers installed that force a re-evaluation of possible correlation.

IV. SYSTEM IMPLEMENTATION (3)

Intelligent Advising

Presenting information in prioritized manner.

- Color-coding used to indicate type of threat
- Spatial, intuitive representation to delineate options
- Minimal to the point reporting and advice display

“patterns” will be remembered and re-enforced.

Track reporting software learns what a contact is over time.

→ measuring → learning → adaptation →

IV. SYSTEM IMPLEMENTATION (4)

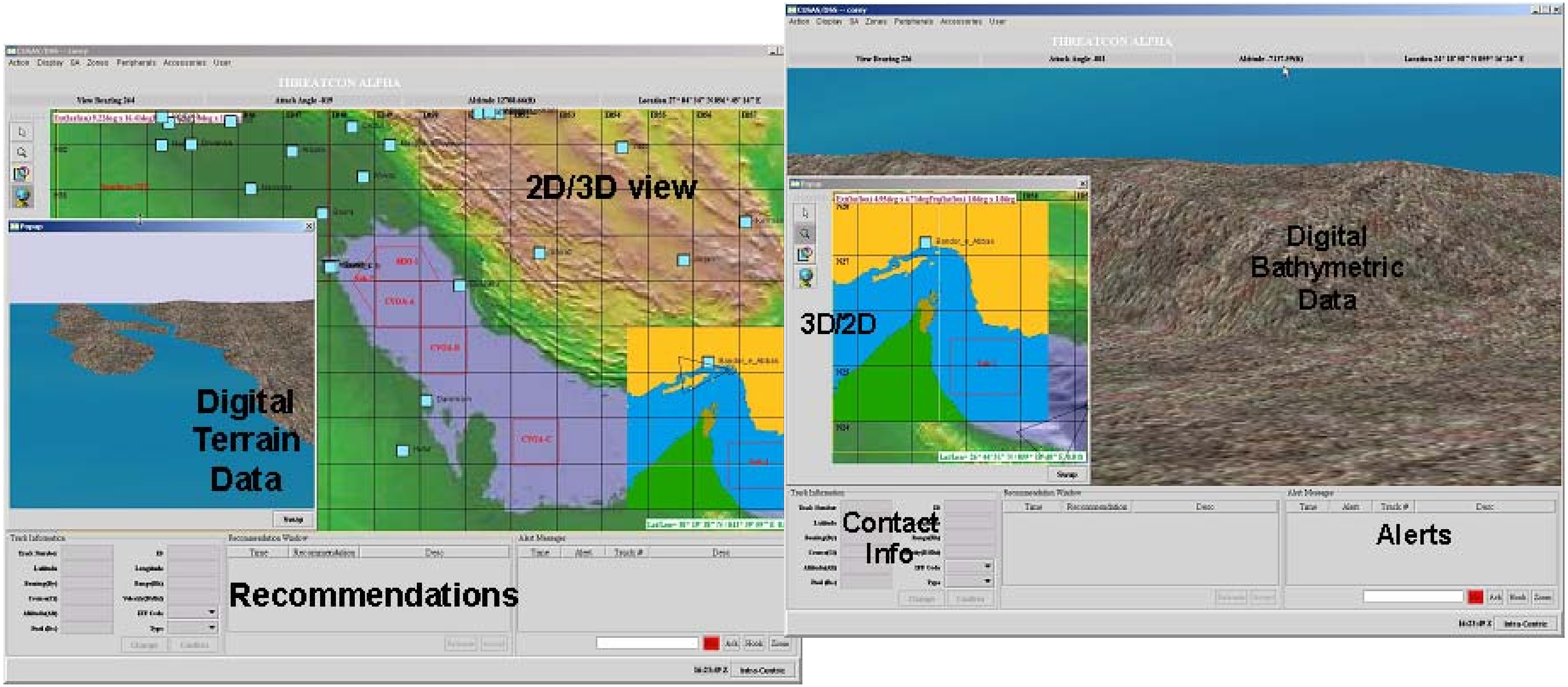
Augmented Human-Machine Interaction

- **Intelligent agents provide**
  - qualification and quantification of information uncertainty,
  - utilities of particular decisions,
  - risk aversion,
  - Tradeoffs.

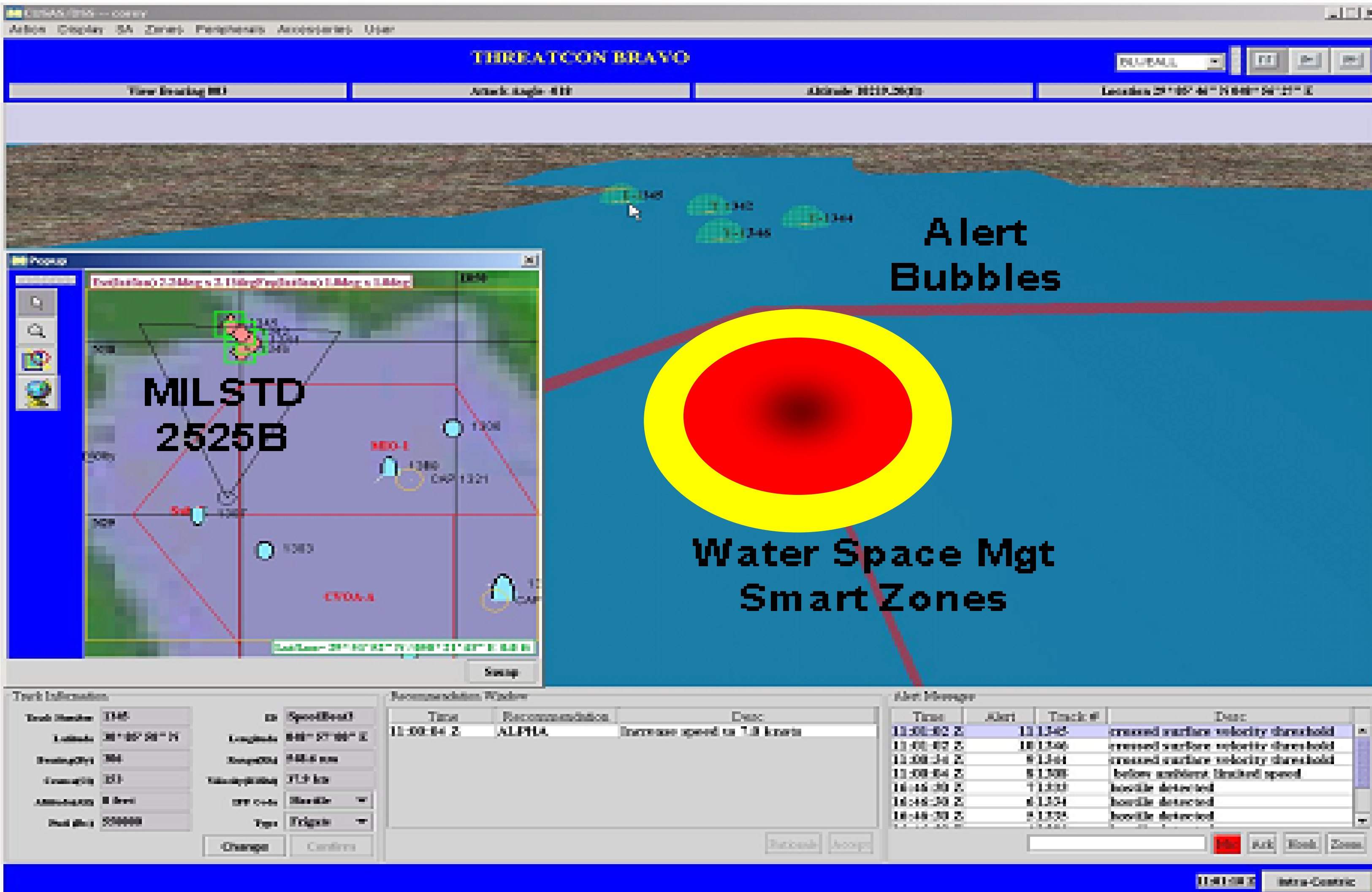
- **Special agents to**
  - coordinate,
  - Synchronize,
  - Arbitrate,
  - play human surrogate roles,
  - Communication exchanges.

IV. SYSTEM IMPLEMENTATION (5)

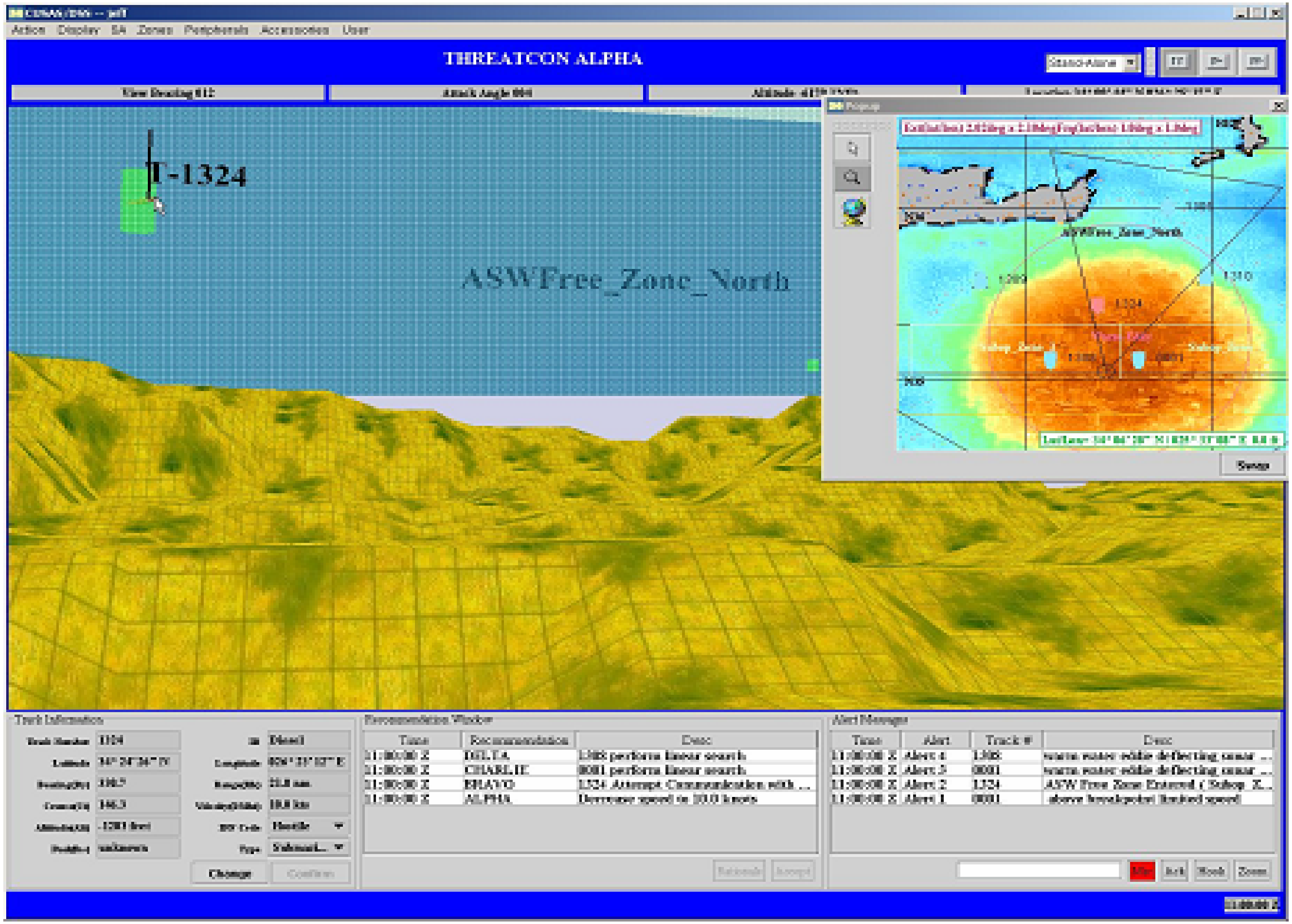
Augmented Human-Machine Interaction (Cont.)



IV. SYSTEM IMPLEMENTATION (6)



IV. SYSTEM IMPLEMENTATION (7)



V. CONCLUSION

V . Conclusion

- Our software helps drive the ship in a tactically safe manner.
- Software agents work with the humans in a carefully thought through and trained manner.
- Systematic intelligent assistance to reduce stress and overwhelming information overload
- Primarily for tactical decision making alternatives regarding maneuver, contact, and collision avoidance.
- Not a combat “auto-pilot” or fully automated undersea combatant control.