ECII/ECSI 3206:
Artificial Intelligence [and expert systems]
Topic 5: Fuzzy logic and Fuzzy Logic Systems

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Introduction to Fuzzy Logic

Fuzzy-This defines when something is not clear or when something is vague[vagueness]

Fuzzy Logic- This is a method of reasoning that resembles human reasoning and it involves finding all the possibilities between a digital Value of YES or NO, True or False, 0 or 1.

Forms of Knowledge in Fuzzy Logic

- Knowledge exists in two forms when considered within a fuzzy logic perspective
  - Objective knowledge[mathematical form]
  - Subjective knowledge[linguistic form]

Fuzzy logic can coordinate these two forms of knowledge in a logical way.

Human vs Computer Decision making

- Unlike computers , human decision making includes a range of possibilities between YES and NO i.e
  - Certainly YES
  - Possibly YES
  - Cannot say
  - Possibly NO
  - Certainly NO

Cont…

- Fuzzy Logic works on the levels of possible inputs to achieve some desired output
- It can be implemented in the form of Hardware, Software or Both H/W and S/W.

Merits of FLS

- Fuzzy logic Systems can take imprecise, distorted, noisy input information.
- FLSs are easy to construct and understand.
- Mathematical concepts within fuzzy reasoning are very simple.
- You can modify a FLS by just adding or deleting rules due to flexibility of fuzzy logic.
- Fuzzy logic is a solution to complex problems in all fields of life, including medicine, as it resembles human reasoning and decision making.

Demerits of FLS

- They are understandable only when simple.
- There is no systematic approach to fuzzy system designing.
- They are suitable for the problems which do not need high accuracy.

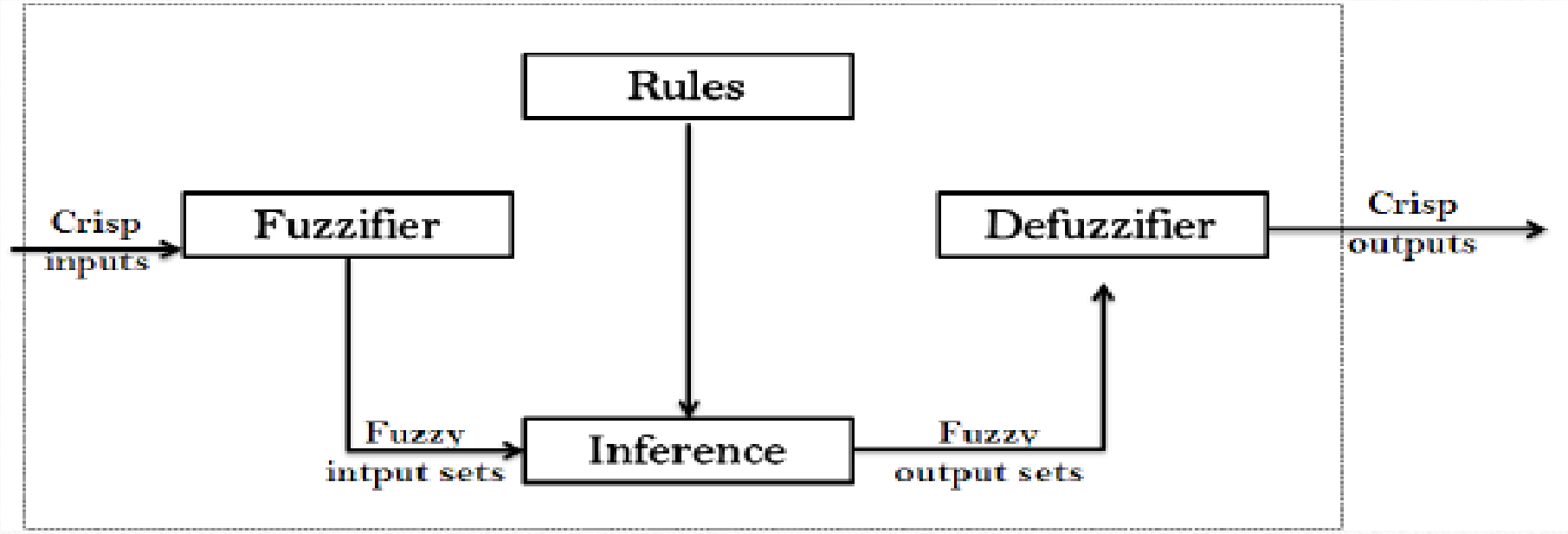
Applications of F.L.S

- Automotive Systems[Gearbox , Vehicle A/C]
- Electronic goods[TV, Camera, Fridge, Washing Machine]
- Navigation Systems[Autopilot]
- Robot Vision

Fuzzy Logic Systems Architecture

- It is made up of four main parts as follows:
  - Fuzzification module
  - Knowledge base
  - Inference engine
  - Deffuzification module
  - Member Function

Diagram of a F.L.S



Member function

1.Fuzzification module

- Fuzzification is a process of transforming *crisp values* into grades of membership for linguistic terms of fuzzy sets.
  The purpose is to allow a fuzzy condition in a rule to be interpreted.

- -It transforms *crisp input* into fuzzy sets e.g It splits input X into 5 steps LP,MP,S,MN,LN

2. Knowledge base/Rules

-This component stores the IF …… THEN rules provided by the various experts in a given field

-A collection of rules referring to a particular system is known as a fuzzy rule base.

- IF (a set of conditions) are satisfied THEN (a set of consequents) can be inferred.

Cont..

- IF(x_1 isA_1, x_2 isA_2, x_n is A_n) THEN(y_1 is B_1, y_2 is B_2, y_n is B_n) where linguistic variables x_i, y_j take the values of fuzzy sets A_i and B_j respectively.
- Example
  - IF there is "heavy" rain and "strong" winds THEN there must "severe" flood warnings.

    Here, heavy , strong , and severe are fuzzy sets qualifying the variables rain, wind, and flood warnings respectively.

3.Inference Engine/Intelligence/Fuzzy Inference

- It is the core element of a fuzzy system.
- It simulates human reasoning process by making reference to the inputs and the IF…THEN rules that are stored in the knowledge base then conducts the fuzzy reasoning process(*Approximate reasoning*)
- It uses the principles of ***Modus Ponens*** and ***Modus Tollens***

Cont..

- **Modus Ponens**
  - If P and P → Q are premises, we can us Modus Ponens to derive Q. e.g If you have a password, you can log into your TUK account. Having a password[P],that implies that you can log into your TUK account[P → Q].

Cont…

- **Modus Tollens**
  - If P → Q and ¬Q are premises, we can use Modus Tollens to derive ¬P. e.g If you have a password ,you can log into your TUK account P → Q .If you cannot log into your TUK Account [¬Q], that means that you don’t have a password[¬P].

4. Defuzzification module

- This component transforms the fuzzy set obtained by Inference engine into *Crisp output*
- Defuzzification is the reverse process of Fuzzification.

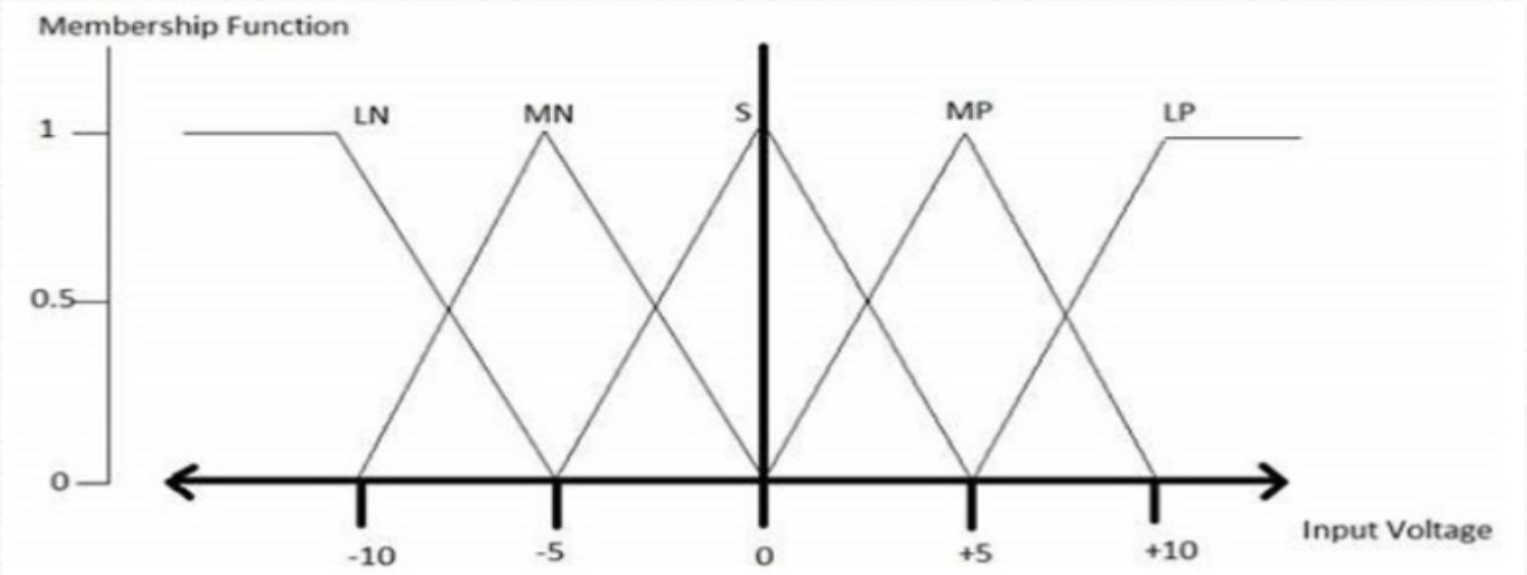
Member Function

- It is a function which allows us to quantify linguistic terms and represent fuzzy sets graphically.
- The member function for a fuzzy set A on the universe of X is given as below
  - $M_A: X \rightarrow [0,1]$

    [Where the distance between 0 and 1 represent the degree/value of membership.]

Graphical Representation of a member function

- This example assumes a five level Fuzzifier



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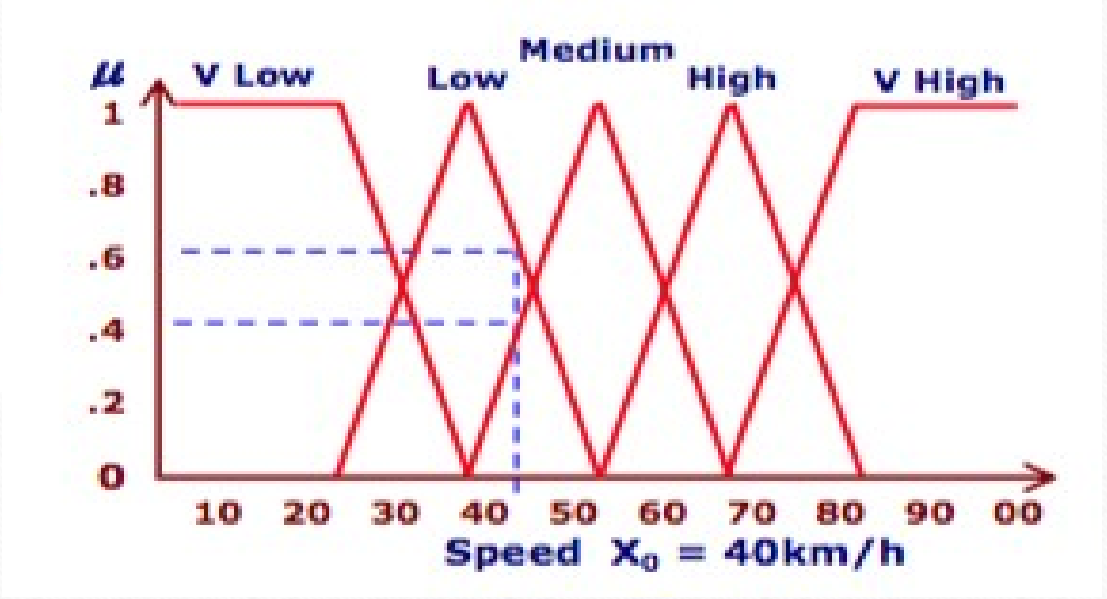
- Member function Graph for the speed of a car [assuming that the medium speed is 55km/h]. Consider a car moving at 44km/h..

grade $\mu_A(x_0) = 0.6$ belongs to fuzzy low, and grade $\mu_B(x_0) = 0.4$ belongs to fuzzy medium.



Crisp Logic vs Fuzzy(non crisp) Logic

- Consider the examples below: Example 1.
  - If someone is >=1.8 m in height, we say you are “tall”, otherwise, we say you are “not tall”. “Tall” students qualify to be members of a basketball team while “non tall” students don’t qualify. What if a student is 1cm shorter e.g 1.79m?

Cont….

- A student of 1.79m would belong to both “tall” and “not tall” but what varies is the degree of membership.
- As a student’s height increases, their membership within the “tall” category would also increase while their membership within the “non tall” category would decrease

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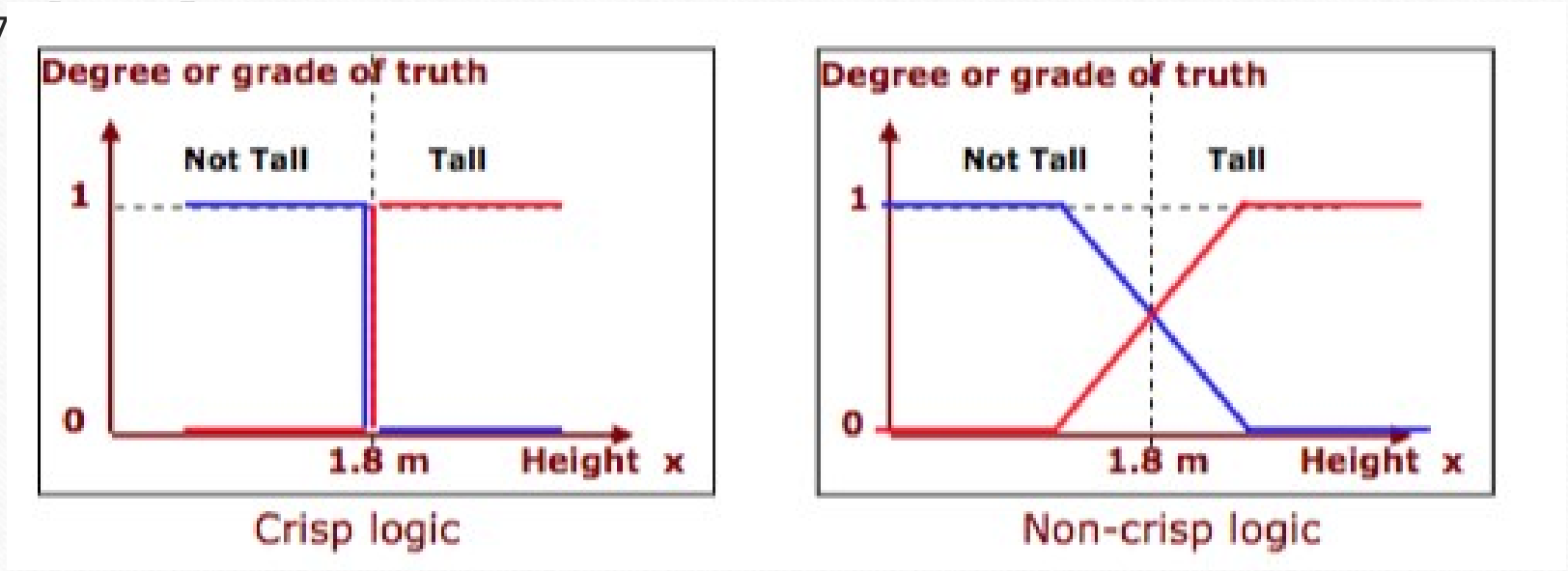
- Representation in the form of crisp and non crisp[fuzzy v



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- Consider the examples below: Example 2.
  - Consider the set of numbers between 1 and 12 .
  - This can be represented as 1>=x<=12
    - Consider the prime numbers within this set{2,3,5,7,11}(crisp set)
    - How would the graphical representation of the prime numbers look like?

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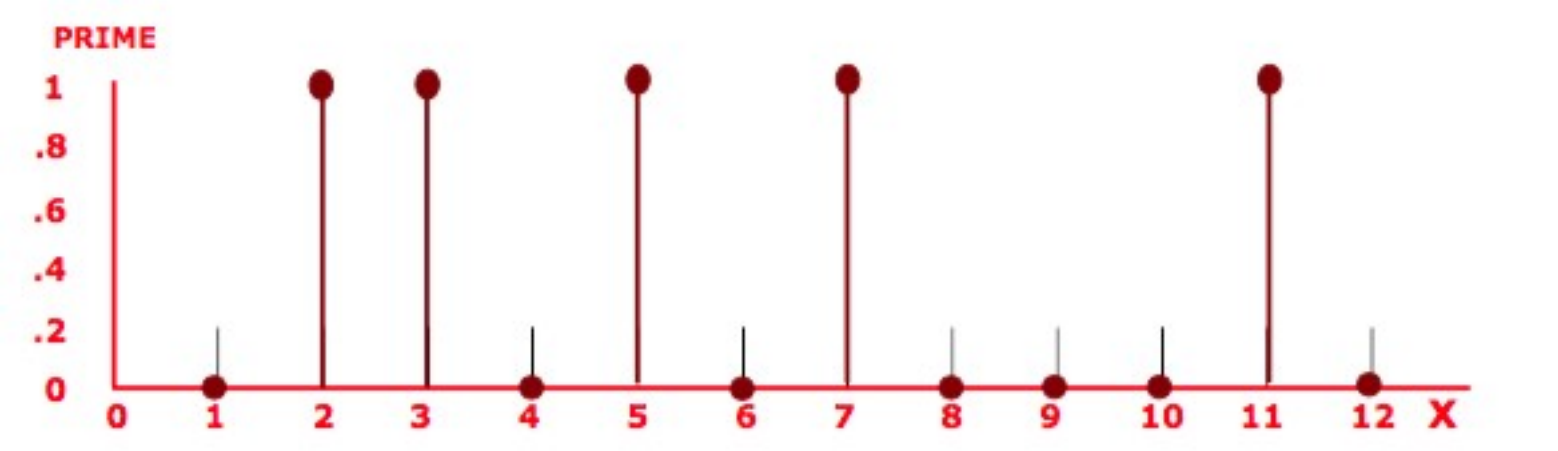

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- Also using the same set of 1to 12, Consider a set of all small numbers between 1 and 12.(non crisp set)
  - We make the assumption that 1 is a small number but 12 is not a small number. Therefore , we can represent this using a **Universal space**.[A universal space is a way used to describes the start, end and increment of a set] e.g Universal Set x={1,12,1}
    - How would the graphical representation of the prime numbers look like?

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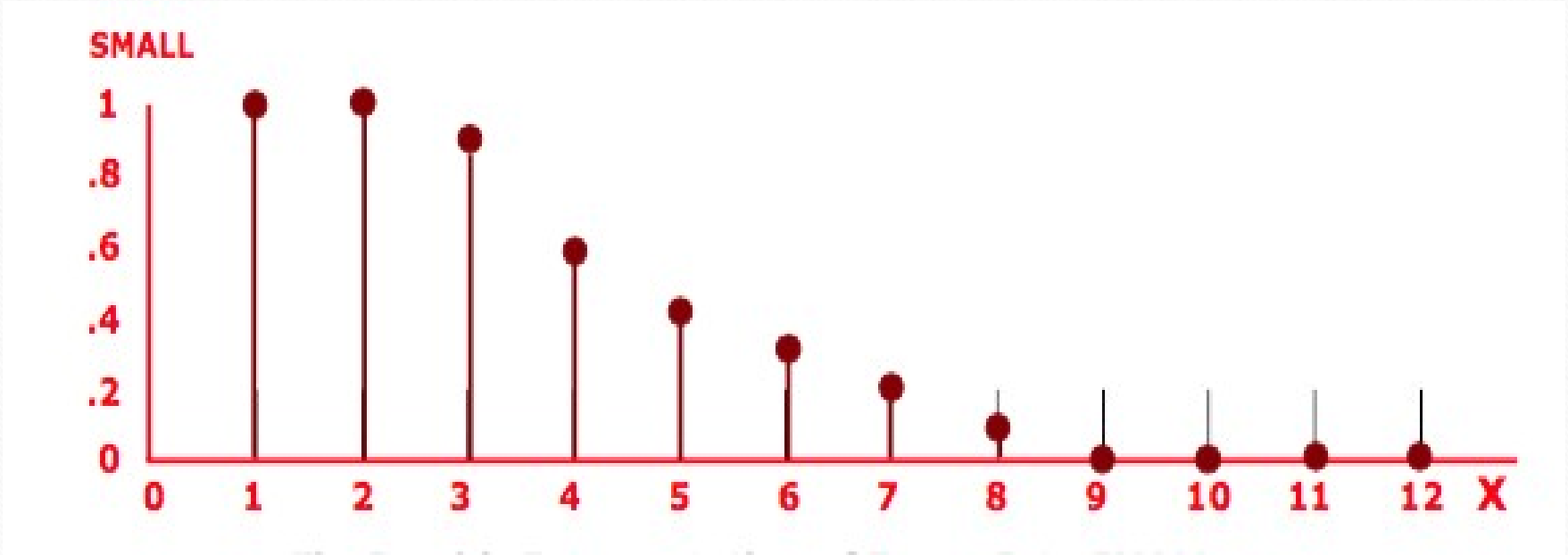

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- Universal sets can be finite or infinite.
  Any universal set is finite if it consists of a specific number of different elements, that is, if in counting the different elements of the set, the counting can come to an end, else the set is infinite.

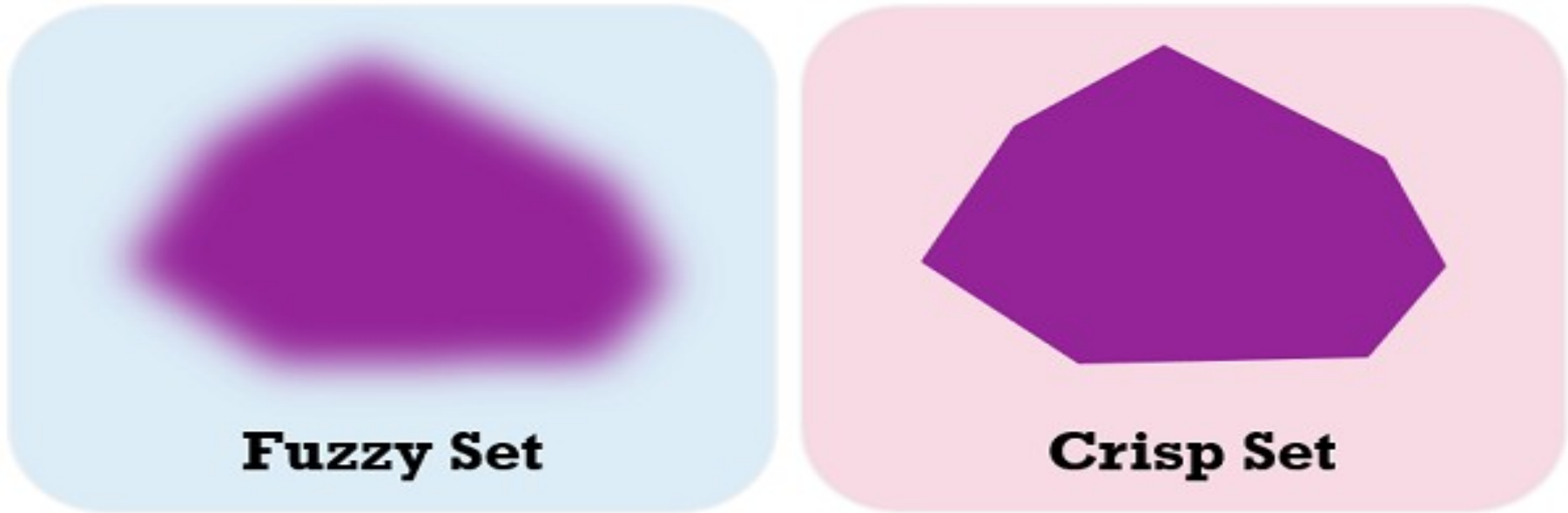
Examples:

1. Let N be the universal space of the days of the week. N = {Mo, Tu, We, Th, Fr, Sa, Su}. [N is finite]

2. Let M={1,3,5,7,9,...}. [M is infinite]

3. Let L={u|u is a lake in a county}. [L is finite]
(Although it may be difficult to count the number of lakes in a county, but L is still a finite universal set.)

Fuzzy vs Crisp[Non Fuzzy set]



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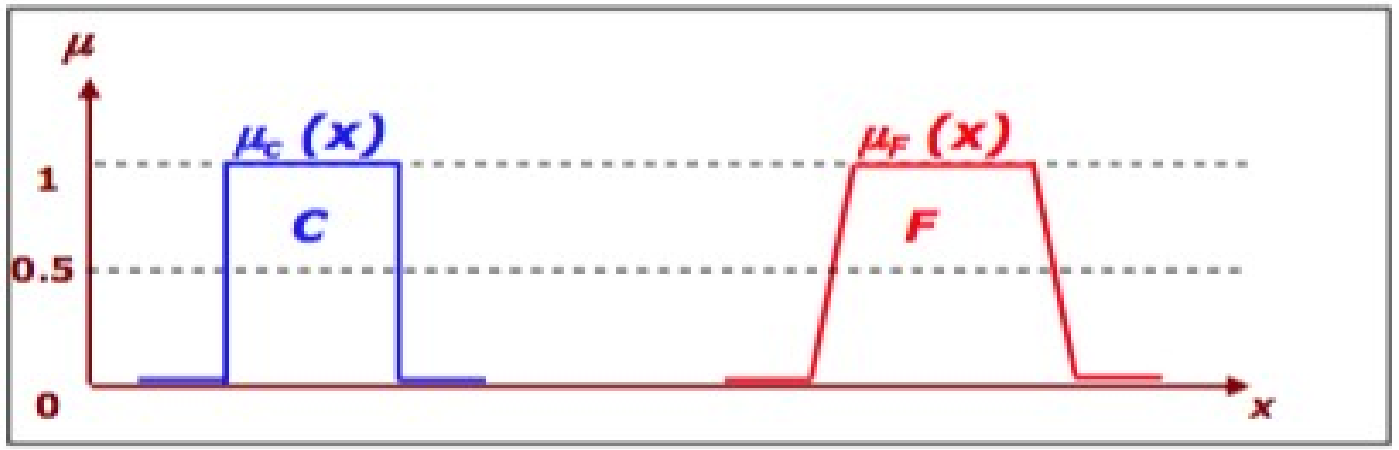
- A Fuzzy Set is any set that allows its members to have different degree of membership, called membership function, in the interval [0 , 1].

Capturing Uncertainty

- A member function for a Crisp set and non crisp set. Crisp set is a subset of fuzzy set

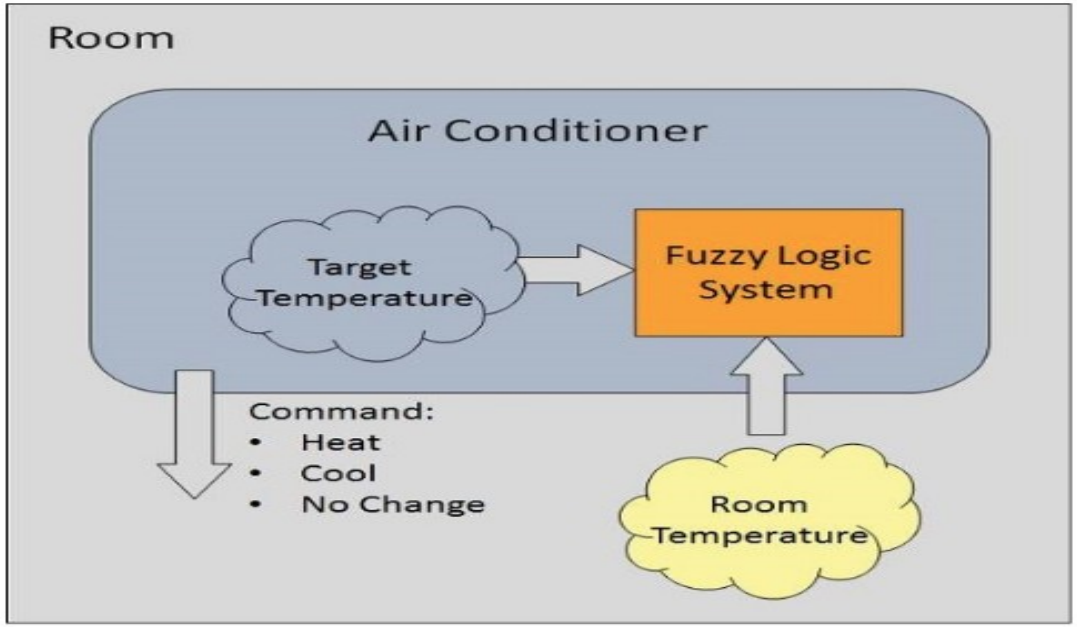


Algorithm For Functioning of FLS

- 1.define linguistic variables/terms
- 2.Construct membership function[m.f]
- 3.Construct Rule base/Knowledge Base
- 4.Convert Crisp input into a fussy dataset using member function[Fuzzification]
- 5.Evaluate rules in the Knowledge Base
- 6. Combine results for each Rule
- 7.Convert Fuzzy output into Crisp output[Deffuzification]

Real world Example

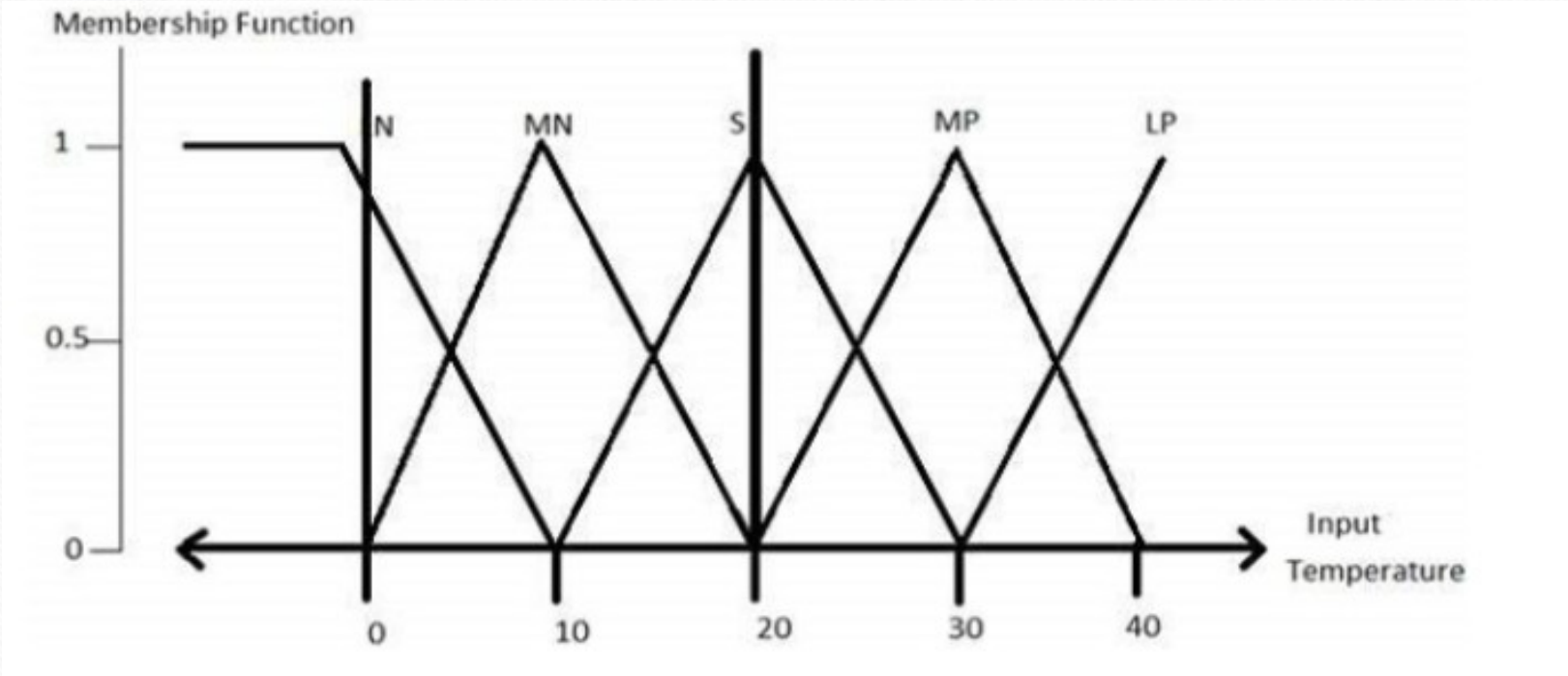
- Consider an Air conditioning System with a 5 level Fuzzy Logic System. The system adjusts temperature by comparing the room temp
temperature.



1. Define linguistic Variables

- The temperature ranges can be either :
  - VC-Very cold
  - C-Cold
  - W-warm/Normal
  - H-Hot
  - VH-very Hot

2. Construct member Function[m.f]



3.Construct Knowledge Base/Rule Base

RoomTemp. /Target	Very_Cold	Cold	Warm	Hot	Very_Hot
Very_Cold	No_Change	Heat	Heat	Heat	Heat
Cold	Cool	No_Change	Heat	Heat	Heat
Warm	Cool	Cool	No_Change	Heat	Heat
Hot	Cool	Cool	Cool	No_Change	Heat
Very_Hot	Cool	Cool	Cool	Cool	No_Change

4.Convert Crisp input into a fussy dataset using member function[Fuzzification]

- In this case , we will convert the table in Step 3. into rules

RULE	CONDITION	ACTION
1	IF Room Temp=C or VC and T.T=W THEN	HEAT
2	IF Room Temp=H or VH and T.T=W THEN	COOL
3	IF Room Temp=W and T.T=W THEN	NO CHANGE

Other steps[5,6,7]

- After these the Air conditioning system will perform the next three remaining steps so as to make adjustments to the target temperature
  - 5.Evaluate rules in the Knowledge Base
  - 6. Combine results for each Rule
  - 7.Convert Fuzzy output into Crisp output[Deffuzification]