MEBN Logic: A Key Enabler for Network Centric Warfare

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Outline

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

• 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
Reasoning Challenges

- 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
Example Scenario

• 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.

Example Scenario

• 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
US 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
Situation Modeling with MEBNs

- 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
Example MFrAg

- **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")
Instantiating Asset MFrags

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

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

Quiddity*Suite

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<th>Probabilities</th>
<th>Target of Provoked Attack</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cruiser 1 engages attack - trigger moderate severity</td>
<td>Provoked attack</td>
<td>69.3%</td>
<td>Cruiser 1: 34.3%</td>
</tr>
<tr>
<td>Cruiser 2 engages attack - trigger high severity</td>
<td>Other</td>
<td>30.7%</td>
<td>Cruiser 1: 65.7%</td>
</tr>
<tr>
<td>Goatboat approaching Cruiser 1</td>
<td>Provoked attack</td>
<td>34.4%</td>
<td>Cruiser 1: 65.6%</td>
</tr>
<tr>
<td>Goatboat not approaching Cruiser 1</td>
<td>Other</td>
<td>65.6%</td>
<td>Cruiser 1: 34.4%</td>
</tr>
<tr>
<td>Goatboat approaching last</td>
<td>Provoked attack</td>
<td>70.0%</td>
<td>Cruiser 1: 39.0%</td>
</tr>
<tr>
<td>Goatboat not approaching last</td>
<td>Other</td>
<td>30.0%</td>
<td>Cruiser 1: 61.0%</td>
</tr>
<tr>
<td>Goatboat probability cannot localize Cruiser 1</td>
<td>Provoked attack</td>
<td>60.0%</td>
<td>Cruiser 1: 40.0%</td>
</tr>
<tr>
<td>Goatboat probability cannot localize</td>
<td>Other</td>
<td>40.0%</td>
<td>Cruiser 1: 60.0%</td>
</tr>
</tbody>
</table>
Modeling Features

- 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)
Updated Plan Beliefs

- 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
MEBN/Quiddity Summary

• 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
Conclusion

- 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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