Lecture 11: Expert Systems

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Contents

1 Introduction to Expert Systems

What is an expert system?

Definition 1 (Expert Systems)**.** (ES) are computer programs that try to replicate knowledge and skills of human experts in some area, and then solve problems in this area (the way human experts would).

- ES take their roots in *Cognitive Science* — the study of human mind using combination of AI and psychology.
- ES were the first successful applications of AI to real-world problems solving problems in medicine, chemistry, finance and even in space (Space Shuttle, robots on other planets).
- In business, ES allow many companies to save $ millions

Historical perspective

1943 Post, E. L. proved that any computable problem can be solved using a set of IF-THEN rules.

1961 General Problem Solver (GPS) by A. Newell and H. Simon.

1969 Dendral Feigenbaum, Buchanan, and Lederberg (1971). was the first system that showed the importance of *domain-specific knowledge* (expertise).

1970s MYCIN Shortliffe and Buchanan (1975) medical diagnosis system introduced the use of *certainty factors*.

1982 R1 (aka XCON) by McDermott was the first commercial ES (by 1986 it was saving DEC $40 millions p.a.).

1982-83 Case-based reasoning ES (Schank, 1982; Kolodner, 1983; Lebowitz, 1983).

Early Expert Systems

- In 1961, A. Newell and H. Simon wrote a program called *General Problem Solver* (GPS) that could solve many different problems using only a small set of rules.
- GPS used a strategy known as *means-ends analysis*.
- GPS produced solutions very similar to those people came up with.
- Methods that can be applied to a broad range of problems are called **weak** methods (because they use weak information about the problem domain). Their performance, however, is also usually weak.

Knowledge-based systems

- DENDRAL (Feigenbaum et al., 1971) was a program that used rules to infer molecular structure from spectral information. The challenge was that the number of possible molecules was so large, that it was impossible to check all of them using simple rules (weak method).
- The researchers consulted experts in chemistry and added several more specific rules to their program. The number of combinations the program had to test was reduced dramatically.
- DENDRAL demonstrated the importance of the *domain-specific* knowledge.

Main areas of application

The main areas of application of ES are (Waterman, 1986):

Interpretation — drawing high-level conclusions based on data.

Prediction — projecting probable outcomes.

Diagnosis — determining the cause of malfunctions, disease, etc.

Design — finding best configuration based on criteria.

Planning — proposing a series of actions to achieve a goal.

Monitoring — comparing observed behaviour to the expected behaviour.

Debugging and Repair — prescribing and implementing remedies.

Instruction — assisting students in learning.

Control — governing the behaviour of a system.

Advantages and limitations of ES

Advantages

- Increased productivity (find solutions much faster than humans).
- Availability of expertise (human experts can be at one place at a time).
- Can be used in dangerous environments (e.g. in space).

Limitations

- Difficulty in engineering, especially acquiring the expertise.
- Mistrust by the users.
- Effective only in specific areas (areas of expertise).

2 Rule-based Expert Systems

Declarative and procedural knowledge

- In rule-based approach, the symbolic knowledge is divided into two types:

  Declarative : these are propositions describing facts, objects or events that are true (i.e. happening or that we observe).

  Procedural : these are logical rules (inferences) that we can use to reason using the facts and make decisions.

- There is evidence that human brain learns and remembers these types of knowledge is somewhat different ways. Rules (procedural knowledge) are usually harder to describe and forget.

Facts (Propositions)

- Facts usually are represented in a form of logical *propositions*:

  Pif is a dog Dog has four legs 4 is a sum of 2 and 2

- Facts can be True or False.

Rules (Implications)

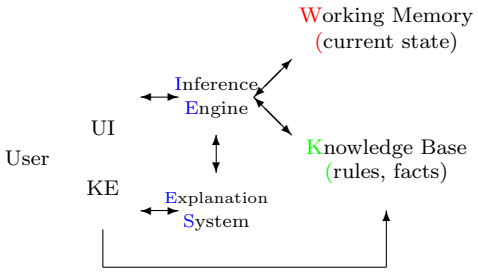
- Rules have the form:

	IF	*condition*	THEN	*action*
Example 2.	IF	*Pif is a dog*	THEN	*Pif has four legs*
	IF	*the price is high*	THEN	*sell*

- Condition can be a fact or a collection of facts. Action can be adding another fact, asking a question, etc.
- The IF... part is called the *left-hand-side* (or the *antecedent*, the *premise*) of a rule. The THEN... part is called the *right-hand-side* (or the *consequent*) of a rule.

Architecture of ES

Main components of a classical rule-based expert system:



Knowledge base, working memory, inference engine, explanation system, user interface and knowledge base editor.

Main components of ES

Knowledge Base contains all the knowledge of ES in a form of rules (procedural knowledge) and facts (declarative knowledge). Can be compared with a hard disk drive of PC, or long-term memory of the human brain.

Working Memory contains only the facts describing the current state of a problem. Can be compared with RAM of PC, or short-term memory of the human brain.

Inference Engine implements the reasoning process. In brief, it finds rules in the knowledge base that correspond to the contents of working memory and applies them to the problem.

User interface may provide interaction facilities, where ES asks the user some questions. The answers are interpreted into facts in working memory and used in reasoning.

Knowledge base editor gives the possibility to examine and edit the knowledge base.

Example: Weather forecast ES

1	IF	*cyclone*	THEN	*clouds*
2	IF	*anticyclone*	THEN	*clear sky*
3	IF	*pressure is low*	THEN	*cyclone*
4	IF	*pressure is high*	THEN	*anticyclone*
5	IF	*arrow is down*	THEN	*pressure is low*
6	IF	*arrow is up*	THEN	*pressure is high*

Complex patterns

- The condition part of a rule may have several facts connected by logical operators NOT, AND, OR:

IF	(*arrow is down* AND *clear sky*) OR (*arrow is up* AND *clouds*)	THEN	*broken barometer*

- Such a complex proposition (pattern) is just a more complex fact.
- A rule will match the working memory only if the whole condition (i.e. the whole proposition) is True.
- Logical rules for *negation* (NOT), *conjunction* (AND) and *disjunction* (OR) are used to evaluate the condition.

Advantages and limitations of Rule-Based systems

Advantages

- Automated logic and reasoning
- Explain of solutions.

Example 3.

IF	*x has wings*	THEN	*x is a bird*
IF	*x is a bird*	THEN	*x can fly*

How about an ostrich?

Limitations

- It is hard to describe all cases by rules.
- The knowledge is very task dependent and difficult to adapt.

3 Case-Based Expert Systems

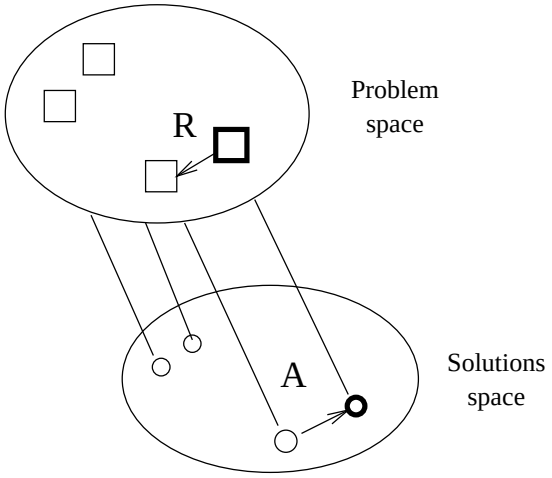
Case-Based Reasoning systems

- Instead of facts and rules, CBR systems use *cases* and their entire *solutions*.

Case:	Age	Gender	M. Income (£ K)	M. Expenses (£ K)	Home owner	Credit score
1	21	0	2	1	0	3
2	18	1	1	2	0	1
3	50	1	6	2	1	5
4	23	0	3	1	1	4
5	40	1	3	2	0	2

- Cases can have quite complex descriptions using symbolic and numerical values
- CBR is based on the concepts of *similarity* and *analogy*. Similarity is used to find similar cases, and analogy is used to find solutions for similar cases.

Problem (case) and solution spaces



R : retrieval of a similar case from problem space

A : adaptation of a solution from solution space

Operation cycle of CBR

In general, can be described using four **RE**s:

- **RE**trieve the most similar case or cases.
- **RE**use the case(s) to attempt to solve the problem.
- **RE**vise the proposed solution if necessary.
- **RE**tain the new solution as a part of a new case.

Retrieval and Reuse

- To solve a new case, a CBR systems **retrieves** an old similar case.
- There are two main methods to retrieve similar cases

  Nearest-neighbour : is based on comparing the cases using some distance (e.g. Euclidean distance)

  $$\|a - b\| = \sqrt{(a_1 - b_1)^2 + \cdots + (a_m - b_m)^2}$$

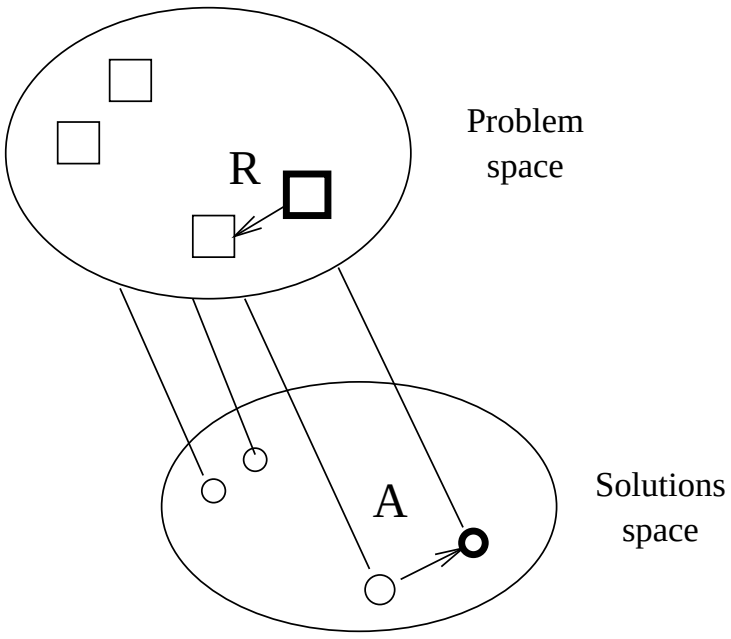
  where $a = (a_1, \ldots, a_m)$ and $b = (b_1, \ldots, b_m)$ are two cases.

  Inductive retrieval : is based on learning which feature of the case carries the most useful information to predict the solution (highest information gain).

- The solution of a retrieved case is **reused** to for the new case.

Revise and Retain

- Because the new case is most likely different from all the old cases, the solution of a retrieved case can be **revised** or **adapted**.
- If the solution was a success, then the new case is **retained** in the database together with the new solution.



Rule-Based vs Case-Based

- In rule-based systems a solution is achieved through an application of many rules, inference of facts, etc.
- In case-based systems the whole problem definition (case) is compared with similar problems, and the entire solution is applied at once.
- Rule-based systems usually work better for well-defined problems that do not change with time.
- Case-based systems can be used where problems are less understood and are dynamic.

Additional Reading

1. Gottschalk (2006):

   Expert systems at stage IV of the knowledge management technology stage model: The case of police investigations

2. Richter (2009):

   The search for knowledge, contexts, and Case-Based Reasoning

References

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