Rule-Based (Expert) Systems
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Russell and Norvig, 3rd Edition, Sections 9.3 and 9.4

These slides are new and can contain mistakes and typos.
Please report them to Sven (skoenig@usc.edu).

Example: Taxonomic Knowledge

• “All office machines get their energy from wall outlets.”
• “All printers are office machines.”
• “All laser printers are printers.”
• “Hobbes is a laser printer.”
Example: Taxonomic Knowledge

- Knowledge base in first-order logic
  - FORALL x IsOfficeMachine(x) IMPLIES HasEnergySource(x, WallOutlet)
  - FORALL x IsPrinter(x) IMPLIES IsOfficeMachine(x)
  - FORALL x IsLaserPrinter(x) IMPLIES IsPrinter(x)
  - IsLaserPrinter(Hobbes)
- We can use resolution to show that the knowledge base entails
  - HasEnergySource(Hobbes, WallOutlet)
- But the knowledge base and resolution are difficult to understand by non-experts and resolution is often slow (and non-trivial to implement), so we are looking for alternative ways to represent knowledge and reason with it.

Modus Ponens

\[ \frac{P, P \text{ IMPLIES } Q}{Q} \quad \frac{P(A), \text{ FORALL } x (P(x) \text{ IMPLIES } Q(x))}{Q(A)} \]

- Using KB ⊨ S to show KB ⊨ S is sound but not complete.

- Example:
  - P IMPLIES Q, NOT P IMPLIES Q ⊨ Q
  - but neither P IMPLIES Q, NOT P IMPLIES Q ⊨ Q
  - nor P IMPLIES Q, NOT P IMPLIES Q, NOT Q ⊨ FALSE
Modus Ponens

- Modus Ponens uses a fact “P(A)” and a rule “if P(x) then Q(x)” to produce a new fact “Q(A)”.

![Diagram showing Modus Ponens]

- Fact
  - Fact about a patient
  - Knowledge the adventurer has about the cave system in the Wumpus World

- If-then rule
  - Medical knowledge
  - Rules of the Wumpus World

Rule-Based Systems (= Production Systems)

- Knowledge base split into rule and working memory
- Rule memory (contains rules, does not change during execution):
  - if IsOfficeMachine(x) then HasEnergySource(x, WallOutlet)
  - if IsPrinter(x) then IsOfficeMachine(x)
  - if IsLaserPrinter(x) then IsPrinter(x)

- Working memory (contains facts, changes during execution):
  - IsLaserPrinter(Hobbes)
Forward Chaining

- Forward chaining is data-driven
- When a new fact $p$ is added to working memory
  for each rule $R$ such that $p$ unifies with a premise of $R$
  if the other premises of $R$ are known
  then add the conclusion of $R$ to working memory and repeat

Rule memory:
- if IsOfficeMachine($x$) then HasEnergySource($x$, WallOutlet)
- if IsPrinter($x$) then IsOfficeMachine($x$)
- if IsLaserPrinter($x$) then IsPrinter($x$)

Working memory:
- IsLaserPrinter(Hobbes)
- IsPrinter(Hobbes)

remember: a sentence inferred by a sound
inference rule can be put into the KB before
the inference rule is used again.
Forward Chaining

• Rule memory:
  if IsOfficeMachine(x) then HasEnergySource(x, WallOutlet)
  if IsPrinter(x) then IsOfficeMachine(x)
  if IsLaserPrinter(x) then IsPrinter(x)

• Working memory:
  IsLaserPrinter(Hobbes)
  IsPrinter(Hobbes)
  IsOfficeMachine (Hobbes)
  HasEnergySource(Hobbes, WallOutlet)

Could use actions other than “add (to working memory)” here, such as “delete from working memory” or “print”

• Working memory:
  IsLaserPrinter(Hobbes)
Forward Chaining

• Match phase (= find all applicable rules/unification binding combinations)
• Conflict resolution phases (= choose one rule/unification binding)
  • Don’t fire (= use) a rule again with the same unification bindings
  • Use more recent facts from working memory
  • Use more specific rules
    if Mammal(x) then add Legs(x,4)
    if Mammal (x) and Human(x) then add Legs(x,2)
  • Use rules of higher given priority
    if ControlPanel(x) and Dusty(x) then execute Dust(x)
    if ControlPanel(x) and WarningLightOn(x) then execute Evacuate
• Act phase (= execute the conclusion of the chosen rule/unification binding)

Backward Chaining

• Backward chaining is query-driven (= hypothesis-driven)
• When a new query q is asked
  if a fact q’ is in working memory that unifies with q
    then return the unifier of q and q’
  else
    for each rule R such that q unifies with the conclusion of R
      pose each premise of R as new query and repeat
Backward Chaining

- Rule memory:
  if IsOfficeMachine(x) then HasEnergySource(x, WallOutlet)
  if IsPrinter(x) then IsOfficeMachine(x)
  if IsLaserPrinter(x) then IsPrinter(x)

- Working memory:
  IsLaserPrinter(Hobbes)

Query: HasEnergySource(Hobbes, WallOutlet)?
New Query: IsOfficeMachine(Hobbes)?

IsLaserPrinter(Hobbes) holds because it is in working memory.
Rule-Based Systems (= Production Systems)

- Forward chaining
  - good for design (for example, configuration planning)
  - good for some diagnosis (find out everything we can from symptoms)

- Backward chaining
  - good for some diagnosis (confirm hypothesis about diagnosis)

Rule-Based Systems (= Production Systems)

- Modularity
- Control isolated from knowledge base
- Easy Modification
- Explanation capability for its conclusions
Rule-Based Systems (= Production Systems)

• Conclusions are often not certain
  • if IsOfficeMachine(x) then HasEnergySource(x, WallOutlet)
  • If IsOfficeMachine(x) then it is highly likely that HasEnergySource(x, WallOutlet)

• We discuss probabilistic expert systems later to address this issue.