Neural Networks
Introduction

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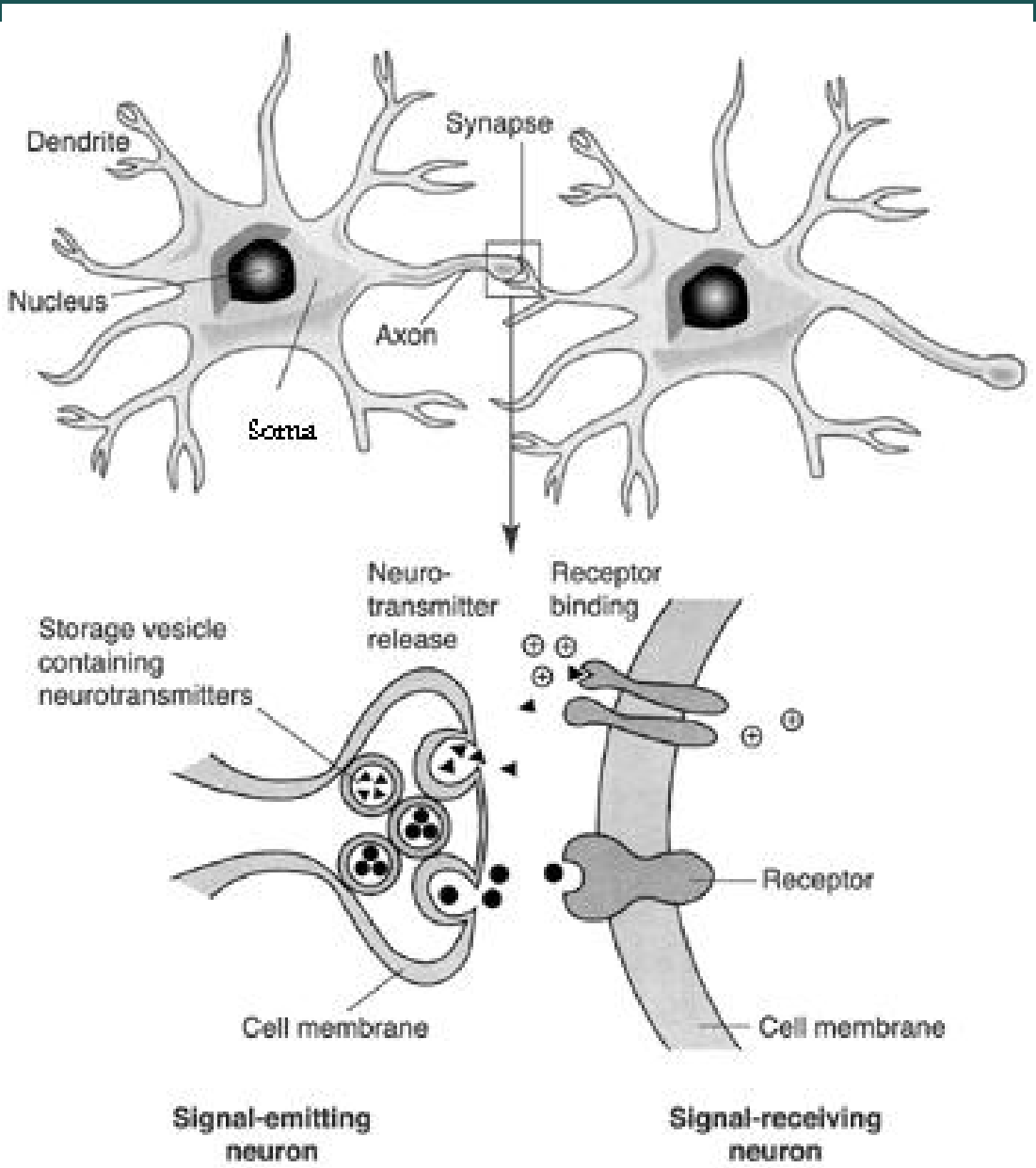
- Computational Intelligence provides us the opportunity to find a solution for the problems which were merely solvable by human intelligence.
- Computational intelligence machine can learn and remember similar to human brain
- Although the processor elements of a computer (semi-conductors) act much faster than processor elements of human brain (neurons), human response is faster than a computer.
  - In human brain, neurons work in parallel and are tightly connected together
  - In computer the calculations are doing sequentially.
- Artificial neural networks mimic brain capability of computation and learning.

Biological Neural Networks

- The simplest unit of neural networks called *neurons*
- Neurons transfer the information from sensing organs to brain and from brain to moving organs
- Each neuron is connected to other neurons and they totally make the neural network system.
- There are more than 100 billion neurons in human body most of which are located in brain.
- A biological neuron includes three fandamental parts:
  - **Dendrites:** Receive signals from other neurons.
    - The neurotransmitter chemicals are released to transmit the signals through synaptic gaps
  - **Soma** or body of the cell which accumulates all input signals.
  - When the input signals reach an action potential threshold, they are transmitted to other neurons through **Axon**



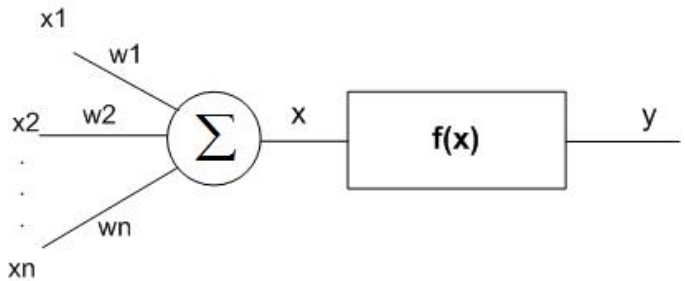
http://people.eku.edu/ritchisong/301images/synapseNIAAA.gif

Biological Neural Networks

- Each neuron can adapt itself with environment changes
- The neural network structure is changing based on reinforcement and weakening the synaptic connections.
- Learning is obtained by changing the synaptic gaps.

Artificial Neural Networks

- Artificial neural networks is inspired by biological neural networks.
- So the structure of artificial neural networks are based on:
  - Simple elements called neurons where information is processed.
  - Signals are transformed through the connections between neurons.
  - To each connection, a *weight* is assigned which is multiplied to the transferring signal.
  - At each neuron, there is an *activation function* which is normally a nonlinear function. This function provides the output of the neuron.



A neuron

- $X = w_1x_1 + w_2x_2 + ... + w_nx_n, \quad X = W^Tx, \quad y = f(X)$

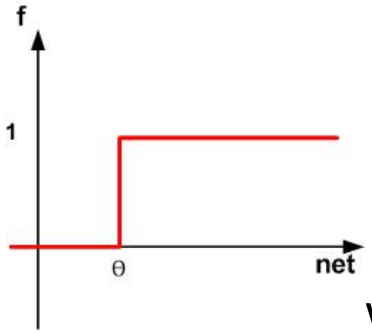
Neuron Modeling of NN

- McCullouch-Pitts model is introduced in 1943 and the first network is designed
- They found out that more precise computations is achieved by combining several neurons in a NN system.
- The model considers several drastic simplifications:
  - It allows only binary states (0-1)
  - Operates under a discrete time assumption
  - Wights and neuron's threshold are fixed
- Nowadays, computing algorithms employ a varieties of neuron models with more diversified features.

- Each artificial neural network (NN) is distinguished by
  - Pattern of connection between neurons (Neural network structure)
  - Method of weight adjusting mechanism (Learning)
  - Activation function
- By adjusting the weights, (synaptic gaps in biological neurons) the neural network learn a pattern.

Activation Function

- The simplest definition of activation function is binary with threshold.



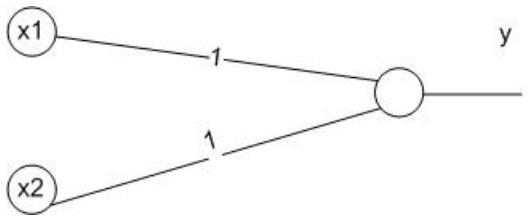
where $net = W^T X$, and θ is threshold level to fire neuron

- Therefore, output y is defined as $y = \begin{cases} 1 & net \geq \theta \\ 0 & net < \theta \end{cases}$
- The use of threshold will be more discussed in Perceptron and classification.
- Any function $f(net)$ that is monotonically nondecreasing and continuous s.t. $net \in R$ and $f(net) \in (-1, 1)$ can be considered as a NN activation function

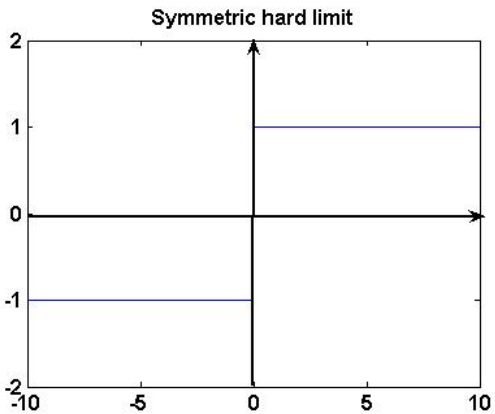
- Example:And

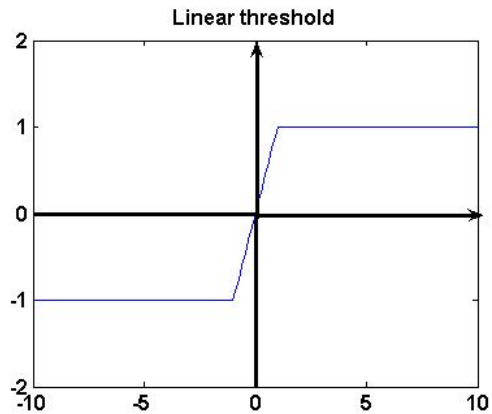
x_1	x_2	$\rightarrow$	y
1	1		1
1	0		0
0	1		0
0	0		0

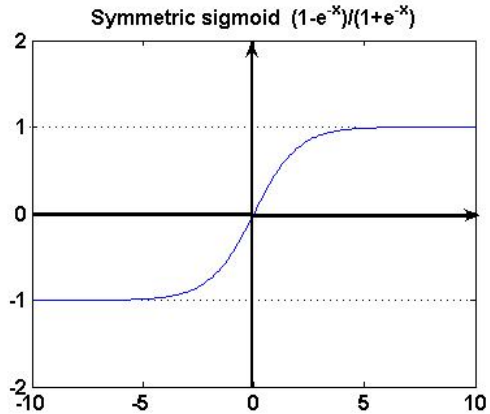
$$y = \begin{cases} 1 & net \geq \theta \\ 0 & net < \theta \end{cases}, \theta = 2$$

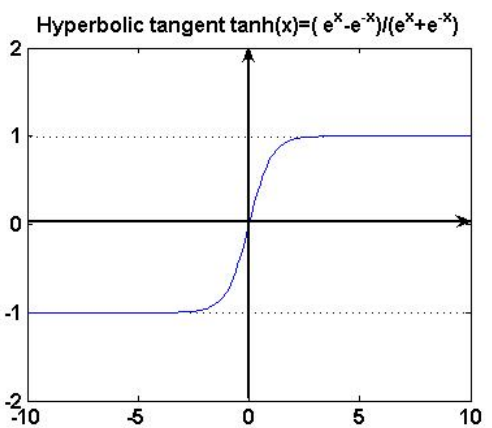


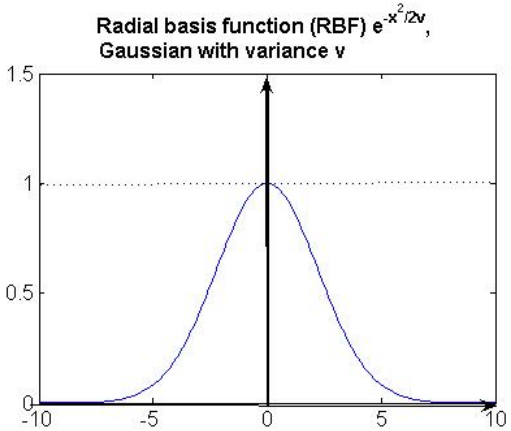
- Most popular activation functions:
  - Linear It is usually used in output layer when continuous functions are required (such as in control): $f(net) = net$







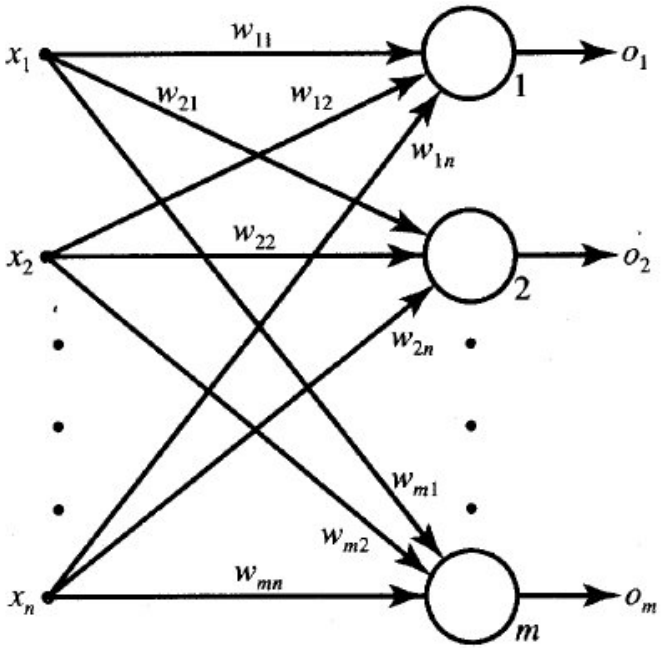




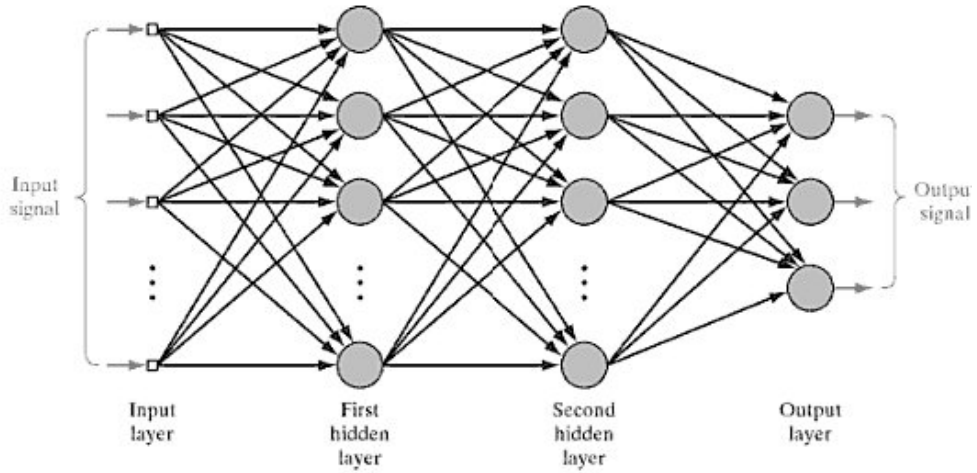
- The output of each neuron can be
  - unipolar binary: 0 and 1
  - bipolar: -1 and 1
- Sometimes, unipolar functions cannot represent the output properly.
- Unipolar functions are not proper functions for generalization as well

Neural Architecture

- Neurons at NN are arranged in layers
- Neurons in the same layer behave in the same manner.
- Key factors in determining the behavior of a neuron are its activation function and the pattern of its weight connections
- Within each layer, neurons usually have the same activation function and the same pattern of connections to other neurons.
- Neural nets are often classified to:
  1. **Single Layer**
     - includes one layer of connection weights.
     - input units: the units which receive signals from the outside world
     - output units which the response of the net can be read.
  2. **Multi Layer**
     - It has layers of nodes between the input units and the output units. (hidden units)
     - Multilayer nets can solve more complicated problems than can single-layer nets, but training may be more difficult.

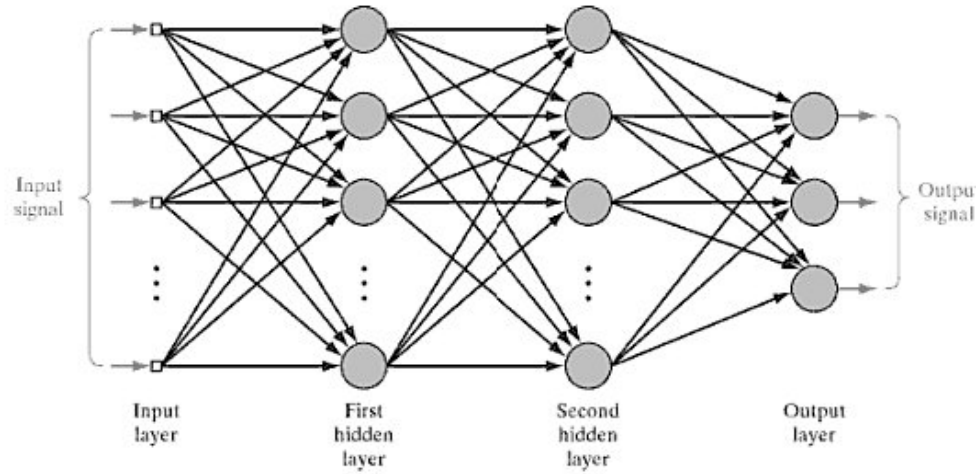


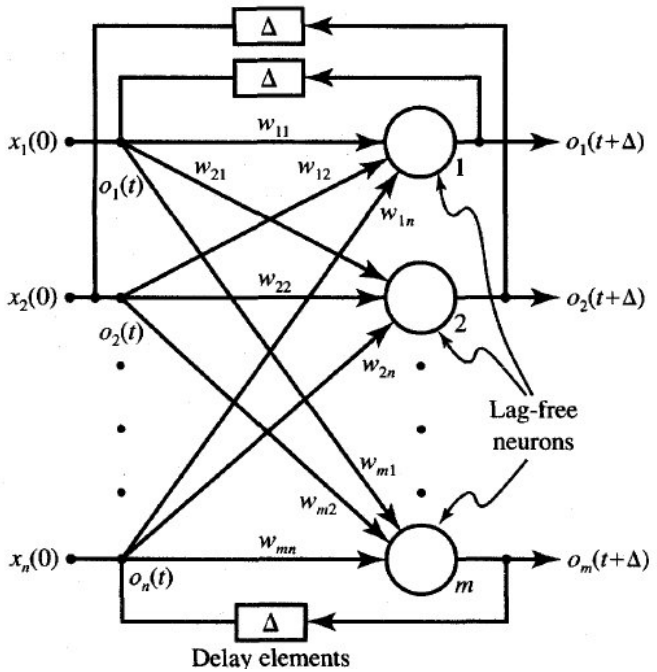
Single layer Network



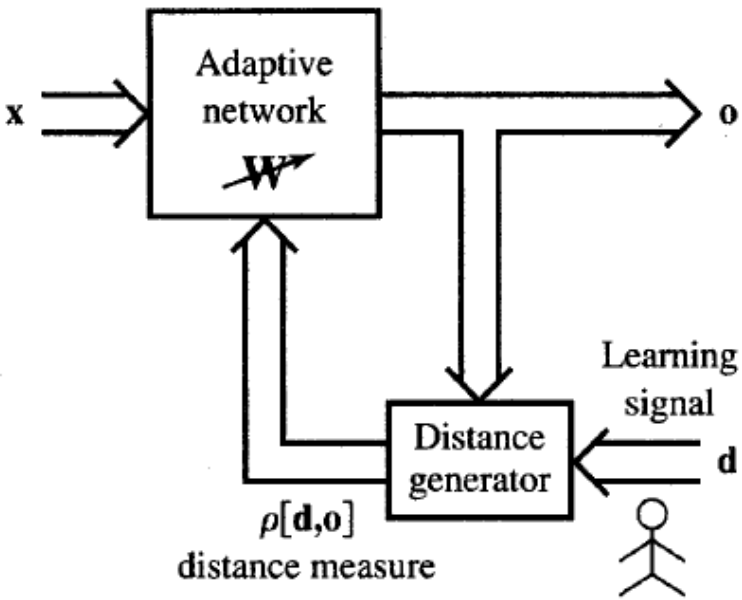
Multi Layer Network

- The NN based on type of the connection can also be categorized to:
  1. **Feed Forward Networks**
     - the signals flow from the input units to the output units, in a forward direction.
     - Like Multilayer perceptrons, RBF, etc
  2. **Feedback Networks**
     - It can be obtained from the feed forward network and a feedback connection form the neurons' outputs to their inputs.
     - Like Hopfield networks

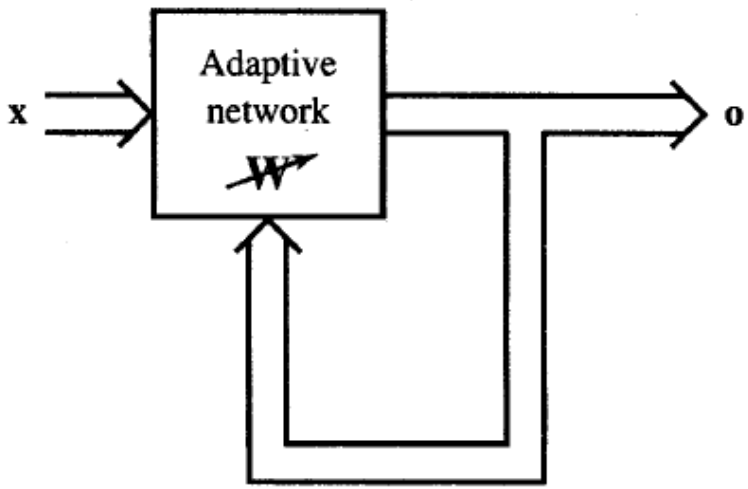




- Training NN (Adjusting the weights)
- - Supervised
  - Unsupervised



(a)



(b)

- How much the artificial neural networks are similar to the biological neural networks?
  - It varies in different type of artificial neural networks based on its application.
  - For some researchers such as engineers high performance of the network in calculations and function approximation is more important.
  - In some research areas like neurology, emulating the biological behavior is more attractive.
- In general the artificial NNs and biological neural networks are similar in
  1. The processing elements (neurons) receive signals
  2. Signals can be modified by weights (synaptic gaps)
  3. Processing elements gather the weighted inputs
  4. Under specified condition, the neuron provides output signal
  5. Output of a neuron can be transferred to other neurons
  6. The power of each synapse (weights) varies in different experience.

- Neural Networks (NNs) capabilities
  - Learning
  - Parallel Processing
  - Generalization
    - When a NN is trained, it can generalize its knowledge to the inputs which has not seen before
    - For example if a NN is used for recognizing letters, if it receive a noisy input, it still can recognize it and deliver the letter without noise.
  - Fault toleration
    - NN can tolerate its malfunctioning in some circumstances.
    - Human is born with 100 billion neurons which some of them die but learning does not stop!!
    - Artificial NN should behave the same.

Neural Network Applications

1. Signal Processing
   - Such as eliminating echo on telephone lines
2. Control (NN can be applied for nonlinear systems)
   - Identification, unmodeled dynamics, variable parameters
   - Observation
   - Control of nonlinear system
3. Pattern Recognition
   - Handwriting
   - Finger print
4. Medical
   - Help in diagnosing diseases based on symptoms
5. Speech Recognition
   - In classic methods, some rules are defined for standard pronunciation of letters and a look-up table for exceptions.
   - In NN, there is no need to extract the rules and exceptions. NN is trained based on I/o data.

Reference Books

- **Text Book:**
  - Introduction to Artificial Neural Systems, J. K. Zurada, West publishing company, 2nd edition 2006
- **Other Reference Books:**
  - Neural networks and learning machines, S. S. Haykin, Prentice Hall , third edition,2008
  - Fundamentals of Neural Networks, M. B. Menhaj, Amirkabir University of Technology, 2009 (in Farsi)

Topics

Topic	Date	Refs
Introduction (Fundamental concepts and models of NN)	Weeks 1,2	Chapter 2
Single Layer Perceptron, Feed-forward Networks	Weeks 3-5	Chapter 3,4
Radial Bases Functions	Week 6	
Single Layer Feedback Networks,	Week 7	Chapter 5
Associative Memories	Weeks 8,9	Chapter 6
Self-Organizing Networks	Weeks 10,11	Chapter 7
Competitive Networks and ART	Weeks 12,13	
Applications of Neural Networks in Control and Identifications	Week 14,15	