
MEBN Logic: A Key Enabler for Network Centric Warfare

June 16, 2005

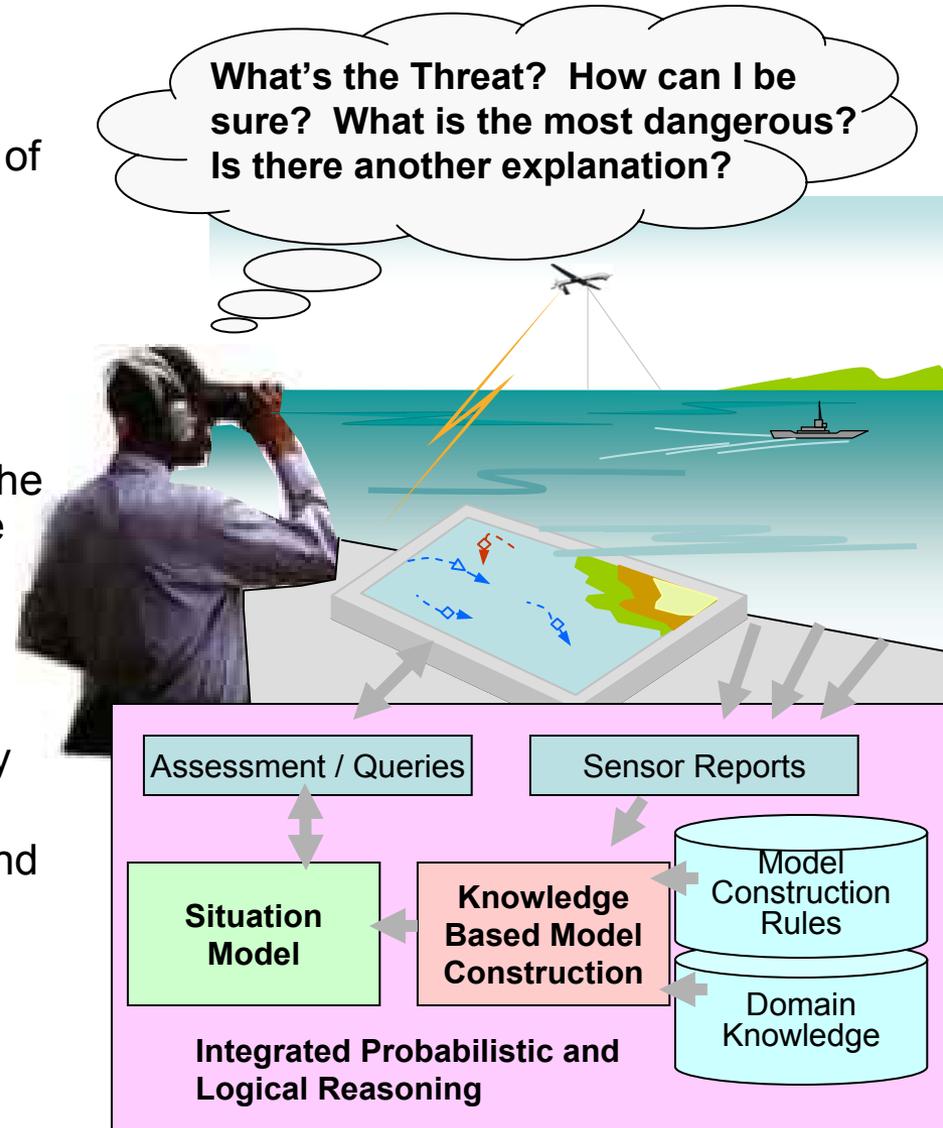
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- Supporting Situation Awareness
 - Example: Libyan Gunboat Threat ID
 - Multi-Entity Bayesian Networks
 - Situation-Specific Model Construction



- Situation awareness
 - Essential to sound decision making
 - Requires rapid processing of large volumes of information
 - Automated support is needed
- Current Systems:
 - Rule-based methods for storing expert knowledge
 - Flexible, simple, but unable to comply with the increasing complexity of today's battlespace
 - Usually poor treatment of uncertainty
 - Bayesian Networks
- Our Approach:
 - Domain knowledge is stored in a Multi-Entity Bayesian Network model (MEBN)
 - Quiddity*Suite is used to query the model and perform the Bayesian reasoning process
- Benefits
 - Improved situation awareness
 - More time to explore alternatives



- Fuse uncertain, ambiguous and conflicting evidence
- Reason about multiple entities of various types
- Compare different hypotheses to explain evidence
- Infeasible to consider all possible hypotheses from the outset
- Set of hypotheses that should be considered can change as evidence appears

- Territorial dispute:
 - Libya claims waters in Gulf of Sidra below Line of Death.
 - US claims these are international waters.
- Setting:
 - US Aegis cruiser is just below LOD.
 - Libyan gunboat turns and heads rapidly toward cruiser.
 - **Is this an attack?**
- Complicating factors:
 - Another Aegis cruiser is further below LOD.
 - Gunboat probably could not detect cruiser at range at which it turned.
 - Libya had air asset that was probably better platform for launching attack.



Ref: Marvin Cohen, Jared Freeman, and Steve Wolf, "Metarecognition In Time-Stressed Decision-Making", 1996.

- Scenario illustrates:
 - Reasoning with uncertainty
 - Generating alternative pictures of the situation
 - Deciding whether to act immediately, reflect more, or collect more information
- Their claim: “They were hardly Bayesians”
 - No pre-enumerated set of hypotheses
 - Each cue interpreted in alternative ways within different situation pictures
- Our Claim: Situation-specific Bayesian network construction can model Officers’ reasoning

- Initial hypothesis: patrol
 - Default for all ships
 - Conflicts with fast speed of gunboat



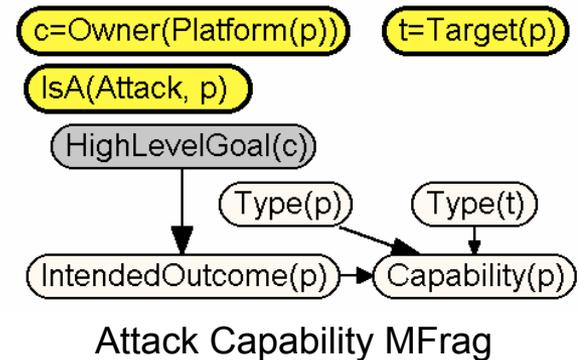
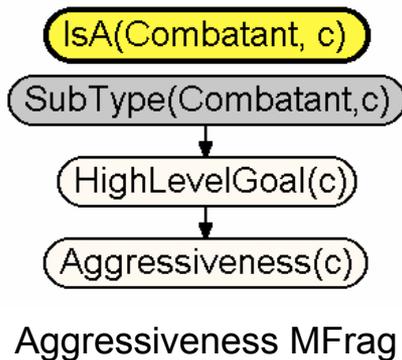
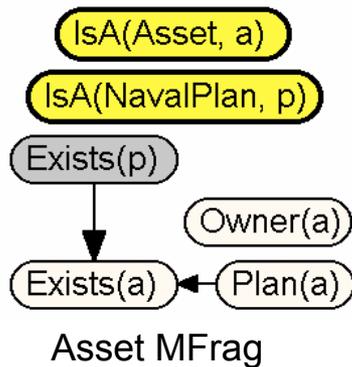
- Second hypothesis: gunboat is attacking own ship
 - Could be provoked by own ship under Line of Death
 - Consistent with direct rapid approach
 - Conflicts with inability to localize

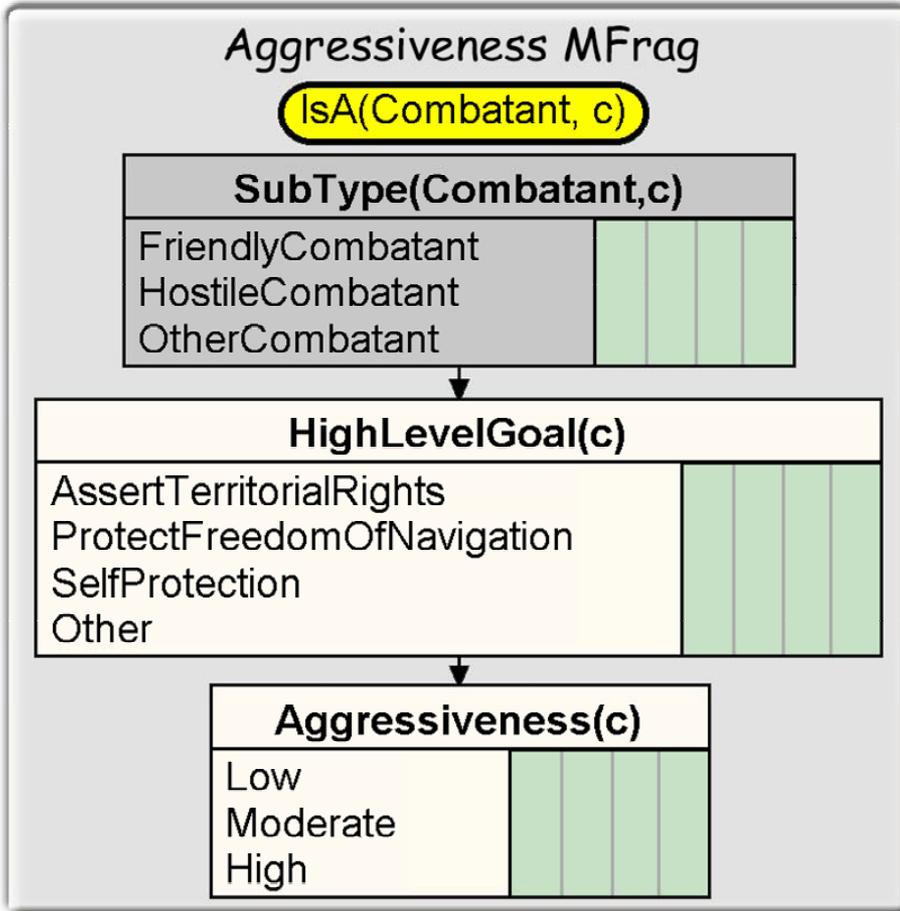


- Third hypothesis: opportunistic attack (attack any ship that comes within range)
 - Consistent with fast speed
 - Does not require that gunboat could localize cruiser at time of turn

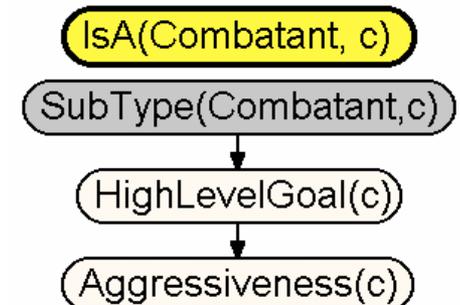


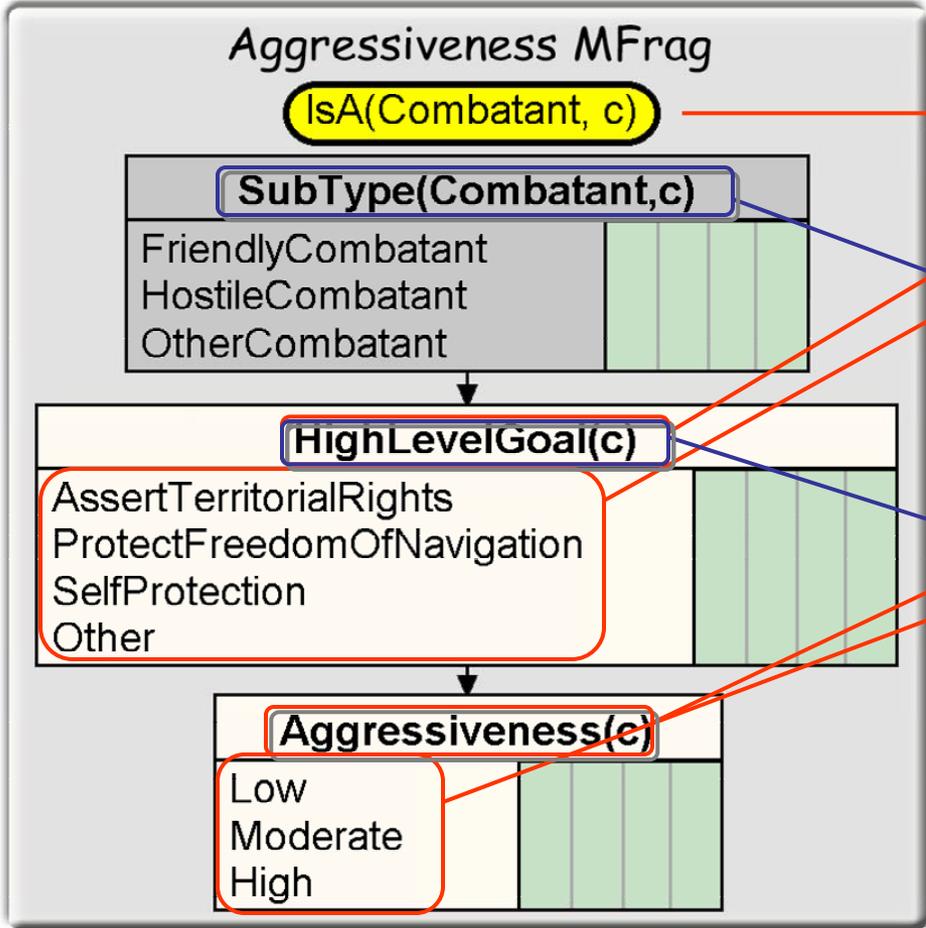
- Model entities of interest in domain with MEBN Fragments (*Mfrags*)
 - naval assets (Libyan gunboat, Aegis cruiser...)
 - plans (attack, patrol...)
 - reports (speed, direction...)
- Based on incoming evidence, incrementally assemble situation-specific model





- c is an ordinary variable (“the combatant”)
- yellow: context constraint (“c must be a Combatant”)
- gray: input node (“c is which subtype of Combatant”)
- white: resident nodes (“the high level goal of c”, and “how the aggressiveness of c depends on the high level goal”)

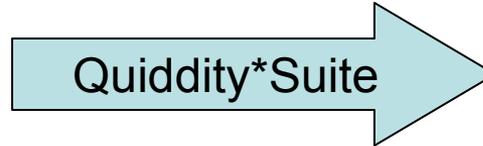
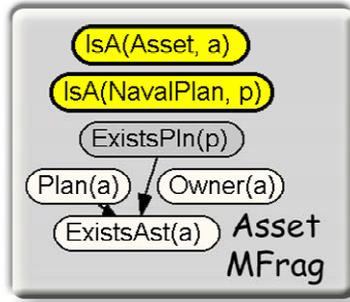




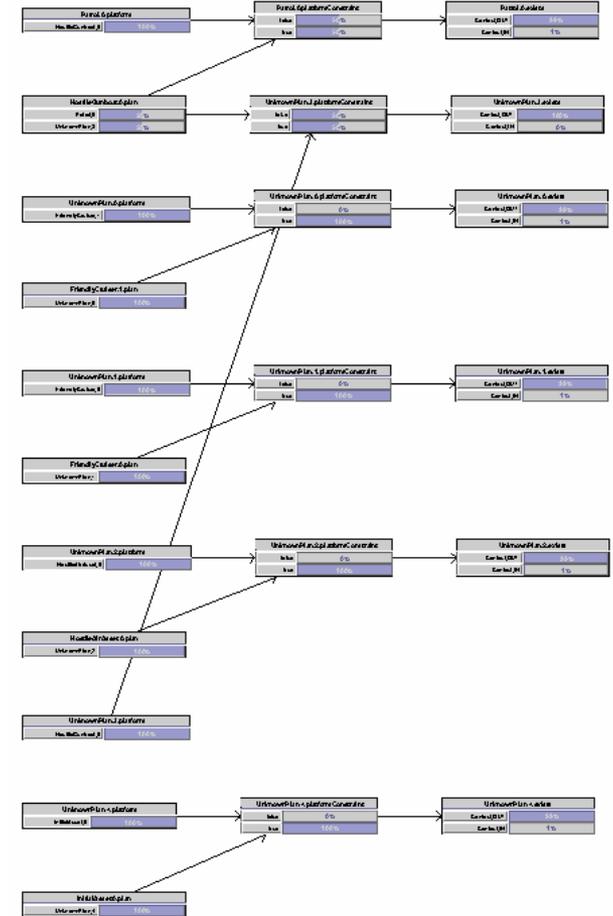
Quiddity Implementation

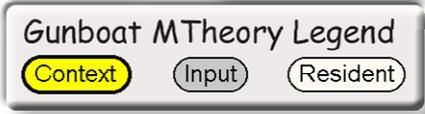
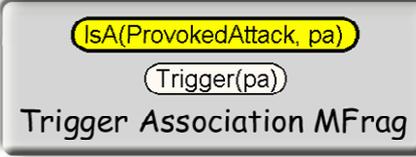
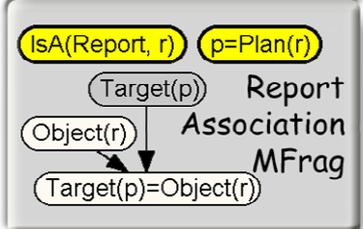
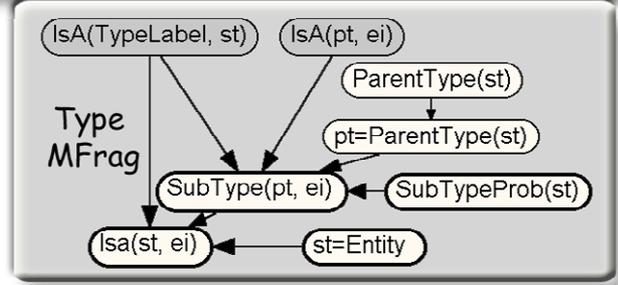
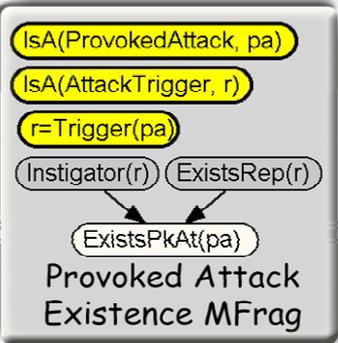
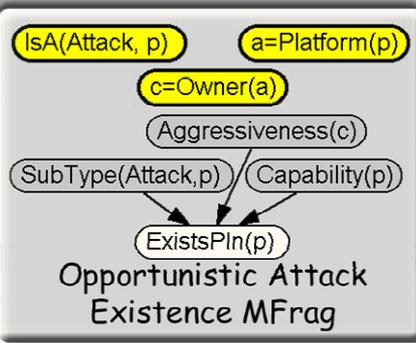
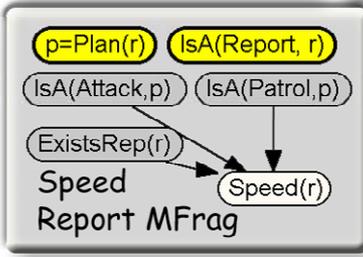
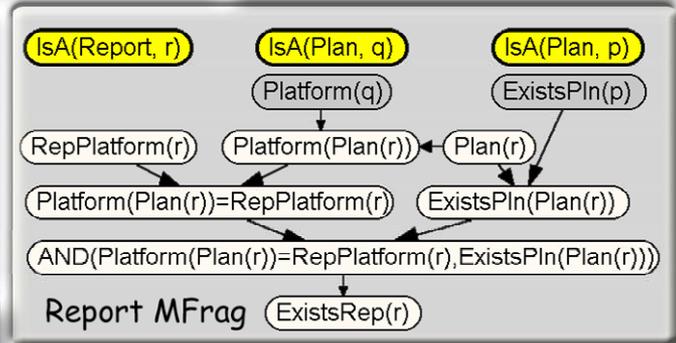
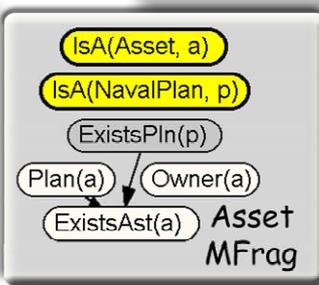
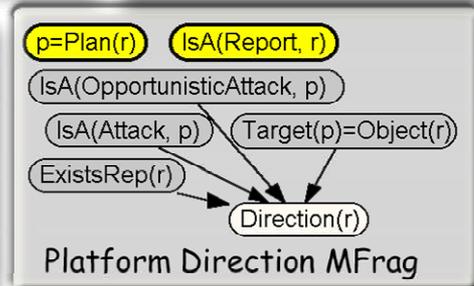
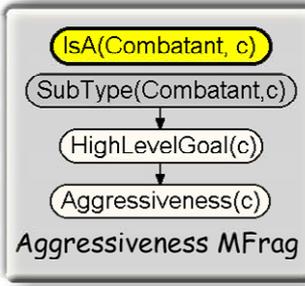
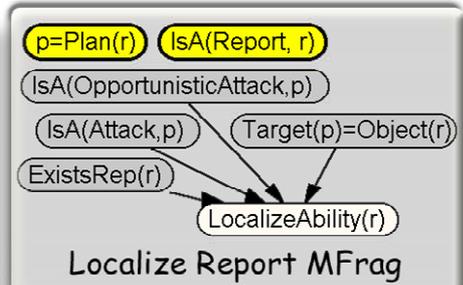
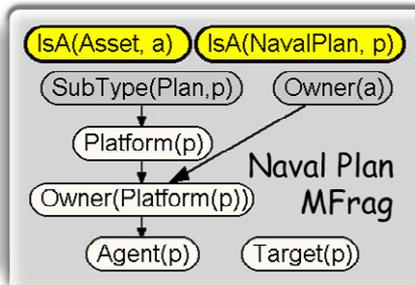
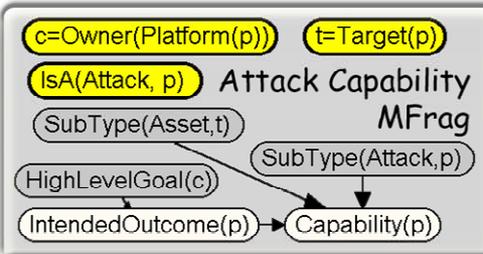
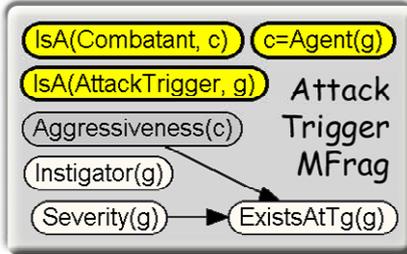
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49 frame Combatant isa Frame.
50 slot name.
51 slot highLevelGoal.
52 facet domain = [AssertTerritorialRights, .
53                 ProtectFreedomOfNavigation, .
54                 SelfProtection, .
55                 Other].
56 facet parents = [SubType].
57 facet distribution = function st {
58     Friendly Combatant: [0, 0.25, 0.25, 0.25];
59     Hostile Combatant: [0.35, 0, 0.30, 35];
60     Other Combatant: [0.25, 0.25, 0.25, 0.25];
61 slot aggressiveness.
62 facet domain = [Low, Moderate, High].
63 facet parents = [highLevelGoal].
64 facet distribution = function hlg {
65     switch hlg {
66     AssertTerritorialRights: [0.1, 0.5, 0.4];
67     ProtectFreedomOfNavigation: [0.4, 0.5, 0.1];
68     SelfProtection: [0.9, 0.1, 0.0];
69     Other: [0.3, 0.6, 0.1];
70     };
71 };
72 end;.
    
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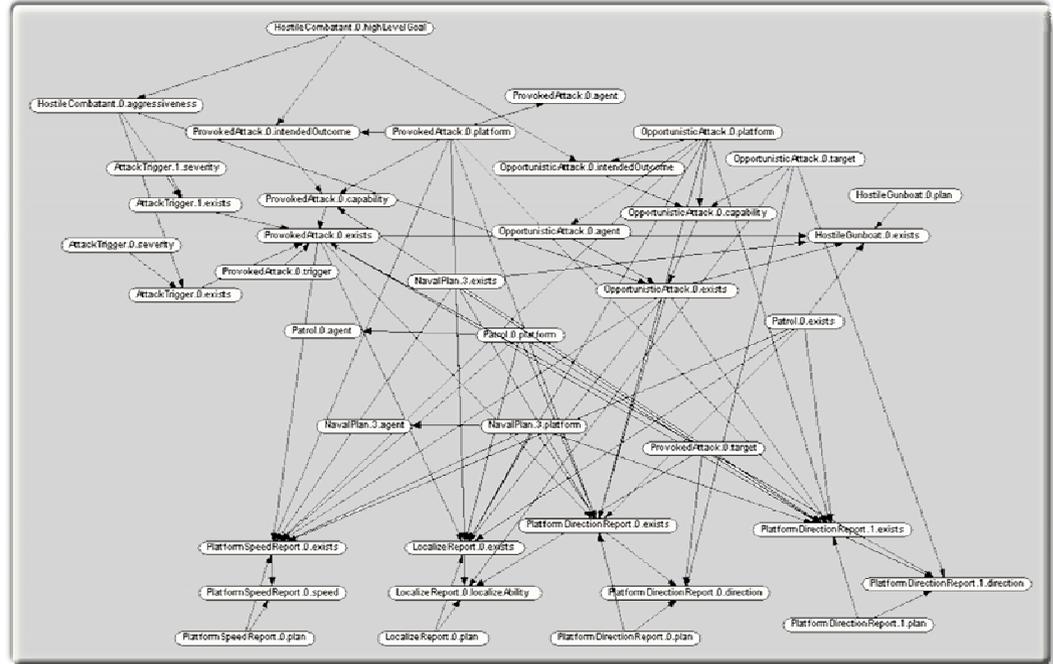
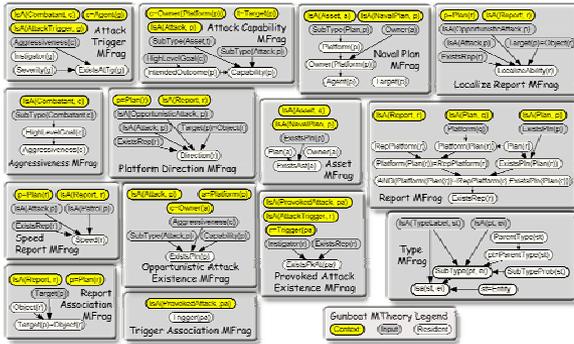


- Instantiate 4 Asset MFrag
 - 2 US cruisers
 - Libyan gunboat + air asset
 - instantiates default plans for each



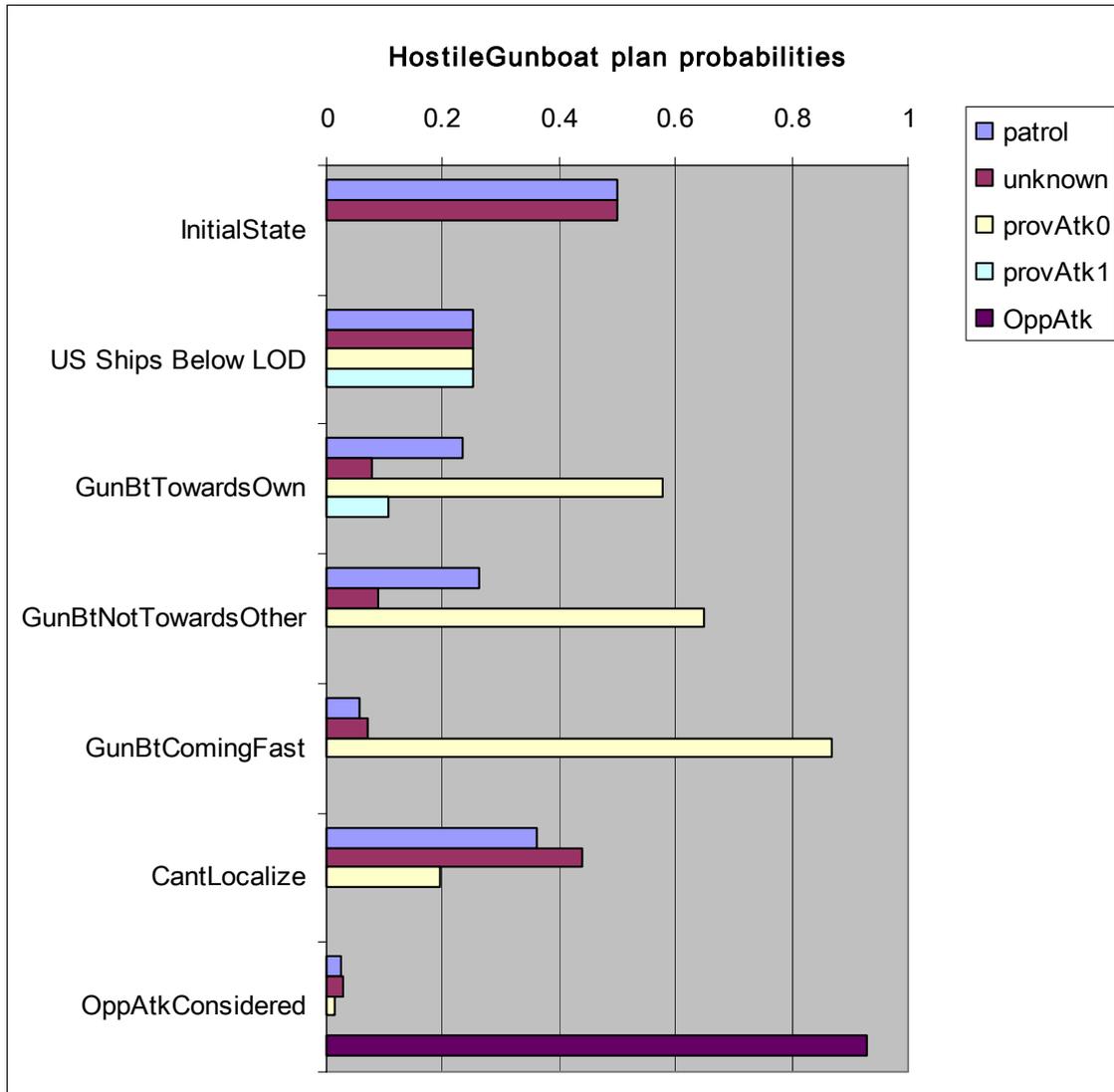


Evidence (ordered as input into the model)	Hypotheses	Probabilities	Target of Provoked Attack
Cruiser 1 instigates attack - trigger moderate severity Cruiser 2 instigates attack - trigger high severity	Provoked attack Other	69.2% 30.8%	Cruiser 1: 31.5% Cruiser 2: 68.5%
Gunboat approaching Cruiser 1	Provoked attack Other	81.4% 18.6%	Cruiser 1: 77.9% Cruiser 2: 22.1%
Gunboat not approaching Cruiser 2	Provoked attack Other	78.8% 21.2%	Cruiser 1: 89.0% Cruiser 2: 11.0%
Gunboat approaching fast	Provoked attack Other	93.2% 6.8%	Cruiser 1: 96.3% Cruiser 2: 3.7%
Gunboat probably cannot localize Cruiser 1	Provoked attack Other	62.2% 37.8%	Cruiser 1: 79.5% Cruiser 2: 20.5%
	Provoked attack Patrol Other	42.7% 31.5% 25.7%	Cruiser 1: 70.0% Cruiser 2: 30.0%
	Provoked attack Patrol Opportunistic attack Other	4.7% 2.5% 90.8% 2.1%	Cruiser 1: 51.5% Cruiser 2: 48.5%



Evidence (ordered as input into the model)	Hypotheses	Probabilities	Target of Provoked Attack
Cruiser 1 instigates attack - trigger moderate severity	Provoked attack Other	69.2% 30.8%	Cruiser 1: 31.5% Cruiser 2: 68.5%
Cruiser 2 instigates attack - trigger high severity	Provoked attack Other	81.4% 18.6%	Cruiser 1: 77.9% Cruiser 2: 22.1%
Gunboat approaching Cruiser 1	Provoked attack Other	78.8% 21.2%	Cruiser 1: 89.0% Cruiser 2: 11.0%
Gunboat not approaching Cruiser 2	Provoked attack Other	93.2% 6.8%	Cruiser 1: 96.3% Cruiser 2: 3.7%
Gunboat approaching fast	Provoked attack Other	62.2% 37.8%	Cruiser 1: 79.5% Cruiser 2: 20.5%
Gunboat probably cannot localize Cruiser 1	Provoked attack	42.7%	Cruiser 1: 70.0%
	Patrol	31.5%	Cruiser 2: 30.0%
	Other	25.7%	
	Other	4.7%	Cruiser 1: 51.5%
	Provoked attack	2.5%	Cruiser 2: 48.5%
	Opportunistic attack	90.8%	
	Other	2.1%	

- MEBN/Quiddity*Suite model can
 - Instantiate hypotheses (patrol & other) by default
 - Generate new hypotheses based on evidence (provoked attack)
 - Use reports (speed/direction) to update relative beliefs in hypotheses
 - Use “conflict” to trigger critique of initial assessment & initiate evidence collection to “tip the balance” (seek localization report)
 - Reassess relative beliefs when new hypothesis is instantiated (rebut original arguments)



- Probabilities of the considered hostile gunboat plans
- First: Patrol + Other
- Then Provoked Attacks on Ship1 or Ship2
- More likely Provoked Attack on Ship1 when coming toward Ship1, and fast
- But can't localize Ship1
- Since Other is high, consider Opportunistic Attack



- Store domain knowledge in “small pieces” that can be reused in future occasions
- Allow model extensibility to deal with increased scenario complexity
- Use Bayesian learning to infer possible pattern correlations given a corpus of data
- Deal with type, association and existence uncertainty
- Threat hypothesis management in real time

- MEBN/Quiddity*Suite combines strengths of BNs and FOL
- Model agrees with qualitative reasoning of historical actors
- Model is easily extended to richer and more complex situation assessment cases
- MEBN/Quiddity*Suite is an appealing technology for addressing complex command and control problems

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