

NPTEL ONLINE CERTIFICATION COURSES

Course Name: Fuzzy logic and Neural Networks

Faculty Name: Prof. D. K. Pratihar

Department : Mechanical Engineering

Week 4

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Topic

Lecture 04: Optimal Design of Fuzzy Reasoning and Clustering Tools

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CONCEPTS COVERED

Concepts Covered:

- Nature-inspired Optimization Tools
- Optimization of Fuzzy Reasoning Tool
- Optimization related to Fuzzy Clustering

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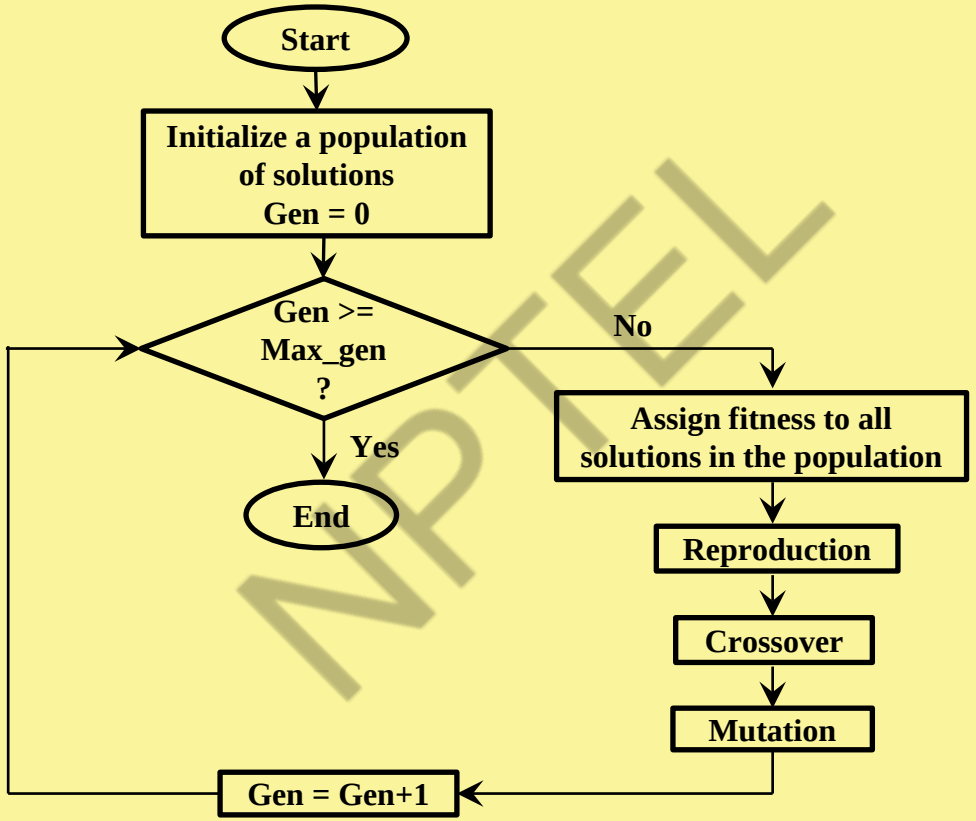
Nature-inspired Optimization Tools

- Genetic Algorithms (GA)
- Genetic Programming (GP)
- Evolution Strategies (ES)
- Evolutionary Programming (EP)
- Particle Swarm Optimization (PSO)
- Ant Colony Optimization (ACO)
- Artificial Immune system (AIS)
- Artificial Bee Colony (ABC)
- Others

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Genetic Algorithm (GA)

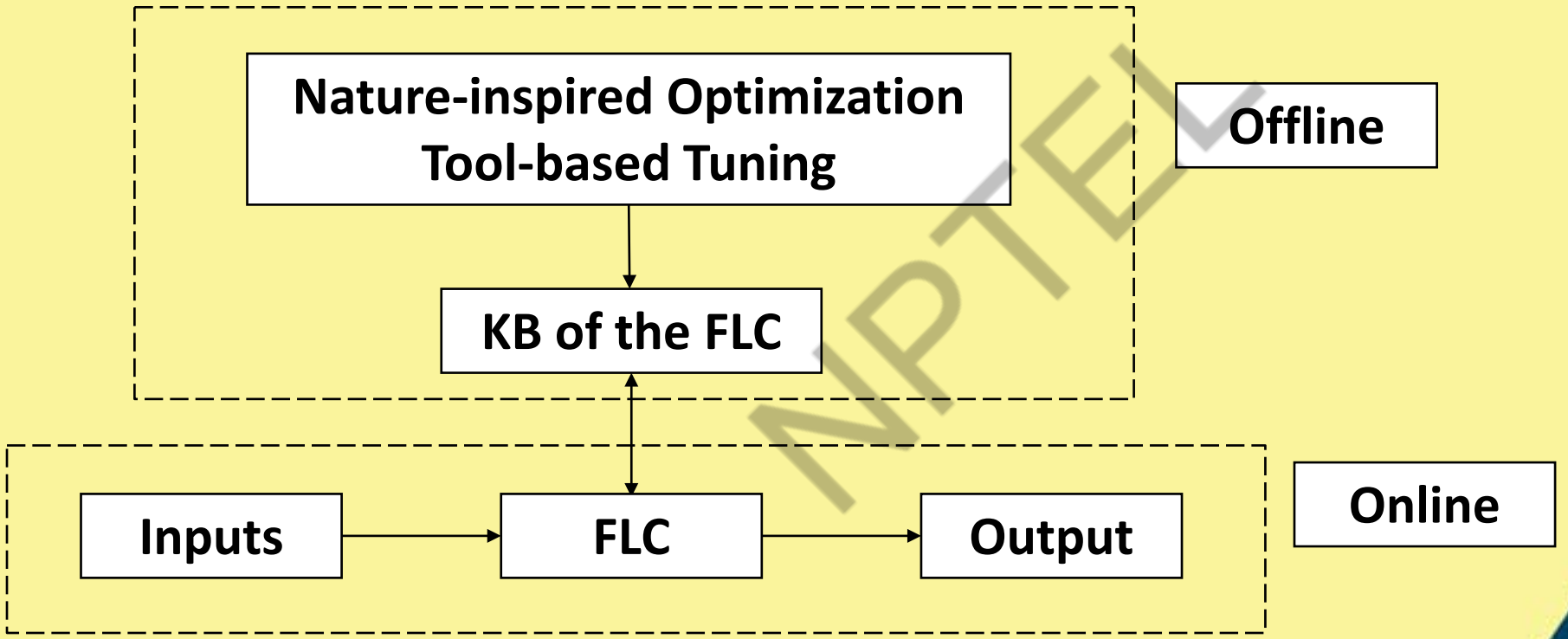
Working cycle



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Optimization of Fuzzy Reasoning Tool

- Performance of Fuzzy Logic Controller (FLC) depends on its KB consisting of Data Base (DB) and Rule base (RB)



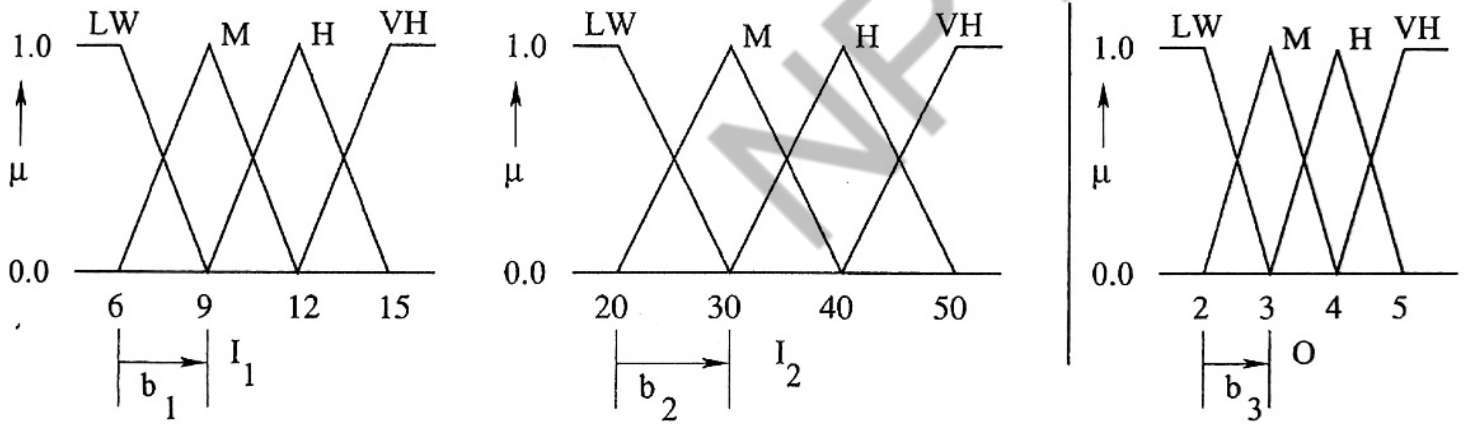
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Developed Approaches

Approach 1 : GA–based tuning of manually constructed FLC

Numerical Example

A binary-coded GA is used to obtain optimal DB and RB of a fuzzy reasoning tool. There are two inputs: I_1 and I_2 and one output: O of the process. The membership function distributions of the inputs and output are shown below.



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The manually-constructed RB is given below

	I_2				
I_1		LW	M	H	VH
	LW	LW	LW	M	H
	M	LW	M	H	H
	H	M	M	H	VH
	VH	M	H	VH	VH

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A binary-coded GA is used to optimize both DB as well as RB of the fuzzy reasoning tool with the help of a set of training cases (refer to the table given below.)

Sl. No.	I_1	I_2	O
1	10.0	28.0	3.5
2	14.0	15.0	4.0
. . .	. . .	. . .	. . .
T	17.0	31.0	4.6

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An initial population of the BCGA is created at random, as shown below

Sl. No.	GA-string
1	10110011011101110001010111001
2	01100101101101000101011010
. . .	. . .
N	10100011101011101001001101110 11

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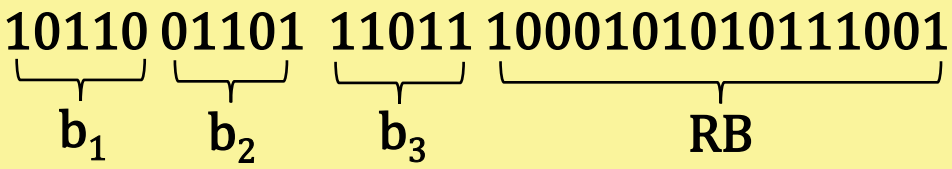
Starting from the left most bit-position five bits are assigned to represent each of the b values (that is, b_1, b_2 and b_3) and the next 16 bits represent the RB of the fuzzy reasoning tool. Determine the deviation in prediction for the first training case by using the first GA-string. The b values are assumed to vary in the ranges given below.

$$2.0 \leq b_1 \leq 4.0$$
$$5.0 \leq b_2 \leq 15.0$$
$$0.5 \leq b_3 \leq 1.5$$

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Solution:

GA-string



To determine the real value of b_1:

D.V. = 22

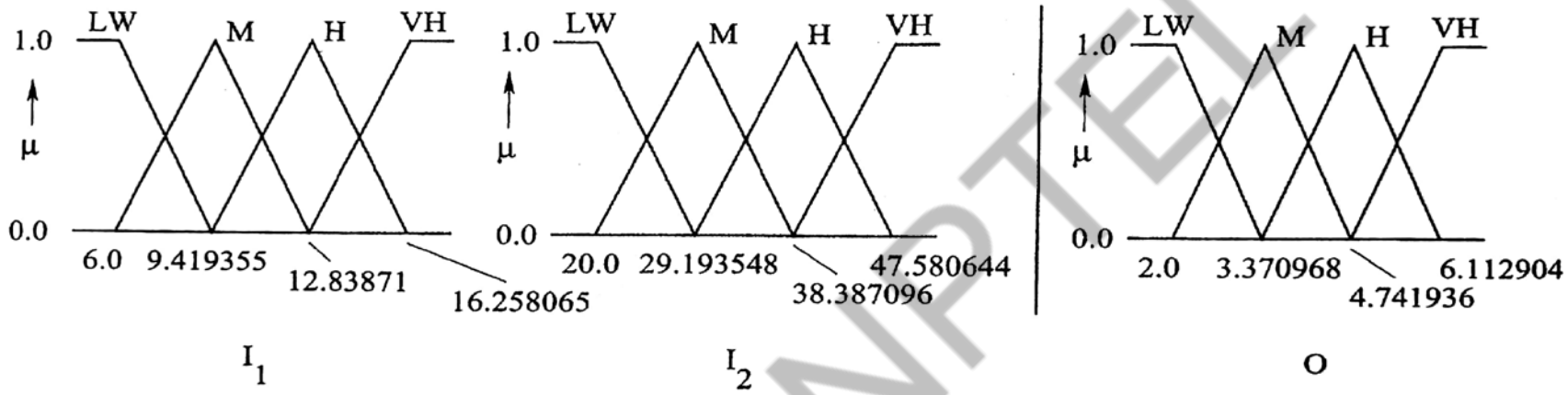
Using linear Mapping rule, we get

b_1 = 3.419355

Similarly, we get b_2 = 9.193548, b_3 = 1.370968

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Corresponding to b_1, b_2 and b_3, the modified membership function distributions are found to be as follows:



LW: Low; M: Medium; H: High; VH: Very High

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Corresponding to the sub-string: 1000101010111001, the RB is found to be as follows:

		I_2			
		LW	M	H	VH
I_1	LW	LW	-	-	-
	M	LW	-	H	-
	H	M	-	H	VH
	VH	M	-	-	VH

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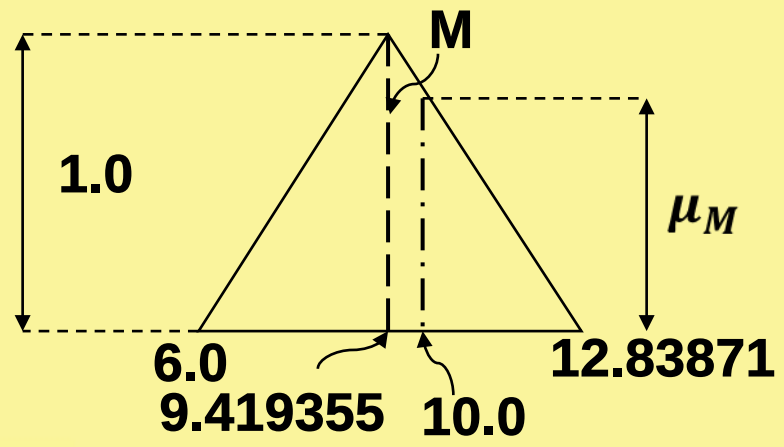
For the inputs: $I_1 = 10.0, I_2 = 28.0$

The fired present rules are as follows:

If I_1 is M AND I_2 is LW Then O is LW,

If I_1 is H AND I_2 is LW Then O is M.

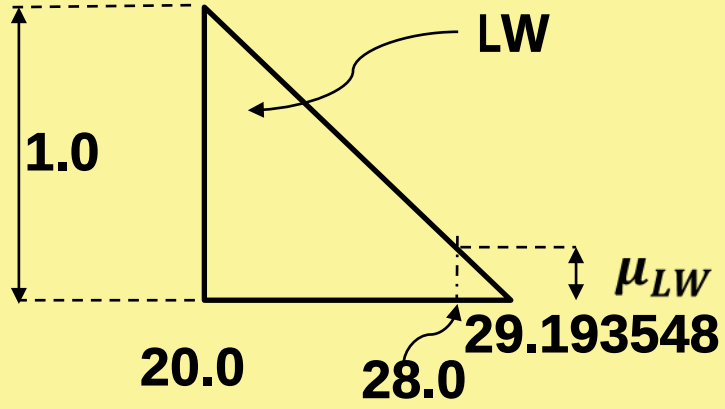
Membership values' calculation



$$\frac{\mu_M}{1.0} = \frac{12.83871 - 10.0}{12.83871 - 9.419355}$$

$$\therefore \mu_M = 0.83$$

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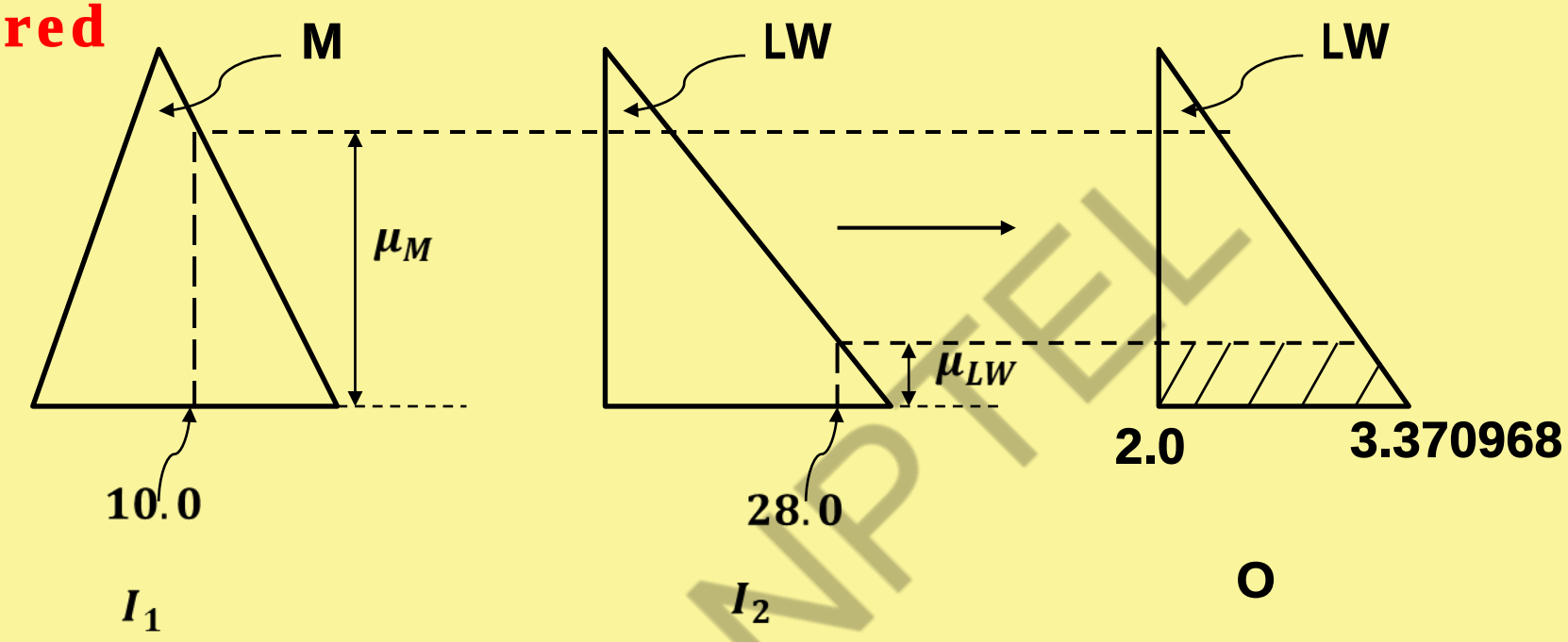


$$\frac{\mu_{LW}}{1.0} = \frac{29.193548 - 28.0}{29.193548 - 20.0}$$

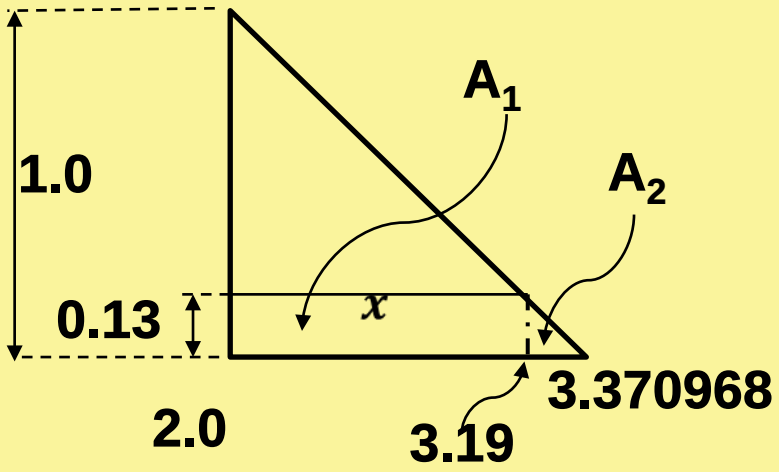
$$\therefore \mu_{LW} = 0.13$$

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1st Fired Rule



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$$\frac{x}{3.370968 - 2.0} = \frac{1.0 - 0.13}{1.0}$$

$$\Rightarrow \quad x = 1.19$$

Area $A_1 = (3.19 - 2.0) \times 0.13 = 0.1547$

$C_1 =$ Center of Area $= 2.595$

Area $A_2 = \frac{1}{2} \times (3.370968 - 3.19) \times 0.13 = 0.01176$

$C_2 =$ Center of Area

$$= 3.19 + \frac{1}{3} \times (3.370968 - 3.19)$$

$$= 3.25$$

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Total Area $A' = A_1 + A_2 = 0.16646$

Center of combined area

$$C' = \frac{A_1 C_1 + A_2 C_2}{A_1 + A_2}$$

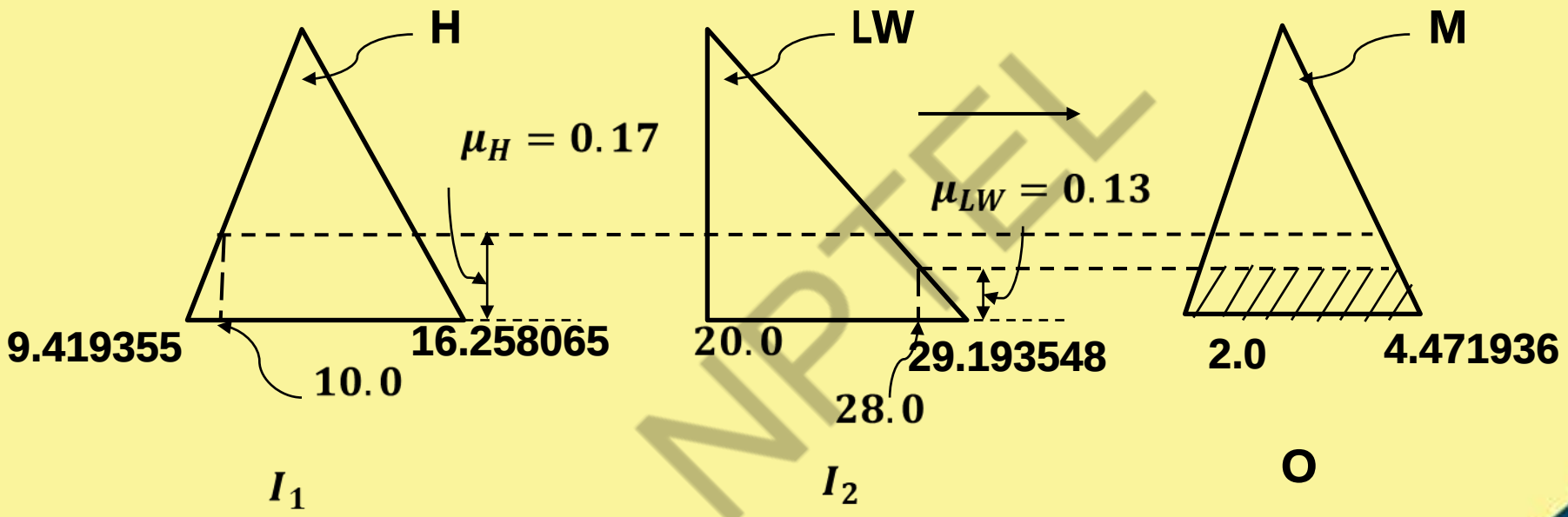
$$= \frac{0.1547 \times 2.595 + 0.01176 \times 3.25}{0.16646}$$

$$= 2.64$$

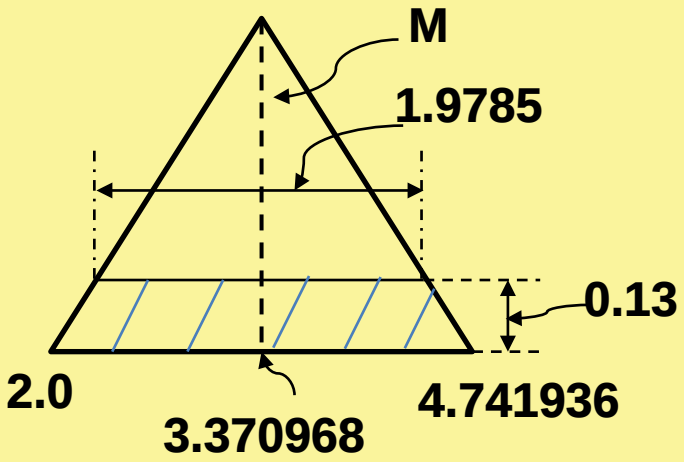
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2nd Fired Rule



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Total area $A'' = \frac{1}{2} \times (1.9785 + 2.741936) \times 0.13$

$= 0.3068$

Center of the fired area $C'' = 3.370968$

By using Center of Sums method of de-fuzzification:

Crisp output $O = \frac{A'C' + A''C''}{A' + A''}$

$$= \frac{0.16646 \times 2.64 + 0.3068 \times 3.370968}{0.16646 + 0.3068}$$

$$= 3.1138$$

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Deviation $d_1 = |3.5 - 3.1168| = 0.3832$
corresponding to the first training case.
Pass all the training cases and determine the deviation values as follows:

Sl. No.	I_1	I_2	O	Deviation in prediction
1	10.0	28.0	3.5	d_1
2	14.0	15.0	4.0	d_2
⋮	⋮	⋮	⋮	⋮
T	17.0	31.0	4.6	d_T

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We calculate: $\bar{d} = \frac{\sum_{i=1}^{T} d_i}{T}$

Sl. No.	GA-string	Fitness
1	10110011011101110001010101110011	f_1
2	01100101101101000101011101100 10	f_2
⋮	⋮	⋮
N	10100011101011101001001101110 11	f_N

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Approach 2: Automatic design of FLC using GA

•Let us consider the same numerical example given above for Approach 1. However, it is assumed that RB used in Approach 1 is missing. As there are four linguistic terms for each of the two variables, there are 4 x 4 = 16 possible combinations of them. The output of each of these 16 rules is not pre-defined and this task of determining an appropriate RB is given to the GA. As four linguistic terms are used to represent the output, only two bits may be used to represent each of them. For example, the linguistic terms: LW, M, H, and VH are indicated by 00, 01, 10 and 11, respectively. Thus, the GA-string will be 5 + 5 + 5 + 16 + 2 x 16 = 63-bits long. Table A shows the population of GA-strings. Determine the deviation in prediction for the first training scenario: $I_1 = 10.0, I_2 = 28.0, O = 3.5$

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Table A

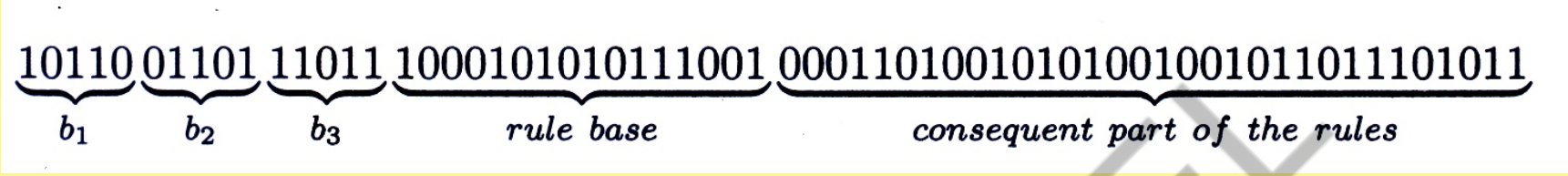
A population of GA-strings.

Sl. No.	GA-string
1	10110011011101110001010101110010001101001010100100101101101011
2	01100101101101000101011101100101000011010101110001010100001010 1
⋮	⋮
N	10100011101011101001001101110110011101010001110010101000110010 1

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Approach 2 (contd.)

- Let us consider the first GA-string shown in Table A

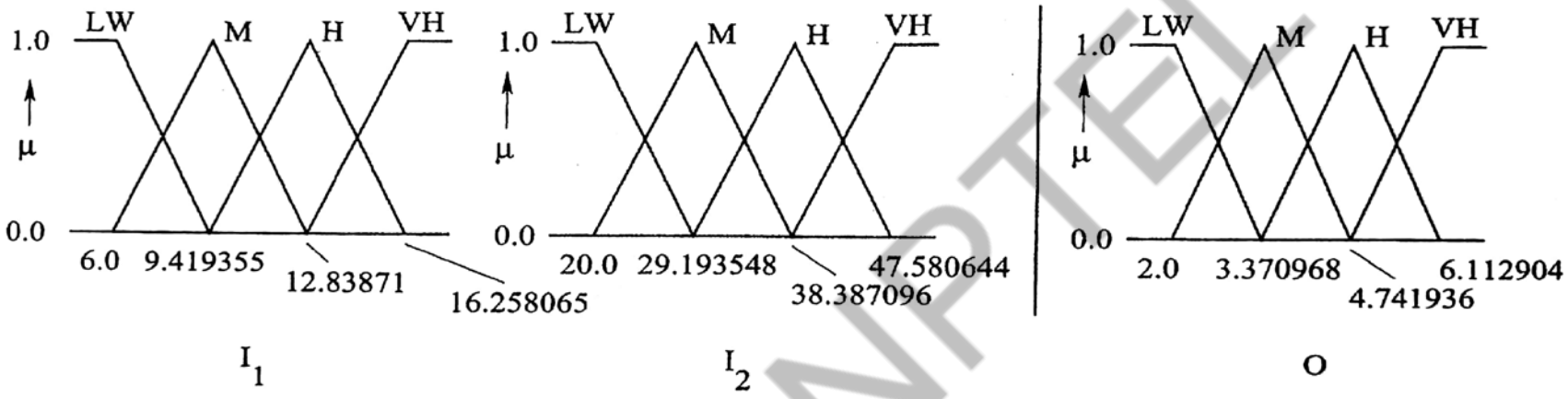


- Corresponding to the sub-string: 101100110111011, the real values of b_1, b_2 and b_3 are found to be equal to 3.419355, 9.193548 and 1.370968, respectively (refer to previous example). The modified membership function distributions of the input and output variables will be the same with those shown in Fig. A. The sub-strings: 1000101010111001 and 00011010010101001001011011101011 indicate that the following rules are present in the RB of the FLC (refer to Table B)

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Corresponding to b_1, b_2 and b_3, the modified membership function distributions are found to be as follows:

Fig. A



LW: Low; M: Medium; H: High; VH: Very High

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•Now, corresponding to the first training scenario, the output is calculated for the inputs: I_1=10.0 and I_2=28.0, in the following way. The input I_1=10.0 may be declared either M or H and other input I_2=28.0 may be called either LW or M. Therefore, only the following two rules are being fired from a total of eight shown in Table B

Table B

Rules represented by the GA-substring

		I_2			
		LW	M	H	VH
I_1	LW	LW	-	-	-
	M	M	-	M	-
	H	H	-	M	H
	VH	VH	-	-	VH

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- If I_1 is M AND I_2 is LW Then O is M
- If I_1 is H AND I_2 is LW Then O is H

- Using the above two fired rules of the FLC (Mamdani approach), fuzzified output corresponding to the said input variables has been obtained and the Center of Sums method of de-fuzzification is used to determine its crisp value. The output of the controller is found to be equal to 4.056452.

- Therefore, the absolute value of deviation in prediction, that is, d_1 can be determined as follows:

- $d_1 = |3.5 - 4.056452| = 0.556452$

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•The values of absolute deviation in predictions ($d_2, d_3, \ldots d_T$) can be determined for 2-nd, 3-rd,...,T-th training scenarios, respectively, using the similar procedure.

Absolute values of deviation in prediction for the training cases.

Sl. No.	I_1	I_2	O	Deviation in prediction
1	10.0	28.0	3.5	d_1
2	14.0	15.0	4.0	d_2
⋮	⋮	⋮	⋮	⋮
T	17.0	31.0	4.6	d_T

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•The average of absolute values of deviation in predictions ($\bar{d}$) can be calculated like the following:

•
$$\bar{d} = \frac{\sum_{i=1}^{T} d_i}{T}$$

•The fitness of first GA-string, that is, f_1 is made equal to $\bar{d}$. Similarly, the fitness values of other strings of the GA-population can be obtained.

A population of GA-strings.

Sl. No.	GA-string	
1	10110011011101110001010101110010001101001010100100101101101011	f_1
2	01100101101101000101011101100101000011010101110001010100001010 1	f_2
⋮	⋮	⋮
N	10100011101011101001001101110110011101010001110010101000110010 1	f_N

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•The population of GA-strings is modified utilizing different operators, such as reproduction, crossover and mutation.

•Note: The GA-optimized RB of the FLC obtained above may contain some redundant rules. To identify the redundant rules, the concept of importance factor has been used. To determine the importance of a rule, both its probability of occurrence as well as worth have been considered.

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Optimization related to Fuzzy Clustering

- To Maximize Distinctness and compactness and minimize the no. of outliers

Fuzzy C-Means Clustering

- Number of clusters to be made
- Initial matrix of membership values
- Level of cluster fuzziness, g
- The said variables can be encoded in the GA-string and their optimal values can be obtained through a number of iterations.

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Entropy-based Fuzzy Clustering

- Parameter α indicating the relationship between Euclidean distance and similarity

- Parameter β: Threshold value of similarity

- Parameter γ: Outliers

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References

References:

- Soft Computing: Fundamentals and Applications by D.K. Pratihar, Narosa Publishing House, New-Delhi, 2014

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Conclusion

Conclusion:

- Brief introduction to GA
- Optimization of FLC
- Optimization related to Fuzzy Clustering

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Topic

Lecture 05: Introduction to Neural Networks

CONCEPTS COVERED

Concepts Covered:

- Biological and Artificial Neurons
- Artificial Neural Networks
- Supervised and Un-supervised Learning
- Incremental and Batch modes of Training

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Introduction to Neural Networks

- Proposed by McCulloh and Pitts, 1943

- Biological nervous system consists of a large number of interconnected processing units called neurons operating in parallel

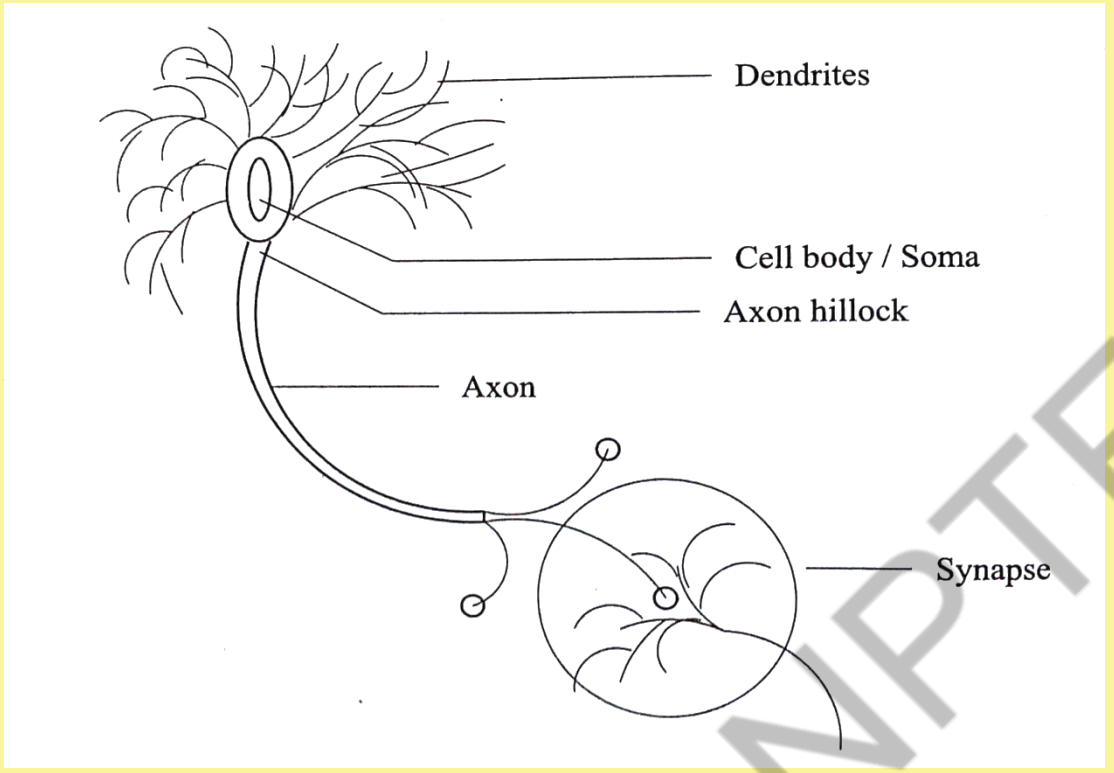
- Human brain contains approximately 10^{11} neurons. Our brain is a highly complex parallel computer

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Biological Neuron

•Consists of dendrites (a bush of thin fibers); cell body (also known as soma); axon (a long cylindrical fiber), synapse; and others

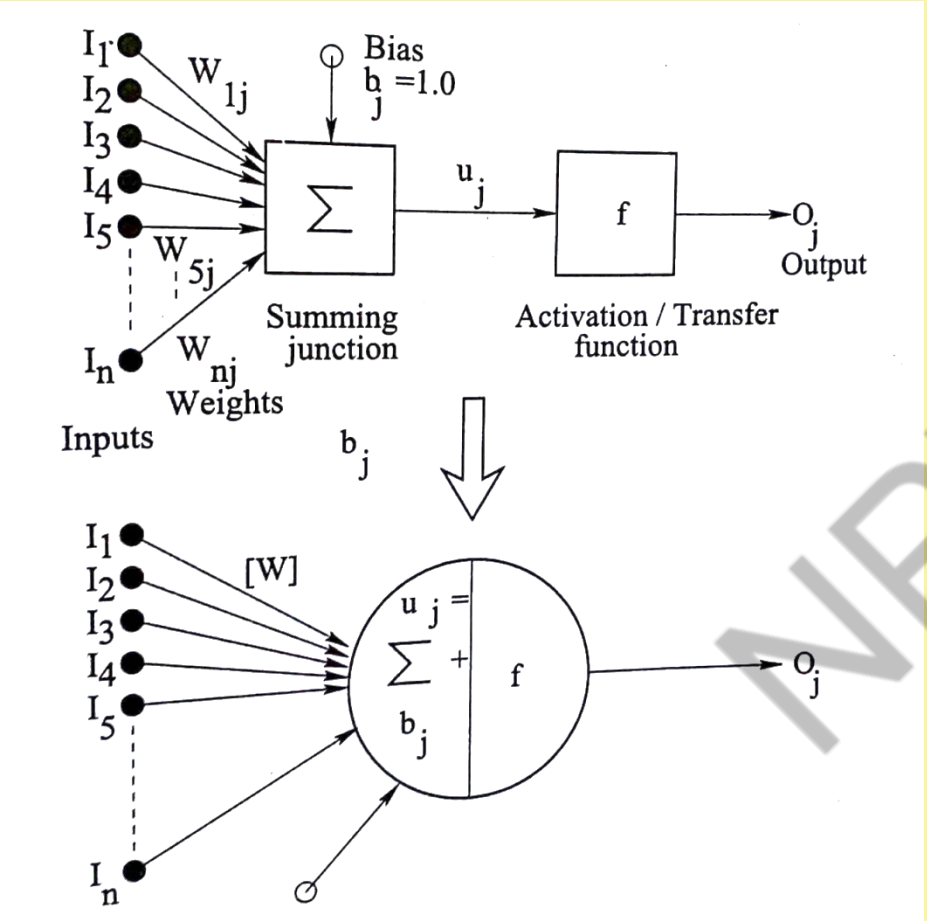
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A schematic view showing a biological neuron.

Artificial Neuron:



$$O_j = f(u_j) = f\left(\sum_{k=1}^{n} I_k W_{kj} + b_j\right)$$

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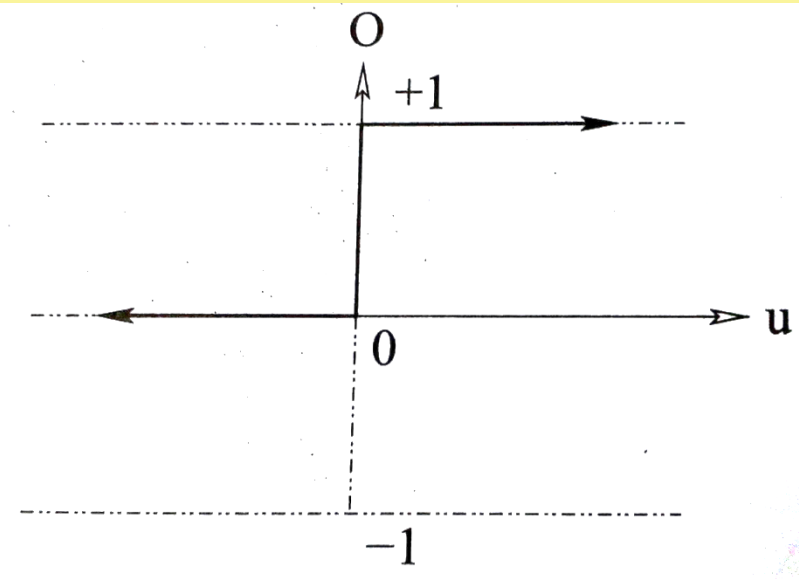
Types of transfer functions:

- Hard-limit
- Linear
- Log-sigmoid
- Tan-sigmoid, and others

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Transfer functions

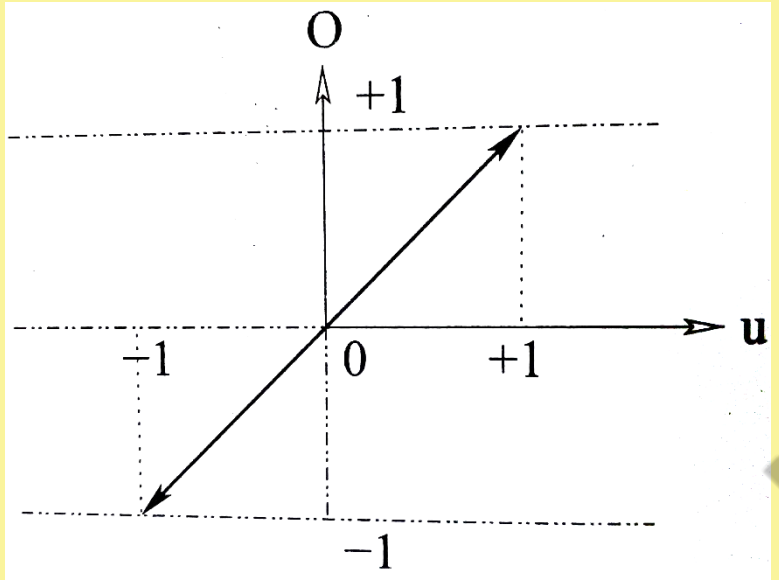
Hard-limit TF:



$$O = \begin{cases} 0.0, \text{ if } u < 0.0 \\ 1.0, \text{ otherwise} \end{cases}$$

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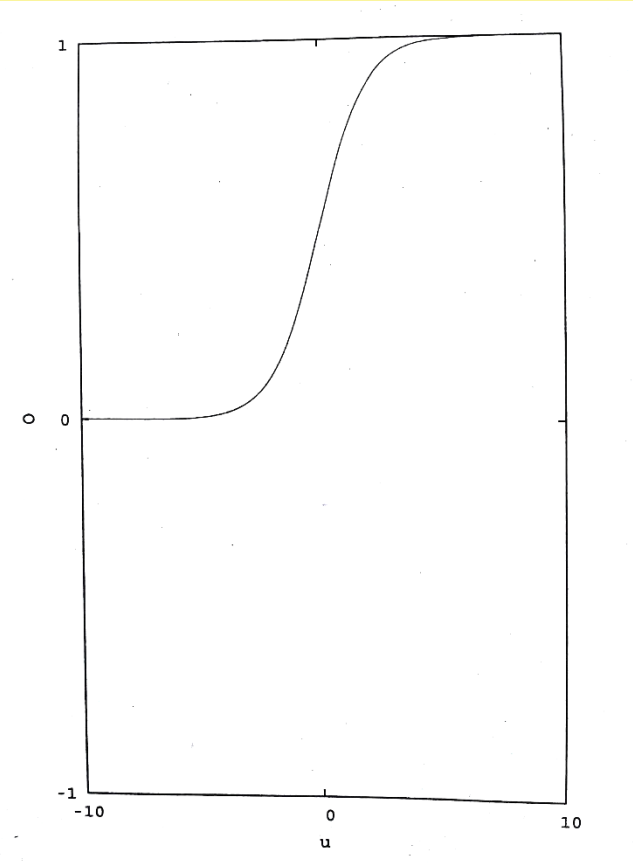
Linear TF:



O = u

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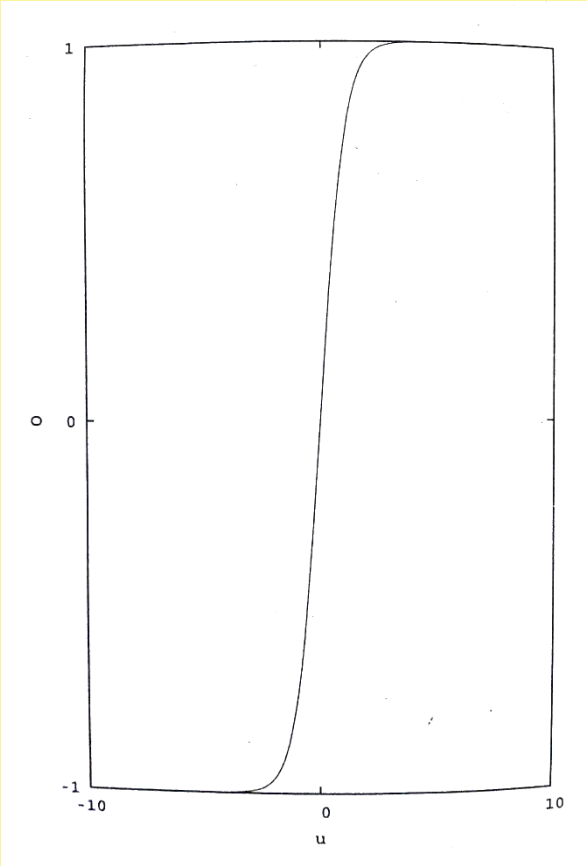
Log-Sigmoid TF:



$$O = \frac{1}{1 + e^{-au}}$$

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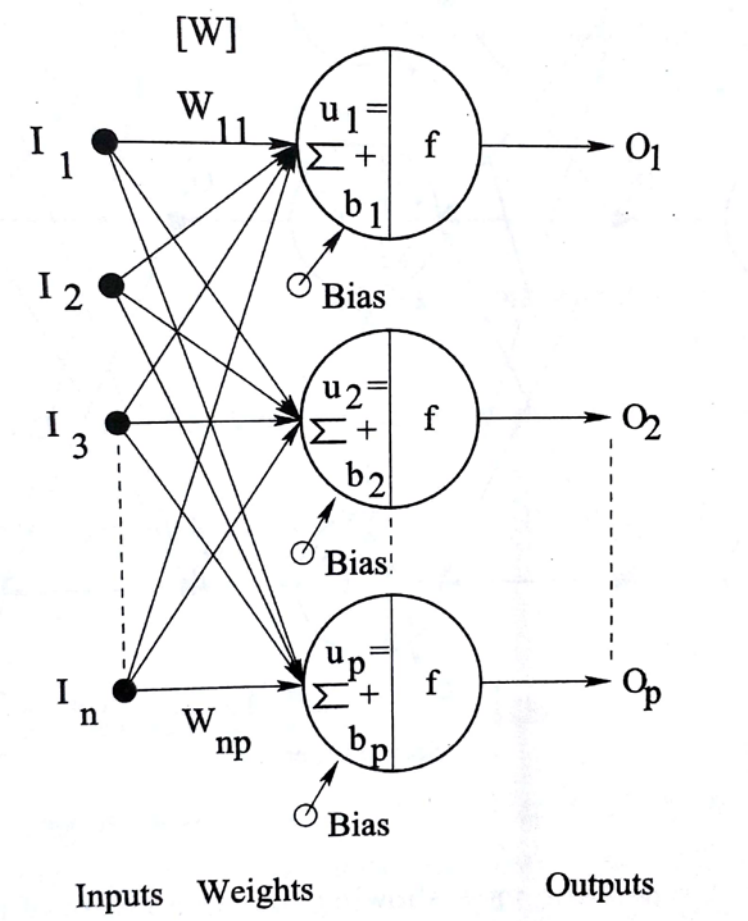
Tan-Sigmoid TF:



$$O = \frac{e^{au} - e^{-au}}{e^{au} + e^{-au}}$$

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One layer of Neurons:



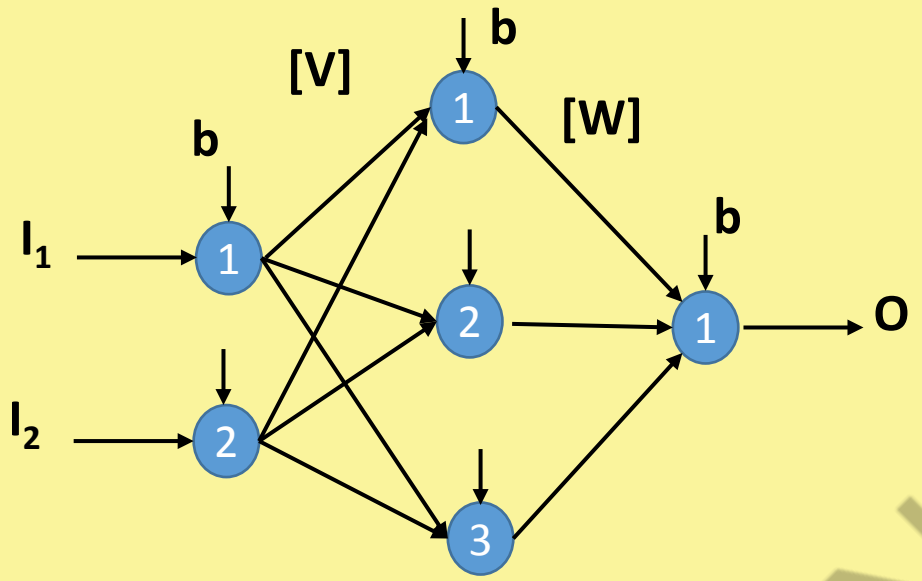
$$[W] = \begin{bmatrix} W_{11} & W_{12} & \ldots\ldots & W_{1p} \\ W_{21} & W_{22} & \ldots\ldots & W_{2p} \\ . & . & & . \\ . & . & & . \\ W_{n1} & W_{n2} & \ldots\ldots & W_{np} \end{bmatrix}$$

Output of k-th neuron

$$O_k = f\left(\sum_{j=1}^{n} I_j W_{jk} + b_k\right)$$

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Multiple Layers of Neurons (Artificial Neural Network)



2-3-1 Network

I_1, I_2 :Inputs

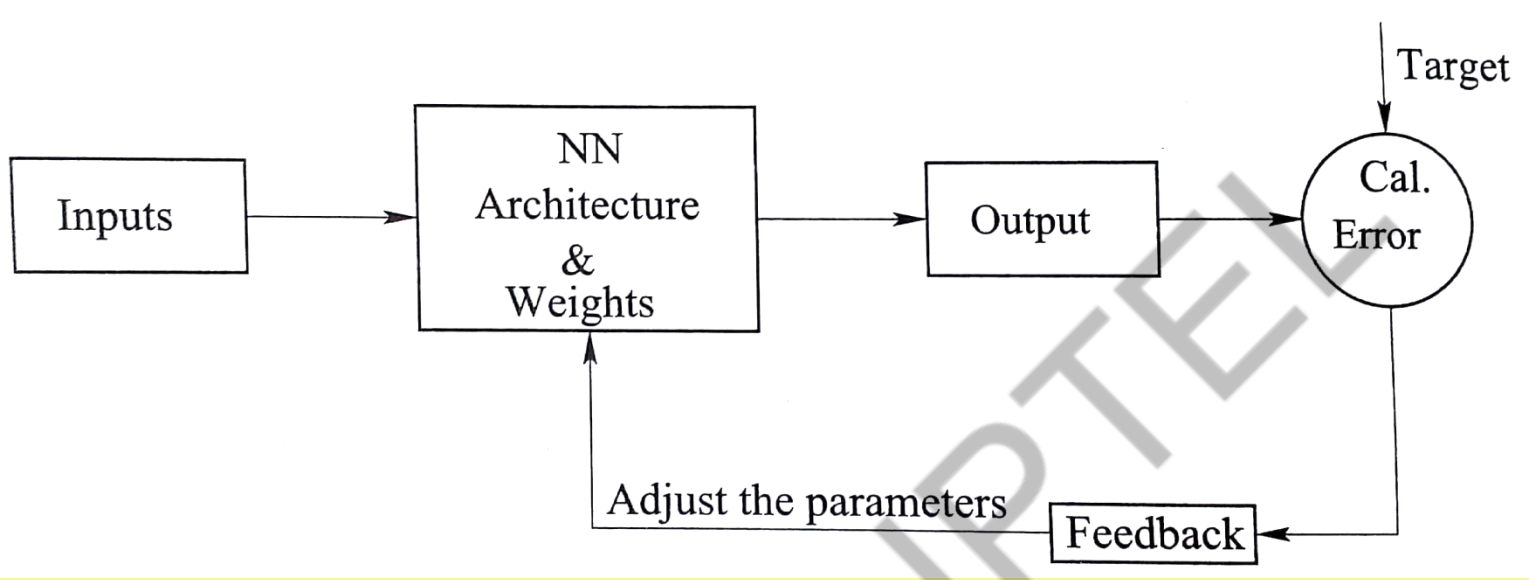
b: Bias value

[V], [W]: Connecting weights

O : Output

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Static vs. Dynamic Neural Networks



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- **Static NN:** No error compensation
- **Dynamic NN:** Error is fed back to the network to modify its architecture and update the weights.

Training of Neural Networks

- **Supervised Learning / Learning with Teacher**

  The outputs of the network are compared with the corresponding target values and the error is calculated. It is then fed back to the network for updating of the same.

- **Un-Supervised Learning / Learning without Teacher**

  Competition, cooperation and updating

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Incremental vs. Batch Modes of Training

- **Incremental Training / On-line Training:**

A particular training scenario is passed through the network, output(s) is/are calculated and then error is determined by comparing it/them with the target(s). The error is propagated to modify the network

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Incremental vs. Batch Modes of Training (cont.)

- **Batch Training / Off-line Training:**

  The whole training set consisting of a large number of scenarios, is passed through the network and an average error in predictions is determined. The network will be updated based on this average error.

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References

References:

- Soft Computing: Fundamentals and Applications by D.K. Pratihar, Narosa Publishing House, New-Delhi, 2014

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Conclusion

Conclusion:

- Structure of Artificial Neural Network has been explained
- Principle of Supervised and Un-supervised Learning has been discussed
- Incremental and Batch modes of training have been defined

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Thank you!

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