KNOWLEDGE REPRESENTATION

Introduction

- Although search is a "universal weak method" for problem solving...
- ...real problems require methods with more edge.
- One way to provide this is to use explicit knowledge.
- This means we need to represent knowledge explicitly.
- This lecture introduce the need for *explicit knowledge representation*...
- ...and describes *rules* as one particular means of knowledge representation.

The Need for Knowledge

- “Weak” (search-based) problem-solving does not scale to real problems.
- To succeed, problem solving needs *domain specific knowledge*.
- In search, knowledge = heuristic.
- But heuristics are *implicit* knowledge — hard to understand, modify, ...
- In mid 1970s, attention shifted to *explicit* 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?
- Led to an area known as *knowledge representation*.
- 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

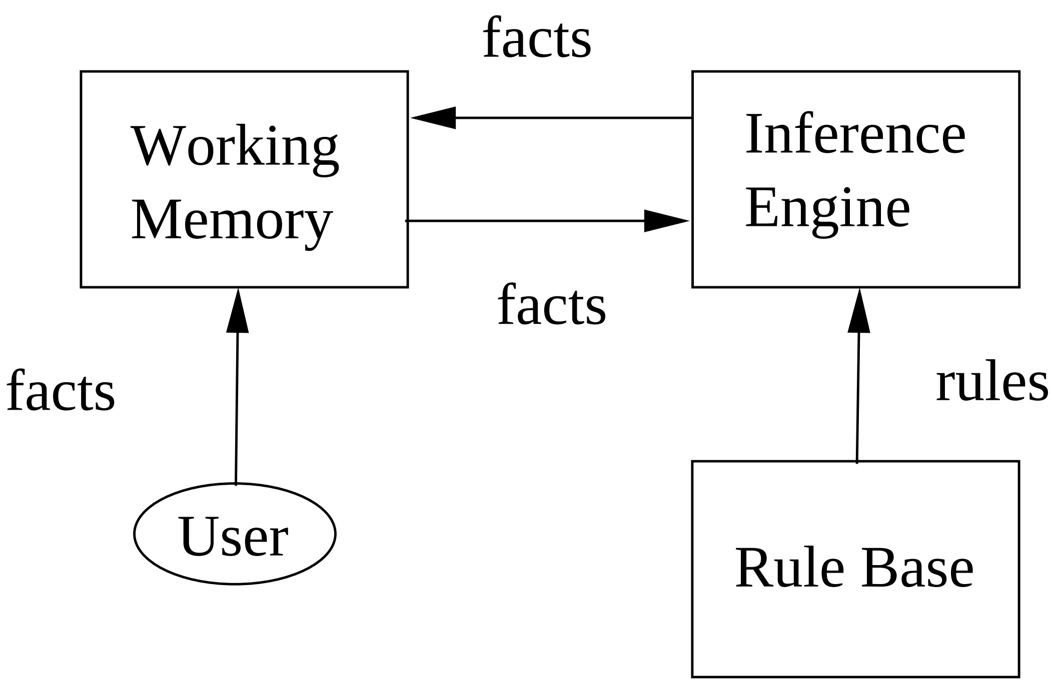
- Knowledge is specified as a collection of *production rules*.
- Each rule has the form

$$condition \longrightarrow action$$

  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*.



- 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*.

Meta Knowledge

- 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
```

Summary

- This lecture has introduced the idea of knowledge representation, and some of the requirements of a knowledge representation scheme.
- We also looked at how production rules might be used for knowledge representation …
- …and looked at how both forward and backward chaining are used in rule-based systems.
- Next lecture will look expert systems as a application of rule-based systems.