Comp305

Biocomputation

Lecturer: Yi Dong

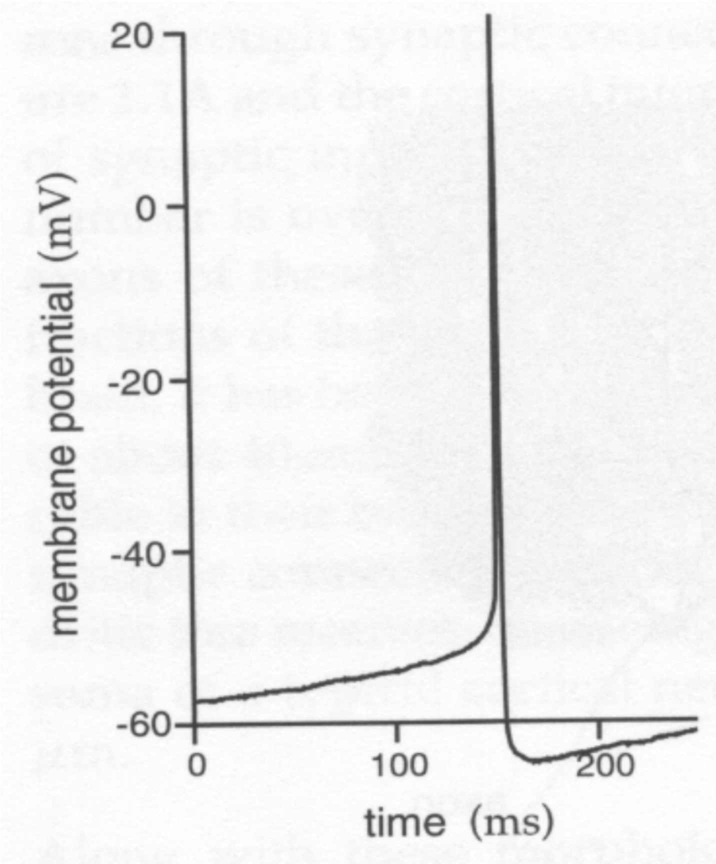
Comp305 Part I.

Artificial Neural Networks

Topic 1.

Historical/Biological Introduction

Nerve fibers. Trains of Spikes.



Neurons

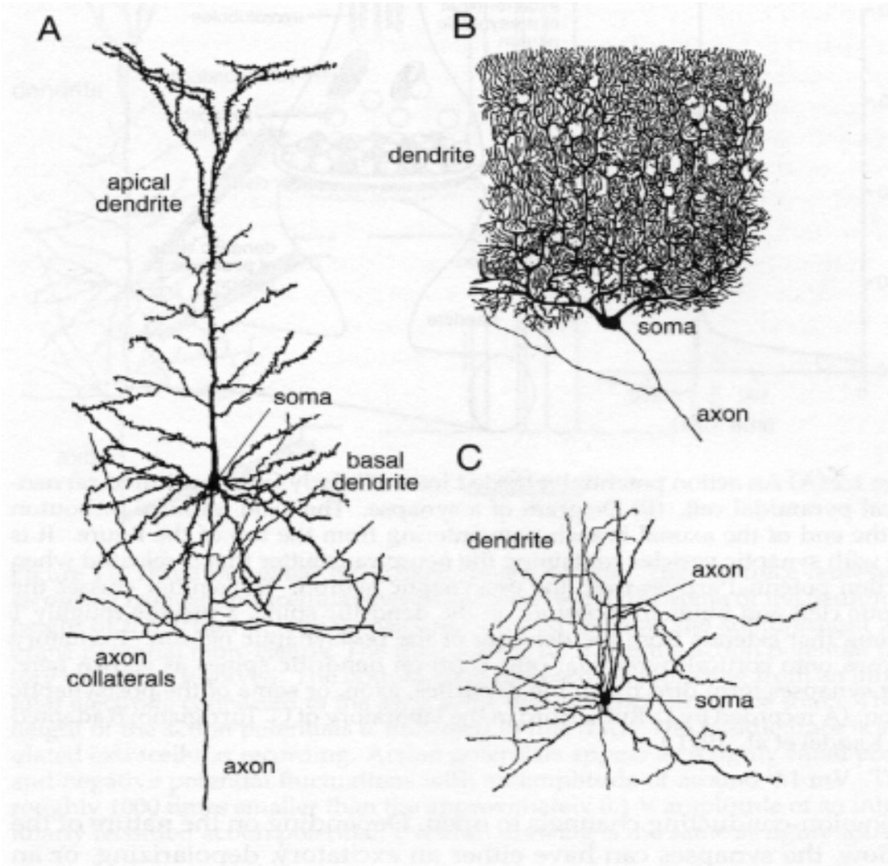
- propagate signals rapidly over large distances.
- in response to over-threshold stimuli generate *electrical pulses called action potentials* or *spikes* that can travel down nerve fibers.
- represent and transmit information by firing sequence of spikes in various temporal patterns.

Biological Excitability

- The membrane potential may change in response to electrical perturbation from other neurons.

- If the perturbation is sufficiently large, **above a threshold** in intensity and duration, the response is a large amplitude electrical wave, propagating from the stimulated points to the rest of the tissue.

Neuron Components

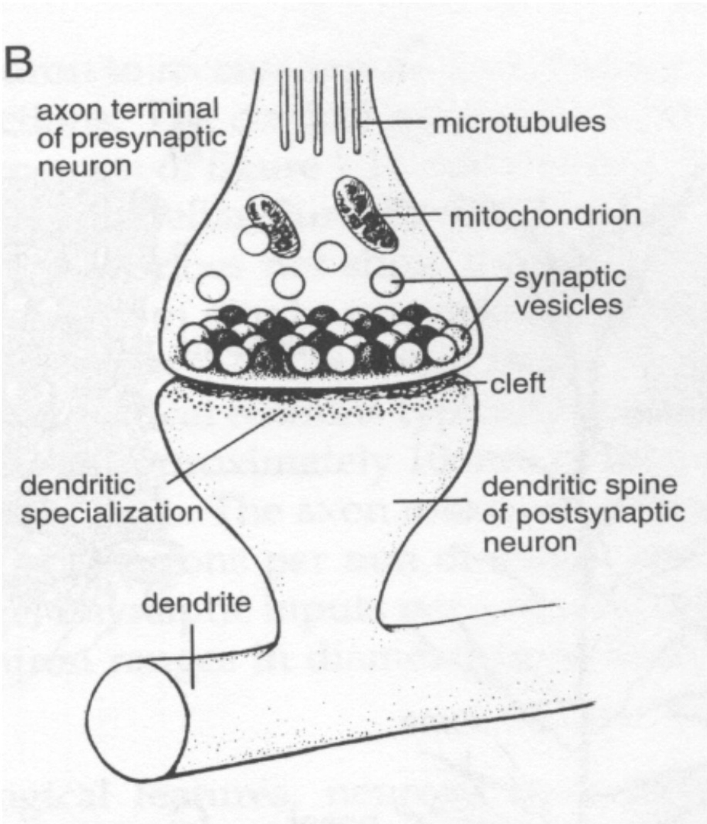


Cerebral Cortex

- Important morphological specializations of neurons are the dendrites that receive inputs from other neurons, soma (the cell body), and the axon that carries the neuronal output to other cells.

- The elaborate branching structure of the dendritic tree allows a neuron to receive inputs from many other neurons through synaptic connections.

Trans-synaptic stimulation – External Mechanism

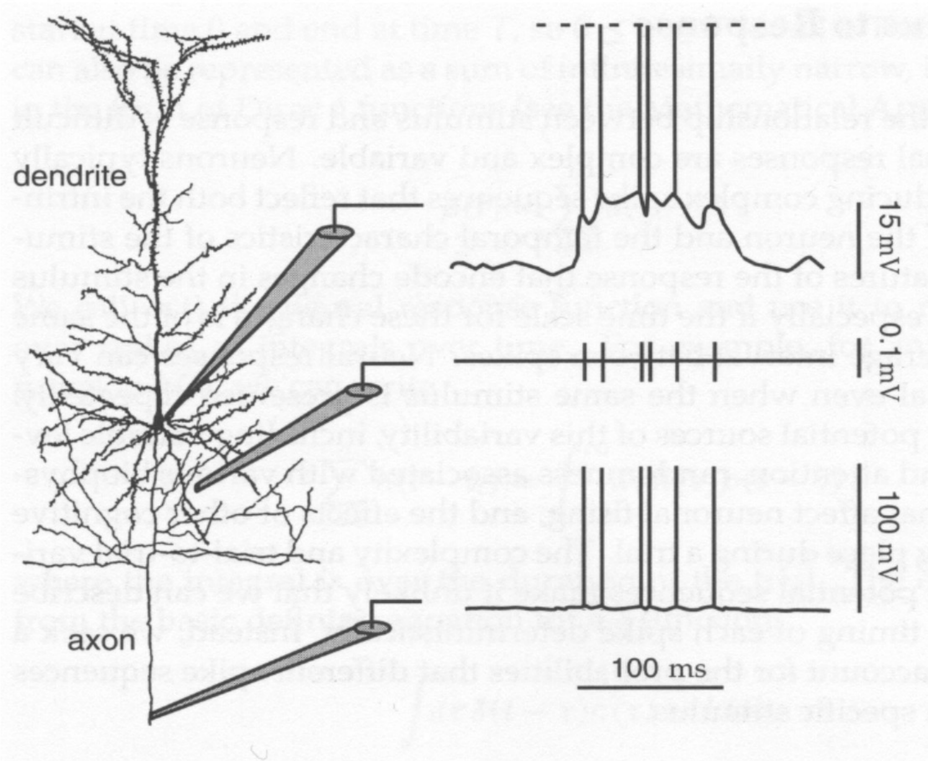


Trans-synaptic stimulation of a neuron requires usually

- either a repetition of impulses in time at the same synapse (*temporal summation*).
- or the simultaneous arrival of impulses at a sufficient number of adjacent synapses (*spatial summation*)

to make the “density” of excitation high enough at some region of the neuron.

Records from a Neuron



- **The top recording from soma** shows rapid spikes riding on top of a more slowly varying subthreshold potential.

- **The bottom trace** shows intracellular recording from axon some distance out of soma. The subthreshold membrane potential waveform, apparent in the soma recording, is completely absent on the axon due to attenuation, while the action potential sequence in the two recordings is the same.

- The difference in records from soma and from the axon illustrates the important point that

spikes, but not subthreshold potentials, propagate regeneratively down the axons.

Summary: Neuron Signal Processing

Neuron	Input	Dendrites: From huge number of neurons, sometimes very distant ones
	Excitation	From a repetition of impulses in time at the same synapse (***temporal summation***) or from the simultaneous arrival of impulses at a sufficient number of adjacent synapses (***spatial summation***) to make the "density" of signal high enough at some region of the neuron to overcome ***the excitation threshold***. There are ***refractory periods.***
	Output	Axon: To huge number of neurons, sometimes very distance ones
Neuron-to-Neuron	Propagation	**spikes, but not subthreshold potentials, propagate regeneratively down the axons.**

Topic of This Lecture

A basic abstract model for a biological neuron.

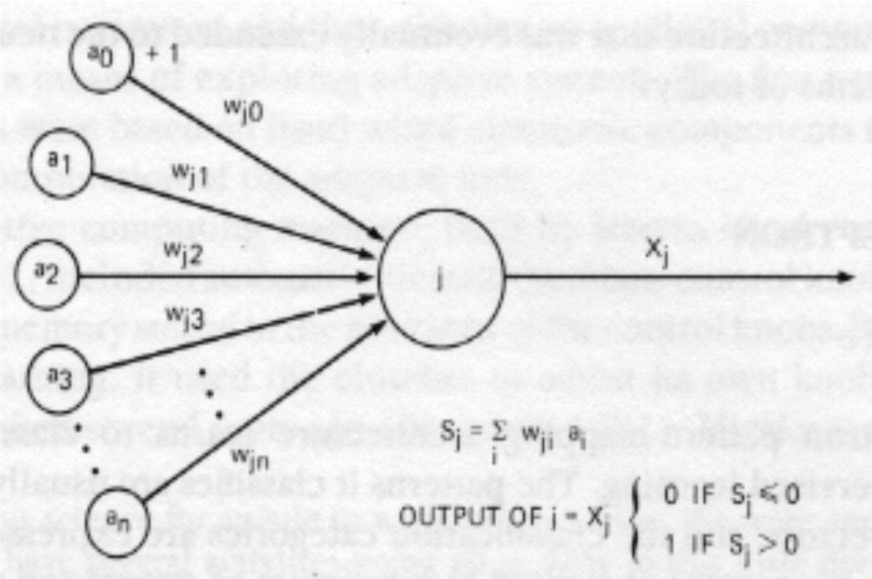
One More Thing. Weights of Connections.

- Neuron gets ***fired if*** it has received from the presynaptic neurons a ***summary impulse***, which ***is above a certain threshold***.

- Signal from a single synapse may sometime overcome the threshold and push a neuron to fire an action potential, but other synapses can achieve this only by simultaneously delivering their signals: **Some inputs are more important!**

- Therefore, **input from every synapse, or "connection", to the neuron in the abstract model must be assigned with some value *w*, called connection strength or *weight of connection***, to describe the importance of a connection.

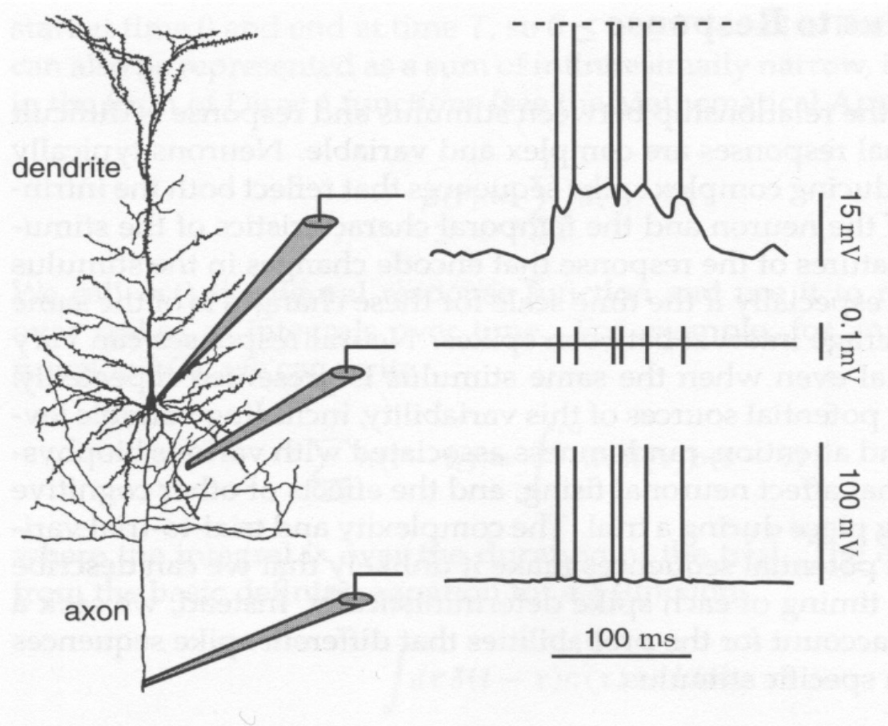
Abstract Model of a Neuron

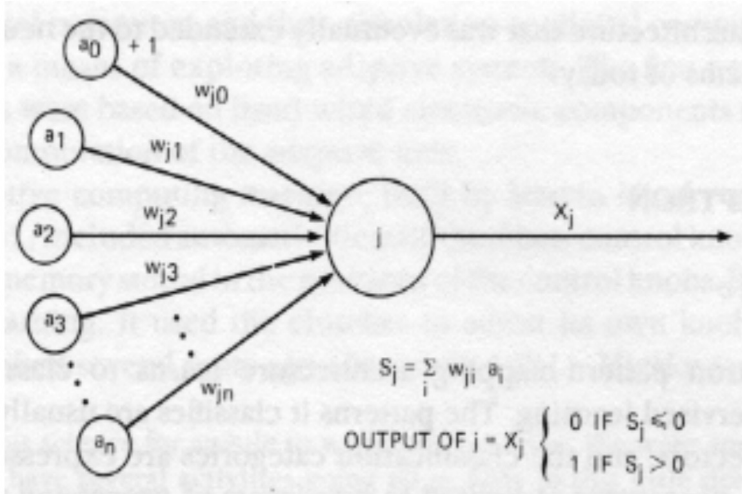


- Shown is an abstract neuron ***j*** with ***n+1*** inputs.
- Each input ***i*** transmits a real value a_i .
- Each connection is assigned with the weight w_{ji}.

- The ***total input S***, *i.e.* the sum of the products of the inputs with the corresponding weights, ***is compared with the threshold*** (equal to 0 in this case), and the ***outcome X_j is produced consequently***.

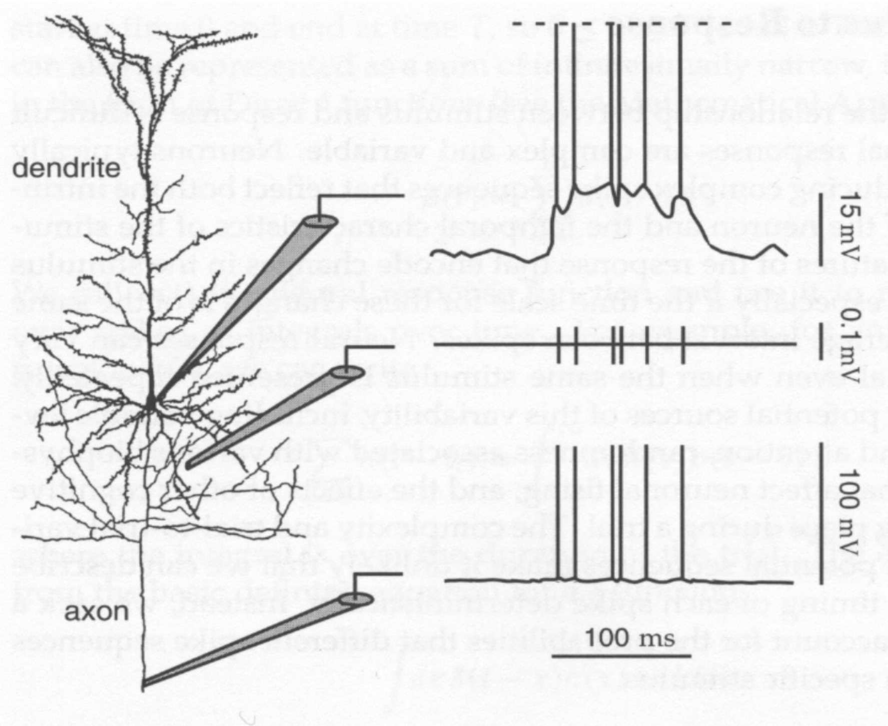
Abstract Neuron vs. Biological Neuron

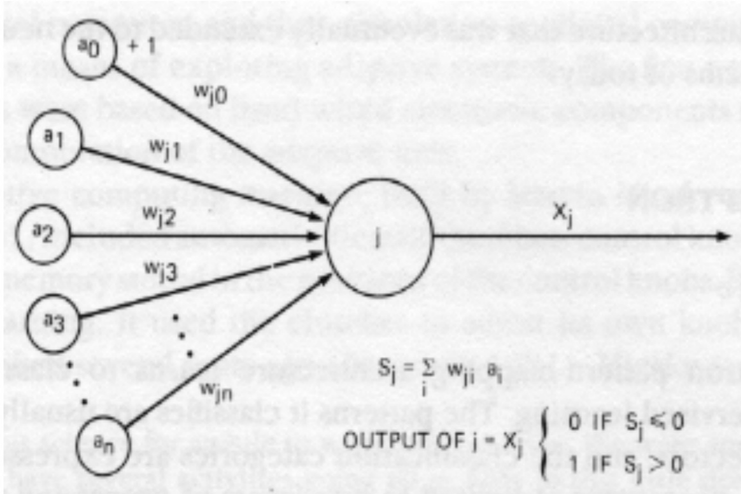




What are the similarities between the biological neuron and the abstract neuron (model)?

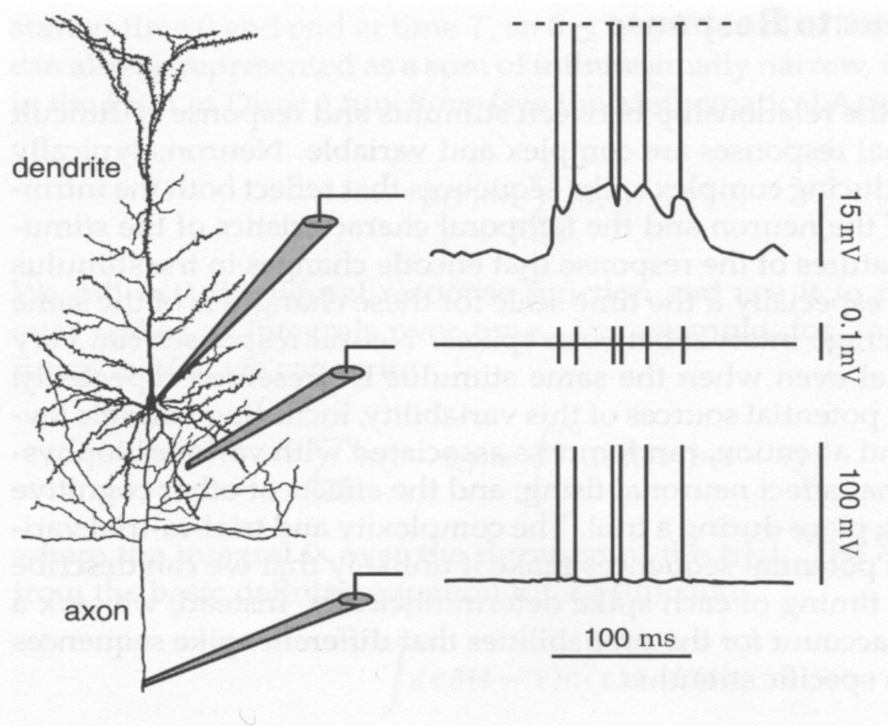
Abstract Neuron vs. Biological Neuron: Components

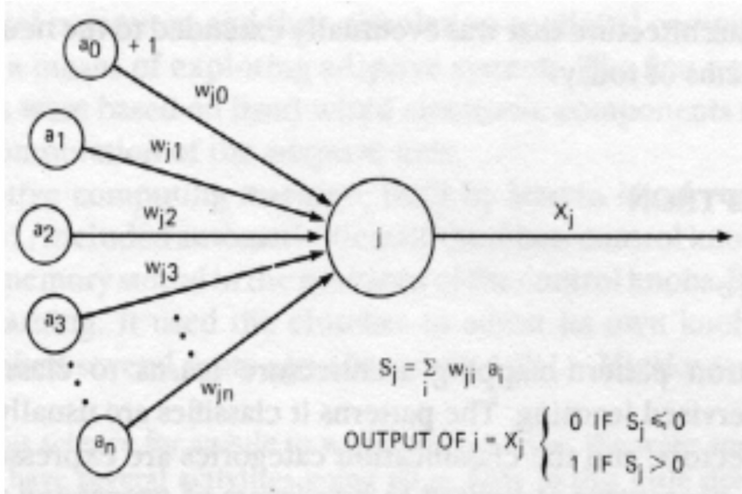




- Inputs $a_0, \cdots a_n$ of the abstract neuron vs. dendrites of the biological neuron;
- The neuron body (the circle) vs. Soma of the biological neuron;
- Output X of the abstract neuron vs. Axon of the biological neuron;

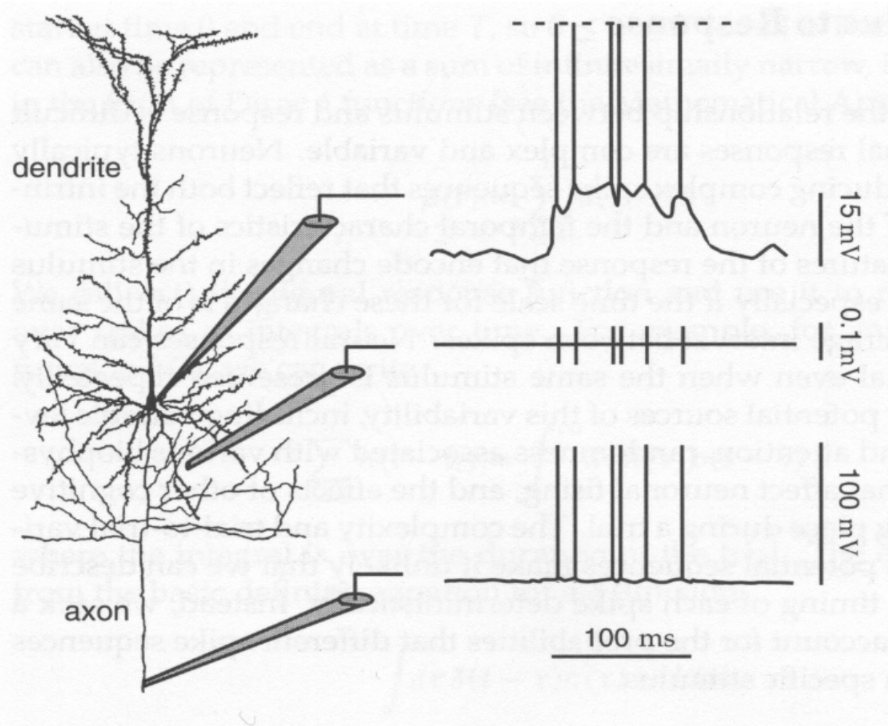
Abstract Neuron vs. Biological Neuron: Components

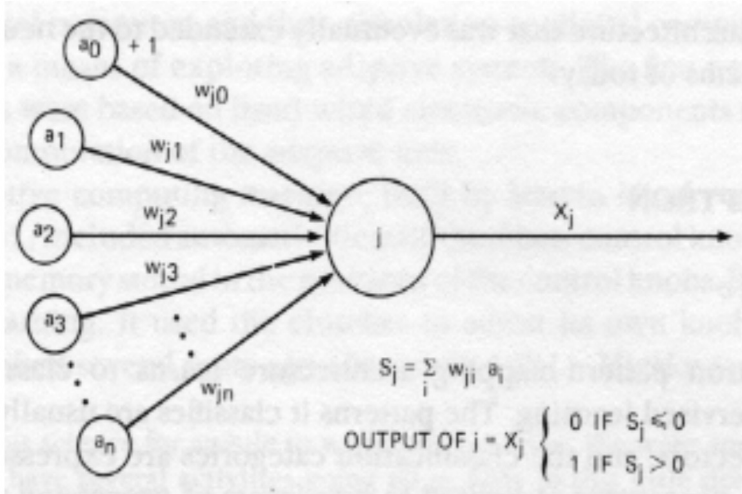




- The threshold of the abstract neuron vs. The excitation potential threshold;
- Weights of input connections of the abstract neuron vs. The importance of presynaptic neurons.

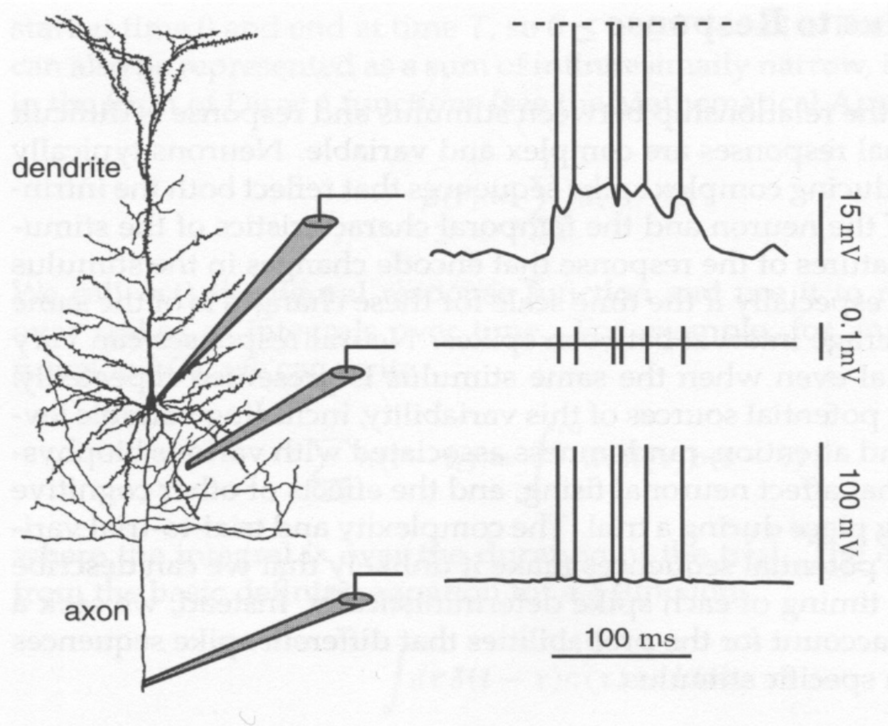
Abstract Neuron vs. Biological Neuron: Mechanism

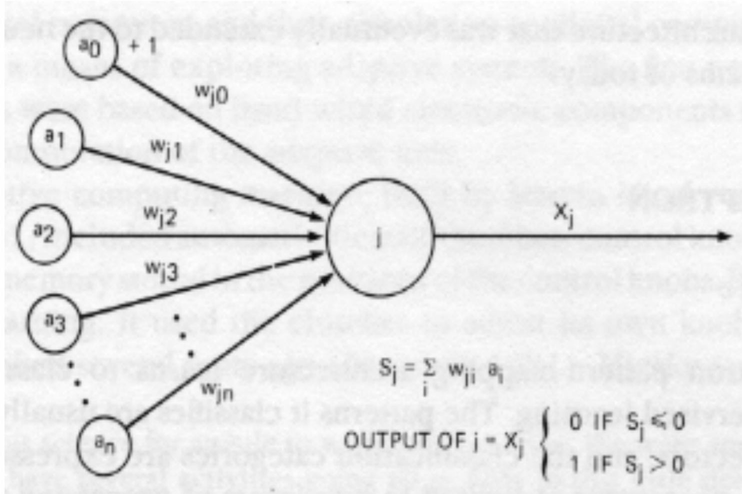




- The abstract neuron is excited when weighted sum is above the threshold 0 vs. The biological neuron is excited when the signal density (spatial or temporal summation) is above the excitation potential threshold.

Abstract Neuron vs. Biological Neuron: Mechanism





- Output is either 1 or 0. vs. Only the spikes are remembered.

Summary

Neuron	Input	Dendrites: From huge number of neurons, sometimes very distant ones
	Excitation	From a repetition of impulses in time at the same synapse (***temporal summation***) or from the simultaneous arrival of impulses at a sufficient number of adjacent synapses (***spatial summation***) to make the “density” of signal high enough at some region of the neuron to overcome ***the excitation threshold***. There are ***refractory periods.***
	Output	Axon: To huge number of neurons, sometimes very distance ones
Neuron-to-Neuron	Propagation	**spikes, but not subthreshold potentials, propagate regeneratively down the axons.**

Summary

Neuron	Input	Dendrites: From huge number of neurons, sometimes very distant ones	Multiple Inputs
	Excitation	From a repetition of impulses in time at the same synapse (***temporal summation***) or from the simultaneous arrival of impulses at a sufficient number of adjacent synapses (***spatial summation***) to make the "density" of signal high enough at some region of the neuron to overcome ***the excitation threshold***. There are ***refractory periods.***	The abstract neuron is excited (output is equal to 1) when **weighted sum** is above the threshold 0.
	Output	Axon: To huge number of neurons, sometimes very distance ones	Single Output.
Neuron-to-Neuron	Propagation	**spikes, but not subthreshold potentials, propagate regeneratively down the axons.**	The output is binary.

Before Going into Technical Details...

It looks like we have already been quite clear about the biological neuron processing. But ...

Final Caution

- **Massive and hierarchical networking of the brain** seems to be the fundamental precondition for the emergence of consciousness and complex behaviour.

- **So far**, however, biologists and neurologists have concentrated their research on uncovering the properties of **individual neurons**.

Final Caution

- Today, the mechanisms for the production and transport of signals from one neuron to another are well understood physiological phenomena, but

how these individual systems cooperate

to form complex and massively parallel system capable of incredible information processing feats still constitutes

the biggest mystery of the brain**.**

Final Caution

- Mathematics, biophysics and computer science can provide invaluable help in the complex interdisciplinary study of the brain.

- However, we should

  be careful with metaphors and paradigms

  commonly introduced when dealing with the nervous system.

Final Caution

- It seems to be a constant in the history of science to compare the brain to the most complicated contemporary device produced by human industry.
  - **In ancient times**, the brain was compared to a **pneumatic machine**,
  - **in the Renaissance to clockwork,**
  - **at the end of the nineteenth century to the telephone network.**

- **Today**, it is popular to consider **computers** the paradigm par excellence of a nervous system.

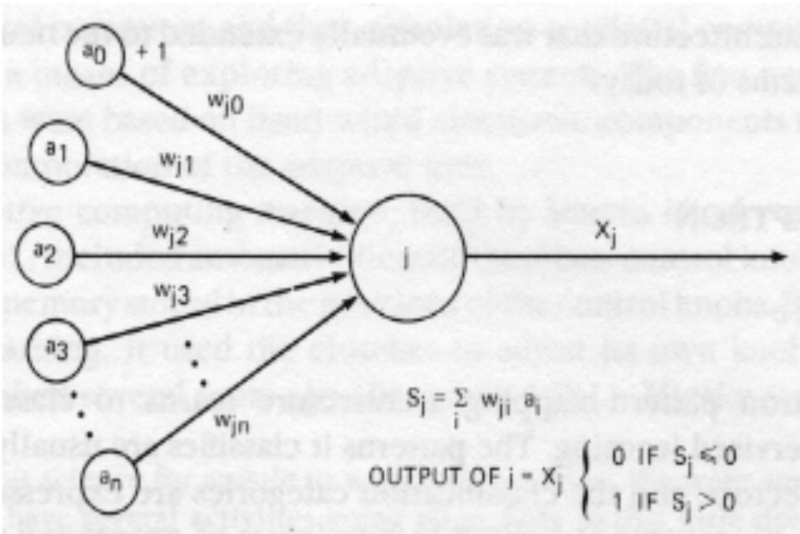
Final Caution

- It is rather paradoxical that when ***John von Neumann*** wrote his classical description of future universal computers, he tried to choose terms that would

***describe computers in terms of brains*,**

not brains in terms of computers.

Abstract Model of a Neuron

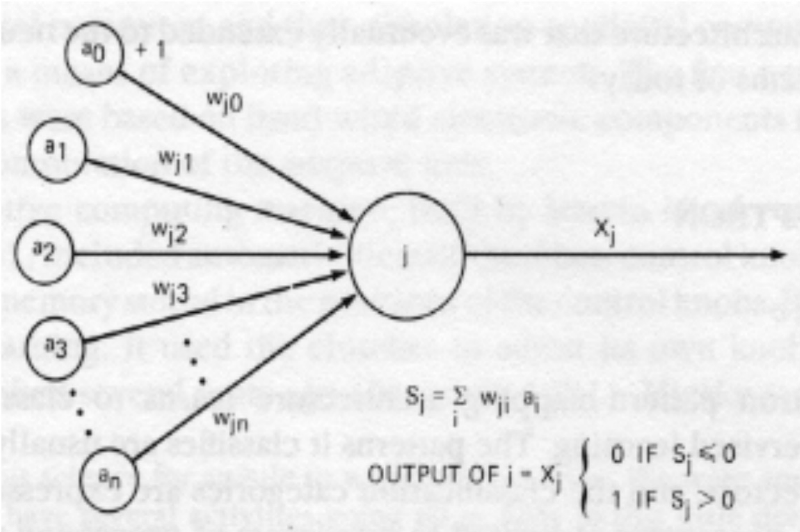


- Shown is an abstract neuron ***j*** with ***n+1*** inputs.

- Each input ***i*** transmits a real value a_i .

- Each connection is assigned with the weight w_{ji}.

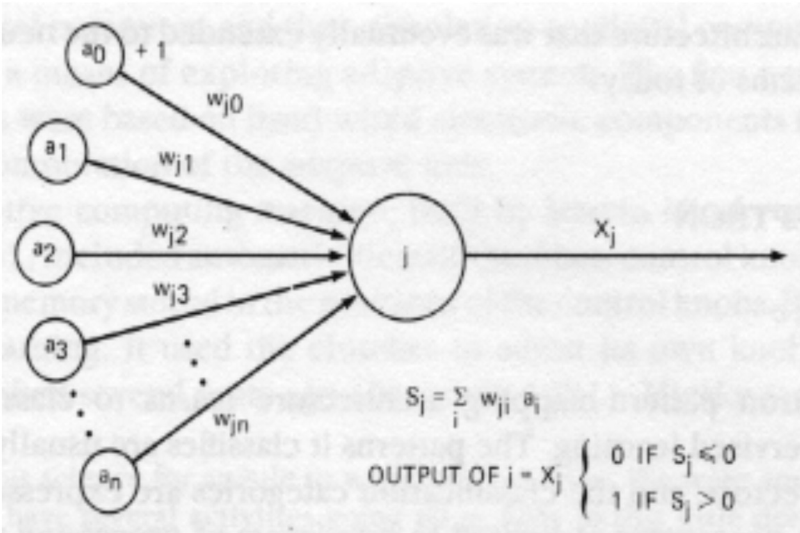
Abstract Model of a Neuron



- The ***total input S***, *i.e.* the sum of the products of the inputs with the corresponding weights, ***is compared with the threshold*** (equal to 0 in this case), and the ***outcome*** X_j ***is produced consequently.***

What Are NOT Clear in the Abstraction?

- Type of Inputs?
- Type of Weights?
- What can we do with such an abstraction?



The McCulloch-Pitts Neuron (1943)

McCulloch and Pitts demonstrated that

"…because of the all-or-none character of nervous activity, neural events and the relations among them can be treated by means of the propositional logic".