Artificial Neural Networks

陳柏琳, Berlin Chen 2002

berlin@csie.ntnu.edu.tw

29322411 ext 203

Textbook and References

- Textbook
  - J. M. Zurada, "Introduction to Artificial Neural Systems," West Publishing Company, 1992
- References
  - Simon Haykin, "Neural Networks: A Comprehensive Foundation, Second Edition," Prentice Hall, 1999
  - 蘇木春、張孝德，機器學習：類神經網路、模糊系統以及基因演算法則，全華科技圖書股份有限公司
  - 拉蒙卡哈，研究科學的第一步 — 給年輕探索者的建議，究竟出版社
  - Rita Carter, “Mapping the Mind”。 洪蘭譯， 大腦的秘密檔案，遠流出版社

Grading

1. Midterm and Final Project: 45%
2. Exercises: 30%
3. Attendance and Presentation: 25%

1. Introduction

Motivation

- Human brain composed of neurons (神經元) switching at speeds about a million times slower than computer gates
  - Neurons: 10^{-3} sec
  - Silicon chips: 10^{-9} sec
- Yet, human are more efficient than computers at computationally complex tasks
  - Speech Understanding, Image Processing etc.
- Develop artificial neural systems which could process information as efficiently as the human brain does

Human Nervous System

- Ramón y Cajál (拉蒙卡哈), 1911
  - Introduce the idea of neurons as structural constituents of the brain ☞
- 10^{11} neurons,
  10^{4} synapses per neuron

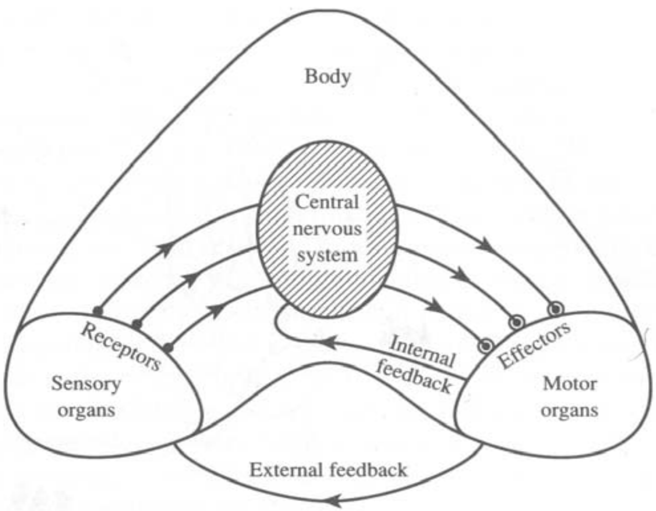


Figure 2.1 Information flow in nervous system.

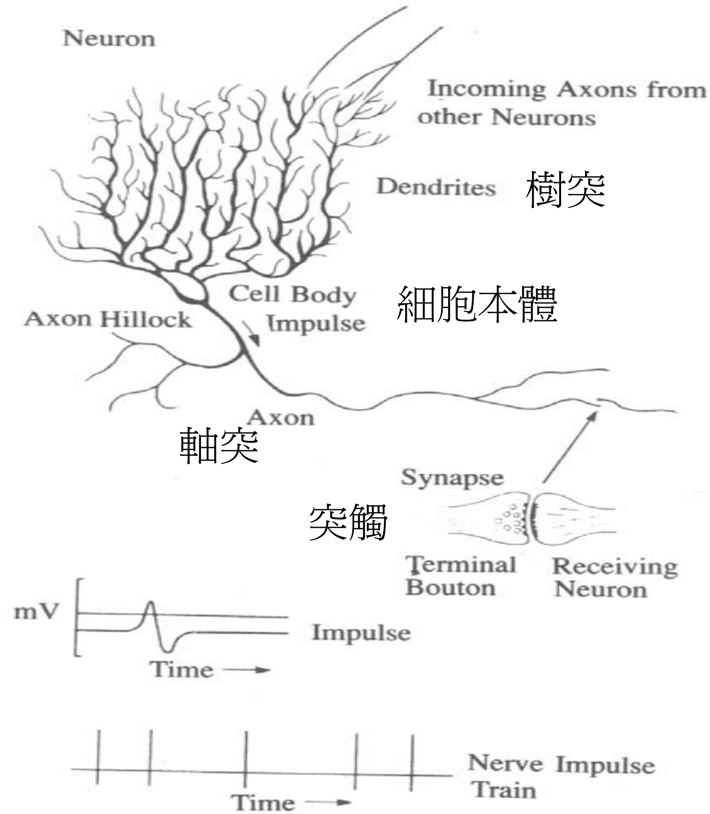


Figure 2.2 Schematic diagram of a neuron and a sample of pulse train.

Ramón y Cajál (拉蒙卡哈), 1852-1934

- 神經解剖學者、諾貝爾獎(1906)得主
- 推翻舊有學說
  - 腦神經系統內的細胞都是融合在一起(多核細胞體)、或細胞間細胞質流通形成神經網路
- 提出新學說
  - 腦神經是由個別的神經元組成，在神經元內訊號以單一方向傳遞訊號(樹突→細胞本體→軸突→突觸)

神經元內/間訊號傳遞

- 樹突的主要功能就是接受其它神經元所傳遞而來的信號
- 若導致位於軸突丘 的細胞膜電位 超過某一特定閥值 (threshold)時，則所謂的「活化電位」(action potential) 的脈衝就會被激發出來
- 藉由管狀似的軸突傳遞至其它相連接的神經元。
- 軸突的終點處是「突觸」，這種細胞間的信號傳遞以化學性的方式居多

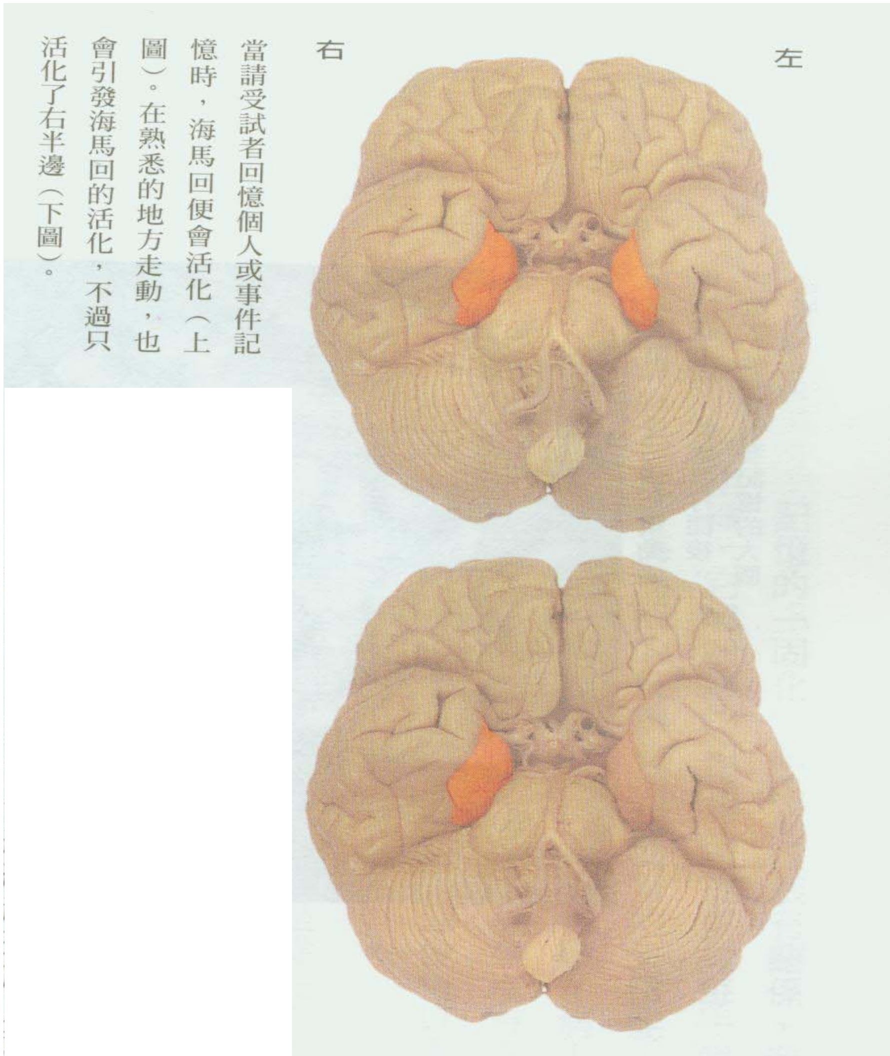
參考自蘇木村教授著作

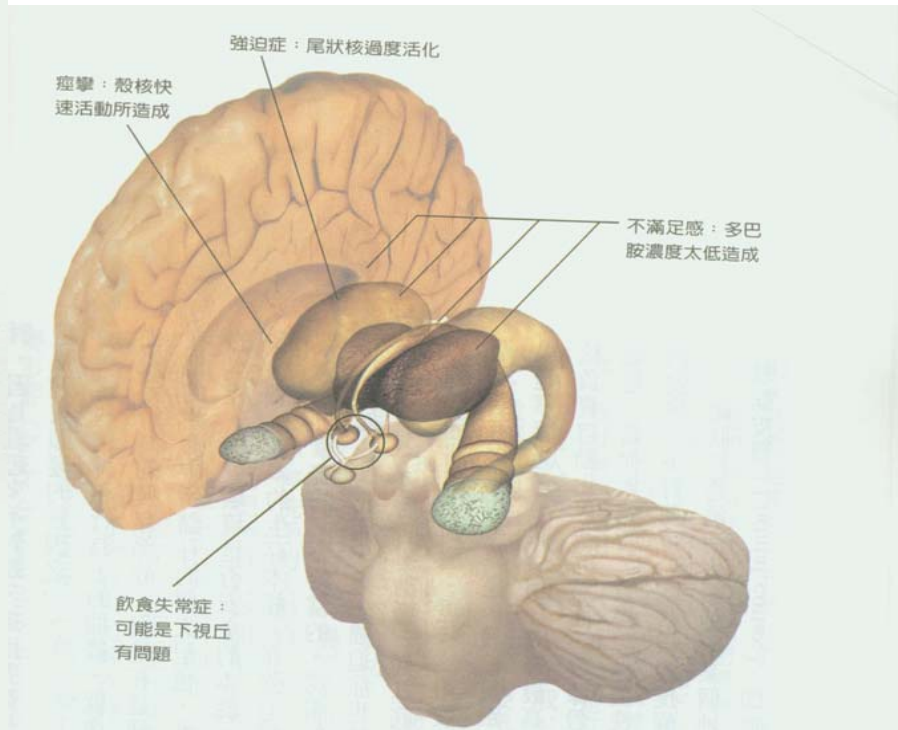
大腦功能的研究

- 基本上，有兩種不同的途逕來嘗試研究大腦的功能
  - 通常生物神經學家(neurobiologists)採用由下而上的方式，藉由對單一神經細胞的刺激與反應(stimulus and response) 特徵的瞭解，進而對由神經細胞聯結而成的網路能有所認識
  - 而心理學家(psychologists) 採取的是由上而下的途逕，他們從認知 (cognition) 與行爲反應來瞭解大腦

參考自蘇木村教授著作

大腦功能的研究 (cont.)





參考自洪蘭教授譯著

Artificial Neural Systems

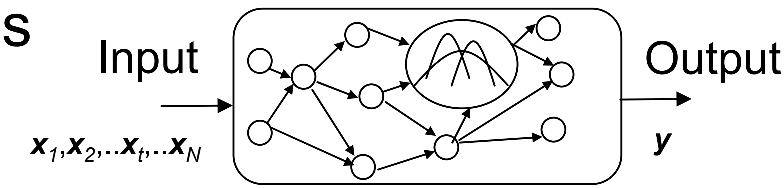
- Reproduce some of the flexibility and power of the human brain by artificial means
- Computation is performed by a dense mesh of artificial neurons and their connections
  - Neurons perform as summing and linear/nonlinear mapping junctions (threshold units for firing)
  - Neurons are organized in layers and operate in parallel
  - Each connection strength expressed by a numerical values (a weight) which can be modified
- Many technical jargon terms used
  - Artificial neural systems, artificial neural networks, neural computing, self-organizing networks etc.

Attractiveness of Artificial Neural Systems

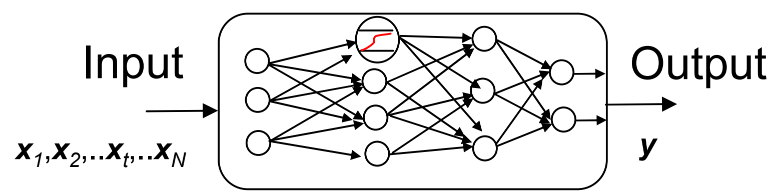
- Neuroscientists: modeling of biological neural networks
- Psychologists: possible prototype structures of human-like information processing
- Physicists: nonlinear dynamic systems
- Mathematicians: mathematical modeling of complex large systems phenomena
- Electrical and computer engineers: signal processing
- Computer scientists: massive parallel computation

Neural Networks vs. Classical Information-processing Approaches

- Classical information-processing approaches
  - First formulate a mathematical model of environmental observations, validate the model with real data, and then build the design on the basis of the model, e.g. HMM modeling approaches



- Neural Networks
  - The design is directly based on the real-life data, with the data set being permitted to speak for itself
  - Provide implicit model of the environment, but also perform the information-processing function of interest



Characteristics of Artificial Neural Systems

- Neuron models
  - Linear or non-linear threshold (activation) functions
- Architectures
  - Single neuron, single-layer, multi-layer, recurrent etc.
- Learning modes
  - Learning algorithms
  - Learning with a teacher/Learning without a teacher

Applications and Examples

- Classification
- Function Approximation
- Control for Real-World Applications
- Memory and Restoration of Patterns
- Optimization
- Feature Detection and Clustering

Classifier

- A simple classifier designed to classify eight points $P_i(x_1,x_2,x_3)$, i=1…8, in three-dimension space into two categories
  - Sum the inputs x_1,x_2 and x_3 with unit weights
  - Output 1 when $x_1+x_2+x_3>0$, otherwise -1

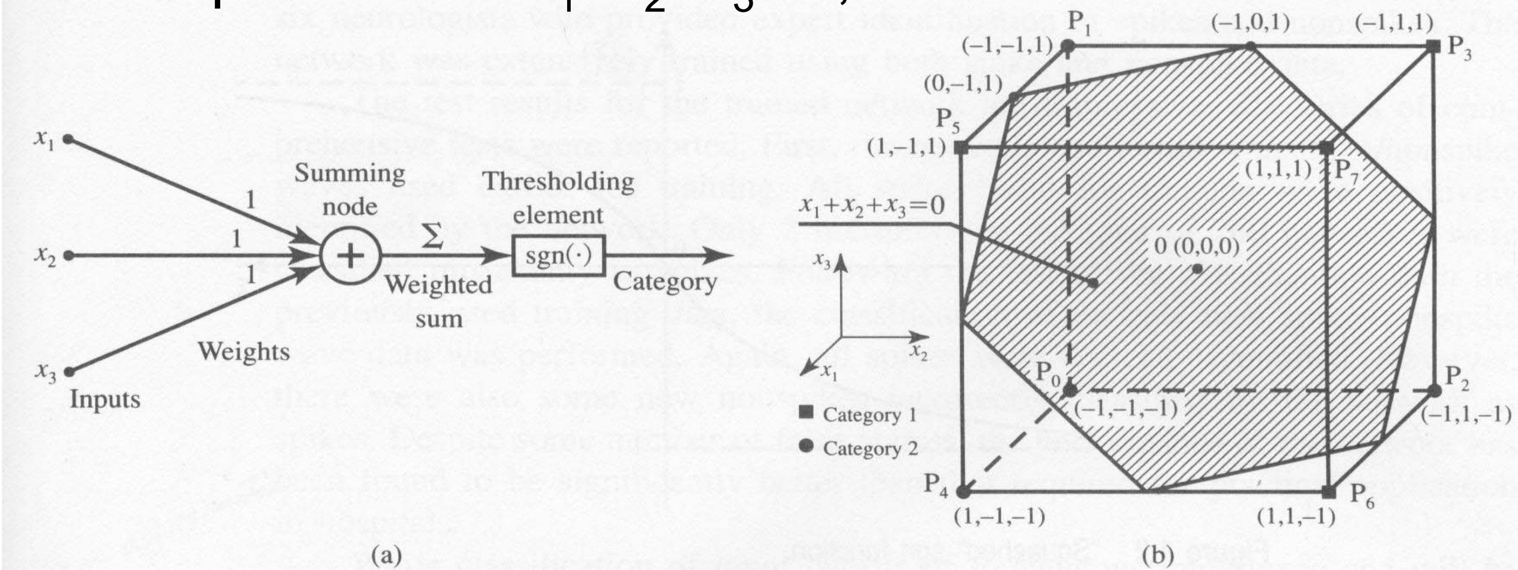


Figure 1.1 Partitioning of the set of cube vertices: (a) single-unit diagram and (b) implemented partitioning.

Classifier (cont.)

- No single-unit classifier exists for classifying points, for example P_2, P_3, P_5, into a category and the other points into the other category
- The unit with a squash sgn function as the threshold function has fine granularity than the one with a regular binary-output (1 or -1) sgn function
- Neurologists developed a layered neural system with squash sgn function to detect the brain EEG signal

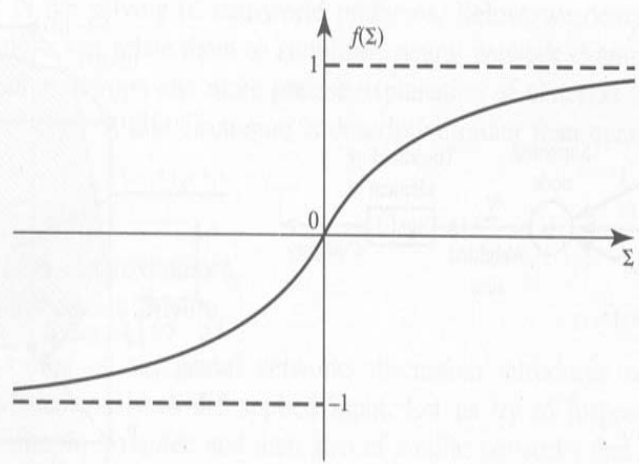


Figure 1.2 "Squashed" sgn function.

Classifier (cont.)

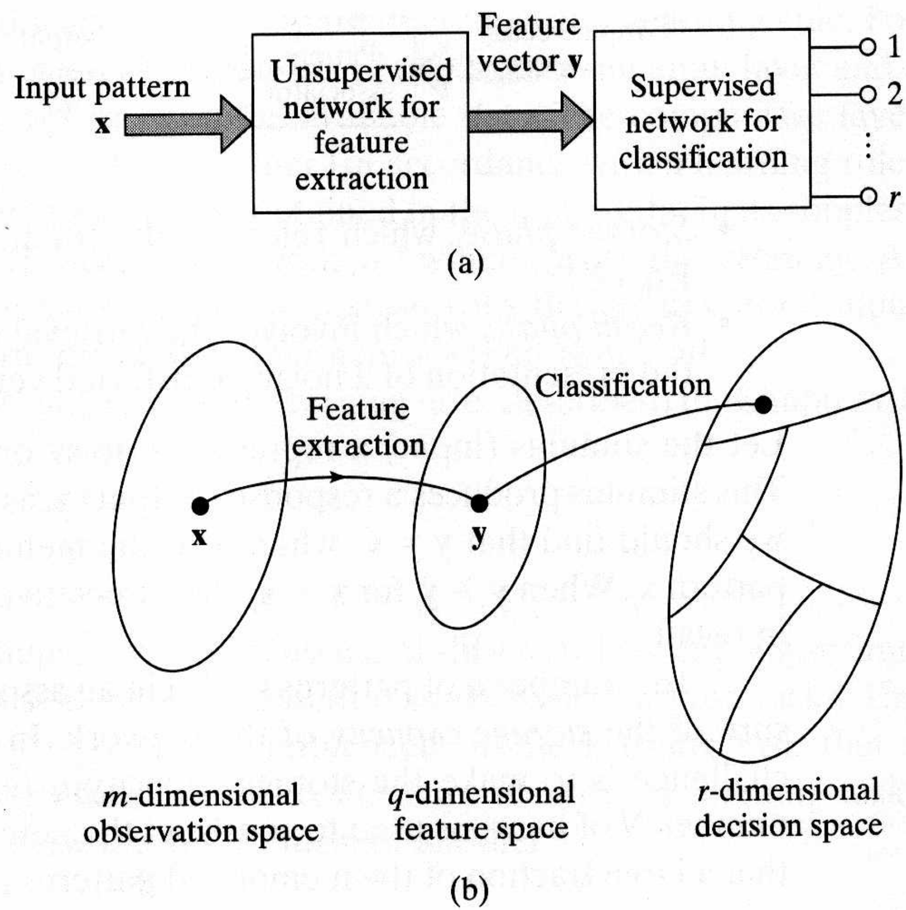


FIGURE 2.10 Illustration of the classical approach to pattern classification.

Function Approximation

- An example of function approximation for mathematical modeling

$$h(x) = 0.8 \sin \pi x, \quad -1 \le x \le 1$$

  - Implemented with a two-layer (1-10-1) neural network with squash threshold function

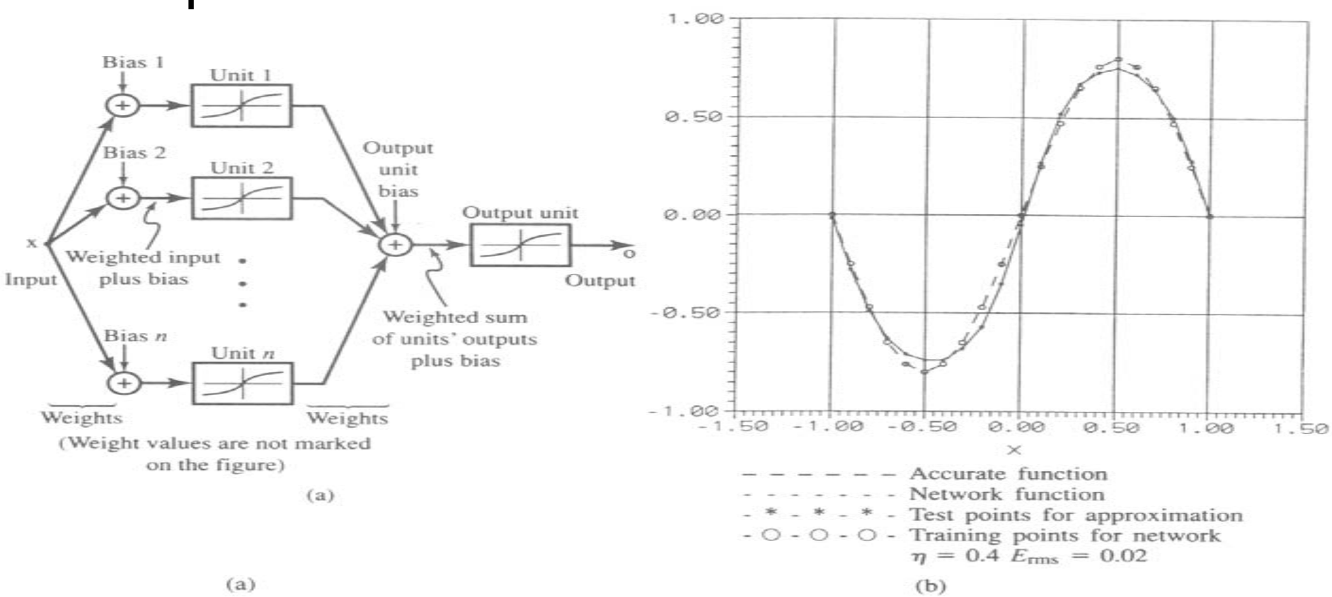


Figure 1.3 Neural network with continuous units as function approximator: (a) block diagram and (b) example approximation of Equation (1.2).

Function Approximation (cont.)

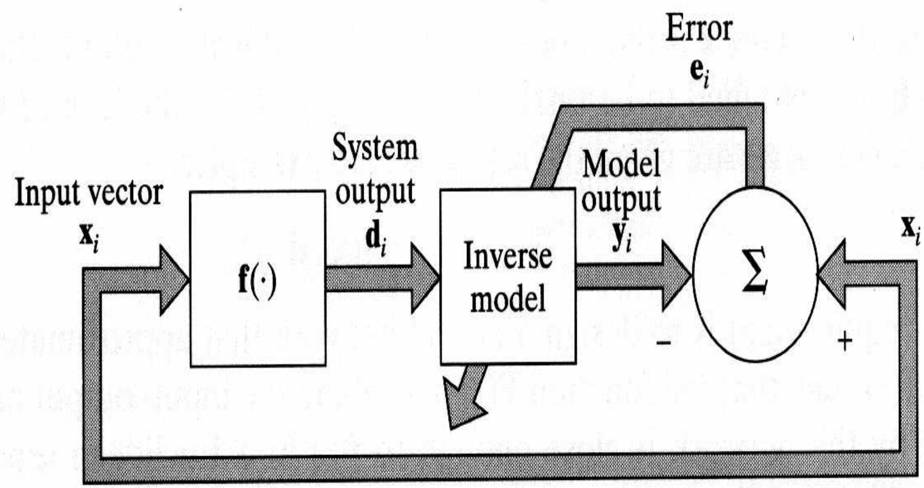


FIGURE 2.12 Block diagram of inverse system modeling.

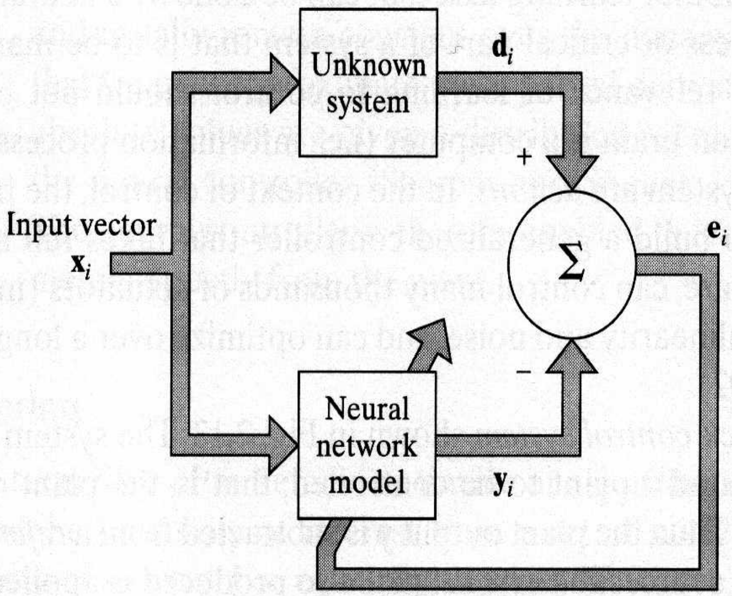
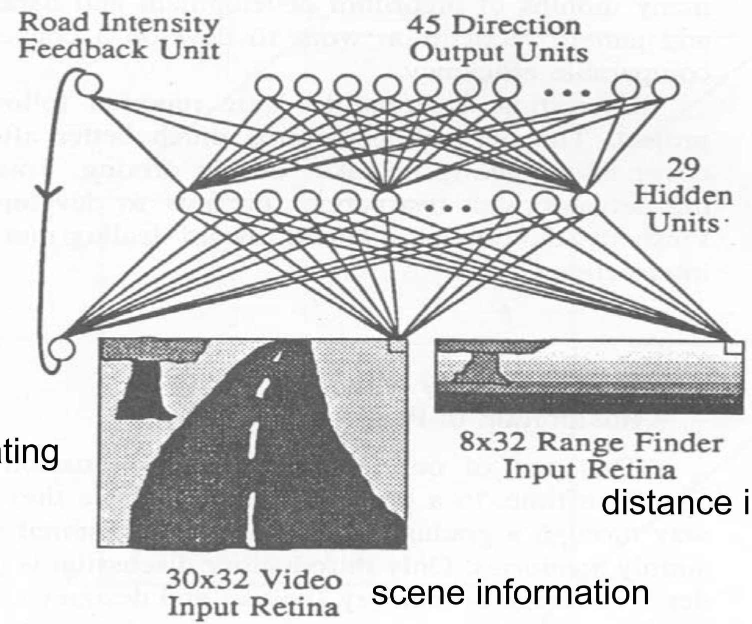


FIGURE 2.11 Block diagram of system identification.

Control for Real-World Applications

- An example for providing the right direction for the vehicle to follow the road
  - ALVIN project, 1989 (Autonomous Land Vehicle In a Neural Network)
    - 1200 computer-generated images as training examples
      - Half-hour training
      - The salient features have been directly acquired by the network itself



An additional information from previous image indicating the darkness or lightness of the road

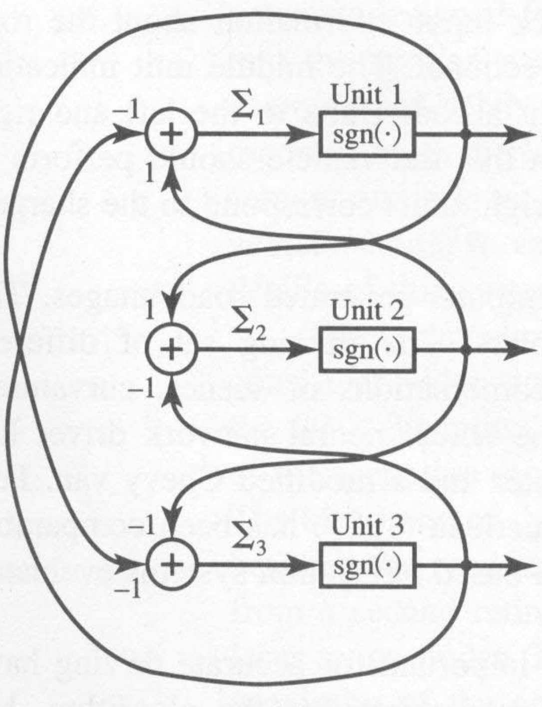
distance information

scene information

Figure 1.4 Architecture of autonomous vehicle driver. SOURCE: (Pomerleau 1989) © Morgan-Kaufmann; reprinted with permission.

Memory and Restoration of Patterns

- An example for gradually reconstructing a stored pattern, we called *memory*



(a)

	Case	Unit Number	Present Output O	Σ	sgn Σ	Next Output O
Started from P_7	1	1	1	0	x	1
		2	1	0	x	1
		3	1	−2	−1	−1
	2	1	1	2	1	1
		2	1	2	1	1
		3	−1	−2	−1	−1
Started from P_2	3	1	−1	2	1	1
		2	1	0	x	1
		3	−1	0	x	−1
Started from P_4	4	1	1	0	x	1
		2	−1	2	1	1
		3	−1	0	x	−1

x stands for sgn (0).
Encircled are updated outputs.

(b)

sgn(.)>0, 1
sgn(.)=0, don't change
sgn(.)<0, -1

Figure 1.5 Simple neural network memory: (a) network diagram and (b) listing of updates.

Memory and Restoration of Patterns (Cont.)

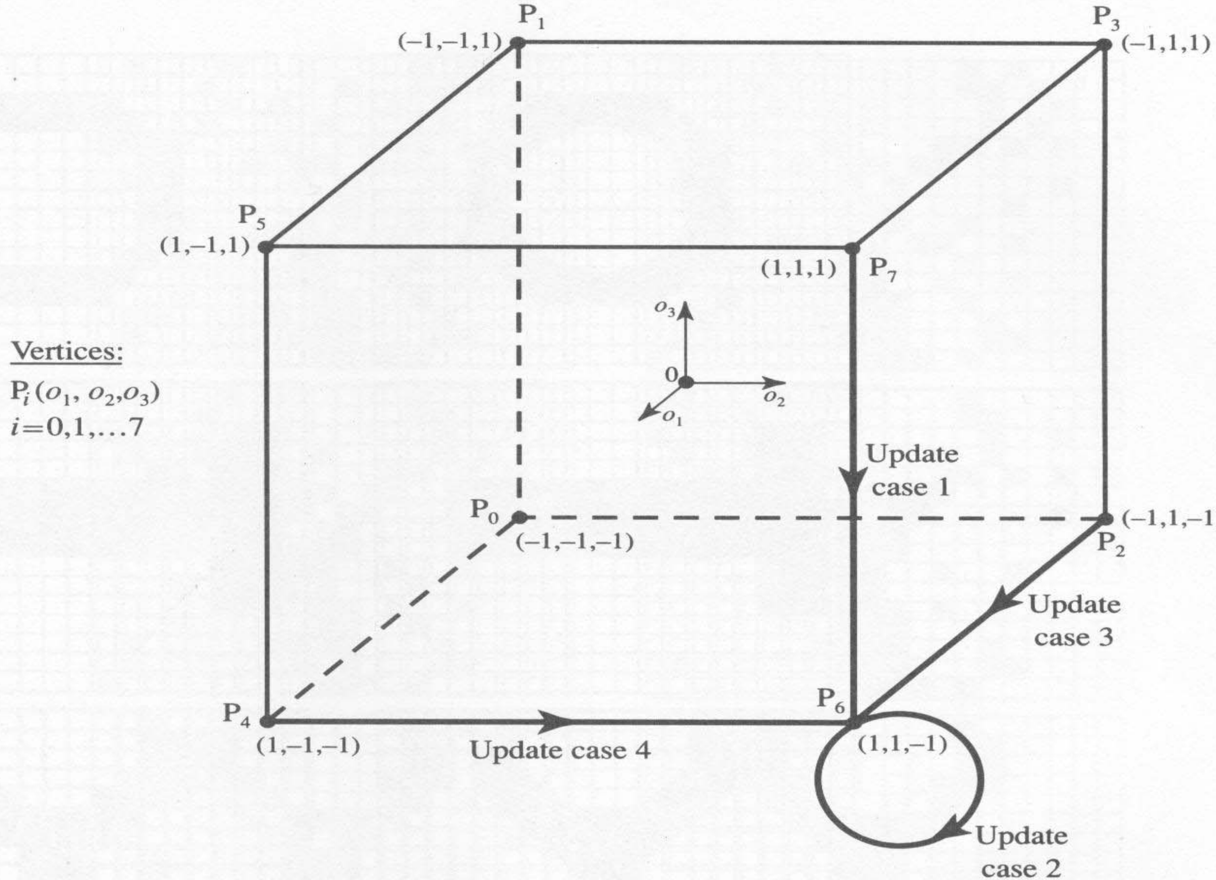


Figure 1.6 Graphical interpretation of the memory network from Figure 1.5.

Memory and Restoration of Patterns (Cont.)

- Neural network to restore heavily distorted image

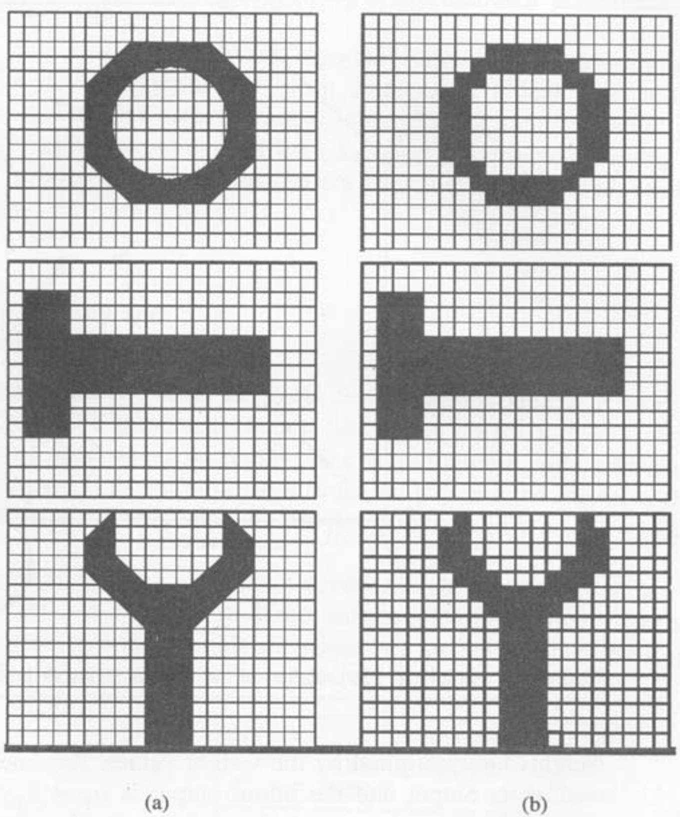


Figure 1.7 Memory network applications: (a) images of three mechanical parts and (b) images converted to bit-map forms.

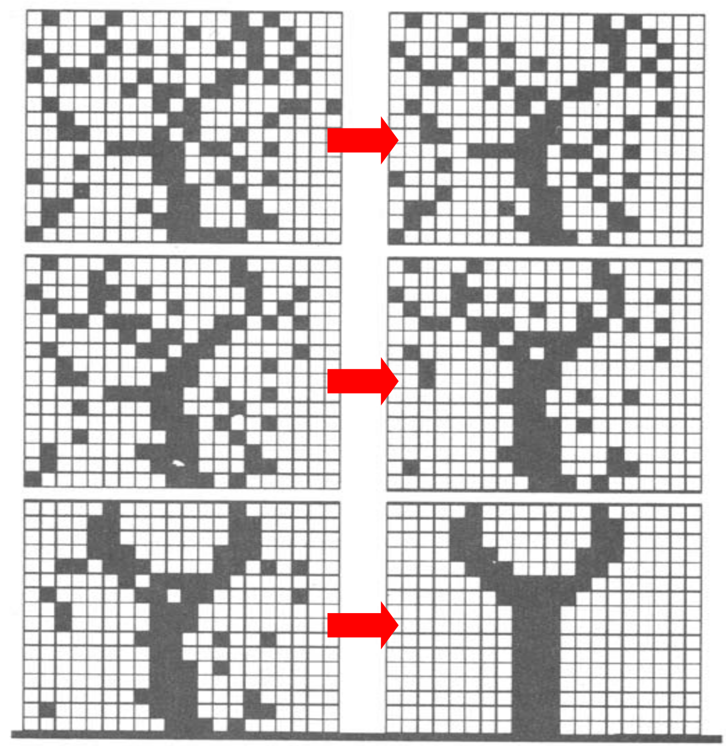


Figure 1.8 Restoration of the wrench image.

Optimization

- The purpose of optimization is to minimize certain cost functions defined by the user
  - An example for converting an analog values to a binary number
    - A number of connecting elements not shown in the figure
    - Analog-to-digital conversion error

$$\text{Error} = (x - 2v_1 - v_0)^2$$

energy function (↑ Error)

$0 \le x \le 3.5$

$x \cong 2v_1 + v_0$

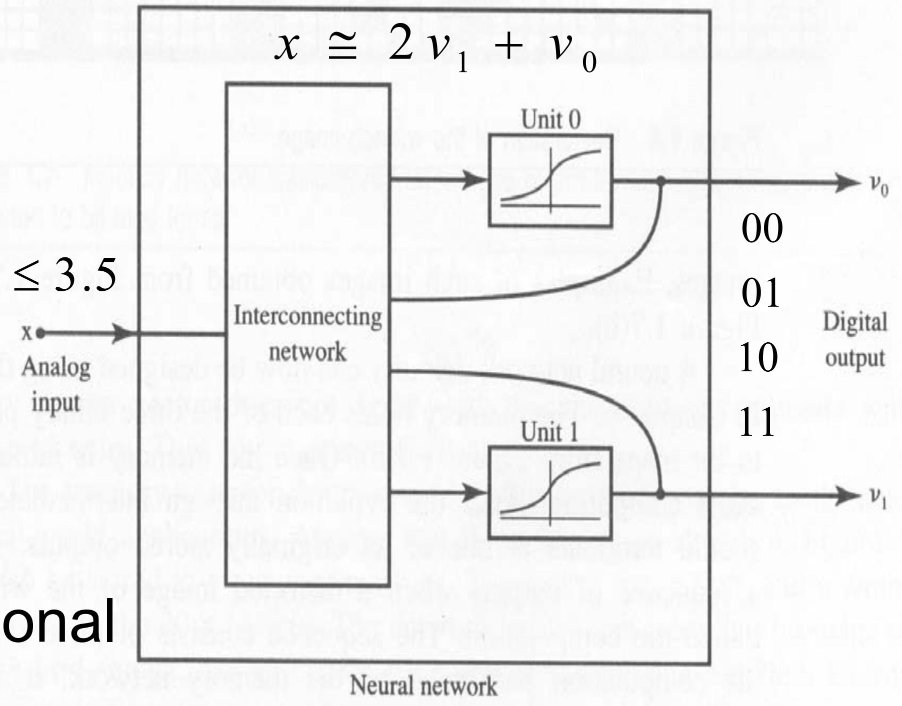


Figure 1.9 Block diagram of a two-bit A/D converter.

  - Applicable for combinational optimization

Feature Detection and Clustering

- Detect regularly appearing components of inputs
  - Indicate the true signal components as opposed to the noise that random and would not form any clusters
- Group certain measurement results together into a cluster
- Clustering and feature extracting networks exhibit remarkable properties of self-organization

Feature Detection and Clustering

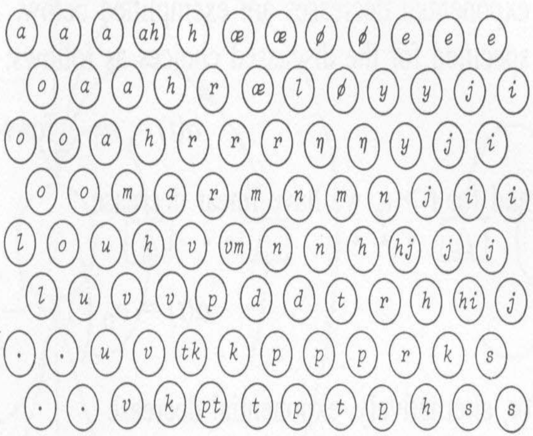


Figure 7.22 Speech phoneme map after training. [from Kohonen (1990). © IEEE; reprinted with permission.]

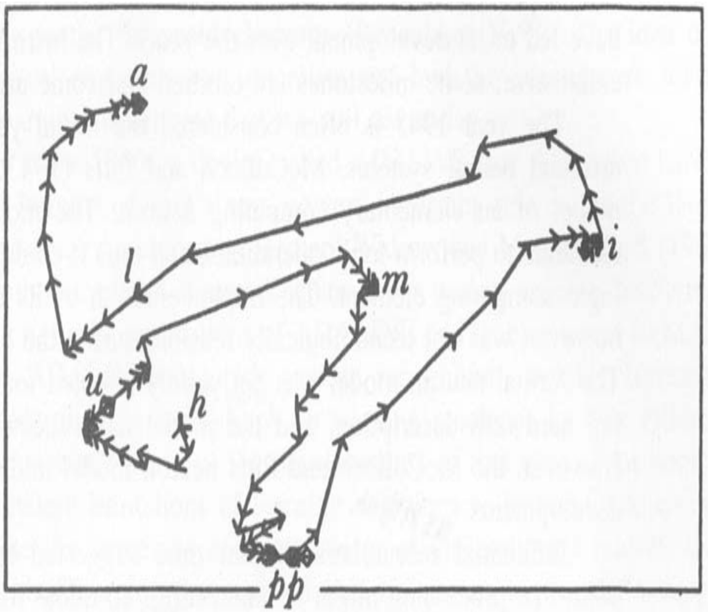
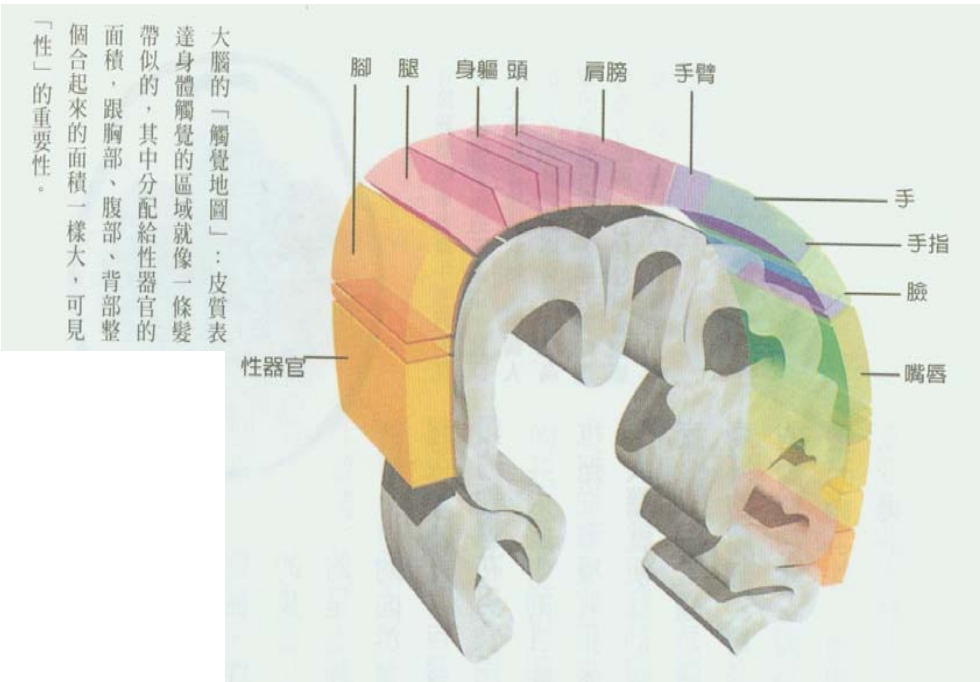


Figure 1.11 Phonotopic map of the Finnish word *humpilla* as an example of extracted features of speech. SOURCE: (Kohonen, 1988) © IEEE; reprinted with permission.

Feature Detection and Clustering (cont.)



參考自洪蘭教授譯著

Feature Detection and Clustering (cont.)

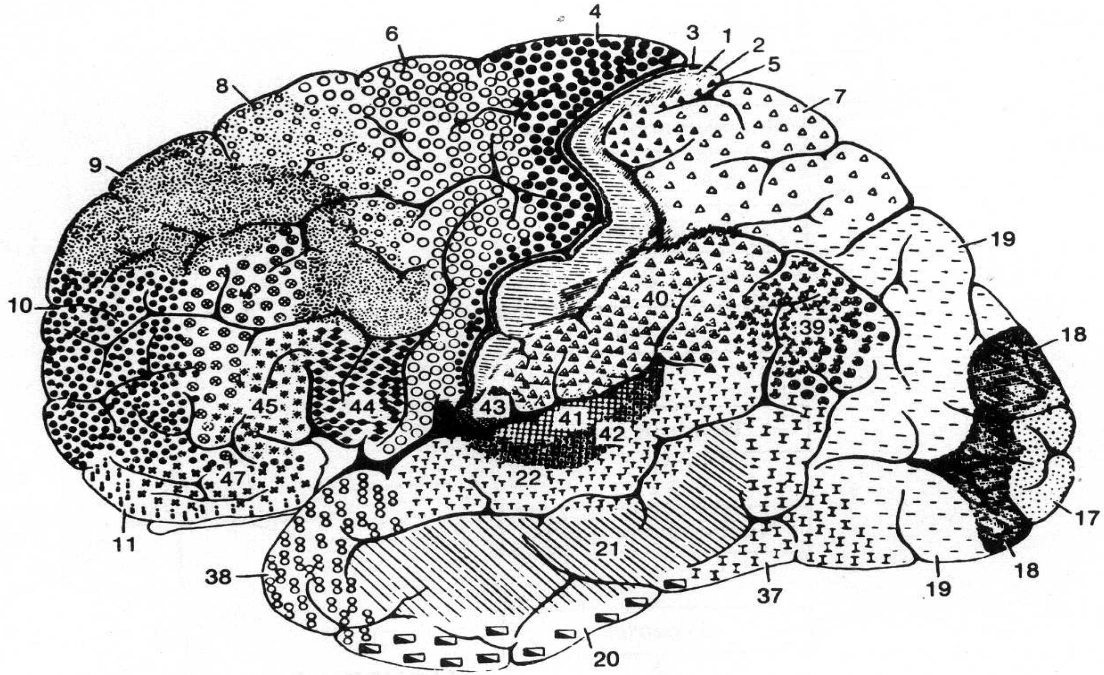


FIGURE 1.4 Cytoarchitectural map of the cerebral cortex. The different areas are identified by the thickness of their layers and types of cells within them. Some of the most important specific areas are as follows. Motor cortex: motor strip, area 4; premotor area, area 6; frontal eye fields, area 8. Somatosensory cortex: areas 3, 1, 2. Visual cortex: areas 17, 18, 19. Auditory cortex: area 41 and 42. (From A. Brodal, 1981; with permission of Oxford University Press.)

History Summary

- 1943, McCulloch and Pitts
  - First formal model of the elementary computation neuron that could perform arithmetical logic operations
- 1949, Hebbian
  - Information could be stored in neural connections
  - Hebbian learning rule
- 1958, Frank Rosenblatt
  - The neuron-like element called a *perceptron* (知感機), a trainable machine capable of training to do classification by modifying the connections to the threshold elements
- 1960,1962, Bernard Widrow and Marcian Hoff
  - Widrow-Hoff learning rule: minimize the summed square error during training when performing classification tasks

History Summary

- The obstacles stared from 1960s to early 1980s
  - No efficient Training Algorithms for Layered networks
  - Relatively modest computational resources available then
  - AI area emerged as a dominant and promising research field
  - The challenges were not answered until mid-1980s
- 1982,1984, John Hopfield
  - Recurrent neural architecture for associative memories
- 1986, James McClelland and David Rumelhart
  - New training rules (back-propagation algorithm) to remove the barriers caused form network training
  - Open the new era for the computing potential of layered network