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.
• 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

Nervous System (NS)
- Peripheral NS
  - Autonomic NS
  - Somatic NS
    - Sympathetic NS
    - Parasympathetic NS
- Central NS
  - Brain
    - Forebrain
    - Midbrain
    - Hindbrain
  - Spinal Cord
    - Forebrain
    - Midbrain
    - Hindbrain

Telencephalon
- Cerebral Cortex
  - Basal Ganglia
  - Hippocampus
  - Amygdala
- Diencephalon
  - Thalamus
  - Hypothalamus
- Mesencephalon
  - Tectum
  - Tegmentum
- Metencephalon
  - Pons
  - Cerebellum
- Myelencephalon
  - Medulla

Telencephalon  Diencephalon  Mesencephalon  Metencephalon  Myelencephalon
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Biological Neural Network

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

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Lecture 1

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