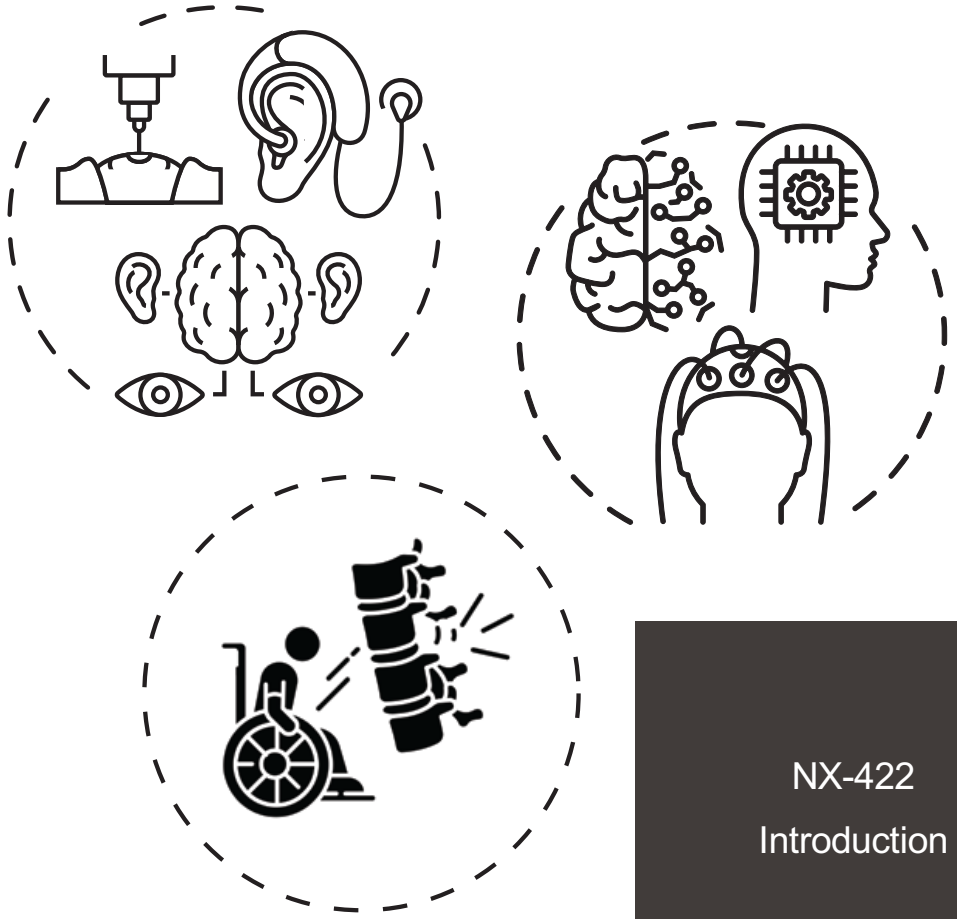
EPFL



Neural Interfaces

NX-422

Introduction

Stéphanie P. Lacour,
Giuseppe Schiavone
Mahsa Shoaran


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 9.15am
  - 3 lecturers: SP Lacour, week 1 then G. Schiavone until Oct 31 then M Shoaran until Dec 5
  - TA hours: Thursdays and Fridays 45min starting at 11.15am

- **Guest lecturers**
  - Dr. Carolina Aguilar, Inbrain Bioelectronics
  - Thursday, November 2214 2024, 9.15 – 11am

- **Problem solving sessions**
  - 4 sessions
  - on **Oct. 3**, 10.15 – 12-noon,
  - on **Oct. 17**, 10.15 – 12-noon,
  - on **Nov. 13**, 10.15 – 12-noon
  - on **Nov. 28**, 11.15 – 12-noon
  - Sessions are managed by TAs

- **On-line Q&As during the semester using the ED Channel (NX-422)**

Weekly lectures

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

- The course has a **high-content load**:
  - Review and study every week
  - Attend AE/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 3-4 students from at least 2 distinct sections, ideally 3 sections
  - Case study of your choice
  - Project registration: **September 19, 2025 midnight**
  - **2 reports:**
    - **October 10, 2025, midnight** / 2-page outline (not graded)
    - **December 19, 2025** – noon, 12-page report following project assessment
  - Project presentations: **December 11-12, 2025**
    - **Each group and each group member to present**
    - 12 min talk
    - 5 min Q&A led by other groups
    - 2 parallel sessions

AE/TA sessions

- **Questions on the lectures**
  - in class, Th & Fr, 11.15-12-noon
  - AEs and a couple of TAs
  - using the Ed-Channel

- **Problem solving**
  - Concrete examples of how to design a neural interface
  - session in 2x45min: review proposed problems and solutions and time for Q&A
  - session 1: **Oct. 3**, Neural signals and electrodes
  - session 2: **Oct. 17**, Microfabrication and mechanical designs
  - session 3: **Nov. 13**, Implantable circuits I
  - session 4: **Nov. 28**, Implantable circuits II

- **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 19**: on-line project registration
  - On **October 10**: 2-page report
  - **December 12-13**: group presentations (oral)
  - On **December 19** (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 one at a third of the semester, long one 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 to 90min (TBD)
  - In-class, closed book with a cheat-sheet
  - quiz 1: **October 31** at 9.30am, room TBC
  - quiz 2: **December 5** at 9.30am, room TBC

Course schedule 1/2

Teachers

SP Lacour (SL)
G. Schiavone (GS)
M. Shoaran (MS)

week	month	day	time	AAC231	Topic (tentative titles)	course type	teacher	tasks
1	September	11	9.15am	AAC231	Introduction	lecture	SPL	
			10.15	AAC231	What is a neural interface?	lecture	SPL	
			11.15	AAC231	Examples	lecture	SPL	
1	September	12	9.15am	AAC231	Clinical neural interfaces	lecture	SPL	
			10.15	AAC231	Clinical neural interfaces	lecture	SPL	
			11.15	AAC231	Project intro	project	TAs	
2	September	18	9.15am	AAC231	Introduction by Mahsa Shoaran	lecture	MS	
			10.15	AAC231	Miniaturized CMOS interfaces	lecture	MS	
			11.15	AAC231	Project time	project	TAs	
2	September	19	9.15am	AAC231	The nevous system: anatomy	lecture	GS	
			10.15	AAC231	The nevous system: physical properties	lecture	GS	
			11.15	AAC231	Neural signals	lecture	GS	project registration deadline
3	September	25	9.15am	AAC231	Electrode as a transducer - Recording	lecture	GS	
			10.15	AAC231	Electrode as a transducer - Recording	lecture	GS	
			11.15	AAC231	Project time	project	TAs	
3	September	26	9.15am	AAC231	Electrode as a transducer - Stimulation	lecture	GS	
			10.15	AAC231	Electrode as a transducer - Stimulation	lecture	GS	
			11.15	AAC231	Project time	project	TAs	
4	October	2	9.15am	AAC231	Electrode as a transducer - Stimulation	lecture	GS	
			10.15	AAC231		lecture	GS	
			11.15	AAC231	project time	project	TAs	
4	October	3	9.15am	AAC231	Electrode design and manufacturing - Clinical electrodes	lecture	GS	
			10.15	AAC231	Problem set 1- Electrode characterisation	exercise	TAs	exercise 1
			11.15	AAC231		exercise	TAs	
5	October	9	9.15am	AAC231	Electrode design and manufacturing - Microfabricated electrodes (Si)	lecture	GS	
			10.15	AAC231		lecture	GS	
			11.15	AAC231	Project time	project	TAs	
5	October	10	9.15am	AAC231	Electrode design and manufacturing - Microfabricated electrodes (thin films)	lecture	GS	
			10.15	AAC231		lecture	GS	
			11.15	AAC231	project time	project	TAs	2pager submission
6	October	16	9.15am	AAC231	Electrode design and manufacturing - Microfabricated electrodes (organics)	lecture	GS	
			10.15	AAC231	Multimodal neural interfaces	lecture	GS	
			11.15	AAC231	project time	project	TAs	
6	October	17	9.15am	AAC231	Packaging	lecture	GS	
			10.15	AAC231	Problem set 2- Implant fabrication	exercise	TAs	exercise 2
			11.15	AAC231		exercise	TAs	
7	October	23	9.15am	AAC231	week off			
			10.15	AAC231				
			11.15	AAC231				
7	October	24	9.15am	AAC231				
			10.15	AAC231				
			11.15	AAC231				
8	October	30	9.15am	AAC231	Biointegration	lecture	GS	
			10.15	AAC231		lecture	GS	
			11.15	AAC231	project time	project	TAs	
8	October	31	9.15am	AAC231	QUIZ 1 starting at 9.15am, 1 hour		GS	QUIZ 1
			10.15	AAC231	in class		GS	
			11.15	AAC231			GS	

Course schedule 2/2

Teachers

SP Lacour (SL)
G. Schiavone (GS)
M. Shoaran (MS)

9	November	6	9.15am	AAC231	Neural amplifiers: CMOS design review	lecture	MS	
			10.15	AAC231		lecture	MS	
			11.15	AAC231	project time	project	TAs	
9	November	7	9.15am	AAC231	Neural amplifiers	lecture	MS	
			10.15	AAC231		lecture	MS	
			11.15	AAC231	project time	project	TAs	
10	November	13	9.15am	AAC231	Problem set 3 - CMOS amplifiers	exercise	TAs	exercise 3
			10.15	AAC231	Problem set 3 - CMOS amplifiers	exercise	TAs	
			11.15	AAC231	project time	project	TAs	
10	November	14	9.15am	AAC231	Guest lecture		G	
			10.15	AAC231			G	
			11.15	AAC231	project time	project	TAs	
11	November	20	9.15am	AAC231	Digitization and compression of neural signals	lecture	MS	
			10.15	AAC231		lecture	MS	
			11.15	AAC231	project time	project	TAs	
11	November	21	9.15am	AAC231	Neural signal compression	lecture	MS	
			10.15	AAC231		lecture	MS	
			11.15	AAC231	project time	project	TAs	
12	November	27	9.15am	AAC231	Neurostimulation	lecture	MS	
			10.15	AAC231		lecture	MS	
			11.15	AAC231	project time	project	TAs	
12	November	28	9.15am	AAC231	Prediction of neurological disorders	lecture	MS	
			10.15	AAC231		lecture	MS	
			11.15	AAC231	Problem set 4 - Neural interface electronics	exercise	TAs	exercise 4
13	December	4	9.15am	AAC231	Closed-loop interfaces and BMIs	lecture	MS	
			10.15	AAC231		lecture	MS	
			11.15	AAC231	project time	project	TAs	
13	December	5	9.15am	AAC231	QUIZ 2 starting at 9.15am, 1:15 hour (+25%)		MS	QUIZ 2
			10.15	AAC231	in class		MS	
			11.15	AAC231			MS	
14	December	11	9.15am	AAC231	project presentations		SPL, MS, TAs	
			10.15	AAC231	project presentations		SPL, MS, TAs	
			11.15	AAC231	project presentations		SPL, MS, TAs	
14	December	12	9.15am	AAC231	project presentations		SPL, MS, TAs	
			10.15	AAC231	project presentations		SPL, MS, TAs	
			11.15	AAC231	project presentations		SPL, MS, TAs	
15	December	18	9.15am	AAC231	PROJECT REPORT		SPL, MS, TAs	
			10.15	AAC231			SPL, MS, TAs	
			11.15	AAC231			SPL, MS, TAs	
15	December	19	9.15am	AAC231	PROJECT REPORT		SPL, MS, TAs	
			10.15	AAC231			SPL, MS, TAs	
			11.15	AAC231			SPL, MS, TAs	REPORT DEADLINE

Course contacts

- Lecturers
  - Stéphanie P. Lacour stephanie.lacour@epfl.ch
  - Giuseppe Schiavone giuseppe.schiavone@epfl.ch
  - Mahsa Shoaran mahsa.shoaran@epfl.ch
- Teaching assistants and Assistants Etudiants
  - 9 TAs, 6 AEs
- Moodle page: section Neuro-X / master / NX-422

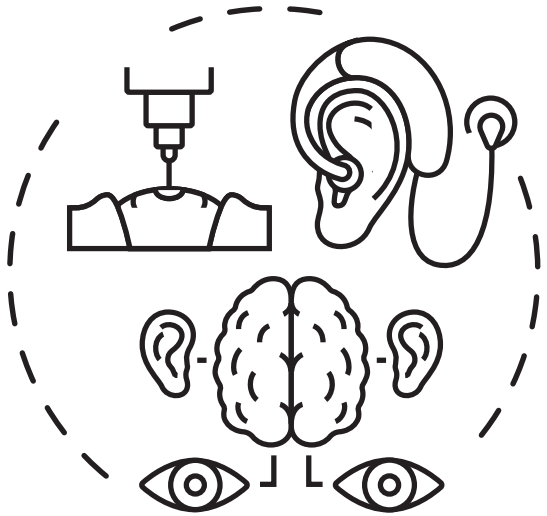
Neural interfaces

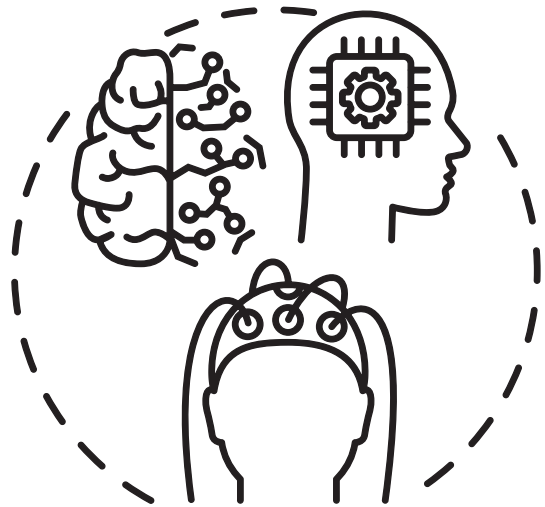
Why?

What?

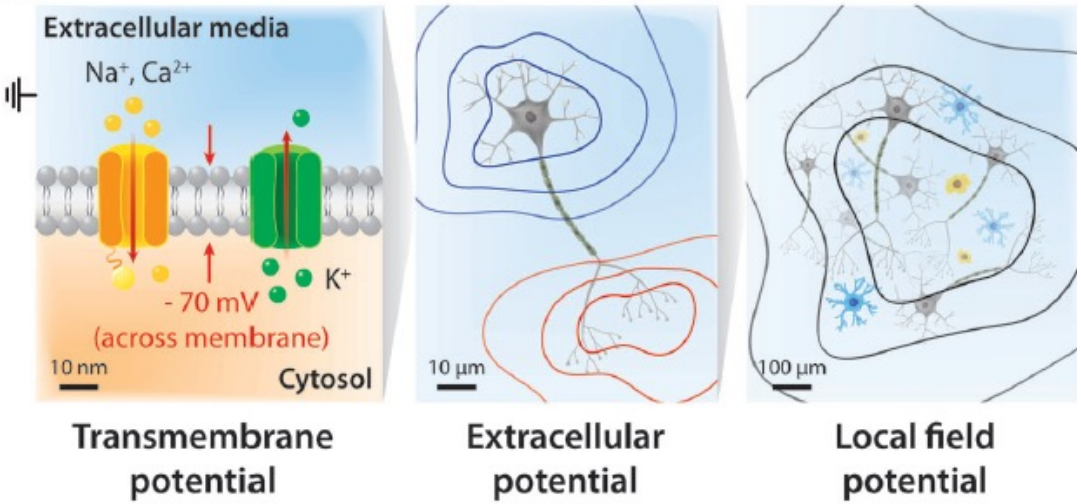
Where?

How?

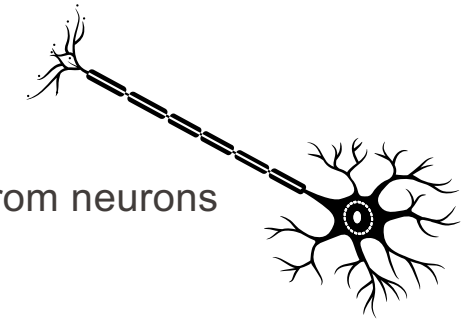


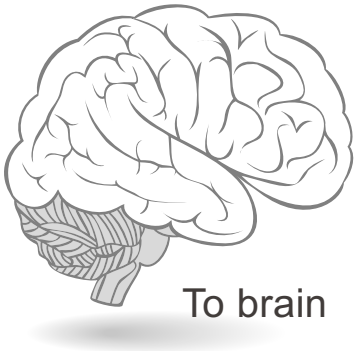


Neural interfaces
encode / decode neural information



neural
”languages”





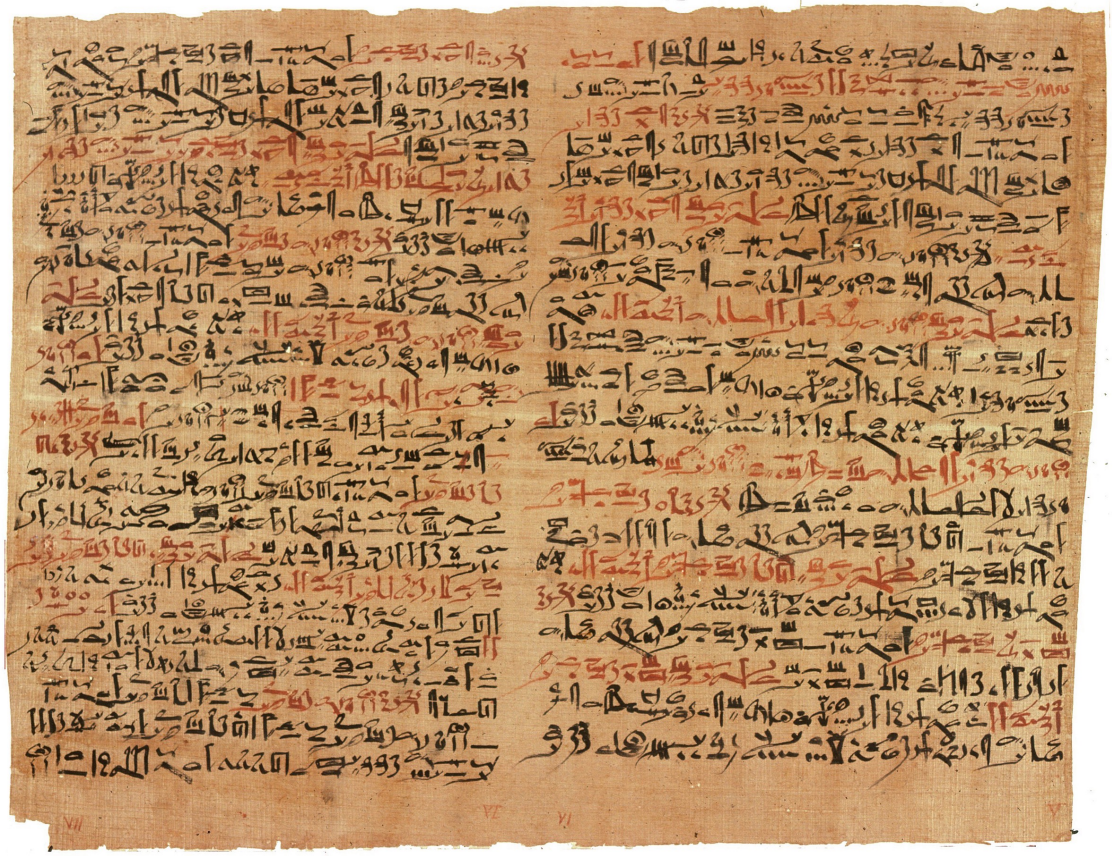
To behaviour

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

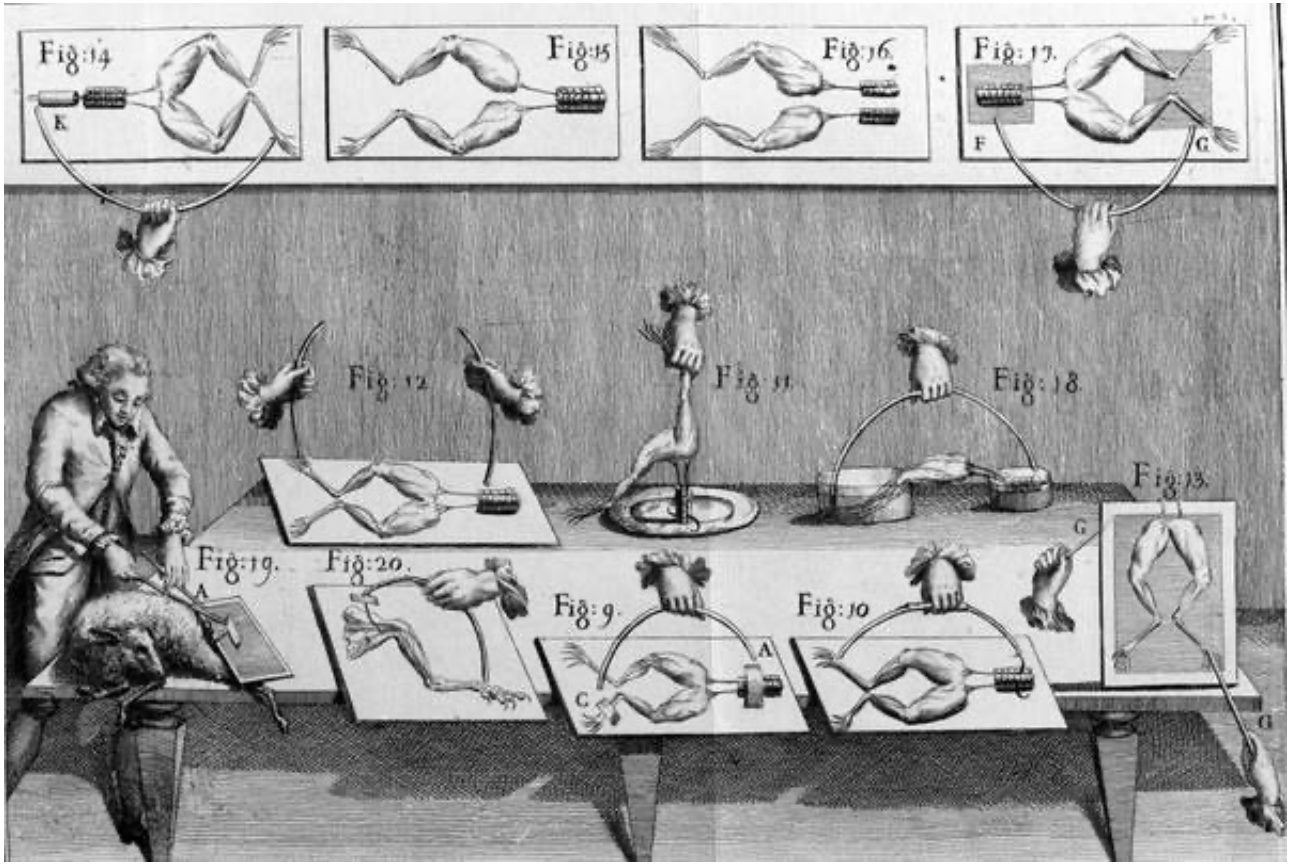
“Big toe”

3’000 before J.C.

Bioelectricity

Luigi Galvani

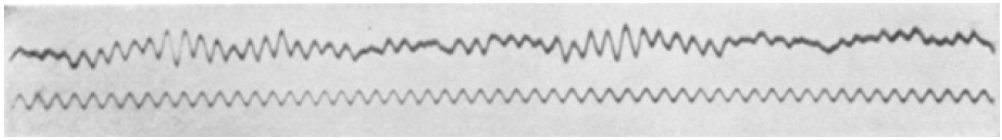
1780



Electro-encephalography

Hans Berger

1924

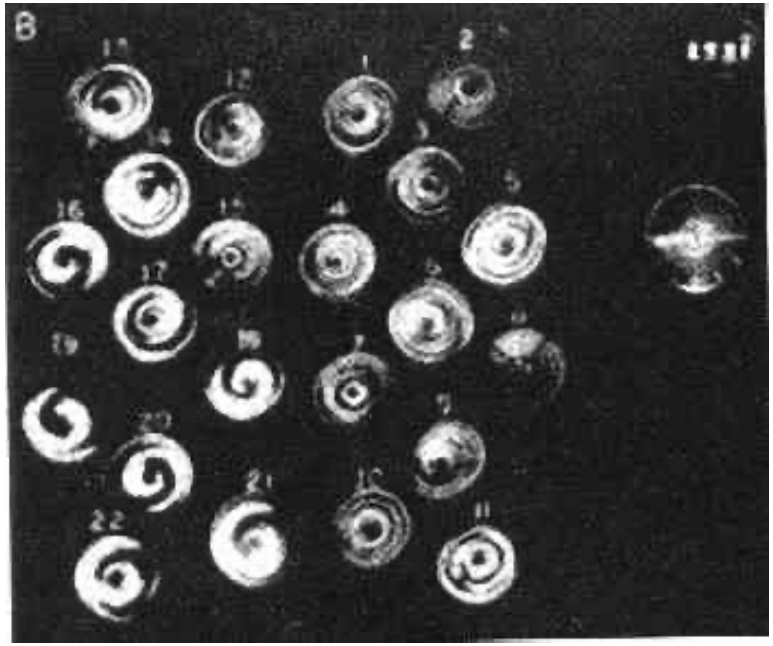


EEG
signal 10Hz

The toposcope

Gray Walter

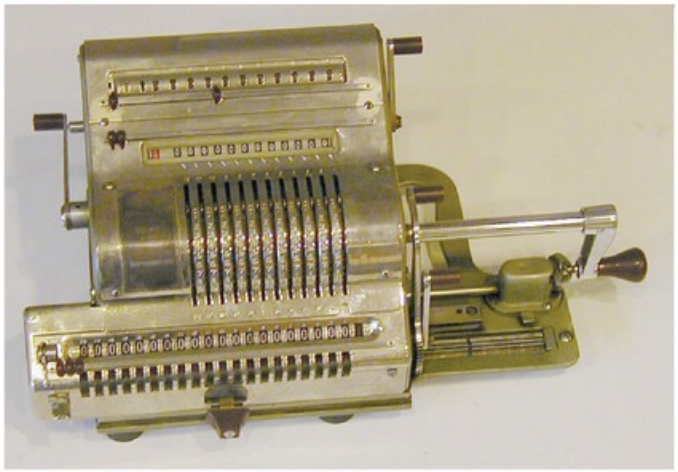
1957

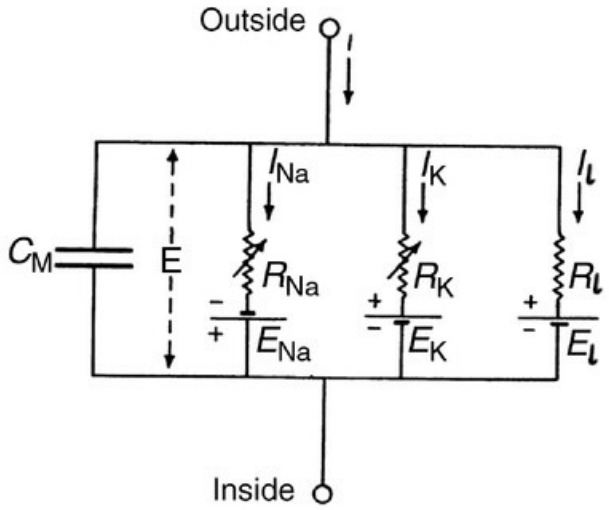


Electroencephalography and Clinical Neurophysiology
Volume 3, Issue 3, August 1951, Pages 281-292

The action potential

1952



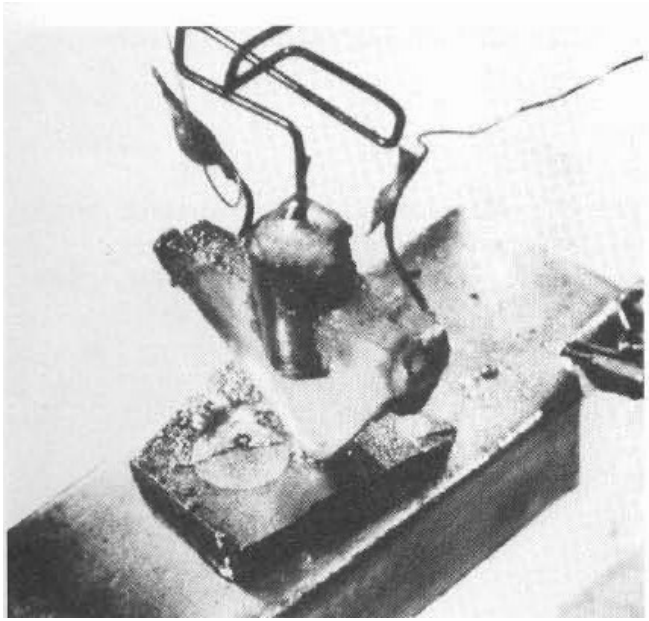


Hodgkin et Huxley

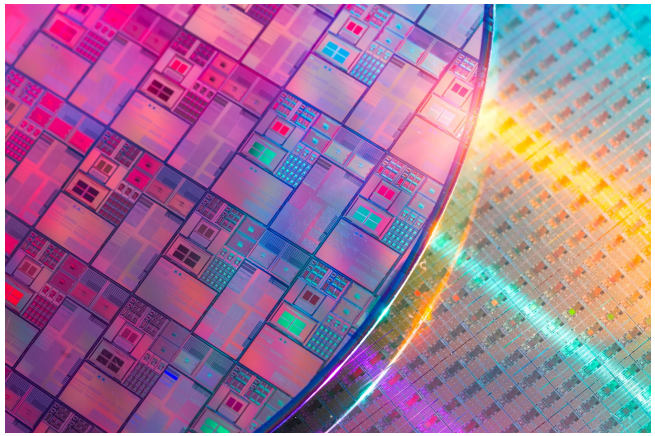
1952

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

point contact
transistor



microprocessors



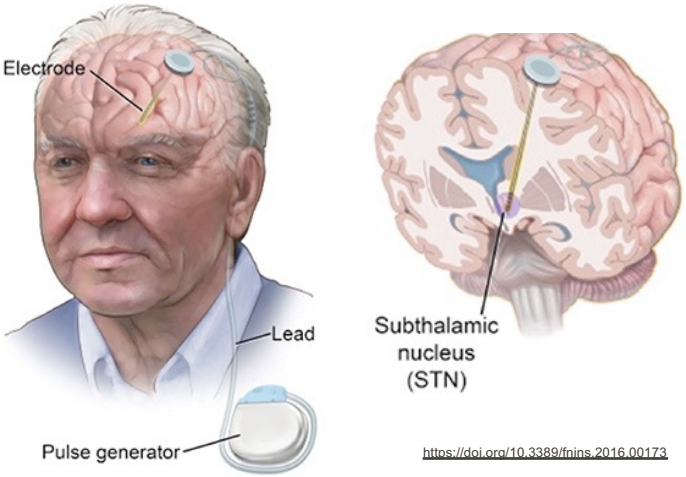
Transistors

1947. Shockley, Bardeen, Brattain

2024. >5nm process technology

Neuroprosthetics

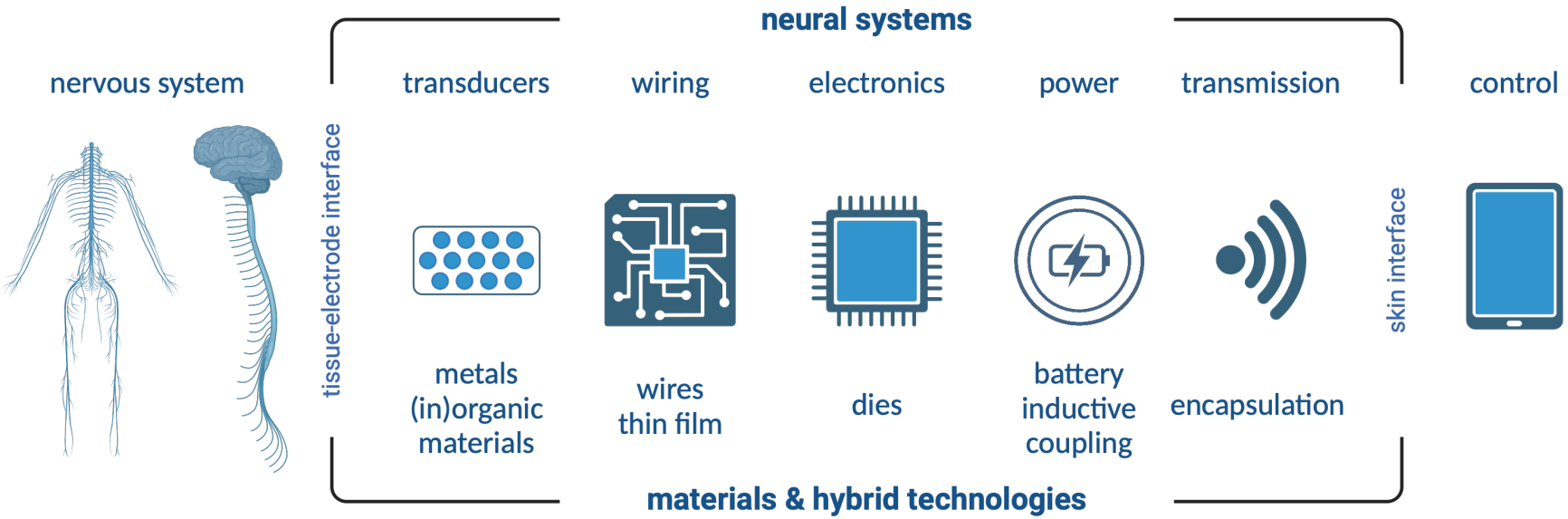
cochlear implants



deep brain stimulation

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

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

Rhythmlinks

https://pressrelease.brainproducts.com/choosing-your-electrode-technology/

Example 1. EEG and sleep stages

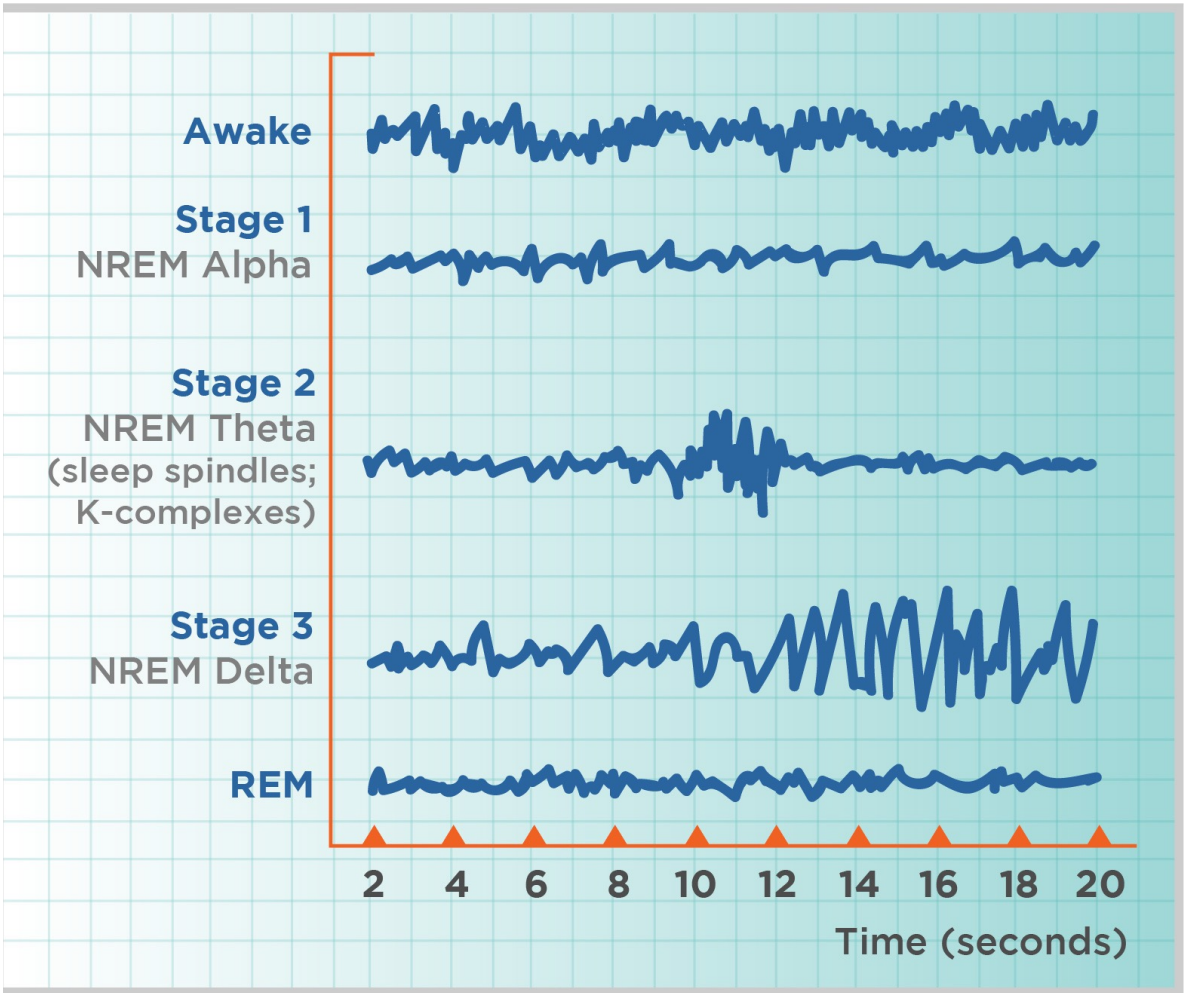
EEG cap

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

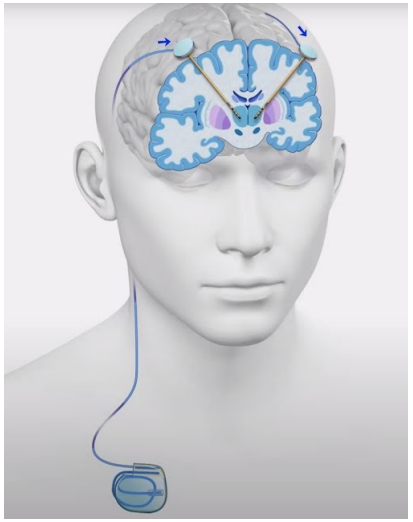


https://courses.lumenlearning.com/waymaker-psychology/chapter/stages-of-sleep/

Example 2. Deep Brain Stimulation

- **Parkinson disease**
  - chronic, progressive neurodegenerative disorder affecting movement control
  - primarily due to the loss of dopaminergic neurons in the substantia nigra pars compacta
  - leads to disruption of the basal ganglia circuitry, imparing motor function

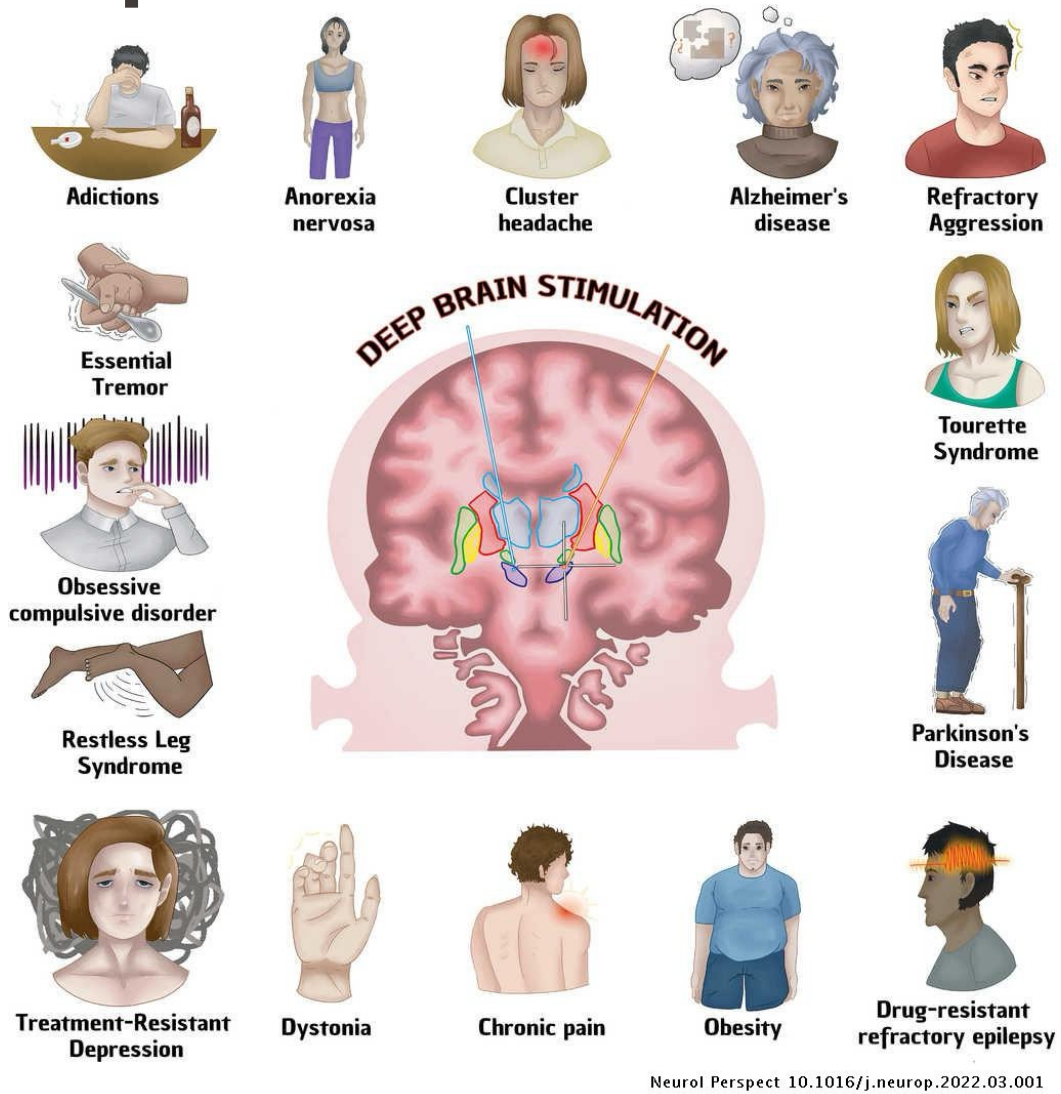
- DBS implant



- https://www.youtube.com/watch?v=YD59_d0Q-Kg

DOI: 10.1016/j.neurop.2022.03.001

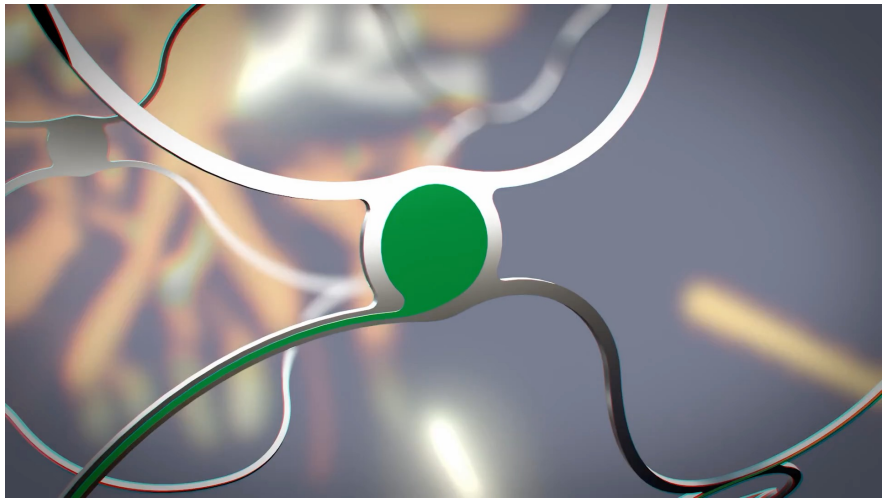
Example 2. Deep brain stimulation



Example 3. Invasive Brain Computer Interfaces

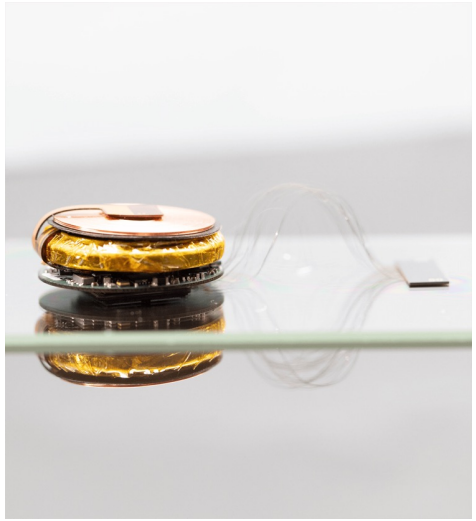
- Electrodes implanted in the brain to record and/or stimulate neural activity
- Applications:
  - control of robotic arms, cursors
  - speech decoding
  - closed-loop neuromodulation
- Signal captured:
  - action potentials
  - local field potentials

an endovascular approach



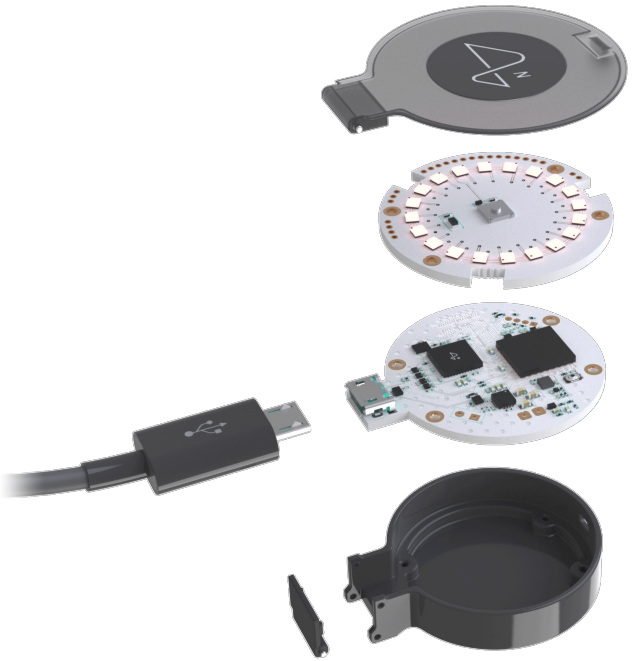
https://synchron.com/platform

Example 3. Invasive Brain Computer Interfaces



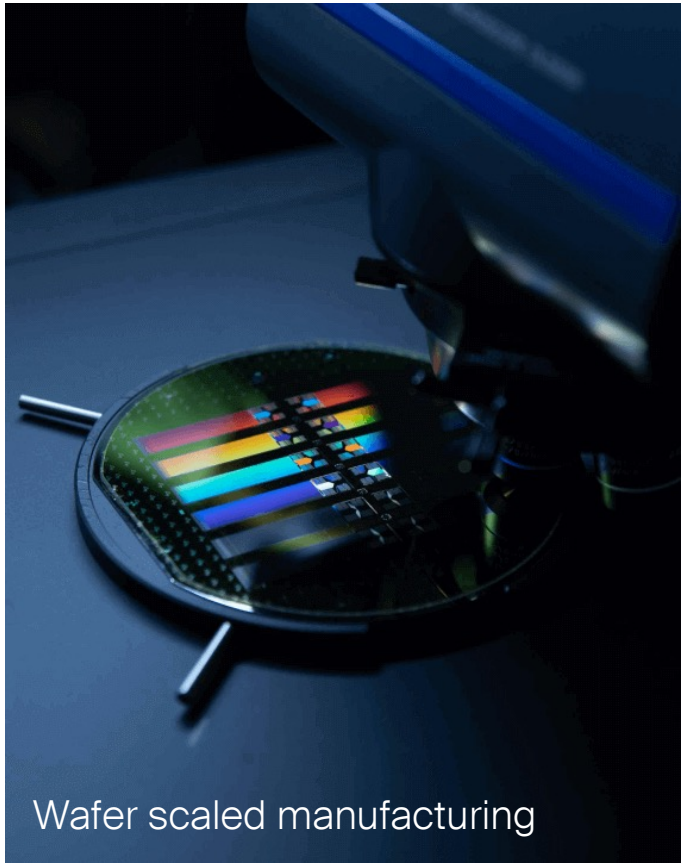
Micron scale threads
1024 microelectrodes

Sealed implantable electrodes
Process – stimulate - transmit

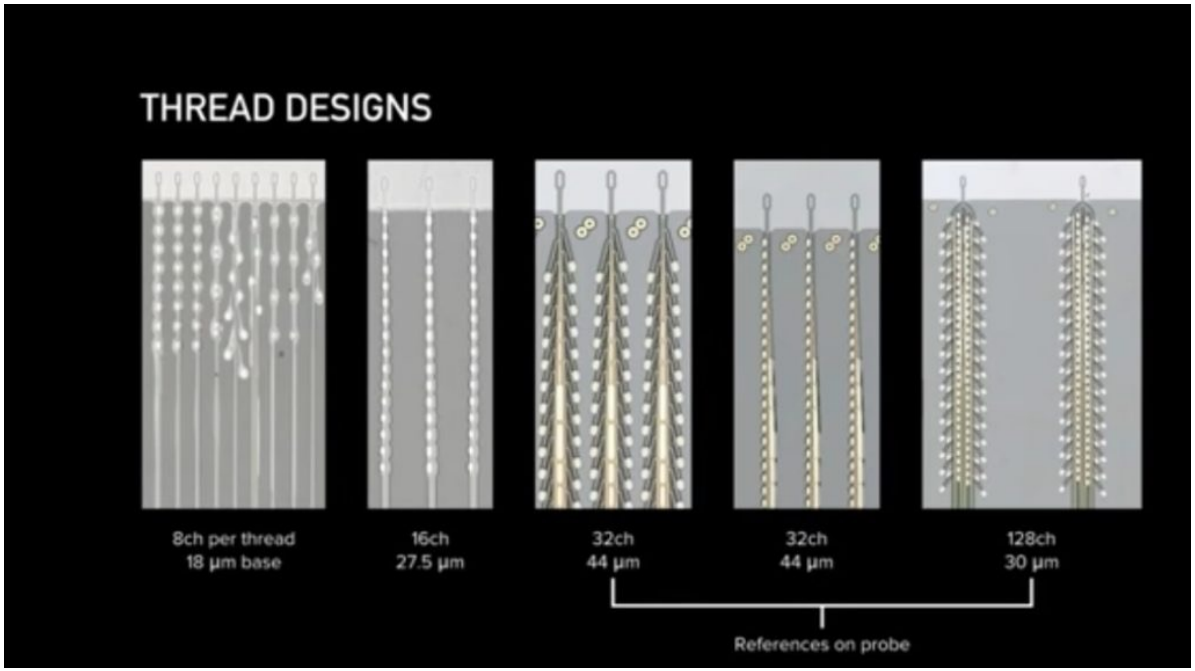


Inductive charger
https://neuralink.com/platform

Example 3. Invasive Brain Computer Interfaces



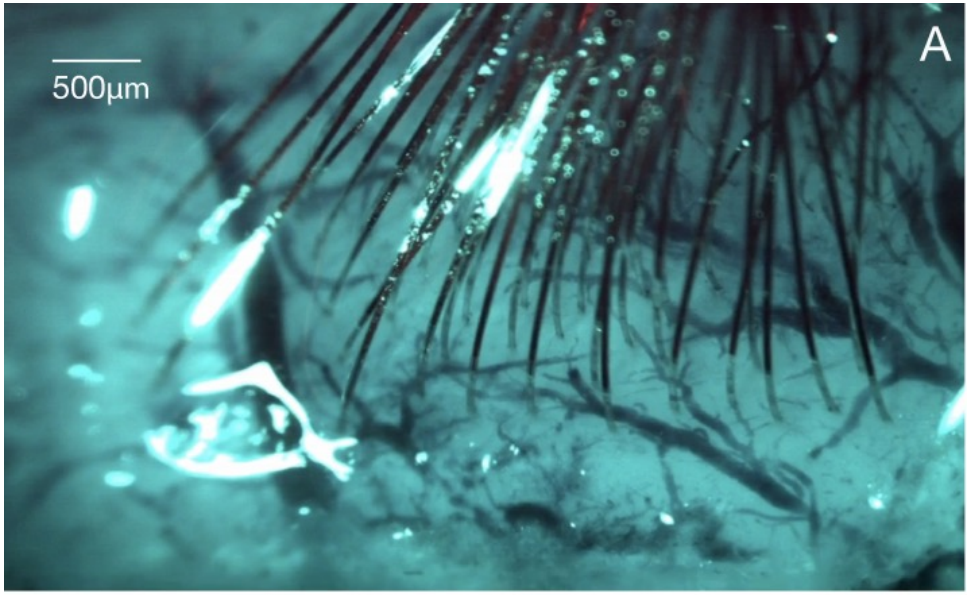
Wafer scaled manufacturing



Micron scale threads
2048 microelectrodes

Example 3. Miniaturized and high density brain electrodes

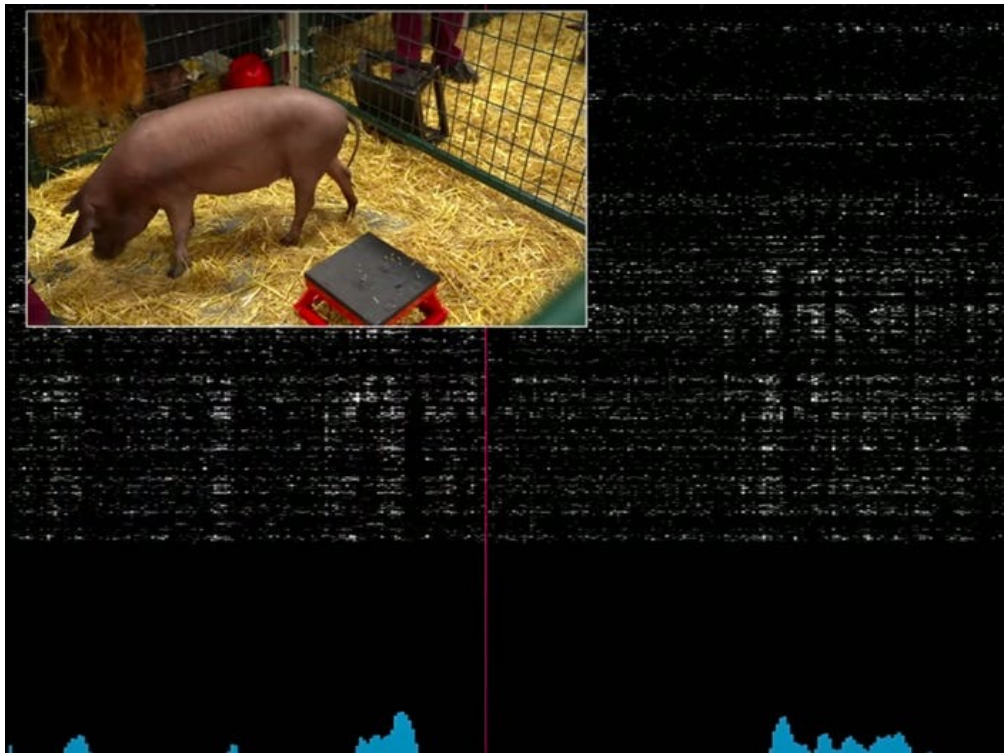
Robot-assisted neurosurgery



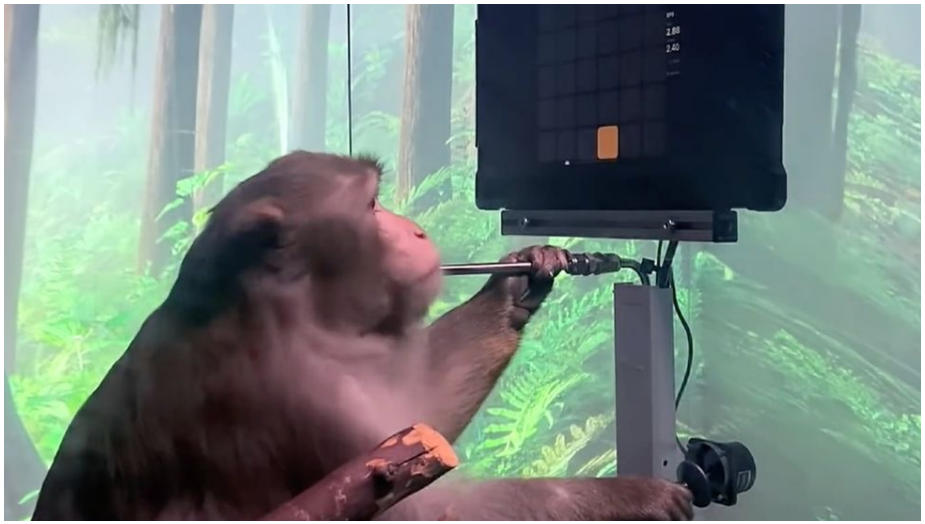
Neural electrodes: platinum/polyimide ‘threads’

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