KNOWLEDGE REPRESENTATION

Introduction

- When we use heuristics to help solve search problems, we are applying knowledge about the problem domain to help focus search.
- This knowledge is *implicit*.
- The history of AI suggests that it is helpful to make this implicit knowledge *explicit*, that is make it clear what the knowledge is.
- It seems that doing this makes it easier to solve problems.
- Doing this is the subject of *knowledge representation*¿

The Knowledge Principle

- Ed Feigenbaum:

  "... power exhibited ... is primarily a consequence of the specialist knowledge employed by the agent and only very secondarily related to ... the power of the [computer]"
  "Our agents must be knowledge rich, even if they are methods poor."

The Role of Knowledge

- Knowledge about a domain allows problem solving to be *focussed* — not necessary to exhaustively search.
- *Explicit* representations of knowledge allow a *domain expert* to understand the knowledge a system has, add to it, edit it, and so on.

  Knowledge engineering.
- Comparatively *simple* algorithms can be used to *reason* with the knowledge and derive *new* knowledge.

Knowledge Representation

- Question: How do we *represent* knowledge in a form amenable to computer manipulation?
- Desirable features of KR scheme:
  - *representational adequacy*;
  - *inferential adequacy*;
  - *inferential efficiency*;
  - *well-defined syntax & semantics*;
  - *naturalness*.

Representational Adequacy

- A KR scheme must be able to actually represent the knowledge appropriate to our problem.
- Some KR schemes are better at some sorts of knowledge than others.
- *There is no one ideal KR scheme!*

Inferential Adequacy

- KR scheme must allow us to make new *inferences* from old knowledge.
- It must make inferences that are:
  - *sound* — the new knowledge actually does follow from the old knowledge;
  - *complete* — it should make all the right inferences.
- Soundness usually easy; completeness very hard!

- Example. Given knowledge...

  Michael is a man.
  All men are mortal.

  the inference

  Simon is mortal.

  is not sound, whereas

  Michael is mortal.

  is sound.

Inferential Efficiency

- A KR scheme should be *tractable* — make inferences in reasonable (polynomial) time.
- Unfortunately, *any* KR scheme with interesting *expressive power* is not going to be efficient.
- Often, the more *general* a KR scheme is, the *less efficient* it is.
- Use KR schemes tailored to problem domain — less general, but more efficient.
- (Any KR scheme with expressive power = first-order logic is *undecidable*.)

Syntax and Semantics

- It should be possible to tell:
  - whether any construction is "grammatically correct".
  - how to read any particular construction — no *ambiguity*.

  Thus KR scheme should have *well defined syntax*.
- It should be possible to precisely determine, for any given construction, exactly what its meaning is.

  Thus KR scheme should have *well defined semantics*.
- *Syntax is easy; semantics is hard!*

Naturalness

- Ideally, KR scheme should closely correspond to our way of thinking, reading, and writing.
- Allow *knowledge engineer* to read & check *knowledge base*.
- Again, *more general* a KR scheme is, less likely it is to be readable & understandable.

Rules

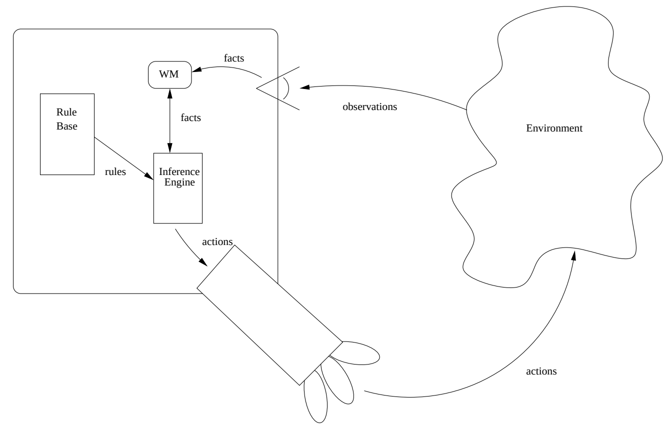
- Knowledge is specified as a collection of *production rules*.
- Each rule has the form

  $$condition \longrightarrow action$$

  which may be read

  if *condition* then *action*.
- The *condition* (antecedent) is a *pattern*.
- The *action* (consequent) is an operation to be performed if rule *fires*.

- A rule-based (production) system has a *working memory* of *facts* against which *condition* is matched.
- Action is often a *fact* to be added to working memory.
- Rule fires if match is successful; Mechanism that fires rules is *inference engine*.
- The production system fits into our notion of agent as follows.



- Example rule base:

```
R3:  IF animal has feathers
     THEN animal is a bird

R4:  IF animal is a bird
     THEN animal can fly

R5:  IF animal can fly
     THEN animal is not scared of heights
```


Relation to search

- Using rules can be thought of as just another form of search.
- Facts are states.
- Working memory is the agenda.
- Rules are the operations on states.
- This suggests that there are schemes for applying rules which are similar to breadth-first search etc.
- We will look at these next.

- Another example:

```
R1:  IF animal has hair
     THEN animal is a mammal

R2:  IF animal gives milk
     THEN animal is mammal

R3:  IF animal has feathers
     THEN animal is a bird

R4:  IF animal can fly
     AND animal lays eggs
     THEN animal is bird
```



```
R5:  IF animal eats meat
     THEN animal is carnivore

R6:  IF animal has pointed teeth
     AND animal has claws
     THEN animal is carnivore

R7:  IF animal is mammal
     AND animal has hoofs
     THEN animal is ungulate

R8:  IF animal is mammal
     AND animal chews cud
     THEN animal is ungulate
```



```
R9:  IF animal is mammal
     AND animal is carnivore
     AND animal has tawny colour
     AND animal has dark spots
     THEN animal is cheetah

R10: IF animal is mammal
     AND animal is carnivore
     AND animal has tawny colour
     AND animal has black stripes
     THEN animal is tiger
```



```
R11: IF animal is ungulate
     AND animal has long legs
     AND animal has dark spots
     THEN animal is giraffe

R12: IF animal is ungulate
     AND animal has black stripes
     THEN animal is zebra

R14: IF animal is bird
     AND animal does not fly
     AND animal has long legs
     AND animal has long neck
     THEN animal is ostrich
```

```
R14: IF animal is bird
     AND animal does not fly
     AND animal can swim
     AND animal is black and white
     THEN animal is penguin

R15: IF animal is bird
     AND animal is good flyer
     THEN animal is albatross
```


Forward Chaining

- Given a set of rules like these, there are essentially two ways we can use them to generate new knowledge:
  - *forward chaining* — data driven;
  - *backward chaining* — goal driven.
- In what follows…

  let `(c,a)` be a rule.

  let `fires(c,WM)` be true if condition `c` fires against working memory `WM`.
- Forward chaining algorithm is as follows.


```
var WM : set of facts
var goal : goal we are searching for
var RuleBase : set of rules
var firedFlag : BOOLEAN
repeat
  firedFlag = FALSE
  for each (c,a) in RuleBase do
    if fires(c,WM) then
      if a == goal then return success
      end-if
      add a to WM
      set firedFlag to TRUE
    end-if
  end-for
until firedFlag = FALSE
return failure
```


- Example. Suppose

  ```
  WM = { animal has hair,
         animal eats meat,
         animal has tawny colour,
         animal has dark spots}
  ```

  and goal is

  ```
  animal is cheetah
  ```

- Note that *all rules which can fire do fire*.
- Can be inefficient — lead to spurious rules firing, unfocussed problem solving (cf. breadth-first search).
- Set of rules that can fire known as *conflict set*.
- Decision about which rule to fire — *conflict resolution*.
- Number of strategies possible (cf. heuristic search):
  - *most specific rule first* (with most antecedents).
  - *most recent first*;
  - *user specified priorities*.

- Another solution: *meta-knowledge*, (i.e., *knowledge about knowledge*) to guide search.

```
IF
  conflict set contains any rule (c,a) such that
  a = ‘‘animal is mammal’’
THEN
  fire (c,a)
```

- So meta-knowledge encodes knowledge about how to guide search for solution.
- Explicitly coded in the form of rules, as with "object level" knowledge.

Backward Chaining

- Backward chaining means reasoning from *goals* back to *facts*.
- The idea is that this focusses the search.
- Thinking of the rules as building a tree connecting facts
  - In backward chaining, every path ends with the goal.
- Since, in general, there are more initial facts that goals
  - More of the paths built will be solutions than in forward chaining (we hope :-).


```
var WM : set of facts
var RuleBase : set of rules
var firedFlag : BOOLEAN
function prove(g : goal)
  if g in WM then
return TRUE
  if there is some (c,a) in WM
        such that a == g then
     for each precondition p in c do
        if not prove(p,WM) then return FALSE
     return TRUE
  else
     return FALSE
end-function
```

- Example. Suppose

```
WM = { animal has hair,
       animal eats meat,
       animal has tawny colour,
       animal has dark spots}
```

- and goal is

```
animal is cheetah
```


Semantic Networks

- Taxonomic reasoning can be more efficient not in logic.
- Developed by Quillian in 1968, for *semantic memory*.
- Models the "associations" between ideas that people maintain.
- Semantic net is a *labelled graph*.
  - nodes in graph represent *objects*, *concepts*, or *situations*;
  - arcs in graph represent *relationships between objects*.

Key types of arc:

- $x \xrightarrow{subset} y$

  "x is a kind of y" ($\subset$)

  Example: $penguin \xrightarrow{subset} bird$
- $x \xrightarrow{member} y$

  "x is a y"

  Example: $opus \xrightarrow{member} penguin$
- $x \xrightarrow{R} y$

  "x is R-related to y"

  Example: $bill \xrightarrow{friend} opus$
- Inference is then by traversing arcs.

- *Binary* relations are easy and natural to represent.
- Others kinds of relation are harder.
- Unary relations (properties).

  Example: “Opus is small”.
- Three place relations.

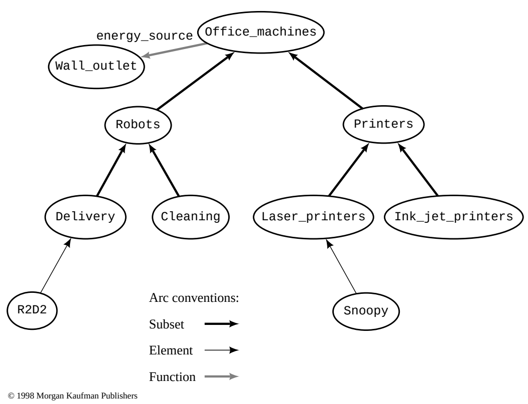
  Example: “Opus brings tequila to the party.”
- Some binary relations are problematic . . .

  “Opus is larger than Bill.”

- *Quantified* statements are very hard for semantic nets.

  Examples:
  - “every dog has bitten a postman”
  - “every dog has bitten every postman”
- *Partitioned* semantic nets can represent these.
- Of course, expressions like this are very easy to represent in first order logic.

- Example semantic net:



Frames

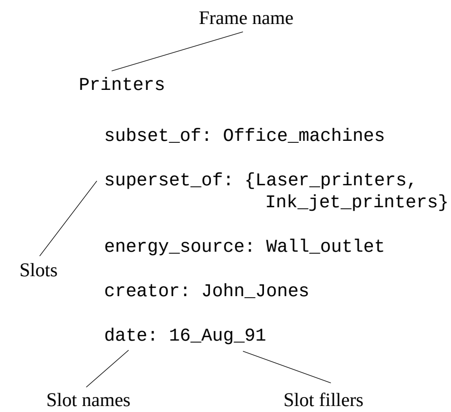
- Frames are a kind of *structured* knowledge representation mechanism.
- All information relevant to a particular concept is stored in *frame* which resembles C `struct`, PASCAL `record`, Java object. . .
- Each frame has a number of *slots*.
- Each slot may be *filled* by:
  - a value;
  - a pointer to another frame;
  - a procedure.
- Slots may have *default values* associated with them.
- Frames = OO!

- Frames are typically used to represent the *properties* of objects, and the relationships between them.
- Frames may represent:
  - *generic concepts* (cf classes) or
  - *specific items* (cf objects).
- Most important kind of link between frames:

  is-a

- Facilitates reasoning about object properties.
- Allows *default values* to be *inherited*.

- Example frame system:



- How to reason with frame systems?
- Easy to answer questions such as
  is x a y?
  Simply follow the *is-a* links.
- Example: Is snoopy a laser printer?
- (Problem of *multiple inheritance* — Nixon diamond.)
- Also useful for *default* reasoning.
  Simply *inherit* all default values that are not explicitly provided.
- Example: Does snoopy the printer have a wall outlet?

- *Scripts* are a variant of frames, for representing *stereotypical sequences of events*.
- A script is thus a frame with a set of prescribed slots, for example:
  - Some initial conditions;
  - Some final conditions;
  - Some state description;
  - Some actions; and
  - Some actors
- The structure of the script is heavily domain dependent.

- Example:

```
SCRIPT
Name: RESTAURANT
Roles: Customer, Waiter, Cook, Cashier
Entry condition: Customer is hungry
Props: Food, table, money, menu, tip
Events:
 1/ Customer enters restaurant
 2/ Customer goes to table
 3/ Waiter brings menu
 4/ Customer orders food
 5/ Waiter brings food
 6/ Customer eats food
...
```



```
...
10/ Customer leaves restaurant

Main concept: 6

Results: Customer not hungry,
         Customer has less money,
         Restaurant has more money,
         Waiter gets tip
```


- Scripts developed by Roger Schank for *understanding stories*.
- Used to help *understand language*.
- Scripts provide *context* information without which sentences cannot be understood:
  - sentences are not unconstrained sequences of words;
  - stories are not unconstrained sequences of sentences.
- Schank developed SAM (Script Applier Mechanism) that could *fill in gaps* in stories.
- Also able to "explain" elements of stories, e.g., people get upset or angry when story deviates from script.

Problems with Frames & Semantic Nets

- Both frames and semantic nets are essentially *arbitrary*.
- Both are useful for representing certain sorts of knowledge.
- But both are essentially *ad hoc* — lack precise meaning, or *semantics*.
- Inference procedures poorly defined & justified.
- The *syntax* of KR scheme is *irrelevant*.
- *Logic* generalises these schemes... and that is both an advantage and a disadvantage.

Summary

- This lecture has introduced the idea of knowledge representation, and some of the requirements of a knowledge representation scheme.
- We also looked at several knowledge representation schemes:
  - production rules
  - semantic nets
  - frames
  - scripts
- Next lecture will look the role of logic in knowledge representation.