# Biosignal Processing



## ▼ Introduction

// in progress

## ▼ 1. Dataset

**Read Data and Extract the channels data**

First of all, we analyze directory tree and role of each file.

```
sub-NORB00027
    └── ses-1
        ├── eeg
        │   ├── sub-NORB00027_ses-1_coordsystem.json
        │   ├── sub-NORB00027_ses-1_electrodes.tsv
        │   ├── sub-NORB00027_ses-1_task-EEG_channels.tsv
        │   ├── sub-NORB00027_ses-1_task-EEG_eeg.edf
        │   ├── sub-NORB00027_ses-1_task-EEG_eeg.json
        │   └── sub-NORB00027_ses-1_task-EEG_events.tsv
        └── sub-NORB00027_ses-1_scans.tsv
```

In `ses-1/eeg/`

▼ The file `sub-NORB00027_ses-1_coordsystem.json` contains metadata about the coordinate system used for EEG data.

```
{
  "EEGCoordinateSystem": "MNI305",
```

```
  "EEGCoordinateUnits": "mm"
}
```

- `"EEGCoordinateSystem": "MNI305"`: This indicates that the EEG data coordinates are referenced to the **MNI305** space. MNI305 refers to an average brain template, also known as the **Montreal Neurological Institute (MNI) 305** reference system. It's a standardized space used for neuroimaging data that aligns individual brain anatomy to a common framework, facilitating comparison and analysis across subjects.
- `"EEGCoordinateUnits": "mm"`: This specifies that the units of measurement for the EEG data coordinates are in **millimeters (mm)**. This is important for precise localization of EEG electrodes or sources within the brain.

▼ The file `sub-NORB00027_ses-1_electrodes.tsv` you've provided is a **tab-separated values (TSV)** file that contains the **3D spatial coordinates** and **material information** for EEG electrodes placed on a subject's scalp

```
name    x   y   z   type    material
Fp1 -32 77  19  cup Ag/AgCl
Fp2 32  77  19  cup Ag/AgCl
F3  -52 35  57  cup Ag/AgCl
F4  52  35  57  cup Ag/AgCl
C3  -69 -29 69  cup Ag/AgCl
C4  69  -29 69  cup Ag/AgCl
P3  -54 -92 44  cup Ag/AgCl
P4  54  -92 44  cup Ag/AgCl
O1  -31 -116    -7  cup Ag/AgCl
O2  31  -116    -7  cup Ag/AgCl
F7  -72 32  5   cup Ag/AgCl
F8  72  32  5   cup Ag/AgCl
T3  -83 -21 -4  cup Ag/AgCl
T4  83  -21 -4  cup Ag/AgCl
T5  -73 -74 -8  cup Ag/AgCl
```

```
T6  73  -74 -8  cup Ag/AgCl
FZ  0   37  84  cup Ag/AgCl
CZ  0   -34 105 cup Ag/AgCl
PZ  0   -98 66  cup Ag/AgCl
```

- **name**: This column lists the **standardized names** of the EEG electrodes. For example, “Fp1” refers to the electrode positioned on the left side of the forehead.
- **x, y, z**: These columns provide the **3D Cartesian coordinates** of each electrode in millimeters. The coordinates are based on the MNI305 reference space, which is a standardized brain template. The **x-coordinate** indicates the position left (+) or right (-) of the midline, the **y-coordinate** indicates the position anterior (+) or posterior (-) relative to a central point, and the **z-coordinate** indicates the position superior (+) or inferior (-) relative to a horizontal plane.
- **type**: This indicates the **type of electrode** used, which in this case is “cup”. Cup electrodes are small, round, and typically made of a conductive material that can hold conductive gel to improve signal quality.
- **material**: This specifies the **material composition** of the electrodes, which is “Ag/AgCl” for all listed electrodes. Ag/AgCl stands for **silver/silver chloride**, a common material used for EEG electrodes due to its good conductivity and stable electrochemical properties

▼ The file `sub-NORB00027_ses-1_task-EEG_channels.tsv` is a **tab-separated values (TSV)** file that describes the characteristics and settings of EEG channels used during a recording session.

```
name    type    units   description sampling_frequency
low_cutoff  high_cutoff notch   status
Fp1 EEG uV  electrode   200 0.5 100 n/a good
Fp2 EEG uV  electrode   200 0.5 100 n/a good
F3  EEG uV  electrode   200 0.5 100 n/a good
F4  EEG uV  electrode   200 0.5 100 n/a good
C3  EEG uV  electrode   200 0.5 100 n/a good
```

```
C4  EEG uV  electrode   200 0.5 100 n/a good
P3  EEG uV  electrode   200 0.5 100 n/a good
P4  EEG uV  electrode   200 0.5 100 n/a good
O1  EEG uV  electrode   200 0.5 100 n/a good
O2  EEG uV  electrode   200 0.5 100 n/a good
F7  EEG uV  electrode   200 0.5 100 n/a good
F8  EEG uV  electrode   200 0.5 100 n/a good
T3  EEG uV  electrode   200 0.5 100 n/a good
T4  EEG uV  electrode   200 0.5 100 n/a good
T5  EEG uV  electrode   200 0.5 100 n/a good
T6  EEG uV  electrode   200 0.5 100 n/a good
FZ  EEG uV  electrode   200 0.5 100 n/a good
CZ  EEG uV  electrode   200 0.5 100 n/a good
PZ  EEG uV  electrode   200 0.5 100 n/a good
```

- **name**: This column lists the **names of the EEG channels**, which correspond to the electrode placemen.
- **type**: Indicates the **type of data** recorded by the channel, which is EEG (Electroencephalography) in this case.
- **units**: Specifies the **units of measurement** for the EEG signal, which is microvolts (uV).
- **description**: Provides a **brief description** of the channel, here simply noted as “electrode”.
- **sampling_frequency**: The **rate at which the EEG data is sampled**, measured in Hertz (Hz). In this file, it’s **200 Hz**, meaning the EEG signal is recorded 200 times per second.
- **low_cutoff**: The **low-frequency cutoff** for filtering the EEG signal, measured in Hz. It’s **0.5 Hz** here, indicating that frequencies below 0.5 Hz are filtered out to remove slow drifts or artifacts.
- **high_cutoff**: The **high-frequency cutoff** for filtering the EEG signal, measured in Hz. It’s **100 Hz** here, meaning that frequencies above 100 Hz are filtered out to remove high-frequency noise.

- **notch**: Indicates whether a **notch filter** is applied to remove power line noise. “n/a” suggests that no notch filter is applied or it’s not applicable.
- **status**: Describes the **quality or condition** of the channel. “good” indicates that the channel is functioning properly and the data quality is acceptable.

▼ The file `sub-NORB00027_ses-1_task-EEG_eeg.edf` is the actual **EEG data file** in the **European Data Format (EDF)**. This format is widely used for storing and exchanging recordings of neurophysiological signals, such as EEG, ECG, EMG, and other biosignals.

▼ The `sub-NORB00027_ses-1_task-EEG_eeg.json` file contains metadata about an EEG recording session.


```
{
  "TaskName": "EEG",
  "TaskDescription": "Resting EEG",
  "SamplingFrequency": 200,
  "EEGChannelCount": 19,
  "EOGChannelCount": 0,
  "ECGChannelCount": 0,
  "EMGChannelCount": 0,
  "MiscChannelCount":  0,
  "TriggerChannelCount":  0,
  "EEGPlacementScheme": "10-10",
  "EEGReference": "common",
  "PowerLineFrequency": 60,
  "SoftwareFilters": "n/a",
  "RecordingDuration": 596.24,
  "RecordingType": "continuous"
}
```


- **“TaskName”: “EEG”**: This indicates the name of the task during which the EEG data was recorded. In this case, the task is simply named “EEG”.

- **“TaskDescription”: “Resting EEG”**: Provides a description of the task. “Resting EEG” suggests that the EEG data was recorded while the subject was at rest, not performing any specific cognitive task.
- **“SamplingFrequency”: 200**: The rate at which EEG data is sampled, measured in Hertz (Hz). Here, it’s **200 Hz**, meaning the EEG signal is recorded 200 times per second.
- **“EEGChannelCount”: 19**: The number of EEG channels used in the recording. This dataset used 19 channels.
- **“EOGChannelCount”: 0**: The number of EOG (Electrooculography) channels. EOG records eye movements and is often used to track blinks and saccades. Zero indicates that no EOG channels were used.
- **“ECGChannelCount”: 0**: The number of ECG (Electrocardiography) channels. ECG records the electrical activity of the heart. Zero indicates that no ECG channels were used.
- **“EMGChannelCount”: 0**: The number of EMG (Electromyography) channels. EMG records the electrical activity of muscles. Zero indicates that no EMG channels were used.
- **“MiscChannelCount”: 0**: The number of miscellaneous channels that might be used for other types of data. Zero indicates none were used.
- **“TriggerChannelCount”: 0**: The number of trigger channels used to mark events or stimuli presentation. Zero indicates no such channels were used.
- **“EEGPlacementScheme”: “10-10”**: Indicates the electrode placement scheme used. The “10-10” system is an internationally recognized method to describe the location of scalp electrodes and is an extended version of the 10-20 system, providing more detailed electrode placement.
- **“EEGReference”: “common”**: Describes the reference electrode used in the EEG recording. *“common” suggests a common average reference, where the signals from all electrodes are averaged and this average is used as the reference for each channel.*

- **“PowerLineFrequency”: 60**: The frequency of the power line, measured in Hz. This is important for identifying and filtering out electrical noise from the power supply, which can contaminate the EEG signal.
- **“SoftwareFilters”: “n/a”**: Indicates what software filters, if any, were applied to the EEG data. “n/a” suggests that no software filters were applied or the information is not available.
- **“RecordingDuration”: 596.24**: The total duration of the EEG recording, measured in seconds. Here, the recording lasted approximately 596.24 seconds.
- **“RecordingType”: “continuous”**: Describes the type of EEG recording. “continuous” means the EEG was recorded in a single, uninterrupted session.

▼ The file `sub-NORB00027_ses-1_task-EEG_events.tsv` is a **tab-separated values (TSV)** file that logs events occurring during an EEG recording session.

```
onset   duration    trial_type  value   sample
0.005   0   discontinuity   2   1
0.005   0   eyes_closed 65  1
41.305  0   discontinuity   2   8261
48.455  0   discontinuity   2   9691
135.175 0   discontinuity   2   27035
197.245 0   discontinuity   2   39449
296.025 0   discontinuity   2   59205
299.395 0   discontinuity   2   59879
375.725 0   discontinuity   2   75145
```

- **onset**: The time at which an event starts, relative to the beginning of the EEG recording, measured in seconds. For example, the first event occurred at **0.005 seconds** after the recording started.
- **duration**: The length of time the event lasts, measured in seconds. In this file, all events have a duration of **0 seconds**, indicating they are instantaneous events.

- **trial_type**: A description of the type of event. There are two types listed:
  - **discontinuity**: This likely indicates a break or interruption in the EEG data recording or an artifact that caused a discontinuity in the signal.
  - **eyes_closed**: This signifies that the subject closed their eyes, which is a common condition in resting-state EEG studies to standardize the state of visual input.
- **value**: A numerical code assigned to each trial_type for easy identification. "2" is associated with discontinuities, and "65" with the eyes_closed event.
- **sample**: The index of the EEG data sample at which the event occurred. Since the sampling frequency is **200 Hz**, the sample number can be used to calculate the exact time of the event. For instance, the event at sample "8261" occurred at **41.305 seconds** into the recording.

▼ The file `sub-NORB00027_ses-1_scans.tsv` is a **tab-separated values (TSV)** provides information about the EEG data file and its acquisition timing.

```
filename    age_acq_time
eeg/sub-NORB00027_ses-1_task-EEG_eeg.edf        0.2541
```

- **filename**: This column lists the **path and name of the EEG data file**. The file `eeg/sub-NORB00027_ses-1_task-EEG_eeg.edf` is an **EDF (European Data Format)** file, which is a standard file format for storing neurophysiological data.
- **age_acq_time**: Represents the **age of the subject at the time of acquisition**, measured in years. However, the value "0.2541" seems unusually low for a typical age and might represent a different metric or be recorded incorrectly. It could potentially be the age in years calculated from the date of birth to the acquisition date, which would make sense if the subject is an infant (**approximately 3 months old**), or it could be a different time-related metric specific to the study.

# ▼ 2. Load channels data

- First, we need to load the EEG data from the provided files. The `sub-NORB00027_ses-1_task-EEG_eeg.edf` file contains the raw EEG data.
- We'll use a library like `mne` (MNE-Python) to read the data. If you haven't already installed it, you can do so using `pip install mne`.

  ▼ **About `mne` python library**

  The Python MNE library is an **open-source package** designed for exploring, visualizing, and analyzing human neurophysiological data. It's specifically tailored for working with data from modalities like **MEG (Magnetoencephalography)**, **EEG (Electroencephalography)**, **sEEG (stereotactic EEG)**, **ECoG (Electrocorticography)**, and more [1][2].

  MNE is particularly useful for researchers and professionals in neuroscience, cognitive science, and related fields who work with electrophysiological data. Its comprehensive set of tools and active community make it a go-to library for neurophysiological data analysis [1][2].

  [1] MNE — MNE 1.7.0 documentation - Identity Digital. https://mne.tools/stable/index.html.
  [2] mne · PyPI. https://pypi.org/project/mne/.

- To read raw `.edf` data, we use `mne.io.read_raw_edf()` function which takes data path as input. Another parameter is `preload=True`, which means preload data into memory for data manipulation and faster indexing. If True, the data will be preloaded into memory (fast, requires large amount of memory).

  `mne.io.read_raw_edf()` function returns an instance of Raw object which is simply an entity keep data with additional internal functions (methods) and attributes (which act on its own data).

```
import mne
import matplotlib.pyplot as plt
```

```
# Load the EEG data
data_path = '/workspaces/biosignal-processing/final/sub-NORB00027/ses-1/eeg/sub-NORB00027_ses-1_task-EEG_eeg.edf'
raw = mne.io.read_raw_edf(data_path, preload=True)
```

We evenly can convert Raw object to dataframe (a kind of table/matrix representation our data) by `raw.to_data_frame()` . For example,

```
d = raw.to_data_frame()
d
```

[24] ✓ 0.0s

| | time | Fp1 | Fp2 | F3 | F4 | C3 | C4 | P3 | P4 | O1 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.000 | 37.794060 | 38.802208 | 35.275967 | 41.127494 | 32.365882 | 67.594096 | 31.063564 | 48.486317 | 17.823710 |
| 1 | 0.005 | 40.119658 | 42.150950 | 36.210545 | 44.238100 | 33.409961 | 71.876571 | 33.488515 | 53.148359 | 16.666285 |
| 2 | 0.010 | 39.887098 | 43.190215 | 33.874101 | 45.966214 | 31.437811 | 67.362611 | 31.871881 | 49.418725 | 16.434800 |
| 3 | 0.015 | 37.794060 | 41.920002 | 31.888124 | 46.542252 | 29.465662 | 65.047760 | 30.370721 | 48.719419 | 16.897770 |
| 4 | 0.020 | 34.538222 | 38.802208 | 30.603080 | 45.274968 | 30.509741 | 63.658850 | 31.409985 | 50.817338 | 17.129255 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 118395 | 591.975 | 36.398701 | 34.067780 | 40.182499 | 33.869414 | 40.370489 | 35.533410 | 38.684839 | 32.985027 | 17.823710 |
| 118396 | 591.980 | 33.840542 | 32.682093 | 36.444189 | 32.026092 | 38.514348 | 34.838955 | 37.530100 | 33.334680 | 19.675591 |
| 118397 | 591.985 | 30.003305 | 30.026194 | 32.004946 | 30.528393 | 35.034084 | 32.524104 | 35.451571 | 31.120210 | 19.907076 |
| 118398 | 591.990 | 27.328867 | 28.525034 | 29.318036 | 29.721939 | 32.249873 | 32.408361 | 33.834936 | 30.537455 | 19.907076 |
| 118399 | 591.995 | 26.980027 | 29.102404 | 28.967570 | 29.606732 | 30.509741 | 33.334301 | 30.717142 | 31.353312 | 21.064502 |

118400 rows × 20 columns

### ▼ Additional

Summarize statistic on each channel

```
d.describe()
```

✓ 0.2s

| | time | Fp1 | Fp2 | F3 | F4 | C3 | C4 | P3 | P4 | O1 |
|---|---|---|---|---|---|---|---|---|---|---|
| count | 118400.000000 | 118400.000000 | 118400.000000 | 118400.000000 | 118400.000000 | 118400.000000 | 118400.000000 | 118400.000000 | 118400.000000 | 118400.000000 |
| mean | 295.997500 | 7.270163 | 6.427694 | 6.844579 | 6.264259 | 7.354548 | 6.816291 | 6.967986 | 7.751543 | 5.453543 |
| std | 170.896401 | 32.345300 | 32.354484 | 31.915020 | 32.390927 | 29.892493 | 30.749590 | 29.739084 | 30.370865 | 30.914219 |
| min | 0.000000 | -230.580000 | -229.790000 | -232.130000 | -229.380000 | -229.930000 | -229.980000 | -229.330000 | -230.770000 | -231.370000 |
| 25% | 147.998750 | -5.578351 | -6.925442 | -5.845440 | -7.029292 | -4.176888 | -4.976483 | -4.040491 | -3.495452 | -5.787770 |
| 50% | 295.997500 | 7.212440 | 6.354052 | 6.771356 | 6.104377 | 7.423991 | 6.829257 | 6.929526 | 7.693449 | 5.323515 |
| 75% | 443.996250 | 20.003232 | 19.518073 | 19.621795 | 19.583669 | 18.792853 | 18.403512 | 18.015017 | 18.998901 | 16.550542 |
| max | 591.995000 | 245.470000 | 242.960000 | 246.140000 | 242.280000 | 245.010000 | 243.870000 | 243.420000 | 246.390000 | 242.480000 |

# ▼ 3. Visualization

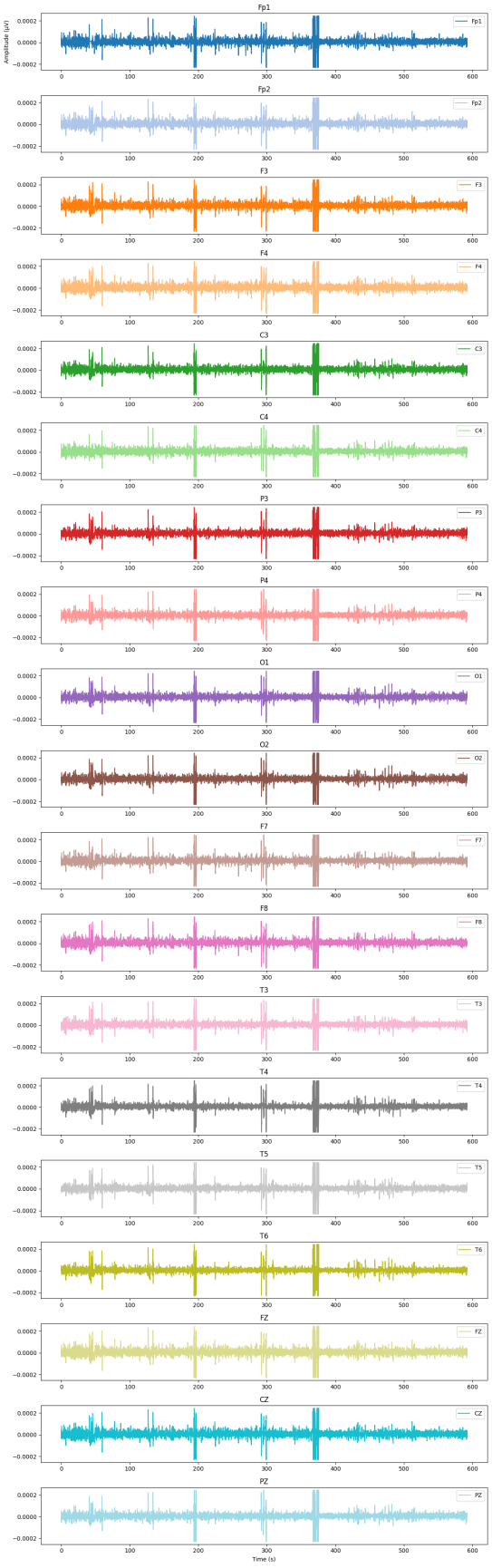
**Plot the original data in time-series with the full of title, units**

### ▼ Plot manually with matplotlib

#### ▼ Script code

```
# ========== Visualizing each channel purely with num
py ==============
# data and channel names
data, times = raw[:]
ch_names = raw.ch_names
n_channels = len(ch_names) # num channel

# Subplots
fig, axes = plt.subplots(n_channels, 1, figsize=(12,
2*n_channels))

# Plot each channel in a separate subplot
colors = plt.cm.get_cmap('tab20', n_channels) # each
channel has its own color

for i in range(n_channels):
    axes[i].plot(times, data[i], label=ch_names[i], c
olor=colors(i))
    axes[i].set_title(ch_names[i])
    axes[i].legend(loc='upper right')

# Set labels for the x-axis and y-axis
axes[-1].set_xlabel('Time (s)')
axes[0].set_ylabel('Amplitude (μV)')

# Display the plot
plt.tight_layout()
plt.show()
```

#### ▼ Result Figure(s)

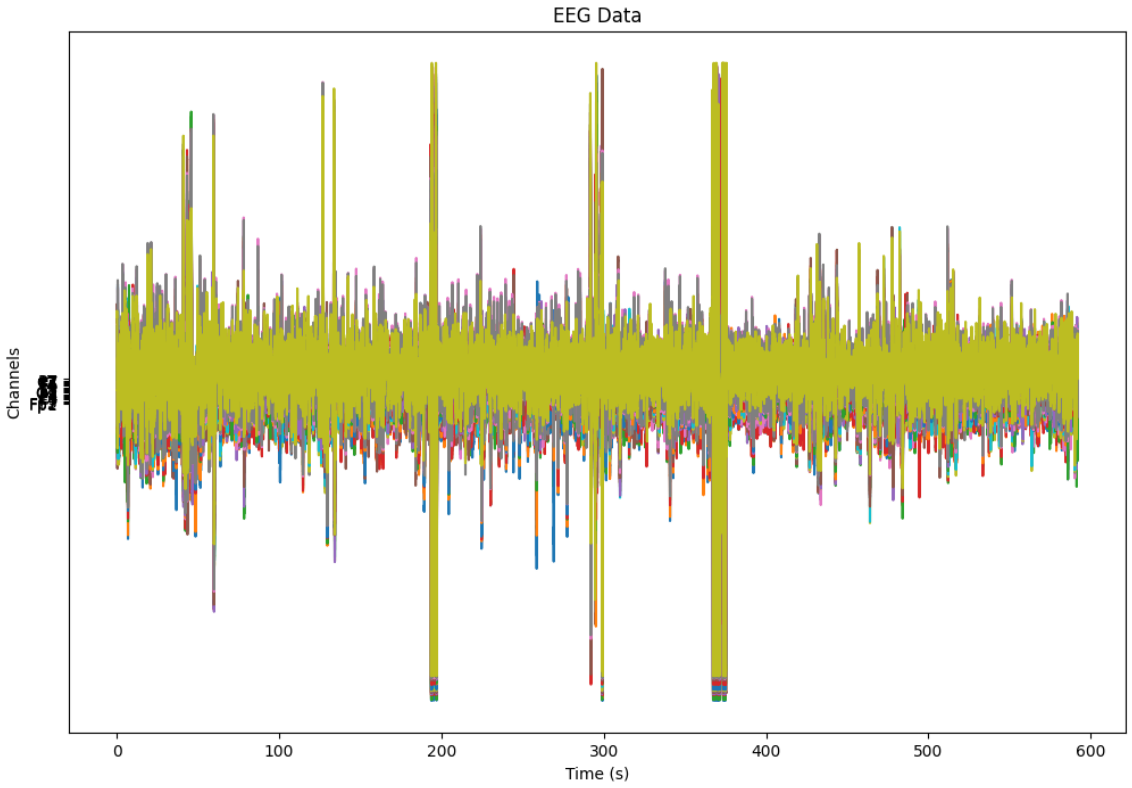

Fp1
Fp2
F3
F4
C3
C4
P3
P4
O1
O2
F7
F8
T3
T4
T5
T6
FZ
CZ
PZ
Amplitude (μV)
Time (s)

▼ **Comment:**

The general pattern may appear consistent across channels, indicating synchronized neural activity

Although the visualizations of each channel look similar, there are tiny differences between them. The following figure represents all signals in one plot.

▼ **Plot mannualy (with matplotlib)**

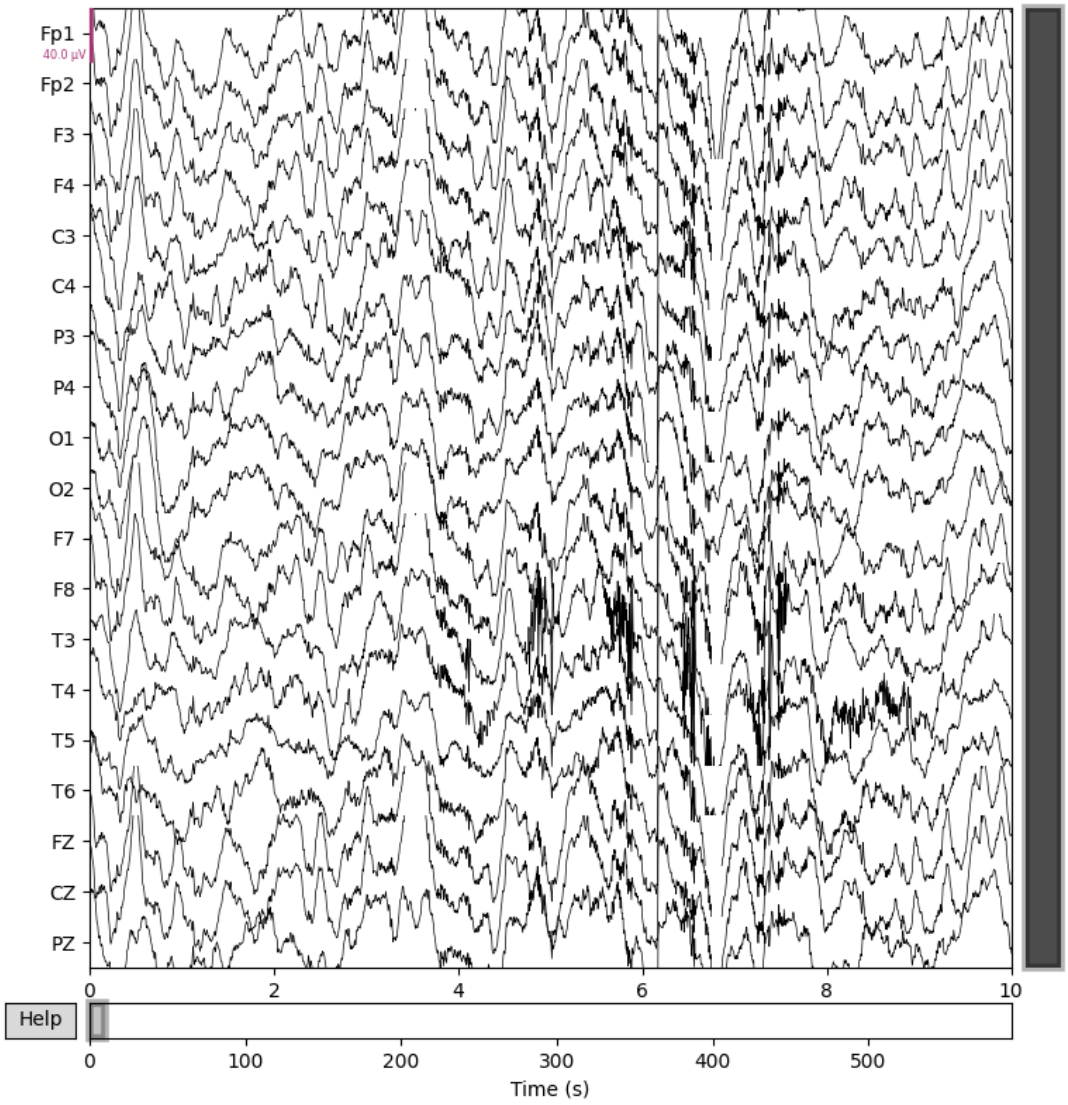



▼ **Plot with** `mne`

▼ **Script code**

```
# ==== Visualize with MNE =========
# Plot the original data in time-series with the full
title, units
raw.plot(title='Raw EEG data', show_options=True)
```

### ▼ Result Figure(s)




- Analyze the data to identify signal and noises
- Design filters to eliminate the DC component, Electricity noise, and others (if contaminated)
- Apply the filters to the data to reduce the noises and increase the SNR (signal to noise ratio) as well. Show the noise reduction and SNR increasing values

- Show the difference between the original data and processed data in both time domain and frequency domain
- Design spectrogram for each data channels with frequency resolution of 1 Hz