Neuroscience in A3D3: annual project updates

October 7th, 2022

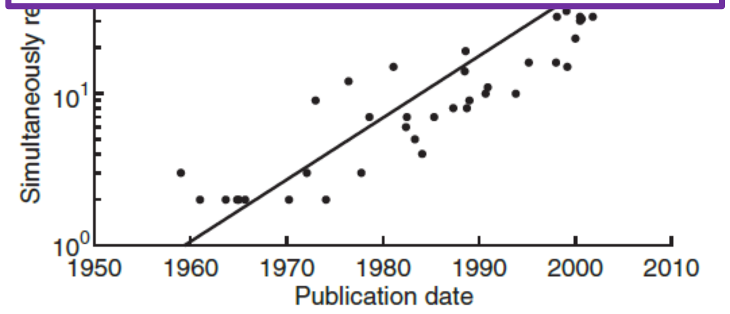
A3D3: using ML for low-latency, real-time neuroscience

- Neural data growing rapidly (measuring big brain networks)

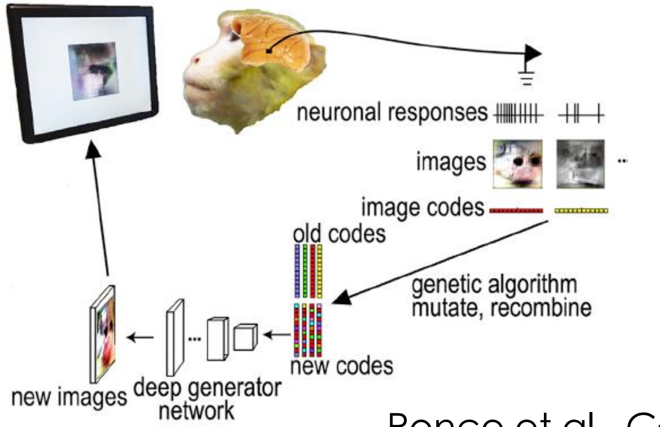
- Real-time manipulations allow *causal* manipulations of brain circuits to understand function

- Data-driven approaches allow for hypothesis generation and discovery

A3D3 Seminar on October 24 from Dr. Nick Steinmetz – state of the art large-scale neural measurements



Stevenson & Kording, *Nature Neuroscience* 2011



Ponce et al., *Cell* 2019

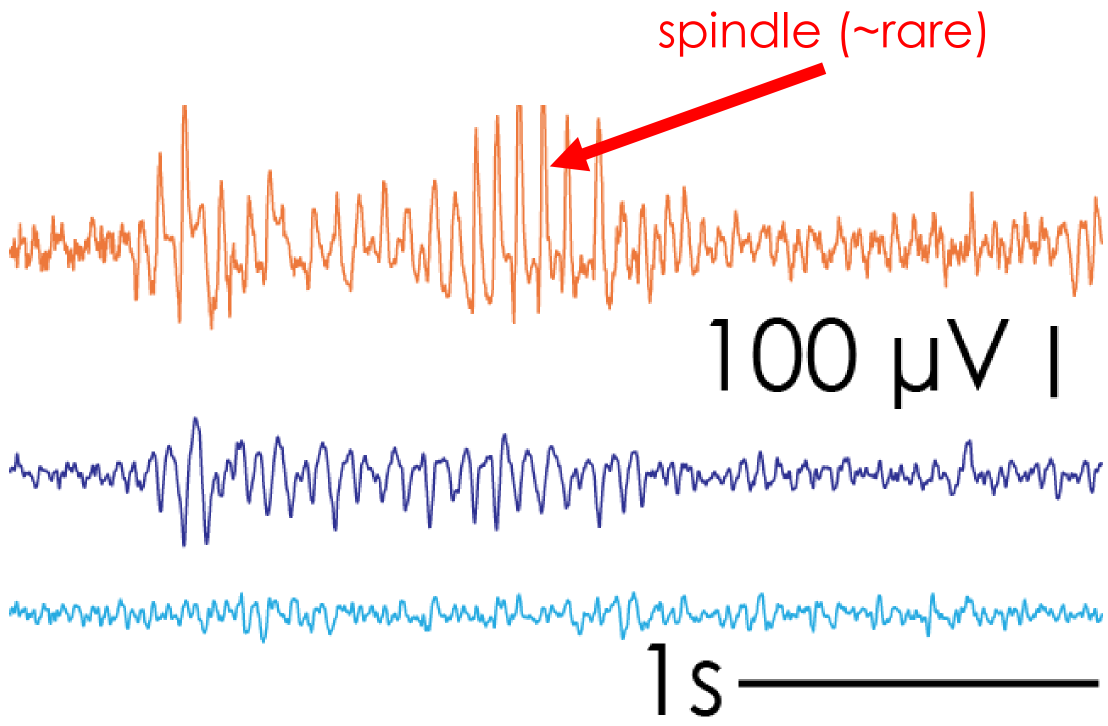
Main teams

- UW – tools for low-latency detection/prediction of neural events
  - Faculty: Amy Orsborn, Eli Shlizerman, Scott Hauk
  - Trainees: Michael Nolan, Jinguan Li, Trung Le, Leo Scholl, Xiaohan Lu, Aidan Yokuda, Lauren Petersen

- Purdue – tools for large-scale data analysis and system-identification
  - Faculty: Maria Dadarlat, Eli Shlizerman
  - Trainees: Megan Lipton, Seungbin Park

Low-latency example application: closed-loop stimulation to alter sleep-spindle events

Local field potential measurements
(electrical activity of groups of neurons)



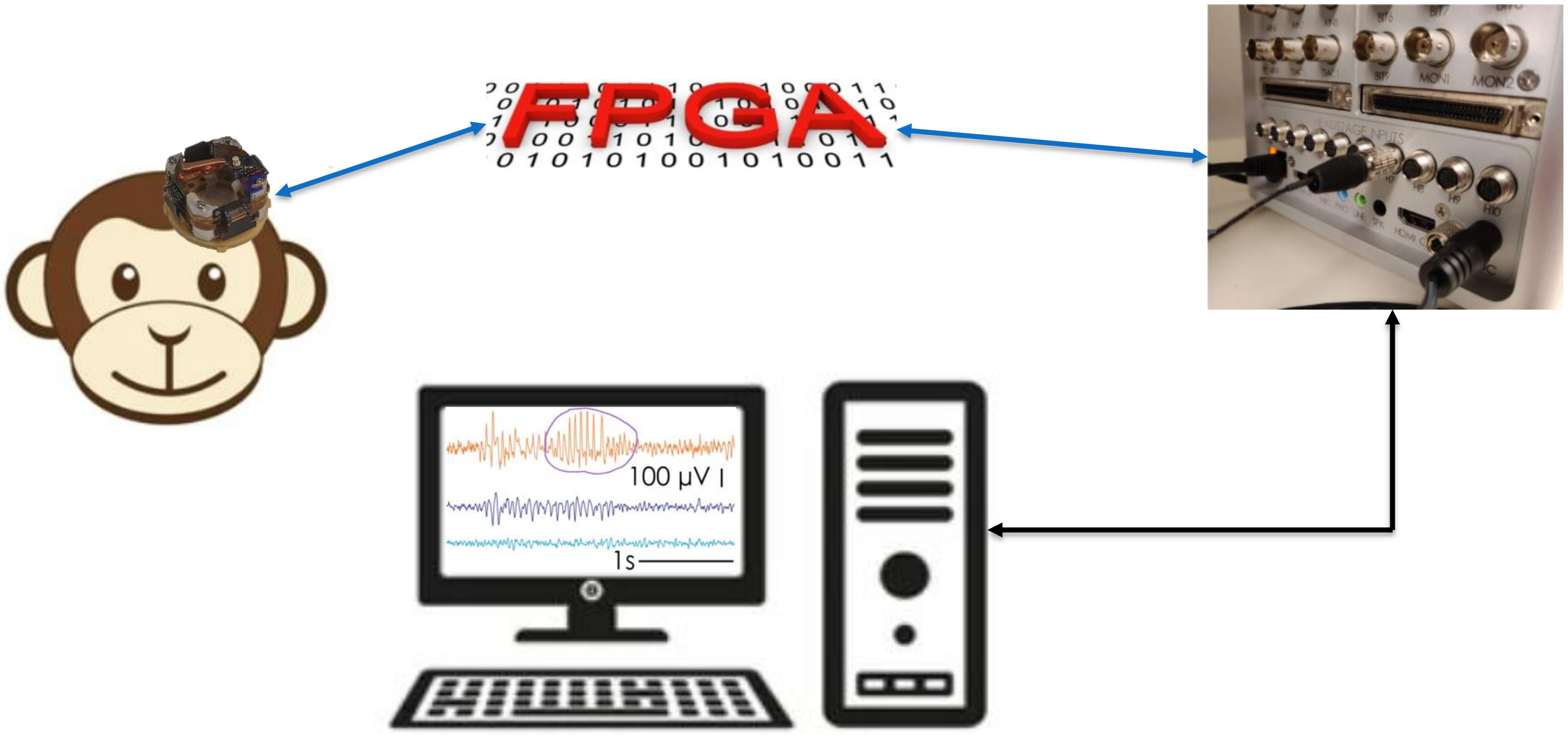
- "Spindles" are oscillation events that occur during sleep/rest
- Thought to contribute to learning

- **Currently:** *detect* a spindle starting and stimulate to disrupt

- **Goal:** predict spindle will occur, stimulate to prevent

Low-latency example application: closed-loop stimulation to alter sleep-spindle events

Detect brain state (spindles), stimulate in real-time to disrupt
→ Insights into brain state's impact on brain function/behavior



Achieving this requires completing 3 major goals:

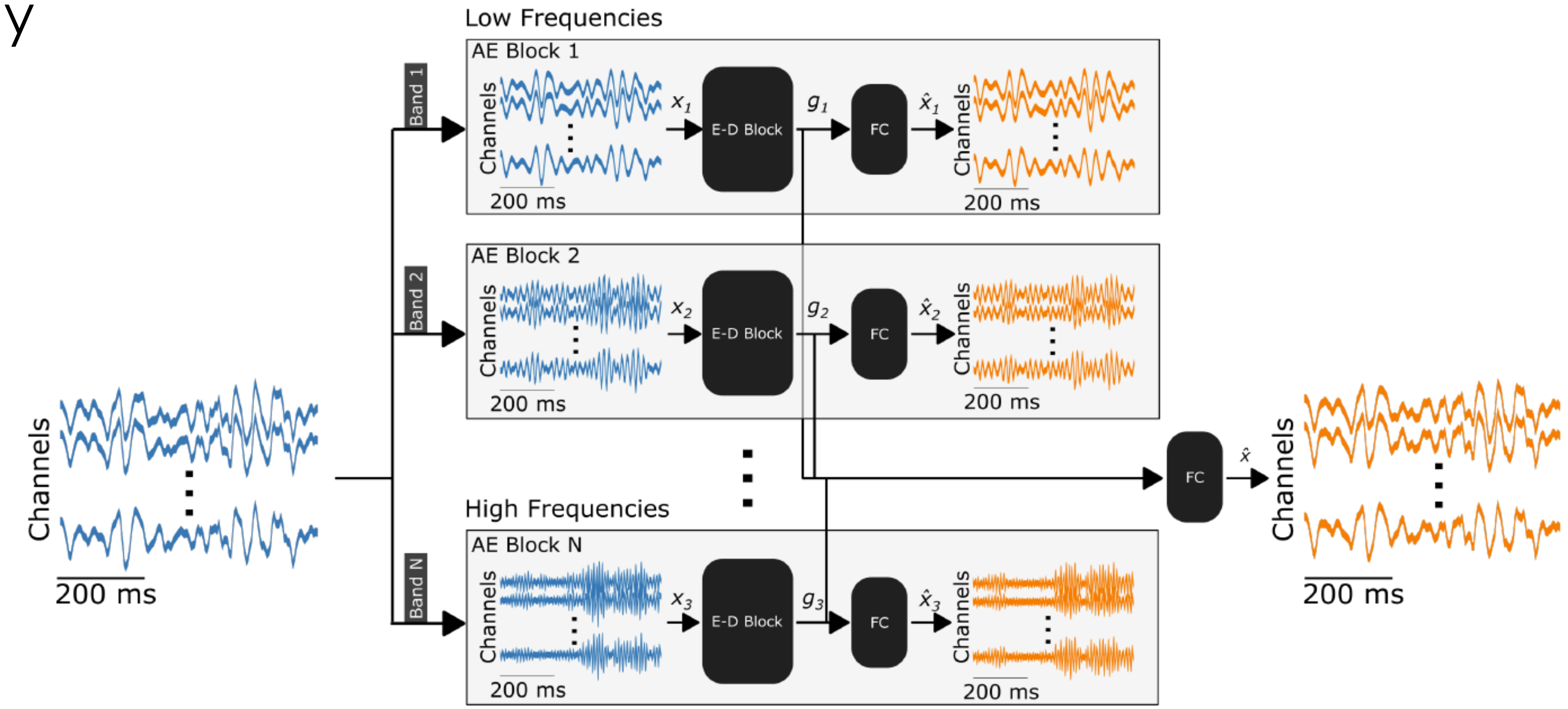
1. New algorithms to reconstruct/predict neural signals
2. New algorithms to predict spindle events
3. Hardware-implementation for low-latency prediction

Progress on goal 1.

Algorithms to reconstruct/predict broad-band neural signals (1/3)

- Found that existing autoencoder methods for neural data are band-limited to model size
  - Limits reconstructions of broad-band neural data such as micro-electricorticography

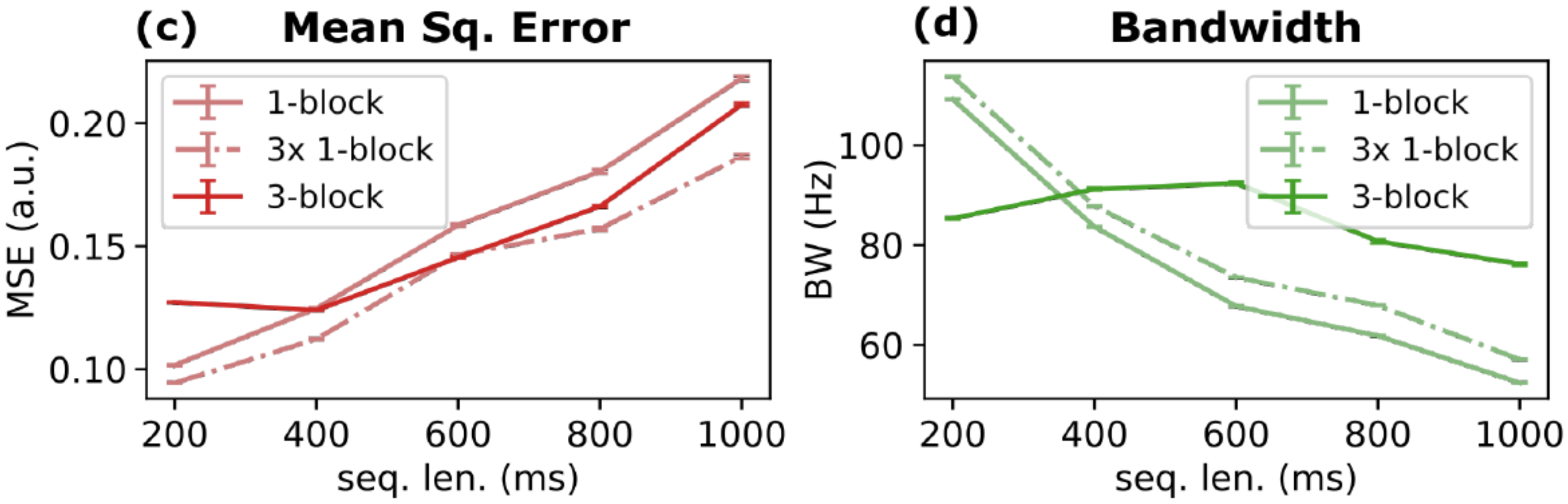
- Developed new Multi-block Recurrent Auto-Encoder (MRAE) to increase model bandwidth more efficiently:



Nolan, Pesaran, Shlizerman & Orsborn, *bioarxiv 2022*

Progress on goal 1.
Algorithms to reconstruct/predict broad-band neural signals (2/3)

- MRAE architecture improves reconstruction accuracy and bandwidth for longer reconstruction time windows
- MRAE method is more scalable
  - better reconstruction accuracy for fixed model size



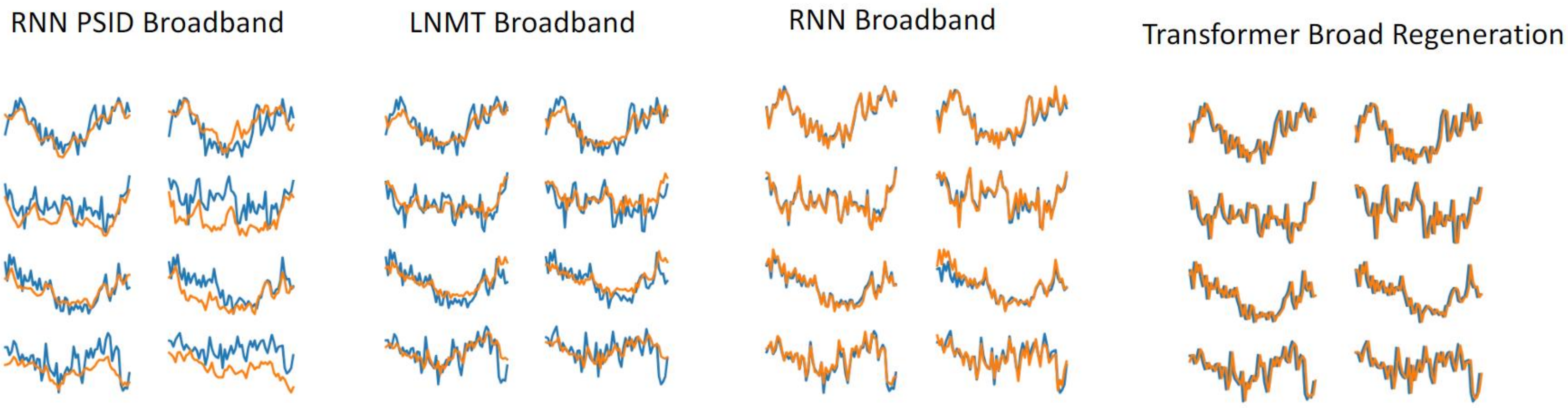
Nolan, Pesaran, Shlizerman & Orsborn, *in prep*

Progress on goal 1.

Algorithms to reconstruct/predict broad-band neural signals (3/3)

- Alternative model architecture using transformers may significantly improve reconstruction bandwidth

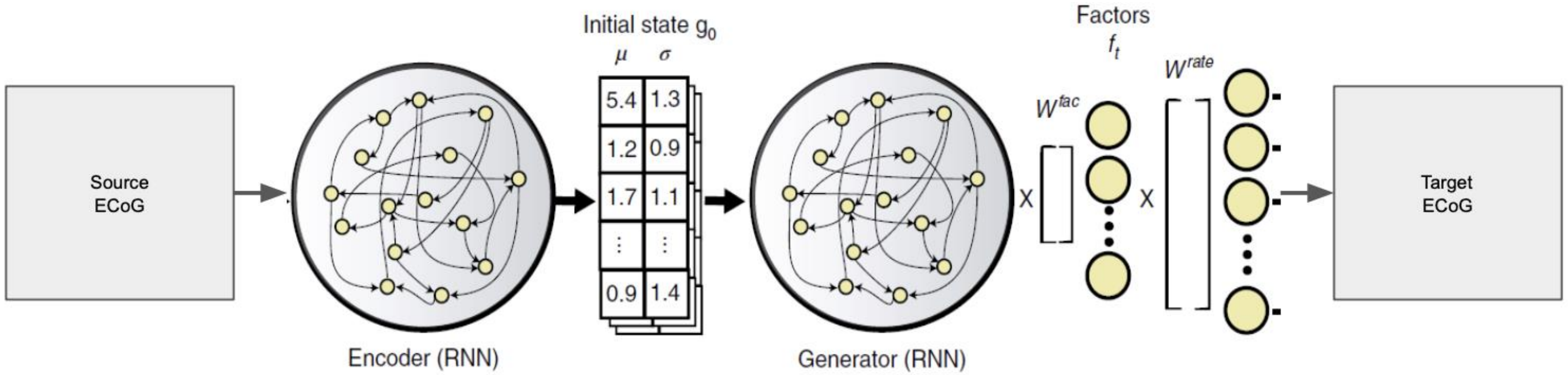
RNN PSID = current state of the art



Li, Scholl, Rajeswaran, Shlizerman & Orsborn, *in prep*

Progress on goal 3.
FPGA implementation of algorithms for neural data

- Use existing published model (Latent Factor Dynamical Analysis, LFADs; Pandarinath et al., Nature Methods 2018)
- Apply to publicly available datasets
  - Neural Latent Benchmarks (https://neurallatents.github.io/)
- Scale down model to explore FPGA implementation with hsl4ml

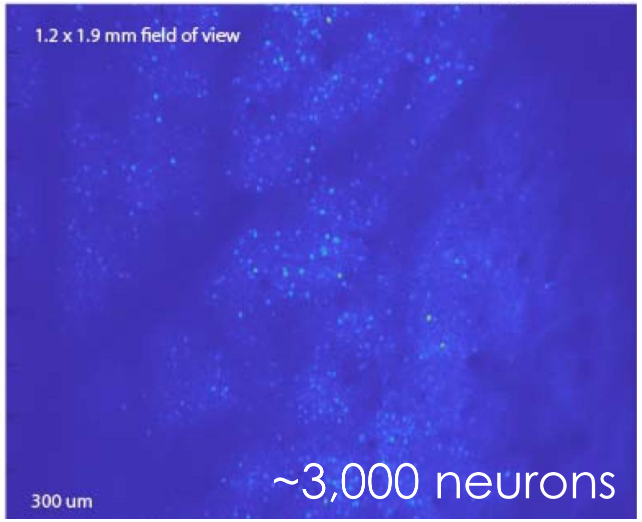


Xiaohan Lu, Aiden Yokuda, Michael Nolan, Scott Hauk, Shih-Chieh Hsu, *in prep*

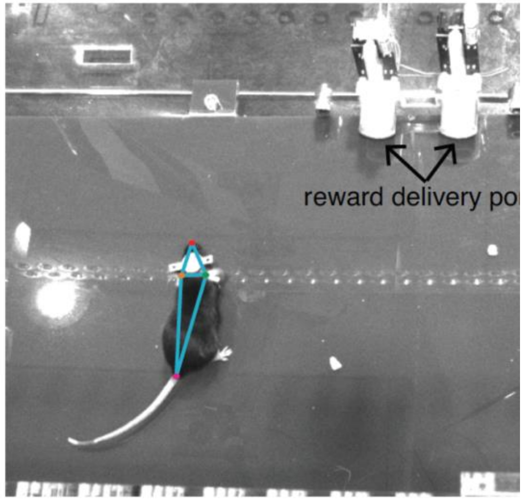
Large-scale data analysis example: data-driven feature extraction

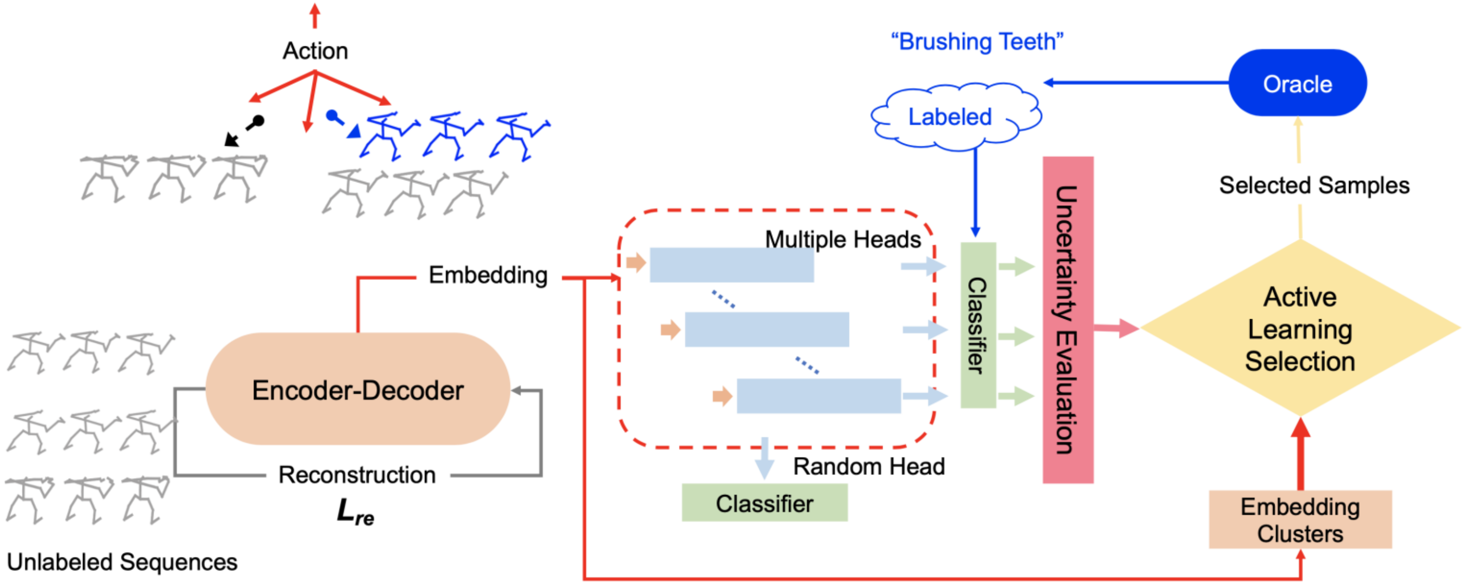
- Large-scale brain recording + behavioral monitoring
  - → Identify brain-behavior relationships, structure from the data

- Semi-supervised encoder-decoder methods



Dadarlat lab, Purdue





Li & Shlizerman, Arxiv 2020

Key Outcomes and Achievements

- Training and professional development
  - NeuroAI weekly seminar (https://github.com/shlizee/NeuroAI) to promote discussion at the intersection of AI and neuroscience (undergrad, grad, postdoc, faculty)
  - Postbacc Lauren Petersen started in Orsborn lab August 2022
  - Neuro-AI workshop hosted at UW September 2022

- Communication and outreach with research community
  - NeuroAI seminars (open to all)
  - Conference workshop proposal planned for Computational Systems Neuroscience Conference (CoSYNe), 2023
  - Submitted algorithm to Neural Latents Benchmark challenge, currently the #1 entry in some performance categories

Key Products

- Poster presentations
  - Nolan, Pesaran, Shlizerman, & Orsborn, AI@UW workshop, University of Washington, May 2022
  - Lipton & Dadarlat, Neural Control of Movement Conference, July 2022

- Papers
  - Nolan, Pesaran, Shlizerman & Orsborn, "Multi-block RNN autoencoders enable broadband ECoG signal reconstruction", *bioarxiv 2022*
  - Le, Shlizerman, "STNDT: Modeling Neural Population Activity with a Spatiotemporal Transformer", Arxiv 2022
  - Dadarlat, Canfield, & Orsborn, "Neural plasticity in sensorimotor brain-machine interfaces" *Annual Reviews of Biomedical Engineering*, in press

Impact

- Within neuroscience:
  - Developing improved modeling capabilities for broadband neural data will allow autoencoder approaches to be applied to a wider range of studies
  - Developing improved methods for multi-modal modeling for neuroscience will open new ways to mine rich datasets (e.g. neural and behavioral recording; multi-scale neural measurements)
  - Developing the first methods to implement these approaches with low latency will enable new real-time applications
- Other disciplines:
  - Potential extensions of multi-modal modeling methods to other experimental datasets
  - Anomaly detection in time-series signals has broad applications
- Teaching & Education:
  - Cross-discipline training in ML and neuroscience will increase workforce skills in neural engineering

Next year

- Continued progress on existing efforts:
  - Broadband neural signal reconstruction and prediction algorithms
  - Un/semi-supervised clustering of neural data
  - Hardware implementation of existing algortihms
- New directions
  - Extend algorithms to new datasets, modalities
  - Explore transformer network applications
  - Joint behavior + neural data feature learning