Biologically Inspired Computing: Neural Computation

Lecture 2

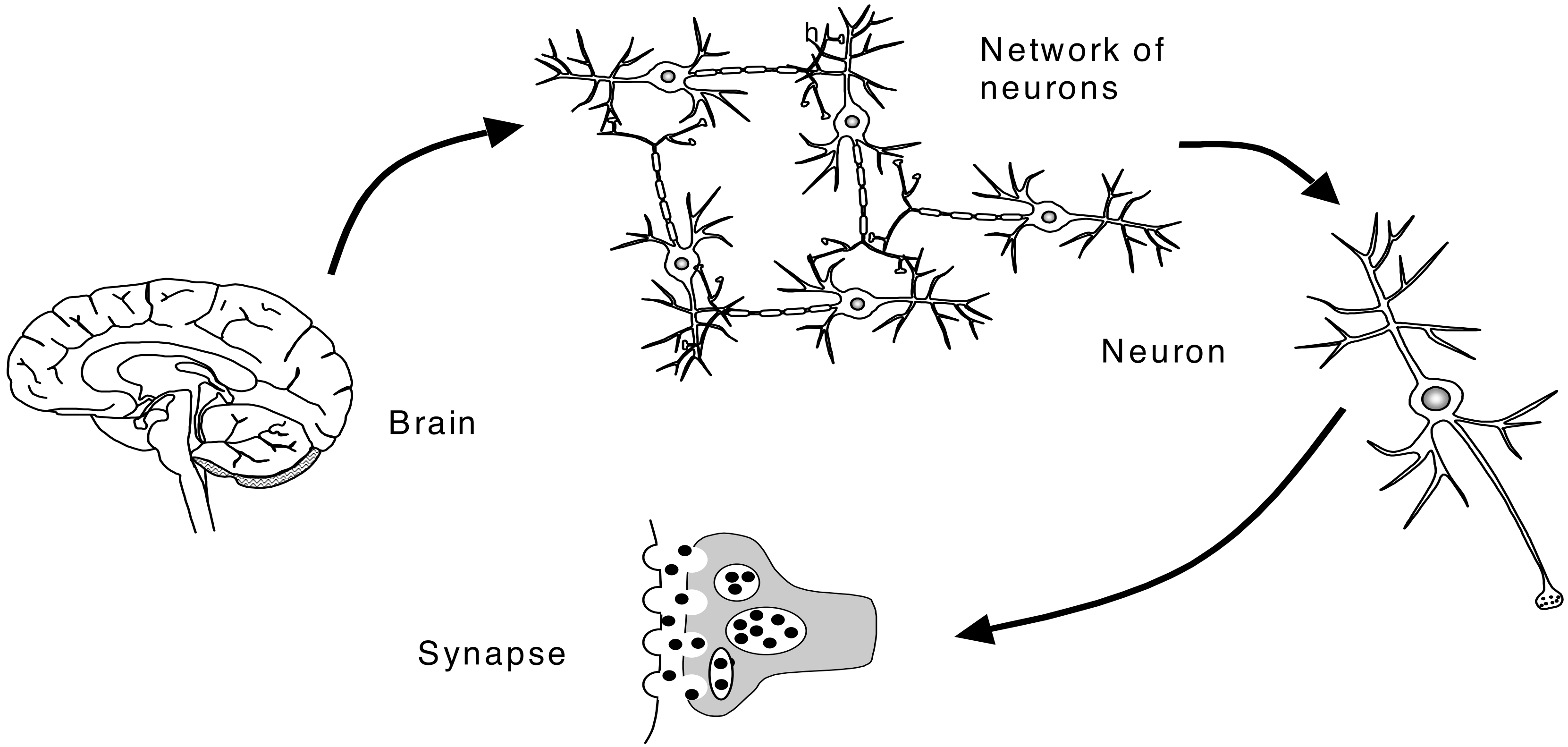
Patricia A. Vargas

Lecture 2

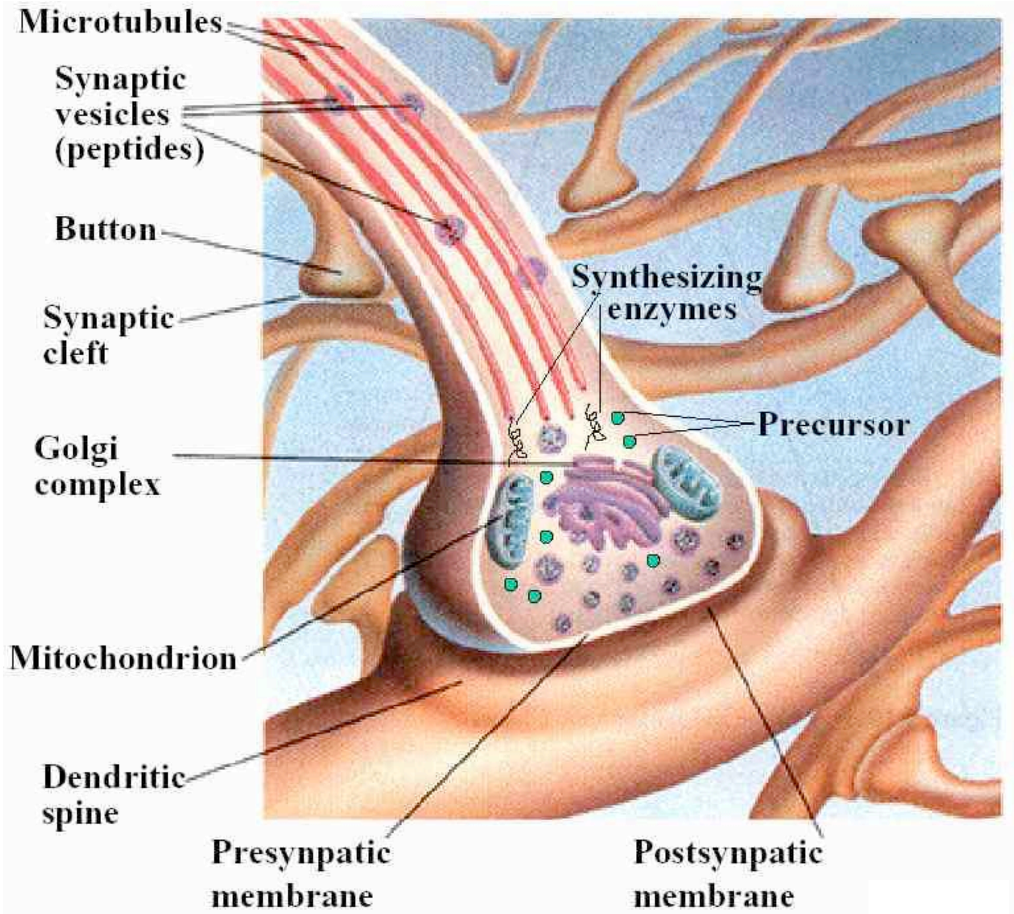
I. Lecture 1 – Revision
II. Artificial Neural Networks (Part I)
    I. Artificial Neuron
    II. Neural Network Architectures
    III. Learning Paradigms

Biological Neural Network

- How does our brain process all the information it receives/ perceives and what are the main mechanisms involved?



The Synapse



A neuron activation is also called spiking, firing, or triggering of an action potential.

Synaptic Plasticity

- The synaptic plasticity I defined by the capability of changing or modifying the synapses.
- Exploring the synaptic plasticity is crucial for the great majority of learning algorithms designed for artificial neural networks.

Artificial Neural Networks (ANN)

- History

1943	McCulloch e Pitts
1948	Wiener
1949	Hebb
1957	Rosenblatt
1958	Widrow e Hoff
…	…
1969	Minsky e Papert
…	…
1960-1980	Kohonen, Grossberg, Widrow, Anderson, Caianiello, Fukushima, Aleksander
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1974	Werbos
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1982	Hopfield
1986	Rumelhart e McClelland

Artificial Neural Networks

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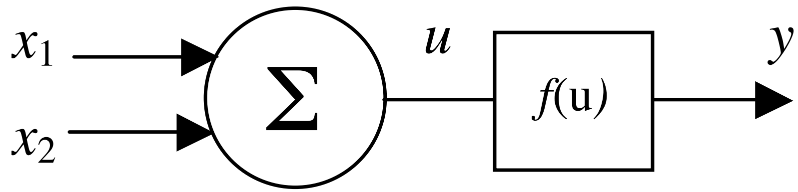
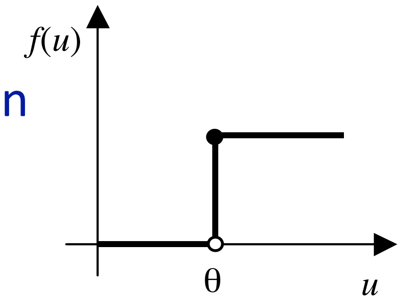
- McCulloch and Pitts (1943)
  - first artificial neuron model



  - x_1 *and* x_2:
  - u: result of the summing junction
  - $f(u)$: activation function
  - y : output



  - MCCULLOCH, W.S. & PITTS, W. "A logical calculus of the ideas immanent in nervous activity", Bulletin of Mathematical Biophysics, vol. 5, pp. 115-133, 1943.

Artificial Neural Networks

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- Norbert Wiener (1948)
  - WIENER, N. (1948) "Cybernetics", The MIT Press.

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- Donald Hebb (1949)
  - Hebbian Learning
  - Hebb, D.O. (1949), "The organization of behavior", New York, Wiley.

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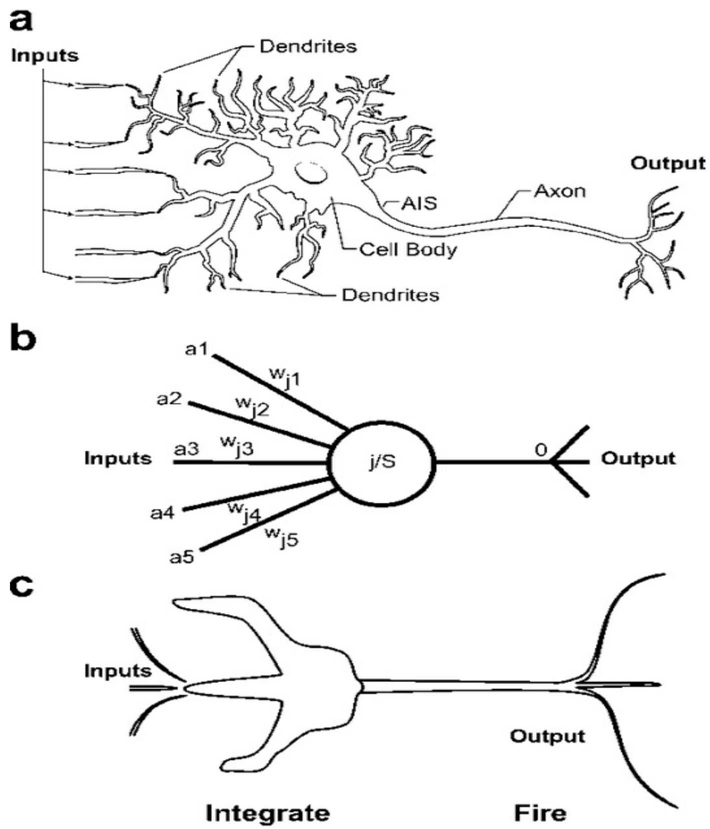
- Frank Rosenblatt (1957)
  - Perceptron



  - Rosenblatt, F. (1958), "The perceptron: A probabilistic model for information storage and organization in the brain, Psychological Review, v65, n6, pp: 386-408.

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- Widrow-Hoff Learning Rule (1958)
  - LMS (Least Mean-Square) algorithm
  - Widrow and Hoff (1960), "Adaptive Switching Circuits", IRE WESCON convention record, pp: 96-104.
  - Widrow and Lehr (1990), "30 years of adaptive neural networks: perceptron, madaline, and backpropagation", Proc. Of the Inst. of Electrical and Electronics Engineers, v78, pp: 1415-1442.

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1986	Rumelhart e McClelland

- Marvin Minsky and Seymour Papert (1969)
  - Book: "Perceptrons".
  - This book marked the beginning of the "dark era" in ANN research – the field stagnated for more than 10 years.
  - New updated version of the book was published in 1988.

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- Hopfield (1982)
  - Hopfield ANN: a recurrent artificial neural network
  - HOPFIELD, J.J. (1982), "Neural networks and physical systems with emergent collective computational abilities", *Proceedings of the National Academy of Sciences of the U.S.A., vol. 79, pp. 2554-2558.*

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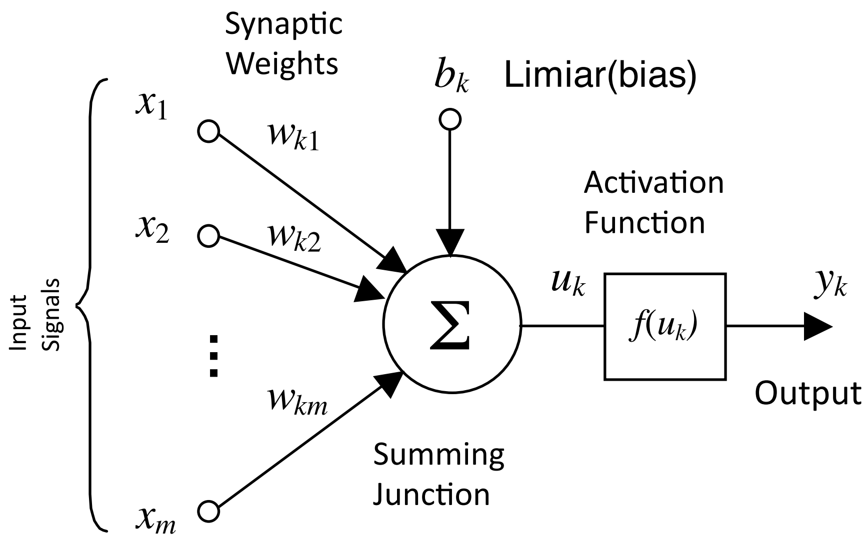
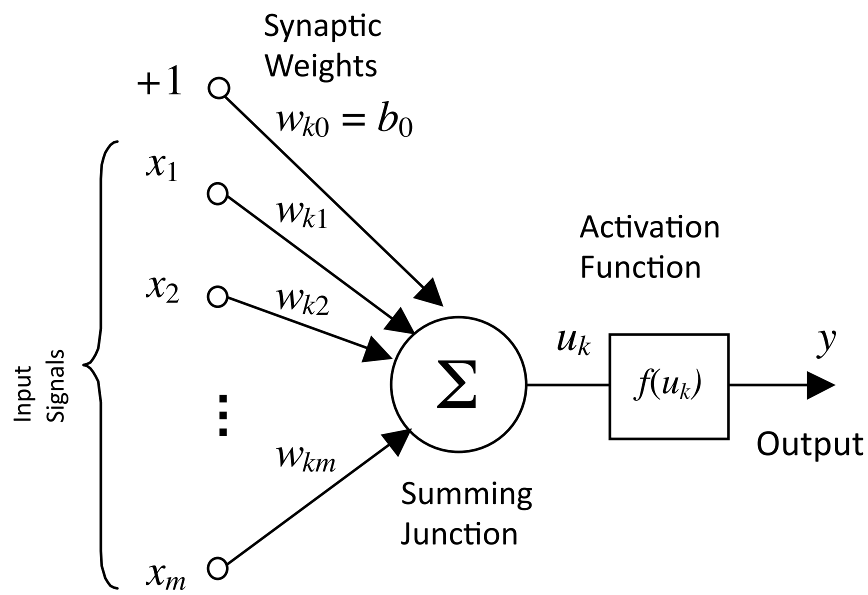
- Rumelhart and McClelland (1986)
  - Backpropagation Algorithm to train Multi-Layer perceptron ANN.
  - RUMELHART, D.E. & MCCLELLAND, J.L. (1986), "Parallel Distributed Processing: Explorations in the Microstructure of Cognition", vols. 1 & 2, The MIT Press.

Artificial Neural Networks

- Generic Artificial Neurons



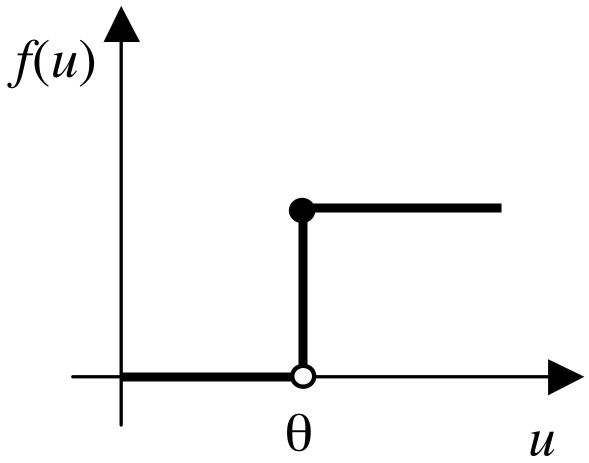


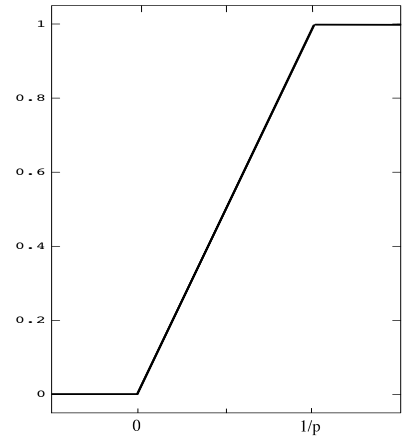
$$y_k = f(u_k) = f\left(\sum_{j=1}^{m} w_{kj} x_j + b_k\right)$$

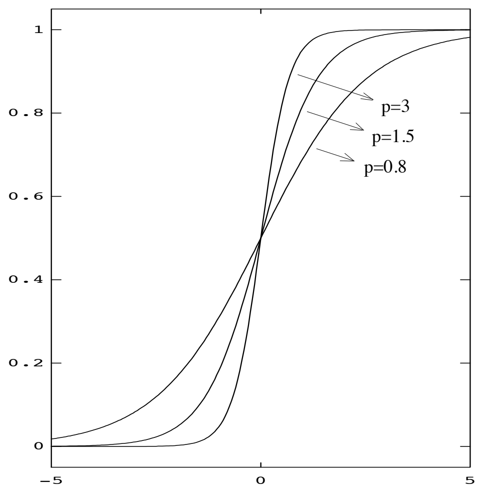
$$y_k = f(u_k) = f\left(\sum_{j=0}^{m} w_{kj} x_j\right)$$

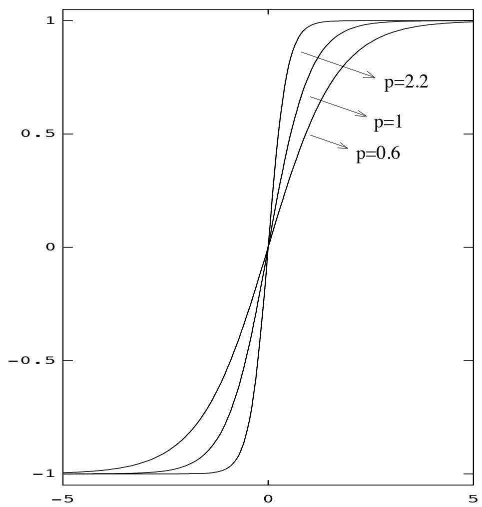
Artificial Neural Networks

- Activation functions



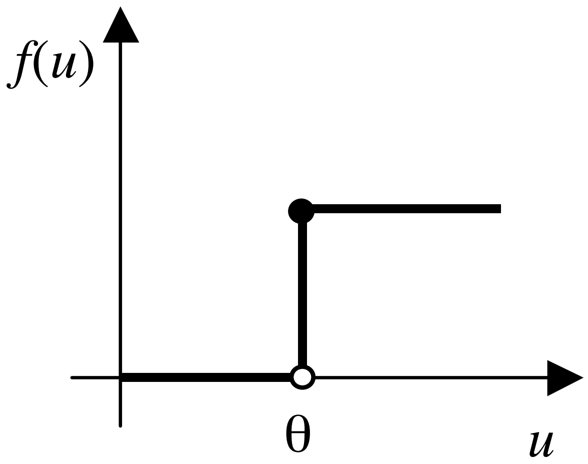






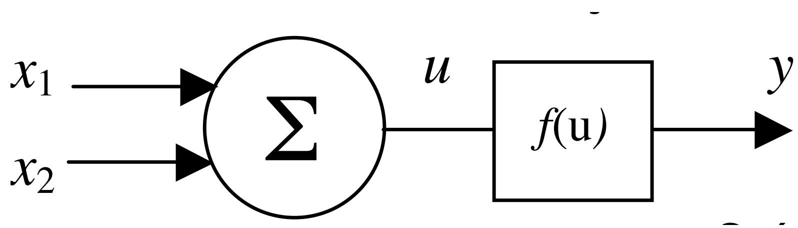
Artificial Neural Networks

- Activation functions: Threshold Function



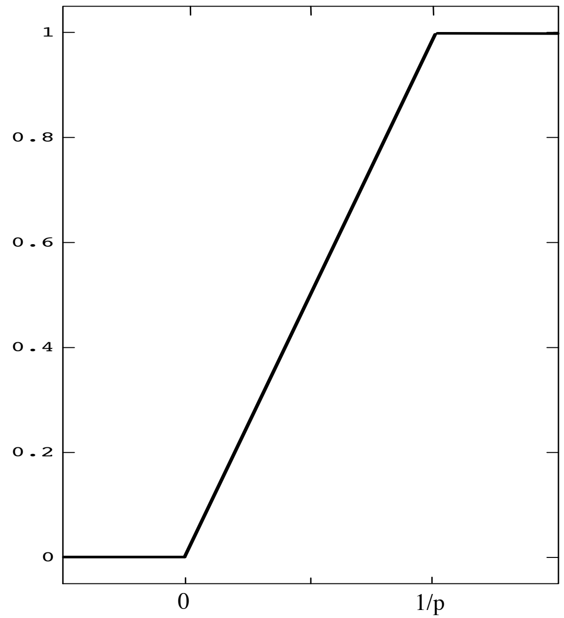
If $u \geq \Theta$ then "fire"

If $u < \Theta$ then "don't fire"



Artificial Neural Networks

- Activation functions: Piece-wise linear function



If $pu_k \geq 1$ then $f(u_k) = 1$

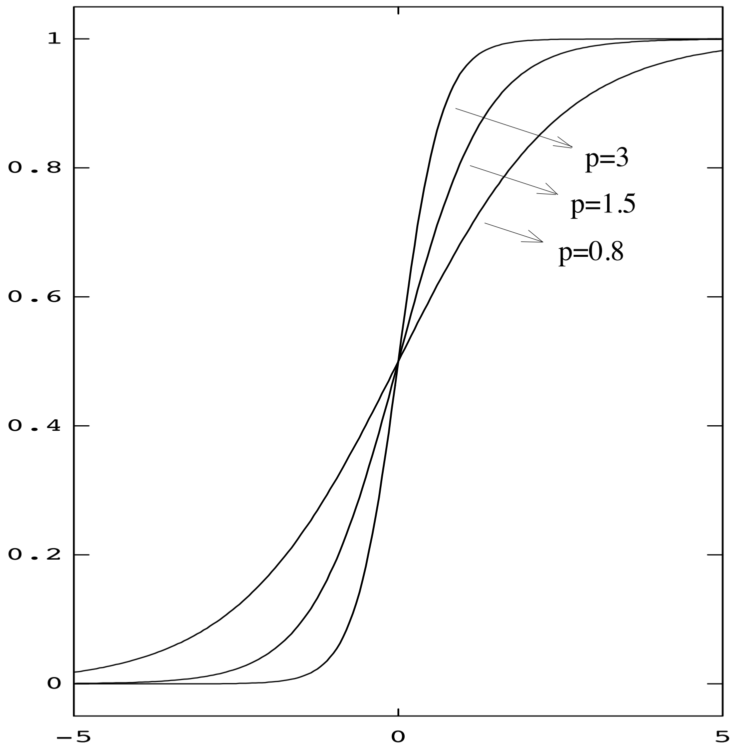
If $0 < pu_k < 1$ then $f(u_k) = pu_k$

If $pu_k \leq 0$ then $f(u_k) = 0$

- p is constant and positive

Artificial Neural Networks

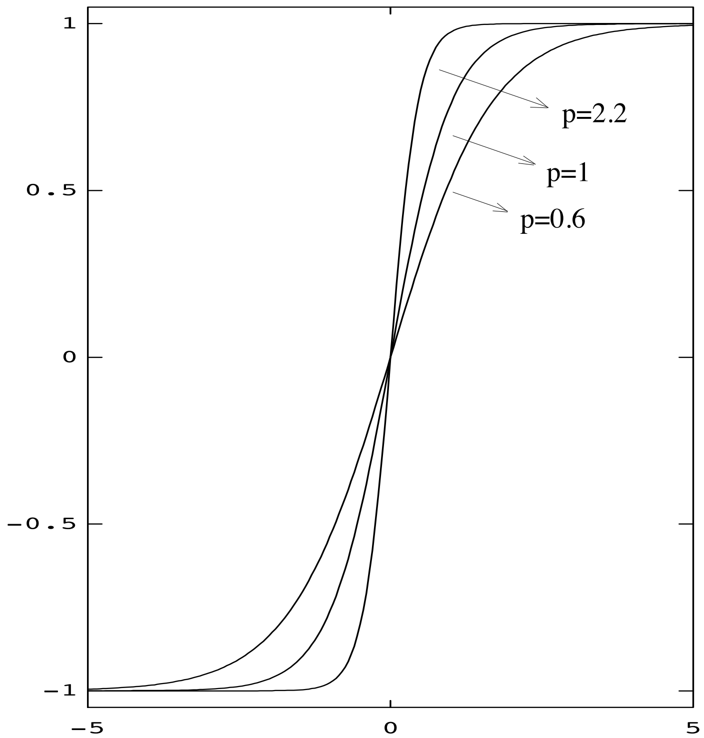
- Activation functions: Sigmoid function



$$y = f(\mathbf{u}_k) = \frac{e^{p\mathbf{u}_k}}{e^{p\mathbf{u}_k} + 1} = \frac{1}{1 + e^{-p\mathbf{u}_k}}$$

Artificial Neural Networks

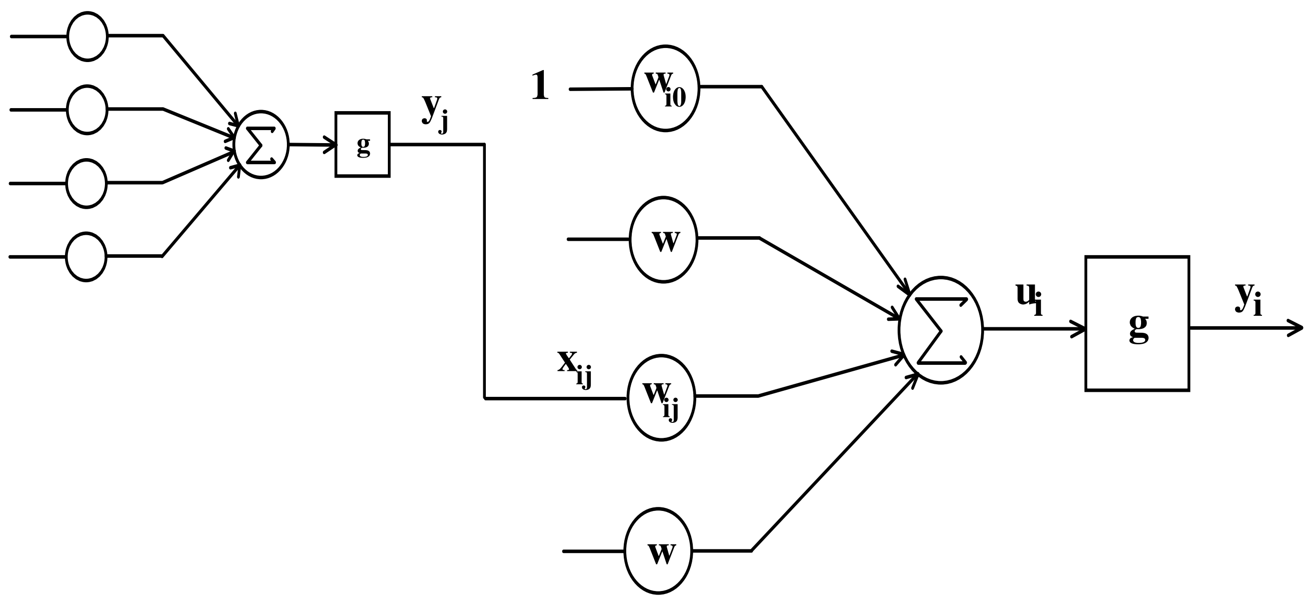
- Activation functions: Hyperbolic tangent function



$$y = f(\mathbf{u}_k) = \tanh(p\mathbf{u}_k) = \frac{e^{p\mathbf{u}_k} - e^{-p\mathbf{u}_k}}{e^{p\mathbf{u}_k} + e^{-p\mathbf{u}_k}}$$

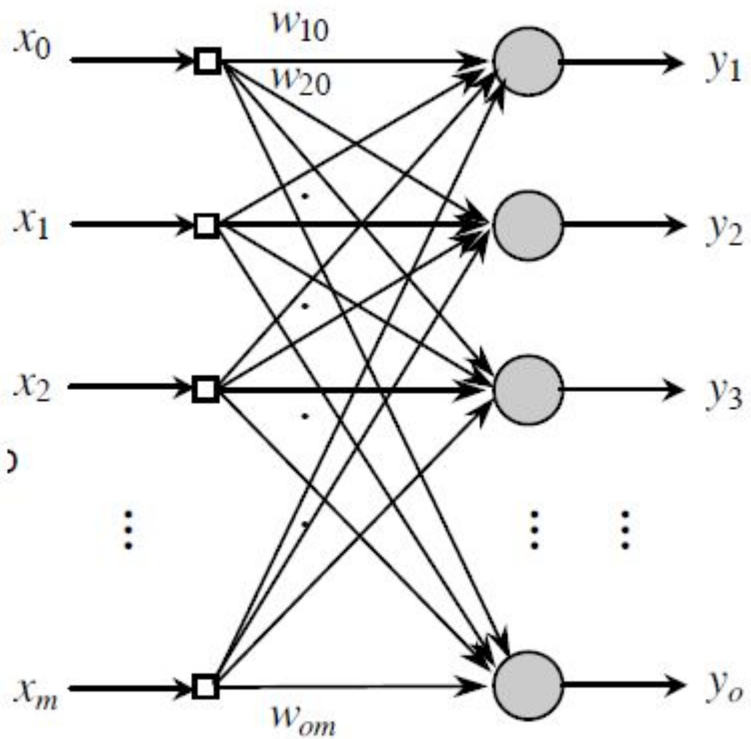
Artificial Neural Networks

- Architectures



Artificial Neural Networks

- Architectures: Single-layer Feedforward Networks

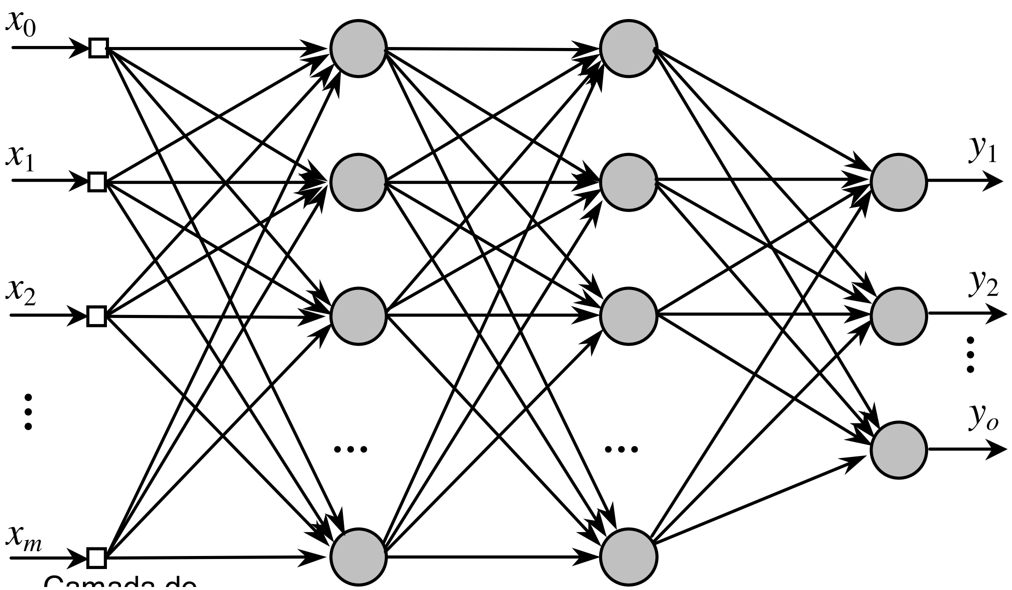


$$\mathbf{W} = \begin{bmatrix} w_{10} & w_{11} & \cdots & w_{1m} \\ \vdots & \vdots & \ddots & \vdots \\ w_{o0} & w_{o1} & \cdots & w_{om} \end{bmatrix}$$

$$y_i = f(\mathbf{w}_i.\mathbf{x}) = f(\Sigma_j\, w_{ij}.x_j)\ \ , j = 1,\ldots,m.$$

Artificial Neural Networks

- Architectures: Multilayer Feedforward Networks

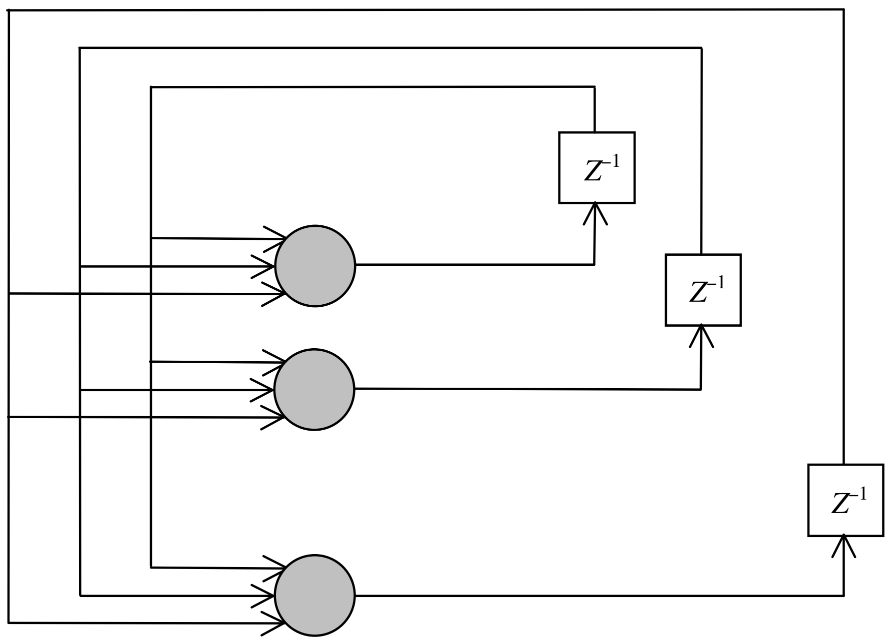


W^k is the synaptic weight matrix of layer k

$$\mathbf{y} = \mathbf{f}^3(\mathbf{W}^3\, \mathbf{f}^2(\mathbf{W}^2\, \mathbf{f}^1(\mathbf{W}^1\mathbf{x})))$$

Artificial Neural Networks

- Architectures: Recurrent Neural Networks



Ex: Hopfield Neural Network

Artificial Neural Networks

- Learning Paradigms

$$w(t+1) = w(t) + \Delta w(t)$$

I. Supervised Learning

II. Unsupervised Learning

III. Reinforcement Learning

Lecture 2

I. Lecture 1 – Revision

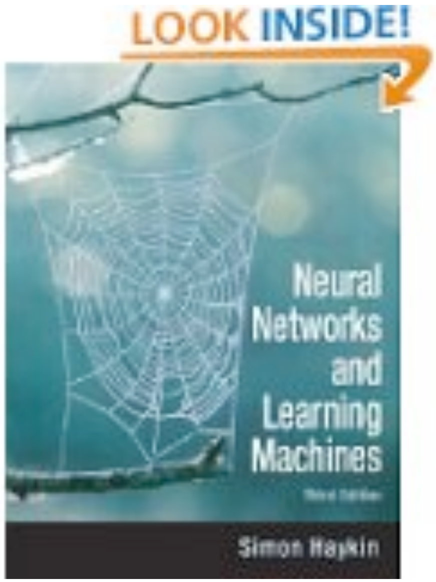
II. Artificial Neural Networks (Part I)

Lecture 2

Reading list/Homework

- Read Chapter 1.3 and 1.6 (inclusive) from the book:

  "Neural Networks and Learning Machines" (3rd Edition)
  by Simon O. Haykin (Nov 28, 2008)



- Answer questions 6-7 from the Tutorial material

Lecture 2

Related videos:

- The Human Brain Project (Overview)

http://www.youtube.com/watch?v=JqMpGrM5ECo

Lecture 3

What's next?

Artificial Neural Networks

(Part II)