

Artificial Intelligence, Blockchain, e Criptovalute nello Sviluppo Software

Lezione 4.B: Cognitive Models in Software Development – Measuring brain signals

Giancarlo Succi

Dipartimento di Informatica – Scienza e Ingegneria
Università di Bologna
g.succi@unibo.it



Sources

- This presentation has been elaborated based on these sources and customized for the needs of this presentation:
 - A. Gramfort, M. Luessi, E. Larson, D. A. Engemann, D. Strohmeier, C. Brodbeck, R. Goj, M. Jas, T. Brooks, L. Parkkonen, et al., “MEG and EEG data analysis with MNE-python,” *Frontiers in neuroscience*, vol. 7, p. 267, 2013
 - A. Gramfort, M. Luessi, E. Larson, D. A. Engemann, D. Strohmeier, C. Brodbeck, L. Parkkonen, and M. S. Hämäläinen, “MNE software for processing MEG and EEG data,” *Neuroimage*, vol. 86, pp. 446–460, 2014.
 - J.-M. Schoffelen and J. Gross, “Source connectivity analysis with MEG and EEG,” *Human brain mapping*, vol. 30, no. 6, pp. 1857–1865, 2009.



Sources

- W. Klimesch, M. Doppelmayr, T. Pachinger, and B. Ripper, “Brain oscillations and human memory: EEG correlates in the upper alpha and theta band,” Neuroscience letters, vol. 238, no. 1-2, pp. 9–12, 1997.
- I. Crk, T. Kluthe, and A. Stefkic “Understanding programming expertise: An empirical study of phasic brain wave changes,” ACM Transactions on Computer-Human Interaction (TOCHI), vol. 23, no. 1, pp. 1–29, 2015
- Wikipedia - 10–20 system (EEG)
- additional resources as specified in each slide
- The team composing it included Sergei Bakaleinik (main writer), Sara Busechian, Gcinizwe Dlamini, and Giancarlo Succi

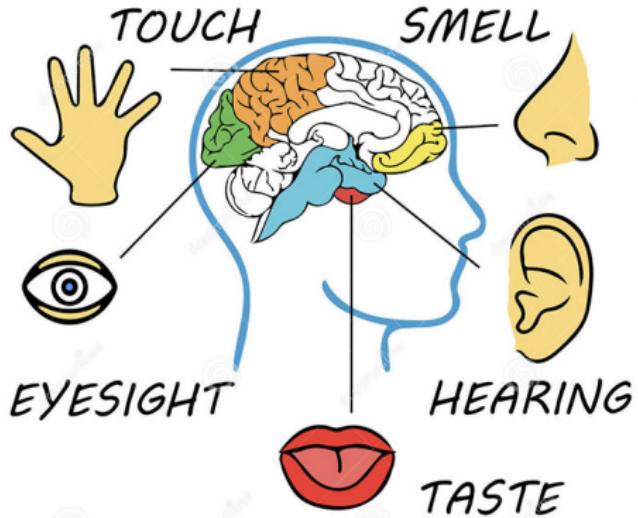


Content

- Concept of brain signals
- From nervous system to senses
- Kind of brain signals
- Measuring Brain Signals
- Inferring mental states from brain signals
- From frequencies to brainwave names
- Sample of situations, explained by brainwaves
- Collecting brain signals using EEG
- EEG software and device that we use
- Understanding the output of EEG
- Steps in the processing of EEG data
- About the MNE
- Steps undertaken in Python to analyse data from EEG
- Main techniques in analyzing EEG



Concept of brain signals



Senses to brain lobes

Taken from <http://udel.edu/~livcar/Art205/Project%202/>



Concept of brain signals

- The brain is the main component of the nervous system.
- It is responsible for all mental operations such as concentration, thinking, learning, and motor control.
- These capabilities are implemented through neurons.
- Our brain produces many messages to the body in the form of electrical or chemical signals.
- Electrical signals are also so called “brain waves.”
- From the Wikipedia:

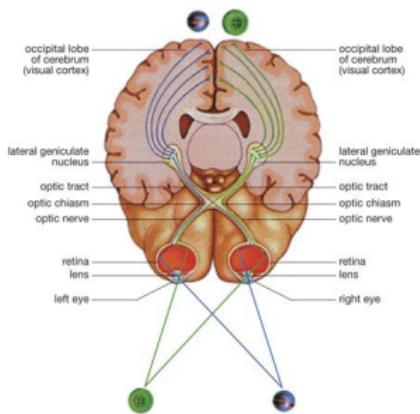
Neural oscillations, or brainwaves, are rhythmic or repetitive patterns of neural activity in the central nervous system.

Taken from https://en.wikipedia.org/wiki/Neural_oscillation



From nervous system to senses (1/3)

- **Sight** : Light which entering the eye forms an inverted image on the retina. The light activates receptors on the retina, and those convert light to nerve signals.

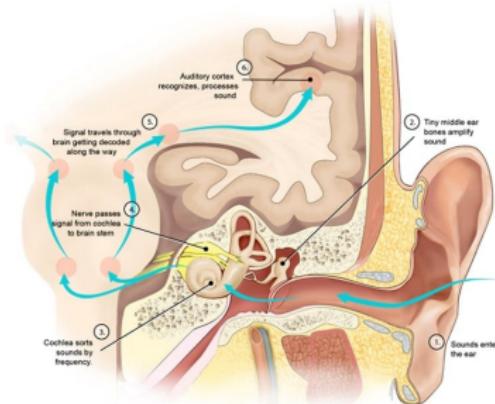


Taken from <https://theconversation.com/curious-kids-how-does-our-brain-send-signals-to-our-body-124950>
Image taken from <https://www.pinterest.ca/pin/381539399665835505/>



From nervous system to senses (2/3)

- **Hearing** : Every sound we hear is the result of sound waves entering our ears and causing our tympanic membrane to vibrate. These vibrations are converted into nerve signals and the cerebral cortex processes electrical signals.

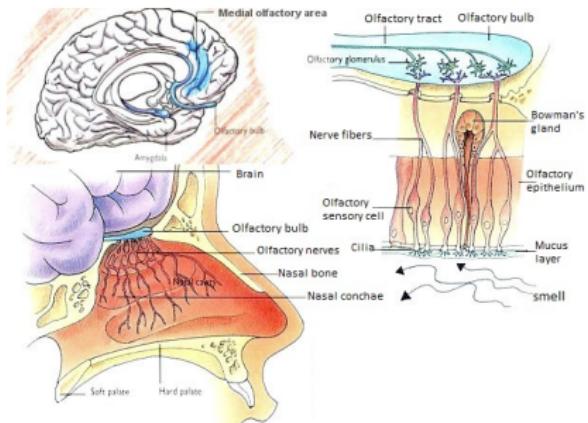


Taken from <https://theconversation.com/curious-kids-how-does-our-brain-send-signals-to-our-body-124950>
Image taken from <https://theconversation.com/your-next-hearing-aid-could-be-a-video-game-89218>



From nervous system to senses (3/3)

- **Smell** : When smell molecules enter the nose, they break down and bind to olfactory receptors, which are activated and send signals through the olfactory nerve to the brain.



Taken from <https://theconversation.com/curious-kids-how-does-our-brain-send-signals-to-our-body-124950>
Image taken from <https://universe-review.ca/R10-16-ANS06.htm#smell>

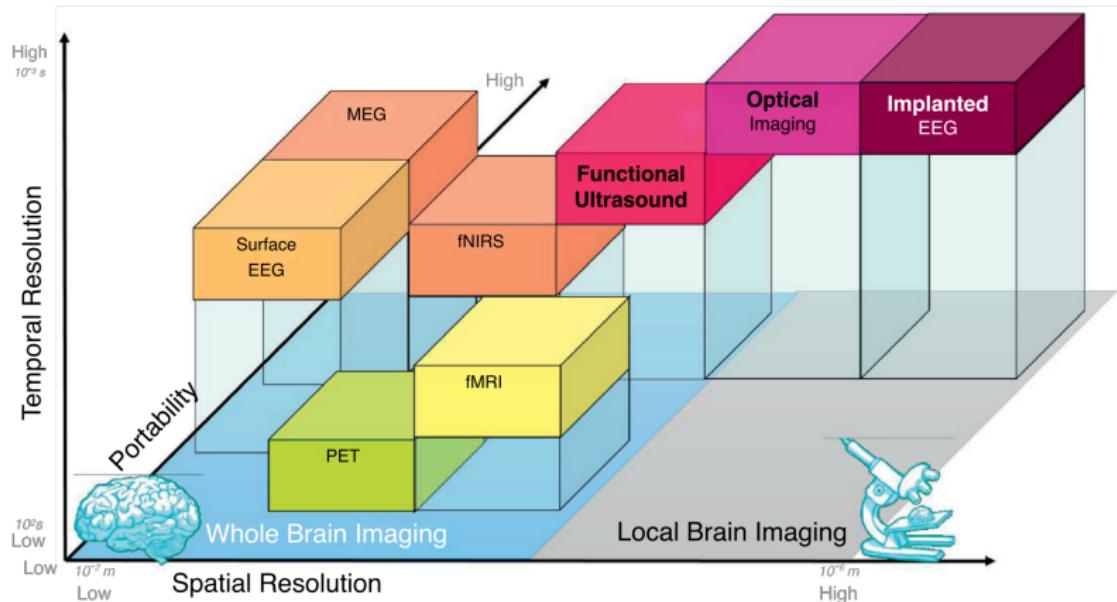


Kind of brain signals

- Brain signals have a different nature:
 - electrical,
 - chemical.
- Examples: smell, convert chemical to electrical signals; sight send electrical signals to brain.



Measuring Brain Signals (1/10)



Taken from https://en.wikipedia.org/wiki/Functional_neuroimaging



Measuring Brain Signals (2/10)

In this presentation we more focus on electric waves. Common methods of functional neuroimaging include next devices (techniques):

- Electroencephalography (EEG)
- Magnetoencephalography (MEG)
- Positron emission tomography (PET)
- Functional magnetic resonance imaging (fMRI)
- Functional near-infrared spectroscopy (fNIRS)
- Single-photon emission computed tomography (SPECT)
- Functional ultrasound imaging (fUS)

Taken from https://en.wikipedia.org/wiki/Functional_neuroimaging



Measuring Brain Signals (3/10)

- PET, fMRI, fNIRS, and fUS can measure localized changes in cerebral blood flow related to neural activity.
- Regions of the brain which are activated when a subject performs a particular task.
- Other methods of neuroimaging involve the recording of electrical currents or magnetic fields, for example EEG and MEG.
- MEG measures brain activity with high temporal resolution, but is limited in its ability to localize that activity
- fMRI does a much better job of localizing brain activity for spatial resolution, but with a much lower time resolution
- fUS can reach an interesting spatio-temporal resolution but is also limited by the neurovascular coupling

Taken from https://en.wikipedia.org/wiki/Functional_neuroimaging



Measuring Brain Signals (4/10)

- Electroencephalography (EEG)



Taken from <https://tebmedtourism.com/eeg/>



Measuring Brain Signals (5/10)

- Magnetoencephalography (MEG)



Taken from <https://en.wikipedia.org/wiki/Magnetoencephalography>



Measuring Brain Signals (6/10)

- Positron emission tomography (PET)



Taken from <https://petscanhub.ie/resources/patient-information-for-pet-imaging/>



Measuring Brain Signals (7/10)

- Functional magnetic resonance imaging (fMRI)

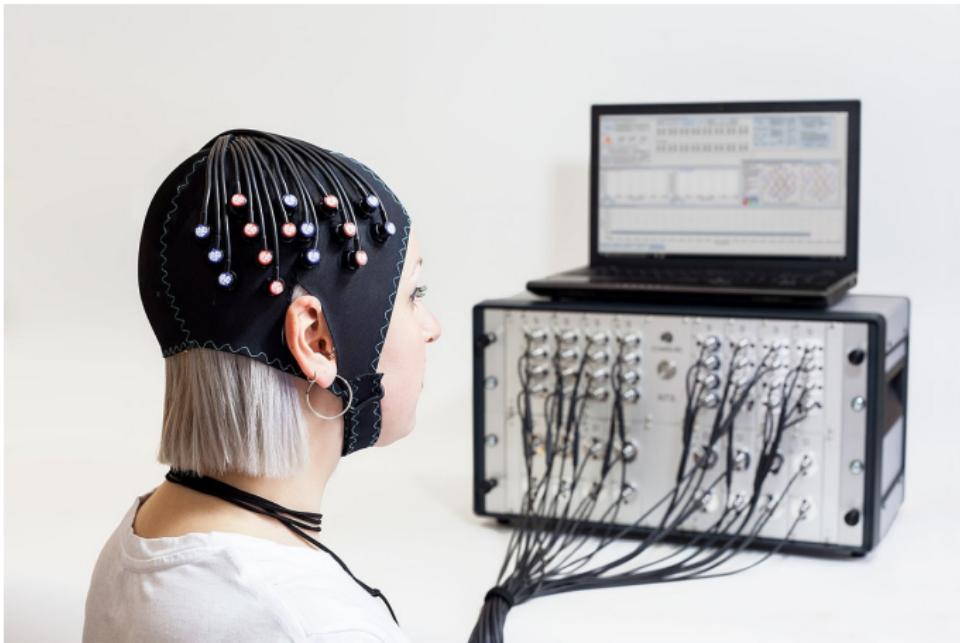


Taken from <https://www.eurekalert.org/multimedia/pub/188089.php>



Measuring Brain Signals (8/10)

- Functional near-infrared spectroscopy (fNIRS)



Taken from https://en.wikipedia.org/wiki/Functional_near-infrared_spectroscopy



Measuring Brain Signals (9/10)

- Single-photon emission computed tomography (SPECT)



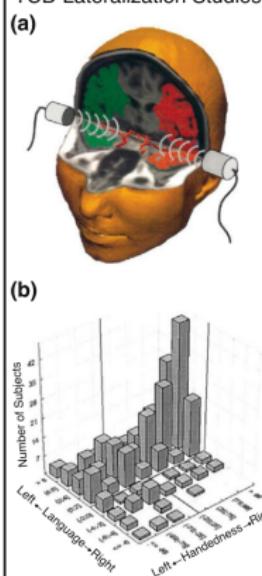
Taken from <https://wa.kaiserpermanente.org/kbase/topic.jhtml?docId=acc4790>



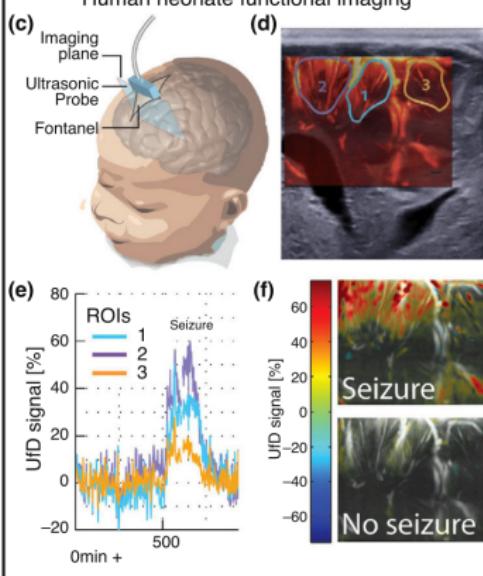
Measuring Brain Signals (10/10)

- Functional ultrasound imaging (fUS)

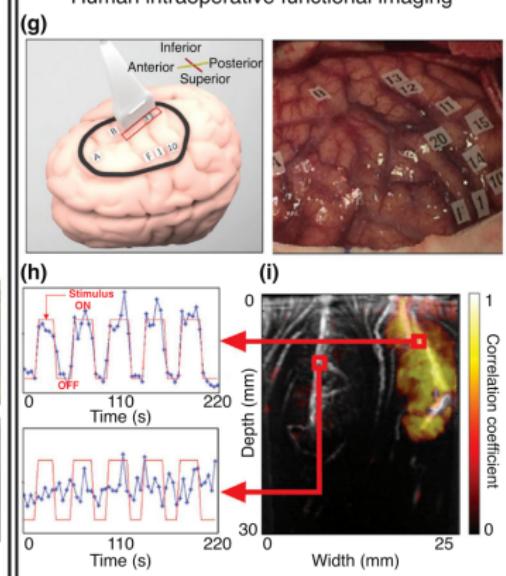
TCD Lateralization Studies



Human neonate functional imaging

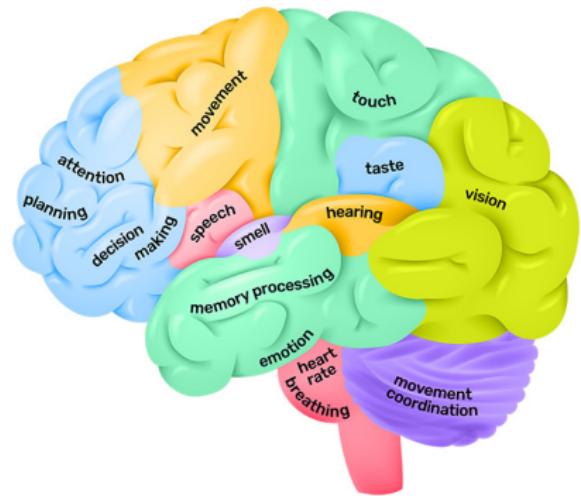


Human intraoperative functional imaging





Inferring mental states (1/2)



Taken from <https://qbi.uq.edu.au/brain/brain-anatomy/lobes-brain>



Inferring mental states (2/2)

Based on brainwaves, we can find such states of human as:

- attention;
- emotions;
- memory processing;
- hearing;
- etc.



Collecting brain signals using EEG (1/5)

- Why we use EEG
 - portable
 - easier to set up
 - not too expensive
- EEG is an electrophysiological monitoring method to record electrical activity on the scalp that has been shown to represent the macroscopic activity of the surface layer of the brain underneath.
- It is typically noninvasive, with electrodes placed along the scalp.

Taken from <https://en.wikipedia.org/wiki/Electroencephalography>

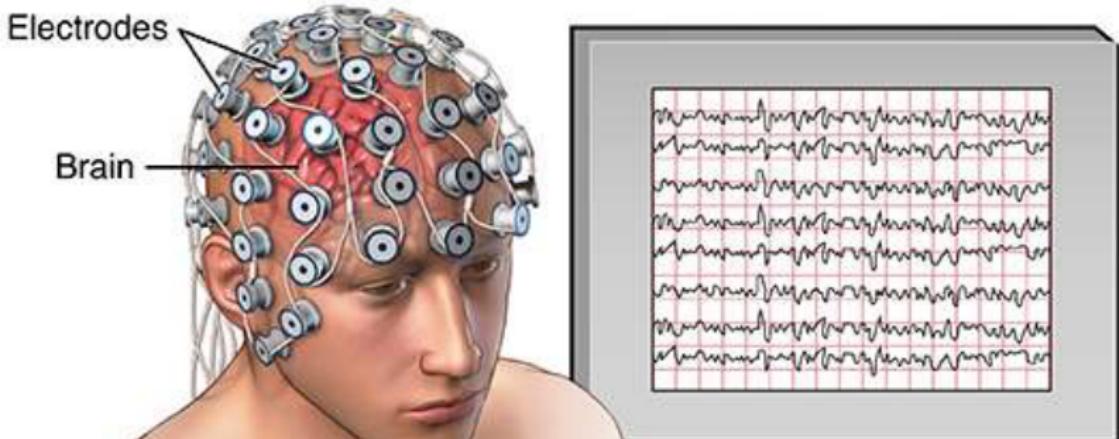


Collecting brain signals using EEG (2/5)

For collecting brain signals using EEG :

- cap
- wired or wireless device connected to electrodes
- software for recording and processing EEG data

Electroencephalogram (EEG)





Collecting brain signals using EEG (3/5)

Here known brainwaves:

- 1 – 5 Hz: δ (delta) wave
- 4 – 8 Hz: θ (theta) wave
- 8 – 12 Hz: α (alpha) wave
- 12 – 25 Hz: β (beta) wave
- > 25 Hz: γ (gamma) wave
- 7,5 – 12,5 Hz: μ (mu) waves



Collecting brain signals using EEG (4/5)

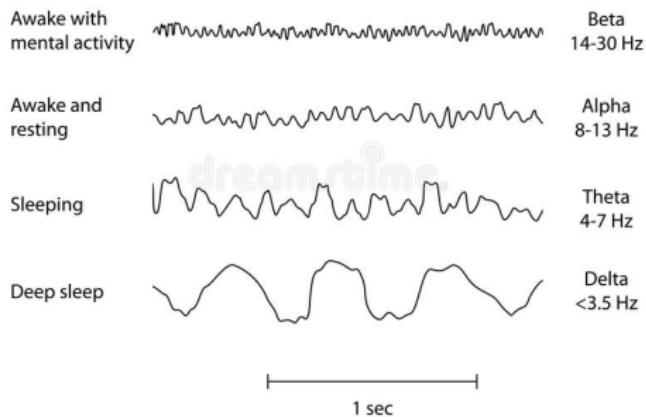
- Neural oscillations are observed throughout the central nervous system at all levels, and include spike trains, local field potentials, and large-scale oscillations which can be measured by EEG.
- In general, oscillations can be characterized by their frequency, amplitude and phase.
- These signal properties can be extracted from neural recordings using time-frequency analysis.

Taken from https://en.wikipedia.org/wiki/Neural_oscillation



Collecting brain signals using EEG (5/5)

Normal Adult Brain Waves



Taken from <https://www.dreamstime.com/royalty-free-stock-photo-normal-brain-waves-eeg-image29444815>



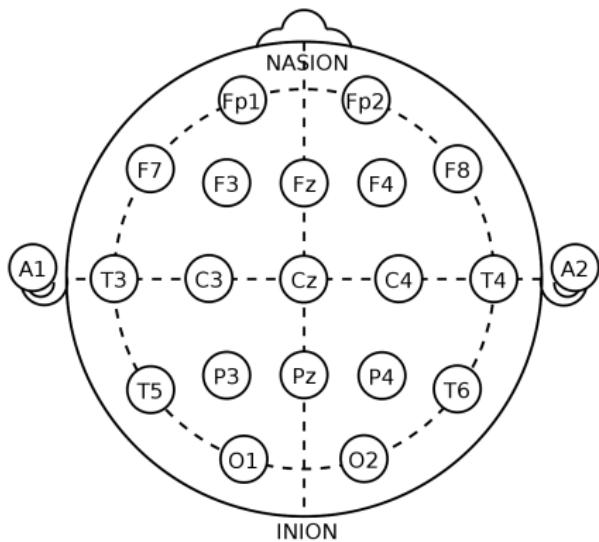
EEG and fMRI

- In our research we have found out that the precision obtained by fMRI can be reasonably approximated using EEG
 - In particular attention and concentration can be well detected allowing deductions on effective development practices
 - We have already visualized the effect of pair programming during the first lecture
-
- Sources:
 - Rozaliya Amirova, Vladimir Ivanov, Sergey Masyagin, Aldo Spallone, and Giancarlo Succi. Preliminary findings on tools for the analysis of mental activity of programmers using EEG data from portable devices. In 23nd Euromicro Conference on Digital System Design, DSD 2020, Portorose, Slovenia, August 26-28, 2020. IEEE, 2020
 - Sara Busechian, Vladimir Ivanov, Alan Rogers, Ilyas Sirazitdinov, Giancarlo Succi, Alexander Tomasov, and Jooyong Yi. Understanding the Impact of Pair Programming on the Minds of Developers. In Proceedings of the 40th International Conference on Software Engineering Companion, ICSE-NIER'18, Gothenburg, Sweden, May-June 2018. ACM



EEG software and device

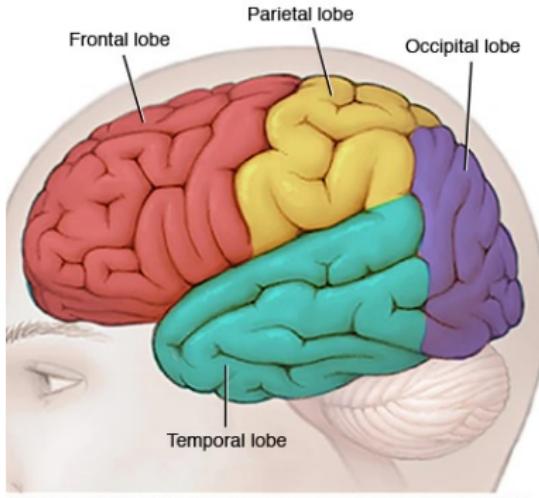
For recording we use software, cap and device from Mitsar. The device is wireless, the cap is 24-channel EEG Smart BCI in which the electrodes are placed according to scheme 10-20.



Taken from [https://en.wikipedia.org/wiki/10%20-20_system_\(EEG\)](https://en.wikipedia.org/wiki/10%20-20_system_(EEG))



EEG software and device that we use



© MAYO FOUNDATION FOR MEDICAL EDUCATION AND RESEARCH. ALL RIGHTS RESERVED.

Each electrode location has a letter designating the lobe or brain region from which it reads: prefrontal (Fp), frontal (F), temporal (T), parietal (P), occipital (O) and central (C).

Taken from <https://www.sv.uio.no/psi/english/research/projects/human-time-data/documents/data-lifecycle/eeg-2.%20electrode-placement/>

Image taken from <https://www.mayoclinic.org/brain-lobes/img-20008887>



Exporting EEG Data from EEG Studio

EEG Studio by Mitsar can be used for recording and processing of EEG data. You can also export the data by choosing many suitable formats: text, binary, BrainLoc, EDF, WinEEG, WinHRV, Loreta, etc. (in our purpose - the European Data Format (EDF)), where to save and what should be exported: entire examination or some individual part of examination.



Steps in processing of EEG data

Trial - a test of the performance, qualities, or suitability of someone or something.

A number of event-triggered EEG trials are required for quantification, including some seconds before and after the event. The event can be external or internal (e.g., acoustic, or visual stimulation).



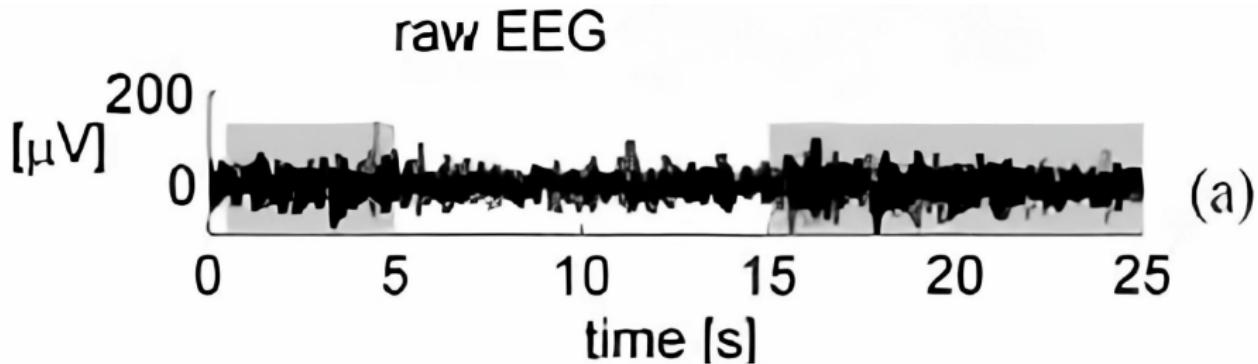
Steps in processing of EEG

Once the frequency band has been determined, the processing procedure consists of the following steps:

- bandpass filtering of each event-related trial
- squaring of each amplitude sample to obtain power samples
- averaging over all trials
- calculation of ERD/ERS.



Steps in processing of EEG

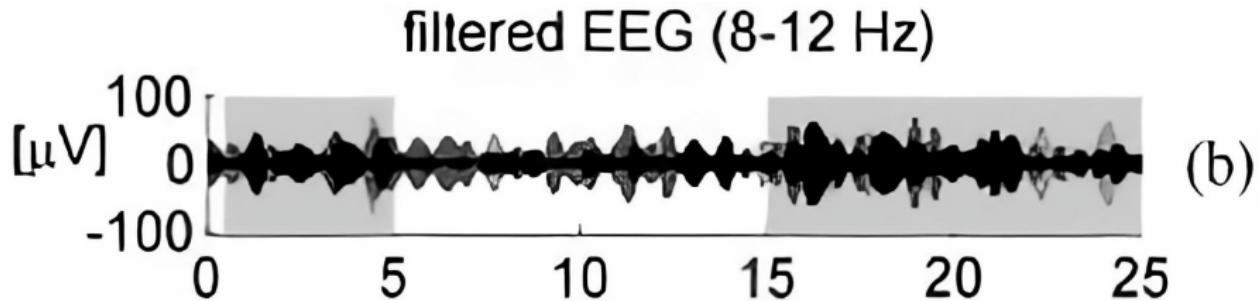


Raw EEG, on one of channels



Steps in processing of EEG data

Band-pass filtering



An epoch is the EEG obtained in each trial under the same conditions. The EEG signals from the frontal channels were then filtered in a specific frequency band using the fast Fourier transformation.



Steps in processing of EEG data

Band-pass filtering

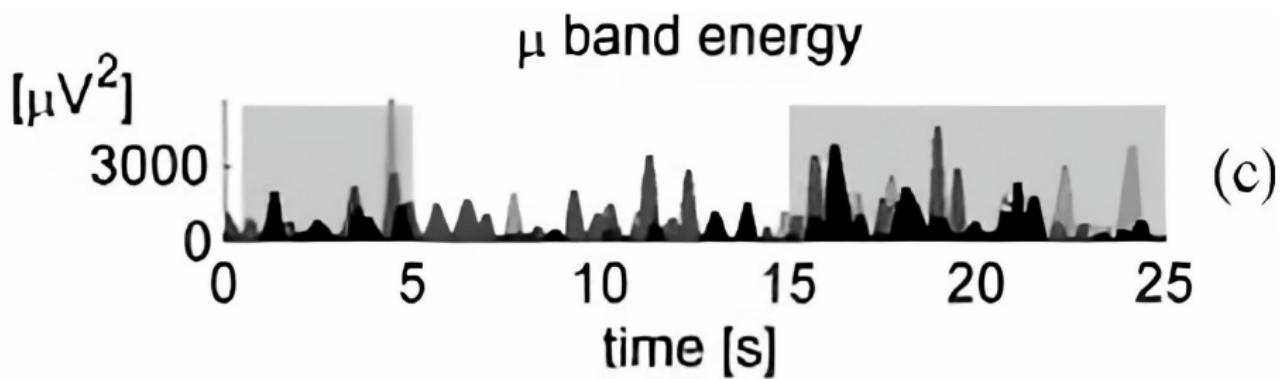
The first step in analyzing the data is to set up the waves ranges, which can differ based on age. The variability of alpha waves in age groups has been shown to have a normal distribution ($\mu = 10Hz, \sigma = 1Hz$) and tonic changes, increasing from childhood to adulthood and then decreasing according to the formula used for the Individual Alpha Frequency(IAF).

$$IAF = 11.95 - 0.053 * Age$$



Steps in processing of EEG data

Squaring

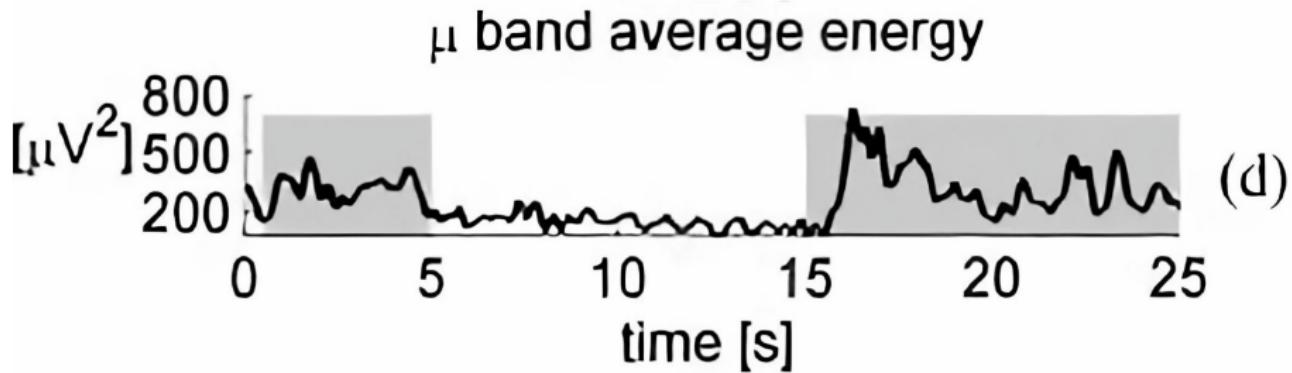


The signal energy can be calculated by squaring the filtered EEG from each epoch.



Steps in processing of EEG data

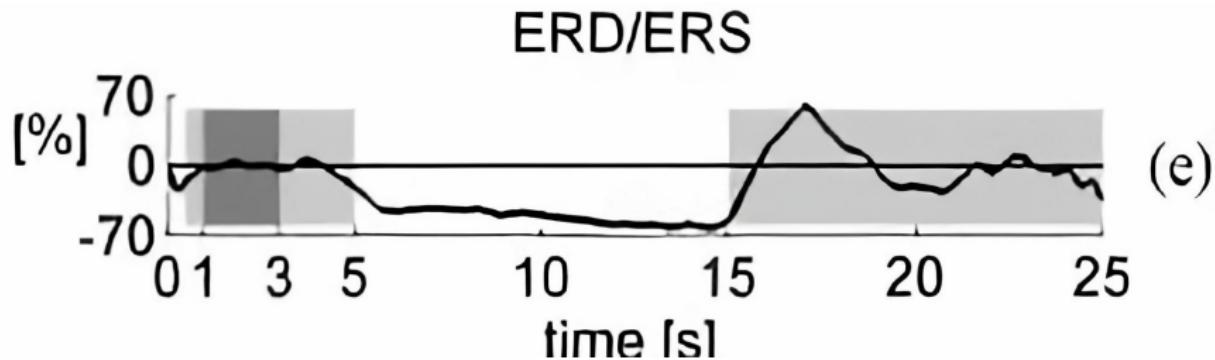
Averaging



The average energy of all epochs then need to be calculated. The signal energy is used in this case to prevent the cancellation of positive and negative EEG amplitudes during the average process.



Steps in processing of EEG data ERD/ERS



Finally, because ERD/ERS are expressed as percentages, the average energy of a previous reference period is computed. As a result, the signal energy can be calculated in relation to the reference period.



About the MNE

MNE-Python is a subproject of the larger academic software package MNE, with the goal of developing and incorporating a set of algorithms that allow users to assemble complete data analysis pipelines covering most stages of MEG or EEG data processing. MNE-Python is a powerful EEG processing tool that provides the following features: filtering, individual component analysis, statistics, minimum normal estimation, etc. Temporal frequency analysis as well as nonparametric and connectivity studies are all possible with MNE-Python.



About the MNE

MNE analysis software selects the highest quality current distribution as a representation of all recorded currents, combining the best spatial resolution with the best temporal resolution. In addition, the frequencies of the sensor and source spaces are processed simultaneously, and anomalies can be cleaned using signal processing techniques. MNE-Python is automated with free surface power spectrum analysis tools paired with fast Fourier transformation algorithms to automatically perform a Fourier analysis of the collected data.



Analysing EEG in Python (1/2)

- 1) with `mne.io.read_raw_edf` | read raw EEG data
- 2) with `mne.io.concatenate_raws` | concatenate raw (if necessary)
- 3) with `raw_exp.info['sfreq']` | get the sample frequency for main part of experiment
- 4) with `part_exp.pick_channels` | choose specific channels for analysis purposes
- 5) with `mne.filter.notch_filter` | and params
`x=part_exp.get_data, Fs=sfreq, freqs=[50, 100]` | filter data from AC line noise



Analysing EEG in Python (2/2)

- 6) with `mne.filter.filter_data` use bandpath filtering. here we use IAF
- 7) with `scipy.signal.spectral.stft` perform Short Time Fourier Transform
- 8) calculate ERD and remove outliers



Main techniques in EEG analyzing

The next step is to count the number of waves in the corresponding interval. This allows us to assess brain activity at each time point. The analysis is then focused on three techniques:

- ERD,
- Correlations of brainwaves.
- Mann–Whitney U-test



Main techniques in EEG analyzing

ERD. Definition

Event-related desynchronization (ERD) reflects a decrease of oscillatory activity related to internally or externally paced events. The increase of rhythmic activity is called event-related synchronization (ERS). They represent the dynamical states of thalamocortical networks associated with cortical information processing changes.



Main techniques in EEG analyzing

ERD. Calculation

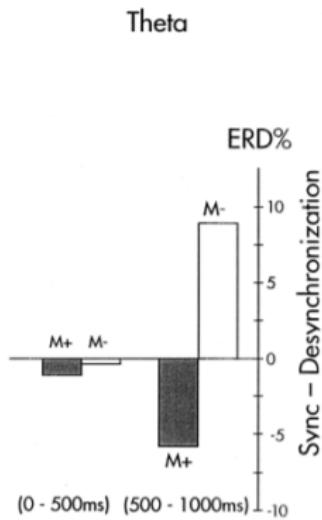
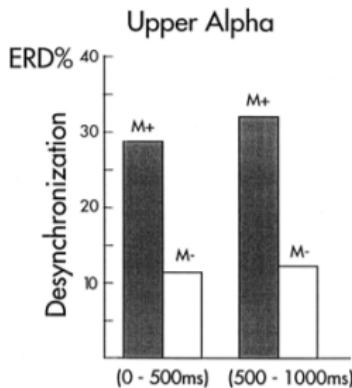
As a result, more time-consuming work should result in a larger ERD difference between rest and programming periods. ERD is calculated using the formula shown below:

$$ERD = \frac{amplitude_{rest} - amplitude_{programming}}{amplitude_{programming}} * 100\% \quad (1)$$



Main techniques in EEG analyzing

Interpretation of ERD



ERD/ERS



Main techniques in EEG analyzing

Interpretation of ERD

In a similar experiment the time course of event-related desynchronization ERD in the upper alpha and theta bands during a semantic judgment task of the type used by Klimesch et al. was analyzed separately for good (M+) and bad memory performers (M-). The results show that good memory performance (M+) is reflected by a significantly greater degree of desynchronization in the upper alpha band. The opposite is true for the theta band, where good memory performance is reflected by a greater degree of synchronization, as measured by negative ERD values.



Main techniques in EEG analyzing

Correlation

Correlation is a statistical measure that measures how close two variables are to each other. Correlation measures the relationship, but it does not show whether x causes y or vice versa, or whether the relationship is caused by a third - perhaps unknown - factor. It can be calculated using the formula:

$$r = \frac{\bar{xy} - \bar{x}\bar{y}}{\sigma_x \sigma_y} \quad (2)$$



Main techniques in EEG analyzing

The Mann-Whitney U-test is a statistical test can be used to assess the differences between two independent samples on the level of a characteristic measured quantitatively. It allows detecting differences in the value of a parameter between small samples. U-statistics can be calculated as:

$$U = \sum_{i=1}^n \sum_{j=1}^m S(X_i, Y_j) \quad (3)$$

with

$$S(X, Y) = \begin{cases} 1 & \text{if } Y < X \\ \frac{1}{2} & \text{if } Y = X \\ 0 & \text{if } Y > X \end{cases} \quad (4)$$



Questions?

End of lecture four – part B.