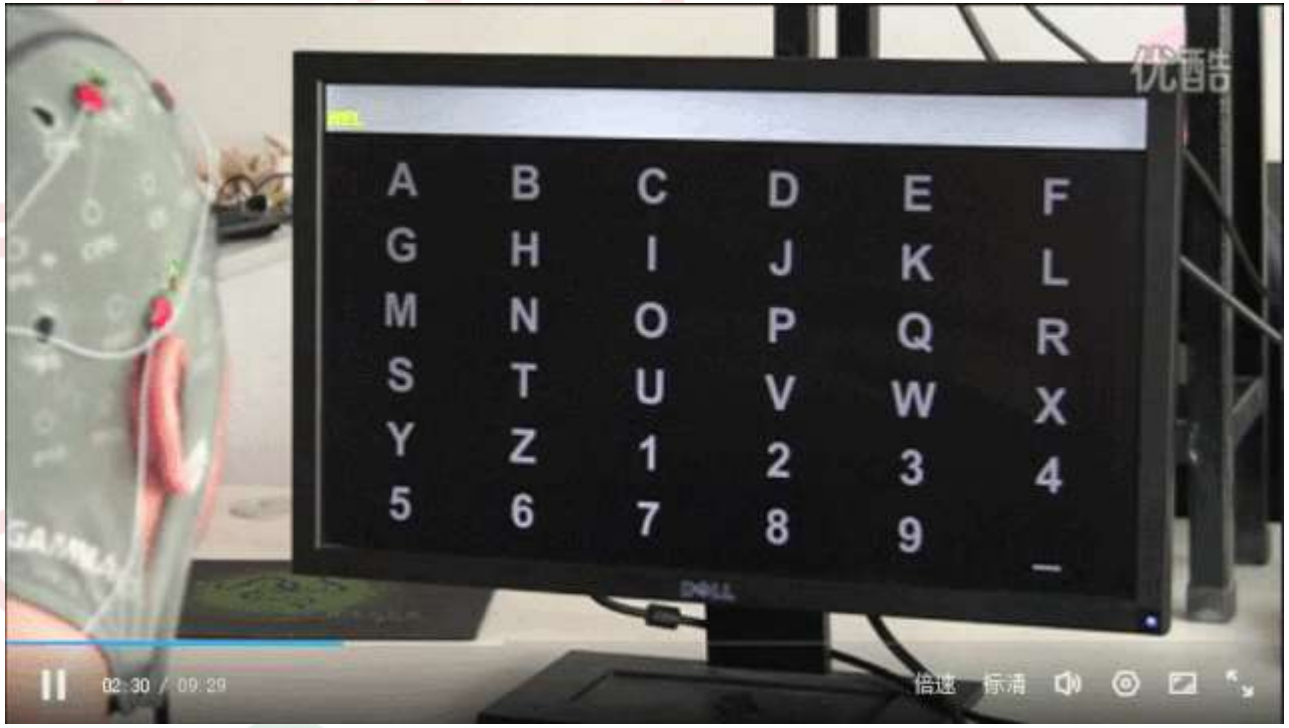
Computational Neuroscience

Mohamed Abdelhack
Postdoctoral Fellow
Krembil Centre for Neuroinformatics
9-April-2022

Outline

- Personal journey into comp neuro
- How modelling can help (Marr’s levels of analysis)
- Imaging/Modelling different scales of neuronal structures
- Examples of advances in the field
  - Handwriting BCI
  - Visual reconstruction of images
  - Robotic arm movement
- Career prospects?
- Required knowledge to enter the field

My story with Neuroscience

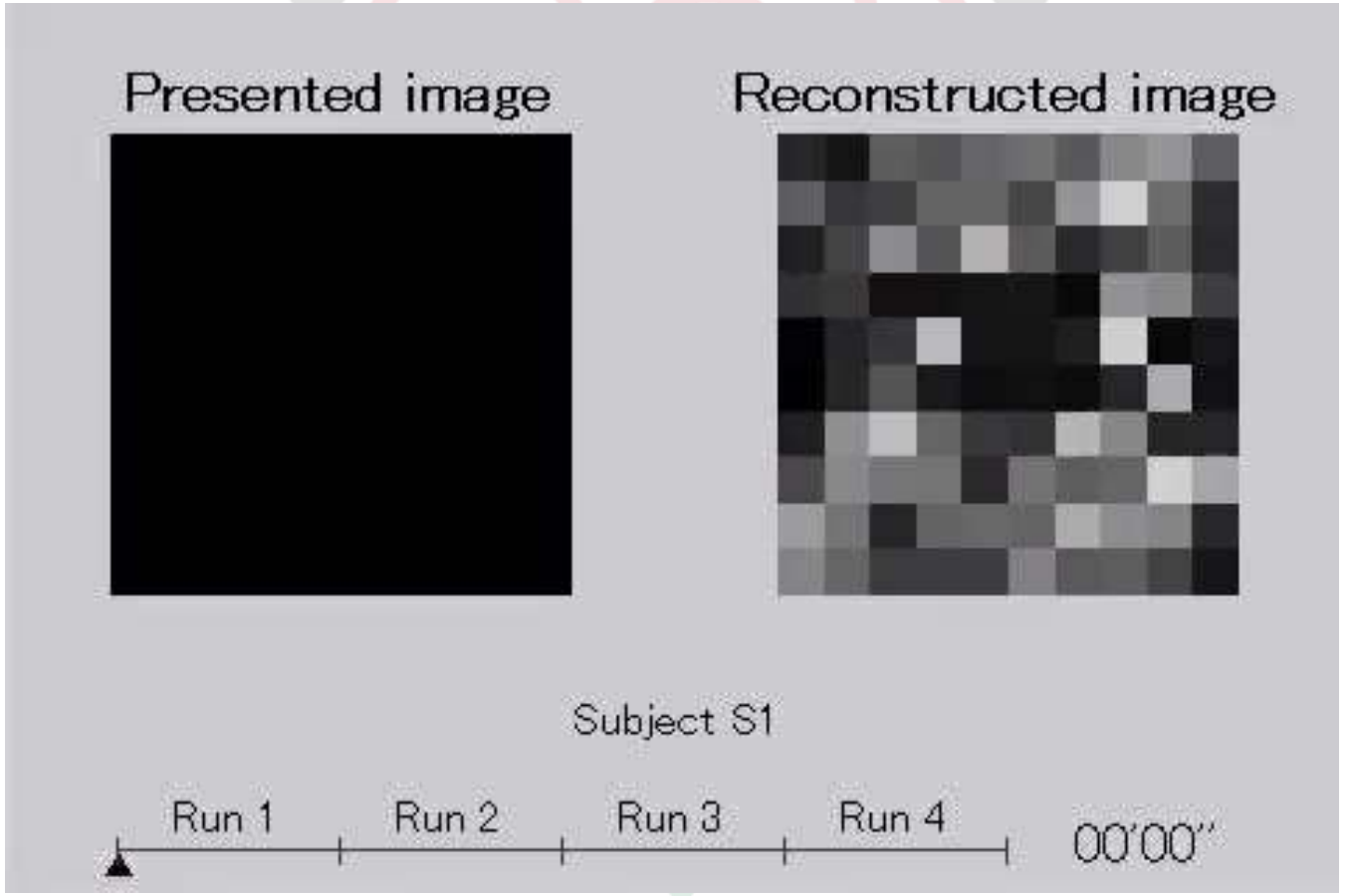


https://ar.wikipedia.org/wiki/%D8%AF%D8%A8%D9%84%D8%AC%D8%A9_%D8%A3%D8%A8%D8%B7%D8%A7%D9%84_%D8%A7%D9%84%D8%AF%D9%8A%D8%AC%D9%8A%D8%AA%D8%A7%D9%84_(%D8%A7%D9%84%D8%AC%D8%B2%D8%A1_%D8%A7%D9%84%D8%A3%D9%88%D9%84)

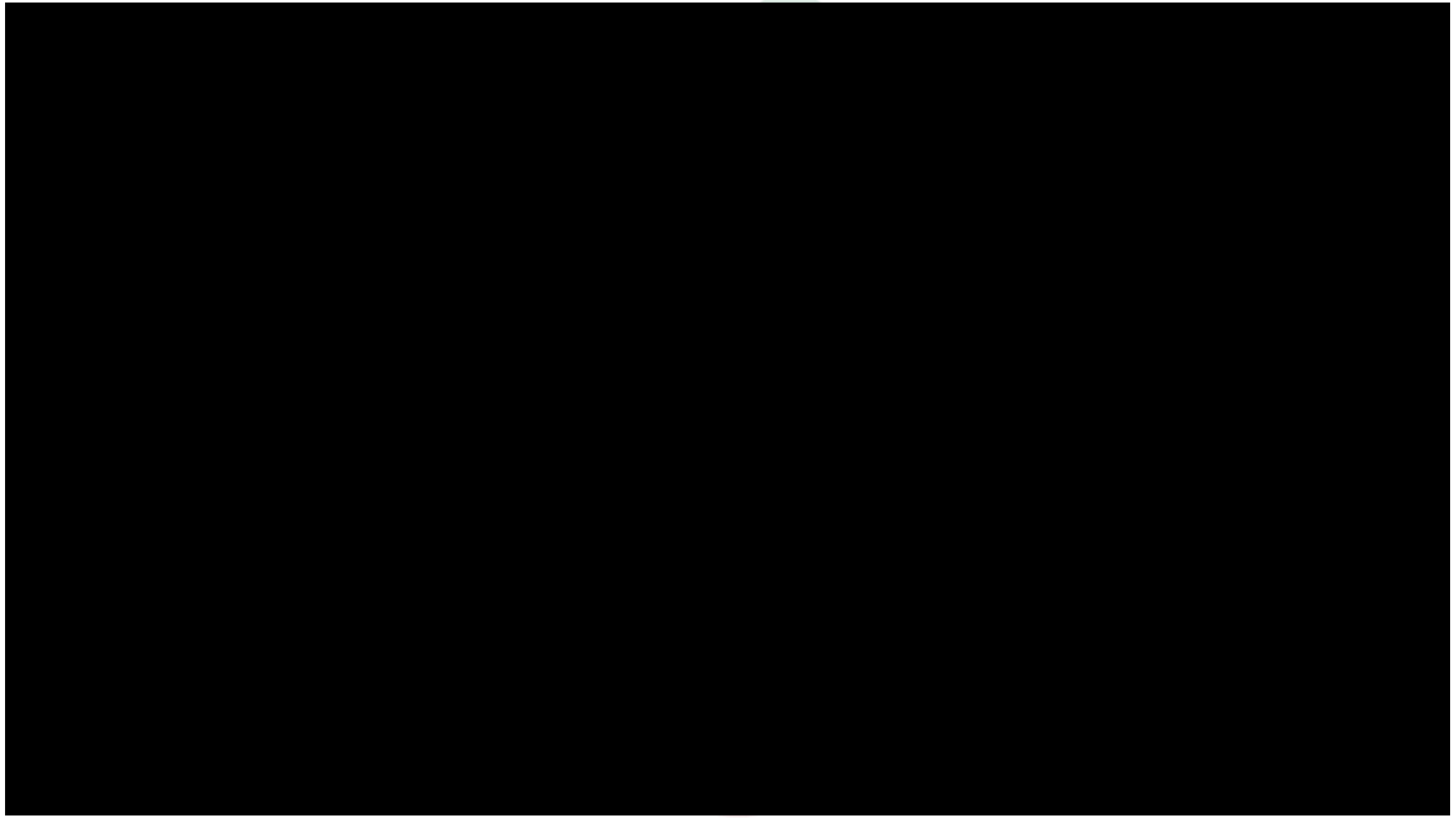
https://www.programmersought.com/article/65257129037/

لما تعمل تجربة مفروض تتعمل في المعمل في البيت

From BCI to Comp-Neuro



Miyawaki et al. 2008



https://youtu.be/inaH_i_TjV4

Horikawa et al. 2013

So What is computational neuroscience?!

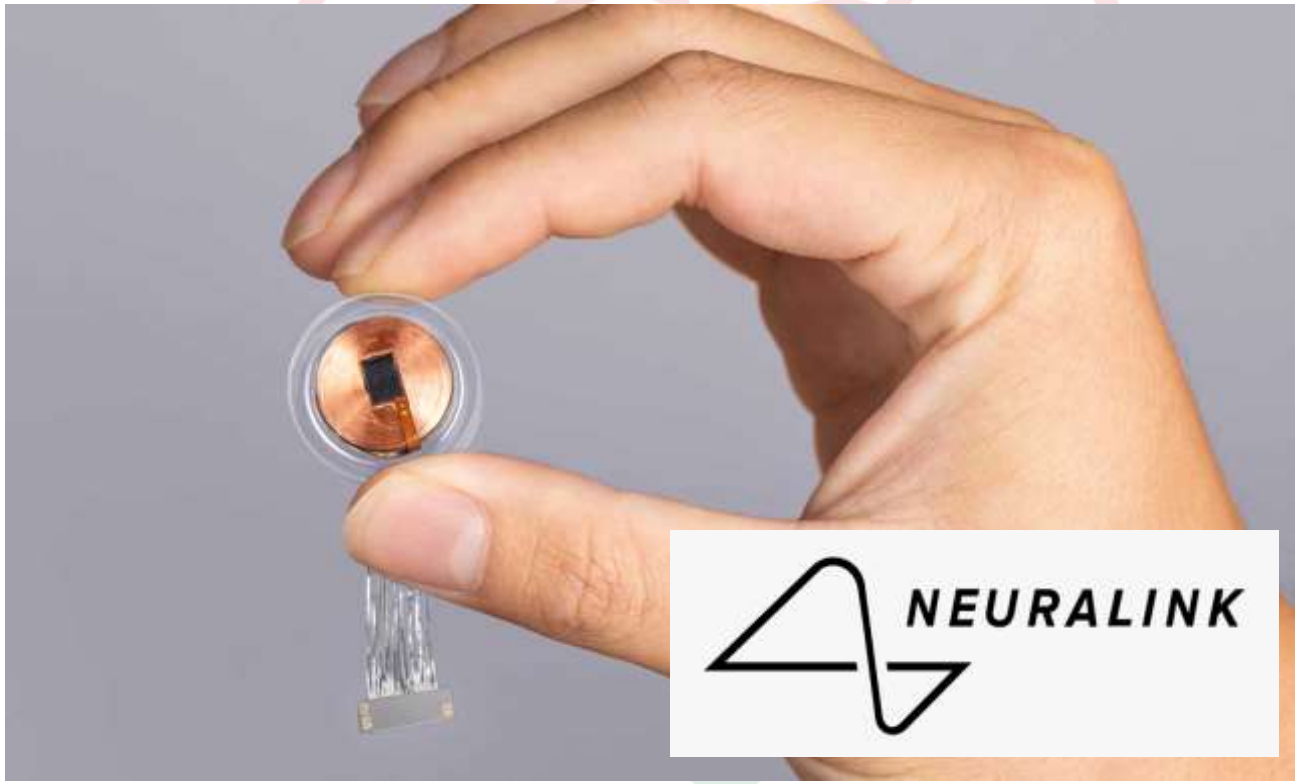


Photo: Neuralink

So What is computational neuroscience?!

https://www.imdb.com/title/tt2210581/

That’s actually neuro-tech, a small part of computational neuroscience

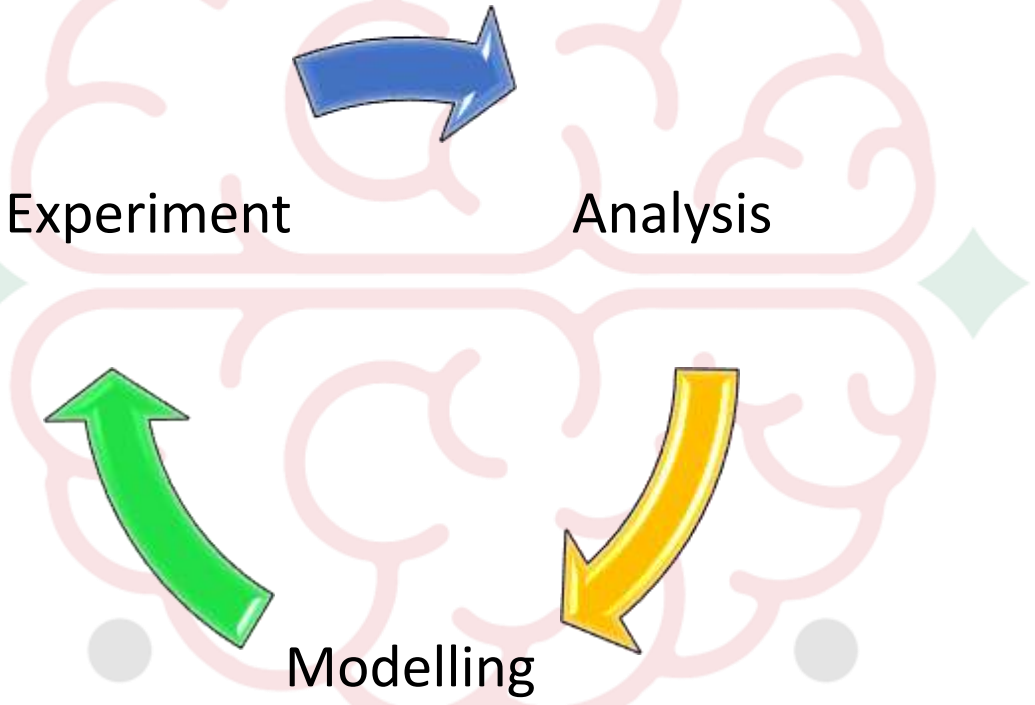
https://youtu.be/pcApwQxbagg

So What is computational neuroscience actually?!

Theoretical analysis and computational modeling are important tools for characterizing what nervous systems do, determining how they function, and understanding why they operate in particular ways. (Dayan and Abbott 2001).

- Descriptive (What?)
- Mechanistic (How?)
- Interpretive (Why?)

Experimental modelling cycle

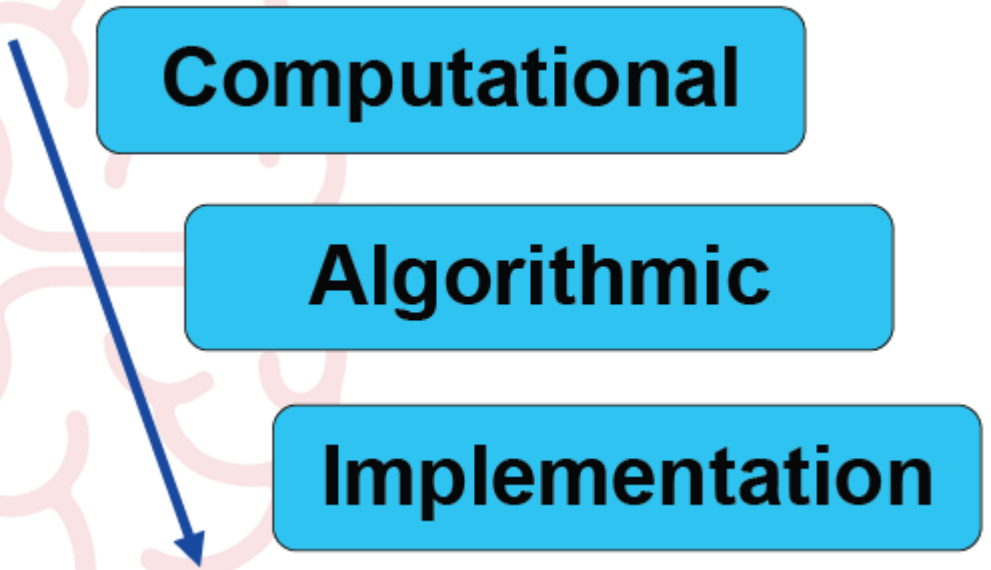


Why neural modelling?

- Guide new experiments
- Understand the underlying mechanisms giving rise to experimental data
- Aggregate experimental data into a compact form
- Understand reasons for neurological/mental illness
- Predict the effect of medications
- Devise new brain-inspired technologies

Marr’s Levels of Analysis (Marr 1982)

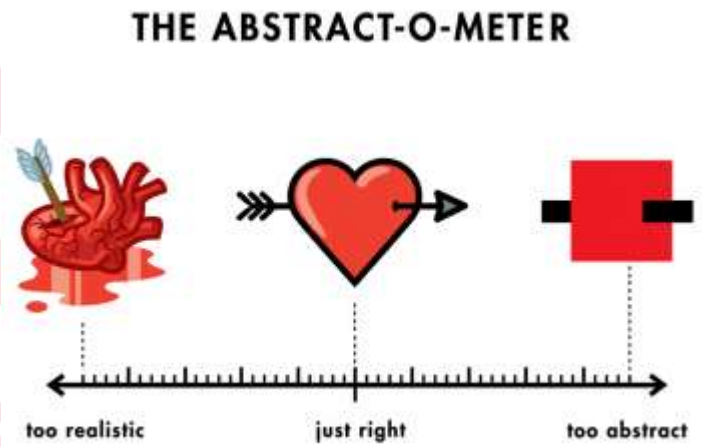
- What does the system do and why?
- How does the system do what it does?
- How is the system physically realized?

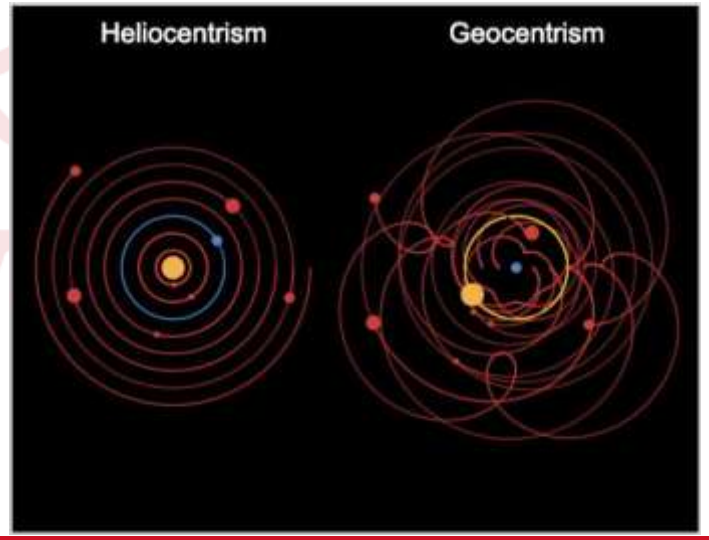


https://blog.shakirm.com/2013/04/marrs-levels-of-analysis/

All models are wrong some are useful

Models simplify the real phenomena into artificial but nonetheless useful entities/processes.

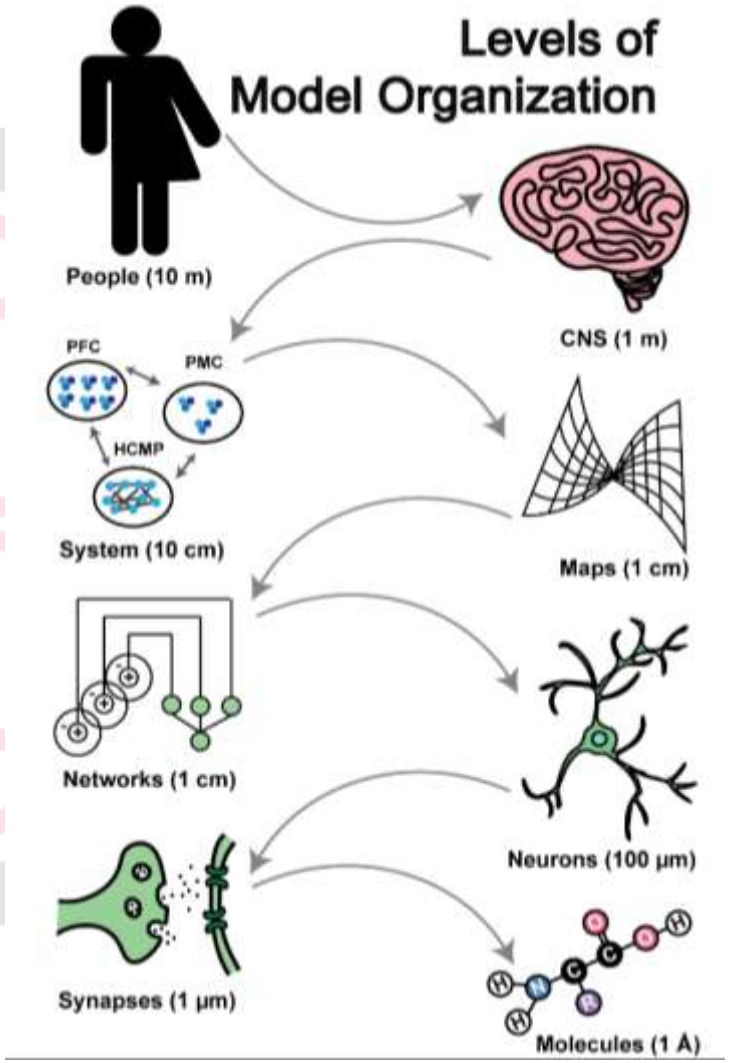




https://computersciencewiki.org/index.php/Abstraction

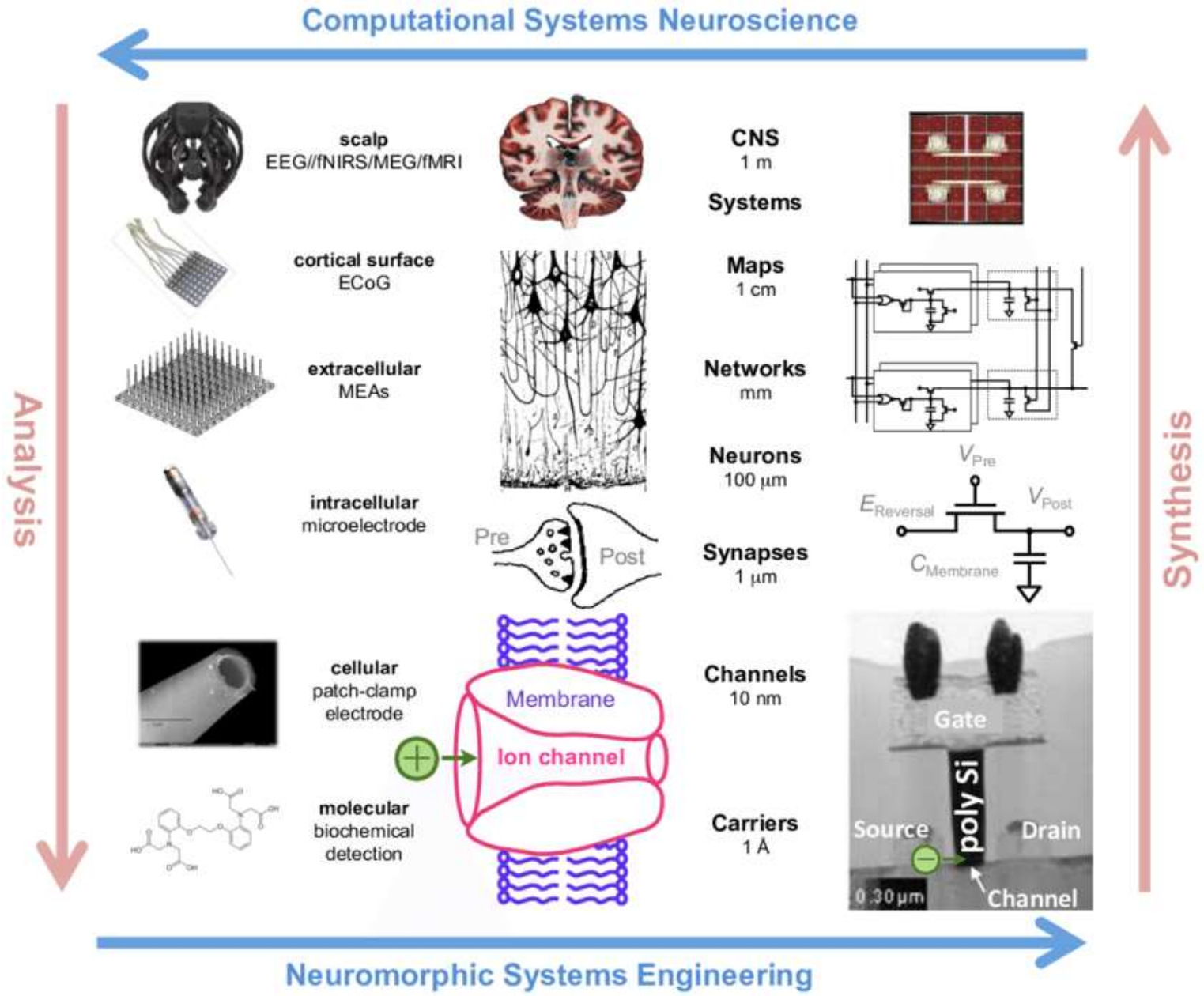
http://www.malinc.se/math/trigonometry/geocentrismen.php

Scales of Modelling



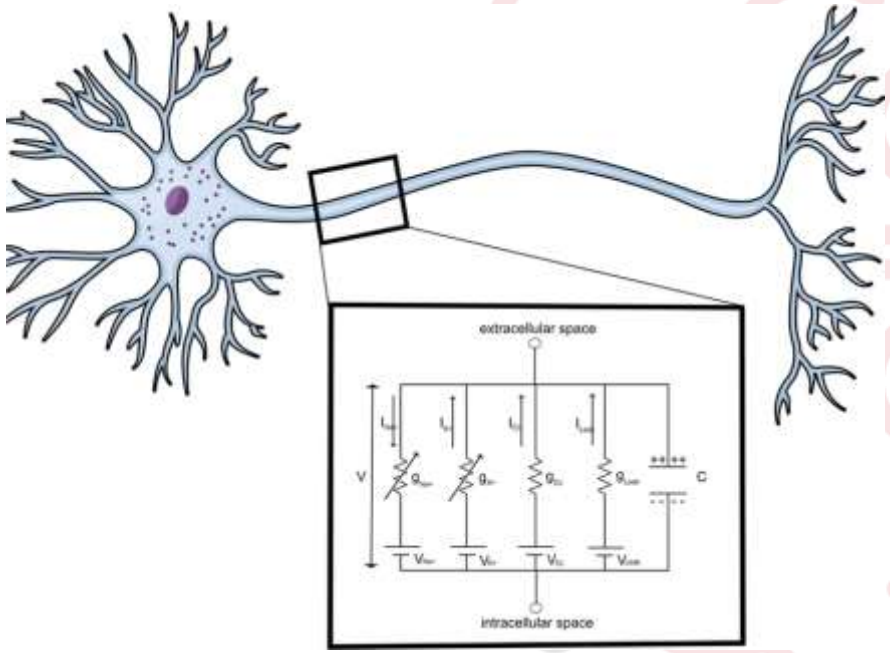
Walsh et. al 2021

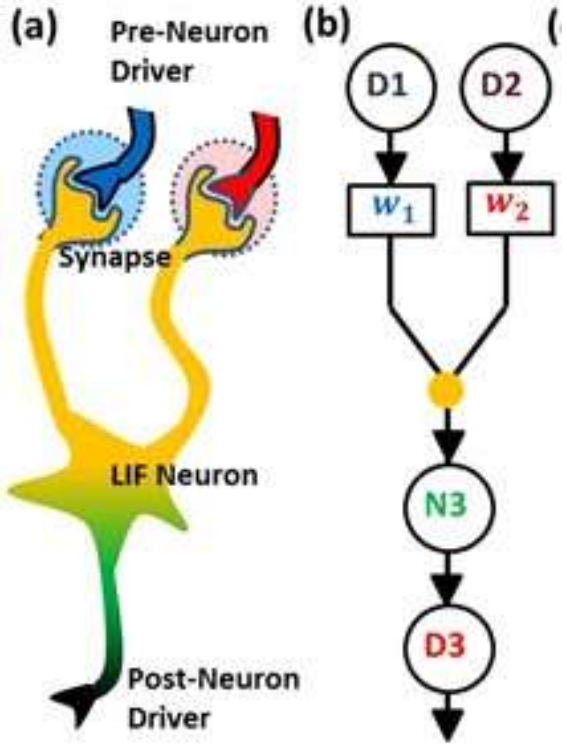
Modified from Trappenberg (2009), Fundamentals of Computational Neuroscience… Sourced from Neuromatch Academy



Broccard et al. 2017

Membrane and Neuron Level

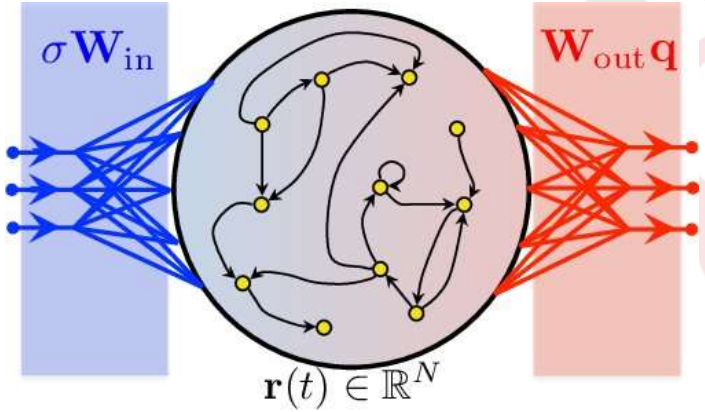




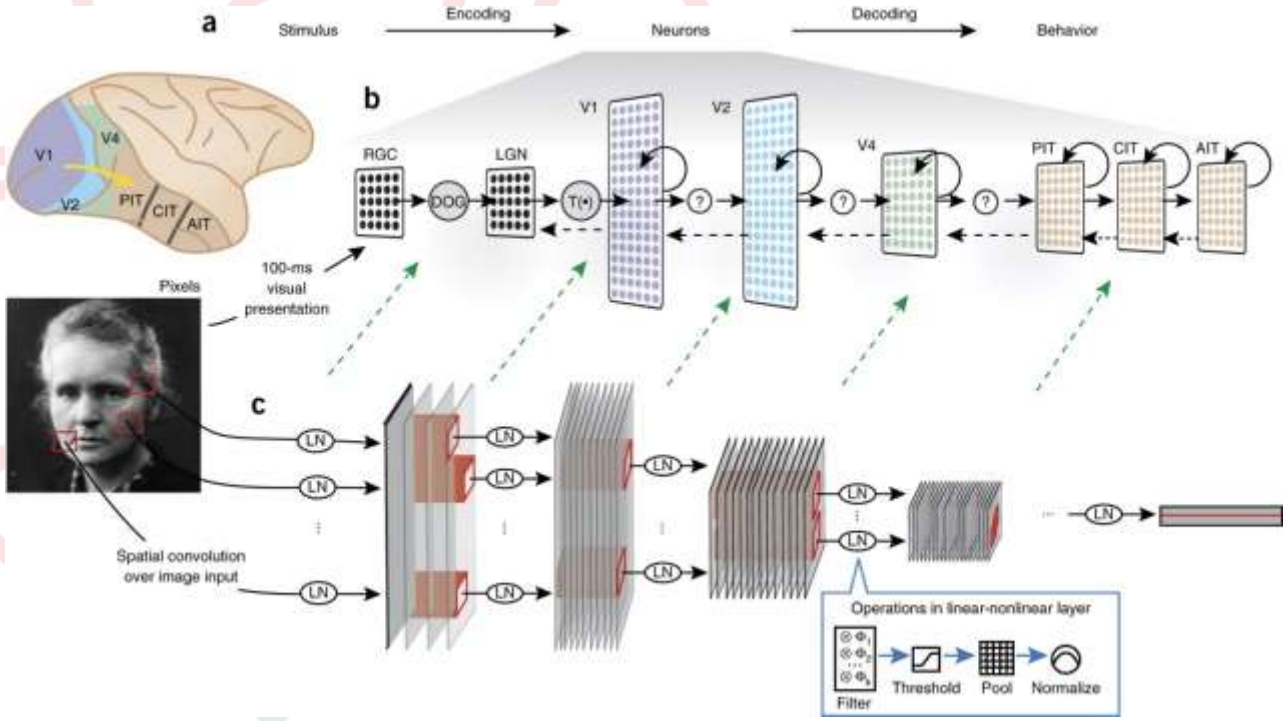
Isaković et al. 2018

Dutta et al. 2017

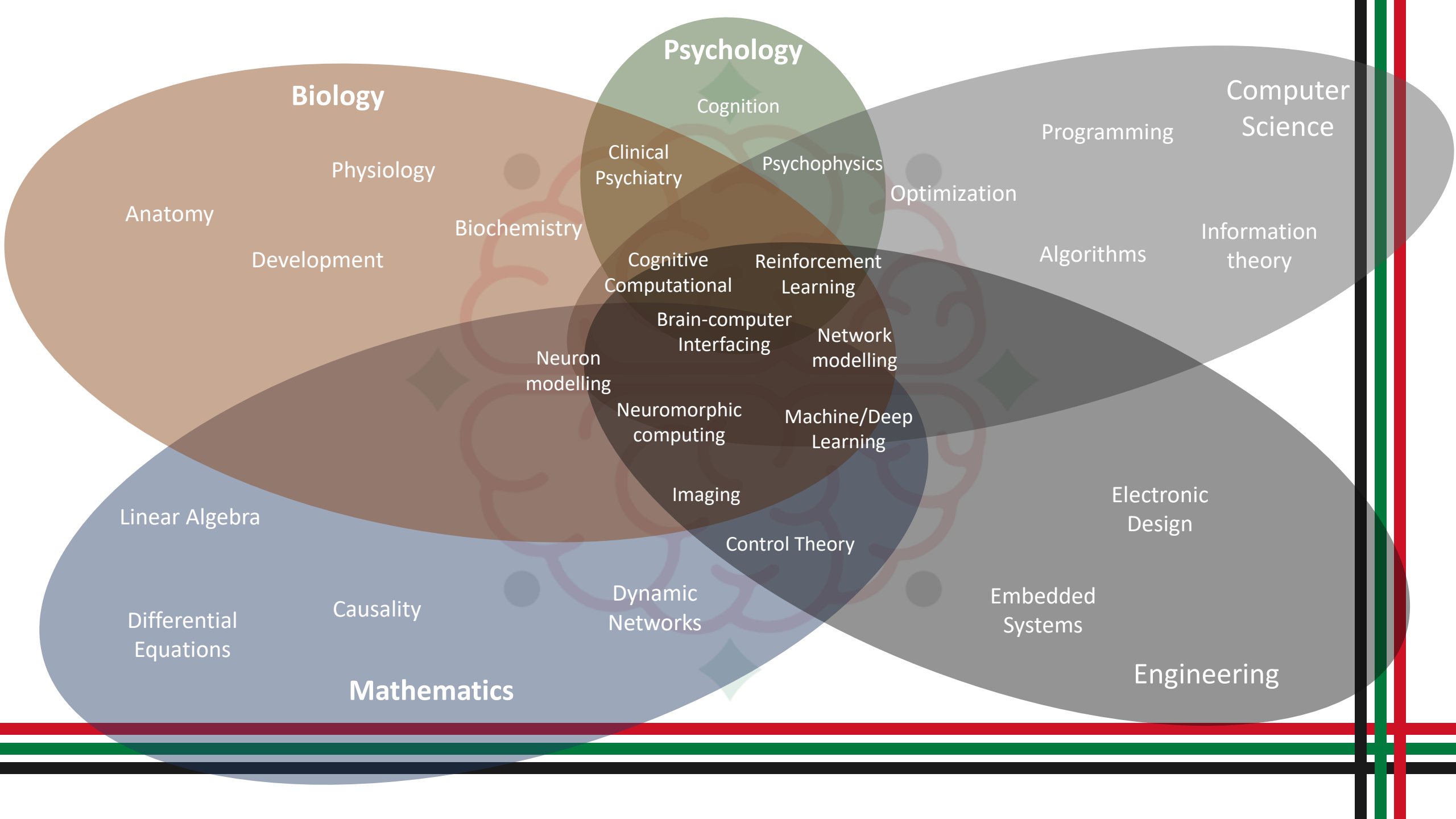
Network and System Level



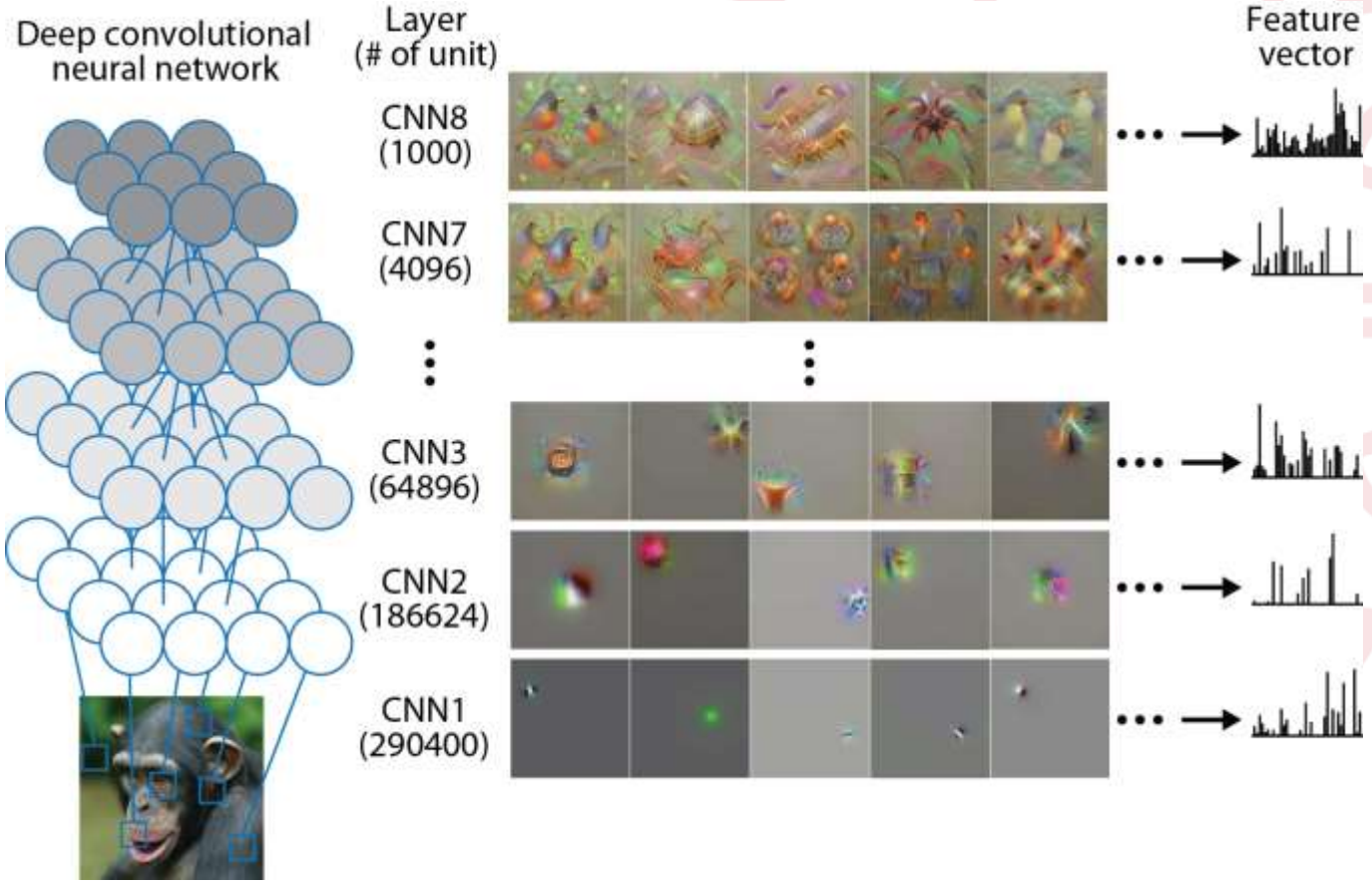
Lu et al. [2018]



Yamins and DiCarlo [2016]


Psychology
Biology
Computer Science
Cognition
Programming
Clinical Psychiatry
Psychophysics
Physiology
Optimization
Anatomy
Biochemistry
Information theory
Development
Algorithms
Cognitive Computational
Reinforcement Learning
Brain-computer Interfacing
Network modelling
Neuron modelling
Neuromorphic computing
Machine/Deep Learning
Imaging
Electronic Design
Linear Algebra
Control Theory
Dynamic Networks
Embedded Systems
Causality
Differential Equations
Engineering
Mathematics

Example: Deep Neural Networks are good models of vision



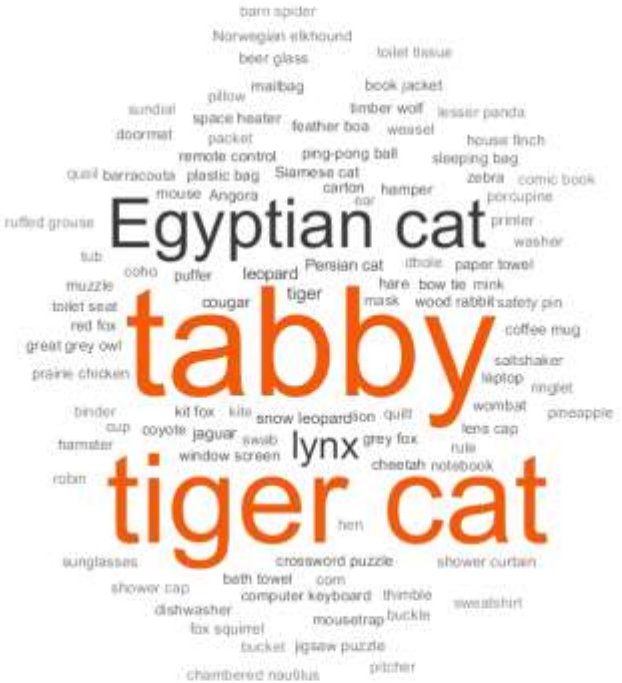
Horikawa and Kamitani, 2017

Papers about similarity between brain and DNN

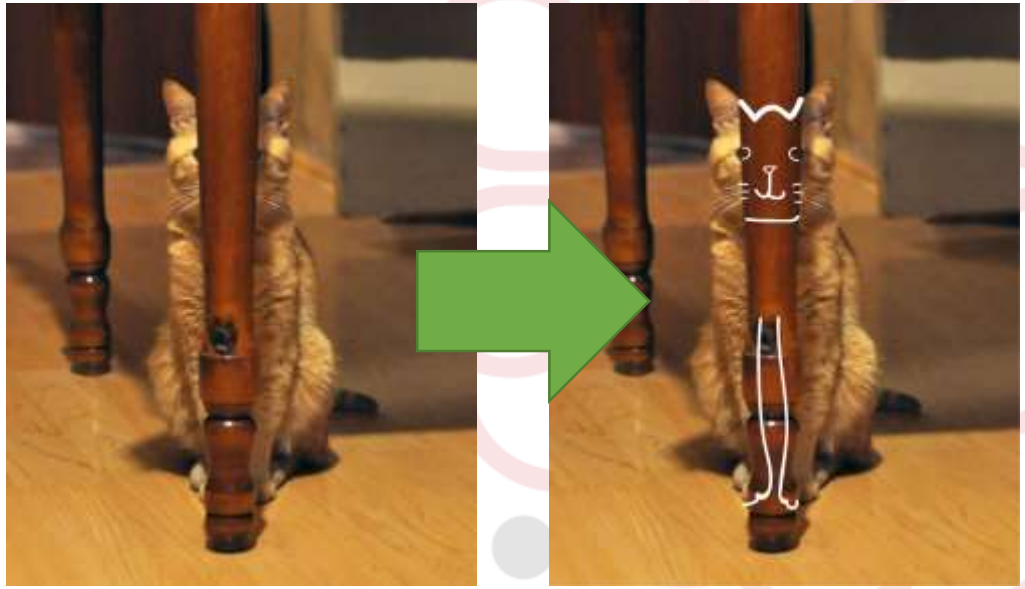
- Cadieu et al., 2014
- Khaligh-Razavi and Kriegeskorte, 2014
- Yamins et al., 2014
- Güçlü and van Gerven, 2015

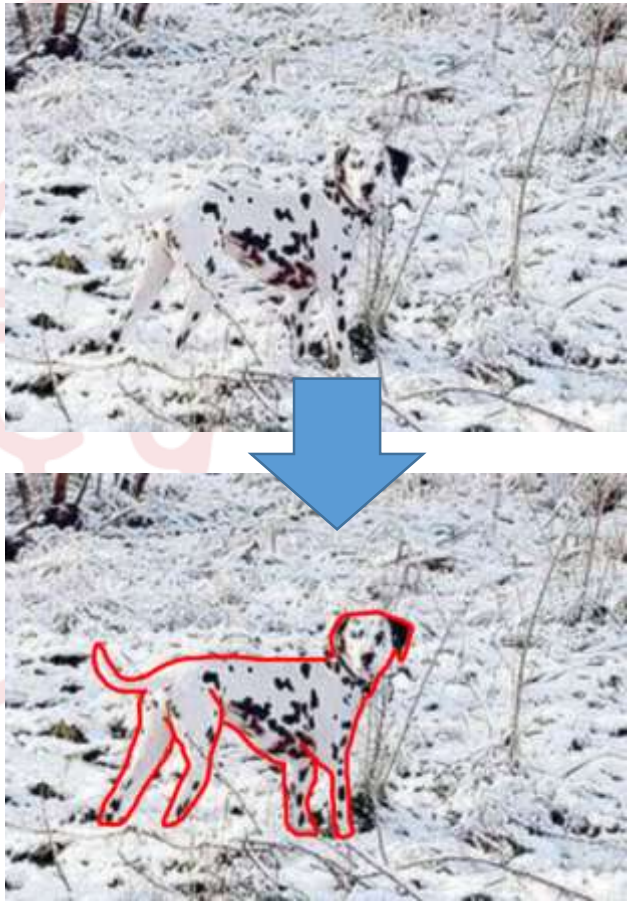
Brain Score screenshot

But they fail when images are blurred



Human vision robustness

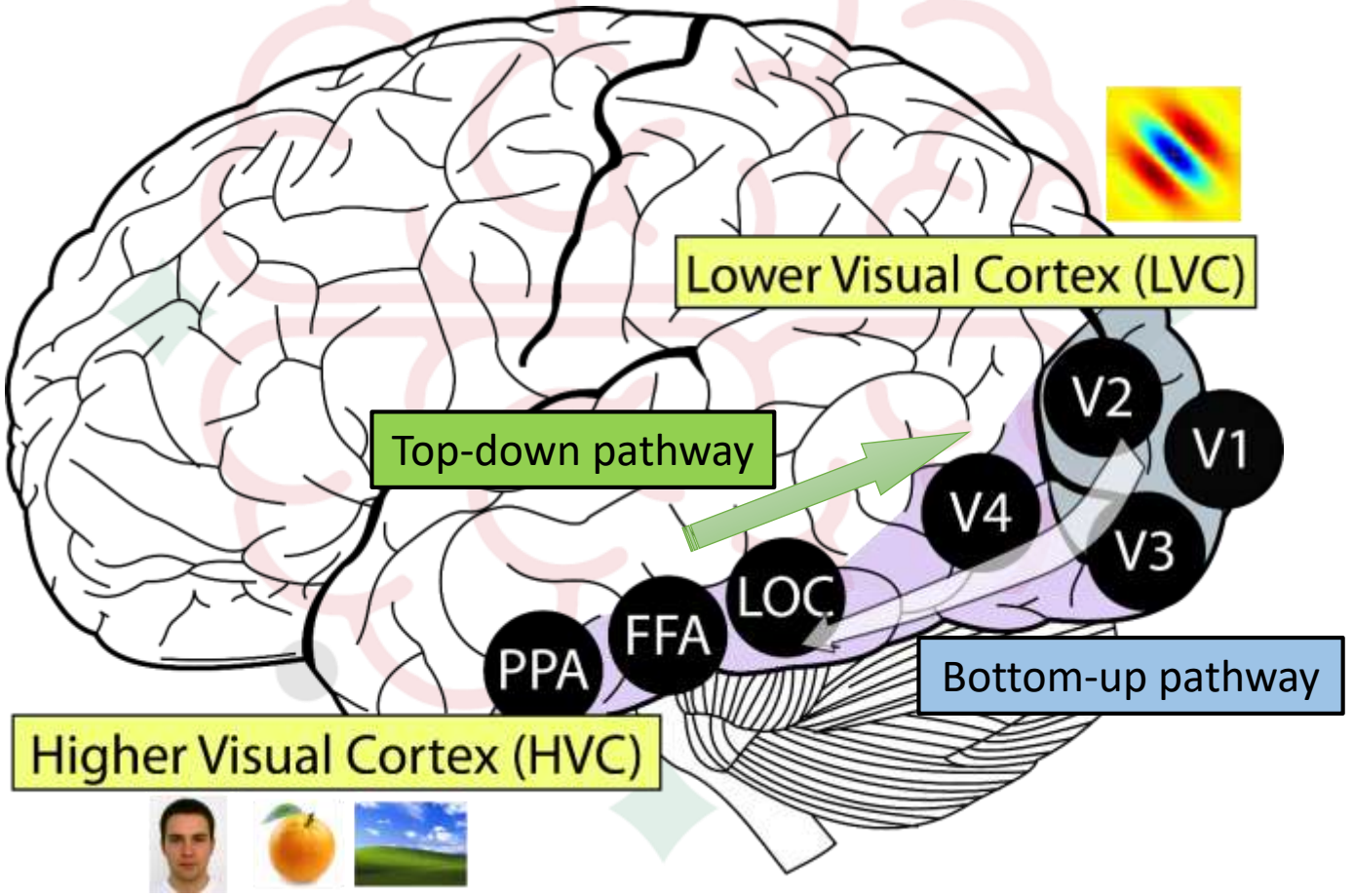


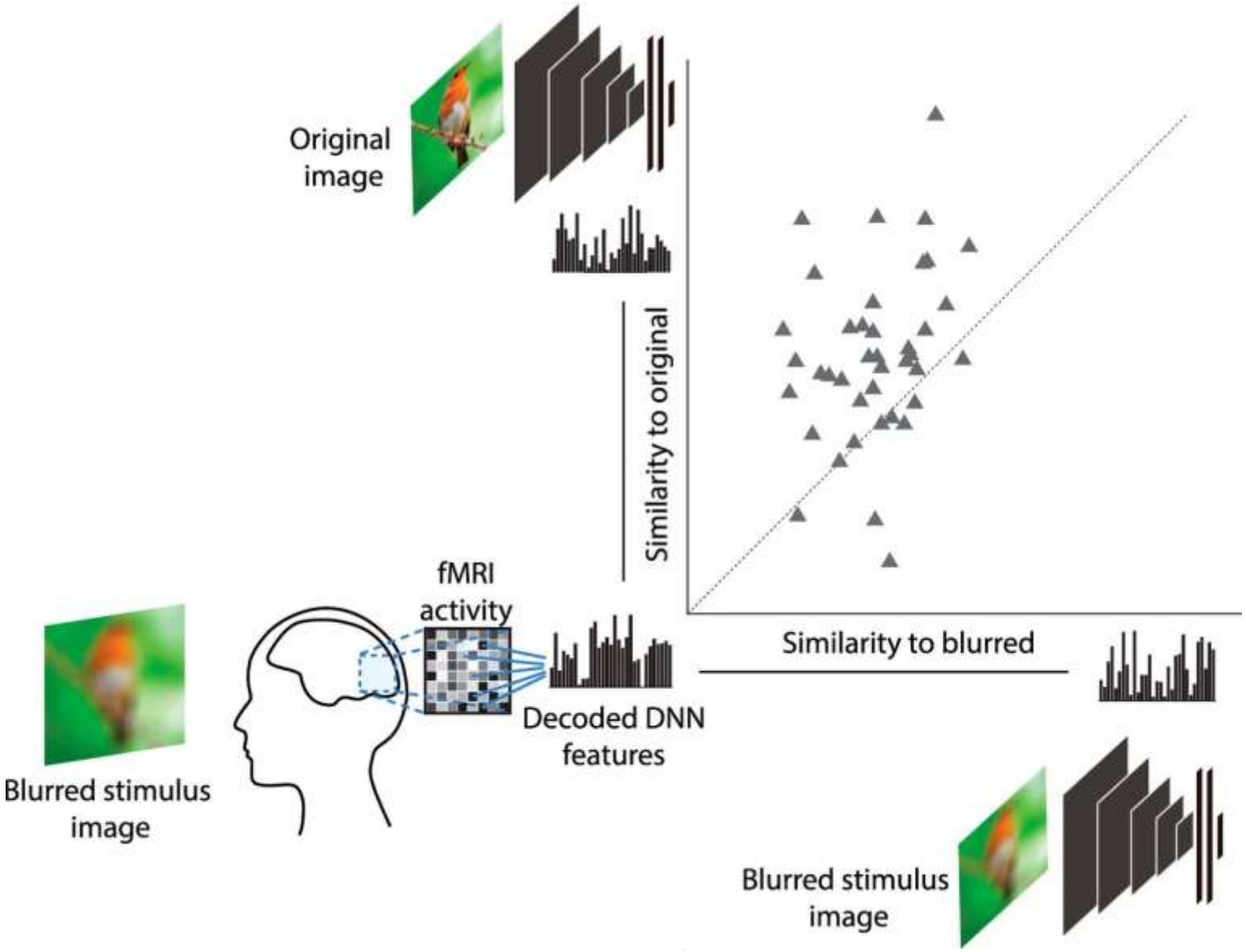


https://www.pinterest.ca/pin/505458758183864903/

https://joemonster.org/mg/show/113765

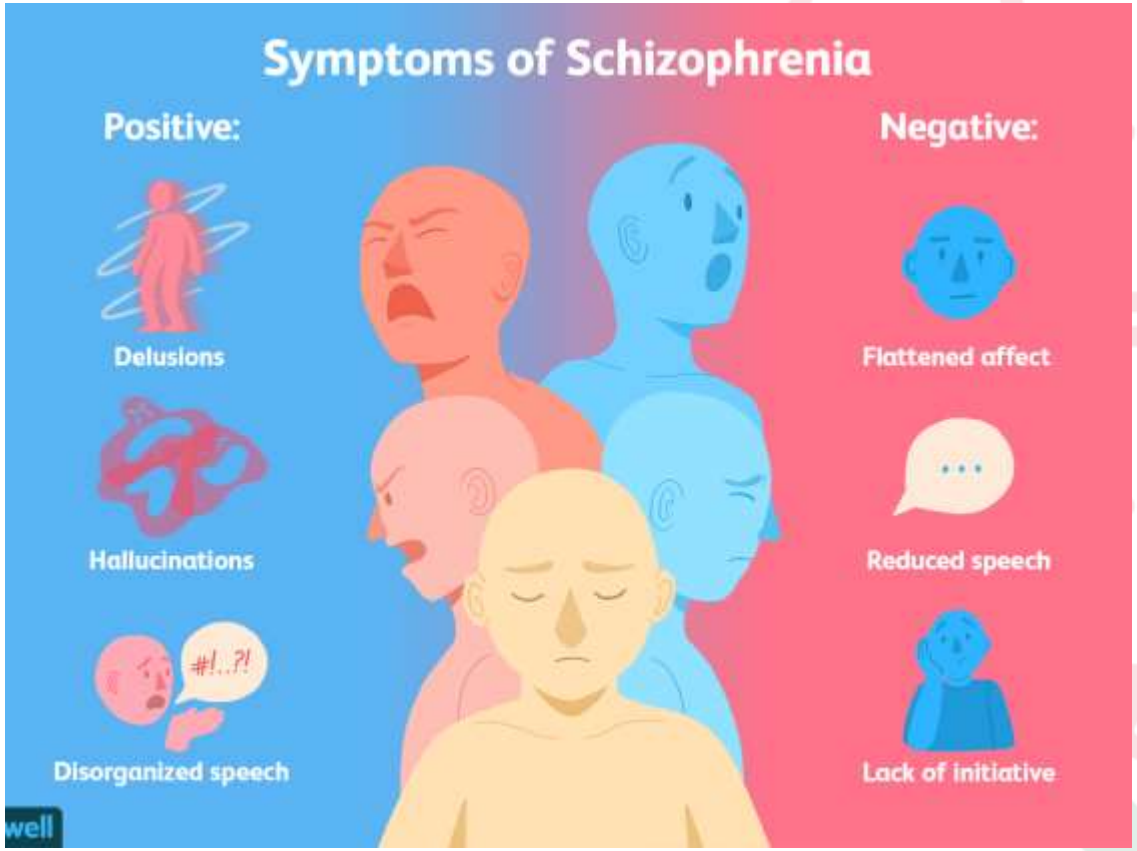
What do we already know?

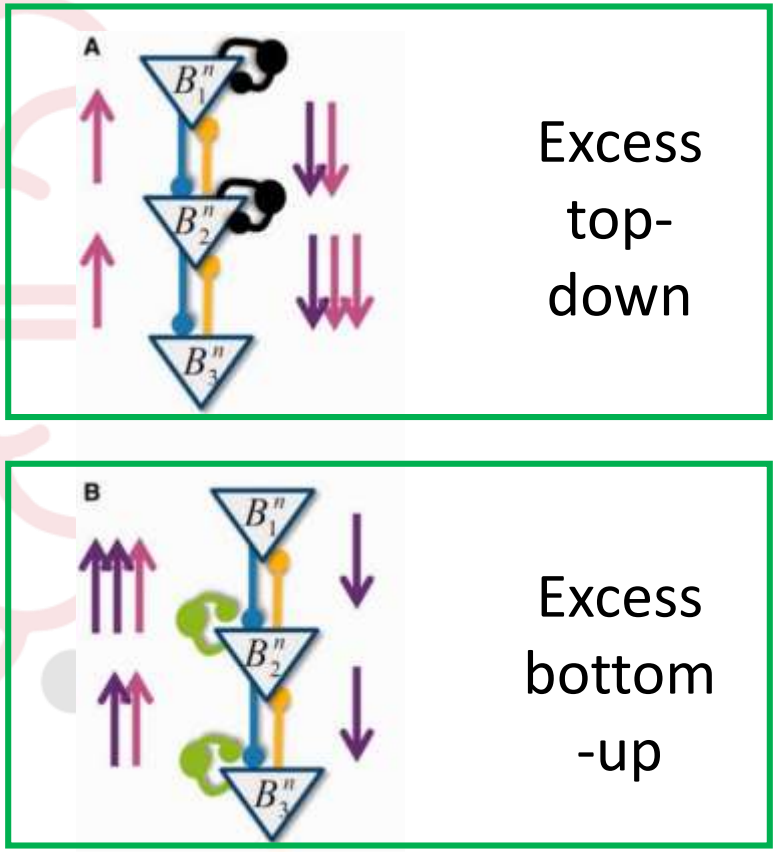




Abdelhack and Kamitani (2018), *eNeuro*

Application in mental health





https://www.verywellmind.com/what-are-the-symptoms-of-schizophrenia-2953120

Jardri and Denève, 2013

Career Prospects?

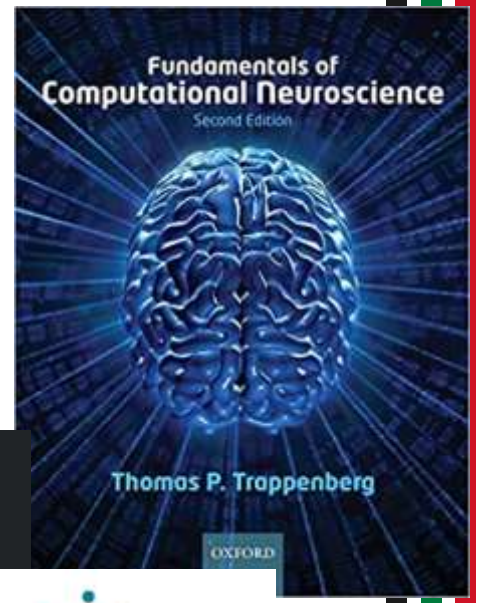
- Academic (most options)
- Industry
  - Brain Computer Interfacing
    - Non-invasive (Emotiv, Kernel, Next Mind… etc)
    - Invasive (Neuralink??)
    - Peripheral nervous system (Facebook Reality Labs)
  - Brain-inspired AI development (DeepMind)
  - Medical AI (Mental health and Neurology)

How to dive into comp neuro?

Background

- Calculus: differential equations, integration
- Statistics: Probability distribution, Bayes law, hypothesis testing
- Programming: Python (preferred), MATLAB (if you already know it)
- Linear Algebra: Matrix operations, Eigen decomposition
- Neuroscience: Basic understanding of brain anatomy and function
- Machine Learning: Regression, Deep Learning (optional)

How to dive into comp neuro?



- Book: Fundamentals of Computational Neuroscience – Trappenberg
- Online courses: Neuromatch Academy (academy.neuromatch.io) APPLICATIONS NOW OPEN!
- Data to work on:
  - https://openneuro.org/
  - http://brainliner.jp/
  - http://neuromorpho.org/

Example code: Just check a paper you are interested in, they usually release the code on Github

Conference: Neuromatch Conference (ONLINE), COSYNE, MAIN

Hackathons

- https://brainhack.org/
- https://www.br41n.io/

Arabs in Neuroscience Initiative

We started this initiative in 2020 as a networking group.

We went public only a month ago:

- Twitter @ArabsInNeuro
- Instagram @arabsineuro

We are offering and Intro into Computational Neuroscience online course

Intro into Computational Neuroscience Course

Crash course teaching preliminary knowledge necessary for entering the field of computational neuroscience with hands-on exercises (June 13-24)

Instructors:

- Samar ElSheikh (Krembil Centre for Neuroinformatics)
- Rawan Elsubaie (Sainsbury Wellcome Centre)
- Moataz Assem (University of Cambridge)
- Ramzi Halabi (Krembil Centre for Neuroinformatics)
- Yahia Ali (Georgia Tech)
- Mohamed Abdelhack (Krembil Centre for Neuroinformatics)

Contact

Find me on

Twitter: @mabdelhack

LinkedIn: https://www.linkedin.com/in/mabdelhack/

Website: https://mabdelhack.github.io/

Or you can follow Arabs in Neuroscience

Acknowledgements

- Arabs in Neuroscience team
- Neuromatch Academy team (many of the slides here contain information from their materials)
- Egypt Scholars Dar Team
- Developers of online meeting and seminars software :D