Stream of Consciousness: Real-Time Intracranial Electroencephalography Data Streaming and Processing

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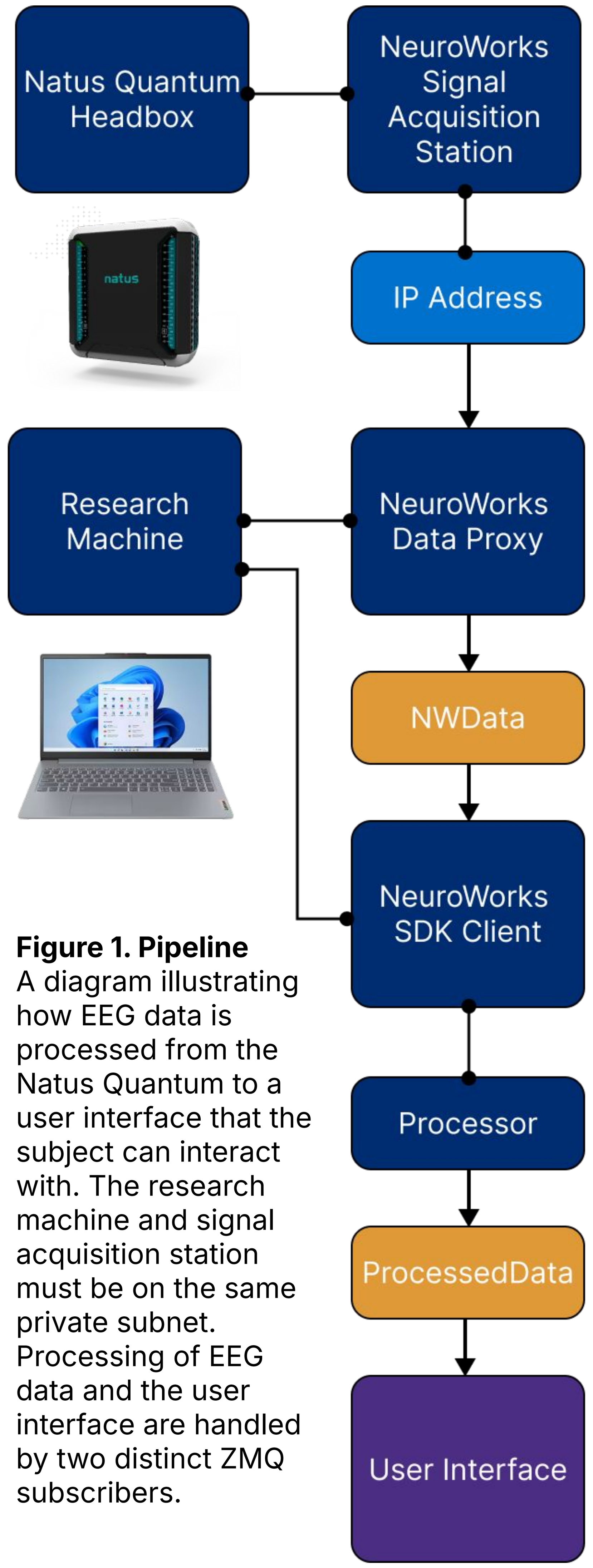
GitHub Repository

Abstract

Brain-computer interfaces (BCI) have the potential to transform the lives of people living with disabilities. A fundamental component of BCI is the robust, real-time streaming and processing of neural data. Invasive BCI have sensors that are surgically implanted into a patient's brain for access to high quality neural measurements. An example of such a sensor are stereo-electroencephalography (sEEG) electrodes, which are typically implanted in patients with epilepsy. These electrodes can be connected to a Natus Quantum, an FDA-cleared commercial neural signal amplifier, which runs for the entirety of the patient's stay in the hospital. We developed and implemented a software framework using Python and ZeroMQ that interfaces with the Natus Quantum for efficient and robust streaming of neural signals. This enables us to use an existing clinical device that's already in the clinical workflow for real-time neural data acquisition, visualization, and decoding for BCI applications.

Methods



- ❑ Natus Quantum headbox is connected to a computer in the hospital ("Neuroworks Signal Acquisition Station") where EEG signals are sent.
- ❑ NW Data Proxy allows a separate Research Machine to access raw EEG data in real-time.
- ❑ Raw EEG data is published to a topic for ZeroMQ subscribers.
- ❑ Processors perform batch processing on incoming EEG data.
- ❑ Processed data is published to a topic for ZeroMQ subscribers.
- ❑ Examples of user interfaces:
  - ❑ EEG Visualizer
  - ❑ Motor Imagery Experimental Task
  - ❑ BCI Controlled Pong Video Game

Figure 1. Pipeline
A diagram illustrating how EEG data is processed from the Natus Quantum to a user interface that the subject can interact with. The research machine and signal acquisition station must be on the same private subnet. Processing of EEG data and the user interface are handled by two distinct ZMQ subscribers.

EEG Visualizer

The visualizer was implemented with Python using Matplotlib. It is a ZeroMQ subscriber that receives processed data from the "ProcessedData" topic and and visualizes EEG recordings from a specified number of channels in real-time.

Customization
- # of channels
- Window size
- Y-axis spacing between different channels

Visualizer time delay depends on
- # of channels being plotted
- Batch size of data

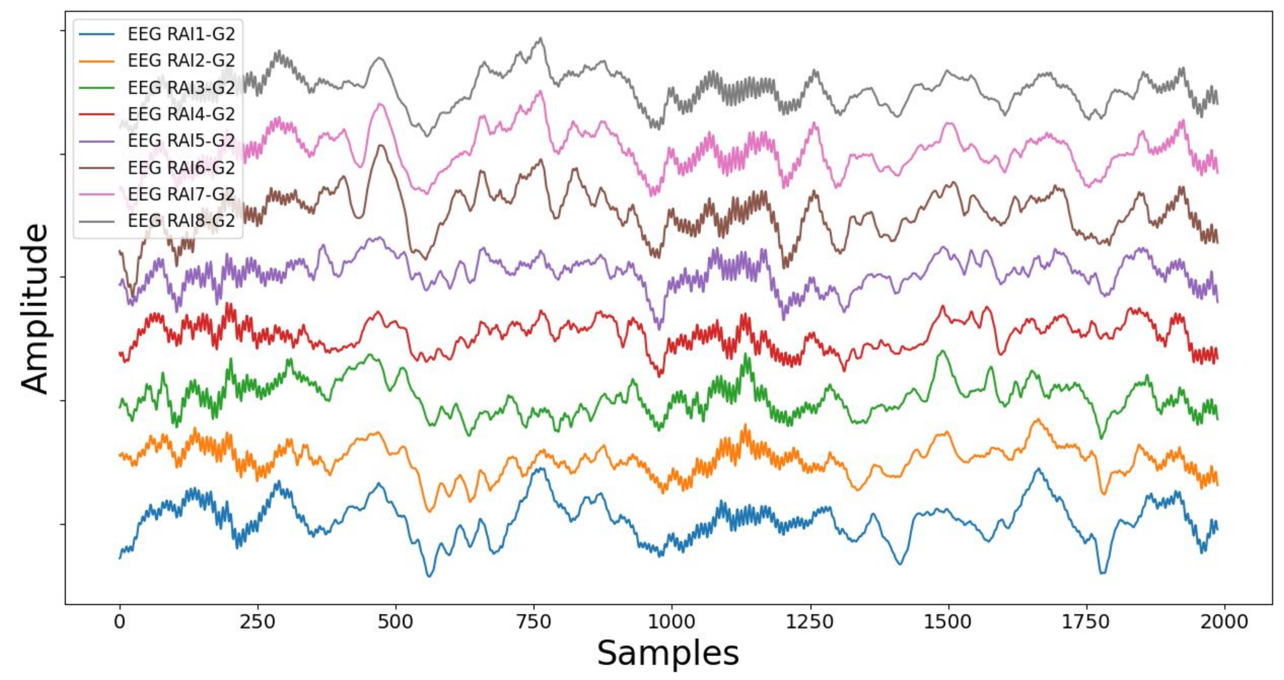


Figure 2. Visualization of streamed neural activity. Neural measurements from a subset of 8 sEEG channels (indicated by color) are shown in real time,measurements are offset on the y-axis from one another. The windows size of the visualization is 2000 samples.

Example BCI Task: Motor-Imagery Pong Video Game

A custom motor-imagery experimental task was implemented with Python using PsychoPy. Serves as a user interface for subjects to perform experimental tasks while neural data is recorded in real-time. Recorded data can be used to train a motor imagery classification model via supervised learning.

Common spatial pattern (CSP) is applied to generate 8 components that the neural data can be projected onto and used as features for training a linear discriminant analysis (LDA) model.
- Implemented CSP+LDA pipeline on public motor imagery dataset (binary classification)
  - 90% accuracy (test set)

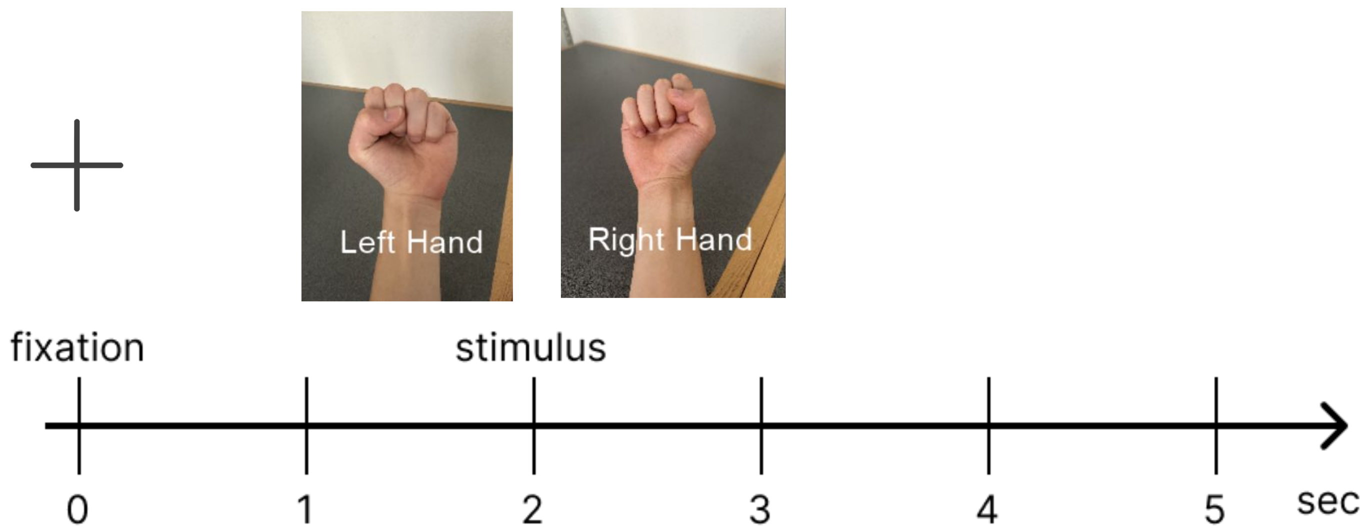


Figure 3. Motor imagery experimental task. Subject will imagine making a closed fist using the indicated hand, neural data is captured to train a BCI decoder. (Seconds 0-2): Subject presented a fixation screen at beginning of trial to establish a baseline of neural activity. (Seconds 2-5): Image of left or right hand was shown to cue subject to perform imagined movement of that particular hand.

Real-time predictions from the motor imagery classification model can be used to control a paddle in the video game, Pong, which was implemented with Python using PyGame.

Batches of EEG data from the Natus Quantum are collected and processed. The processed data would be projected onto the CSP components and inputted into a machine learning model for motor imagery prediction. The prediction would serve as a control signal for the paddle's movement.

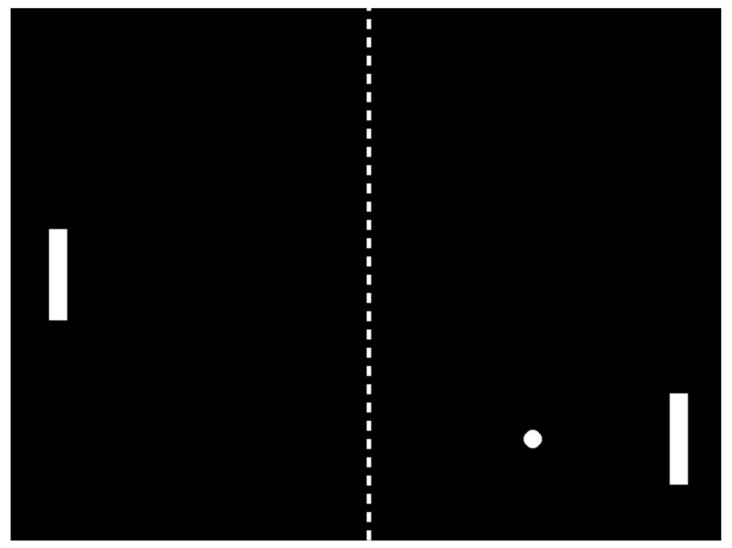


Figure 4. Pong video game. For example, the subject could control the paddle going up by imagining right hand movement and going down by imaging left hand movement. The trained neural decoder would predict user intention in real-time from the neural measurements.

Acknowledgements

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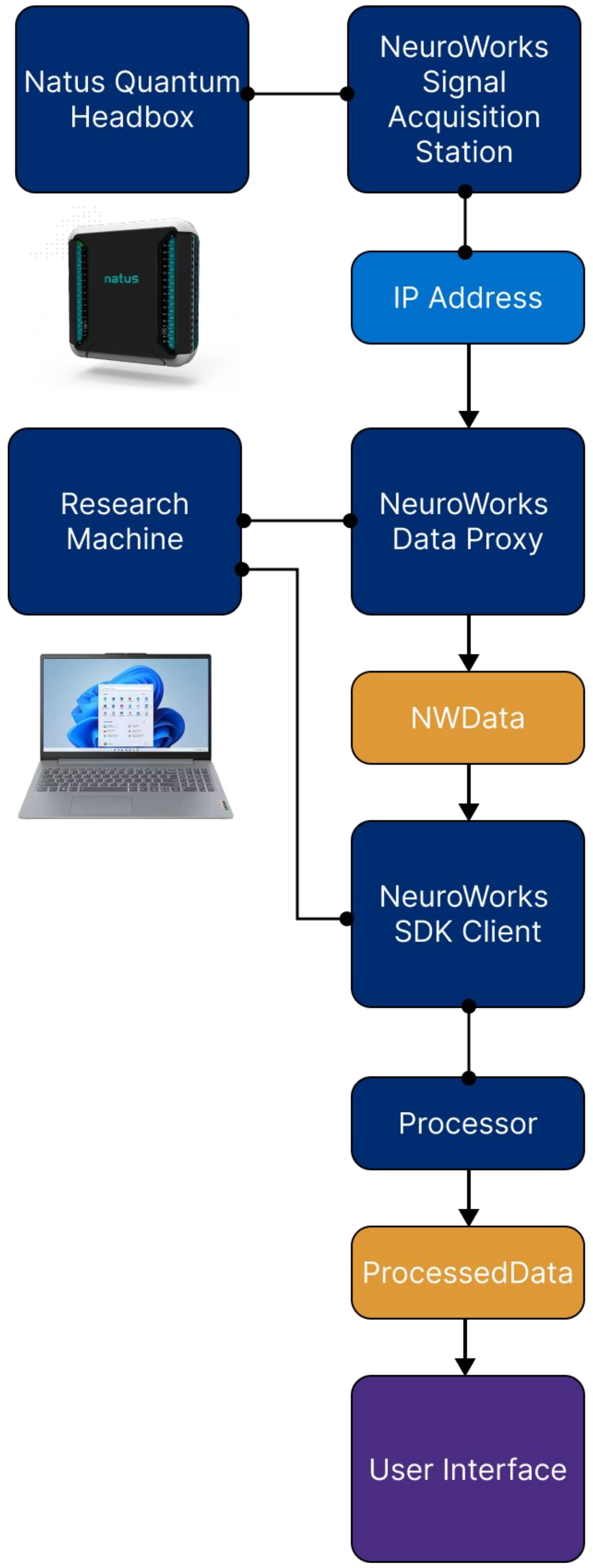

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NW Data Proxy allows a separate Research Machine to access raw EEG data in real-time.

Raw EEG data is published to a topic for ZeroMQ subscribers.

Processors perform batch processing on incoming EEG data.

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Examples of user interfaces include:

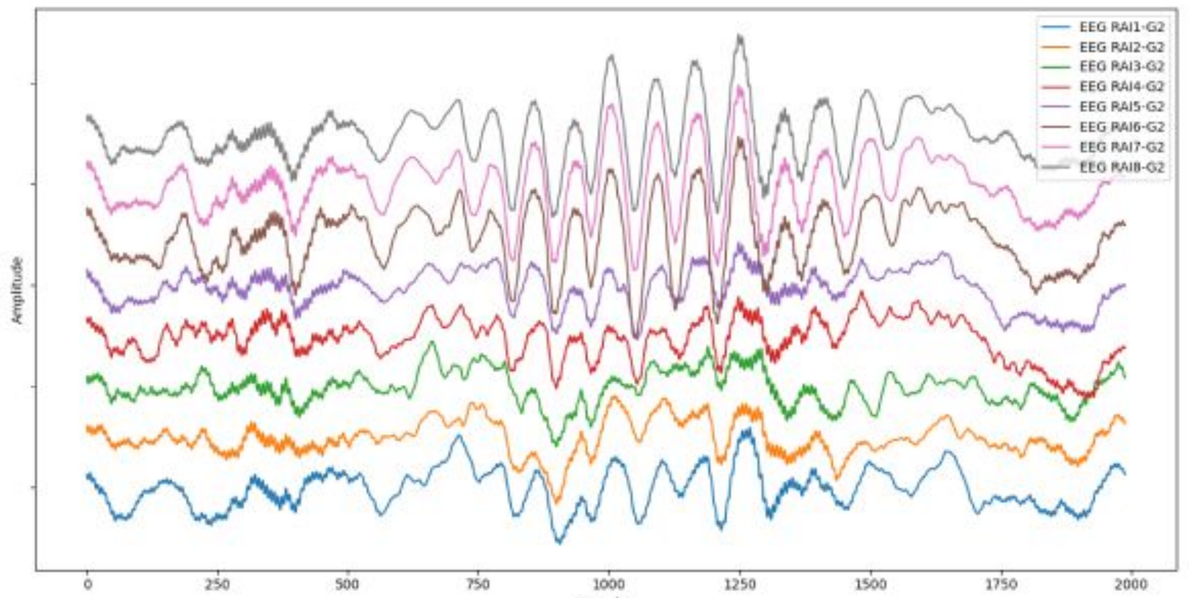
- EEG Visualizer
- Motor Imagery Experimental Task
- BCI Controlled Pong Video Game

EEG Visualizer

A ZeroMQ subscriber received processed data from the "ProcessedData" topic and and visualizes EEG recordings in real time.

The number of channels to be plotted, window size, and spacing of neural signals from different channels can be specified by the user.

The plot updates with each batch of data, and saves it in a csv file after it is visualized. The time delay of the visualizer is dependent on the number of channels being plotted and batch size.

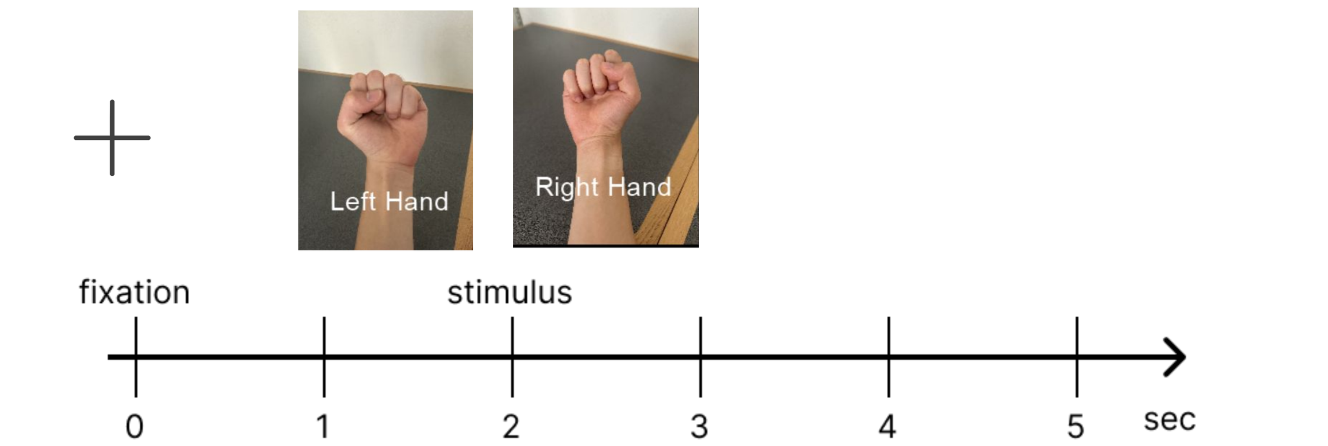


Neural measurements from a subset of 8 sEEG channels (indicated by color) are shown in real time,measurements are offset on the y-axis from one another. The windows size of the visualization is 2000 samples.

	1 Channel	2 Channels	4 Channels	8 Channels	16 Channels	32 Channels	64 Channels	128 Channels
Batch Size 10	1 ms							140 ms per iter
Batch Size 50	1 ms	1 ms	1 ms	1 ms	1 ms	1 ms	40 ms per iter	150 ms per iter
Batch Size 100	1 ms	1 ms	1 ms	1 ms	1 ms	1 ms	1 ms	70 ms per iter
Batch Size 200	1 ms	1 ms	1 ms	1 ms	1 ms	1 ms	2 ms	2 ms

Example BCI Task: Motor-Imagery Pong Video Game

Neural data can be recorded and saved as the experimental motor imagery task is running. Common spatial pattern (CSP) is applied to generate 8 components that the neural data can be projected on and used as features for a linear discriminant analysis classification model.



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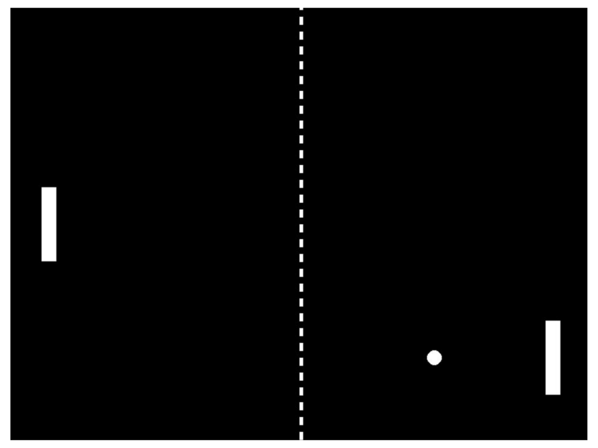

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