

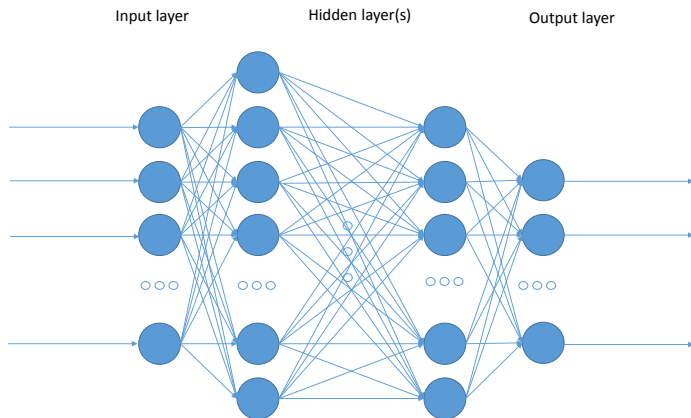
# Machine Learning, Lecture 8: Artificial Neural Networks

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# What is *Artificial Neural Network* ?



Biology inspired mathematical abstraction

# Artificial Neural Network

- ▶ Brain (human or animal) consists of neurons.
- ▶ Basic idea is to combine together a number of neurons.
- ▶ Perceptron is the mathematical model of a single neuron.
- ▶ Perceptron has a number of drawbacks which motivate creation of artificial neural networks
  - ▶ Does not provide probabilistic outputs.
  - ▶ Does not suited for more than two classes.
  - ▶ Learns linear decision boundaries only.

## The model of a single neuron

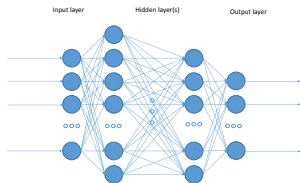
$$f(a) = \text{activation function}; \quad \text{where} \quad a = \sum_{j=1}^d w_j x_j = \mathbf{w}^T \mathbf{x};$$

where  $\mathbf{x} \in \mathbb{R}^d$  is the input vector. The neuron has  $d$  weights the same number as inputs.

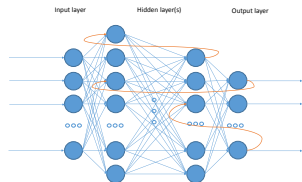
Note, *activation or saturation* function - sigmoid function (logsig, tansig etc.) Note, some times bias or intercept is added.

$$a = \sum_{j=1}^d w_j x_j + b = \mathbf{w}^T \mathbf{x} + b;$$

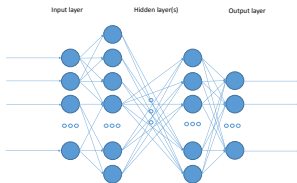
# Assembling neurons together



Fully connected feed forward neural network



Recurrent neural network



Restricted connectivity feed forward neural network

# ANN

- ▶ Modeling of nonlinear processes
- ▶ Classification (Next lecture)
- ▶ ... .

## More practical approach

- ▶ Nonlinear process and function approximation
- ▶ Pattern recognition and classification
- ▶ Clustering
- ▶ Time Series and Dynamic Systems

# Modeling of nonlinear processes

- ▶ Topology (network connectivity)
- ▶ Number of the neurons on each level
- ▶ Activation function
- ▶ training method

# ANN

- ▶ How many layers do one need?
- ▶ How many neurons are necessary?
- ▶ Universal approximation theorem:
  - ▶ G.Cybenko (1989) Single hidden layer with finite number of neurons (multilayer perceptron) can approximate continuous functions on a compact subsets of  $\mathbb{R}^n$ . Some weak assumptions about activation function were made. Algorithmic aspects were not touched.
  - ▶ K.Hornik (1991) Demonstrated importance of the choice of architecture over the choice of activation function.
- ▶ While there is no constructive analytic approach to select structure of the network there exist number of rules which may be used.



# Most popular activation functions

Activation function some times referred as transfer function.

- ▶ logsig - Log - sigmoid transfer function
- ▶ tansig - Tan-sigmoid
- ▶ purelin - Linear function

# Training techniques

- ▶ Levenberg-Marquardt backpropagation.
- ▶ Bayesian regularization backpropagation.
- ▶ Scaled conjugate gradient backpropagation.
- ▶ Resilient backpropagation.

# Finishing touches

- ▶ Initialization
- ▶ Stopping criteria
- ▶ Training time is measured in *epochs*. An epoch is a measure of the number of times all of the training vectors are used once to update the weights.
- ▶ What does NN-based nonlinear function looks like? Relatively simple case

$$y = \left( \sum_{k=1}^l c_k \phi_k \left( \sum_{j=1}^m \omega_{k,j}^T x \right) \right)$$

$l$  is the number of neurons on hidden layer,  $m$  is the number of inputs,  $\phi_i$  are activation functions.

Example ?

Let us continue in the computer class