Probabilistic Ontology: The Next Step for Net-Centric Operations

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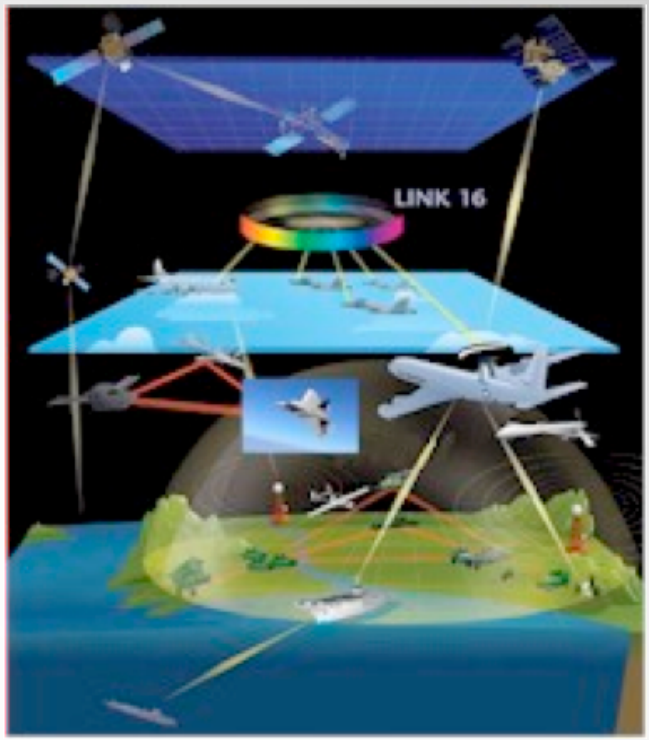
In the olden days…

- 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

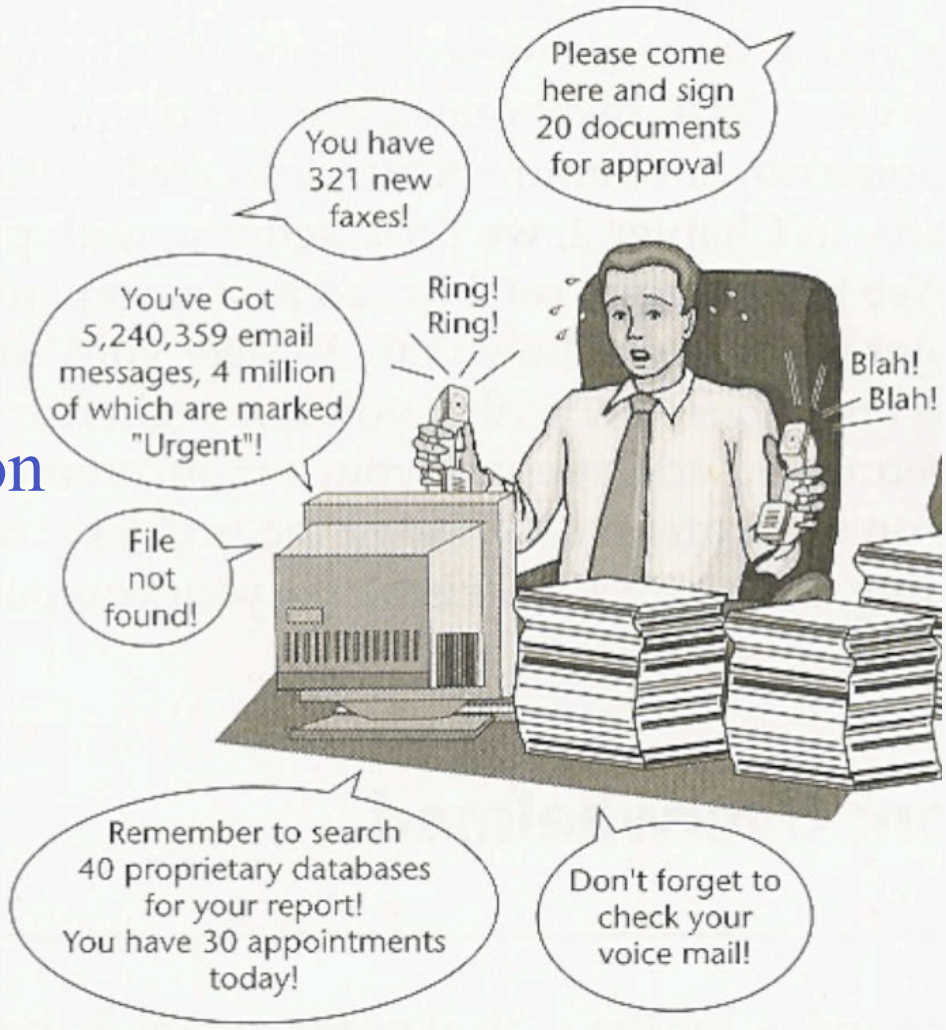
- Autonomous software agents interoperate seamlessly
- Each agent has timely access to mission-critical information
- Agents are not overloaded with unnecessary information
- Information is properly synchronized and up-to-date
- Data from disparate sources is fused into mission-relevant knowledge
- Multi-level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



The Bandwidth Fallacy

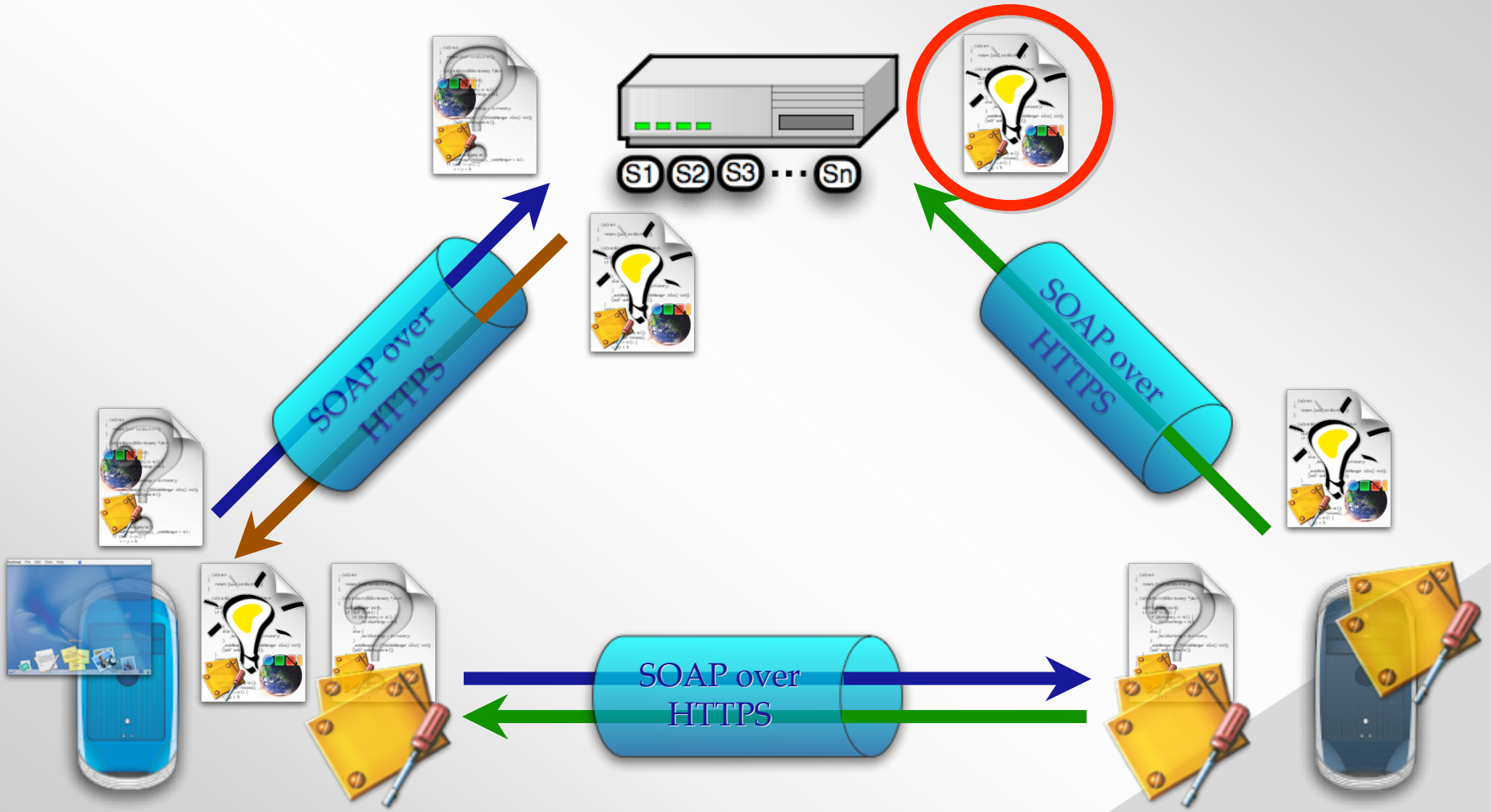
Massive Volumes of Data
+ Unlimited Bandwidth
⇒ Net-Centric Vision

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

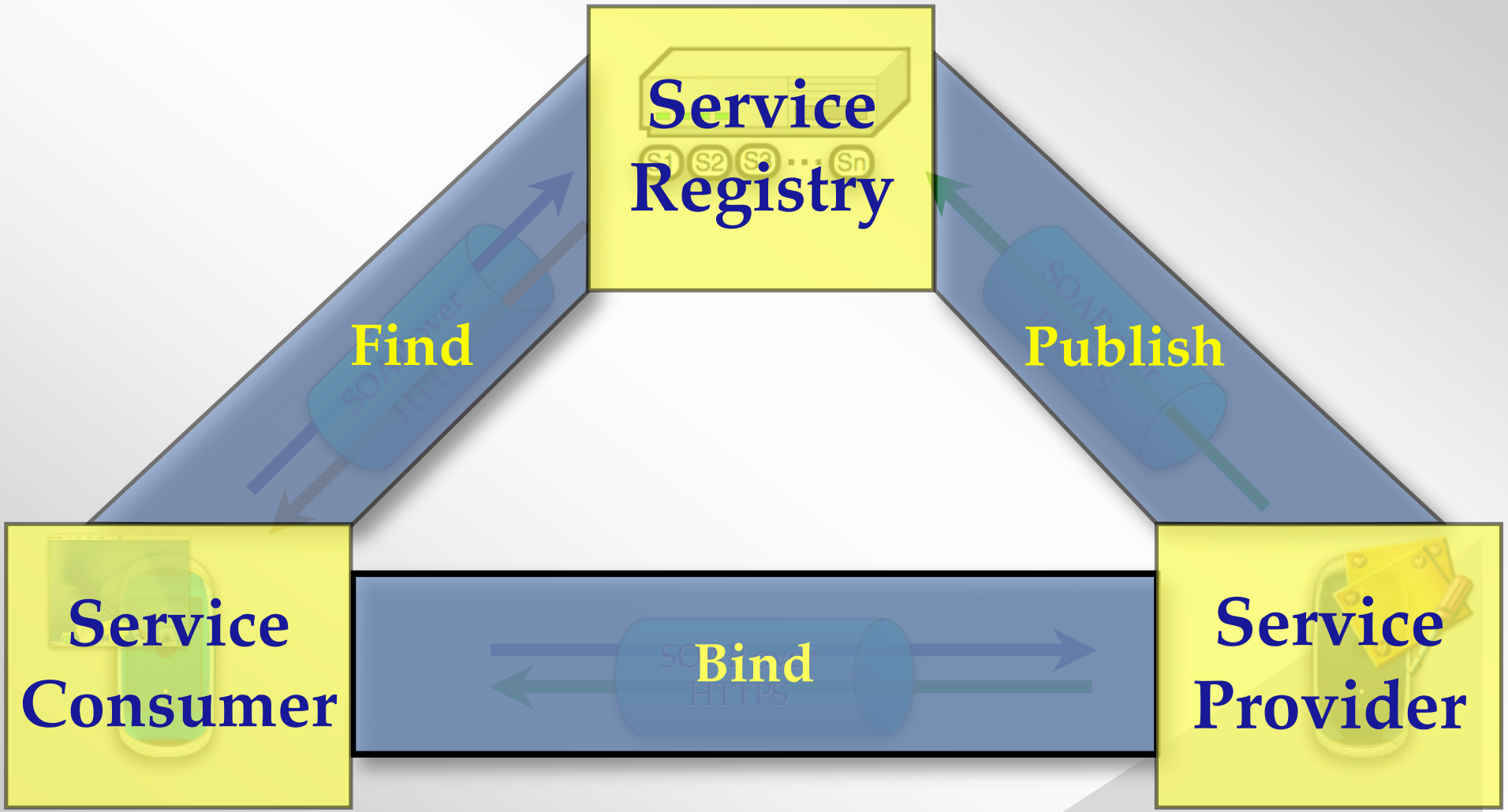


Daconta, M.; Obrst, L.; and Smith, K.; (2003)

Web Services: Enabling Interoperability



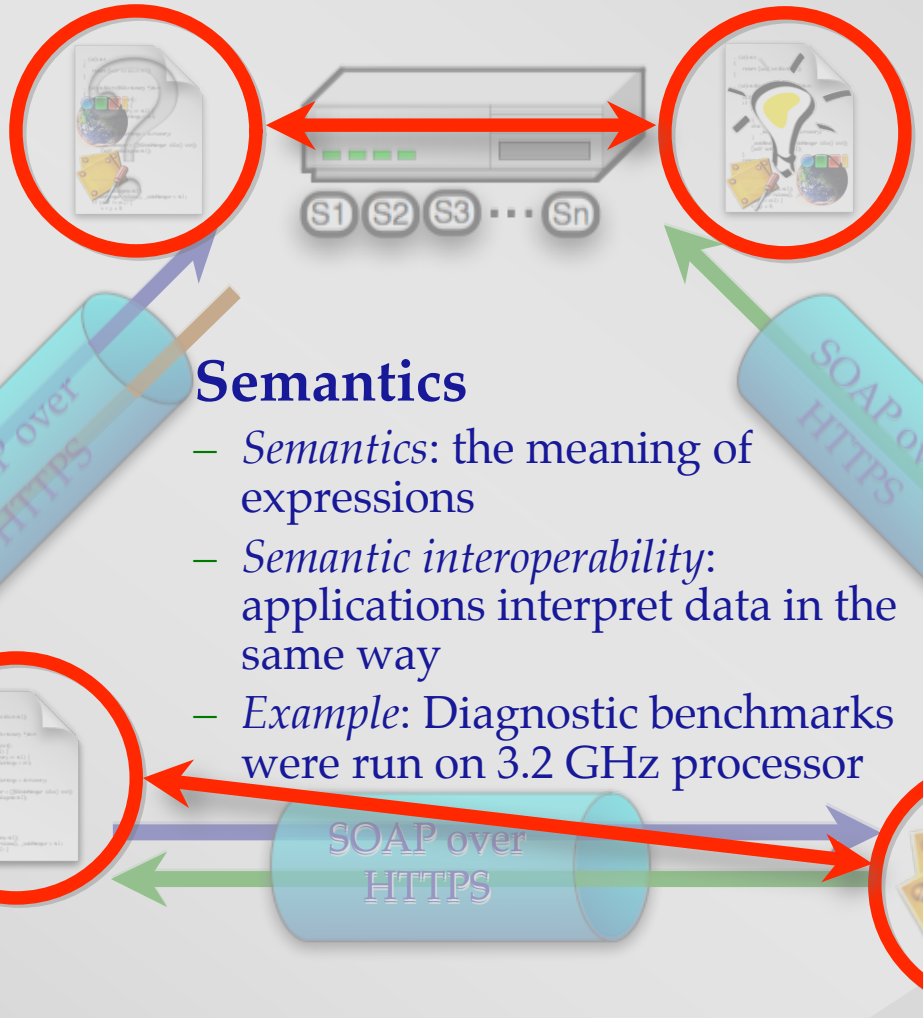
The P-F-B Triangle



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

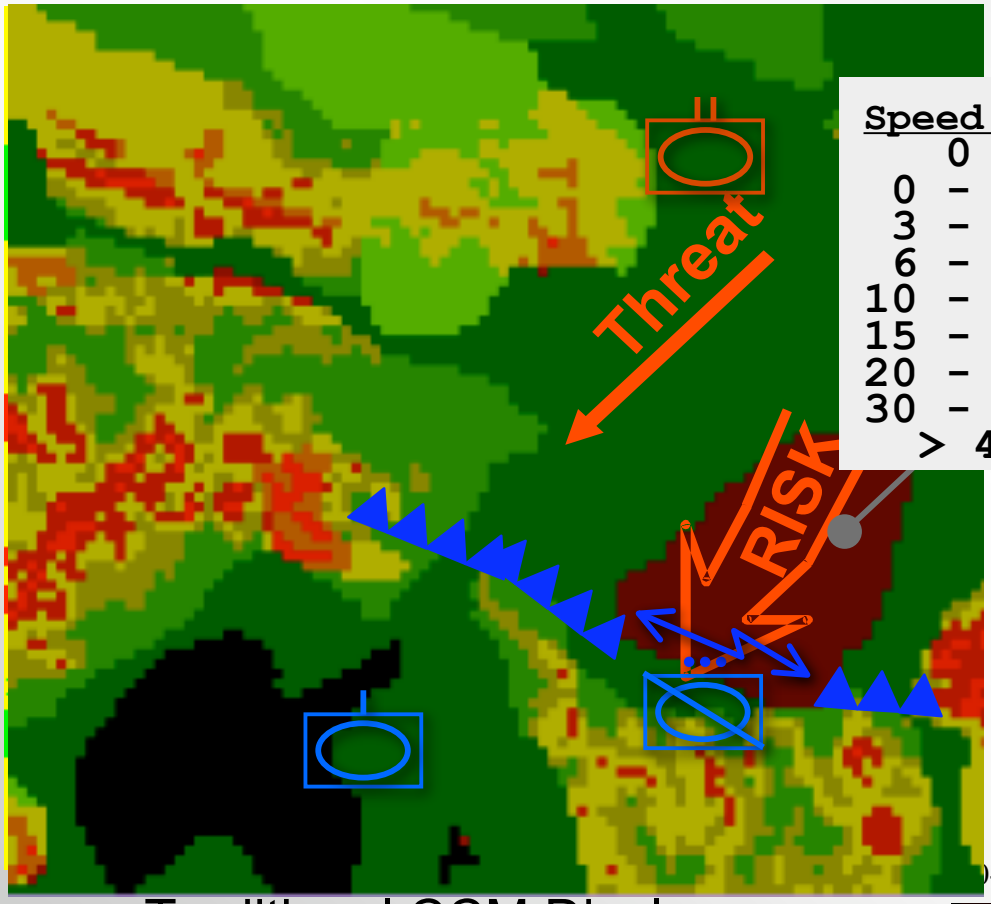
Semantics in Net-Centric Services

- 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)

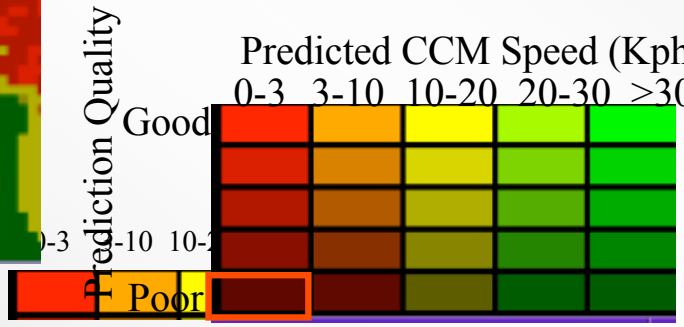
Example: Geospatial Services

- 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



Speed Range	Prob%
0	28
0 - 3	3
3 - 6	3
6 - 10	4
10 - 15	5
15 - 20	6
20 - 30	11
30 - 45	15
> 45	26



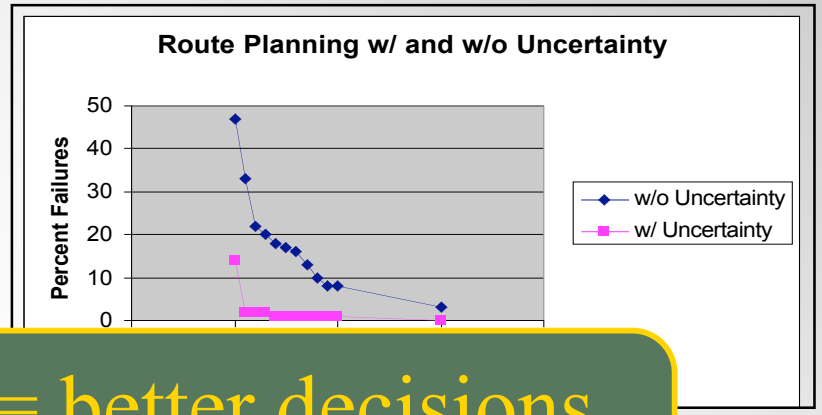
Traditional CCM Display

CCM Display with Uncertainty

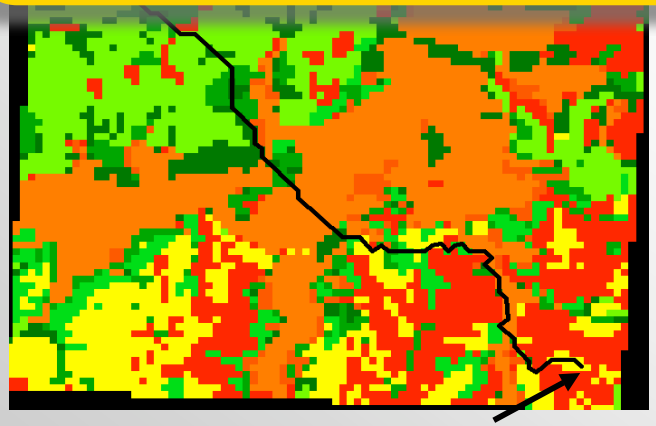
(from Wright, 2002)

Decision Impact of Uncertainty

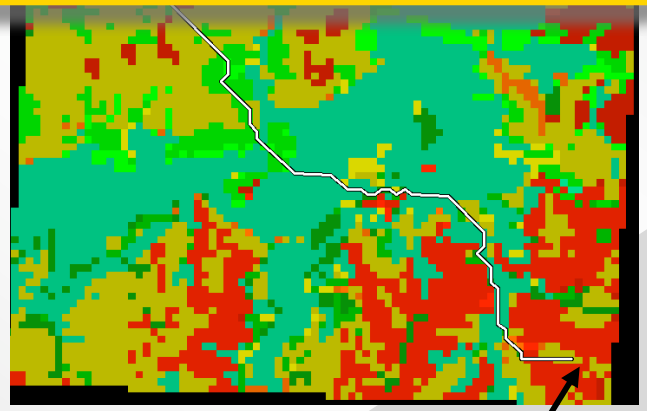
- Simulation Experiment
- "Ground Truth" CCM product
- "Database" CCM product
- 100 simulated mission - random routes
- Percent Mission Failures as a function of t



Fewer mission failures = better decisions
when uncertainty information is exploited



Finish



Finish

(Wright, 2002)

Ontologies and Uncertainty

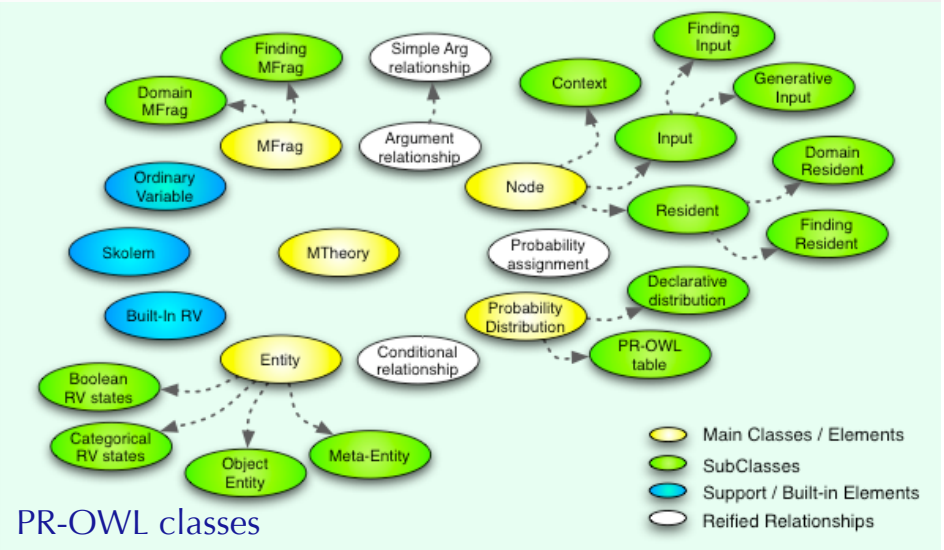
- Semantically aware systems are essential to the net-centric vision.
- Ontologies are a means to semantic awareness
- Representing and reasoning with uncertainty is essential
- But...

STANDARD ONTOLOGY LANGUAGES PROVIDE NO SUPPORT FOR REPRESENTING UNCERTAINTY IN A PRINCIPLED WAY

PR-OWL: A Language for Expressing Probabilistic Ontologies

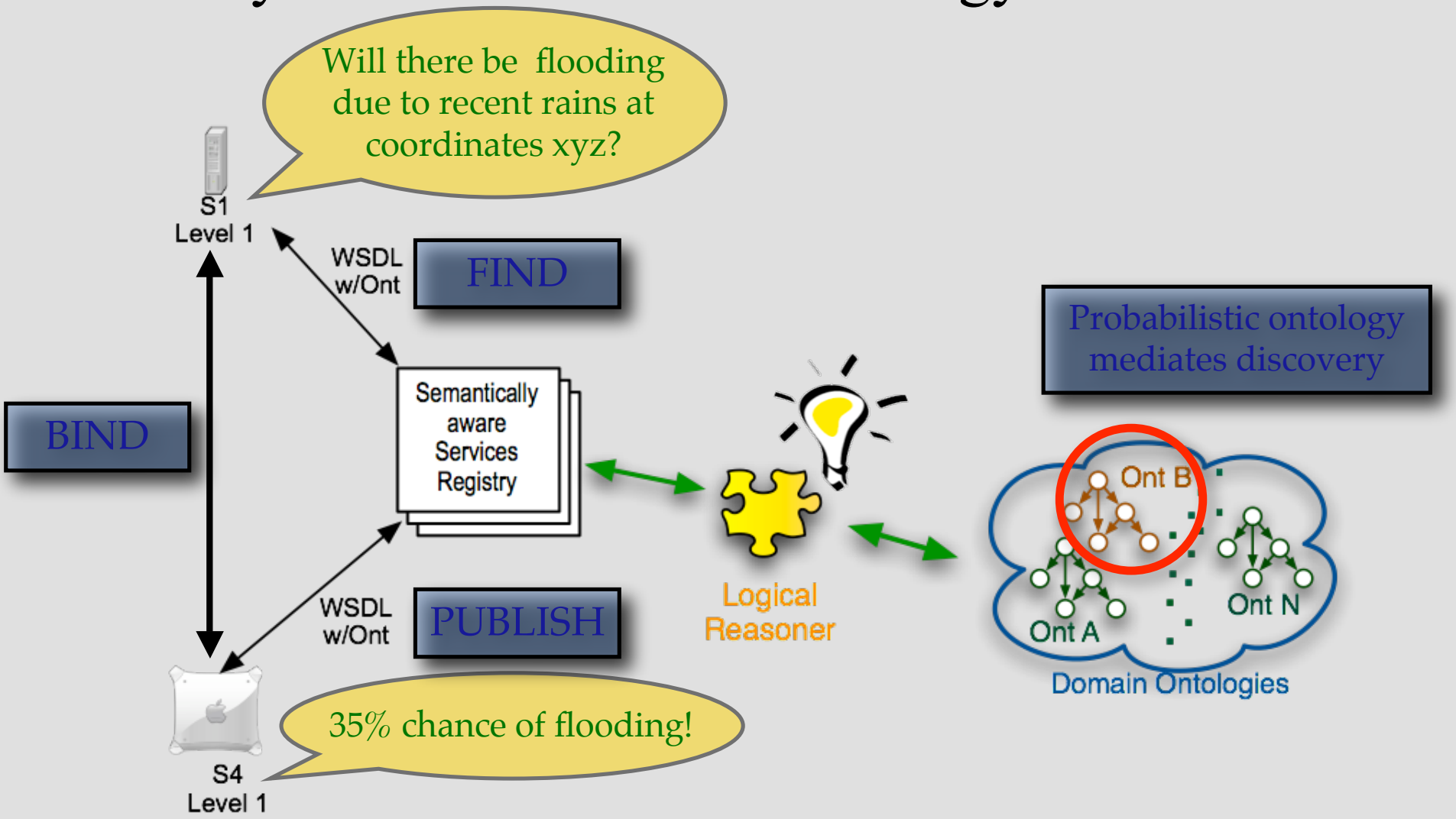
- Extends W3C recommended OWL ontology language
- Based on expressive probabilistic logic
- Represents probabilistic knowledge in XML-compliant format.
- Open-source, freely available solution for representing knowledge and associated uncertainty in a principled manner.
- Reasoner under development at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

(Costa, 2005)



PR-OWL classes

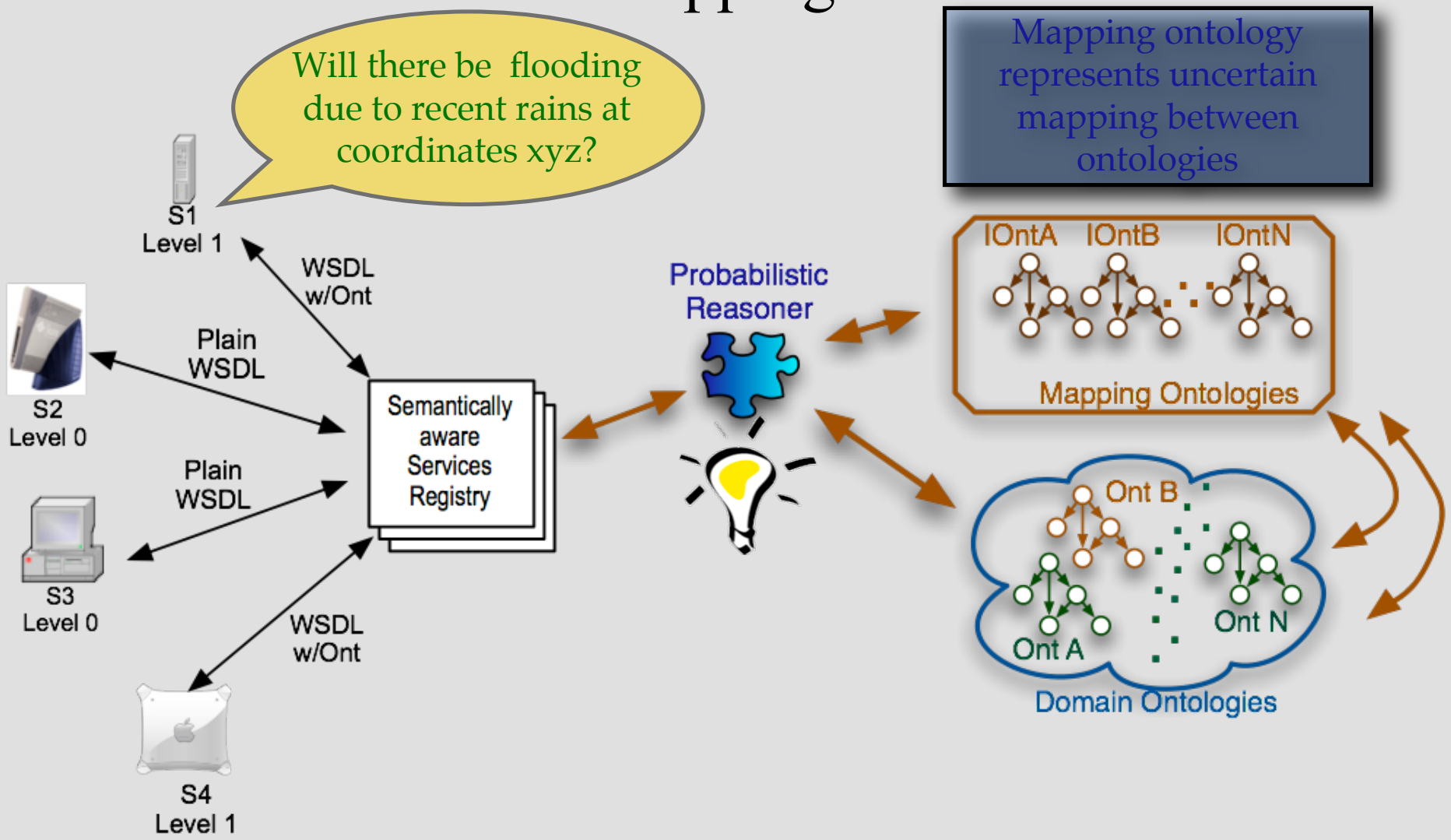
Discovery with Probabilistic Ontology



(Costa, et al., 2006)

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

Probabilistic Semantic Mapping



(Costa, et al., 2006)

SOA Level 0: Semantically unaware (legacy system)
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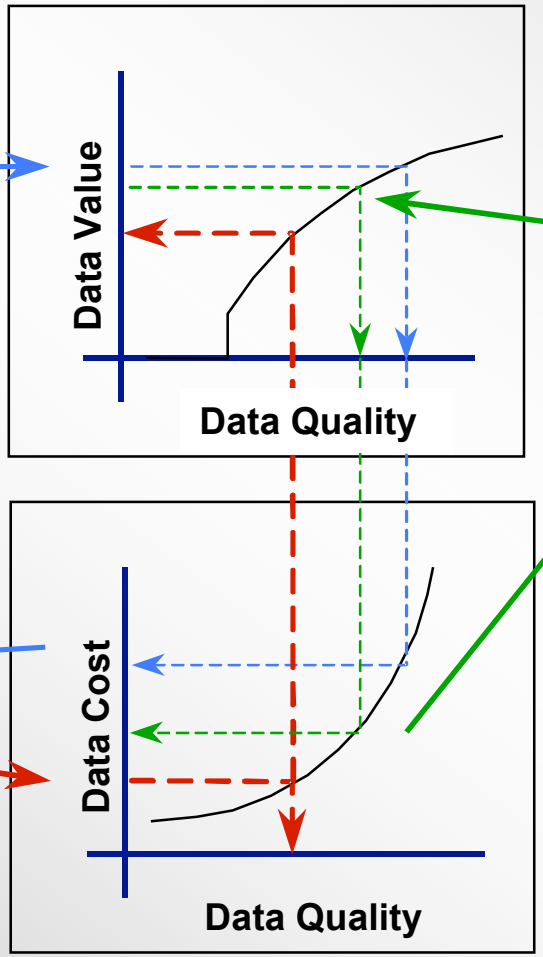
Vision: Analysis of the Future

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!"

- 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

(Wright, 2002)

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!