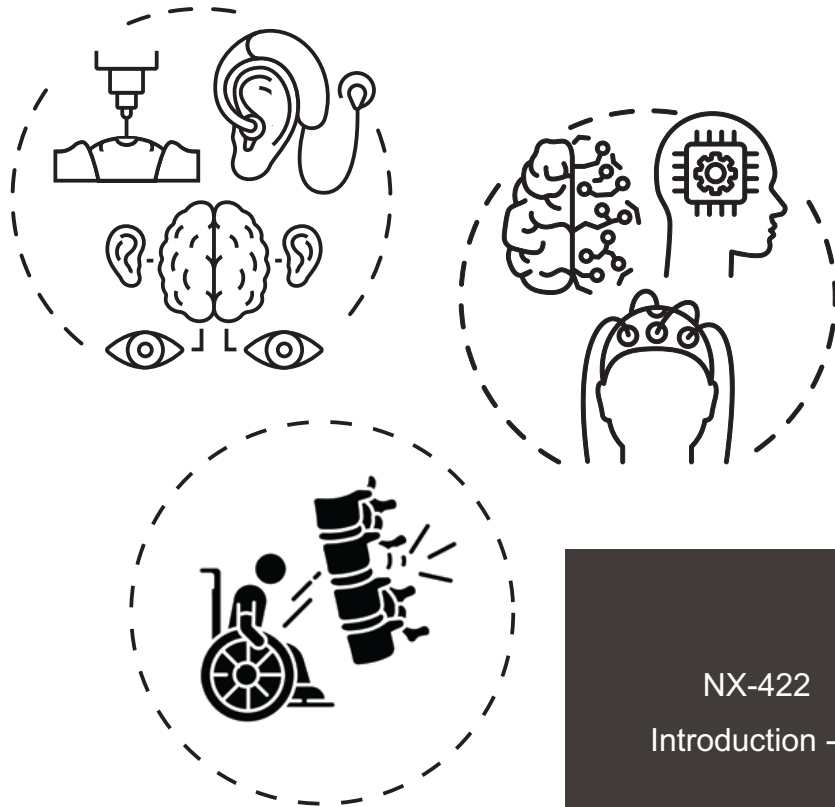




Neural Interfaces

NX-422

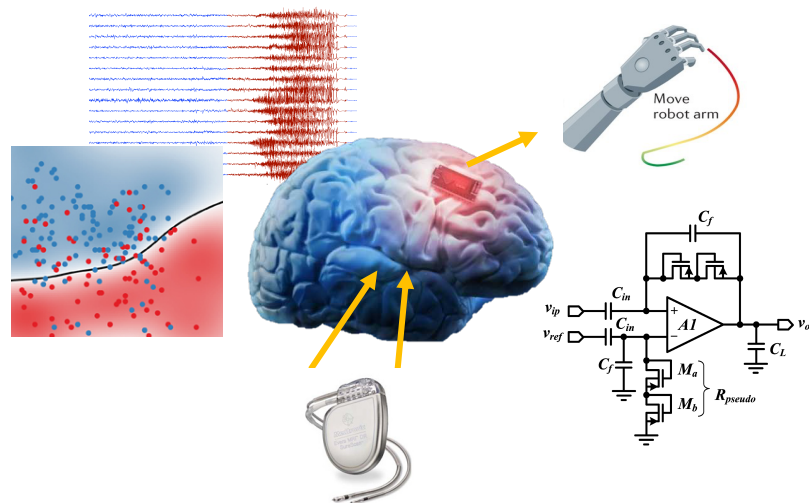
Introduction - 2

Mahsa Shoaran

IEM and Neuro-X Institutes

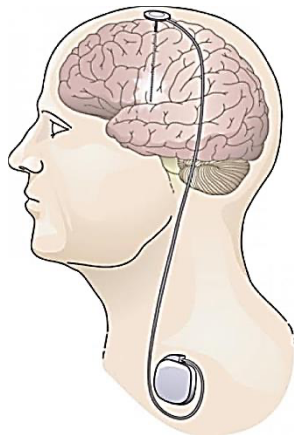
Neural Interfaces: An interdisciplinary field that overlaps with many areas of **Engineering, Neuroscience, and Computer Science** including:

- microfabrication
- biomaterials
- neurophysiology
- electrochemistry
- **circuits and electronics**
- computational neuroscience
- neurology & neurosurgery
- mechanical engineering
- control, signal processing
- AI and machine learning...



- No textbook, **research-oriented**
- We will use impactful papers published in the field, including the most recent innovations and breakthrough system demonstrations
- Some reading materials or book chapters will be posted on moodle
- General reference book on **integrated circuits**:
 - Design of Analog CMOS Integrated Circuits, B. Razavi
 - Analysis and Design of Analog Integrated Circuits, P. R. Gray and R. G. Meyer

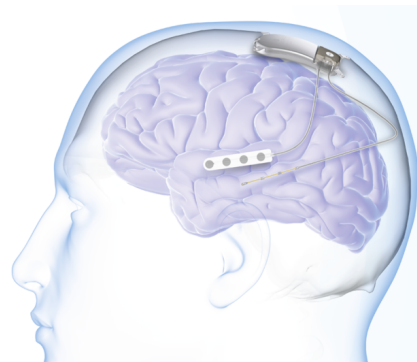
Examples of Neural Interface Technologies



Deep-Brain Stimulation
(DBS) for Parkinson's



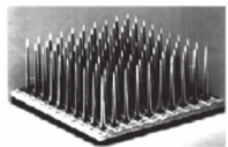
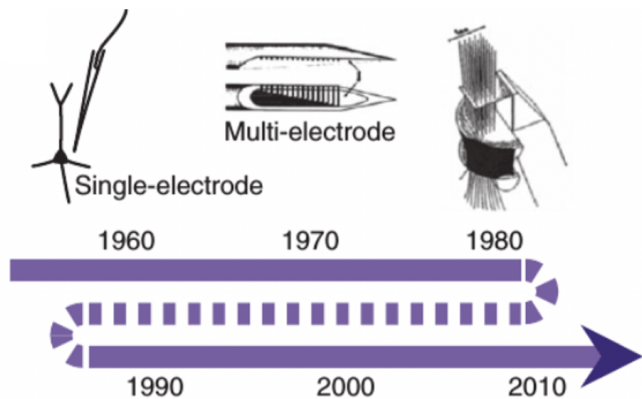
Epilepsy Implants



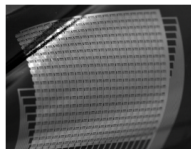
Motor Prosthetics
(Brain-Machine Interfaces)

<https://vnstherapy.com/>
<https://www.neuropace.com/>
<https://www.medtronic.com/>
<https://www.brown.edu/braingate>

Trend: Higher Channel Counts

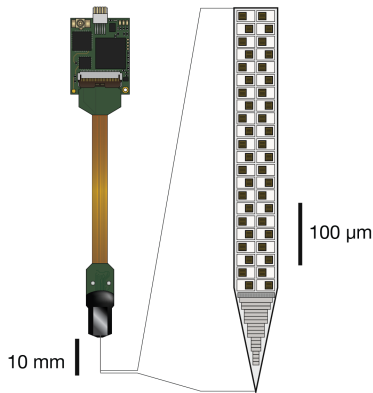


Utah array

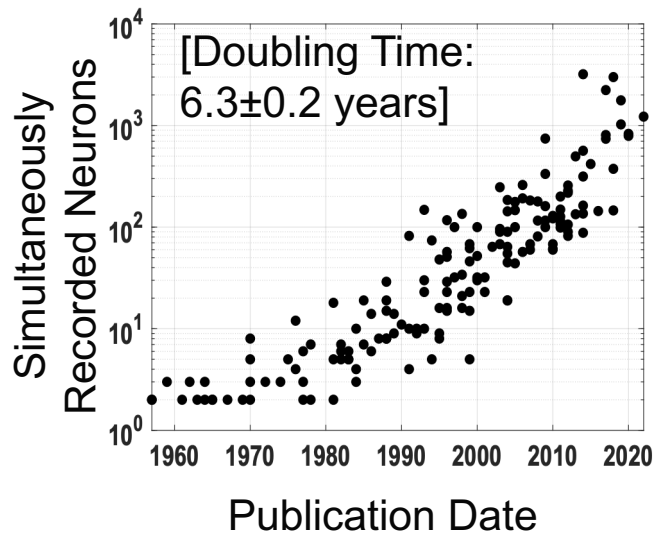
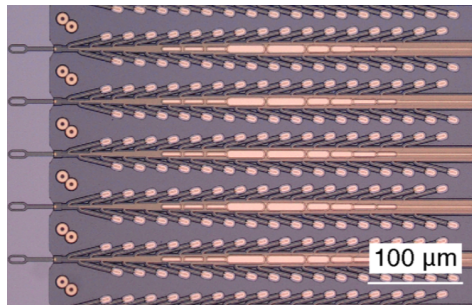


Surface electrodes

Neuropixels, 960CH

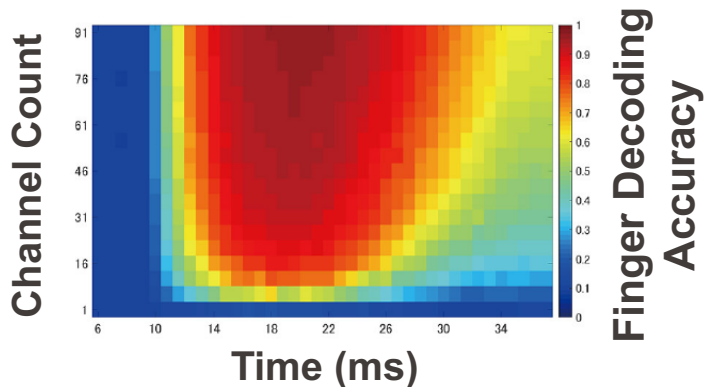
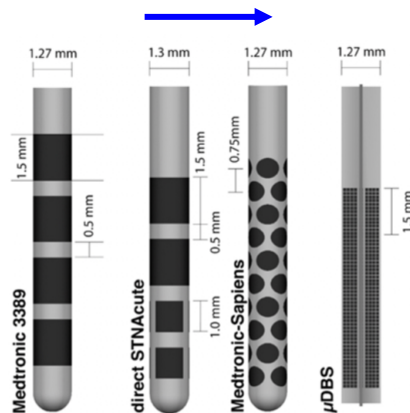
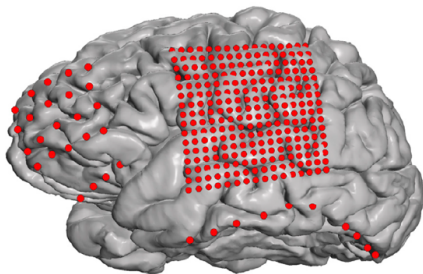


Nerualink threads, 3072CH



Source: <https://stevenson.lab.uconn.edu/scaling/>

High-Channel-Count Sensing & Stimulation



Epilepsy

- Early detection of seizure onset
- Precise localization of seizure foci

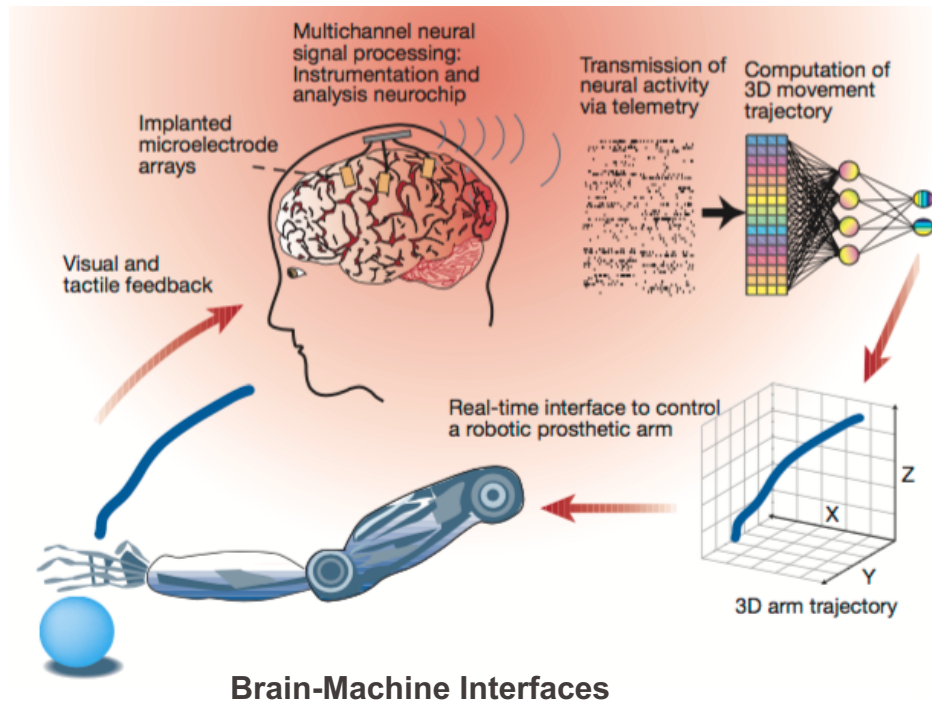
Movement Disorders

- Improved symptom detection/suppression
- Reduced side effects of stimulation

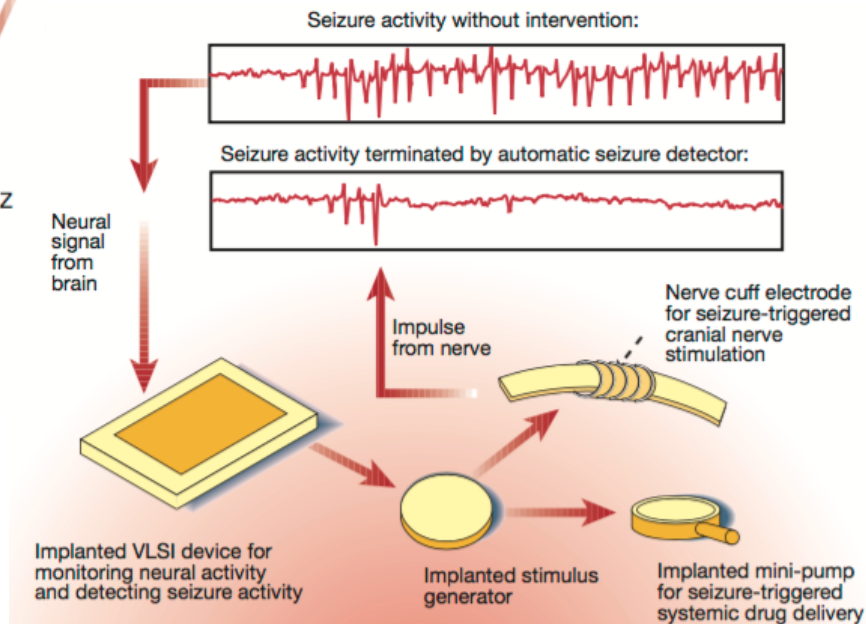
Motor Prosthetics

- Precise motor decoding
- More natural prosthetic control

Two Types of Neural Interfaces

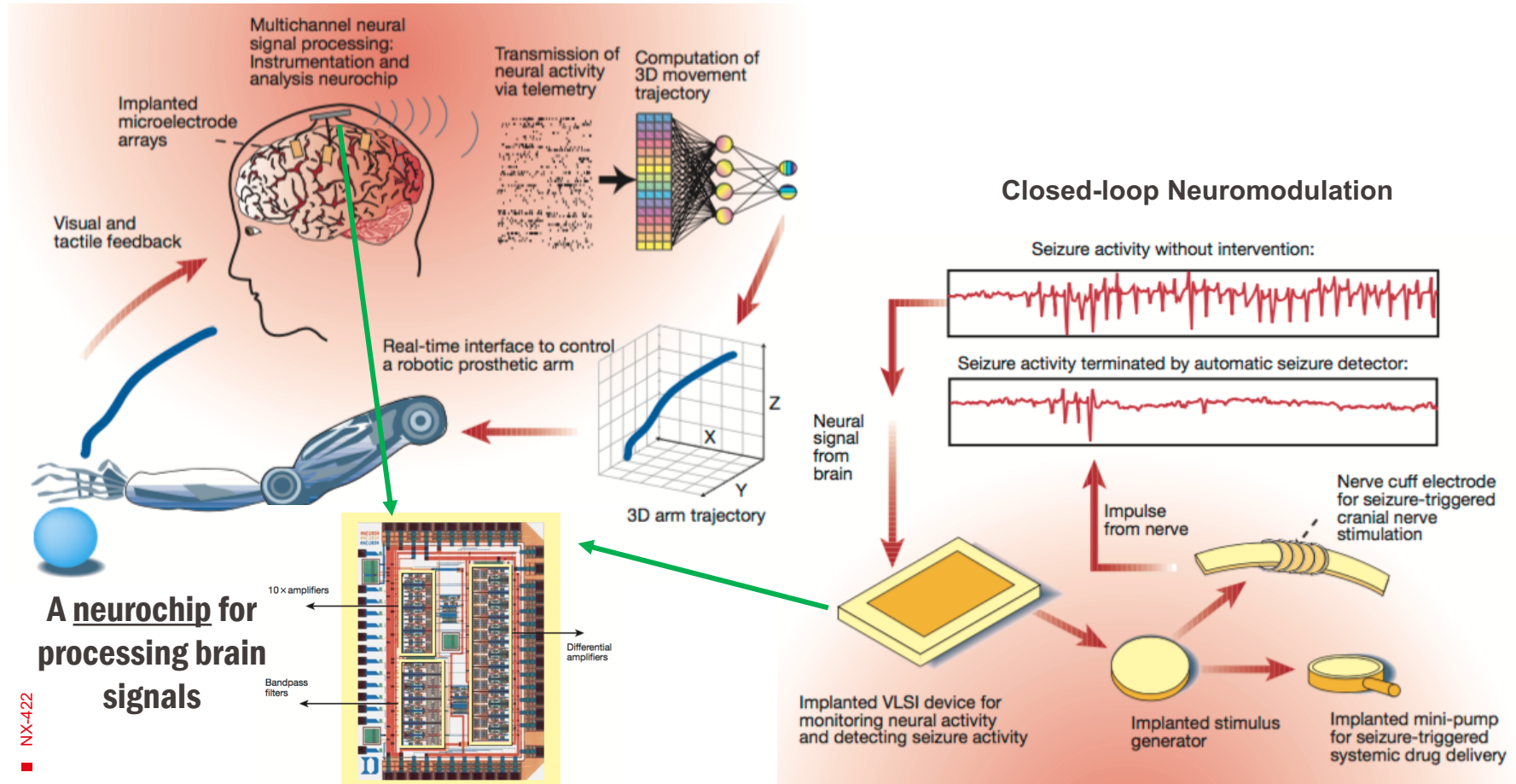


Closed-loop Neuromodulation

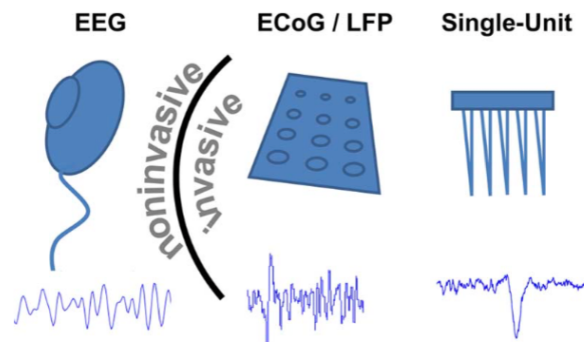
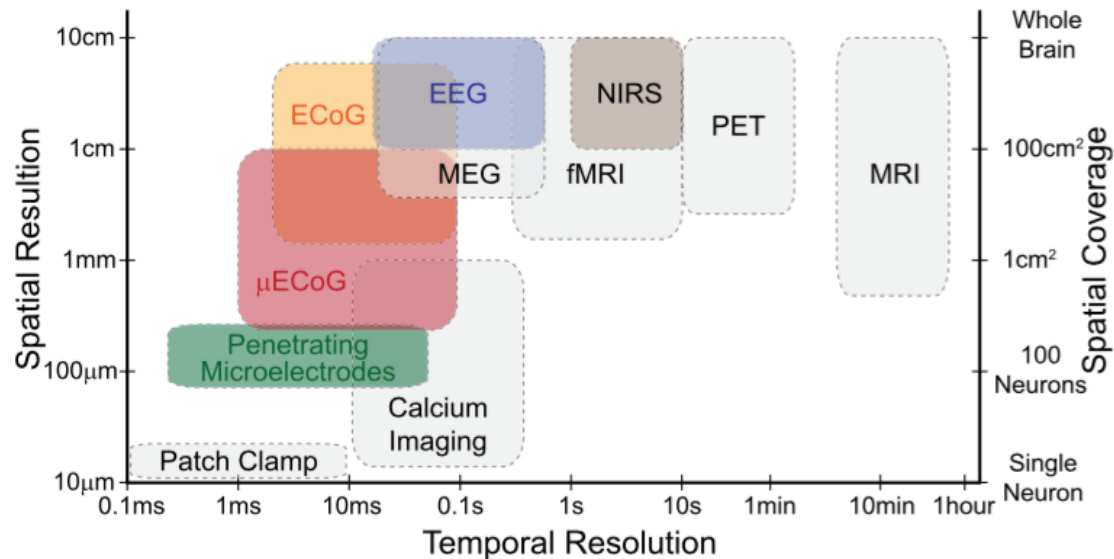


M. A. L. Nicolelis, Nat 2001

Two Types of Neural Interfaces

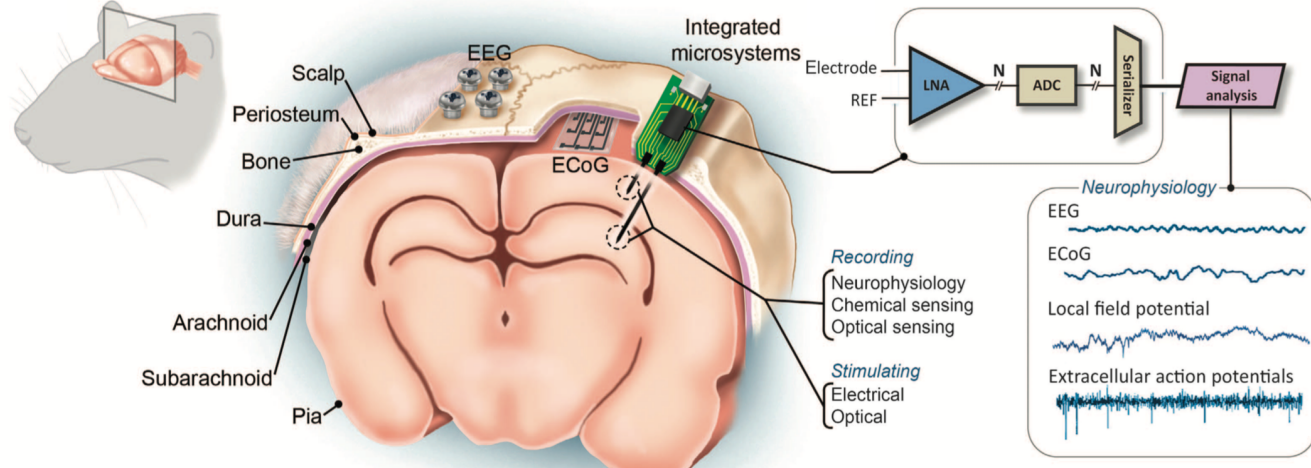
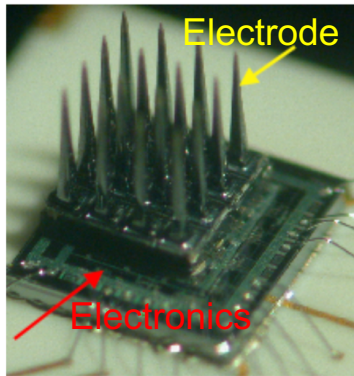


Neural Recording: Resolution and Coverage

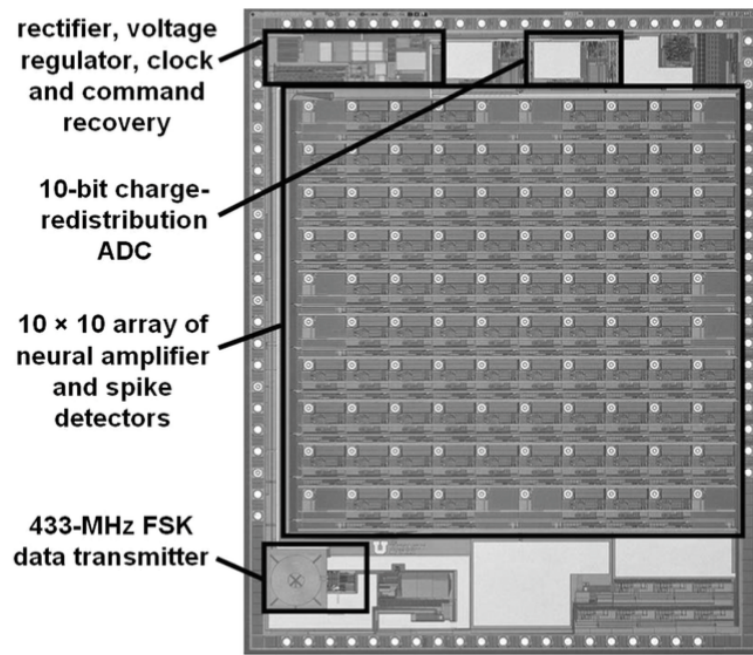
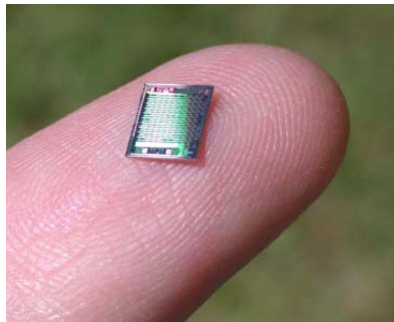


Integration of electrode array and electronics:

- Miniaturization
- Encapsulation
- Telemetry
- Heat dissipation
- On-chip processing
- ...



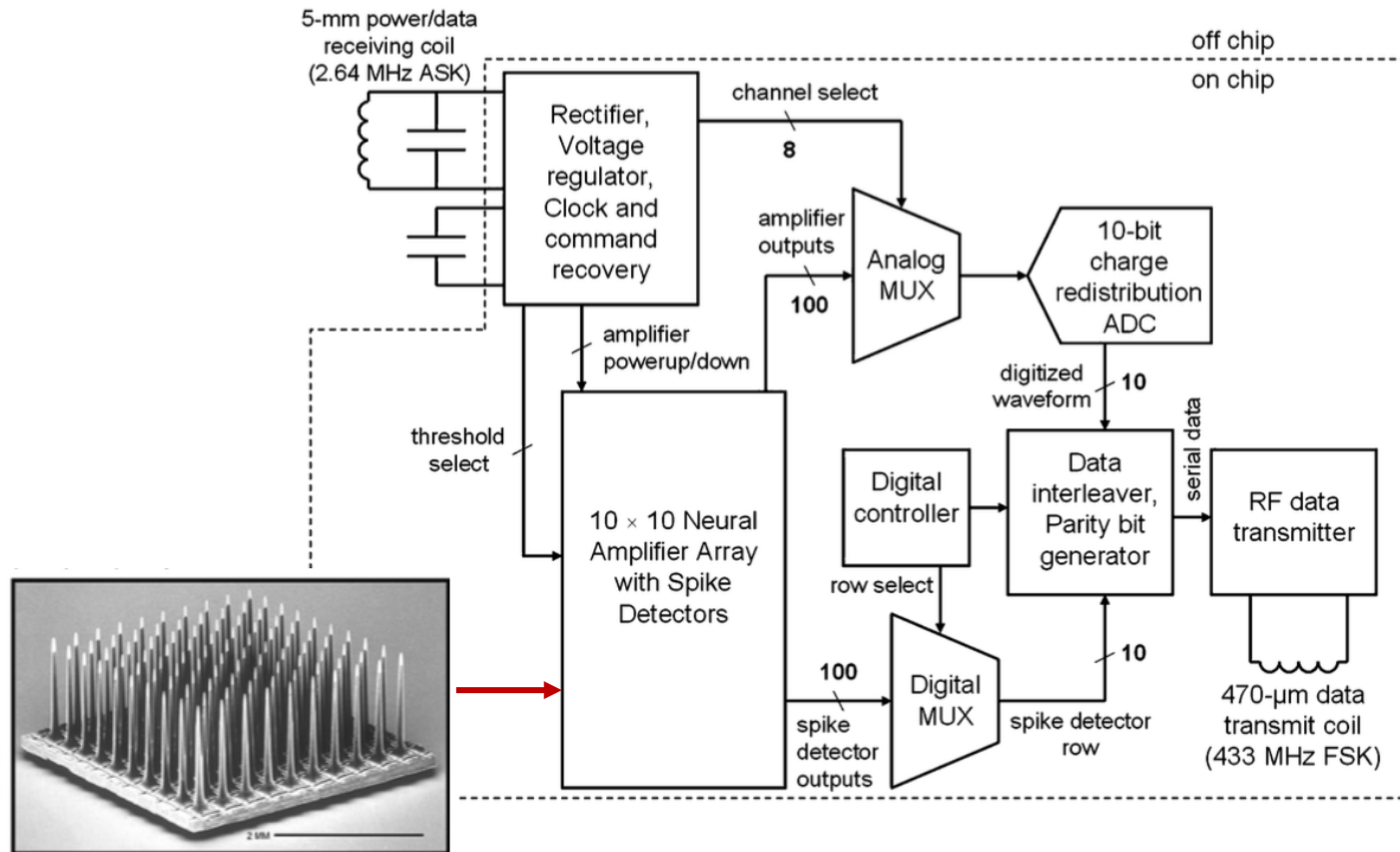
- Microchips include **amplification, filtering, digitization, compression, processing: feature extraction/spike detection/classification, wireless power and data telemetry, bias generation, stimulation, ...**
- Power and area are highly limited



Die photo of 4.7 mm x 5.9 mm chip

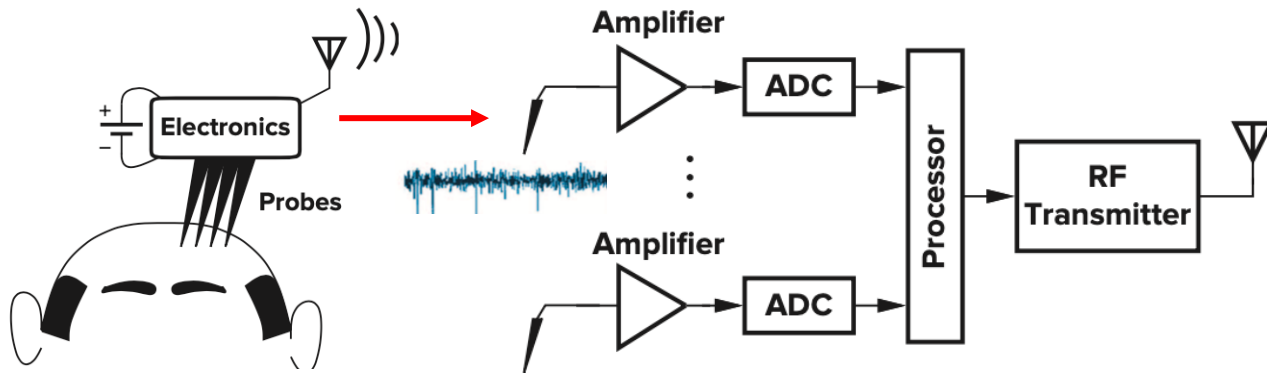
R. Harrison, JSSC 2003

Neural Recording Systems

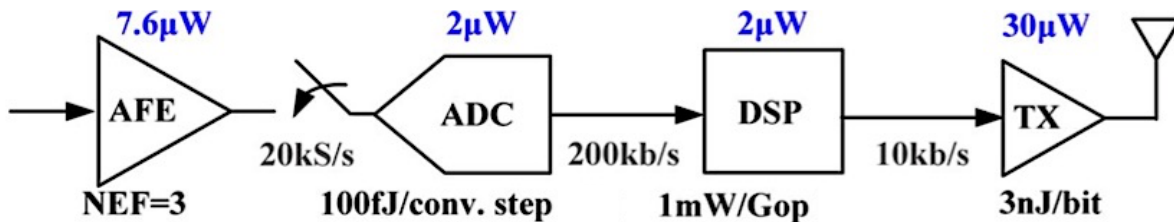


R. Harrison, JSSC 2003

Neural Interface: Analog and Digital Circuit Design

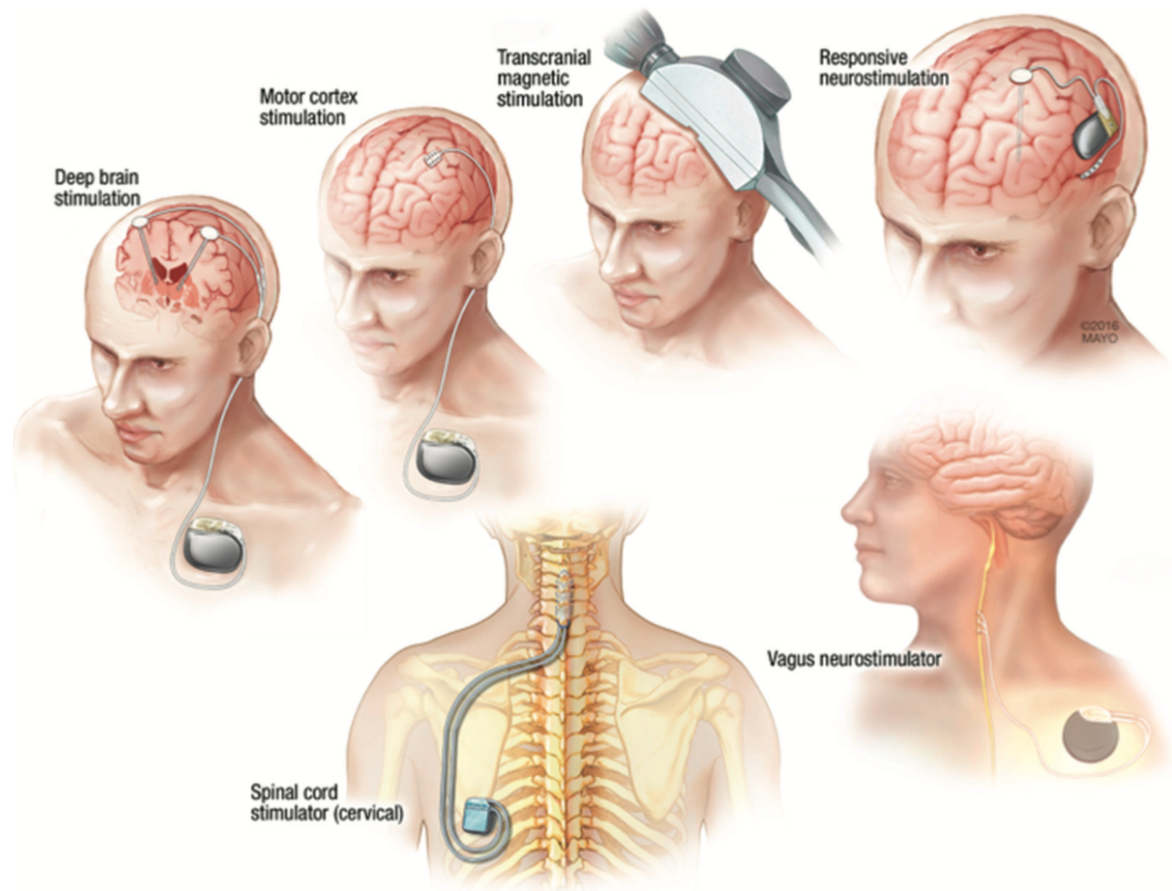


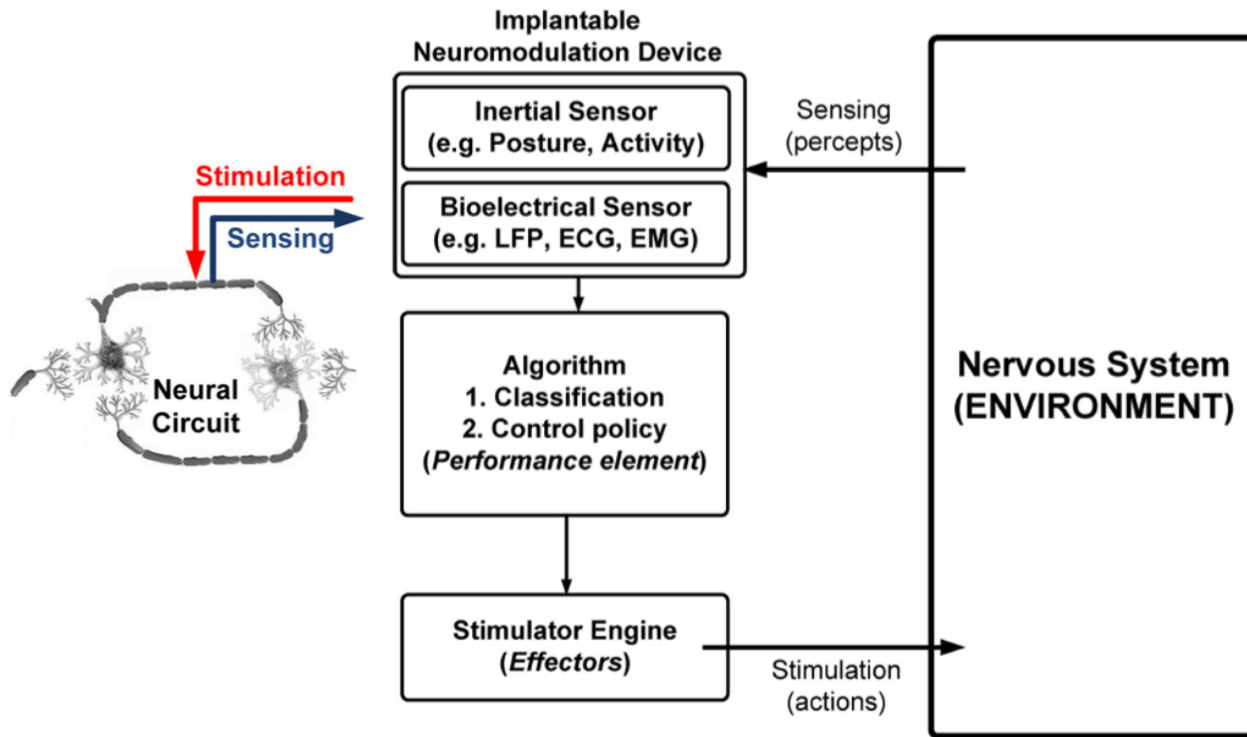
- The typical circuit blocks used in sensors for medical monitoring and their associated energy cost and power consumption



F. Chen et al, JSSC'12

Neurostimulation (Neuromodulation)





S. Stanslaski et al, TNSRE'12

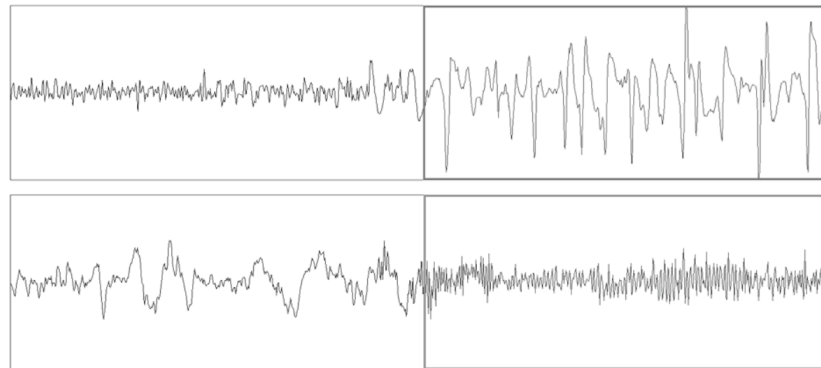
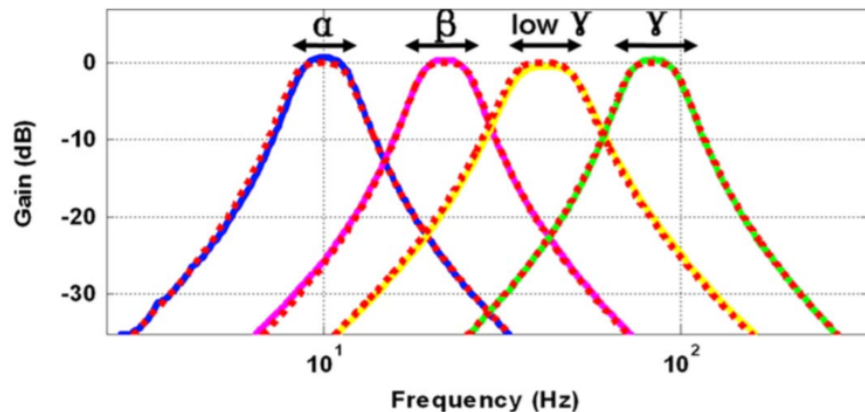
Frequency Components of Neural Signals

- < 4 Hz : **Delta** (slow wave sleep)
- 4–8Hz: **Theta** (REM)
- 8 – 12 Hz : **Alpha** (drowsiness)
- 12 – 30 Hz : **Beta** (decision-making, motor planning)
- 30 – 100 Hz: **Gamma** (sensory attentive)

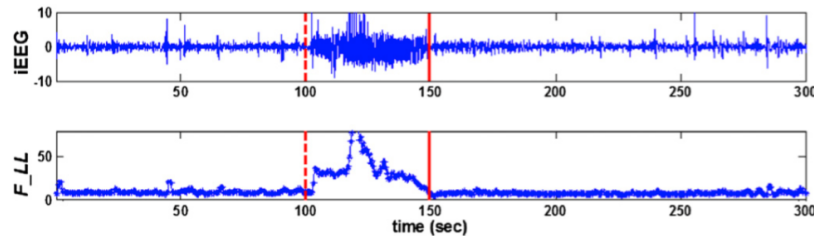
These help distinguish various disease states

- Slowing of EEG: Alzheimer's. Higher Beta: in Parkinson's. Reduced connectivity over Theta band: mental disorders ...

Feature (Biomarker) Extraction



$$\text{Line length} = \sum_{i=2}^N |x_i - x_{i-1}|$$



- Seizure patterns vary among patients >> need a classifier

