Knowledge representation and reasoning

It should be clear that generating sequences of actions by inference in FOL is highly non-trivial.

Ideally we’d like to maintain an expressive language while restricting it enough to be able to do inference efficiently.

Further aims:

• To give a brief introduction to semantic networks and frames for knowledge representation.
• To see how inheritance can be applied as a reasoning method.
• To look at the use of rules for knowledge representation, along with forward chaining and backward chaining for reasoning.


Frames and semantic networks

Frames and semantic networks represent knowledge in the form of classes of objects and relationships between them:

• The subclass and instance relationships are emphasised.
• We form class hierarchies in which inheritance is supported and provides the main inference mechanism.

As a result inference is quite limited.

We also need to be extremely careful about semantics.

The only major difference between the two ideas is notational.

Example of a semantic network

Frames

Frames once again support inheritance through the subclass relationship.

has, hairlength, volume etc are slots.
long, loud, instrument etc are slot values.
These are a direct predecessor of object-oriented programming languages.
Defaults

Both approaches to knowledge representation are able to incorporate defaults:

<table>
<thead>
<tr>
<th>Rock musician</th>
<th>Dementia Evilperson</th>
</tr>
</thead>
<tbody>
<tr>
<td>subclass: Musician</td>
<td>subclass: Rock musician</td>
</tr>
<tr>
<td>has: ear problems</td>
<td>has: image: gothic</td>
</tr>
<tr>
<td>* hairlength: long</td>
<td>* hairlength: short</td>
</tr>
<tr>
<td>* volume: loud</td>
<td></td>
</tr>
</tbody>
</table>

Starred slots are typical values associated with subclasses and instances, but can be overridden.

Multiple inheritance

Both approaches can incorporate multiple inheritance, at a cost:

- What is hairlength for Cornelius if we’re trying to use inheritance to establish it?
- This can be overcome initially by specifying which class is inherited from in preference when there’s a conflict.
- But the problem is still not entirely solved—what if we want to prefer inheritance of some things from one class, but inheritance of others from a different one?

Other issues

- Slots and slot values can themselves be frames. For example Dementia may have an instrument slot with the value Electricarp, which itself may have properties described in a frame.
- Slots can have specified attributes. For example, we might specify that:
  - instrument can have multiple values
  - Each value can only be an instance of Instrument
  - Each value has a slot called owned_by and so on.
- Slots may contain arbitrary pieces of program. This is known as procedural attachment. The fragment might be executed to return the slot’s value, or update the values in other slots etc.

Rule-based systems

A rule-based system requires three things:

1. A set of if – then rules. These denote specific pieces of knowledge about the world. They should be interpreted similarly to logical implication. Such rules denote what to do or what can be inferred under given circumstances.
2. A collection of facts denoting what the system regards as currently true about the world.
3. An interpreter able to apply the current rules in the light of the current facts.
Forward chaining

The first of two basic kinds of interpreter begins with established facts and then applies rules to them.

This is a data-driven process. It is appropriate if we know the initial facts but not the required conclusion.

Example: XCON—used for configuring VAX computers.

In addition:

- We maintain a working memory, typically of what has been inferred so far.
- Rules are often condition-action rules, where the right-hand side specifies an action such as adding or removing something from working memory, printing a message etc.
- In some cases actions might be entire program fragments.

The basic algorithm is:

1. Find all the rules that can fire, based on the current working memory.
2. Select a rule to fire. This requires a conflict resolution strategy.
3. Carry out the action specified, possibly updating the working memory.

Repeat this process until either no rules can be used or a halt appears in the working memory.

Example

Progress is as follows:

1. The rule dry_mouth → ADD thirsty fires adding thirsty to working memory.
2. The rule thirsty → ADD get_drink fires adding get_drink to working memory.
3. The rule working → ADD no_work fires adding no_work to working memory.
4. The rule get_drink AND no_work → ADD go_bar fires, and we establish that it’s time to go to the bar.
Conflict resolution
Clearly in any more realistic system we expect to have to deal with a scenario where two or more rules can be fired at any one time:

- Which rule we choose can clearly affect the outcome.
- We might also want to attempt to avoid inferring an abundance of useless information.

We therefore need a means of resolving such conflicts. Common conflict resolution strategies are:

- Prefer rules involving more recently added facts.
- Prefer rules that are more specific. For example
  \[\text{patient_coughing} \rightarrow \text{ADD lung_problem}\]
  is more general than
  \[\text{patient_coughing AND patient_smoker} \rightarrow \text{ADD lung_cancer}.\]
- Allow the designer of the rules to specify priorities.
- Fire all rules simultaneously—this essentially involves following all chains of inference at once.

Reason maintenance
Some systems will allow information to be removed from the working memory if it is no longer justified.

For example, we might find that

\[\text{patient_coughing}\]

and

\[\text{patient_smoker}\]

are in working memory, and hence fire

\[\text{patient_coughing AND patient_smoker} \rightarrow \text{ADD lung_cancer}\]

but later infer something that causes \text{patient_coughing} to be withdrawn from working memory.

The justification for \text{lung_cancer} has been removed, and so it should perhaps be removed also.

Pattern matching
In general rules may be expressed in a slightly more flexible form involving variables which can work in conjunction with pattern matching.

For example the rule

\[\text{coughs}(X) \text{ AND smoker}(X) \rightarrow \text{ADD lung_cancer}(X)\]

contains the variable \(X\).

If the working memory contains \text{coughs}(neddy) and \text{smoker}(neddy) then

\(X = \text{neddy}\)

provides a match and

\[\text{lung_cancer}(\text{neddy})\]

is added to the working memory.

Backward chaining
The second basic kind of interpreter begins with a goal and finds a rule that would achieve it.

It then works backwards, trying to achieve the resulting earlier goals in the succession of inferences.

Example: MYCIN—medical diagnosis with a small number of conditions.

This is a goal-driven process. If you want to test a hypothesis or you have some idea of a likely conclusion it can be more efficient than forward chaining.
Example

Example with backtracking

If at some point more than one rule has the required conclusion then we can backtrack.

Example: Prolog backtracks, and incorporates pattern matching. It orders attempts according to the order in which rules appear in the program.

Example: having added

\[ \text{up early} \rightarrow \text{ADD tired} \]

and

\[ \text{tired AND lazy} \rightarrow \text{ADD go bar} \]

to the rules, and \text{up early} to the working memory: