Self Supervised Learning for In Vivo Localization of Microelectrode Array

Tianxiao He[1*], Malhar Patel[1*], Chenyi Li[1], Anna Maslarova[2], Mihály Vöröslakos[2], Nalini Ramanathan[1], Wei-Lun Hung[1], György Buzsáki[2], Erdem Varol[1,2]

[1]Department of Computer Science, New York University, [2]Neuroscience Institute, Grossman School of Medicine, New York University

TL; DR

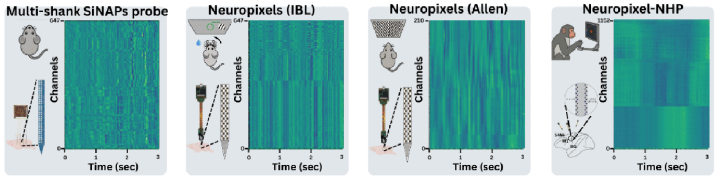
Task. In vivo localization of recording sites/channels in high density probe[1]

Approach. domain adapt a self supervised model [2] to decode anatomical identity from raw LFP signals and generalize across labs/species

Findings/Novelty. LFP encodes rich anatomical information [3]; Lfp2Vec enables zero-shot transfer to new subjects/labs; and learns generalizable embeddings across tasks by adapting a pre-trained audio model [4]

Datasets

- **SiNAPs probe:** 7 sessions, 3212 channels, 193K trials, spontaneous task
- **Neuropixels:** 14 sessions, 1360/2131 channels, 82K/213K trials, visual
- **Neuropixel-NHP:** 3 sessions, 1152 channels, 552K trials, motor task



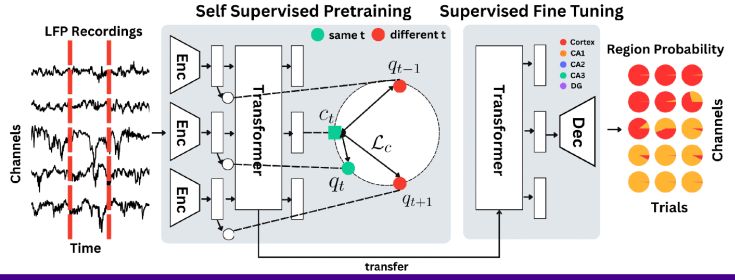
Lfp2Vec: Self Supervised Learning Framework

Given raw 3s LFP waveforms for each channel, predict its brain regions y

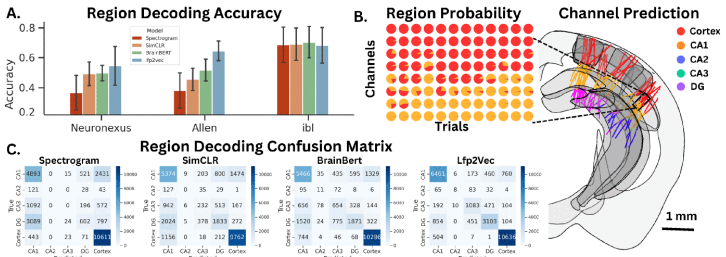
- **tokenize** each channel trial using 1d CNN into x
- **domain adaptively pretrain** with unlabeled LFP data [2] using w2v2 loss [4]
  - discretize x into q, mask and encode x using transformer to produce c
  - true quantized target q pulled close to its context vector c for each t

$$\mathcal{L}_{\text{SSL}} = -\sum_{t\in\mathcal{T}} \log \exp(\text{sim}(c_t, q_t)/\tau) / \sum_{k\neq t} \exp(\text{sim}(c_t, q_k)/\tau)$$

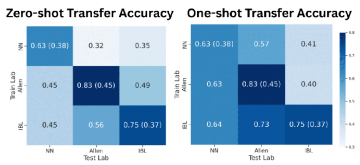
- **fine tuning** for three downstream tasks using cross entropy loss



Zero-shot localization across subjects/labs/species

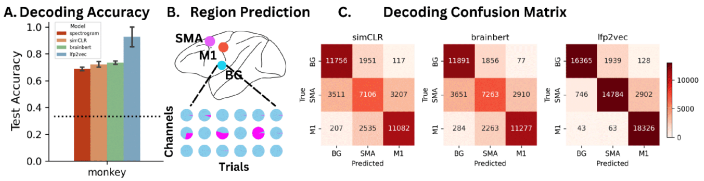


- **Across Subjects**, Lfp2Vec enables zero-shot region decoding within same lab, outperforming spectral power features and SSL baselines
- Channel prediction across Allen dataset shows anatomical consistency

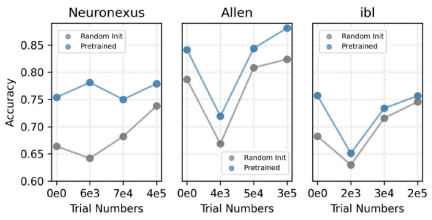


- **Across Lab**, Lfp2Vec enables zero-shot transfer with similar probe/setup (Allen/IBL)
- One-shot enables transfer across different probe/setup (Allen/NN)

- **Across Species**, Lfp2Vec enables zero-shot region decoding in macaque
- Confusion matrix shows Lfp2vec acheives lowest misclassification, especially between nearby cortical regions (SMA/M1)



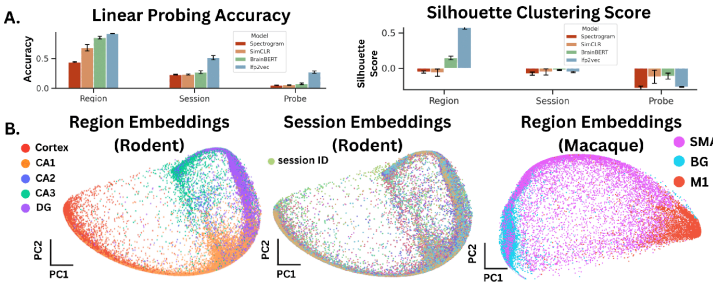
Effect of Data Scaling and OOD pretraining



- Lfp2Vec scales with data
- **Transfer learning** from audio-initialized models achieve high accuracy with 10× fewer LFP trials

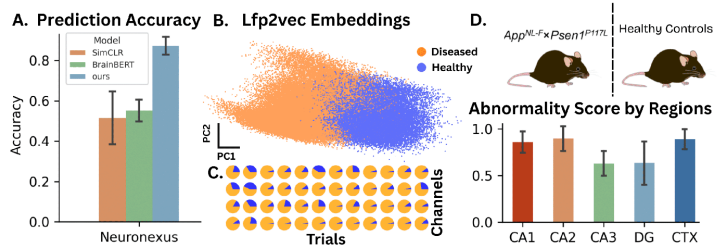
Lfp2Vec learns region-aware embeddings

- Across species channel embeddings cluster by region in Lfp2Vec
- Linear probe accuracy, silhouette score of region/session/probe clusters show embeddings are not biased by session/probe identity



Lfp2Vec Transfer to Disease Classification

- Lfp2Vec can be fine tuned to predict disease better than baselines
- Abnormality study shows Lfp2Vec learns disease region specific pattern



References & Acknowledgements

[1] Sunkin et al. NAR, 2013

[2] Kostas et al. Frontiers, 2021

[3] Tolossa et al. eLife, 2024

[4] Baevski et al. NeurIPS, 2020

Manuscript

Video Overview

Job Posting

This research was supported by the National Institute of Mental Health (NIMH) R00MH128772 and R01NS113782-01A1.