Introduction to Computational Neuroscience

Lecture 1: Introduction
Objectives of the course

• get an idea of the common approaches to study the brain
Objectives of the course

• get an idea of the common approaches to study the brain

• understand the differences between how brains and computers process information
Objectives of the course

• get an idea of the common approaches to study the brain

• understand the differences between how brains and computers process information

• develop a critical thinking about neuroscience news and literature
Organization of the course

https://courses.cs.ut.ee/2016/neuro
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https://courses.cs.ut.ee/2016/neuro

Raul Vicente  raulvicente@gmail.com
Ardi Tampuu  arditampuu@gmail.com
Organization of the course

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Raul Vicente  raulvicente@gmail.com
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Group of Computational Neuroscience

Ulikooli 17: room 208
Schedule of the course

• 14 Lectures (Monday 14:15 @ room 110)
• 7 Practical (Thursday 12:15 @ room 102)
Schedule of the course

• Excursion to the Experimental Psychology lab
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**Basics**

**Analyses**

**Models**

**Cognitive**

**Applications**

lunes, 5 de septiembre de 16
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Grading system

Differentiated: A-F

- Exam (30%)
- Homework (35%)
- Project (35%)

You can collect up to 110 points, 90+ will give you A, 80+ B, 70+ C and so on.

50% for each component to get a final assessment

Bonus exercises (up to 10%)
Exam

- 20 questions
- 2-3 paragraphs
- lecture/practice material

Structure and function

Q₂: The nervous system (NS) of vertebrates is divided in central and peripheral parts. Name a few characteristics of the central NS and of the peripheral NS. You can consider characteristics of each division regarding both its structure/anatomy and function.

Q₃: Name the two main types of cells found in a nervous system and describe their main roles.

Q₄: Describe what is a synapse and what happens at the synapse when an action potential (spike) reaches the end of an axon.

Windows to the brain

Q₅: What is the main goal of structural brain imaging? What is the main goal of functional brain imaging?

Q₆: Describe what is the typical neuronal signal one obtains from an extracellular recording? Which is the neuronal signal typically obtained from intracellular recordings?
Project

- 2-4 people
- 15 pages
- small research (data collection, data analysis, model, essay...)
- presentation
Project (ANN playing Atari)
Project (visual illusions)

- N = 238
- 10, 15 ... 1 rpm = 134
- 10, 5 ... 15 rpm = 104
- Gender:
  - Males: 63
  - Females: 175
- Age: group from 20-29 = 172
- Education:
  - Secondary school = 88
  - Bachelor degree = 80
- Country of origin: 30 countries (Estonia, Latvia, Syria, Israel, Australia, etc.)
Pre-requisites

• Basic programming (e.g. Matlab, Python)
• Not be scared of small data analysis or a simple equation
• Understand that this is an interdisciplinary topic
What is computational neuroscience?
What is neuroscience?
What is neuroscience?

Scientific effort to understand how the brain works
>30000 scientists attended the last SfN meeting
Why?

- your brain (a spongy, 1.5 kg of tissue) is the most complex structure we know
Network more complex than any social network
100 billion neurons & 100 trillion synapses
Why?

• your brain (a spongy, 1.5 kg of tissue) is the most complex structure we know

• single organ that controls the body (CEO + data scientist of your body)
Heart rate, temperature, pressure, sleep,...
Coordinated movement of muscles and glands
Why?

- your brain (a spongy, 1.5 kg of tissue) is the most complex structure we know

- single organ that controls the body (CEO + data scientist of your body)

- >1000 disorders of the brain and the NS
Parkinson, Alzheimer, autism, multiple sclerosis, depression, schizophrenia, addiction,...
Parkinson tested from phone call... with >95% accuracy!
Stimuli
- Photons
- Pressure
- Chemicals

Behavior
- Movement
- Language
Intelligent agents

Input:
- Sensors
- Data

Artificial Intelligence

Output:
- Movement
- Language
What is computational neuroscience?

to understand how the brain “computes” or processes information

i.e., how neuronal circuits implement input-output relations
Brain as metaphors of current technology...
Computational Neuroscience uses the computer as a tool and as analogy.
Machines vs Brains

vs.

lunes, 5 de septiembre de 16
Machines vs Brains

precise, symbolic data
memory / computation
centralized processing
sequential
programming
clock-driven
fast & hot

vs.

low resolution, ambiguous data
memory & computation
distributed processing
parallel
learn
event-driven
slow & cool
Computer wins by KO

What is the prime factorization of 238434728?
Brain wins by KO

Invariance of recognition

• Try to program a computer to do the same...
Brain wins by KO

Novel examples need to be recognized...

• Try to program a computer to do the same...
Brain wins by KO

Recognition when only part of an object is visible...

• Try to program a computer to do the same...
Brain wins by KO

- Try to program a robot to move smoothly...
Amazon mechanical turks for human intelligence
Approaches to computational neuroscience?
Bottom-up approach (bio)

A reductionist approach:

Collect data, organize it, and see what behavior emerges at the next level!

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<th>object of study</th>
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<td>chemistry</td>
<td>transmitters and receptors</td>
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<tr>
<td>cell biology</td>
<td>neurons</td>
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<tr>
<td>computer science</td>
<td>networks</td>
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<tr>
<td>neurology</td>
<td>systems</td>
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<tr>
<td>psychology</td>
<td>behavior or thought</td>
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Top-down approach (eng)

Functional:
What information processing problem is being solved?

Algorithm:
What information processing steps are carried out to solve it?

(Biophysical) Implementation:
How is the algorithm implemented in biological hardware?

David Marr
Biologists
if model deviates from details of known physiology is inadmissibly inaccurate

Computational neuroscience

CS, physicists
if models fail to simplify do not allow any useful generalization to be made
3 lines of research from our lab
Simulation | Data analysis | AI
Simulating neural systems

• To better predict and guide experiments
Simulating neural systems

• To better predict and guide experiments

• Framework for thinking clearly:

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<tr>
<th>Mathematical formalization</th>
<th>Consistency</th>
<th>True?</th>
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<tbody>
<tr>
<td>Inconsistency</td>
<td>Falsehood</td>
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Different scales

Molecular level (Ca dynamics)

Cellular level (multi-compartmental)

Local circuits (network dynamics)
Human brain project

1 billion Euro
65536 cores
Data analysis

Functional & Structural connectivity

Brain oscillations

Machine learning (classifiers, regressions)
Machine Learning: algorithms that learn from data

• “Teaches” the algorithm with correct examples to learn the relation between neuronal signals $X$ and behavior $Y$ (or stimulus)

• What? Where? When?

$X \sim$ spikes, LFP, EEG, fMRI

$Y \sim$ behavior, stimuli
Ardi + Tambet

Decoding animal position from brain activity
Decoding animal position from brain activity

Ardi + Tambet
Decoding animal position from brain activity

Ardi + Tambet
Comparing biological and artificial vision

Along the ventral stream, the human brain represents increasingly more complex visual features. The very same phenomenon emerges in deep artificial neural networks designed to classify visual images: each consecutive layer of a deep neural network codes for more complex visual features than the previous layer. In this study, we compare biological and artificial visual processing systems.
Playing Atari with Deep Reinforcement Learning
Playing Atari with Deep Reinforcement Learning
IA that in few hours learns to play better than humans!
It does not know the game rules, nor what is a ball, nor that blocks can be broken,...
It does not know the game rules, nor what is a ball, nor that blocks can be broken,...

Its only obsession in life is to increase the reward!
Multiagent Cooperation and Competition with Deep Reinforcement Learning

Video: competitive mode of playing
Multiagent Cooperation and Competition with Deep Reinforcement Learning

Video: cooperative mode of playing
Open questions

- How are memories encoded and retrieved?
- What does the activity of the brain at rest represents?
- How do brains simulate the future plans and events?
- What makes human intelligence different?
- Why do brains sleep and dream?
- What is consciousness?
To know more

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