Fuzzy Expert Systems

What is fuzzy thinking?

- Experts rely on common sense when they solve problems

- How can we represent expert knowledge that uses vague and ambiguous terms in a computer?

- Fuzzy logic is not logic that is fuzzy, but logic that is used to describe fuzziness. Fuzzy logic is the theory of fuzzy sets, sets that calibrate vagueness.

- Fuzzy logic is based on the idea that all things admit of degrees. Temperature, height, speed, distance, beauty – all come on a sliding scale.

- The motor is running *really hot*. Tom is a *very tall* guy.

- Boolean logic used sharp distinctions. It forces us to draw lines between members of a class and non-members.

- For instance, we may say, Tom is tall because his height is 181 cm. If we drew a line at 180cm, we would find that David, who is 179cm, is short.

- Fuzzy Logic reflects how people think. It attempts to model our sense of words, our decision making and our common sense. As a result, it is leading to new, more human, intelligent systems.

What are fuzzy systems?

- It works on fuzzy logic, which superset of conventional (Boolean) logic that has been extended to handle the concept of partial truth -- truth values between "completely true" and "completely false".

- It provides a systematic, intuitive and mathematical means of handling uncertainty in natural and artificial systems

Different types of uncertainty:

- Classical uncertain
  - “Will I get a HD for this unit?”
  - Uncertain and precise
  - Mostly can be handle by probability theory

- Vague
  - “Steve is tall”
  - Certain but imprecise
  - Can be handle by fuzzy sets and fuzzy logic

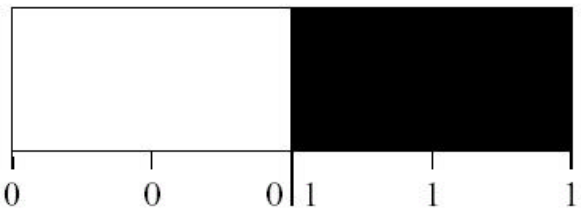
- Imprecise
  - o "Mark weighs between 50kg and 65 kg"
  - o Uncertain and imprecise
  - o Probability or possibilities theory

Fuzzy Logic?

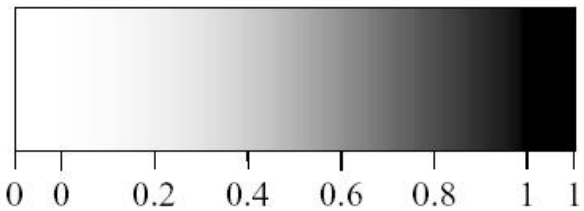
- **Fuzzy Logic** is a set of mathematical principles for knowledge representation based on degrees of membership.

- Unlike two-valued Boolean logic, fuzzy logic is multi-valued. It deals with *degrees of membership* and *degrees of truth*.

- Fuzzy logic uses the continuum of logical values between 0 (completely false) and 1 (completely true). Instead of just black and white, it employs the spectrum of colours, accepting that things can be partly true and partly false at the same time.



(*a*) Boolean Logic.



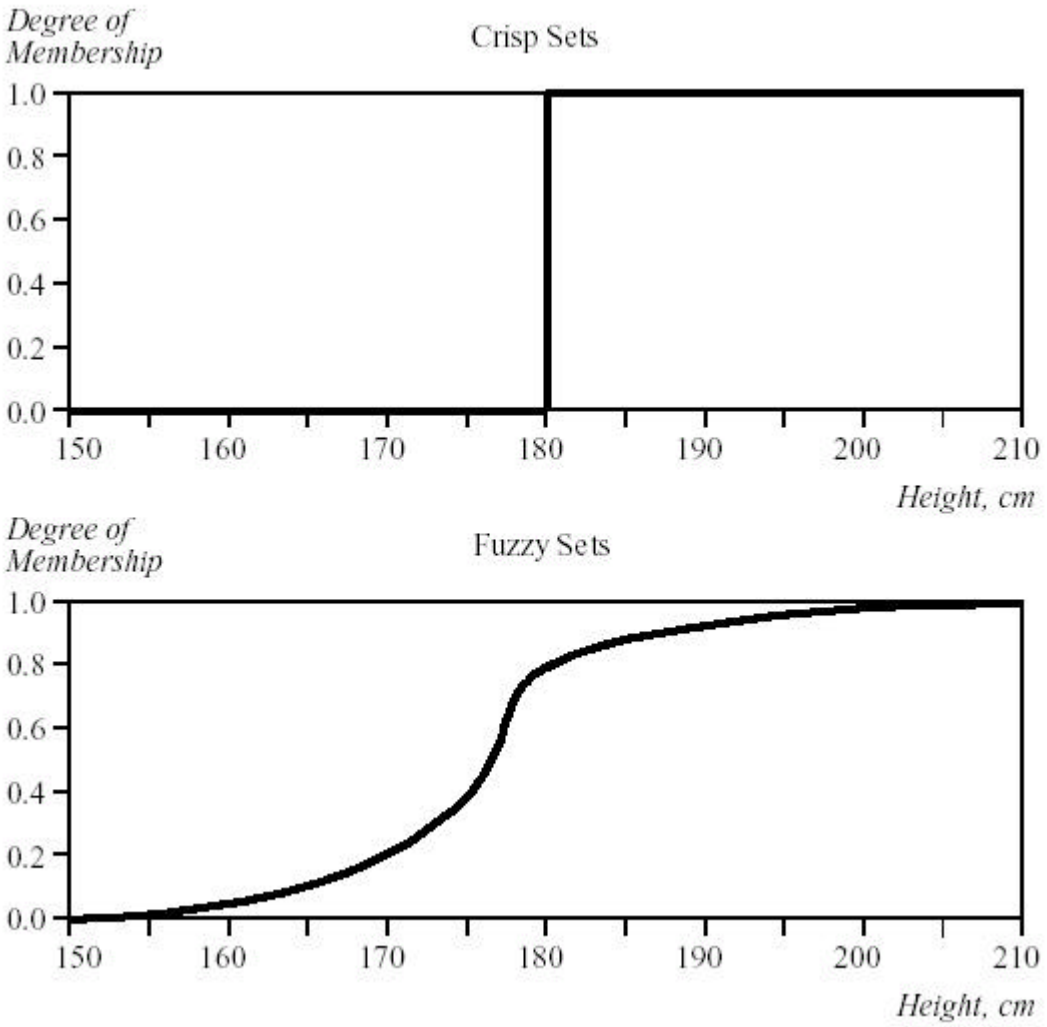
(*b*) Multi-valued Logic.

What are fuzzy sets?

- is a class of objects in which there is no sharp boundary between those objects that belong to the class and those that do not. (ì – membership)

- The classical example in fuzzy sets is tall men. The elements of his fuzzy set “tall men” are all men, but their degrees of membership depend on their height.

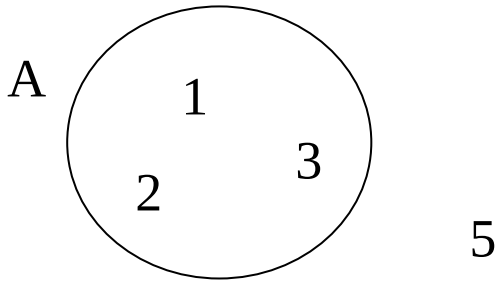
Name	Height, cm	Degree of Membership	
		Crisp	*Fuzzy*
Chris	208	1	1.00
Mark	205	1	1.00
John	198	1	0.98
Tom	181	1	0.82
David	179	0	0.78
Mike	172	0	0.24
Bob	167	0	0.15
Steven	158	0	0.06
Bill	155	0	0.01
Peter	152	0	0.00



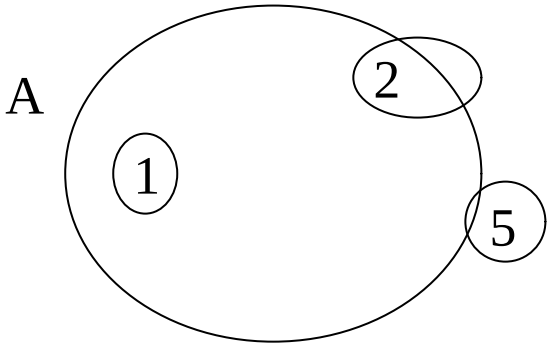
- The x-axis represents the *universe of discourse* – the range of all possible values applicable to a chosen variable. In our case, the variable is the man height. According to this representation, the universe of men's heights consists of all tall men.

- The y-axis represents the membership value of the fuzzy sets. In our case, the fuzzy set of "tall men" maps height values into corresponding membership values.

- Crisp set A = {1, 2, 3}, $\mu_1(A)=1$, $\mu_5=(A)=0$

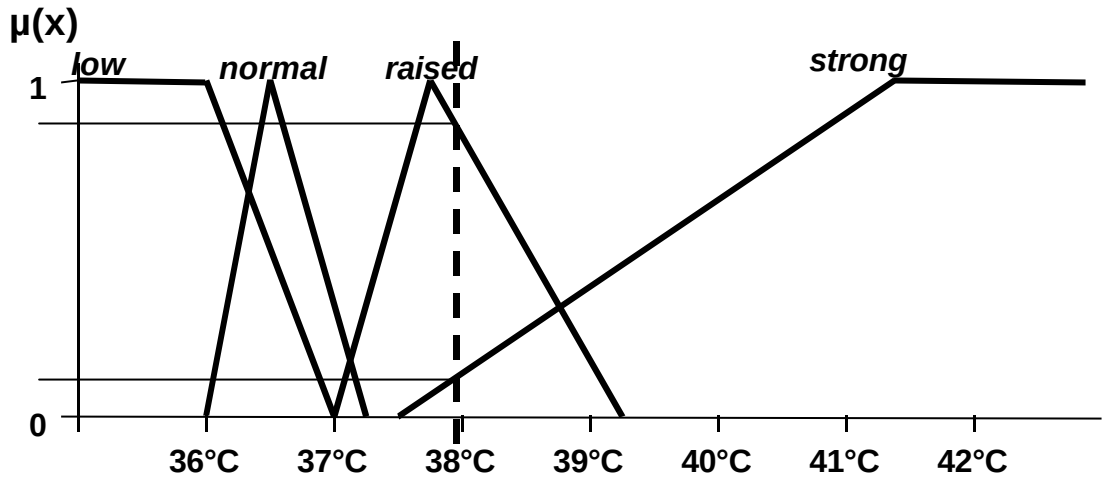


- Fuzzy set A={1.0/1, 0.6/2, 0.1/5}, $\mu_1(A)=1$, $\mu_5(A)=0.1$



Fuzzy memberships

- distribution of truth of a variable



- The distribution of the four membership functions are as follows:-

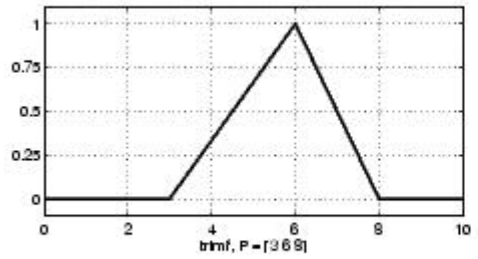
  low temp={(1,35),(1,36),(0,37)}
  normal temp={(0,36),(1,36.8),(0,37.2)}
  raised temp={(0,37),(1,37.8),(0.9,38),(0,39.2)}
  strong fever={(0,37.5),(0.5,39.5),(0.9,41)}

- A person with temperature at 38 C has pretty much *raised temperature* but just slightly *strong fever*

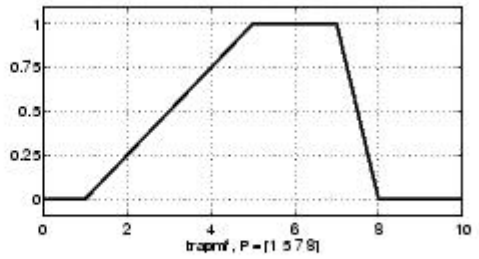
- The membership value at 38 C for *raised temperature* is 0.9 and for *strong fever* is 0.1, and for others is 0.

- show the degree of truth or confidence

- 4 common types of fuzzy membership functions:
  - triangular (3 parameters) trapezoidal(4 para)

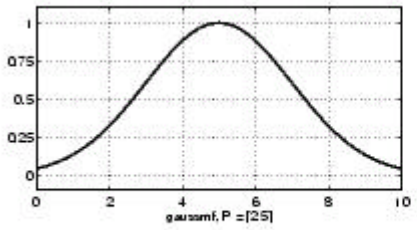


trimf

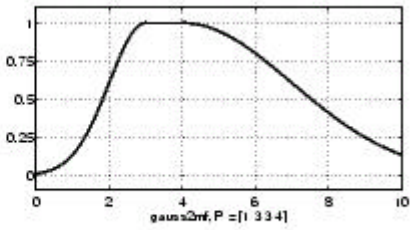


trapmf

  - gaussian (2 parameters)

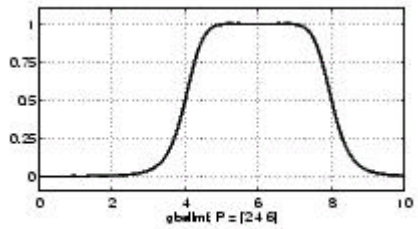


gaussmf



gauss2mf

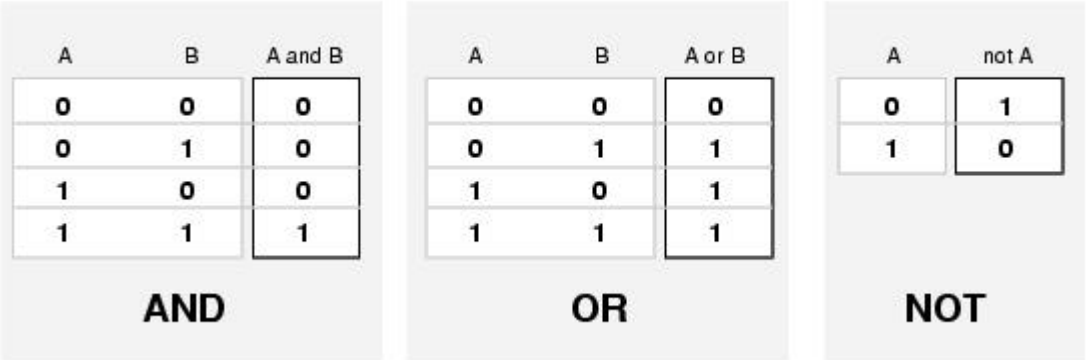
  - generalised bell (3 parameters)



gbellmf

Logic operation

- is a superset of standard Boolean logic



A	B	A and B
0	0	0
0	1	0
1	0	0
1	1	1

AND

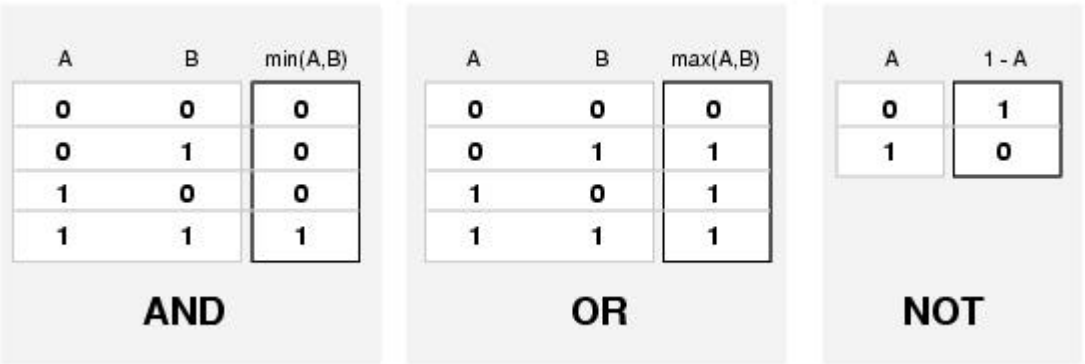
A	B	A or B
0	0	0
0	1	1
1	0	1
1	1	1

OR

A	not A
0	1
1	0

NOT

- in fuzzy logical reasoning, AND is the *min* operation, OR is the *max* operation, and NOT becomes *1-A*



A	B	min(A,B)
0	0	0
0	1	0
1	0	0
1	1	1

AND

A	B	max(A,B)
0	0	0
0	1	1
1	0	1
1	1	1

OR

A	1 - A
0	1
1	0

NOT

- in the case if A=0.5, B=0.7, and C = A OR B, then C = max(0.5,0.7)=0.7

- if we are looking for F = A and B, then F=min(0.5,0.7)=0.5

Linguistic variables and hedges

- At the root of fuzzy set theory lies the idea of linguistic variables

- A linguistic variable is a **fuzzy variable**. For example, the statement “John is tall” implies that the linguistics variable John takes the linguistic value tall.

- In fuzzy expert systems, linguistic variables are used in fuzzy rules.

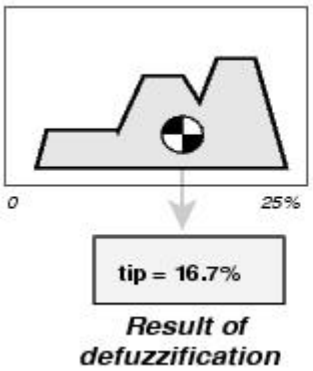
Main Components of a fuzzy system

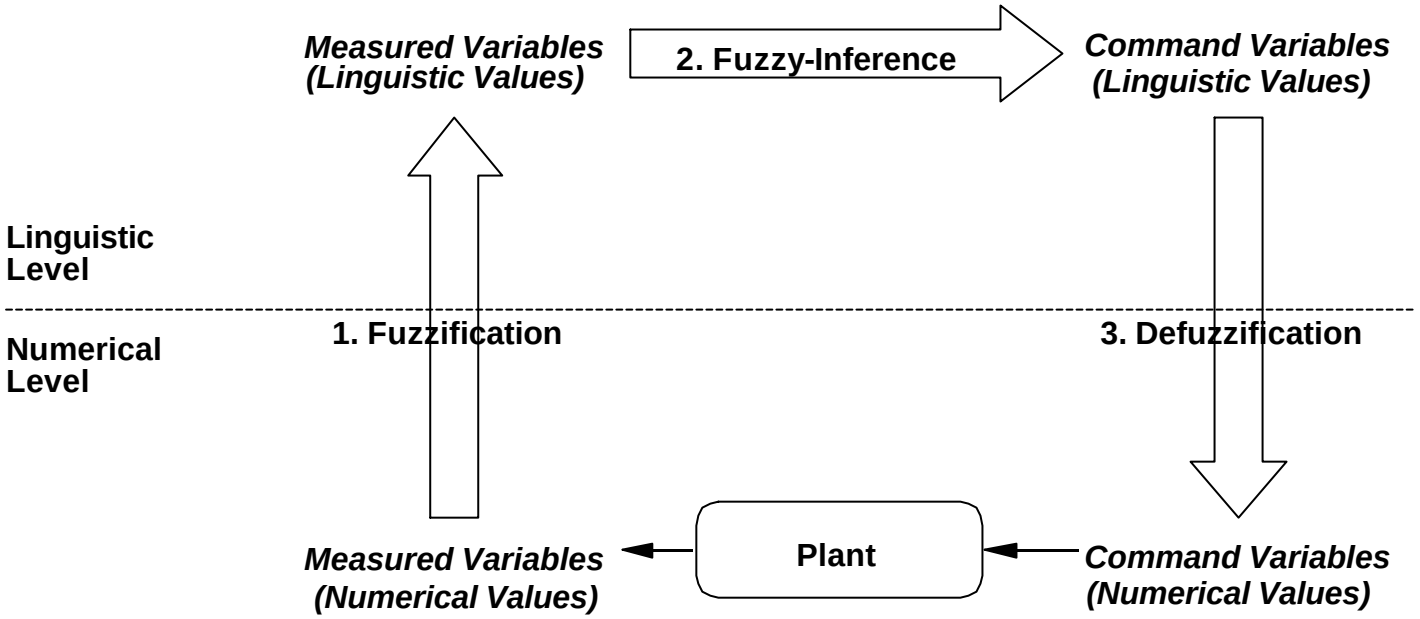
- There are basically three main components:-

    1. **Fuzzification** – convert values to fuzzy inputs by using membership functions

    2. **Fuzzy inference** – using fuzzy rules to form fuzzy output

    3. **Defuzzification** – using output membership functions and defuzzification techniques to produce system output value.
        - the commonly used defuzzification method is known as centroid


0
25%
5. Defuzzify the aggregate output (centroid).
tip = 16.7%
Result of defuzzification


Measured Variables (Linguistic Values)
2. Fuzzy-Inference
Command Variables (Linguistic Values)
Linguistic Level
Numerical Level
1. Fuzzification
3. Defuzzification
Measured Variables (Numerical Values)
Plant
Command Variables (Numerical Values)

Fuzzy Rules

- Using if-then rule statements to formulate the conditional statements that comprise fuzzy logic.

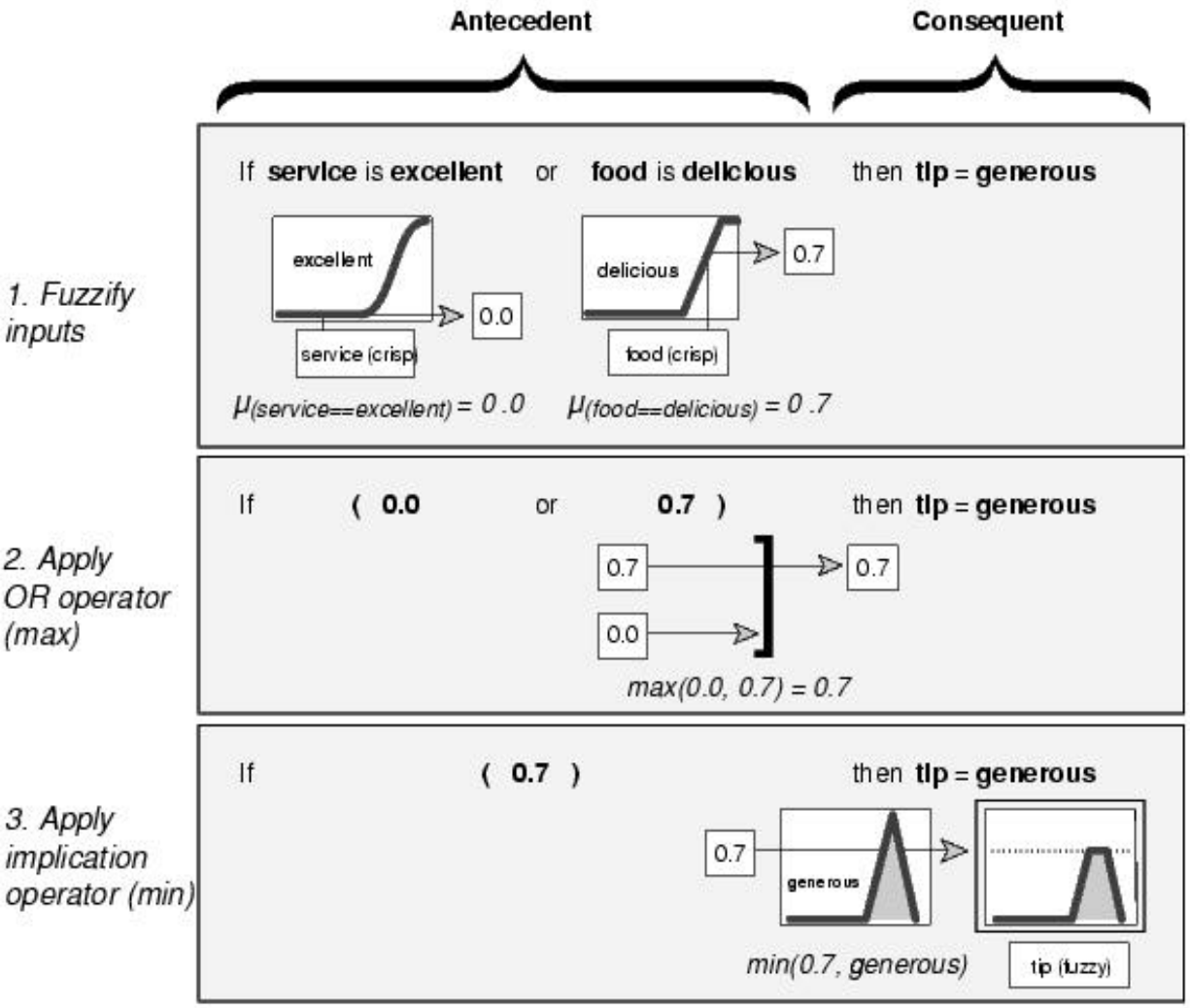
- A single fuzzy if-then rule assumes the form

  if *x* is *A* then *y* is *B*

  where A and B are linguistic values defined by fuzzy sets on the ranges (universes of discourse) X and Y, respectively

  - Example:

    if *service* is *good* then *tip* is *average*



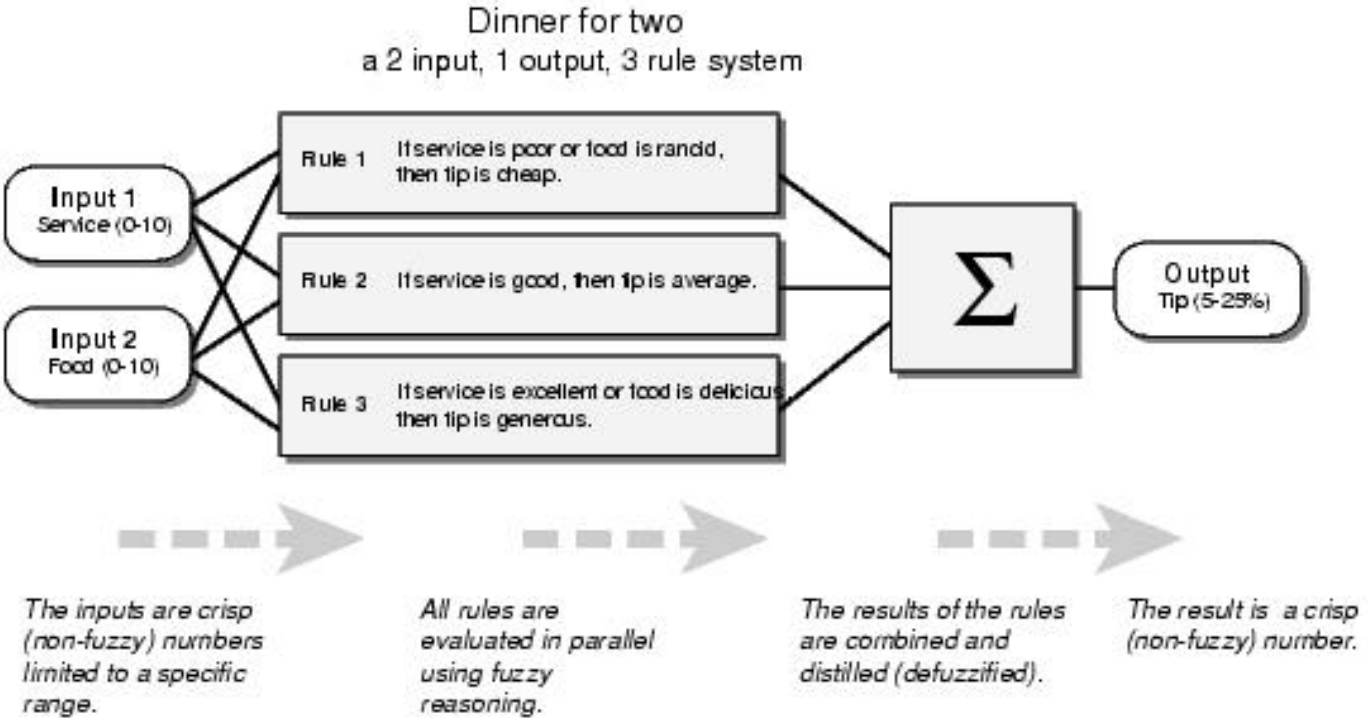
Fuzzy inference systems

- Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic

- The process of fuzzy inference involves all of the pieces that are described in the previous slides: membership functions, fuzzy logic operators, and fuzzy rules

- The two main types of inference systems:-
    1. Mamdani-type
    2. Sugeno-type

- These two types of inference systems vary somewhat in the way outputs are determined



Advantages of using fuzzy logic

- Conceptually easy to understand.

  The mathematical concepts behind fuzzy reasoning are very simple.

- Flexible.

  You can modify and add on fuzzy rules without starting from scratch.

- Tolerant of imprecise data.

  Everything is imprecise if you look closely enough, but more than that, most things are imprecise even on careful inspection.

- Can model nonlinear functions of arbitrary complexity.

  Can create a fuzzy system to match any set of input-output data.

- Can be built on top of the experience of experts.

- Is close to natural language.

Disadvantages of using fuzzy logic

- Creating the fuzzy rules base

  It is difficult to create the fuzzy rules base from input-output data if no fuzzy rule extraction technique is used

- Accuracy of the inference depends directly to the number of fuzzy rules used in complex problem

- The increase in input variables and fuzzy membership used will increase the number of fuzzy rules exponentially.

  Number of fuzzy rules = M^I

  where M = number of membership function
  I = number of input variables

Fuzzy Clustering

- Traditionally, each data point is said to be belonging to a cluster or not belonging to a cluster

- In fuzzy clustering, each data point belongs to a cluster to some degree that is specified by a membership grade.

- Non-overlapping cluster

	Cluster 1	Cluster 2	Cluster 3
John	1	0	0
Mary	0	0	1
Terry	0	1	0
Patrick	1	0	0

- Overlapping cluster

	Cluster 1	Cluster 2	Cluster 3
John	1	1	0
Mary	0	0	1
Terry	0	1	1
Patrick	1	0	1

- Fuzzy clustering

	Cluster 1	Cluster 2	Cluster 3
John	0.5	0.4	0.1
Mary	0.1	0.1	0.8
Terry	0	0.6	0.4
Patrick	0.6	0.1	0.3

- Fuzzy C-means (FCM) originally introduced by Jim Bezdek in 1981 is popular in generating fuzzy clusters.