This chapter describes the inference engine design principles and techniques used in expert system development. Also the inference technique used in ESQ is discussed briefly.
6.1 Inference Engines

In expert systems, an inference engine deduces new knowledge from available knowledge and observations. In principle, an inference engine accepts observations in the form of user inputs and using its knowledge-base it deduces new knowledge by applying logical rules as illustrated in figure 6.1. In addition to knowledge discovery, an expert system is also expected to provide a justification and explanation about its decision. Therefore, an inference engine should not only produce expert-level decisions but also back it up with the reasoning process that leads to such decisions.

![Diagram showing the process of inference engine inferring new facts from available knowledge](image)

Figure 6.1: Inference Engine infers new facts from available knowledge

Knowledge bases are an essential component in an expert system as they contain facts and rules about the knowledge domain. The knowledge core is acquired from experts in the domain, and additional knowledge can be obtained from text books, manuals and other resources. This process is known as knowledge acquisition and it is discussed in Chapter 5. The acquired knowledge is then organized as a collection of rules known as production rules. The production rules are in an IF-THEN format known as condition and action. A simple example:

IF (traffic_light is red) THEN (slowdown)
To explain this simple rule, traffic_light is the premise, which means the hypothesis, and slowdown is the consequent, known as the action to perform. So if the traffic light is red, the rule is fired, and the action is completed, i.e. the car will slow down. Production rules are one type of knowledge representation. There are also frames, and semantic nets, which were explained in depth in Chapter 5.

The inference engines are built using different reasoning techniques. The backward-chaining and forward-chaining are the most frequently used techniques. However, hybrid techniques that use a mixture of both techniques have been developed for improved accuracy and efficiency.

6.2 Forward-chaining Technique

In a rule-based expert system, the domain knowledge is represented by a set of IF-THEN production rules and data is represented by a set of facts about the current situation. The inference engine compares each rule stored in the knowledge base with facts contained in the database. When the IF (condition) part of the rule matches a fact, the rule is fired and its THEN (action) part is executed. The fired rule may change the set of facts by adding a new fact as shown in figure 6.2. Letters in the database and the knowledge base are used to represent situations or concepts. (Negnevitský, 2005)
The matching of the rule IF parts to the facts produce inference chains. The inference chain indicates how an expert system applies the rules to reach a conclusion. To illustrate chaining inference techniques, consider a simple example.

Suppose the database initially includes facts A, B, C, D and E and the knowledge base contains only three rules:

Rule 1: IF \( Y \) is true 
\[ \text{AND } D \text{ is true} \]
\[ \text{THEN } Z \text{ is true} \]

Rule 2: IF \( X \) is true 
\[ \text{AND } B \text{ is true} \]
\[ \text{AND } E \text{ is true} \]
\[ \text{THEN } Y \text{ is true} \]
Rule 2: IF A is true
THEN X is true

The inference chain shown in figure 6.3 indicates how the expert system applies the rules to infer fact Z. First Rule 3 is fired to deduce new fact X from given fact A. Then Rule 2 is executed to infer fact Y from initially known fact B and E, and already known fact X. Finally, Rule 1 applies initially known fact D and just-obtained fact Y to arrive at conclusion Z.

![Inference Chain Diagram]

Figure 6.3: An example of inference chain

There are two principal ways in which rules are executed: (a) forward chaining and (b) backward chaining

The example discussed above, uses forward chaining. Forward chaining is the data driven reasoning. The reasoning starts from the known data and proceeds forward with that data. Each time only the top-most rule is executed. When fired, the rule adds a new fact in the database. Any rule can be executed only once. The match-fire cycle stops when no further rules can be fired. (Negnevitsky, 2005)

6.2.1 Expert Systems with Forward-chaining Inference Engine

Cremer et al., (1988) present a research on distributed rule-base Applicative State Transition, AST-systems, which focus on parallel
programming. They incorporate forward chaining through the use of Official Production System, OPS, because it was the most successful tool for writing expert systems. The advantages which the authors have deduced were that forward chaining fires rules in a certain order, and in their case, order is of great value as well as the flexibility it provided them.

Another study by Akin and Altin (1991) on a rule-based fuzzy controller for a nuclear power plant proves that when it came to critical areas such as nuclear power plants speed and fast responses are important, and that's why they focused their study on forward chaining inference. Another paper focusing on monitoring traffic also needs quick responses and also supports the use of forward chaining due to its reliability. (Cucchiara et al., 2000)

Siu et al., (1997), in their paper present a Fuzzy expert system, built using FuzzyCLIPS, and certainty factors. FuzzyCLIPS is fuzzy extension to the famous CLIPS, C Language Integrated Production System. The system proposed in the research has the ability to identify causes of typical vibration problems in rotating machinery. FuzzyCLIPS incorporates forward chaining because facts are given initially. The study is supported by test cases.

Bacchus and Whye-The (1998), propose a paper on making forward chaining relevant. They portray the advantages of forward chaining such as keeping a description of the current state of the system, and the power of ordered search rules. However, only a single weakness exists and that it does not have a clear vision of the goal. Therefore, they present two algorithms which give more information and guidance toward the goal, and removes irrelevant information.
As for ABIS, a language for intelligent systems, presented by Poletykin et al., (2008), the system was based on relational data models and forward chaining. And ABIS has passed all the stages of testing and proved right for future development.

6.3 Backward-chaining Technique

Backward chaining is the goal-driven reasoning. In backward chaining, an expert system has the goal (a hypothetical solution) and the inference engine attempts to find the evidence to prove it. First, the knowledge base is searched to find rules that might lead to the desired solution. Such rules must have the goal in their THEN (action) parts. If such a rule is found and the IF (condition) part matches data in the database, then the rule is fired and the goal is proved. However, this is rarely the case. Thus the inference engine puts aside the rule it is working with (the rule is said to be in the stack) and sets up a new goal, a sub-goal, to prove the IF part of this rule. Then the knowledge base is searched again for rules that can prove the sub-goal. The inference engine repeats the process of stacking the rules until no rules are found in the knowledge base to prove the current sub-goal.

6.3.1 Expert Systems with Backward-chaining Inference Engine

PROSPECTOR is one of the first expert systems to incorporate backward-chaining. Its knowledge area is evaluating geological sites and determines the possibility of finding rare minerals (Belward and Valenzuela, 1991). PROSPECTOR gained more fame after it has suggested a search in a geological area and discovered a molybdenum deposit which cost one-hundred million US dollars.
In the area of medicine, a medical expert system for neonates was presented by Miksch et al., (1993), the system uses both frame representation and backward chaining to produce quick calculated responses for nutrient for neonates. The VIE-PNN, Vienna Expert System for Parental Nutrition of Neonates, has the advantage of reducing calculation errors because the physician has input some dosages manually in extreme conditions. However, due to the lack of interactivity throughout the program, this can be a big disadvantage to the system, because at certain points, the physician may want to stop the calculations and check the patient.

Rajkumar and Bardina (2003), propose, in a paper, a Web-based Weather Expert System, which supports important shuttle decisions of “go/no go” in the NASA intelligent launch and range operations program. WES takes into account many factors that affect the launch decision. WES accepts the goal and works through backward chaining to fire the necessary rules until the value is determined for the goal variable. Their preference for backward chaining is firing only the necessary rules needed to prove the goal; however they concluded that it’s better to combine both techniques of forward and backward chaining for more accurate and efficient performance.

6.4 Hybrid Technique

Hybrid techniques combine forward and backward chaining techniques. This indicates that the inference engine will perform forward-chaining and then backward-chaining. This is used to confirm a diagnosis or a hypothesis which has reached through forward chaining.
6.4.1 Expert Systems with Hybrid Inference Engine

A paper presented by Doraiswami and Jiang (1989), portrays an intelligent sensor to monitor power systems performance, stability, and failure diagnosis. They incorporate both forward and backward chaining which proved successful because they used forward chaining for monitoring the condition of the power system and uses backward chaining to isolate the failure.

DESPLATE is an expert system designed for abnormal shape diagnosis in the plate mill (Tung et al., 1990). The expert system combines forward and backward chaining, the former is used to narrow the search for faults, and then the latter is used to prove a certain fault assumed by the former. And if in some cases backward chaining cannot be carried out, forward chaining is continued. This confirms that DESPLATE expert system inference cannot depend on a single inference mechanism.

An interesting paper combines both chaining techniques presented by Luo et al., (2005). An expert system was proposed to analyse the data gathered from modern digital protective relays and report the data which relate to fault disturbances and the expected protection operation. The inference engine uses forward chaining first for predicting the expected protection operation, and then backward chaining to validate and diagnose the actual protection operation. The authors focus on the strength provided by combining both techniques and future improvements to expand the knowledge base and increase accuracy of results.
6.5 How do we choose between forward and backward chaining?

The answer is to study how a domain expert solves a problem. If an expert first needs to gather some information and then tries to infer from it whatever can be inferred, we have to choose the forward chaining inference technique. However, if the domain expert starts with a hypothetical solution and then attempts to find facts to prove it, we have to choose the backward chaining inference technique.

6.6 Inference Technique for ESOA

In the inference engine modelling of ESOA, for the assessment process each time the inference engine has to interact with the student model. Here the diagnosis of the student knowledge is performed using the forward chaining inference technique. Since I have used JESS as the expert system tool and JESS inference engine supports forward inference technique, ESOA is designed nicely (discussed in chapter 7).