# 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*:

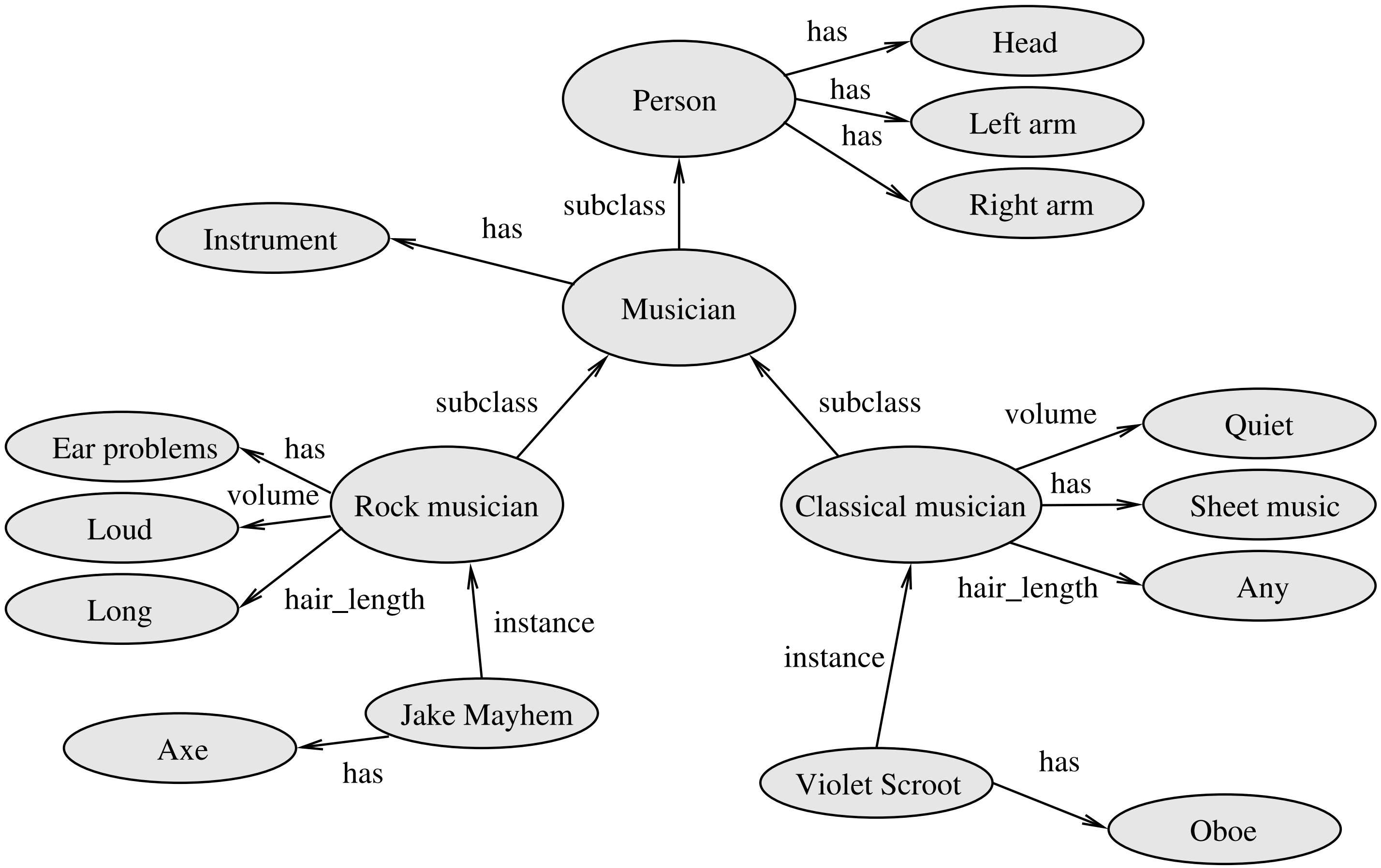
- The *subclass* and *instance* relationships are emphasised.
- We form *class hierarchies* in which *inheritance* is supported and provides the main *inference mechanism*.

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*.

**Rock musician**

| | |
|---|---|
| subclass: | Musician |
| has: | ear problems |
| hairlength: | long |
| volume: | loud |

**Musician**

| | |
|---|---|
| subclass: | Person |
| has: | instrument |

`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*:

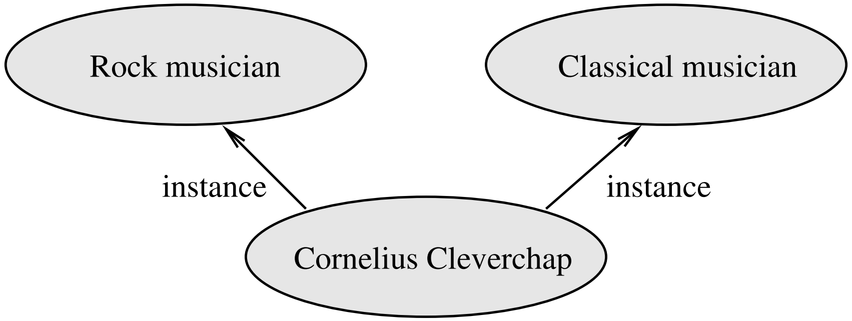
| **Rock musician** | |
|---|---|
| subclass: | Musician |
| has: | ear problems |
| * hairlength: | long |
| * volume: | loud |

| **Dementia Evilperson** | |
|---|---|
| subclass: | Rock musician |
| hairlength: | short |
| image: | gothic |

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:

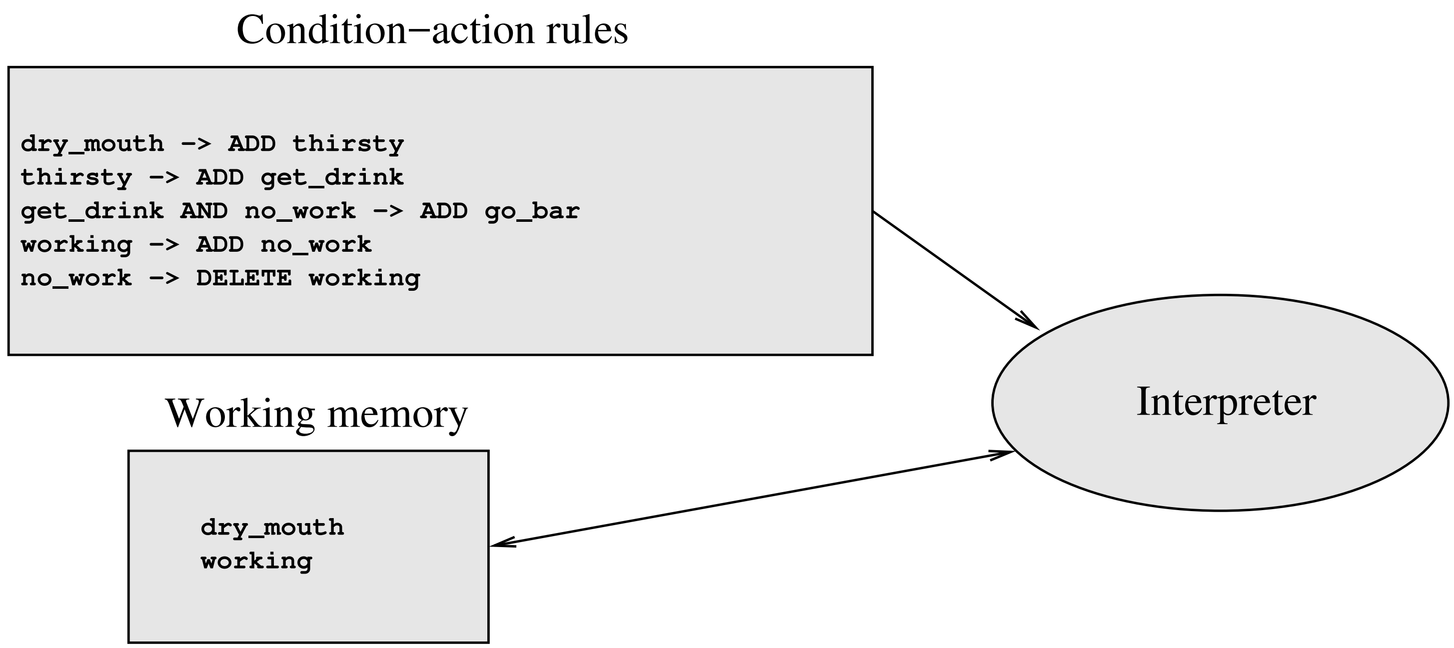
- We maintain a *working memory*, typically of what has been inferred so far.
- Rules are often *condition-action rules*, where the right-hand side specifies an action such as adding or removing something from working memory, printing a message *etc.*
- In some cases actions might be entire program fragments.

# 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.


Condition−action rules
dry_mouth -> ADD thirsty
thirsty -> ADD get_drink
get_drink AND no_work -> ADD go_bar
working -> ADD no_work
no_work -> DELETE working
Working memory
dry_mouth
working
Interpreter

# Example

Progress is as follows:

1. The rule

   $$\texttt{dry\_mouth} \rightarrow \text{ADD } \texttt{thirsty}$$

   fires adding thirsty to working memory.

2. The rule

   $$\texttt{thirsty} \rightarrow \text{ADD } \texttt{get\_drink}$$

   fires adding get_drink to working memory.

3. The rule

   $$\texttt{working} \rightarrow \text{ADD } \texttt{no\_work}$$

   fires adding no_work to working memory.

4. The rule

   $$\texttt{get\_drink} \text{ AND } \texttt{no\_work} \rightarrow \text{ADD } \texttt{go\_bar}$$

   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

`patient_coughing`

and

`patient_smoker`

are in working memory, and hence fire

`patient_coughing` AND `patient_smoker` $\rightarrow$ ADD `lung_cancer`

but later infer something that causes `patient_coughing` to be *withdrawn* from working memory.

The justification for `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

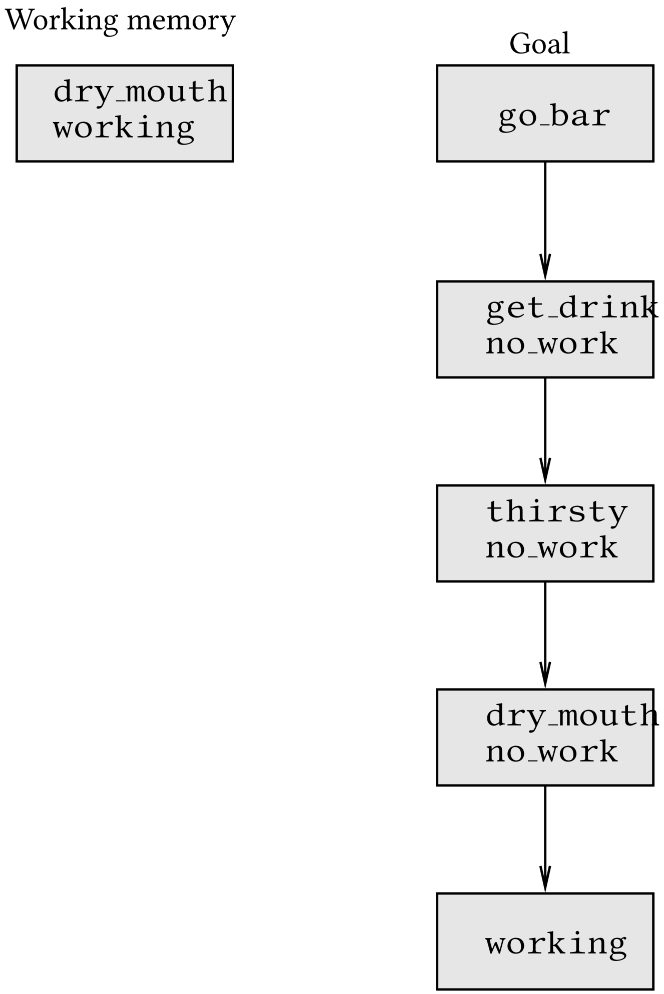
The second basic kind of interpreter begins with a *goal* and finds a rule that would achieve it.

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




To establish go_bar we have to establish get_drink and no_work. These are the new goals.

Try first to establish get_drink. This can be done by establishing thirsty.

thirsty can be established by establishing dry_mouth. This is in the working memory so we're done.

Finally, we can establish no_work by establishing working. This is in the working memory so the process has finished.

# 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

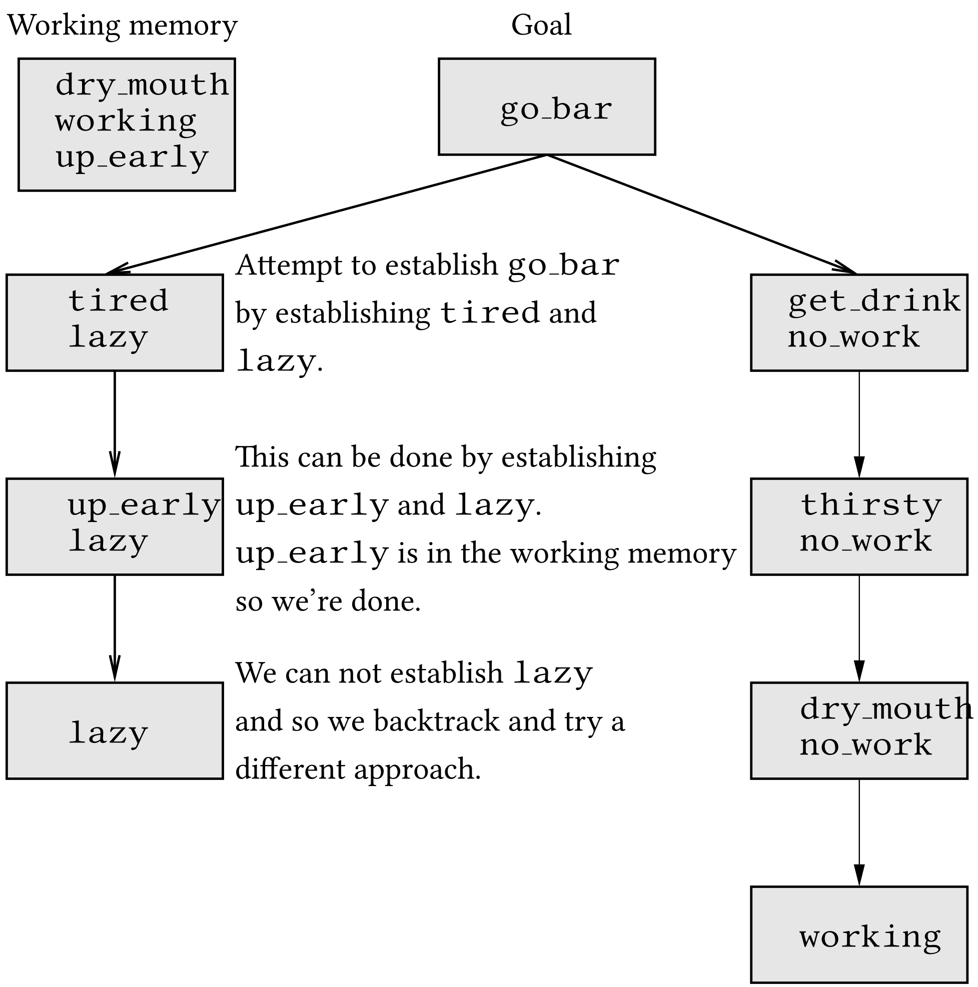
$$\texttt{up\_early} \rightarrow \text{ADD } \texttt{tired}$$

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




Attempt to establish `go_bar` by establishing `tired` and `lazy`.

This can be done by establishing `up_early` and `lazy`. `up_early` is in the working memory so we're done.

We can not establish `lazy` and so we backtrack and try a different approach.

Process proceeds as before