Soft Computing:
Neural Networks and Fuzzy Logic

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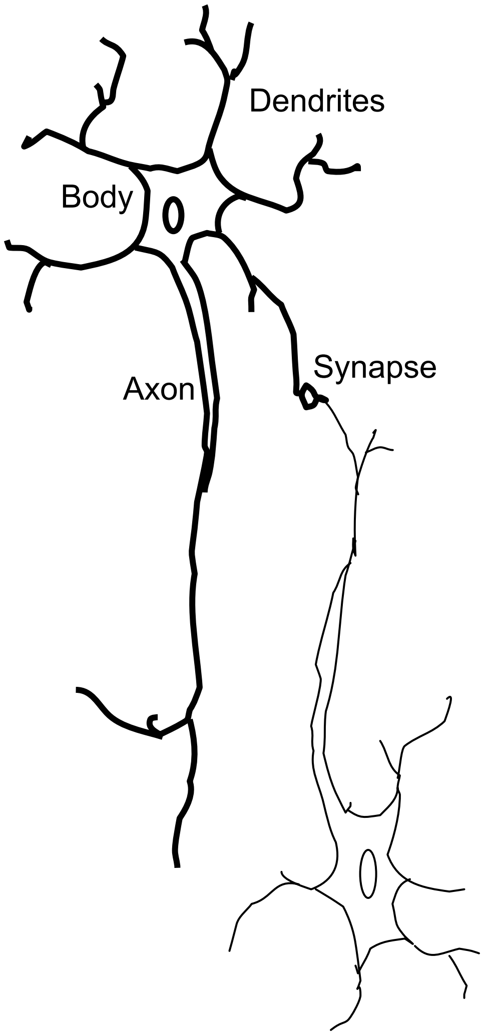
Neural Networks

Biological Neurons



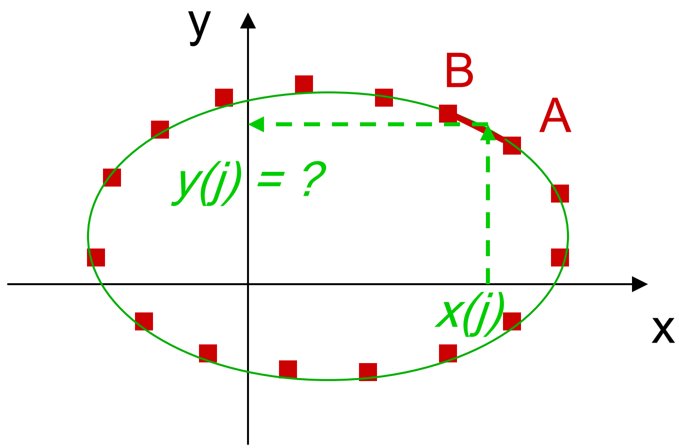
- **Dendrites** carry electrical signals in into the neuron body. The neuron **body** integrates and thresholds the incoming signals. The **axon** is a single long nerve fiber that carries the signal from the neuron body to other neurons. A **synapse** is the connection between dendrites of two neurons.

- Incoming signals to a dendrite may be inhibitory or excitatory. The strength of any input signal is determined by the strength of its synaptic connection. A neuron sends an impulse down its axon if excitation exceeds inhibition by a critical amount (threshold/ offset/bias) within a time window (period of latent summation).

- *Memories* are formed by the modification of the **synaptic strengths** which can change during the entire life of the neural systems.

- Biological neurons are rather slow (10^{-3} s) when compared with the modern electronic circuits. ==> The brain is faster than an electronic computer because of its massively parallel structure. The brain has approximately 10^{11} highly connected neurons (approx. 10^{4} connections per neuron).

Discreet vs. Continuous Modelling of Physical Objects and Processes

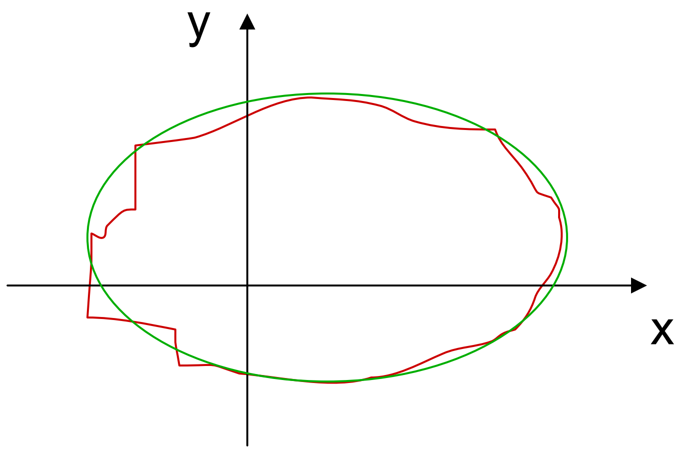


DISCREET MODEL

- *sampling => INTEPOLATION COST*

  y(j) = y(A) +

  [x(j)-x(B)] · [y(B)-x(A)] / [x(A)-x(B)]



CONTINUOUS MODEL

- *NO sampling =>*

  NO NTEPOLATION COST

Analog Computer vs. Neural Network Modelling of Continuous Physical Objects and Processes

- Both the Analog Computers and the Neural Networks are *continuous modelling devices.*

- The Analog Computer (AC) allows to *solve the linear or nonlinear differential and/or integral equations representing mathematical model* of a given physical process. The coefficients of these equations must be exactly known as they are used to program/adjust the coefficient-potentiometers of the AC's computing-elements (OpAmps). The AC doesn't follow a sequential computation, all its computing elements perform simultaneously and continuously. An interesting note, "because of the difficulties inherent in analog differentiation the [differential] equation is rearranged so that it can solved by integration rather than differentiation." [A.S. Jackson, *Analog Computation*, McGraw-Hill Book Co., 1960].

- The Neural Network (NN) doesn't require a prior mathematical model. A *learning algorithm* is used to adjust, sequentially by trail and error during the learning phase, the synaptic-weights /coefficient-potentiometers of the neurons/computing-elements.

  As the AC, the NN don't follow a sequential computation, all its neuron performing simultaneously and continuously. The neurons are also integrative-type computing/processing elements.

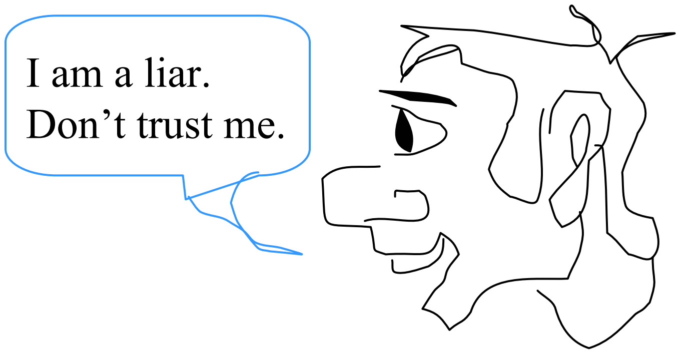
Fuzzy Logic

Pioneered by **Zadeh** in the mid '60s fuzzy logic provides the formalism for *modeling the approximate reasoning mechanisms specific to the human brain*.

"In more specific terms, what is central about fuzzy logic is that, unlike classical logical systems, it aims at modeling the imprecise modes of reasoning that play an essential role in the remarkable human ability to make rational decisions in an environment of uncertainty and imprecision. This ability depends, in turn, on our ability to infer an approximate answer to a question based on a store of knowledge that is inexact, incomplete, or not totally reliable." ["Fuzzy Logic," *IEEE Computer Magazine,* April 1988, pp. 83-93:]

Fuzzy Logic

◊ **Bivalent Paradox as Fuzzy Midpoint**



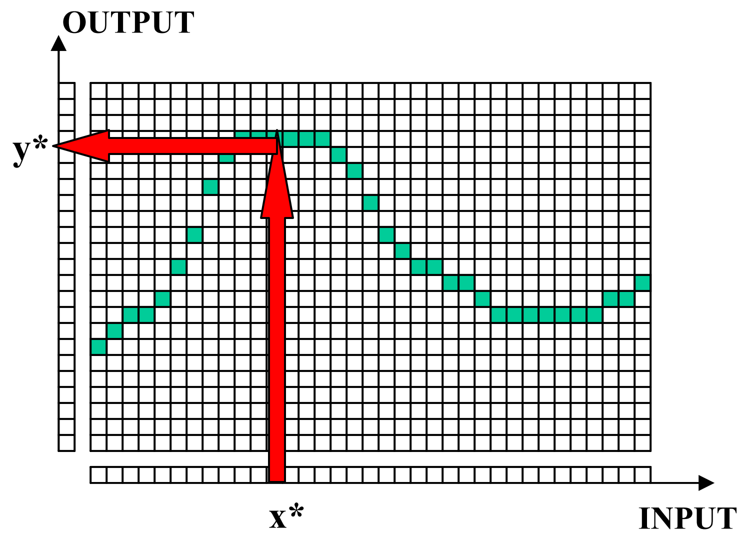
The statement **S** and its negation $\bar{\mathbf{S}}$ have the same truth-value $\mathbf{t}\,(\mathbf{S}) = \mathbf{t}\,(\bar{\mathbf{S}})$.

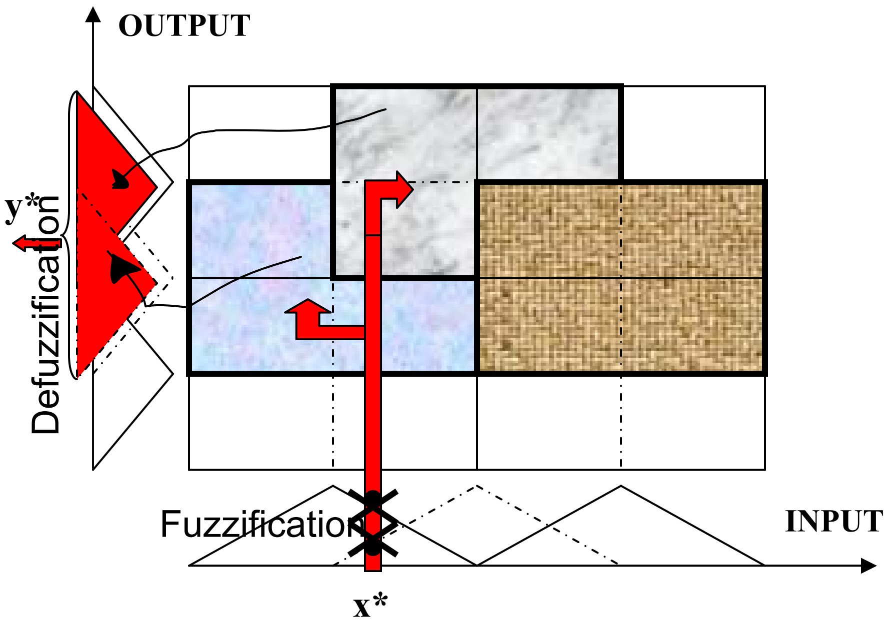
In the binary logic: $\mathbf{t}\,(\bar{\mathbf{S}}) = 1 - \mathbf{t}\,(\mathbf{S})$, and

$\mathbf{t}\,(\mathbf{S}) = 0$ or 1, ==> $0 = 1$!??!

Fuzzy logic accepts that $\mathbf{t}\,(\bar{\mathbf{S}}) = 1 - \mathbf{t}\,(\mathbf{S})$, without insisting that $\mathbf{t}\,(\mathbf{S})$ should only be 0 or 1, and accepts the **half-truth**: $\mathbf{t}\,(\mathbf{S}) = 1/2$.

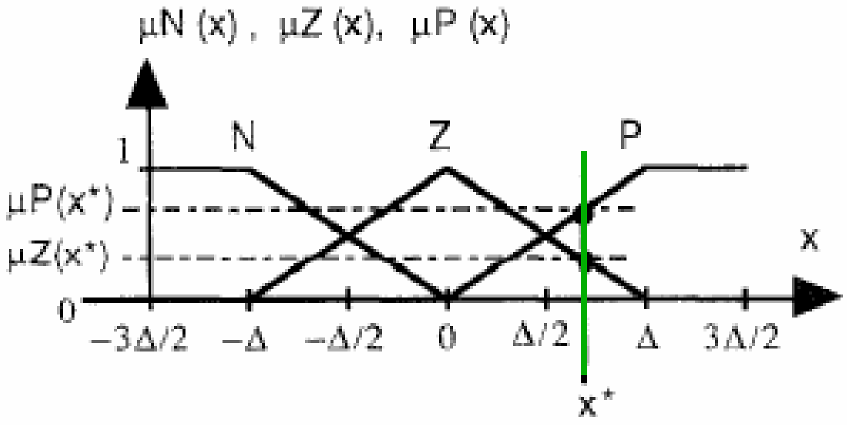
Fuzzy Logic Control

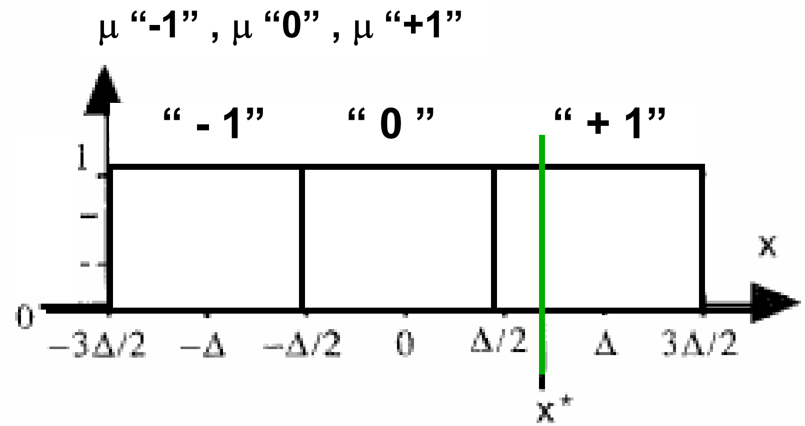




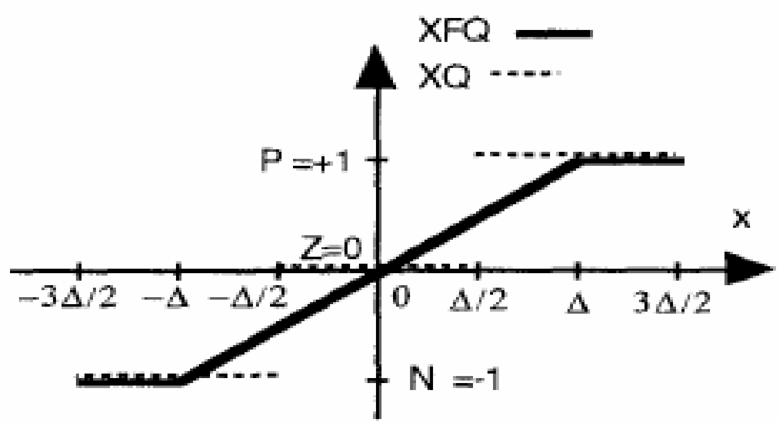
Classic control is based on a detailed I/O function OUTPUT= **F** (INPUT) which maps each high-resolution quantization interval of the input domain into a high-resolution quantization interval of the output domain.
=> Finding a mathematical expression for this detailed mapping relationship **F** may be difficult, if not impossible, in many applications.

Fuzzy control is based on an I/O function that maps each very low-resolution quantization interval of the input domain into a very low-low resolution quantization interval of the output domain. As there are only 7 or 9 fuzzy quantization intervals covering the input and output domains the mapping relationship can be very easily expressed using the"if-then" formalism. (In many applications, this leads to a simpler solution in less design time.) The overlapping of these fuzzy domains and their linear membership functions will eventually allow to achieve a rather high-resolution I/O function between crisp input and output variables.





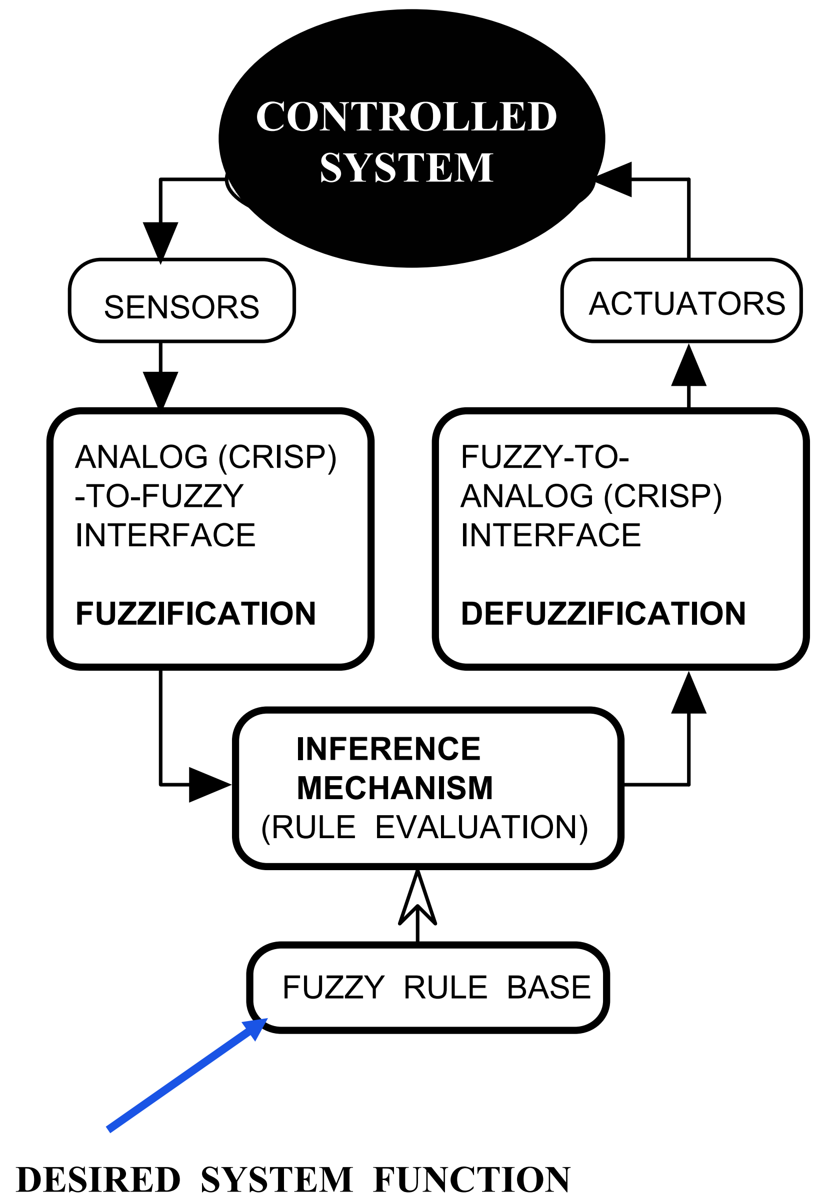
Membership functions and the quantization characteristics for a **3-set (*N*, *Z*, and *P*) fuzzy partition** of the domain where the analog variable ***x*** is defined. ***XFQ* are the crisp analog values recovered after a defuzzification** of the fuzzy converted value *x*. It also shows the truncated information ***XQ* recovered from an *A/D* converter with 3 quantization levels** (**"-1", "0",** and **"+1**) defined over the same domain for ***x***.



The basic idea of “fuzzy logic control” (FLC) was suggested by **L.A. Zadeh**, “A rationale for fuzzy control,” *J. Dynamic Syst. Meas. Control,* vol.94, series G, pp.3-4,1972.

FLC provides a non analytic alternative to the classical analytic control theory. ==> “**But what is striking is that its *most important and visible application today is in a realm not anticipated when fuzzy logic was conceived, namely, the realm of fuzzy-logic-based process control*,**” [**L.A. Zadeh**, “Fuzzy logic,” *IEEE Computer Mag.,* pp. 83-93, Apr. 1988].

Early FLCs were reported by Mamdani and Assilian in 1974, and Sugeno in 1985.



The key benefit of FLC is that the desired system behavior can be described with simple “if-then” relations based on very low-resolution models able to incorporate **empirical engineering knowledge**. FLCs have found many practical applications in the context of **complex ill-defined processes that can be controlled by skilled human operators**: water quality control, automatic train operation control, elevator control, etc.,