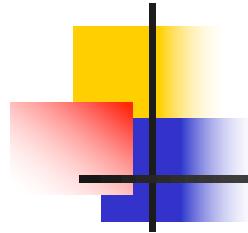


# *Modelleerimine ja Juhtimine Tehisnärvivõrgudega*

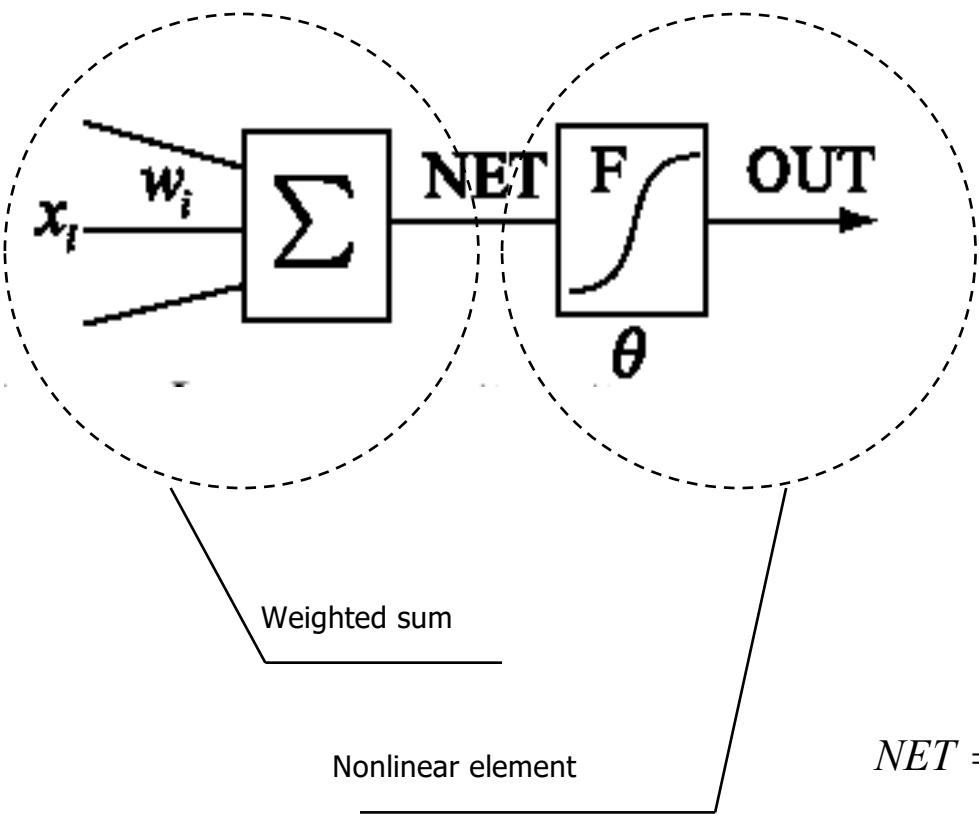
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*Identification and Control with  
artificial neural networks*

*Eduard Petlenkov,*



## Artificial neuron



Input vector:

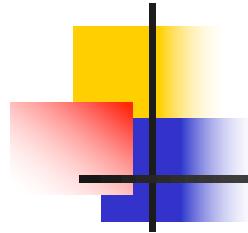
$$X = \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix}$$

Vector of weight coefficients:

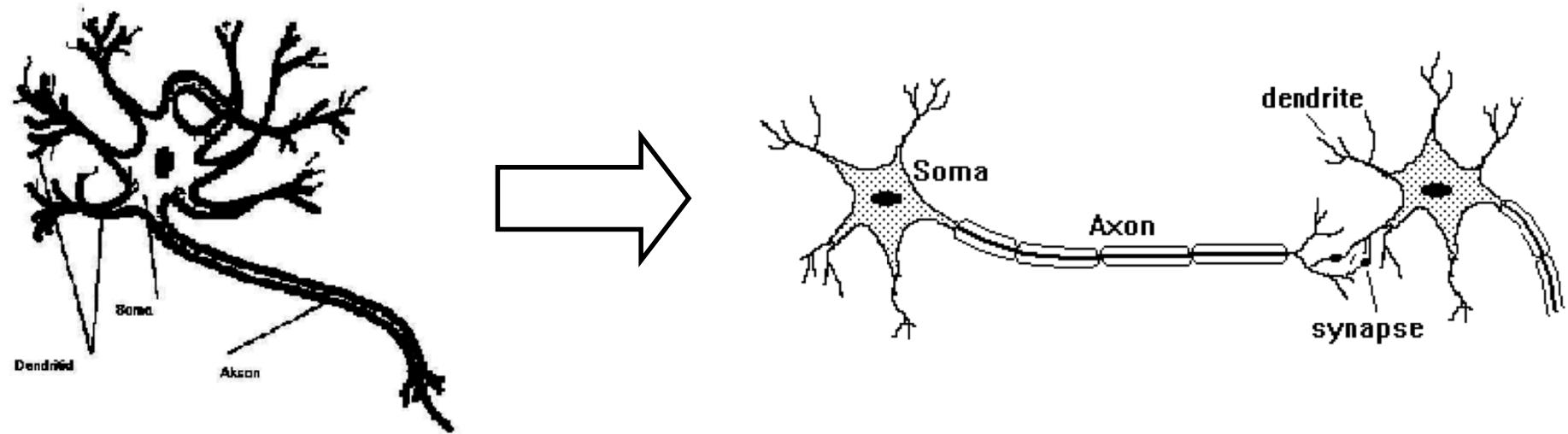
$$W = [w_1 \dots w_n]$$

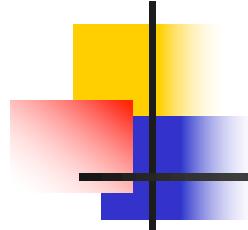
Weighted sum:

$$NET = W \cdot X = [w_1 \dots w_n] \cdot \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix} = w_1 x_1 + \dots + w_n x_n$$



## Biological neuron and biological neural networks

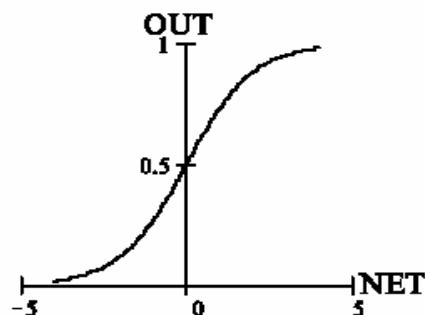




## Activation functions (1)

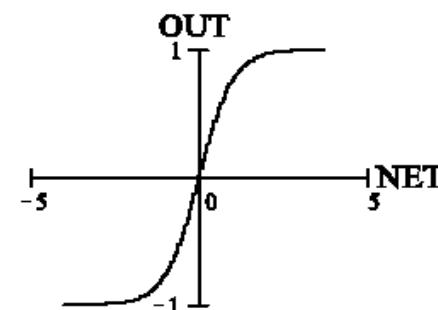
$$OUT=f(NET)$$

Sigmoid functions are having an "S" shape (**sigmoid curve**)



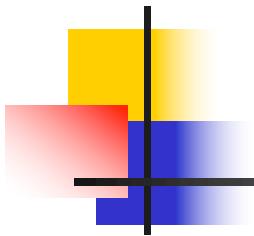
1 Logistic function

$$OUT = \frac{1}{1 + e^{-NET}}$$

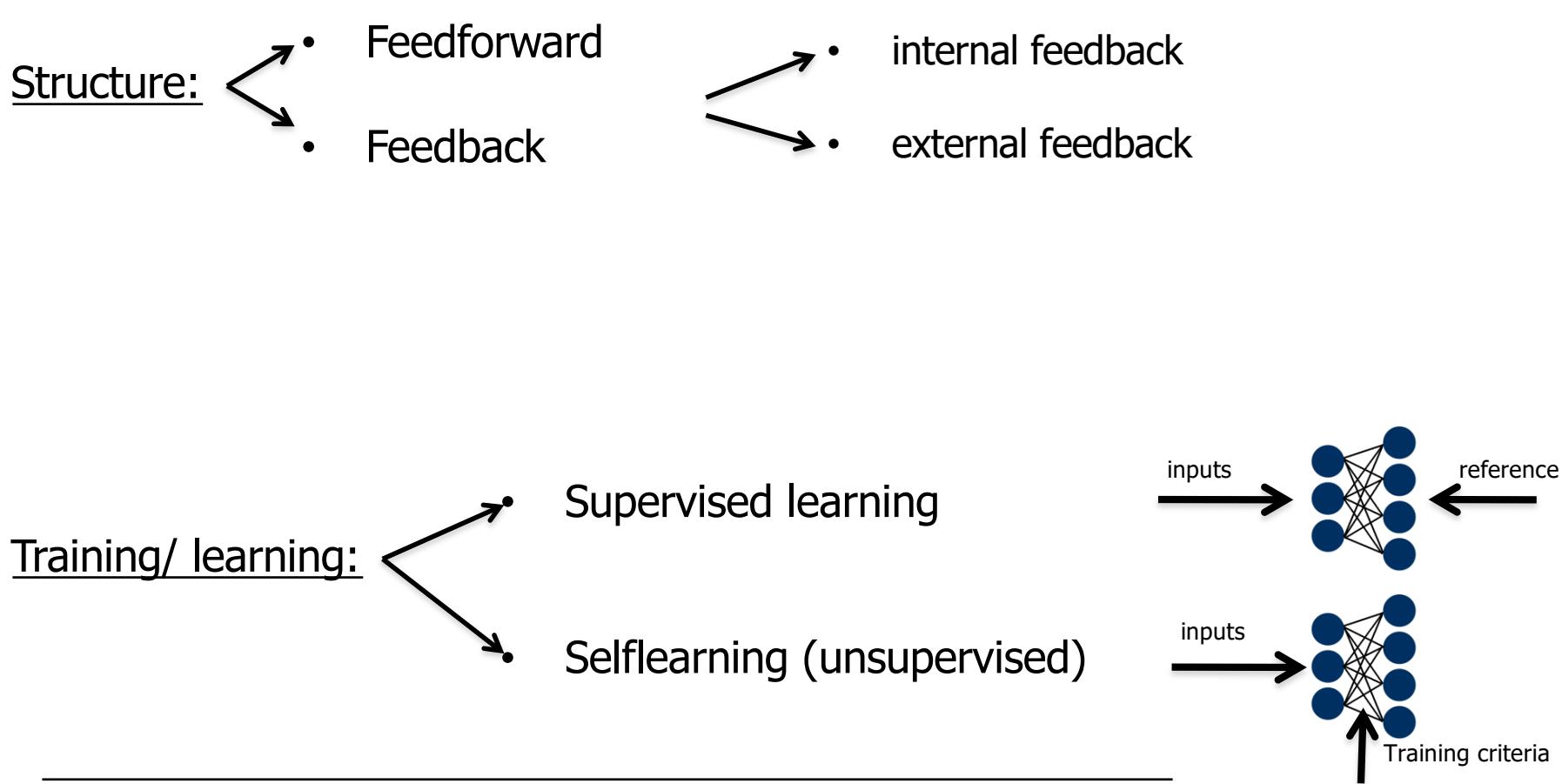


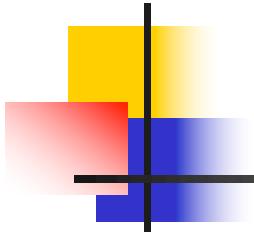
2 Hyperbolic tangent

$$OUT = \frac{e^{NET} - e^{-NET}}{e^{NET} + e^{-NET}}$$

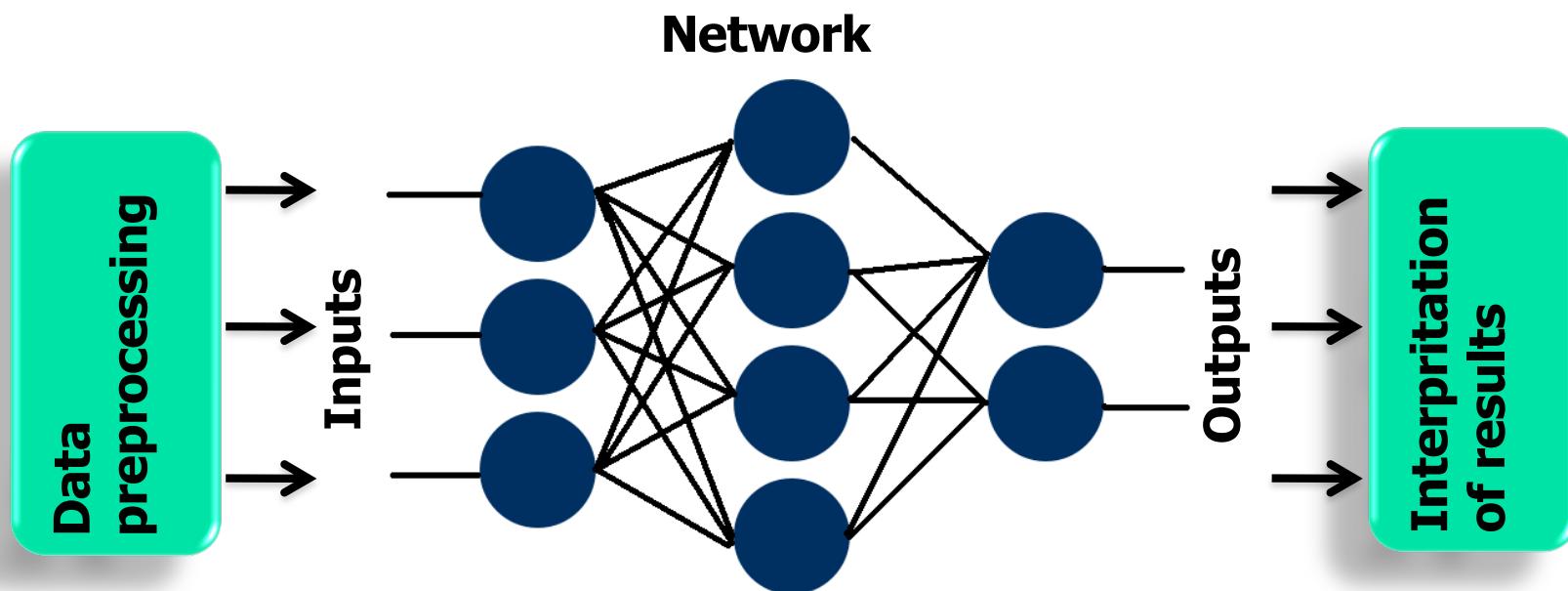


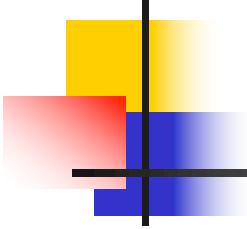
## Types of artificial neural networks





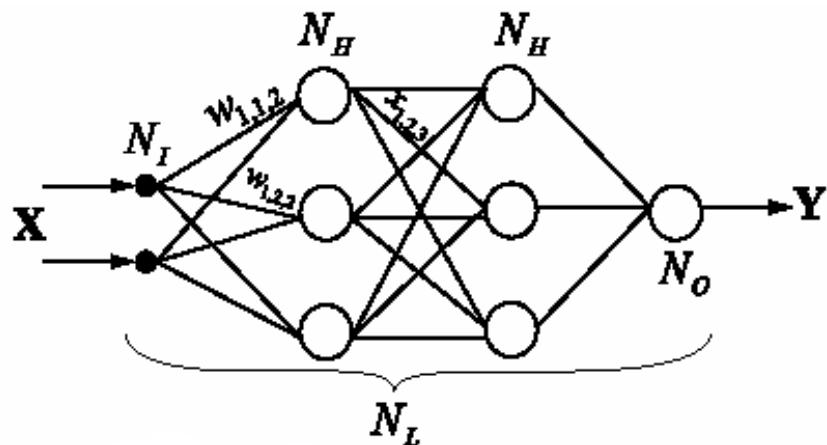
## How to use artificial neural networks





## Feedforward neural networks and multilayer perceptron

Feedforward networks are networks in which an output of a neuron can be connected only with an input of a next layer neuron.



*“from each to each”*

$N_I$  - Input layer

$N_O$  - Output layer

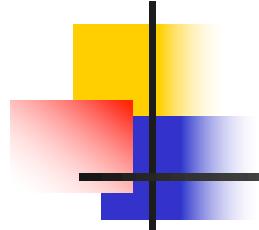
$N_H$  - Hidden layer

$w_{ijl}$  - Weighting coefficients, where

$i$  is the number of the neuron's input

$j$  - neuron's number in the layer

$l$  - number of the layer



## Mathematical function of a two-layer perceptron

$$X = \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix}; \quad Y = \begin{bmatrix} y_1 \\ \vdots \\ y_m \end{bmatrix}; \quad W_1 = \begin{bmatrix} w_{111} & \cdots & w_{n11} \\ \vdots & \ddots & \vdots \\ w_{1k1} & \cdots & w_{nk1} \end{bmatrix}; \quad \Theta_1 = \begin{bmatrix} \theta_{11} \\ \vdots \\ \theta_{k1} \end{bmatrix}; \quad W_2 = \begin{bmatrix} w_{112} & \cdots & w_{k12} \\ \vdots & \ddots & \vdots \\ w_{1m2} & \cdots & w_{km2} \end{bmatrix}; \quad \Theta_2 = \begin{bmatrix} \theta_{12} \\ \vdots \\ \theta_{m2} \end{bmatrix};$$

$F_1$  - Activation function of the hiddent layer neurons;

$F_2$  - Activation function of the output layer neurons.

$$Y = F_2(\underbrace{W_2(F_1(W_1 X - \Theta_1)) - \Theta_2}_{\text{output of the first layer}})$$

$\overbrace{\qquad\qquad\qquad}$

output of the network