COMP219: Artificial Intelligence

Lecture 16: Forward and Backward Chaining

Overview

- Last time
  - Introduced the reasons for explicit knowledge representation
  - Discussed properties of knowledge representation schemes
  - Introduced rules as a form of knowledge representation

- Today
  - Introduce algorithms for reasoning with rules
  - Discuss some of the problems of rule-based representations

- Learning outcome covered today:

  Distinguish the characteristics, and advantages and disadvantages, of the major knowledge representation paradigms that have been used in AI, such as production rules, semantic networks, propositional logic and first-order logic;

Rule-Based System Architecture

- A collection of rules
- A collection of facts
- An inference engine

- We might want to
  - See what new facts can be *derived*
  - *Ask* whether a fact is implied by the knowledge base and facts already known

Control Schemes

- Given a set of rules, there are essentially two ways we can use them to generate new knowledge
  - ***forward chaining***
  - starts with the facts, and sees what rules apply (and hence what should be done) given the facts
    - data driven
  - ***backward chaining***
  - starts with something to find out, and looks for rules that will help in answering it
    - goal driven

Fire Alarm Example


```
R1: IF hot AND smoky THEN fire
R2: IF alarm_beeps THEN smoky
R3: IF fire THEN sprinklers_on

F1: alarm_beeps [Given]
F2: hot [Given]
```

- We need to make the consequents actions

Fire Alarm Example


```
R1: IF hot AND smoky THEN ADD fire
R2: IF alarm_beeps THEN ADD smoky
R3: IF fire THEN DO switch_sprinklers_on
                 ADD sprinklers_on

F1: alarm_beeps [Given]
F2: hot [Given]
```

Fire Alarm Example


```
R1: IF hot AND smoky THEN ADD fire
R2: IF alarm_beeps THEN ADD smoky
R3: IF fire THEN DO switch_sprinklers_on
                 ADD sprinklers_on

F1: alarm_beeps [Given]
F2: hot [Given]
```

Forward Chaining

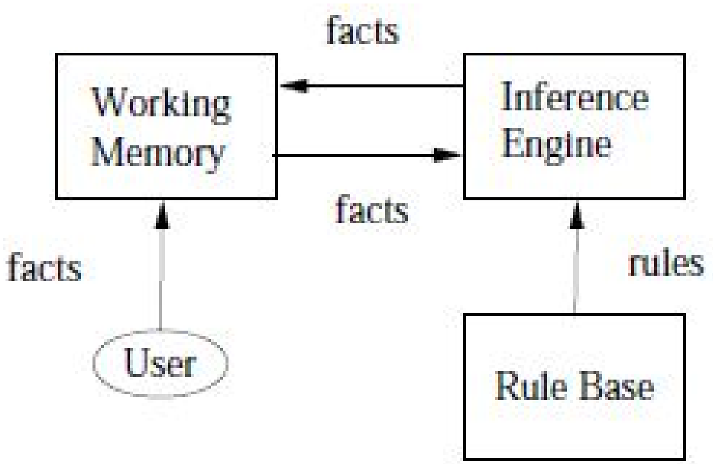
Use F1 and R2 to get F3 smoky

Use F2 and F3 and R1 to get F4 fire

Use F4 and R3 to get F5 sprinklers_on

Forward Chaining

- In a forward chaining system
  - Facts are held in a *working memory (WM)*
  - Condition-action rules represent actions to take when specified facts occur in working memory
  - Often the actions involve adding or deleting facts from working memory



Extending the Example


```
R1: IF hot AND smoky THEN ADD fire
R2: IF alarm_beeps THEN ADD smoky
R3: IF fire THEN DO switch_ sprinklers_on
                 ADD sprinklers_on
R4: IF dry THEN DO switch_on_humidifier
                 ADD humidifier_on
R5: IF sprinklers_on THEN DELETE dry

F1: alarm_beeps;    F2: hot;     F3: dry
```

Now ***two*** rules match: R2 ***and*** R4

Which rule to use?

- Use R2:
  - Add smoky: now R1 and R4 match
- Use R1:
  - Add fire: now R3 and R4 match
- Use R3:
  - Add sprinklers_on: R4 and R5 match
- Use R5:
  - Delete dry: now R4 does not match

- Note that R4 is never used in this sequence; so the choice can affect the result
- We have a ***conflict***: we need a conflict resolution strategy to select the right rule

Forward Chaining Algorithm

```
Repeat
   Collect rules whose conditions match facts in WM.
   If more than one rule matches:
     Use conflict resolution strategy to eliminate
     all but one.
   Do actions indicated by the rules (add facts to WM
   or delete facts from WM).
Until problem is solved or no condition match.
```

Conflict Resolution Strategy

- There are a number of approaches
  - Physically order the rules
    - hard to add rules to these systems
  - Data ordering
    - arrange problem elements in priority queue
    - use rule dealing with highest priority elements
  - Specificity or maximum specificity
    - based on number of conditions matching
    - choose the one with the most matches

More Strategies

- Recency ordering
  - Data (based on order facts added to WM)
  - Rules (based on rule firings)
- Context limiting
  - partition rule base into disjoint subsets
  - we may order the subsets and we may also have preconditions
- Random selection
- Can also have combinations to break ties

Meta Knowledge

- Another solution: use meta-knowledge (i.e. knowledge about knowledge) to guide search
- Example of meta-knowledge

```
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 to solve the problem
- Explicitly coded in the form of rules, as with “object level” knowledge

Properties of Forward Chaining

- Can be inefficient - lead to spurious rules firing, and unfocused problem solving (*cf*. breadth-first search)
- Set of rules that can fire known as *conflict set*
- Decision about which rule to fire - *conflict resolution*

- Different conflict resolutions may give different behaviour and different results

Application Areas

- Computer system configuration
  - Many possible set ups: forward chain from user needs
- Reactive robots
  - Get facts from environment and respond appropriately
- Conversational agents
  - Decide on the meaning of natural language input to give an appropriate response

Backward Chaining

- Same rules/facts may be processed differently, using backward chaining interpreter
- Backward chaining means reasoning from goals *back to* facts
- The idea is that this focuses the search
- Starts from a *goal* or *hypothesis*
  - Should I switch the sprinklers on?

Backward Chaining Algorithm

To prove goal G:

```
If G is in the initial facts, it is
proven.

Otherwise, find a rule which can be
used to conclude G, and try to prove
each of that rule's conditions (make
conditions sub-goals).
```

- We add goals, not facts to working memory

Fire Alarm Example


```
R1: IF hot AND smoky THEN ADD fire
R2: IF alarm_beeps THEN ADD smoky
R3: IF fire THEN DO switch_ sprinklers_on
                 ADD sprinklers_on
F1: alarm_beeps;    F2: hot
```

- Goal: switch_sprinklers_on

Backward Chaining
R3 justifies goal if fire
R1 justifies fire if hot and smoky
Hot is a fact: R2 justifies smoky if alarm beeps
Alarm beeps is a fact

Using Prolog

- Prolog supports backward chaining directly:

```
alarm_beeps.
hot.

fire :- hot, smoky.
smoky :- alarm_beeps.
switch_on_sprinklers :- fire.
```

Conflict resolution is handled by clause order

Forward Chaining in Prolog

```
go(X):-member(sprinklers_on,X).
go(X):-member(fire,X), write([switching,sprinklers,on]),
        go([sprinklers_on | X]).
go(X):-member(hot,X), member(smoky,X), go([fire | X]).
go(X):-member(alarm_beeps,X), go([smoky | X]).

?- go([hot,alarm_beeps]).
```

- Argument (the maintained list) acts as working memory
- Member succeeds if fact in working memory
- Conflict resolution through ordering of clauses

Exercise

Consider the following financial advice scenario:

```
R1: IF NOT savings_adequate THEN DO invest_savings
                  ADD savings_invested

R2: IF savings_adequate AND income_adequate THEN
            DO invest_stocks ADD stocks_invested

R3: IF NOT has_children THEN ADD savings_adequate

R4: IF has_partner AND partner_employed THEN
                  ADD income_adequate


F1: has_children
F2: has_partner
F3: partner_employed
```

Should I invest in stocks?

Forward vs Backward Chaining

- Depends on problem, and on properties of rule set
- If you have clear hypotheses, backward chaining is likely to be better
  - Goal driven
  - Diagnostic problems or classification problems
    - Medical expert systems
- Forward chaining may be better if you have no clear hypothesis and want to see what can be concluded from current situation
  - Data driven
  - Synthesis systems
    - Configuration
    - Reactive systems

Properties of Rules

- Rules are a natural representation
- They are inferentially adequate
- They are representationally adequate for some types of information/environments
- They can be inferentially inefficient (basically doing unconstrained search)
- They can have a well-defined syntax, but lack well-defined semantics
  - Conflict resolution can change their meaning

Problems for Rules

- Inaccurate or incomplete information (inaccessible environments)
- Uncertain inference (non-deterministic environments)
- Non-discrete information (continuous environments)
- Default values
  - Anything that is not stated or derivable is false: they make the *closed world assumption*

Summary

- We have looked at rules, which have often been used as a form of knowledge representation
- They can be used in either a data driven or a goal driven manner
  - Forward vs backward chaining

- Next time
  - We will look at a different form of knowledge representation: structured objects