Probabilistic Ontology: The Next Step for Net-Centric Operations

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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.
Vision: A Net-Centric World

- Autonomous software agents interoperate seamlessly
- Each agent has timely access to mission-critical information
- Agents are not overloaded with unnecessary information
- Information is properly synchronized and up-to-date
- Data from disparate sources is fused into mission-relevant knowledge
- Multi-level security permits needed access while preventing non-authorized use
The Bandwidth Fallacy

Massive Volumes of Data
+ Unlimited Bandwidth
⇒ Net-Centric Vision

Data, data everywhere,
and not the time to think!

Web Services: Enabling Interoperability

SOAP over HTTPS
The P-F-B Triangle

- Find
- Publish
- Bind

Service Registry

Service Consumer

Service Provider
Why Semantics?

**Syntax**
- *Syntax*: rules of formation for a data type
- *Syntactic interoperability*: applications can process each other’s data formats
- *Example*: 3.2 is a legal floating point number

**Semantics**
- *Semantics*: the meaning of expressions
- *Semantic interoperability*: applications interpret data in the same way
- *Example*: Diagnostic benchmarks were run on 3.2 GHz processor

Semantic interoperability is a much stronger requirement than type consistency
Semantics in Net-Centric Services

- Semantics in stovepipe systems are in the mind of the human
  - Natural language documentation
  - Code
- Net-centric systems require formal, machine-interpretable semantics
- Semantic information in service descriptions enables consumers and providers to have a common understanding of:
  - What does the service do?
  - What inputs does it require and what results does it produce?
  - What are conditions (constraints/policies) for use?
  - How to invoke it? (Address & WSDL description)
Example: Geospatial Services

- Manual geospatial analysis is tedious, time-intensive, error-prone, and difficult to share
- Advanced Automated Geospatial Tools (AAGTs) delivered through Net-Centric Services promise to provide unprecedented military advantage
  - Reduce time to produce analysis
  - Avoid rework and reduce bandwidth by sending results not raw data
- Semantic interoperability is essential
Uncertainty in Geospatial Data

(from Wright, 2002)

Traditional CCM Display

CCM Display with Uncertainty

<table>
<thead>
<tr>
<th>Speed Range</th>
<th>Prob %</th>
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<tbody>
<tr>
<td>0</td>
<td>28</td>
</tr>
<tr>
<td>0 - 3</td>
<td>3</td>
</tr>
<tr>
<td>3 - 6</td>
<td>3</td>
</tr>
<tr>
<td>6 - 10</td>
<td>4</td>
</tr>
<tr>
<td>10 - 15</td>
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<tr>
<td>20 - 30</td>
<td>11</td>
</tr>
<tr>
<td>30 - 45</td>
<td>15</td>
</tr>
<tr>
<td>&gt; 45</td>
<td>26</td>
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</tbody>
</table>

Predicted CCM Speed (Kph)

0-3 3-10 10-20 20-30 >30

Prediction Quality

Good

Poor

(from Wright, 2002)
Decision Impact of Uncertainty

- Simulation Experiment
- “Ground Truth” CCM product
- “Database” CCM product
- 100 simulated mission - random routes
- Percent Mission Failures as a function of travel time multiplier ("fudge factor")

Fewer mission failures = better decisions when uncertainty information is exploited

(Wright, 2002)
Ontologies and Uncertainty

- Semantically aware systems are essential to the net-centric vision.
- Ontologies are a means to semantic awareness
- Representing and reasoning with uncertainty is essential
- But...

**Standard ontology languages provide no support for representing uncertainty in a principled way**
PR-OWL: A Language for Expressing Probabilistic Ontologies

- Extends W3C recommended OWL ontology language
- Based on expressive probabilistic logic
- Represents probabilistic knowledge in XML-compliant format.
- Open-source, freely available solution for representing knowledge and associated uncertainty in a principled manner.
- Reasoner under development at University of Brasilia

(Costa, 2005)
Will there be flooding due to recent rains at coordinates xyz?

35% chance of flooding!

SOA Level 0: Semantically unaware (legacy system)
SOA Level 1: Understands and uses Semantics

(Costa, et al., 2006)
Will there be flooding due to recent rains at coordinates xyz?

**SOA Level 0:** Semantically unaware (legacy system)

**SOA Level 1:** Understands and uses Semantics

(Costa, et al., 2006)
1. Commander: “I need a minimum of 80% of my predictions from system xxx to be correct, to successfully plan and execute this mission. I need it in 2 days”

2. Producer: “It will take 5 days and cost $zz to produce the data for this mission. Here is what I can do in 2 days. It will provide you an accuracy of 60% of your predictions”

3. Commander: “That’s not good enough. If I give you three days can you give me 75% accuracy on these predictions?”

4. Producer: “Yes, I can do that!”

(Wright, 2002)

- Different organizations simultaneously produce data to different requirements and different specifications
- Requirements redefined “on the fly”
- Probabilistic ontologies represent semantics of data quality and mediate interchange of data among interoperable systems
In Closing…

- Explicit semantics is necessary for interoperable systems
- Semantic information needs to include uncertainty
  - Mission performance is affected when uncertainty is not properly incorporated
  - Annotating a standard ontology with “uncertainty attributes” is not enough.
  - Rich relational representation with uncertainty is needed
- Usable methodologies for building and maintaining probabilistic ontologies are needed
Thank You!