Project: Energy-Efficient and Interpretable Neuromorphic Decoding for Neural Signal and Movement Decoding

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Description: The Neuromorphic Cognitive Systems group at UZH and ETHz has pioneered ultra-low-power, event-driven neural interface systems using spiking neural networks (SNNs) (https://doi.org/10.1038/s41467-021-23342-2, https://doi.org/10.1109/JPROC.2015.2444094). In parallel, the INL group at EPFL has developed all-in-one energy-efficient and interpretable neural decoding algorithms and chips such as *MiBMI* (ISSCC'24, JSSC'24), *NeuralTree* (ISSCC'22, JSSC'22), and *REST* (ICML'24) for implantable brain–computer interface (BCI) and closed-loop neuromodulation applications.

This project investigates how to co-design **reliable**, **efficient**, and **interpretable** neuromorphic processing architectures for neural or muscle signal decoding. The goal is to develop a spiking neural network for detecting and interpreting neural activity, to decode movement intentions from EMG, ECoG. LFP, signals, intracortical spikes, possibly fusing multiple signal types together including accelerometer data, e.g. from IMUs.

The other goal of this project is to quantify the trade-offs between state-of-the-art digital decoders based on deep learning with the neuromorphic system developed, toward the design of ultra-low-power, adaptive, and real-time implantable neural interfaces.

Objectives

1. Dataset and task
   - Select a relevant neural dataset: for bio-signal processing (ECoG, LFP, or EEG with pathological events).
   - Pre-process data comparing conventional spectral analysis techniques with event-based feature extraction methods.

2. Decoder design and evaluation (software-level)
   - Implement an interpretable decoder (e.g., based on SNNs and NeuralTree) for the selected task
   - Implement an anomaly-detection neural network using recurrent networks of spiking neurons
   - Quantify accuracy, latency, model size, and compute/energy cost
   - Assess the performance gap between these implementations and state-of-the-art conventional ones by quantifying the trade-offs between accuracy, latency, and energy efficiency that define optimal neuromorphic designs

EMG · spike encoding · excitatory pool · output neurons

— input-to-excitatory
····· input-to-inhibitory

W_{out}

W_{EI}

W_{IE}

inhibitory pool

MiBMI in a Handwriting Decoding Task

Hello

192 Channels

Neural Recording

Intracortical Signal

Neural Signal Processing

Multi-Unit Activity

Data Binning & Smoothing

Neural Activity Map

DNC-Based Neural Decoding

Task-Related Neural Activity

Time

Channel No.

Test Trial

h   e   l   l   o

#1   #2   #3   #4   #5

Trial

Distinctive Neural Code (DNC)

Classification in DNC Space

Multi-Label Output

e ✘

h ✘

l ✘

o ✔