Module 6: Hybrid System

Theoretical Background

A Hybrid System is a type of control system that combines two or more different types of systems, typically a continuous and a discrete system, into a single unified system. Hybrid systems are commonly used in applications that require both real-time control and decision-making capabilities, such as robotics, automation, and transportation.

The continuous system is responsible for handling the physical dynamics of the system, while the discrete system is responsible for handling the logical and decision-making aspects. The two systems interact with each other to achieve the desired control objectives.

One of the main advantages of hybrid systems is their ability to handle complex and dynamic environments, where traditional control methods may not be sufficient. By combining the strengths of different types of systems, hybrid systems can provide more robust and adaptable control solutions.

In recent years, the development of advanced technologies such as artificial intelligence and machine learning has led to the emergence of new types of hybrid systems, such as Neuro Genetic Hybrid Systems. These systems combine the principles of neural networks and genetic algorithms to create intelligent and adaptive control solutions.

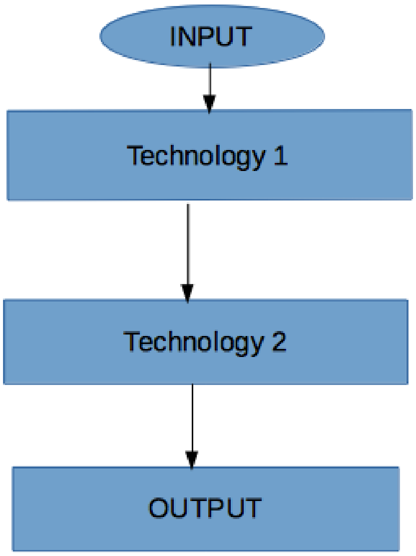
Overall, hybrid systems theory is an important area of research and development in control engineering, as it offers a flexible and powerful approach to solving complex control problems in a wide range of applications.

Hybrid Systems computing uses more than one computational technique to solve various real world problems. This integration of multiple systems in one enables us to get highly intelligent results. These results are potent as well as adaptive to any new environment.

Most of the techniques are inspired by natural intelligent biological processes. One of the most popular examples of Hybrid System is Neural Networks. Other famous examples include Fuzzy Systems and Genetic Algorithms. There are the various types of Hybrid Systems:

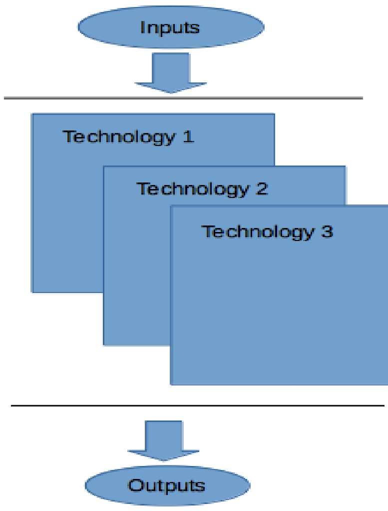
Sequential Hybrid Systems

1. As the name suggests, this system exhibits a pipe-like flow structure
2. It is also the weakest hybrid system
3. Sequential Hybrid System is characterized by a very straightforward structure and exhibits integration or congregation of a variety of technologies.
4. GA preprocessor is an ideal example of these types of systems.
5. The basic functionality of a Sequential Hybrid System in the following image.



Embedded Hybrid Systems

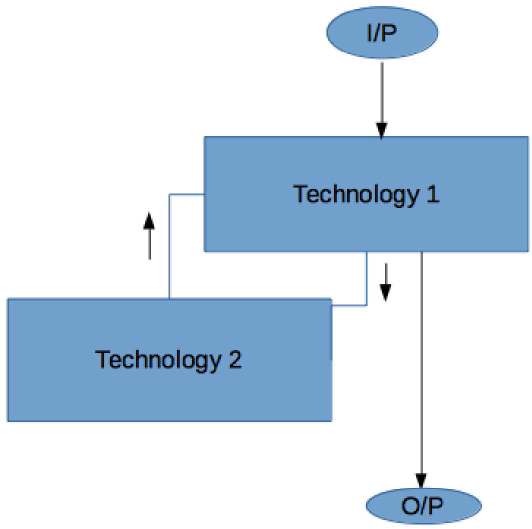
- Embedded hybrid systems undertake an intertwined process flow in soft computing.
- In this type of system no technology can be used without the involvement of other hybrid technologies.
- Most popular example is the Neural Network and Fuzzy Logic hybrid system.
- An Embedded Hybrid System's basic functionality is displayed in the following image



Auxiliary Hybrid System

- In this system a particular technology includes the other technology as a subroutine. This subroutine technology can call again to process information that will be used further in the overall system.

- Examples include neuro-genetic system which uses Genetic algorithms to optimize the neural networks input parameters
- An Auxiliary Hybrid System works like this



Examples of Hybrid Systems:

1. Neuro-Fuzzy Hybrid system

2. Fuzzy Genetic Hybrid System

3. Neuro - Genetic Hybrid System

Neuro-Fuzzy Hybrid systems:

The Neuro-fuzzy system is based on fuzzy system which is trained on the basis of the working of neural network theory. The learning process operates only on the local information and causes only local changes in the underlying fuzzy system. A neuro-fuzzy system can be seen as a 3-layer feedforward neural network. The first layer represents input variables, the middle (hidden) layer represents fuzzy rules and the third layer represents output variables. Fuzzy sets are encoded as connection weights within the layers of the network, which provides functionality in processing and training the model.

Working flow:

- In the input layer, each neuron transmits external crisp signals directly to the next layer.
- Each fuzzification neuron receives a crisp input and determines the degree to which the input belongs to the input fuzzy set.
- The fuzzy rule layer receives neurons that represent fuzzy sets.
- An output neuron combines all inputs using fuzzy operation UNION.
- Each defuzzification neuron represents the single output of the neuro-fuzzy system.

Advantages:

- It can handle numeric, linguistic, logic, etc kind of information.

- It can manage imprecise, partial, vague, or imperfect information.
- It can resolve conflicts by collaboration and aggregation.
- It has self-learning, self-organizing and self-tuning capabilities.
- It can mimic the human decision-making process.

Disadvantages:

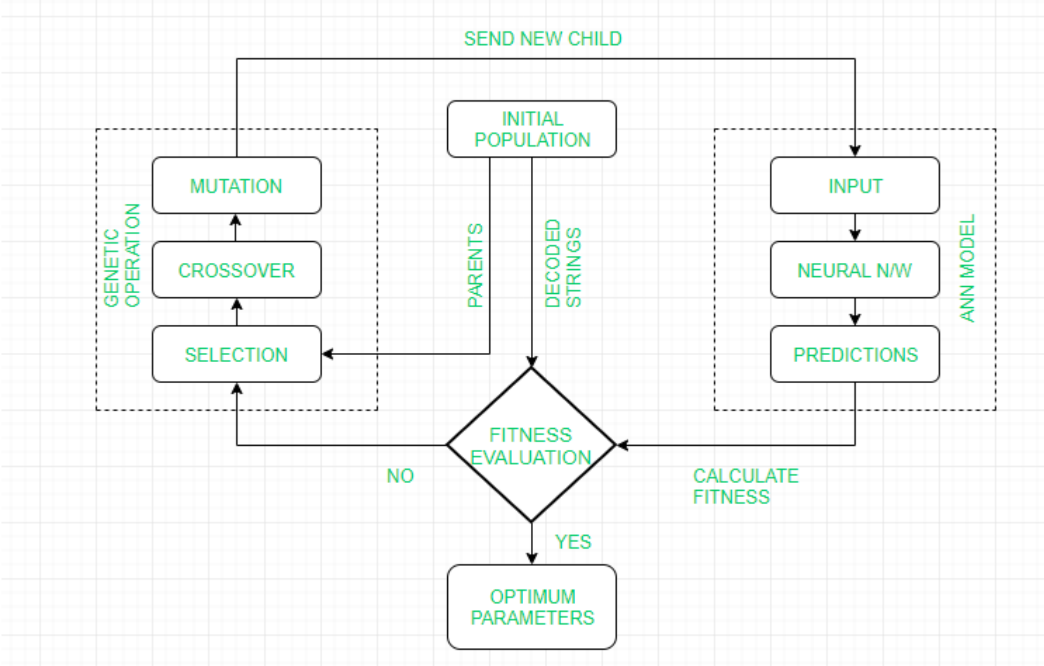
- Hard to develop a model from a fuzzy system
- Problems of finding suitable membership values for fuzzy systems
- Neural networks cannot be used if training data is not available.

Applications:

- Student Modelling
- Medical systems
- Traffic control systems
- Forecasting and predictions

(B) Neuro Genetic Hybrid systems:

A Neuro Genetic hybrid system is a system that combines **Neural networks**: which are capable to learn various tasks from examples, classify objects and establish relations between them, and a **Genetic algorithm**: which serves important search and optimization techniques. Genetic algorithms can be used to improve the performance of Neural Networks and they can be used to decide the connection weights of the inputs. These algorithms can also be used for topology selection and training networks.



Working Flow:

- GA repeatedly modifies a population of individual solutions. GA uses three main types of rules at each step to create the next generation from the current population:
    1. **Selection** to select the individuals, called parents, that contribute to the population at the next generation
    2. **Crossover** to combine two parents to form children for the next generation
    3. **Mutation** to apply random changes to individual parents in order to form children

- GA then sends the new child generation to ANN model as a new input parameter.
- Finally, calculating the fitness by the developed ANN model is performed.

Advantages:

- GA is used for topology optimization i.e to select the number of hidden layers, number of hidden nodes, and interconnection pattern for ANN.
- In GAs, the learning of ANN is formulated as a weight optimization problem, usually using the inverse mean squared error as a fitness measure.
- Control parameters such as learning rate, momentum rate, tolerance level, etc are also optimized using GA.
- It can mimic the human decision-making process.

Disadvantages:

- Highly complex system.
- The accuracy of the system is dependent on the initial population.
- Maintenance costs are very high.

Applications:

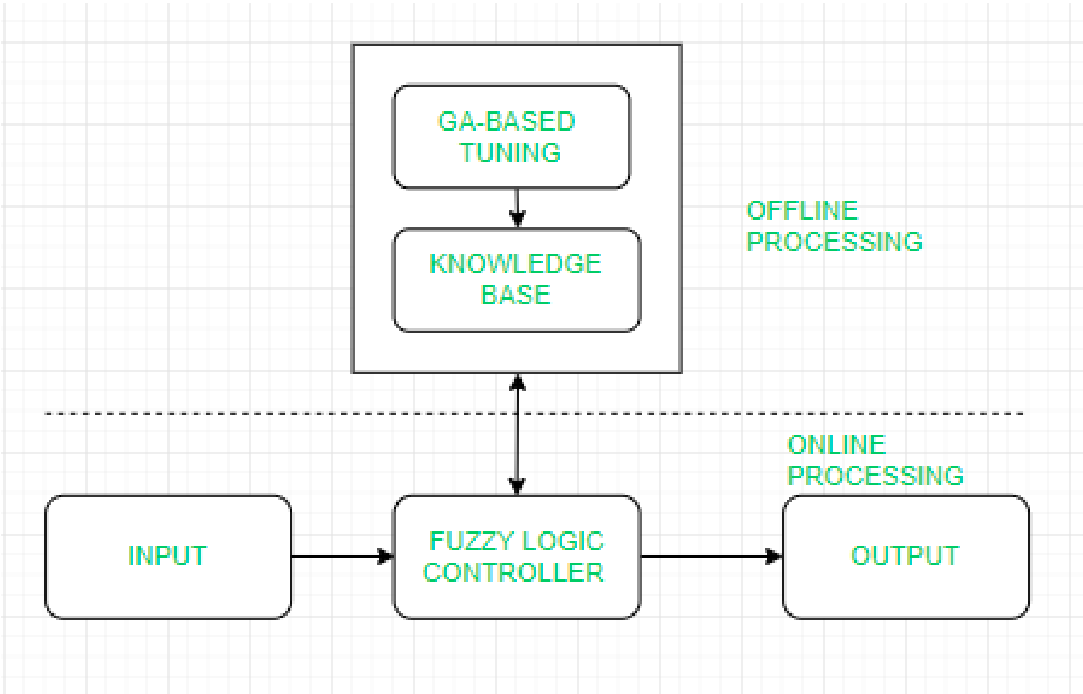
- Face recognition
- DNA matching
- Animal and human research
- Behavioral system

(C) Fuzzy Genetic Hybrid systems:

A Fuzzy Genetic Hybrid System is developed to use fuzzy logic-based techniques for improving and modeling Genetic algorithms and vice-versa. Genetic algorithm has proved to be a robust and efficient tool to perform tasks like generation of the fuzzy rule base, generation of membership function, etc.

Three approaches that can be used to develop such a system are:

- Michigan Approach
- Pittsburgh Approach
- IRL Approach



Working Flow:

- Start with an initial population of solutions that represent the first generation.
- Feed each chromosome from the population into the Fuzzy logic controller and compute performance index.
- Create a new generation using evolution operators till some condition is met.

Advantages:

- GAs are used to develop the best set of rules to be used by a fuzzy inference engine
- GAs are used to optimize the choice of membership functions.
- A Fuzzy GA is a directed random search over all discrete fuzzy subsets.
- It can mimic the human decision-making process.

Disadvantages:

- Interpretation of results is difficult.
- Difficult to build membership values and rules.
- Takes lots of time to converge.

Applications:

- Mechanical Engineering
- Electrical Engine
- Artificial Intelligence
- Economics

An adaptive neuro-fuzzy inference system or adaptive network-based fuzzy inference system (ANFIS) is a kind of artificial neural network that is based on Takagi–Sugeno fuzzy inference system. Since it integrates both neural networks and fuzzy logic principles, it has potential to capture the benefits of both in a single framework. Its inference system corresponds to a set of fuzzy IF–THEN rules that have learning capability to approximate nonlinear functions. Hence, ANFIS is considered to be a universal estimator. For using the ANFIS in a more efficient and optimal way, one can use the best parameters obtained by genetic algorithm.

- **ANFIS Architecture:**
- **1. Representing Takagi-Sugeno Fuzzy Model**
- For simplicity, we assume that the fuzzy inference sytem under consideration has two inputs x and y and one output z. For a first-order Takagi-Sugeno fuzzy model, a common rule set with two fuzzy if-then rules is the following:
- Rule 1: If x is A1 and y is B1, then f1=p1x+q1y+r1;
- Rule 2: If x is A2 and y is B2, then f2=p2x+q2y+r2;

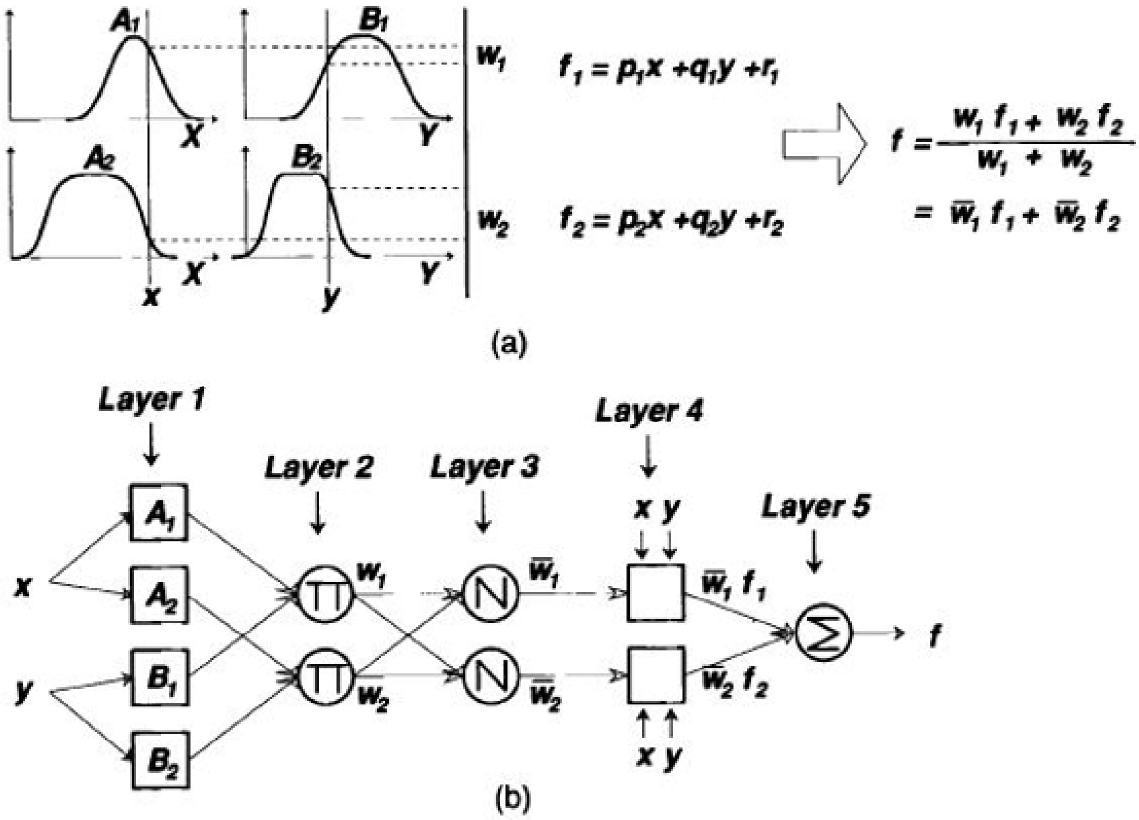


Figure 1(a) illustrates the reasoning mechanism for this Takagi-Sugeno model; the corresponding equivalent ANFIS architecture is as shown in Figure 1(b), where nodes of the same layer have similar functions, as described next. (Here we denote the output of the ith node in layer l as Ol,i)

- Layer 1 Every node i in this layer is an adaptive node with a node function

$$O_1, i = \mu_{Ai}(x), \quad for\ i = 1, 2, or$$
$$O_1, i = \mu_{Bi-2}(y), \quad for\ i = 3, 4,$$

- where x (or y) is the input to node i and Ai (or Bi-2) is a linguistic label (such as "small" or "large") associated with this node. In other words, O1,i is the membership grade of a fuzzy set A (=A1 , A2 , B1 or B2) and it specifies the degree to which the given input x (or y) satifies the quantifier A.

$$\mu_A(x) = \frac{1}{1 + |\frac{x - c_i}{a_i}|^{2b}},$$

- where {ai, bi, ci} is the parameter set. As the values of these parameters change, the bell-shaped function varies accordingly, thus exhibiting various forms of membership function for fuzzy set A. Parameters in this layer are referred to as premise parameters.
- **Layer 2** Every node in this layer is a fixed node labeled anfis, whose output is the product of all the incoming signals:

$$O_{2,i} = w_i = \mu_{Ai}(x)\mu_{Bi}(y), i = 1, 2.$$

- Each node output represents the firing strength of a rule. In general, any other T-norm operators that perform fuzzy AND can be used as the node function in this layer.
- **Layer 3** Every node in this layer is a fixed node labeled N. The ith node calculates the ratio of the ith rule's firing strength to the sum of all rules' firing strenghts:

$$O_{3,i} = \bar{w}_i = \frac{w_i}{w_1 + w_2}, i = 1, 2.$$

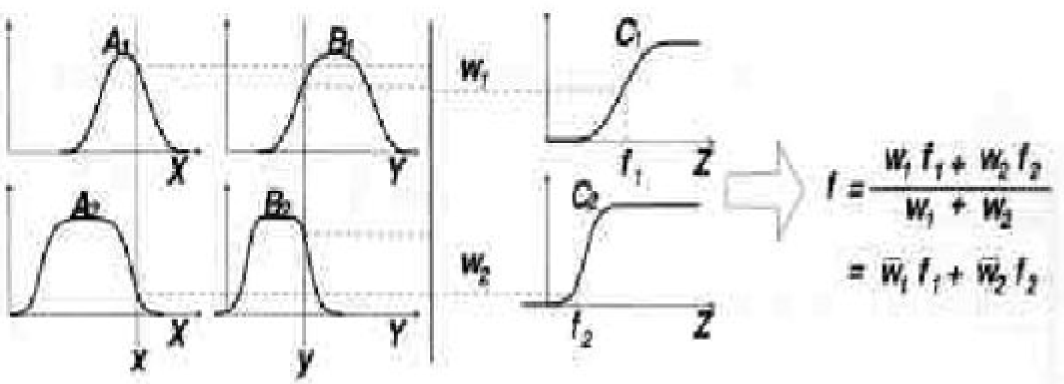
- For convenience, outputs of this layer are called normalized firing strengthes.
- **Layer 4** Every node i in this layer is an adaptive node with a node function:

$$O_{4,i} = \bar{w}_i f_i = \bar{w}_i(p_i x + q_i y + r_i),$$

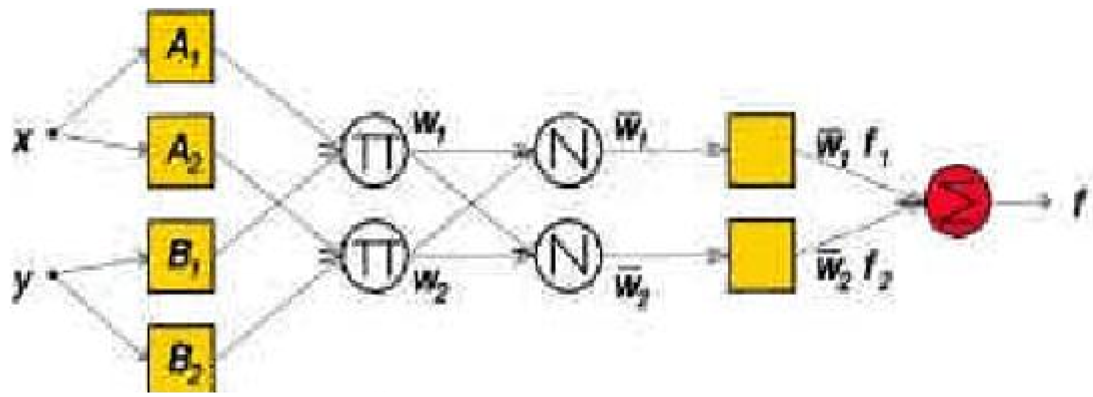
- where anfis is a normalized firing strength from layer 3 and {pi, qi, ri} is the parameter set of this node. Parameters in this layer are referred to as consequent parameters.
- **Layer 5** The single node in this layer is a fixed node labeled anfis, which computes the overall output as the summation of all incoming singals:

$$\text{overall output} = O_{5,i} = \sum_i \bar{w}_i f_i = \frac{\sum_i w_i f_i}{\sum_i w_i}$$

- Thus we have constructed an adaptive network that is functionally equivalent to a Sugeno fuzzy model.
- **2. Representing Tsukamoto Fuzzy ModelS:**



- *Figure 2(a)*



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- *Figure 2: (b)*
- ***Figure 2: (a) A two-rule Tsukamoto fuzzy model; (b) The equivalent ANFIS architecture***
- The extension from TS ANFIS to Tsukamoto ANFIS is straightforward, as show in Figure 2, where the output of each rule (fi, i=1, 2) is induced jointly by a consequent membership function and a firing strength.
- **3. Representing Mamdani Fuzzy Model**
- For the Mamdani fuzzy inference system with max-min composition, a corresponding ANFIS can be constructed if discrete approximations are used to replace the integrals in the centroid defuzzification scheme introduced in here. However, the resulting ANFIS is much more complicated than either TS ANFIS or Tsukamoto ANFIS. The extra complexity in structure and computation of Mamdani ANFIS with max-min composition does not necessarily imply better learning capability or approximation power. If we adopt sum-product composition and centroid defuzzification for a Mamdani fuzzy model, a corresponding ANFIS can be constructed easily based on Theorem directly without using any approximation at all.

Expert System

An expert system is a computer program that is designed to solve complex problems and to provide decision-making ability like a human expert.

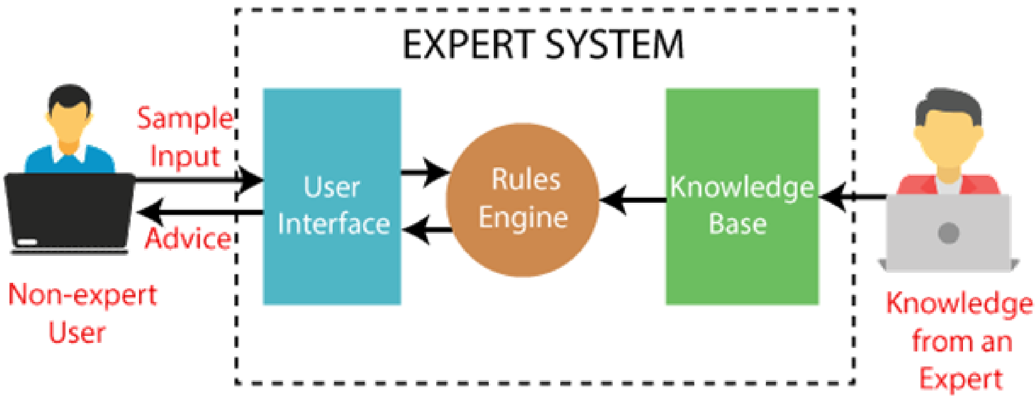
It solves the most complex issue as an expert by extracting the knowledge stored in its knowledge base. The system helps in decision making for complex problems using **both facts and heuristics like a human expert**.

It is called so because it contains the expert knowledge of a specific domain and can solve any complex problem of that particular domain.

These systems are designed for a specific domain, such as **medicine, science,** etc.

The performance of an expert system is based on the expert's knowledge stored in its knowledge base. The more knowledge stored in the KB, the more that system improves its performance.

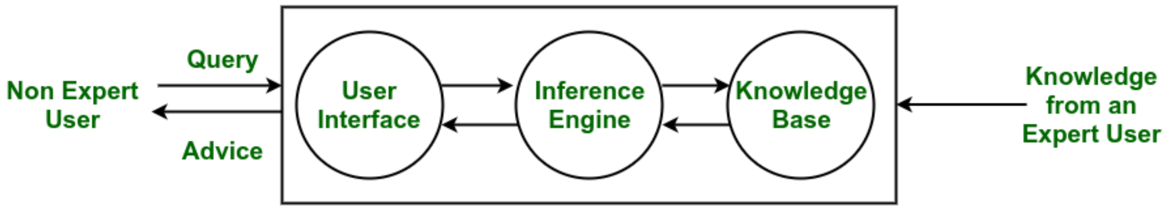
One of the common examples of an ES is a suggestion of spelling errors while typing in the Google search box.



Characteristics of Expert System

- **High Performance:** The expert system provides high performance for solving any type of complex problem of a specific domain with high efficiency and accuracy.
- **Understandable:** It responds in a way that can be easily understandable by the user. It can take input in human language and provides the output in the same way.
- **Reliable:** It is much reliable for generating an efficient and accurate output.
- **Highly responsive:** ES provides the result for any complex query within a very short period.

Components of an Expert System :



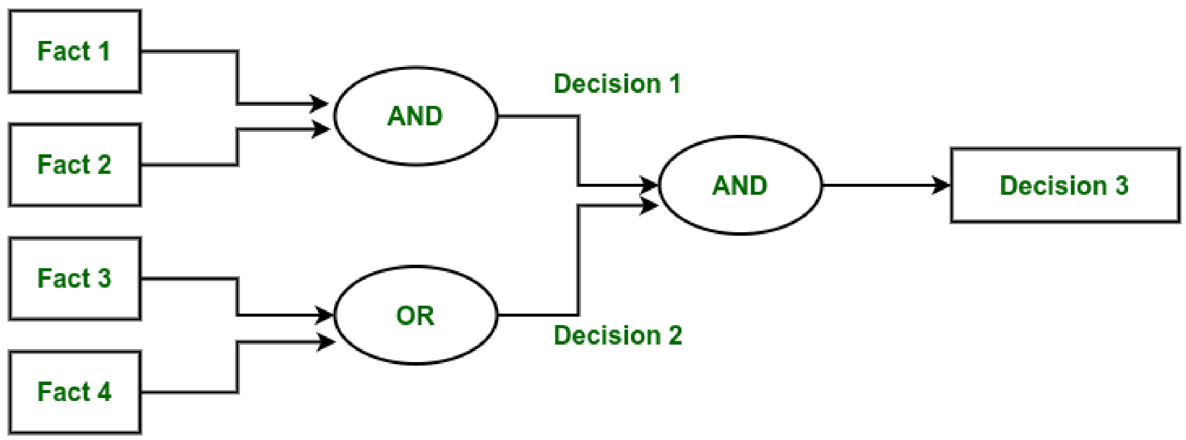
- **Knowledge Base –**
  The knowledge base represents facts and rules. It consists of knowledge in a particular domain as well as rules to solve a problem, procedures and intrinsic data relevant to the domain.
- **Inference Engine –**
  The function of the inference engine is to fetch the relevant knowledge from the knowledge base, interpret it and to find a solution relevant to the user's problem. The inference engine acquires the rules from its knowledge base and applies them to the known facts to infer new facts. Inference engines can also include an explanation and debugging abilities.
- **Knowledge Acquisition and Learning Module –**
  The function of this component is to allow the expert system to acquire more and more knowledge from various sources and store it in the knowledge base.
- **User Interface –**
  This module makes it possible for a non-expert user to interact with the expert system and find a solution to the problem.

- **Explanation Module –**
  This module helps the expert system to give the user an explanation about how the expert system reached a particular conclusion.

The Inference Engine generally uses two strategies for acquiring knowledge from the Knowledge Base, namely –

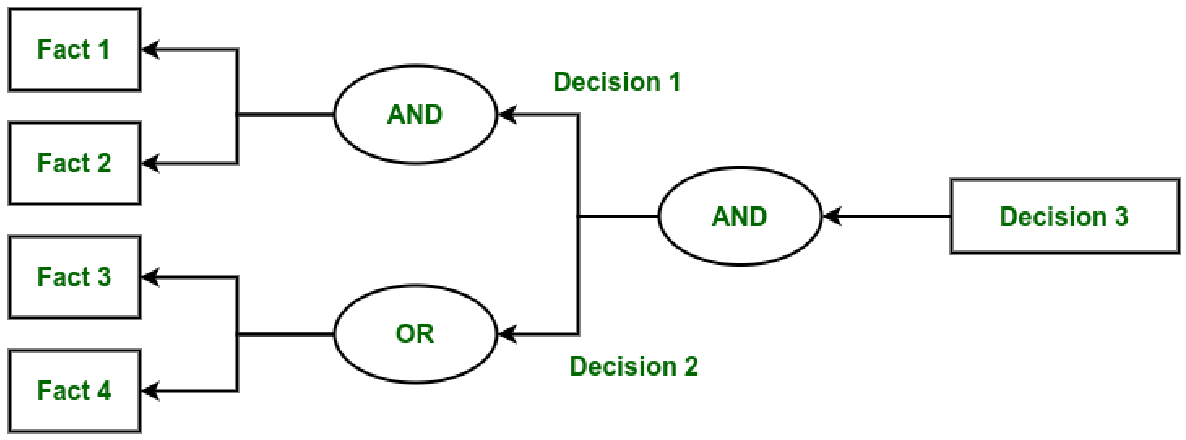
- Forward Chaining
- Backward Chaining

Forward Chaining –
Forward Chaining is a strategic process used by the Expert System to answer the questions – What will happen next. This strategy is mostly used for managing tasks like creating a conclusion, result or effect. Example – prediction or share market movement status.



Forward Chaining

Backward Chaining –
Backward Chaining is a storage used by the Expert System to answer the questions – Why this has happened. This strategy is mostly used to find out the root cause or reason behind it, considering what has already happened. Example – diagnosis of stomach pain, blood cancer or dengue, etc.



Backward Chaining

Characteristics of an Expert System :

- Human experts are perishable, but an expert system is permanent.
- It helps to distribute the expertise of a human.
- One expert system may contain knowledge from more than one human experts thus making the solutions more efficient.
- It decreases the cost of consulting an expert for various domains such as medical diagnosis.
- They use a knowledge base and inference engine.
- Expert systems can solve complex problems by deducing new facts through existing facts of knowledge, represented mostly as if-then rules rather than through conventional procedural code.
- Expert systems were among the first truly successful forms of artificial intelligence (AI) software.

Limitations :

- Do not have human-like decision-making power.
- Cannot possess human capabilities.
- Cannot produce correct result from less amount of knowledge.
- Requires excessive training.

Advantages :

- Low accessibility cost.
- Fast response.
- Not affected by emotions, unlike humans.
- Low error rate.
- Capable of explaining how they reached a solution.

Disadvantages :

- The expert system has no emotions.
- Common sense is the main issue of the expert system.
- It is developed for a specific domain.
- It needs to be updated manually. It does not learn itself.
- Not capable to explain the logic behind the decision.

Applications :

The application of an expert system can be found in almost all areas of business or government. They include areas such as –

- Different types of medical diagnosis like internal medicine, blood diseases and show on.
- Diagnosis of the complex electronic and electromechanical system.
- Diagnosis of a software development project.
- Planning experiment in biology, chemistry and molecular genetics.
- Forecasting crop damage.
- Diagnosis of the diesel-electric locomotive system.
- Identification of chemical compound structure.
- Scheduling of customer order, computer resources and various manufacturing task.
- Assessment of geologic structure from dip meter logs.
- Assessment of space structure through satellite and robot.
- The design of VLSI system.
- Teaching students specialize task.
- Assessment of log including civil case evaluation, product liability etc.

Expert systems have evolved so much that they have started various debates about the fate of humanity in the face of such intelligence, with authors such as Nick Bostrom (Professor of Philosophy at Oxford University), pondering if computing power has transcended our ability to control it.

- **Objective Questions:**

What is a hybrid system?

A) A system that uses a combination of renewable and non-renewable energy sources

B) A system that combines two different programming languages

C) A system that utilizes both analog and digital components

D) A system that integrates both hardware and software components.

Answer: D) A system that integrates both hardware and software components.

Which of the following is an example of a hybrid system?

A) A solar-powered calculator

B) A gasoline-powered car

C) A wind turbine

D) A smartphone

Answer: B) A gasoline-powered car. A hybrid system combines two or more different technologies or energy sources to provide power or perform a task. A gasoline-powered car is an example of a hybrid system because it uses both an internal combustion engine and an electric motor to provide power and improve fuel efficiency. The other options listed are not examples of hybrid systems because they rely solely on one technology or energy source.

- **Short Answer Questions:**

Q.1 Differentiate between NNFS & NNGA?
Q.2 Explain ANFIS architecture?
Q.3 Explain how NNFS used for?
Q.4 Explain Types of Hybrid System?
Q.5 Explain ANFIS algorithm?