→ Introduction to Prolog,

- Prolog is a language that is particularly suited to programs that involves symbolic or non-numeric computation.
- For this reason it is a frequently used language in AI where manipulation of symbols and inference ~~engine~~ about them is a common task.
- Prolog consists of a series of predicate or rules and facts.
- A program is run by presenting some query and seeing if this can be proved against these known rules and facts.

* Symbols,

English	Predicate Calculus	Prolog
and	$\wedge$	,
or	$\vee$	;
if	$\rightarrow$	:-
not	$\sim$	not

* Variables begin with an uppercase letter.

* Object names, function names, must begin with a lowercase letter.

Eg: happy (x) :- hasmoney(x), has_friends (x).

LHS ← if ← RHS (premises)

LHS ↓ Single positive literal (conclusion)

* Module 4,

* Fuzzy logic - Fuzzy Systems.

↳ Introduction,

↳ The world fuzzy refers to things which are not clear or vague.

↳ Any event, process, or function that is changing continuously cannot always be defined as true / false.

↳ Define them in a fuzzy manner,

↳ [0,1].

Boolean or Crisp	Fuzzy Logic.
↓	↓
5'10	Tall.

→ young, tall, good, or high are fuzzy variables.

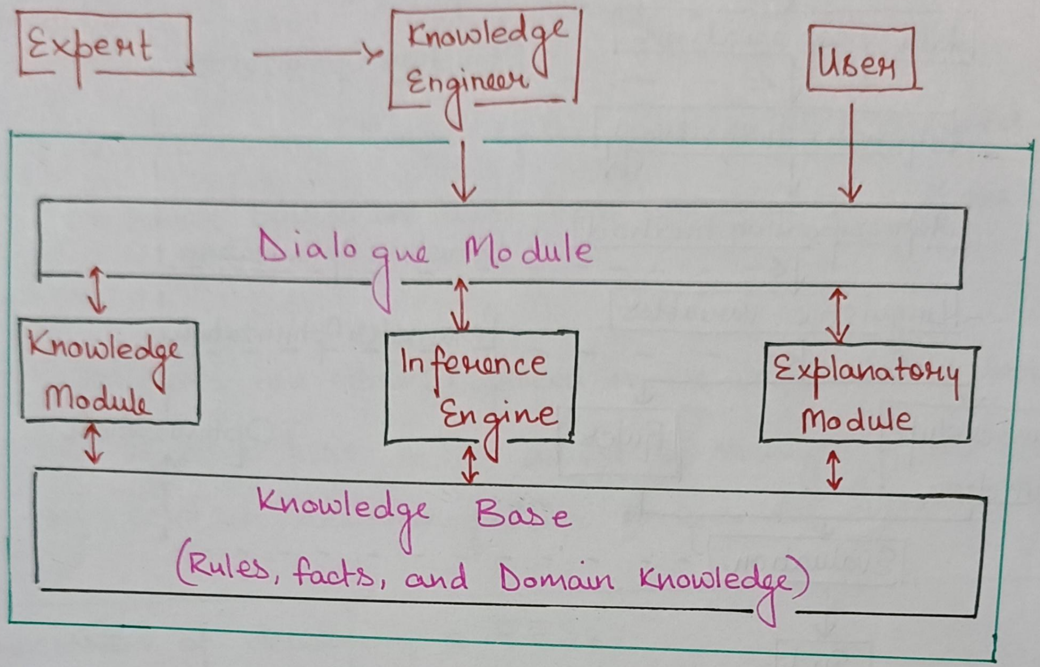
→ A Fuzzy Set is any set that allows its members to have different degree of memberships, called membership function, in the interval [0,1].

· Definition,

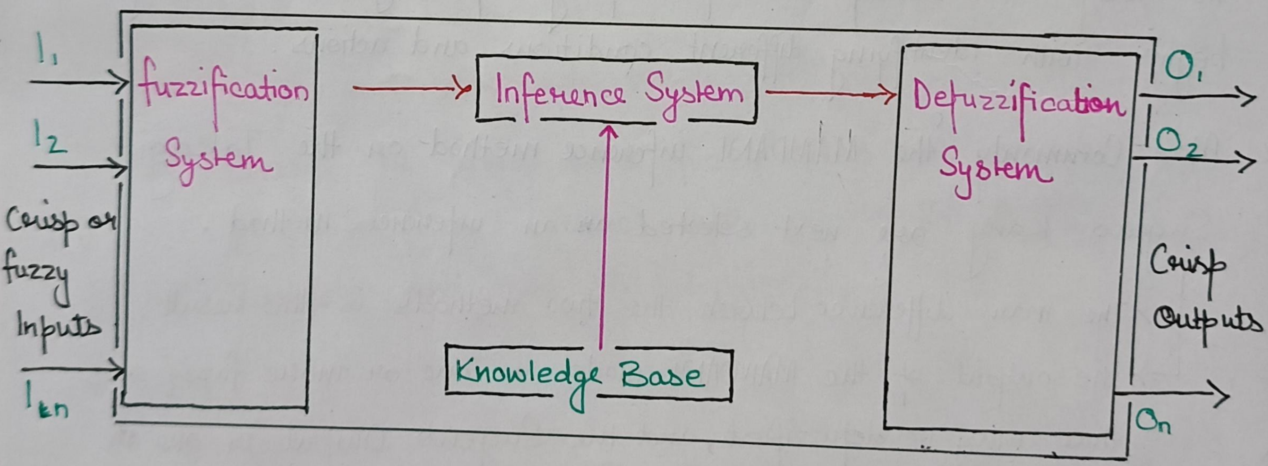
↳ A fuzzy set A, defined in the universal space X, is a ~~fuzzy set~~ function defined in X which assumes values in the range [0,1].

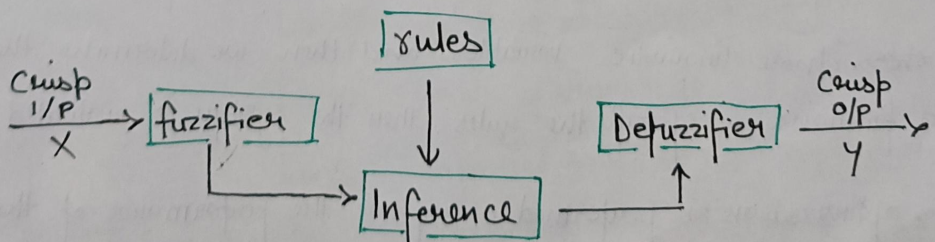
Fuzzy

Fuzzy Expert Systems Development:

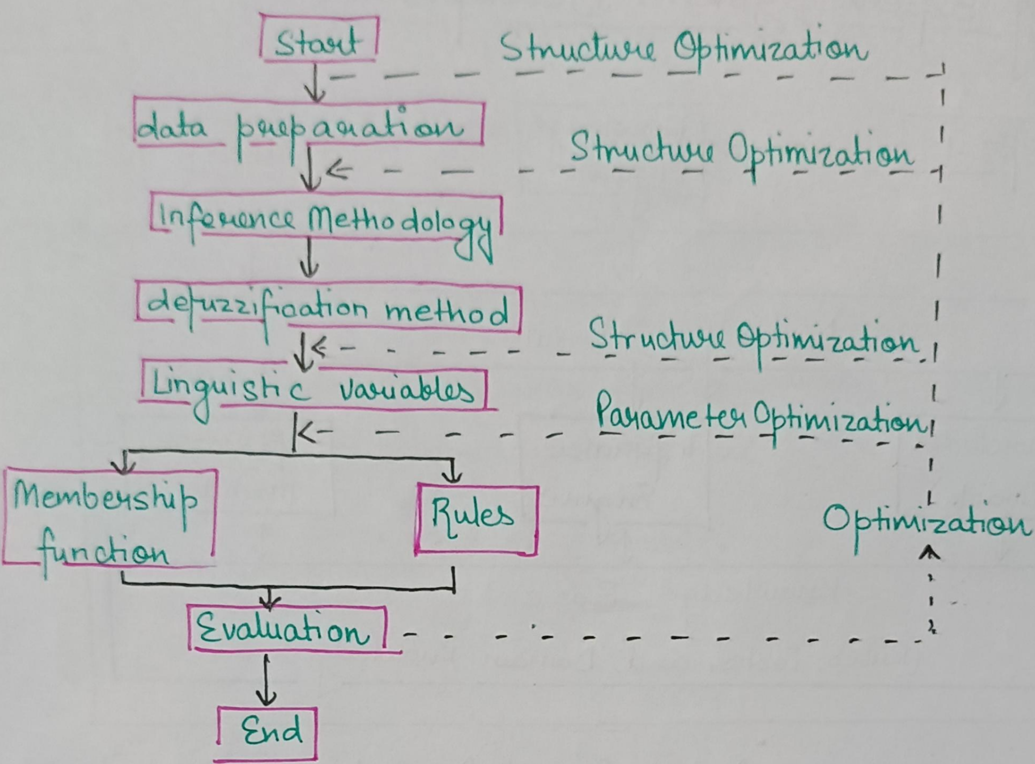


* FES uses membership functions & set of fuzzified inference rules to solve a problem.





$$y = f(x)$$



* The design and Development of a fuzzy expert system normally begins with identifying different conditions and actions.

* Most Commonly, the MAMDANI inference method or the Takagi-Sugeno-Kang are next selected as an inference method.
    - The main difference between the two methods is the result.
    - The output of the MAMDANI model is one or more fuzzy sets that must be defuzzified, and the Sugeno Output is one or more real functions that should be evaluated directly.

* Then, we ~~chose~~ choose linguistic variables and then we determine the membership functions & specify the rules. Then the system is evaluated.

* At the end, optimization is performed to improve the performance of the initial system.

Fuzzy Inference Engine,

* Building a fuzzy Expert System,

Eg: • A service center keeps spare parts & repairs failed ones.
• A customer brings a failed item and recieves a spare of same type.
• Failed parts are repaired, placed on the shelf and thus become spares.
• The objective here is to advise a manager of the service center on certain decision policies to keep the customer satisfied.

* Process of developing a FES,

- Specify the problem and define linguistic variables.
- Determine Fuzzy Sets.
- Elicit and construct fuzzy rules.
- Encode the fuzzy sets, fuzzy rules and procedures to perform fuzzy inference into the expert system.
- Evaluate and tune the system.

* Step 1,

↳ Linguistic variables,
- m → avg waiting time
- ρ → repair utilisation factor
- s → no. of servers
- n → initial no. of spare parts.

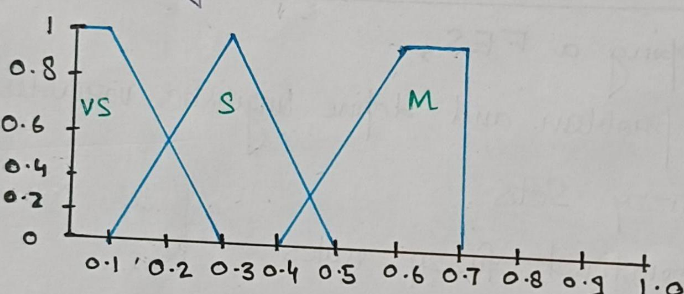
* we define the linguistic variables and their ranges.

Eg.

Linguistic variables (m)

Linguistic Value	Notation	Numerical Range (Normalised)
Very Short	VS	0 - 0.3
Short	S	0.1 - 0.5
Medium	M	0.4 - 0.7

* Step 2, {Determining fuzzy Sets}
  - Triangular or Trapezoidal } based on degree of membership.
  - MinMax Normalisation is performed to bring the data into desired range.



VS → [0, 0.3]

S → [0.1, 0.5]

M → [0.4, 0.7]

* Step 3, {Elicit & construct fuzzy Rules}
  - Need of Expert.
  - Eg.

no. of servers \ mean delay	VS	S	M
L	M	S	VS
S	RL	RS	S
M	VL	L	M

- If (f=L) then (n=S)
- If (f=VS) and (s=L) then (n=L).

Step 4,

- Encode the fuzzy sets, fuzzy rules & procedures to perform fuzzy inference into expert system.
  - C/C++/Java can be used to build the System.
  - MATLAB FL toolbox or fuzzy Knowledge Builder.

★ Step 5,

- Evaluate & tune the system.
  - Define test cases based on the linguistic ~~varia~~ variables.

★ FUZZY INFERENCE,

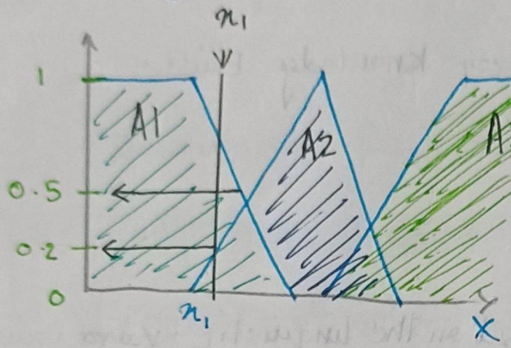
- MAMDANI
- SUGENO.

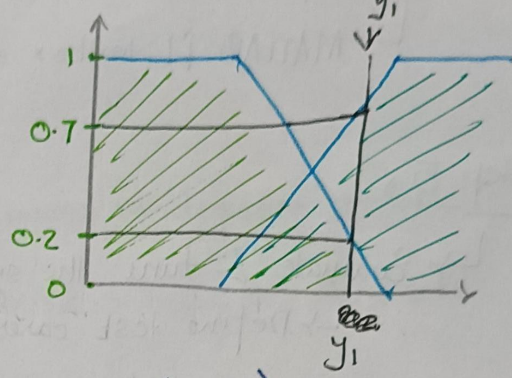
★ MAMDANI,

- In 1975, Prof. Ebrahim Mamdani of London University built one of the first fuzzy systems to control a steam engine and boiler combination.
- 4-steps,
  - fuzzification of the i/p variables.
  - rule evaluation
  - aggregation of the rule outputs
  - defuzzification.

① **Fuzzification**,

↳ Take crisp i/p x1 & y1 and determine the degree to which these i/p's belong to each ~~other~~ of the appropriate fuzzy sets.





$\mu(x = A1) = 0.5$

$\mu(x = A2) = 0.2$

$\mu(y = B1) = 0.1$

$\mu(y = B_2) = 0.7$

② **Rule Extraction**,

↳ Take the fuzzified inputs and apply them to the antecedents of the fuzzy rules.

OR → $\mu_A \cup \mu_B(x) = \max[\mu_A(x), \mu_B(x)]$

AND → $\mu_A \cap \mu_B(x) = \min[\mu_A(x), \mu_B(x)]$

③ **Aggregation**,

↳ Unification of outputs of all rules.

↳ We take the membership functions of all consequents previously clipped or scaled and combine them into a single fuzzy set.

z is $C1$ (0.1)

$\downarrow$

z is $C2$ (0.2)

$\downarrow$

z is $C3$ (0.5)

$\downarrow$

$\sum$

↳ Defuzzification,

↳ Converts fuzzy set into crisp output.

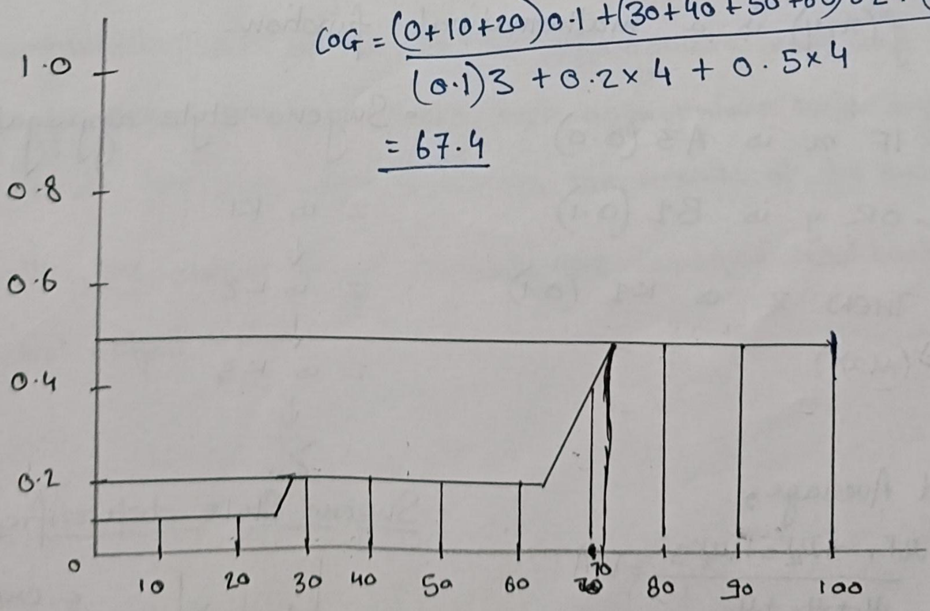
↳ Centroid technique.

↳ It finds the point where a vertical line would slice the aggregate set into two equal masses.

$$COG = \frac{\int_a^b \mu_A(x)\, x\, dx}{\int_a^b \mu_A(x)\, dx}$$

$$COG = \frac{(0+10+20)0.1 + (30+40+50+60)0.2 + (70+80+90+100).0.5}{(0.1)3 + 0.2\times 4 + 0.5\times 4}$$

$$= 67.4$$



★ Sugeno Fuzzy Inference,

↳ Mamdani-style inference, as we have just seen, requires us to find the centroid of a two-dimensional shape by integrating across a continuously varying function. In general, this process is not computationally efficient.

↳ Sugeno Style fuzzy inference is very similar to the Mamdani method. Sugeno changed only a rule consequent. Instead of a fuzzy set, he used a mathematical function of the i/p variable. The format of the Sugeno-style fuzzy rule is,

Crisp

IF x is A ⟶ fuzzy set

AND y is B

THEN z is $f(x,y) = K$

where, x, y and z are linguistic variables; A and B are fuzzy sets on universe of discourses X and Y, respectively; and $f(x,y)$ is a mathematical function.

Eg:

IF x is A3 (0.0)

OR y is B1 (0.1)

THEN z is K1 (0.1)

(max)

• Sugeno-style aggregation.

z is K1

↓

z is K2

↓

z is K3

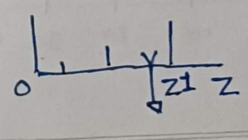
↓

Σ

• Weighted Average,

$$\frac{\mu_1 K_1 + \mu_2 K_2 + \mu_3 K_3}{\mu_1 + \mu_2 + \mu_3} = WA$$

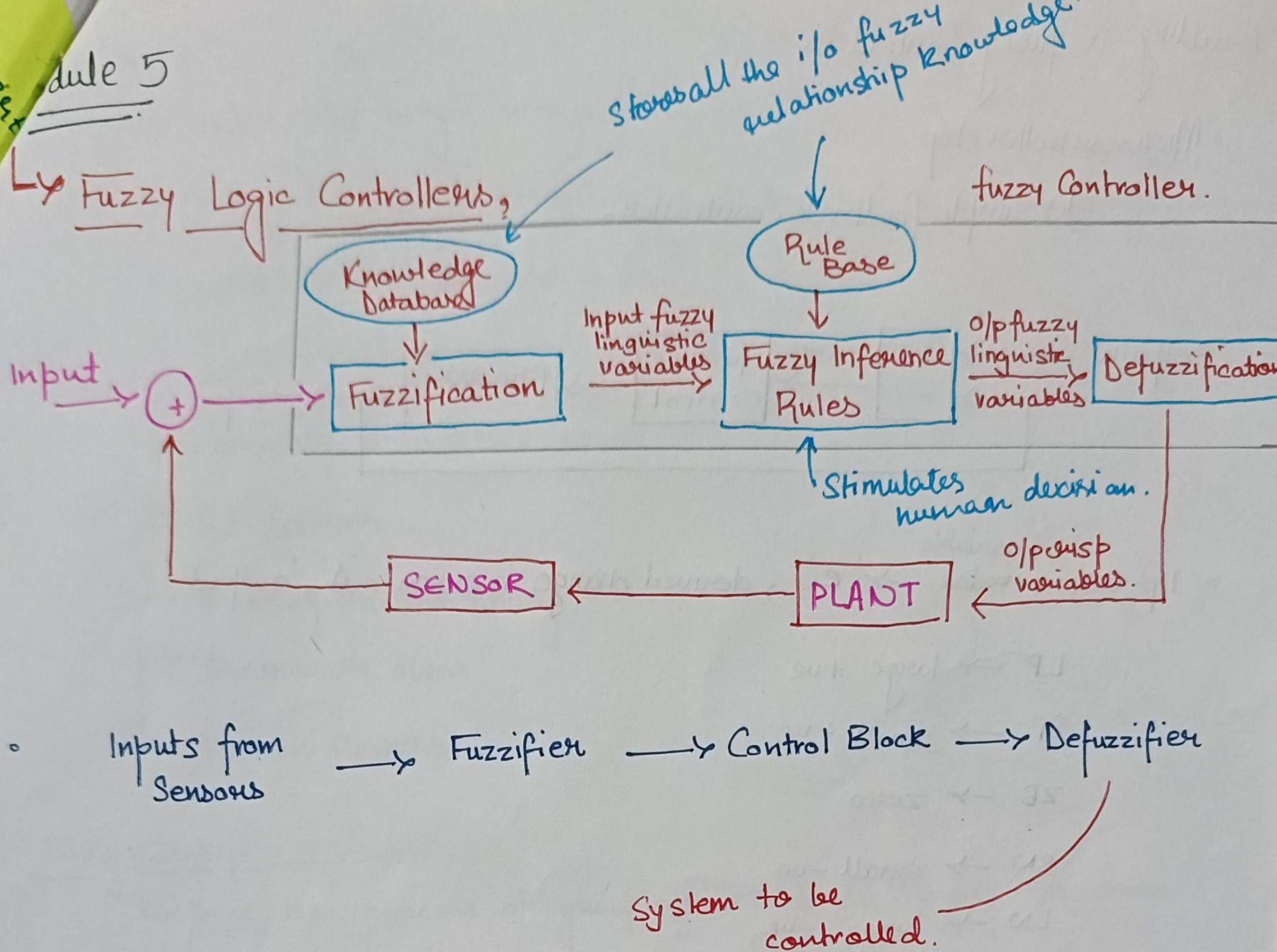
• Sugeno Style defuzzification,



← crisp output.

Module 5

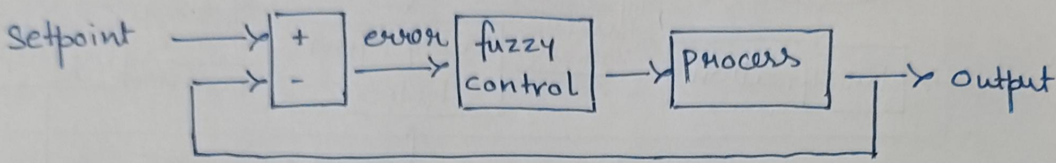
Fuzzy Logic Controllers



- FLC's are very simple conceptually. They consist of an ~~output~~ input stage, processing stage and output stage.
- The input stage maps sensor or other inputs, such as switches, thumbwheels, and so on, to the appropriate m.f. and truth values.
- The processing stage invokes each appropriate rule and generates a result for each, then combines the results of the rules.
- finally, the output stage converts the combined result back into a specific control output value.

◦ Building a fuzzy Controller,

- Microcontroller chip.
  - ↳ Simple feedback controller,



- I/p error ~~value~~ variable → 'e', derived change in error = 'Δ', 'output'

  LP → large +ve

  SP → small +ve

  ZE → zero

  SN → small -ve

  LN → large -ve

- Rule Base,

  R1 → IF e = ZE AND Δ = ZE THEN output = ZE

  R2 → IF e = ZE AND Δ = SP THEN output = SN.

★ Various Industrial applications,

- Aerospace,
  - ↳ Altitude control of spacecraft
  - ↳ Satellite altitude control
  - ↳ Flow and mixture regulation in aircraft deicing vehicles.
- Automotive,
  - ↳ Trainable fuzzy systems for idle speed control.
  - ↳ Traffic control
  - ↳ Intelligent highway systems.

Defense,

- Underwater target recognition.
- Automatic target recognition of thermal infrared images.
- Naval decision support aids.

- Electronics,
  - Humidity in a clean room
  - AC systems
  - Washing Machine timing
  - Microwave ovens
  - Vacuum Cleaners.

→ Fuzzy Classification,

It is the process of grouping individuals having the same characteristics into a fuzzy set.

* Goal,

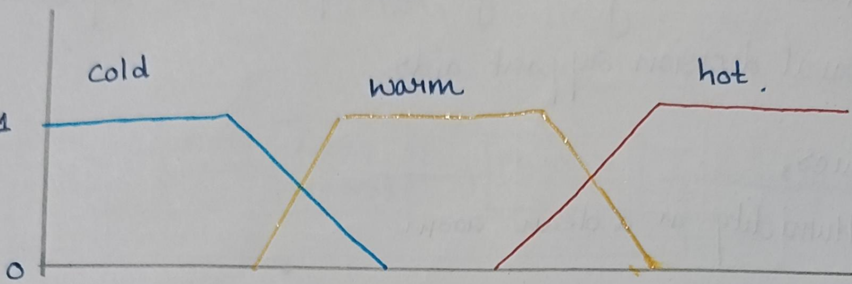
- Create fuzzy 'category memberships' function.
- To convert objectively measurable parameters to 'category memberships'.
- This is used for classification.

→ Slowest	→	0.0 - 0.25
Slow	→	0.25 - 0.50
Fast	→	0.50 - 0.75
Fastest	→	0.75 - 1.00

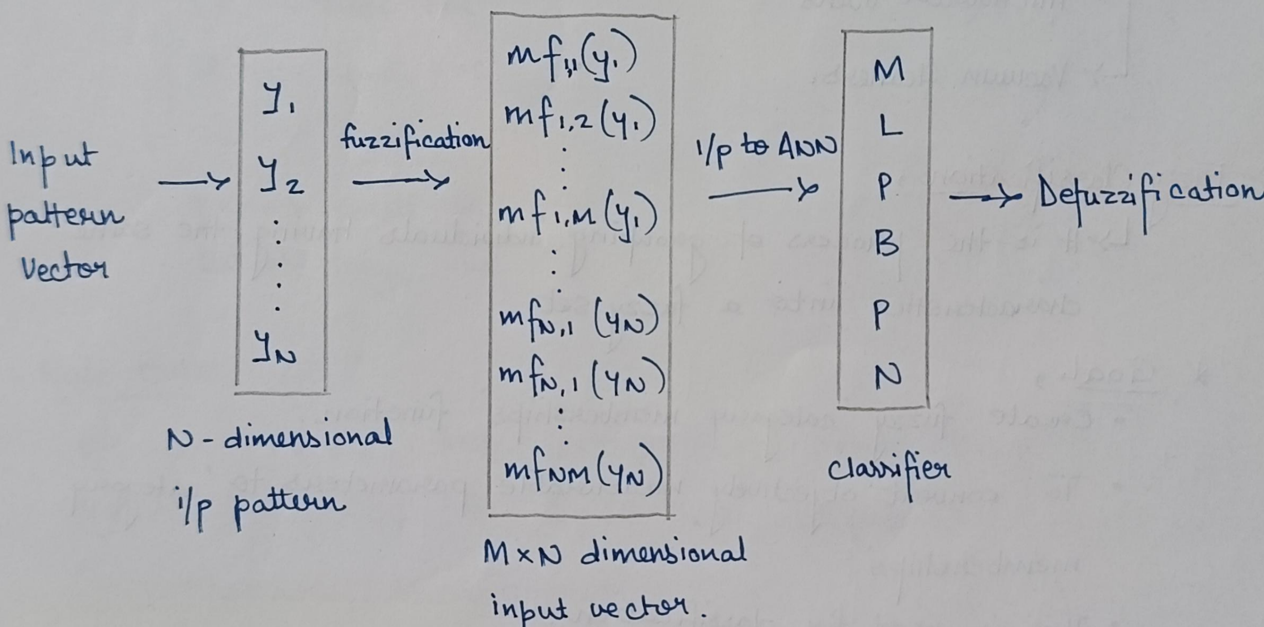
Ann is 28	0.8 in young
Bob is 35	0.1 in young
Charlie is 23	1.0 in young
Don is 54	0.0 in young.

- Categories do not refer to final classes,
  - ↳ They refer to overlapping ranges of features values.

Eg:

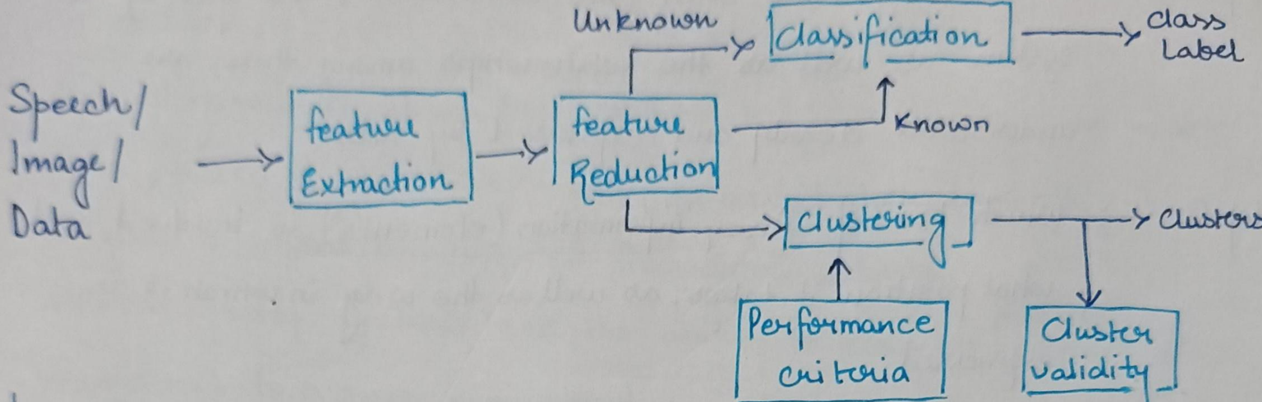


* Neuro fuzzy Classification,



- Fuzzy Clustering vs Hard Clustering,
  - ↳ It assigns a membership value to each point in each possible cluster, and assigns the point to the cluster in which it has the highest 'membership'.
  - ↳ Each datapoint can belong to more than one cluster.
  - ↳ Each datapoint is uniquely ~~identified~~ assigned to one and only one cluster.

Fuzzy Pattern Recognition.



↳ Can be classified into two categories.

- ↳ Supervised. → set of human-annotated training samples.
- ↳ Unsupervised. → identify patterns based on the i/p features.

↳ During the training process, the system learns to distinguish b/w different classes of samples by associating a distinctive set of features values with each class.

↳ Fuzzy pattern recognition, on the other hand, assigns fuzzy membership values to all classes for each object.

- Fuzzy Pattern recognition systems are desiged to handle uncertainity and imprecision in data classification.
  - → Membership Values. {0 to 1 range, instead of crisp values}
  - → Handling Ambiguity. {useful when objects do not belong to one class}
  - → feature Utilization. {They use a set of features to evaluate the MF.}
  - → Practical Applications. {In realworld, credit Scoring, medical diagnosis, image recognition}

• Fuzzy Optimization,

Step 1 → In this stage, the state, the constraints, and goals of the system as well as the relationships among them are understood clearly and expressed by sets.

Step 2 → which kind of fuzzy information (elements) is involved and what position it takes, as well as the way in which it is expressed.

Step 3 → Based on S1 and S2, an appropriate fuzzy optimization model will be built, by adopting some mathematical tools.

Step 4 → On the basis of S2, the fuzzy information including ambiguity and vagueness has been distinguished.

Step 5 → Transformation of the fuzzy optimization model into an equivalent or an approximate crisp optimization model.
- → Optimal Solution
- → Interpretation
- → Transformation.

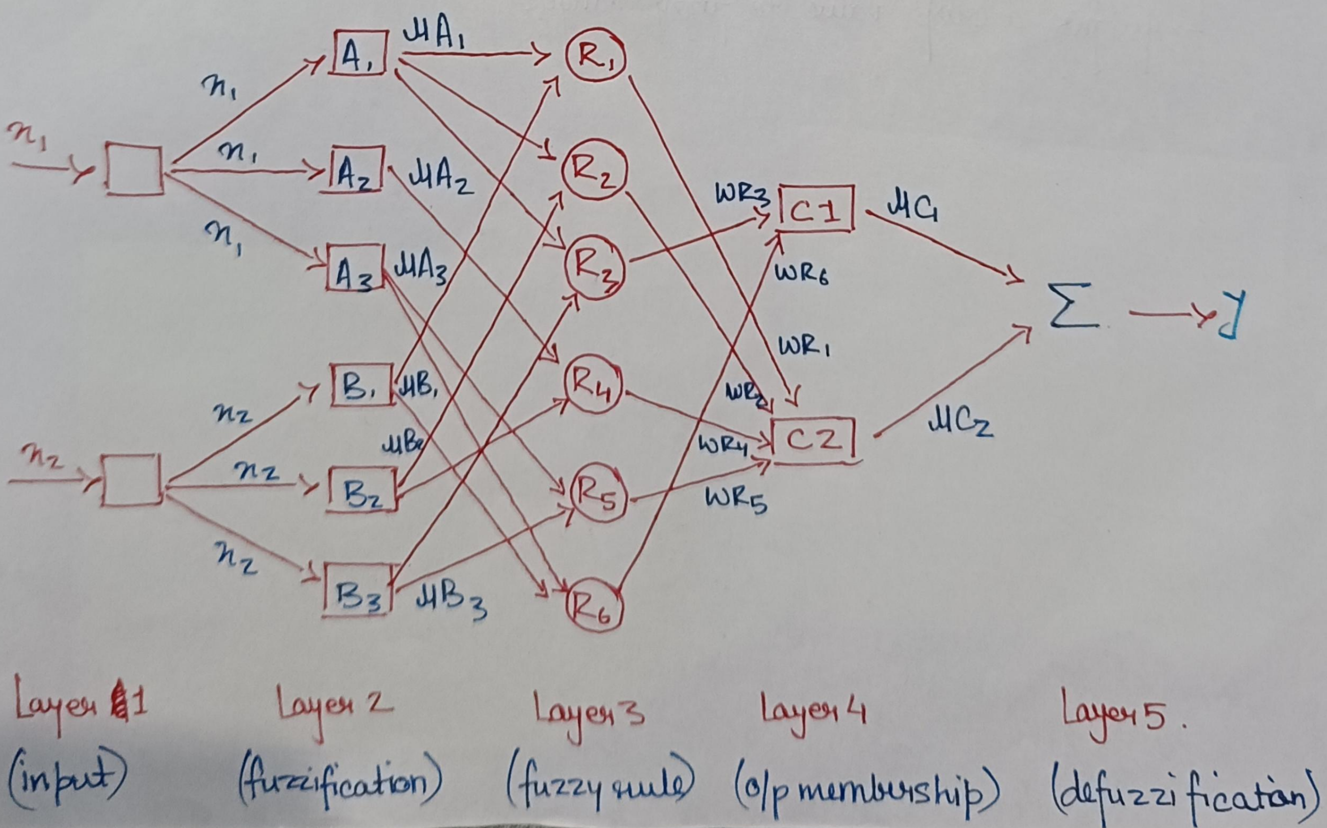
Type of optimal solution is determined.

Step 6 → Solving the crisp optimization model.
- → Rule-based or hybrid algorithms can be developed.

Step 7 → Validity Examination
- → Obtained optimal solution is not always acceptable, so there is a need to check its validity.
- → fuzzy modeling process should be improved iteratively.

...uro fuzzy System,

- fuzzy logic and neural networks are natural complementary tools, in building intelligent systems. While neural networks are low level computational structures that perform well when dealing with raw data, fuzzy logic deals with reasoning on a higher level using linguistic information acquired from domain experts.
- However, fuzzy systems lack the ability to learn and cannot adjust themselves to a new environment.
- Integrated neuro-fuzzy systems can combine the parallel computation & learning abilities of neuro networks with the human like knowledge representation and explanation abilities of fuzzy systems.
- As a result, neural networks become more transparent, while fuzzy systems become capable of learning.



* Type 1 and Type-2 fuzzy expert system,

* T1 fuzzy systems are working with a fixed membership function.

* In T1 fuzzy set, Expert should determine the degree of achieving the characteristics of the object.

* Eg: If a ball is red, then how much, 85%, 70% or 50%.

→ T2 fuzzy system, the membership function keeps fluctuating.

* In T2 fuzzy set, Expert can't determine exactly the degree of achieving the characteristics.

* Eg: If a ball is red, then how much, 75 to 80%, 85-90% or 95 to 100%.

* Mem. Func^n in fuzzy System, → To solve a problem.

→ Assigns a crisp value to fuzzy range.

- The combination of fuzzy logic and neural networks constitute a powerful means for designing intelligent systems.
- Domain knowledge can be put into a neurofuzzy system by human experts in the form of linguistic variables & fuzzy rules.

Triangular MF;

$$y_i^{(2)} = \begin{cases} 0, & \text{if } x_i^{(2)} \leq a - b/2 \\ 1 - \dfrac{2|x_i^{(2)} - a|}{b}, & \text{if } a - \dfrac{b}{2} < x_i^{(2)} < a + \dfrac{b}{2} \\ 0, & \text{if } x_i^{(2)} \geq a + \dfrac{b}{2} \end{cases}$$