



Supporting Early Decision-Making in the Presence of Uncertainty

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ALESSIO DI SANDRO²

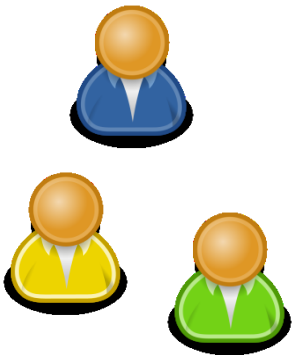
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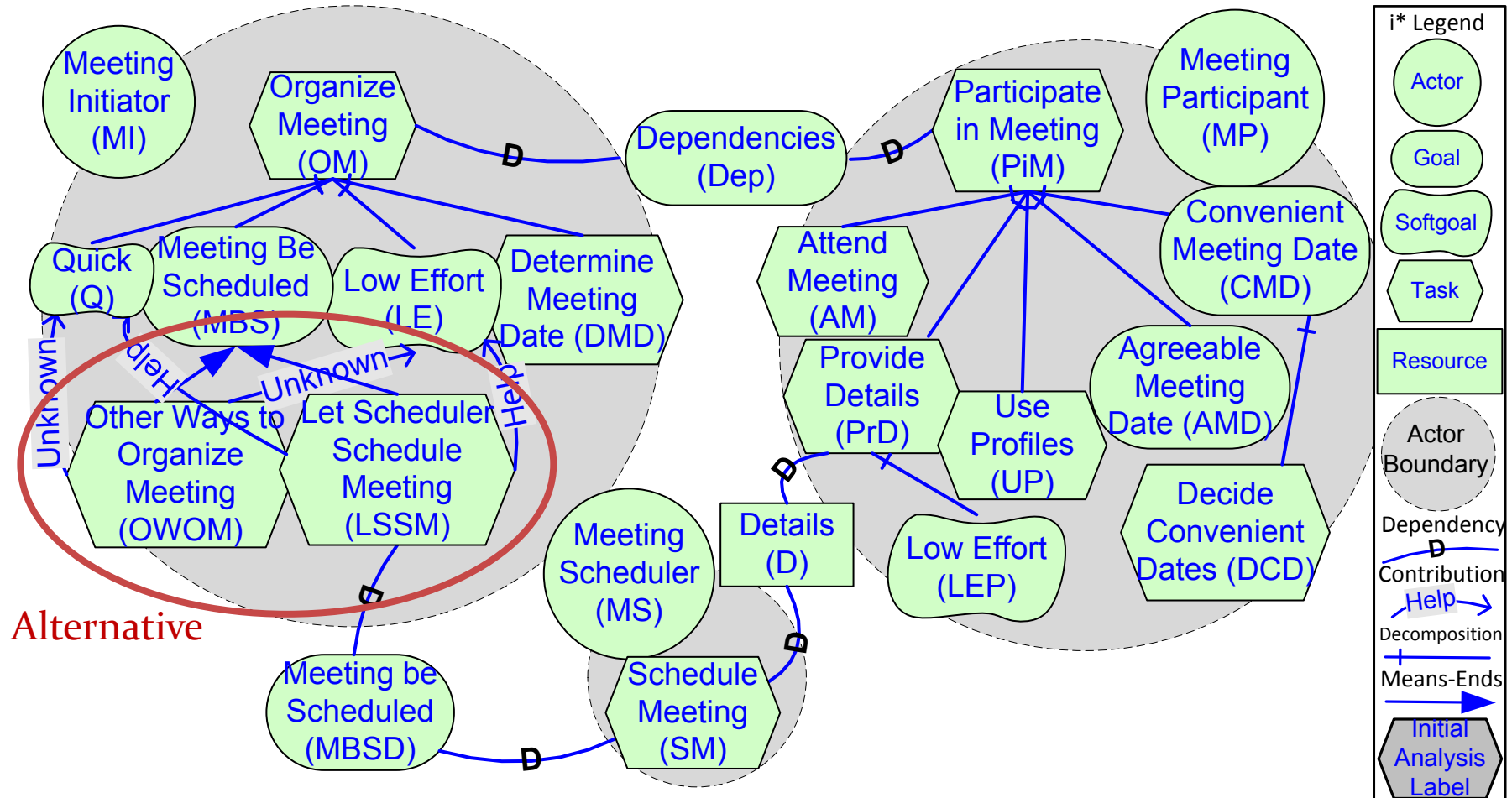
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Early RE Analysis

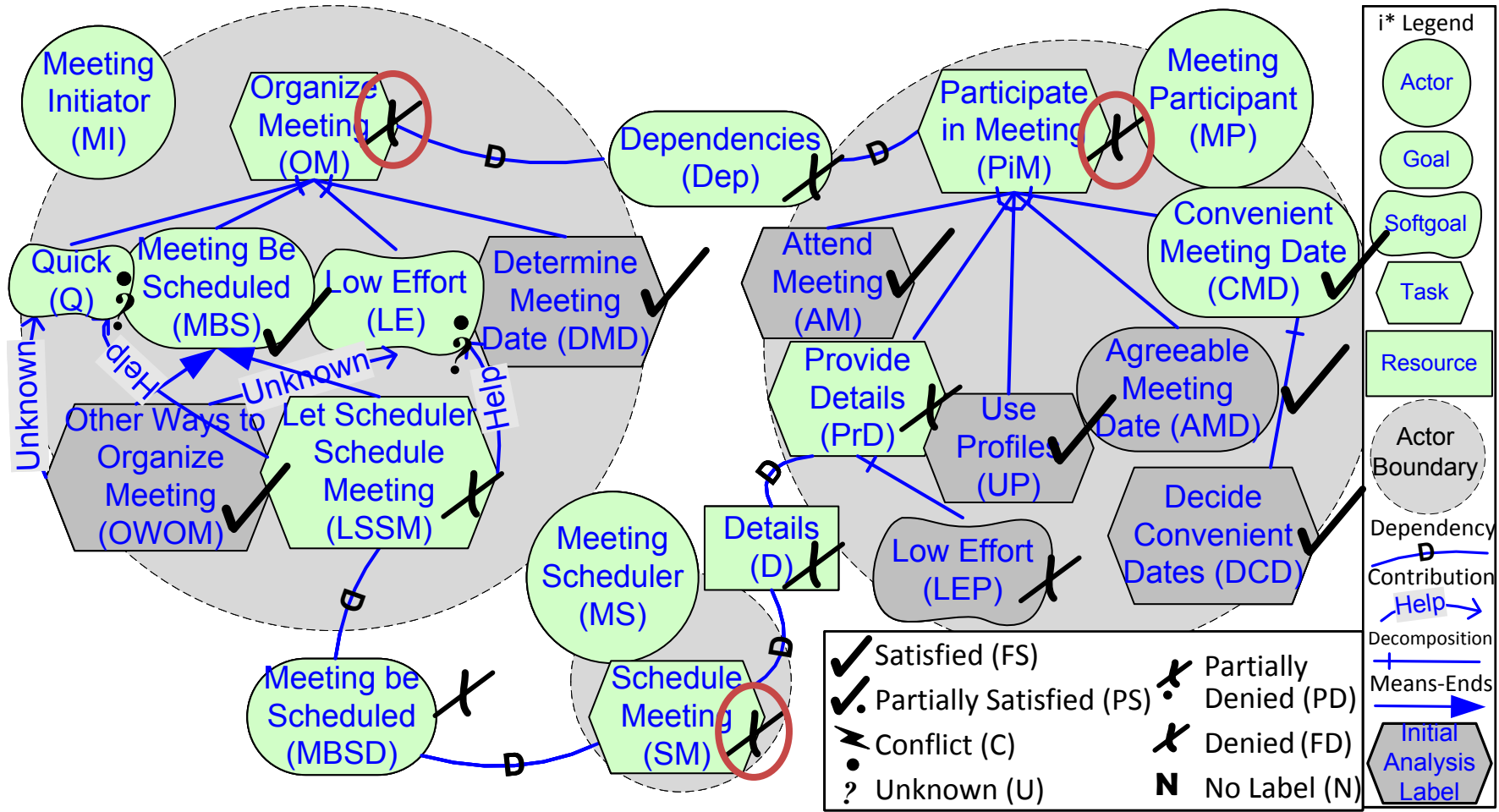
- Who is involved? What do they need? ...
- Large space of possible alternative requirements
- Example... Meeting Scheduler



Running Example: Meeting Scheduler



Early Decision Making (e.g., Horkoff & Yu)

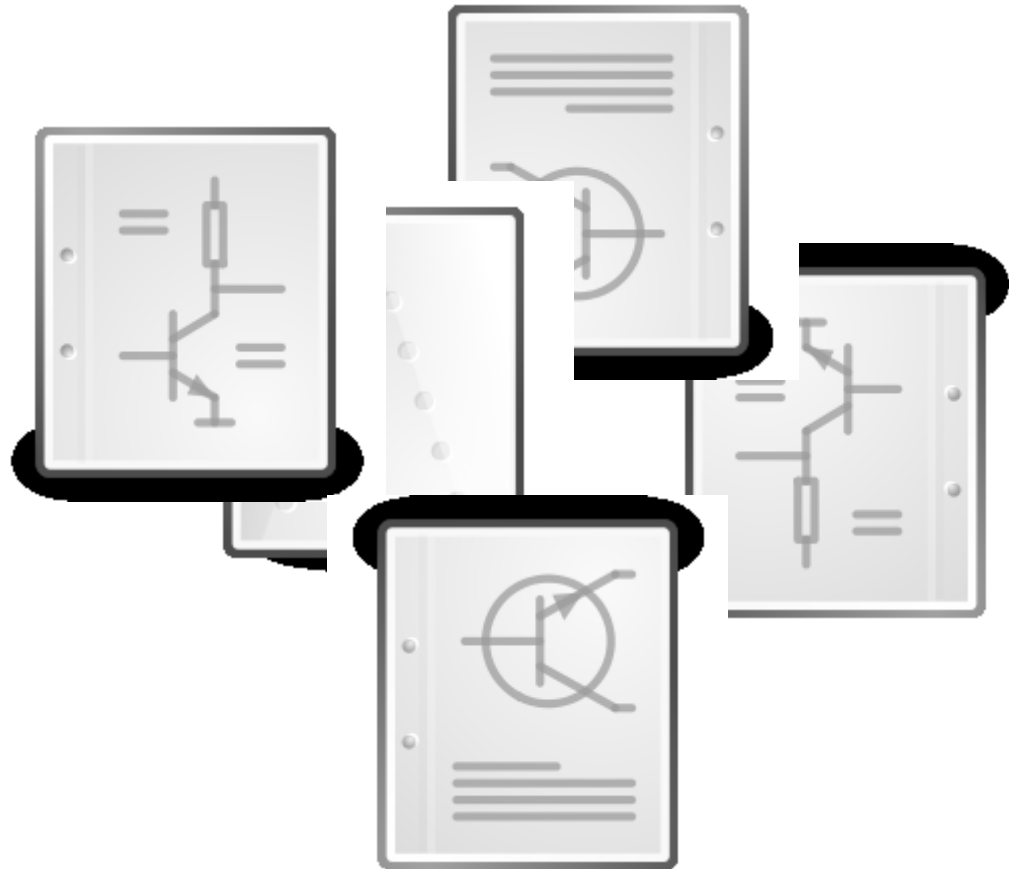


Uncertainty in Early RE

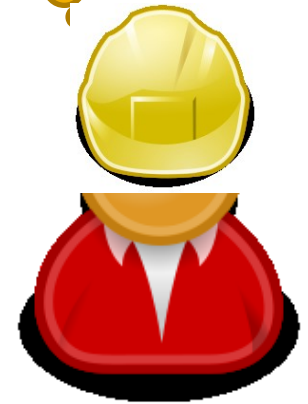
During RE elicitation, it is common to uncover uncertainties



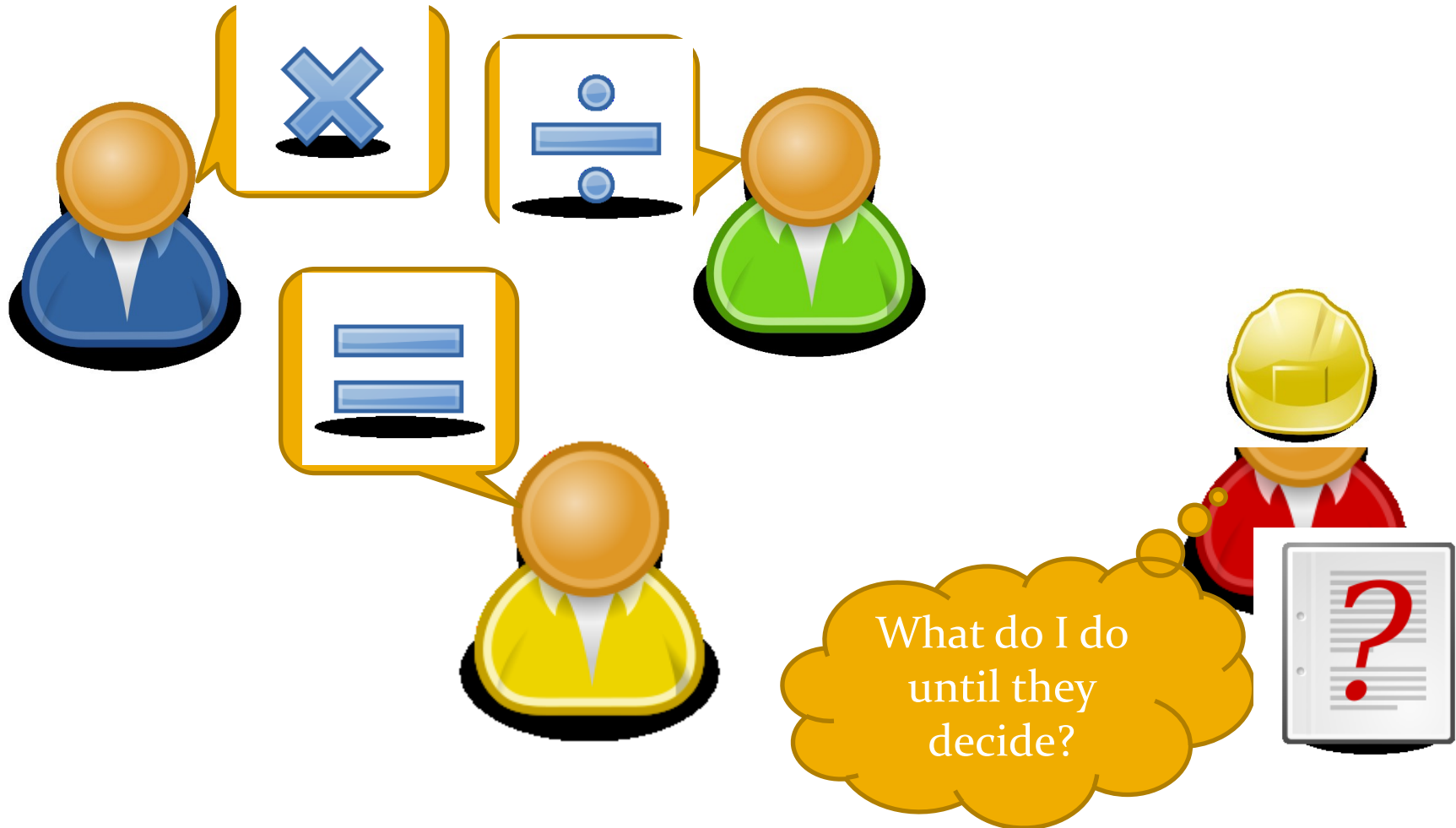
Alternative Designs



Hmm, I don't
yet know all the
possibilities.



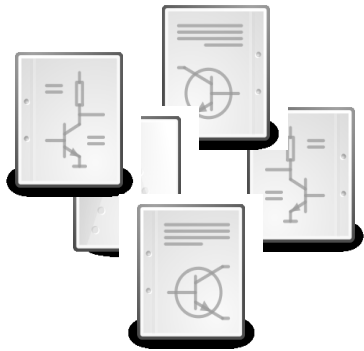
Conflicting Stakeholder Opinions



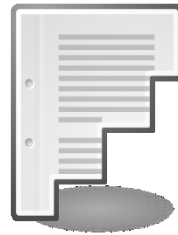
Incomplete Information



Uncertainty in Requirements Engineering



Many design alternatives



Incomplete information



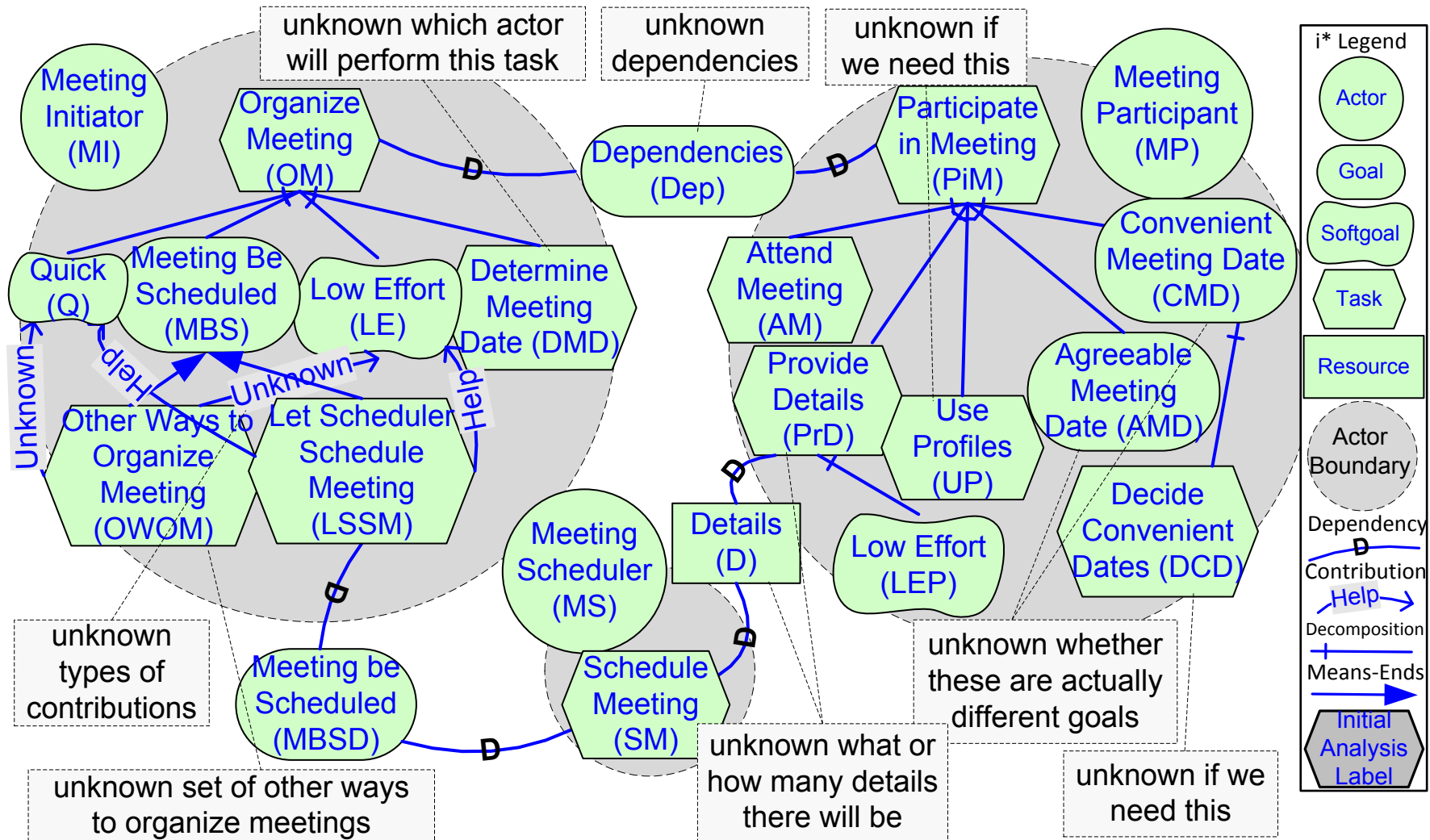
Conflicting stakeholder opinions



Uncertainty about the content of the model.



Meeting Scheduler Uncertainty



Early Decision Making with Uncertainty

- May not be able to resolve all uncertainties before decisions must be made!
- **We need methods and tools to support early decision-making and trade-off analysis in the presence of uncertainty**

Our Approach: Goal Model Analysis + MAVO

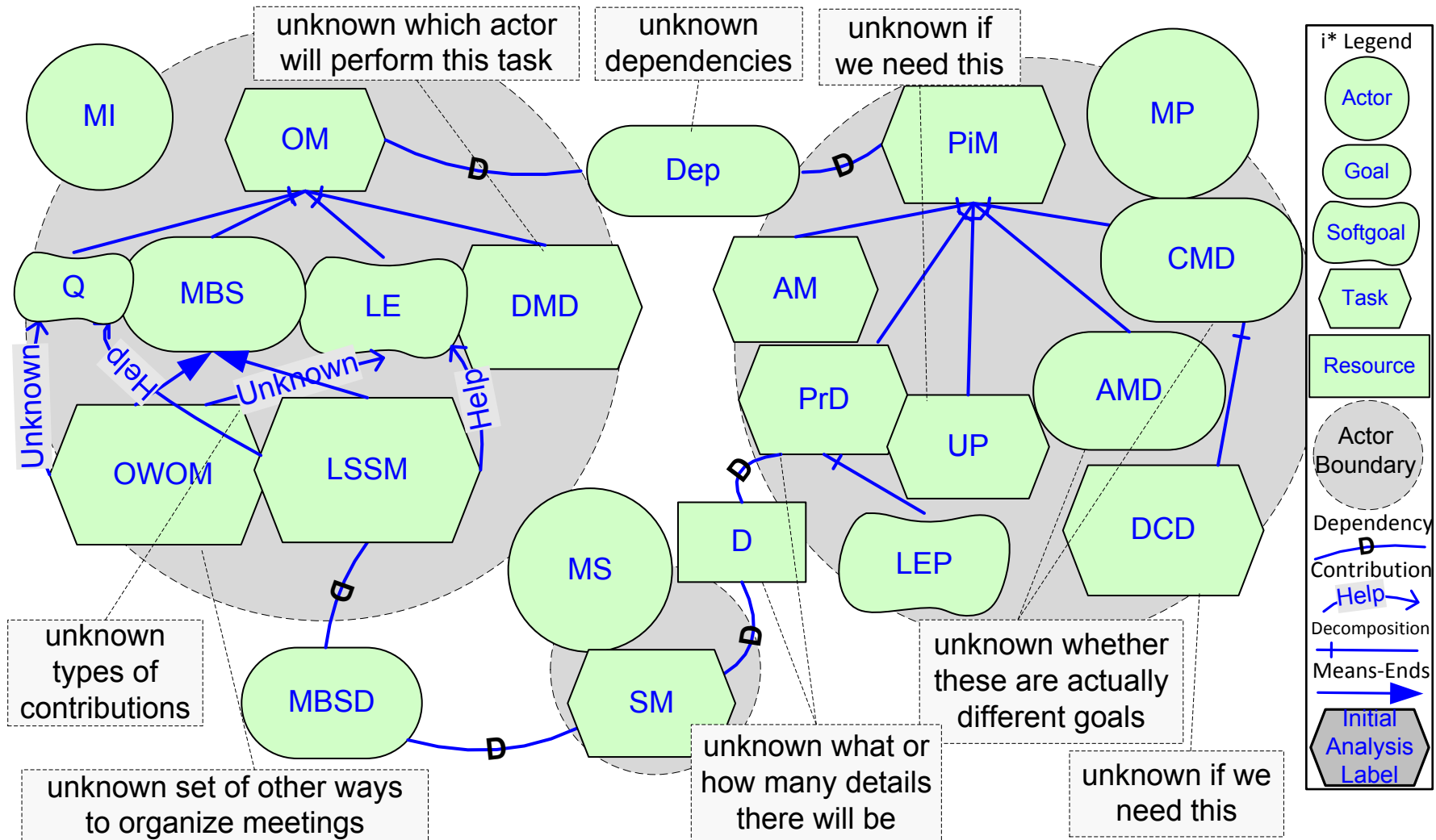
- To tackle this challenge we make use of existing, established RE Techniques
 - Goal modeling and goal satisfaction analysis (e.g., Horkoff & Yu, 2010, 2102)
 - The *MAVO* framework for formally capturing and reasoning over model uncertainty (Salay et al., 2012)

- We focus on the design-time uncertainty of the modeler, and not the intrinsic, run-time uncertainty of environment

- Use possibilistic rather than probabilistic uncertainty

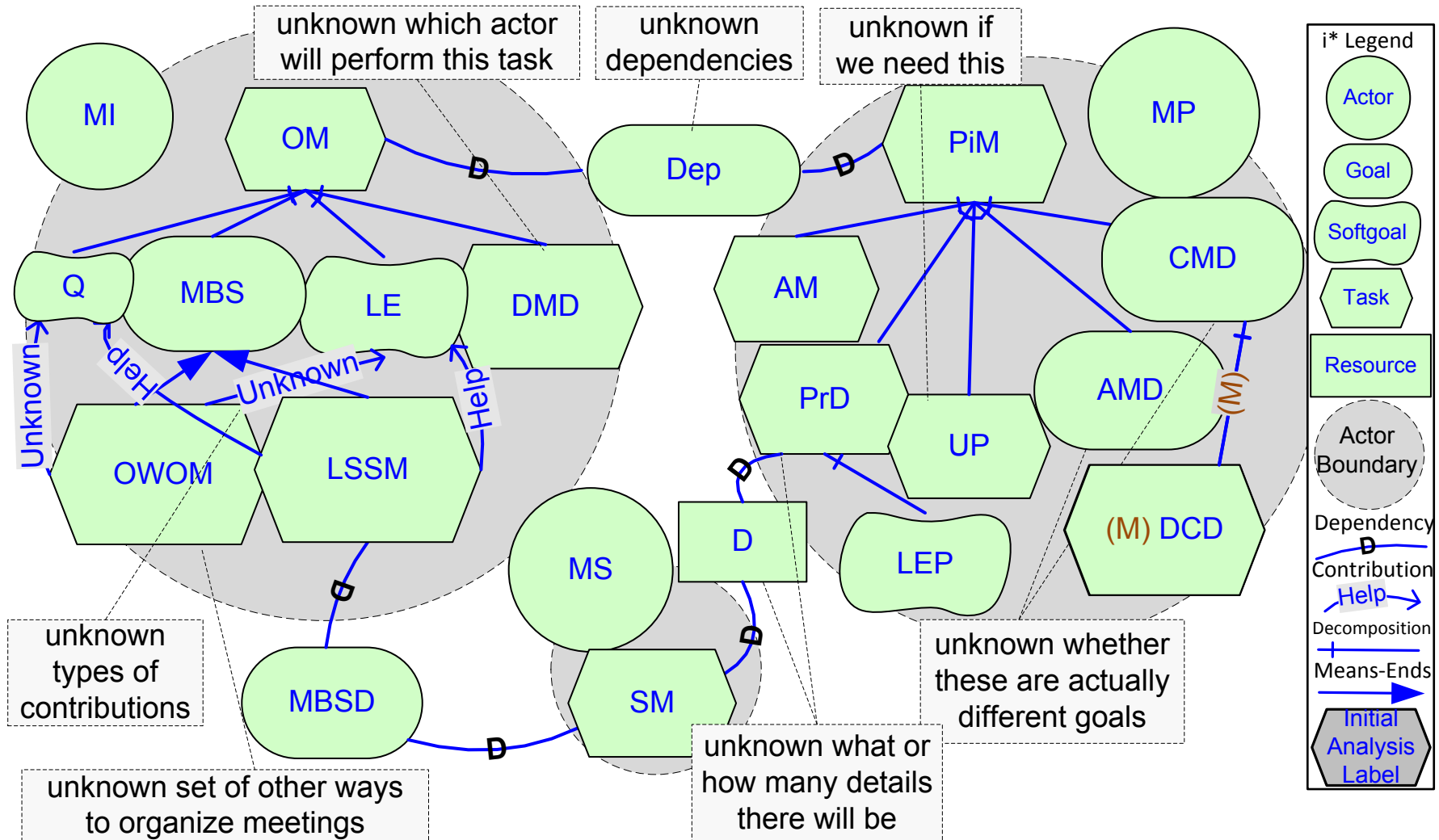
Background: Capturing Uncertainty with MAVO

(Salay et al., RE'12)



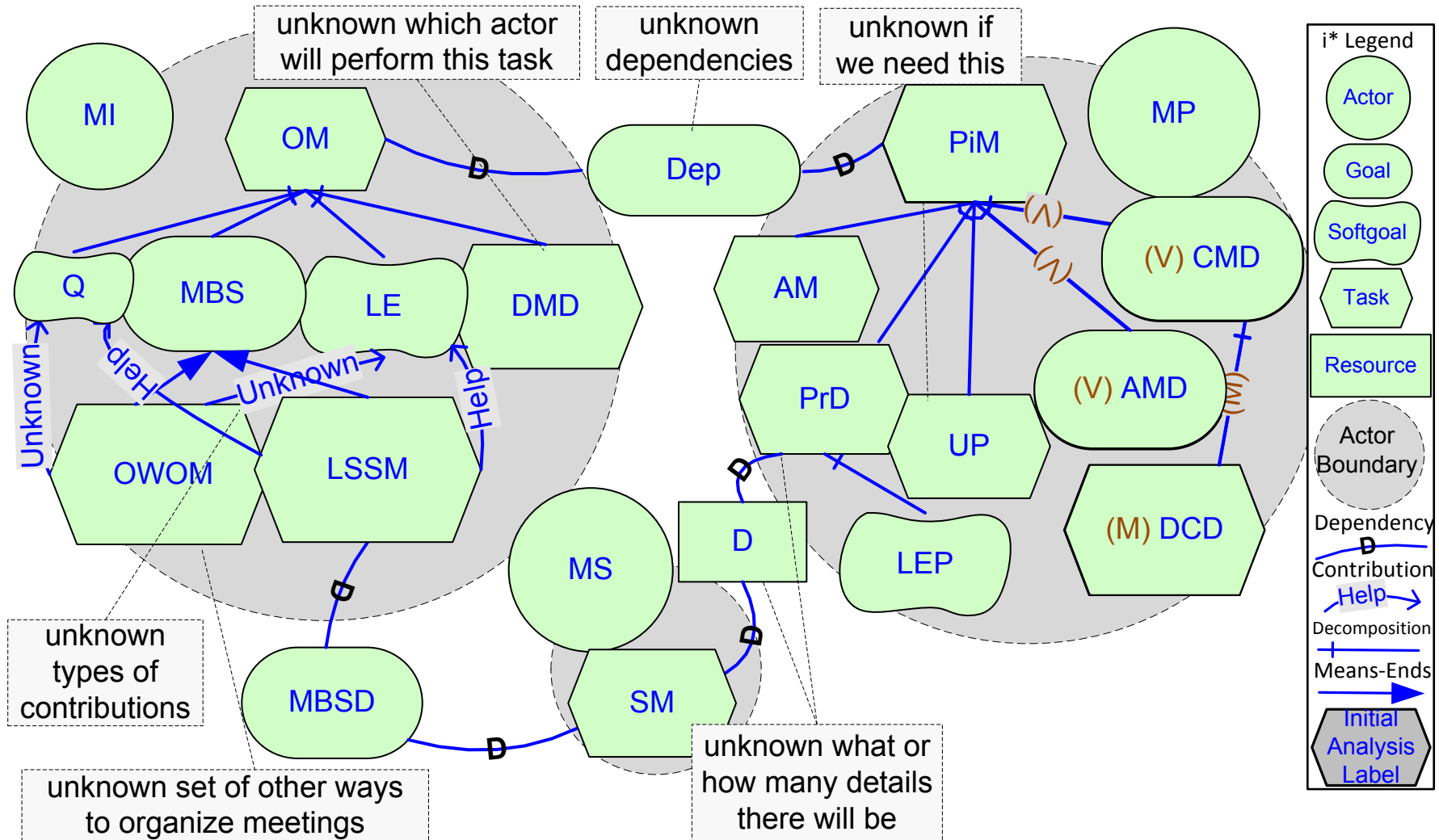
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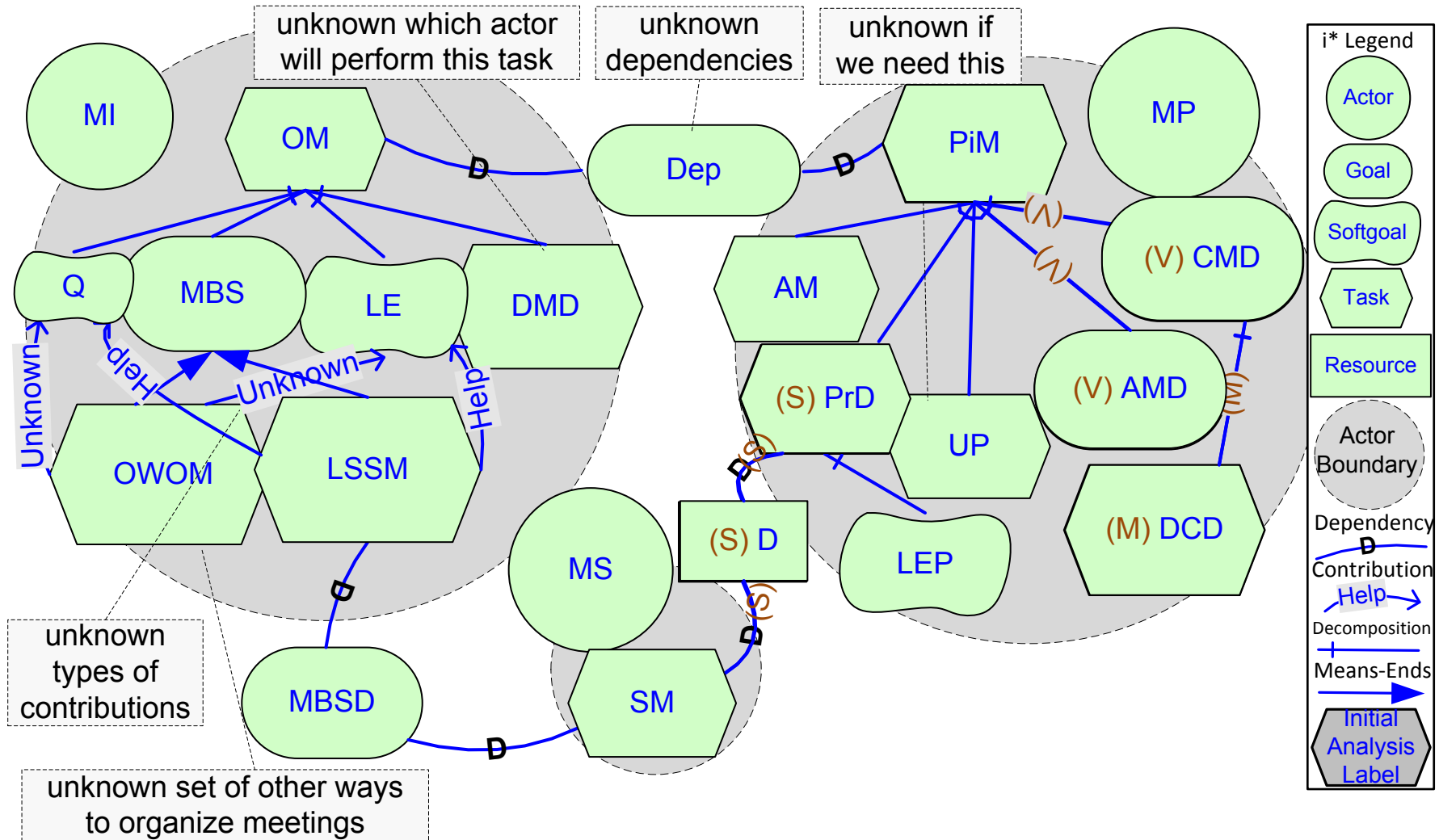
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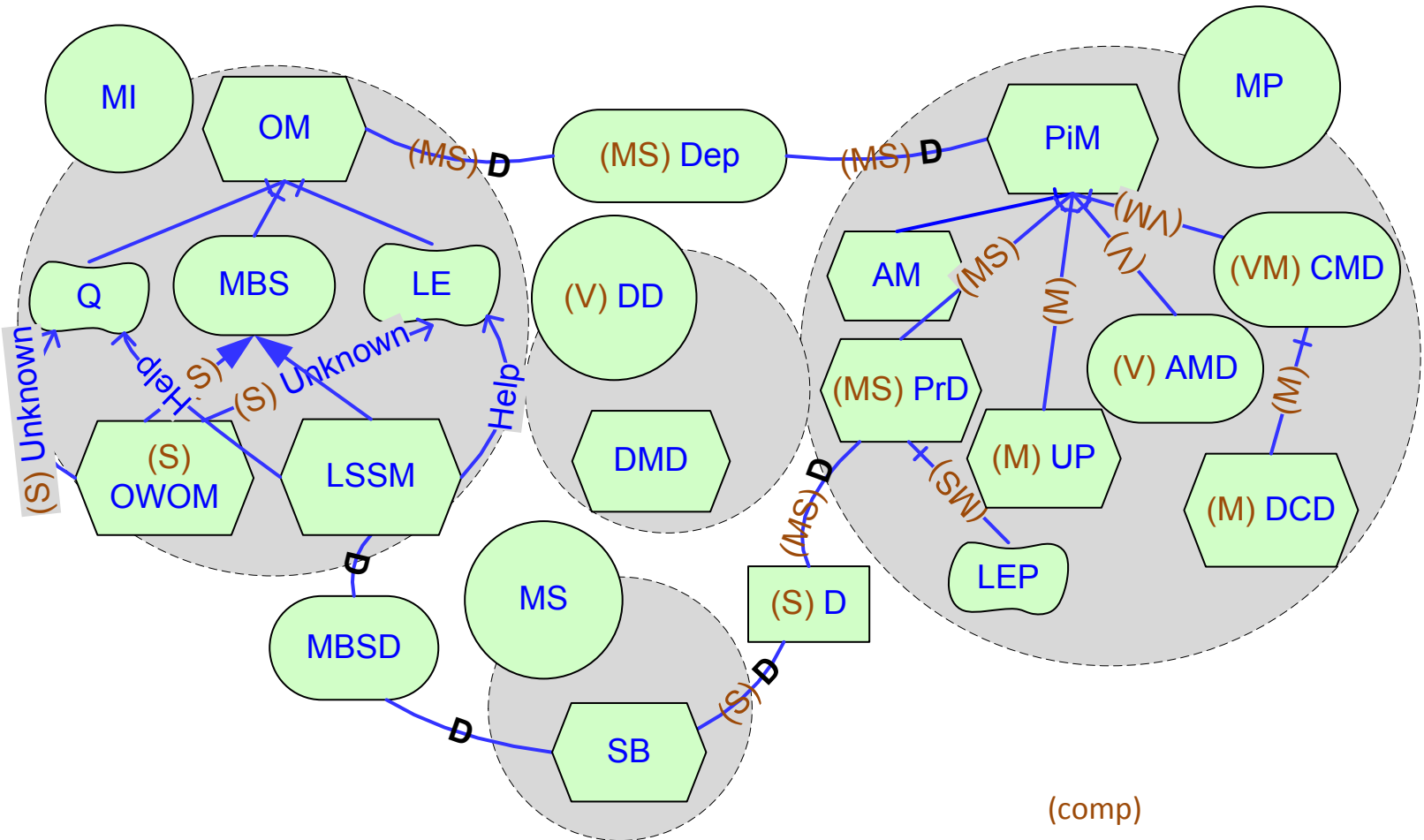


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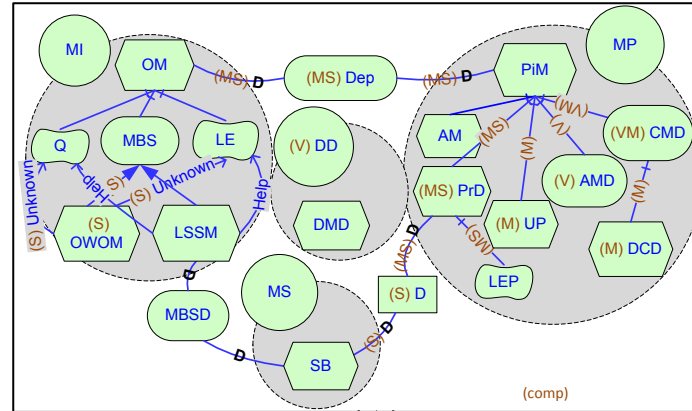
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Capturing Uncertainty with MAVO

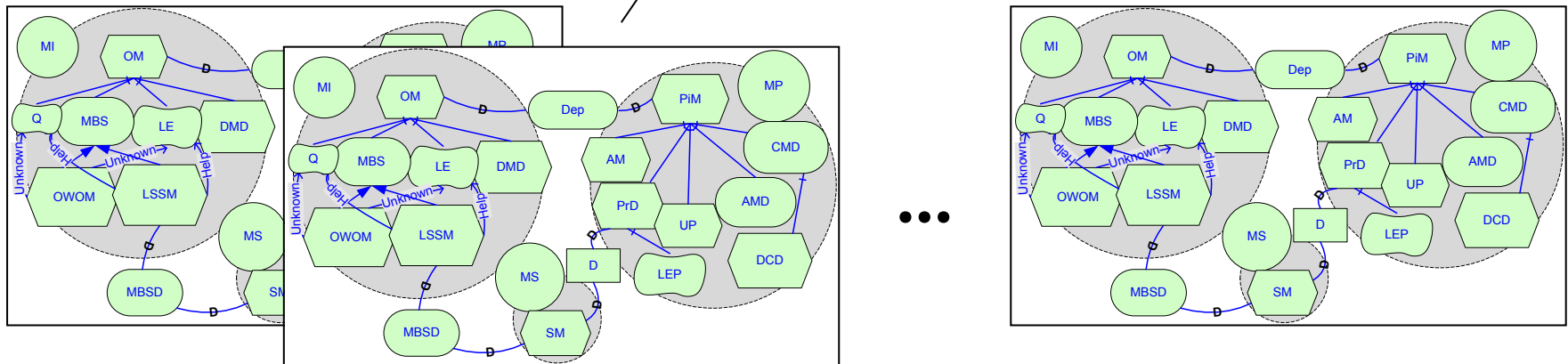


Background: Concretizations



MAVO model capturing uncertainty

Set of **certain** “concrete” models, “concretizations”



Methodology

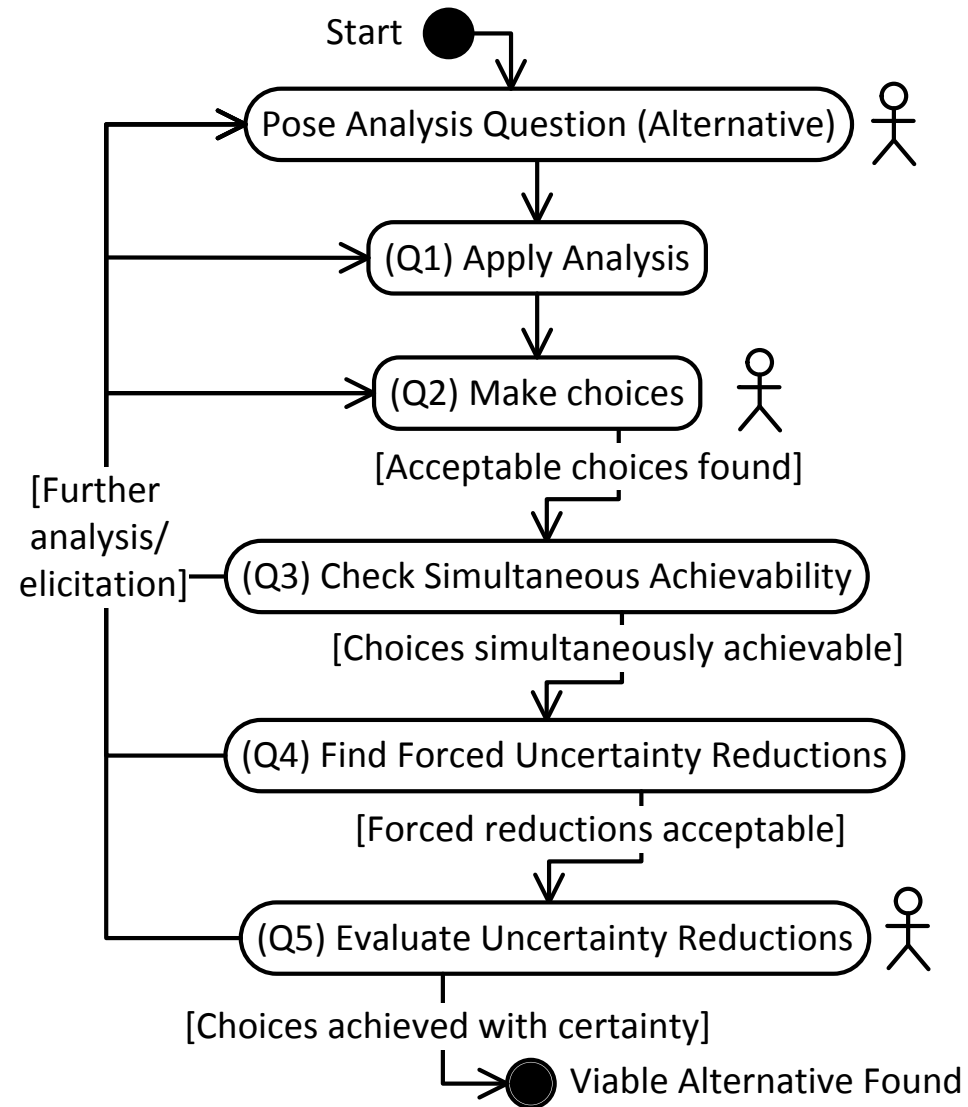
Q1 What are the analysis results given a particular analysis alternative in the goal model, considering model uncertainties?

Q2 Can viable choices be made over the set of results from Q1?

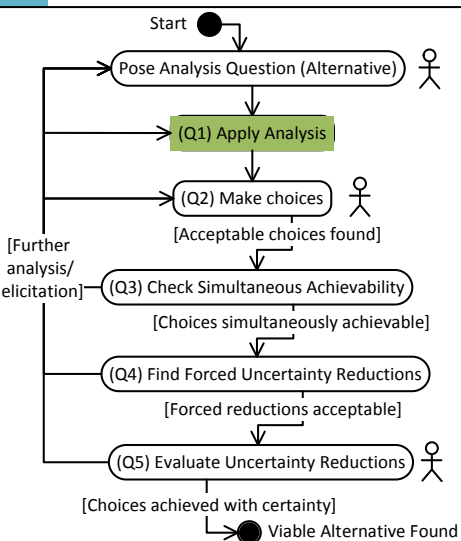
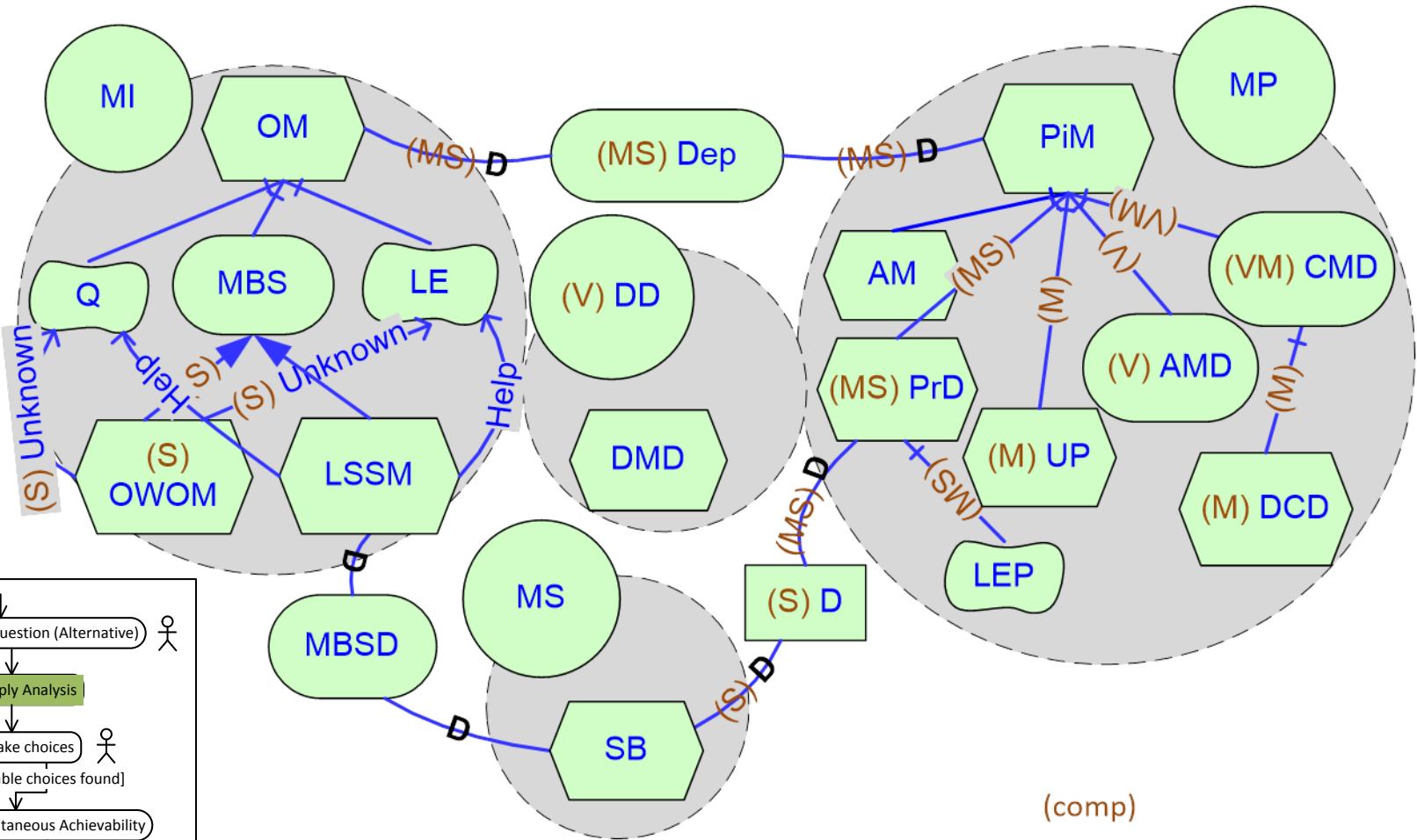
Q3 Can viable choices be achieved simultaneously?

Q4 Given choices, what uncertainty reductions are forced? How can we target elicitation?

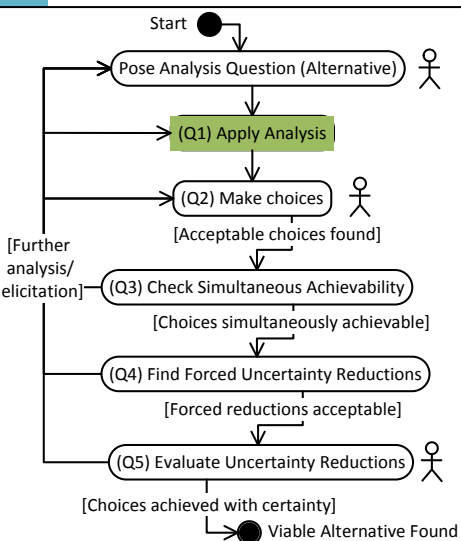
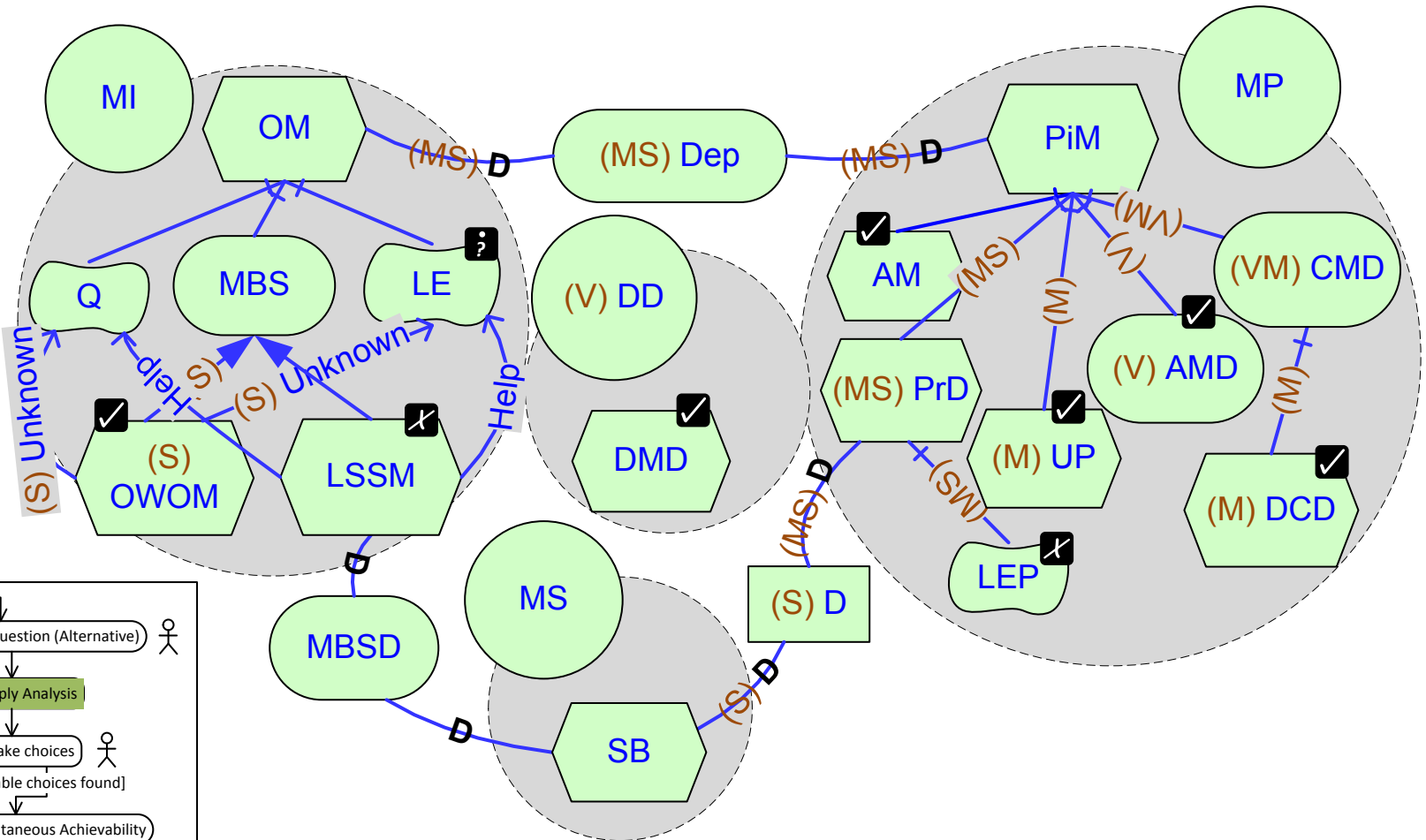
Q5 Are suggested uncertainty reductions reasonable? If not, iterate over the model and backtrack.



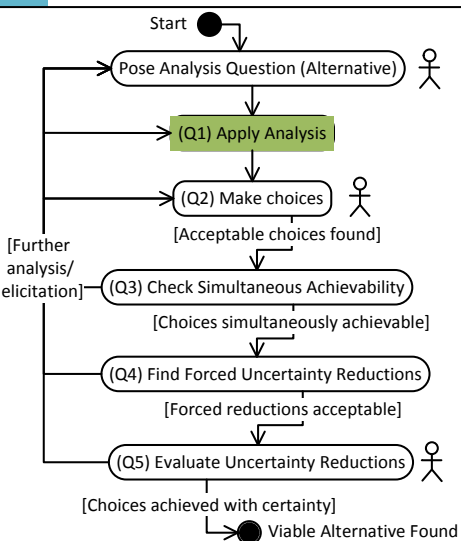
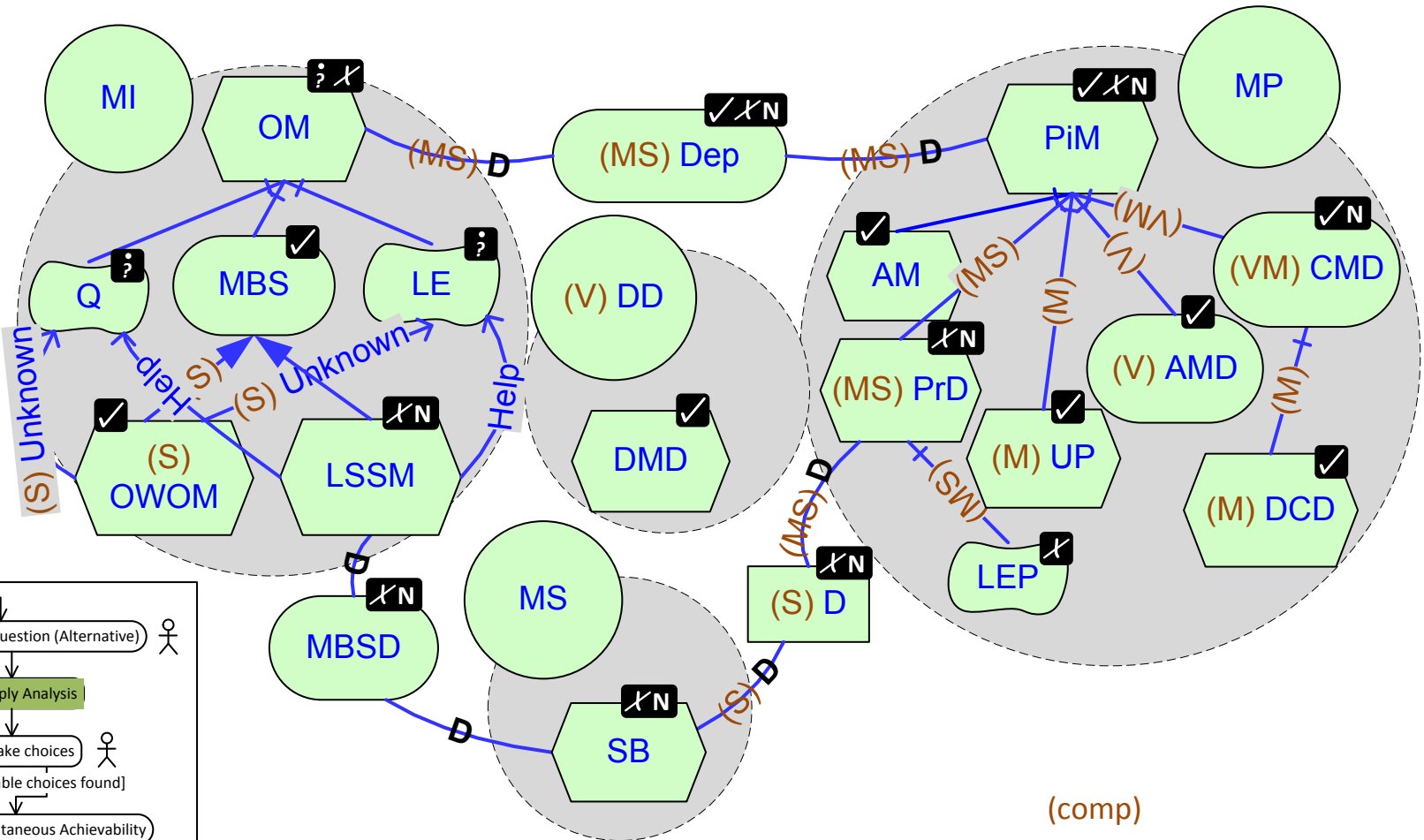
Answering Q1: Determining Labels



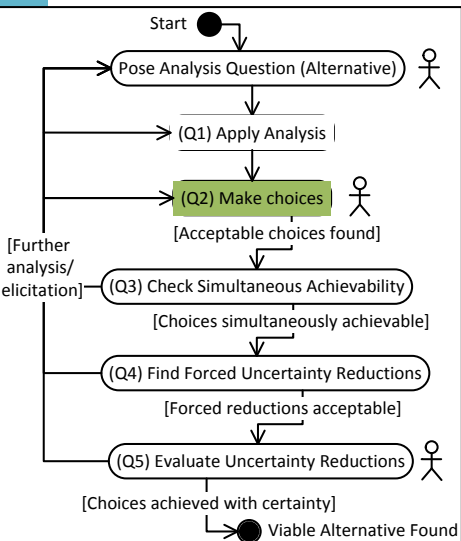
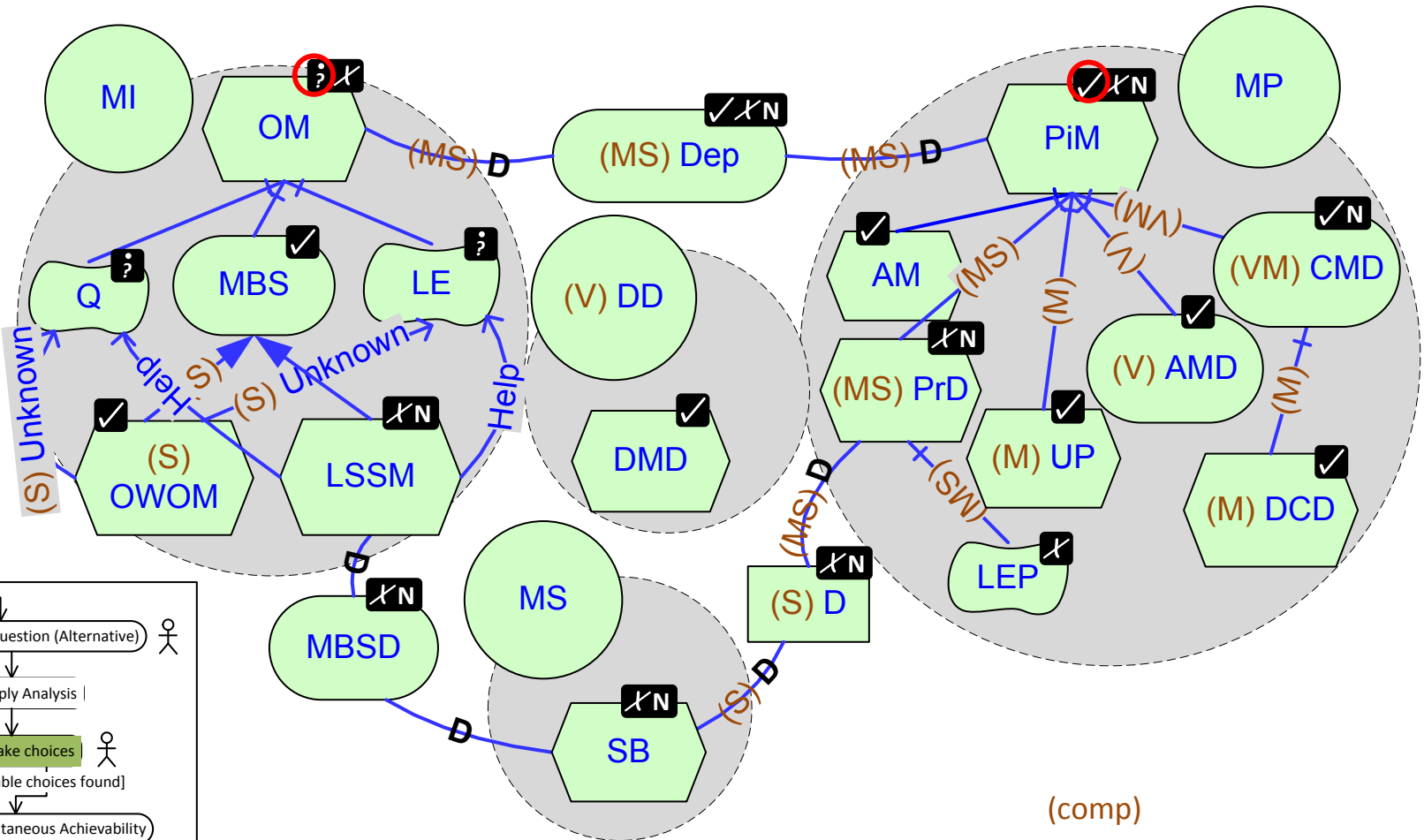
Answering Q1: Determining Labels



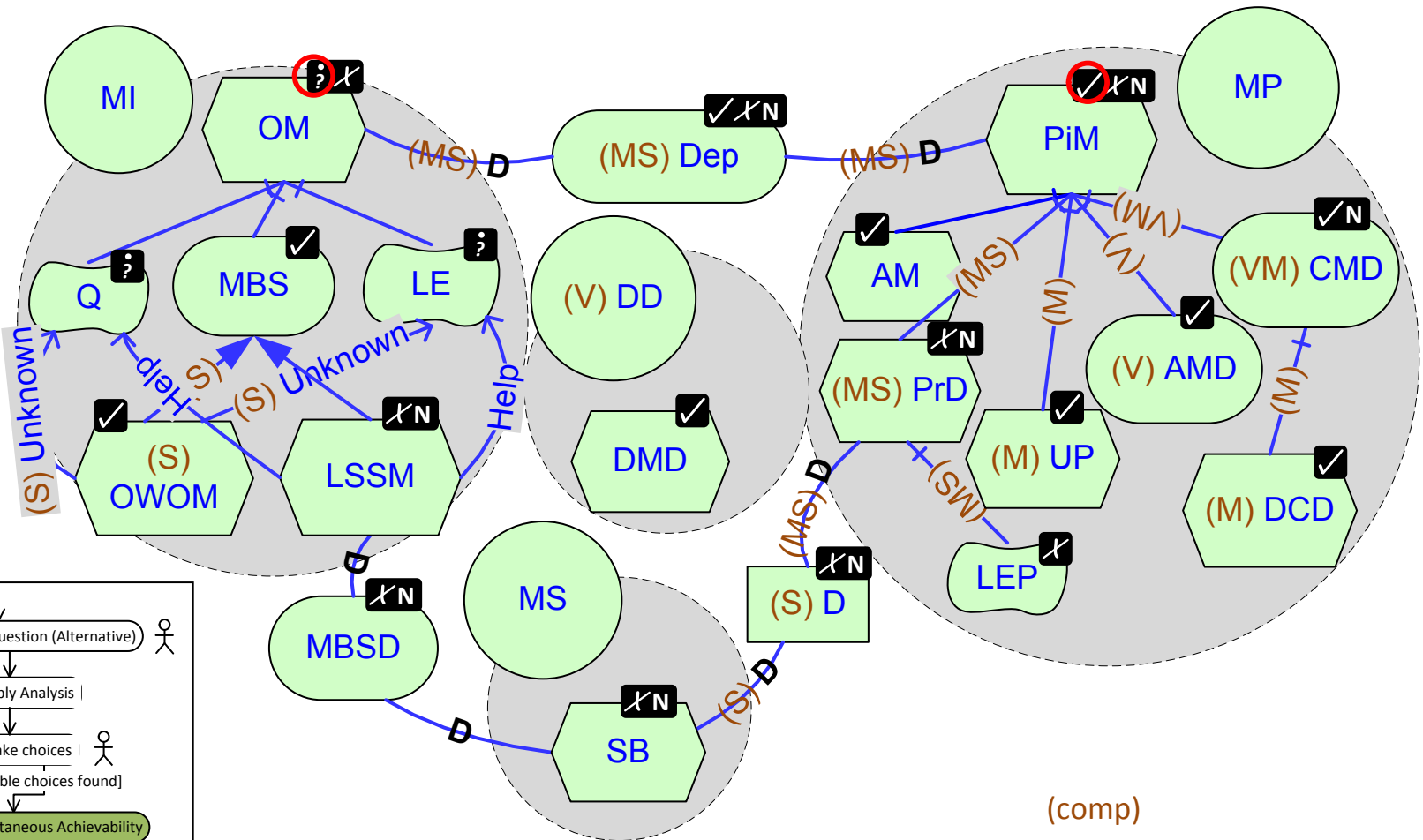
Answering Q1: Determining Labels



Answering Q2: Making Choices

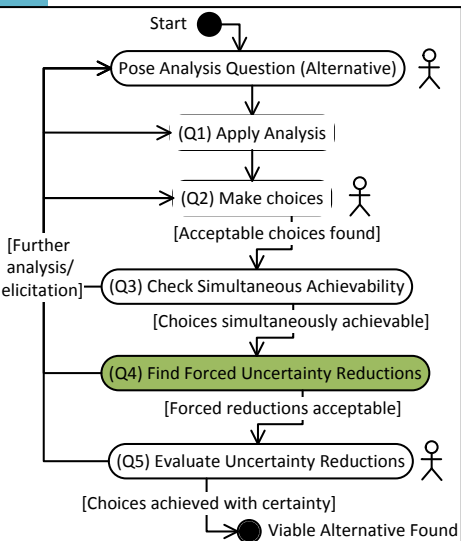
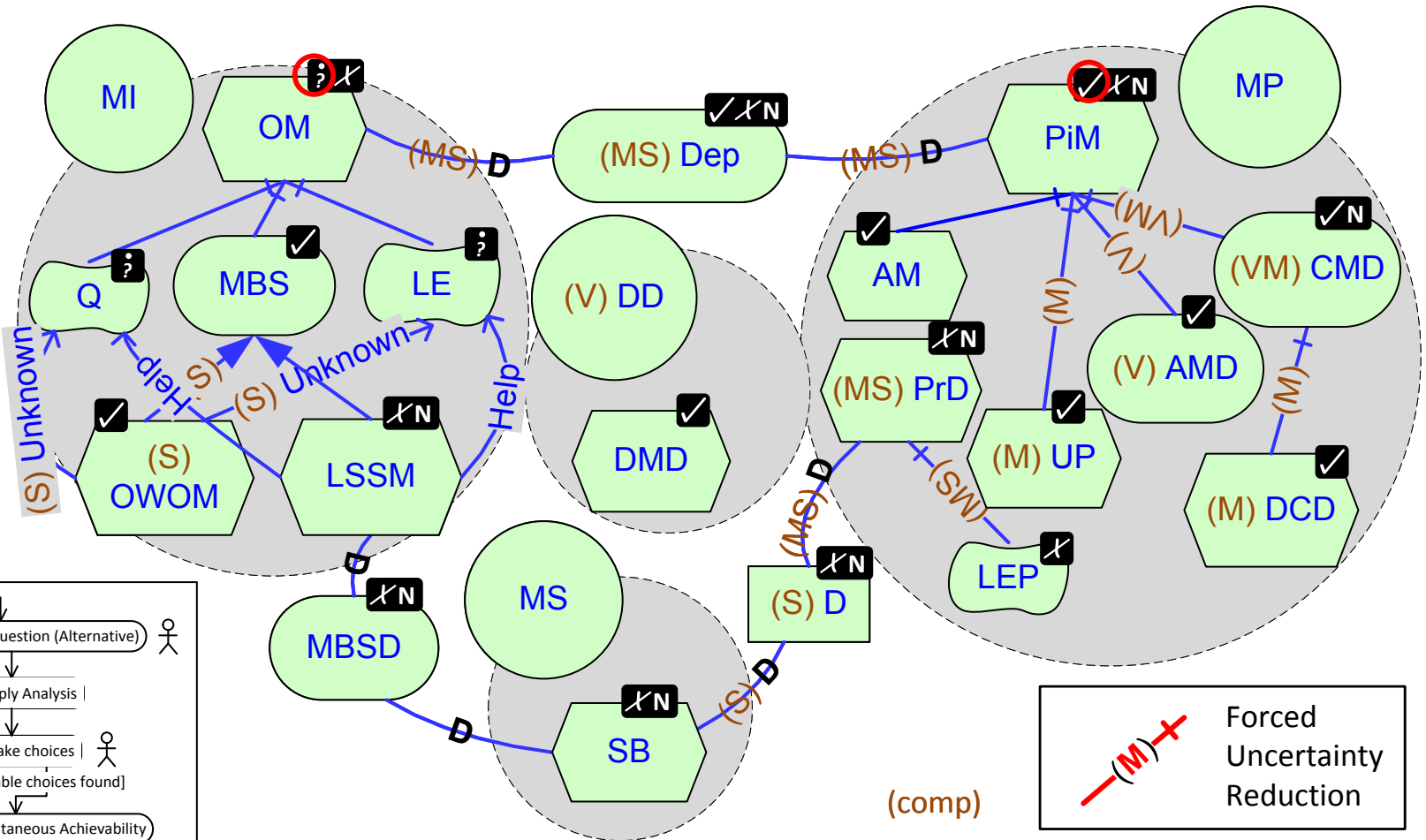


Q3: Checking Simultaneous Achievement

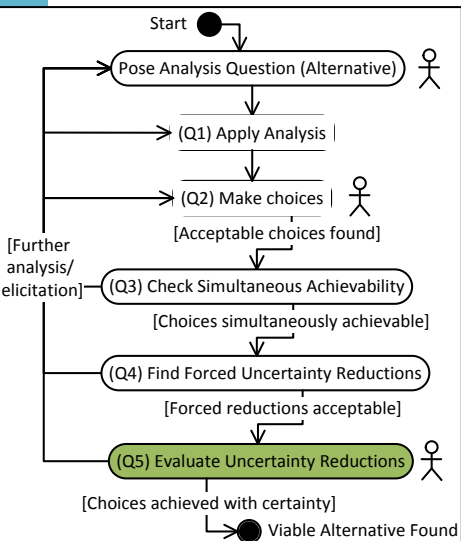
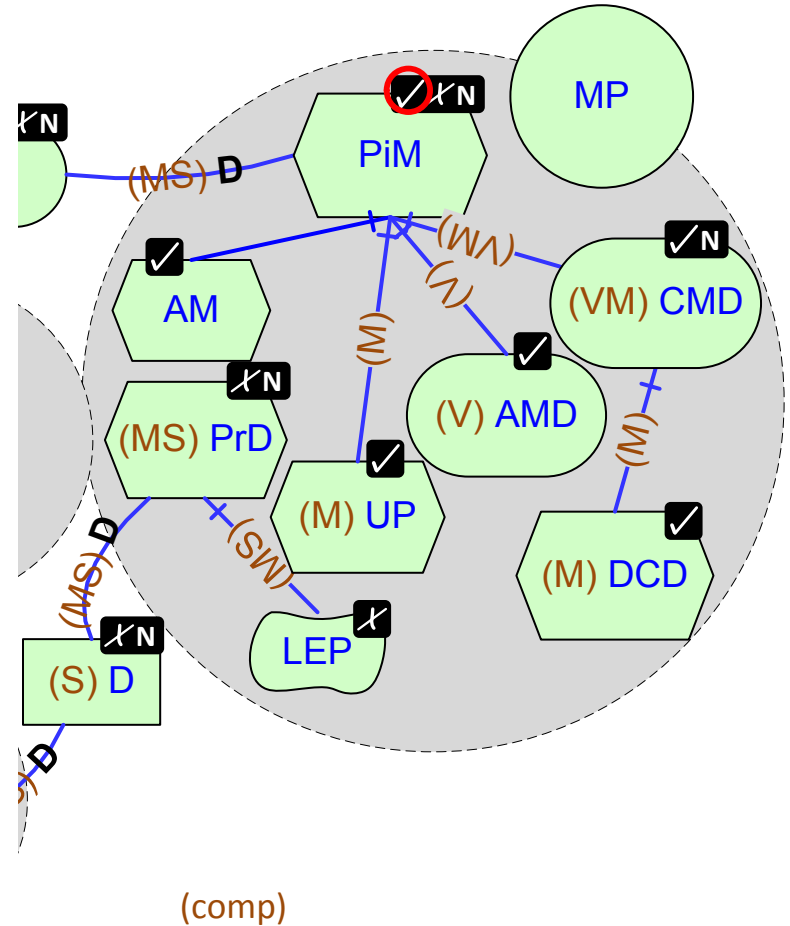


In our example, choices are simultaneously achievable (achievable together in at least one concretization)

Q4: Finding forced Uncertainty Reductions

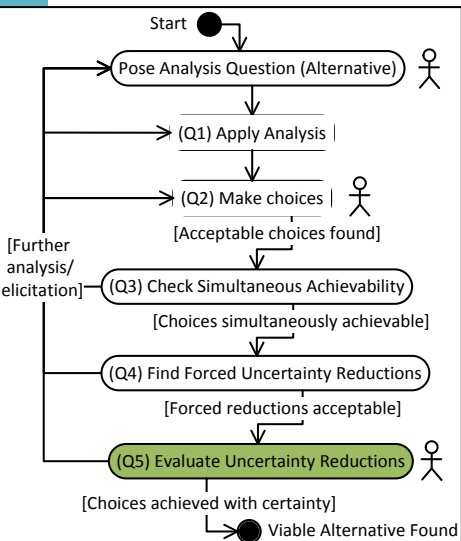
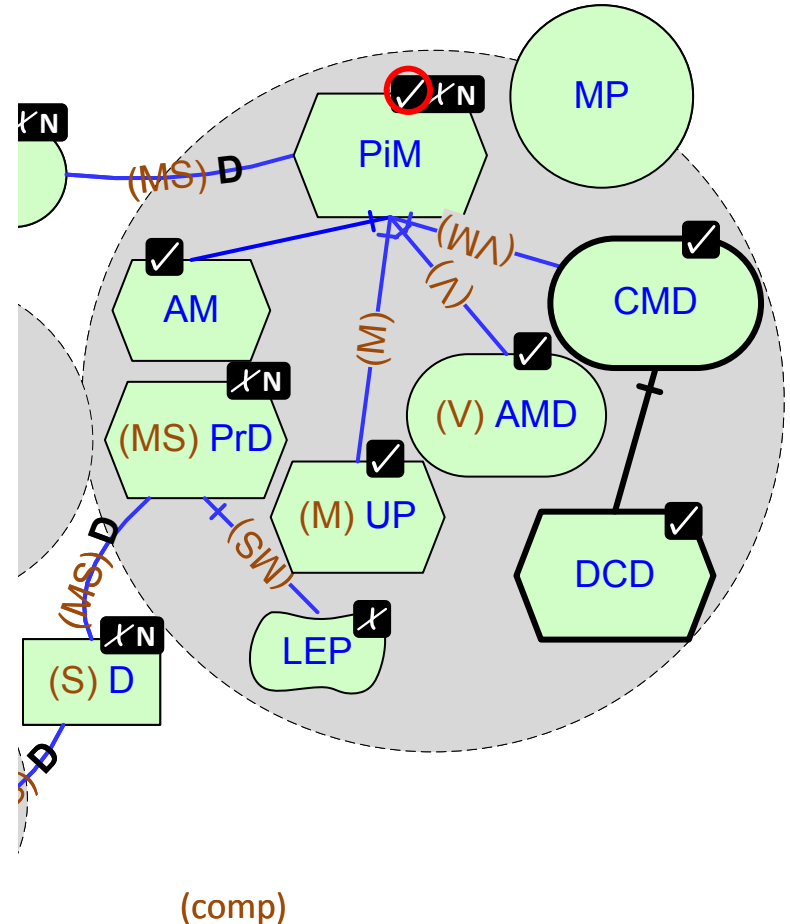


Q5: Evaluate Uncertainty Reductions



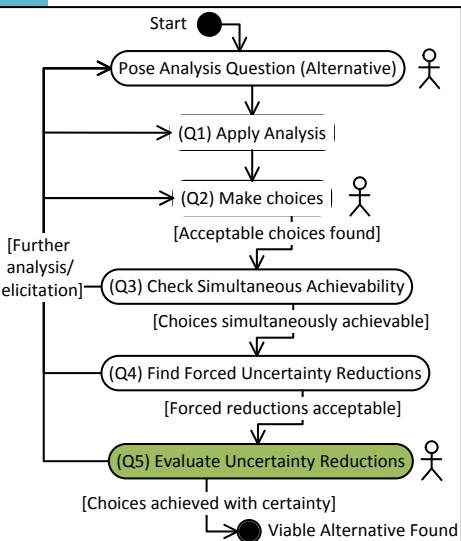
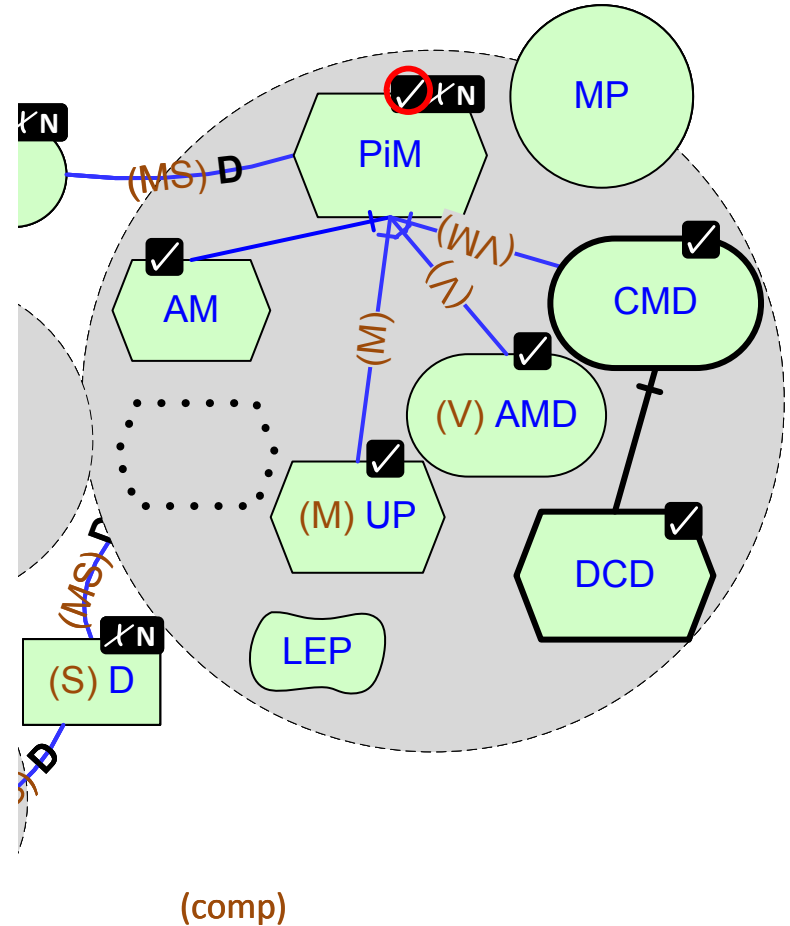
Answering Q3 produces an example concretization

Q5: Evaluate Uncertainty Reductions



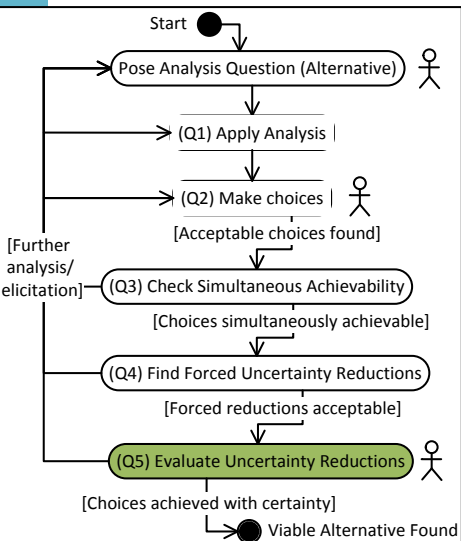
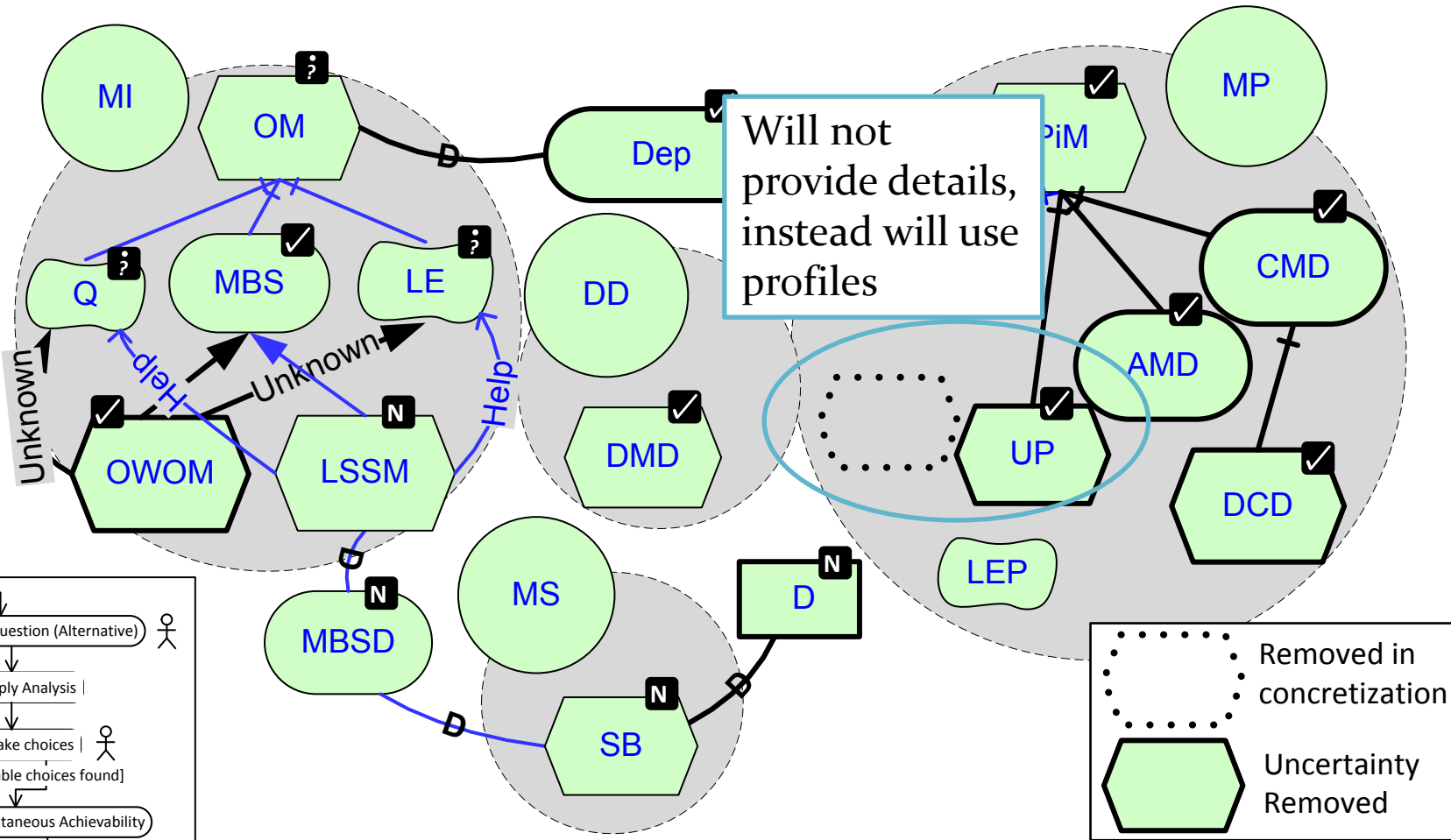
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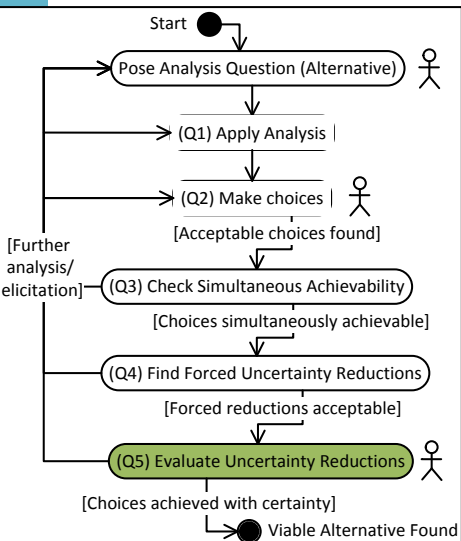
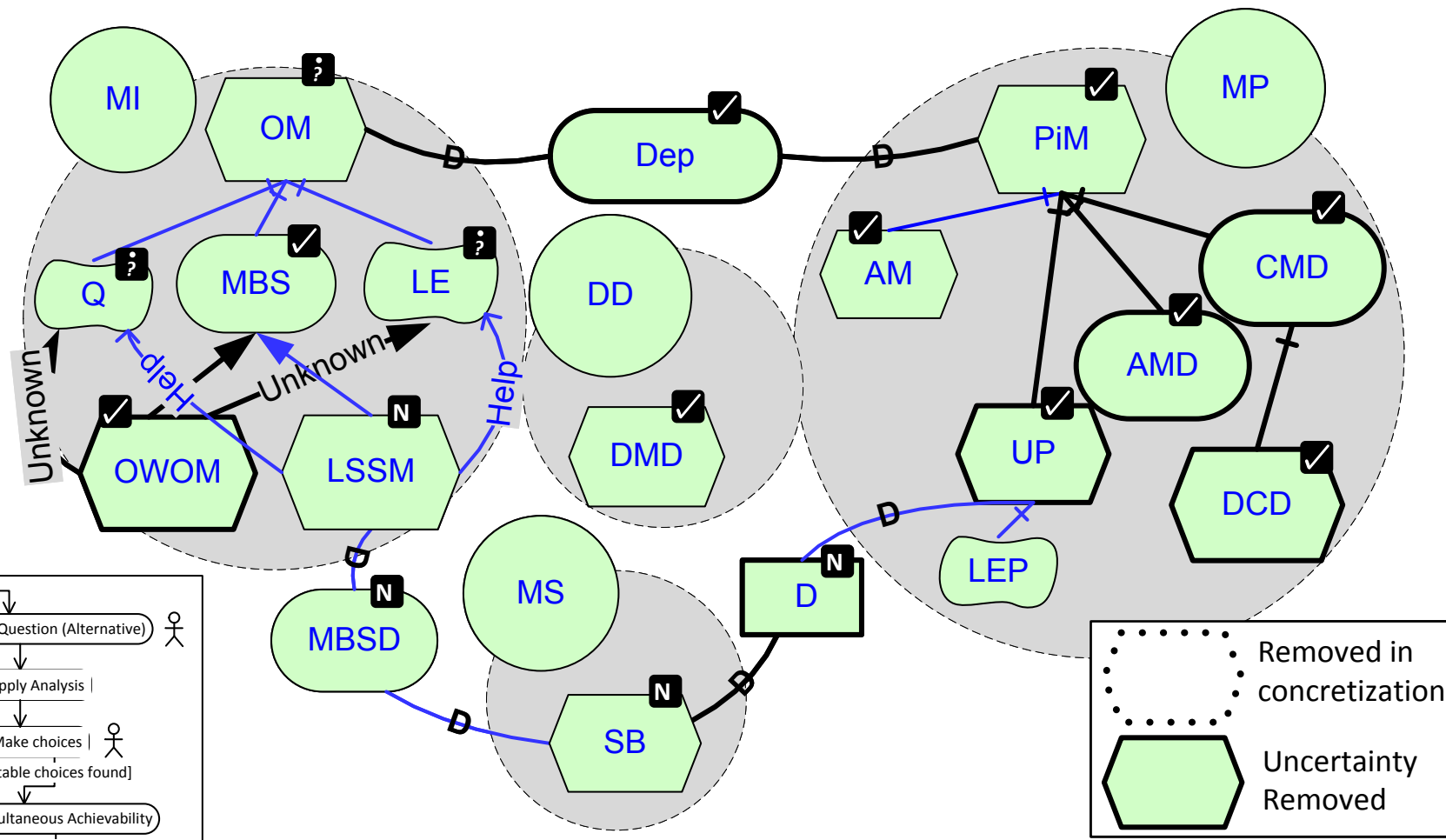


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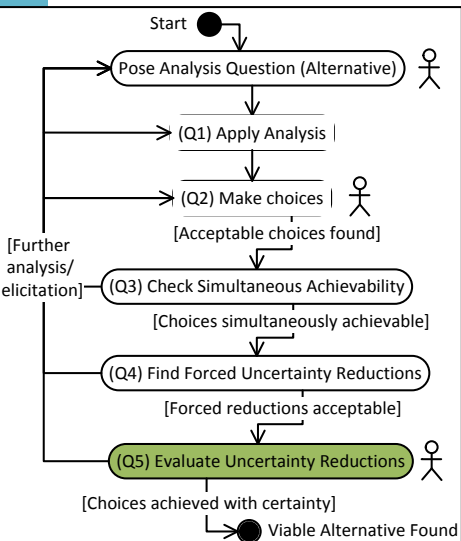
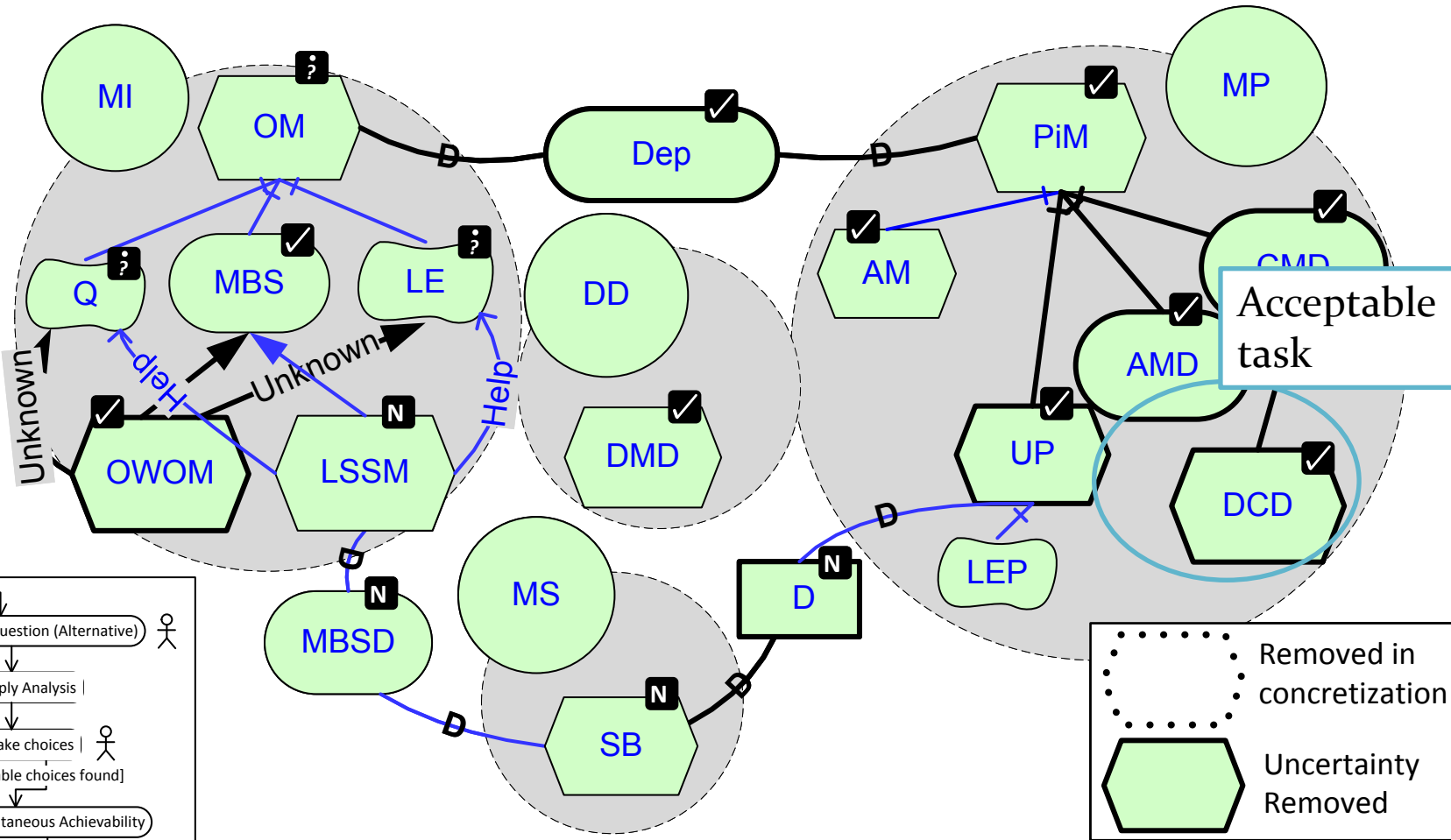
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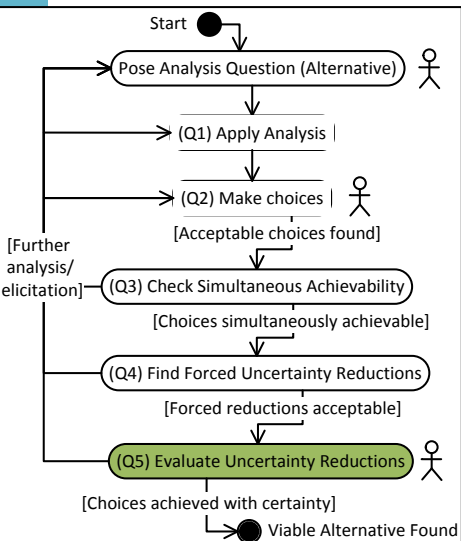
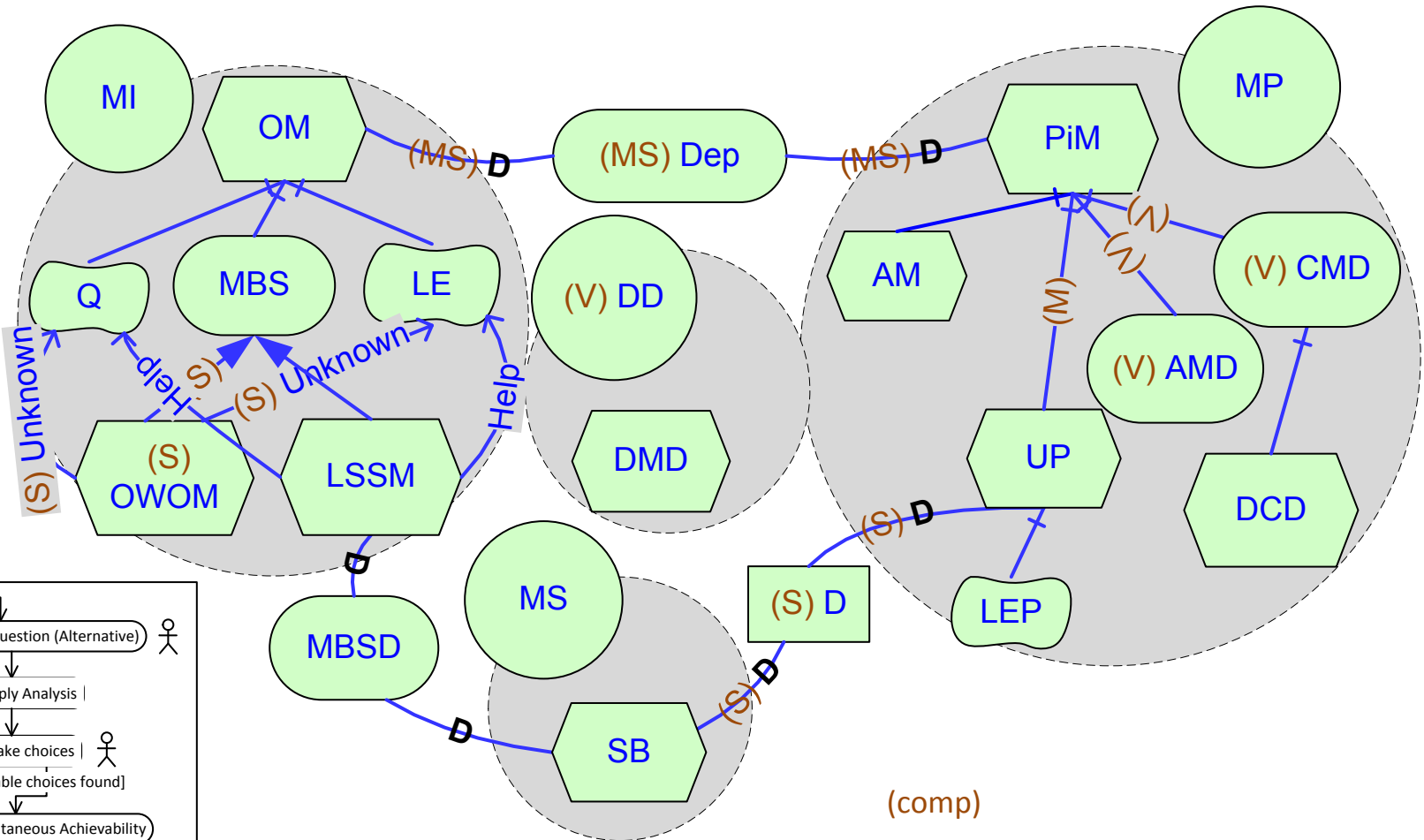
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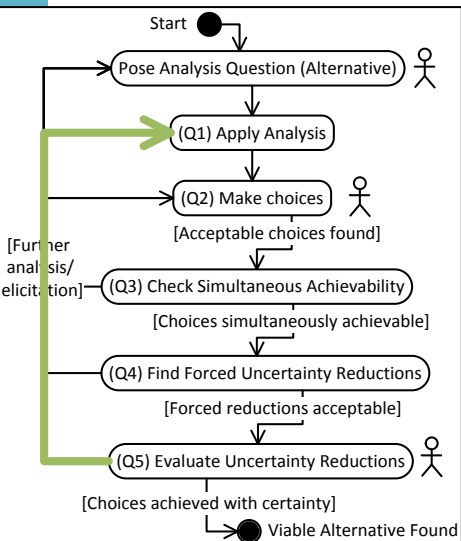
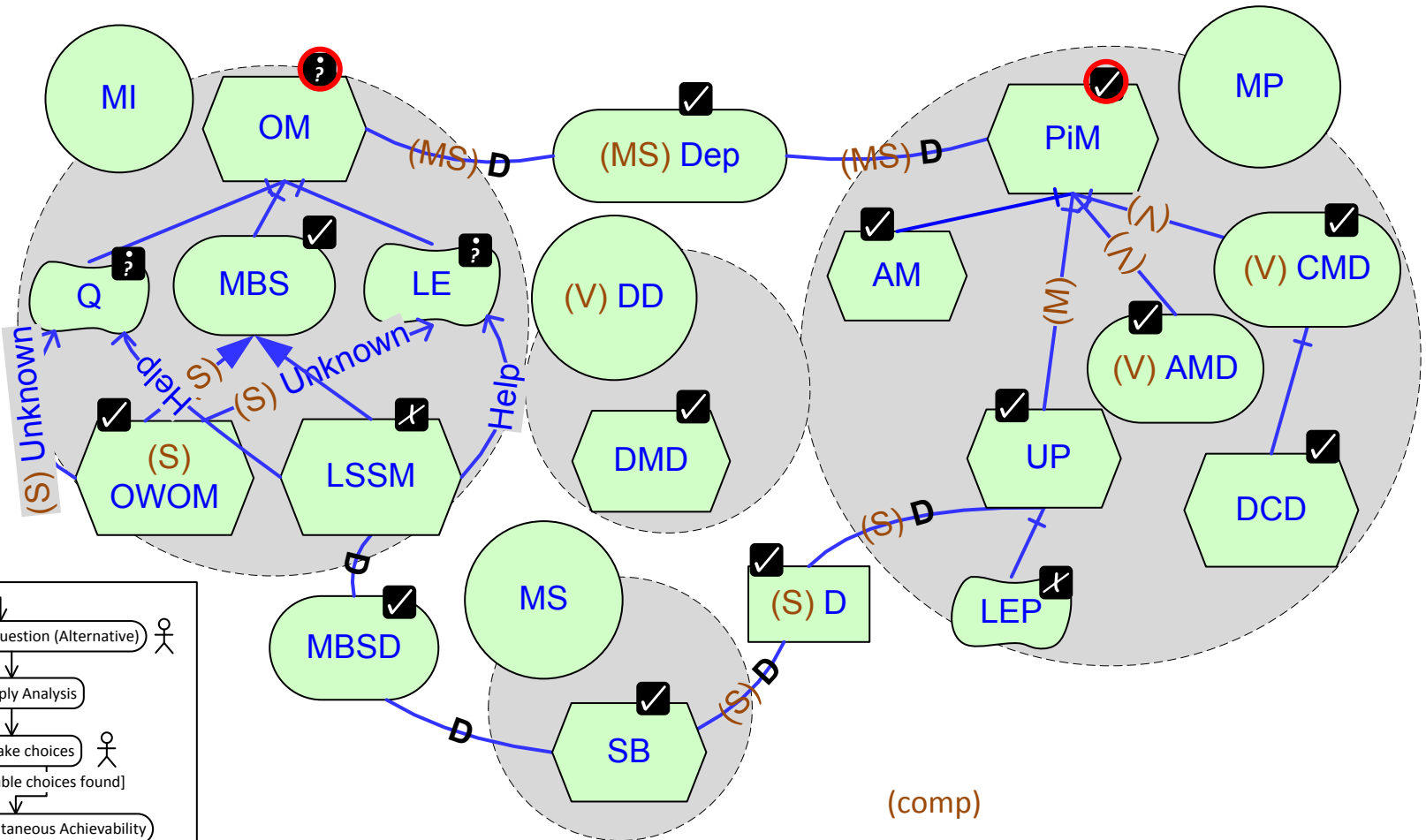
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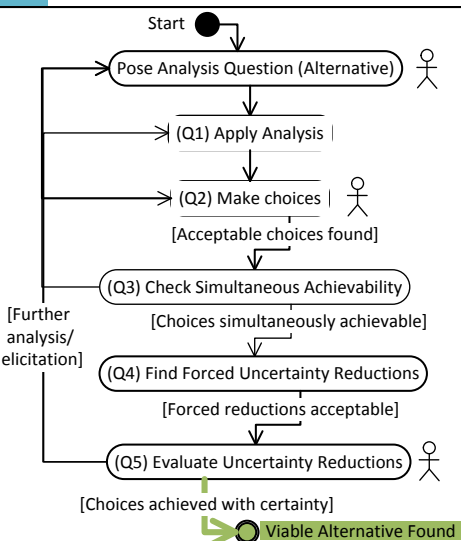
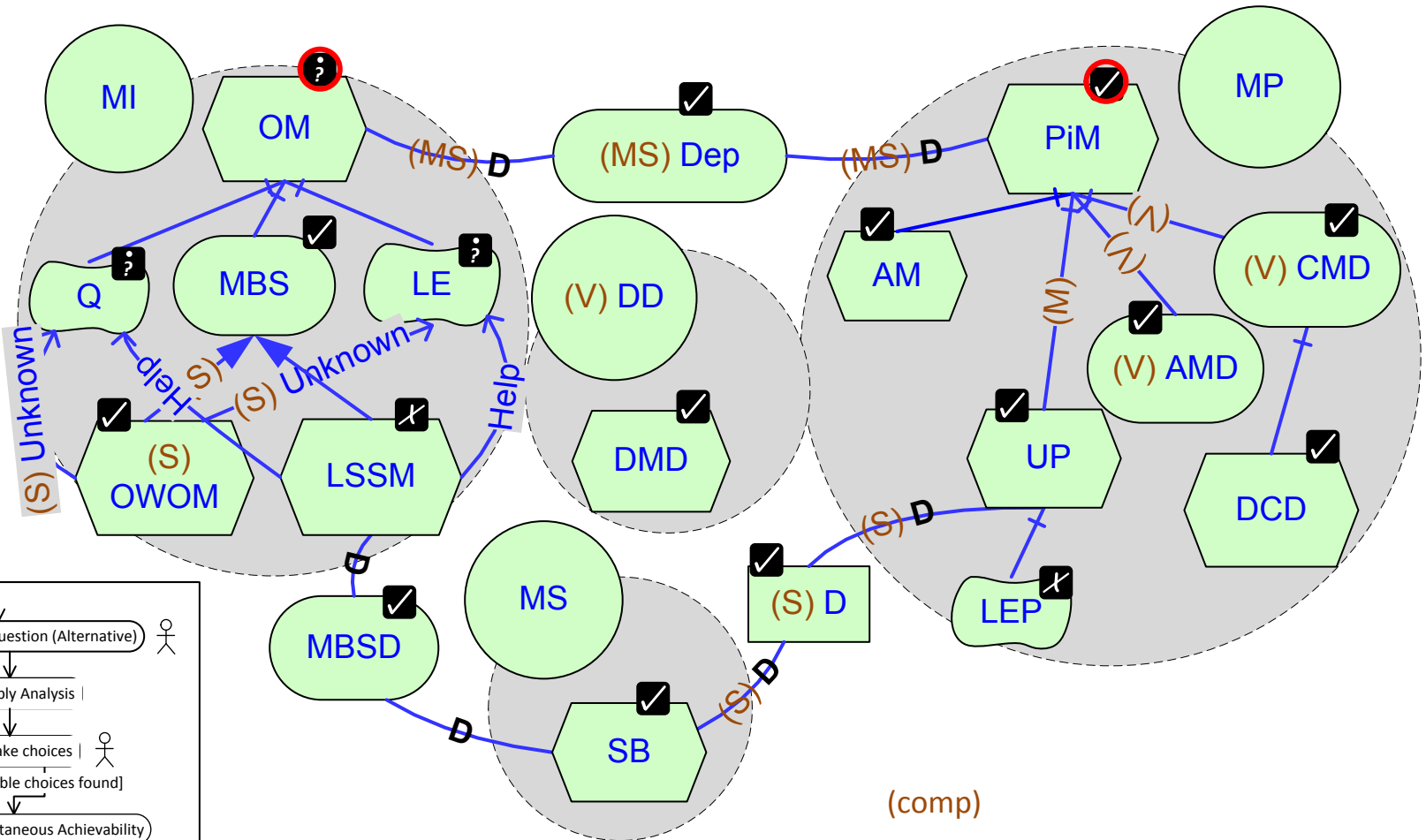
Apply Changes to Uncertain Model



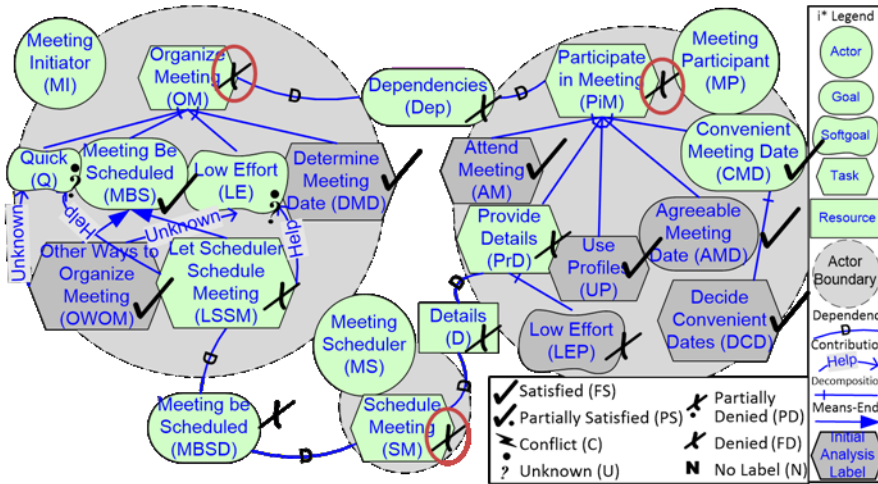
Re-evaluate...



Re-evaluate...

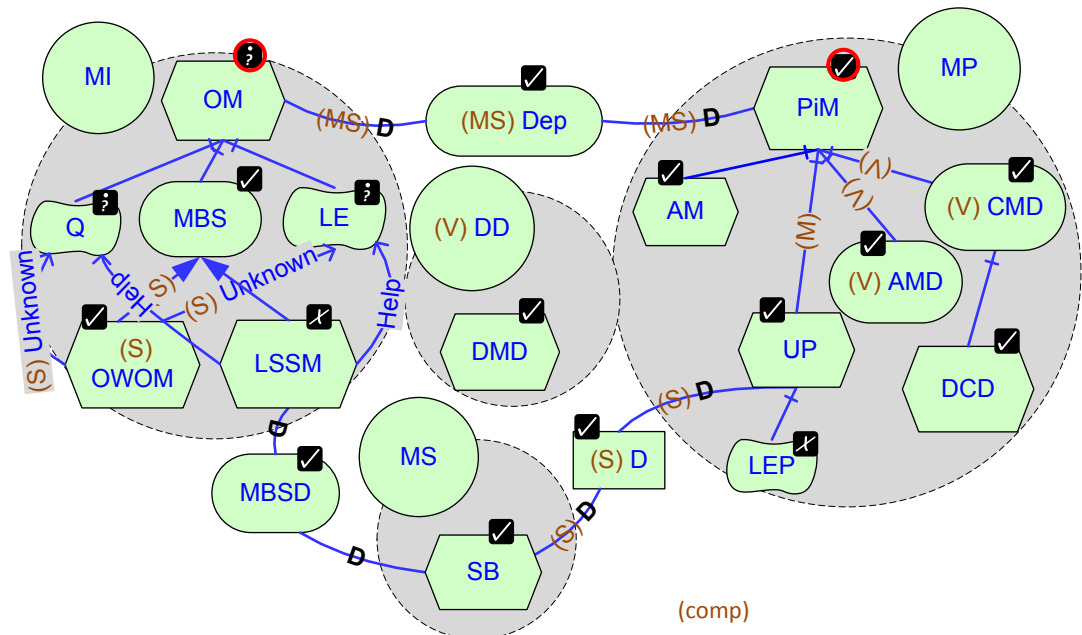


Final Result



Without explicit uncertainty

With explicit uncertainty

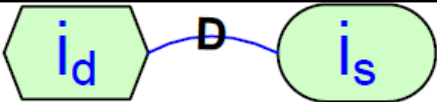
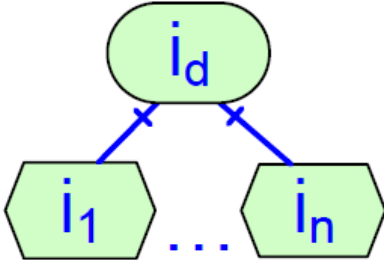
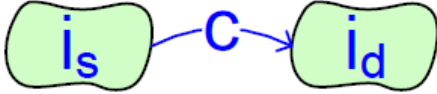



How

Implementation details...

Formal Background: Goal Model Analysis

- Goal model analysis has been implemented using propositional logic (Giorgini et al.'12, Horkoff & Yu'10, '12)

Link Type		Original Rule
Dependency		$(v \in V) v(i_s) \Rightarrow v(i_d)$
Decomposition		$(\bigwedge_{j=1}^n FS(i_j)) \Rightarrow FS(i_d)$ \dots $(\bigvee_{j=1}^n FD(i_j)) \Rightarrow FD(i_d)$
Contribution		$(c = \text{Make}) FS(i_s) \Rightarrow FS(i_d)$ ←  $(c = \text{Help}) FS(i_s) \Rightarrow PS(i_d)$ \dots $(c = \text{Unk}, v \in V) v(i_s) \Rightarrow U(i_d)$ $(c \in \{\text{Make, Help} \dots\}) U(i_s) \Rightarrow U(i_d)$

Formal Background: Uncertainty with MAVO

i* Metamodel

FOL Theory: $\langle \Sigma, \Phi \rangle$

Σ – Signature - Sorts representing entity types
(e.g., Actor, Intention, Task)

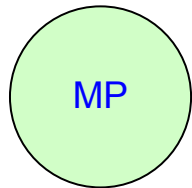
Predicates representing relations
(e.g., task decomposes goal)

Φ – Sentences - i* well-formedness constraints

Meeting Scheduler i* Model

$FO(G) = \langle \Sigma \cup \Sigma_G, \Phi \cup \Phi_G \rangle$

Σ_G and Φ_G are model G -specific predicates and constraints



Σ_G has unary predicates $MP(\text{Actor}), AM(\text{Task}), \dots$,
and binary predicates $AMinMP(\text{Task}, \text{Actor}), \dots$

Φ_G contains the following sentences:

(Complete) $(\forall x : \text{Actor} \cdot MP(x) \vee MS(x) \vee DD(x) \vee \dots) \wedge$
 $(\forall y : \text{Task}, x : \text{Actor} \cdot in(y, x) \Rightarrow (AMinMP(y, x) \vee \dots)) \wedge \dots$

MP:

(Exists_{MP}) $\exists x : \text{Actor} \cdot MP(x)$

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(Distinct_{MP-MS}) $\forall x : \text{Actor} \cdot MP(x) \Rightarrow \neg MS(x)$

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similarly for all other element and relation predicates

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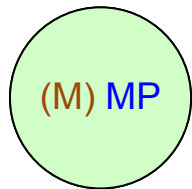
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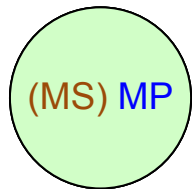
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(MSV)
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~~(Distinct_{MP=MI}) $\forall x : \text{Actor} \cdot MP(x) \Rightarrow \neg MI(x)$~~

similarly for all other element and relation predicates

GM Analysis with MAVO Uncertainty – Formalization

□ Add i^* analysis to FO MAVO encoding

- Extended encoding:

$$FO^e(G) = \langle \Sigma \cup \Sigma_G \cup \Sigma_{label} \cup \Phi \cup \Phi_G \cup \Phi_l \cup \Phi_p \rangle$$

Language-
specific (i^*)

Instance-
model specific

Analysis
Labels

Initial
Analysis
Labels

Propagation
Constraints

- Example Σ_{label} :

$$FS(i)$$

- Example Φ_l constraint:

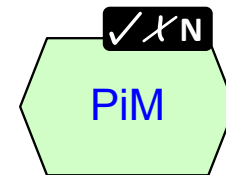
$$\forall i : \text{Intention} \cdot \text{OWOM}(i) \Rightarrow FS(i)$$

- Example Φ_p constraint:

$$\forall t : \text{Task}, g : \text{Goal} \cdot (\text{Make}(t, g) \wedge FS(t)) \Rightarrow FS(g)$$

Answering Q1: Determining Labels

- Goal model analysis with MAVO, basic idea: assign an analysis label to an intention if there exists a concretization such that the intention has that label
- E.g., there is at least one concretization where PiM has a ✓ label, at least one where it has a ✗ label, and at least one where it has a N label



$$\Phi \cup \Phi_G \cup \Phi_l \cup \Phi_p \wedge (\exists i : \textit{Intention} \cdot \textit{PiM}(i) \wedge \textit{FS}(i))$$

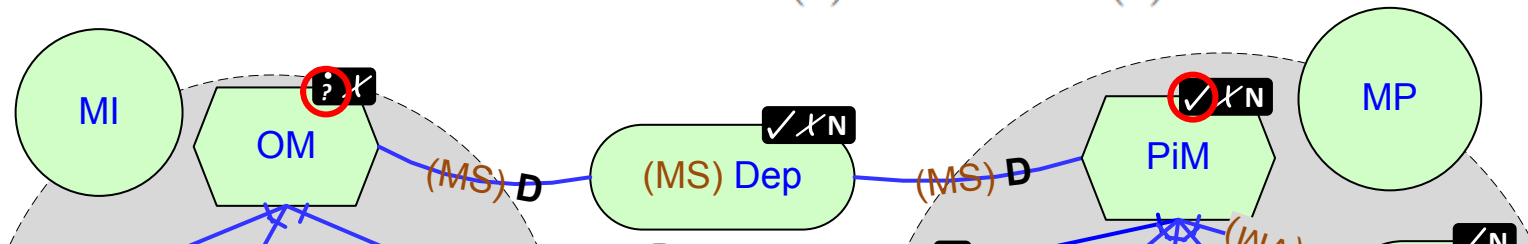
Q3: Checking Simultaneous Achievement

- Add choices to the formalism as constraints and check for satisfiability:

$$\Phi \cup \Phi_G \cup \Phi_l \cup \Phi_p \wedge \Phi_c$$

- Where Φ_c is the encoding of the user's choices, for example:

$$\begin{aligned} \forall i : \text{Intention} \cdot \text{OM}(i) &\Rightarrow \text{U}(i) \\ \forall i : \text{Intention} \cdot \text{PiM}(i) &\Rightarrow \text{FS}(i) \end{aligned}$$



- Answering Q4: Use method from Salay et al., FASE'13

Experience

- Implemented the automated parts of our method (Q₁, Q₃, Q₄) in the Model Management Tool Framework (MMTF)
 - Encoded FO representation and passed it to an SMT solver (z3)
- Running times for Q₁, 3 and 4 on Meeting Scheduler model ranged from 0.18 to 20.72 seconds

- Applied to method to two larger cases
 - Info study (described briefly in study, available online)
 - Smart Grid Study (current work)

Conclusions and Future Work

- ❑ Provided a method to support decision making in early RE with the presence of uncertainty
- ❑ Used existing RE approaches: goal model analysis + MAVO
- ❑ Provided methodology, showing how to answer 5 analysis questions (Q1-5)
- ❑ Provided examples + tooling

- ❑ Future work:
 - Improve usability of MAVO labels + analysis labels
 - Extend method and implementation to support “backward” analysis
 - More examples and validation

Thank you!

- Questions?
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