Neuro-fuzzy hybrid System

- Neural n/w are low-level computational structures that perform well when dealing with raw data.
- fuzzy logic deals with reasoning on a higher level, using linguistic info.
- fuzzy s/ms lack the ability to learn and cannot adj with new envmt
- NN can learn
- Integrated neuro-fuzzy s/ms can combine the ||el computation and learning ability of NN with human-like knowledge rep. and explanation abilities of fuzzy systems.
- As a result, NN become more transparent, while fuzzy s/m become capable of learning.

→ • A neuro-fuzzy s/m is a NN which is functionally equivalent to a fuzzy inference model.

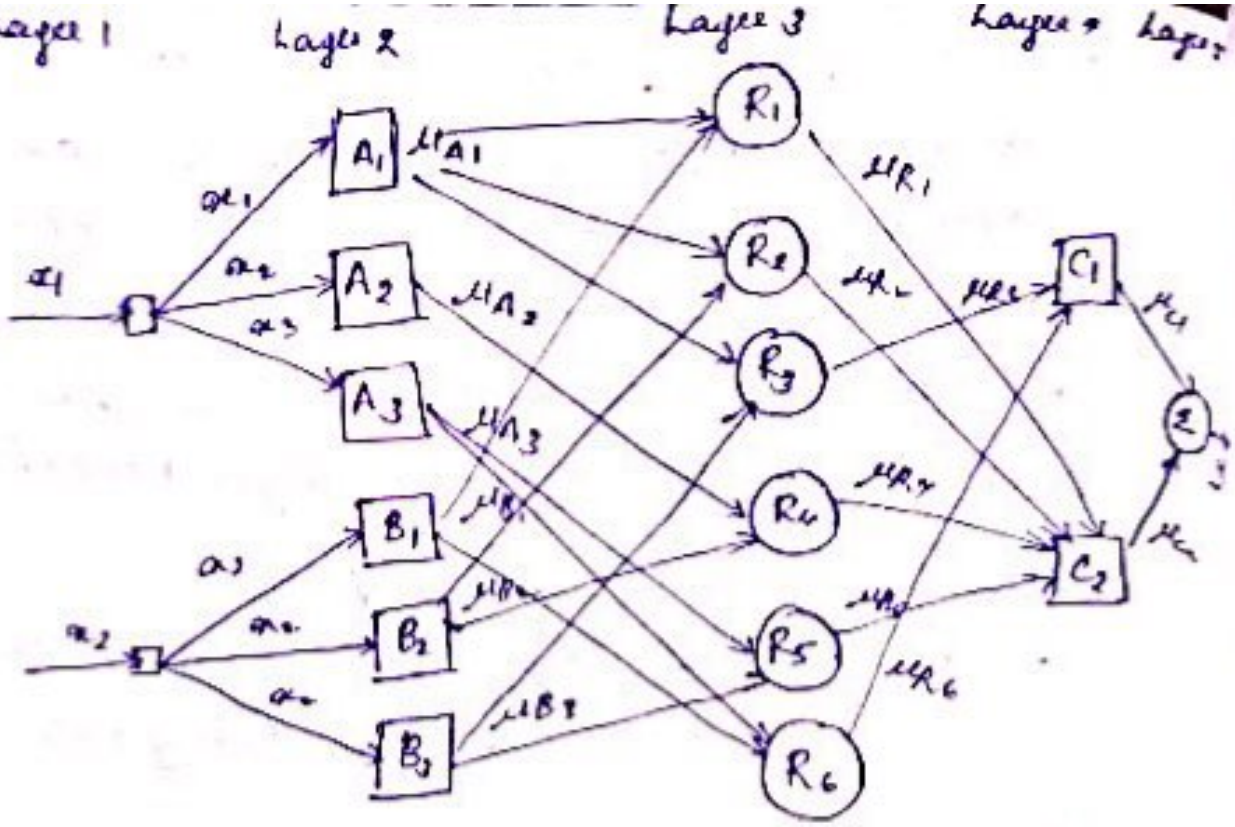
- Neuro-fuzzy s/m can be trained to develop IF-THEN fuzzy rules and determine membership fns for input and o/p variables of the s/m
- Structure of Neuro-fuzzy s/m is similar to a multi-layer neural n/w
  - Input and o/p layers
  - 3 hidden layers (that rep mem. fn and fuzzy rules)

Layer-1

The input layer. Each neuron in this layer transmits external crisp signals directly to the next layer. i.e., $y_i = x_i$

Layer 2

- Fuzzification layer.
- Neurons in this layer rep fuzzy sets used in the antecedents of fuzzy rules
- A fuzzifier neuron receives a crisp i/p and determines the degree of membership to the neuron's fuzzy set.
- Activation fn of neuron in layer two are set to triangular mem. fns.



Layer 3

- Fuzzy rule layer
- Each neuron in this layer corresponds to a single fuzzy rule
- A fuzzy rule neuron recieves i/p from the fuzzifier neuron that rep. fuzzy set in the rule antecedents.
- For eg. neuron R_1, which corresponds to Rule 1, recieves i/p from neuron A_1 and B_1

o/p : $y_i = a_{1i} \times a_{2i} \times \dots \times a_{ki}$ | $y_{R_1} = \mu_{A_1} \times \mu_{B_1} = \mu_{R_1}$

Layer 4

- Output membership layer
- Neurons in this layer rep. fuzzy sets used in the consequent of fuzzy rules
- An o/p mem. neuron combines all its i/p by using the fuzzy opn union. (probabilistic OR)

eg: The value of μ_{C_1} rep the integrated firing strength of F. Rule neurons $R_{3 \& 6}$

$$y_i = \alpha_{1i} \oplus \alpha_{2i} \oplus \cdots \oplus \alpha_{Li}$$

$$y_4 = \mu_{R_3} \oplus \mu_{R_6} = \mu_{C_1}$$

Layer 5

- Defuzzifn layer
- Each neuron in this layer rep a single o/p of the neuro-fuzzy s/m
- It takes the o/p fuzzy sets clipped by the respective integrated firing strengths and combines them into a single fuzzy set.

- We can apply std fuzzifn methods like centroid method.
- We use the sum - product composition & it calculates the crisp o/s as the weighted avg of the centroids of all o/p mem. fns.

eg:- Wtd avg of c_1 and c_2 is

$$y = \frac{\mu_{c_1} * a_{c_1} * b_{c_1} + \mu_{c_2} * a_{c_2} * b_{c_2}}{\mu_{c_1} * b_{c_1} + \mu_{c_2} * b_{c_2}}$$

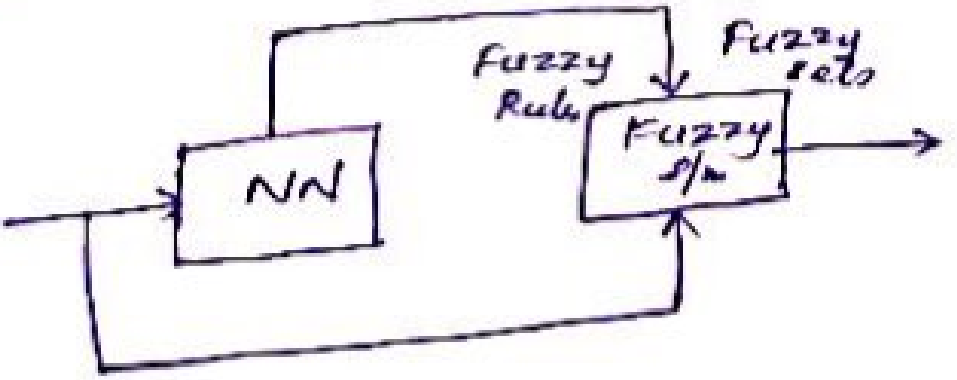
Neuro-fuzzy system can learn through std NN learning alg including back propagation alg.

Clarification

1. Cooperative N.F.S
2. Concurrent N.F.S
3. Hybrid NFS.

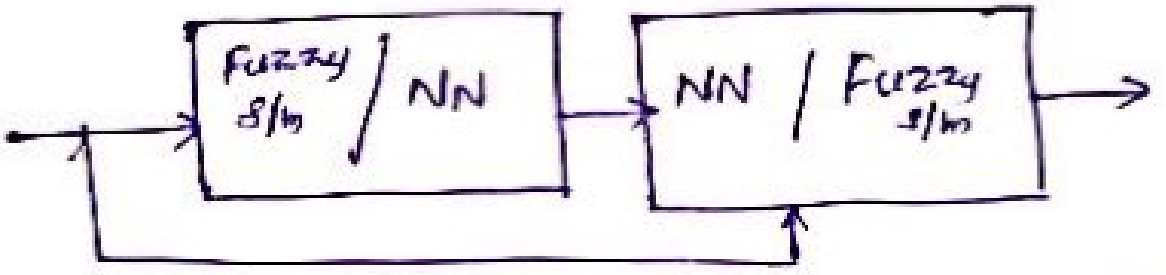
1. Cooperative Neuro f.s.

- In this the NN are used only in an initial phase.
- NN determines the sub-blocks of the fuzzy s/m using training data, after this NN are removed and only f.s is executed. (Structure not strictly interpretable)



2. Concurrent NFS

- NN works together with the F.S
- ie, the i/p enters in the F.S, are preprocessed and then the NN process the o/ps of the concurrent s/m or in reverse way. (The result are not strictly interpretable)



3. Hybrid Neuro-F. S

A hybrid NFS uses a learning alg based on gradients or inspired by NN theory to determine its parameters (fuzzy sets and fuzzy rules) through the patte (I/p & O/p)

Neuro - Fuzzy Hybrid systems:-

* A neuro - fuzzy hybrid system is a learning mechanism that utilizes the training and learning algorithms from neural networks to find parameters of a fuzzy systems (ie, fuzzy set, fuzzy rules, fuzzy numbers).

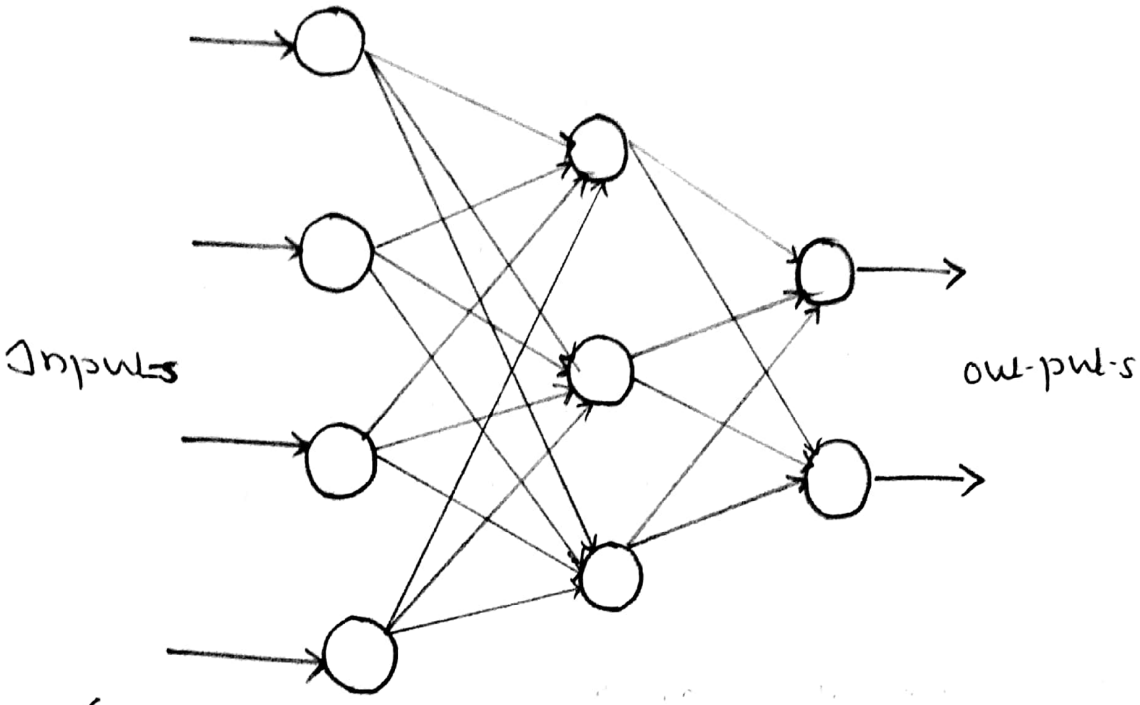
* Neuro - fuzzy hybridization is termed as Fuzzy Neural Network (FNN) or Neuro - Fuzzy systems (NFS)

* Neuro - fuzzy is divided into 2 areas.
  - ⇒ Linguistic Fuzzy modeling (mainly the Mamdani model)
  - ⇒ Precise Fuzzy modeling (mainly the sugeno model)

Comparison of neural and Fuzzy processing:-

Neural processing	Fuzzy processing
mathematical model not necessary	Mathematical model not necessary.
Learning can be done from scratch.	A priori knowledge is needed.
There are several learning algorithms.	Learning is not possible.
Black-box behavior	Simple interpretation and implementation.

Characteristics of Neuro-Fuzzy Hybrids



(Fig:- Architecture of neuro-fuzzy hybrid system)

A fuzzy system-based NFS is trained by means of a data-driven learning method. At any stage of the learning process it can be represented as a set of fuzzy rules.

An NFS is given by a 3 layer feed forward neural network model. The first layer corresponds to the input variable, and second and third layer correspond to the fuzzy rules and output variables respectively. The fuzzy sets are converted to (fuzzy) connection weights.

Classification of Neuro-Fuzzy hybrid systems:-

1. Cooperative NFS

In this type of system, both ANN and Fuzzy Systems work independently from each other. The ANN attempts to learn the parameters from the fuzzy systems. The 4 different kinds of Cooperative Fuzzy Neural Networks are:

(a)

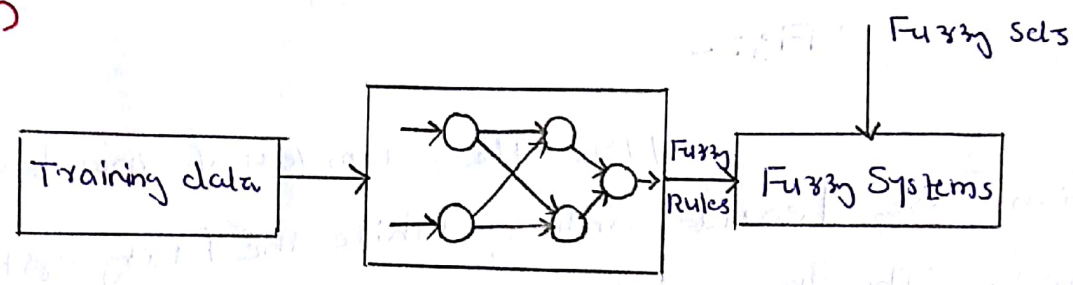


Fig: (A)

Here, the FNN learns the fuzzy sets from the given training data. This is done by fitting membership functions with a neural network, the fuzzy sets then being determined offline. This is followed by the initialization to form the fuzzy system by fuzzy rules, that are given.

(b)

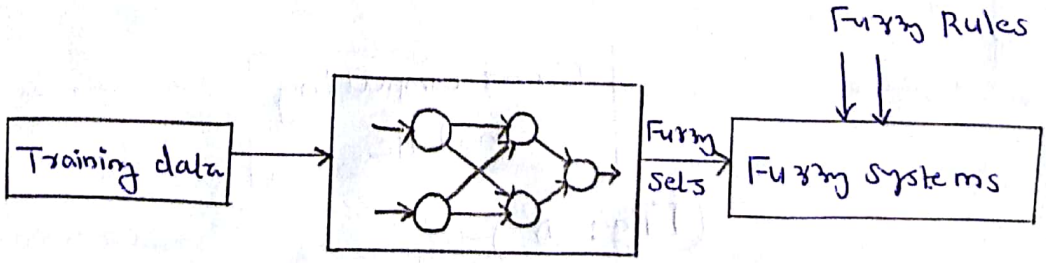


Fig:- B

Here, the neural network learn off-line before the Fuzzy system is initialized. The rule learning happens

usually by clustering on self-organizing feature maps.

(c)

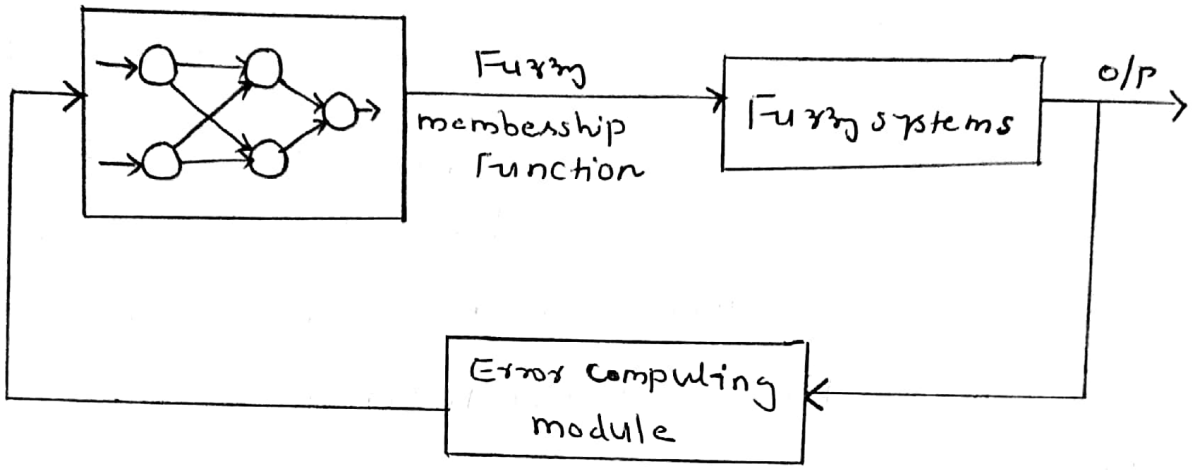
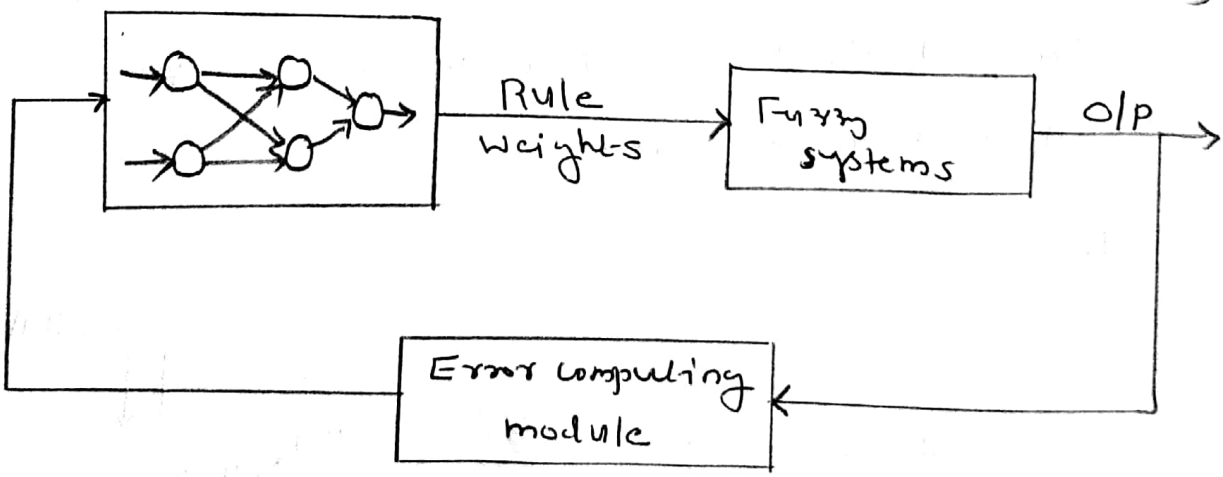


Fig: c

Here, the parameters of membership functions are learnt online, while the fuzzy system is applied. This means that initially, fuzzy rules and membership functions must be defined beforehand. Also inorder to improve and guide the learning step, the error has to be measured.

(d)

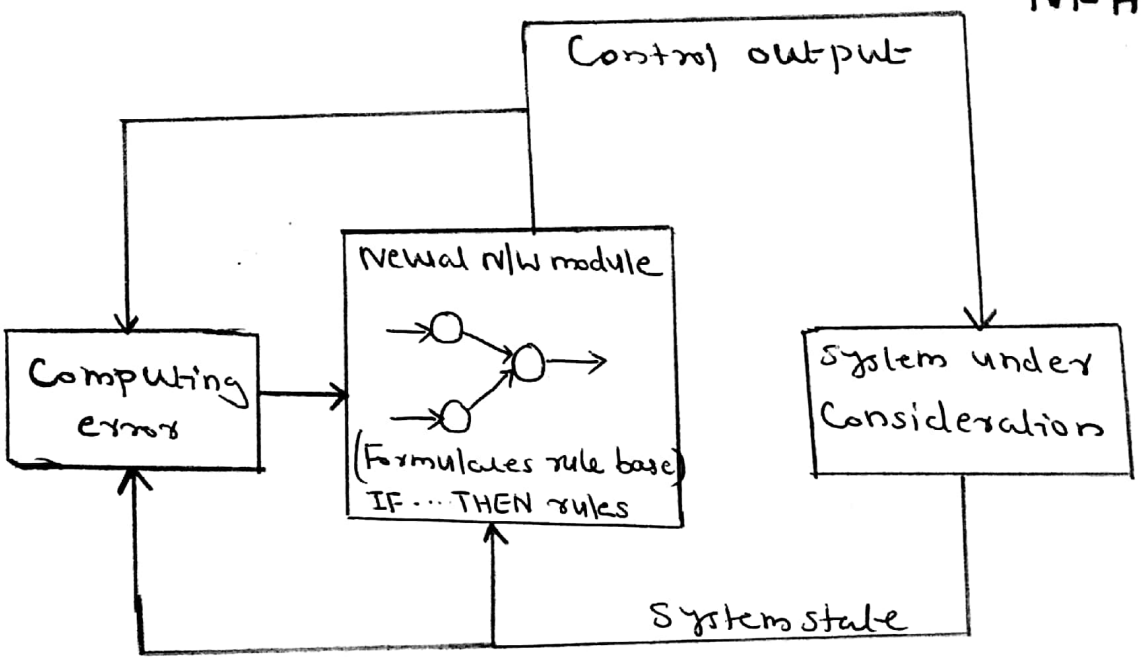


(Fig: D)

The above model determines the rule weights for all fuzzy rules by a neural network.

A rule is determined by its rule weight - interpreted as the influence of a rule. They are then multiplied with the rule output.

2. General Neuro - Fuzzy hybrid systems (General NFHS)



(Fig: - General neuro Fuzzy hybrid system)

Here, the rule base of a Fuzzy system is assumed to be a neural network.

Fuzzy sets are regarded as weights and the rules, input and o/p variables as neurons.

Any shape such as Gaussian or triangular or bell shaped or trapezoidal, can be considered as a membership function with an arbitrary set of parameters.