

Neural Interfaces

NX-422

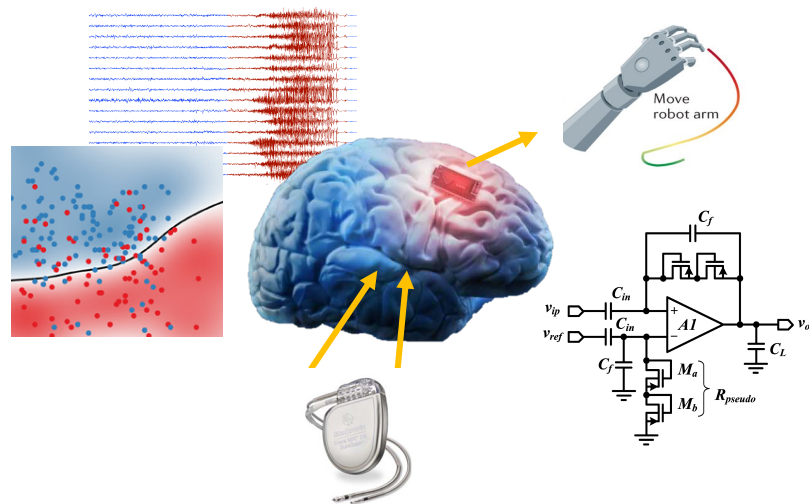
Introduction – Neural interface electronics

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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...

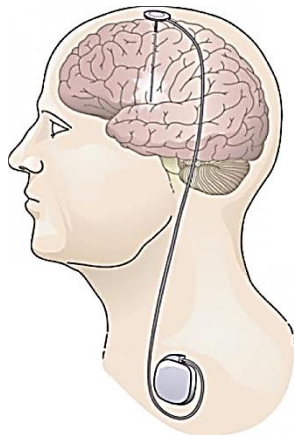


- No textbook, **research-oriented**
- We will use impactful papers published in the field, including the most recent innovations and breakthrough system demonstrations

- 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

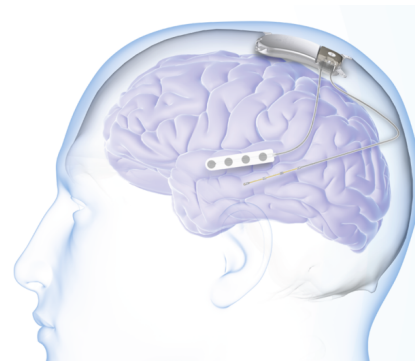
Examples of Neural Interface Technologies



Deep-Brain Stimulation
(DBS) for Parkinson's



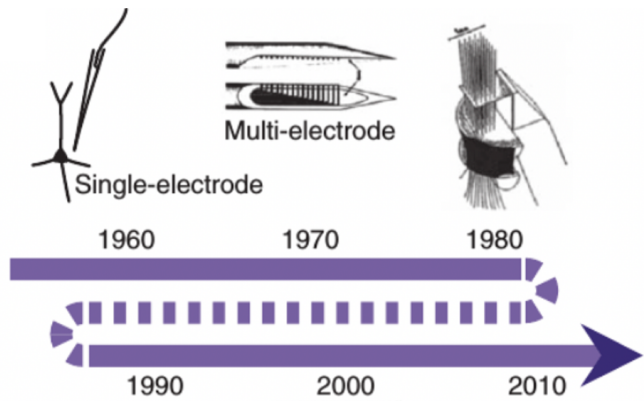
Epilepsy Implants



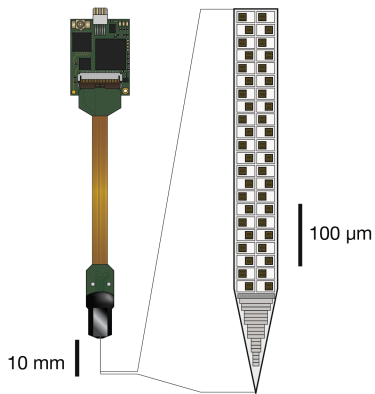
Motor Prosthetics
(Brain-Computer Interfaces
or BCI)

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

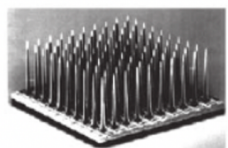
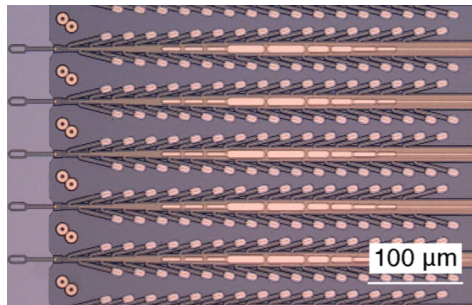
Trend: Higher Channel Counts



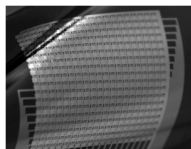
Neuropixels, 960CH



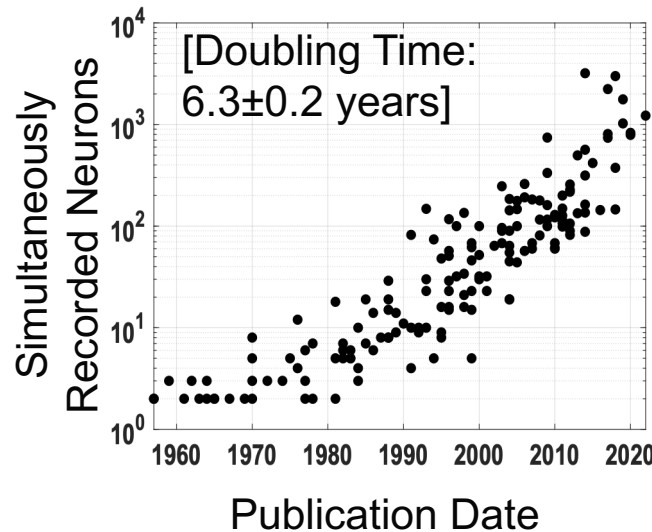
Nerualink threads, 3072CH



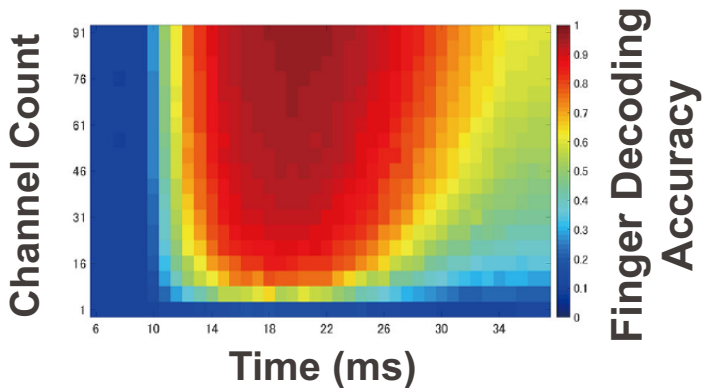
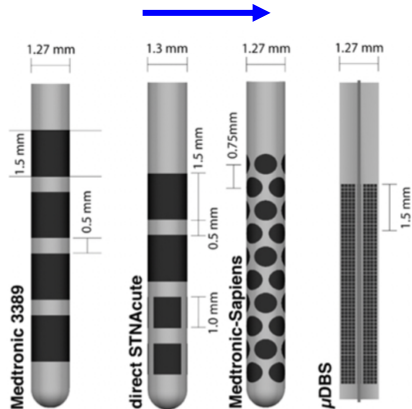
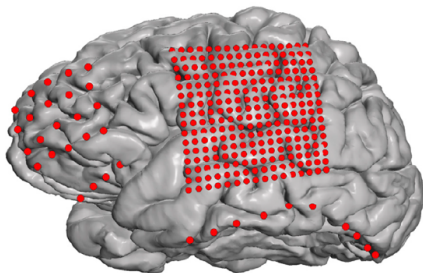
Utah array



Surface electrodes



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



Epilepsy

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

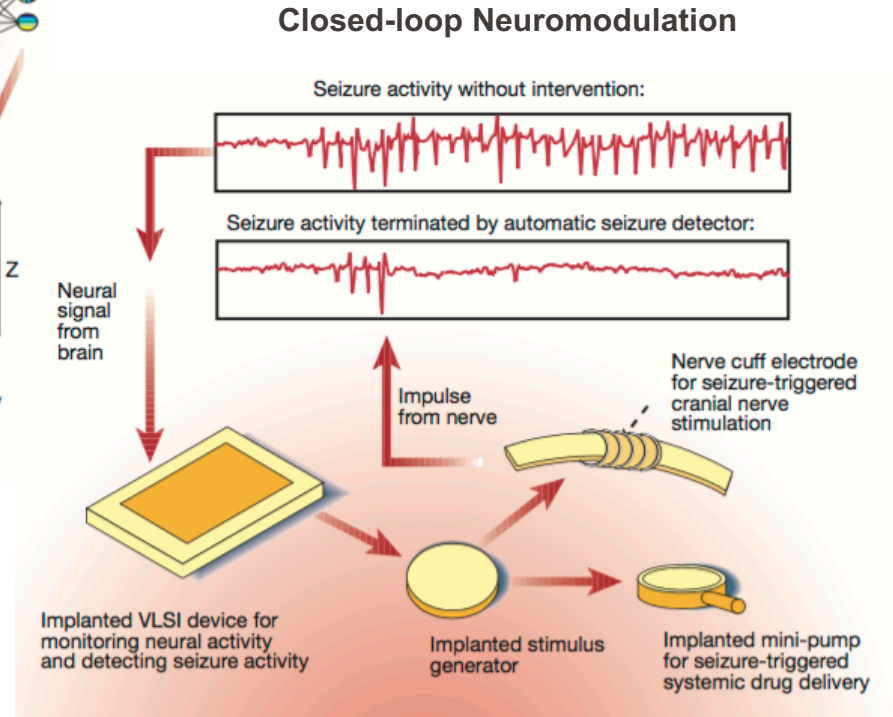
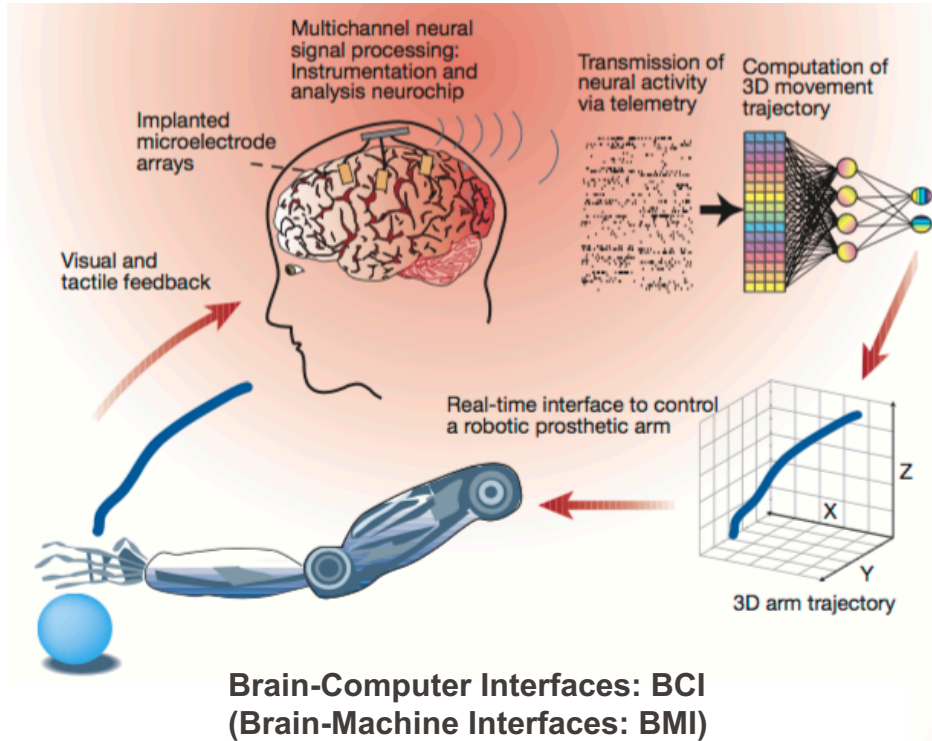
Movement Disorders

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

Motor Prosthetics

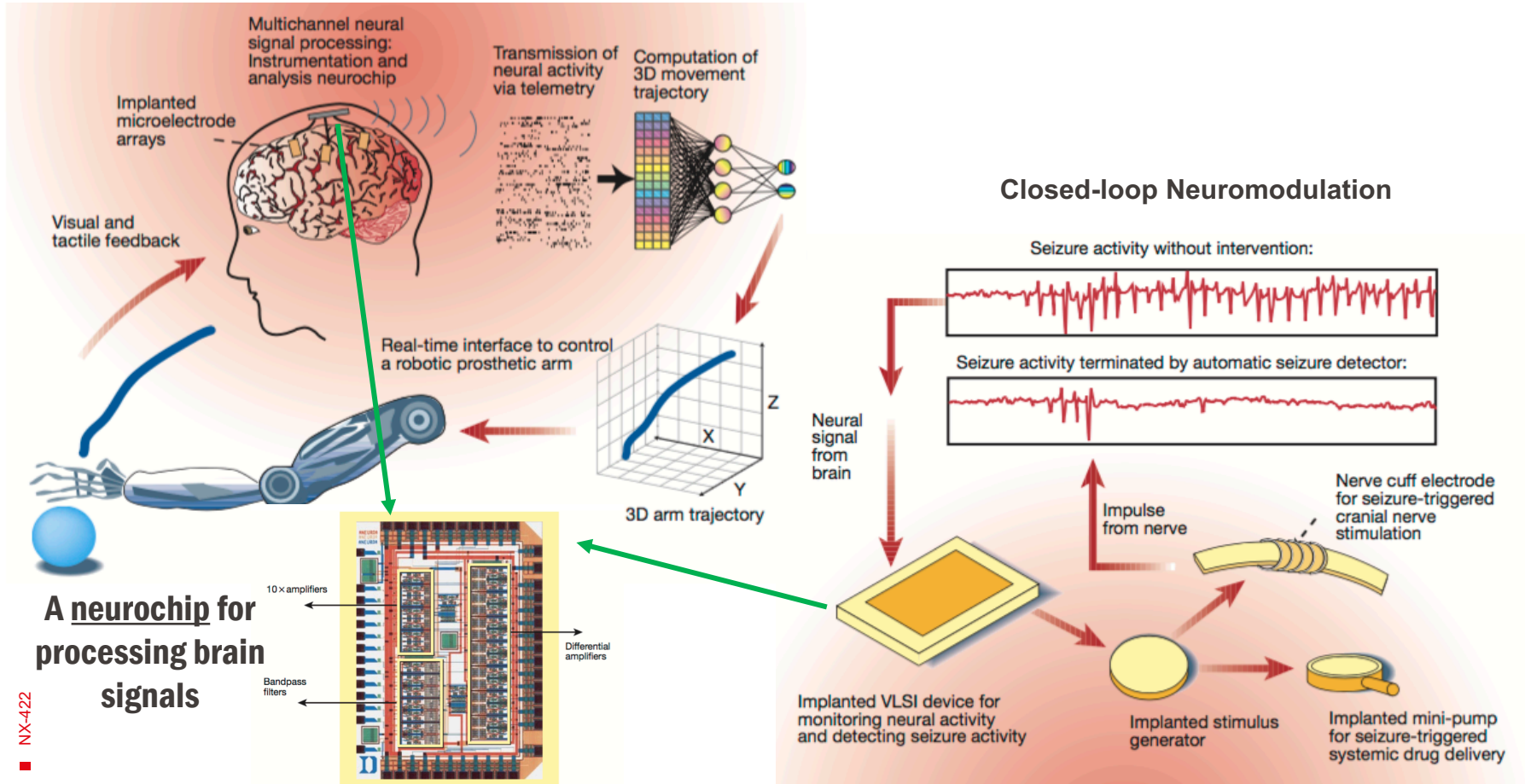
- Precise motor decoding
- More natural prosthetic control

Two Types of Neural Interfaces

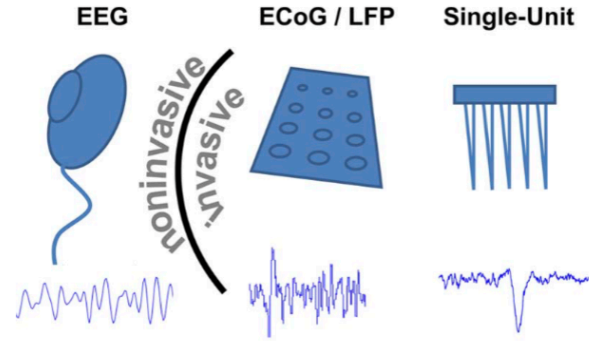
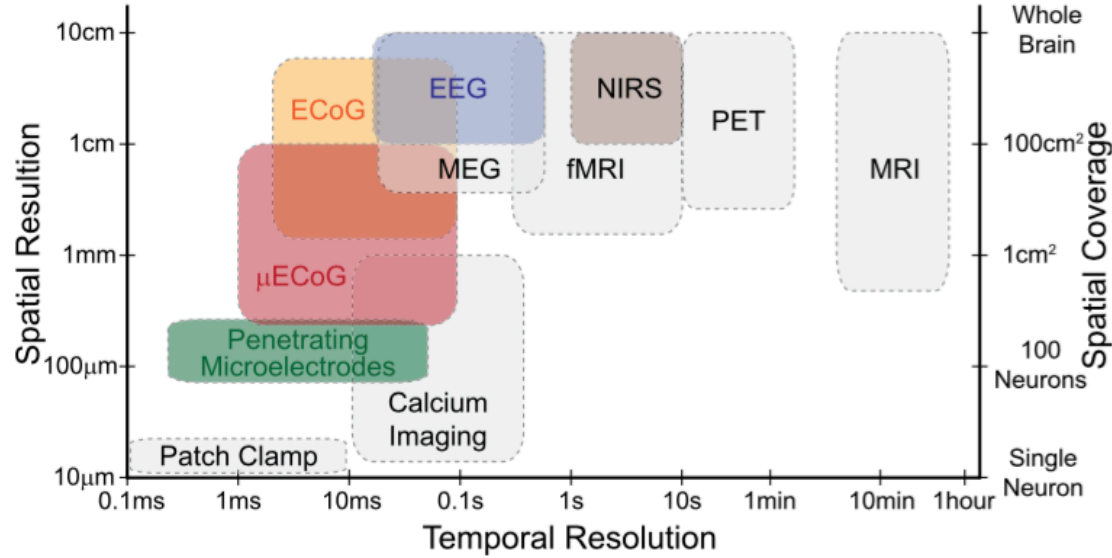


M. A. L. Nicolelis, Nat 2001

Two Types of Neural Interfaces

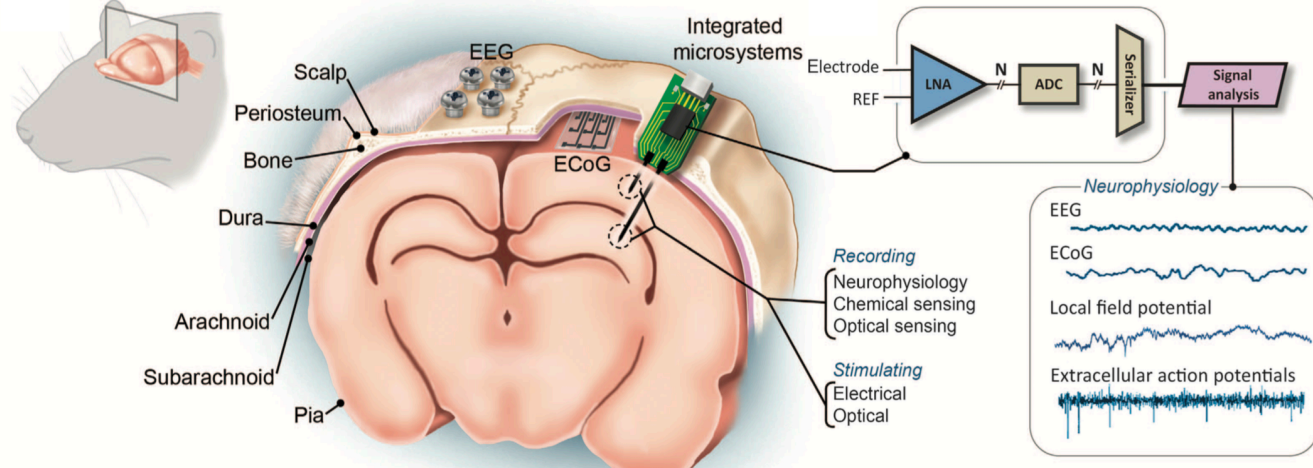
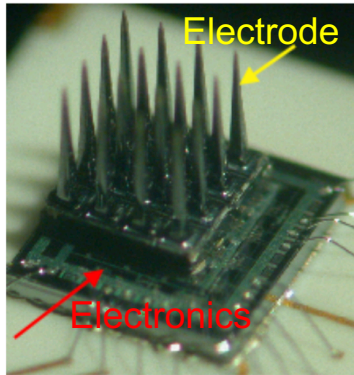


Neural Recording: Resolution and Coverage

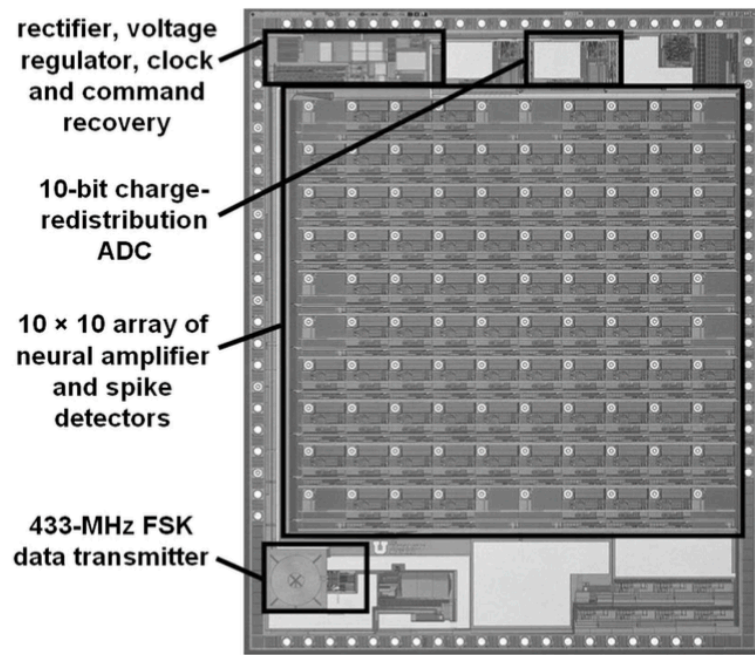
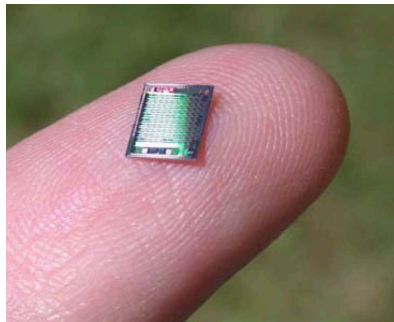


Integration of electrode array and electronics:

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

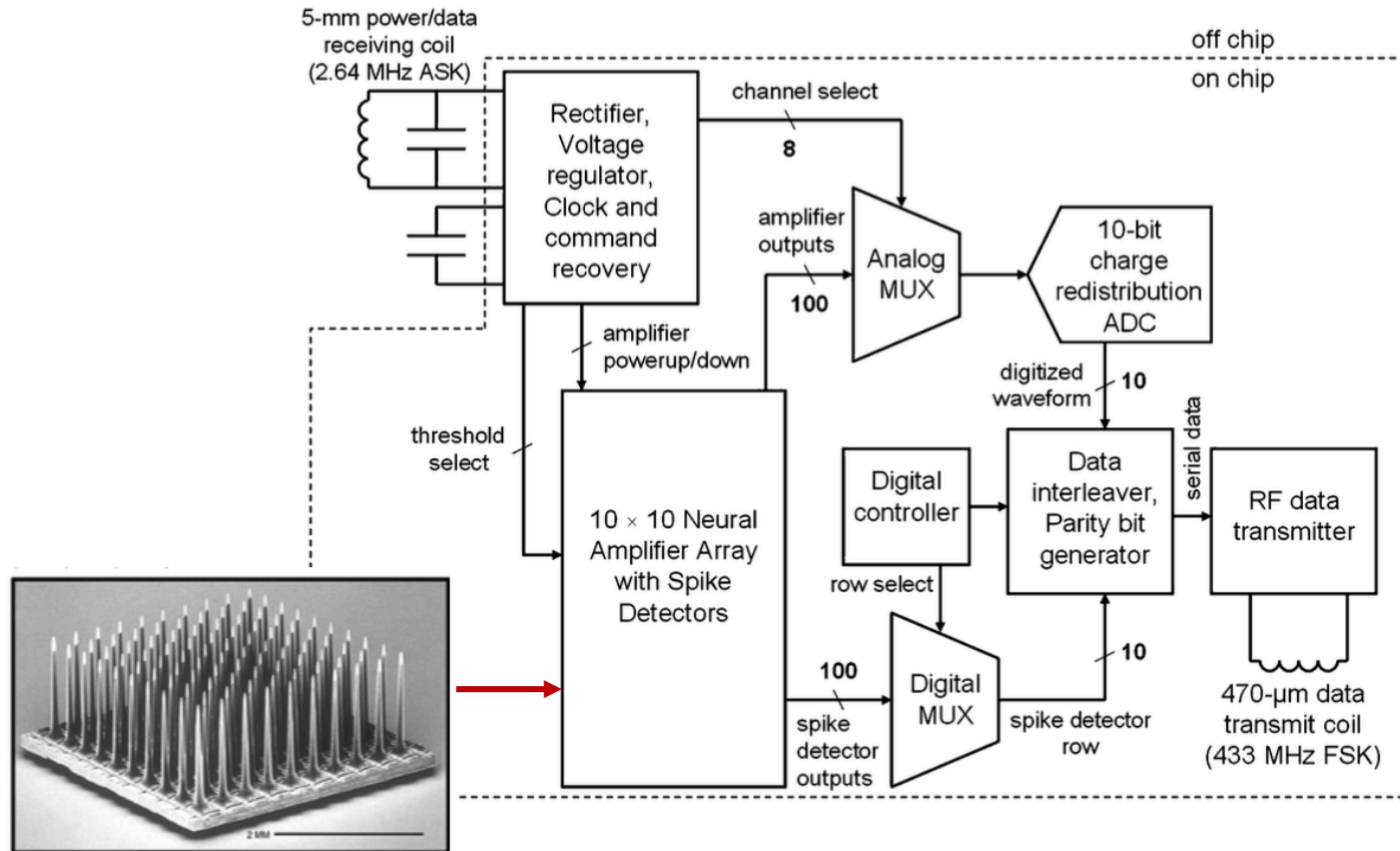


- Microchips include **amplification, filtering, digitization, compression, processing: feature extraction/spike detection/classification, wireless power and data telemetry, bias generation, stimulation, ...**
- Power and area are highly limited

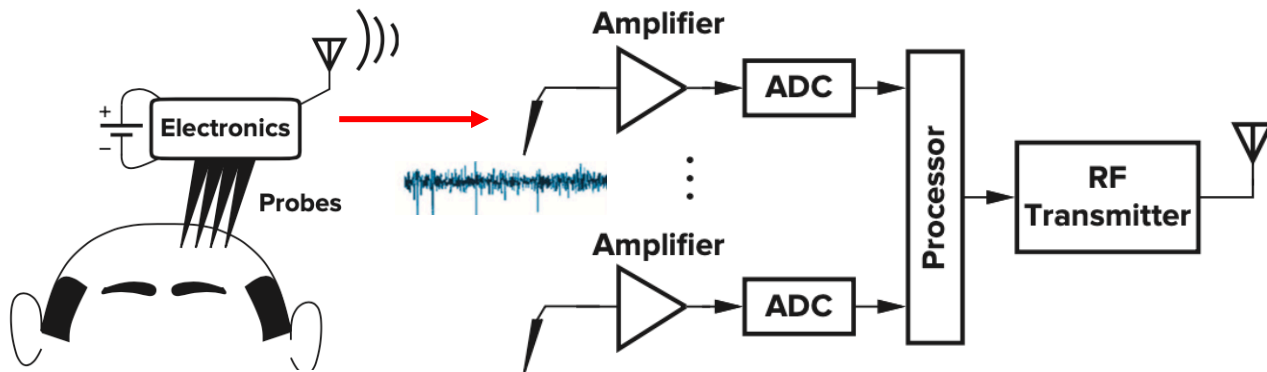


Die photo of 4.7 mm x 5.9 mm chip

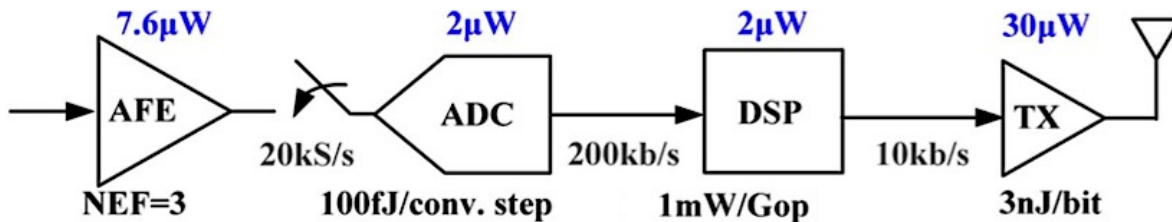
R. Harrison, JSSC 2003



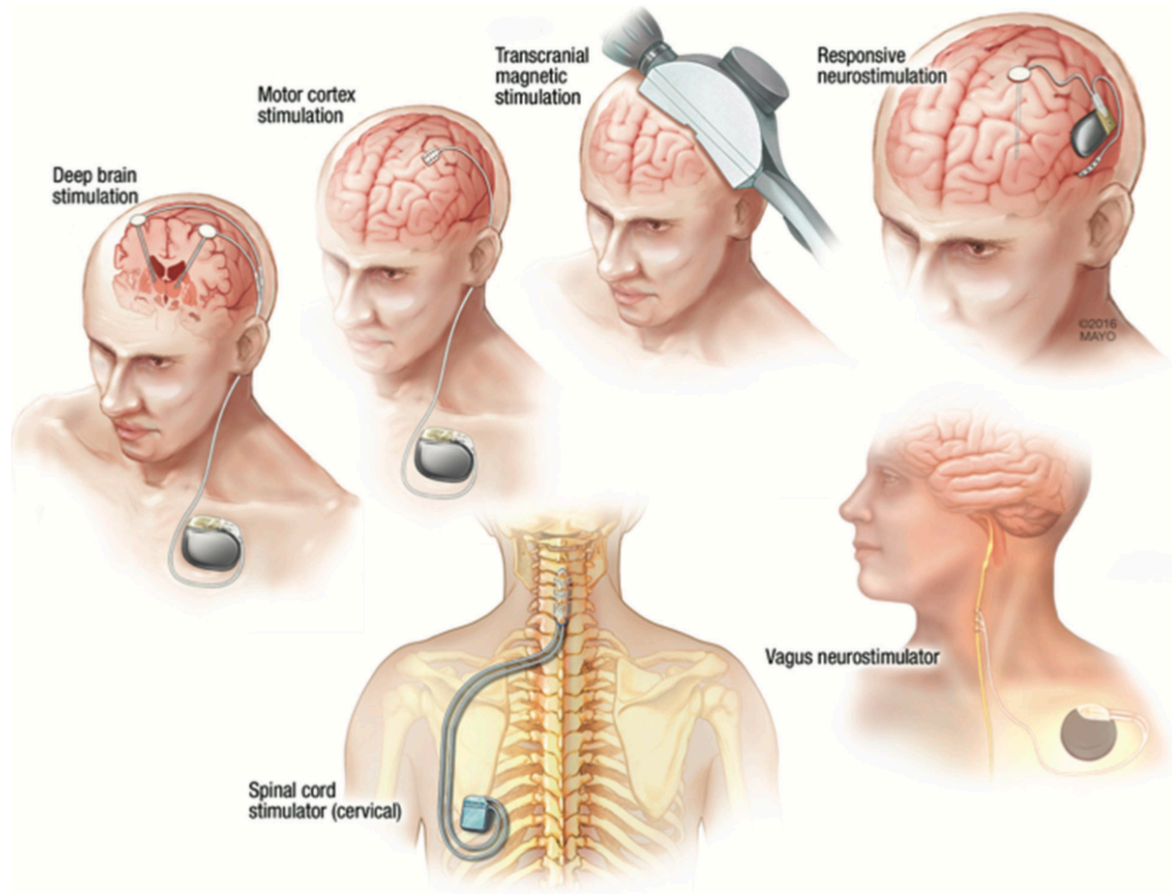
R. Harrison, JSSC 2003

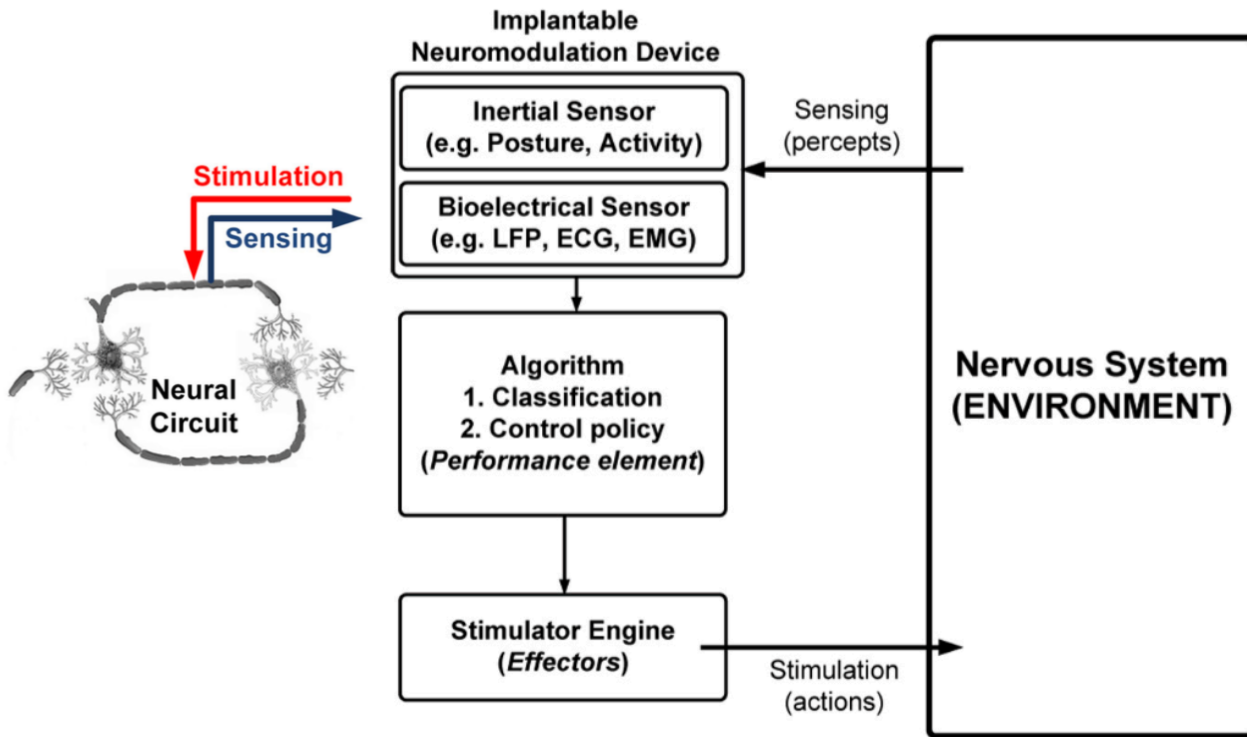


- The typical circuit blocks used in sensors for medical monitoring and their associated energy cost and power consumption



F. Chen et al, JSSC'12



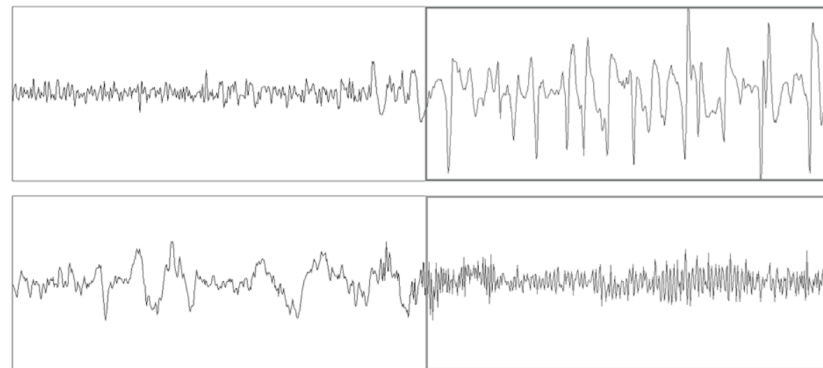
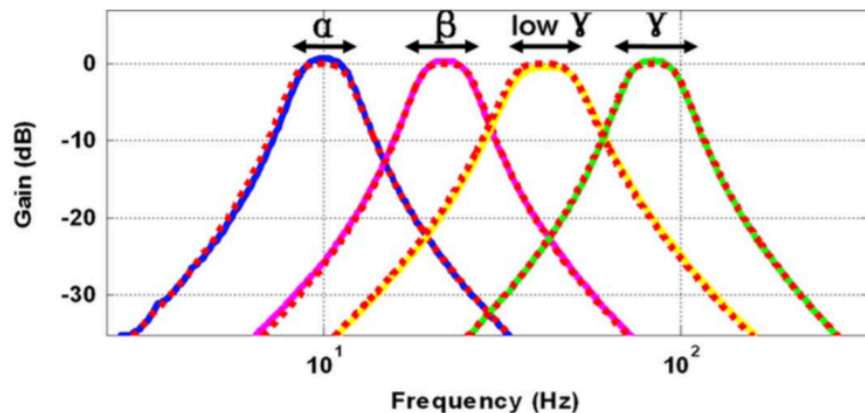


S. Stanslaski et al, TNSRE'12

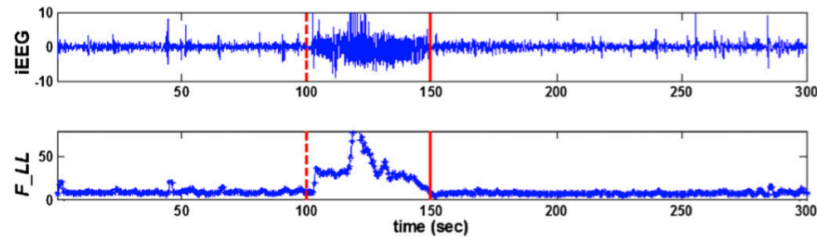
- < 4 Hz : **Delta** (slow wave sleep)
- 4–8Hz: **Theta** (REM)
- 8 – 12 Hz : **Alpha** (drowsiness)
- 12 – 30 Hz : **Beta** (decision-making, motor planning)
- 30 – 100 Hz: **Gamma** (sensory attentive)

These help distinguish various disease states

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



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



- Seizure patterns vary among patients >> need a classifier

