CS522 Advanced Database Systems
Classification: Introduction to Artificial Neural Network

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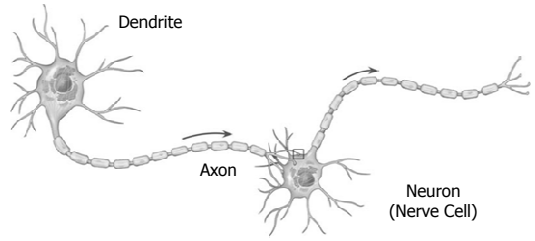
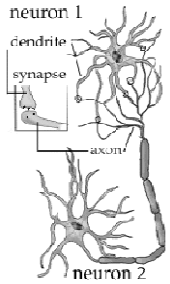
Biological Neural Network



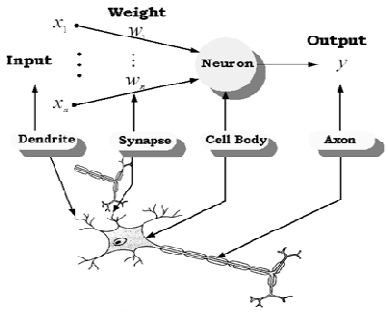
- Dendrites receives signals from other neurons
- Axons gives signals to other neurons

Synapse

- *Synapse* is the contact point between a dendrite and an axon
- Human brain learns by changing the strength of the synaptic connection between neurons upon repeat stimulation by the same impulse



Modeling a Neuron



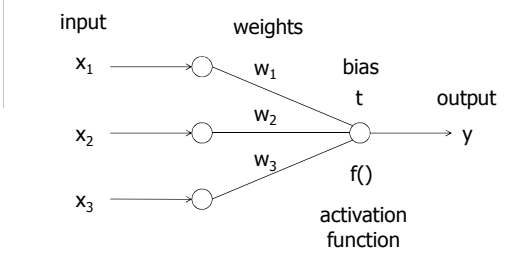
… Modeling a Neuron

- In a Biological Neural Network (BNN), learning results are saved at synapses
- In a Artificial Neural Network (ANN), learning results are saved in the *weights*

Example

A1	A2	A3	C
0	1	0	1
1	1	0	0
0	0	1	1
1	0	1	0
0	0	0	0
0	1	1	?

Perceptron



Input, Weights, and Bias

- Input $\mathbf{X}=[x_1,x_2,x_3]$
  - One per attribute
- Weights $\mathbf{W}=[w_1,w_2,w_3]$
  - One per input
  - Typically initialized to random values in the range [-1.0,1.0] or [-0.5,0.5]
- Bias t
  - Typically a value in the range of [-1.0,1.0]

Output

$$y = f(x_1w_1 + x_2w_2 + ... + x_nw_n + t)$$
$$= f(x_1w_1 + x_2w_2 + ... + x_nw_n + x_0w_0)$$
$$= f(\mathbf{X} \bullet \mathbf{W})$$
$$= f(\mathbf{X}\mathbf{W}^T)$$

`t` can be written as x_0w_0 where $x_0=1$ and $w_0=t$

Common Activation Functions

Step Function

$$y = \begin{cases} 1 & \mathbf{X} \bullet \mathbf{W} \geq 0 \\ 0 & \mathbf{X} \bullet \mathbf{W} < 0 \end{cases}$$

Sign Function

$$y = \begin{cases} 1 & \mathbf{X} \bullet \mathbf{W} \geq 0 \\ -1 & \mathbf{X} \bullet \mathbf{W} < 0 \end{cases}$$

Linear Function

$$y = \mathbf{X} \bullet \mathbf{W}$$

Sigmoid Function

$$y = \frac{1}{1 + e^{-\mathbf{X} \bullet \mathbf{W}}}$$

Learning

- Initialize **`w`** and `t` to random values
- For each training record `(`**`x`**`, y')`
  - Compute the predicted output `y`
  - Update each weight w_i

$$w_i = w_i + \lambda(y' - y)x_i$$

λ is the *learning rate*

About Learning Rate

- Between 0 and 1
- Control the speed of adjustment
- Dynamic learning rate, e.g. `1/t` where `t` is the number of iterations so far

Learning Example

W=[0.3,0.3,0.3], t=-0.5, λ=0.5

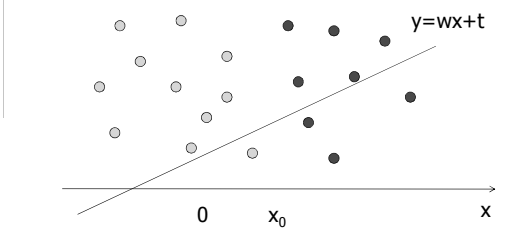
$$y = \begin{cases} 1 & 0.3x_1 + 0.3x_2 + 0.3x_3 - 0.5 \geq 0 \\ 0 & 0.3x_1 + 0.3x_2 + 0.3x_3 - 0.5 < 0 \end{cases}$$

	A1	A2	A3	C
R1	0	1	0	1
R2	1	1	0	0
R3	0	0	1	1
R4	1	0	1	0
R5	0	0	0	0

… Learning Example

After	[**W**, t]
	[0.3, 0.3, 0.3, -0.5]
R1	[0.3, 0.8, 0.3, 0]
R2	[-0.2, 0.3, 0.3, -0.5]
R3	[-0.2, 0.3, 0.8, 0]
R4	[-0.7, 0.3, 0.3, -0.5]
R5	[-0.7, 0.3, 0.3, -0.5]

Intuition Behind Perceptron Learning …



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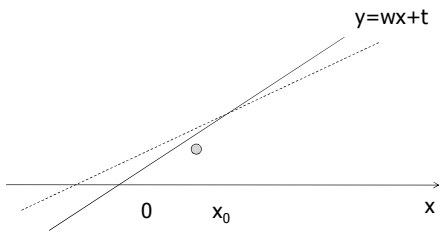

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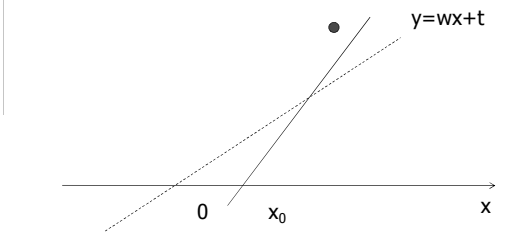

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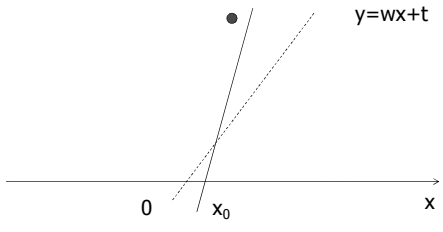
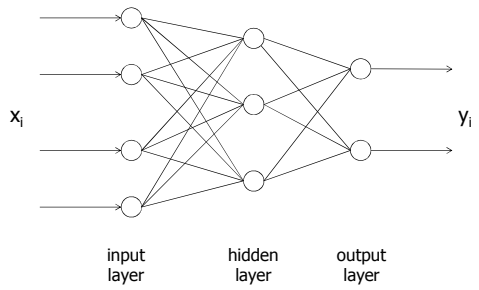


Multilayer ANN



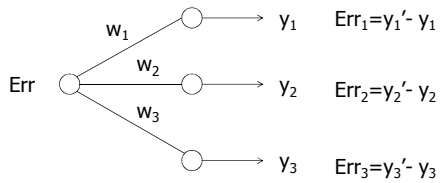
Terminology

- Nodes/units
- Layers and number of layers
- Feed-forward and recurrent
- Fully connected

Learning

- Each node in a hidden or output layer is a perceptron
- The output of a node is used as the input for the nodes in the next layer
- Can we use the same perceptron learning process for multilayer ANN learning??

Understand Backpropagation



$Err=w_1*Err_1+w_2*Err_2+w_3*Err_3$

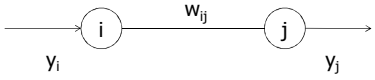
Adjust Weights

- To minimize sum of squared error

$$E(\mathbf{W}) = \sum_{i=1}^{n} (y_i' - y_i)^2$$

$$= \sum_{i=1}^{n} (y_i' - f(\mathbf{X} \bullet \mathbf{W}))^2$$

Delta Rule – Linear Activation Function



$$\Delta w_{ij} = \lambda y_i (y_j' - y_j)$$

Delta Rule – Nonlinear Activation Function …

For output nodes:

$$\Delta w_{ij} = \lambda y_i f_j'(\mathbf{X} \bullet \mathbf{W})(y_j' - y_j)$$

$$Err_j = f_j'(\mathbf{X} \bullet \mathbf{W})(y_j' - y_j)$$

See Delta Rule at http://www.learnartificialneuralnetworks.com/backpropagation.html

… Delta Rule – Nonlinear Activation Function

For hidden nodes:

$$\Delta w_{ij} = \lambda y_i f_j'(\mathbf{X} \bullet \mathbf{W}) \sum_{k=1}^{n} w_{jk} Err_k$$

$$Err_j = f_j'(\mathbf{X} \bullet \mathbf{W}) \sum_{k=1}^{n} w_{jk} Err_k$$

See Delta Rule at http://www.learnartificialneuralnetworks.com/backpropagation.html

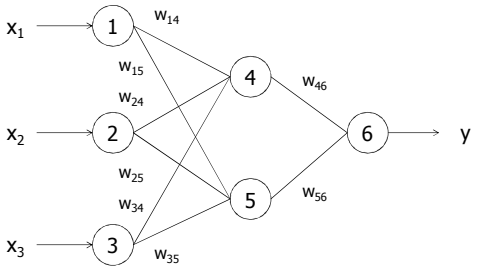
Sigmoid Activation Function

$$f(x) = \frac{1}{1+e^{-x}}$$

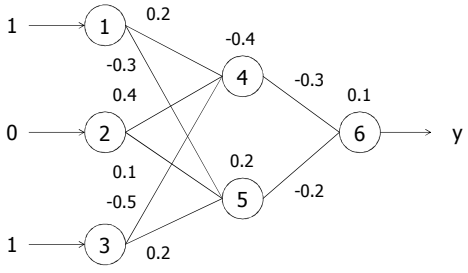
$$f'(x) = \frac{e^{-x}}{(1+e^{-x})^2} = (1-f(x))f(x)$$

$$f'(\mathbf{X} \bullet \mathbf{W}) = (1-f(\mathbf{X} \bullet \mathbf{W}))f(\mathbf{X} \bullet \mathbf{W}) = (1-y)y$$

Multilayer ANN Example



Initial Values



Initial Values

x_1	x_2	x_3
1	0	1

t_4	t_5	t_6
-0.4	0.2	0.1

w_{14}	w_{15}	w_{24}	w_{25}	w_{34}	w_{35}	w_{46}	w_{56}
0.2	-0.3	0.4	0.1	-0.5	0.2	-0.3	-0.2

$\lambda = 0.9$

Forward Computation

Activation function: $f(x) = \frac{1}{1+e^{-x}}$

Node	**X•W**	f(**X•W**)
4	-0.7	0.332
5	0.1	0.525
6	-0.105	0.474

Backward Propagation …

Assume y′=1

Node	f′(**X•W**)	Err
6	0.249	0.131
5	0.249	-0.0065
4	0.222	-0.0087

… Backward Propagation

w_{46}	w_{56}	t_6	
-0.261	-0.138	0.218	
w_{15}	w_{25}	w_{35}	t_5
-0.306	0.1	0.194	0.194
w_{14}	w_{24}	w_{34}	t_4
0.192	0.4	-0.508	-0.408

Input and Output of ANN

- Input
  - One input node for each binary or numeric attribute
  - What about categorical attributes??
- Output
  - One output node for a 2-class problem
  - K output nodes for a k-class problem

About ANN

- Multilayer feed-forward networks can approximate any function
- Determining the network topology is a empirical process
- Good at handling redundant features, but sensitive to noise
- Weight adjustment may converge to local minimum
- Training can be time consuming

Readings

- Textbook Chapter 9.2