Problem Solving Paradigms: Causal Reasoning

6.871 – Lecture 14
Outline

• Problem Solving Paradigms
  – What are they and what are they good for

• Causal reasoning as a PSP
  – ABEL

• Causal reasoning + rules + debugging
  – GORDIUS
A Recipe

• Study how experts characterize problems and solution methods, especially their technical vocabulary

• Mimic their representation, capture the abstractions

• Mimic their problem solving mechanism
This Works Because

- There are generic task types that span many domains
- There are a modest number of problem solving paradigms and their knowledge representations
- Each generic task has a variety of appropriate problem solving paradigms

- *Representations* indicate how to look at the world: capture the important abstractions of the problem domain.
- *Problem solving paradigms* organize representational, inferential and computational processes; indicate when and how to draw conclusions.
Caveats

• A problem solving paradigm suggests control structures and inference mechanisms
  – but is not synonymous with them.
• A knowledge representation suggests certain data-structures and control structures
  – but it is not synonymous with them.
• Problem solving paradigms and knowledge representations are knowledge level constructs, not mechanisms or data structures.
What’s In A PSP?

- A representation for factual knowledge.
- Inferential methods
- A control structure dictating when to employ the inferential methods and with what purpose.
Why Concentrate on Paradigms?

- Special purpose programming languages for the paradigm can be created and reused.
- Knowledge acquisition tools specific to the paradigm can be designed and reused.
- Maintainability is improved.
- Need for "programming hacks" reduced.
- Emphasizes the search for the right level of abstraction.
A Basic Paradigm: Means Ends Analysis

Current

Achieve Preconditions

Operate Relevant Operator

Detect Differences

Reduce Remaining Differences

Goal

Operator Difference Table

<table>
<thead>
<tr>
<th></th>
<th>Walk</th>
<th>Bike</th>
<th>Taxi</th>
<th>Bus</th>
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<tr>
<td>&lt;1</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-5</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
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<tr>
<td>5-50</td>
<td></td>
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<td>x</td>
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<tr>
<td>50-500</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

Choose Relevant Operator

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Diagnosis: A Classic Generic Task

• PSPs
  – Bayesian statistics
    • Naïve Bayes’ rule
    • Sequential Bayesian diagnosis
  – Frequency and invoking strength: Internist
  – Empirical associations: Mycin
  – Causal: ABEL
The Intuition

• A flooded basement
• An auto accident
ABEL

• Domain?

• Representation?
ABEL Representations

- low bicarb
- low potassium
- high chlorine
- high sodium
- low water volume

causes

Lower-GI-fluid-loss

constituent-of

- water-loss
- bicarb-loss
- sodium-loss
- potassium-loss
- chloride-loss

Lower-GI-fluid-loss
<table>
<thead>
<tr>
<th></th>
<th>Lower GI Fluid</th>
<th>Plasma Fluid</th>
</tr>
</thead>
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<tr>
<td>Na</td>
<td>100–110</td>
<td>138–148</td>
</tr>
<tr>
<td>K</td>
<td>30–40</td>
<td>4–5</td>
</tr>
<tr>
<td>Cl</td>
<td>60–90</td>
<td>100–110</td>
</tr>
<tr>
<td>HCO₃</td>
<td>30–60</td>
<td>24–28</td>
</tr>
</tbody>
</table>

**Compared to plasma:**
Lower GI Fluid is rich in HCO₃ and K; low in Na and Cl

**Loss of GI Fluid results in**
- reduced fluid in (hypovolemia)
- reduced K (hypokalemia)
- reduced HCO₃ (hypobicarbonatemia)
- increased Cl (hyperchloremia)
- increased Na (hypernatremia)
ABEL

• Causal knowledge represented at multiple levels of description
• Each causal relation characterized by constraints among severity, duration, etc. between cause and effect
• Each causal relation described at next more detailed level
• Each disease node described using network of nodes and causal links at next more detailed level
• Goal: assemble a causal explanation of all findings using a network of causal relations at many levels of detail.
• Models interactions between the hypothesized diseases
Multiple Levels

Aggregate Level

Composite node

Focus Link

Detailed Level

Elaboration Structure

Focus Node

causes

causes

causes

causes

Focus Link

Detailed Level

Elaboration Structure

Focus Node

causes

causes

causes

causes
ABEL: Multiple Levels

Clinical Level

dehydration causes diarrhea

Intermediate Level

dehydration causes Lower-GI-Loss

Pathophysiological Level

dehydration causes Sodium-Loss

causes water-Loss

causes Lower-GI-Loss

canst-of diarrhea

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Accounting For Multiple Causes

- **Diarrhea-1** causes **Metabolic Acidosis-1**
- **Metabolic Acidosis-1** causes **Metabolic Acidosis-2** and **Metabolic Acidosis-3**
- **Metabolic Acidosis-1** causes **Shock-1**
- **Metabolic Acidosis-2** and **Metabolic Acidosis-3** causes **Shock-1**

Diagram:

- Arrows indicate cause relationships: `causes`
- Focus points: `focus`
ABEL: Modeling Feedback

Increased Respiration Rate causes Low pH-1

Low pCO2-1 causes Hi pH-3

Low pH-1 is a component of Low pH-2

Low pH-2 causes Low HCO3-1

Hi pH-3 causes component of Low pH-1
ABEL Operations

• Elaboration: Makes connections across levels of detail by filling in the structure below
• Aggregation: Makes connections across levels of detail by filling in the structure above
• Component Decomposition: Relates disorders at the same level of detail by breaking up a node into component parts
• Component Summation: Relates disorders at the same level of detail by summing (arithmetically) contributions of components parts.
• Projection: Forges causal links at the same level of detail in the search for etiologic explanation
Combining Paradigms

• Gordius:
  – Generate – test – debug
  – Rules + Causal Models

• What’s generate and test as a PSP?
  – Dendral as an example
  – What did Dendral’s tester tell you?
GORDIUS

• Domain/task?
Processes

- Deposition
- Intrusion
- Fault
- Uplift/subsidence
- Tilt
Rules Model Interactions

Pattern constraints
- Igneous(IGN)
- Same-type(R1, R2)
- Parallel(e1, e2)

Events:
- create rock1
- intrude IGN through rock1
Local Matching
Debugging

• Dependency maintenance
  – height affected by:
    • shale is produced underwater
    • shale deposit depth
    • height is unchanged since deposition
    • sea level unchanged since deposition

• Repair strategies
  – “unchanged” assumption
  – parameter value assumption
  – time ordering assumption
Summary

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