The Application of a Course-of-Action Ontology to Support OPFOR COA Selection and Assessment

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Outline

- Introduction
- Application Overview – Empire Challenge 10 / Green Devil II Exercise
- Utility Theory Overview
- Ontology Overview
- EC 10 Application
- Conclusion

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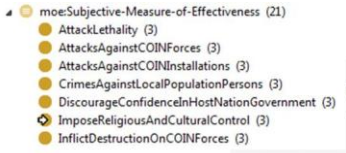
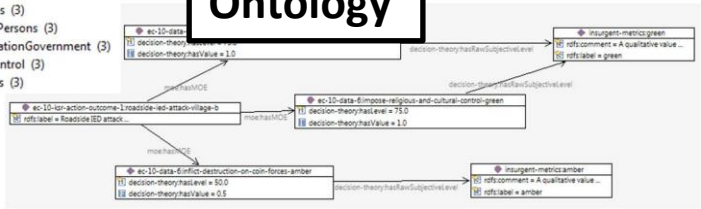
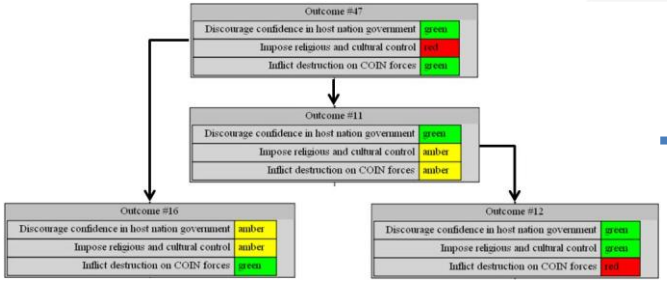
Introduction – Problem Context



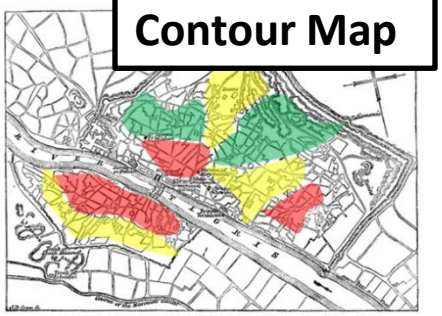
Ontology



Preference Model



Contour Map



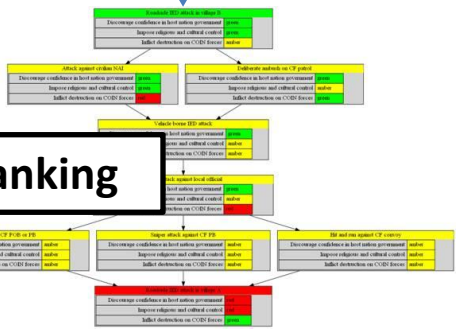
Map courtesy of: http://www.1902encyclopedia.com/B/BAG/baghdad.html

Course of Action	Expected COA Outcome		
	Discourage confidence in host nation government	Impose religious and cultural control	Inflict destruction on COIN forces
Vehicle borne IED attack	green	amber	amber
Attack against CF FOB or PB	amber	amber	amber
Attack against civilian NAI	green	green	red
Sniper attack against CF PB	amber	amber	amber
Sniper attack against local official	green	amber	red
Deliberate ambush on CF patrol	green	amber	green
Hit and run against CF convoy	amber	amber	amber
Roadside IED attack in village A	red	red	green
Roadside IED attack in village B	green	green	amber

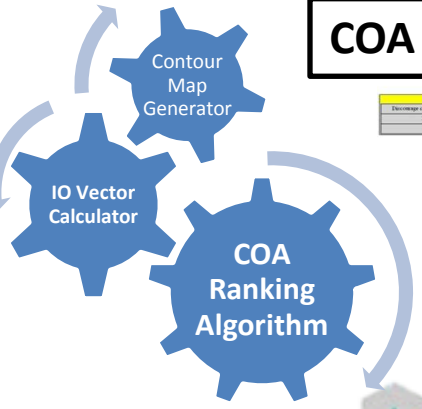
Possible COAs

COA Selection and Assessment

COA Ranking



COA Selection and Assessment Algorithms



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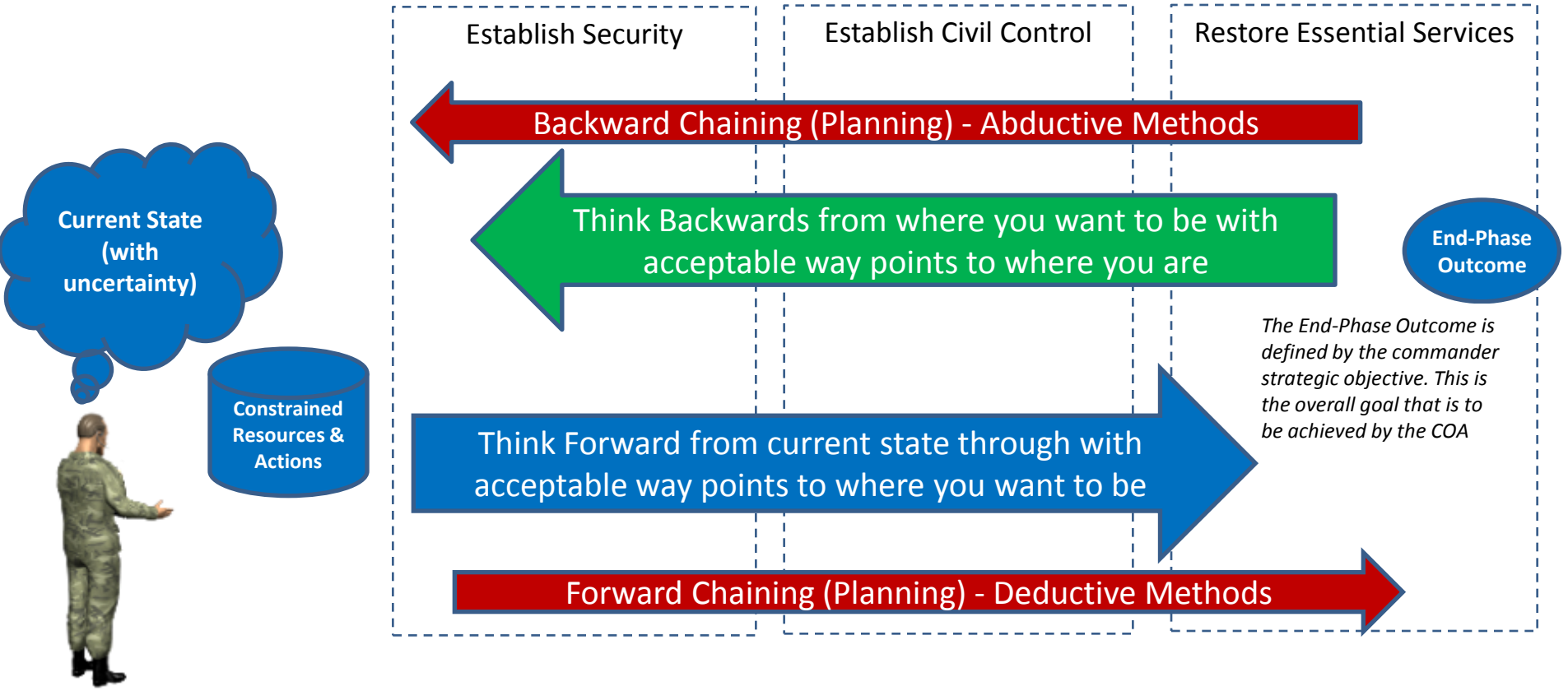
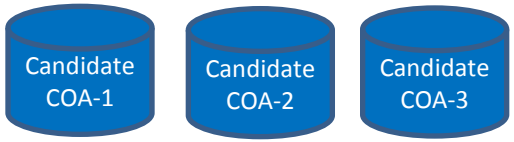
Introduction – CONOPS



Establish COAs (generally 3) that will successfully transition from the current state to the desired final state.



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Application Overview

- Empire Challenge 10 / Green Devil II Exercise
- Problem
  - Determine why an OPFOR insurgent group was pursuing a given course of action
  - Predict the next course of action that the insurgent group would pursue
- The OPFOR has the following goals
  - Short Term – inflict damage
  - Medium Term – discourage confidence in host nation government
  - Long Term – impose cultural and religious control

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Utility Theory Overview

- The COA selection / assessment decision problem as a utility-theoretic multi-attribute decision problem
- Utility theory was originally developed in economics to measure the desirability of a good or alternative from the perspective of an agent
- A utility function is given by:
  - $u : O \rightarrow \Re$, where
  - O are the possible alternatives
  - $\Re$ is a real-valued number
- A common form of utility function is a weighted sum of attribute values:
  - $u(o_i) = \sum_k w_k * a_k[o_i]$
  - w_k is an attribute weight
  - $\sum_k w_k = 1, w_k \geq 0.0$
- The set of attribute value scores $a_k[o_i]$ is the IO vector
- A preference is a relation between alternatives such that $u(o_i) \geq u(o_j)$

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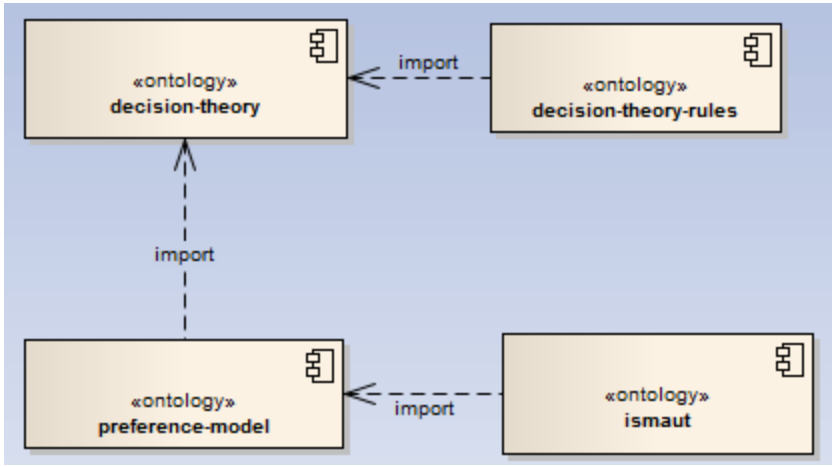
Ontology Overview – Core



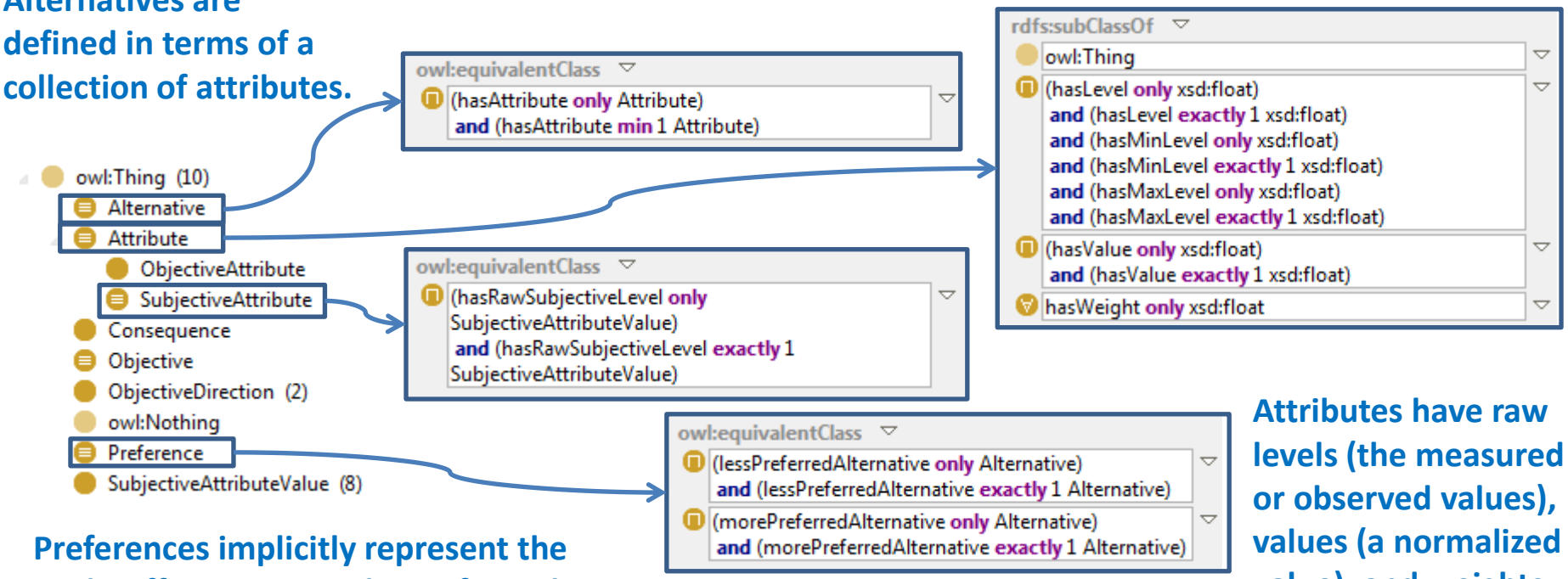
- owl:Thing (10)
  - Constraint
  - ConstraintTerm
  - decision-theory:Alternative
  - decision-theory:Attribute
  - decision-theory:Consequence
  - decision-theory:Objective
  - decision-theory:ObjectiveDirection (2)
  - decision-theory:Preference
  - decision-theory:SubjectiveAttributeValue (8)
  - decision-theory-rules:DeletionTrigger
  - decision-theory-rules:DominanceTrigger
  - ISMAUTProblem
  - ISMAUTProblemGenerator
  - ObjectiveFunction
  - owl:Nothing
  - preference-model:PreferenceModel

- spin:ConstructTemplates
  - ConstructDominatedSet
  - ConstructNonDominatedSet
  - DefaultLevelEvaluator
  - DefaultLevelEvaluatorNoRawLevel
  - DominanceCalculator
  - FourAttributeDominanceCalculator
  - LinearValueFunctionCalculatorTemplate
  - MaxMaxMaxDominanceCalculator
  - OneMaxTwoMinDominanceCalculator
  - PiecewiseLinearLowerBoundValueFunctionCalculatorTemplate
  - PiecewiseLinearUpperBoundValueFunctionCalculatorTemplate
  - PiecewiseLinearValueFunctionCalculatorTemplate
  - RawSubjectiveLevelCalculatorTemplate
  - SubjectiveLevelCalculatorTemplate
  - SubjectiveValueCalculatorTemplate
  - TwoMaxOneMinDominanceCalculator

- The core ontology defines the basic concepts, relations and rules for modeling decision problems.
- Concepts include: attributes, alternatives and preferences
- Rules include: dominance, value functions and level calculators

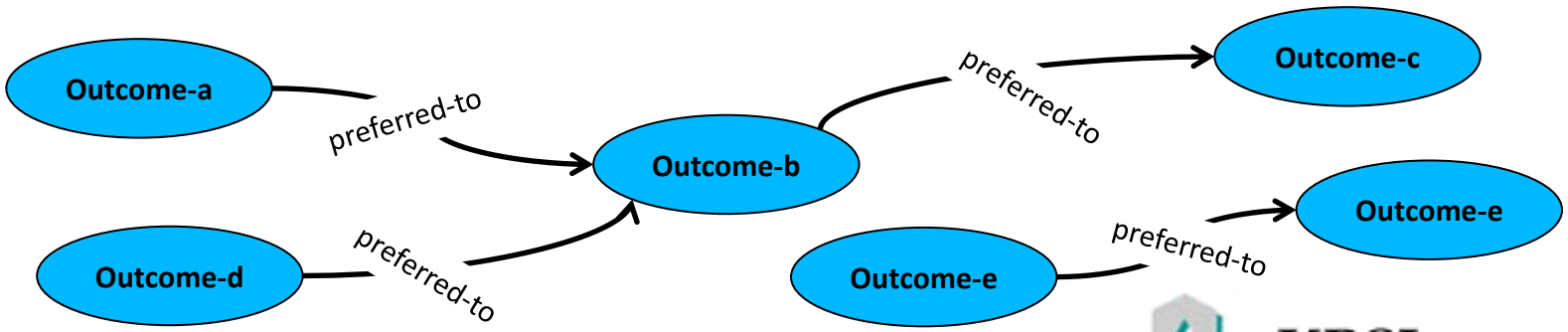
Alternatives, Attributes, Preferences

Alternatives are defined in terms of a collection of attributes.



Attributes have raw levels (the measured or observed values), values (a normalized value), and weights.

Preferences implicitly represent the trade-offs among attributes from the perspective of a decision maker.



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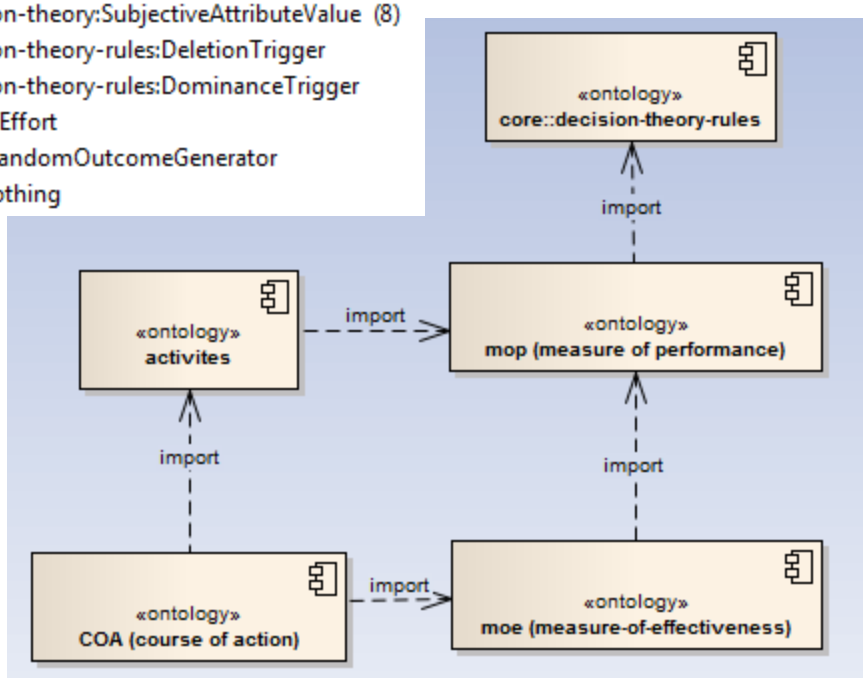
Ontology Overview – Course of Action

- owl:Thing (10)
  - activities:Activity
  - activities:ActivityTarget
  - COA-Phase
  - Course-of-Action
  - decision-theory:Alternative
  - decision-theory:Attribute
  - decision-theory:Consequence
  - decision-theory:Objective
  - decision-theory:ObjectiveDirection (2)
  - decision-theory:Preference
  - decision-theory:SubjectiveAttributeValue (8)
  - decision-theory-rules:DeletionTrigger
  - decision-theory-rules:DominanceTrigger
  - LineOfEffort
  - moe:RandomOutcomeGenerator
  - owl:Nothing

- The course of action ontology defines the basic concepts and relations for modeling COA selection decision problems
- Concepts include: COAs, phases, lines of effort, measures of effectiveness



- owl:Thing (10)
  - decision-theory:Alternative
    - Outcome
  - decision-theory:Attribute
    - decision-theory:ObjectiveAttribute
    - decision-theory:SubjectiveAttribute
      - mop:Subjective-Measure-of-Performance
      - Subjective-Measure-of-Effectiveness
  - decision-theory:Consequence
  - decision-theory:Objective
  - decision-theory:ObjectiveDirection (2)
  - decision-theory:Preference
  - decision-theory:SubjectiveAttributeValue (8)
  - decision-theory-rules:DeletionTrigger
  - decision-theory-rules:DominanceTrigger
  - owl:Nothing
  - RandomOutcomeGenerator

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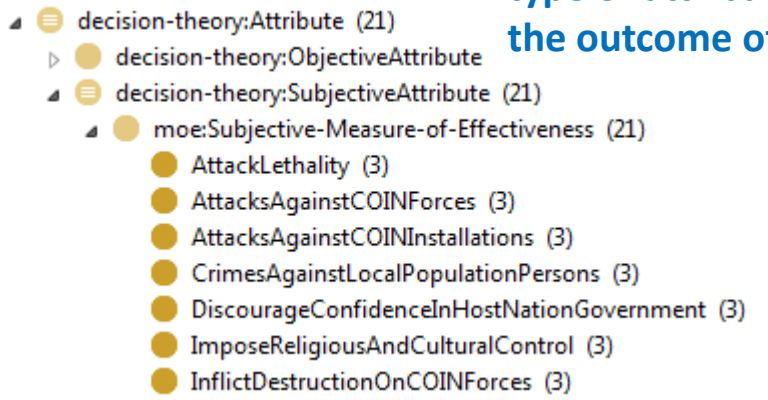
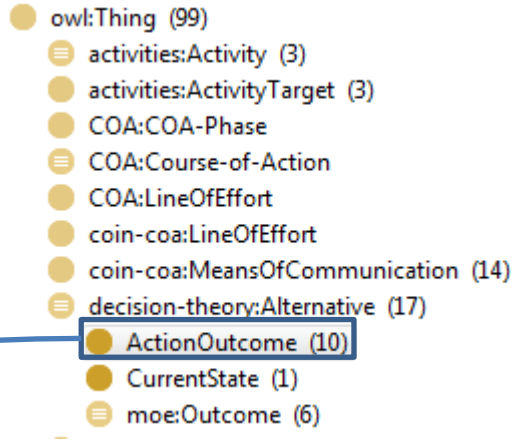
Outcomes and MOEs

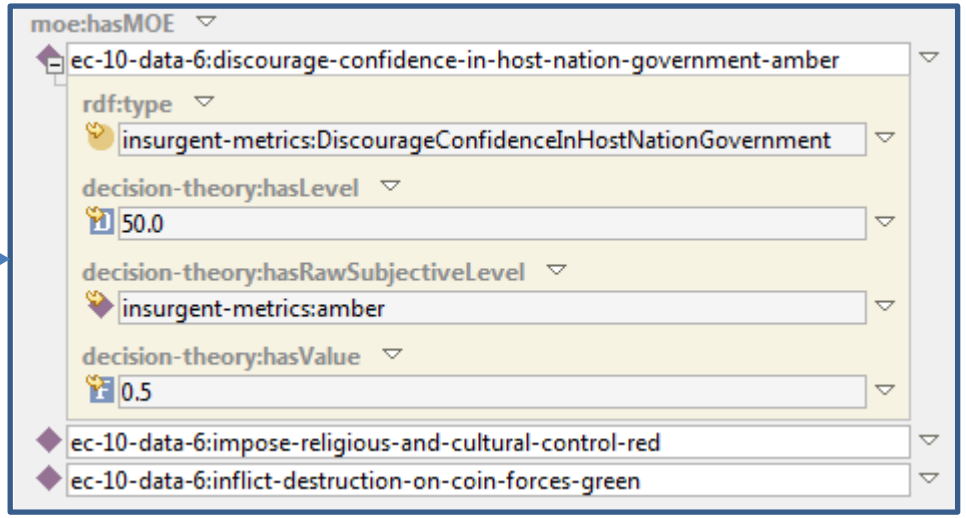
Measures-of-Effectiveness are a type of attribute used to describe the outcome of an action.

An action outcome is an alternative that represents the result of a COA. Preferences are asserted over action outcomes.





[Resource]	rdfs:label
attack-against-cf-fob-or-pb	Attack against CF FOB or PB
attack-against-civilian-nai	Attack against civilian NAI
deliberate-ambush-on-cf-patrol	Deliberate ambush on CF patrol
hit-and-run-against-cf-convoy	Hit and run against CF convoy
roadside-ied-attack-village-a	Roadside IED attack in village A
roadside-ied-attack-village-b	Roadside IED attack in village B
sniper-against-pb	Sniper attack against CF PB
sniper-attack-against-local-official	Sniper attack against local official
vehicle-borne-ied-attack	Vehicle borne IED attack



Instances of action outcomes are the specific result of a COA, described by MOEs. MOEs have subjective levels (red, amber, green), numeric level and normalized value.

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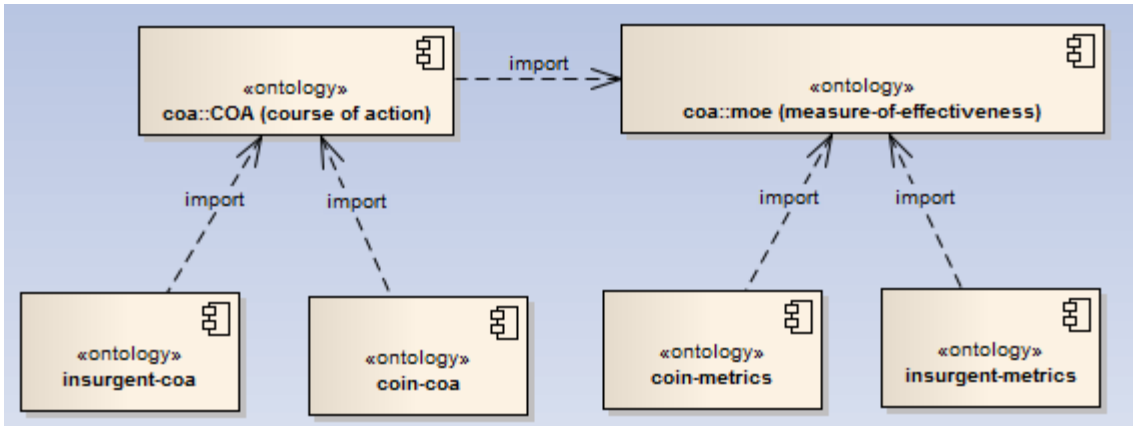
Ontology Overview – COIN



- The COIN ontology defines the basic concepts and relations for modeling COIN domain knowledge
- Concepts include: specific COIN and insurgency activities and measures of effectiveness

- owl:Thing (27)
  - activities:Activity (3)
    - Ambush
    - COINActivity (3)
      - AttackInsurgentBase
      - AttendCivilMeeting
      - ClearHoldBuild
      - ConductInvestigativeTraining
      - CordonAndSearchOperation
      - DisruptIEDCell
      - EngageTribalLeaders
      - ProvideEconomicStimuli
      - ProvideMedicalServices (1)
      - PublicizeIOActivity (2)
      - RepairInfrastructure
      - SupportInfrastructureBuildingProject
      - SupportRestorationOfCommerce
      - SupportRestorationOfEssentialServices
    - Propaganda
    - Raid
    - Seizure

- moe:Subjective-Measure-of-Effectiveness (60)
  - AfghanOnAfghanViolence (17)
  - AssassinationRate (3)
  - BudgetExecution
  - CapitalFlight
  - CivilianAccessibility (12)
  - CombinedActionOperations
  - DrivingTechnique
  - DurationOfOperations
  - ExternalFoodPrices
  - FreedomOfMovement
  - HighTechnologyInserts
  - HostNationTaxCollectionComplianceRate (8)
  - IEDReportingEfficiency (17)
  - InsurgentMedicalHealth
  - InsurgentVillageOfOrigin

- moe:Subjective-Measure-of-Effectiveness (21)
  - AttackLethality (3)
  - AttacksAgainstCOINForces (3)
  - AttacksAgainstCOINInstallations (3)
  - CrimesAgainstLocalPopulationPersons (3)
  - DiscourageConfidenceInHostNationGovernment (3)
  - ImposeReligiousAndCulturalControl (3)
  - InflictDestructionOnCOINForces (3)

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EC 10 Application – Example

- Using SPIN / SPARQL rule-based inference, a preference graph is generated by the following steps
  - Create an IO vector by inferring a qualitative value, followed by a utility-theoretic value for a collection of possible and actual COA outcomes
  - Elicit a preference model from an SME over a collection of possible COA outcomes (independent of how those outcomes are achieved)
  - Infer a preference graph over a collection of possible COAs that is consistent with the preference model

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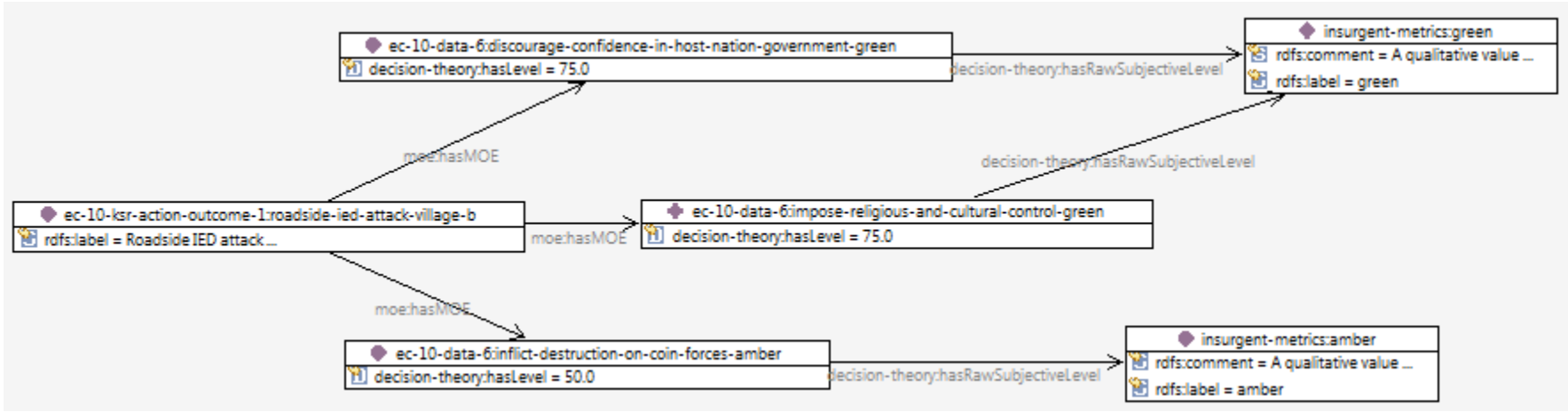
IO Vector Calculation – Step 1



decision-theory:levelEvaluator

Setting the level value = **insurgent-metrics:amber** for the level band [**33.0 66.0**].

Setting the level value = **insurgent-metrics:green** for the level band [**66.0 100.0**].

Setting the level value = **insurgent-metrics:red** for the level band [**0.0 33.0**].

spin:body

```
CONSTRUCT {
   ?this decision-theory:hasRawSubjectiveLevel ?arg3 .
}
WHERE {
   ?this decision-theory:hasLevel ?hasLevel .
   OPTIONAL {
      ?this decision-theory:hasRawSubjectiveLevel ?existingRawLevel .
   } .
   FILTER (!bound(?existingRawLevel)) .
   FILTER ((?hasLevel <= ?arg2) && (?hasLevel >= ?arg1)) .
}
```

- Each event or action is defined using multiple MOEs
- Each MOE is described in terms of the source numeric level and a subjective green / amber / red level
- Rules transform the number level into the subjective level

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EC10 Application - IO Vector Calculation

	Expected COA Outcome		
Course of Action	Discourage confidence in host nation government	Impose religious and cultural control	Inflict destruction on COIN forces
Vehicle borne IED attack	green	amber	amber
Attack against CF FOB or PB	amber	amber	amber
Attack against civilian NAI	green	green	red
Sniper attack against CF PB	amber	amber	amber
Sniper attack against local official	green	amber	red
Deliberate ambush on CF patrol	green	amber	green
Hit and run against CF convoy	amber	amber	amber
Roadside IED attack in village A	red	red	green
Roadside IED attack in village B	green	green	amber

- Each event or action is defined using multiple MOEs
- Each MOE is described in terms of the source numeric level and a subjective green / amber / red level
- Rules transform the number level into the subjective level
- The result of the transformation of a numeric level to a subjective level can be displayed as a COA effect prediction table
- Each row is a COA; the columns represent the subjective levels that are the predicted effect of executing the event

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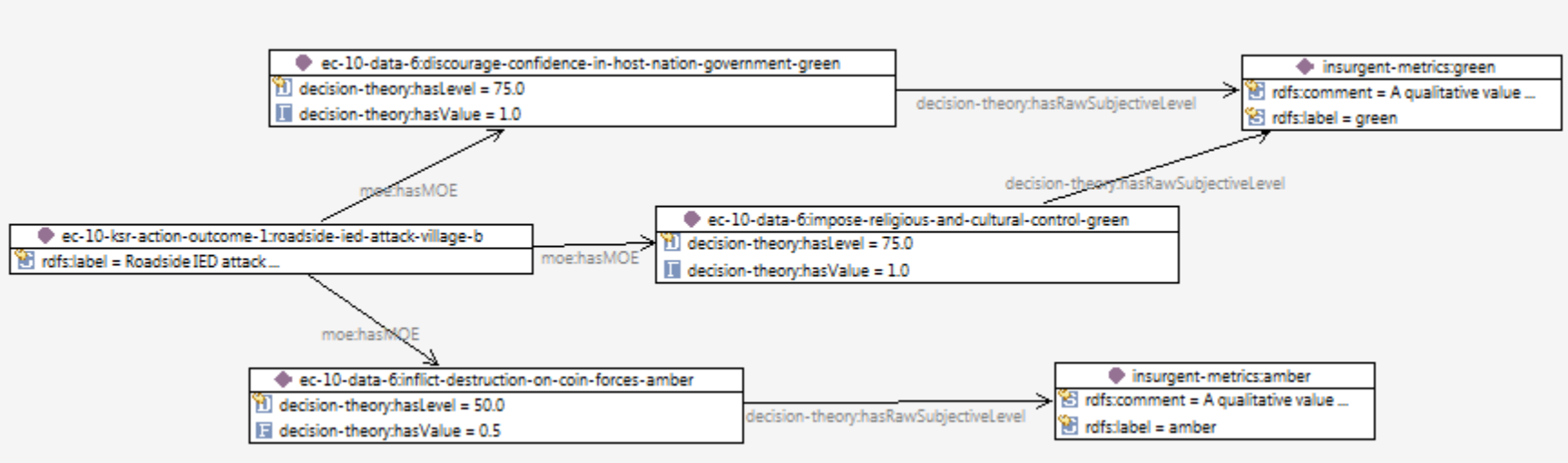
IO Vector Calculation – Step 2



decision-theory:valueFunction

Setting the value = **0.0** for the raw value **insurgent-metrics:red**.

Setting the value = **0.5** for the raw value **insurgent-metrics:amber**.

Setting the value = **1.0** for the raw value **insurgent-metrics:green**.

spin:body

```
# Level evaluator for high values
CONSTRUCT {
   ?this decision-theory:hasValue ?hasLevel .
}
WHERE {
   ?this decision-theory:hasRawSubjectiveLevel ?level .
   FILTER (?level = ?hasRawSubjectiveLevel) .
}
```

- **The IO vector results from applying a value function to each attribute**
- **This value function converts the subjective level to a numeric (utility-theoretic) value**

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IO Vector Calculation

Course of Action	Discourage confidence in HN government	Impose religious and cultural control	Inflict damage on COIN forces
Vehicle borne IED attack	1.00	0.50	0.50
Attack against CF FOB or PB	0.50	0.50	0.50
Attack against civilian NAI	1.00	1.00	0.00
Sniper attack against CF PB	0.50	0.50	0.50
Sniper attack against local official	1.00	0.50	0.00
Deliberate ambush on CF patrol	1.00	0.50	1.00
Hit and run against CF convoy	0.50	0.50	0.50
Roadside IED in village A	0.00	0.00	1.00
Roadside IED in village B	1.00	1.00	0.50

- The IO vector results from applying a value function to each attribute
- This value function converts the subjective level to a numeric (utility-theoretic) value
- The IO vector for each COA is displayed in tabular form
- Each row is a COA; the columns represent the (utility-theoretic) values that are the predicted effect of executing the event

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Preference Modeling

- Preferences are asserted over a collection of *possible outcomes* (independent of how those outcomes are achieved)
- For example, an SME playing the role of an insurgent leader might have the following preferences:
  - Outcomes with the best values for the feature "inflict destruction on COIN forces" are most preferred
  - For outcomes with the same value for the feature "inflict destruction on COIN forces", prefer outcomes with the best values for the feature "discourage confidence in host nation government"
  - For outcomes with same value for the feature "inflict destruction on COIN forces", and "discourage confidence in host nation government" , prefer outcomes with the best values for the feature "impose religious and cultural control"

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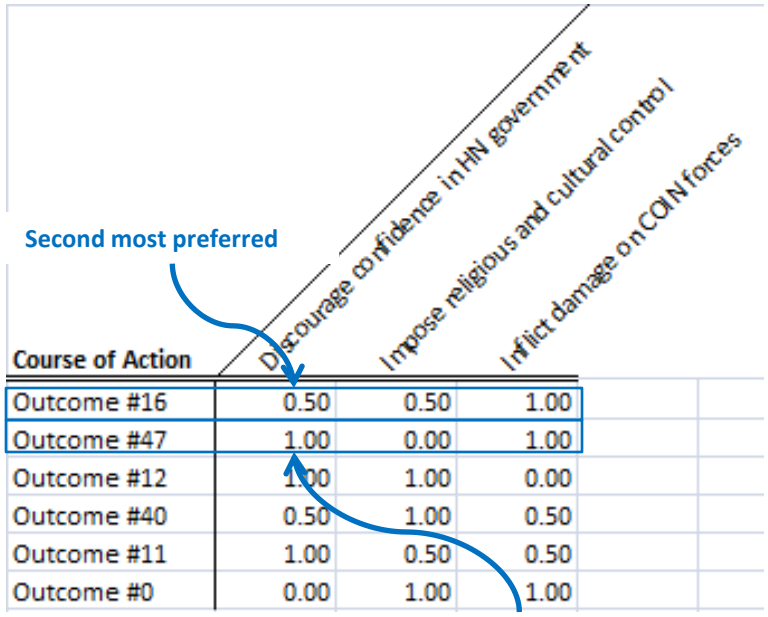
Preference Modeling

	Expected COA Outcome		
Course of Action	Discourage confidence in host nation government	Impose religious and cultural control	Inflict destruction on COIN forces
Outcome #16	amber	amber	green
Outcome #47	green	red	green
Outcome #12	green	green	red
Outcome #40	amber	green	amber
Outcome #11	green	amber	amber
Outcome #0	red	green	green



Course of Action	Discourage confidence in HN government	Impose religious and cultural control	Inflict damage on COIN forces
Outcome #16	0.50	0.50	1.00
Outcome #47	1.00	0.00	1.00
Outcome #12	1.00	1.00	0.00
Outcome #40	0.50	1.00	0.50
Outcome #11	1.00	0.50	0.50
Outcome #0	0.00	1.00	1.00

- **According to the preference model just outlined, the most preferred COA in the table above is #47; followed by #16**

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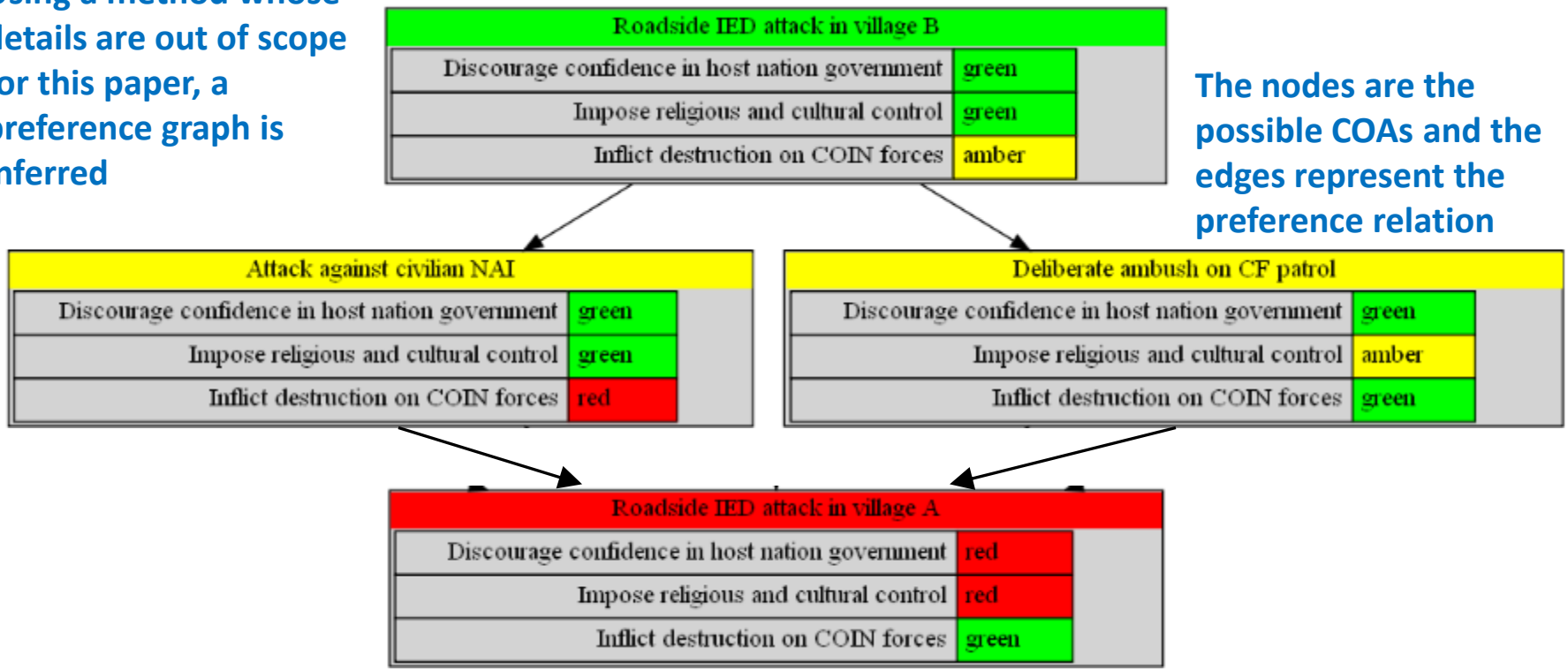
Preference Graph

Using a method whose details are out of scope for this paper, a preference graph is inferred



The nodes are the possible COAs and the edges represent the preference relation

Nodes with a green title bar are the most preferred. Nodes with a red title bar are the least preferred. Nodes with an amber title bar lie somewhere in between

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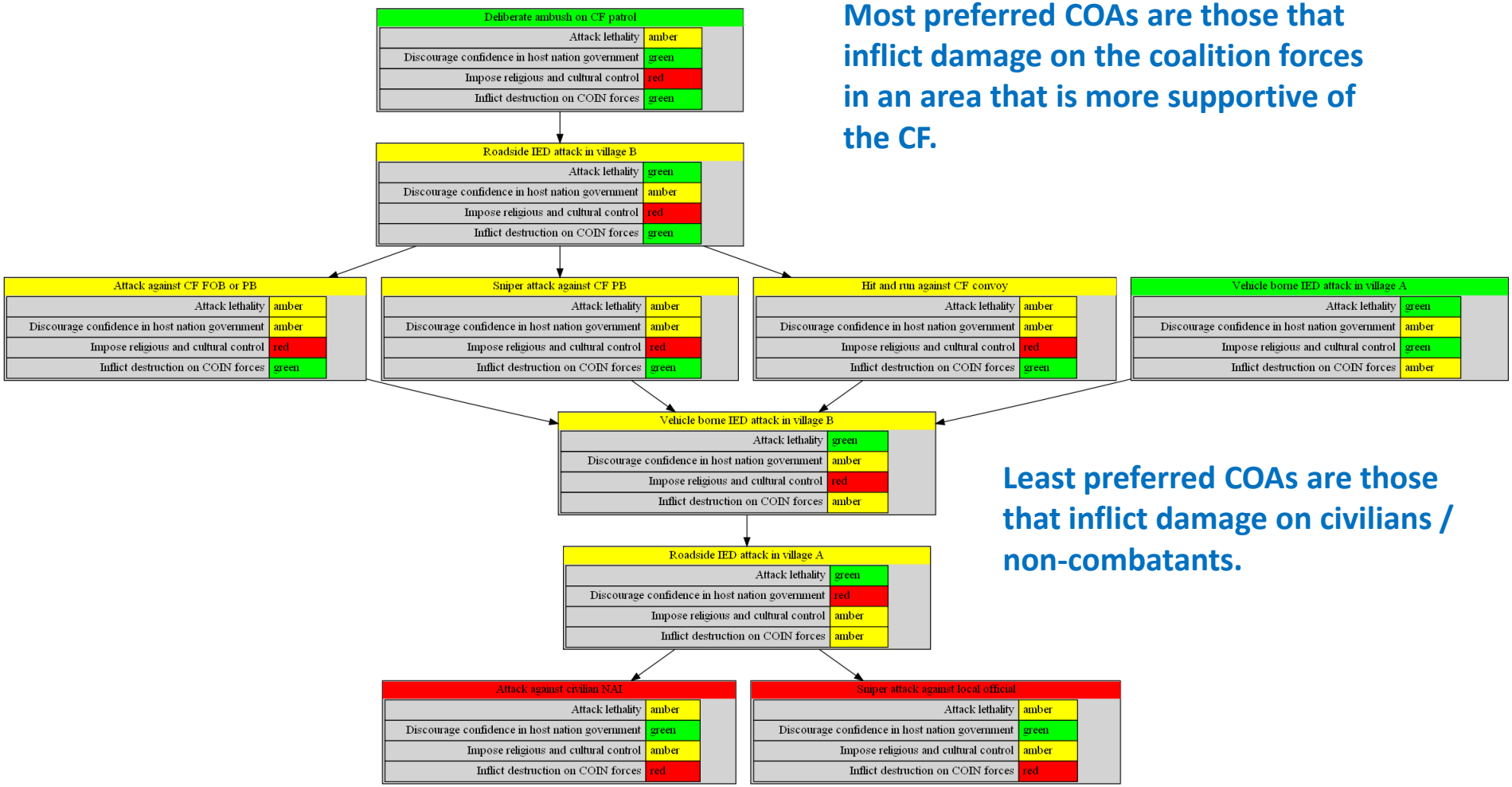
EC10 Preference Graph



Most preferred COAs are those that inflict damage on the coalition forces in an area that is more supportive of the CF.

Least preferred COAs are those that inflict damage on civilians / non-combatants.

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Conclusion

- Initial results from the EC 10 demo showed promise for this approach
- Relatively broad and deep model of the COA domain
  - IO feature vectors for describing COA effects, utility-theoretic preference models
- Visualization of the COA preference space clearly showing the most- and least-preferred COAs
- Extensive use of inference to support a “code-free” processing chain

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