POLITECNICO DI MILANO

Neuroengineering (10 ECTS)
class introduction: 2021-2022

Prof. Pietro Cerveri
pietro.cerveri@polimi.it

Neuroengineering part I

Prof. Alessandra Pedrocchi
alessandra.pedrocchi@polimi.it

Neuroengineering part II

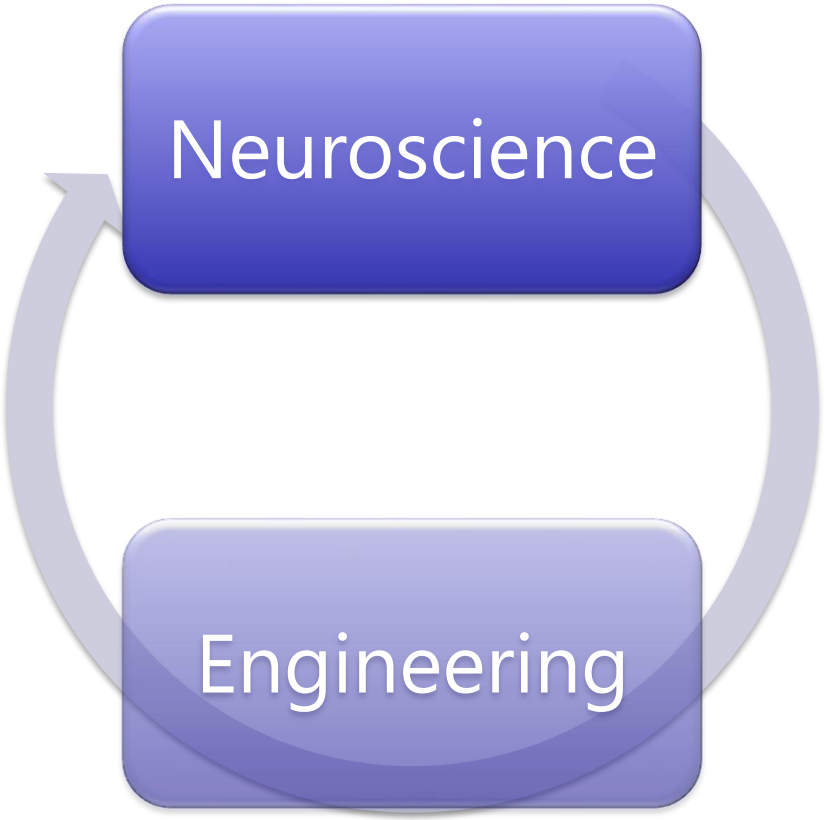
What is NeuroEngineering?

Research at the interface between neuroscience and information technology

This includes, but is not limited to, research in neuroscience, cognitive science, computer science, electronic engineering and psychology covering the areas of:

- Knowledge modeling and reasoning
- Machine learning
- Motor control modelling
- Neuro- and biomimetics robotics
- Life-like perception systems
- Neural interfaces
- Neuroprostheses
- Neurons on silicon
- Neuroimage

Neuroengineering



Models and technologies to understand and interface the CNS

- Reasoning, perception and motion planning and control
- Meth's and tech's for neurology/neuro-rehabilitation
- Meth's and tech's for neurobiology

Studying the brain functions using basic sciences (physics, chemistry, mathematics,…)

Why do neurosciences interest a bioengineer?

SNC

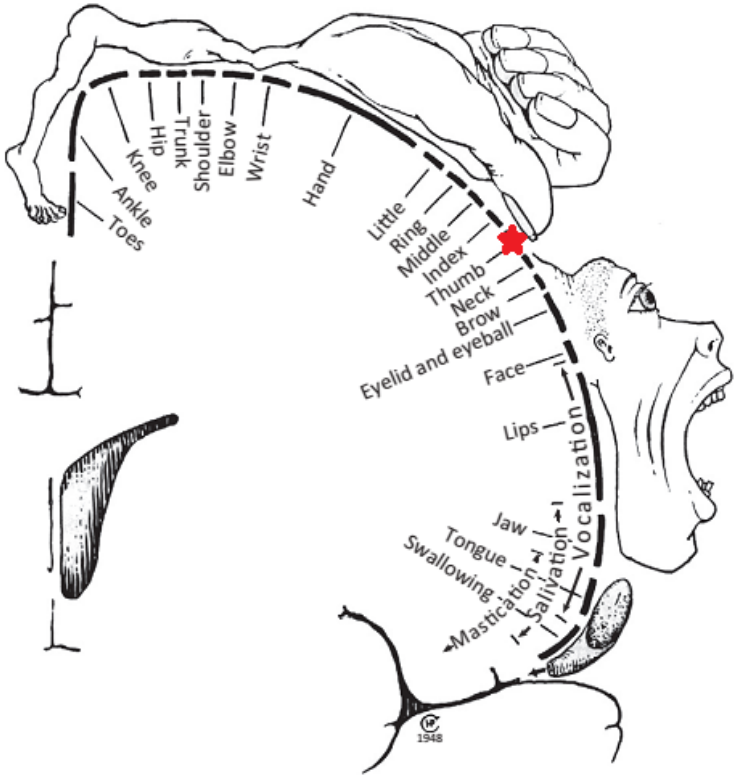
- Learns, adapts, generalizes and predicts

MODELLING MOTOR CONTROL

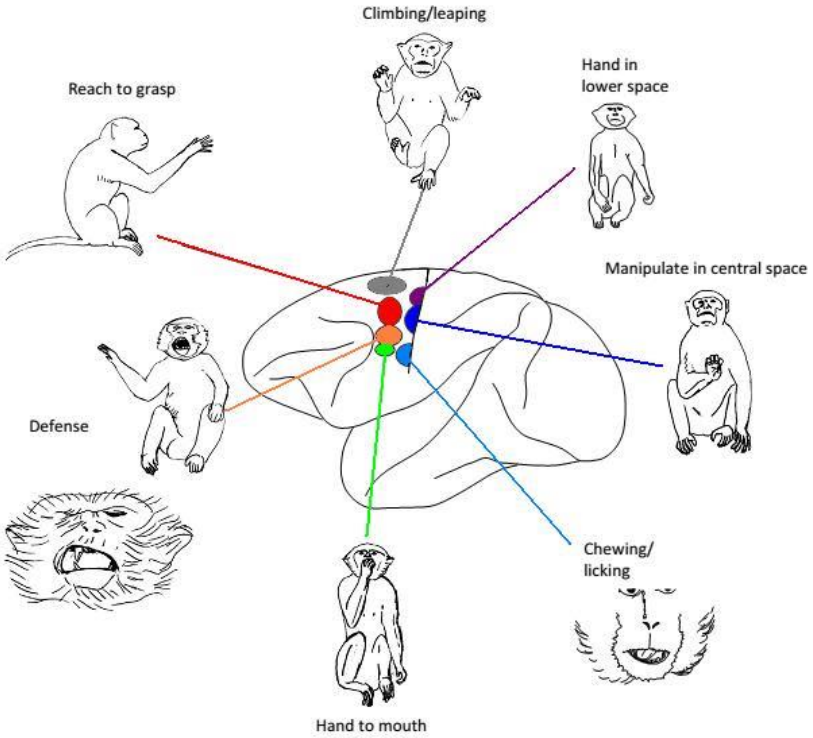
and

COMPUTATIONAL NEUROSCIENCE

Beyond connectionism to connectivity and plasticity



Trends in Cognitive Sciences



Trends in Cognitive Sciences

What we need in our brain to work?

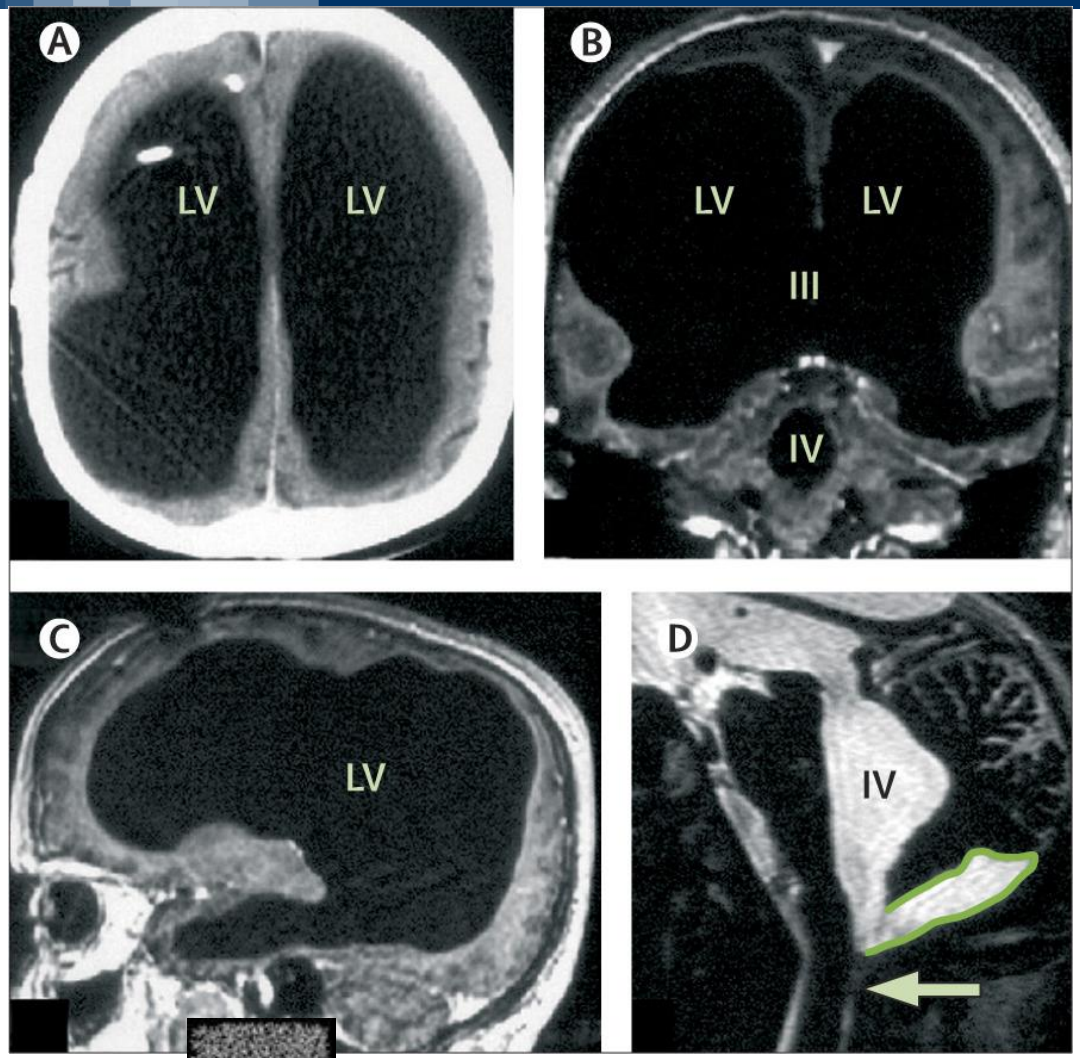


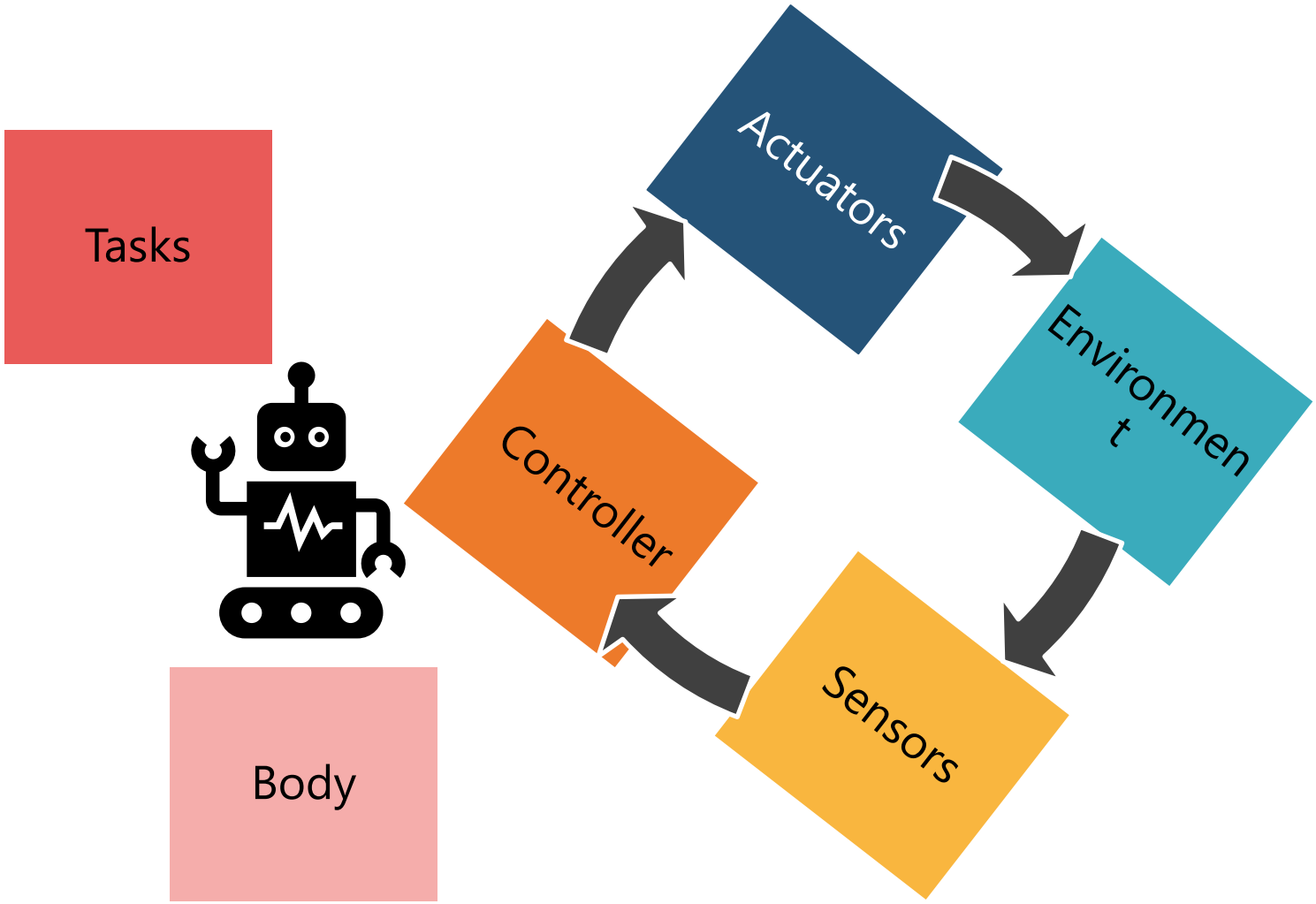
Figure
Massive ventricular enlargement, in a patient with normal social functioning

(A) CT; (B, C) T1-weighted MRI, with gadolinium contrast; (D) T2-weighted MRI. LV=lateral ventricle. III=third ventricle. IV=fourth ventricle. Arrow=Magendie's foramen. The posterior fossa cyst is outlined in (D).

Brain of a white-collar worker
Dr Lionel Feuillet, MD, Henry Dufour, PhD, Jean Pelletier, PhD
The Lancet Volume 370, Issue 9583, (July 2007) DOI: 10.1016/S0140-6736(07)61127-1

ELSEVIER

Why do neurosciences interest a bioengineer?



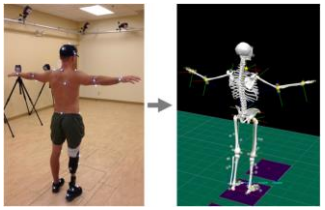
CONTROLLER

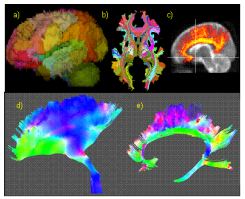
MIMICKS BRAIN CRICUITS

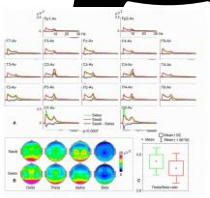
TASKS

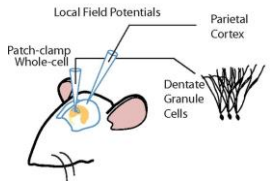
MIMICK THE HUMAN ONE

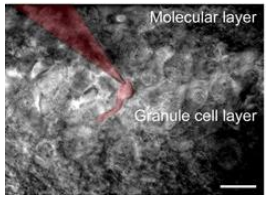
A MULTI SCALE PROBLEM





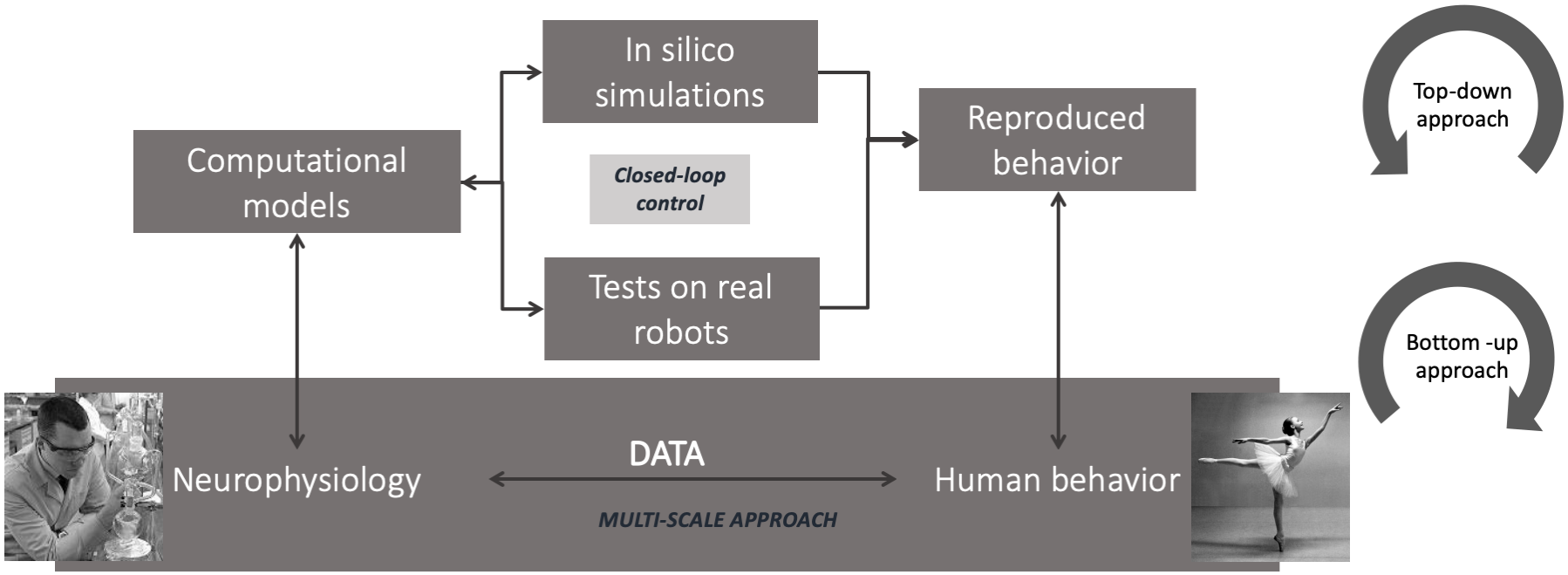




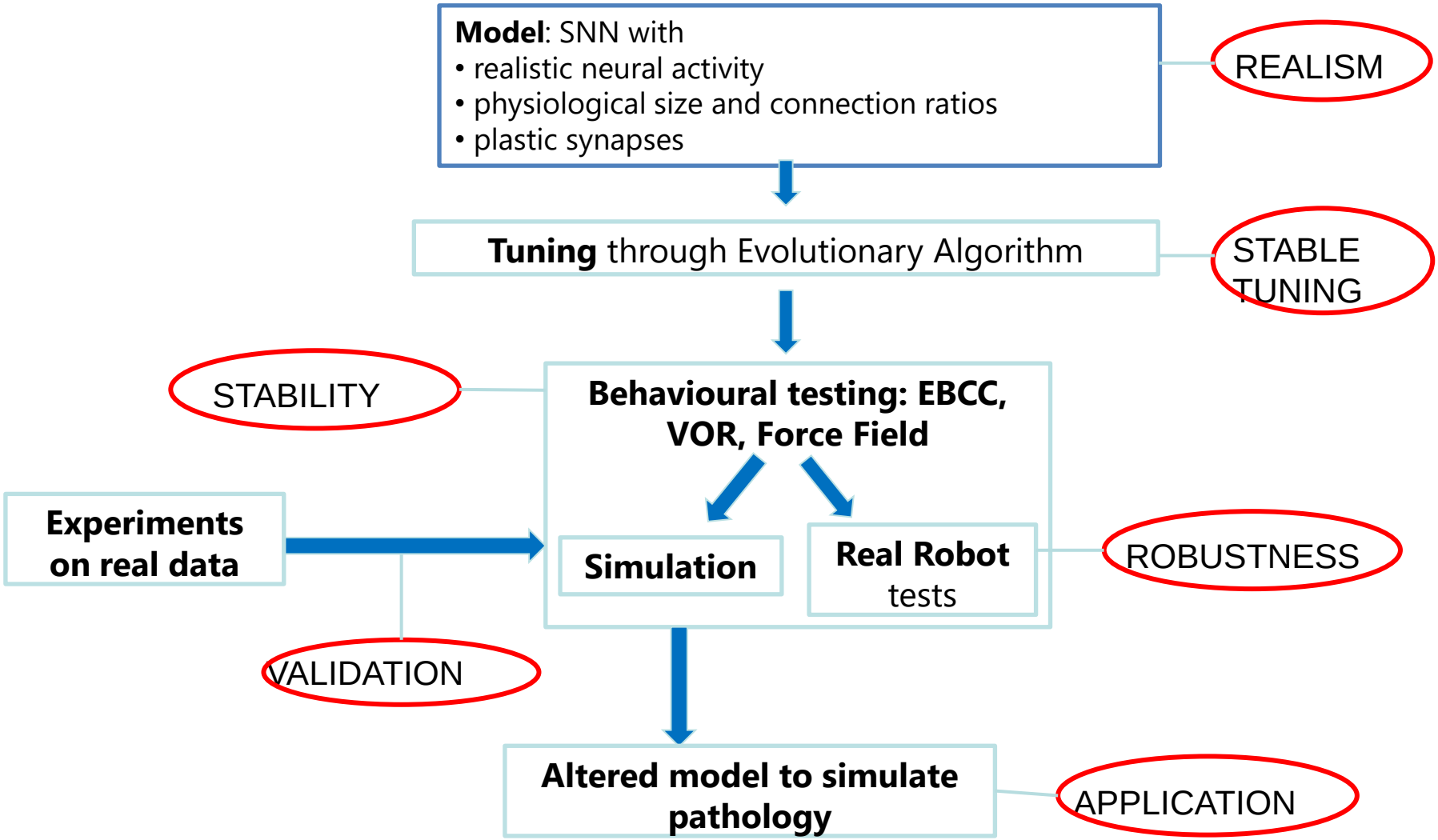


Approaches to neurorobotics design

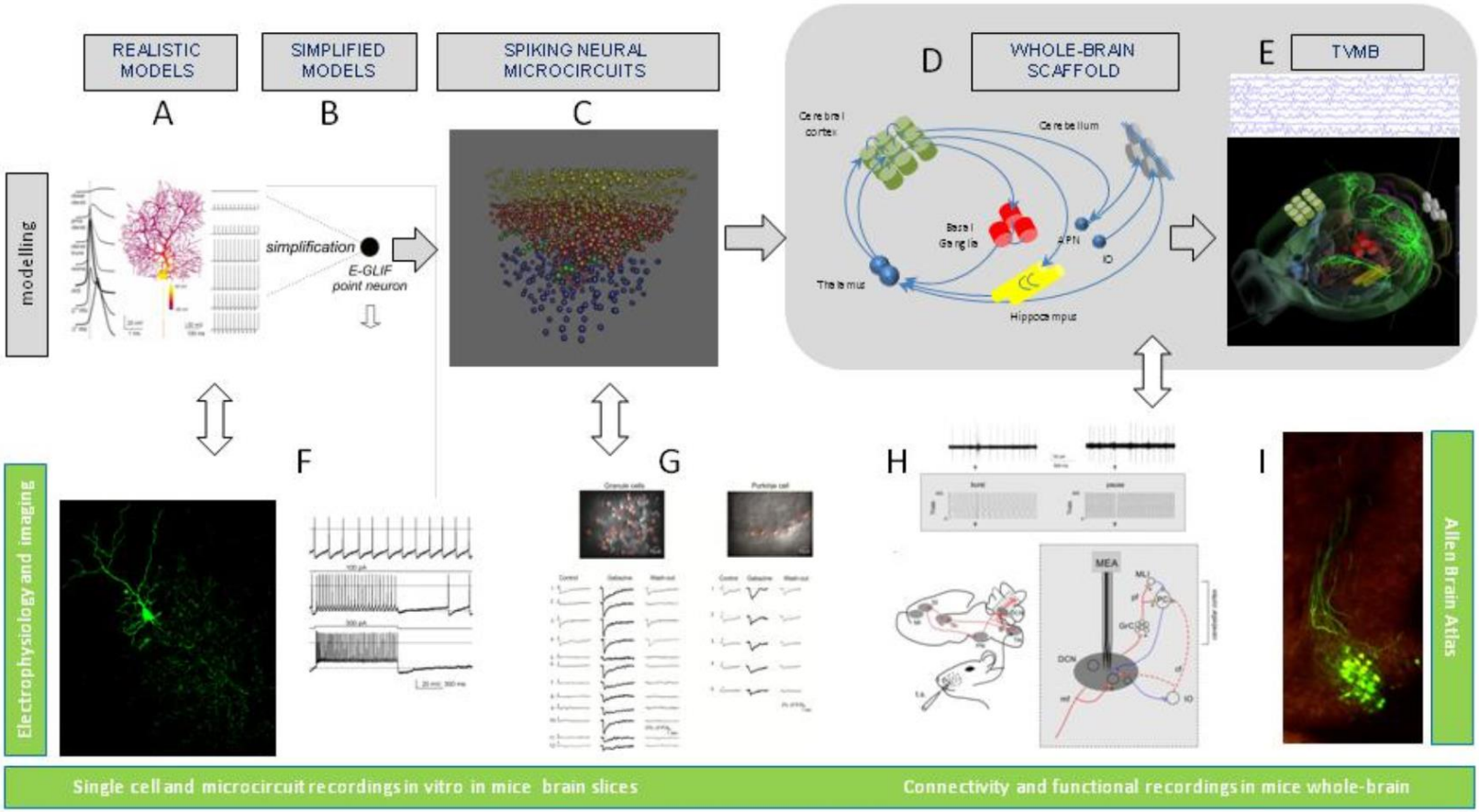
D'Angelo et al. Funct. Neurol 2013
D'Angelo et al. Front. Cell. Neuroscience, 2016



Brain computational modelling



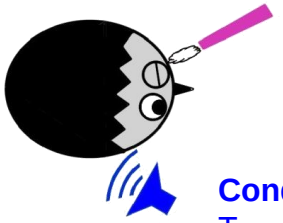
The goal



Courtesy Egidio D'Angelo

One example

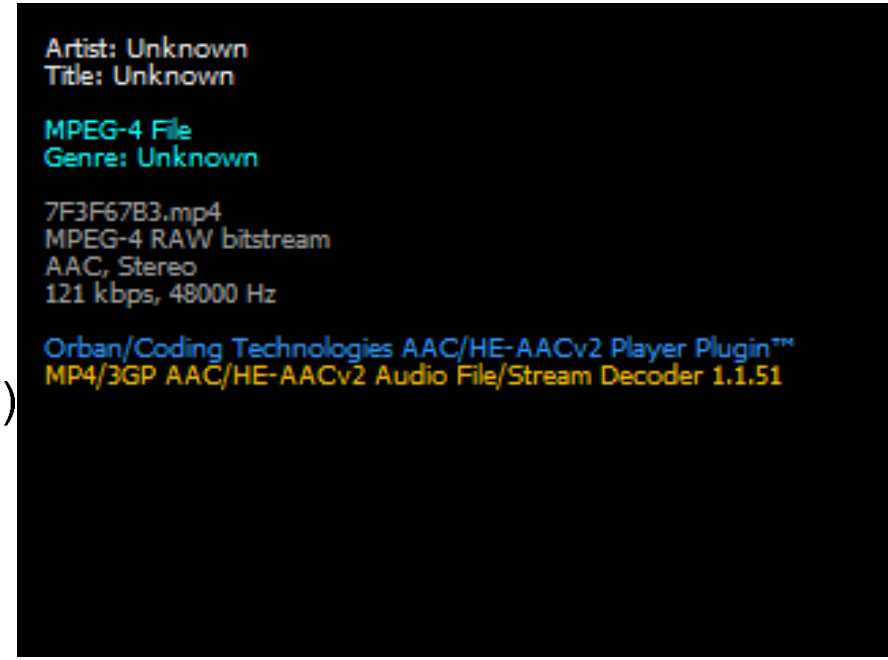
EBCC
(EyeBlink Classical Conditioning)



Unconditioned Stimulus
Airpuff → Start of CF activity

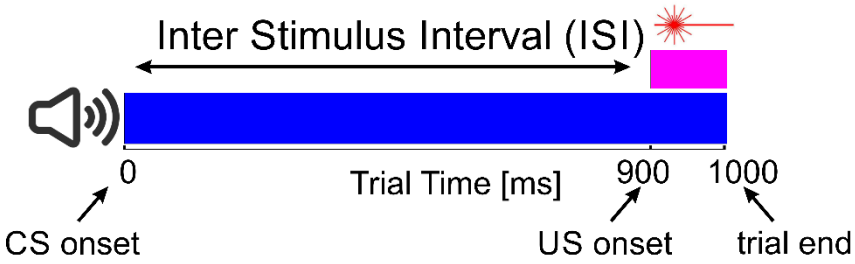
Conditioned Stimulus
Tone → Start of MF activity

Conditioned Response, anticipating US
Anticipated blink and reduced US sensation



During the Acquisition Phase (13 Trials)

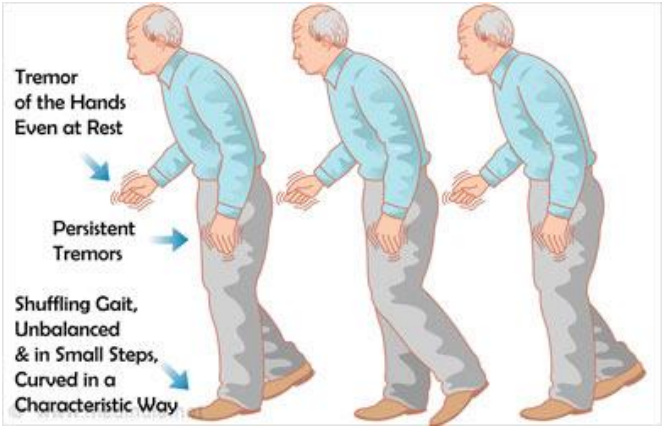
Conditioned Stimulus (CS) = Tone
Unconditioned Stimulus (US) = Laser Beam



NAO wants to protect himself from the US

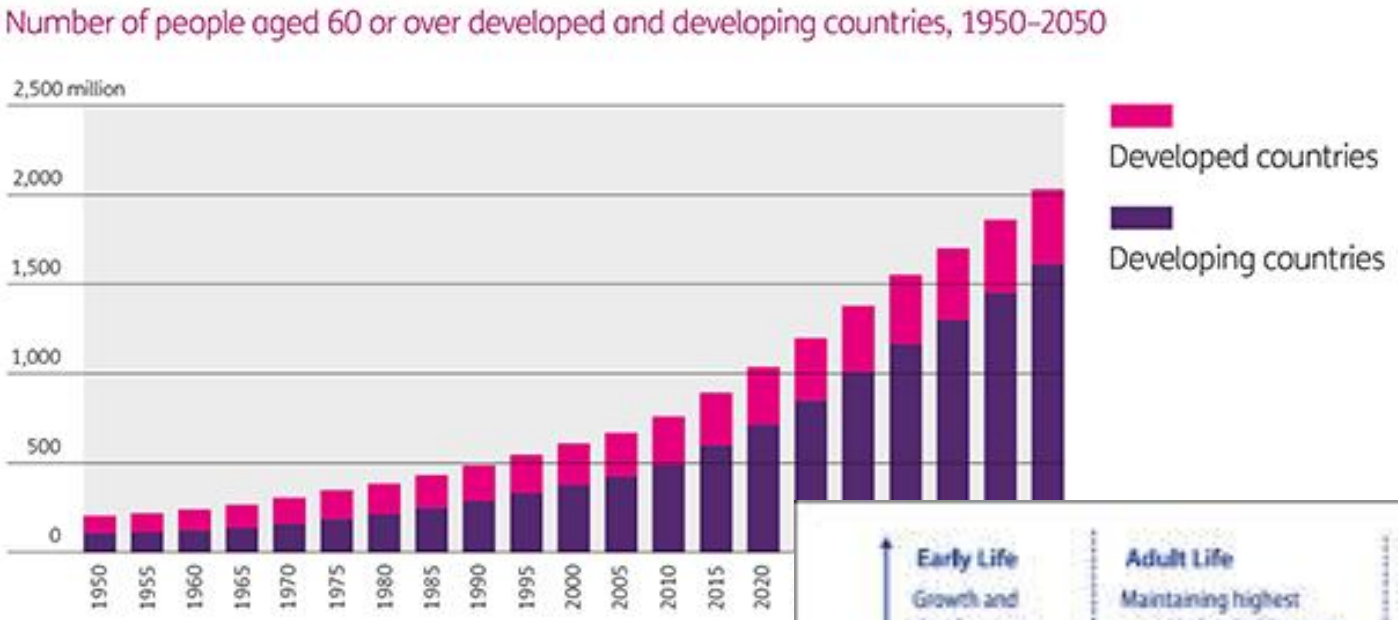
Neuromotor disorders and pathologies

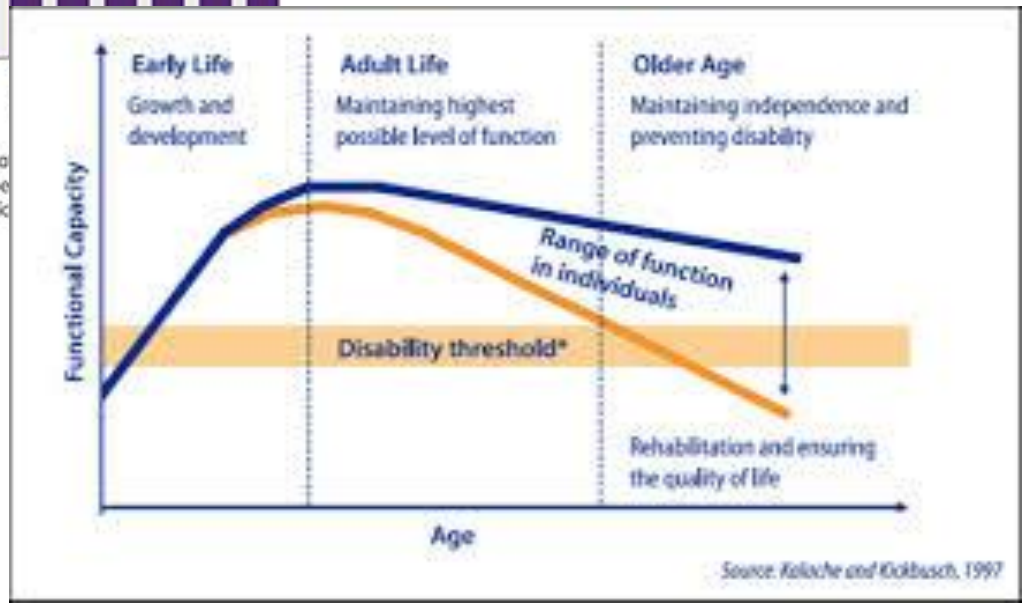
Dystonia
Multiple sclerosis
Cerebrovascular accidents (stroke, TBI)
Spine Injuries
Parkinson Disease
Muscular distrophy
Cerebellar patients…



Ageing… active ageing/chronicity

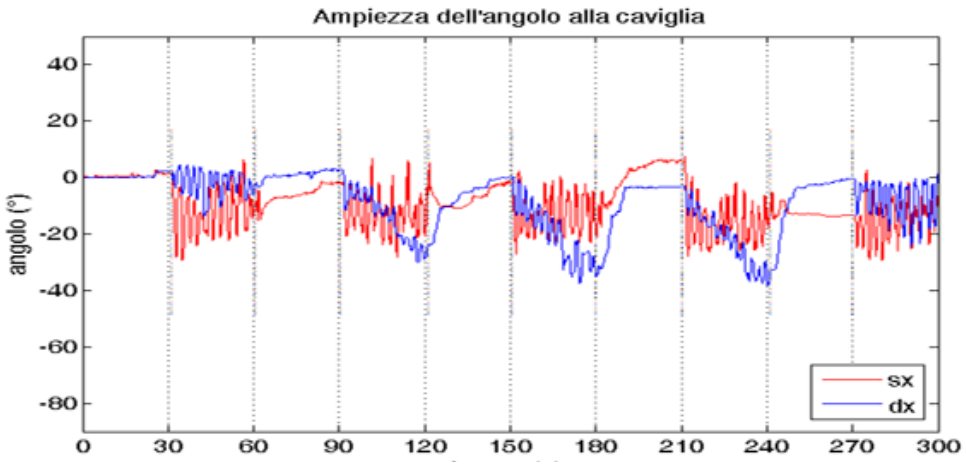
United Nations Department of Economic and Social Affairs

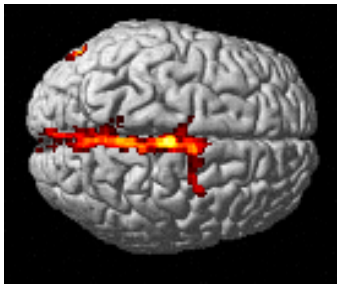




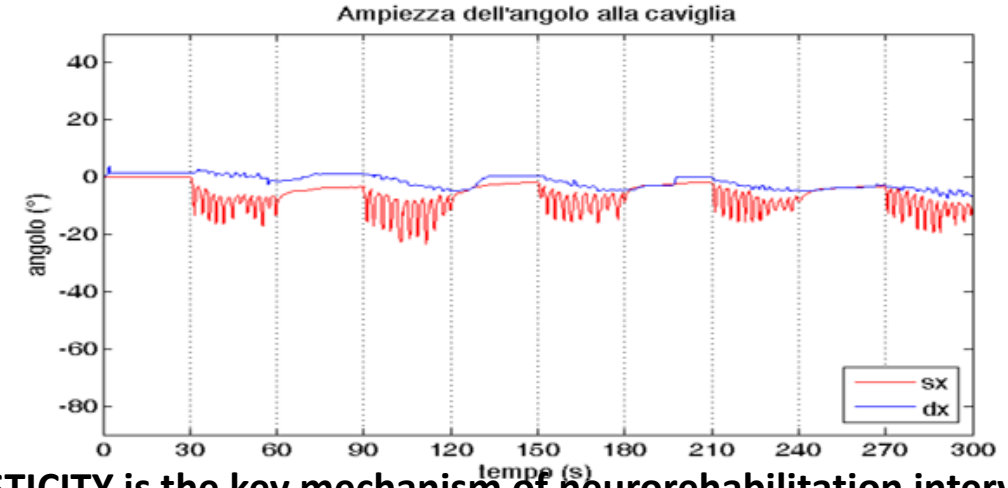
Goal 1: promote/drive neural plasticity

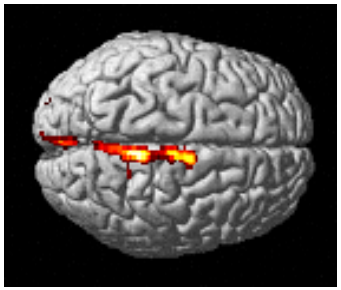
pre





post



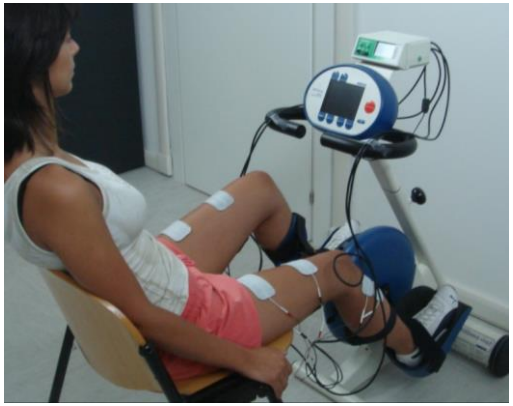


NEUROPLASTICITY is the key mechanism of neurorehabilitation intervention

Factors influencing neuroplasticity:

- repetitive motor tasks
- active (instead of passive) movements
- timing of sensori-motor stimulus presentation

What does(neuro)engineering mean for clinics?



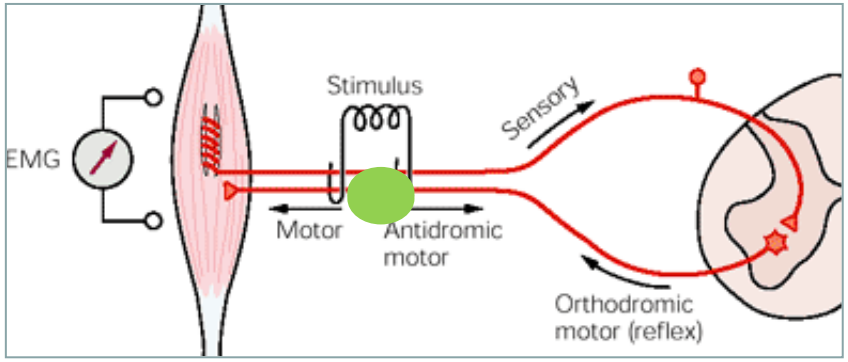
4 reasons to use robots in rehab

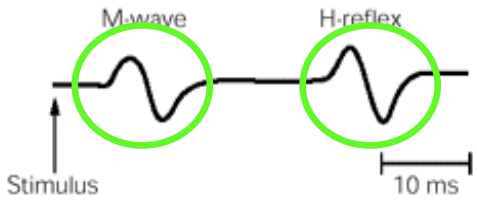
- Robotic device can be a vehicle to translate intensity into a rehabilitation program
- Robotic devices can be used to explore the effectiveness of the type of assistance
- Robots can be an objective evaluation tool affording insights into motor recovery process.
- Rehabilitation robot can act as a tool to alter experimental conditions

C Duret, A-G Grosmaire, HI Krebs, Robot-Assisted Therapy in Upper Extremity Hemiparesis: Overview of an Evidence-Based Approach, Frontiers in Neurology, 2019

Externally modulated proprioception -FES

Functional Electrical Stimulation (FES) is the electrical stimulation of a mixed nerve in order to produce a goal oriented (functional) movement.

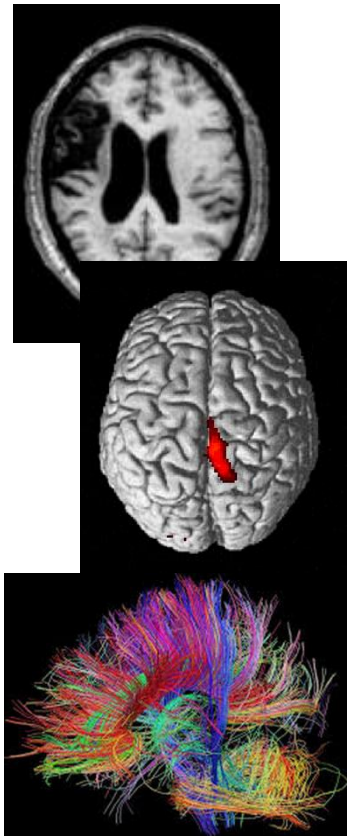




- extra information to be coded by the natural proprioceptive feedback
- extra proprioceptive feedback

- CARRYOVER ENIGMA!!! 45% gets carryover (Merletti et al., 1979)

Neuroengineering towards clinical translation



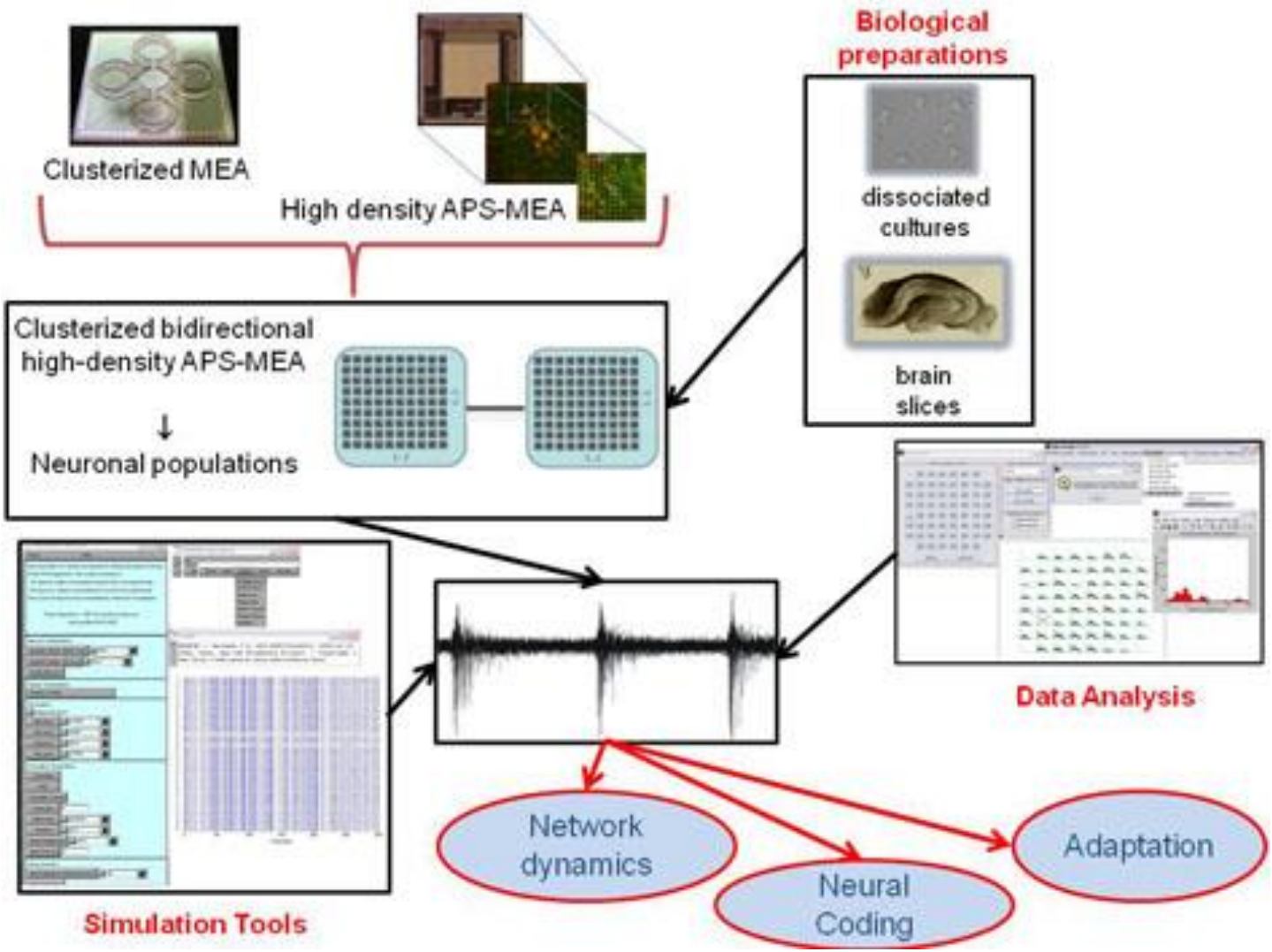
Subject-specific early prediction outcome → **Set of subject-specific therapy** → **Prediction of therapy effects**

Patient rehabilitation pathway

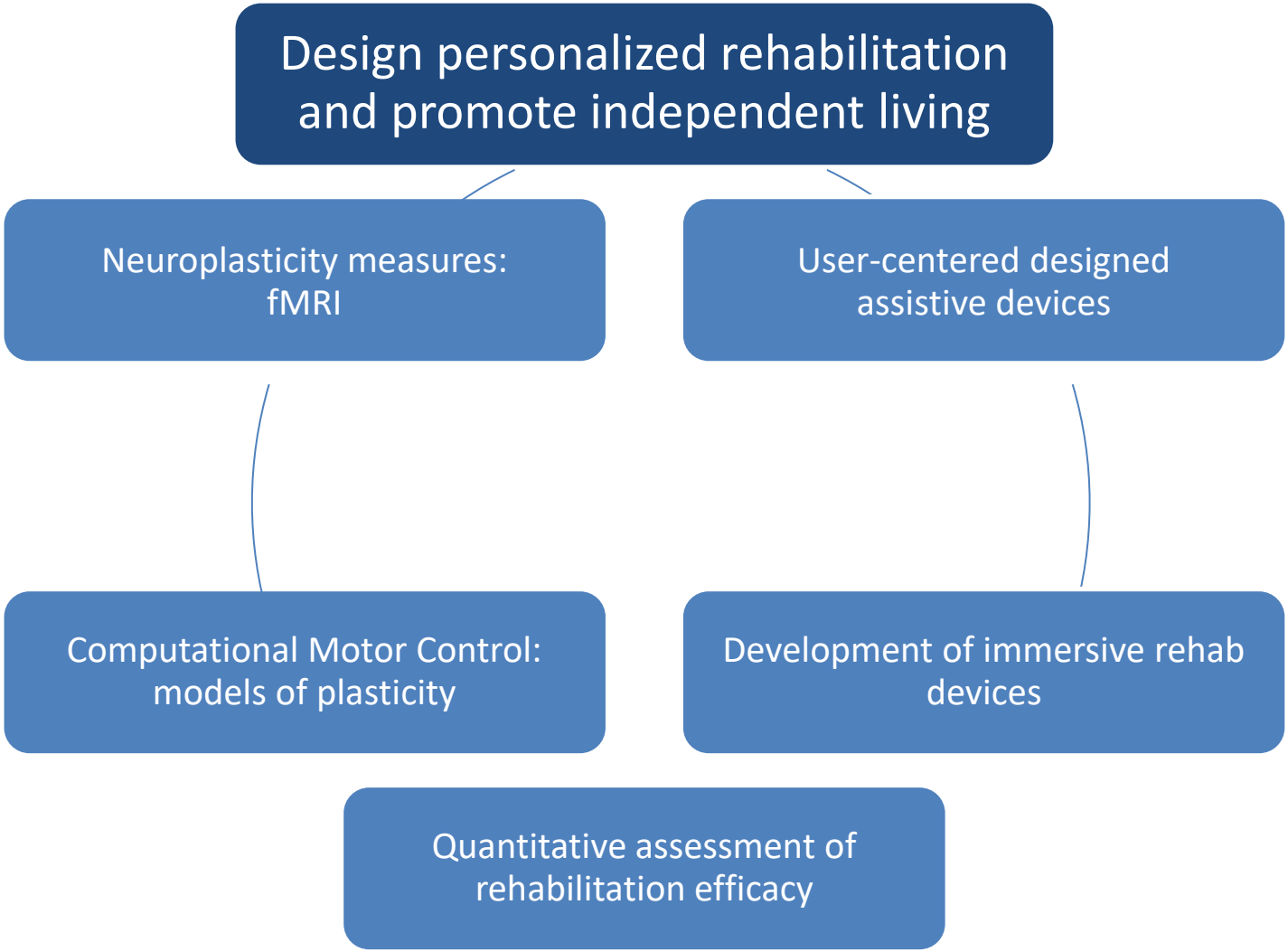
Prediction of plasticity modification

Goal 2: assistive robots to promote independent living

Neuroengineering in biological experiments



The loop


Design personalized rehabilitation and promote independent living
Neuroplasticity measures: fMRI
User-centered designed assistive devices
Computational Motor Control: models of plasticity
Development of immersive rehab devices
Quantitative assessment of rehabilitation efficacy

Journal club

13/09/21	W1	Course presentation	Artificial neural networks (ANN)	Perceptron, learning and delta rule	PRACTISE basic NN (group 2)
20/09/21	W2	PRACTISE basic NN (group 1)	Multi-layer ANN and backpropagation	Deep learning paradigm	PRACTISE FFNN (group 2)
27/09/21	W3	PRACTISE FFNN (group 1)	Convolutional neural networks (CNN)	Autoencoder NN	Master thesis presentation
04/10/21	W4	SEMINAR Python/TensorFlow (group 1)	GRADUATION	Encoding/Decoding networks	SEMINAR Python/TensorFlow (group 2)
[illegible]/21	W5	Generative Adversarial Net (non duplicated)	Concepts of explainable AI	Computational Neuroscience 1	PRACTISE EBRAINS platform (group2)
18/10/	W6	PRACTISE EBRAINS platform (group1)	Computational neuroscience2	Neurorobotics	Comp. neuroscience journal club (group2)
25/10/21	W7	Comp. neuroscience journal club (group 1)	Rehabilitation robotics 1	Rehabilitation Robotics 2	Rehab Robotics journal club (group2)
01/11/21	W8	NO CLASS	Neuroprosteses 1	Neuroprostheses 2	Rehab robotics journal club (group1)
08/11/21	W9	NO CLASS	NO CLASS	in vitro neuroengineering 1 flipped + 2	interdisciplinary seminars (non duplicated)
15/11/21	W10				
22/11/21	W11				
29/11/21	W12				
06/12/21	W13				
13/12/21	W14		Project workshops		
20/12/21	W15	Public presentation of finalist projects			

- Week assignment of a paper along with questions for guiding the discussion
- group 1 and group 2 in presence discussion with the professor (remote participation is possible but not recommended)