PROGNOS: Applying Probabilistic Ontologies to Distributed Predictive Situation Assessment in Naval Operations

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Case Study - Arabian Sea MSO
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Problem Statement

• Current technology provides lower-level multi-sensor data fusion through stove-piped systems

• High Bandwidth Net-Centric systems such as FORCENet can manage thousands of tracks through many and diverse sensors.

• Humans are responsible for the higher-level fusion, creating a situational awareness and performing their own predictive analysis

• Cognitive overflow, among other issues, hamper this process, preventing optimal decision-making
Prognos Purpose

• Provide consistent higher-level fusion through state-of-the-art knowledge representation and reasoning
• Enable predictive analysis with principled hypothesis management

Queries

Predictions & Impact Assessments

Streaming Evidence

PROGNOS
High-Level Fusion Architecture
Architecture Components

- Interoperability with FORCENet and external systems via a set of interchange POs
- Hybrid reasoning in support for a Hypothesis Management engine
- Internal entity storage module in FORCENet formatting
- Task-specific POs for optimal mission-based inferences
- Domain-agnostic PO library in support to general reasoning and HMng.
- Simulation module for both system training and evaluation
Incoming data or new queries trigger a new cycle of the hypothesis management process.

- Both are assessed with respect to relevance and impact to existing hypothesis, either creating a new hypothesis or extending an existing one.
- In conjunction with the knowledge management POs, they can also trigger the hypothesis discovery engine.
Enabling Technologies

• Multi-Entity Bayesian Networks
  ‣ Combine the expressivity of FOL with the inferential power of Bayesian Networks
  ‣ Built on a rigorous mathematical foundation

• PR-OWL Probabilistic Ontology Language
  ‣ Combine the advantages of semantic-enabled approaches with support for principled uncertainty representation and reasoning.

• Spatio-Temporal Hypothesis Management
  ‣ Extends current HM techniques to a higher level of expressivity, enabling sophisticated analyses over very large numbers of hypotheses.

• Efficient Distributed Hybrid Inference
  ‣ Addresses both discrete and continuous random variables
  ‣ Unscented transformation has been shown to be more accurate than traditional linearization methods
Behavior of a Surface Vessel
Modeling TOI of a Vessel
PR-OWL: A Bayesian extension to the OWL Ontology Language

A Bayesian Framework for Probabilistic Ontologies

What is PR-OWL?

PR-OWL is an open research work aimed to extend the OWL ontology Web language so it can represent probabilistic ontologies. In other words, it is a probabilistic extension to OWL that provides a framework for authoring probabilistic ontologies and is based on the Bayesian first-order logic called Multi-Entity Bayesian Networks (MEBN).

A More Detailed Explanation

Uncertainty is ubiquitous. Any representation scheme intended to model real-world actions and processes must be able to cope with the effects of uncertain phenomena.

What is an uncertain phenomenon?

A major shortcoming of existing Semantic Web technologies is their inability to represent and reason about uncertainty in a sound and principled manner. This not only hinders the realization of the original vision for the Semantic Web, but also raises an unnecessary barrier to the development of new, powerful features for general knowledge applications.

The overall goal of our research is to establish a Bayesian framework for probabilistic ontologies, providing a basis for plausible reasoning services in the Semantic Web. As an initial effort towards this broad objective, this dissertation introduces a probabilistic extension to the Web ontology language OWL(2), thereby creating a crucial enabling technology for the development of probabilistic ontologies.

The extended language, PR-OWL (pronounced as "prowl"), adds new definitions to current OWL while retaining backward compatibility with its base language. Thus, OWL-built legacy ontologies will be able to interoperate with newly developed probabilistic ontologies. PR-OWL moves beyond deterministic classical logic (Frege, 1879; Peirce, 1885), having its formal semantics based on MEBN probabilistic...
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