Representing COA with probabilistic ontologies
Outline

- Introduction
- Literature Review
- Related Work
- Proposed Approach
- Summary
Planning Operations is an increasingly complex activity

Different approaches have been suggested to support Course of Action development

There is no unique solution

In this work, we propose Probabilistic Ontologies as an efficient alternative to support COA development
Introduction

- Decision-making in complex situations
  - Uncertainty
  - Cost and time constraints
  - Significant potential for negative results (existence of multiple variables and conflicting goals)

- Decision Support Systems (DSS)
  - A way to address above issues
  - Research and evaluation since early 1970s
  - AI-based algorithms (i-DMSS)
Introduction

- Generic Military Decision process

  *Do while* environment *is not* in the desired end-state:
  i. Receive incoming orders (hierarchy) or requests
  ii. Generate Plan (output is a set of possible actions)
  iii. Execute plan in order to achieve the desired effects (actions)
  iv. Compute changes in environment (updates)
Military Decision-Making Process

- Brazilian Armed Forces characteristics (OOTW)
  - Increase participation in Haiti
  - Supporting relief operations
  - Monitoring the national borders
  - Decision process largely similar to the US Joint Operation Planning Process

- Case Study – Joint Air Operations
JP 3-30 Command and Control for Joint Air Operations
EBO

- “Coordinated sets of actions directed at shaping the behavior of friends, foes, and neutrals in peace, crisis, and war.” (SMITH, 2002)

- Effects
  - Occur simultaneously on all levels of a military operation
  - Are interrelated and tend to cascade into successions of indirect effects in an unpredictable way

- Goal (of the planning)
  - To identify the most likely outcomes (effects) that are sufficient for reach the desired end state
Literature Review

The Three Domains in EBO (SMITH, 2002)
Probabilistic Ontologies (Costa, 2005)

“A probabilistic ontology is an explicit, formal knowledge representation that expresses knowledge about a domain of application. This includes:

- Types of entities that exist in the domain;
- Properties of those entities;
- Relationships among entities;
- Processes and events that happen with those entities;
- Statistical regularities that characterize the domain;
- Inconclusive, ambiguous, incomplete, unreliable, and dissonant knowledge related to entities of the domain;
- Uncertainty about all the above forms of knowledge;

where the term entity refers to any concept (real or fictitious, concrete or abstract) that can be described and reasoned about within the domain of application.”
Traditional ontologies lack built-in mechanisms for representing or inferring with uncertainty.

Require ad-hoc extensions, resulting in many different approaches in the last 10 years.

PR-OWL, PR-OWL 2 (COSTA 2005, CARVALHO 2008)

- Extends W3C’s OWL
- Based on Multi-Entity Bayesian Network – MEBN (LASKEY 2008)
MEBN represents domain information as a collection of inter-related entities and their respective attributes;

Knowledge about attributes of entities and their relationships is represented as a collection of repeatable patterns, known as MEBN Fragments (MFrags);

A set of MFrags that collectively satisfies first-order logical constraints ensuring a unique joint probability distribution is a MEBN Theory (MTheory);

An MFragment can be seen as a “chunk of domain knowledge” that encapsulates a pattern that can be instantiated as many times as needed to represent a specific situation.
isA(act, Activity)
isA(obj, Object)
isA(rgn, Region)

isActivityToObject(act, obj)
isA(t, TimeStep)

isRequestedAction(act, obj, rgn, t)

AccumulatedEffect(act, obj, rgn)
Addressed EBO’s concepts

1. Model effects that are cumulative over time
2. Identify the most likely outcomes that are sufficient to reach the desired end state
3. Implement a process that incorporates accruing information during the decision cycle
4. Develop an implementation that captures how uncertainty of the shared awareness and cognitive aspects impact the cause and effect relations, temporal relations and dynamic futures of a situation
## Related Work

<table>
<thead>
<tr>
<th>Work</th>
<th>EBO Concept</th>
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<tbody>
<tr>
<td><strong>HAIDER; LEVIS, 2007</strong></td>
<td>X</td>
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<td><strong>DARR; BENJAMIN; MAYER, 2009</strong></td>
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<td><strong>MOFFAT; FELLOWS, 2010</strong></td>
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<td><strong>BÉLANGER; GUITOUNI; PAGEAU, 2009</strong></td>
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<td><strong>WAGENHALS; HAIDER; LEVIS, 2006</strong></td>
<td>X</td>
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<tr>
<td><strong>MATHEUS et al, 2009</strong></td>
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<td><strong>BOURY, 2007</strong></td>
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Related Work Summary Based on the Four Addressed EBO Concepts
### Proposed Approach

- Aims to support the Joint Operation Planning Process (JOPP) at the Joint Force Component Command level

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<tbody>
<tr>
<td><strong>JO</strong></td>
<td>Warning Order/Planning Directive</td>
<td>Command Initiation</td>
<td>Mission Analysis</td>
<td>COA Development</td>
<td>COA Analysis/Wargaming</td>
<td>COA Approval</td>
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<td><strong>R</strong></td>
<td>Command Intent</td>
<td>Understand intent and scenario</td>
<td>Reason about situation</td>
<td>COA determination</td>
<td>COA alternative evaluation</td>
<td>Choose the best available COA</td>
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<td><strong>L</strong></td>
<td>Represent Intent</td>
<td>Generate causal relations</td>
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<td>Track changes in scenario</td>
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### Six steps for the Joint Operations Planning Process

1. **Command Initiation**
   - Understand intent and scenario
   - Reason about situation

2. **Mission Analysis**
   - COA determination

3. **COA Development**
   - COA alternative evaluation

4. **COA Analysis/Wargaming**
   - Generate space states
   - Generate probabilities
   - Generate constraints
   - Problem solving methods
   - Establish a war-game environment
   - Generate different scenarios
   - Compare results
   - Generate a scored list based on the established metric for comparison

5. **COA Approval**
   - Decision

6. **Supporting Plan/Order**
   - Update COA
• MTheory will help COA determination by answering queries;
• The probabilistic part of the KB was modeled with seven classes;

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
<th>Individuals</th>
</tr>
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<tbody>
<tr>
<td>Activity</td>
<td>The possible type of missions during an operation</td>
<td>Air_defense_Supression, Attack_Bridge, Attack_Runway, Reconnaissance</td>
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<tr>
<td>COA</td>
<td>The course of action we are interested in</td>
<td>AirSuperiorityCampaign,</td>
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<tr>
<td>Object</td>
<td>The subject of the action</td>
<td>Target1_Bridge, Target2_AAA</td>
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<tr>
<td>Phase</td>
<td>The phases within a COA</td>
<td>AirStrike</td>
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<tr>
<td>Region</td>
<td>The region where the subject is</td>
<td>Sector_ALFA1, Sector_GAMA2</td>
</tr>
<tr>
<td>Report</td>
<td>The evidence with the information about the Object, Activity, Phase, Region and TimeStep.</td>
<td>Rpt0,Rpt1, Rpt2</td>
</tr>
<tr>
<td>TimeStep</td>
<td>The time when activities should occur (time is considered discrete)</td>
<td>T0,T1,T2</td>
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Knowledge base description for COA determination
Proposed Approach

COA MTheory
The model also has the local probability distribution tables (LPD) for the resident nodes of interest;

<table>
<thead>
<tr>
<th>Effect</th>
<th>Recon</th>
<th>Attack</th>
<th>SEAD</th>
<th>Recon</th>
<th>Attack</th>
<th>SEAD</th>
<th>Recon</th>
<th>Attack</th>
<th>SEAD</th>
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<tr>
<td>High</td>
<td>.70</td>
<td>.60</td>
<td>.80</td>
<td>.60</td>
<td>.50</td>
<td>.55</td>
<td>.55</td>
<td>.20</td>
<td>.40</td>
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<tr>
<td>Medium</td>
<td>.20</td>
<td>.20</td>
<td>.10</td>
<td>.25</td>
<td>.30</td>
<td>.20</td>
<td>.30</td>
<td>.30</td>
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<tr>
<td>Low</td>
<td>.05</td>
<td>.15</td>
<td>.05</td>
<td>.10</td>
<td>.15</td>
<td>.15</td>
<td>.10</td>
<td>.35</td>
<td>.20</td>
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<tr>
<td>None</td>
<td>.05</td>
<td>.05</td>
<td>.05</td>
<td>.05</td>
<td>.05</td>
<td>.10</td>
<td>.05</td>
<td>.15</td>
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<table>
<thead>
<tr>
<th>ObjType</th>
<th>Soft</th>
<th>Medium</th>
<th>Hard</th>
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</thead>
<tbody>
<tr>
<td>Effect's LPD</td>
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</table>
After all instances and LPDs are included in the hybrid ontology, a query can be posted to the model to assess a specific outcome;

A Specific Situation Bayesian Network – SSBN (Laskey 2008) is the result of a query on the planned outcome of the AirStrike phase [?hasAccomplishedPhaseGoal (?AirStrike )];

In the resulting SSBN, there are planned effects accumulated from $T_0$, $T_1$ and $T_2$ for the activity Attack_Bridge to object Target1_Bridge and the activity Air_Defense_Suppression over object Target2_AAA;

The same inference process will happen to the COA evaluation.
SSBN for the query ?hasAccomplishedPhaseGoal(?AirStrike).
The SSBN does not fully support the decision process, since no information on utility and alternatives is considered;

Thus, to provide full support to the COA determination process it is necessary to resort to Multi-Entity Decision Graphs (MEDGs) (LASKEY, 2008), which is the extension of MEBN that includes support to decision-making;

MEDGs are for MEBNs what Influence Diagrams (ID) are for Bayesian Networks.
Influence Diagram for COA Determination.
Summary

To fully support EBO it is necessary to have the ability to describe:

- Cumulative effects
- Temporal relations and Dynamic futures
- The most likely outcomes that are sufficient for planning
- Incorporate novel information during the decision cycle

The research presented here mainly addresses the cognitive domain of the problem, attempting to improve the COA representation using a probabilistic ontology.

The model was implemented using PR-OWL (COSTA, 2005), a probabilistic ontology that is being supported by UnBBayes, a graphical modeling tool that includes a PR-OWL plugin (UNBBAYES, 2011).

As future work, we will incorporate:

- The planning formalism
- Description of command intent
Questions??????
References

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