THE AMERICAN UNIVERSITY IN CAIRO

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CSCE 363/3611 - Digital Signal Processing

Motor Imagery

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Neural Engineering

- Neural Engineering is a field of research that focuses on engineering methods to investigate the function of the central and peripheral nervous system and manipulate its behavior

- Neural Interfaces are systems that can help restore sensory function, communication, and control to impaired humans

- The main principle is that disabled people would have their brains or parts of their brains fully functional

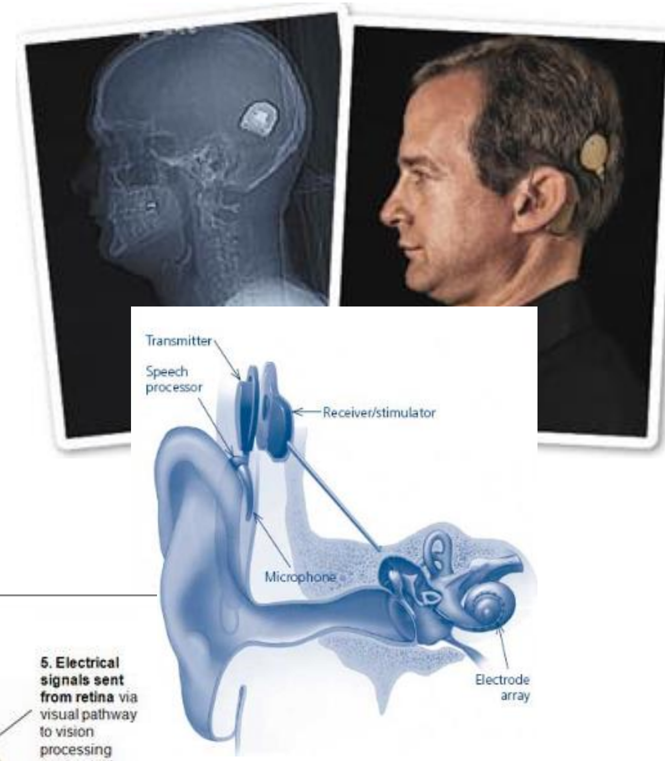
- Neural Interfaces make use of functional parts to restore a lost function

- Objectives of Neural Engineering:
  1- Understand Brain Function
  2- Provide Therapeutic, Assistive and Augmentative Technology

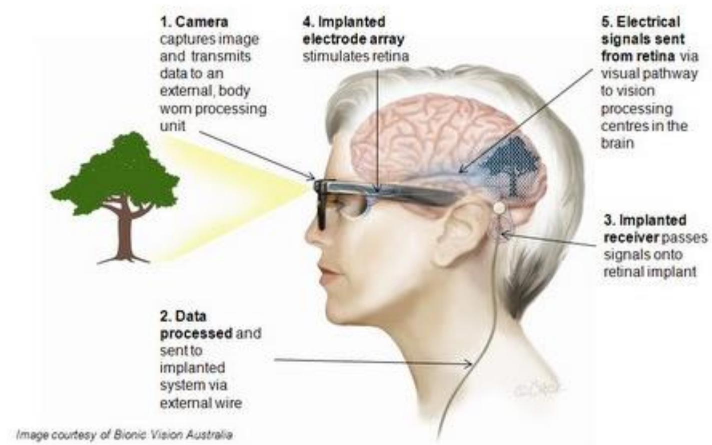
Neural Engineering

- Examples of Neural Interfaces:

Motor Brain-Machine Interface



Cochlear Implant

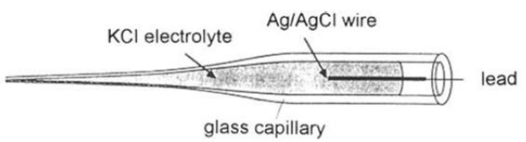


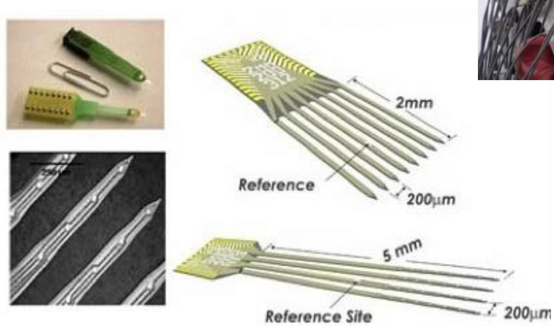
Visual Prosthesis

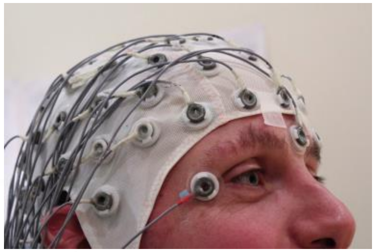
Neural Engineering

- Types of Neural Interfaces

- Neural Interfaces
  - Invasive
    - Single Recording Sites
    - Multiple Recording Sites
  - Non-Invasive
    - EEG
    - fMRI



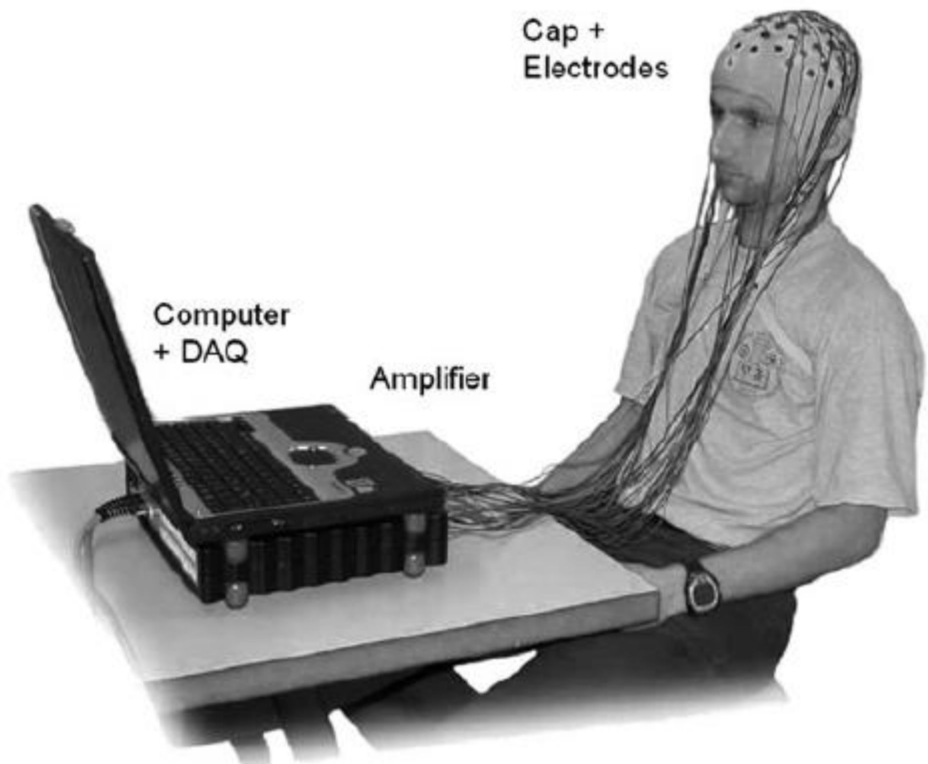




Brain-Computer Interfaces (BCIs)

- A BCI is a non-invasive device that provides the brain with a new, non-muscular communication and control channel

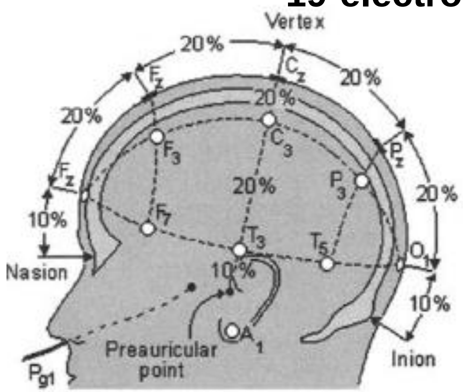
- Electroencephalography (EEG) refers to recording electrical activity from the scalp with electrodes

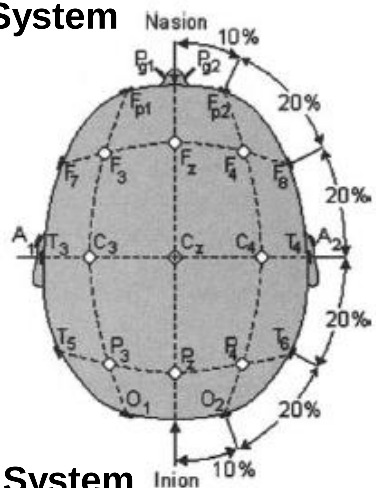


Brain-Computer Interfaces (BCIs)

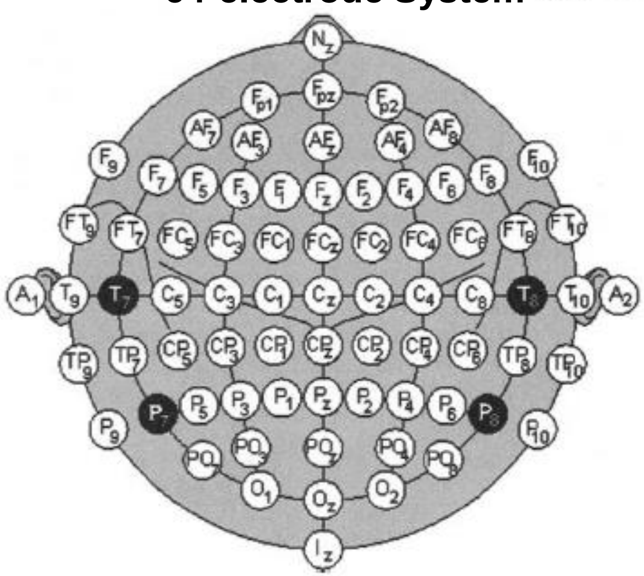
- Many EEG-based BCI systems use an electrode placement strategy suggested by the International 10/20 system

19-electrode System

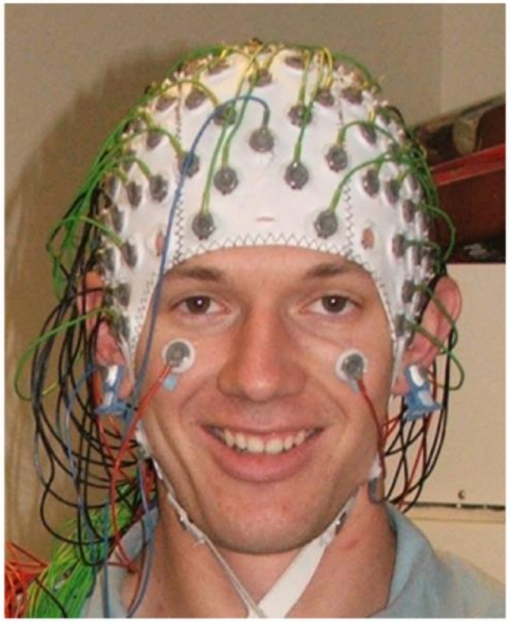




64-electrode System

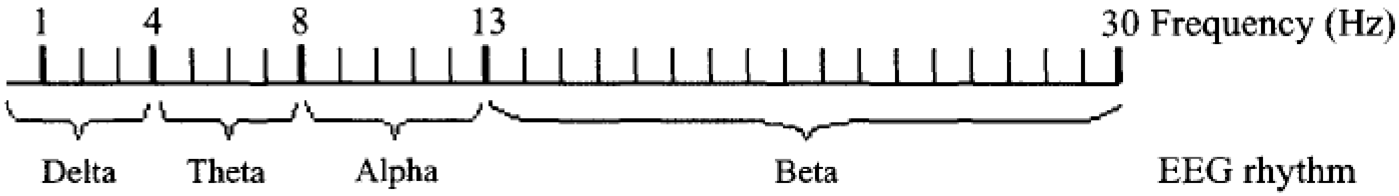


F: Frontal
C: Central
P: Parietal
O: Occipital
T: Temporal



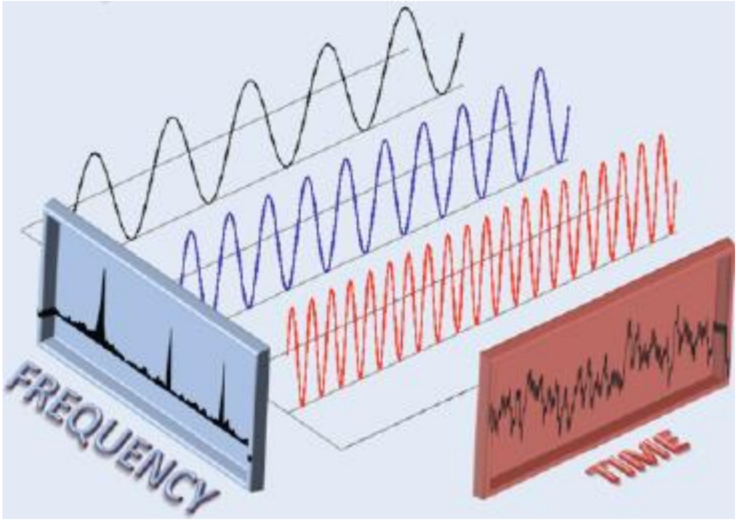
EEG Frequency Bands

- Signals recorded from EEG are split into several bands



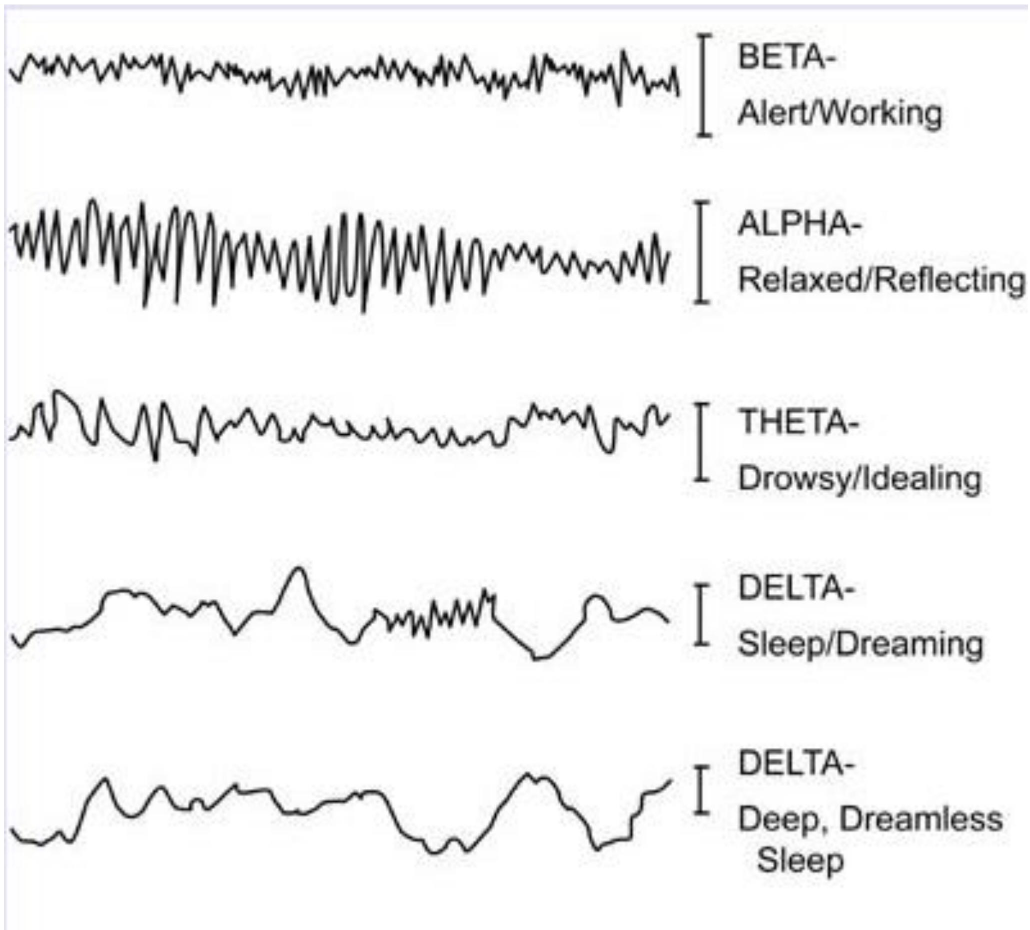
- Each frequency band has some correlation with different mental functions

- We need first to briefly discuss what frequency-domain representation means



EEG Frequency Bands

- EEG frequency bands and consciousness

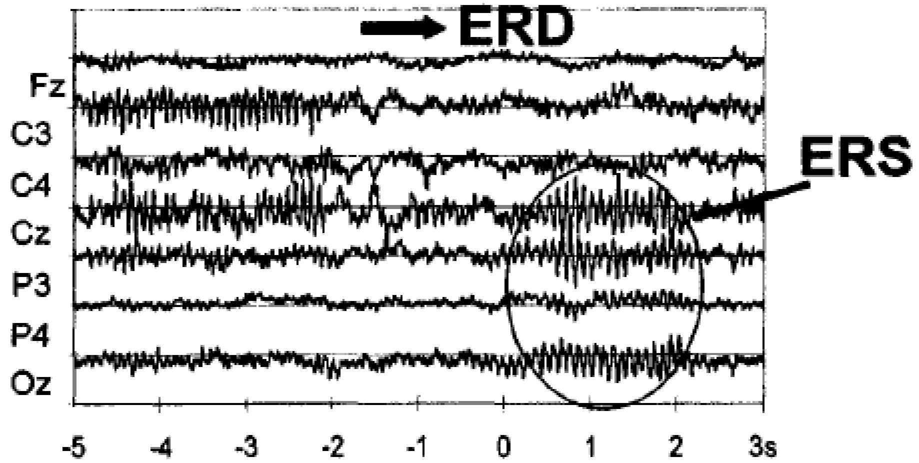


EEG Frequency-domain Features: ERD and ERS

- A particular component of EEG is characterized by the occurrence of an event-related desynchronization (ERD) and an event-related synchronization (ERS)

- A decrease in the synchronization of neurons causes a decrease of power in specific frequency bands and this phenomenon is defined as an ERD while the opposite is termed as ERS

- Example: ERD and ERS detected during movement planning and after movement onset (Time 0)

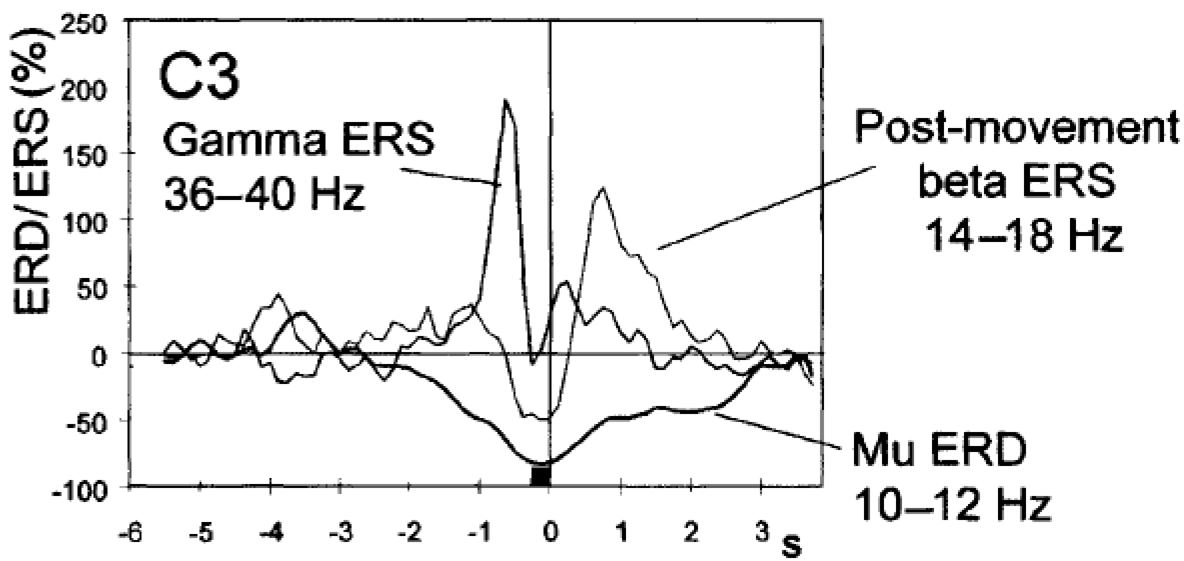


EEG Frequency-domain Features: ERD and ERS

- An ERD in the mu rhythm (10 - 12 Hz) starts prior to movement onset and peaks after onset of movement before recovering to baseline

- A short-lived ERD in the central beta rhythm occurs prior to movement onset and is immediately followed by an ERS that peaks after movement onset

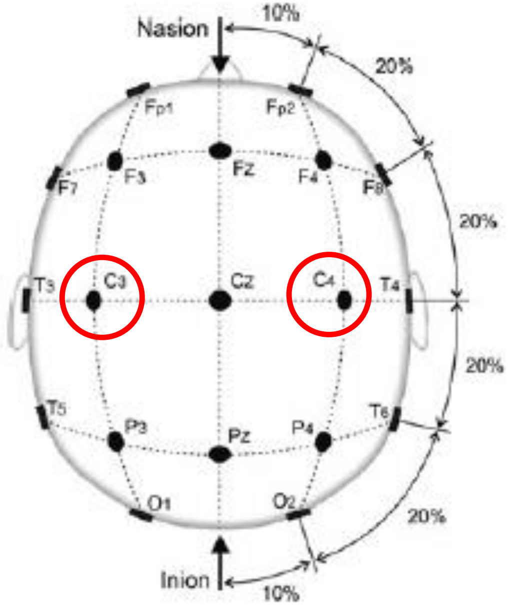
- Oscillations and ERS are also found around the 40-Hz gamma band



Motor Imagery Task

- Motor imagery refers to tasks in which the subject is instructed to imagine certain movements while recording his EEG

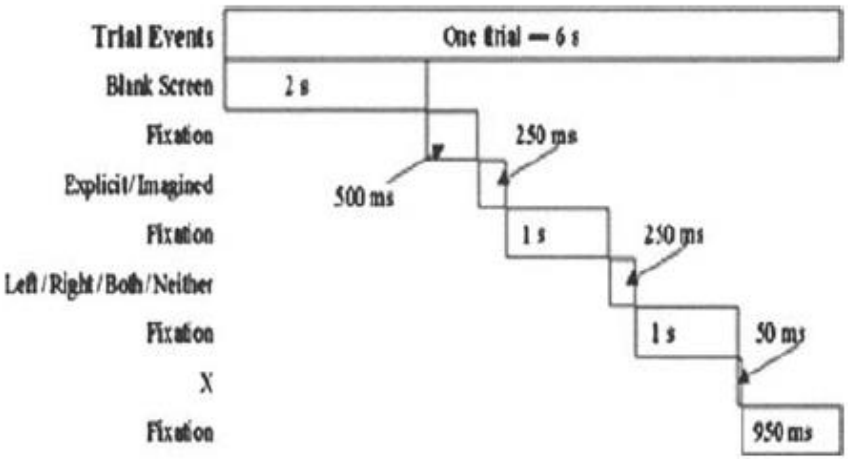
- Electrodes positioned at locations C3 and C4 are often used for such tasks as they record over the Motor Cortex



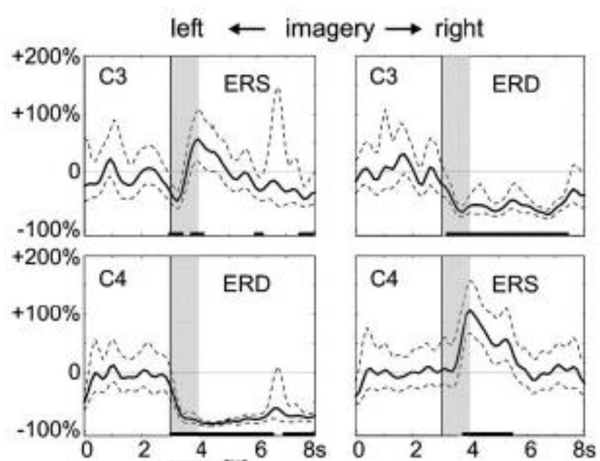
- C3 records EEG activity related to right side movements while C4 records EEG activity related to left side movements

Motor Imagery Task

- Example: During the training phase, the user is asked to imagine one of four things: moving his left hand, moving his right hand, moving both hands or nothing according to the sequence below

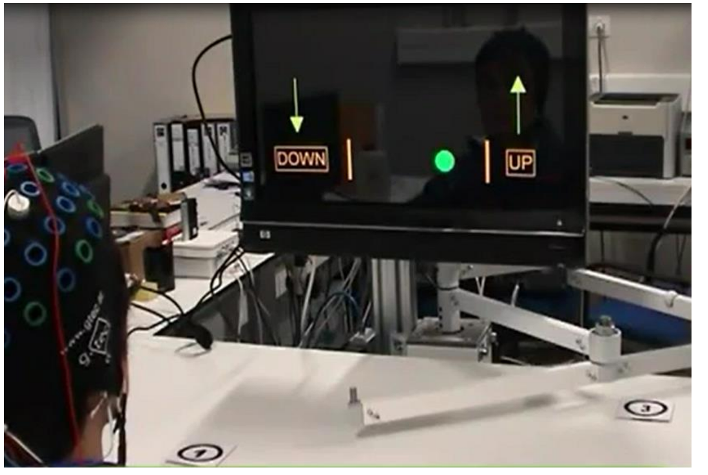


- ERD and ERS on C3 and C4 in band power 11-13 Hz



Motor Imagery Task Applications

- Moving a Robotic Arm



http://www.youtube.com/watch?v=JgNX3c6TEPs

- Controlling a wheelchair

http://www.youtube.com/watch?v=JyJj32MsAUo

Algorithm to Implement

1. Apply Common Average Reference (CAR) filter to the data
2. For each electrode do the following:

    2.1 Bandpass the signal once in the Mu band and another in the Beta band

    2.2 For each trial of each class of movement:

        2.5.1 Find the relative change in the Mu band comparing the trial (5 seconds) to the pre-onset signal (5 seconds)

        2.5.2 Find the relative change in the Beta band comparing the trial (5 seconds) to the pre-onset signal (5 seconds)

    2.3 Apply K-Nearest Neighbor (KNN) classifier examining K from 1 to 10 once for the Mu band data and once for the Beta band data

    2.4 Compute the 10-fold classification error for each value of K

3. Identify the electrode, band and value of K that achieve the least 10-fold classification error

Common Average Reference (CAR) Filter

- Eliminates the common noise across electrodes
- The mean of all channels at each time instant acts as a reference
- This reference is subtracted from each channel. It can be represented as follows

$$r_i(j) = s_i(j) - \frac{1}{N}\sum_{k=1}^{N} s_k(j)$$

where $s_i(j)$ represents the raw signal recorded on electrode i at time j, $r_i(j)$ represents the filtered signal and N is the total number of channels

K-nearest Neighbor (KNN) Classifier

- Most basic instance-based method

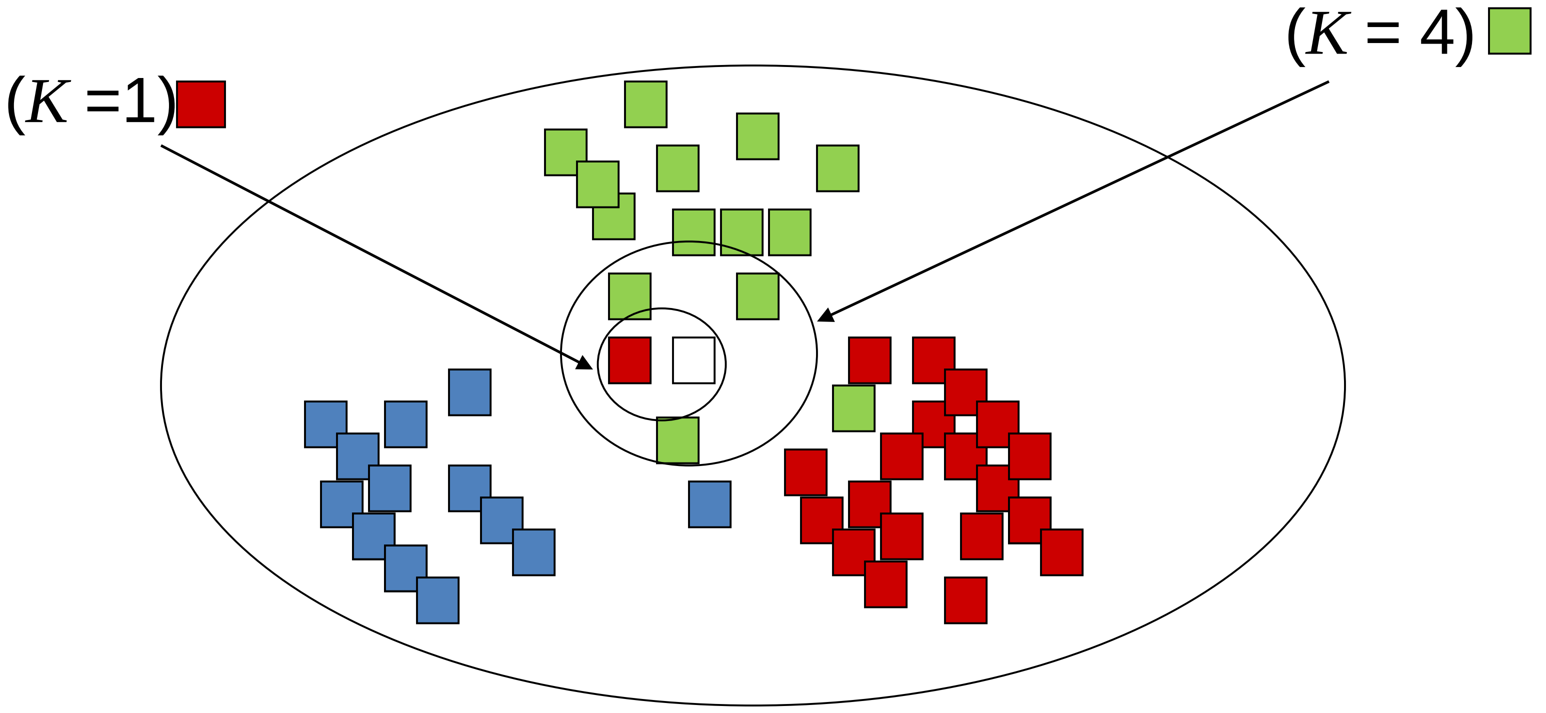
- Uses Euclidean distance to determine how dissimilar a pair of points are

$$d(\mathbf{x}_i, \mathbf{x}_j) = \sqrt{\sum_{r=1}^{n} (x_{ir} - x_{jr})^2}$$

- For any new input vector, the nearest K points are considered

- A majority voting scheme is used to classify the new input vector

K-nearest Neighbor (KNN) Classifier



How to Choose *K*?

Cross-validation:

- 80% of training data for training and 20% for validation
- Find target value of the 20% part using the 80% and compute the corresponding error

Training Data

80% **20%**

$K = 1 \rightarrow \text{Error} = E_1$

$K = 2 \rightarrow \text{Error} = E_2$

.
.
.

$K = M \rightarrow \text{Error} = E_M$

Training Data

20% **80%**

$K = 1 \rightarrow \text{Error} = E_1$

$K = 2 \rightarrow \text{Error} = E_2$

.
.
.

$K = M \rightarrow \text{Error} = E_M$

The partitioning and validation process is repeated a number of times (for example 10 times) with different partitioning

How to Choose *K*?

Cross-validation:

- Find $K = k^*$ that minimizes the average error for the validation data

$$k^* = \arg\min_{k} \overline{E_k} \qquad \text{, where} \qquad \overline{E_k} = \frac{1}{L}\sum_{l=1}^{L} E_l$$

k = 1, 2, …, M, where M is the maximum number of neighbors

L is the total number of partitionings examined

- The obtained K is then used to classify the test data