Neural Networks
Basics

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Course outline

- Basic aspects
- Simple Artificial Neural Networks
- Multi-Layer Perceptron
- Other Artificial Neural Networks
- Applications
- Practical experiments

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Topics

- Introduction
- Bioinspired and natural computing
- Nervous systems
- Artificial Neural Networks
- Architecture
- Learning paradigms and algorithms

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Introduction

- Since the very begining, human beings have been inspired by nature

https://www.gettyimages.com

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Biomimicry

https://www.dawn.com/news/1297127

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Biomimicry

Use nature as inspiration to create and apply new technologies

https://www.dawn.com/news/1297127

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Nature inspired technologies

- Engineering processes
  - Composed by pre-manufactured parts
  - Follow well defined procedures
  - Obey a clear management system
- Nature processes
  - Designed by evolution
  - Modulated by biochemistry processes
  - Controlled by nervous systems and social interactions

Natural computing

- Computing inspired by nature
  - Cellular automata
  - Quantum computing
  - Bioinspired Computing
    - Biocomputing
    - Bioinspired Engineering
    - Bioinspired Methods
    - Bioinspired Systems
    - Bioinspired Technologies

Bioinspired Computing

- Investigate computational algorithms inspired by Biological processes
  - Adaptation
    - Learning
    - Evolution
    - Physiology
  - Self-Organisation
  - Competition
  - Cooperation

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Bioinspired Computing

- Main sub-areas
  - Artificial Neural Networks (ANNs)
  - Evolutionary Computation (EC)
  - Swarm Intelligence (SI)
    - ACO, PSO, …
  - Artificial Immune Systems (AISs)
  - Molecular-Based Computing (MC)
    - DNA computing

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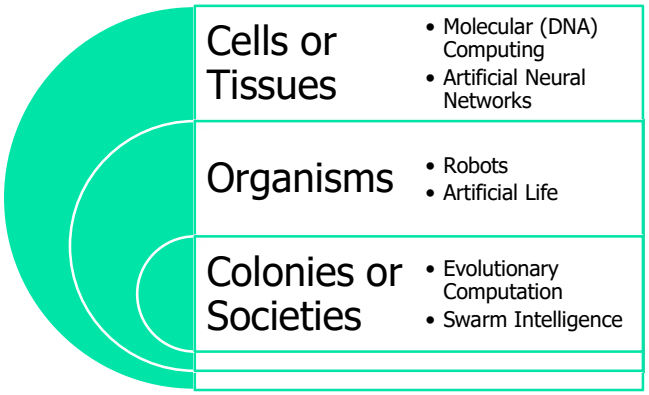
Bioinspired

- Inspiration can occur at different levels



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Bioinspired Computing

- Successfully applied to the solution of
  - Pattern Recognition problems
    - ANN, AIS, EC
  - Optimisation problems
    - SI, MC
  - Many problems from Biology
    - Bioinformatics
    - Environmental Computing

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Why Neural Networks?

- Conventional computers overcome humans in various domains
  - Calculating of complex numerical equations
  - Management of thousands of files
- On the other hand, in several tasks, humans are better than conventional computers
  - Face recognition in a crowd
  - Natural language processing
  - Pattern recognition tasks

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Conventional computers

- Von Neumann
  - One of the main names in Computer History
  - Proposed the general purpose computer architecture currently used
    - Suggested that programs and data could be stored in the computer
    - Von Neumann Architecture

- Before his death
  - Wrote the notes "the computer and the brain" for the Silliman Seminars, Yale University

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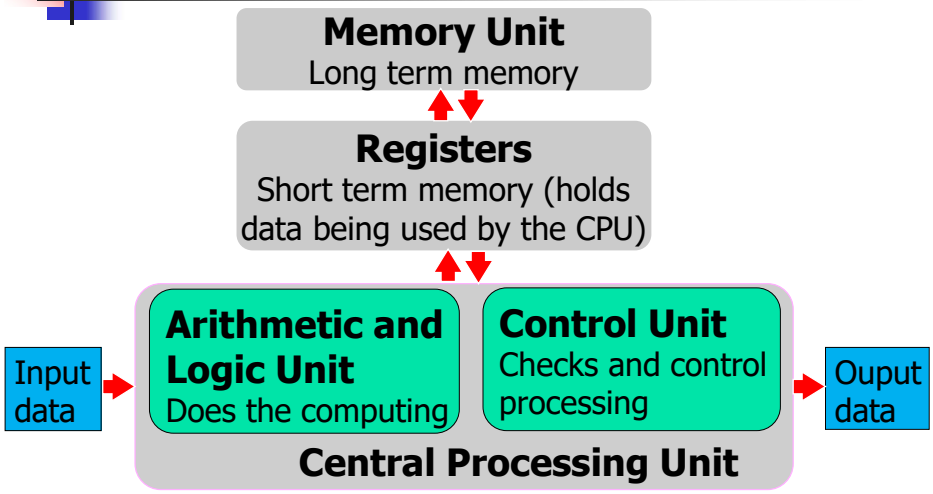
Von Neumann Architecture



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The nervous system

- Works entirely differently from conventional computers
  - Neurons are much slower than current processors
  - Slowness is offset by large number of massively connected neurons
  - For certain operations, much faster than conventional computers
    - Vision, hearing and control

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The human brain

- Has approximately 100 billion cells
- Each brain cell is connected to thousands of other brain cells
  - Totaling ≈ a quadrillion (a million of billion) of connections
  - Brain total wiring:
    - Mean distance from the earth to the moon (almost 4×10^5 km
- To work, consumes about 20 watts
  - Complete desktop consumes 200 watts

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The human brain

- Information transmission rate for each sense

Sensory system	Bits per second
eyes	10,000,000
skin	1,000,000
ears	100,000
smell	100,000
taste	1,000

https://www.britannica.com/science/information-theory/Physiology

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The human brain

- High processing and storage capacity
  - Human brain can perform up to 100 billion operations per second
    - 38 peta operations per second
      - Equivalent to a 38 petaflop computer
    - A13 bionic chip: 1 trillion operations per second
  - 1% of a mouse brain can store approximately 1,000 terabytes of data

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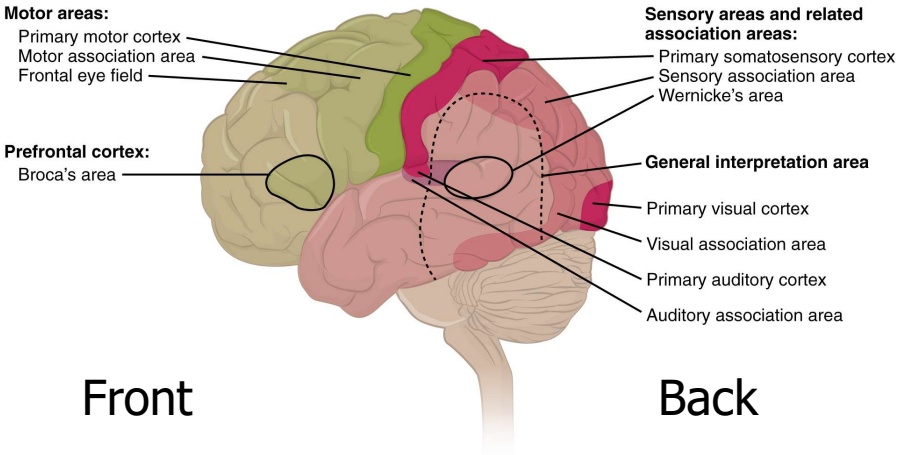
Brain anatomy (architecture)



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Von Neumann X Neural system

Feature	Von Neumann architecture	Neural system architecture
Processor	Complex High speed One or few	Simple Low speed Large number
Memory	Separated from processor Local Non-addressable content	Integrated to processor Distributed Addressable content
Processing	Central Sequential Stored programs	Distributed Parallel Learning
Confiability	Very vulnerable	Robust
Adequation	Numerical and symbolic	Perception
Operational environment	Well defined Very restrict	Poorly defined No restriction

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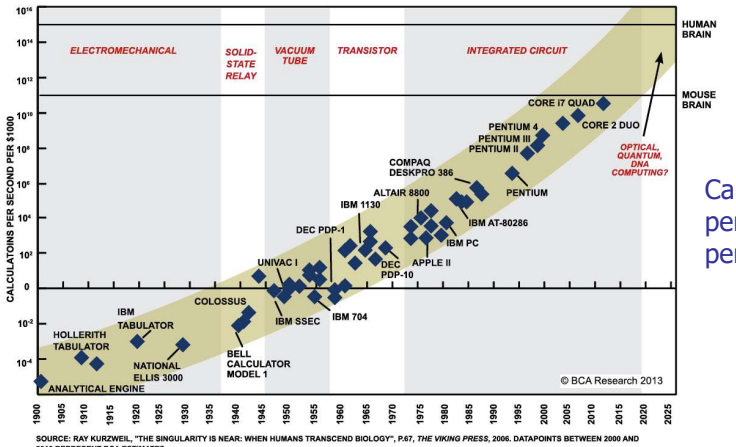
Processing capacity



Calculations per second per US$ 1000

SOURCE: RAY KURZWEIL, "THE SINGULARITY IS NEAR: WHEN HUMANS TRANSCEND BIOLOGY", P.67, *THE VIKING PRESS*, 2006. DATAPOINTS BETWEEN 2000 AND 2012 REPRESENT BCA ESTIMATES.

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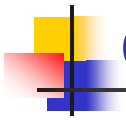

Quiz 1

- Mark the aspects where the nervous system is better than the Von Neuman architecture
  - A) Processing power
  - B) Remember phone number
  - C) Numerical processing
  - D) Storage capacity

Artificial Neural Networks (ANNs)

- Distributed systems inspired by the human nervous system (brain)
  - Composed of multiple processing units ("neurons")
  - Interconnected by a large number of connections ("synapses")
- Efficient in several situations where traditional methods are inadequate

Artificial Neural Networks (ANNs)

- ANN research started with the wish to understand
  - How the brain works and
  - How model its functioning
- Initial successes of ANN were shaded by:
  - Progresses in digital technology
  - Exaggerated promises about the capacity of the first models and algorithms

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Artificial Neural Networks (ANNs)

- Three main research goals
  - Investigate the behaviour and structure of the nervous system (mainly the brain)
  - Develop mathematical foundations to explain and support design of better ANNs
  - Propose and apply new ANNs to solve real problems, each time better

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A bit of history

- (300 BC) Aristotle wrote: of all animals, man proportionally has the largest brain
- (1700) Descartes believed that mind and brain were separate entities
- (1911) Ramon y Cajal formulated the idea of neurons as basic brain structures

A bit of history

- (1943) McCulloch & Pitts
  - McCulloch-Pitts developed the mathematical formulation of ANNs
    - Nodes performed simple logic functions
      - Each node could execute a different function
    - Showed that any function written by a combination of logic functions could be modelled by an ANN
    - Proved, theoretically, that any mathematical function could be implemented using sum-of-product units

A bit of history

- (1949) Hebb developed the first training algorithm for ANNs (Hebbian learning)
  - If two nodes are simultaneously active, the connection between them can be strengthened
- (1959) Rosenblatt implemented the first ANN
  - Single layer network
  - Algorithm for iterative adjustment of weights
  - Proved theorem of convergence

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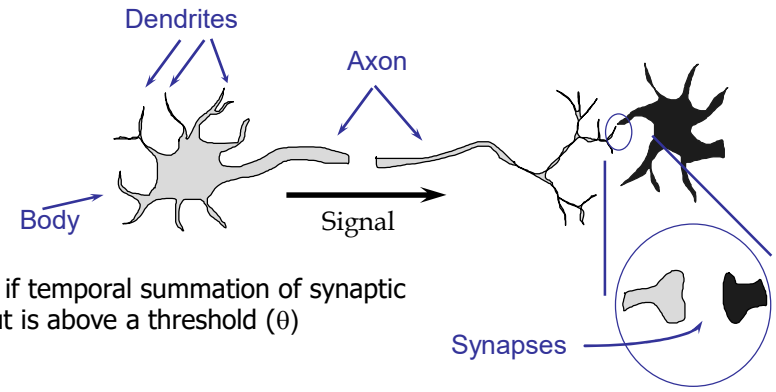
Natural neuron

- A simplified neuron and its connections:



Fire if temporal summation of synaptic input is above a threshold (θ)

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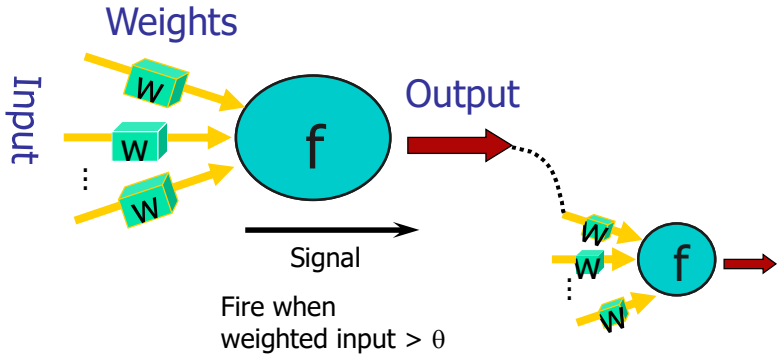
Artificial neuron

- Model of a very simplified neuron



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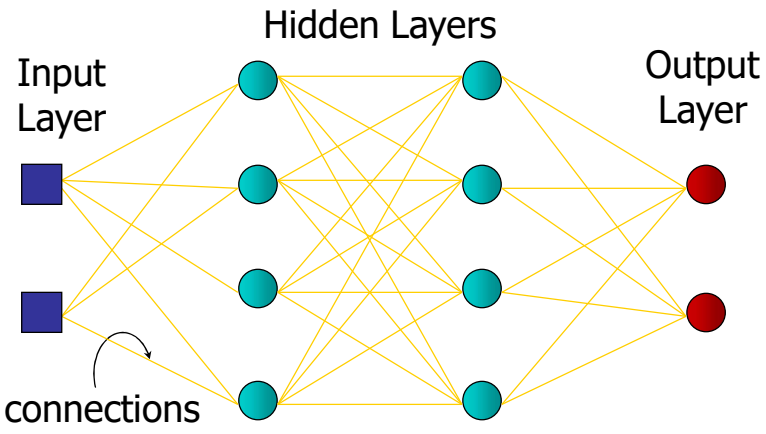
Typical ANN



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ANN main characteristics

- Learn by example
  - Nonparametric statistical inference
- Can be easily adapted to new situations
  - Plasticity *X* diversity dilemma
- Generalisation capability
- Redundance
  - Fault tolerance

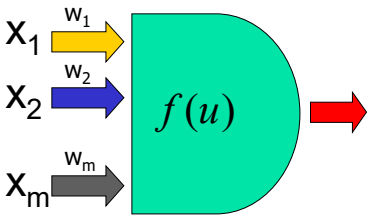
Foundations

- Main aspects of ANN
  - Architecture
    - Processing units (nodes)
    - Connections
    - Topology
  - Learning
    - Algorithms
    - Paradigms

Processing units

- Function: receive inputs from a set of units A, compute a function on these inputs and send the result to a set of units B
- Total input

$$u = \sum_{j=1}^{N} x_j w_j$$



Processing units

- Activation function
  - Define activation state of the node
  - Use total input and/or previous activation state
- Output function
  - Node output
  - Usually, identity function

Processing units

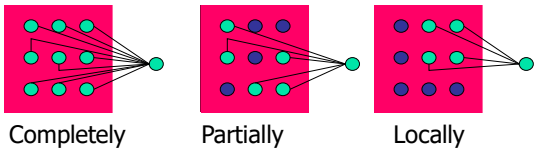
- Representation
  - Local: units represent well defined objects (Ex. words, faces, etc.)
  - Distributed: units represent abstract concepts
    - Participates in the definition of several objects
- Unit location
  - Hidden
  - Output

Connections

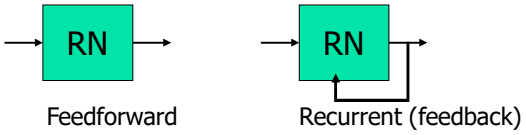
- Define how the nodes are interconnected
- Encode the network knowledge
- Types de weighted connections ($w_{ik}(t)$)
  - Excitatory: ($w_{ik}(t) > 0$)
  - Inhibitory: ($w_{ik}(t) < 0$)
  - Inexistent: ($w_{ik}(t) = 0$)
- Number of node's connections
  - *Fan-in*
  - *Fan-out*

Topology

- Number of layers
- Coverage of connections

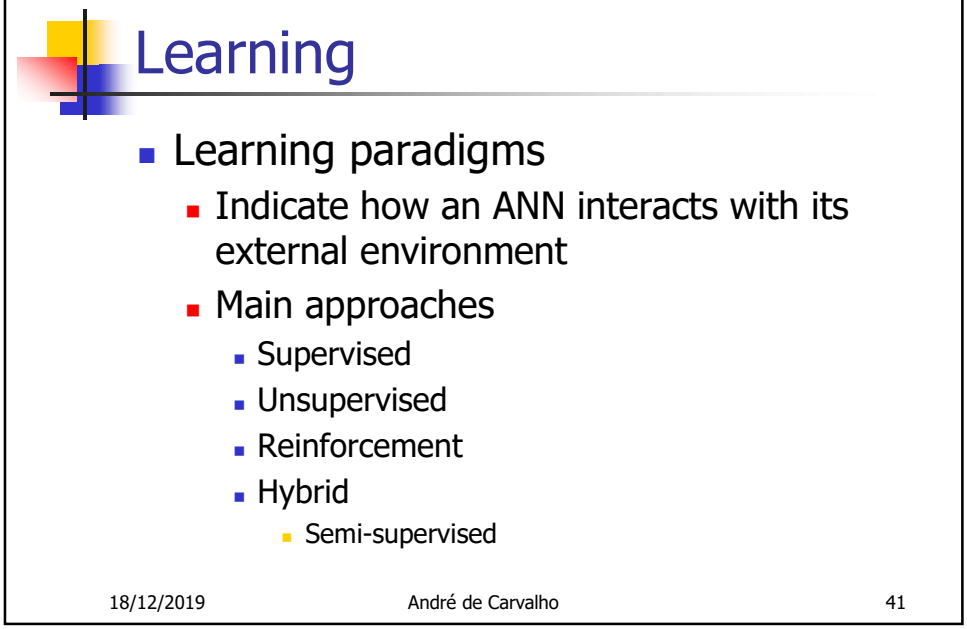


- Arrangement of connections



Learning

- Learning algorithms
  - Set of well defined rules used to teach a network to solve a given problem
  - Main approaches
    - Error correction
    - Hebbian
    - Competitive
    - Boltzmann (simulated annealing)
  - Differ on how the network weights are updated


Learning
Learning paradigms
Indicate how an ANN interacts with its external environment
Main approaches
Supervised
Unsupervised
Reinforcement
Hybrid
Semi-supervised
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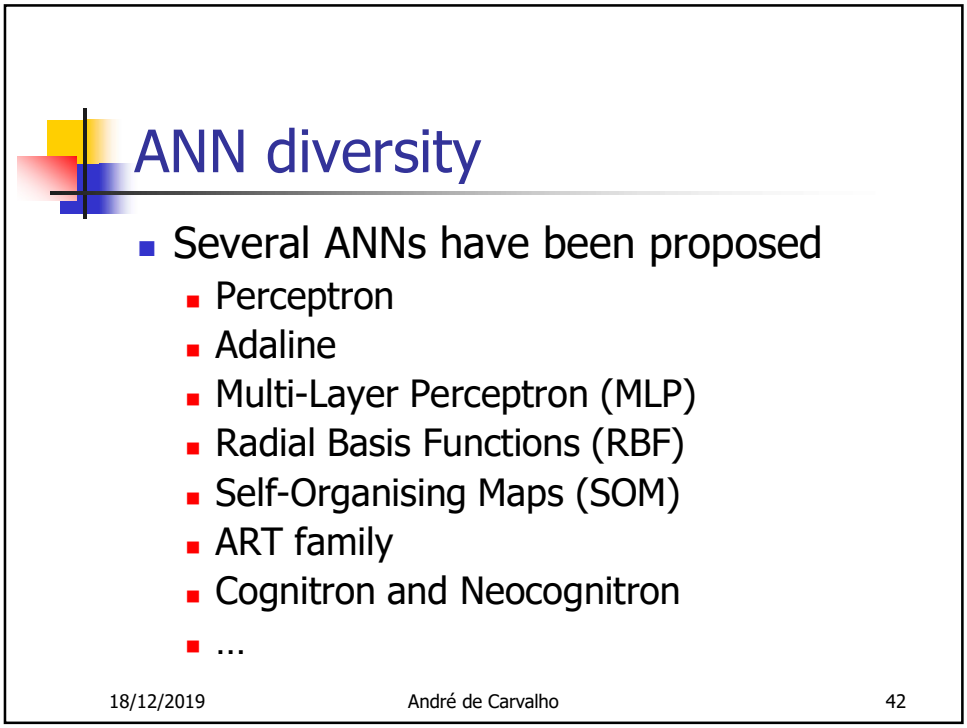
ANN diversity
Several ANNs have been proposed
Perceptron
Adaline
Multi-Layer Perceptron (MLP)
Radial Basis Functions (RBF)
Self-Organising Maps (SOM)
ART family
Cognitron and Neocognitron
...
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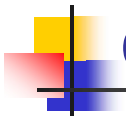

Quiz 2

- What are the main aspects of an ANN?
  - A) Neurons and connections
  - B) Architecture and learning algorithm
  - C) Fan-in and fan-out
  - D) Excitatory and inhibitory connections

Next: Simple Neural Networks

