High-Level Fusion: Issues in Developing a Formal Theory

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GMU-AFCEA Critical Issues in C4I
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"…The commander is compelled ... to reach decisions on the basis of situations that cannot be predicted … The problem is to grasp, in innumerable special cases, the actual situation which is covered by the mist of uncertainty, to appraise the facts correctly and to guess the unknown elements, to reach a decision quickly and then to carry it out forcefully and relentlessly."

Helmuth von Moltke, 1800-1891

Paret, P.; Craig; A.G.; Gilbert, F. (1986) Makers of Modern Strategy: From Machiavelli to the Nuclear Age. London, UK: Oxford University Press (Page 289)

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In the olden days…

- We fought big wars
  - Against monolithic enemies
  - Who employed rigid doctrine
  - And fought in predictable ways
- We built stovepipe systems
  - Used by a single organization for a single purpose
  - Built on idiosyncratic database schema and input-output formats
  - Requiring labor-intensive manual transformation of outputs for use by another stovepipe

…and then the world changed.

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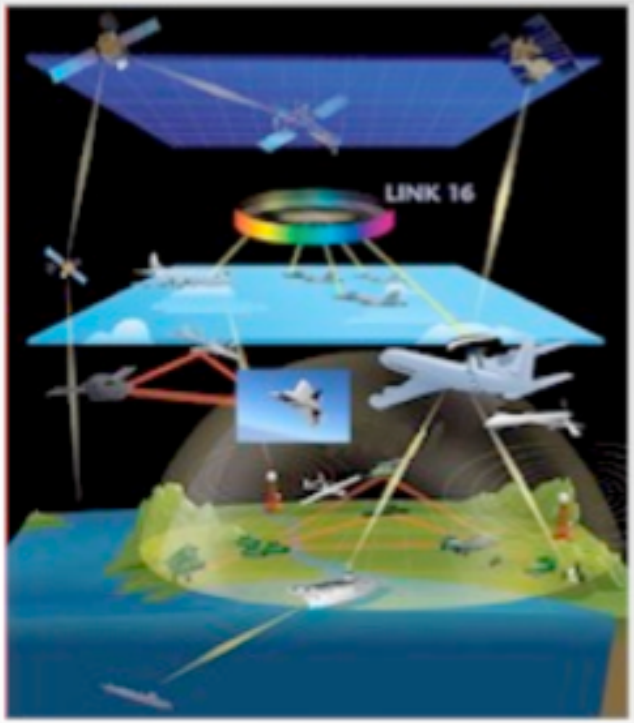
The Way of the Future

- Autonomous software agents interoperate seamlessly
- Collective behavior emerges to address information needs
- Each agent has timely access to mission-critical information
- Agents are not overloaded with unnecessary information
- Information is properly synchronized and up-to-date
- Multi-level security permits needed access while preventing non-authorized use



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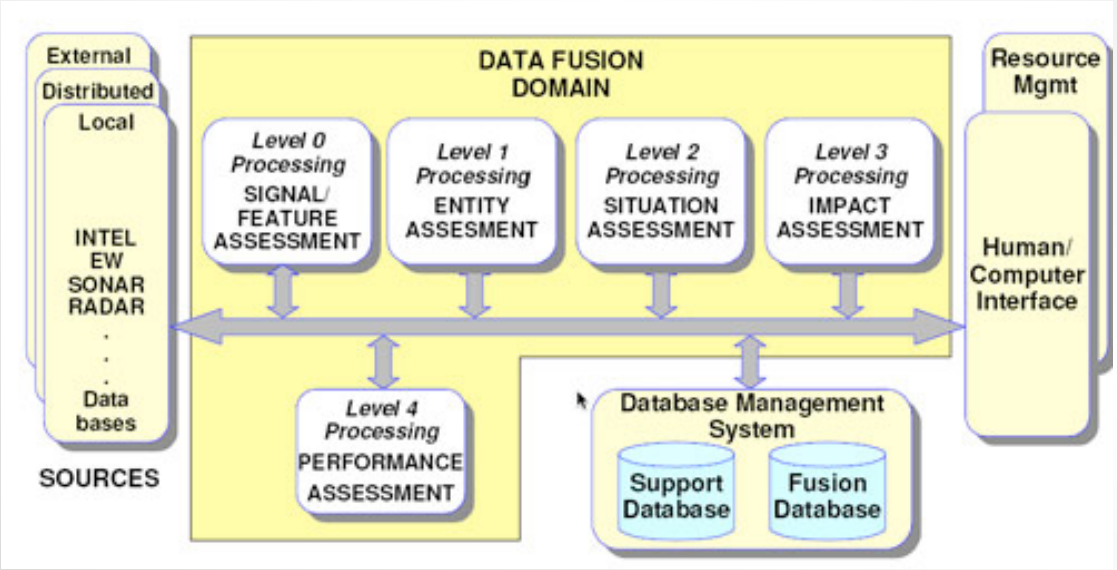
Data Fusion

- ***Data Fusion*****:** *the integration of data and knowledge collected from disparate sources by different methods into a consistent, accurate, and useful whole.* (Encarta World English Dictionary, 2009)
- JDL Fusion Model (as modified by Steinberg & Bowman, 1999):



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Traditional Fusion Systems

- Focus primarily on physical properties
- Reports closely tied to physical features
- Semantics implicit and hard-wired
- Limited expressivity
- Most level 2+ fusion is left to humans
- Can handle only standardized messages, special-case scenarios, and specific sensor types

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HLF Example: Common Operational Picture (COP)

- Display of friendly and enemy troop locations, terrain and cultural features, infrastructure, etc.
  - Provide timely and accurate information
  - Enable shared situational awareness across multiple commands
  - Provides tailored, decision-focused information for individual users
- User-defined operational picture (UDOP) provides tailored decision-relevant information
- COP supports shared situation awareness

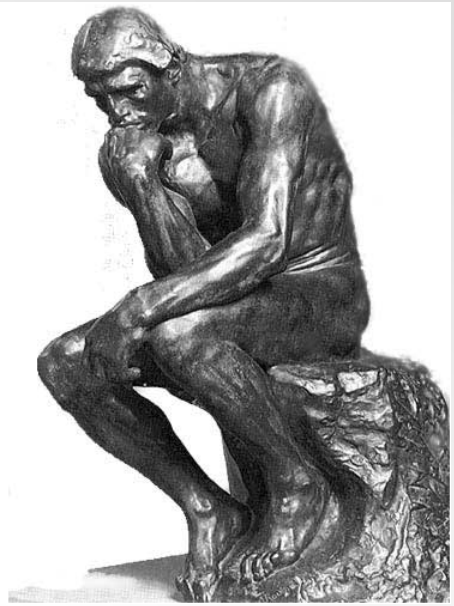
Source: http://defense-update.com/features/du-3-05/c4i-7.htm

Some Capabilities Users Need

- View / manipulate geospatial display
- Select object or group of objects and view information
  - Current
  - Rolled back in time
  - Projected into the future
- Update / evolve / repair COP as new evidence arrives
- Share information with other users
  - Peers within organization, up and down command chain, partner organizations
  - More than just screenshots
- Construct interpretation of situation
  - Supported by computer recommendations
  - Collaboratively with other users
- Receive alerts based on conditions of interest

HLF Requirements

- Fuse data from large numbers of distributed interoperating sensors
- Accept heterogeneous reports
  - At multiple levels of JDL hierarchy
  - Differing semantics
  - Both hard (physical domain) and soft (informational domain)
- Reason about complex situations
  - Involving many entities interacting in space and time
  - Hypotheses of interest only indirectly tied to sensor reports
- Manage pervasive uncertainty
- Accommodate changing threat and environment



Capabilities Needed Under the Hood

- *Represent*:
  - Entities, including conventional and irregular units and their constituent components
  - Ambient “green, gray and pink” populations as well as their cultural and military relations
  - Behaviors over time and space
  - Interactions, events and situations
- *Aggregate* observations to entities, and lower-level entities to higher-level entities
- *Fuse* multi-source intelligence data to generate and evaluate hypotheses
- *Project* situation into the future
- *Qualify* results according to credibility
- *Interoperate* with other users and systems

http://www.emergencymgmt.com/health/Biosurveillance-Common-Operating-Picture.html

HLF and Representation

- Semantics used to be in mind of human
- HLF requires formal representation of semantics:
  - Entities of different types
  - Attributes and behaviors of entities
  - Relationships among entities playing different roles
  - Space and time
  - Human, social, cultural and behavioral (HSCB) factors
  - Observables and their relationship to hypotheses of interest
  - Uncertainty about all of the above

No computation without representation!

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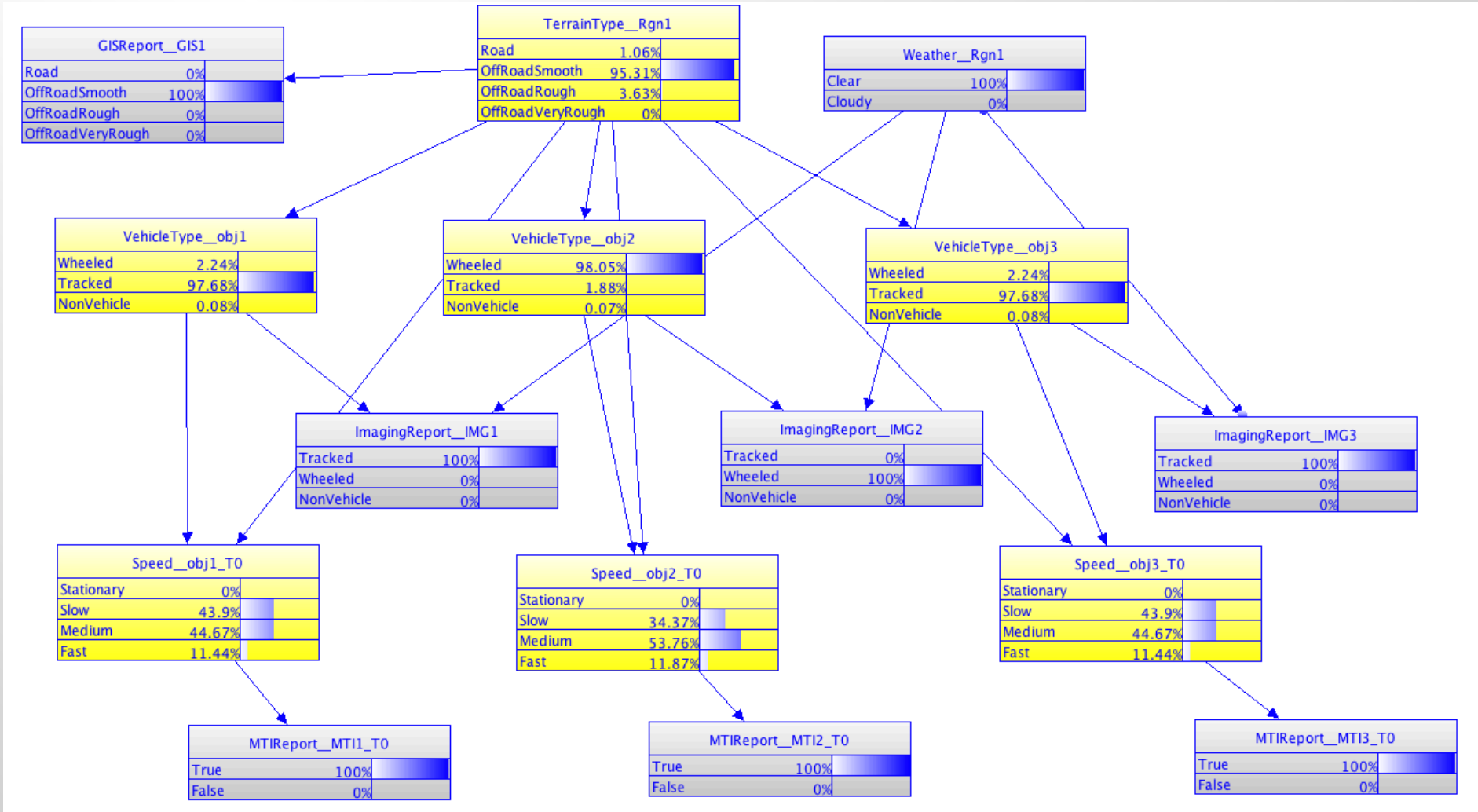
Semantics and HLF

- HLF requires
  - Representing and reasoning with domain semantics
  - Support for uncertainty management
    - Propagate uncertainty through all fusion levels
    - Interchange uncertainty and pedigree along with conclusions
- Traditional semantic technology has no standardized representation for uncertainty
- Traditional uncertainty formalisms cannot represent or properly handle semantics
- A *probabilistic ontology* represents domain semantics and associated uncertainty

Representing Uncertainty



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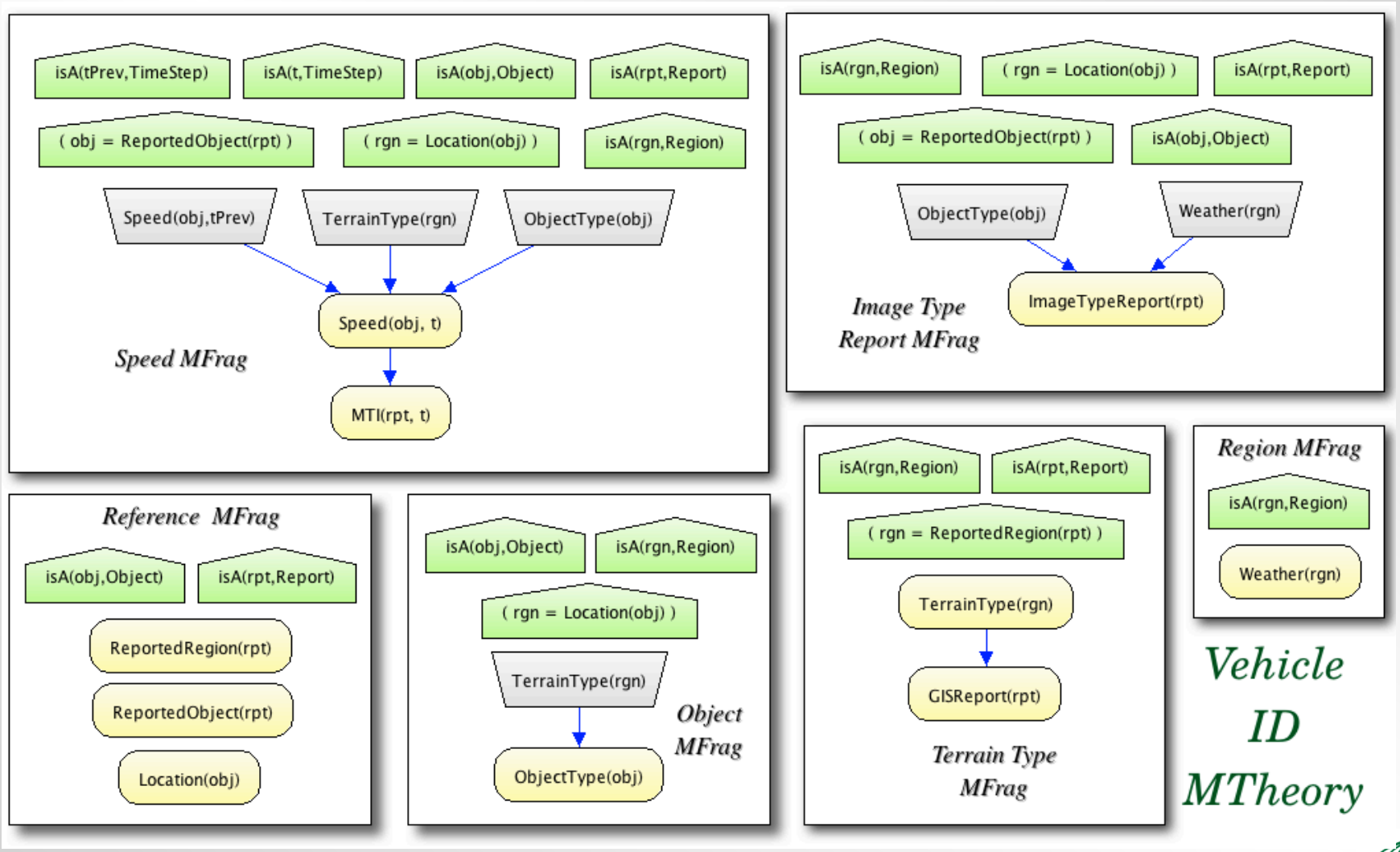
Probabilistic Ontology for Vehicle ID



PR-OWL probabilistic ontology language extends OWL to represent uncertainty

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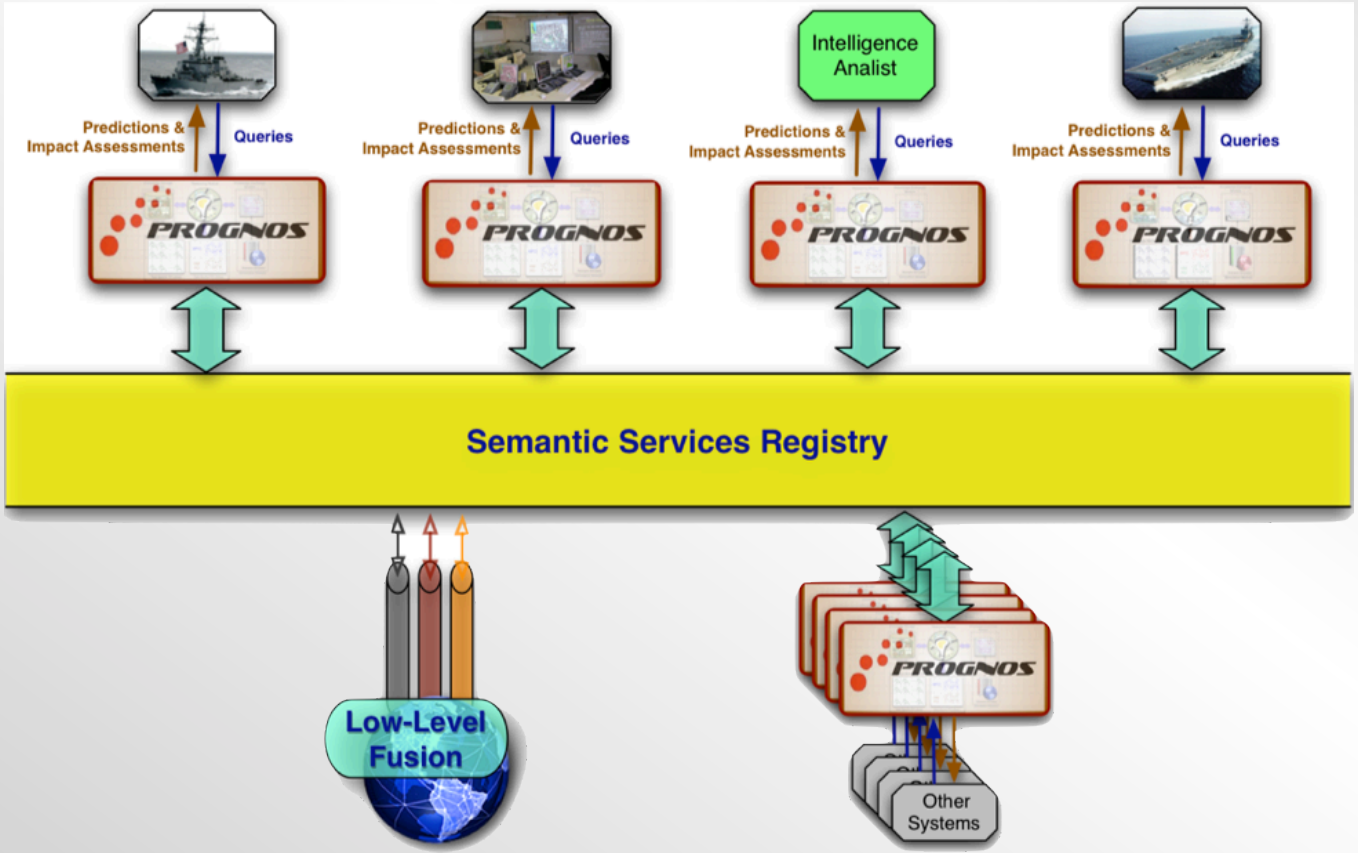
Example: PROGNOS

ONR-sponsored research project to enable predictive situational awareness in maritime domains



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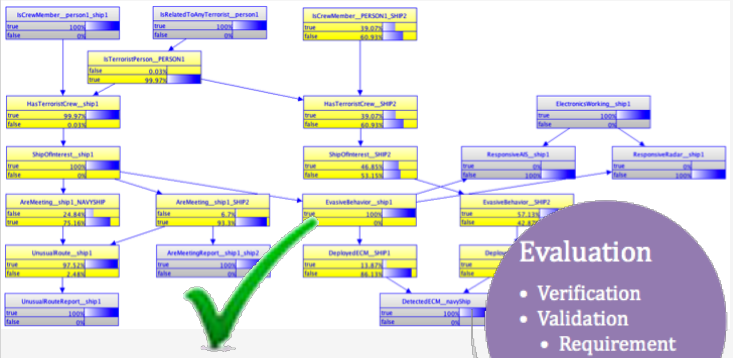
PO Modeling Cycle



Goals
- Queries
- Evidence

Goal: Identify whether a ship is a ship of interest

Query: Does the ship have a terrorist crew member?

Evidence: Crew member related to any terrorist; Crew member associated with terrorist organization

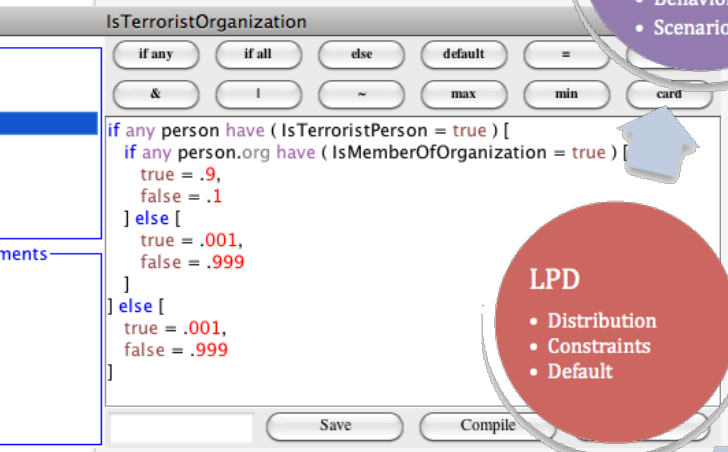
Entities
- Attributes
- Relationships

Ship
Person
Organization
isTerroristPerson
hasCrewMember
isRelatedTo

Evaluation
- Verification
- Validation
  - Requirement
  - Behavior
  - Scenario

Rules
- Deterministic
- Stochastic

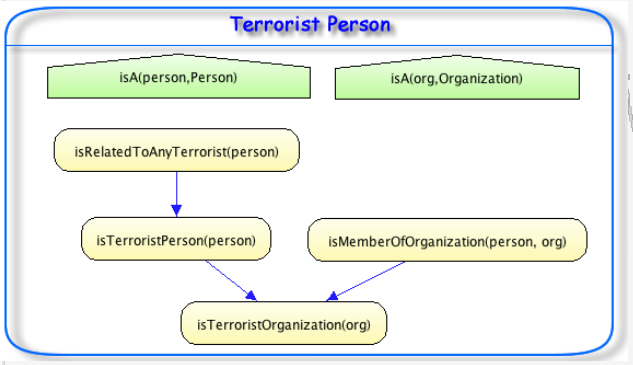
If a crew member is related to a terrorist, then it is more likely that he is also a terrorist

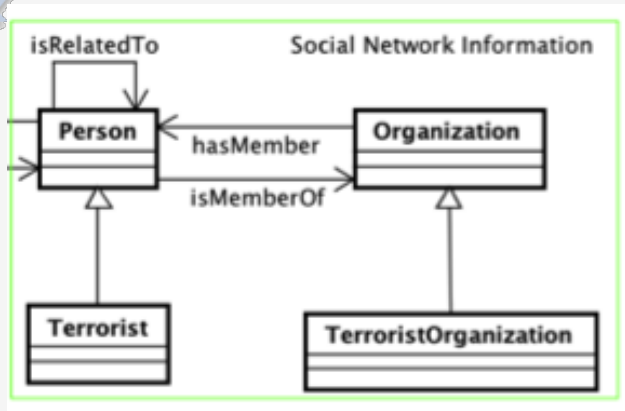


LPD
- Distribution
- Constraints
- Default

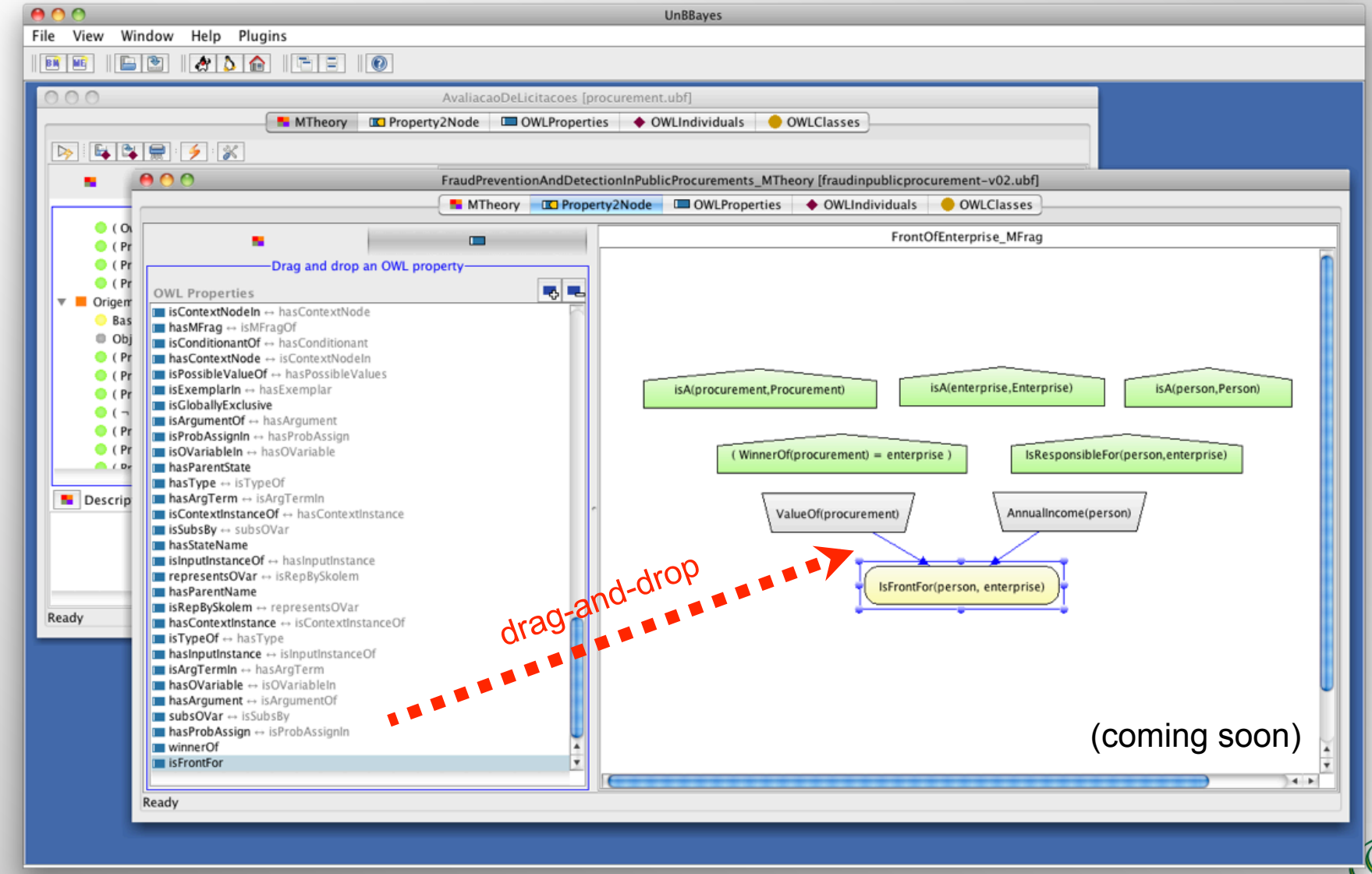
Mapping
- Entities
- MFrag
- Nodes
- Relations

Group
- Entities
- Rules
- Dependencies





Drag-and-Drop OWL Properties



UNBBayes-MEBN open-source PR-OWL tool

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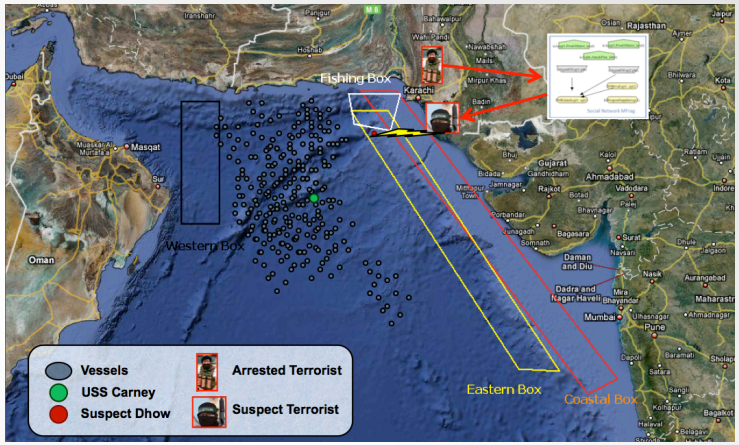
Summary

- HLF automation is required to reduce cognitive overload and provide timely actionable knowledge to decision makers
- Methods should be grounded in foundational theory of HLF
  - Represent semantics
  - Learn from experience
  - Support for uncertainty management
  - Fuse hard and soft information
  - Efficient and scalable inference
  - Solid theoretical foundation



- Probabilistic ontologies:
  - Provide principled representation of domain semantics with associated uncertainty
  - Provide built-in learning theory
  - Enable development of efficient and scalable automated reasoning methods

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