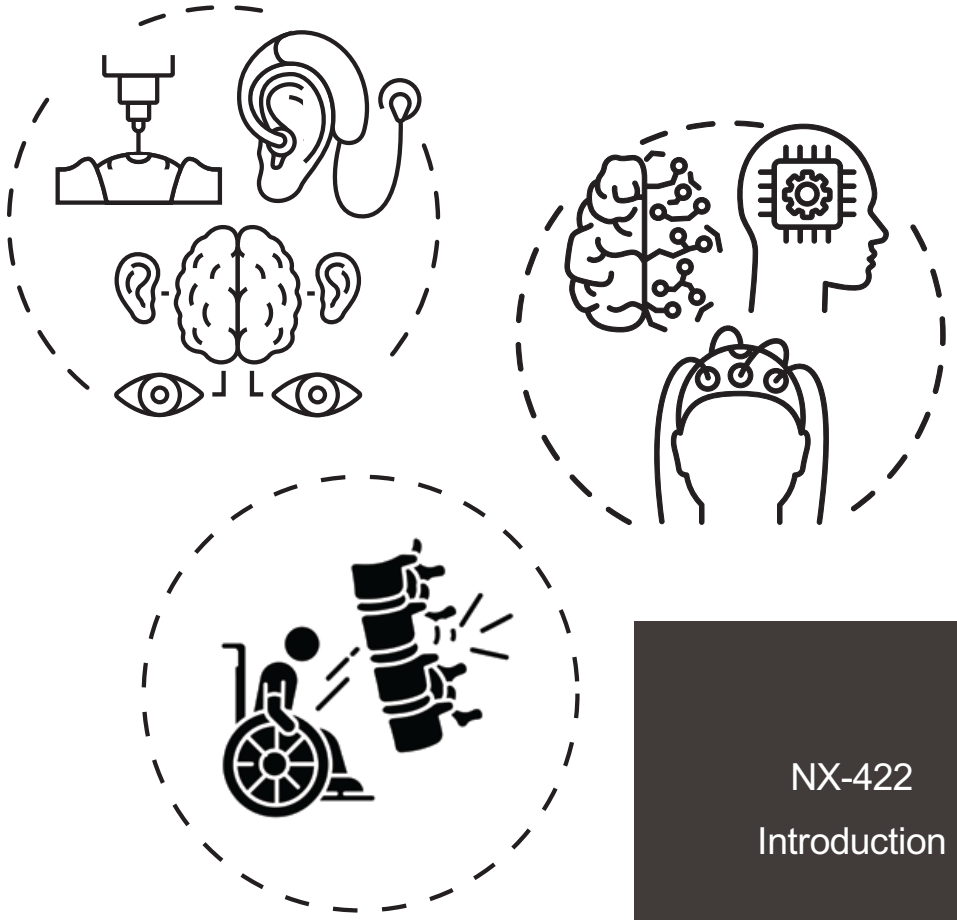


Neural Interfaces

NX-422

Introduction

Stéphanie P. Lacour, Neuro-X Institute

Mahsa Shoaran, IEM


Equal opportunity
makes us brighter
RESPECT
© EPFL


Diversity is
our strength
RESPECT
© EPFL


Listen and dare
to speak up
?!
@ :)
RESPECT
© EPFL


Look out
for each other
RESPECT
© EPFL


Kindness
brings serenity
RESPECT
© EPFL


Together
we go further
RESPECT
© EPFL

Course organisation

- **Weekly lectures**
  - Lectures: Thursdays and Fridays 2 or 3x45min starting at 8.15am
  - 2 lecturers: SP Lacour until Oct 31 then M Shoaran until Dec 6
  - TA hours: Thursdays and Fridays 45min starting at 10.15am

- **Guest lecturers**
  - Dr. Tim Constandinou, Imperial College | Integrated neural systems
  - Thursday, November 22, 2024, 8.15 – 10am

- **Problem solving sessions**
  - 3 sessions of 2x45min
  - on **Oct. 4**, 9.15 - 11.00 am,
  - on **Oct. 18**, 9.15 - 11.00 am,
  - on **Nov. 29**, 9.15 – 11.00 am
  - Sessions are managed by TAs

- **On-line Q&As during the semester using the Moodle Forum**

Weekly lectures

- **Ex-cathedra lectures**
  - Lectures 2x or 3x 45min sessions

- The course has a **high-content load**:
  - Review and study every week
  - Attend TA sessions and ask questions

- You will be **assessed** on
  - The overall concepts
  - Key materials properties and associated technologies
  - Selected device performance
  - **Critical thinking** using quantitative information to justify your approach & choices

Course project

- **Group project**
  - Team of 4 students from at least 2 distinct sections, ideally 3 sections
  - Case study of your choice
  - Project registration: **September 20, 2024**
  - **2 reports:**
    - **October 11, 2024, midnight** / 2-page outline (not graded)
    - **December 20, 2024** – noon, 12-page report following project assessment
  - Project presentations: **December 12-13, 2024**
    - **Each group and each group member to present**
    - 12 min talk
    - 5 min Q&A led by other groups

TA sessions

- **Problem solving**
  - Concrete examples of how to design and plan a neural interface
  - session in 2x45min: review proposed problems and solutions and time for Q&A
  - session 1: **October 4**, Neural signals and electrodes
  - session 2: **October 18**, Microfabrication and mechanical designs
  - session 3: **November 29**, Implantable circuits

- **Support for your team project**
  - 1-2 hour(s) per week per team member is a requirement
  - Each team has a reference TA
  - TA team interacts with project team on a regular basis
  - On **September 20**: on-line project registration
  - On **October 11**: 2-page report
  - **December 13-14**: group presentations (oral)
  - On **December 20** (noon): submission of 12-page team report via moodle

Grading

- **Group project (60%)**
  - Goal: apply and integrate information from the lectures on an application-driven case study
    - 2 reports: short at a third of the semester, long at the end of semester
    - Each student will receive their group grade
    - Final report = 40%, ppt + Q&A session = 20%

- **2 Graded in-class quizzes (2x20%)**
  - Duration: 45min
  - In-class
  - quiz 1: **November 1** at 8.30am
  - quiz 2: **December 6** at 8.30am

Course schedule 1/2

teachers:	SPL- S Lacour
	MS - M Shoaran
	TAs: assistants
	G - Guest lecturer

week	month	day	time	AAC231	Topic (tentative titles)	course type
1	September	12	8.15am	AAC231	Introduction	lecture
			9.15	AAC231	What is a neural interface?	lecture
			10.15	AAC231	Project intro	project
1	September	13	8.15am	AAC231	Examples	lecture
			9.15	AAC231	Clinical neural interfaces	lecture
			10.15	AAC231	Clinical neural interfaces	lecture
2	September	19	8.15am	AAC231	Introduction by Mahsa Shoaran	lecture
			9.15	AAC231	Miniaturized CMOS interfaces	lecture
			10.15	AAC231	Project time	project
2	September	20	8.15am	AAC231	The nevous system: anatomy	lecture
			9.15	AAC231	The nevous system: physical properties	lecture
			10.15	AAC231	Neural signals	lecture
3	September	26	8.15am	AAC231	Electrode as a transducer - Recording	lecture
			9.15	AAC231	Electrode as a transducer - Recording	lecture
			10.15	AAC231	Project time	project
3	September	27	8.15am	AAC231	Electrode as a transducer - Stimulation	lecture
			9.15	AAC231	Electrode as a transducer - Stimulation	lecture
			10.15	AAC231	Project time	project
4	October	3	8.15am	AAC231	Electrode as a transducer - Stimulation	lecture
			9.15	AAC231		lecture
			10.15	AAC231	project time	project
4	October	4	8.15am	AAC231	Electrode design and manufacturing - Clinical electrodes	lecture
			9.15	AAC231	Problem set 1- Electrode characterisation	exercise
			10.15	AAC231		exercise
5	October	10	8.15am	AAC231	Electrode design and manufacturing - Microfabricated electrodes (Si)	lecture
			9.15	AAC231		lecture
			10.15	AAC231	Project time	project
5	October	11	8.15am	AAC231	Electrode design and manufacturing - Microfabricated electrodes (thin films)	lecture
			9.15	AAC231		lecture
			10.15	AAC231	project time	project
6	October	17	8.15am	AAC231	Electrode design and manufacturing - Microfabricated electrodes (organics)	lecture
			9.15	AAC231	Multimodal neural interfaces	lecture
			10.15	AAC231	project time	project
6	October	18	8.15am	AAC231	Packaging	lecture
			9.15	AAC231	Problem set 2- Implant fabrication	exercise
			10.15	AAC231		exercise
7	October	24	8.15am	AAC231	week off	
			9.15	AAC231		
			10.15	AAC231		

Course schedule 2/2

	teachers:	SPL- S Lacour
		MS - M Shoaran
		TAs: assistants
		G - Guest lecturer

8	October	31	8.15am	AAC231	Biointegration	lecture
			9.15	AAC231		lecture
			10.15	AAC231	project time	project
8	November	1	8.15am	AAC231	QUIZ 1 starting at 8.30am, 45min	
			9.15	AAC231	in class	
			10.15	AAC231		
9	November	7	8.15am	AAC231	Neural amplifiers: CMOS design review	lecture
			9.15	AAC231		lecture
			10.15	AAC231	project time	project
9	November	8	8.15am	AAC231	Neural amplifiers: CMOS design review	lecture
			9.15	AAC231		lecture
			10.15	AAC231	project time	project
10	November	14	8.15am	AAC231	Neural amplifiers	lecture
			9.15	AAC231		lecture
			10.15	AAC231	project time	project
10	November	15	8.15am	AAC231	Digitization and compression of neural signals	lecture
			9.15	AAC231		lecture
			10.15	AAC231	project time	project
11	November	21	8.15am	AAC231	Neural signal compression	lecture
			9.15	AAC231		lecture
			10.15	AAC231	project time	project
11	November	22	8.15am	AAC231	guest lecture: Tim Constandinou	
			9.15	AAC231		
			10.15	AAC231	project time	project
12	November	28	8.15am	AAC231	Neurostimulation	lecture
			9.15	AAC231		lecture
			10.15	AAC231	project time	project
12	November	29	8.15am	AAC231	Prediction of neuroligical disorders	lecture
			9.15	AAC231	Problem set 3 - Implantable electronics	exercise
			10.15	AAC231		exercise
13	December	5	8.15am	AAC231	Closed-loop interfaces and BMIs	lecture
			9.15	AAC231		lecture
			10.15	AAC231	project time	project
13	December	6	8.15am	AAC231	QUIZ 2 starting at 8.30am, 45min	
			9.15	AAC231	in class	
			10.15	AAC231		
14	December	12	8.15am	AAC231	project presentations	
			9.15	AAC231	project presentations	
			10.15	AAC231	project presentations	
14	December	13	8.15am	AAC231	project presentations	
			9.15	AAC231	project presentations	
			10.15	AAC231	project presentations	
15	December	19	8.15am	AAC231	PROJECT REPORT	
			9.15	AAC231		
			10.15	AAC231		
15	December	20	8.15am	AAC231	PROJET REPORT	
			9.15	AAC231		
			10.15	AAC231		

Course contacts

- Lecturers
  - Stéphanie P. Lacour stephanie.lacour@epfl.ch
  - Mahsa Shoaran mahsa.shoaran@epfl.ch

- Teaching assistants
  - Scott Erickson scott.erickson@epfl.ch
  - Yasemin Engur yasemin.engur@epfl.ch
  - Amitabh Yadav amitabh.yadav@epfl.ch
  - Desirée Maulà desiree.maula@epfl.ch
  - Pietro Palopoli pietro.palopoli@epfl.ch

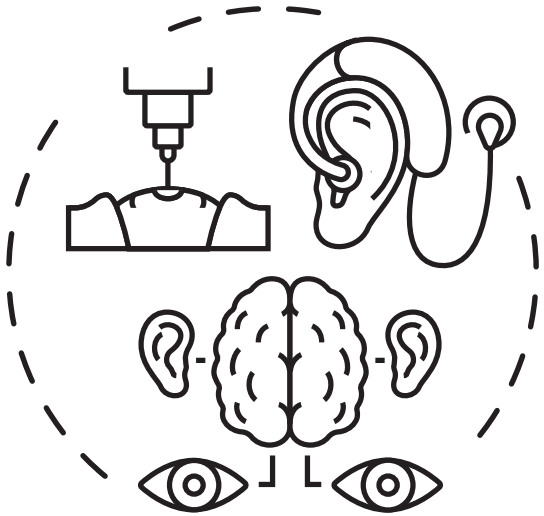
- Moodle page: section Neuro-X / master / NX-422

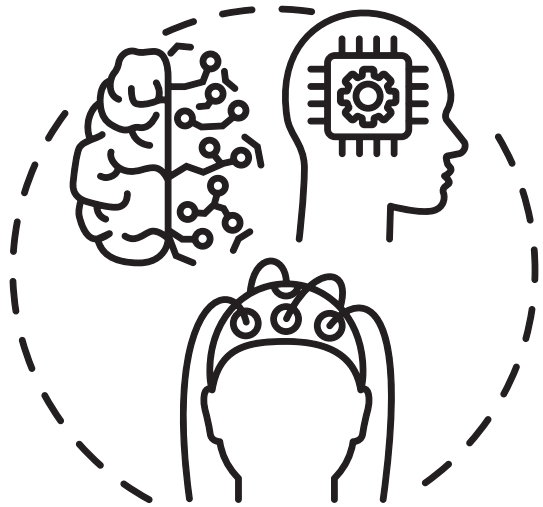
Neural interfaces

What?

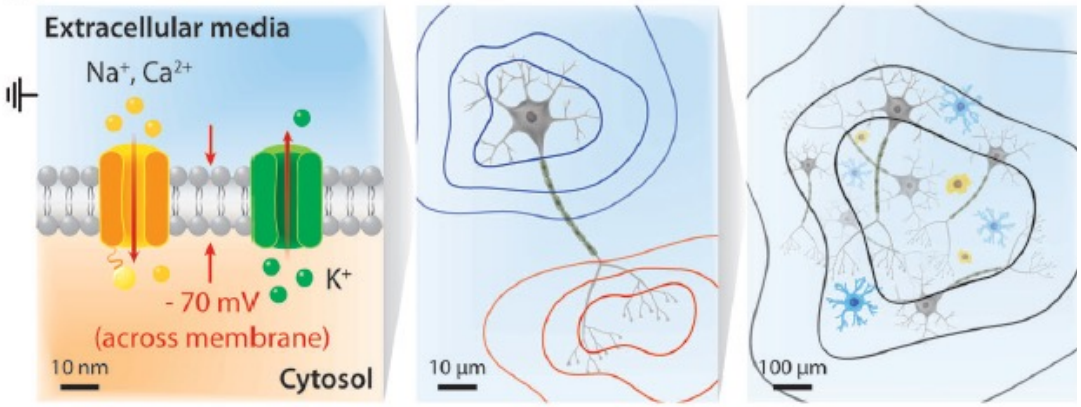
Where?

How?



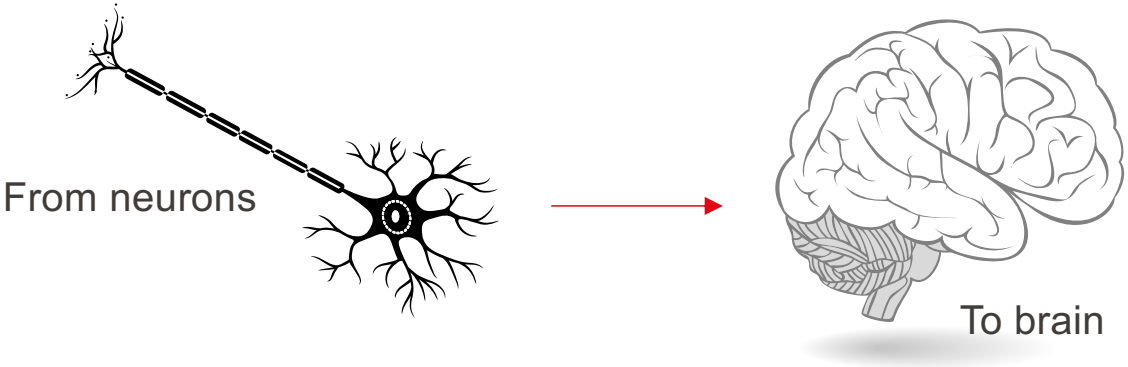


Neural interfaces
encode / decode neural information



Transmembrane potential | Extracellular potential | Local field potential

neural systems

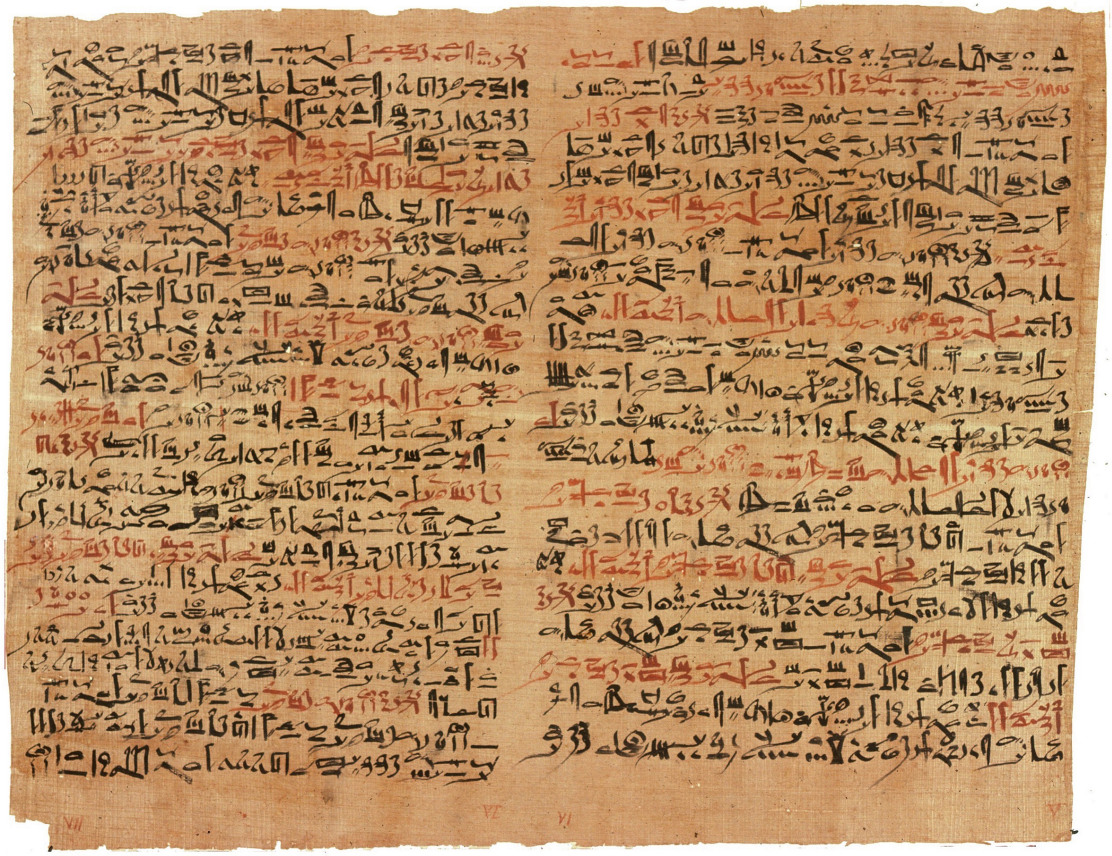


Chem. Soc. Rev. 2019, **48**,1642-1667.

Edwin Smith papyrus

first report on neural anatomy and “treatment” following trauma

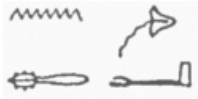
1’600 or 3’000 before J.C.



brain

gyri & sulci

meninges



cerebrospinal liquid

First prosthesis

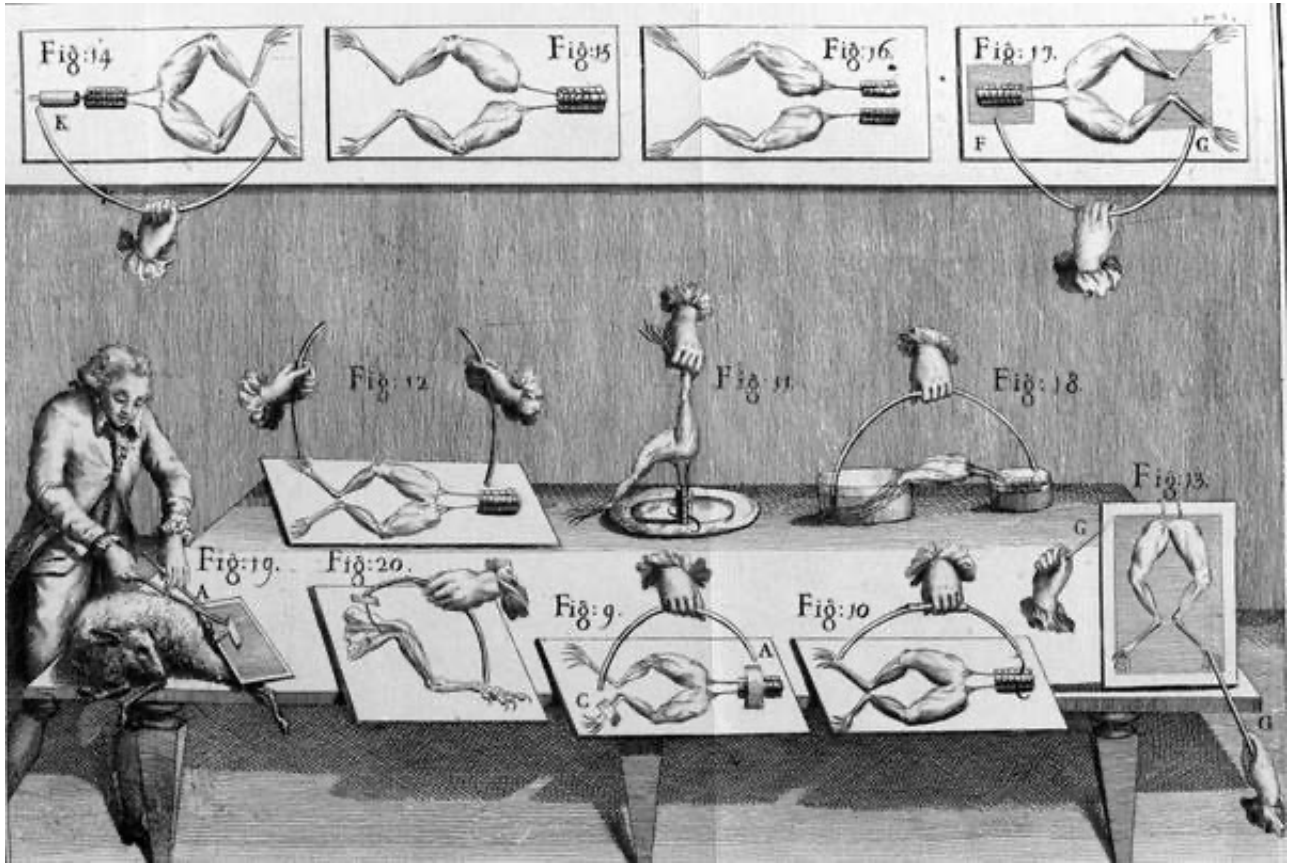
“Big toe”

3’000 before J.C.

Bioelectricity

Luigi Galvani

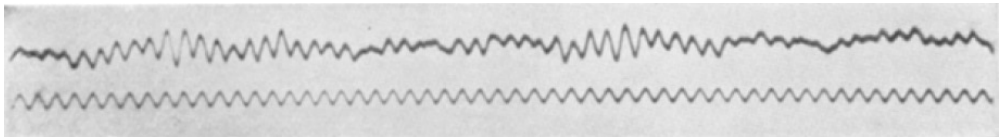
1780



Electro-encephalography

Hans Berger

1929

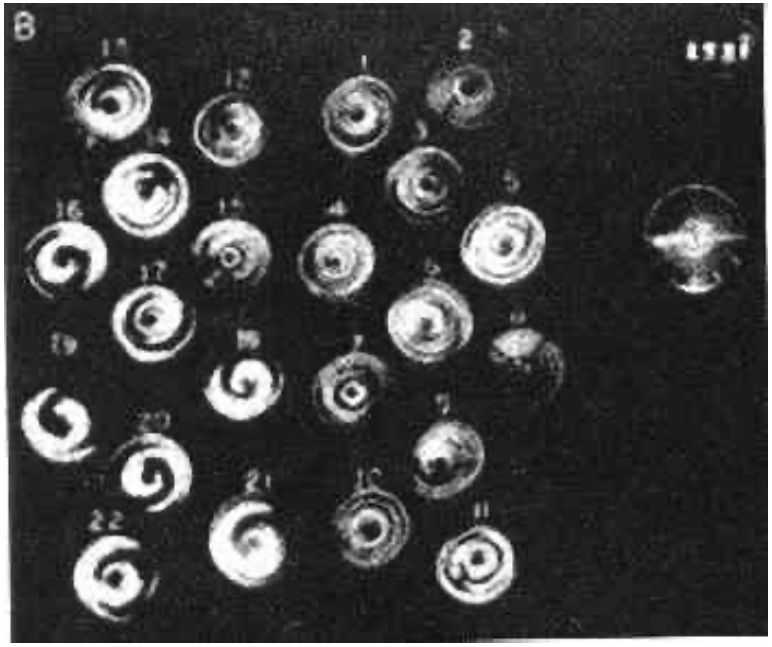


EEG
signal 10Hz

The toposcope

Gray Walter

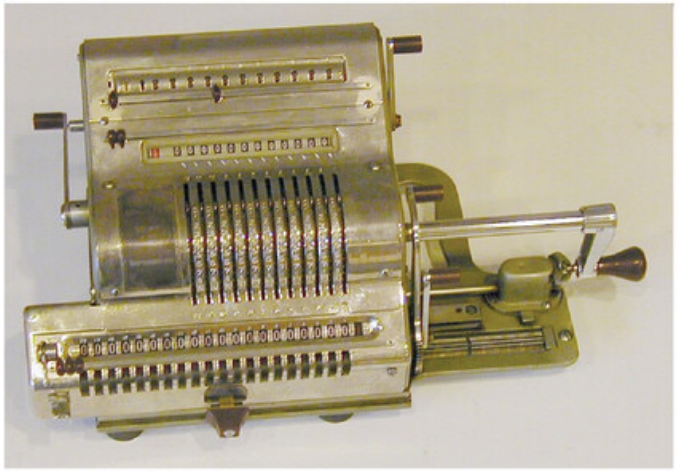
1957

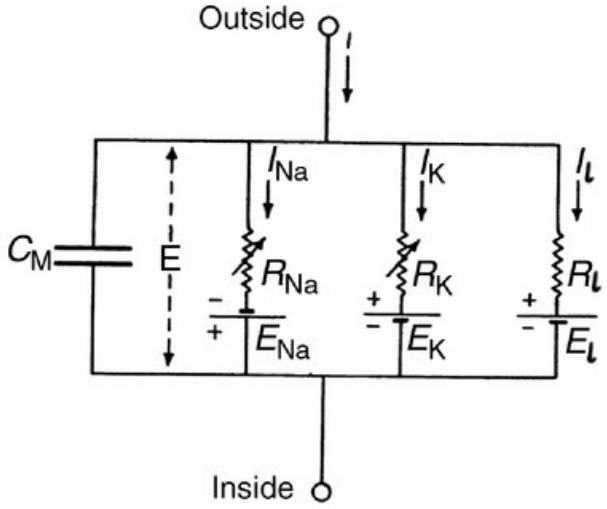


Electroencephalography and Clinical Neurophysiology
Volume 3, Issue 3, August 1951, Pages 281-292

The action potential

1952



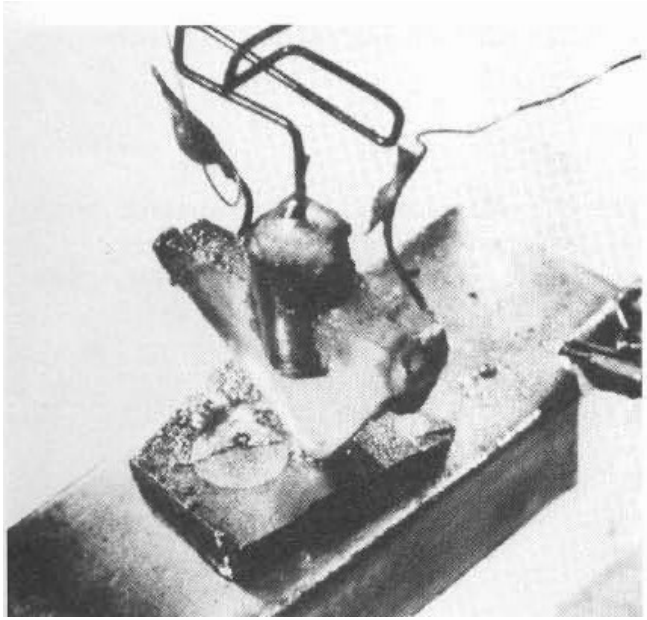


Hodgkin et Huxley

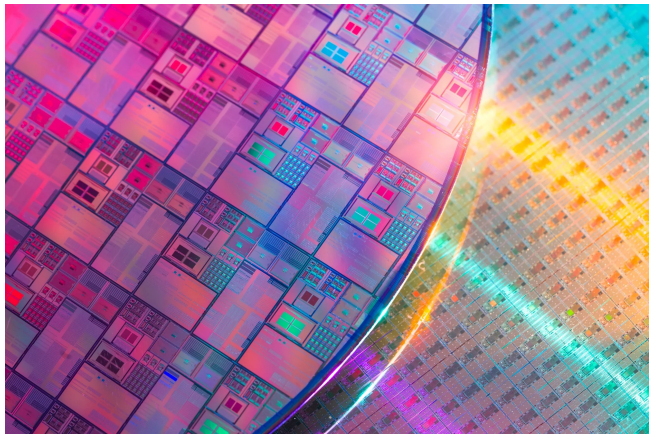
1952

The Journal of Physiology (2023) 601, 15, 3123-3139.

point contact
transistor



microprocessors



Transistors

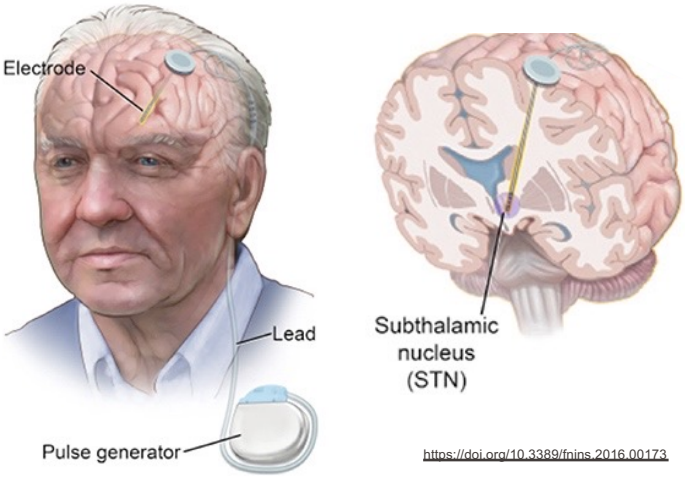
1947. Shockley, Bardeen, Brattain

2024. >5nm process technology

Neuroprosthetics

human-machine interfaces

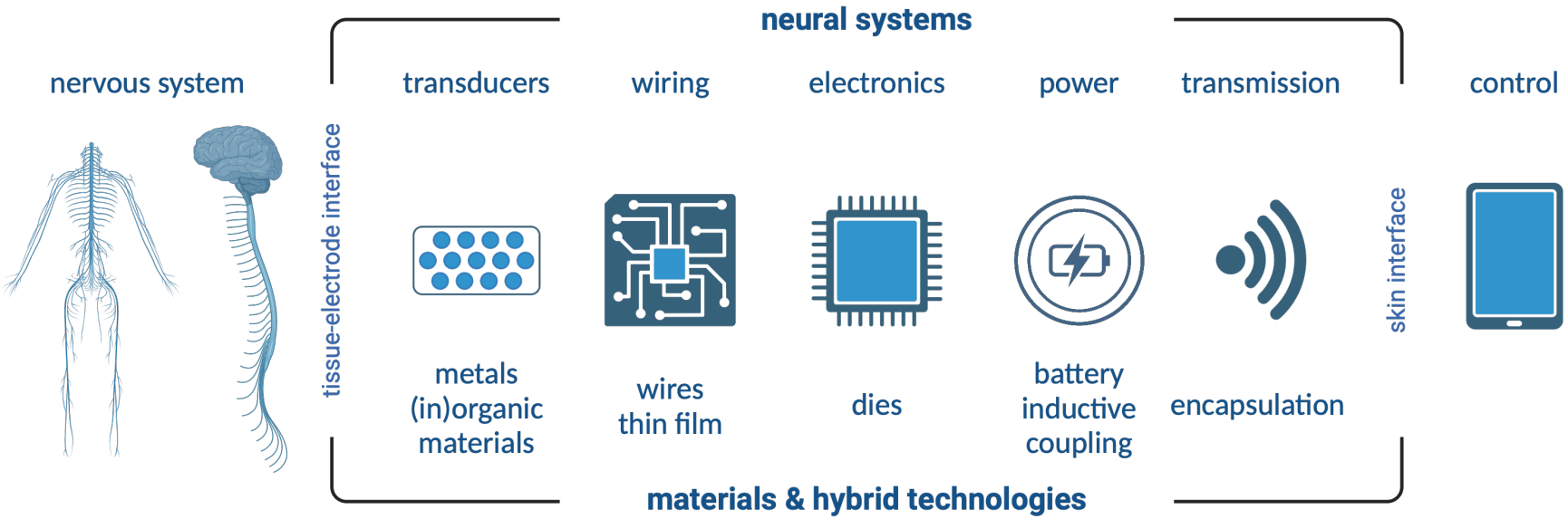
cochlear implants



https://doi.org/10.3389/fnins.2016.00173

deep brain stimulation

Neural interfaces - hardware



Course objectives

- Learn key concepts and enabling materials & technologies
  to **design and engineer neural interfaces (hardware)**

- “Dissect” practical examples highlighting the interdisciplinary nature of the domain.

Example 1. EEG cap

EEG cap

Brain Products

Example 1. EEG and sleep stages

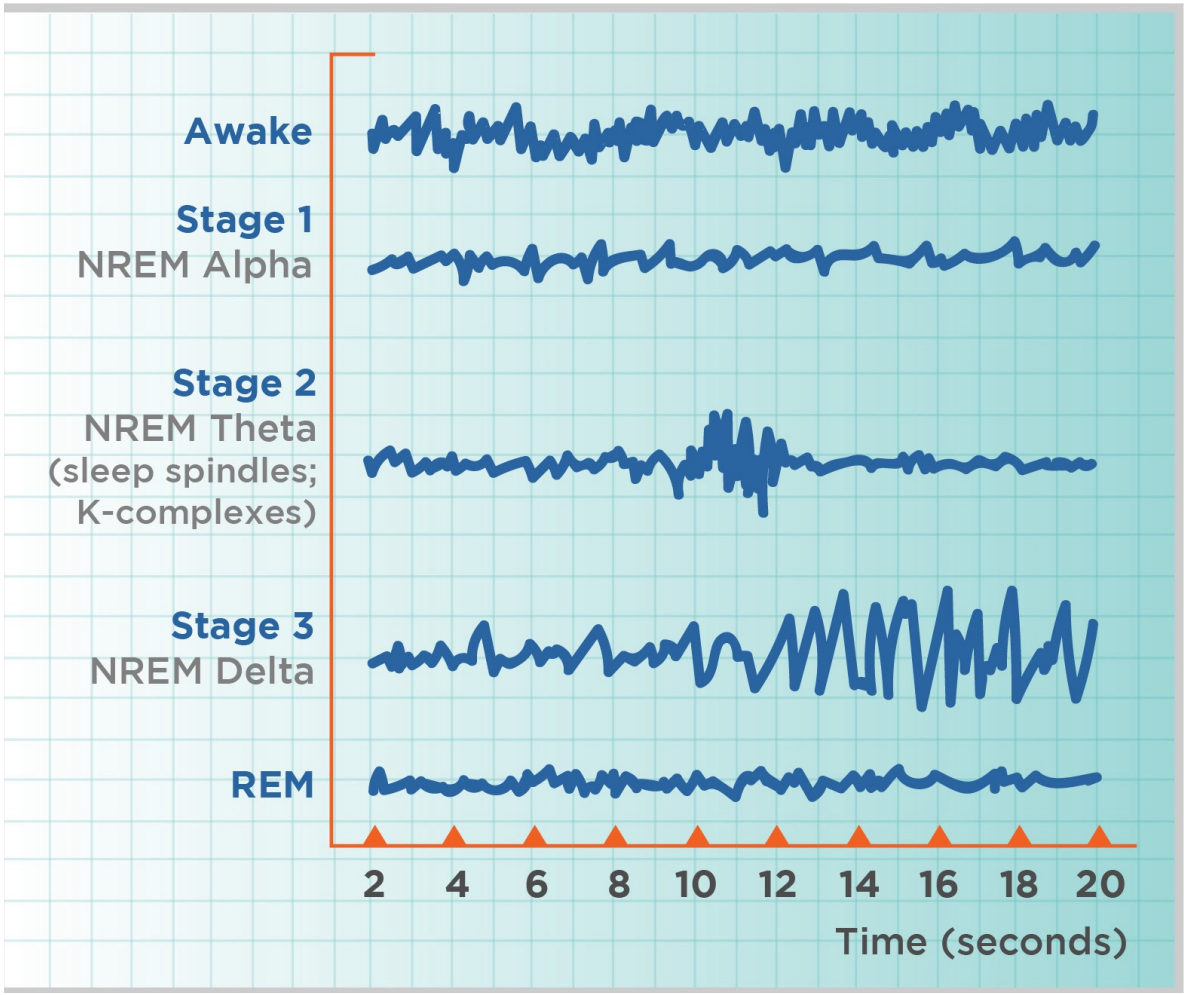
EEG cap

Brain Products

- Defined primarily by electrical activity
- Measured by an electroencephalogram (EEG)
- EEG recordings:

Frequency: number of waves per second

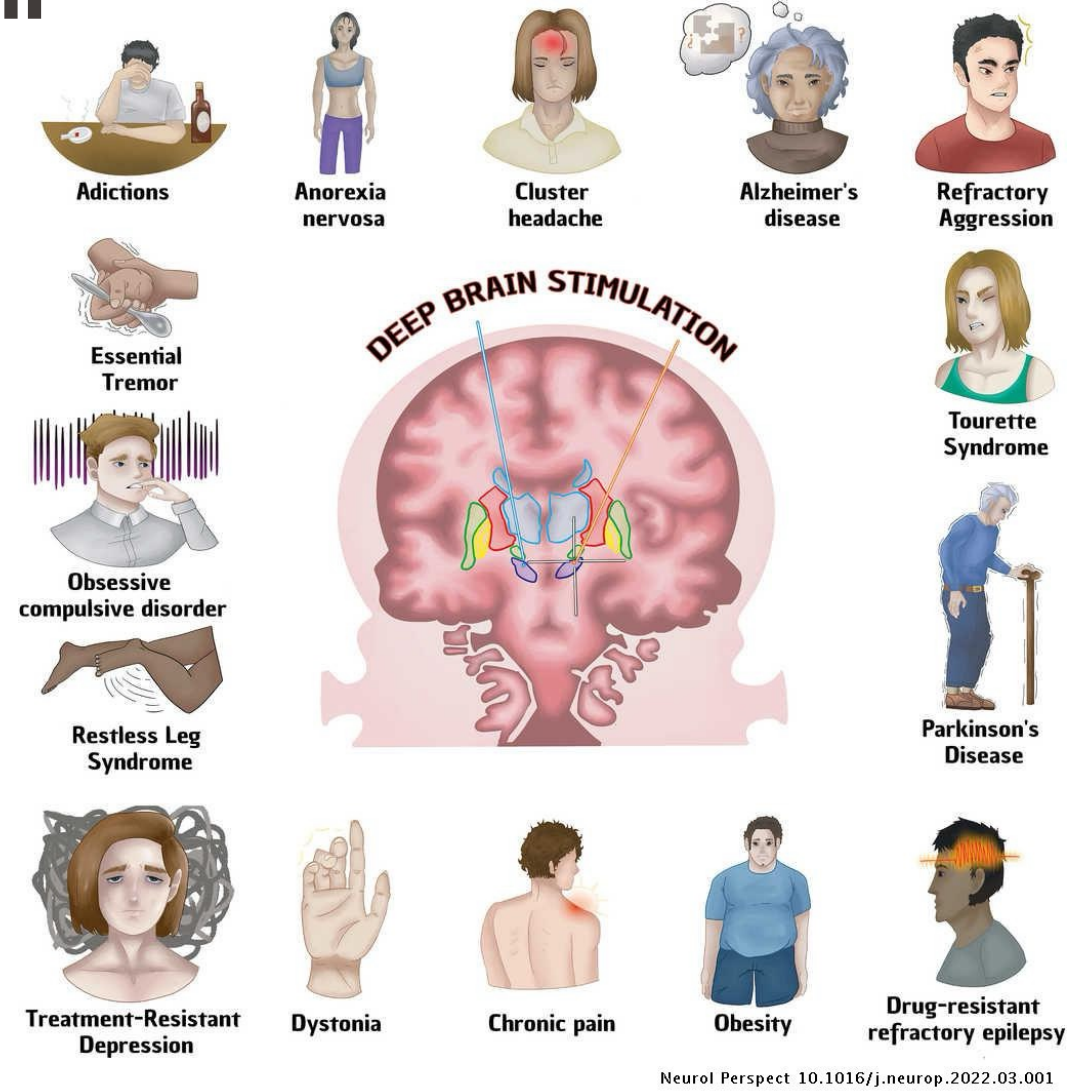
Example 1. 4 stages of sleep



https://courses.lumenlearning.com/waymaker-psychology/chapter/stages-of-sleep/

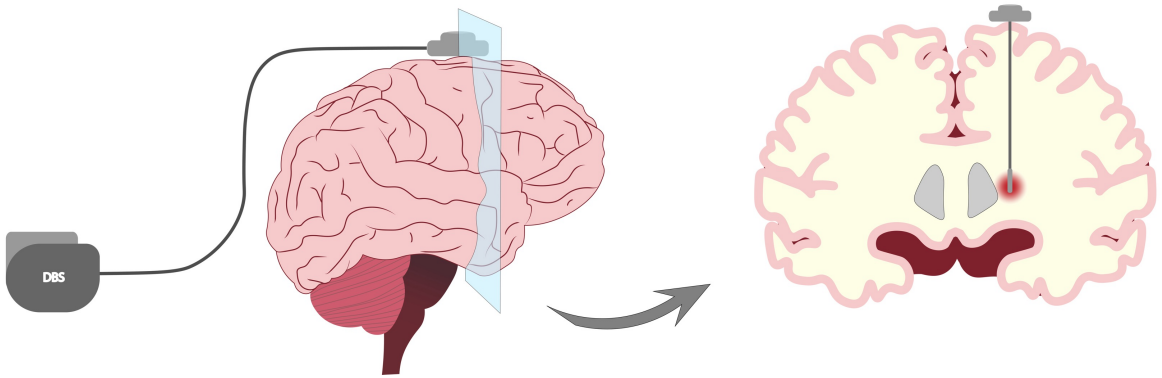
Example 2. Deep brain stimulation

- https://www.uofmhealth.org/conditions-treatments/brain-neurological-conditions/deep-brain-stimulation



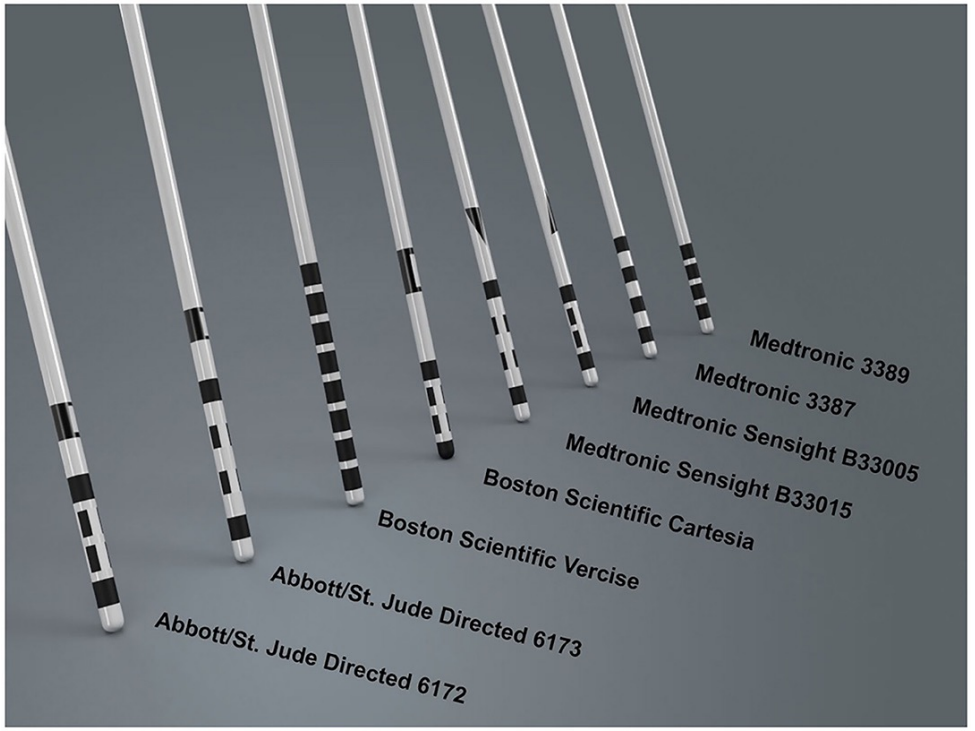
DOI: 10.1016/j.neurop.2022.03.001

Example 2. Deep brain stimulator



Example 2. Deep brain stimulator

- **DBS lead (Electrodes)**
- Extension
- Neurostimulator
- Adjustment



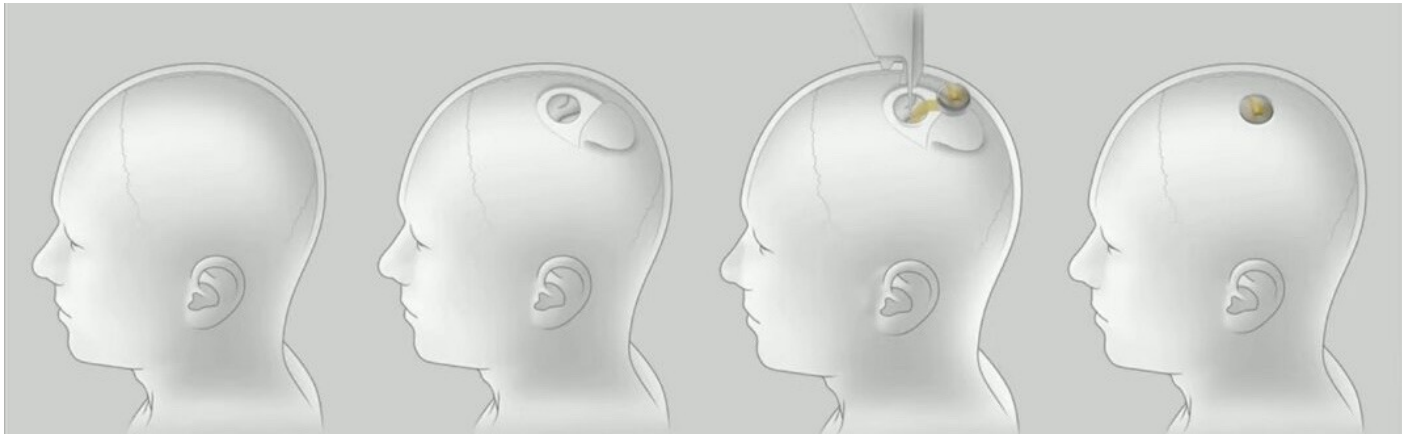
Example 2. Deep brain stimulator

- DBS lead (Electrodes)
- Extension
- **Neurostimulator**
- Adjustment

Example 2. Deep brain stimulator

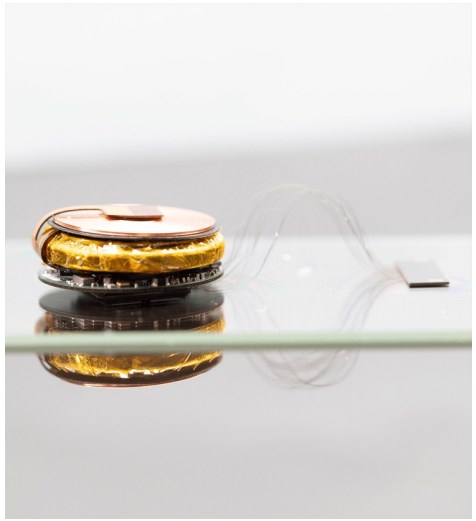
- DBS lead (Electrodes)
- Extension
- Neurostimulator
- **Adjustment**

Example 3. Miniaturized and high-density brain electrodes



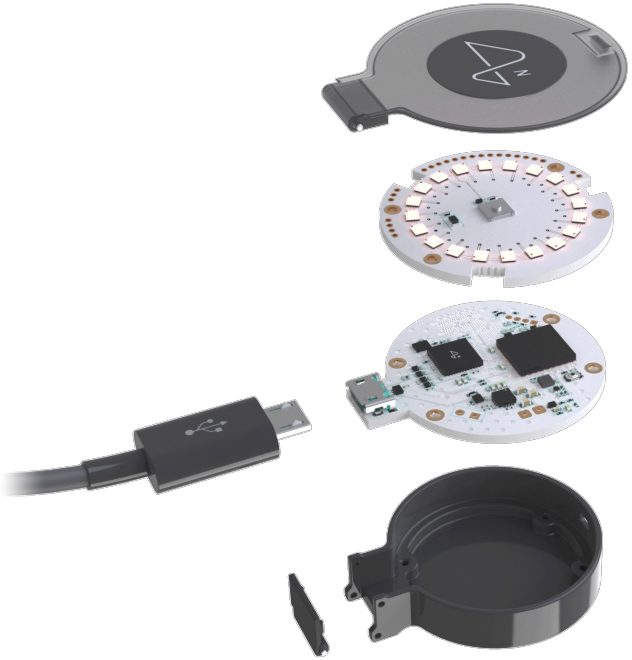
Aim (mid-term): to help people with paralysis to regain independence through the “mind” control of computers and mobile devices.
Need: long-term and high-density brain-computer interfaces

Example 3. Miniaturized and high density brain electrodes



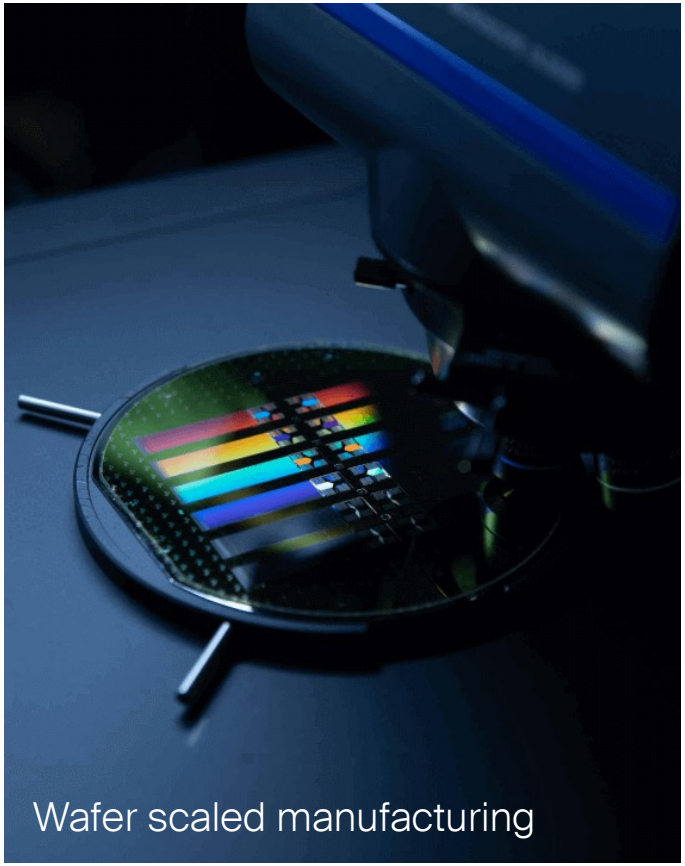
Micron scale threads
1024 microelectrodes

Sealed implantable electrodes
Process – stimulate - transmit

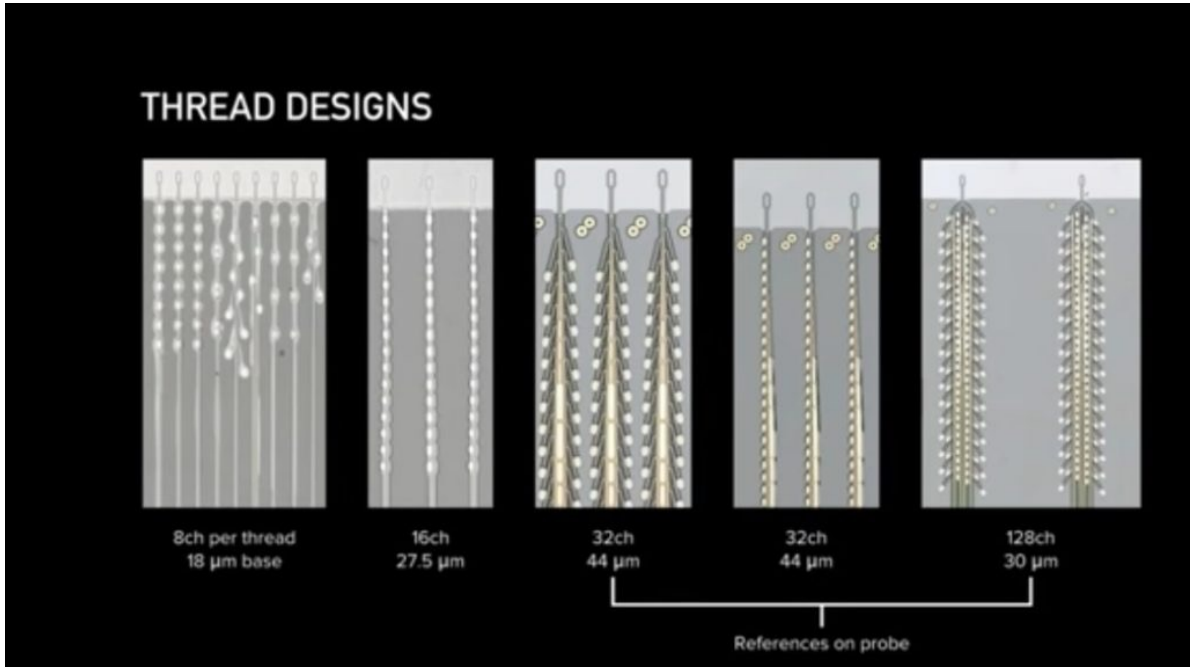


Inductive charger

Example 3. Miniaturized and high density brain electrodes



Wafer scaled manufacturing

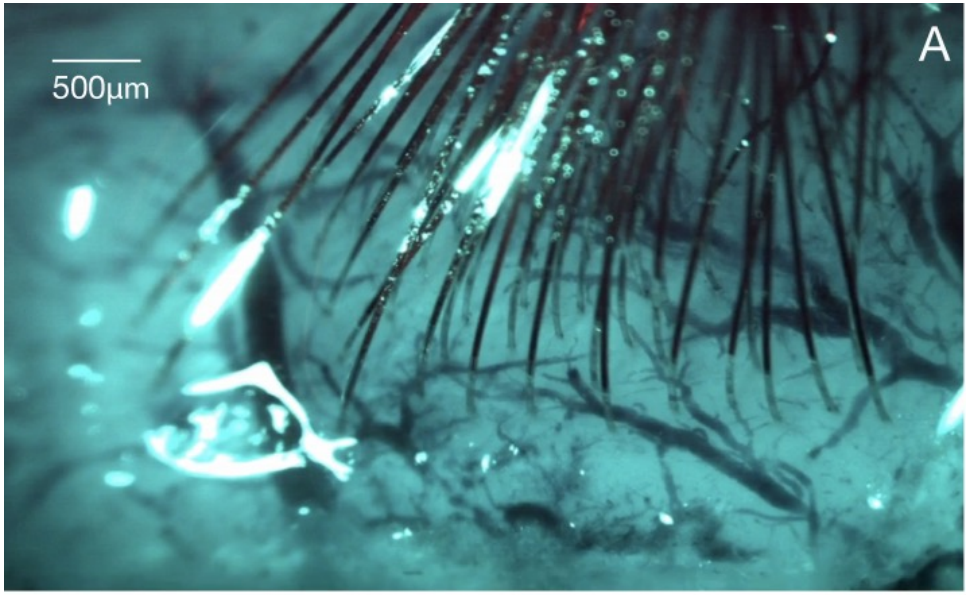


Micron scale threads
2048 microelectrodes

Neuralink @2021

Example 3. Miniaturized and high density brain electrodes

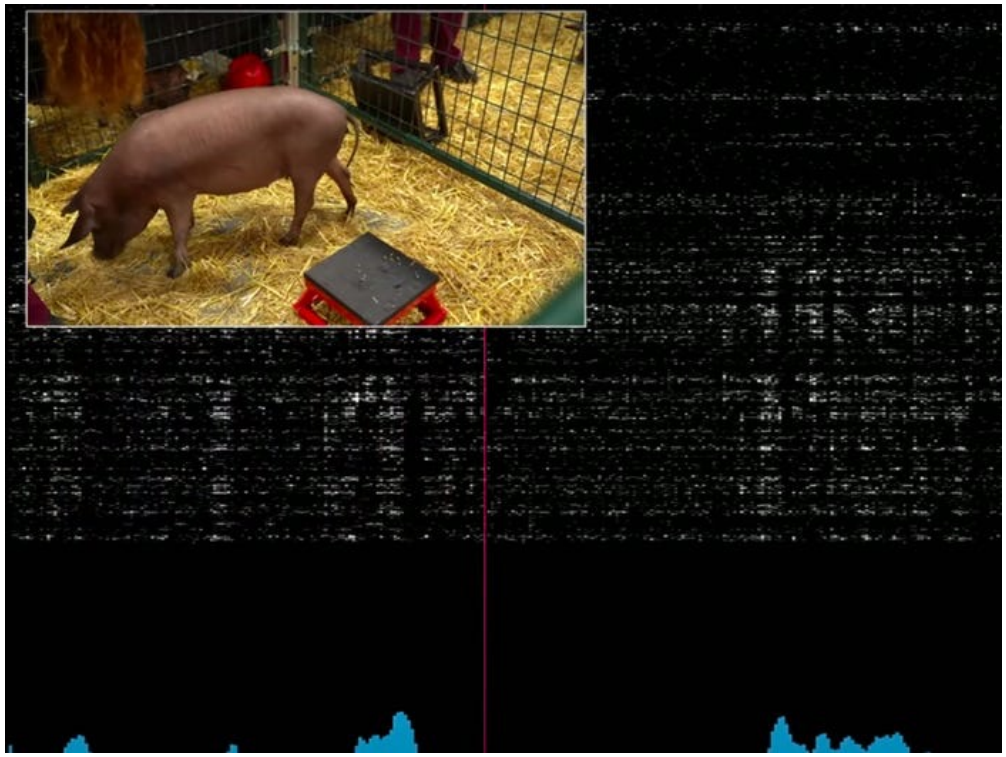
Robot-assisted neurosurgery



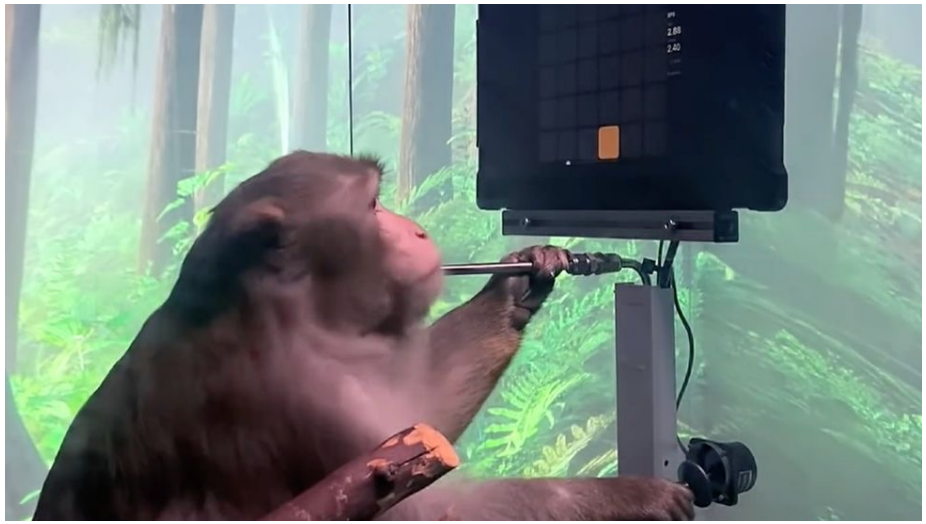
Neural electrodes: platinum/polyimide ‘threads’

Neuralink @2020 - 2022

Exemple 3. translation towards clinical use



Class III medical devices require the highest levels of evaluation and validation before regulatory bodies may grant clinical trials.



Neuralink @2021

Exemple 3. first patient

https://www.youtube.com/watch?v=5SrpYZum4Nk

@Neuralink

What have we learnt from these 3 examples on the design of neural interfaces?

- Map the essential components of a neural interface
- Envision which materials are used to manufacture a neural interface
- List the main challenges in building a neural interface