CS 681 Fall 2008
Designing Expert Systems

Knowledge-Based Reasoning: Part IV
Reasoning Mechanisms and Sample Systems

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Overview

Knowledge Base Organization

Reasoning Mechanisms

Disciple-COA: Critiquing as Expertise Problem

Disciple-WA: Workaround as Expertise Problem

Reading
PhD Advisor Assessment: Overall Reduction Logic

Assess John Doe as a potential PhD advisor for Bob Sharp.

Necessary conditions satisfied? Yes

Assess John Doe as a potential PhD advisor for Bob Sharp in Artificial Intelligence.

Main criteria

Is Doe expert in Bob's area of interest?, etc.

Professional reputation, students learning experience, etc.

Reputation among peers, etc.

Assess whether John Doe would be a good PhD advisor for Bob Sharp with respect to criterion 1.

Assess whether John Doe would be a good PhD advisor for Bob Sharp with respect to criterion n.

Sub-criteria of criterion 1

Assess whether John Doe would be a good PhD advisor for Bob Sharp with respect to criterion 1.1.

Assess whether John Doe would be a good PhD advisor for Bob Sharp with respect to criterion 1.n.
PhD Advisor Assessment: Overall Reduction Logic

Is Doe expert in Bob's area of interest?, etc.

Necessary conditions satisfied? Yes

Professional reputation, students learning experience, etc.

Main criteria

Assess John Doe as a potential PhD advisor for Bob Sharp in Artificial Intelligence.

Overall assessment of John Doe

Assess whether John Doe would be a good PhD advisor for Bob Sharp with respect to criterion 1.

Assessment based on criterion 1.

Assess whether John Doe would be a good PhD advisor for Bob Sharp with respect to criterion n.

Assessment based on criterion n.

Sub-criteria of criterion 1

Assess whether John Doe would be a good PhD advisor for Bob Sharp with respect to criterion 1.1.

Assessment based on criterion 1.1.

Assess whether John Doe would be a good PhD advisor for Bob Sharp with respect to criterion 1.n.

Assessment based on criterion 1.n.
## Criteria and Sub-criteria

<table>
<thead>
<tr>
<th>Necessary conditions</th>
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<tbody>
<tr>
<td>Professional reputation</td>
</tr>
<tr>
<td>Personality and compatibility with student</td>
</tr>
<tr>
<td>Students’ learning experience</td>
</tr>
<tr>
<td>Responsiveness to students</td>
</tr>
<tr>
<td>Support for students</td>
</tr>
<tr>
<td>Quality of student results</td>
</tr>
</tbody>
</table>

1. What is the reputation of the director within the professional community at large?

11. How expert is the director in your areas of interest?

14. Does the director have a research group, or merely a string of individual students?

15. Is the director's research work funded?

24. What is the quality of the dissertation produced with this director?
Criteria and Sub-criteria

- Necessary conditions
- Professional reputation
- Personality and compatibility with student
- Students’ learning experience
- Responsiveness to students
- Support for students
- Quality of student results

12. Does the director publish with students?
14. Does the director have a research group, or merely a string of individual students?
19. Do the director's students go to conferences?
20. Do the director's students make presentations of their work at conferences?
24. What is the quality of the dissertation produced with this director?
Problem Reduction based Question-Answering

General problem solving paradigm:
- natural for the human user;
- appropriate for the automated agent.

The reductions and synthesis operations are guided by introspective questions and answers.

"I Keep Six Honest...
I keep six honest serving-men
(They taught me all I knew);
Their names are What and Why and When
And How and Where and Who.

Rudyard Kipling
Is Bob Sharp interested in the area of expertise of John Doe?

Yes, because Bob Sharp is interested in Artificial Intelligence which is the area of expertise of John Doe.

Therefore we need to

Assess John Doe as a potential PhD advisor for Bob Sharp in Artificial Intelligence.

Is John Doe likely to stay on the faculty of George Mason University for the duration of Bob Sharp's dissertation?

Yes, because John Doe has a tenured position which is a long term position.

Therefore we need to

Assess whether John Doe would be a good PhD advisor for Bob Sharp in Artificial Intelligence.
Assess whether John Doe would be a good PhD advisor for Bob Sharp with respect to professional reputation. Which is a PhD advisor quality criterion?

- professional reputation

**Therefore we need to**

Assess whether John Doe would be a good PhD advisor for Bob Sharp with respect to professional reputation. Which is a criterion for assessing professional reputation?

- reputation among peers

**Therefore we need to**

Assess whether John Doe would be a good PhD advisor for Bob Sharp with respect to reputation among peers.

- research funding
  - ... 

- students learning experience
  - ...
Assess whether John Doe would be a good PhD advisor for Bob Sharp with respect to reputation among peers.

Which is a criterion for assessing reputation among peers?

- research contributions

Therefore we need to

Assess whether John Doe would be a good PhD advisor for Bob Sharp with respect to research contributions.

- research publications...

- research memberships...
We need to assess whether John Doe would be a good PhD advisor for Bob Sharp with respect to research contributions.

Which is a criterion for assessing research contributions?

\[ \text{citations in publications} \]

Therefore we need to assess how cited John Doe is.

What publication cites John Doe?

Rice 2007 because it cites Doe 2000 which is authored by John Doe.

Therefore we conclude that John Doe is cited in Rice 2007.

... 

Knox 2003 because it cites Doe 2001 which is authored by John Doe.

Therefore we conclude that John Doe is cited in Knox 2003.

readings in courses

Therefore we need to assess how many courses use publications by John Doe as readings.
Assess whether John Doe would be a good PhD advisor for Bob Sharp with respect to research contributions.

Which is a criterion for assessing research contributions?

- citations in publications

Therefore we need to

Assess how cited John Doe is.

John Doe is cited in 250 publications.

What publication cites John Doe?

Rice 2007 because it cites …

Therefore we conclude that

John Doe is cited in Rice 2007.

Knox 2003 because it cites …

Therefore we conclude that

John Doe is cited in Knox 2003.

readings in courses

Therefore we need to

Assess how many courses use publications by John Doe as readings.
Assess whether John Doe would be a good PhD advisor for Bob Sharp with respect to research contributions.

Which is a criterion for assessing research contributions?

- citations in publications
- readings in courses

Therefore we need to:

Assess how cited John Doe is.

What publication cites John Doe?

- Rice 2007 cites Doe 2000 ...
- Knox 2003 cites Doe 2001 ...

Therefore we conclude that:

- John Doe is cited in Rice 2007.

Therefore we need to:

Assess how many courses use papers by John Doe as readings.

Therefore we need to:

Assess how many courses use publications by John Doe as reading material.

Very good because the publications by John Doe are highly cited and are used in courses.

What is the level of research contributions of John Doe?

John Doe is cited in 250 publications.

5 courses use publications by John Doe as reading material.
Knowledge Base = Object Ontology + Rules

The object ontology is a hierarchical description of the domain objects.

The diagram illustrates the relationships between different types of university employees and students. The object ontology describes the hierarchical structure of these relationships, with specific instances of each role represented as nodes in the diagram.
The rules specify general problem solving steps described with the objects from the ontology.

Knowledge Base = Object Ontology + Rules

IF
Assess ?O1 as a potential PhD advisor for ?O2

Question
Is ?O2 interested in the area of expertise of ?O1?

Answer
Yes, because ?O2 is interested in ?O3 which is the area of expertise of ?O1.

Condition
?O1 is PhD advisor
is expert in ?O3
?O2 is PhD student
is interested in ?O3
?O3 is PhD research area

THEN
Assess ?O1 as a potential PhD advisor for ?O2 in ?O3
A problem reduction rule is an IF-THEN structure that expresses the condition $C$ under which a problem $P_1$ can be reduced to the simpler problems $P_{11}$, $P_{12}$, …, $P_{1n}$.

This means that one can solve $P_1$ by solving $P_{11}$, $P_{12}$, …, $P_{1n}$.
Partially Learned Problem Reduction Rule

**Informal applicability condition**

**Formal applicability condition (partially learned)**
Reduction Rule with Except When Conditions

IF
<problem>

Condition
<condition 1>

Except when condition
<condition 2>

Except when condition
<condition n>

THEN
$subproblem_1$

\ldots

$subproblem_m$

In addition to the regular rule condition that needs to be satisfied, a rule may contain one or several except when conditions that should not be satisfied for the rule to be applicable.
Rule Application

Assess John Doe as a potential PhD advisor for Bob Sharp.

Is Bob Sharp interested in the area of expertise of John Doe? Yes, because Bob Sharp is interested in Artificial Intelligence which is the area of expertise of John Doe.

Assess John Doe as a potential PhD advisor for Bob Sharp in Artificial Intelligence.

Is John Doe likely to stay on the faculty of George Mason University for the duration of Bob Sharp's dissertation? Yes, because John Doe has a tenured position which is a long term position.

Assess whether John Doe would be a good PhD advisor for Bob Sharp in Artificial Intelligence.

Which is a PhD advisor quality criterion? professional reputation

Assess whether John Doe would be a good PhD advisor for Bob Sharp with respect to professional reputation.

Which is a PhD advisor quality criterion? personality and compatibility with student

Which is a PhD advisor quality criterion? quality of student results

Which is a PhD advisor quality criterion? responsiveness to students

Which is a PhD advisor quality criterion? professional reputation

Assess John Doe as a potential PhD advisor for Bob Sharp in Artificial Intelligence.


Q: Is ?O2 interested in the area of expertise of ?O1?

A: Yes, because ?O2 is interested in ?O3 which is the area of expertise of ?O1.

MAIN CONDITION

<table>
<thead>
<tr>
<th>Var</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>?O1</td>
<td>(PhD advisor, associate professor)</td>
<td>(person)</td>
</tr>
<tr>
<td>?O2</td>
<td>(PhD student)</td>
<td>(person)</td>
</tr>
<tr>
<td>?O3</td>
<td>(computer science)</td>
<td>(PhD research area)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Var</th>
<th>Relationship</th>
<th>Var</th>
</tr>
</thead>
<tbody>
<tr>
<td>?O2</td>
<td>is interested in</td>
<td>?O3</td>
</tr>
<tr>
<td>?O1</td>
<td>is expert in</td>
<td>?O3</td>
</tr>
</tbody>
</table>
A solution synthesis rule is an IF-THEN structure that expresses the condition $C$ under which the solutions $S_{11}, S_{12}, \ldots, S_{1n}$ of the subproblems of $P_1$ can be combined into the solution $S_1$ of the problem $P_1$. 

\[ S_1 \]

\[ S_{11} \quad S_{12} \quad \ldots \quad S_{1n} \]

\[ C \]

\[ S_1 \]

\[ C \]

\[ S_{1a} \]
Overview

Knowledge Base Organization

Reasoning Mechanisms

Disciple-COA: Critiquing as Expertise Problem

Disciple-WA: Workaround as Expertise Problem

Reading
Ontology Matching

Ontology matching allows one to look for instances of complex concepts in the object ontology (i.e. ask questions about the objects in the ontology).

Example:

Is there a course that has as reading a publication by a professor?

Yes, Mason-CS480 that uses as reading Doe 2000 which is a journal article of John Doe who is a professor.
Ontology Matching: Example

Is there a course that has as reading a publication by a professor?

Technique: Formulate the question as a general pattern to match with the object ontology.
Ontology Matching: Example

Q: Is there a course that has as reading a publication by a professor?

A: Mason-CS480 that uses as reading Doe 2000 which has John Doe as an author.

Is this the only answer?
Q: Is there a course that has as reading a publication by a professor?

A: U Montreal-CS780 that uses as reading Doe 2000 which has John Doe as an author.
Assess John Doe as a potential PhD advisor for Bob Sharp.

IF  
Assess ?O1 as a potential PhD advisor for ?O2

Question  
Is ?O2 interested in the area of expertise of ?O1 ?

Answer  
Yes, because ?O2 is interested in ?O3 which is the area of expertise of ?O1.

Condition  
?O1 is PhD advisor
 is expert in  ?O3
?O2 is PhD student
 is interested in  ?O3
?O3 is PhD research area

THEN  
Assess ?O1 as a potential PhD advisor for ?O2 in ?O3

When is the rule applicable?
Let us now see how the agent uses the rules in problem solving.

Let us suppose that the current problem is:
Assess John Doe as a potential PhD advisor for Bob Sharp.

The agent will look into its knowledge base for a rule that has this type of problem in the IF part. Such a rule is shown in the right hand side of the slide. As one can see, the IF problem becomes identical with the problem to be solved if ?O1 is replaced with John Doe and ?O2 is replaced with Bob Sharp.

Next the agent has to check that the condition of the rule is satisfied for these values of ?O1 and ?O2.
The left hand side of the slide shows what condition needs to be satisfied by ?O1 (John Doe), ?O2 (Bob Sharp) and ?O3.
This condition is satisfied if there is any instance of ?O3 in the object ontology that satisfies all the relationships specified in the left hand side of the slide.
Ontology Matching

Rule condition

Object ontology

How is this matching performed?
Is it efficient?
The partially instantiated condition of the rule, shown in the left hand side of the previous slide, is matched successfully with the object ontology fragment shown in the right hand side of the slide.

?O3 matches Artificial Intelligence.

Both ?O3 and Artificial Intelligence are PhD research areas. Indeed, Artificial Intelligence is an instance of Computer Science, which is a subconcept of PhD research area.

Both ?O3 and Artificial Intelligence are the values of the features:

- John Doe is expert in Artificial Intelligence (?O3)
- Bob Sharp is interested in Artificial Intelligence (?O3)

As the result of this matching, the rule’s ?O3 variable is instantiated as follows:

?O3 ← Artificial Intelligence
How is the rule applied in problem solving?

Assess John Doe as a potential PhD advisor for Bob Sharp.

Is Bob Sharp interested in the area of expertise of John Doe?

Yes, because Bob Sharp is interested in Artificial Intelligence which is the area of expertise of John Doe.

Assess John Doe as a potential PhD advisor for Bob Sharp in Artificial Intelligence.

IF
Assess ?O1 as a potential PhD advisor for ?O2

Question
Is ?O2 interested in the area of expertise of ?O1?

Answer
Yes, because ?O2 is interested in ?O3 which is the area of expertise of ?O1.

Condition
?O1 is PhD advisor
is expert in ?O3
?O2 is PhD student
is interested in ?O3
?O3 is PhD research area

THEN
Assess ?O1 as a potential PhD advisor for ?O2 in ?O3
As shown, the rule’s condition is satisfied for the following instantiations of the variables:

- ?O1 ← John Doe
- ?O2 ← Bob Sharp
- ?O3 ← Artificial Intelligence

Therefore the IF problem

Assess John Doe as a potential PhD advisor for Bob Sharp.

is reduced to the following THEN problem:

Assess John Doe as a potential PhD advisor for Bob Sharp in Artificial Intelligence.

Disciple also instantiates the Question/Answer pair of the rule:

Is Bob Sharp interested in the area of expertise of John Doe?
Yes, because Bob Sharp is interested in Artificial Intelligence which is the area of expertise of John Doe.
Assess John Doe as a potential PhD advisor for Bob Sharp.

Is Bob Sharp interested in the area of expertise of John Doe?

Yes, because Bob Sharp is interested in Artificial Intelligence which is the area of expertise of John Doe.

Assess John Doe as a potential PhD advisor for Bob Sharp in Artificial Intelligence.

Is John Doe likely to stay on the faculty of George Mason University for the duration of Bob Sharp's dissertation?

Yes because John Doe has a tenured position which is a long term position.

Assess whether John Doe would be a good PhD advisor for Bob Sharp in Artificial Intelligence.
“One of the most highly developed skills in contemporary Western civilization is dissection; the split-up of problems into their smallest possible components. We are good at it. So good, we often forget to put the pieces back together again.”

Problem Reduction

Rule1(x,...)  Rule2(x,...)

Problem1(a)

Question1/Answer1(a,b)  Question1/Answer1(a,c)

Problem11(a,b)  Problem12(a,b)  Problem11(a,c)  Problem12(a,c)

Question2/Answer2(a,d)
Solution Synthesis

- Problem1(a)
  - Solution(a,b,c,d)
  - Question4/Answer4(a,b,c,d)
  - Partial solution2(a,d) of Problem1(a)
- Problem12(a,c)
  - Solution11(a,c)
  - Question3/Answer3(a,c)
- Rule1(x,…)
- Rule2(x,…)
- Rule3(x,…)
- Rule4(x,…)
- Problem11(a,b)
  - Solution11(a,b)
- Problem12(a,b)
  - Solution12(a,b)
- Problem11(a,c)
  - Solution11(a,c)
- Problem12(a,c)
  - Solution12(a,c)
- Problem2/Answer2(a,d)
  - Solution12(a,c)
Let us consider Problem1(a), an instance of a general problem Problem1(x).

Let us further assume that there are two reduction rules, Rule1(x,…) and Rule2(x,…), that are applicable to reduce this problem as follows:

1) An instance of Rule1(x,…) reduces Problem1(a) to Problem11(a,b) and Problem12(a,b).
2) Another instance of Rule1(x,…) reduces Problem1(a) to Problem11(a,c) and Problem12(a,c).
3) An instance of Rule2(x,…) reduces Problem1(a) to Problem13(a,d).

Each such reduction will lead to a partial solution of Problem1(a), as explained in the following.

Let us assume that Problem11(a,b) has the solution Solution11(a,b) and Problem12(a,b) has the solution Solution12(a,b).
Let us also assume that the solution synthesis rule Rule3(x,…) will synthesize (compose) Solution11(a,b) and Solution12(a,b) into Partial solution1(a,b) of Problem1(a). We associate this partial solution with Question1/Answer1(a,b).
Let us further assume that the same rule Rule3(x,…) will synthesize (compose) Solution11(a,c) and Solution12(a,c) into Partial solution1(a,c) of Problem1(a). We associate this partial solution with Question1/Answer1(a,c).

Similarly, let us assume that we also obtain Partial solution2(a,d) associated with Question2/Answer2(a,d).

The solution of Problem1(a) will be obtained by composing all its partial solutions, Partial solution1(a,b), Partial solution1(a,c) and Partial solution2(a,d), based on another synthesis rule.
Thus we distinguish two types of solution syntheses (compositions):

1) A reduction-level synthesis which is associated with a specific reduction and leads to a partial solution of a problem.

2) A problem-level synthesis which synthesizes the partial solutions of a problem into its complete solution.

Consequently, there are two types of synthesis rules:

1) Reduction-level synthesis rules which are associated with reduction rules.

2) Problem-level synthesis rules which are associated with the problems.

There may be several reduction-level synthesis rules associated with a reduction rule. They may lead to several partial solutions of the IF Problem from the reduction rule. All of them will need to be composed to produce the complete solution of the IF Problem.

There may also be several Problem-level synthesis rules associated with a given Problem. They will lead to alternative complete solutions of the Problem.

The following slides illustrate this process.
Assess to what extent the piece of evidence EVD-Dawn-Mir01-01c supports the hypothesis that Al Qaeda considers self defense as a reason to obtain nuclear weapons.

Assess to what extent the piece of evidence EVD-Reuters-01-01c supports the hypothesis that Al Qaeda considers self defense as a reason to obtain nuclear weapons.
Assess to what extent the piece of evidence EVD-Dawn-Mir01-01c supports the hypothesis that Al Qaeda considers self defense as a reason to obtain nuclear weapons.

Based on EVD-Dawn-Mir01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is medium.

Is there any potentially relevant piece of evidence? EVD-Dawn-Mir01-01c which mentions that Al Qaeda would use nuclear weapons to defend itself.

Problem1(a)

Assess whether Al Qaeda considers self defense as a reason to obtain nuclear weapons.

The likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is medium.

Which is the likelihood of the hypothesis? If any piece of evidence provides very strong support to the hypothesis, then the likelihood of the hypothesis is very high. Therefore we can estimate the likelihood of the hypothesis as medium, which is the maximum likelihood from the list support (medium and low).

Based on EVD-Dawn-Mir01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is medium.

Based on EVD-Reuters-01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is low.

Problem11(a,b,c,d)

Is there any potentially relevant piece of evidence? EVD-Reuters-01-01c which mentions that Al Qaeda would use nuclear weapons to defend itself.

Assess whether Al Qaeda considers self defense as a reason to obtain nuclear weapons.

The likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is medium.

Which is the likelihood of the hypothesis? If any piece of evidence provides very strong support to the hypothesis, then the likelihood of the hypothesis is very high. Therefore we can estimate the likelihood of the hypothesis as medium, which is the maximum likelihood from the list support (medium and low).

Based on EVD-Dawn-Mir01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is medium.

Based on EVD-Reuters-01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is low.

Problem11(a)

Assess to what extent the piece of evidence EVD-Dawn-Mir01-01c supports the hypothesis that Al Qaeda considers self defense as a reason to obtain nuclear weapons.

Based on EVD-Dawn-Mir01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is medium.

Is there any potentially relevant piece of evidence? EVD-Dawn-Mir01-01c which mentions that Al Qaeda would use nuclear weapons to defend itself.

Problem11(a,b)

Assess to what extent the piece of evidence EVD-Dawn-Mir01-01c supports the hypothesis that Al Qaeda considers self defense as a reason to obtain nuclear weapons.

Based on EVD-Dawn-Mir01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is medium.

Is there any potentially relevant piece of evidence? EVD-Dawn-Mir01-01c which mentions that Al Qaeda would use nuclear weapons to defend itself.

Problem11(a,b,c)

Assess to what extent the piece of evidence EVD-Dawn-Mir01-01c supports the hypothesis that Al Qaeda considers self defense as a reason to obtain nuclear weapons.

Based on EVD-Dawn-Mir01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is medium.

Is there any potentially relevant piece of evidence? EVD-Dawn-Mir01-01c which mentions that Al Qaeda would use nuclear weapons to defend itself.

Problem11(a,c)

Assess to what extent the piece of evidence EVD-Dawn-Mir01-01c supports the hypothesis that Al Qaeda considers self defense as a reason to obtain nuclear weapons.

Based on EVD-Dawn-Mir01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is medium.

Is there any potentially relevant piece of evidence? EVD-Dawn-Mir01-01c which mentions that Al Qaeda would use nuclear weapons to defend itself.

Problem11(a,b,c,d)

Assess whether Al Qaeda considers self defense as a reason to obtain nuclear weapons.

The likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is medium.

Which is the likelihood of the hypothesis? If any piece of evidence provides very strong support to the hypothesis, then the likelihood of the hypothesis is very high. Therefore we can estimate the likelihood of the hypothesis as medium, which is the maximum likelihood from the list support (medium and low).

Based on EVD-Dawn-Mir01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is medium.

Based on EVD-Reuters-01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is low.
Let us consider the problem

“Assess whether Al Qaeda considers self defense as a reason to obtain nuclear weapons.”

To facilitate the correspondence with the general case we have annotated the elements of this illustration with the labels from the general case.

Notice that, in this illustration, there is only one rule that reduces Problem1, but there are two reductions, each corresponding to a different instantiation of the reduction rule.

Notice also that this rule reduces Problem1 to a single problem, Problem11. However, we still need to have a reduction-level synthesis to obtain Partial solution1(a,b) of Problem1(a) from Solution11(a,b). In many cases these solutions are identical. However, sometimes one may wish to define Partial solution1(a,b) as a reformulation of Solution11(a,b). In this illustration there is no question/answer pair associated with the reduction-level synthesis.

Finally, notice that Solution(a,b,c,d) is obtained as a composition of Partial solution1(a,b) and Partial solution1(a,c).

The following two slides illustrate the definition of these compositions (syntheses) using the modeling editor of Disciple.
Reduction-level Synthesis

Task
Assess whether Al Qaeda considers self defense as a reason to obtain nuclear weapons.

Question
Is there any potentially relevant piece of evidence?

Answer
EVD-Dawn-Mr01-01c which mentions that Al Qaeda would use nuclear weapons to defend itself

Sub-task
Assess to what extent the piece of evidence EVD-Dawn-Mr01-01c supports the hypothesis that Al Qaeda considers self defense as a reason to obtain nuclear weapons.

Sub-solution
Based on EVD-Dawn-Mr01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is medium.
Problem-level Synthesis

Task
Assess whether Al Qaeda considers self defense as a reason to obtain nuclear weapons

Task Solution
The likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is medium.

Composition Question
Which is the likelihood of the hypothesis?

Composition Answer
If any piece of evidence provides very strong support to the hypothesis, then the likelihood of the hypothesis is very high. Therefore, we can estimate the likelihood of the hypothesis as medium, which is the maximum likelihood from the list [support: medium, low].

Question
Is there any potentially relevant piece of evidence?

Answer
EVD-Dawn-Mir01-01c which mentions that Al Qaeda would use nuclear weapons to defend itself.

Reasoning Subtree Solution
Based on EVD-Dawn-Mir01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is medium.

Question
Is there any potentially relevant piece of evidence?

Answer
EVD-Reuters-01-01c which mentions that Al Qaeda would use nuclear weapons to defend itself.

Reasoning Subtree Solution
Based on EVD-Reuters-01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is medium.

Question
Is there any potentially relevant piece of evidence?

Answer
EVD-Dawn-Mir01-01c which mentions that Al Qaeda would use nuclear weapons to defend itself.

Reasoning Subtree Solution
Based on EVD-Dawn-Mir01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is medium.

Question
Is there any potentially relevant piece of evidence?

Answer
EVD-Reuters-01-01c which mentions that Al Qaeda would use nuclear weapons to defend itself.

Reasoning Subtree Solution
Based on EVD-Reuters-01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is low.
Assess to what extent the piece of evidence EVD-Dawn-Mir01-01c supports the hypothesis that Al Qaeda considers self defense as a reason to obtain nuclear weapons.

What factors determine how a piece of evidence supports a hypothesis? The information provided by the piece of evidence and the extent to which it can be trusted.

Assess to what extent EVD-Dawn-Mir01-01c supports the hypothesis that Al Qaeda considers self defense as a reason to obtain nuclear weapons, assuming that we believe the information provided by EVD-Dawn-Mir01-01c.

Assess the credibility of EVD-Dawn-Mir01-01c.
Assess to what extent the piece of evidence EVD-Dawn-Mir01-01c supports the hypothesis that Al Qaeda considers self defense as a reason to obtain nuclear weapons.

Based only on the information from EVD-Dawn-Mir01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is very high.

Which is the likelihood of the hypothesis? medium which is the minimum likelihood from the list support (medium).

Solution11(a,b) of Problem1(a)

What factors determine how a piece of evidence supports a hypothesis?
The information provided by the piece of evidence and the extent to which it can be trusted.

Problem11(a,b)

Assess to what extent EVD-Dawn-Mir01-01c supports the hypothesis that Al Qaeda considers self defense as a reason to obtain nuclear weapons, assuming that we believe the information provided by EVD-Dawn-Mir01-01c.

Based on EVD-Dawn-Mir01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is medium.

Which is the likelihood of the hypothesis? medium which is the minimum of information support and credibility from the list support for factors (medium and very high).

Solution Synthesis: Example

Problem-level composition

Reduction-level composition
Let us consider the problem
“Assess to what extent the piece of evidence EVD-Dawn-Mir01-01c supports the hypothesis that Al Qaeda considers self defense as a reason to obtain nuclear weapons.”

To facilitate the correspondence with the general case we have annotated the elements of this illustration with the labels from the general case.

Notice that, in this illustration, there is only one rule that reduces Problem1 and one instantiation of the rule.

Notice also that this rule reduces Problem1 to two problems, Problem11 and Problem12.

However, we still need to have a problem-level synthesis (composition) to obtain Solution(a,b,c,d) from Partial solution1(a,b). Notice that, when we define the question/answer pair of the problem-level synthesis, we have to consider the general case where there might be several partial solutions of Problem1 that need to be composed. Indeed, Disciple will learn a general synthesis rule from this example and this rule would need to be applicable both in the case of a single solution and in the case of several partial solutions.

The following two slides illustrate the definition of these compositions (syntheses) using the modeling editor of Disciple.
Reduction-level Synthesis

Teach the agent:

Teaching type: Both  Teaching mode: Modeling

Reasoning Hierarchy | Reasoning Step | Graphical Viewer | Report

Task
Assess to what extent the piece of evidence EVD-Dawn-Mir01-01c supports the hypothesis that Al Qaeda considers self defense as a reason to obtain nuclear weapons.

Question
What factors determine how a piece of evidence supports a hypothesis?

Answer
The information provided by the piece of evidence and the extent to which it can be trusted.

Sub-task
Assess to what extent EVD-Dawn-Mir01-01c supports the hypothesis that Al Qaeda considers self defense as a reason to obtain nuclear weapons, assuming that we believe the information provided by EVD-Dawn-Mir01-01c.

Sub-task
Assess the credibility of EVD-Dawn-Mir01-01c.

Reduction Solution
Based on EVD-Dawn-Mir01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is medium.

Composition Question
Which is the likelihood of the hypothesis?

Composition Answer
medium which is the minimum of information support and credibility, from the list support for factors (very high and medium).

Sub-solution
Based only on the information from EVD-Dawn-Mir01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is very high.

Sub-solution
The credibility of EVD-Dawn-Mir01-01c is medium.
Problem-level Synthesis

Teach the agent:

Teaching type: Both
Teaching mode: Modeling

Reasoning Hierarchy | Reasoning Step | Graphical Viewer | Report

Task
Assess to what extent the piece of evidence EVD-Dawn-Mir01-01c supports the hypothesis that Al Qaeda considers self defense as a reason to obtain nuclear weapons.

Task Solution
Based on EVD-Dawn-Mir01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is medium.

Composition Question
Which is the likelihood of the hypothesis?

Composition Answer
medium which is the minimum likelihood from the list support (medium).

Question
What factors determine how a piece of evidence supports a hypothesis?

Answer
The information provided by the piece of evidence and the extent to which it can be trusted.

Reasoning Subtree Solution
Based on EVD-Dawn-Mir01-01c, the likelihood that Al Qaeda considers self defense as a reason to obtain nuclear weapons is medium.
Overview

Knowledge Base Organization

Reasoning Mechanisms

Disciple-COA: Critiquing as Expertise Problem

Disciple-WA: Workaround as Expertise Problem

Reading
Critiquing means expressing judgments about something according to certain standards.

Example:
Identifying the strengths and weaknesses of a military course of action with respect to the principles of war and the tenets of army operations.

For instance, assess a particular course of action with respect to the Principle of Surprise.
The Course of Action Critiquing Agent

Source: Challenge problem for the DARPA’s High Performance Knowledge Base (HPKB) program.

Background: A military course of action (COA) is a preliminary outline of a plan for how a military unit might attempt to accomplish a mission. After receiving orders to plan for a mission, a commander and staff analyze the mission, conceive and evaluate potential COAs, select a COA, and prepare a detailed plans to accomplish the mission based on the selected COA. The general practice is for the staff to generate several COAs for a mission, and then to make a comparison of those COAs based on many factors including the situation, the commander’s guidance, the principles of war, and the tenets of army operations. The commander makes the final decision on which COA will be used to generate his or her plan based on the recommendations of the staff and his or her own experience with the same factors considered by the staff.

Task: Identify strengths and weaknesses in a COA, based on the principles of war and the tenets of army operations.
Graphical depiction of a preliminary plan. It includes enough of the high level structure and maneuver aspects of the plan to show how the actions of each unit fit together to accomplish the overall purpose.
**COA411 – The Statement**

<table>
<thead>
<tr>
<th>Mission:</th>
<th>BLUE-BRIGADE2 attacks (BLUE-BRIGADE-OP) to penetrate (BLUE-BRIGADE-TASK) RED-MECH-REGIMENT2 at 130600 Aug in order to enable (ENABLE-MILITARY-PURPOSE1) the completion of seize (SEIZE2) OBJ-SLAM by BLUE-ARMOR-BRIGADE1.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Close:</td>
<td>BLUE-TASK-FORCE1, a balanced task force (MAIN-EFFORT1) attacks (ATTACK2) to penetrate (PENETRATE1) RED-MECH-COMPANY4, then clears (CLEAR1) RED-TANK-COMPANY2 in order to enable (ENABLE-MILITARY-PURPOSE2) the completion of seize (SEIZE2) OBJ-SLAM by BLUE-ARMOR-BRIGADE1. BLUE-TASK-FORCE2, a balanced task force (SUPPORTING-EFFORT1) attacks (ATTACK3) to fix (FIX1) RED-MECH-COMPANY1 and RED-MECH-COMPANY2 and RED-MECH-COMPANY3 in order to prevent (PREVENT-MILITARY-PURPOSE1) RED-MECH-COMPANY1 and RED-MECH-COMPANY2 and RED-MECH-COMPANY3 from interfering with conducts of the MAIN-EFFORT1, then clears (CLEAR2) RED-MECH-COMPANY1 and RED-MECH-COMPANY2 and RED-MECH-COMPANY3 and RED-TANK-COMPANY1. BLUE-MECH-BATTALION1, a mechanized infantry battalion (SUPPORTING-EFFORT2) attacks (ATTACK4) to fix (FIX2) RED-MECH-COMPANY5 and RED-MECH-COMPANY6 in order to prevent (PREVENT-MILITARY-PURPOSE4) RED-MECH-COMPANY5 and RED-MECH-COMPANY6 from interfering with conducts of the MAIN-EFFORT1, then clears (CLEAR3) RED-MECH-COMPANY5 and RED-MECH-COMPANY6 and RED-TANK-COMPANY3.</td>
</tr>
<tr>
<td>Reserve:</td>
<td>The reserve, BLUE-MECH-COMPANY8, a mechanized infantry company, follows Main Effort (MAIN-EFFORT1), and is prepared to reinforce (REINFORCING-AMILITARY-FORCE1) MAIN-EFFORT1.</td>
</tr>
<tr>
<td>Security:</td>
<td>SUPPORTING-EFFORT1 destroys (DESTROY1) RED-CSOP1 prior to begin moving across PL-AMBER by MAIN-EFFORT1 in order to prevent (PREVENT-MILITARY-PURPOSE3) RED-MECH-REGIMENT2 from observing (MILITARY-OBSERVE-ACTION1) MAIN-EFFORT1. SUPPORTING-EFFORT2 destroys (DESTROY2) RED-CSOP2 prior to begin moving across PL-AMBER by MAIN-EFFORT1 in order to prevent (PREVENT-MILITARY-PURPOSE6) RED-MECH-REGIMENT2 from observing (MILITARY-OBSERVE-ACTION2) MAIN-EFFORT1.</td>
</tr>
<tr>
<td>Deep:</td>
<td>Deep operations will destroy (DESTROY3) RED-TANK-COMPANY1 and RED-TANK-COMPANY2 and RED-TANK-COMPANY3.</td>
</tr>
<tr>
<td>Rear:</td>
<td>BLUE-MECH-PLT1, a mechanized infantry platoon secures (SECURE1) the brigade support area.</td>
</tr>
</tbody>
</table>

Explain what the units will do to accomplish the assigned mission.
**Fires:** Fires will suppress (SUPPRESS1) RED-MECH-COMPANY1 and RED-MECH-COMPANY2 and RED-MECH-COMPANY3 and RED-MECH-COMPANY4 and RED-MECH-COMPANY5 and RED-MECH-COMPANY6.

**Obstacles:**

**Risk:**

**End State:** At the conclusion of this operation, BLUE-BRIGADE2 will enable (ENABLE-MILITARY-PURPOSE1) accomplishing conducts forward passage of lines through BLUE-BRIGADE2 by BLUE-ARMOR-BRIGADE1. MAIN-EFFORT1 will complete to clear (CLEAR1) RED-MECH-COMPANY4 and RED-TANK-COMPANY2. SUPPORTING-EFFORT1 will complete to clear (CLEAR2) RED-MECH-COMPANY1 and RED-MECH-COMPANY2 and RED-MECH-COMPANY3 and RED-TANK-COMPANY1. SUPPORTING-EFFORT2 will complete to clear (CLEAR3) RED-MECH-COMPANY5 and RED-MECH-COMPANY6 and RED-TANK-COMPANY3.
The principles of war provide general guidance for the conduct of war at the strategic, operational and tactical levels. The tenets of army operations describe the characteristics of successful operations.

**Principles of War**

To what extent does this course of action conform to the principle of:

- Objective?
- Offensive?
- Mass?
- Economy of Force?
- Maneuver?
- Unit of Command?
- Simplicity?
- Security?
- Surprise?

**Tenets of Army Operations**

To what extent does this course of action conform to the tenet of:

- Agility?
- Depth?
- Initiative?
- Synchronization?
- Versatility?
To assess a course of action with respect to a specific principle or tenet one needs a certain amount of information about that course of action, information related to that principle or tenet. This information is obtained by asking a series of questions.

The answer to each question allows one to reduce the current assessment task to a more specific and simpler one.

This process continues until one has enough information to recognize a weakness or a strength.

Each leaf is a solution (a weakness or a strength). The solution corresponding to an intermediate node is the union of the solutions of its immediate children.
Strike the enemy at a time or place or in a manner for which he is unprepared.

Surprise can decisively shift the balance of combat power. By seeking surprise, forces can achieve success well out of proportion to the effort expended. Rapid advances in surveillance technology and mass communication make it increasingly difficult to mask or cloak large-scale marshaling or movement of personnel and equipment. The enemy need not be taken completely by surprise but only become aware too late to react effectively. Factors contributing to surprise include speed, effective intelligence, deception, application of unexpected combat power, operations security (OPSEC), and variations in tactics and methods of operation. Surprise can be in tempo, size of force, direction or location of main effort, and timing. Deception can aid the probability of achieving surprise.
COA411 - Surprise

Which is a factor that characterizes surprise?

- The presence of surprise factors
- Enemy reconnaissance
- The application of surprising levels of combat power
- The presence of deception actions

Assess surprise in COA411 with respect to the presence of surprise factors
Assess surprise in COA411 with respect to countering enemy reconnaissance
Assess surprise in COA411 with respect to the application of surprising levels of combat power
Assess surprise in COA411 with respect to the presence of deception actions

Continues on next slide
Assess surprise in COA411 with respect to countering enemy reconnaissance

Is an enemy reconnaissance unit present?

Yes, RED-CSOP1 which is performing the reconnaissance action SCREEN1

Assess surprise in COA411 where the enemy unit RED-CSOP1 performs the reconnaissance action SCREEN1

No, ...

Continues from previous slide

Continues on next slide
COA411 - Surprise

Assess surprise in COA411 where the enemy unit RED-CSOP1 performs the reconnaissance action SCREEN1

Is the enemy reconnaissance unit destroyed?

Yes, RED-CSOP1 is destroyed by DESTROY1

No, ...

ASSESSMENT: There is a strength with respect to surprise in COA411 because it contains aggressive security/counter-reconnaissance plans, destroying enemy intelligence collection units and activities. Intelligence collection by RED-CSOP1 through SCREEN1 will be disrupted by its destruction by DESTROY1. This and similar actions prevent the enemy for ascertaining the nature and intent of friendly operations, thereby increasing the likelihood that the enemy will be surprised. This is a strength of high importance.

REFERENCE: FM 100-5 pg 2-5, KF 118.1, KF 118.2, KF 118.3 - Surprise is achieved by striking/engaging the enemy in a time, place or manner for which he is unprepared. The enemy can be surprised by the tempo of the operation, the size of the force, the direction or location of the main effort, and timing. Factors contributing to surprise include speed, effective intelligence, deception, application of unexpected combat power, operations security, and variations in tactics and methods of operation.
Mass the effects of overwhelming combat power at the decisive place and time.

Synchronizing all the elements of combat power where they will have decisive effect on an enemy force in a short period of time is to achieve mass. To mass is to hit the enemy with a closed fist, not poke at him with fingers of an open hand. Mass must also be sustained so the effects have staying power. Thus, mass seeks to smash the enemy, not sting him. This results from the proper combination of combat power with the proper application of other principles of war. Massing effects, rather than concentrating forces, can enable numerically inferior forces to achieve decisive results, while limiting exposure to enemy fire.
COA411 - Mass

I need to Assess COA411 with respect to the Principle of Mass

Does COA411 identify a decisive point?

Yes, it identifies the decisive point RED-MECH-COMPANY4.

Therefore I need to

Assess mass for COA411 with RED-MECH-COMPANY4 as the decisive point

Does the main effort act on RED-MECH-COMPANY4 with an adequate force ratio?

Yes, it acts with a force ratio of 10.6

Therefore I need to

Assess mass for COA411 when the main effort acts on RED-MECH-COMPANY4 with the adequate force ratio of 10.6.

Does the main effort get help acting on RED-MECH-COMPANY4?

Yes, it gets help from the supporting action SUPPRESS1, which also acts on RED-MECH-COMPANY4.

Therefore I conclude that

There is a major strength in COA411 with respect to mass because BLUE-TASK-FORCE1 is the MAIN-EFFORT1 and it acts on the decisive point of the COA (RED-MECH-COMPANY4) with a force ratio of 10.6, which exceeds a recommended force ratio of 3.0. Additionally, the main effort is assisted by the supporting action SUPPRESS1 which also acts on the decisive point. This is good evidence of the allocation of significantly more than minimum combat power required at the decisive point and is indicative of the proper application of the principle of mass.
To what extent does this course of action conform to the Principle of Mass?

There is a major strength in COA411 with respect to mass because BLUE-TASK-FORCE1 is the MAIN-EFFORT1 and it acts on the decisive point of the COA (RED-MECH-COMPANY4) with a force ratio of 10.6, which exceeds a recommended force ratio of 3.0. Additionally, the main effort is assisted by supporting action SUPPRESS-MILITARY-TASK1 which also acts on the decisive point. This is good evidence of the allocation of significantly more than minimum combat power required at the decisive point and is indicative of the proper application of the principle of mass.

There is a strength in COA411 with respect to mass because BLUE-TASK-FORCE1 is the main effort of the COA and it has been allocated 33% of available combat power but this is considered just a medium level weighting of the main effort.

There is a strength in COA411 with respect to mass because BLUE-MECH-COMPANY8 is a COMPANY-UNIT-DESIGNATION level maneuver unit assigned to be the reserve. This is considered a strong reserve for a BRIGADE-UNIT-DESIGNATION level COA and would be available to continue the operation or exploit success.

Reference: FM 100-5 pg 2-4, KF 113.1, KF 113.2, KF 113.3, KF 113.4, KF 113.5 - To mass is to synchronize the effects of all elements of combat power at the proper point and time to achieve decisive results. Observance of the Principle of Mass may be evidenced by allocation to the main effort of significantly greater combat power than the minimum required throughout its mission, accounting for expected losses. Mass is evidenced by the allocation of significantly more than minimum combat power required at the decisive point.
Evaluation of COA Agents (DARPA)

Disciple-COA: Identifies strengths and weaknesses in a Course of Action, based on the principles of war and the tenets of army operations.

Disciple-COA demonstrated the generality of its learning methods that used an object ontology created by another group (TFS/Cycorp).

It also demonstrated that a knowledge engineer and a subject matter expert can jointly teach Disciple.

46% increase of KB size in 8 days

Development of Disciple’s KB during evaluation.

Disciple-COA features:
- High knowledge acquisition rate;
- Better performance than the other evaluated systems;
- Better performance than the evaluating experts (many unanticipated solutions).
Overview

- Knowledge Base Organization
- Reasoning Mechanisms
- Disciple-COA: Critiquing as Expertise Problem
- Disciple-WA: Workaround as Expertise Problem
- Reading
Planning means developing a sequence of actions that achieve a desired goal.

Examples:

Develop a plan for a military unit to reconstitute or bypass damage to a transportation infrastructure, such as a damaged bridge, a tunnel or a road.

Develop a plan of how to manufacture a loudspeaker.

Develop a plan of how to travel from one location to another.
Estimate enemy’s best way of working around damage to a transportation infrastructure, such as a damaged bridge or a cratered road.

**Input problem**
- description of a military unit that needs to work around some damage
- description of the damage and of the terrain
- description of the resources in the area that could be used to repair the damage

**Solution**
- detailed plan of actions
- minimum duration
- expected duration
- resources
- link capacity
Sample Workaround Problem and Solution

Workaround solution for a destroyed bridge on larger river:

Narrow gap and install AVLB

**Workaround summary**

**Initial task:**
WORKAROUND-DAMAGE
FOR-DAMAGE DAMAGE200
BY-INTERDICTED-UNIT UNIT91010

**Engineering action:** INSTALL AVLB
MIN-DURATION 11H:4M:58S
EXPECTED-DURATION 14H:25M:56S
RESOURCES REQUIRED (AVLB-UNIT202 BULLDOZER-UNIT201)
LINK CAPACITY AFTER RECONSTRUCTION 2.2521622 VEHIC/MIN
S1 OBTAIN-OPERATIONAL-CONTROL-FROM-CORPS
OF-UNIT UNIT202
BY-UNIT UNIT91010
MIN-DURATION 4H:0M:0S
EXPECTED-DURATION 6H:0M:0S
TIME-CONSTRAINTS: NONE

S2 MOVE-UNIT
FOR-UNIT UNIT202
FROM-LOCATION SITE0
TO-LOCATION SITE100
MIN-DURATION 1H:8M:14S
EXPECTED-DURATION 1H:8M:14S
TIME-CONSTRAINTS: AFTER S1

S3 REPORT-OBTAINED-EQUIPMENT
FOR-EQ-SET AVLB-UNIT202
MIN-DURATION 0S
EXPECTED-DURATION 0S
TIME-CONSTRAINTS: AFTER S2

S4 OBTAIN-OPERATIONAL-CONTROL-FROM-CORPS
OF-UNIT UNIT201
BY-UNIT UNIT91010
MIN-DURATION 4H:0M:0S
EXPECTED-DURATION 6H:0M:0S
TIME-CONSTRAINTS: NONE

S5 MOVE-UNIT
FOR-UNIT UNIT201
FROM-LOCATION SITE0
TO-LOCATION SITE100
MIN-DURATION 1H:8M:14S
EXPECTED-DURATION 1H:8M:14S
TIME-CONSTRAINTS: AFTER S4

S6 REPORT-OBTAINED-EQUIPMENT
FOR-EQ-SET BULLDOZER-UNIT201
MIN-DURATION 0S
EXPECTED-DURATION 0S
TIME-CONSTRAINTS: AFTER S5

S7 NARROW-GAP-BY-FILLING-WITH-BANK
FOR-GAP SITE103
FOR-BR-DESIGN AVLB70
MIN-DURATION 5H:19M:44S
EXPECTED-DURATION 6H:7M:42S
RESOURCES-REQUIRED BULLDOZER-UNIT201
TIME-CONSTRAINTS: AFTER S6

S8 EMPLACE-AVLB
FOR-BR-DESIGN AVLB70
MIN-DURATION 5M:0S
EXPECTED-DURATION 10M:0S
RESOURCES-REQUIRED AVLB-UNIT202
TIME-CONSTRAINTS: AFTER S3, S7

S9 REPORT-EMPLACED-FIXED-BRIDGE
FOR-MIL-BRIDGE FIXED-MILITARY-BRIDGE-EQ
MIN-DURATION 0S
EXPECTED-DURATION 0S
TIME-CONSTRAINTS: AFTER S8

S10 MOVE-EQUIPMENT-OVER-UNSTABILIZED-MIL-BRIDGE
FOR-EQ-SET BULLDOZER-UNIT201
FOR-BR-DESIGN AVLB70
MIN-DURATION 2M:0S
EXPECTED-DURATION 10M:0S
RESOURCES-REQUIRED AVLB-UNIT202
TIME-CONSTRAINTS: AFTER S9

S11 MINOR-BANK-PREPARATION
OF-BANK SITE105
MIN-DURATION 30M:0S
EXPECTED-DURATION 50M:0S
RESOURCES-REQUIRED BULLDOZER-UNIT201
TIME-CONSTRAINTS: AFTER S10

S12 RESTORE-TRAFFIC-LINK
FOR-UNIT UNIT91010
FOR-LINK AVLB70
LINK-CAPACITY 2.2521622 VEHICLES/MIN
MIN-DURATION 0S
EXPECTED-DURATION 0S
TIME-CONSTRAINTS: AFTER S11
S1 OBTAIN-OPERATIONAL-CONTROL-FROM-CORPS
OF-UNIT UNIT202
BY-UNIT UNIT91010

S2 MOVE-UNIT
FOR-UNIT UNIT202
FROM-LOCATION SITE0
TO-LOCATION SITE100
TIME-CONSTRAINTS: AFTER S1

S3 REPORT-OBTAINED-EQUIPMENT
FOR-EQ-SET AVLB-UNIT202
TIME-CONSTRAINTS: AFTER S2

S4 OBTAIN-OPERATIONAL-CONTROL-FROM-CORPS
OF-UNIT UNIT201
BY-UNIT UNIT91010

S5 MOVE-UNIT
FOR-UNIT UNIT201
FROM-LOCATION SITE0
TO-LOCATION SITE100
TIME-CONSTRAINTS: AFTER S4

S6 REPORT-OBTAINED-EQUIPMENT
FOR-EQ-SET BULLDOZER-UNIT201
TIME-CONSTRAINTS: AFTER S5

S7 NARROW-GAP-BY-FILLING-WITH-BANK
FOR-GAP SITE103
FOR-BR-DESIGN AVLB70
TIME-CONSTRAINTS: AFTER S6

S8 EPLACE-AVLB
FOR-BR-DESIGN AVLB70
TIME-CONSTRAINTS: AFTER S3, S7

S9 REPORT-EMPLACED-FIXED-Bridge
FOR-MIL-BRIDGE FIXED-MILITARY-BRIDGE-EQ
TIME-CONSTRAINTS: AFTER S8

S10 MOVE-EQUIPMENT-OVER-UNSTABILIZED-MIL-BRIDGE
FOR-EQ-SET BULLDOZER-UNIT201
FOR-BR-DESIGN AVLB70
TIME-CONSTRAINTS: AFTER S9

S11 MINOR-BANK-PREPARATION
OF-BANK SITE105
MIN-DURATION 30M:0S
TIME-CONSTRAINTS: AFTER S10

S12 RESTORE-TRAFFIC-LINK
FOR-UNIT UNIT91010
FOR-LINK AVLB70
LINK-CAPACITY 2.2521622 VEHICLES/MIN
TIME-CONSTRAINTS: AFTER S11
Planning through task reduction

$T_1$ is a general action/task that accomplishes the goal.

Ask a question about the current situation to determine alternative ways of performing this action. If the answer of $Q_1$ is $A_{11}$, then to perform $T_1$ one could perform $T_{11}$.

When the action to perform (e.g. $T_{11}$) is completely defined, break it down into sub-actions (e.g. $T_{11a}$ and $T_{11b}$). In this case the question and the answer summarize the solution, or could simply be absent.

Continue this reduction process until you obtain elementary actions.
Follow the tree from bottom to top to compose the elementary actions into plans, as follows:

$S_{11b}$ is the union of $S_{11b1} \ldots S_{11bm}$

This leads to alternative plans.

$S_{11}$ is the set of plans obtained by composing the sub-plans from $S_{11a}$ and the sub-plans from $S_{11b}$. 

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Fragment of the object hierarchy

- BRIDGE-CONCEPT
- TEMPORARY-TRAFFIC-LINK
- MILITARY-BRIDGE
  - FLOATING-MILITARY-BRIDGE
    - SUBCLASS-OF
    - M4T6-BRIDGE
      - SUBCLASS-OF
      - M4T6-30
    - SUBCLASS-OF
    - RIBBON-BRIDGE
      - SUBCLASS-OF
      - RB-HEAVY-45
  - SUBCLASS-OF
  - FIXED-MILITARY-BRIDGE
    - AVLB
    - MGB
      - MGB-16
    - BAILEY-BRIDGE
      - BB-24
      - BB-30
    - SUBCLASS-OF
    - AVLB70
      - SUBCLASS-OF
      - MGB-SS16
      - SUBCLASS-OF
      - MGB-SS16-11
      - SUBCLASS-OF
      - MGB-SS16-12
    - SUBCLASS-OF
    - BB-TT24
      - SUBCLASS-OF

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### Sample object descriptions

<table>
<thead>
<tr>
<th>AVLB</th>
<th>subclass-of</th>
<th>FIXED-MILITARY-BRIDGE</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>expected-crossing-time-for-unstabilized-end</td>
<td>10 min</td>
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<tr>
<td></td>
<td>expected-emplacement-time</td>
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<td></td>
<td>max-transverse-slope</td>
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<td></td>
<td>max-uphill-slope-for-eq</td>
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<td>min-crossing-time-for-unstabilized-end</td>
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<td>min-emplacement-time</td>
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<th>AVLB</th>
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<tr>
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<tr>
<td></td>
<td>mlc-rating</td>
<td>70 tons</td>
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<tr>
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<td>weight-in-tons</td>
<td>15 tons</td>
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Fragment of the feature hierarchy

DIMENSION

- SUBCLASS-OF
  - SUBCLASS-OF
    - LENGTH
    - WIDTH
    - HEIGHT

- SUBCLASS-OF
  - MAX-GAP
  - MAX-REducible-GAP
IF the task to accomplish is
WORKAROUND-UNMINED-DESTROYED-BRIDGE-WITH-FIXED-BRIDGE
AT-LOCATION ?O1
FOR-GAP ?O2
BY-UNIT ?O3

Plausible upper bound
?O1 IS BRIDGE
?O2 IS CROSS-SECTION
HAS-WIDTH ?N4
?O3 IS MILITARY-UNIT
MAX-TRACKED-MLC ?N3
MAX-WHEELED-MLC ?N2
?O4 IS AVLB-EQ
CAN-BUILD ?O5
MAX-REDUCIBLE-GAP ?N5
MAX-GAP ?N6
?O5 IS AVLB70
MLC-RATING ?N1
?N1 IS-IN [0.0 150.0]
?N2 IS-IN [0.0 150.0]
  <  ?N1
?N3 IS-IN [0.0 150.0]
  <  ?N1
?N4 IS-IN [0.0 100.0]
?N5 IS-IN [0.0 100.0]
  ≥  ?N4
?N6 IS-IN [0.0 100.0]
  <  ?N4

Plausible lower bound
?O1 IS SITE100
?O2 IS SITE103
HAS-WIDTH ?N4
?O3 IS UNIT91010
MAX-TRACKED-MLC ?N3
MAX-WHEELED-MLC ?N2
?O4 IS AVLB-EQ
CAN-BUILD ?O5
MAX-REDUCIBLE-GAP ?N5
MAX-GAP ?N6
?O5 IS AVLB70
MLC-RATING ?N1
?N1 IS-IN [70.0 70.0]
?N2 IS-IN [25.0 25.0]
  ≤  ?N1
?N3 IS-IN [63.0 63.0]
  ≤  ?N1
?N4 IS-IN [25.0 25.0]
?N5 IS-IN [26.0 26.0]
  ≥  ?N4
?N6 IS-IN [17.0 17.0]
  <  ?N4

THEN accomplish the task
USE-FIXED-BRIDGE-WITH-GAP-REDUCTION-OVER-GAP
AT-LOCATION ?O1
FOR-GAP ?O2
BY-UNIT ?O3
WITH-BR-EQ ?O4
Sample Workaround Problem: Mined Bridge
Detailed sketch
Damage Bridge at Site 100

Site 103: Cross-Section
Damage 200: Mined Bridge
Type: Scatterable
Length: 30 m
Density: 0.006 mines/m^3

Site 104: Far Approach
(Right Approach)
Damage 201: Mined
Type: Scatterable
Length: 200 m
Density: 0.006 mines/m^3

Site 108: Near Approach
(Left Approach)
Damage 205: Mined
Type: Scatterable
Length: 400 m
Density: 0.006 mines/m^3

Bridge/River
Width: 30 m

Site 107: Left Bank
Height: 9 m
Max Slope: 100
Soil Type: Rock
Vegetation: Desert Scrub
Water Depth: 1.0 m
Damage 204: Mined
Type: Scatterable
Length: 9 m
Density: 0.006 mines/m^3

Site 106: River Bed
Soil Type: Sand
Wetness: Wet
Min Water Depth: 1.0 m
Max Water Depth: 2.0 m
Water Width: 14 m
Max Current: 1.5 m/s
Damage 203: Mined
Type: Scatterable
Length: 12 m
Density: 0.006 mines/m^3

Site 105: Right Bank
Height: 9 m
Max Slope: 100
Soil Type: Rock
Vegetation: Desert Scrub
Water Depth: 1.0 m
Damage 202: Mined
Type: Scatterable
Length: 9 m
Density: 0.006 mines/m^3
A general action that accomplishes the goal.

What is the type of obstacle?

Bridge

Workaround-bridge-obstacle-at-location site100 by-unit unit10

What type of workaround strategy to adopt?

repair

Workaround-bridge-obstacle-by-repair at-location site100 by-unit unit10

Assumption: if a bridge is mined than the bed of the corresponding cross-section is mined.
Reduce a task to two simpler sub-tasks

Non-elementary task

Elementary task

How to workaround the bridge by repair?

Repair the bridge and restore the traffic link.

Repair-bridge
at-location site100
by-unit unit10

Restore-traffic-link-to-original-capacity
for-unit unit10
for-link site100
min-duration 0 min
expected-duration 0 min

Workaround-bridge-obstacle-by-repair
at-location site100
by-unit unit10

What is the type of damage to the bridge?

Damage200 consists only of mines
Damaged bridge but no mines
Mined and damaged bridge

Workaround-bridge-with-mines
at-location site100
for-damage-to-bridge damage200
by-unit unit10

Damage200 consists only of mines
Damaged bridge but no mines
Mined and damaged bridge

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Are both sides of the bridge mined?

Yes, both site104 and site108 are mined.

No, only near side

No, only far side

What de-mining techniques will be used?

Vehicle mounted equipment.

Workaround-bridge-with-mines
at-location site100
for-damage-to-bridge damage200
by-unit unit10

Breach-minefields-on-both-sides-of-the-mined-bridge
at-location site100
for-right-approach site104
for-left-approach site108
by-unit unit10

Breach-minefields-on-both-sides-of-the-mined-bridge-with-vehicle-mounted-eq
at-location site100
for-right-approach site104
for-left-approach site108
by-unit unit10
Breach-minefields-on-both-sides-of-the-mined-bridge-with-vehicle-mounted-eq
at-location site100
for-right-approach site104
for-left-approach site108
by-unit unit10

Is vehicle mounted equipment available in the unit?

Yes, Tank-with-plow-Unit101

Breach-minefields-on-both-sides-of-the-mined-bridge-with-own-vehicle-mounted-eq
at-location site100
for-right-approach site104
for-left-approach site108
with-mounted-vehicle-lane-clearing-eq-set Tank-with-plow-Unit101
by-unit unit10
How to perform this breaching?

By breaching the near approach, then the bridge and then the far approach.

1. **Breach-minefields-on-both sides-of-the-mined-bridge-with-own-vehicle-mounted-eq**
   at-location site100
   for-right-approach site104
   for-left-approach site108
   with-mounted-vehicle-lane-clearing-eq-set Tank-with-plow-Unit101
   by-unit unit10

2. **Breach-minefields-on-near approach and bank-with-vehicle-mounted-eq**
   for-approach site108
   for-bank site107
   with-mounted-vehicle-lane-clearing-eq-set Tank-with-plow-Unit101
   by-unit unit10

3. **Report-near approach and bank cleared of mines**
   for-approach site108
   for-bank site107

4. **Remove-mines-on-bridge-using-mine-plow-p**
   at-location site100
   with-mounted-vehicle-lane-clearing-eq-set Tank-with-plow-Unit101
   by-unit unit10

5. **Report-bridge-cleared-of-mines**
   for-bridge site100

6. **Breach-minefields-on-far-approach-and-bank vehicle-mounted-eq**
   for-approach site104
   for-bank site105
   with-mounted-vehicle-lane-clearing-eq-set Tank-with-plow-Unit101
   by-unit unit10

7. **Report-far approach and bank cleared of mines**
   for-approach site104
   for-bank site105
6

Identify-and-mark-extent-of-minefield-on-near-approach and bank-p
for-approach site108
for-bank site107
with-mounded-vehicle-lane-clearing-eq-set Tank-with-plow-Unit101
by-unit unit10

Is mine clearing equipment mounted and ready for use?

Yes, Tank-with-plow-Unit 101 is ready.

Breach-minefields-on-near approach and bank-with-vehicle-mounted-eq
for-approach site108
for-bank site107
with-mounded-vehicle-lane-clearing-eq-set Tank-with-plow-Unit101
by-unit unit10

No, mine clearing equipment must be mounted.

Remove-mines-on-near-approach and bank using mine plow-p
for-approach site108
for-bank site107
with-mounded-vehicle-lane-clearing-eq-set Tank-with-plow-Unit101
by-unit unit10

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What is the width of the minefield and what is the hasty mine recon and marking rate?

The width of the minefield is 400m and the rate of clearing with 2 teams working is \( \frac{400\text{m}/2}{2.5\text{m/min}} \)

Identify-and-mark-extent-of-minefield-on-near-approach and bank
for-approach site108
for-bank site107

min-duration 1 hour 20 min = \( \frac{400\text{m}/2}{2.5\text{m/min}} \)
expected-duration same as minimum
Remove-mines-on-near-approach and bank using mine plow-p
for-approach site108
for-bank site107
with-mounted-vehicle-lane-clearing-eq-set Tank-with-plow-Unit101
by-unit unit10

What is the depth of the minefield and what is the mineplow clearing rate?

The length of the minefield is 400m, the minimum rate of mineplow clearing is 0.05min/m and the expected rate is 0.1min/m

Remove-mines-on-near-approach and bank using mine plow
for-approach site108
for-bank site107
min-duration (400 m * 0.05min/m + 5 min) = 25 min
expected-duration (400 m * 0.1min/m +10 min) = 50 min
resources Tank-with-plow-Unit101
What is the depth of the minefield and what is the mineplow clearing rate?

The min bridge minefield width is 100m, the minimum rate of mine plow clearing is 0.05min/m and the expected rate is 0.1min/m, add 5 min min prep time and 10 min expected prep time.

Remove-mines-on-bridge- using mine plow
for-bridge site100
min-duration (100 m * 0.05min/m) + 5 min prep = 10 min
expected-duration (100 m * 0.1min/m) + 10 exp prep = 20 min
resources Tank-with-plow-Unit101
How to breach the minefield on the far approach?

By first identifying and marking the mines and then removing them.

Identify-and-mark-extent-of-minefield-on-far-approach and bank-p
for-approach site104
for-bank site105

Remove-mines-on-far-approach and bank using mine plow-p
for-approach site104
for-bank site105
with-mounted-vehicle-lane-clearing-eq-set Tank-with-plow-Unit101
by-unit unit10
What is the width of the minefield and what is the hasty mine recon and marking rate?

The width of the minefield is 200m and the rate of clearing with 2 teams working is \( \frac{200 \text{ m}}{2} \div 2.5 \text{ m/min} \).
The depth of the minefield is 250m, the minimum rate of mineplow clearing is 0.05min/m and the expected rate is 0.1min/m.

What is the depth of the minefield and what is the mineplow clearing rate?

Remove-mines-on-far-approach and bank using mine plow-p
for-approach site108
for-bank site107
with-mounted-vehicle-lane-clearing-eq-set Tank-with-plow-Unit101
by-unit unit10

Remove-mines-on-far-approach and bank using mine plow
for-approach site104
for-bank site105
min-duration (200 m * 0.05min/m) +5min= 15 min
expected-duration (200 m * 0.1min/m) +10min= 30 min
resources Tank-with-plow-Unit101
The developed plan

Identify-and-mark-extent-of-minefield-on-near-approach-and-bank for-approach site108 for-bank site107 min-duration 1 hour 20 min expected-duration 1 hour 20 min

Remove-mines-on-near-approach-and-bank-using-mine-plow for-approach site108 for-bank site107 min-duration 25 min expected-duration 50 min resources Tank-with-plow-Unit101

Report-near-approach-and-bank-cleared-of-mines for-approach site108 for-bank site107 min-duration 0 min expected-duration 0 min

Remove-mines-on-bridge-using-mine-plow for-bridge site100 min-duration 10 min expected-duration 20 min resources Tank-with-plow-Unit101

Report-bridge-cleared-of-mines for-bridge site100 min-duration 0 min expected-duration 0 min

Identify-and-mark-extent-of-minefield-on-far-approach-and-bank for-approach site104 for-bank site105 min-duration 40 min expected-duration 40 min

Remove-mines-on-far-approach-and-bank-using-mine-plow for-approach site104 for-bank site105 min-duration 15 min expected-duration 30 min resources Tank-with-plow-Unit101

Report-far-approach-and-bank-cleared-of-mines for-approach site104 for-bank site105 min-duration 0 min expected-duration 0 min

Remove-mines-on-bridge-using-mine-plow for-bridge site100 min-duration 0 min expected-duration 0 min

Restore-traffic-link-to-original-capacity for-unit unit10 for-link site100 min-duration 0 min expected-duration 0 min
Evaluation of Workaround Planners

Disciple-WA: Estimates the best plan of working around damage to a transportation infrastructure, such as a damaged bridge or road.

Disciple-WA demonstrated that a knowledge engineer can use Disciple to rapidly build and update a knowledge base capturing knowledge from military engineering manuals and a set of sample solutions provided by a subject matter expert.

72% increase of KB size in 17 days

72% increase of KB size
in 17 days

Evolution of KB coverage and performance from the pre-repair phase to the post-repair phase.

Disciple-WA features:

• High knowledge acquisition rate;
• High problem solving performance (including unanticipated solutions).
• Demonstrated at EFX’98 as part of an integrated application led by Alphatech.
Tecuci G., Lecture Notes on Knowledge-Based Reasoning – Part IV, 2008 (required).
