Neuron Model

Deep Learning & Applications

What is a Neural Network?

- Neural network is a general name including both
  - Biological neural networks (e.g. human nervous system)
  - Artificial neural networks
- Our main topic is artificial neural networks (ANNs)
- We will sometimes say “neural network” to refer to an ANN

What is a Neural Network?

- Biological neural networks (such as human brain) compute in a different way from today's computers
- The brain is a highly complex, nonlinear, and parallel computer
- It can organize its own structure (connected neurons) to perform certain computations much faster than current computers

What is a Neural Network?

- (Artificial) neural network is a machine that is designed to model the way in which the brain performs a particular task or function of interest; usually
    - implemented by using electronic components
    - or simulated in software on a computer
- Our interest will mostly be on a group of ANNs which do useful computations after a *learning* process
- As the name implies, it is a network of smaller computing units called *neurons*

What is a Neural Network?

- (Definition by Alexander & Morton 1990)
  - A neural network is a massively parallel distributed processor made up of simple processing units, which has a natural propensity for storing experimental knowledge and making it available for use. It resembles the brain in two respects:
    - Knowledge is acquired by the network from its environment through a learning process
    - Interneuron connection strengths, known as synaptic weights, are used to store the acquired knowledge.

What is a Neural Network?

- The procedure used to perform the learning process is called a *learning algorithm*
  - The main idea here is to modify the synaptic weights of the network in some way so as to achieve a desired objective

Benefits of ANNs

- *Nonlinearity:* Neurons can be linear or nonlinear. Nonlinearity also comes from the networking. This is an important property particularly when we are working on nonlinear problems.
- *Input-Output mapping*: An ANN learns how to map inputs to outputs from examples. This is similar to nonparametric statistical inference (a branch of statistics) and tabula rasa learning (biology)
- *Adaptivity:* An ANN trained to work for a specific case can easily be retrained to deal with minor changes in conditions. In fact, it can be designed to do this in a changing environment. But, there is often a critical line between an adaptive system and a robust one.

Benefits of ANNs

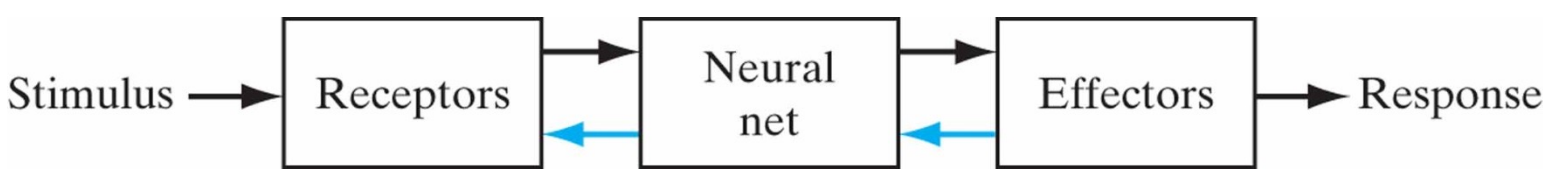
- *Evidential Response:* An ANN can be designed not only to give us a decision but also to give us how confident it is in that decision.
- *Contextual Information:* Knowledge is represented by the structure. Every neuron is potentially affected by all others in the network. Therefore, contextual information is dealt with naturally.
- *Fault Tolerance:* In hardware form, ANNs are fault tolerant in the sense that, if a neuron fails the general performance is only slightly degraded.

Benefits of ANNs

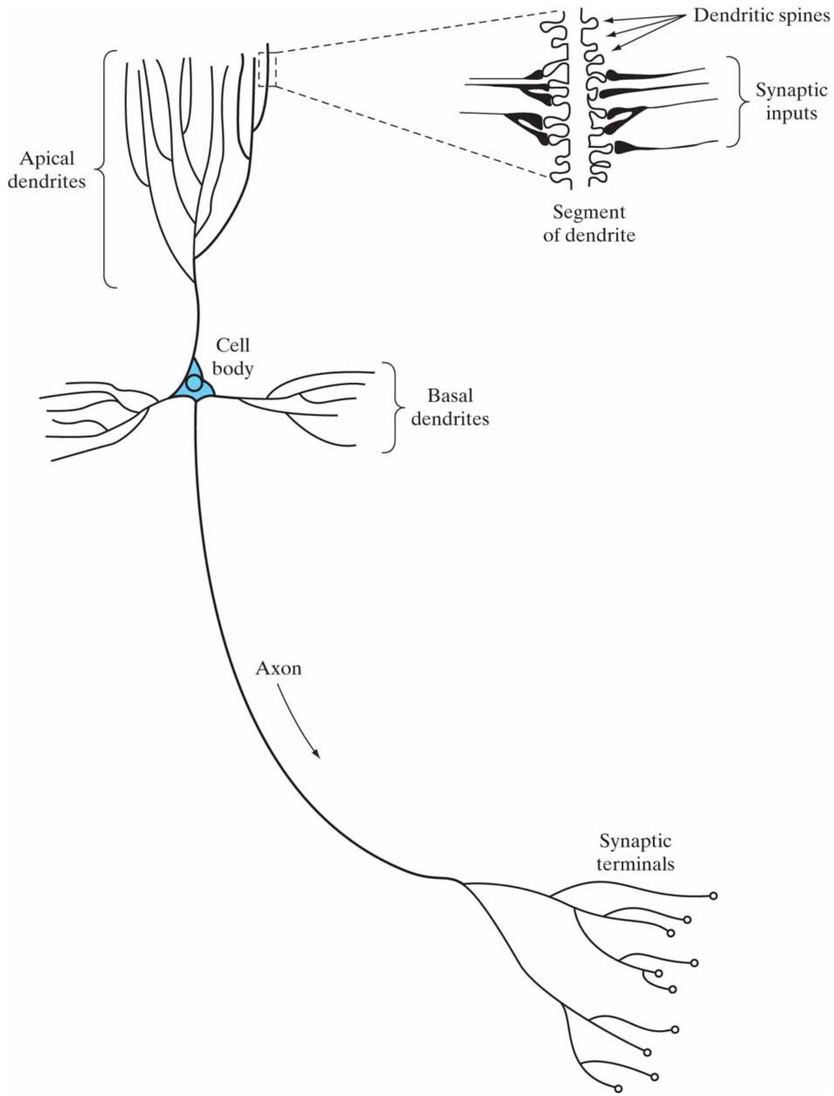
- *VLSI Implementability:* An ANN is well suited to be implemented using very-large-scale-integrated (VLSI) technology.
- *Uniformity of Analysis and Design:* Same notation (neurons being the main unit, etc.) is used in all domains involving the application of neural networks.
- *Neurobiological Analogy:* ANNs are motivated by analogy with the brain, which is a living proof that fault tolerant parallel processing is not only physically possible but also fast and powerful.

Human Brain

- May be viewed as a three-stage system as below
  - Brain (neural net); Receptors convert stimuli into electrical impulses; Effectors convert electrical impulses into responses (system outputs)
  - Left to right arrows: forward transmission: Right to left: feedback
- Neurons are five to six orders of magnitude slower than silicon logic gates
  - Neural events happen in 10^{-3} s range, whereas silicon gate events happen in 10^{-9} s
- Yet, brain makes up for this by having extremely many neurons and complex interconnections between them
  - There are approximately 10 billion neurons in the human cortex and 60 trillion connections (synapses)
- Also, brain is energy efficient (10^{-16} joules per operation per second)
  - Computers today have about 10^{-6} joules per operation per second)

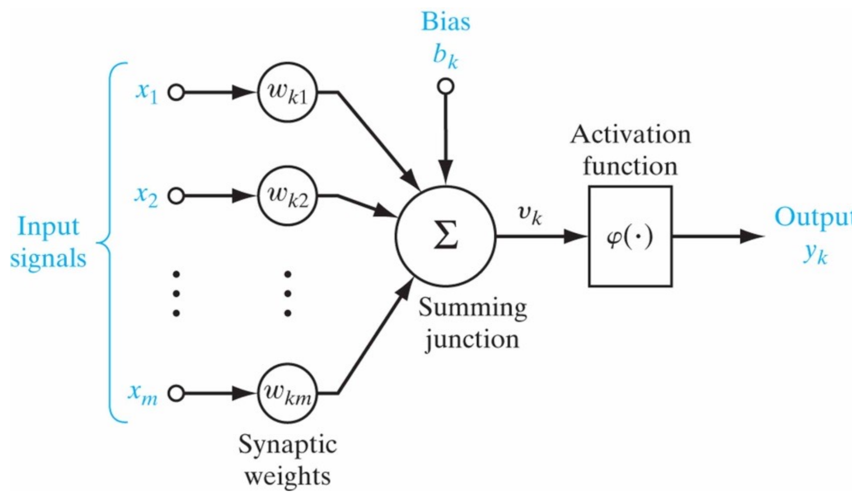


The Pyramidal Cell



Artificial Neuron Models

- A *neuron* is the fundamental information processing unit of a neural network
- The diagram on the right shows a neuron model including
  - A set of *synapses* (Each with a weight, w_{ki})
  - An *adder* (a linear combiner)
  - An *activationfunction*
  - A *bias* value (b_k) to modify the net input of activation function

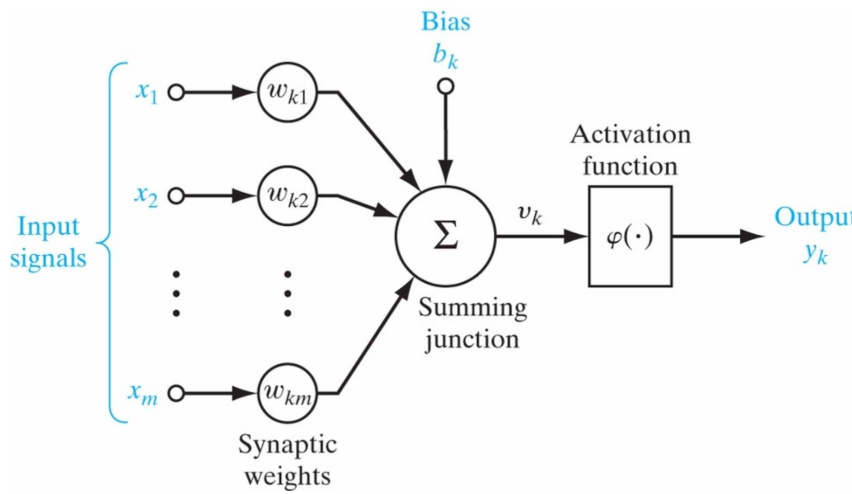


Artificial Neuron Models

- Mathematically, the following pair of equations describe neuron k

$$u_k = \sum_{i=1}^{m} w_{ki} x_i$$

$$y_k = \varphi(u_k + b_k)$$



Artificial Neuron Model

- Use of bias (b_k) applies an affine transformation to u_k

$$v_k = u_k + b_k$$

v_k is called activation potential (or induced local field)

- Using activation potential, instead of the previous equations we can write

$$v_k = \sum_{i=0}^{m} w_{ki} x_i$$

$$y_k = \varphi(v_k)$$

where $x_0 = 1$, and $w_{k0} = b_k$

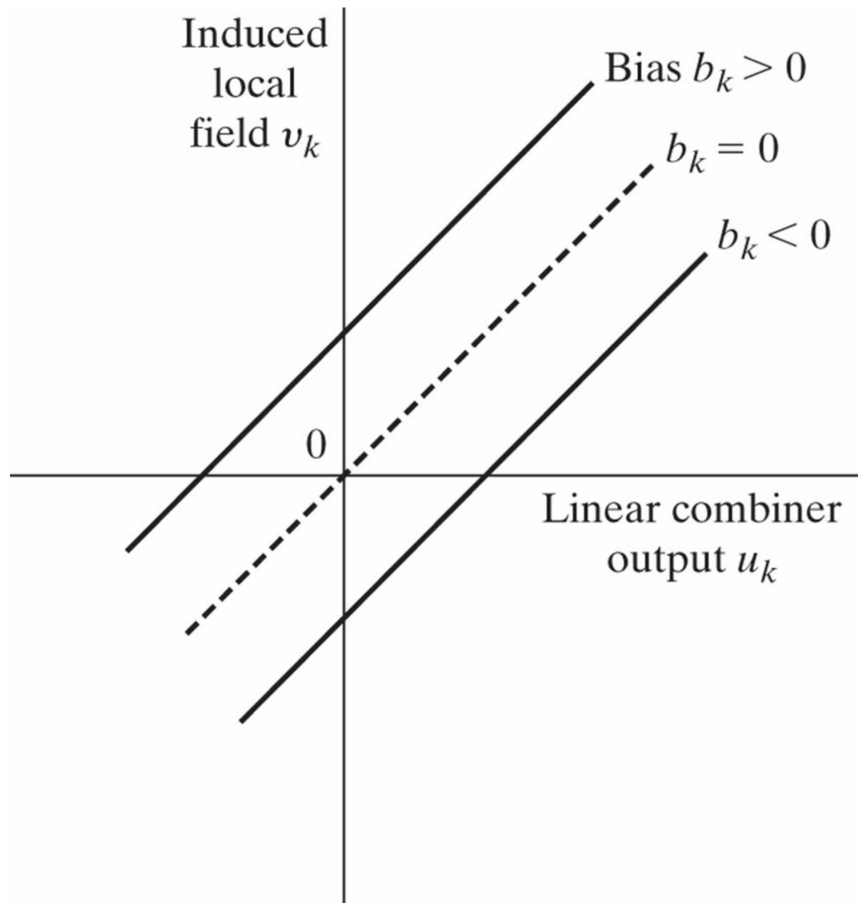


Figure 7 Another nonlinear model of a neuron; w_{k0} accounts for the bias b_k.