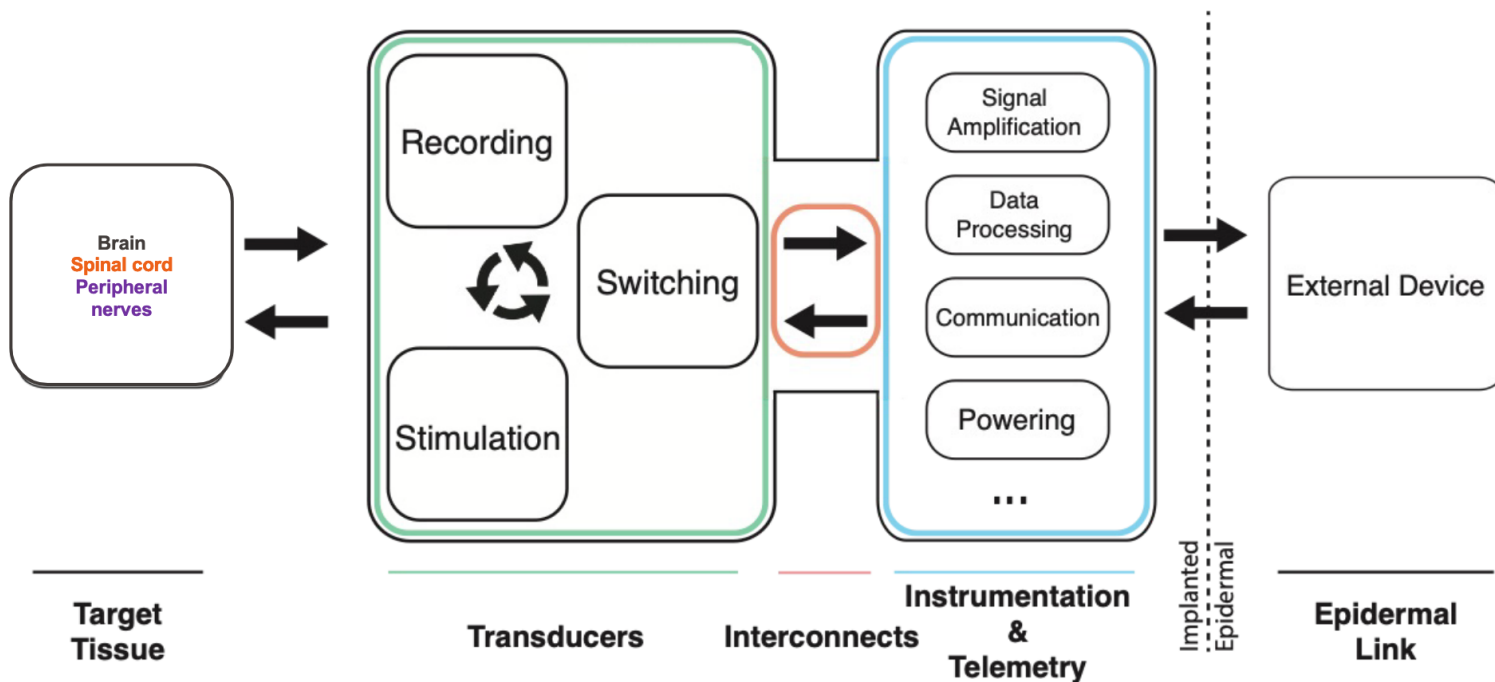


Neural Interfaces

NX-422
Miniaturized
CMOS-based Interfaces

Mahsa Shoaran
IEM and Neuro-X Institutes



- The goal of BCI technology is to give severely paralyzed people alternative ways to communicate

Simple interfaces:

- Paint program, email writing
- TV controls, eating, drinking
- Robotic arm control



- The goal of BCI technology is to give severely paralyzed people alternative ways to communicate

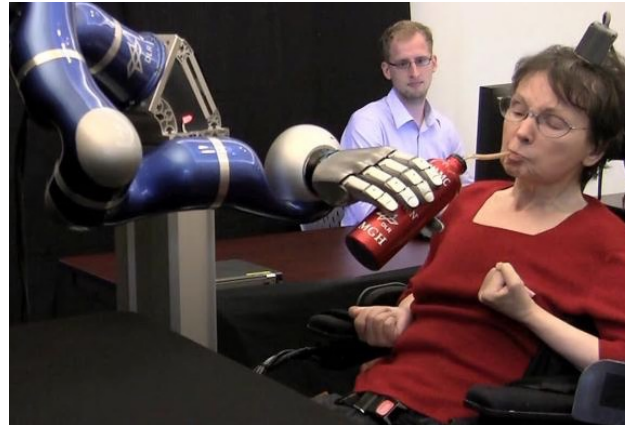
Simple interfaces:

- Paint program, email writing
- TV controls, eating, drinking
- Robotic arm control



Future:

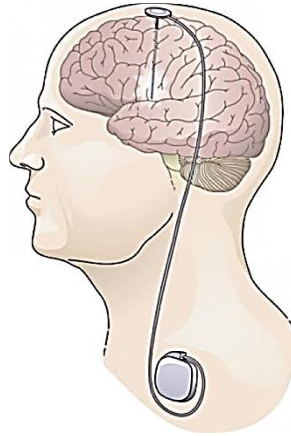
- More electrodes, richer input signal
- Better algorithms and AI for more complex decoding tasks
- **Better hardware for chronic use outside the clinic**



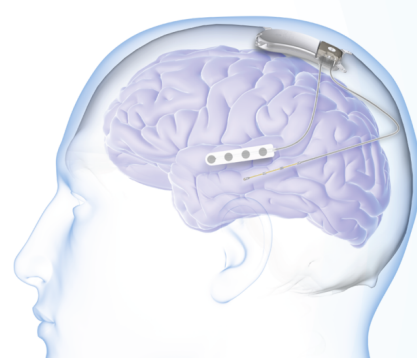
- Neurostimulation to suppress disease symptoms, or replace a function, trigger movement, ...

Future:

- Smaller devices for **minimally-invasive surgery**
- Advanced electronics for **high-resolution recording and safe stimulation**
- Advanced algorithms and circuits for **closed-loop control**

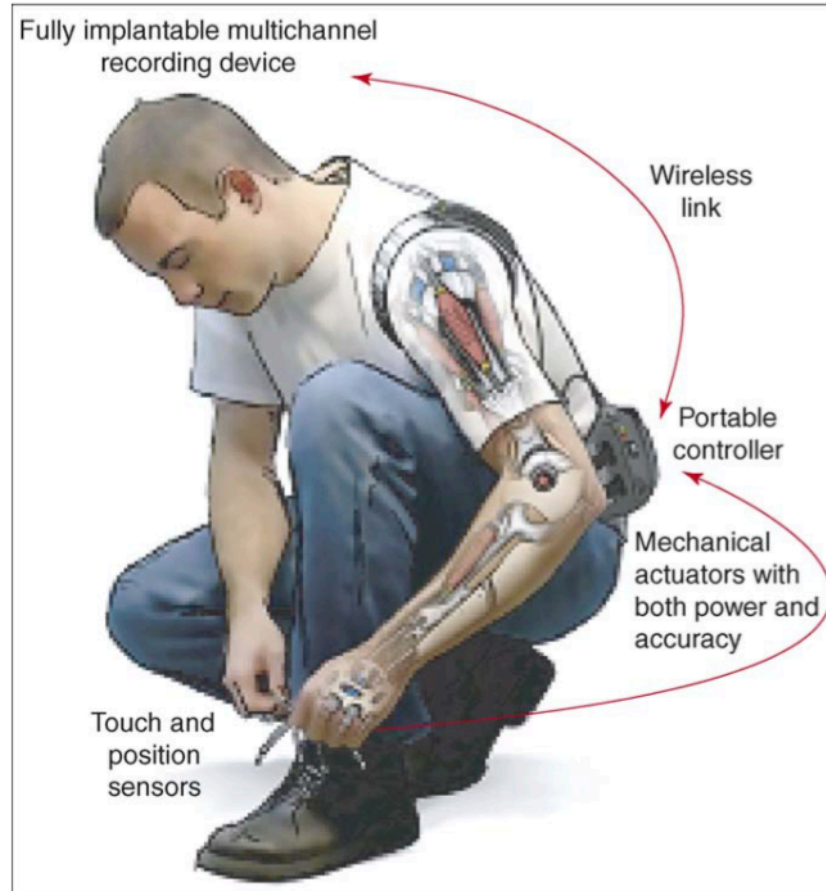


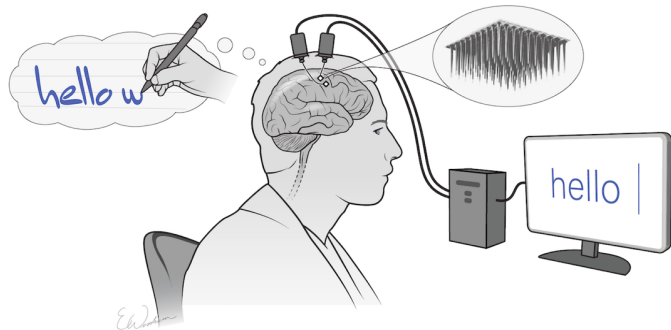
Deep-Brain Stimulation (DBS) for Movement Disorders



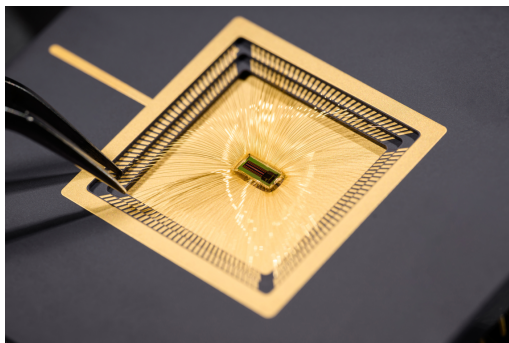
Epilepsy Implants: Seizure Detection and Suppression with Stimulation



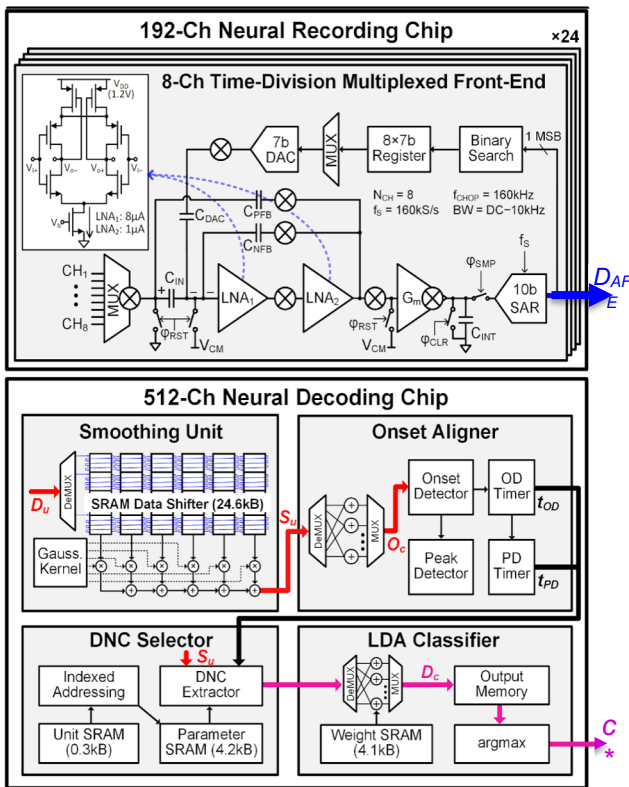




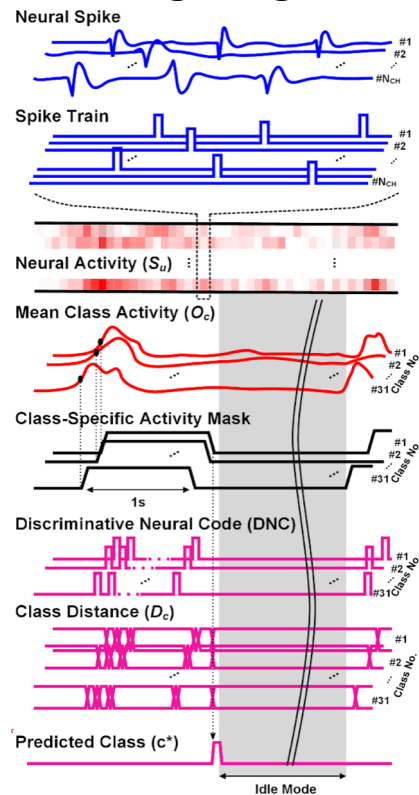
F. R. Willett et al., Nature '21



Hardware Architecture

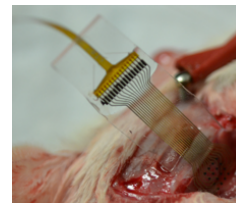
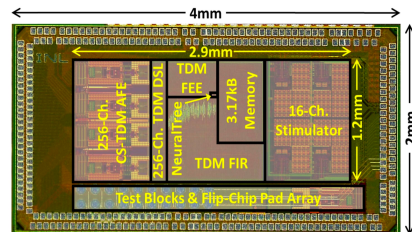
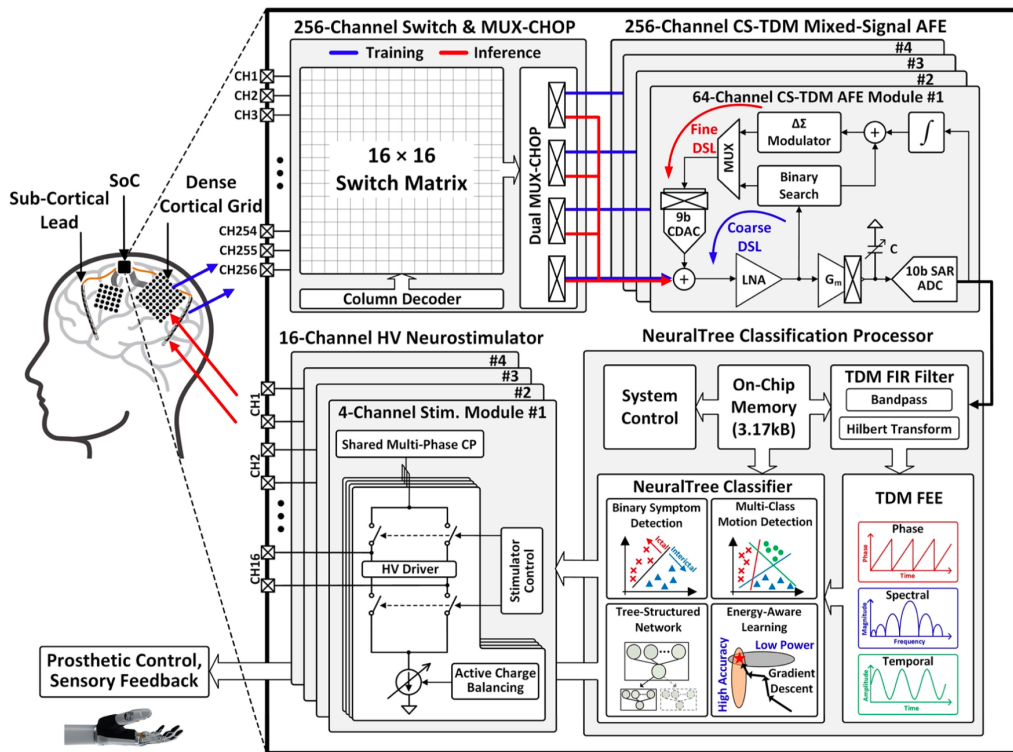


Timing Diagram

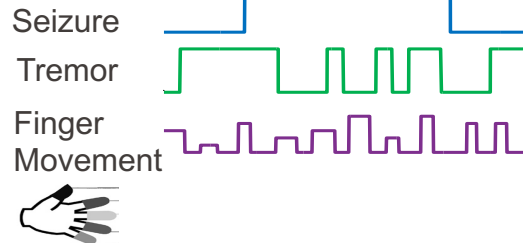


M. Shaeri et al., ISSCC'24, JSSC'24

Closed-loop Neuromodulation SoC with Embedded AI

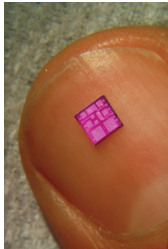
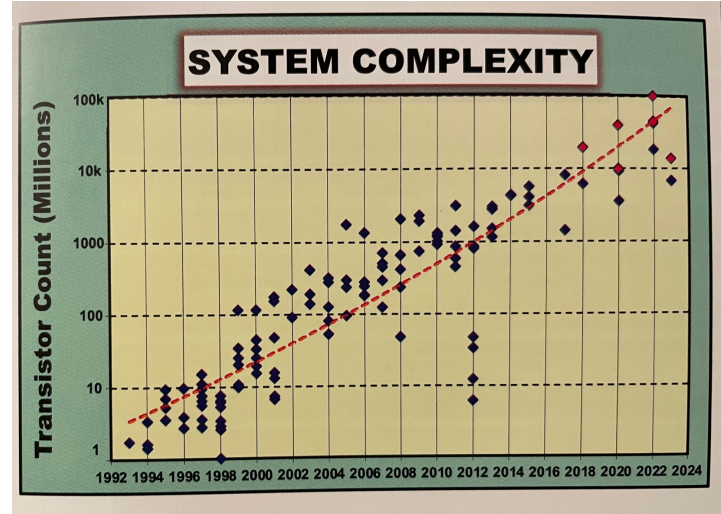
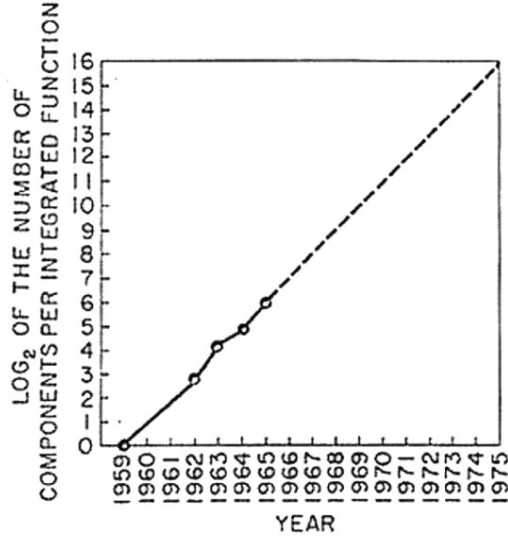
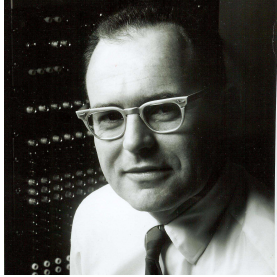


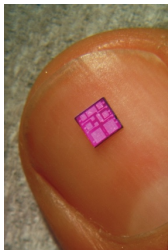
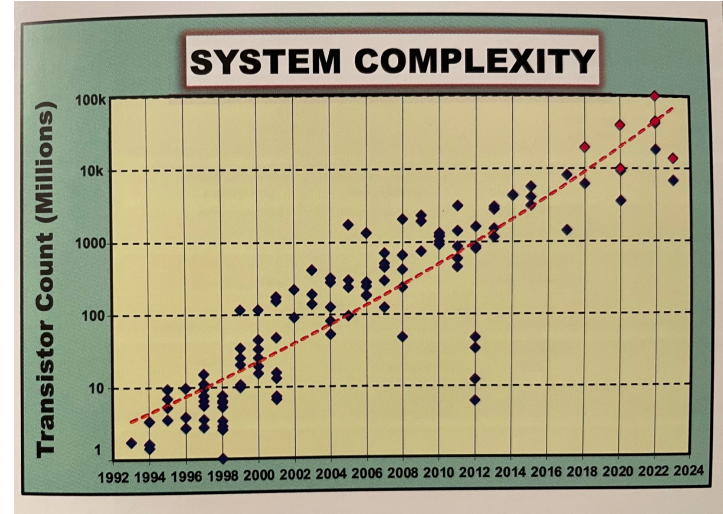
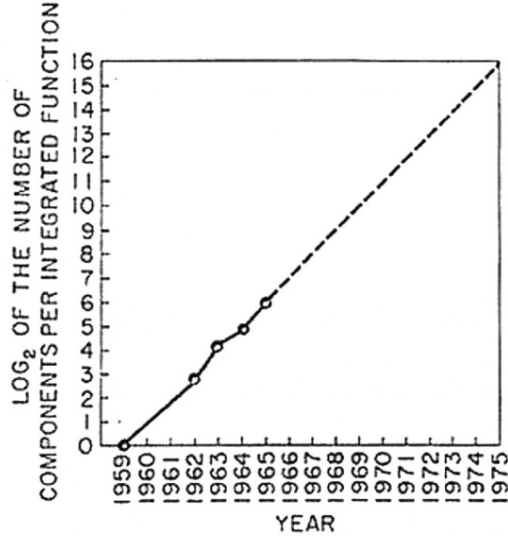
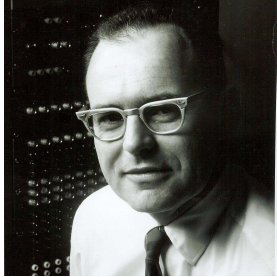
Classifier Output



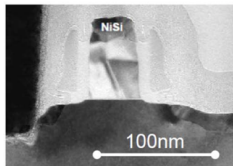
U. Shin et al., ISSCC'22, JSSC'22

Moore's Law: Transistor Scaling & Higher Complexity

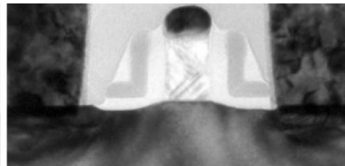




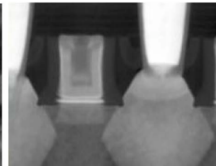
90 nm node



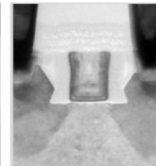
65 nm node



45 nm node



32 nm node



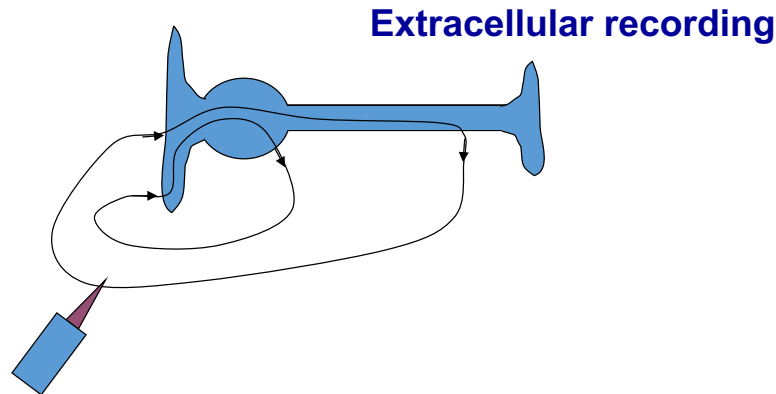
...

- Types of neural signals, miniaturized implantable systems
- Electrical recording, neural amplifiers
 - Low-power and low-noise CMOS design
- Digitization and compression methods and circuits
- Overview of neurostimulation methods and circuits
- Prediction of neurological disorders: hardware implementation
- Closed-loop neuromodulation circuits
- Brain-computer interface systems

- Basic of circuit analysis, basic of electronics (**will not be covered**)
 - Circuit analysis via Laplace transform, basics of RC circuits
 - Impedance descriptions in the s-domain
 - KVL and KCL (materials uploaded to Moodle)
- MOS transistor basics (**will be covered in class**)
 - Recommended preparation: Design of Analog CMOS Integrated Circuits, B. Razavi, 2nd Edition, Chapters 2 and 3

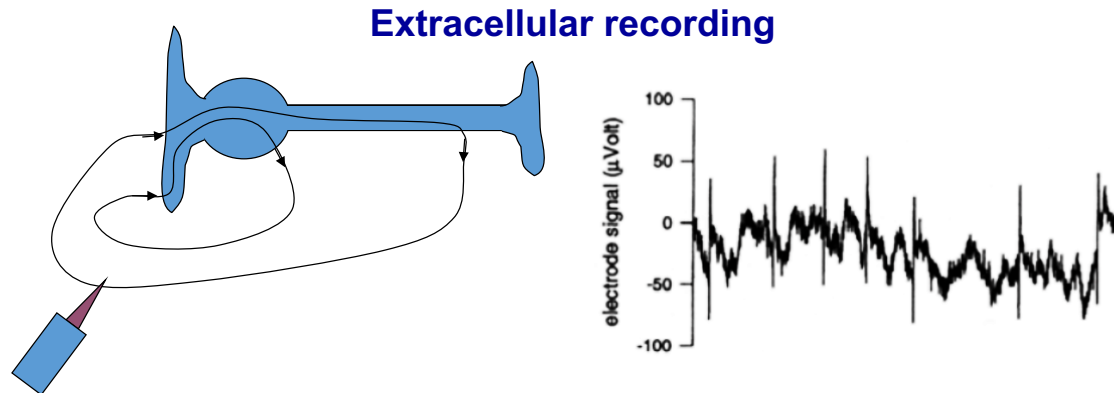
EPFL Extracellular Recording of Action Potentials

- Two electrodes are placed inside the brain in extracellular medium (one for recording, one for reference)
- During an AP, influx of sodium into cell causes large change in voltage potential in the surrounding area relative to distant areas
- This causes a voltage difference between the recording electrode and the (distant) reference electrode
- We detect small voltages outside, from current looping back to dendrite
- The voltage we detect is much less than the differences in membrane voltage



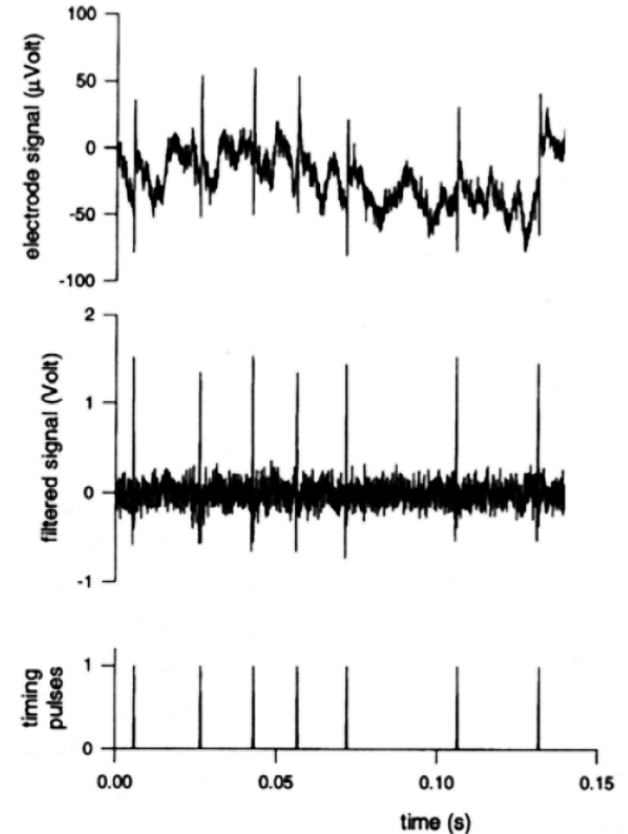
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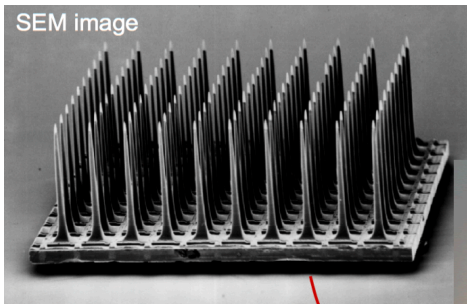
EPFL Extracellular Recording of Action Potentials

- Can observe action potentials (spikes)
- Assumption: neurons convey information in their spikes
- The rate of spikes carries information

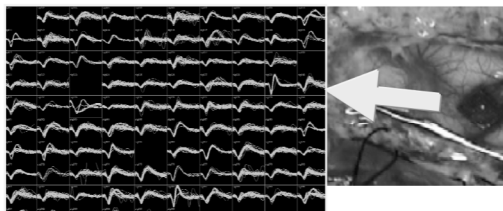
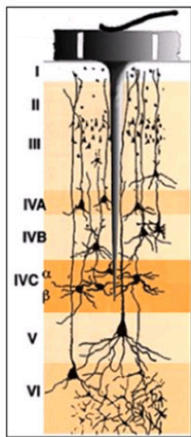
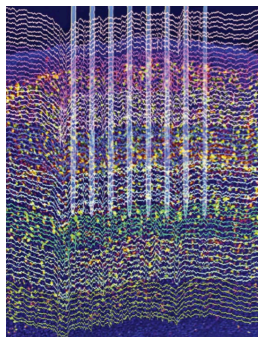
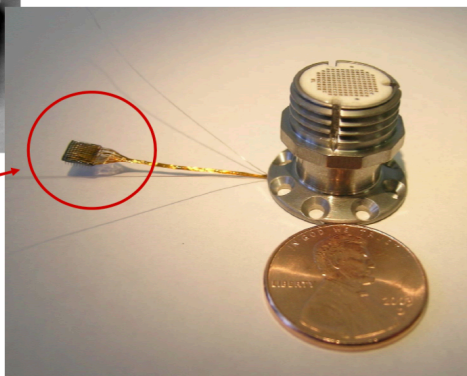


Examples of Extracellular Electrodes

SEM image

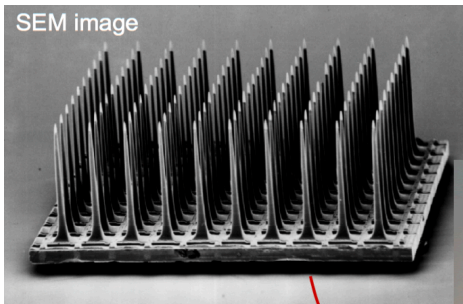


Utah array

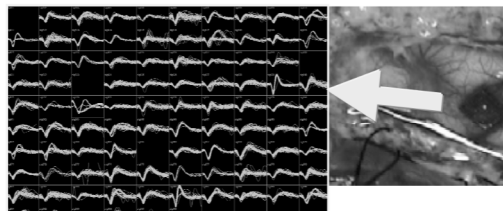
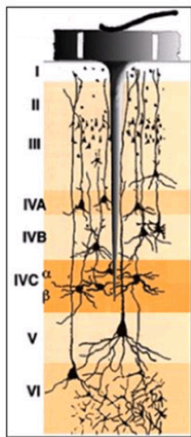
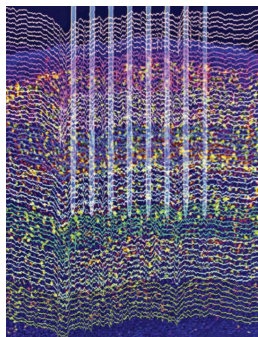
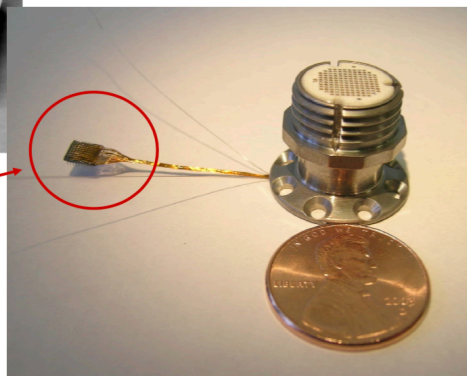


Examples of Extracellular Electrodes

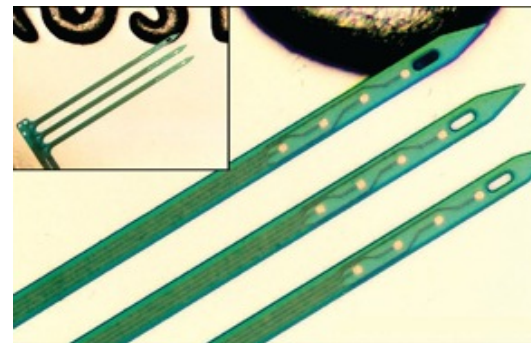
SEM image



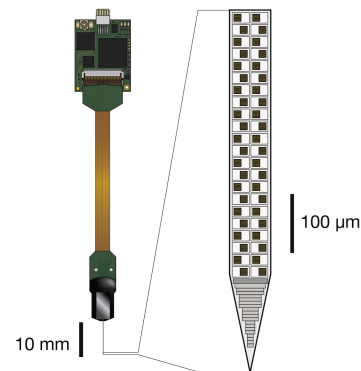
Utah array



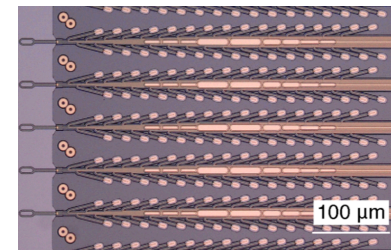
Michigan probes



Neuropixels, 960Ch

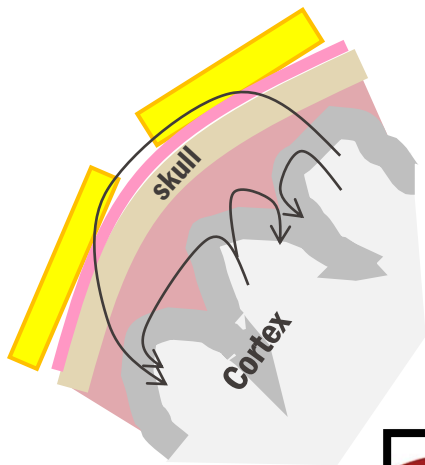


Neural threads, 3072Ch



Neuralink, preprint 2019

- **EEG:** sheet of electrodes on surface of head (on skin): **not invasive**



- **ECoG:** sheet of electrodes on surface of cortex: **invasive but not brain penetrating**

