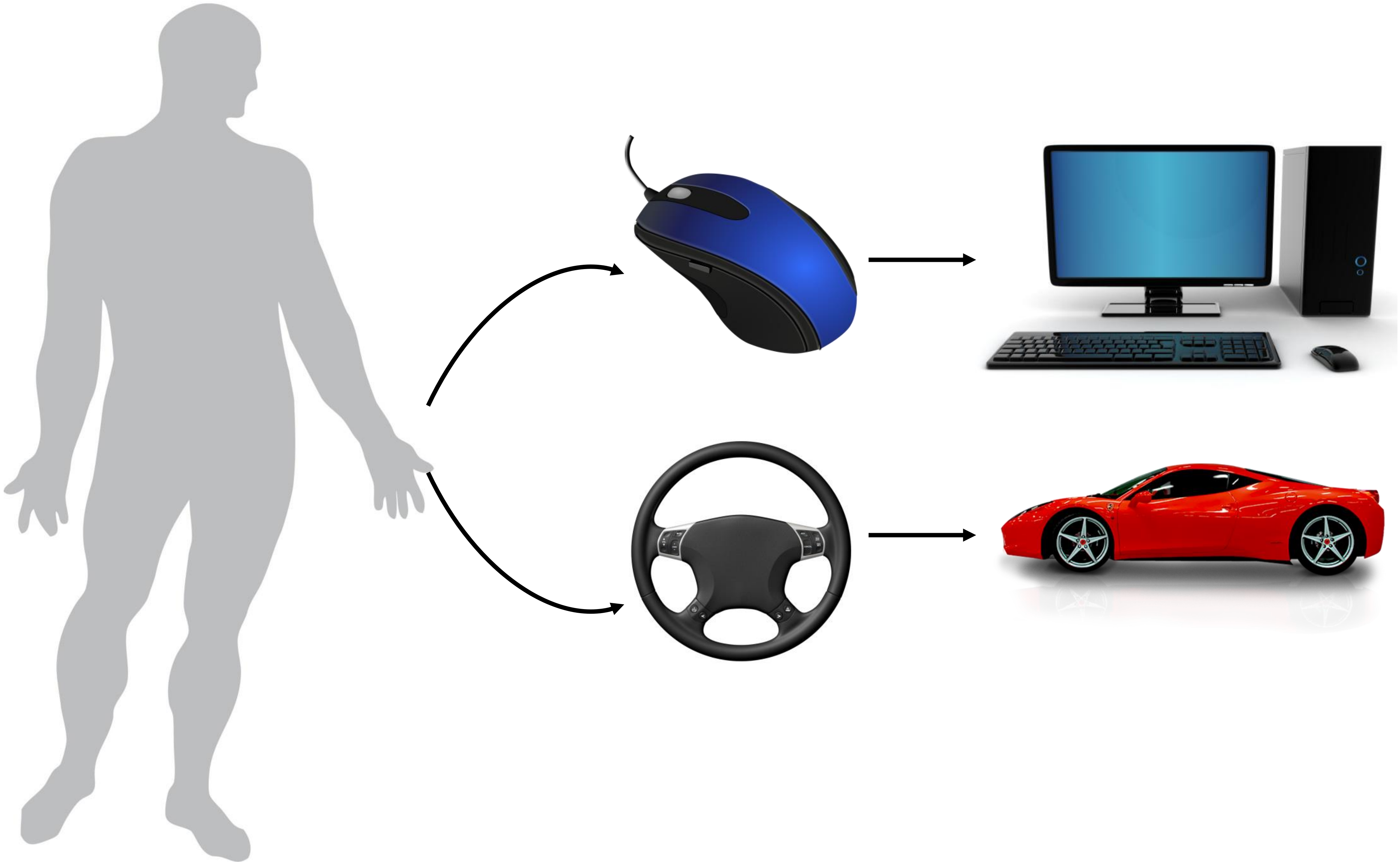
OAC-2117997

Towards Real-time Brain Computer Interfaces Development - Data, Algorithms, and Hardware

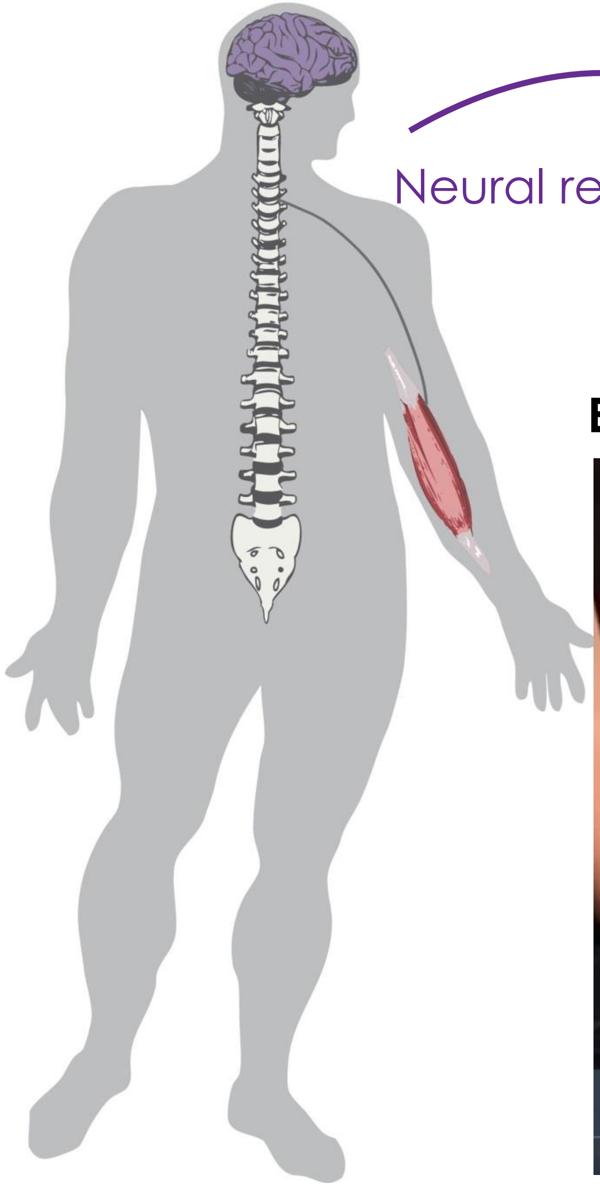
Lauren Peterson (A3D3 PostBac),
Si Jia Li,
Amy Orsborn (PI)

July 10, 2023

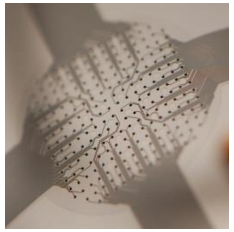
Interfaces give us new abilities



Neural Interfaces can **restore** abilities



Neural recordings

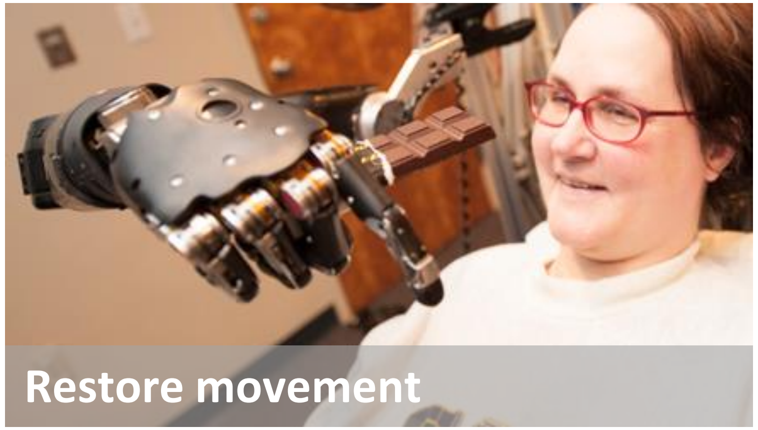


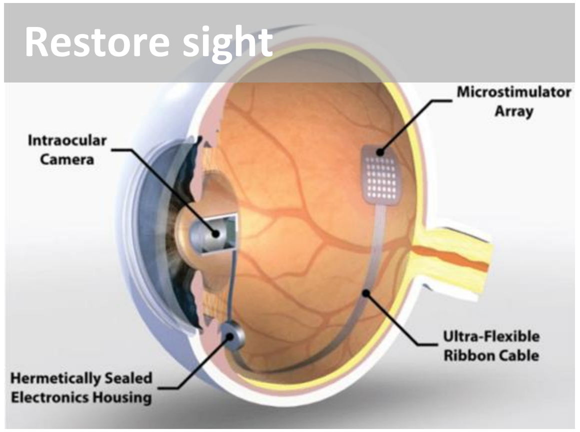
Brain-machine interfaces restore movement to people with paralysis

Collinger et al., *Lancet* 2012

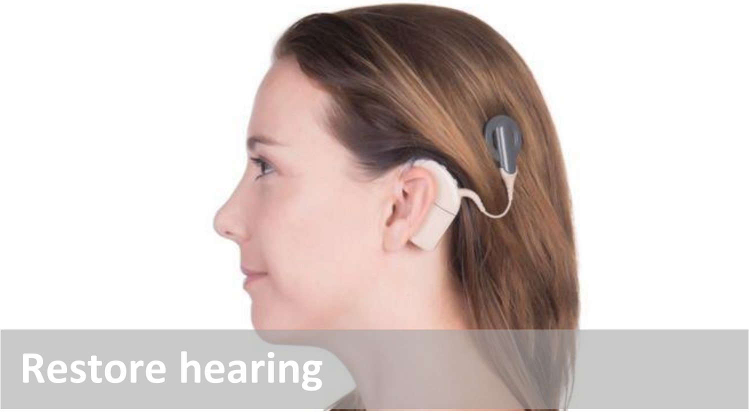
Huge range of applications & implications

Revolutionizing healthcare…


Restore movement



Restore sight


Restore hearing


Treat neuropsychiatric disorders

Revolutionizing HCI…

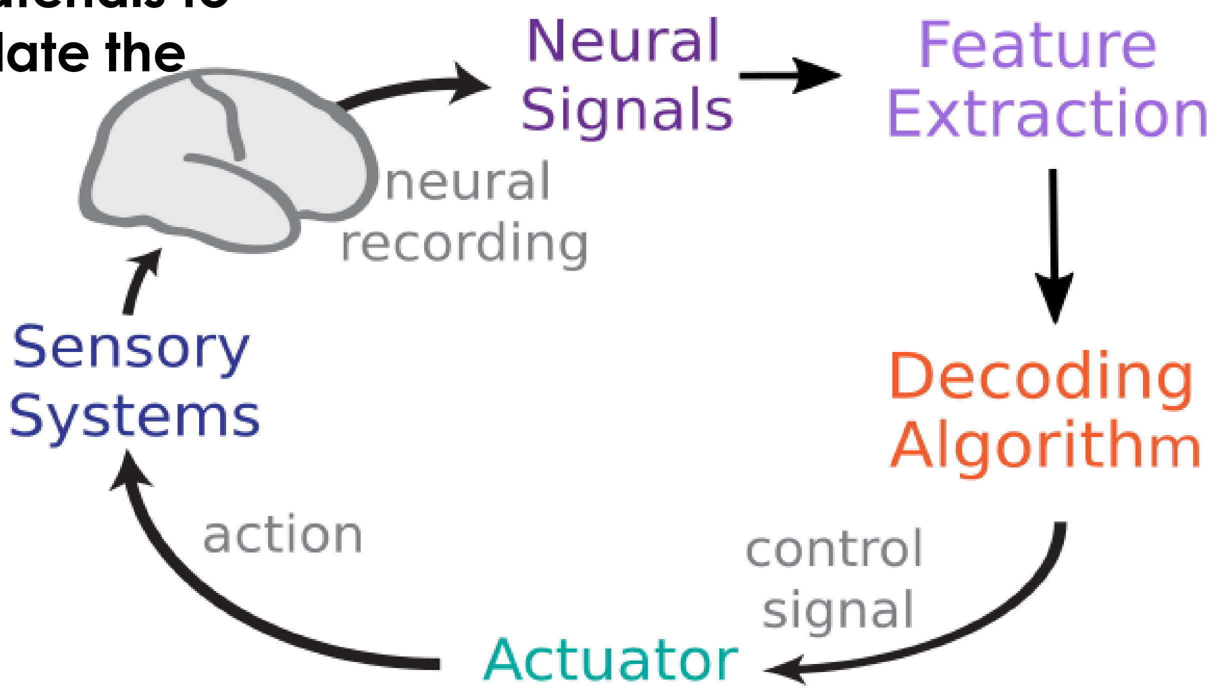
facebook

NEURALINK

CTRL-labs

Requires ***interdisciplinary*** engineering

Hardware and materials to measure/manipulate the nervous system



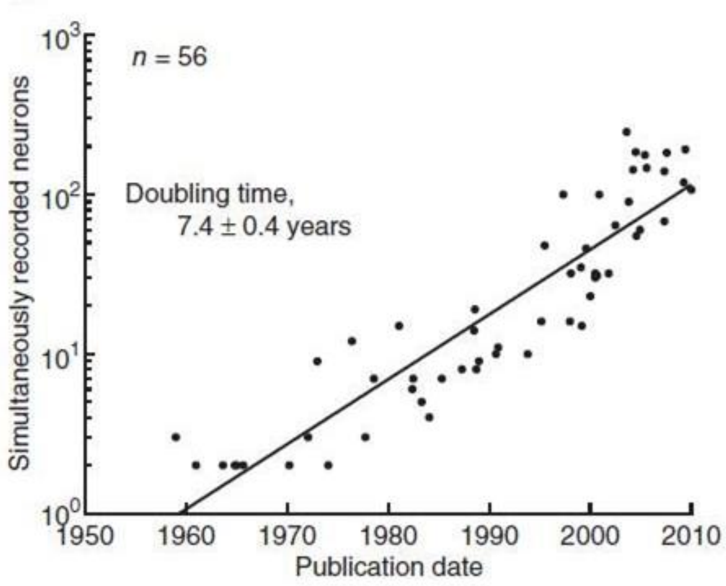
Algorithms to interpret neural activity
(machine learning, data science, neuroscience, …)

Security and ethics
(data encryption, privacy, neuroethics, public policy…)

Devices that can dynamically interact with users
(robotics, control theory, human-computer interaction, neuroscience…)

Neuroengineering needs high-throughput and real-time AI

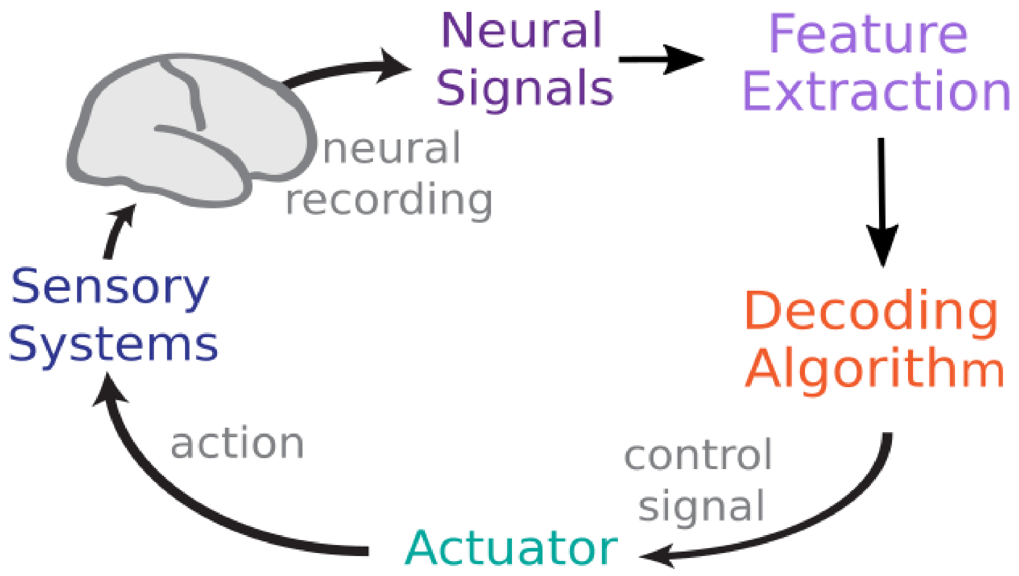
Rapid increase in number, type of measurements



Stevenson and Kording (2011)

Need: data-driven discovery of relevant features, structure in data

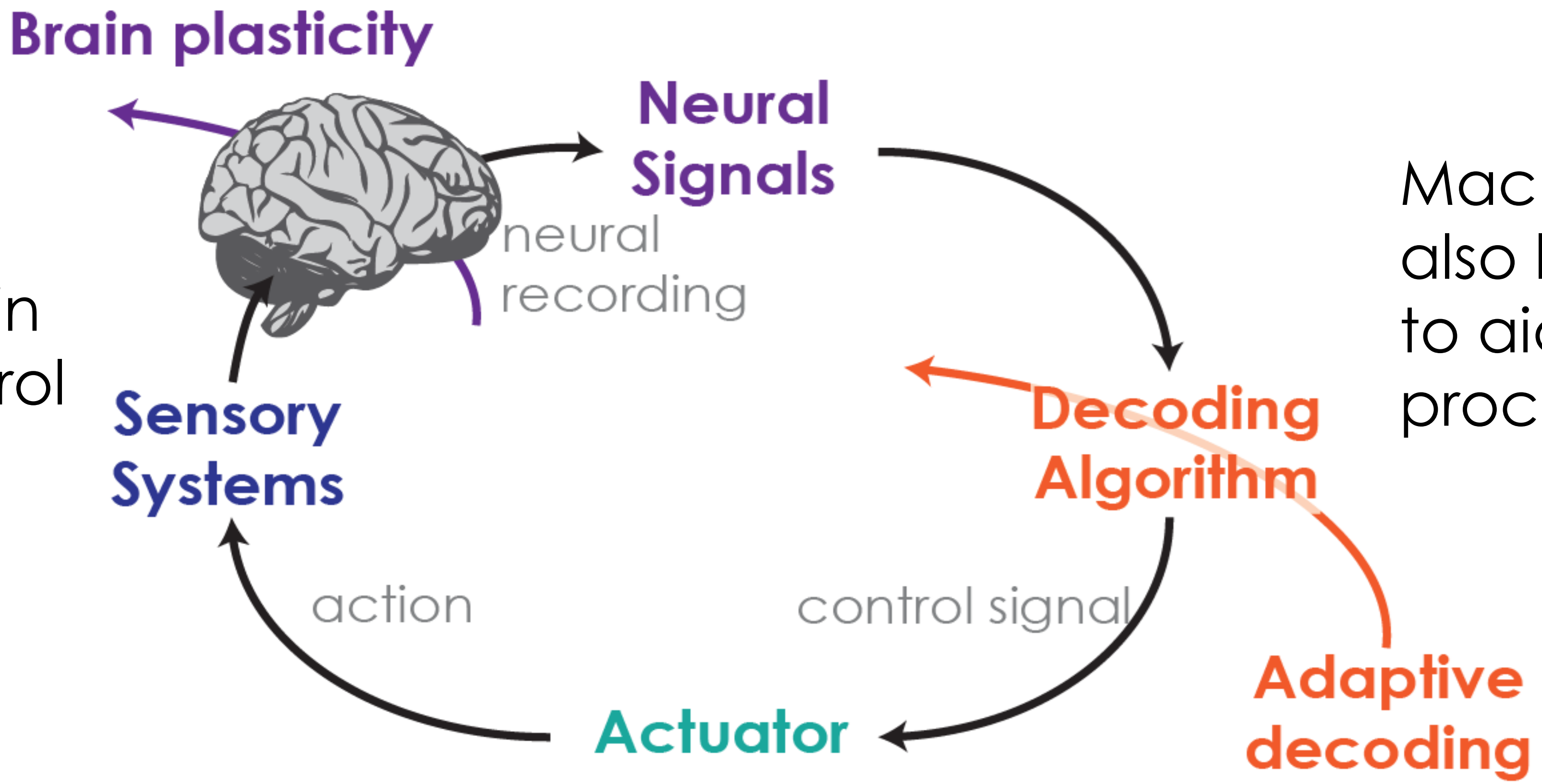
Algorithms must interact with the brain and control device in real-time



Need: low-latency algorithms (<1ms)

How do we make machine learning that interacts with the brain?

Much like you learn to ride a bike, your brain ***learns*** to control a neural interface

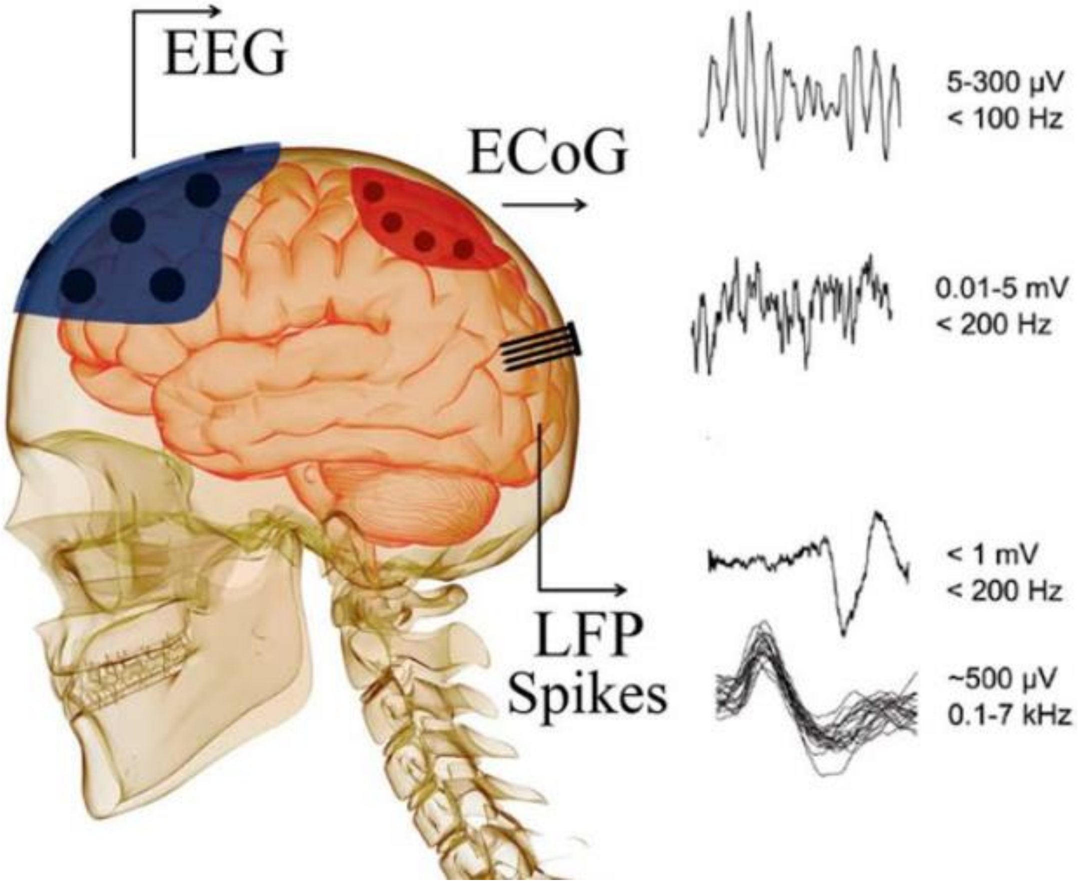


Machines can also learn/adapt to aid this process

Assuring both learners work *together* requires understanding the intersection of neuroscience and machine learning

Madduri, Burden, and Orsborn, *Curr Op BME* 2023 (in press)

We record different types of neural signals



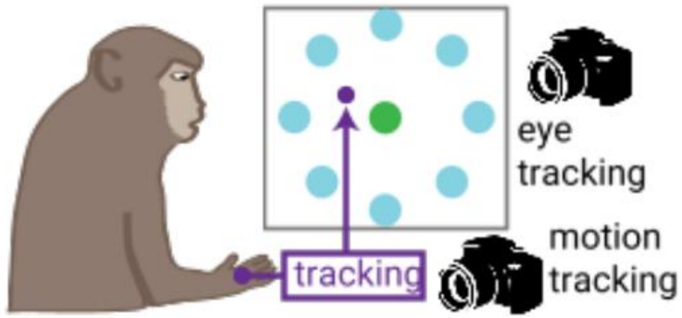
- Electrocorticograph: **continuous** surface potentials
- Local field potentials (LFPs): **continuous** measurement
- Spikes: **discrete** measurement (action potentials of neurons)

Each type of recording gives rise to many types of neural features.

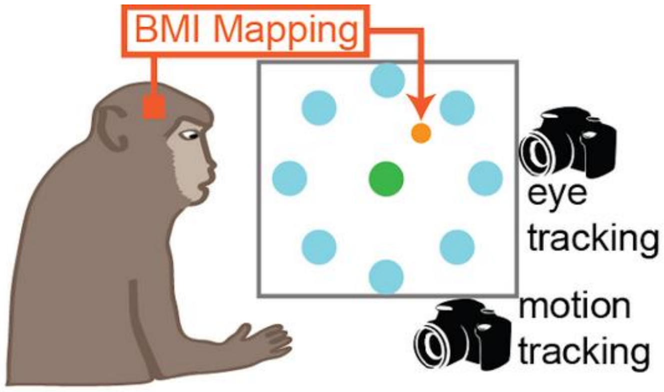
A spectrum of tasks and data structures

more constrained,
structured data,
less time (1hr/day)

less constrained,
unstructured data,
more time



Manual center-out reaching



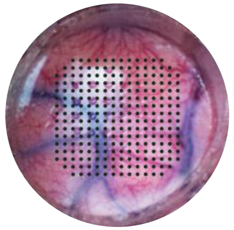
BMI center-out reaching

In cage wireless recording

Berger et al., (2020)

Data-driven discovery
of relevant features, structure in data

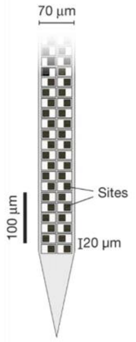
Electrocorticography
244 Electrodes



What are the task-relevant electrodes/features?

What are the underlying dynamics?

Neuropixels
960 sites (2017)



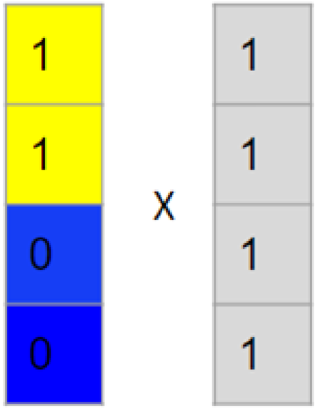
What are the electrodes to stream as the user learns?

Convex feature objective that optimizes for sparseness, smoothness, and relevance

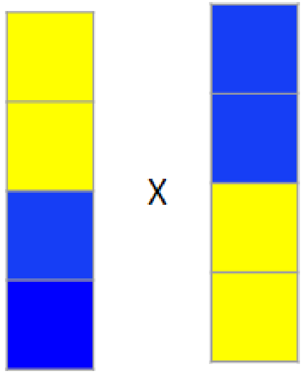
$$\min_{\theta_i} \quad \lambda \theta_i^T \mathbf{1}$$

$$\text{s.t.} \quad 0 \leq \theta_{i,m} \leq 1$$

Minimizing the number of features



Maximize feature selection smoothness

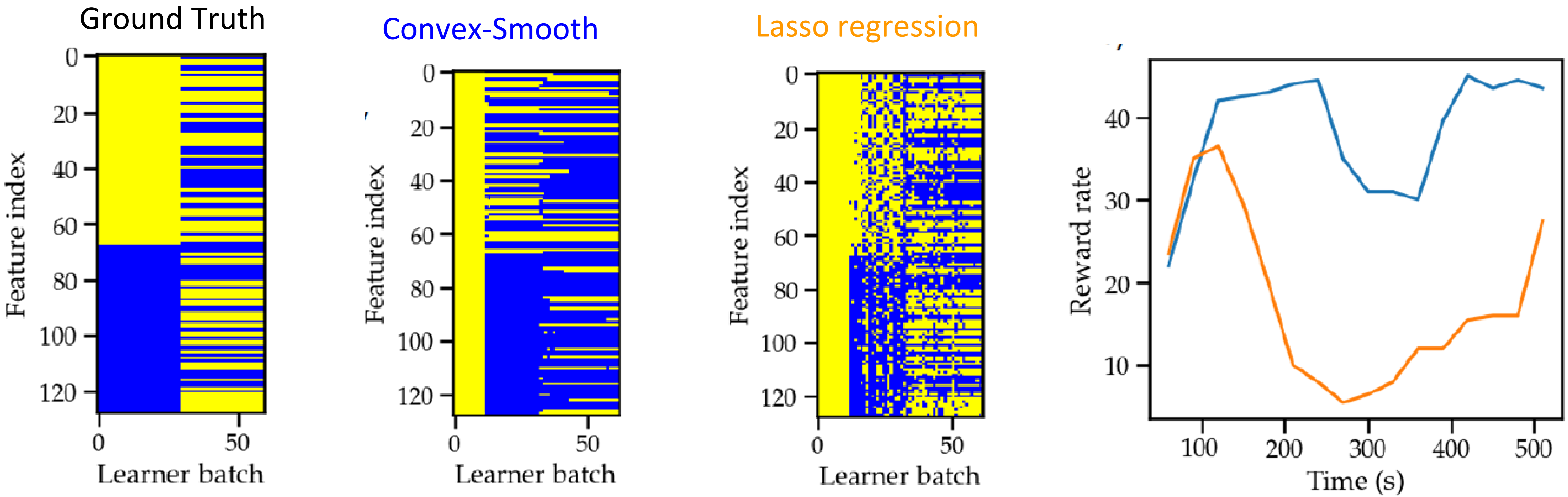


Maximize feature relevance by measuring weight to noise ratio

Convert to a convex optimization problem that is easier to solve (Joshi and Boyd, 2006)

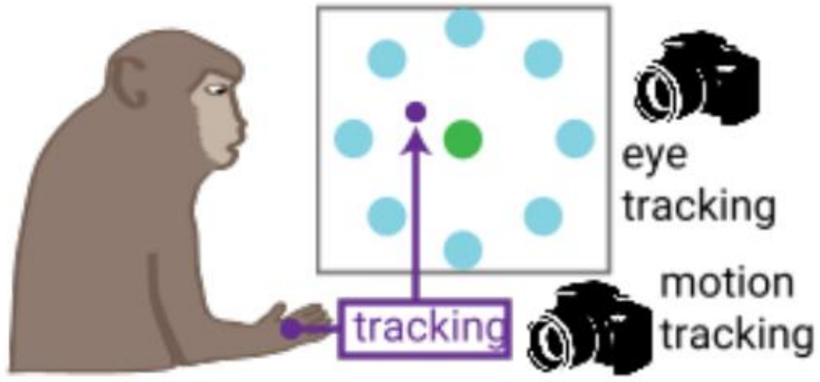
Si Jia Li et al., in prep

Smooth objective helps with online task performance

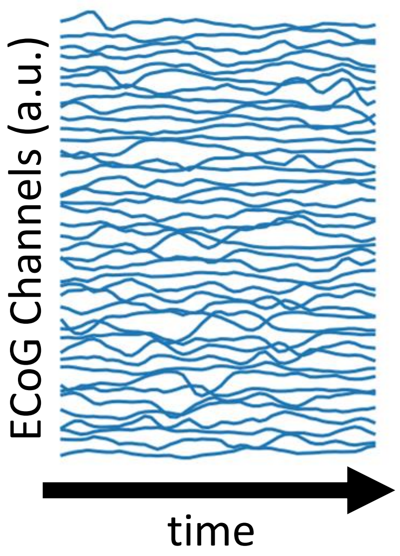


Feature selection applications

Implement in animal experiments



Data driven selection of
ECoG features

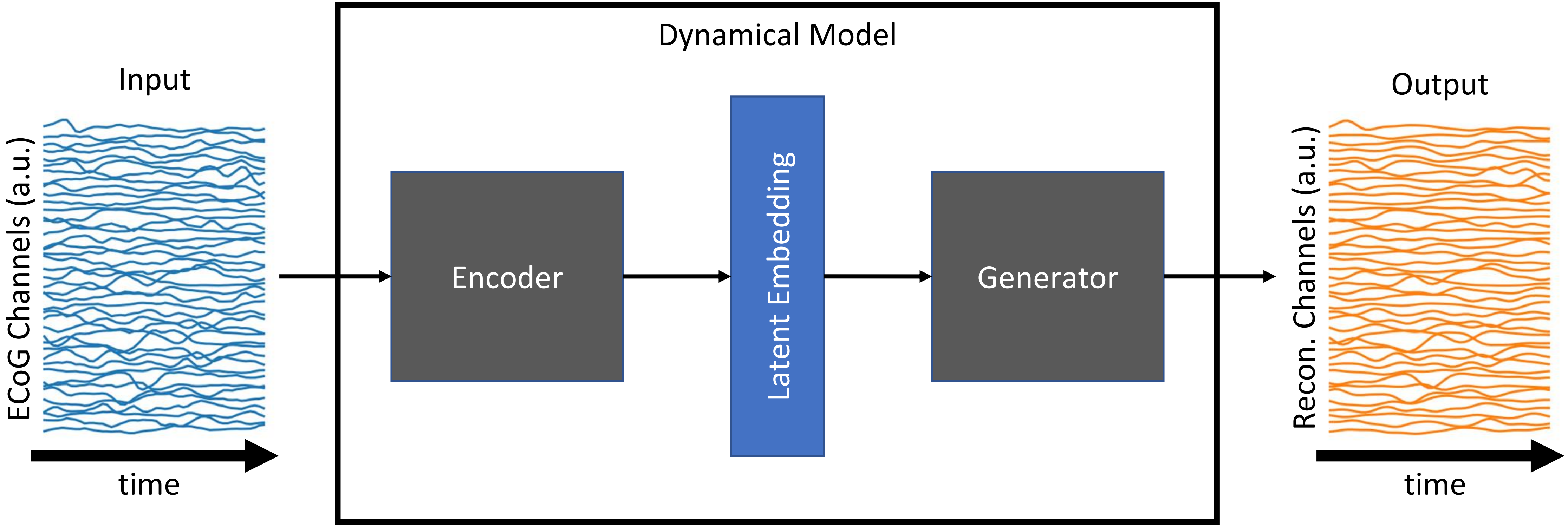


ECoG Signal Reconstruction

How do we build models of neural signal dynamics?

based on work from "Multi-block RNN Autoencoders Enable Broadband ECoG Signal Reconstruction", preprint: doi: https://doi.org/10.1101/2022.09.07.507004

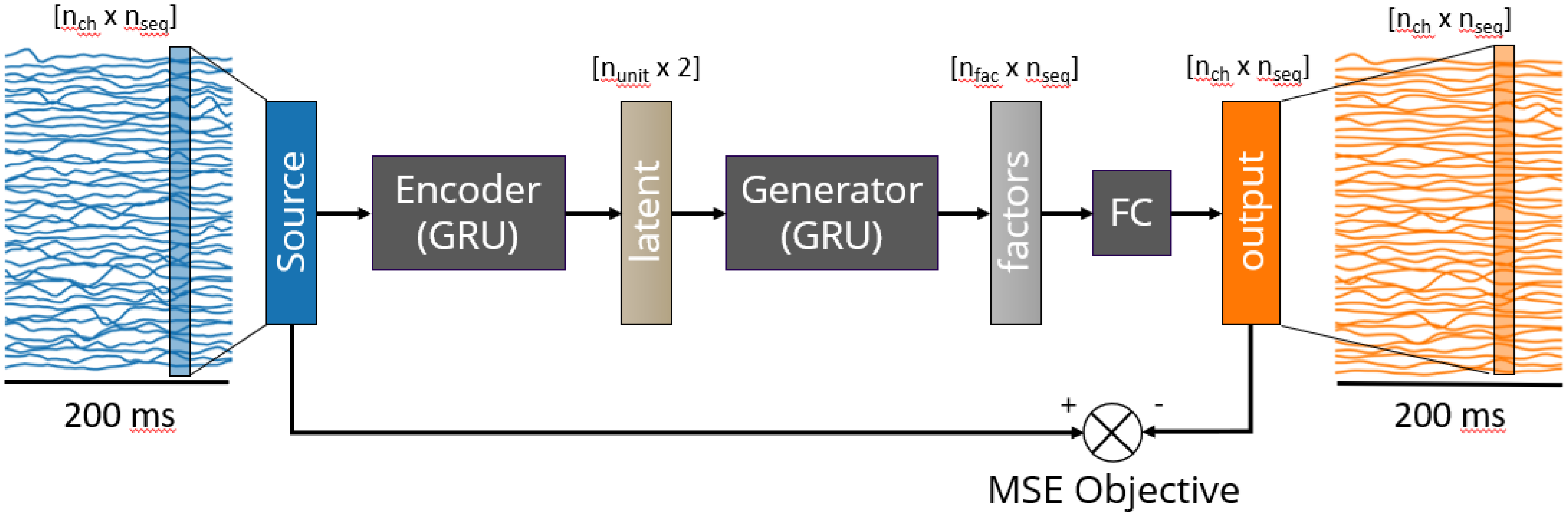
Modeling Neural Dynamics: Recurrent Autoencoders



- Current models have been useful for neuroscience research
- What happens when we use a broadband signal?

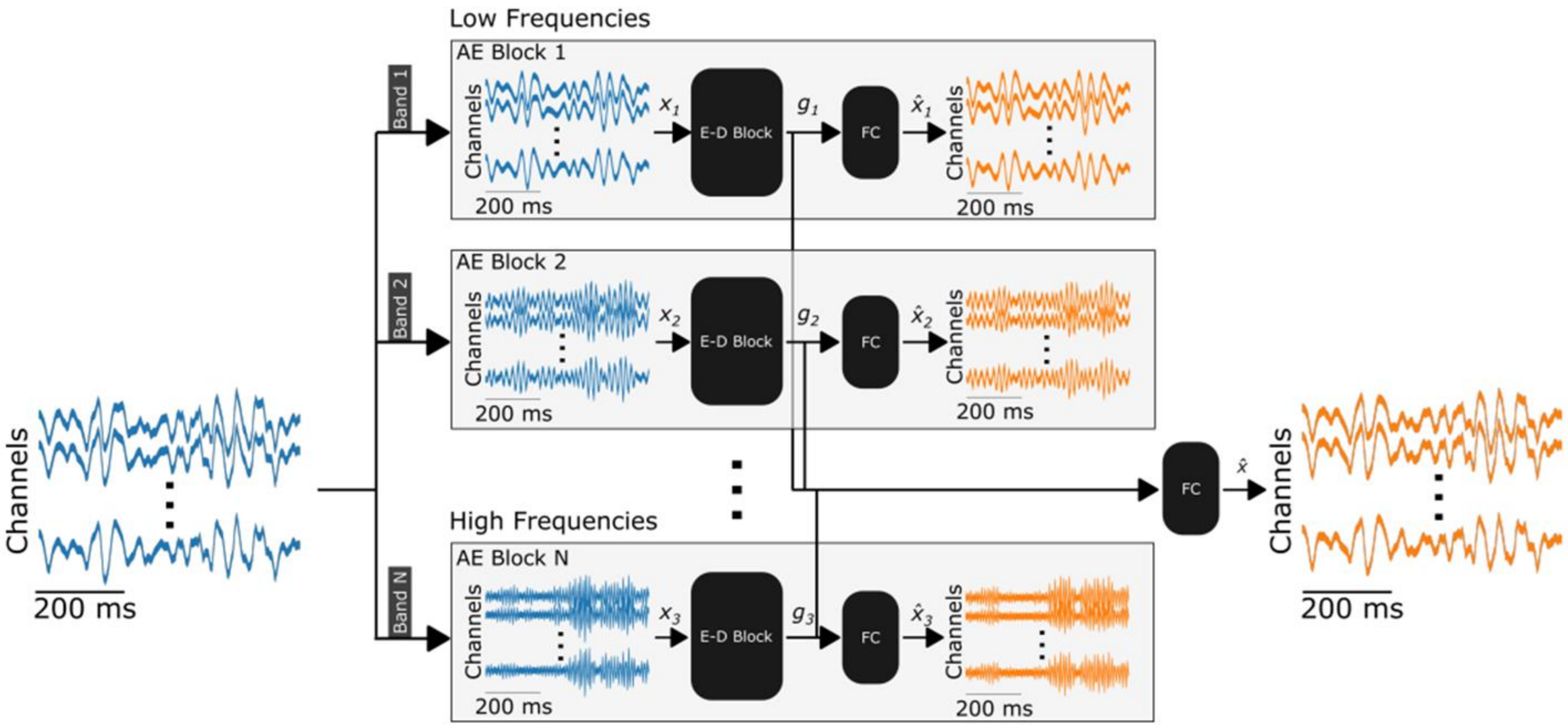
(arXiv:1608.06315)

RNN Autoencoder Models (RAE)



- We make some minor adjustments to handle broadband
- Increasing model size improves performance

Multi-block RAE (MRAE)

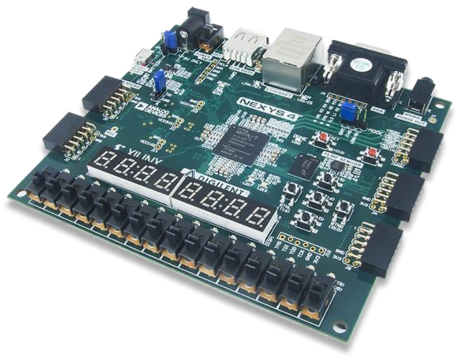


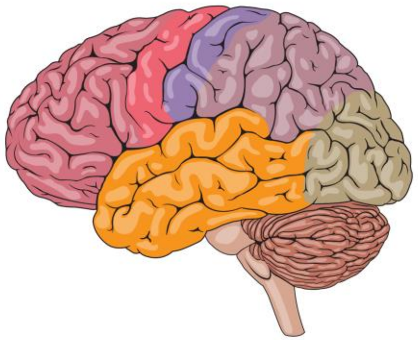
- Performance improves with model size, and scalability is good

from “Multi-block RNN Autoencoders Enable Broadband ECoG Signal Reconstruction”

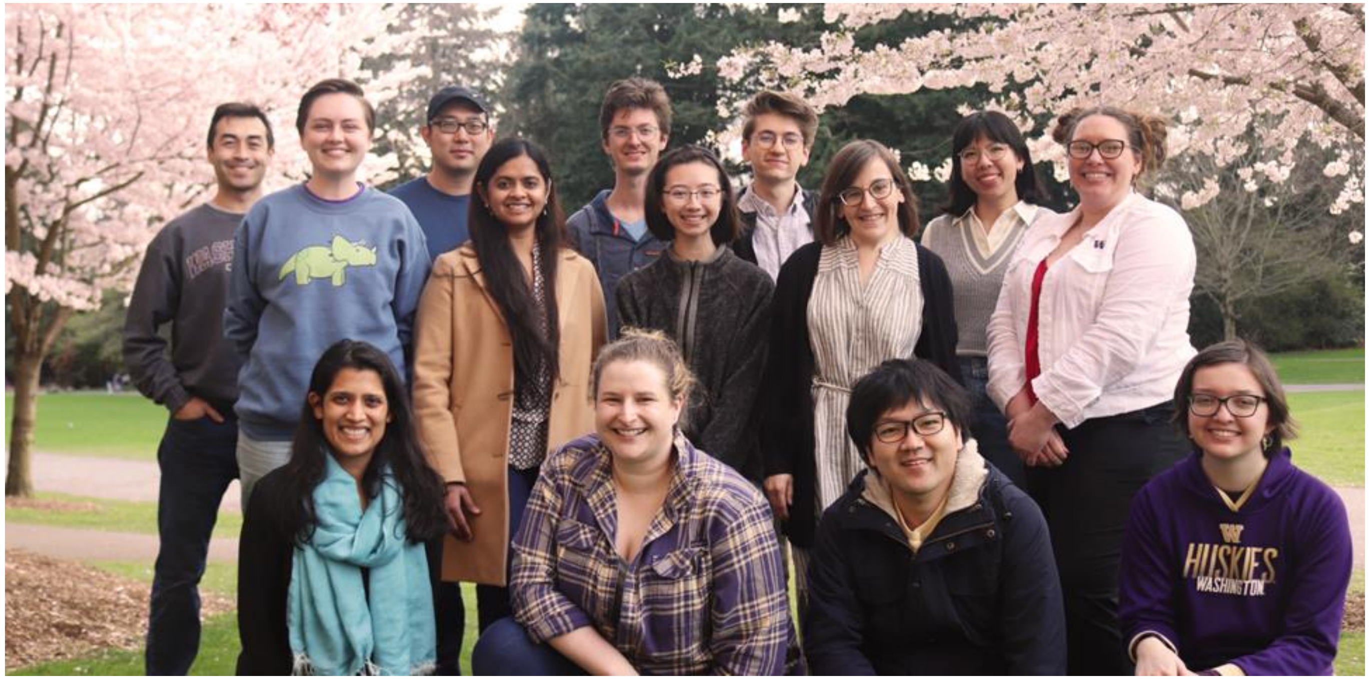
Real-time Applications

- FPGA implementation is in the works
- Collaborating with Shlizerman, Hauck labs to improve performance and latency
- MRAE is scalable, but other emerging technologies (e.g. transformers) might improve reconstruction and prediction, and help us determine which features are the most important





Acknowledgements



Thanks to NSF and A3D3 (OAC-2117997) for funding this research

National Science Foundation

Orsborn Lab Group

Accelerated AI Algorithms for Data-Driven Discovery

Backup slides

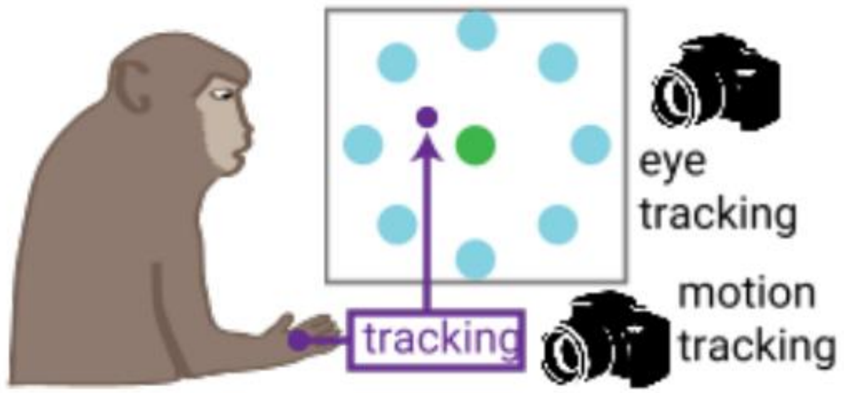
Experimental Subjects

There are 5 monkeys in the lab:

- A & B: brain-computer interface, neuropixels, center-out task
- C: behavioral tasks; will add neural in ~6 months
- D & E: currently used in other projects

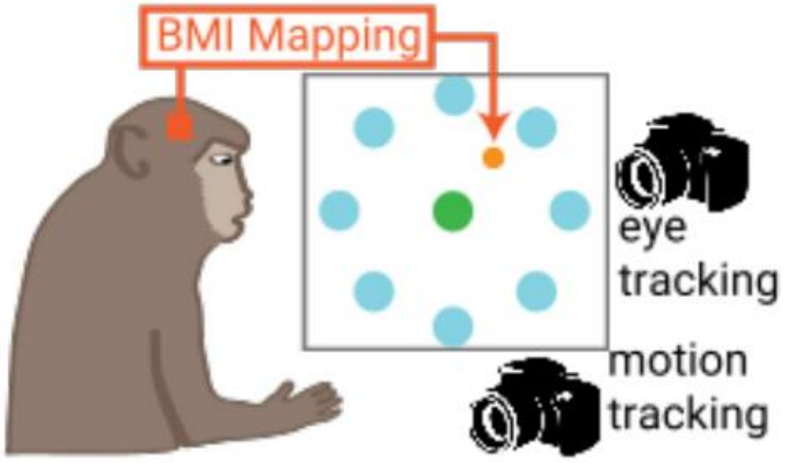
Manual Center-out

- Hand position (3D space) controls cursor position (2D plane) via mapping
  - Subject wears a glove with IR panels, recorded by motion-tracking cameras
  - Cursor position recorded directly
  - Eye tracking recorded by cameras (I currently can’t answer questions about this)
- Brain activity (electrode array) recorded, but not used as input
- Can change the mapping to see how subject adapts and learns a new mapping
- Associated metadata includes:
  - Time stamps, trial tags (trial begin/end, etc)
  - Sampling rate
  - Cursor size, target size, target position
  - Number of channels/samples



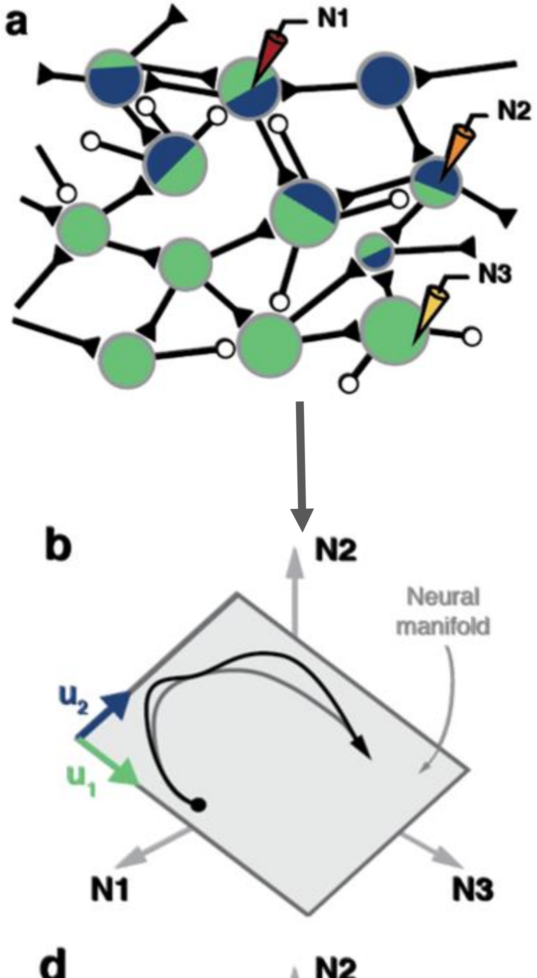
BCI Center-out

- Hand is somewhat restricted
- Neural activity (recorded from electrode array) used as input
    - High frequencies used in linear regression decoder
- Experiment proceeds the same way otherwise
- Same metadata, but no hand position recorded

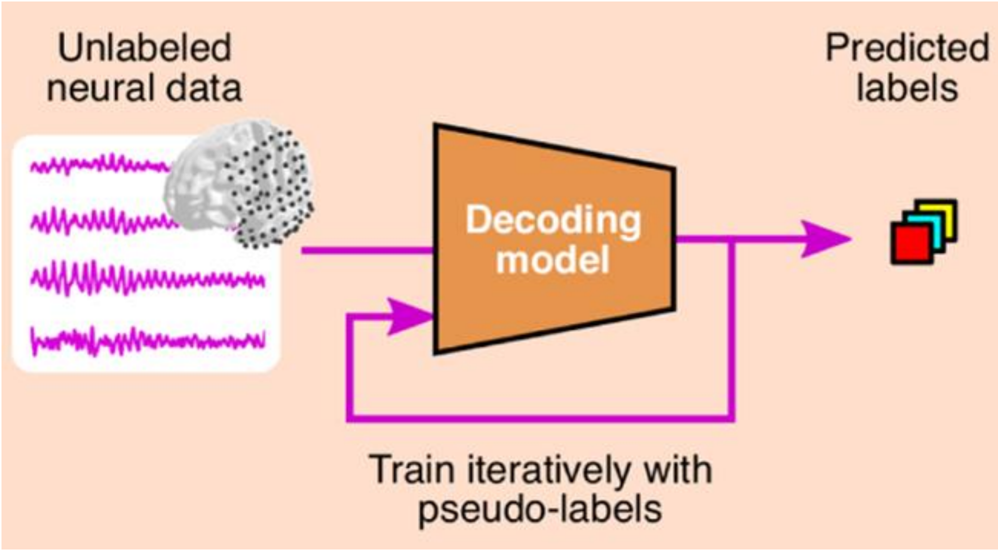


Example types of AI applications in neuroscience

1. Identify relevant features of neural activity (latent structure)



2. Relate neural features to behavior

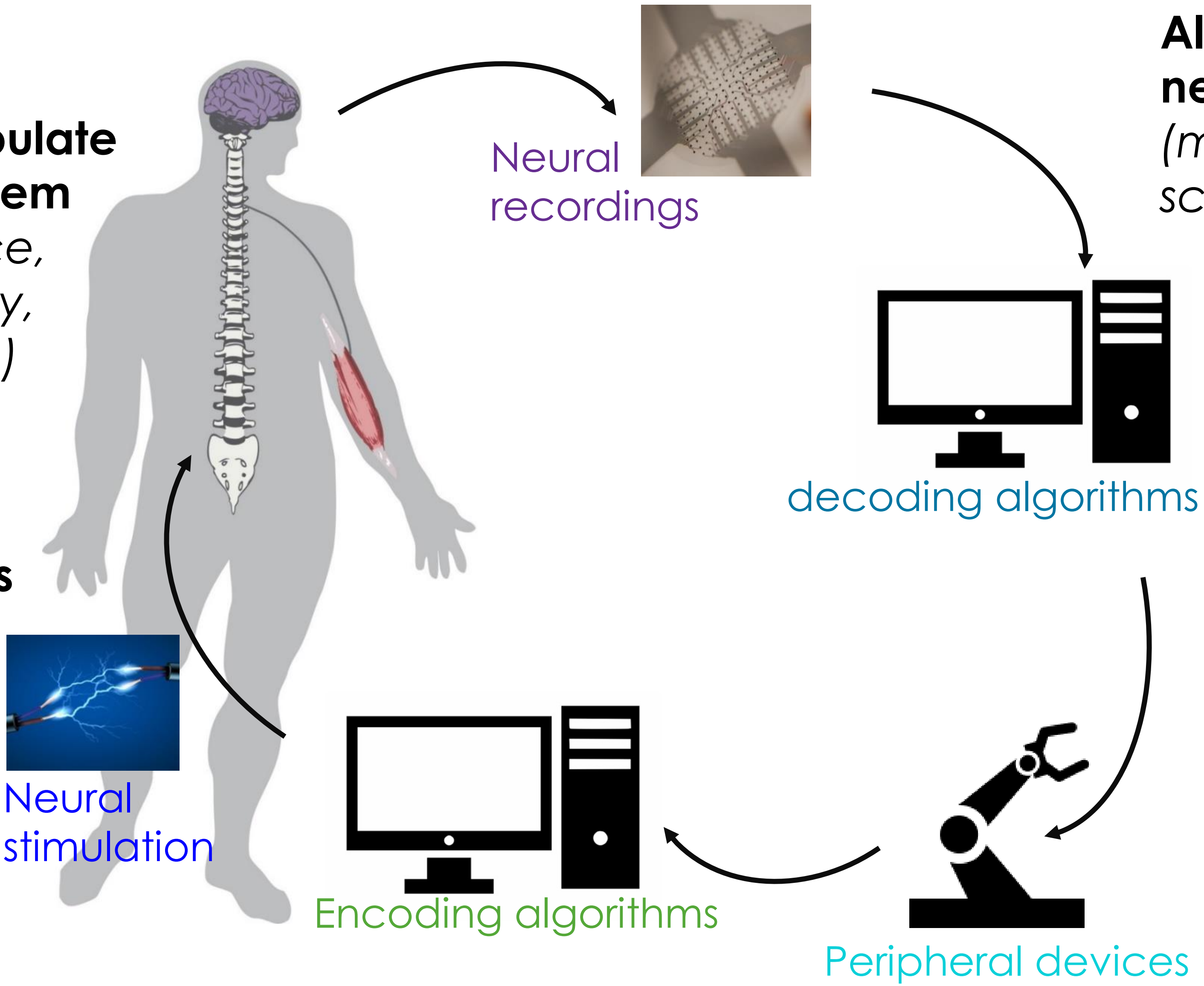


3. Decode behavior in real-time to restore function

Requires ***interdisciplinary*** engineering

Hardware and materials to measure/manipulate the nervous system
(material science, bio-compatibility, circuit design,…)

Algorithms to interpret neural activity
(machine learning, data science, neuroscience, …)



Security and ethics
(data encryption, privacy, neuroethics, public policy…)

Devices that can dynamically interact with users
(robotics, control theory, human-computer interaction, neuroscience…)

Neural recording hardware