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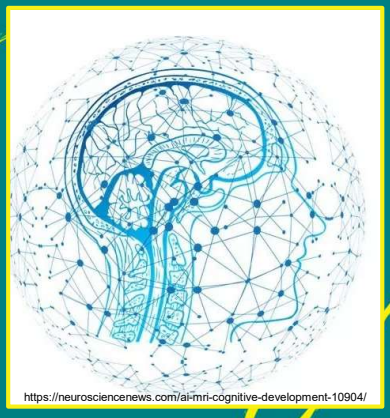
VISER

Intro to Neuroscience Data and Analysis



July 22, 2022

Vandana Srivastava
- Founder, ViSER
- Summer Intern, National Institute of Health (NIH)
- PhD (Computer Science) Student, University of South Carolina, SC

GITHUB:
https://github.com/vsrivas/WWCode_BlockDataPy_July2022

Acknowledgement:
Dr. Christian O'Reilly
Assistant Professor, AI Institute
University of South Carolina

About ViSER and Myself

ViSER

Started in Jan 2019 in NY :

- Promotes STEM, Finance, and OpenData learning among kids and adults through **bootcamps, after-school classes, and workshops** for 3rd grade - high school kids, financial literacy classes for women
- Provides AI-backed, data-driven solutions to small / medium businesses - market Research, training, software development
- Now based in **South Carolina** – Events with the *University of South Carolina* for high school and middle school students in Data Analysis and AI
- website: https://www.go-viser.com/
- email: viserllc@gmail.com

Education

Ph.D. (Computer Science) Student, University of South Carolina
MBA (Financial Management), Pace University, NY
MS (Computational Mathematics), Arizona State University, AZ
MSc(Mathematics), University of Lucknow, India

Work Experience (10+ years)

- Founder ViSER, educational services company, USA (2019 -)
- Vice President, Tantiv4, USA
- Guest Faculty, Indian Institute of Technology (IIT), Delhi, India
- Incentive Analyst - IBM Corporate Office, Armonk, USA
- Assistant Professor- JSS Academy of Technical Education, Amity University, India

https://www.linkedin.com/in/v-srivastava/

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Outline

Introduction of the field of neuroscience	Different data collection techniques, with focus on EEG and MRI	Discuss various softwares available to analyze EEG and MRI data	Results of intracranial EEG data analysis	Discuss why and how AI and ML is used in neuroscience
About Neuroscience 1	**Intro to Neuro Data (EEG and MRI)** 2	**Neuro Data Analysis Tools** 3	**Example of EEG Analysis** 4	**AI / ML in Neuroscience** 5

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1. About Neuroscience

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What is Neuroscience?

*Scientific study of the **nervous system** (Wikipedia)*

Central Nervous System
- Brain
- Spinal Cord

Peripheral Nervous System
(mainly consists of *nerves*)

BUT
When we say "Neuroscience", we mainly refer to
BRAIN AND ITS STUDY

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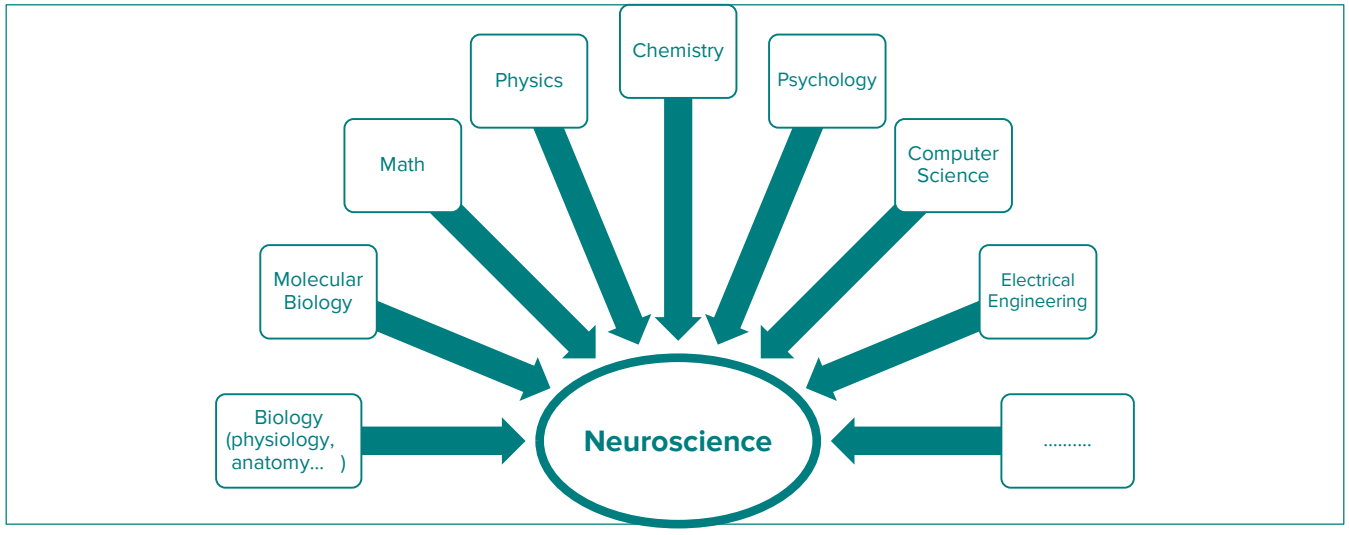
Neuroscience – A Multidisciplinary Field



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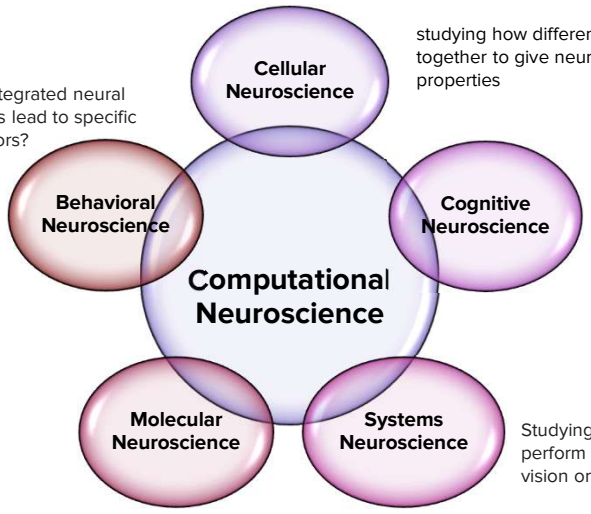
Major Sub-branches of Neuroscience Field



studying how different molecules work together to give neurons their special properties

How integrated neural systems lead to specific behaviors?

How neural mechanisms are responsible for mental activity, such as self-awareness, imagination, and language?

Studying how different neurons align to perform a common function, such as vision or motor functions

Study of different molecules playing crucial brain functions like messengers that allow neurons to communicate with one another,

We will focus on the data generated by the study of BRAIN only --- **Focus on EEG and MRI**

NEUROSCIENCE - EXPLORING THE BRAIN (4th Edition) – Wolters Kluwer publications

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2. Intro to Neuro Data (EEG and MRI)

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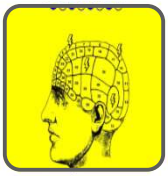
Major Techniques for Collecting Brain Data

Brain Level



Electro Encephalography (EEG) and Magneto Encephalography (MEG)

MEG measures the magnetic fields produced by brain activity
EEG measures the electrical activity

Magnetic Resonance Imaging (MRI)

Uses powerful magnets and radio waves to create a detailed view of the brain

Functional MRI, structural MRI, diffusion MRI

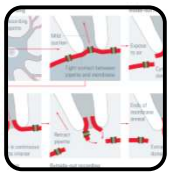
Computerised Tomography (CT)

X-rays to get cross-sectional images of brain

Positron Emission Tomography (PET)

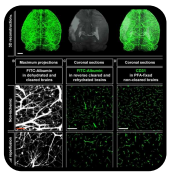
A small amount of low-dose radioactive material is injected into a vein to help visualize the metabolic activity of brain

Cellular level



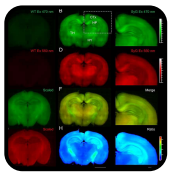
Patch Clamp

Invasive technique to study brain cells



Light and Fluoresent Microscopy

Invasive method



Calcium Imaging and Other....

Bing images – creative commons

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Open Data in Neuroscience

EBRAINS

Created by the EU-funded **Human Brain Project**, having extensive data and tools for brain-related research

Max Planck Institut Leipzig Mind-Brain-Body Dataset - LEMON

NEURO

A free and open platform for validating and sharing BIDS-compliant MRI, PET, MEG, EEG, and iEEG data - 27,543 Participants, **719 Public Datasets**

CONNECTOME COORDINATION FACILITY

Public research data for studies that focus on the connections within the human brain, known as **Human Connectome Projects**

Google images

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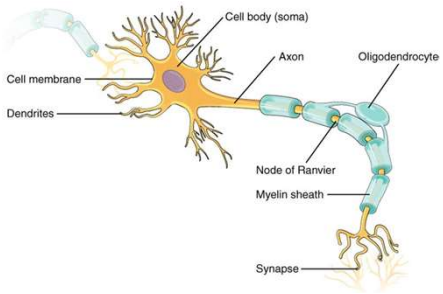
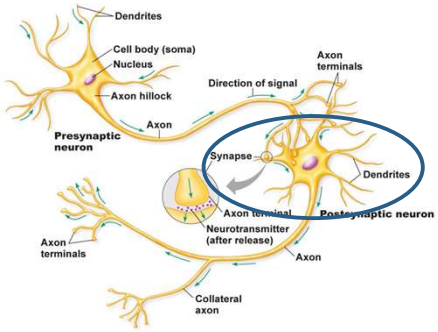
Electrical Activity in Brain Generates EEG Data



Wikimedia commons

NEURONS – The Unit of Brain Activity



https://tinyurl.com/nwc3c2zr

Communication Between Different Neurons

Synchronization of lots (~50 000) of neurons in a very small area of the brain generates EEG signals

Analysis of Neuroscience data: (Spring 2022); Prof Christian O'Reilly, UoSC

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EEG and its applications

- A non-invasive method to record electrical activity in the brain
- Method
  - Tiny electrodes, attached to a wire are placed on the scalp at different locations
  - The electrodes detect small charges generated by neuronal activity in the brain and record them when presented with a **stimulus**
- The activity is measured in microvolts (μV)

Conditions that can be diagnosed using EEG include:

- Epilepsy
- Sleep disorders (such as narcolepsy)
- Head injuries
- Brain infection and hemorrhage
- Alzheimer's disease
- Degeneration of brain tissue
- Metabolic conditions that affect brain tissue
- Hormonal conditions that affect brain tissue
- Stroke, brain tumor, and more

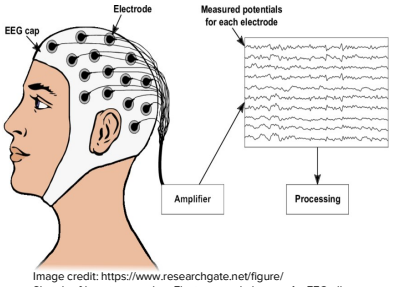

Image credit: https://www.researchgate.net/figure/Sketch-of-how-to-record-an-Electroencephalogram-An-EEG-allows-measuring-the-electrical_fig1_338423585

https://www.hopkinsmedicine.org/health/treatment-tests-and-therapies/electroencephalogram-eeg#:~:text=An%20EEG%20is%20a%20test,activity%20of%20your%20brain%20cells
https://www.ebme.co.uk/articles/clinical-engineering/introduction-to-eeg

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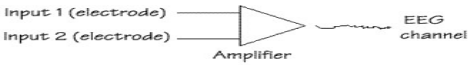
Major Concepts in EEG

Types of Recordings

- **Event Related**
  - EEG is recorded during specific events (stimulus presentation) at intervals
  - Example: Different categories of sounds were played for the participants at different intervals
- **Sleeping**
  - EEG is recorded when the participant is sleeping
  - Can be used to study sleep disorders
- **Resting State**
  - EEG is recorded while the participant is awake but resting (not performing any specific activity) with closed or open eyes

Channel and Montage

EEG systems use a *differential amplifier* to produce each **channel or trace of activity**



- Differential amplifiers measure the voltage difference between the two signals at each of its inputs
- Resulting signal is amplified and then displayed as a channel of EEG activity
- Arrangement in which the input electrodes are connected to the amplifier of the EEG machine is called a **montage**
- *"Electrode"* and *"Channel"* can be used interchangeably

Analysis of Neuroscience data: (Spring 2022); Prof Christian O'Reilly, UoSC

https://www.ebme.co.uk/articles/clinical-engineering/introduction-to-eeg

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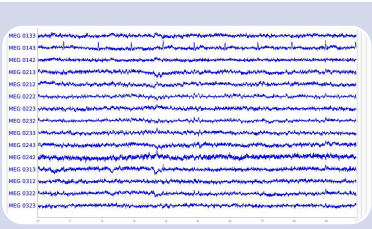
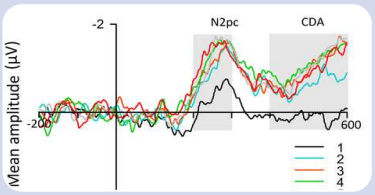
EEG Analysis – Data Structures





Raw

- Continuous data as a time series
- Spectral density of continuous data, sensor locations, information about data, etc
- Shape
  (n_channels, n_samples)

Epoch

- Representing and analyzing equal-duration chunks of the EEG signal called ***epochs***
- Shape

  (n_epochs, n_channels, n_samples)

Evoked

- Data that is averaged across trials (epochs)
- Array of shape

  (n_channels, n_times)

https://mne.tools/stable/auto_tutorials/raw/40_visualize_raw.html#tut-visualize-raw

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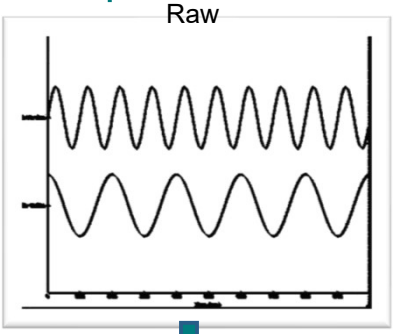
Interpretation of Raw, Epoch, and Evoked Data Structure

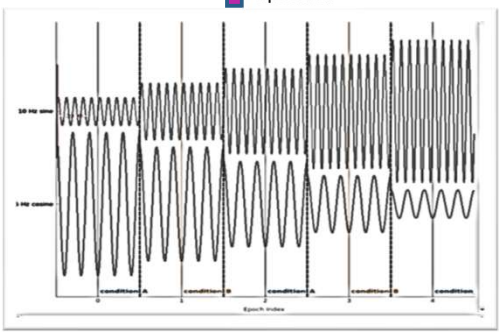
Raw



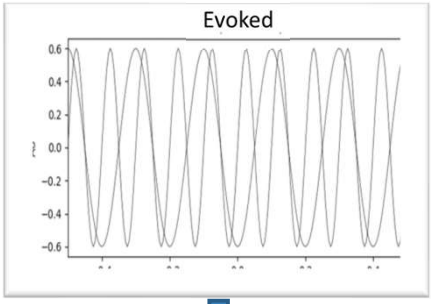
time	J2	J3	J4	X'9	X'10	W'10
0	0	139113	171438	107375	113136	157864
1	16	144289	173294	110402	100148	154250
2	31	147414	173001	113039	87745	148879
...	...	...	...	...	...	...
54059	844672	106886	132863	97902	158254	156399
54060	844688	112160	143703	98195	153176	158450

time	condition	epoch	A2	A3	Z6	Z7
0	-203	51	0	-9361	33180	38747
1	-188	51	0	-6242	33123	31511
2	-172	51	0	-2927	32187	22909
...	...	...	...	...	...	...
46271	438	51	1006	-14745	-15136	-1115
46272	453	51	1006	-10493	14572	3668

Epoched



Evoked



time	A2	A3	A4	A5	Z15
0	-203	1023	1123	1307	57
1	-188	1424	948	1357	18
2	-172	1747	743	1331	-34
...	...	...	...	...	...
41	438	-785	-565	-166	-29
44	484	-2244	-1037	-610	-45
45	500	-2530	-1073	-692	-45

Images credit: https://mne.tools/stable/auto_tutorials/simulation/10_array_objs.html

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Common EEG Analysis Steps

- Read the data (example: using mne)
- Preprocessing:
  - Noise in EEG signals (Artifacts - Heartbeat, sweat, head movement, jaw clinching, eye movement, phone, etc) --- *Drop channels, time windows, Independent Component Analysis (ICA)*
- Analysis
  - "Power Spectral Density (PSD)" analysis for raw or epoched data
  - "Event-Related Potential (ERP)" analysis from evoked data
  - Event analysis
  - More than one channel picking the same signal due to volume conduction
    --- perform connectivity analysis
- Visualization
  - Plot topomaps, ERP, events, PSD, ... (more in the case study)
- Statistical Analysis

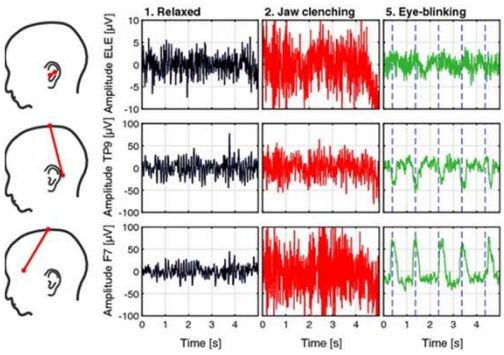

Image: https://biomedical-engineering-online.biomedcentral.com/articles/10.1186/s12938-017-0391-2/figures/3

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MRI and Its Applications

- Well suited for imaging the non-bony parts or soft tissues of the body
- Brain, spinal cord, and nerves, as well as muscles, ligaments, and tendons are seen much more clearly with MRI than with regular x-rays and CT
- In the brain, MRI can differentiate between white matter and grey matter and can also be used to diagnose aneurysms and tumors
- Non-invasive, does not use x-rays or other radiation, preferred when frequent imaging is required for diagnosis or therapy
- fMRI, a special MRI is used to observe brain structures and determine the "activated" (consume more oxygen) brain regions during various cognitive functions

shutterstock.com · 2162500141

https://www.nibib.nih.gov/science-education/science-topics/magnetic-resonance-imaging-mri

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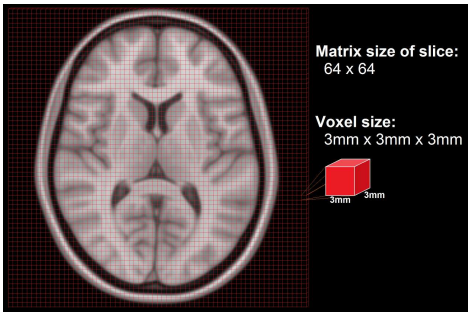
MRI Data

- Volume data is collected to create the complete, 3D image of the brain, recorded at one single timepoint
- Data is measured in **voxels**, which are like the pixels used to display images on screen, only in 3D
- Each voxel has a specific dimension, say, 1mm x 1mm x 1mm: a cube
- Each **voxel contains one value** which stands for the average signal measured at the given location
- A standard anatomical volume, with a voxel resolution of 1mm contains almost 17 million voxels, which are arranged in a 3D matrix of 256 x 256 x 256 voxels
- MRI data formats will have an image and a header part:
  - The **image** is the actual data and is represented by a 3D matrix that contains a value (e.g. gray value) for each voxel
  - The **header** contains information about the data like voxel dimension, voxel extend in each dimension, number of measured time points, a transformation matrix that places the 3D matrix from the image part in a 3D coordinate system, etc.



https://miykael.github.io/nipype-beginner-s-guide/neuroimaging.html

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Common MRI Analysis Steps

- Read the data (example: using NiBabel)
- Pre-processing
  - Intensity non-uniformity correction – To correct the noisy MRI images due to non-uniform magnetic fields
  - Skull-stripping – A process to selects **only** those voxels which are part of brain
  - Normalization – Transforming the brain coordinates of the individual subject to a standardized coordinate system (MNI)
- Analysis
  - Brain tissue segmentation – Classifying the voxels into brain tissues such as white matter, gray matter, or cerebrospinal fluid
- Statistical methods / Machine learning .....

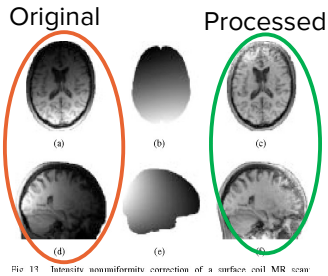
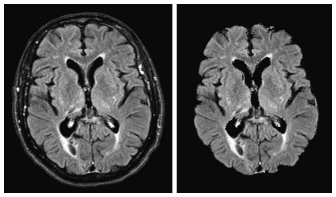


Image credit: Sled, John G., Alex P. Zijdenbos and Alan C. Evans. "A nonparametric method for automatic correction of intensity nonuniformity in MRI data." IEEE Transactions on Medical Imaging 17 (1998): 87-97.



Skull Stripping: Image credit (https://jerrylinew.github.io/cs188/0)

Analysis of Neuroscience data: (Spring 2022); Prof Christian O'Reilly, UoSC

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2. Analysis Tools

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Data Formats in EEG and Neuroimaging

Electroencephalography

Format	Extension(s)	Description
European data format	.edf	Each recording consists of a single .edf file
BrainVision Core Data Format	.vhdr, .vmrk, .eeg	Each recording consists of a .vhdr, .vmrk, .eeg file triplet
EEGLAB	.set, .fdt	Each recording consists of a .set file with an optional .fdt file
Biosemi	.bdf	Each recording consists of a single .bdf file

Neuroimaging

Format	Extension(s)	Description
Nifti	* nii * nii.gz, if compressed	Stores both the data matrix and a header that contains meta data
Dicom	None or sometimes .dcm	Stores raw brain scan data directly from the MRI scanner
Gifti	.gii	Stores surface geometry and vertex-wise data
Cifti, minc, mgh	.nii, .mnc, .mgh	

https://tinyurl.com/3be6uu5y

BIDS (Brain Imaging Data Structure)[1] standardizes the recording of Brain data (EEG, MRI, MEG, PET, ….)

https://bids-specification.readthedocs.io/en/stable/04-modality-specific-files/03-electroencephalography.html

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Major Data Analysis Tools for EEG/MEG and Neuroimaging

- **mne:** python
- **eegkit**: R
- **Neural Data Toolbox** (NDTb) – Matlab
- **livioivil/neuR:** R package for neuroscience data processing and statistical analysis
- **DIPY** is the 3D/4D+ imaging library in Python
- **NiBabel:** provides read/write access to some common medical and neuroimaging file formats, including *ANALYZE*, *GIFTI*, *NIfTI1*, *NIfTI 2*, *CIFTI-2*, *MINC1*, *MINC2*, *AFNI BRIK/HEAD*, *MGH*
- **NiPype**
- **fmri, fsbrain** – R packages

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Some Resources to Learn More...

- edx (accessed July 21, 2022)
  - Fundamentals of Biomedical Imaging: Magnetic Resonance Imaging (MRI)
  - Fundamentals of Neuroscience (series)
- Coursera (accessed July 21, 2022)
  - Neuroscience and Neuroimaging Specialization
  - Computational Neuroscience
- Udemy
  - Complete neural signal processing and analysis: Zero to hero
- Mike X Cohen
  - youtube series on neuroscience ---- for a crash course
- Software documentation (mne, nibabel, etc)
- Support forums:
  - mne

If planning to pursue a career in neuroscience, find the degree programs!

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4. Results of Intracranial EEG Analysis

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Comparative Study of Human iEEG Data

- Collection of data from ten epileptic patients performing eight behavioral tasks from *human intracranial eeg (iEEG) database*
- iEEG recordings were provided in the BrainVision Core Data Format
- iEEG is an invasive way to record EEG
- Subjects were chosen based on channel location and were compared for 2 tasks; **auditory and language**

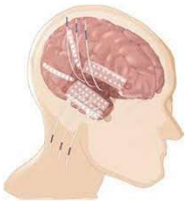
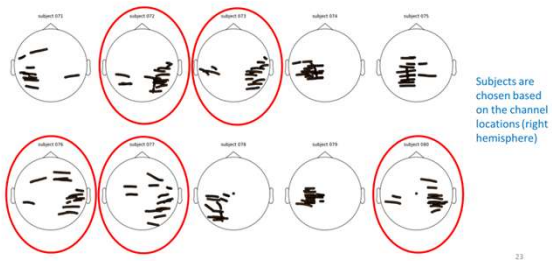


Image credit:
https://onlinelibrary.wiley.com/doi/full/10.1111/j.1528-1167.2010.02910.x

Data Preparation - Selection of Subjects (5/10)



https://search.kg.ebrains.eu/instances/1e5ec1d6-a17d-46ed-8e8b-05c2673dbc0e

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Comparative Study- Selection of Frequency Band

Brain Waves

Band	Frequency
Delta	1-4Hz
Theta	4 – 8 Hz
Alpha	8 – 13 Hz
Beta	13 – 25 Hz
Gamma	> 25 Hz

Chosen tasks involved memory and concentration
Analysis focused on gamma band (>25 hz)

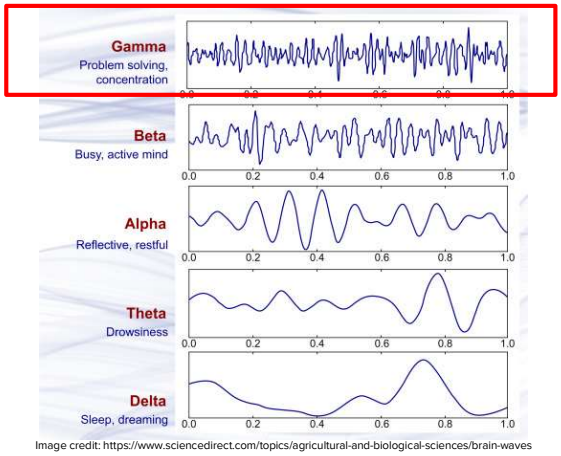

Image credit: https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/brain-waves

https://search.kg.ebrains.eu/instances/1e5ec1d6-a17d-46ed-8e8b-05c2673dbc0e

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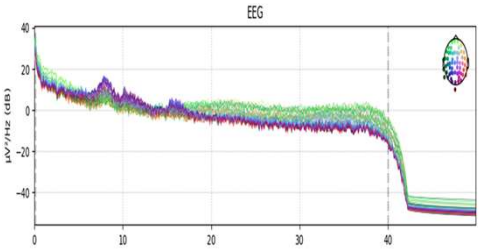
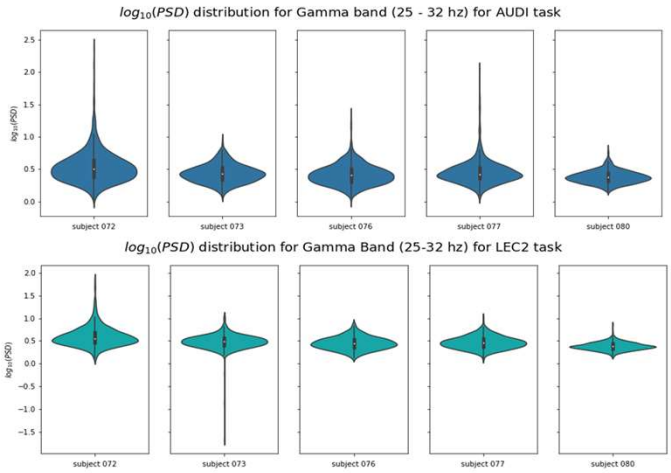
Results: Power Spectral Density (PSD)

Power Spectral Density

Measure of a signal's power content versus frequency



Results: log10(PSD) Distribution in Gamma Band



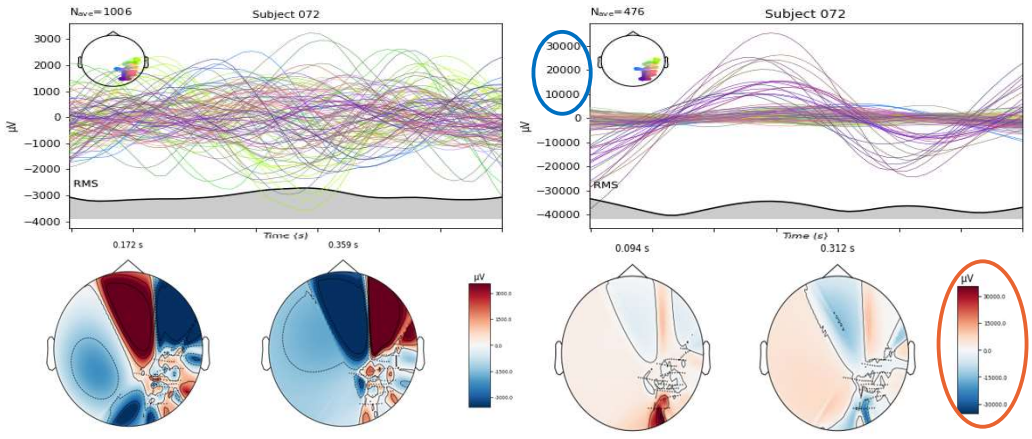
Statistically proved that there is a significant difference in the two distributions for the two tasks (except subject 080)

https://search.kg.ebrains.eu/instances/1e5ec1d6-a17d-46ed-8e8b-05c2673dbc0e

Results: Event Related Potential (ERP)

ERP

Response due to brain activity when subjected to any kind of stimulation such as auditory, motor, or cognitive



Topomap for PEAK values of ERP for task AUDI

Topomap for PEAK values of ERP for task LEC2

HIGH values for task LEC2, indicating high neuronal activity

https://search.kg.ebrains.eu/instances/1e5ec1d6-a17d-46ed-8e8b-05c2673dbc0e

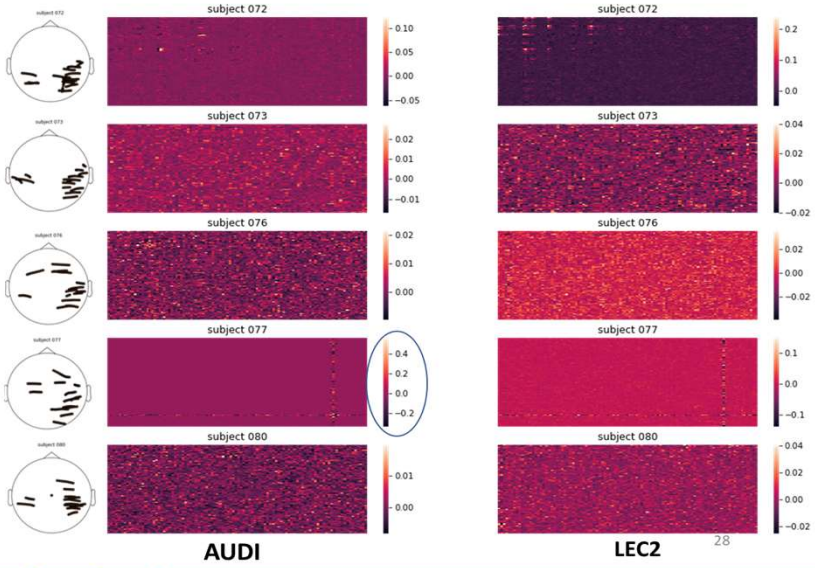
Results: Spectral Connectivity

Connectivity

- More than one channel picking the same signal due to volume conduction
- Perform **connectivity** analysis

Connectivity values are similar for both the tasks

https://search.kg.ebrains.eu/instances/1e5ec1d6-a17d-46ed-8e8b-05c2673dbc0e



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5. How AI and Machine Learning is being used in Neuroscience?

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"Neural Networks in AI", Inspired by Brain

- "Neural Network" concept in AI is inspired by the brain architecture
- Now the NNs are being used to study brain
- Deep learning models are used to show how convolutional layers and recurrent connections in the brain's cerebral cortex control functions, like visual processing, memory, and motor control [1]
- Machine learning can be used to recognize patterns that may be buried inside overly complex neural data [2]
- Detection and classification of brain abnormalities are some of the applications of AI in neuroscience

Why Brain is an Important Application Area of AI?

- Can be used to improve the diagnosis of mental health conditions[1]
  - Need for data-driven assessment: diagnosis today relies on self-reporting, specific feelings, or actions
  - Data is under-utilized: Between 2000 – 2019, ONLY 54 academic papers were published (2020 article, *'ACM Transactions on Computer-Human Interaction '*)
  - **Applying ML to** brain scans, medical data, and the results of a questionnaire about habits, mood, personal circumstances, and demographic data, from large population cohorts **can yield "proxy measures" for brain-related health issues without the need for a specialist's assessment** (GigaScience, Oct 2021, Denis Engemann, Inria Saclay Institute, France)
- Availability of data
  - Human Brain Project – an EU funded initiative to share and analyze brain data
  - Human Connectome Project
  - NIH – The BRAIN Initiative
- More computation power to process images, many software, better diagnostic tools

[1] Communications of ACM, May 2022

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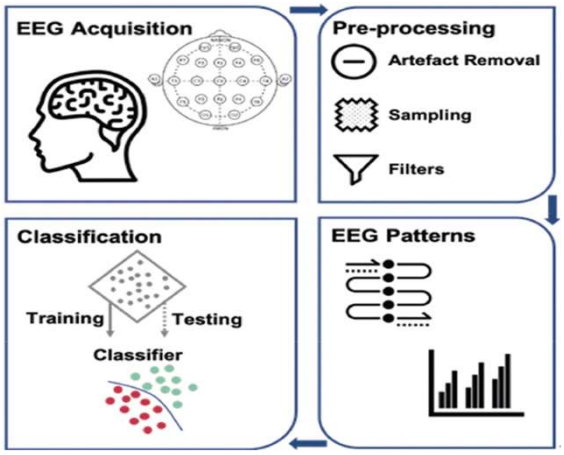
How Machine Learning is Applied to Neuro Data?



EEG recording for a classification problem

Some examples of applications (see reference section for details) :

- Automatic seizure detection based on imaged-EEG signals through fully convolutional networks
- EEG being used as a biomarker in the early detection and classification of dementia
- Detecting and predicting epileptic seizures using machine learning methods

https://journals.sagepub.com/doi/full/10.26599/BSA.2020.9050017

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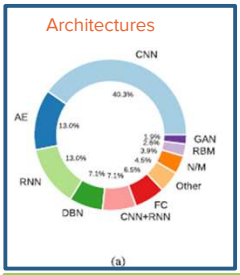
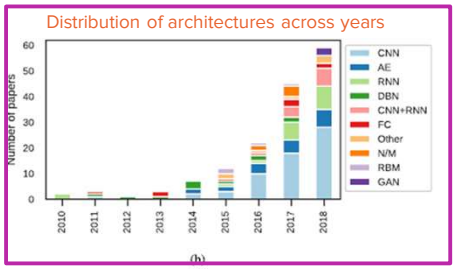
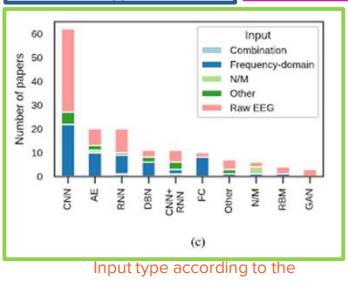
Statistics on Deep Learning for EEG Data

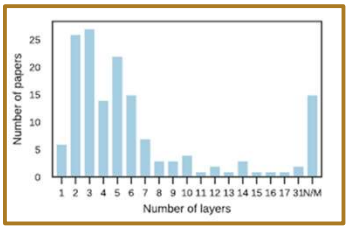
- 154 papers that apply DL to EEG, published between January 2010 and July 2018 and across different application domains such as epilepsy, sleep, brain-computer interfacing, and cognitive and affective monitoring were analyzed
- Research questions:
  a) What are the most frequently used architectures?
  b) How has this changed across years?
  c) Is the choice of architecture related to input characteristics?
  d) How deep are the networks used in DL-EEG?







Input type according to the architecture category



Distribution of the number of neural network layers

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Summary

- People from diverse backgrounds can work in the neuroscience field
- Lot of potential in the research, development, and analysis in the field
- A great opportunity for collaboration
- An exciting area of application for data scientists

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Thank you!

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For Questions or Comments or Slides

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