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.

Further reading: *The Essence of Artificial Intelligence*, Alison Cawsey. Prentice Hall, 1998.

Frames and semantic networks

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

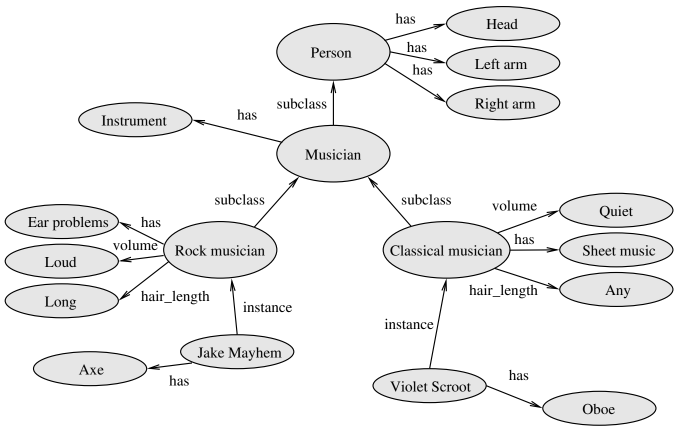
- The *subclass* and *instance* relationships are emphasised.
- We form *class hierarchies* in which *inheritance* is supported and provides the main *inference mechanism*.

As a result inference is quite limited.

We also need to be extremely careful about *semantics*.

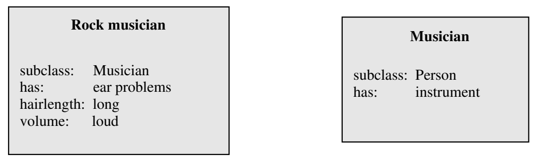
The only major difference between the two ideas is *notational*.

Example of a semantic network



Frames

Frames once again support inheritance through the *subclass relationship*.



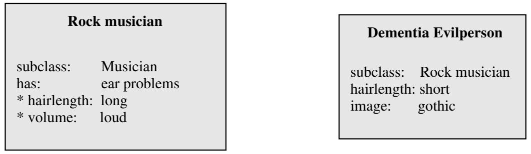
`has`, `hairlength`, `volume` *etc* are *slots*.

`long`, `loud`, `instrument` *etc* are *slot values*.

These are a direct predecessor of *object-oriented programming languages*.

Defaults

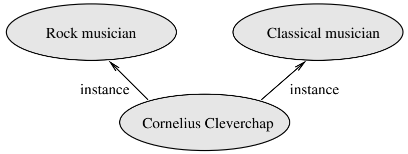
Both approaches to knowledge representation are able to incorporate *defaults*:



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 `Electricharp`, 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:

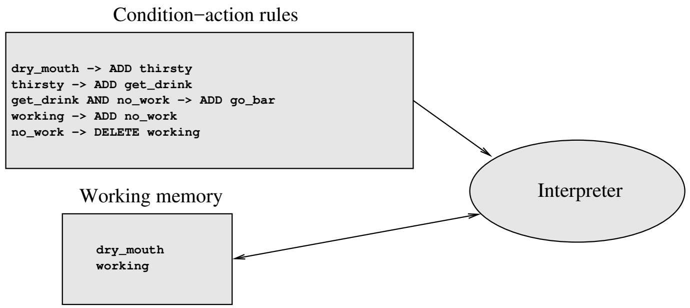
- We maintain a *working memory*, typically of what has been inferred so far.
- Rules are often *condition-action rules*, where the right-hand side specifies an action such as adding or removing something from working memory, printing a message *etc.*
- In some cases actions might be entire program fragments.

Forward chaining

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

  $$\texttt{patient\_coughing} \rightarrow \text{ADD } \texttt{lung\_problem}$$

  is more general than

  $$\texttt{patient\_coughing} \text{ AND } \texttt{patient\_smoker} \rightarrow \text{ADD } \texttt{lung\_cancer}.$$

- 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

$$\texttt{patient\_coughing}$$

and

$$\texttt{patient\_smoker}$$

are in working memory, and hence fire

$$\texttt{patient\_coughing} \text{ AND } \texttt{patient\_smoker} \rightarrow \text{ADD } \texttt{lung\_cancer}$$

but later infer something that causes $\texttt{patient\_coughing}$ to be *withdrawn* from working memory.

The justification for $\texttt{lung\_cancer}$ 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

$$\texttt{coughs}(X) \text{ AND } \texttt{smoker}(X) \rightarrow \text{ADD } \texttt{lung\_cancer}(X)$$

contains the variable X.

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

$$X = \texttt{neddy}$$

provides a match and

$$\texttt{lung\_cancer}(\texttt{neddy})$$

is added to the working memory.

Backward chaining

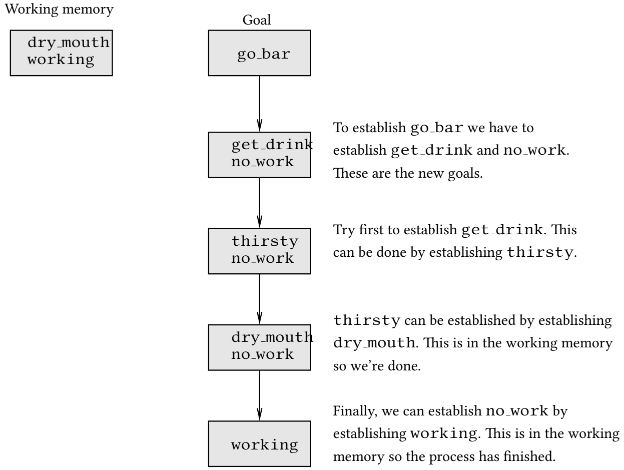
The second basic kind of interpreter begins with a *goal* and finds a rule that would achieve it.

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

$$\texttt{up\_early} \rightarrow \text{ADD } \texttt{tired}$$

and

$$\texttt{tired} \text{ AND } \texttt{lazy} \rightarrow \text{ADD } \texttt{go\_bar}$$

to the rules, and `up_early` to the working memory:

Example with backtracking