Intelligence Analysis and Uncertainty

- Intelligence information comes from reports subject to many kinds of uncertainty
  - Noise in sensors
  - Incorrect, incomplete, deceptive human intelligence
  - Lack of understanding of cause and effect mechanisms in the world
  - etc.

- Effective intelligence analysis requires combining uncertain reports from multiple sources to form a coherent picture of a situation
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

Web Services: Enabling Interoperability

SOAP over HTTPS

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
  - Data structures embedded in 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)

Uncertainty and Ontologies

- Semantically aware systems are essential to multi-INT fusion.
- Ontologies are a means to semantic awareness
  - Explicit, formal representation of entities and relationships in a domain of application
- Representing and reasoning with uncertainty is essential
- But...

**Traditional ontological engineering methods provide no support for representing and reasoning with uncertainty in a principled way**
Issues

- How should uncertainty be represented in semantically aware systems?
- Should ontologies provide a means to express uncertainty?
- How should ontologies and probabilistic reasoning systems work together?

Probability and Ontology

- Much of our domain knowledge is statistical
- Reasoner can use statistical regularities to:
  - Classify instances (Bayesian classifiers)
  - Infer attributes of instances
- Multi-INT fusion systems must exchange more than just conclusions
  - Uncertainties
  - Pedigrees
  - Sources and credibility information
- Representing statistical information in ontologies supports interoperability
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
  - Alpha version released March, 2008 on SourceForge

(Costa, 2005)

Case Study: Bombing in Lahore
**Background**

- **Roles:**
  - IA1 & IA2 – Intelligence Analysts #1 & 2
  - AD – Known Arms Dealer in Islamabad
  - TL1 – TL6 – Tribal Leaders

- **Background information:**
  - IA1 maintains social networks of persons-of-interest in Pakistan; has created a SN around AD
  - IA2 has access to all intel reports associated with Lahore
  - IA2 is currently monitoring a conference of six tribal leaders (TL1-TL6) which is occurring in Lahore

**Information Set #1**

- **New Roles:**
  - P – Person arrested in Lahore
  - B_p – The brother of P
  - C – Religious Advisor, Cleric

- **New Evidence:**
  - Canine unit detects explosive residue on P attempting to leave city
  - P is declared a Person-Of-Interest and added to IA1’s SN
  - SNA reveals:
    - B_p is the brother of P
    - C is the religious advisor of B_p
    - C is also the religious advisor of AD
  - IA1 alerts IA2 of relationship

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**UNBBayes-MEBN**
Multi-Entity Bayesian Networks

- Synthesis of Bayesian networks and first-order logic
  - MEBN is to Bayesian networks as algebra is to arithmetic
- MEBN fragments (MFrags) represent probabilistic relationships among small set of related uncertain hypotheses
- Compose into MEBN Theories (MTheories)
  - Collection of MFrags that satisfies consistency constraints
  - represents probability distribution over model structures of associated first-order logic theory
- Use situation-specific BN (SSBN) to reason over instances

Lahore Incident MFrags I

Plan Agent and Target MFragment

Social Network MFragment

Forensic Report MFragment

Plan Execution MFragment
SSBN Before Adding Evidence

SSBN With Evidence

- Probability of attack on conference has increased from 0.2% to about 10%
Information Set #2:

- New evidence:
  - HUMINT report that TL6 is seen in Karachi entering residence of C
    - C is religious advisor of AD and brother of arrested person P
  - IMINT change detection reports missing car from site of conference

Lahore Incident MFrags II
Probability of attack has increased to 71%

Comments

- This case study illustrates aspects of reasoning that are needed to achieve effective multi-INT fusion
- Enablers for automated support for this kind of reasoning:
  - General knowledge of logical constraints on properties of and relationships among entities of different types
  - General knowledge about likelihoods for properties of and relationships among entities of different types
  - Computationally efficient reasoner for building SSBN from instance-specific reports
- Enablers for multi-INT fusion
  - Shared vocabularies for interchanging all of the above types of information
In Conclusion…

- Uncertainty is ubiquitous in intelligence analysis
- Effective multi-INT fusion requires uncertainty management
- Uncertainty management must work smoothly with semantic technology
- PR-OWL extends OWL ontology language to represent probabilistic information

Thank You!