5. Expert Systems

Course: Introduction to AI
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Definition

in a given domain

Systems that encapsulate the knowledge of experts to be able to perform diagnosis and/or assist in decision making in specific domains

- Given symptoms - disease diagnosis
- Given history of symptoms and treatments - current prescription/treatment
- Given state of production plant - decision of opening/closing a valve

Rules of interaction

Tell — Ask — Tell

- Tell: what is being observed in the environment
- Ask: the action that should be performed
- Tell: the action that has been performed

axioms

"act" → actuators.

sensor ← brain → actuators

Internal machinery

Expertise is encapsulated in a $\boxed{\textit{knowledge base}}$ (a list of context-specific axioms), which is amenable to:

"rules"

- $\boxed{\text{Reasoning}}$: Perform inference given observed data and existing axioms
- Update: Add/remove axioms based on feedback to inferences

I. Case-based expert systems

Works by finding the best match for the case under study with a historical, successful case; and borrows its decision/diagnosis

Steps:

1. Characterise the case to a suitable level of abstraction
2. Match the case feature-by-feature to cases in the database
3. Select the best-match with matching score > threshold
4. Follow its line of reasoning

Scheme of case-based reasoning

1 **Case Retrieval**: Old cases that can be labeled by features (or features derived from features) of the new case,

- *Recall previous cases*
- *Select the best subset*

Challenges:

- Cases may share surface level features even though they may not be relevant
- Need to be compared at more abstract levels
- Derived features need to be extracted efficiently
- Fast retrieval from expansive case libraries

All encapsulated under **indexing problems** which is to assign a label or index that appropriately designates conditions in which cases can be used for inference.

Scheme of case-based reasoning

2. **Propose ballpark solution**: Relevant portion of cases are extracted as proposed solution to new case
   Challenges: What part of the old solution to focus on for the new solution
3. **Adaptation**: Old solution to be used as inspiration for new solution
   Challenges: Finding adaptation strategies; can general strategies be used to define specialized strategies?
4. **Justification and Criticism**: Solution is justified before being tried; compare and contrast to other proposed solutions
   Issues: Strategies for evaluation using cases; generating appropriate hypotheticals and strategies for using them; assignment of blame or credit to old cases

Scheme of case-based reasoning

5. **Evaluation**: Solution is tried out in the real world; feedback obtained; can lead back to adaptation step to improve the solution
6. **Store/update memory**: New case and its solution stored for future use; expands case-based repository
   Challenges: indexing problems; using the right vocabulary to store the new case and solution, and keeping all information accessible

Scheme of case-based reasoning

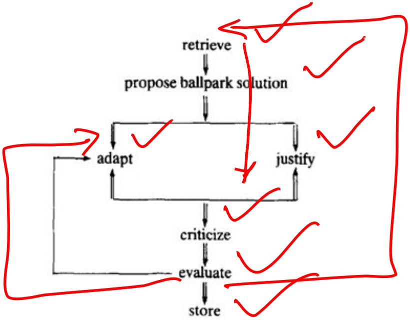


Figure: Case-based reasoning system proposed by Koldoner [1]

[1] An Introduction to Case-Based Reasoning by Janet L. Kolodner

Advantages

- Extensive applicability
  - Design, planning, diagnosis, explanation
- Intuitive
  - Based on how human thinking relates to previously solved problems
- Time efficient
  - Avoids making previously made mistakes while looking for a solution
- Works on partial knowledge of domain
- Learning over time
  - More old cases stored in repository, higher the chances of success of finding a solution for a new case

Example: Car Fault Diagnosis

Retrieve old cases from repository

Old case 1

Problems and Features

- Problem: Front light not working
- Car: VW Golf, 2.0L
- Year: 1999
- Battery voltage: 13.6V
- State of lights: OK
- State of light switch: OK

Solution

- Diagnosis: Front light fuse defect
- Repair: Replace front light fuse

Old case 2

Problems and Features

- Problem: Front light not working
- Car: Passat
- Year: 2000
- Battery voltage: 12.6V
- State of lights: surface damaged
- State of light switch: OK

Solution

- Diagnosis: Bulb defect
- Repair: Replace front light

New case

Problems and Features

- Problem: Brake light not working
- Car: Passat V6
- Year: 2002
- Battery voltage: 12.9V
- State of lights: OK
- State of light switch: ?

- Not all features are well known when mapping to old cases
- Compare features with old cases weighted by importance and find similar cases

Example: Car Fault Diagnosis

(1) which features?
(2) what relevance

Old case 1 — Problems and Features	Similarity	New case — Problems and Features	Similarity	Old case 2 — Problems and Features
Problem: Front light not working	0.8	Problem: Brake light not working	0.8	Problem: Front light not working
Car: VW Golf, 2.0L	0.4	Car: Passat V6	0.8	Car: Passat
Year: 1999	0.7	Year: 2002	0.8	Year: 2000
Battery voltage: 13.6V	0.9	Battery voltage: 12.9V	0.9	Battery voltage: 12.6V
State of lights: OK	1.0	State of lights: OK	0.0	State of lights: surface damaged
State of light switch: OK		State of light switch: ?		State of light switch: OK

(3) how similar

Solution (Old case 1)

- Diagnosis: Front light fuse defect
- Repair: Replace front light fuse

Solution (Old case 2)

- Diagnosis: Bulb defect
- Repair: Replace front light

expert / medicine

ordinary "Human" — drive
— communicate
— work.

avg. weight expert.

$$\text{Similarity} = \frac{(6 \times (0.8 + 0.4 + 1.0)) + (1 \times (0.7 + 0.9))}{20} \boxed{= 0.87}$$

$$\text{Similarity} = \frac{(6 \times (0.8 + 0.8 + 0.0)) + (1 \times (0.8 + 0.9))}{20} \boxed{= 0.59}$$

very important (weight: 6) ⟷

less important (weight: 1) ⟷

Example: Car Fault Diagnosis

Similarity higher with case 1 → Reuse solution

Old case 1

Problems and Features

- Problem: Front light not working

Solution

- Diagnosis: Front light fuse defect
- Repair: Replace front light fuse

New case

Problems and Features

- Problem: Brake light not working

Adapt

Proposed solution

New Solution

- Diagnosis: Brake light fuse defect
- Repair: Replace brake light fuse

Store the new case along with solution in the repository

Case 3

Problems and Features

- Problem: Brake light not working
- Car: Passat V6
- Year: 2002
- Battery voltage: 12.9V
- State of lights: OK
- State of light switch: OK

Solution

- Diagnosis: Brake light fuse defect
- Repair: Replace brake light fuse

(1) Try out this soln

- justify
- evaluated

Case matching: Challenges

- How to?
  - Define level of abstraction
  - Choose the threshold for match
- Data sufficiency?
  - Data needed for good-decision making grows exponentially with depth of abstraction
- Tractability?

(work at scale)

limit

efficient

'cases' represent.

x 3
y 4
z 5
p 7

$\underbrace{3 \times 4 \times 5 \times 7}$

$(n)^{exp}$

Retrospective

Need for a generalised framework for representation and matching

Whilst working with different kinds of knowledge:

- Heuristic knowledge
  Empirical knowledge of correlations
  Symptoms and disease associations
- Deep knowledge
  Causal knowledge based on system understanding
  Anatomy or physics of *this* causing *that*
- Meta knowledge
  Knowledge about knowledge
  Reliability of source; certainty of knowledge

Rule-based systems

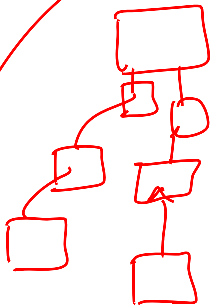
1 Case retrieval
- existing
- new case

matching
similarity
score.

2 . ballpark
3 . adapt.
4 Justification
5 evaluation
6 store (update.

Pre-discussion:

- Goal trees
- Necessity Logic



Case-based → "reasoning"

Rule-based systems

A. Categorical knowledge base

- Uses facts that are known without doubt
- Maps logical relationships between facts to outcome facts
- Represented as *IF* < *antecedents* >-*THEN*< *conclusion* > constructs
  - the antecedent is a collection/conjunction of facts
  - the conclusion is some new fact that follows

Declarative (rule listing) instead of procedural (embedded in structure); easy to modify context by changing rules

Rule-based systems

"expert"

B. Inference in categorical knowledge base

- TELL: Observations
  - Two feet
  - Wings
  - Can't fly
- ASK: What is it? or Is it this?

"ask"

tell

$\boxed{\text{K.B}}$

tell
action/decision

Rule-based systems

FORWARD CHAINING

- Pick rules whose antecedents are all established and add their conclusion to the list of facts
- TERMINATION: Repeat this until one of the facts of interest is proven or no further rules are to be found

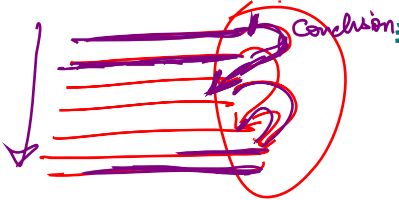
Characteristics:

- Breadth or Depth first depends on the order in which the rules are presented/added to the knowledge base
- Data driven

if A1 A2 A3 A4
THEN C

if A3 A4 A5 A7
THEN D

Rule-based systems



BACKWARD CHAINING

- Take all the rules where the conclusion is the 'target' conclusion
- Prove recursively all the antecedents in the rule

DFS

Characteristics:

- Depth-first
- Goal driven
- BUT: won't end if the knowledge base is cyclic
- TERMINATION: When all propositions with intended conclusion are tried, and one or none is proved.

If A & C D
THEN cow

If cow & B
THEN A

Rule-based systems

TRADE-OFF

- Backward Chaining
  - Works more efficiently when the number of diagnoses are few
  - Cannot handle cyclical knowledge bases
- Forward Chaining
  - Works more efficiently when the number of diagnoses are large
  - Can handle cyclical knowledge bases

Rule-based systems

Characteristics

- Interactive
  - ASK: Does it have this?
  - TELL: Yes/No
- Explanatory
  - List of antecedents that were confirmed

if A1, A2, A3, A4
THEN B

if A2, A3, A5
THEN C

if A3, A5, A7
THEN D

if ~~A7~~, ~~A8~~, A9
THEN D.

1

Rule-based systems

diagnosis in large

Conflict resolution:

- Priority
- Specificity
- Utility
- Recency
- Disjointedness/ Context Limiting

Reasoning under Certainty

- Uses: Simple to organise and reason
- Limitations:
  - Intractable database to capture the world
  - Not all facts are known with 100% confidence

scalability

↓

industry.

Reasoning under Uncertainty

- Aggregating evidence
- Belief propagation

References

1. An Introduction to Expert Systems by Bryan S. Todd, 1992 (Chapter-4)
2. Artificial Intelligence - A Modern Approach by Stuart Russell and Peter Norvig, 2021 (Chapter-9)
3. An Introduction to Case-Based Reasoning by Janet L. Kolodner, 1992

Overview

1. **Introduction**
   - What are expert systems?
   - Rules of Interaction
   - Internal machinery of expert systems
2. **Knowledge base and Inference**
   - Case-based reasoning
   - Challenges-I
   - Rule-based systems
   - Challenges-II
   - Reasoning under Uncertainty