Automated Risk Assessment of Sensor Information Disclosure in Coalition Operations

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- Background:
  - Mechanical Engineering (B.Sc, M.Sc.)
    - Automatic Control Systems and Computation Fluid Dynamics
  - Computer Science (M.Sc., Ph.D.)
    - Machine Learning, Computer Security and Complex Networks
- Current Affiliations
  - Research Scientist at IHMC
  - Graduate Faculty at the Florida Institute of Technology
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- Current Areas of Research
  - Cyber Security and Bio-Inspired Resilience
  - Critical Infrastructure Protection
  - Complex Networks and Distributed Systems
    - Tactical Communication Networks
    - Self-Similarity in Complex Networks
    - Social Network Analysis and Virtual Worlds

Research Team in Ocala, FL

- Marco Carvalho
- Adrian Granados
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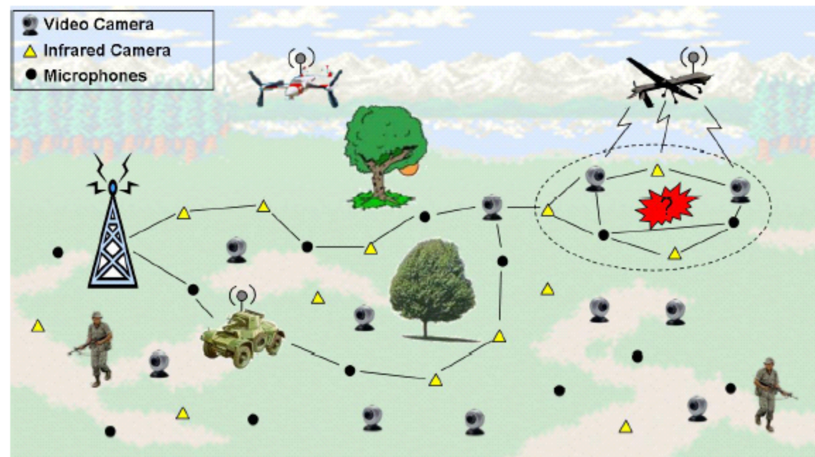
- Massimiliano Marcon
- Giacomo Benincasa

- Graduate Students and collaborators
  - UF (Mechanical and Aerospace Engineering, Industrial Engineering, and Computer Science)
  - UF - Center for Applied Optimization (Gainesville, FL)
  - Harris Center for Information Assurance (Melbourne, FL)

What is the Problem?

- A **sensor network** is deployed in an area of interest
- Sensors have different security **classifications,** or classified **capabilities**

- The Problem: How to **provide information** to friends (troops and coalition partners) **while minimizing the risk of disclosing** the presence and/or location of the **classified sensors**?



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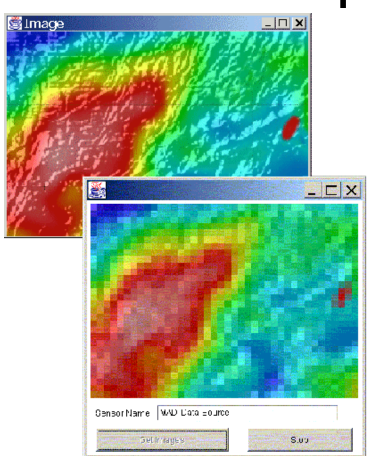
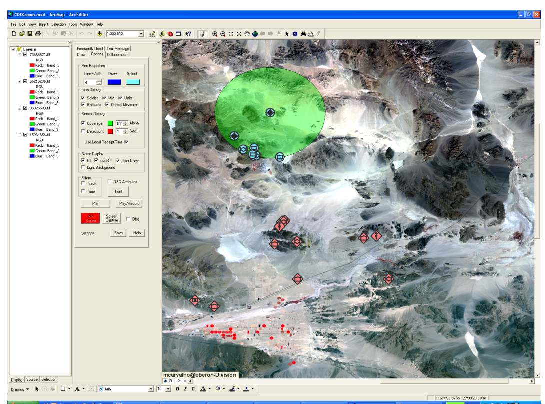
Related Work

- Statistics:
  - Statistical Disclosure Control (SDC)
  - Statistical Disclosure Limitation (SDL)
  - Inference Control
- Data Mining
  - Privacy Preserving Data Mining (PPDM)

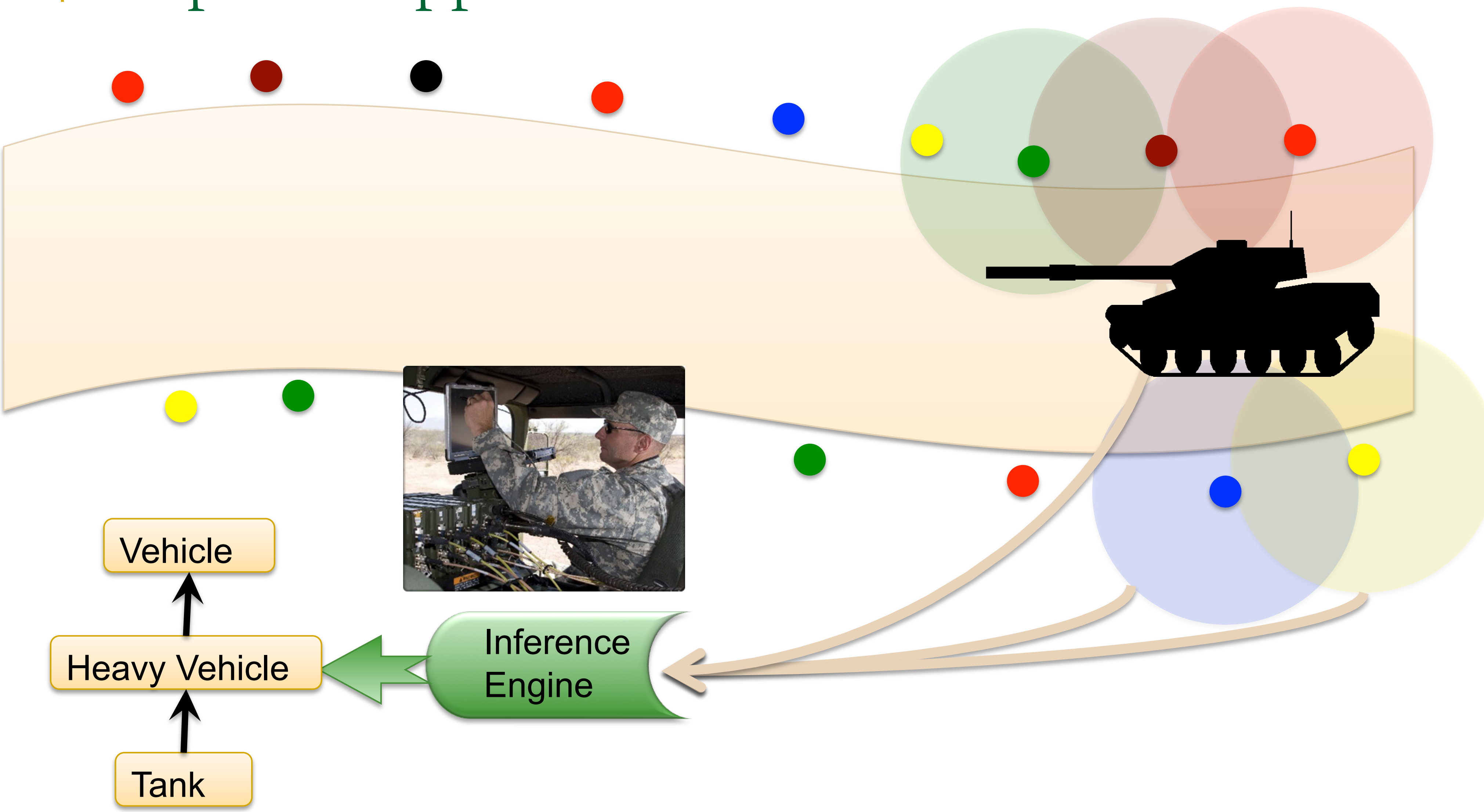
Related Work (cont.)

- ARL Collaborative Technology Alliance
  - Advanced Decision Architectures
    - Policy-governed information exchange
- Information and Sensor Capability Protection
  - Coalition Operations
  - Adversaries in the field, etc.
  - Risk-adaptive access control



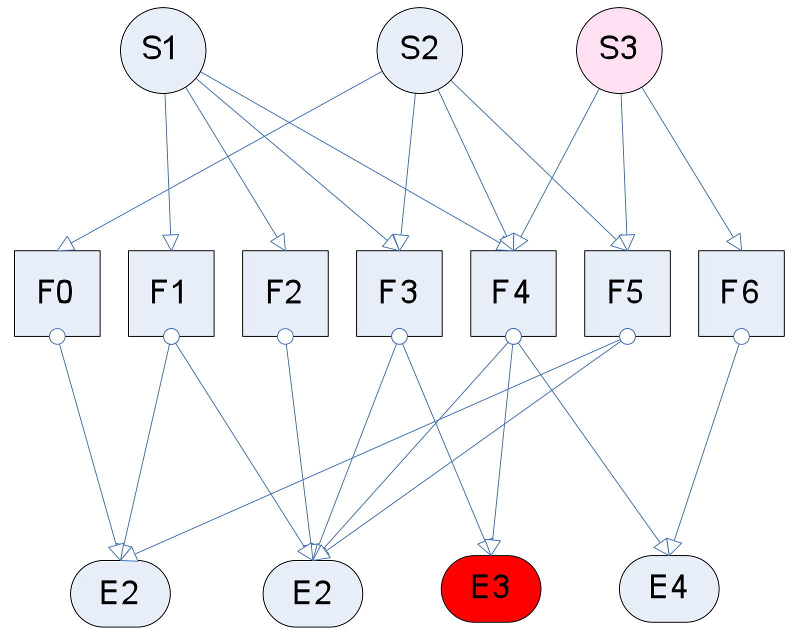


Proposed Approach



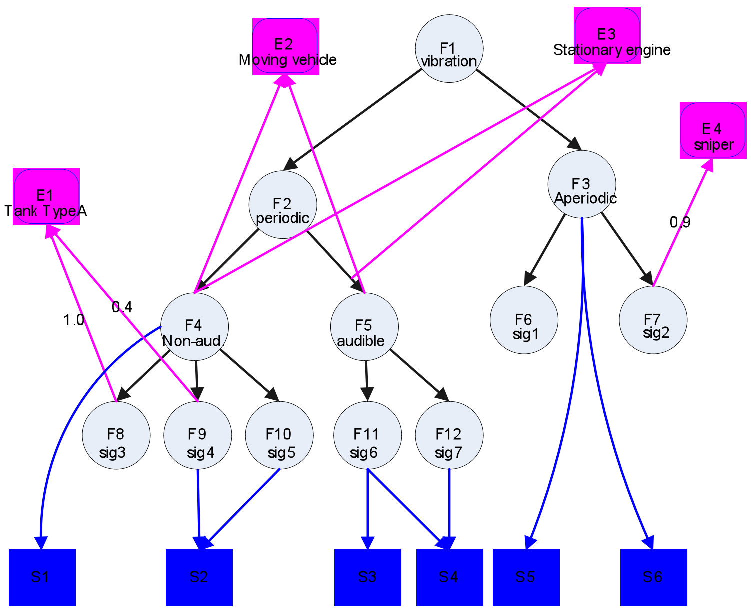
A Simple Example

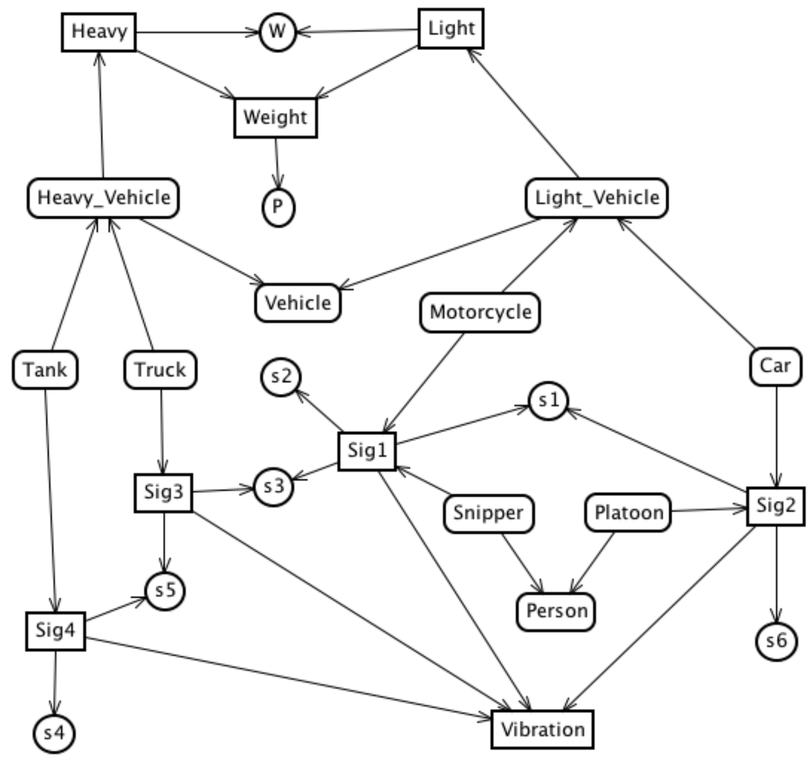
- Reporting E3
  - Ambiguous sources “S2” or “S3”
  - Depending on history of entities previously reported to that soldier, the probability of choosing “S2” is greater than that of choosing “S3”
  - Direct Bayesian inference from the soldier side can be used to estimate the presence of sensor “S3”



A More Complex Scenario

Selective Information Release for Source Protection

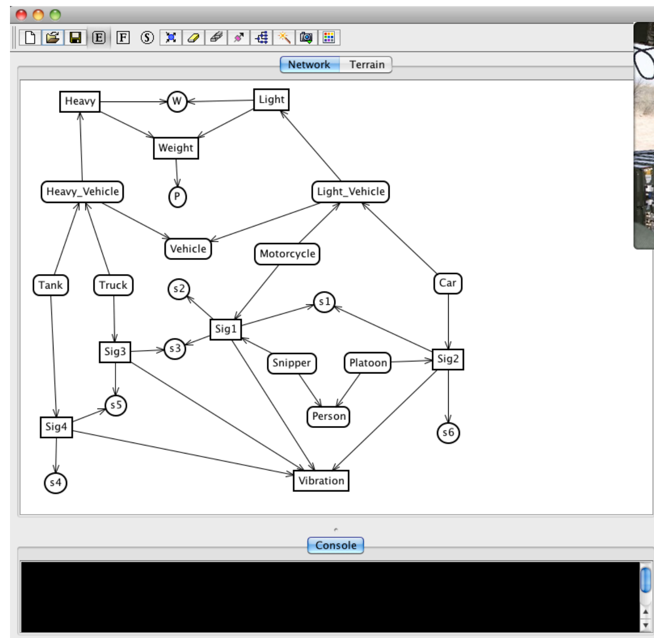


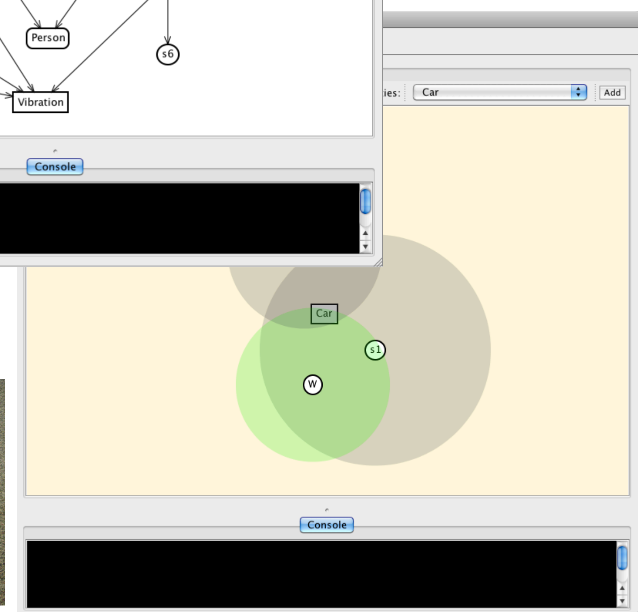


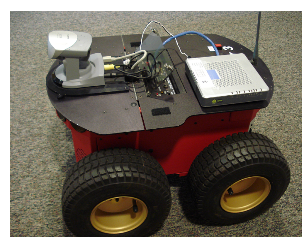
Proposed Solution

- Build an Automatic Source Protection Network (ASPNet), a Bayesian Network that uses an ontology to represent a hierarchy of entities and features

- Use the ASPNet for detecting entities and for assessing the risk of disclosing sensor information using probabilistic inference

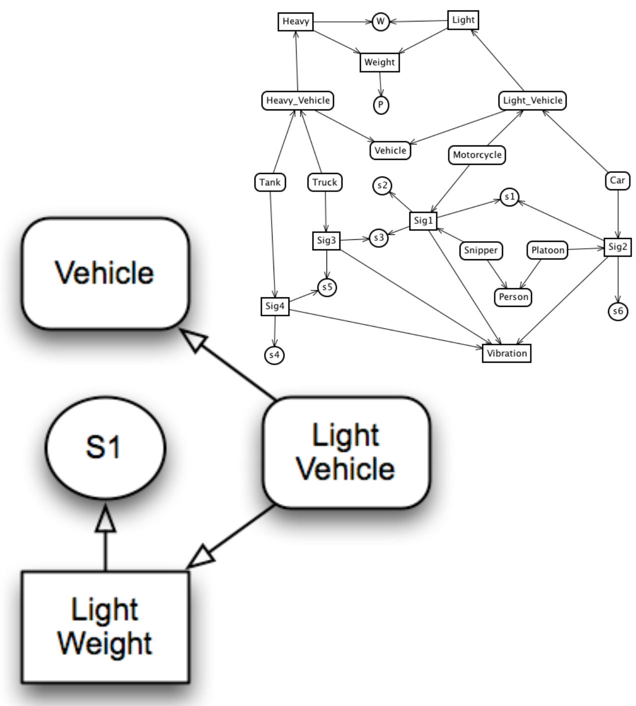




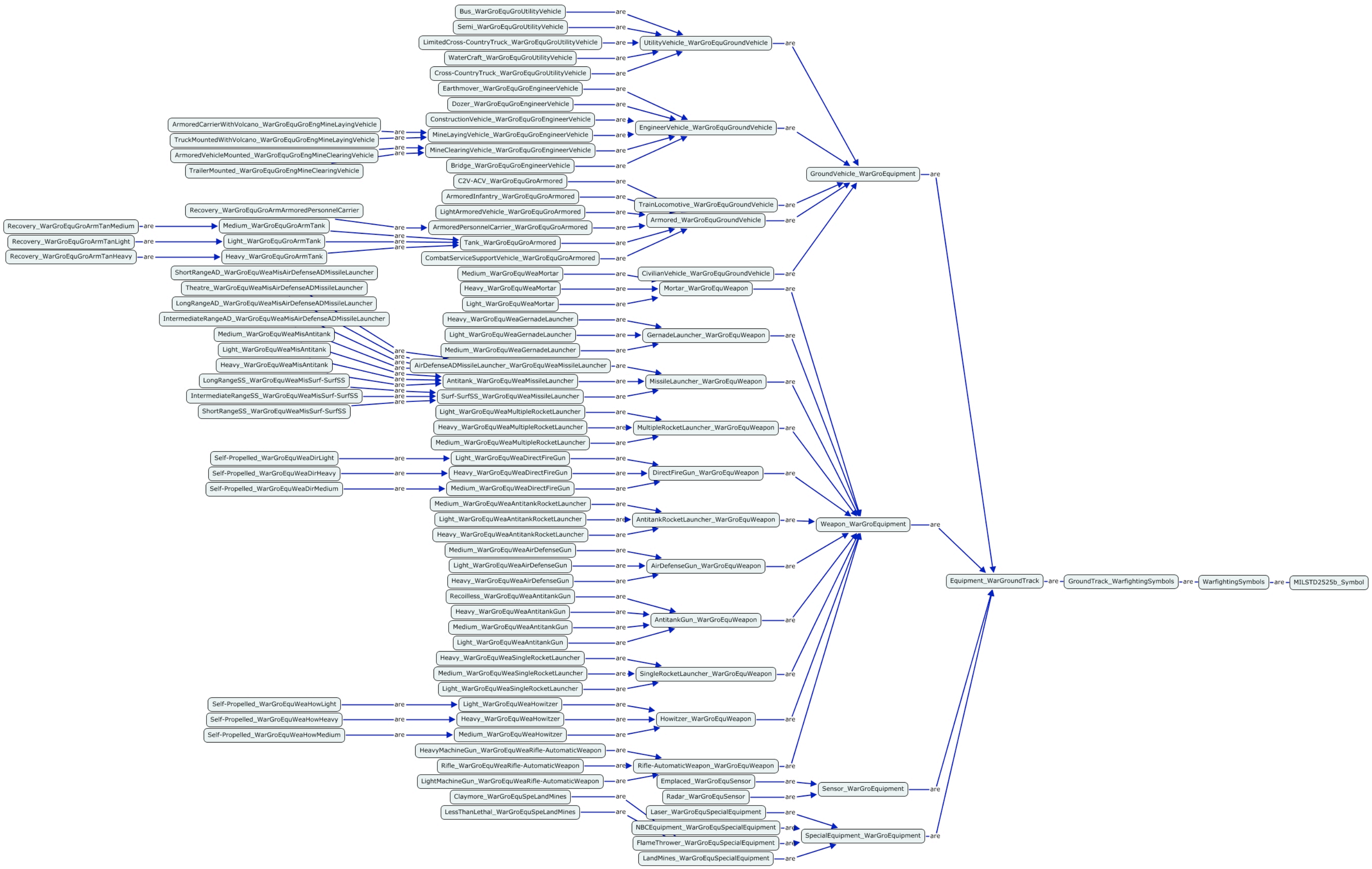


ASPNet Specification

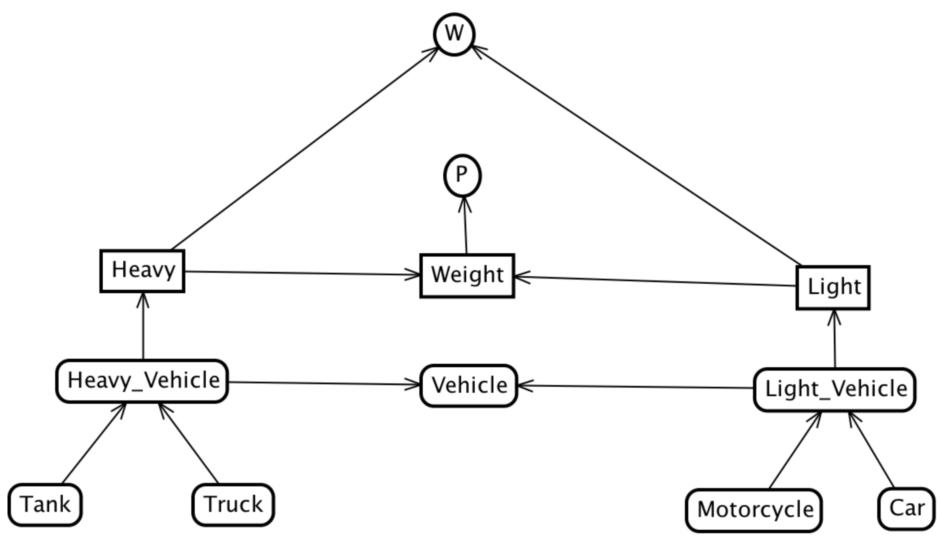
- Bayesian Network
  - Automatically-detected sensor field information, hierarchy of equipment (ontology), and technical database of features and known signatures
- Contains three types of nodes:
  - Entities
  - Features
  - Sensors
- All nodes are binary (true or false)
- Allowed Links:
  - Entities → Parent Entities
  - Entities → Features
  - Features → Parent Features
  - Features → Sensors



Equipment (Entity) Ontology



ASPNet Example

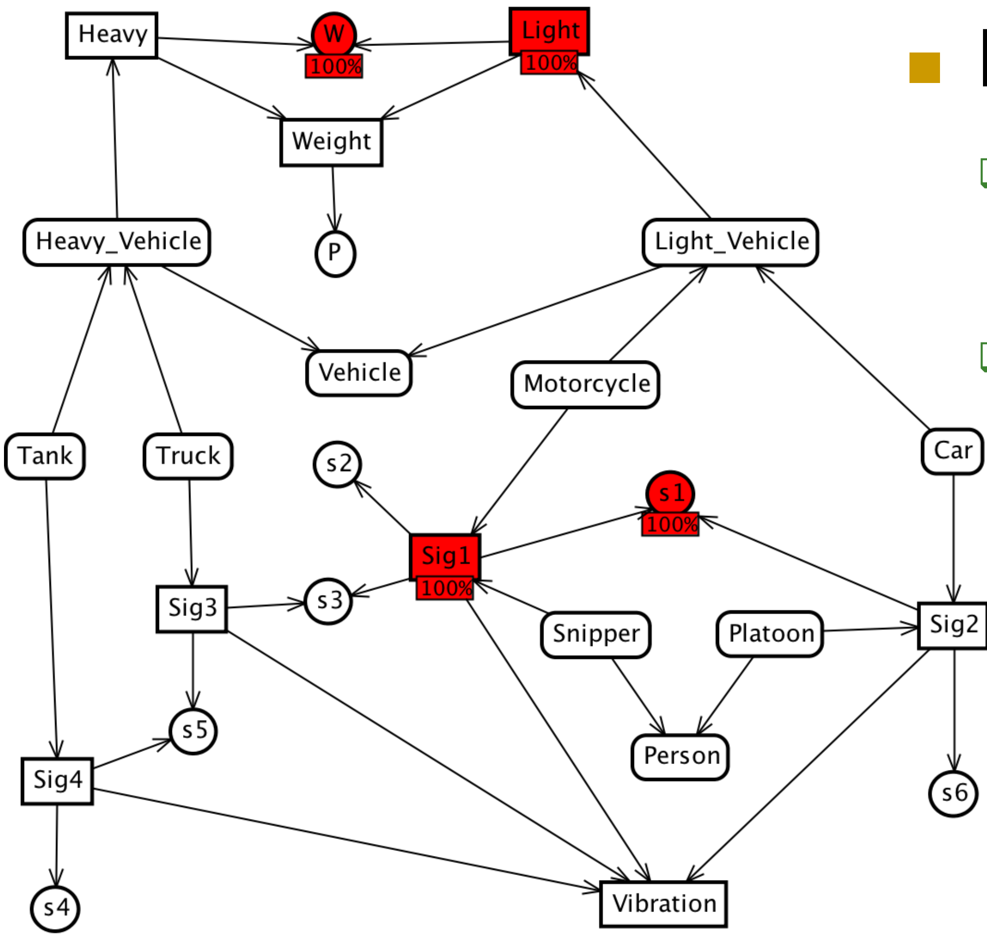


- **Entities:** Vehicle, Heavy_Vehicle, Tank, Truck, Light_Vehicle, Motorcycle, Car
- **Features:** Weight, Heavy, Light
- **Sensors:** W, P

Detecting an Entity

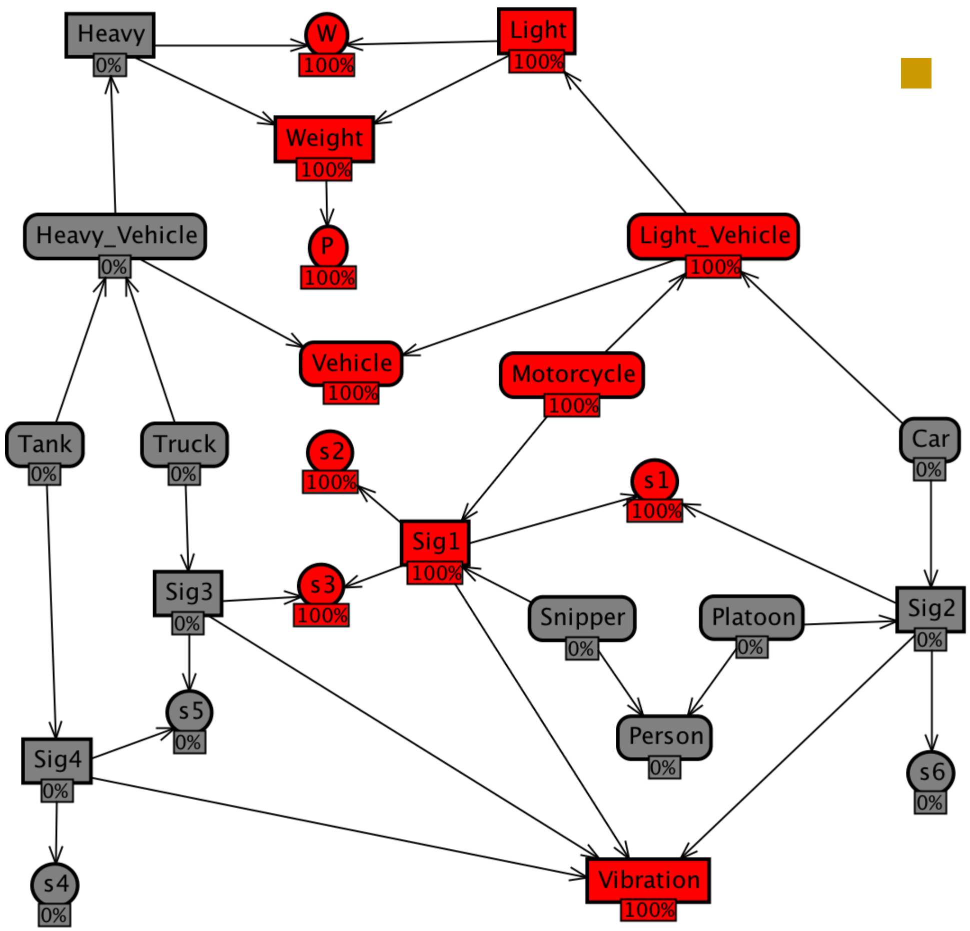
- Gather information provided by the sensors
- Feed that information to the Bayesian Network
- Run an **inference algorithm** over the network
- Pick the entity or entities with **highest probability**

Detection Example



- **Evidence**
  - **W** sensor measured feature **Light**
  - **s1** sensor measured feature **Sig1**

Detection Example (continued)



- **Results of Inference:**
  - The entity is:
    - Vehicle
    - Light_Vehicle
    - Motorcycle

Source Protection Problem

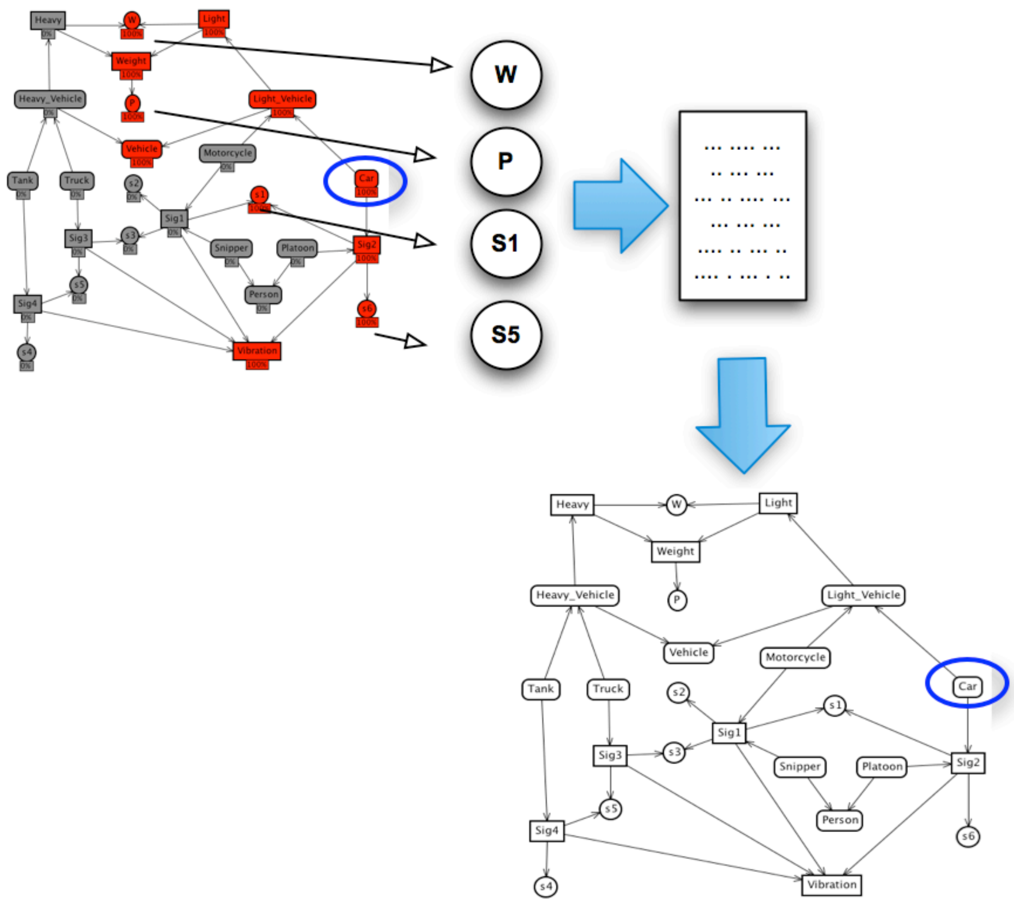
- In the previous example we could disclose to the soldiers that entity is a **Motorcycle**, a **Light_Vehicle** or simply a **Vehicle**
- However, from a **sensor protection** perspective, there is a different risk for each one of these disclosures

Risk of Disclosing a Sensor

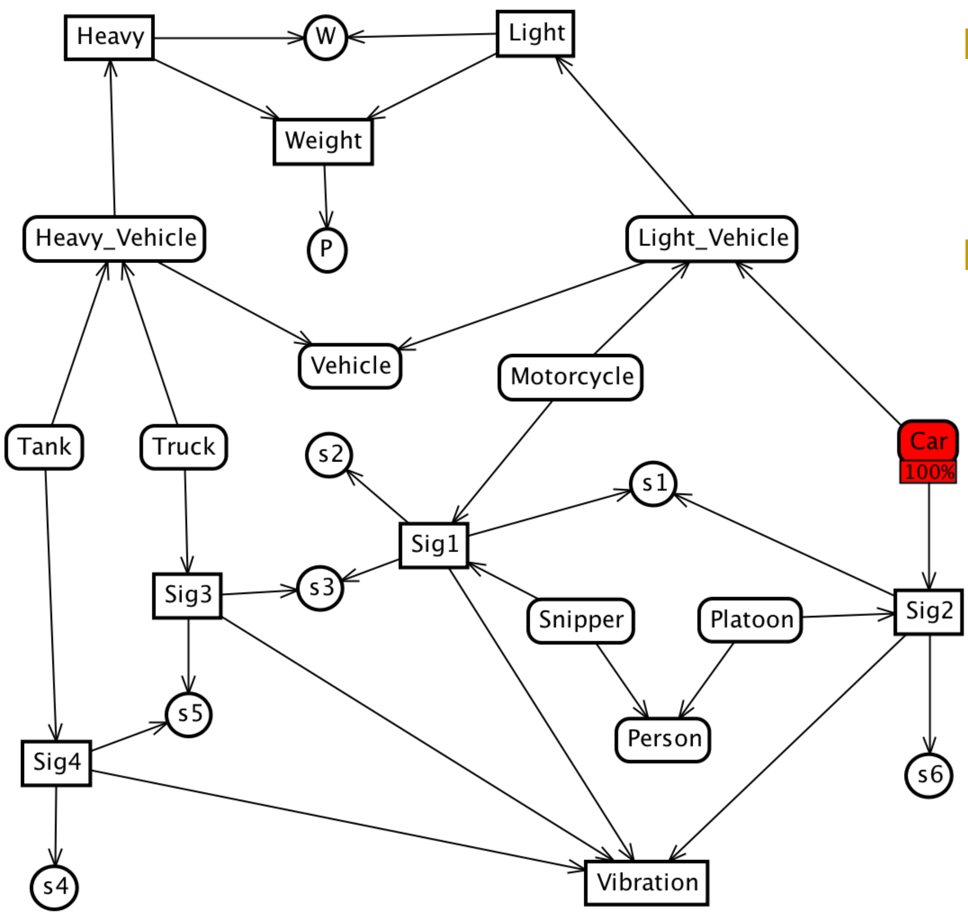
```
Input: N (ASP Network)
Input: e (Entity to be disclosed)
Input: t (Activation threshold)
P ← DoInference(N, {e = true});
F ← {f|f ∈ N ∧ IsFeature(f) ∧ P(f) ≥ t};
S ← {s|s ∈ N ∧ IsSensor(s) ∧ ∃f ∈ F [DetectsFeature(s, f_i)]};
F_s ← {f|f ∈ F ∧ s ∈ S ∧ DetectsFeature(s, f)};
R ← {};
for C ∈ P(S) do
    indexes[1 ... |C|] ← 0;
    i ← 0;
    while C ∉ R ∧ i ≥ 1 do
        s ← C(i);
        indexes[i] ← indexes[i] + 1;
        if indexes[i] ≥ |F_s| then
            indexes[i] ← 0;
            i ← i − 1;
        else
            if i = |C| then
                E ← {};
                for j ∈ {1 ... |C|} do
                    s ← C(j);
                    E ← E ⋃ F_s[indexes[j]];
                end
                P ← DoInference(N, E);
                if P(e) ≥ t then
                    R ← R ⋃ {C};
                end
            else
                i ← i + 1;
            end
        end
    end
end
return R
```

- The risk of disclosing a sensor will be defined as the probability of having used the sensor for detecting the entity
- How is this probability computed?
    - Identify all combinations of sensors that would allow to detect the entity
    - Divide the number of combinations including the sensor by the total number of combinations

Risk Assessment

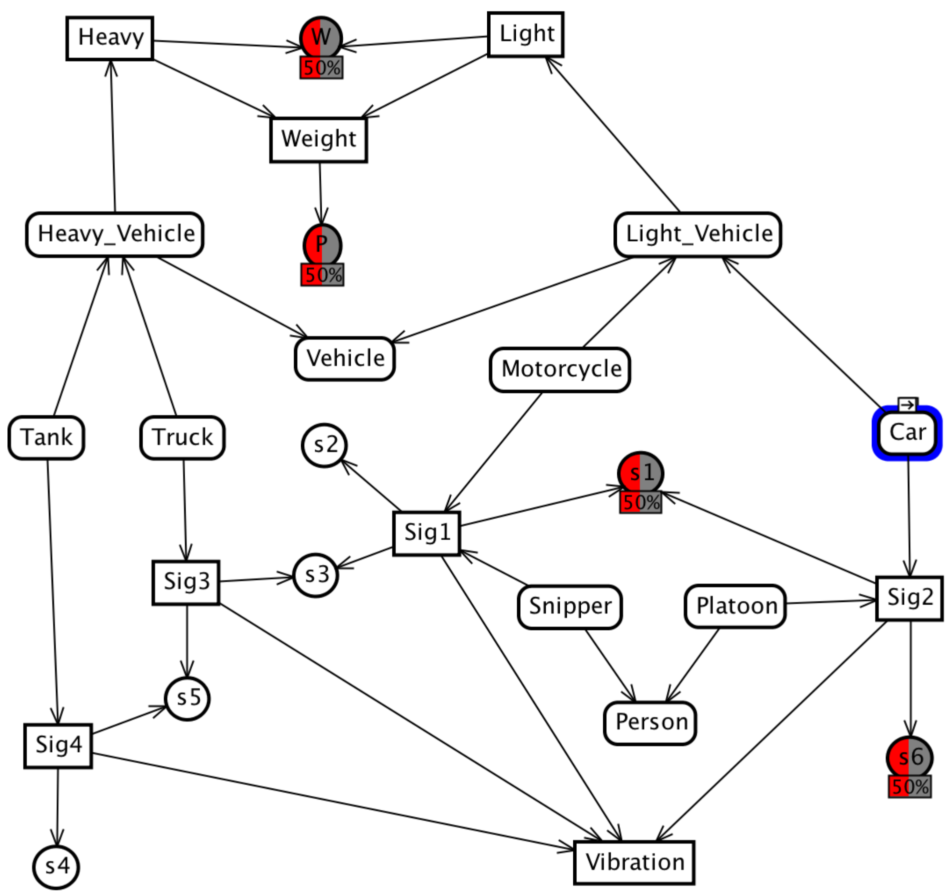


Risk Assessment Example



- Entity to Disclose: **Car**
- Sensor combinations that allow the detection of a **Car:**
  - **{W, s1}**
  - **{W, s6}**
  - **{P, s1}**
  - **{P, s6}**

Risk Assessment Example (continued)



- Sensor combinations:
  - {W, **s1**},
  - {W, s6}
  - {P, **s1**}
  - {P, s6}
- Risk of **s1** = 2 / 4 = 50%

First Evaluation

- **Hypothesis**: Using more abstract ontology classes reduces the risk
- **Evaluation**:
  - Obtained network from Army National Training Center
  - For each child entity, C, assess the risk for each sensor S → Risk(S | C)
  - Then for the parent entity, P, assess the risk for each sensor S → Risk(S | P)
  - Risk(S | C) – Risk(S | P)
  - Average differences

Second Evaluation Using Army National Training Scenario

- **Scenario**: subset of a military exercise dataset from the Army National Training Center
- 161 nodes
  - 51 sensors
    - 18 sensor types
  - 110 entities
    - Ontology has 63 classes of entities

Risk Assessment

Sensor	Entity								
	P07	P0	P	P82	P8	P	4UZ	4U	4
SEH	14.29%	12.50%	8.00%	33.33%	33.33%	8.00%	18.18%	18.18%	16.98%
SQ3IR	14.29%	12.50%	24.00%	33.33%	33.33%	24.00%	36.36%	36.36%	22.64%
SEC	14.29%	12.50%	4.00%	0.00%	0.00%	4.00%	18.18%	18.18%	11.32%
SNH	0.00%	0.00%	36.00%	0.00%	0.00%	36.00%	100.00%	100.00%	52.83%
SW	0.00%	0.00%	12.00%	0.00%	0.00%	12.00%	0.00%	0.00%	7.55%
SQ5	14.29%	12.50%	4.00%	0.00%	0.00%	4.00%	9.09%	9.09%	22.64%
SNU	100.00%	87.50%	48.00%	0.00%	0.00%	48.00%	0.00%	0.00%	3.77%
SN8	0.00%	12.50%	4.00%	0.00%	0.00%	4.00%	0.00%	0.00%	0.00%
SW0	0.00%	0.00%	24.00%	100.00%	100.00%	24.00%	0.00%	0.00%	7.55%
SEY2	14.29%	12.50%	4.00%	0.00%	0.00%	4.00%	27.27%	27.27%	11.32%
SN9	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.89%
SN90	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.89%
SW3	0.00%	12.50%	12.00%	0.00%	0.00%	12.00%	0.00%	0.00%	15.09%
SQ3I6	57.14%	50.00%	56.00%	33.33%	33.33%	56.00%	36.36%	36.36%	22.64%
SWP	0.00%	0.00%	12.00%	0.00%	0.00%	12.00%	0.00%	0.00%	16.98%
SEYO	57.14%	50.00%	16.00%	0.00%	0.00%	16.00%	36.36%	36.36%	37.74%
SWN	0.00%	0.00%	12.00%	0.00%	0.00%	12.00%	0.00%	0.00%	9.43%
SQ3Z	14.29%	12.50%	4.00%	0.00%	0.00%	4.00%	18.18%	18.18%	20.75%

Risk Assessment (continued)

- Using more abstract classes in the ontology only helps to reduce the risk of the sensors involved in discovering the lower level entity type
- It also adds more sensors to the risk assessment, thus increasing the risk of all sensors in general
  - Thus risks of 0% will, in most cases, increase

Risk Assessment

Sensor	Entity								
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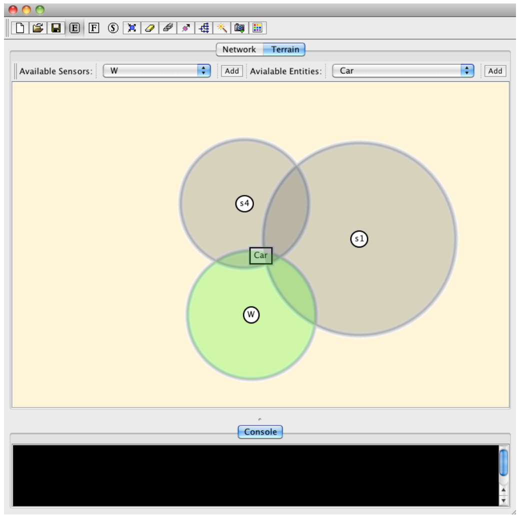
Conclusions and Future Work

- ASP provides sensor disclosure risk estimates for different detections and sensors
- Users can choose explore different hypotheses for information release through the graphical interface
- We are currently adding spatial and temporal reasoning
- The choice of the appropriate level of abstraction for information release is not always intuitive, but it can be facilitated by the proposed approach



Acknowledgments

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Thank you!

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