Biologically Inspired Computation: Neural Computation

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Objectives

- To learn:
  - Neural computation basic concepts.
  - The biological inspiration.
  - The most common and successful artificial neural network (ANN) models.
  - Main applications.
- Material:
  - David Corne's website

Recommended reading

- List of recommend books on a separate list available together with the course material.

Lectures

Patricia

- 6 to 7 lectures
  - Introduction to Neural Computation
  - Biological Inspiration
  - History
  - Artificial Neural Network (ANN) Models
  - Applications

Lecture 1

I. What is Neural Computation?
II. Biological Inspiration

Neural Computation

- What is Neural Computation?

Neural Computation

- What is Neural Computation?
  - The neural computation paradigm comprises a computational architecture based on the interconnection of simple and similar processing units named artificial neurons
  - Connectionist approach to computation.

Neural Computation

- Motivation…

Neural Computation

- Motivation…

"The human brain is a highly complex, non-linear and parallel computer (information processing system)"

Neural Computation

- Motivation…

"The human brain is a highly complex, non-linear and parallel computer (information processing system)"

- What is the human brain good at?

Neural Computation

- Motivation…

"The brain is a highly complex, non-linear and parallel computer (information processing system)"

- What is the human brain good at?
  - Pattern recognition
  - Perception
  - Motor control

Neural Computation

- Motivation…

Neural Computation

- Motivation…

"Not only the human brain"

https://www.youtube.com/watch?v=gZxLUNHEmPw

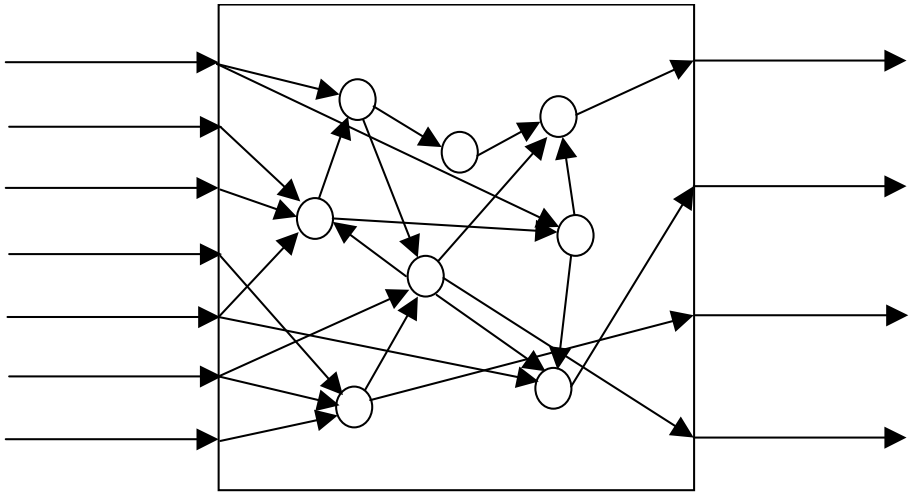
Neural Computation

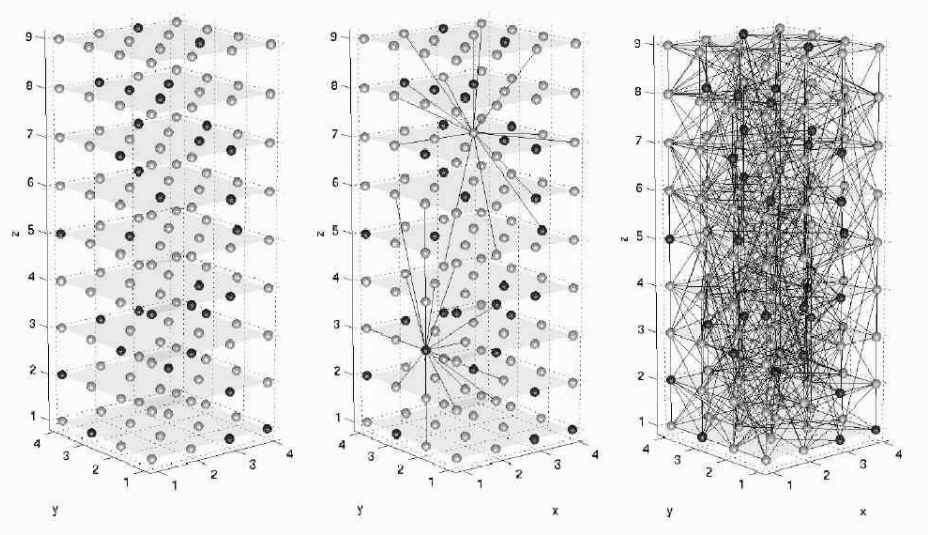
- The neural computation paradigm is inspired by biological neuronal networks

(i.e. brain-inspired computing)

- It encompasses distributed and parallel processing apart from learning algorithms.

Neural Computation





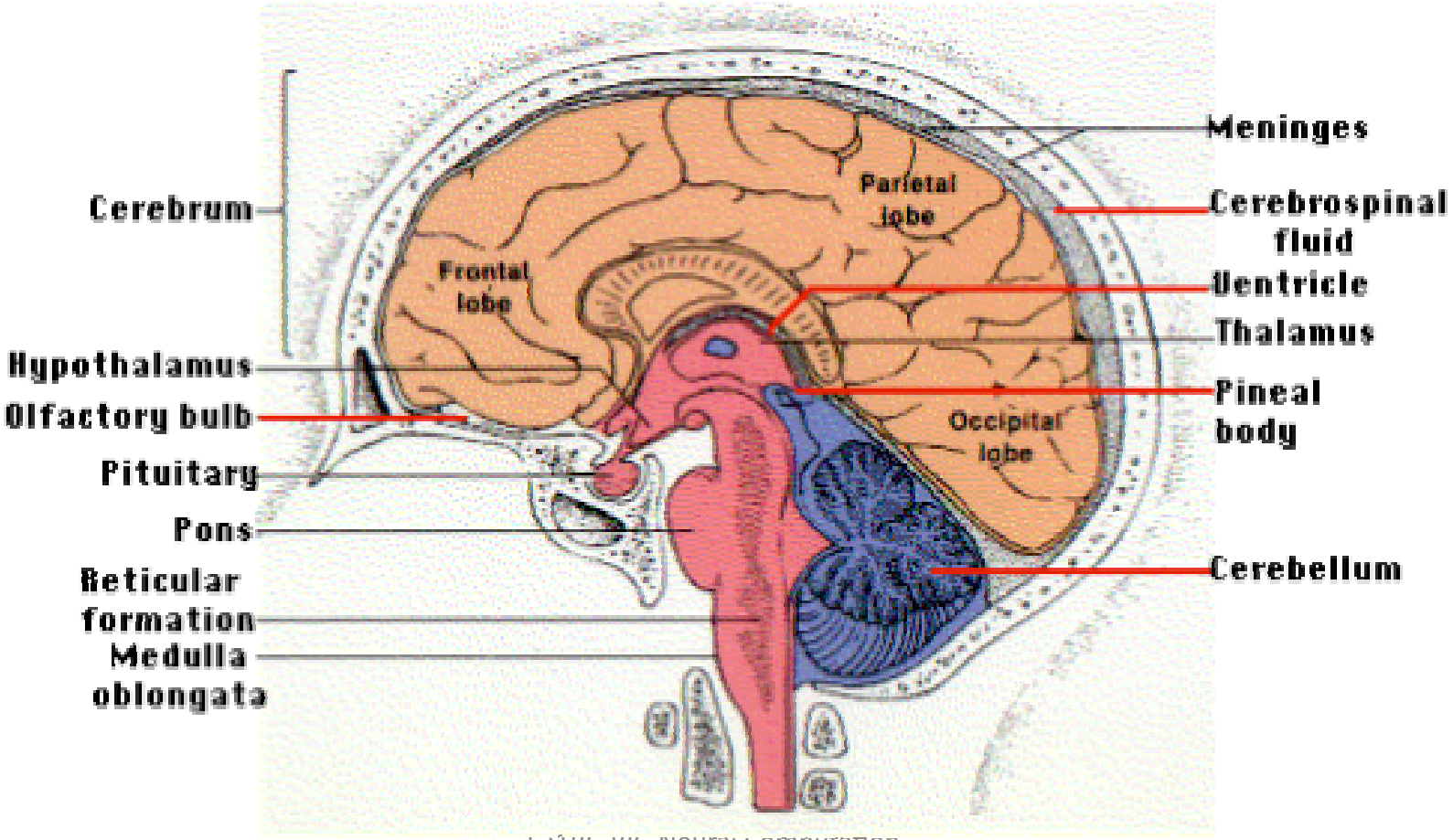
- The dynamics of a neural computer relies basically on two variables: the neuronal state or the state of the neurons and the neural network parameters such as the strength of the connections and thresholds.

Biological Inspiration

- How is our brain organised?
- How does our brain process all the information it receives/perceives?
- What are the main mechanisms behind the cerebral functioning?

Biological Inspiration

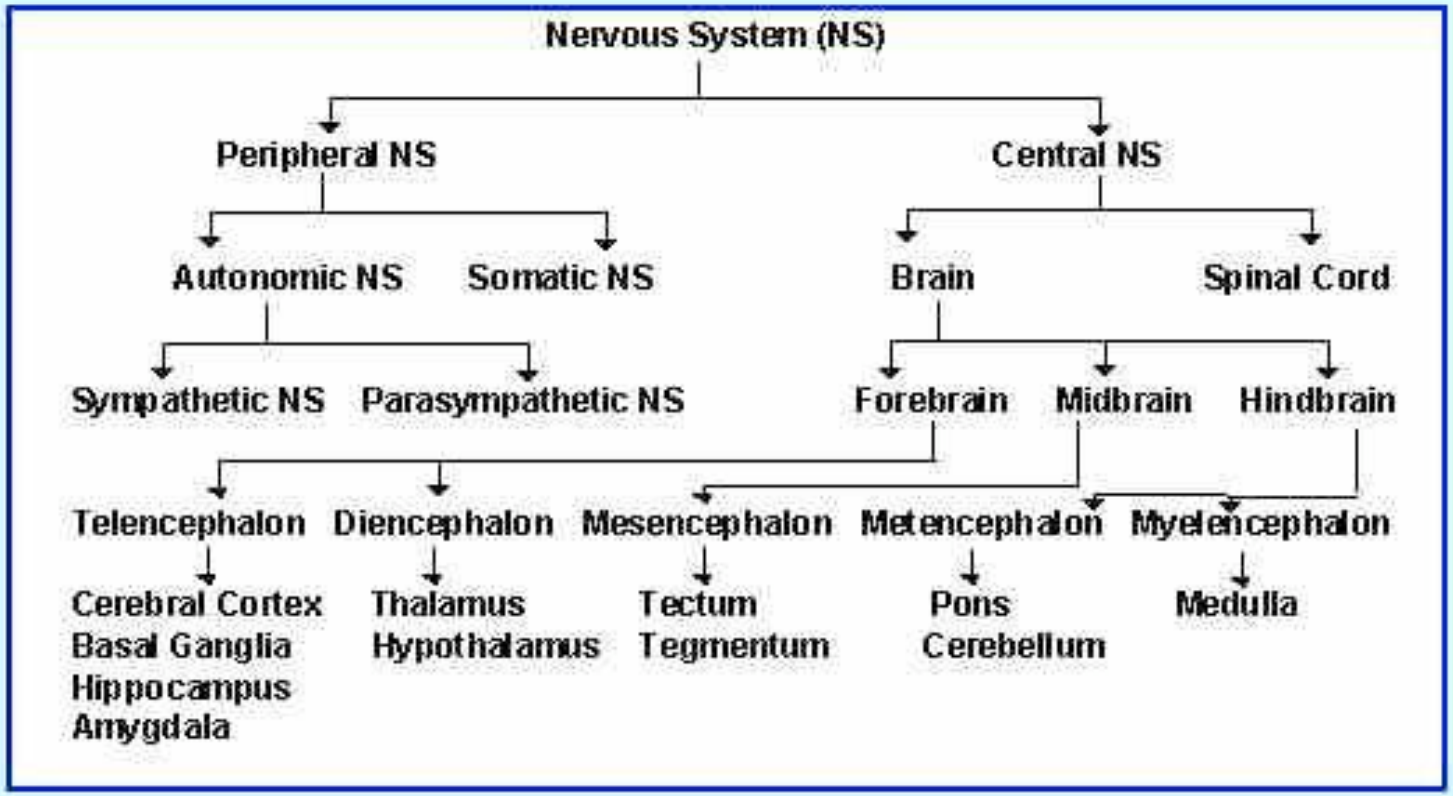
- How is our brain organised?

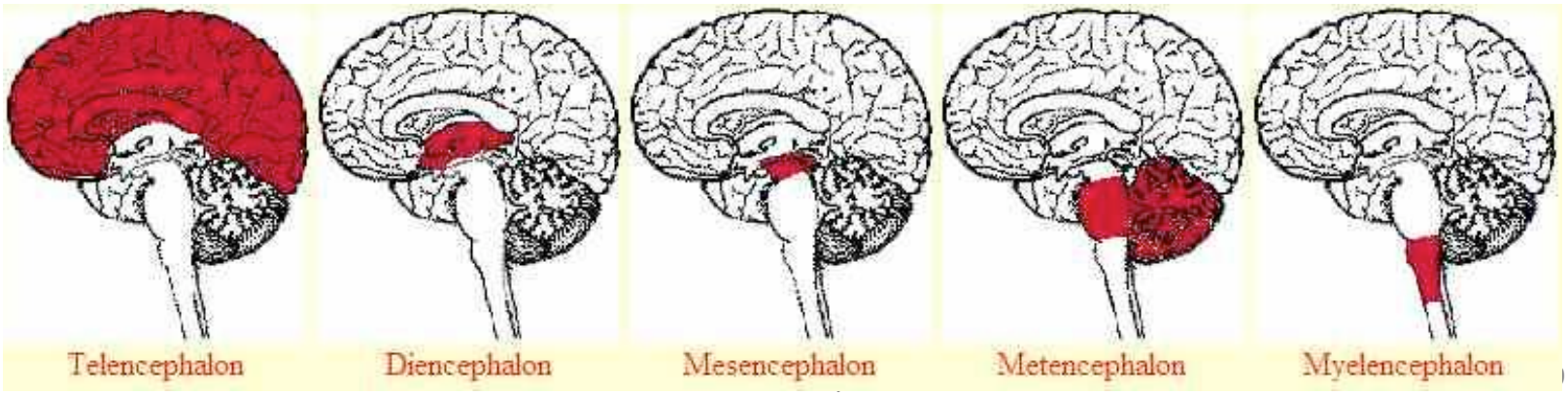


Biological Inspiration

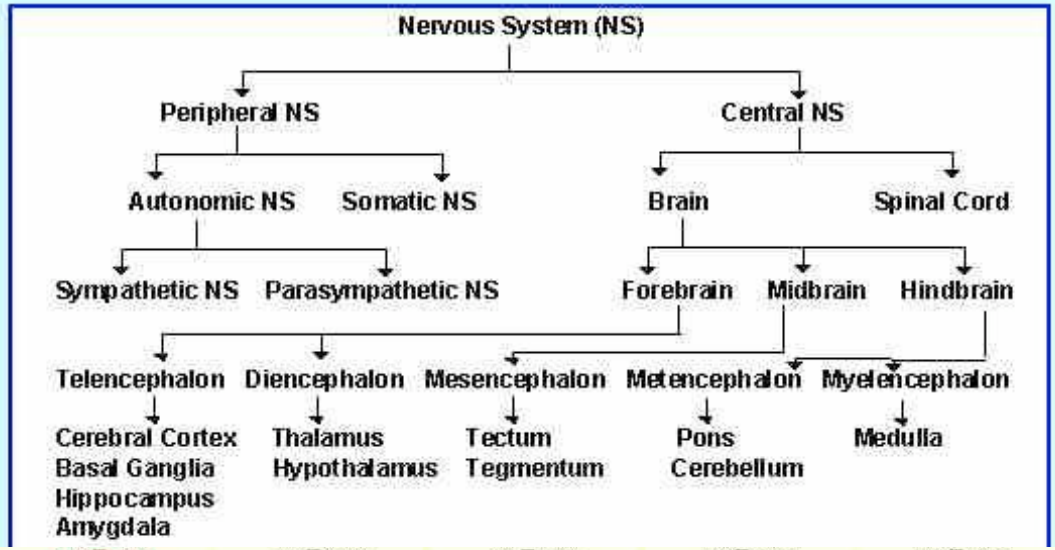
- The brain is part of the nervous system.
- The nervous system (NS) could vary in complexity.
  - Its main role is to process internal and external inputs (sensory stimuli).
  - These inputs could be compared to previous inputs or knowledge, giving rise to body actions or just be stored as new knowledge.
  - The NS can be organised in different levels: systems, structures, layers, molecules, neurons, synapses, etc.

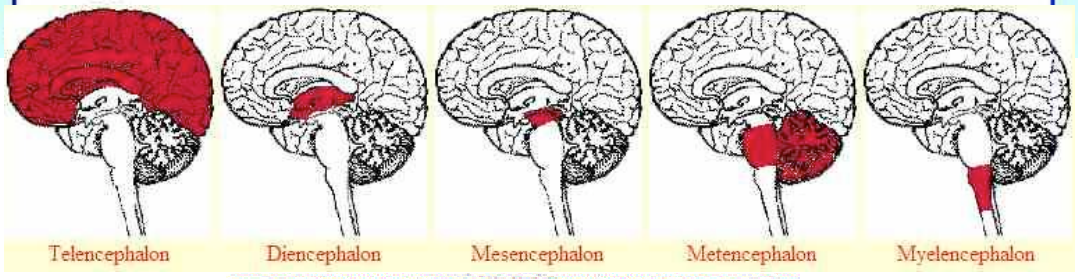
Divisions of the Nervous System

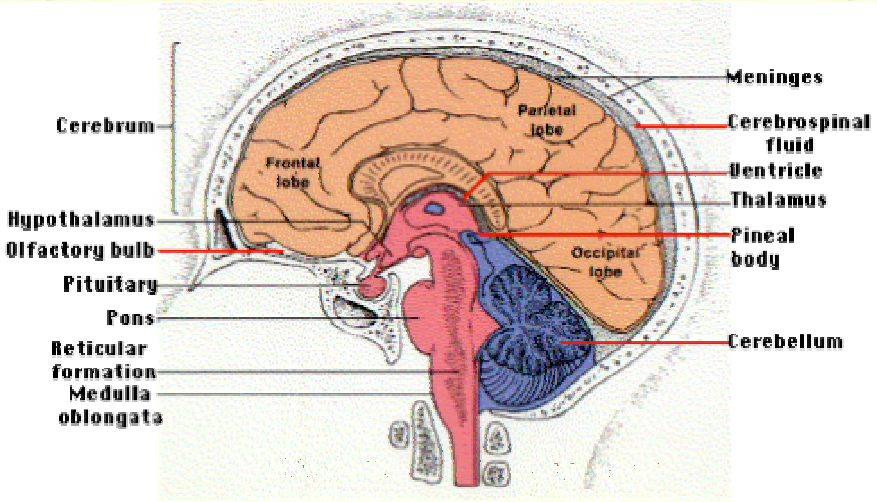




Divisions of the Nervous System

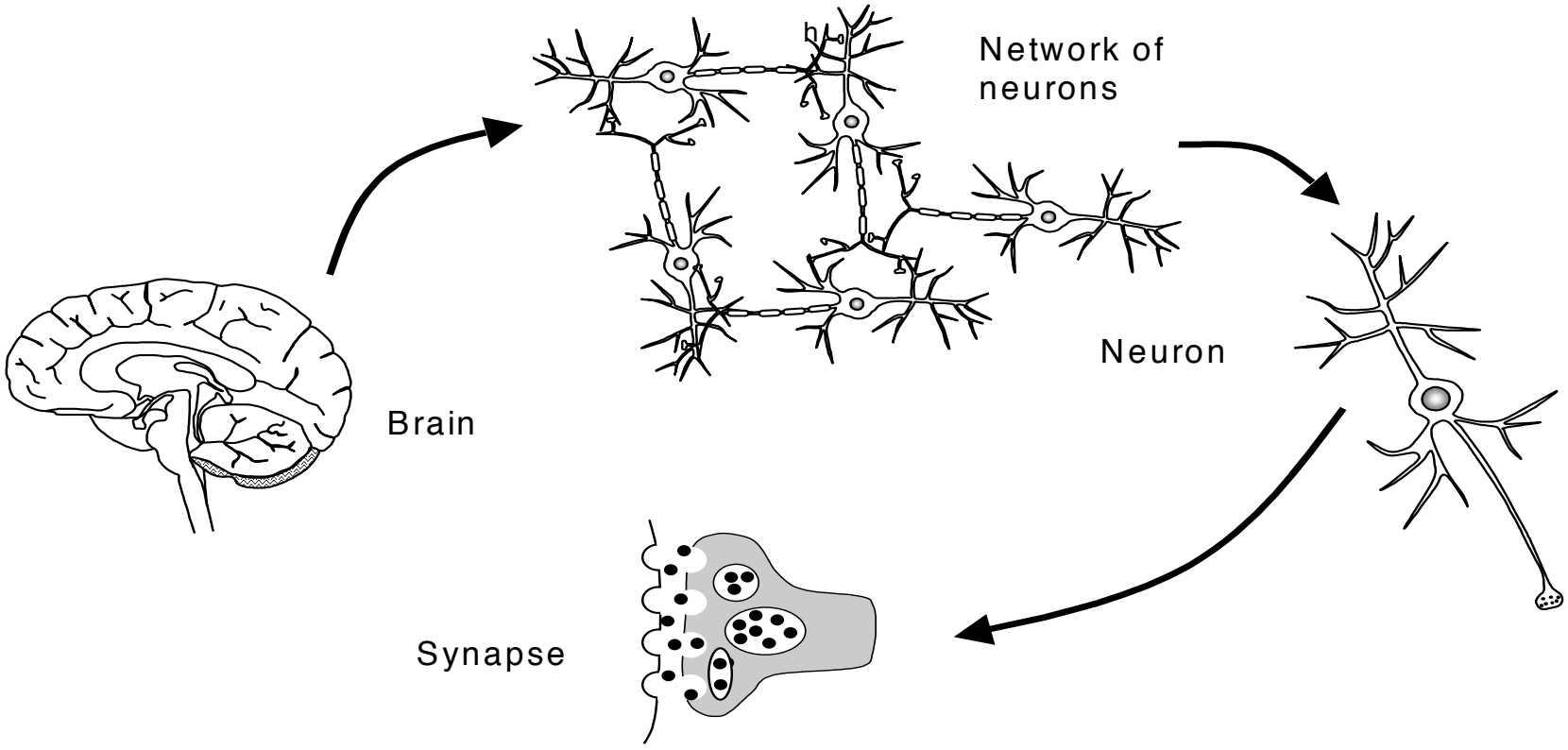




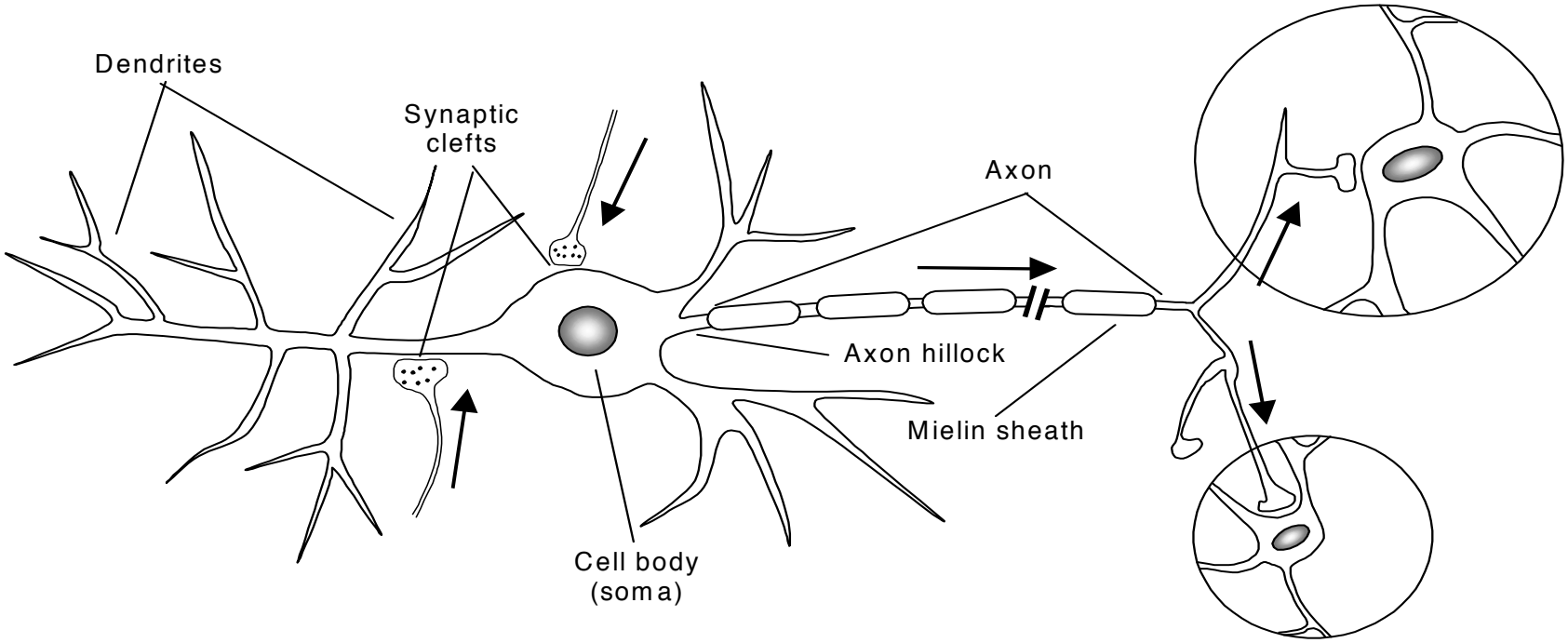


Biological Neural Network

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

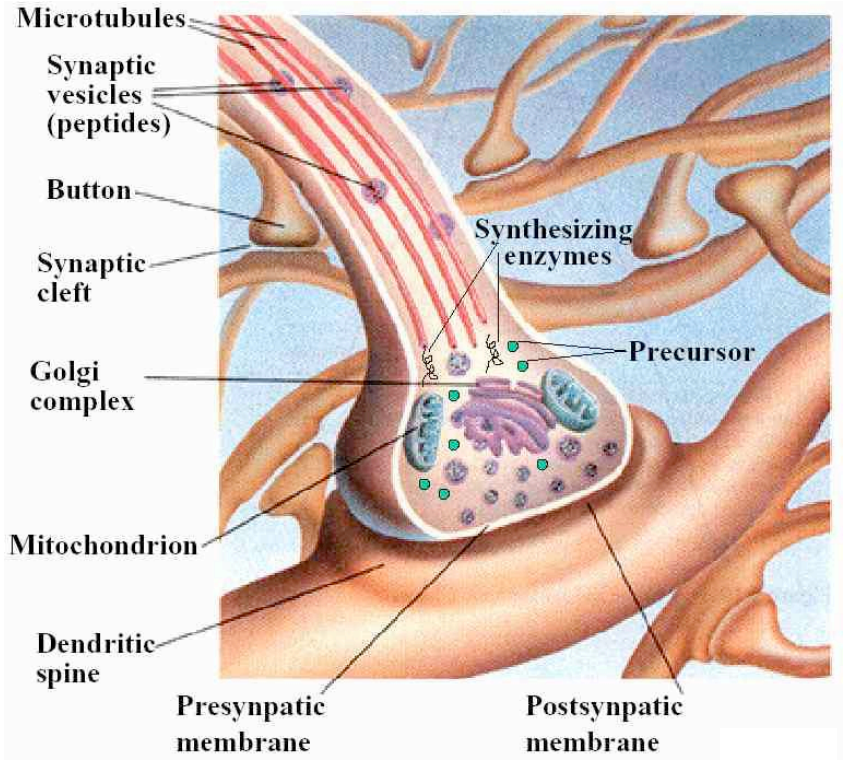


Neuron



- The human brain contains about 80 to 120 billion neurons.
- A neuron is capable of receiving input stimuli (signals) from a 1,000 other neurons and propagate (or not) these signals, according to the stimuli and its internal state, to a 1,000 other neurons.

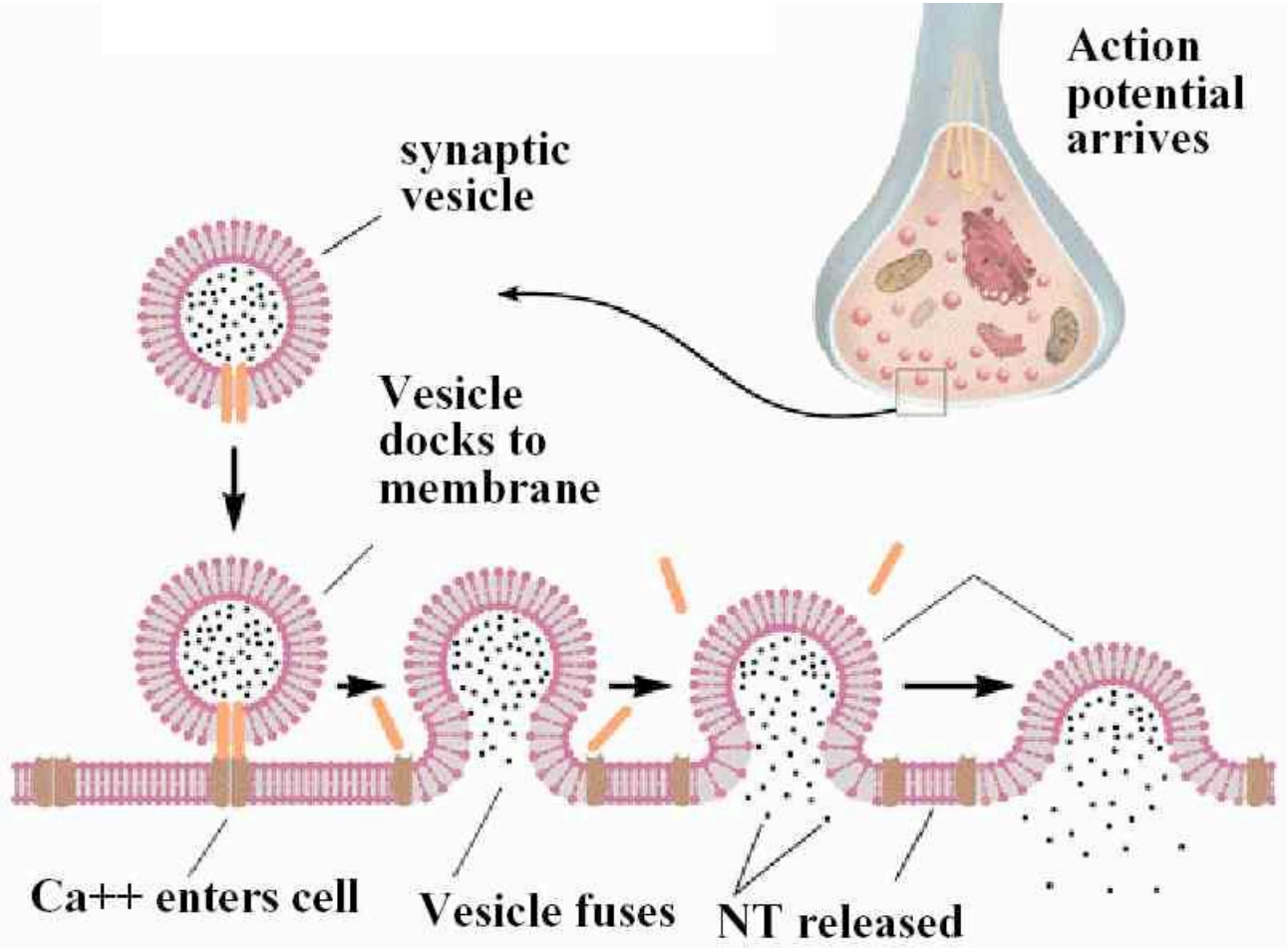
The Synapse



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

http://www.youtube.com/watch?v=LT3VKAr4roo

Neurotransmitters



Other neurotransmitters

- Toxic gases also act as neurotransmitters within our brain.
- Example:
  - Nitric Oxide (NO) - post-synaptic neurotransmitter discovered in 1990.
  - Neurons could modulate neurons in its vicinity and also distant or not physically connected neurons.

Synaptic Plasticity ?

Synaptic Plasticity

- A developing NS is synonymous of a plastic brain: "plasticity"
- The synaptic plasticity is 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.

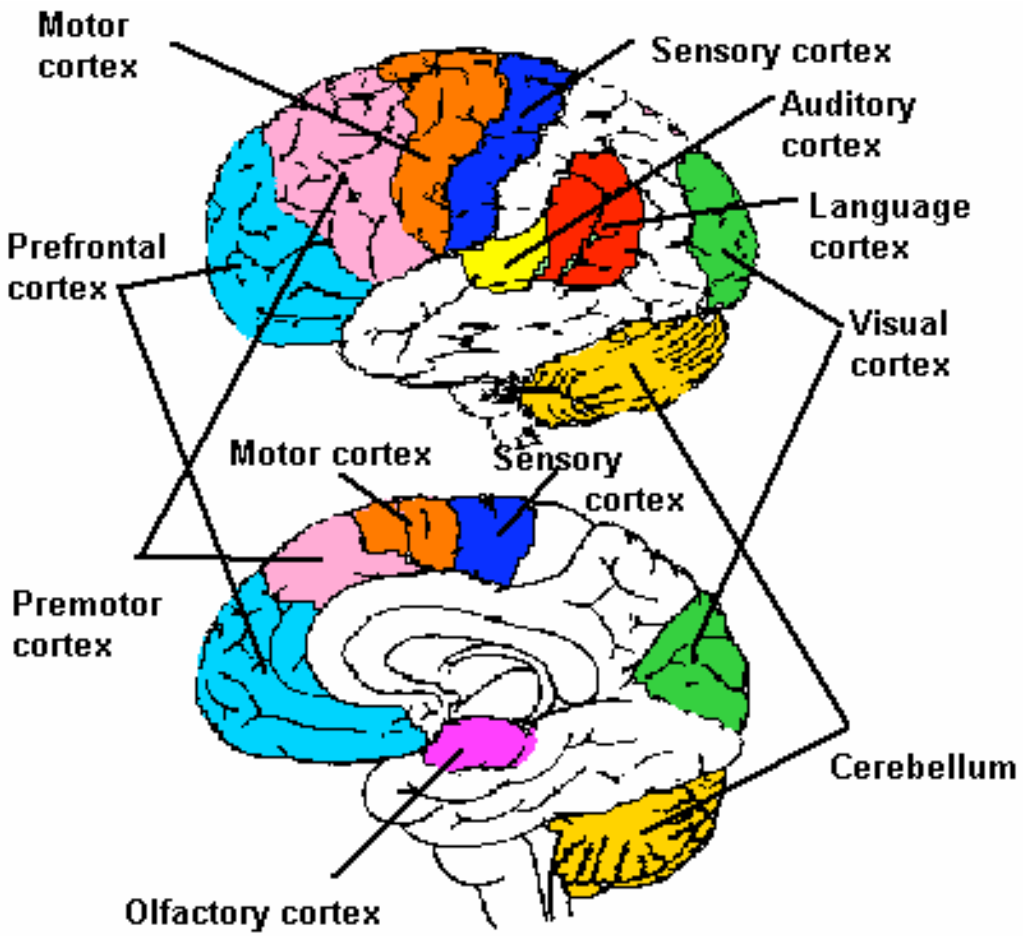
Learning and adaptation AND Synaptic Modulation

- The NS is always suffering modifications and changes.
- The changes may vary in time and could be superficial or profound.
- Major changes occur at the structure of the neuron itself which lead to changes in the synaptic modulation.

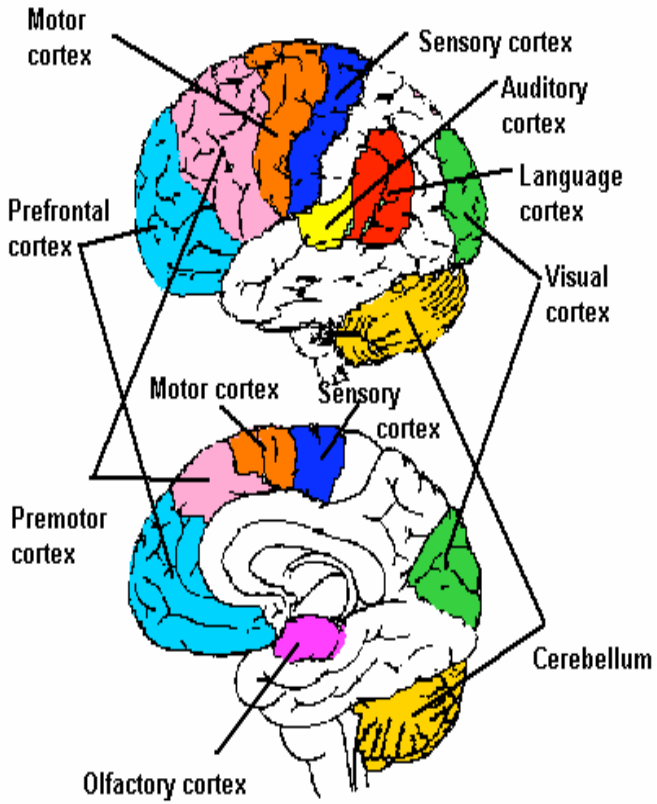
Learning and adaptation AND Synaptic Modulation

- Learning and adaptation are directly linked to synaptic modulation and thus are the most important mechanisms in biological or artificial neural networks.

The grey matter: The cortex



The cortex



Neurons can have feed-forward or feed-back connections.

In the cortex they are organised in bi-dimensional layers.

In a cubic millimeter of the cortex there are approximately 10^5 neurons and 10^9 synapses.

Each neuron grouping might have complex behaviours and functions which can not be observed by analyzing a single neuron.

This gives rise to distributed and parallel processing power of our brain.

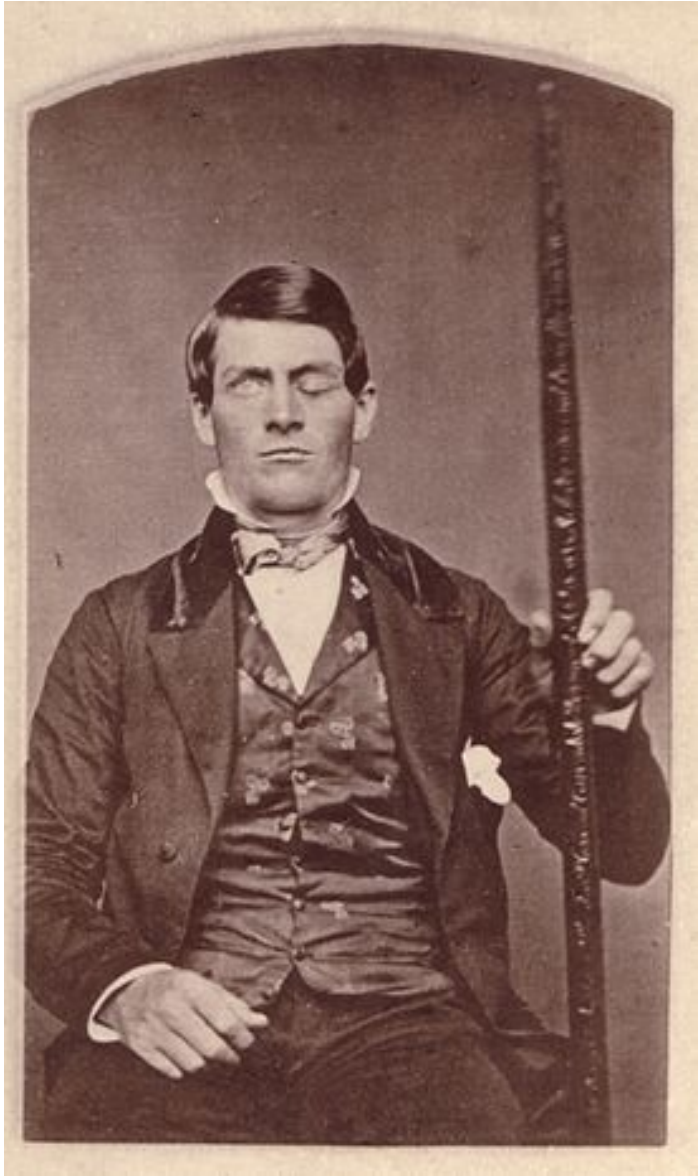
Importance of the Cortex

Computational image reproduction of Phineas Gage brain injury in 1848.

http://www.youtube.com/watch?v=oPAqTP7058Q

Importance of the Cortex

Phineas Gage portrait after the injury



Neural Computation

- 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
...	...
1974	Werbos
...	...
1982	Hopfield
1986	Rumelhart e McClelland

Lecture 1

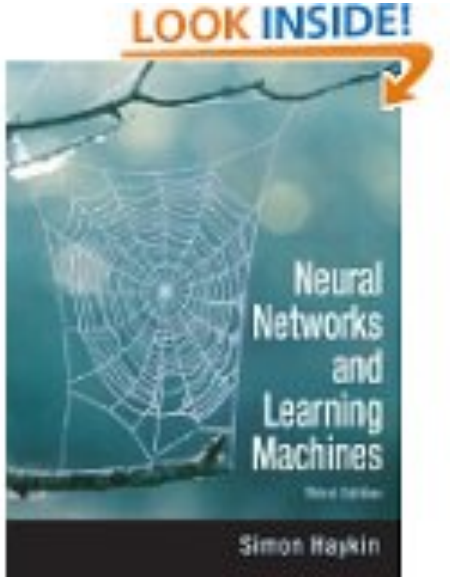
I. What is Neural Computation
II. Biological Inspiration
III. Preliminary Concepts

Lecture 1

Reading list/Homework

- Read Chapter 1.1. and 1.2 (inclusive) from the book:

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



- Answer questions 1-5 from the Tutorial material

Lecture 2

What's next?

Artificial Neural Networks (Part I)