

# Neural Interfaces

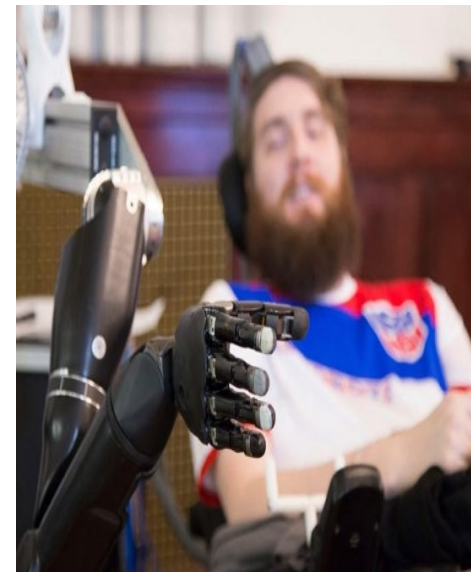
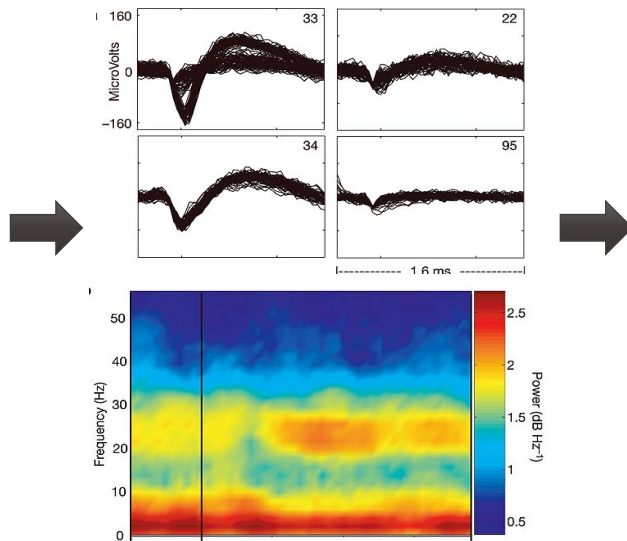
NX-422

Brain-Computer Interfaces (BCIs)

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IEM and Neuro-X Institutes

# Brain-Computer Interfaces (BCIs)

- Record brain signals
- Extract task-related activity
- Decode motor intention

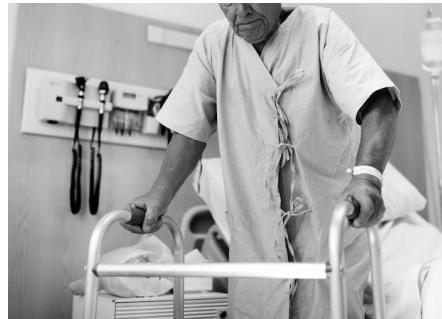


Assist 100 million people with **motor disabilities** caused by

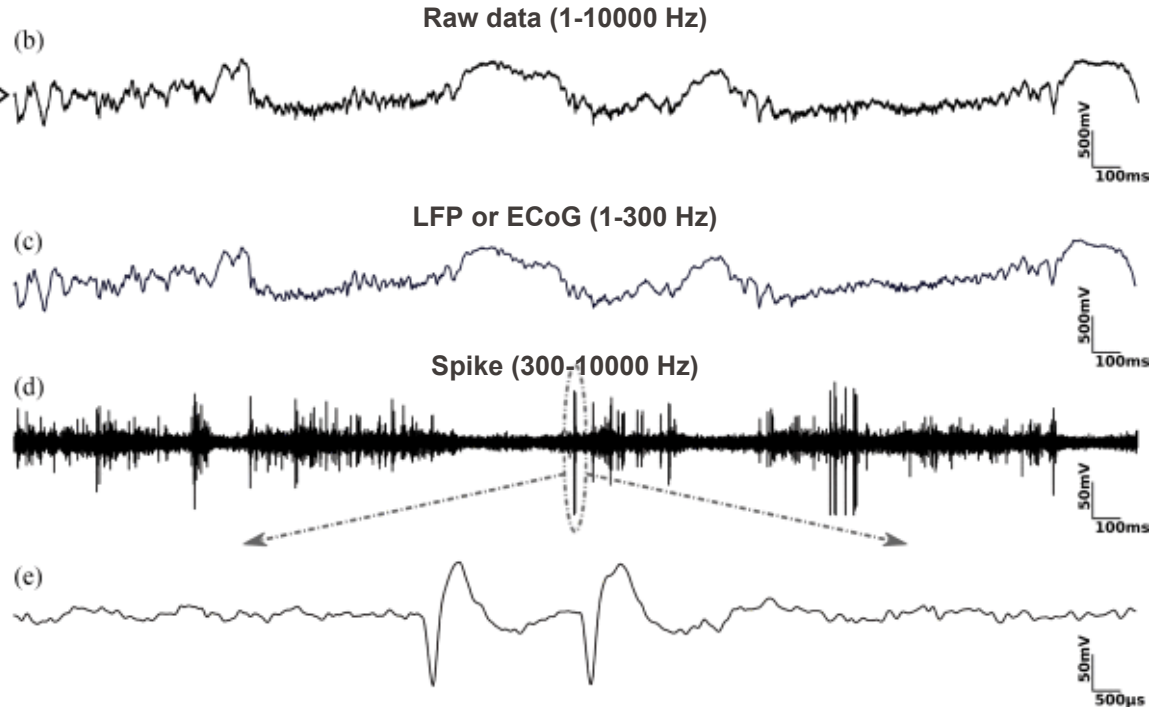
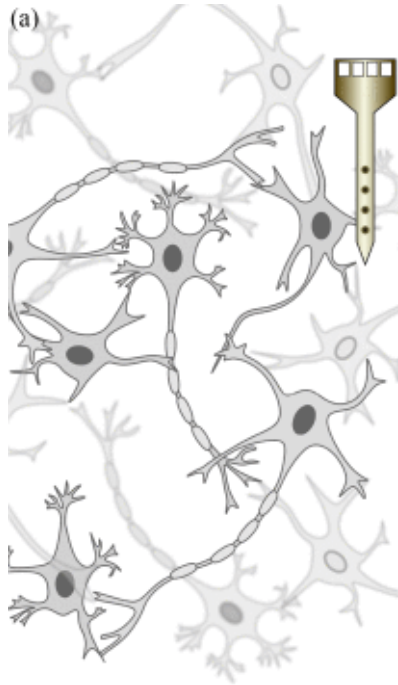
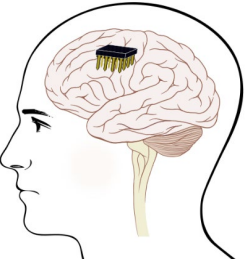
- **Stroke, spinal cord injury, and neurodegenerative diseases**

Leads to:

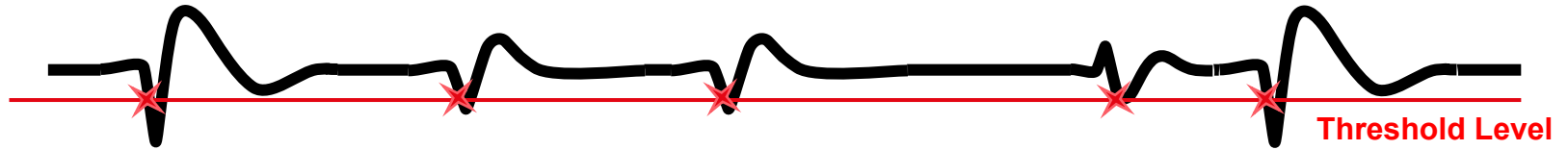
- **Loss of movement & communication**
- **Physical & Emotional Pain**
- **Financial burden** on patients & families



## Intracortical Extracellular Recording



## Spiking Waveforms

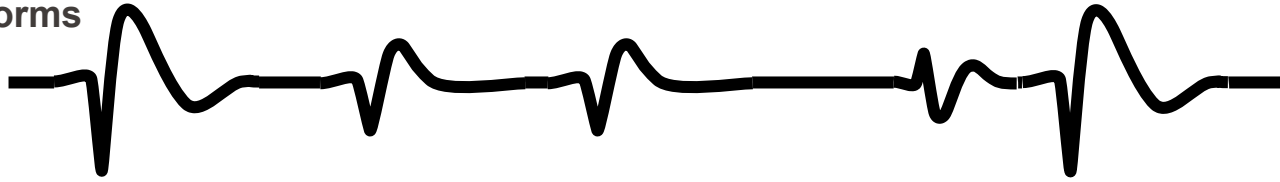


↓  
Threshold  
Crossing

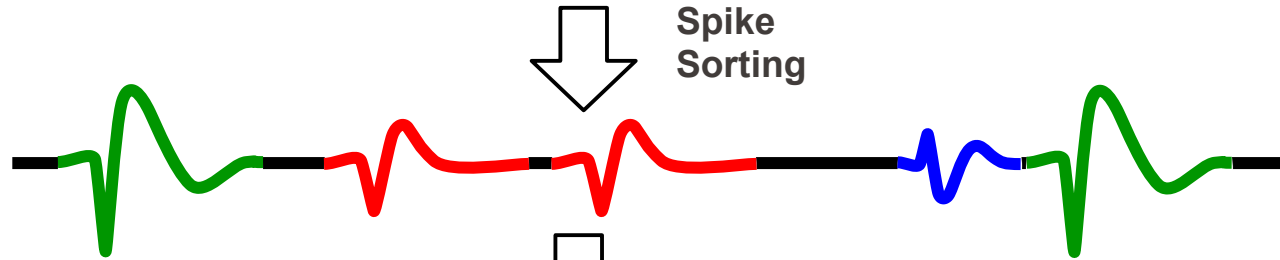
## Multi-Unit Activity (MUA)



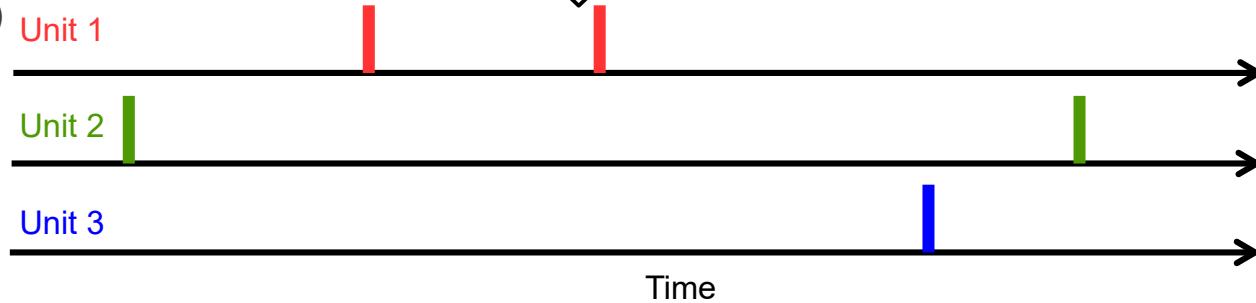
Spiking Waveforms



Sorted Spikes

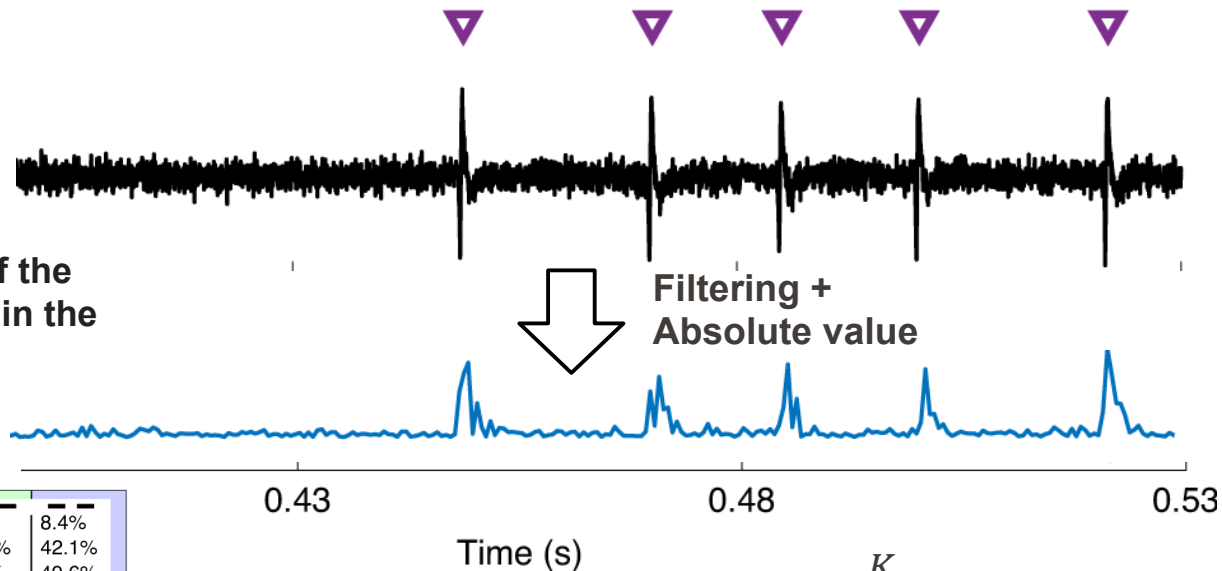


Single-Unit Activities (SUA)

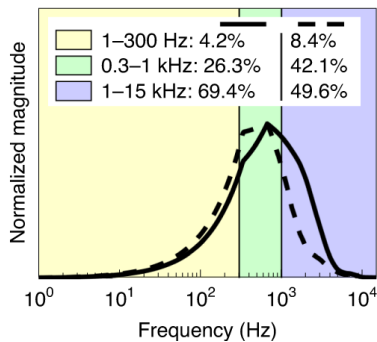


# Spiking-band power (SBP)

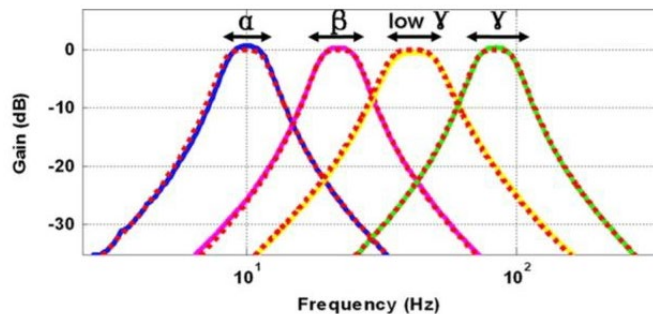
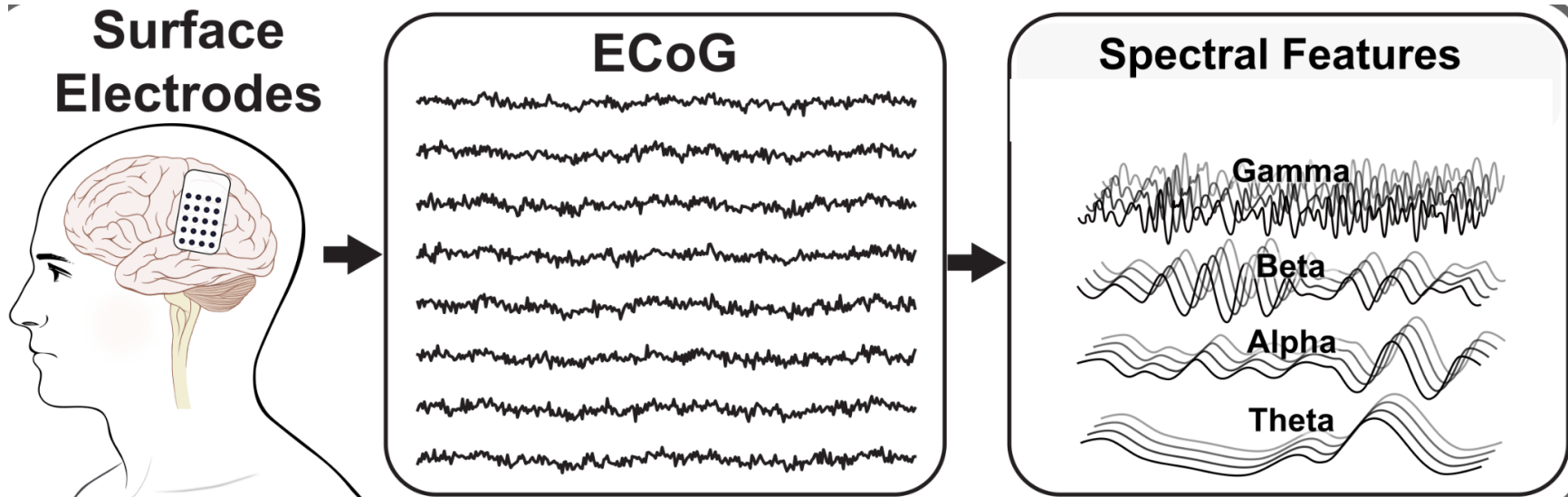
— Raw    ▾ True spike occurrence    — SBP



**SBP: Absolute value of the raw signal filtered within the 300–1000 Hz band**



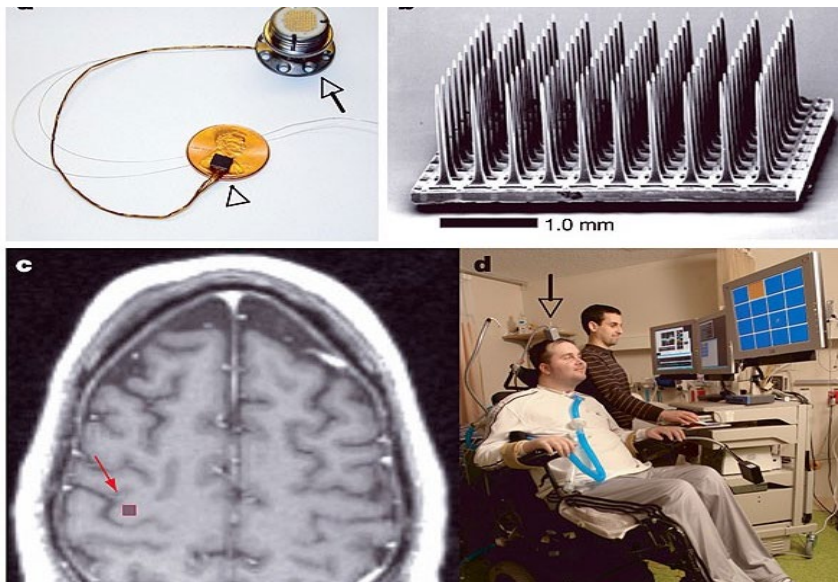
$$X_{SBP} = \sum_{k=1}^K |X_{band,k}|$$



Spectral Energy

$$X_{SE} = \sum_{k=1}^K X_{band,k}^2$$

Band-filtered signal



No. Channels: 96

Feature: MUA

Decoder:  
Linear Regression

The first real-time neuronal control of a **computer cursor** and simple prosthetic devices:

- Implanted **a microelectrode array** in the **primary motor cortex (M1)**.
- Decoded neural activity directly into **velocity** commands.

■

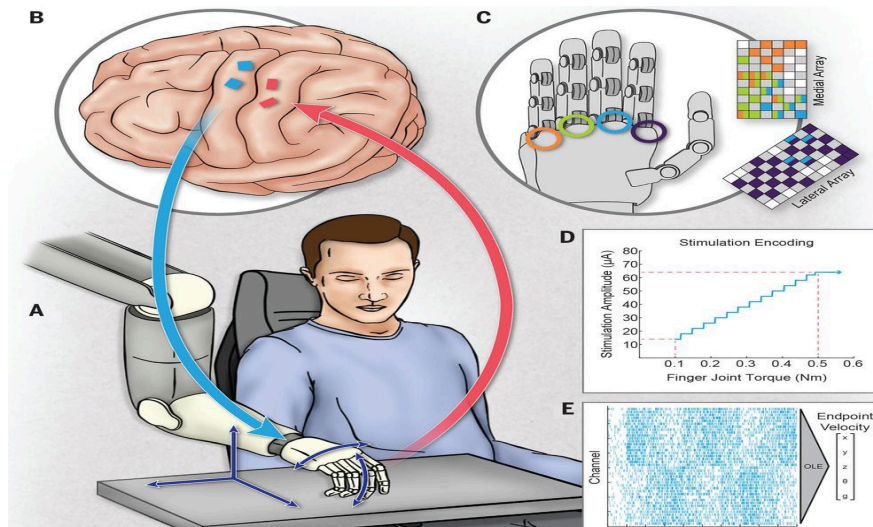


No. Channels: 96
Feature: MUA
Decoder: Kalman filter

The smooth, real-time, 7-dimensional control of a **robotic arm**:

- Recorded neural signal from a **Utah array** in the **primary motor cortex (M1)**.
- Translated signals related to intended movement **velocity** (kinematics) in 3D space, along with dedicated wrist rotation and **grasp** commands.

# Closing the Loop with Sensory Feedback



No. Channels:  
 $2 \times 88$  (recording)  
 $2 \times 32$  (stimulation)

Feature: MUA

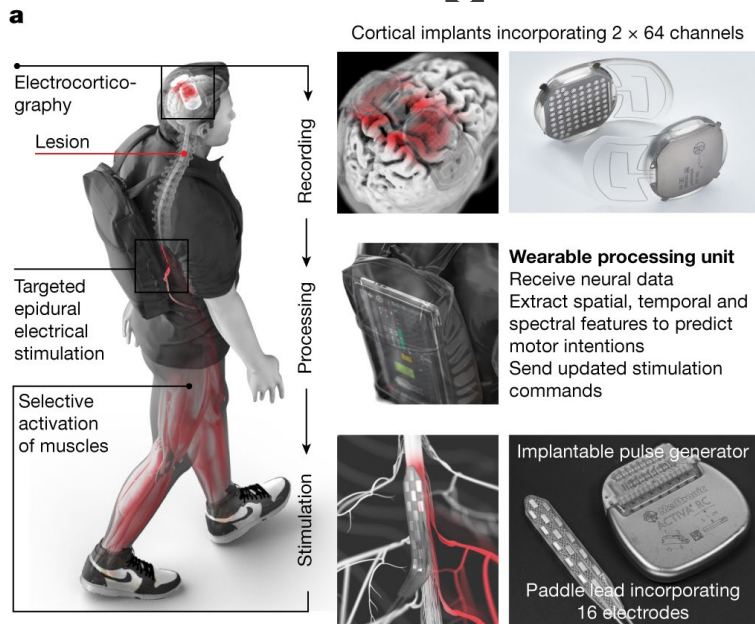
Decoder:  
 Linear Regression

A **closed-loop** Bidirectional BCI that coupled:

- **Motor Control:** Two microelectrode arrays implanted in the **motor cortex** recorded neural activity.
- **Sensory Feedback:** Two microelectrode arrays in the **somatosensory cortex** delivered stimulation pulses to evoke **tactile sensation**.

Enabled the patient to control the robotic arm faster and more **naturally**.

# Restoring Natural Walking with a Brain-Spine Interface<sup>12</sup>



No. Channels:  $2 \times 64$

Feature: Wavelet

Decoder:

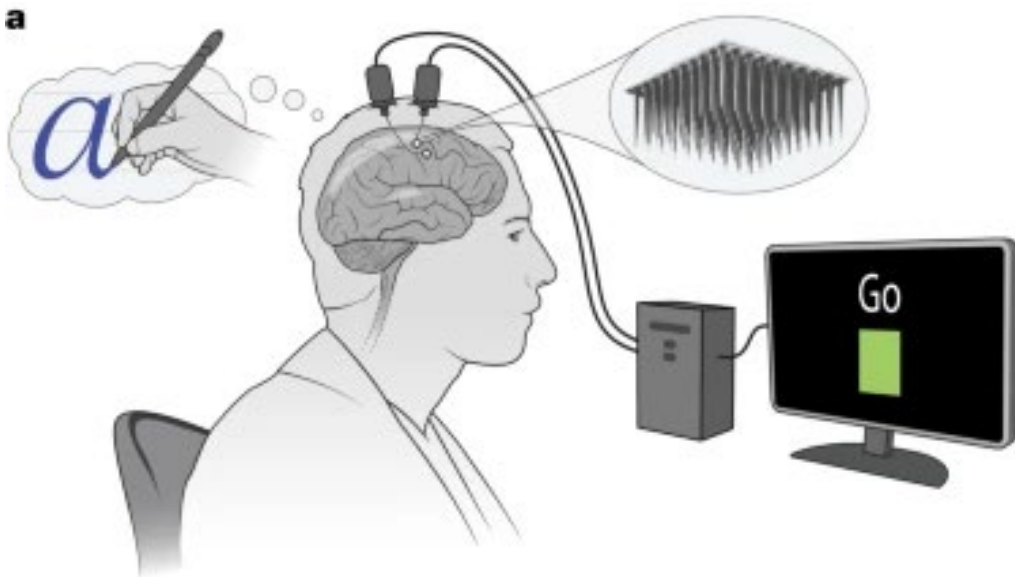
Hidden Markov  
Model (HMM)

+Linear Regression

Restored the **walking** ability of a person with chronic spinal cord injury (SCI):

- **Two ECoG arrays** (surface electrodes) were positioned over the **sensorimotor cortex**.
- The decoded signal was transmitted wirelessly to a spinal implant that applied **targeted epidural electrical stimulation (EES)** to the **lumbar spinal cord**, triggering the leg movements.

# EPFL Brain-to-text communication via handwriting



No. Channels: 2\*96

Feature: MUA

Decoder:  
Recurrent Neural  
Network (RNN)  
+ Language Model

High-speed communication by decoding the brain intent to write **31 characters**:

- Used **two Utah arrays** implanted in the primary motor cortex (M1)
- Reached a peak speed of **90 characters/minute** (**18 words/minute**), 4x faster than point&click typing.
- Demonstrated a high online accuracy of **94.1%**.

■



No. Channels: 2\*96

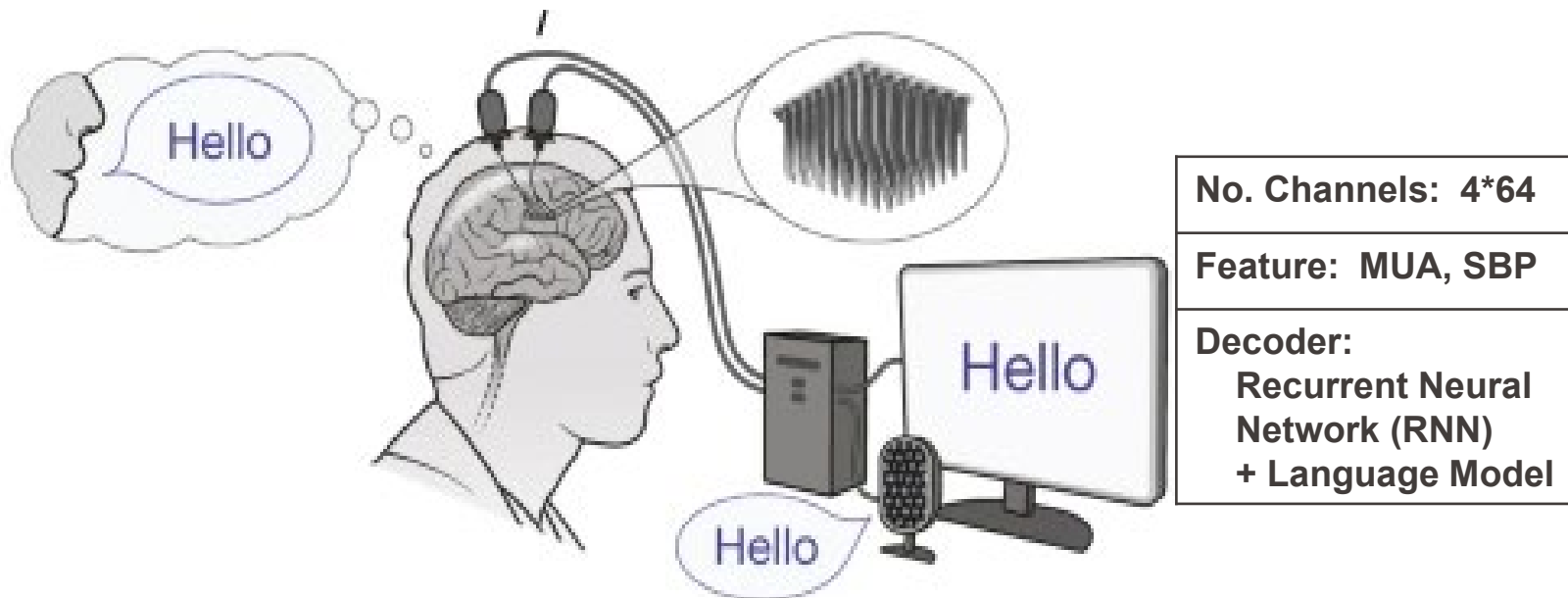
Feature:  
MUA, SUA, ESA

Decoder:  
State-Dependent  
Tuning Model

The Chinese handwriting BCI (**300-1000 characters**):

- **Two Utah** arrays implanted in the **motor cortex**.
- Reached a peak speed of **48 Chinese characters/minute**.
- Achieved a **recognition rate up to 91.1%**, with trajectory reconstruction accuracy of  $\sim 0.35$ .

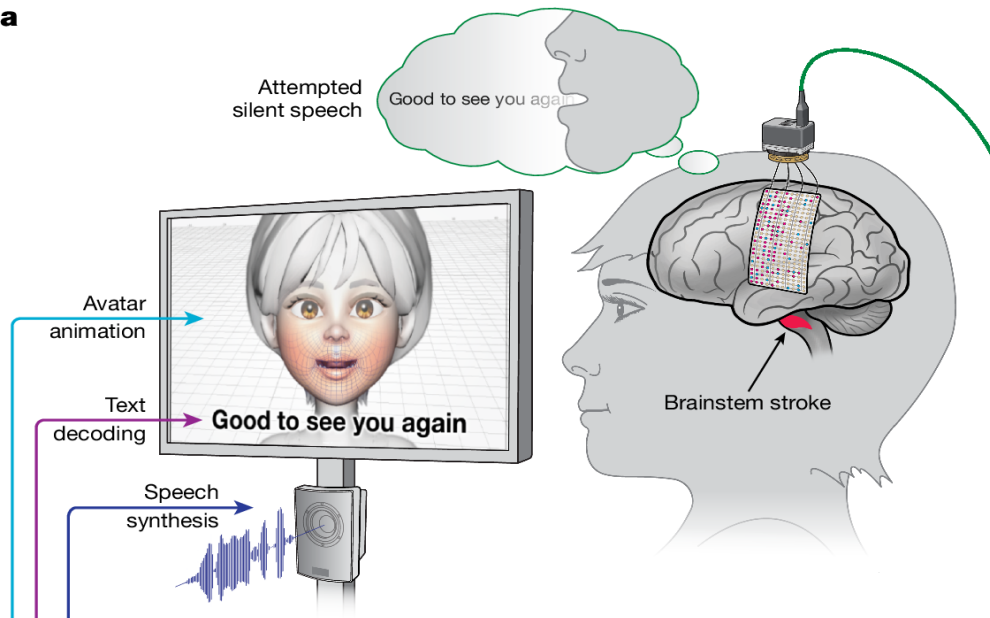
■



Speech BCI designed for unconstrained conversation:

- Used **four Utah** arrays implanted in premotor and speech-related cortices.
- Achieved a **23.8%** Word Error Rate (WER) on a **125,000-word vocab** at a speed of **62 words/minute**.
- **A 9.1% WER** was demonstrated on a 50-word vocabulary.

# EPFL ECoG-based Speech BCI

**a**

No. Channels: 253

Feature: Hi-Gamma

Decoder:  
Recurrent Neural  
Network (RNN)  
+ Language Model

Decoded neural signals into text output, synthesized speech audio, and facial avatar animation:

- Used a high-density **ECoG array**.
- A peak speed of **78 words/minute** (WPM).
- A WER of 8.2% and **25.5%** on a 119-word and a **1024-word vocabularies**, respectively.

# EPFL BCI Next-Generation BCIs

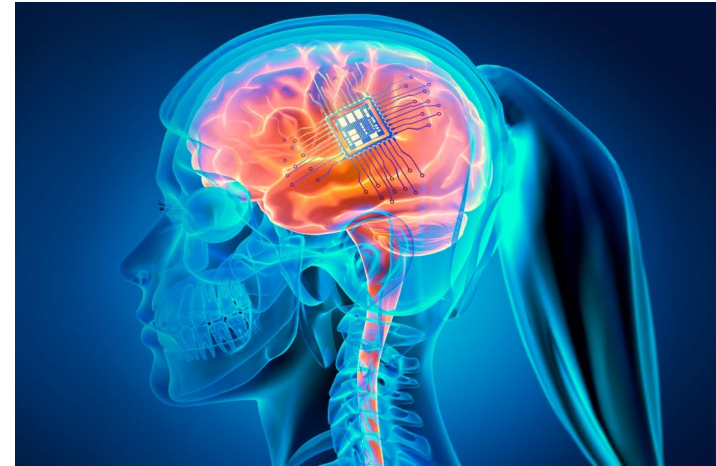
Future: fully implantable, low power, and miniaturized

## Current BCIs



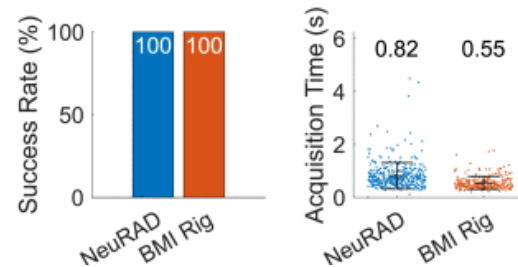
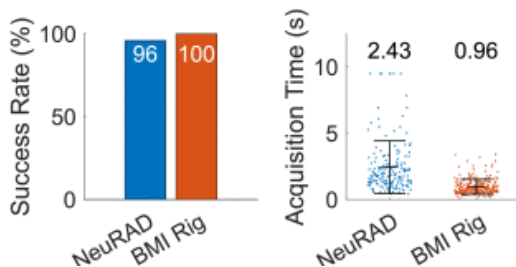
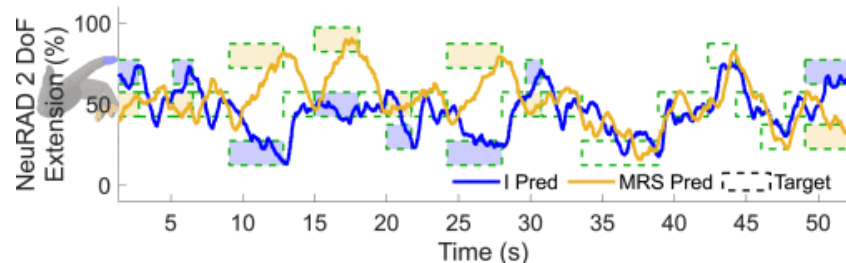
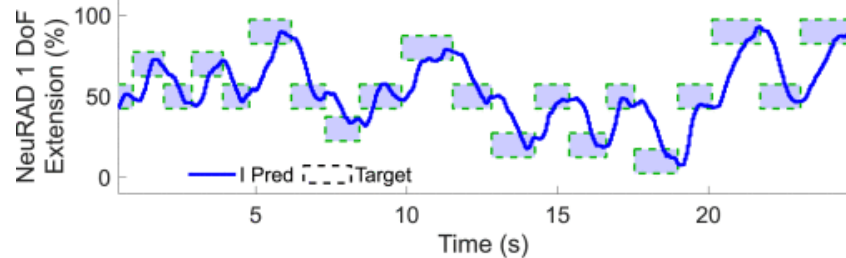
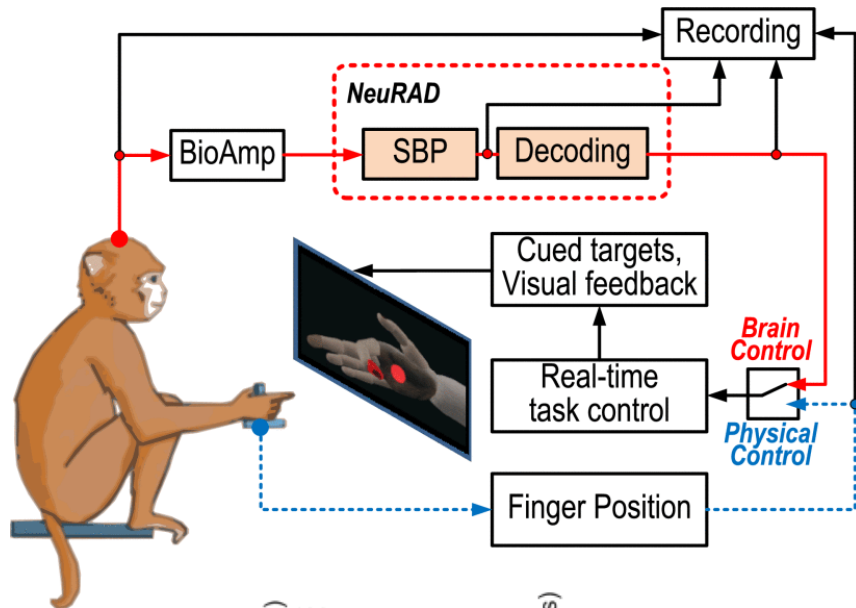
- ✗ Physical size
- ✗ Power consumption
- ✗ Limited mobility

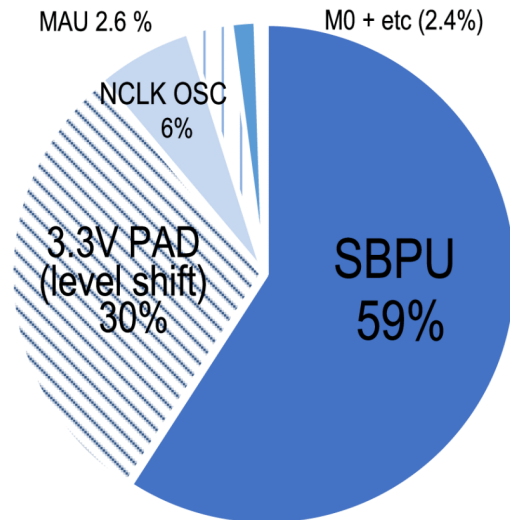
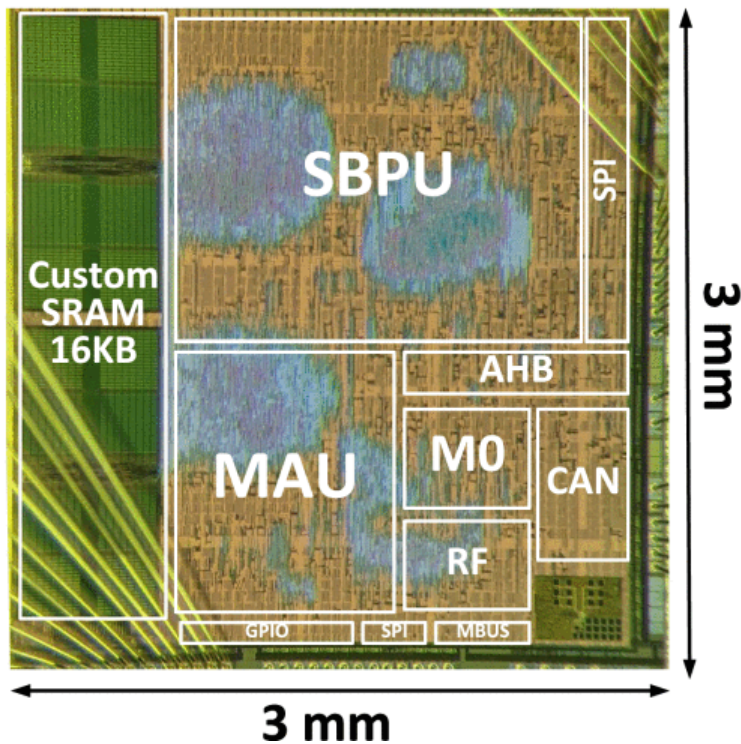
## Future BCIs



- ✓ Efficiency
- ✓ Intelligence
- ✓ Convenience

# NeuRAD: Finger Movement Decoding ASIC



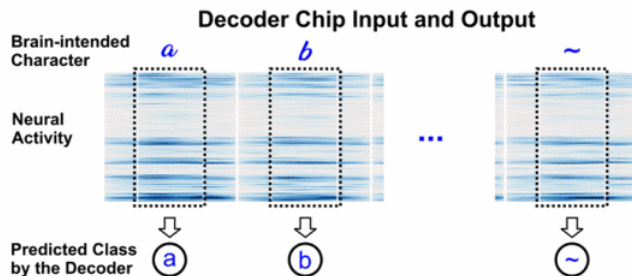
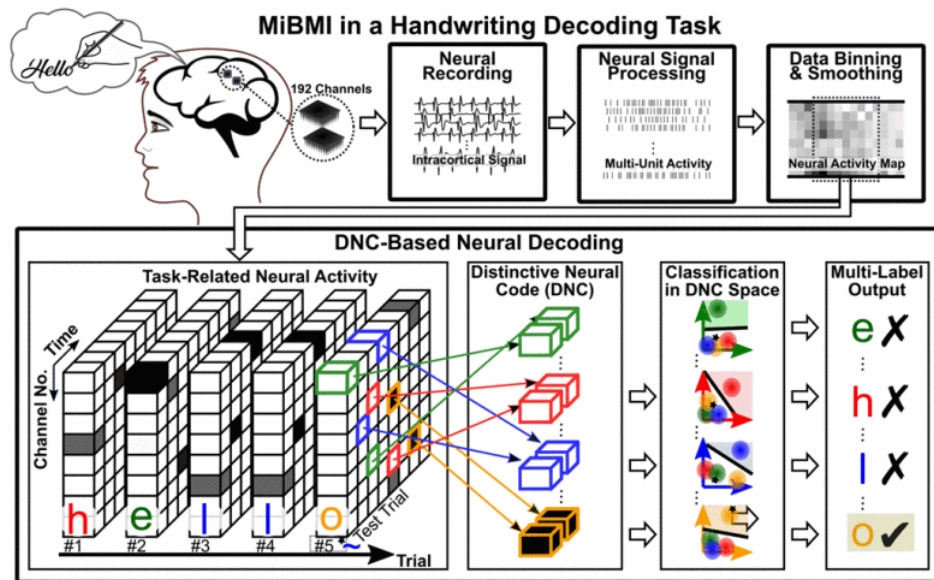


No. Ch.	96
Feature	SBP
Decoder	Kalman filter

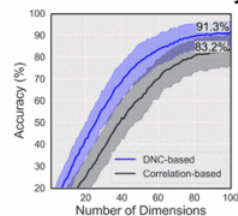
### Power Consumption:

- NeuRAD : 0.58 mW
- Intan RHD2132 (x3): 12.58 mW

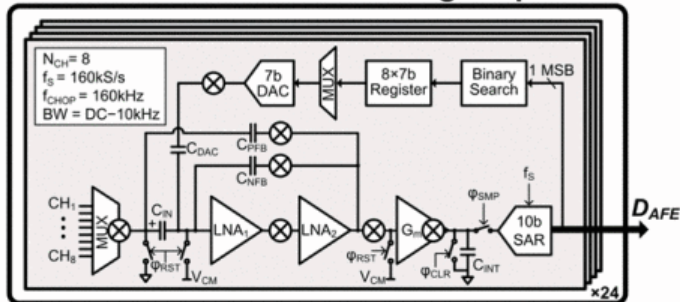
# MiBMI: Brain-to-text Decoding Chip



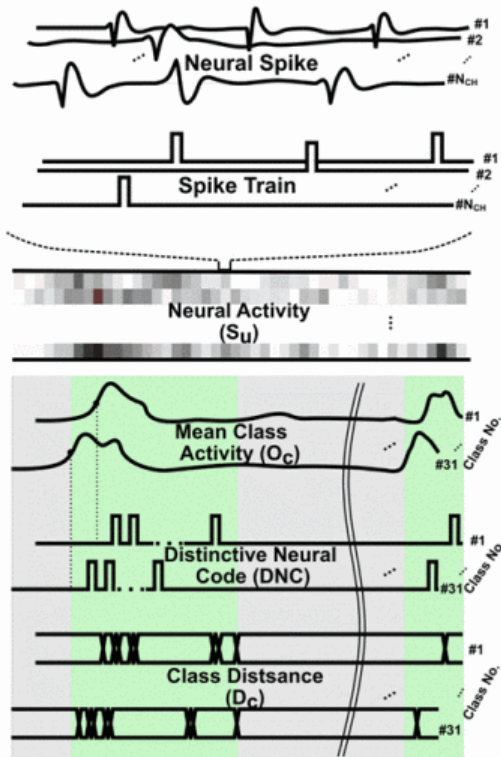
**Decoding Accuracy vs. Feature Dimensionality**



## 192-Ch Neural Recording Chip

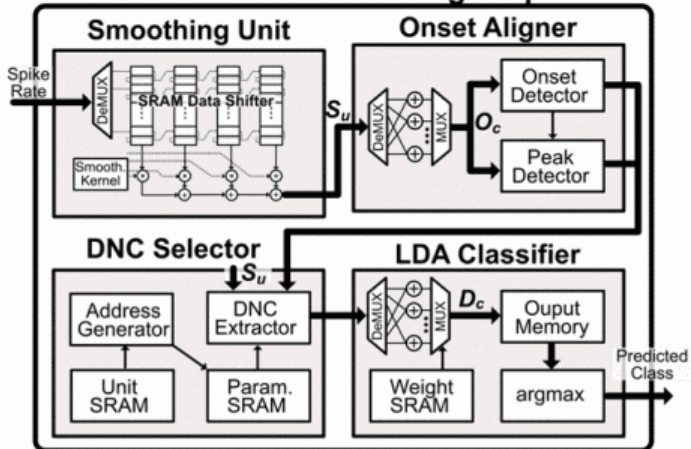


## Timing Diagram

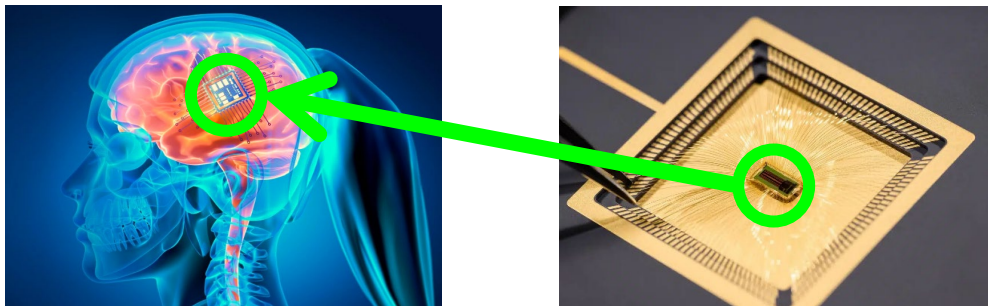


1. Neural activity recording
2. Spike Detection
3. Spike Counting
4. Onset detection
5. DNC extraction
6. LDA classification

## 512-Ch Neural Decoding Chip

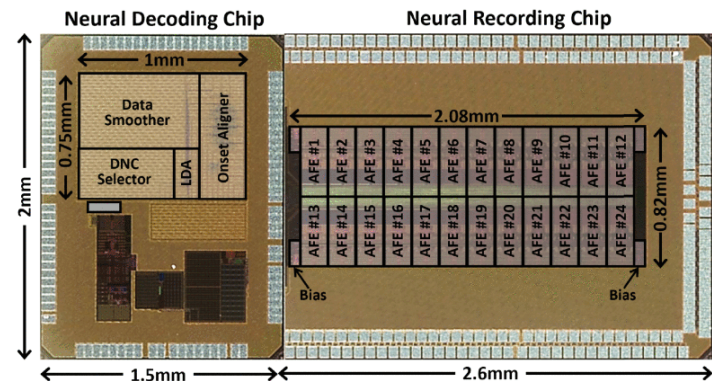


## Brain-to-Text Chip



Fabricated in TSMC 65nm:

- ☑ Recording: 512 Ch.
- ☑ Power: 223  $\mu$ W
- ☑ Size:  $2 \times 4 \text{ mm}^2$
- ☑ 31-character decoding
- ☑ Accuracy: 91-93%
- ☑ Comparable to RNN with 7M parameters



(a)

