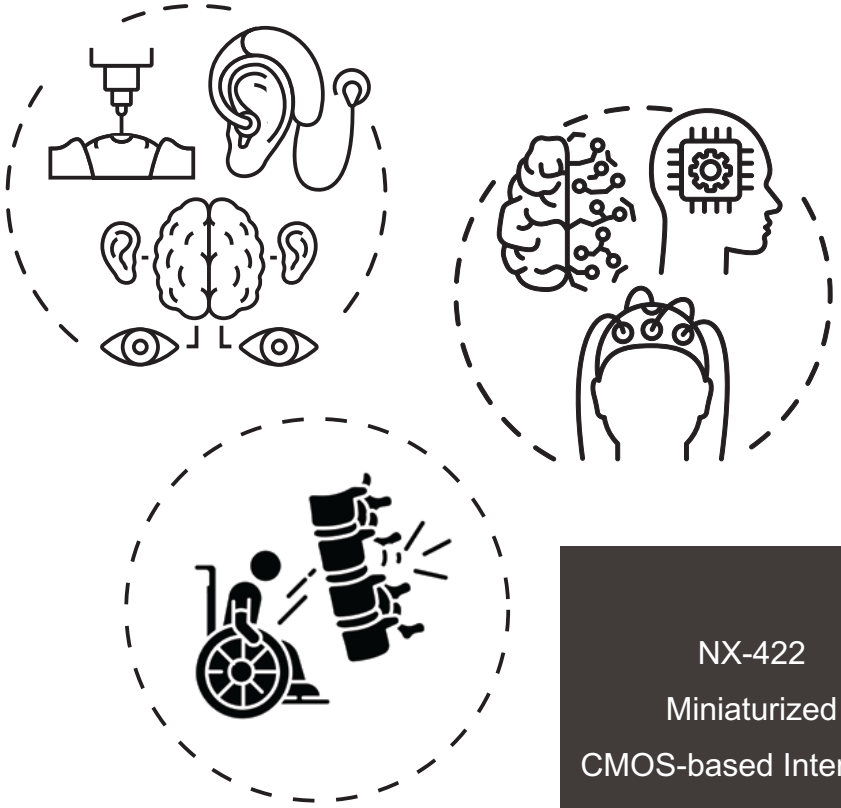


Neural Interfaces

NX-422

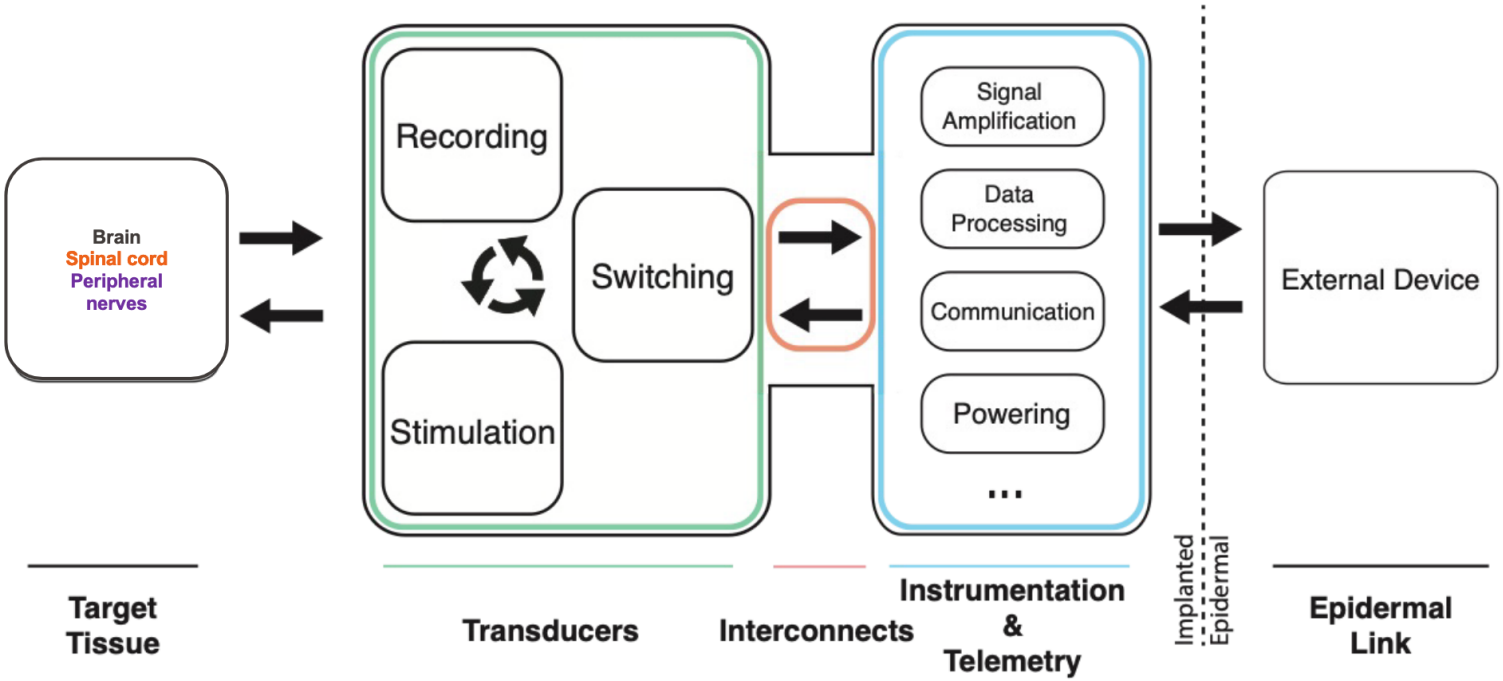
Miniaturized

CMOS-based Interfaces

Mahsa Shoaran

IEM and Neuro-X Institutes

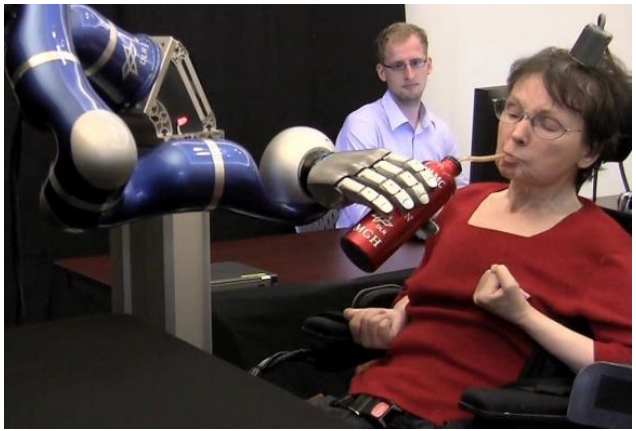
Neural Interface Electronics



The Need for Miniaturization and Better Hardware: BMI

- 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



https://blackrockneurotech.com/

The Need for Miniaturization and Better Hardware: BMI

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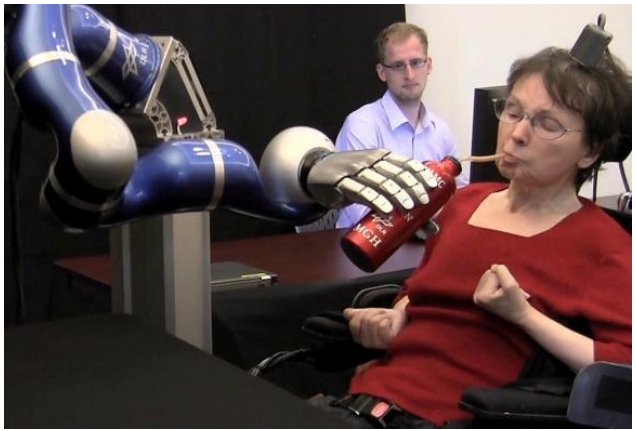


Future:
- More electrodes, richer input signal
- Better algorithms and AI for more complex decoding tasks
- **Better hardware for chronic use outside the clinic**

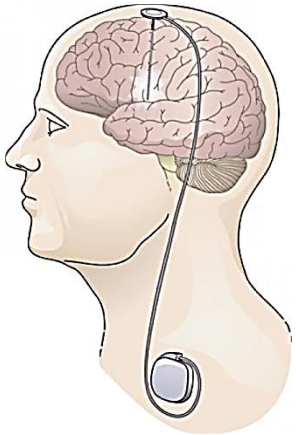
https://blackrockneurotech.com/

The Need for Miniaturization and Better Hardware: Stimulation

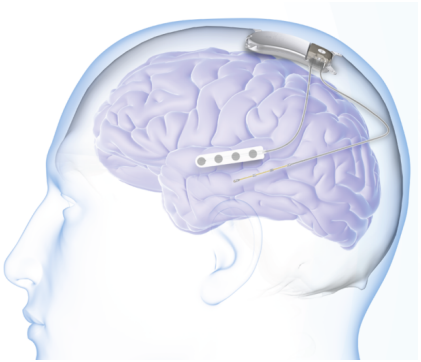
- Neurostimulation to suppress disease symptoms, or replace a function, trigger movement, …

Future:

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



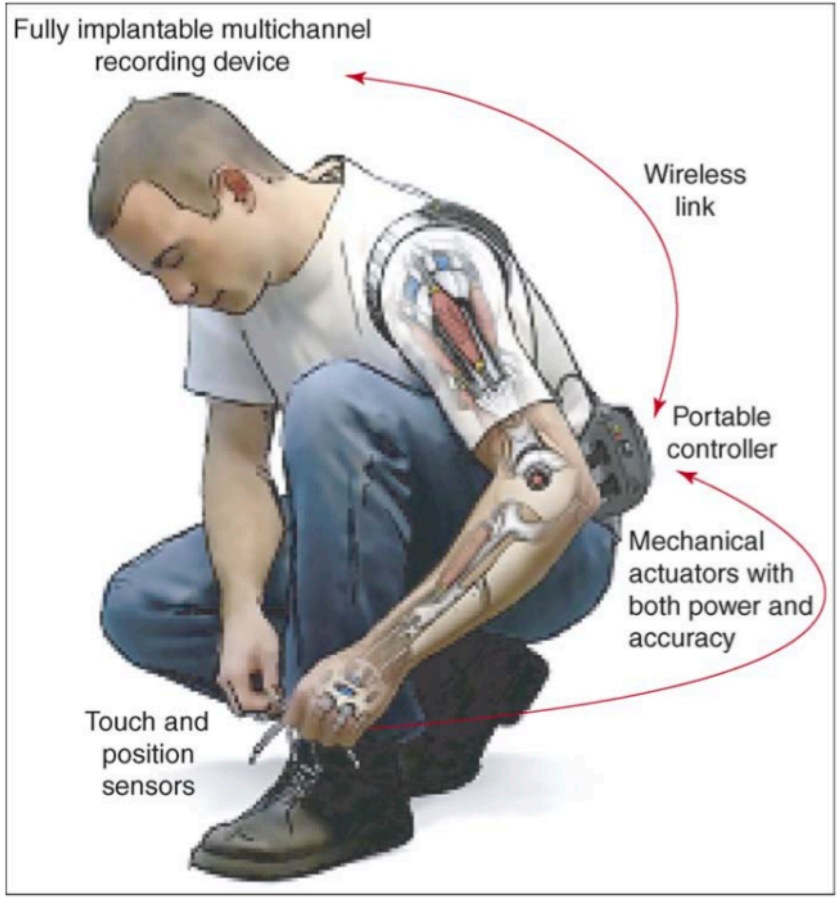
Deep-Brain Stimulation (DBS) for Movement Disorders



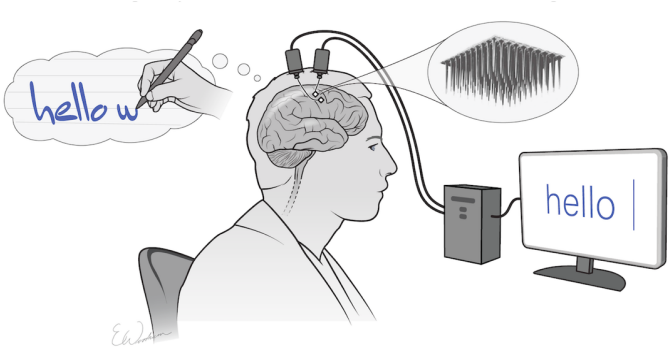
Epilepsy Implants: Seizure Detection and Suppression with Stimulation

https://vnstherapy.com/
https://www.neuropace.com/
https://www.medtronic.com/

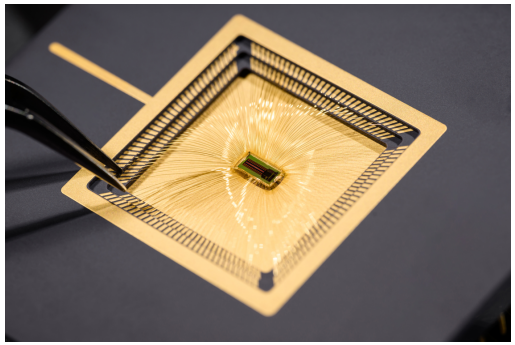
Future: Fully Implantable



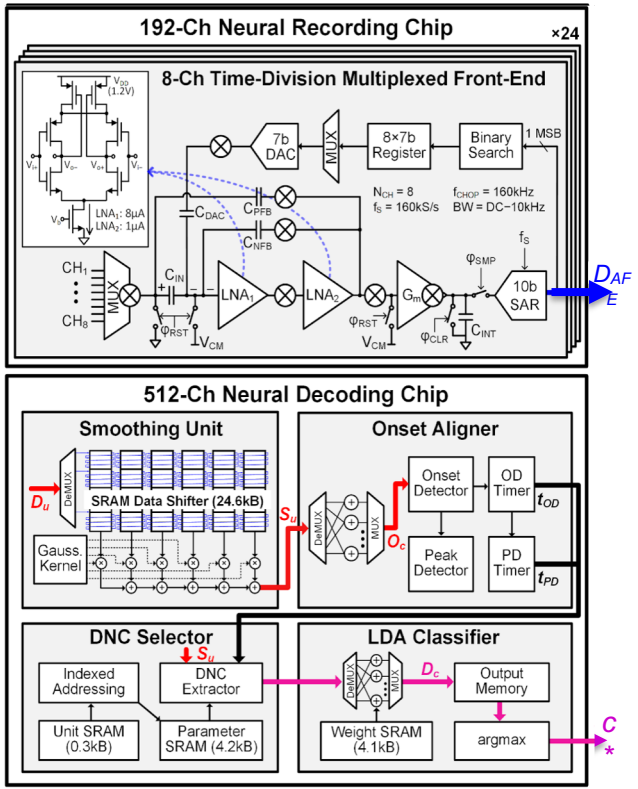
Thought-to-Text Miniaturized Brain-Machine Interface (MiBMI)



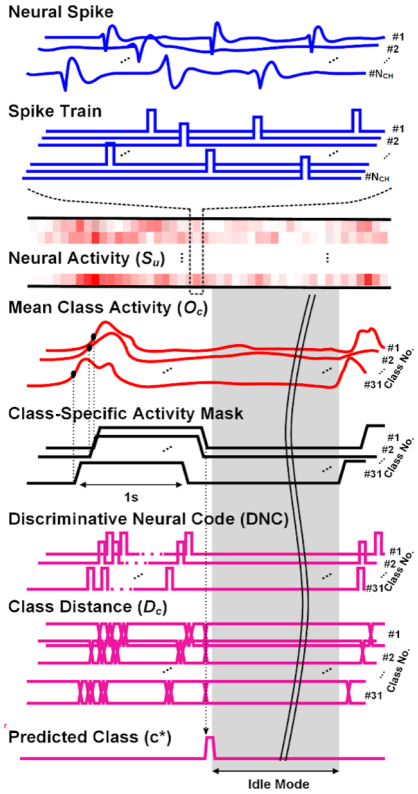
F. R. Willett et al., Nature'21



Hardware Architecture

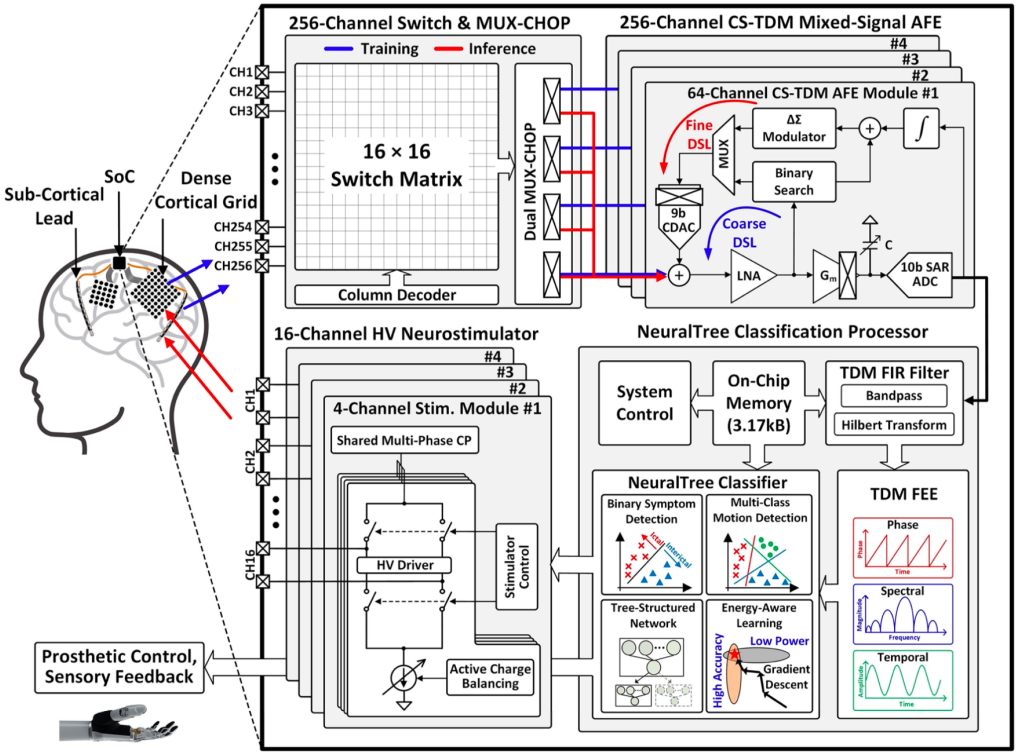


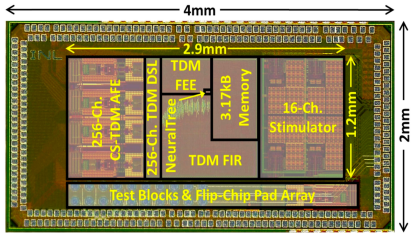
Timing Diagram

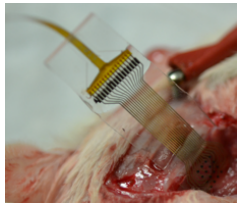


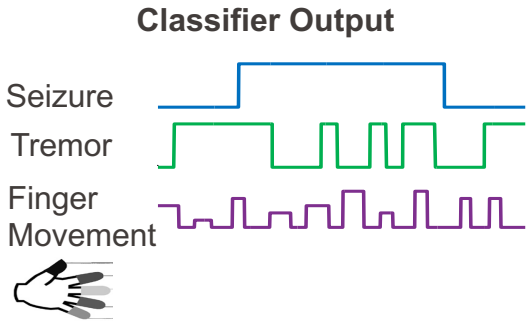
M. Shaeri et al., ISSCC'24, JSSC'24

Closed-loop Neuromodulation SoC with Embedded AI



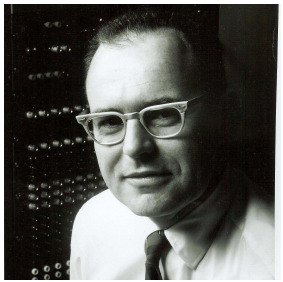


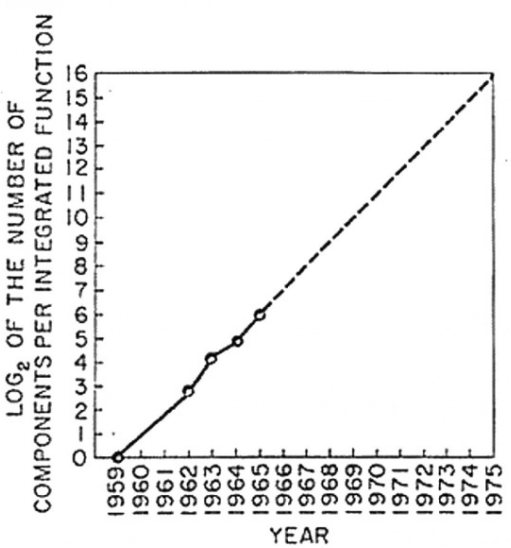


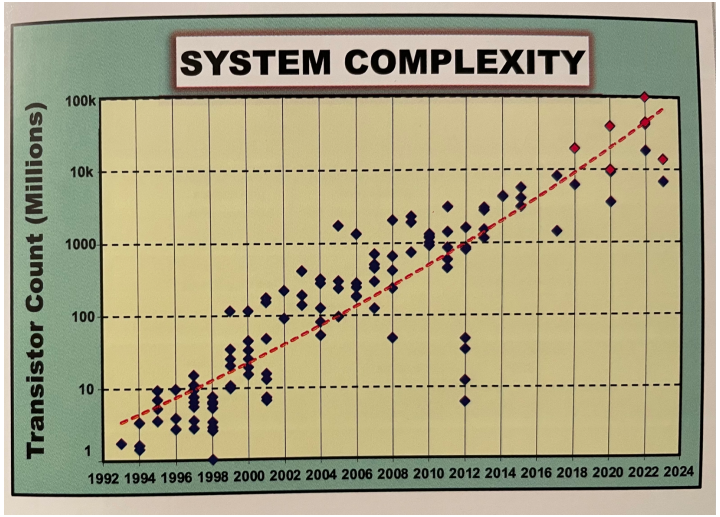


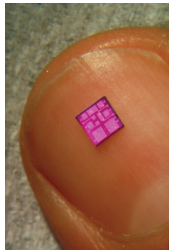
U. Shin et al., ISSCC'22, JSSC'22

Moore's Law: Transistor Scaling & Higher Complexity









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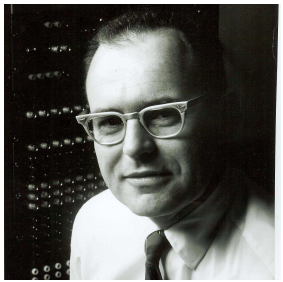
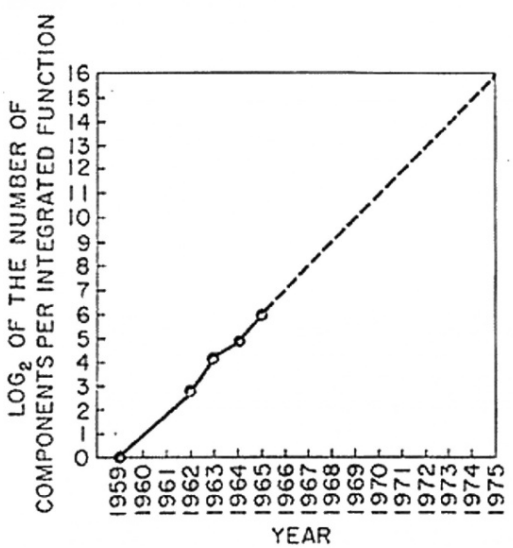
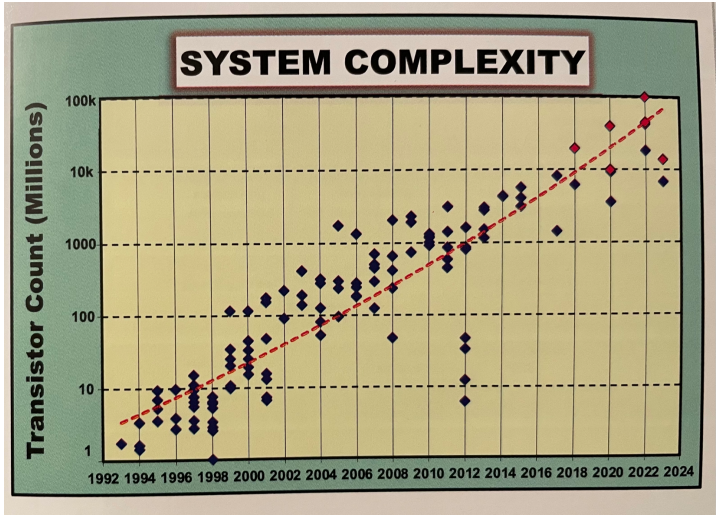
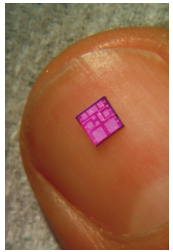
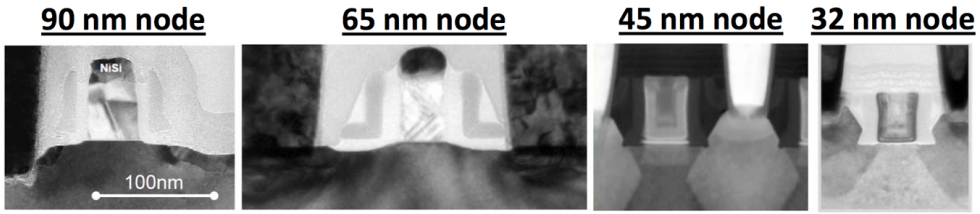










...

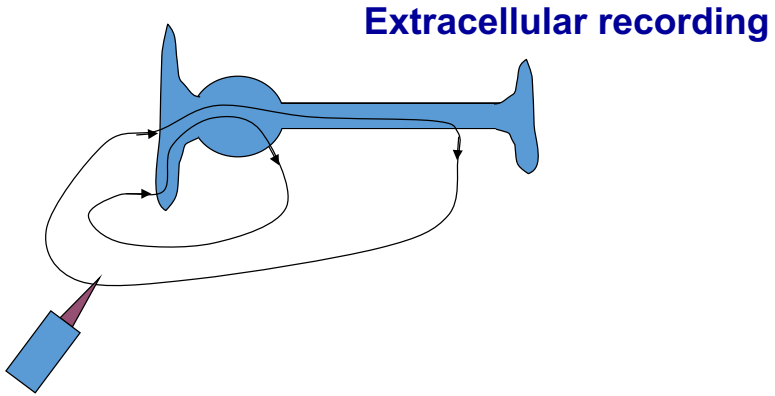
ISSCC'24, *V. Moroz, IEDM*

Course Outline

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

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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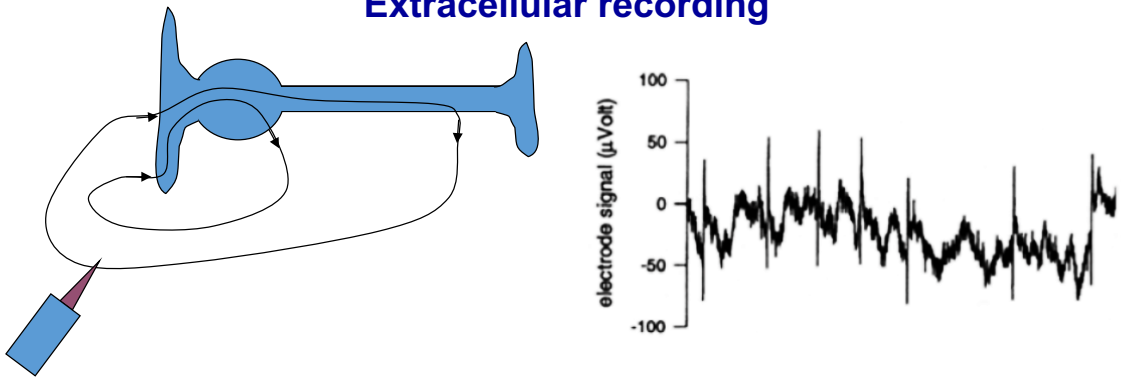
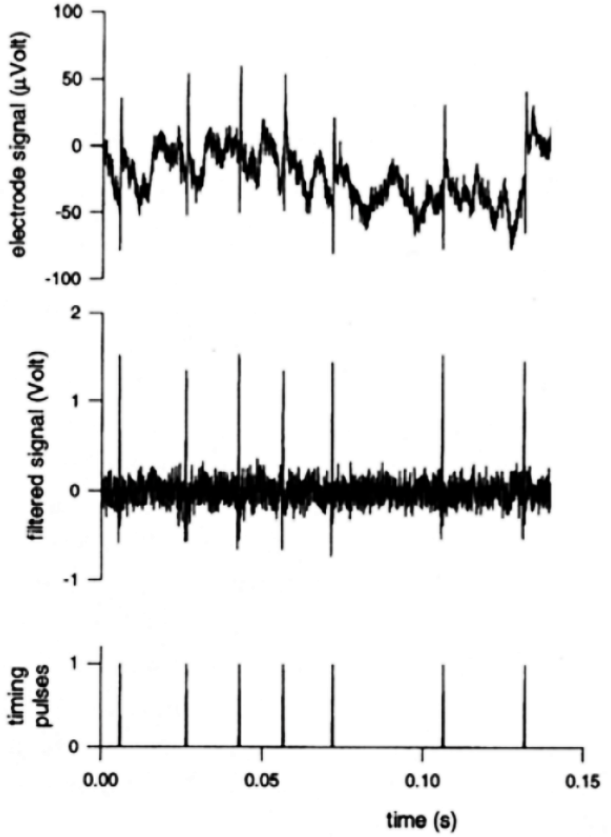
Extracellular recording

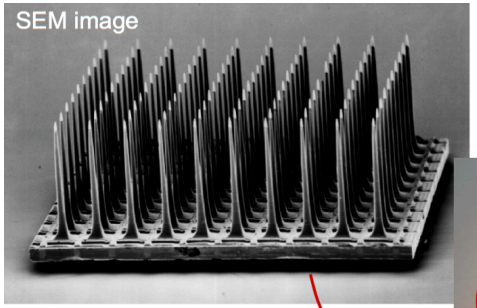


Extracellular Recording of Action Potentials

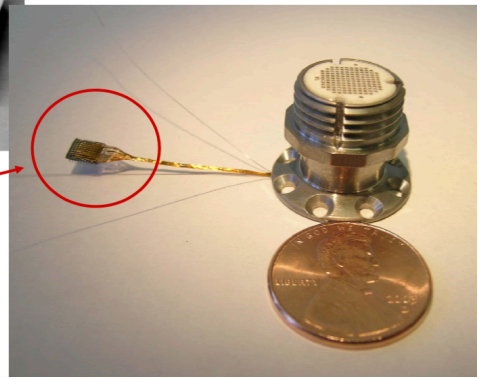
- Can only observe action potentials (spikes)
- Assumption: neurons convey information in their spikes
- The rate of spikes carries information

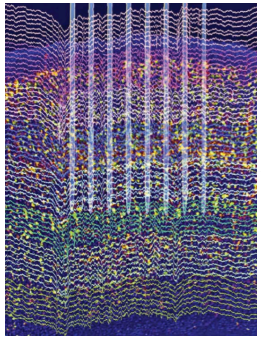


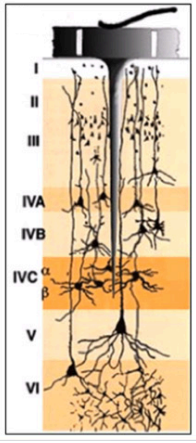
Examples of Extracellular Electrodes

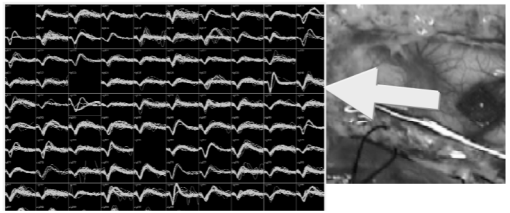


Utah array









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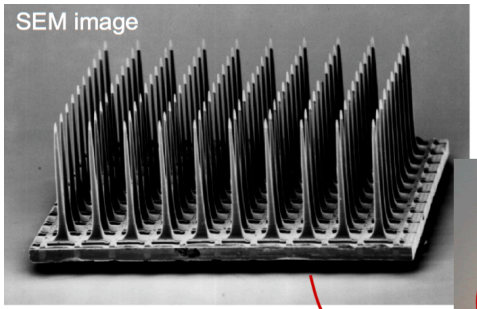
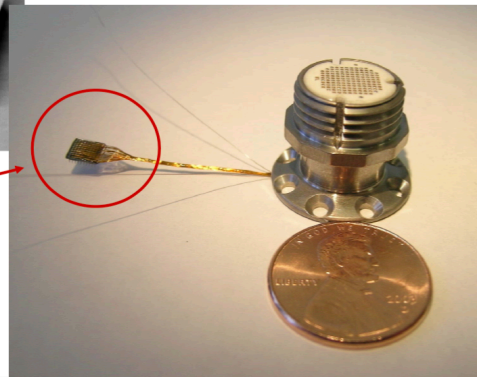
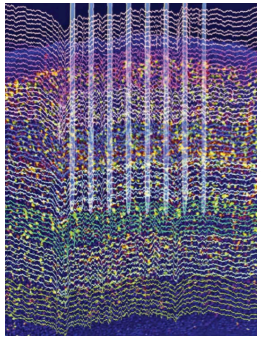
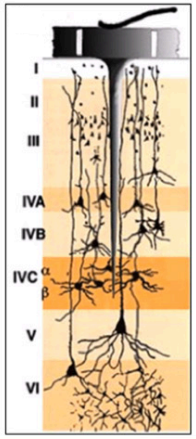
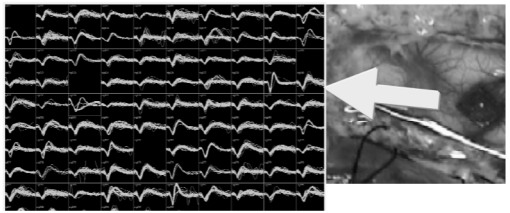


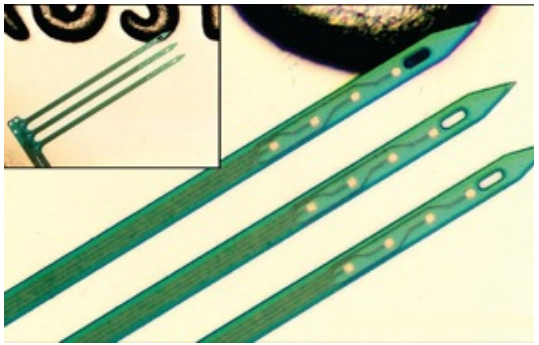




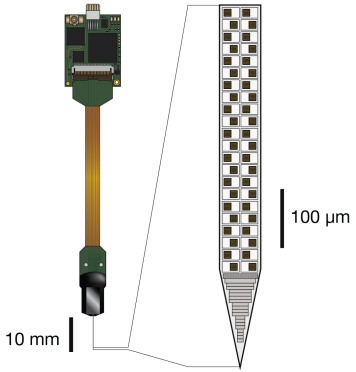




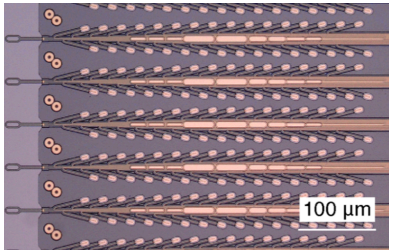
Michigan probes



Neuropixels, 960Ch



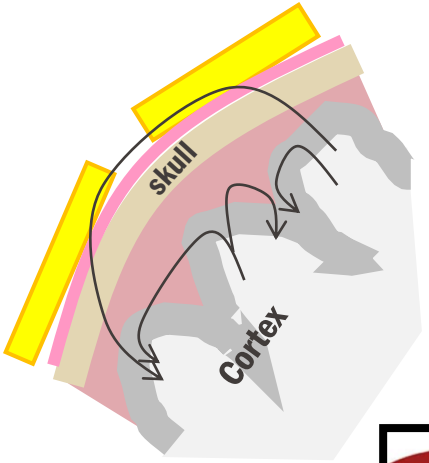
Neural threads, 3072Ch



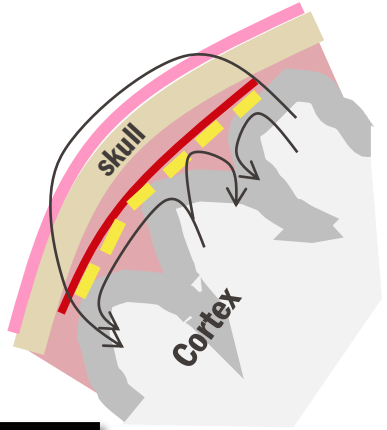
Neuralink, preprint 2019

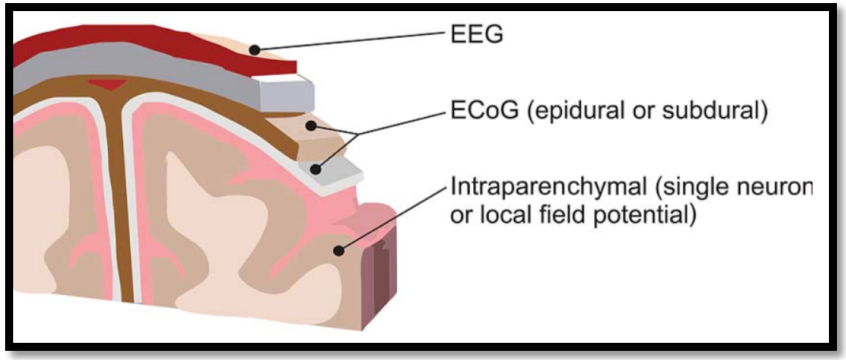
EEG and ECoG

- **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**



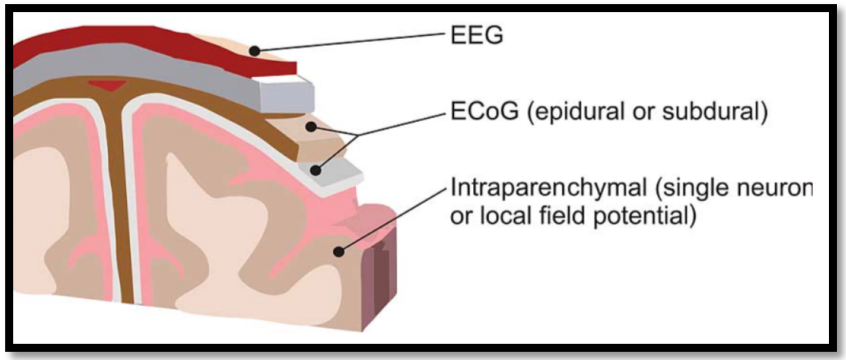


EEG and ECoG

- **Electrocorticography (ECoG) or intracranial EEG (iEEG)**

Compared to EEG, ECoG has a number of favorable characteristics:

- **Higher spatial resolution** (0.5-10mm versus several centimeters for EEG)
- **Higher amplitude**, easier to capture
- **Less vulnerability to artifacts** such as electromyographic (EMG) or electroocular (EOG) activity
- **Broader bandwidth** (i.e., <500Hz versus <50Hz for EEG)



Local Field Potentials (LFPs)

- < 300 Hz : Local Field Potentials (LFP)
- 300 – 10kHz : Single-Unit Activity (AP or “spikes”)

- Local Field Potential (LFP) – electrical activity of all cells **averaged over some spatial neighborhood**
- **High-pass filtering** in <1ms range gives **spikes**
- **LFP signal is lower frequency**