Henrique C. Marques - ITA
José M. P. de Oliveira - ITA
Paulo C. G. da Costa - GMU

Representing COA with probabilistic ontologies

16th ICCRTS

Outline

- Introduction
- Literature Review
- Related Work
- Proposed Approach
- Summary

Introduction

- 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

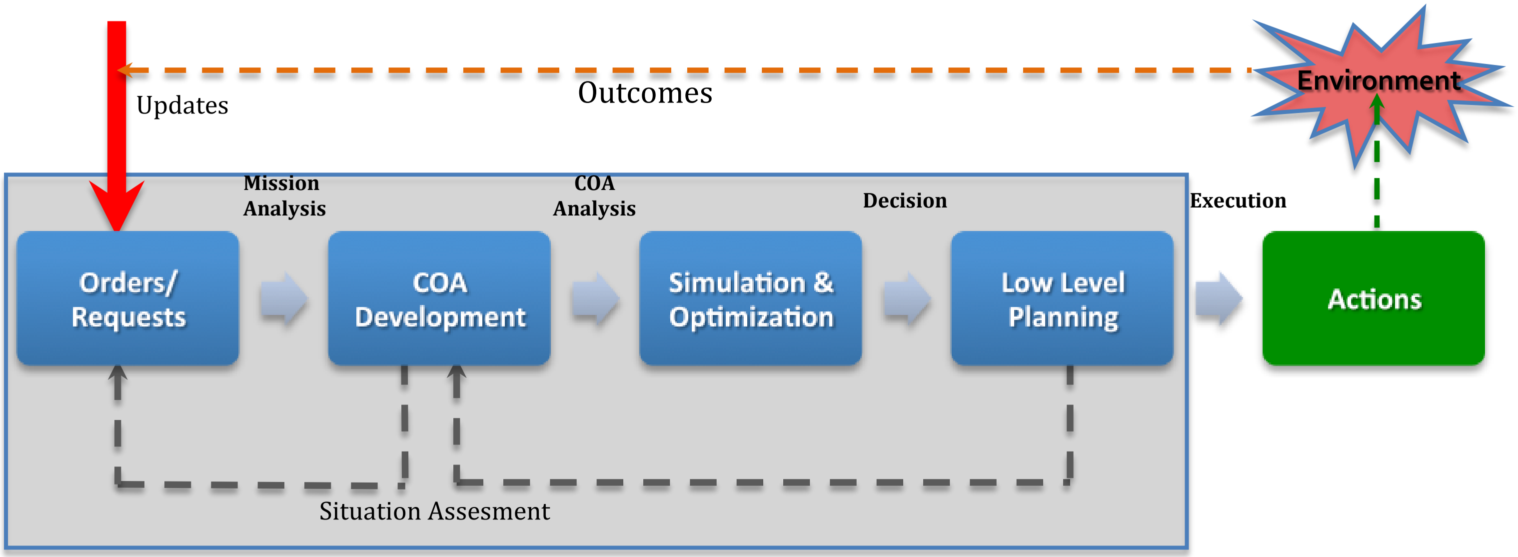
- Decision-making in complex situations
  - Uncertainty
  - Cost and time constraints
  - Significant potential for negative results (existence of multiple variables and conflicting goals)
- Decision Support Systems (DSS)
  - A way to address above issues
  - Research and evaluation since early 1970s
  - 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)

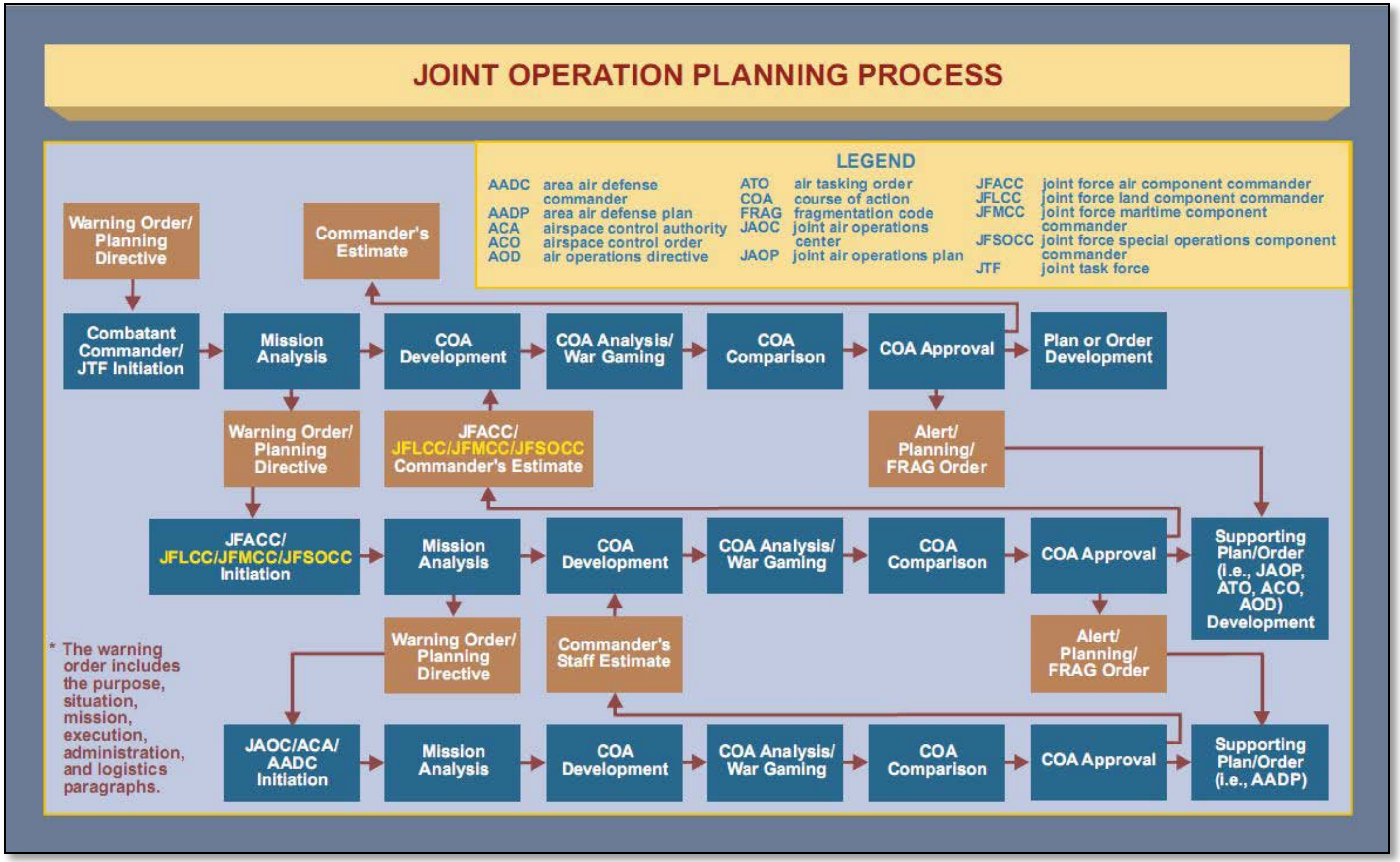


Literature Review

- 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

Literature Review

- JP 3-30 Command and Control for Joint Air Operations

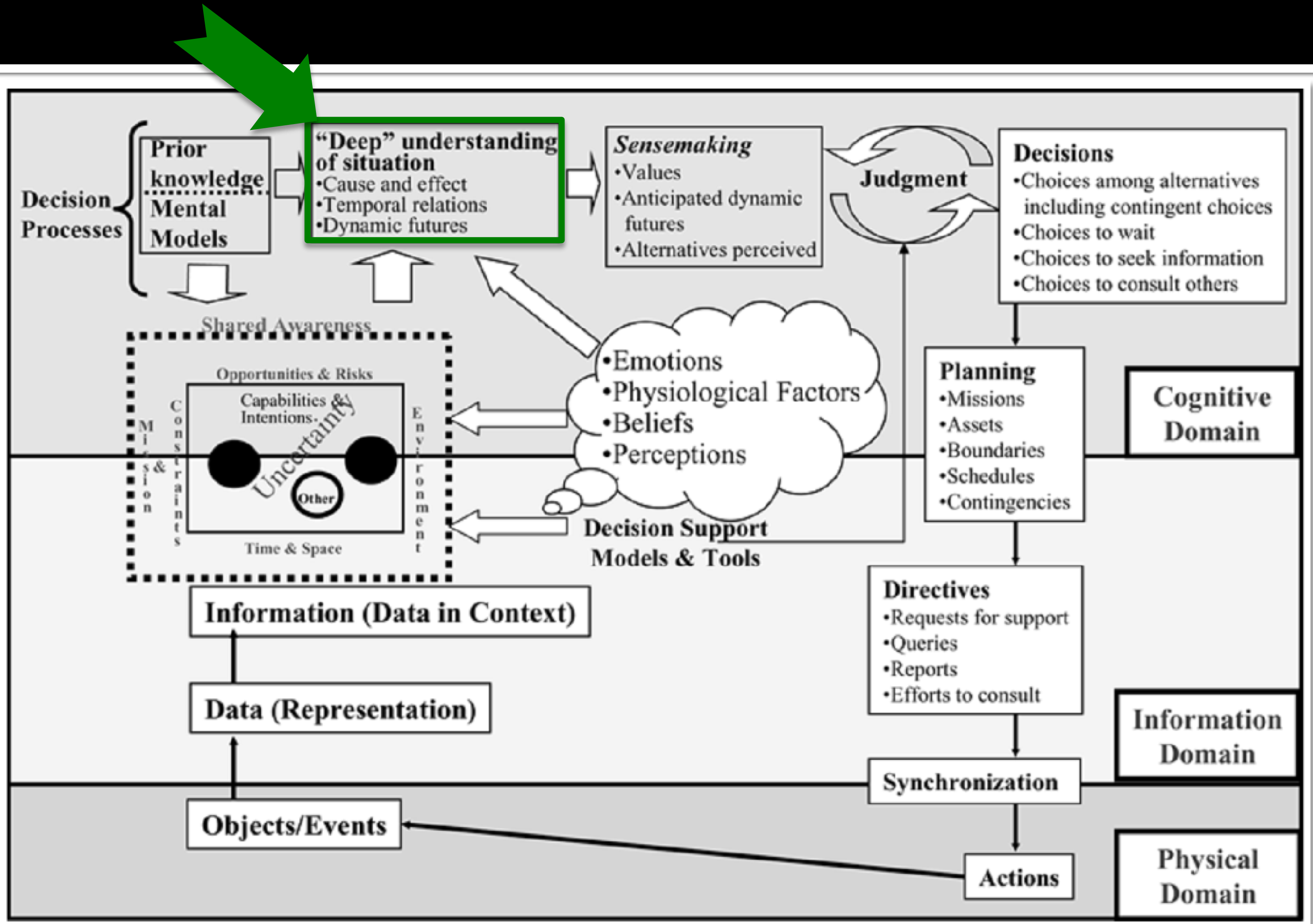


JOPP's 6 steps

Literature Review

- 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)

Literature Review

- 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;*

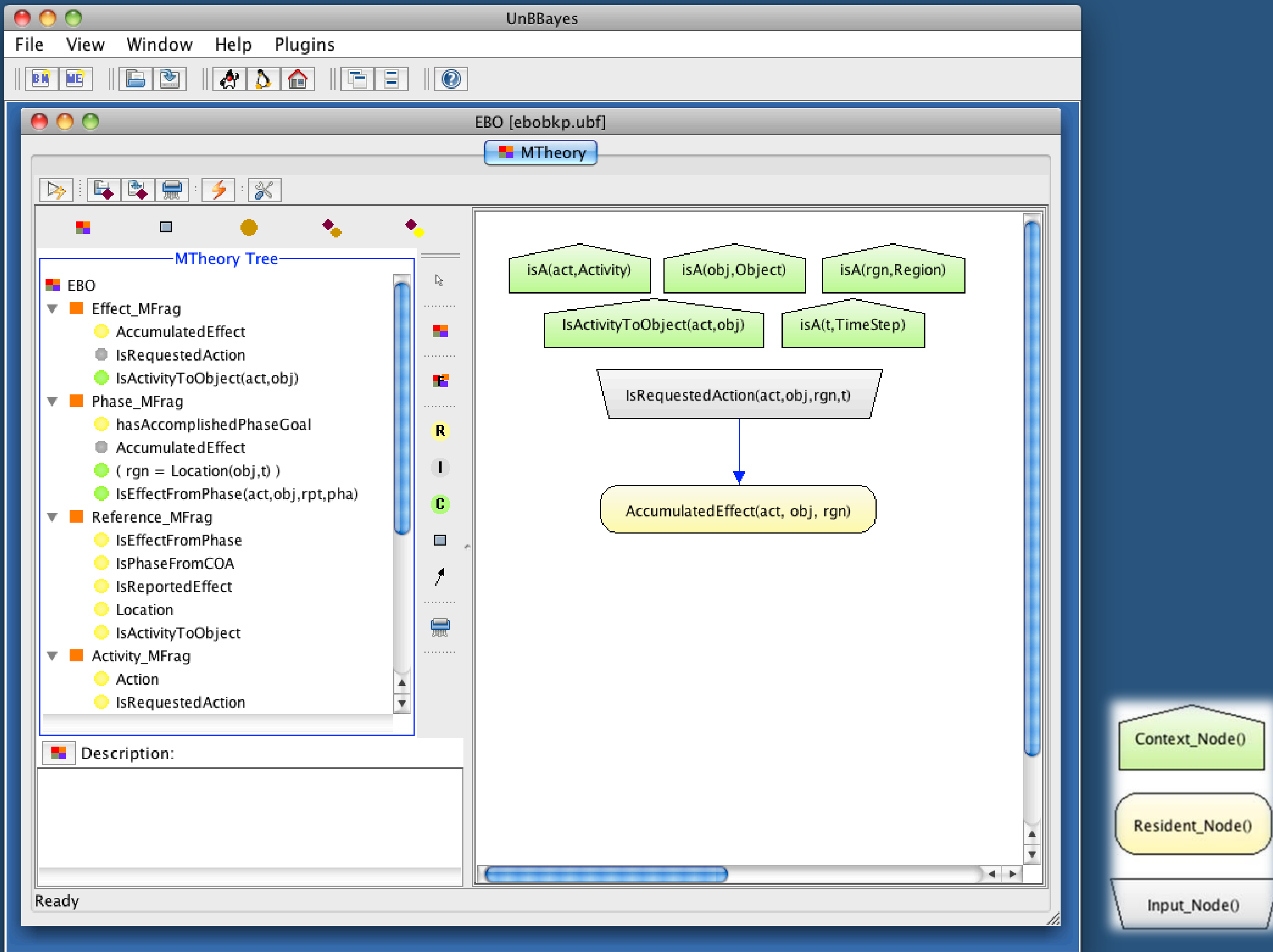
where the term entity refers to any concept (real or fictitious, concrete or abstract) that can be described and reasoned about within the domain of application."

Probabilistic Ontologies

- 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

- 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 MFrag 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.



UnBBayes-MEBN API, 2011

Related Work

- 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

Work	EBO Concept			
	1	2	3	4
HAIDER; LEVIS, 2007	X		X	X
DARR; BENJAMIN; MAYER, 2009		X	X	X
MOFFAT; FELLOWS, 2010		X	X	X
BÉLANGER; GUITOUNI; PAGEAU, 2009		X	X	X
WAGENHALS; HAIDER; LEVIS, 2006	X		X	X
MATHEUS et al, 2009			X	X
BOURY, 2007			X	X

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

	1	2	3	4	5	6
JOPP	Warning Order/ Planning Directive → Command Initiation	Mission Analysis	COA Development	COA Analysis/ Wargaming → COA Comparison	COA Approval	Supporting Plan/Order
Role	•Command Intent	• Understand Intent and scenario • Reason about situation	• COA determination	• COA alternative evaluation	• Choose the best available COA	• Track changes in scenario
Task	• Represent Intent	• Generate causal relations	• 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 metrics for comparison	•Decision	•Update COA

Six steps for the Joint Operations Planning Process

JOPP

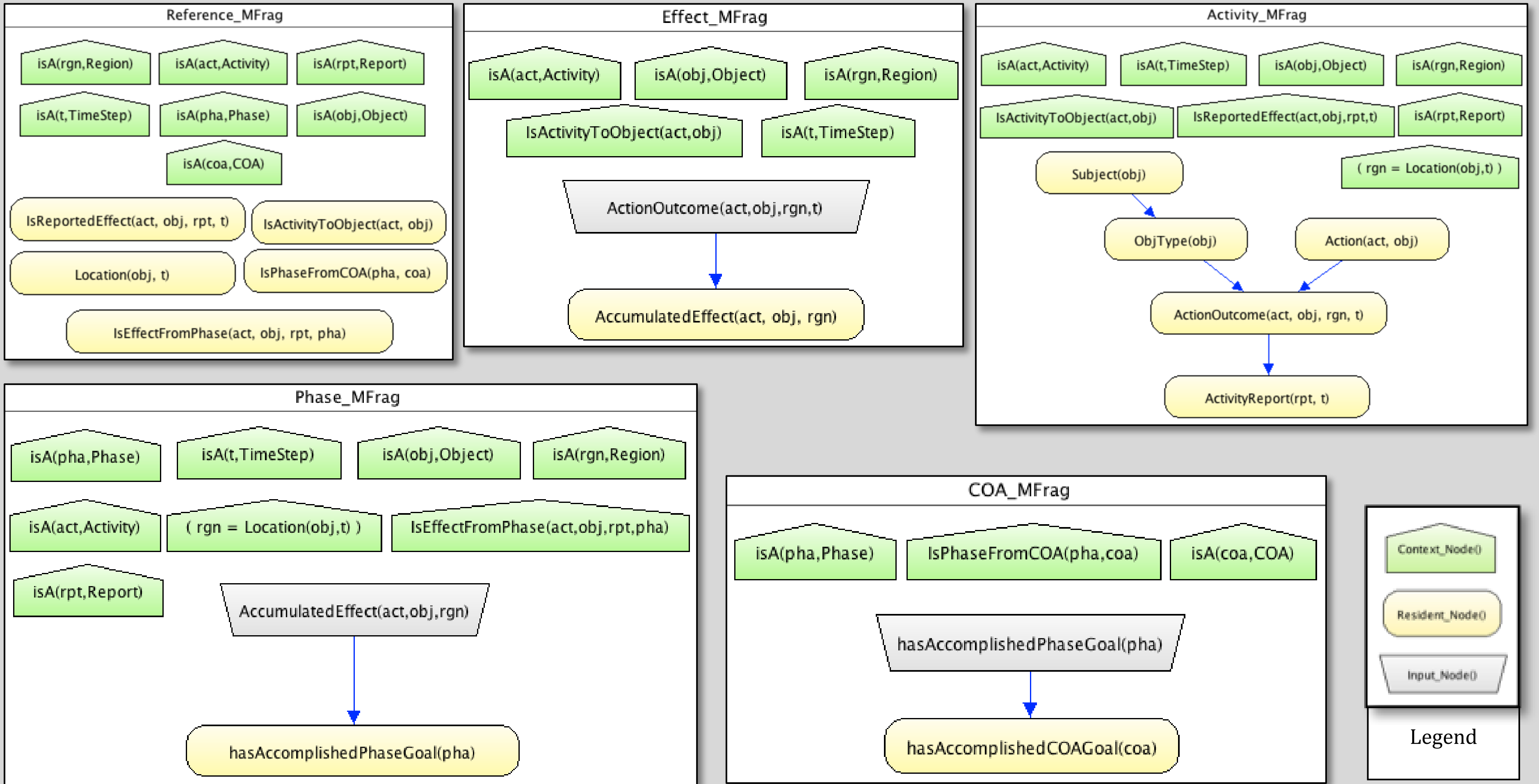
COA Determination

- MTheory will help COA determination by answering queries;
- The probabilistic part of the KB was modeled with seven classes;

Class	Description	Individuals
Activity	The possible type of missions during an operation	Air_defense_Supression, Attack_Bridge, Attack_Runway, Reconnaisance
COA	The course of action we are interested in	AirSuperiorityCampaign,
Object	The subject of the action	Target1_Bridge, Target2_AAA
Phase	The phases within a COA	AirStrike
Region	The region where the subject is	Sector_ALFA1, Sector_GAMA2
Report	The evidence with the information about the Object, Activity, Phase, Region and TimeStep.	Rpt0,Rpt1, Rpt2
TimeStep	The time when activities should occur (time is considered discrete)	T0,T1,T2

Knowledge base description for COA determination

Proposed Approach



COA MTheory

COA Determination

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

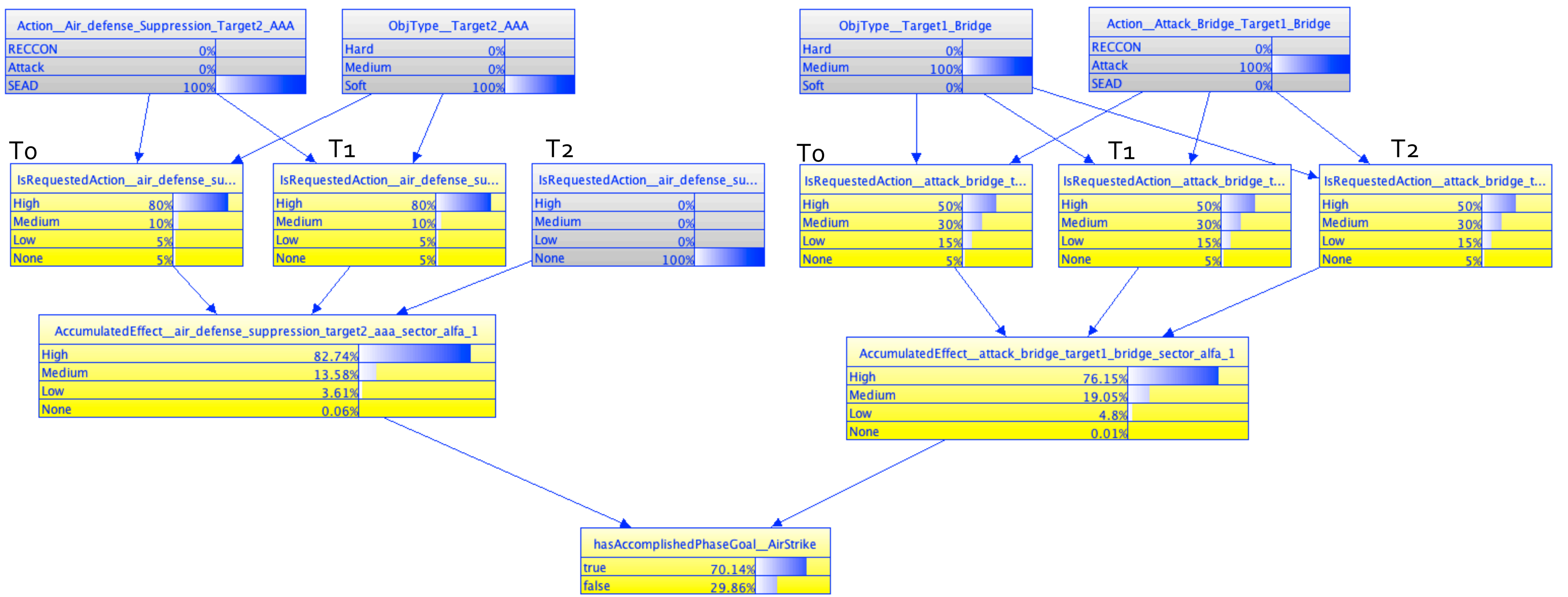
	Action								
Effect	*Reccon*	*Attack*	*SEAD*	*Reccon*	*Attack*	*SEAD*	*Reccon*	*Attack*	*SEAD*
High	.70	.60	.80	.60	.50	.55	.55	.20	.40
Medium	.20	.20	.10	.25	.30	.20	.30	.30	.35
Low	.05	.15	.05	.10	.15	.15	.10	.35	.20
None	.05	.05	.05	.05	.05	.10	.05	.15	.05
	Soft			*Medium*			*Hard*		
	ObjType								

Effect's LPD

COA Determination

- 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 *T0*, *T1* and *T2* 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.

COA Determination



SSBN for the query *?hasAccomplishedPhaseGoal(?AirStrike).*

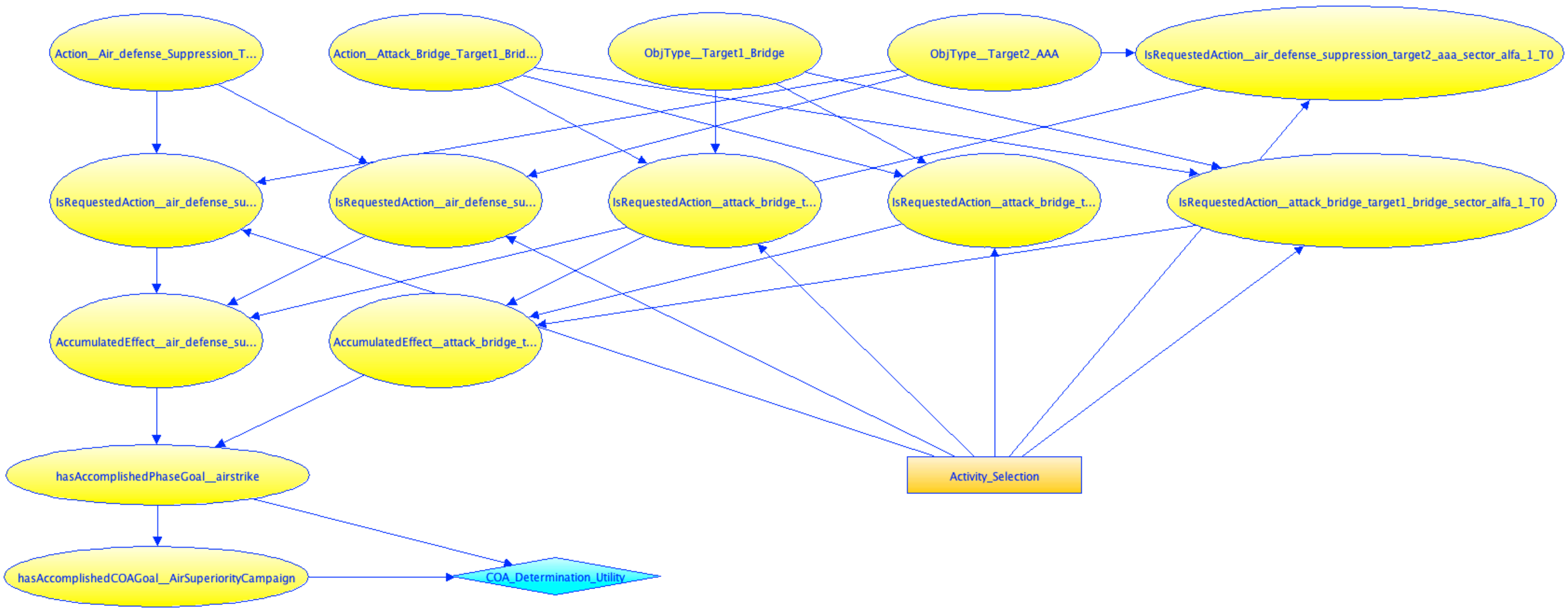
COA Determination

- 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.

COA Determination



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

- **BÉLANGER, M.; GUITOUNI, A.; PAGEAU, N.** Decision support tools for the operational planning process. 14th International Command and Control Research and Technology Symposium. 2009.
- **BOURY-BRISSET, A. C.** Ontological engineering for threat evaluation and weapon assignment: a goal-driven approach. Information Fusion, 2007 10th International Conference on. p. 1-7. 2007.
- **CARVALHO R. N. ; LASKEY K. B.; COSTA P. C. G.** "PR-OWL 2.0 - Bridging the Gap to OWL Semantics," in Proceedings of the 6th International Workshop on Uncertainty Reasoning for the Semantic Web (URSW 2010), collocated with the 9th International Semantic Web Conference (ISWC 2010). p. 73-84. 2010.
- **COSTA, P. C. G.** Bayesian Semantics for the Semantic Web. PhD Diss. Department of Systems Engineering and Operations Research, George Mason University. 315p, July 2005, Fairfax, V A, USA.
- **DARR, T. P.; BENJAMIN, P.; MAYER, R**. Course of action planning ontology. In: Ontology for the Intelligence Community 2009 (OIC 2009). 2009.
- **HAIDER, S.; LEVIS, A.** Effective course-of-action determination to achieve desired effects. Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on, v. 37, n. 6, p. 1140-1150, nov. 2007. ISSN 1083-4427.
- **WAGENHALS, L. W.; LEVIS, A.; HAIDER, S.** Planning, Execution and Assessment of Effects Based Operations (EBO). Technical Report. Air Force Research Laboratory / IFSA, 2006**.**
- **LASKEY, K. B.** MEBN: A Language for First-Order Bayesian Knowledge Bases. Artificial Intelligence, 172(2-3). 2008. Available from internet: http://ite.gmu.edu/~klaskey/papers/Laskey_MEBN_Logic.pdf .
- **MOFFAT, J.; FELLOWS, S.** Using genetic algorithms to represent higher-level planning in simulation models of conflict. Advances in Artificial Intelligence, v. 2010, n. Article ID 701904, p. 11, 2010.
- **SMITH, E. A.** Effects Based Operations: Applying Network Centric Warfare in Peace, Crisis and War. CCRP, 2002.
- **UNBBAYES.** UnBBayes Project. 2011. Available from Internet: http://unbbayes.sourceforge.net/

Henrique C. Marques – hmarques@ita.br
José M. P. de Oliveira – parente@ita.br
Paulo C. G. da Costa – pcosta@c4i.gmu.edu

Representing COA with probabilistic ontologies

16th ICCRTS