



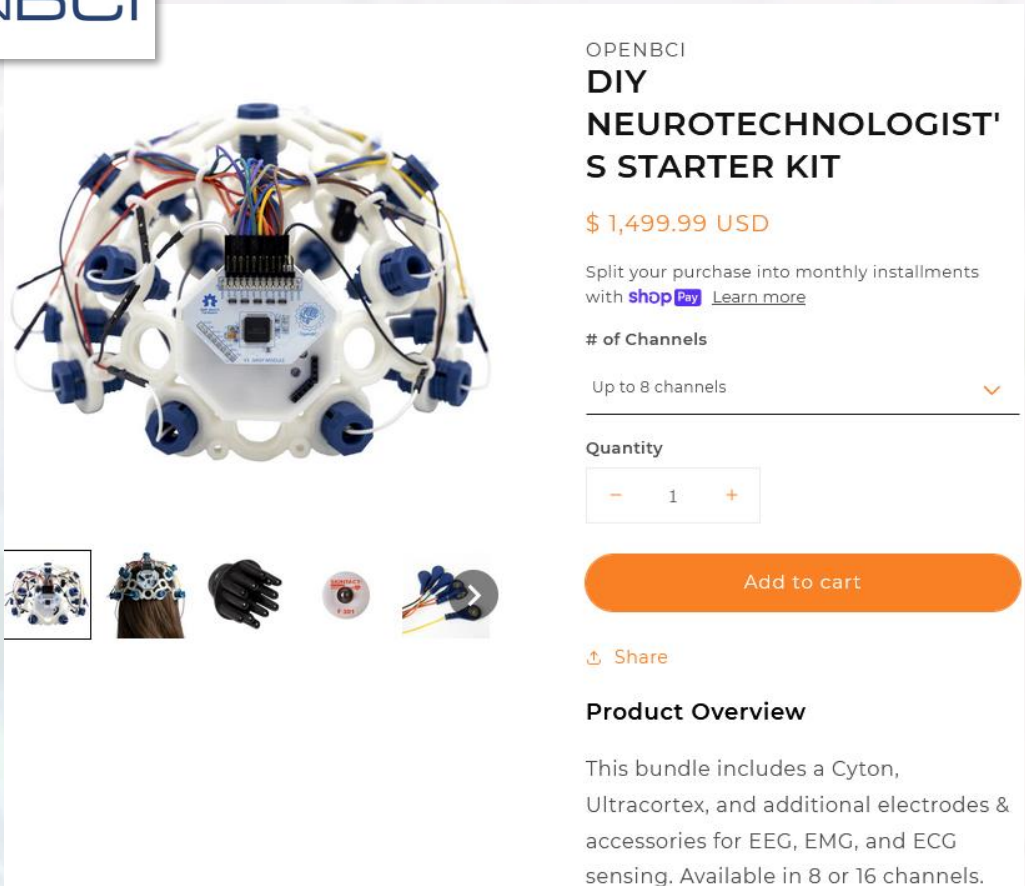
Institute of  
Language, Communication  
and the Brain

Summer school

# Motor imagery-based Brain Computer Interface: theory and practice with OpenVibe

—  
C. Zielinski

# Let's start with a little demo... EEG in real time



OPENBCI  
**DIY NEUROTECHNOLOGIST'S STARTER KIT**

\$ 1,499.99 USD

Split your purchase into monthly installments with [shop Pay](#) [Learn more](#)

# of Channels

Up to 8 channels

Quantity

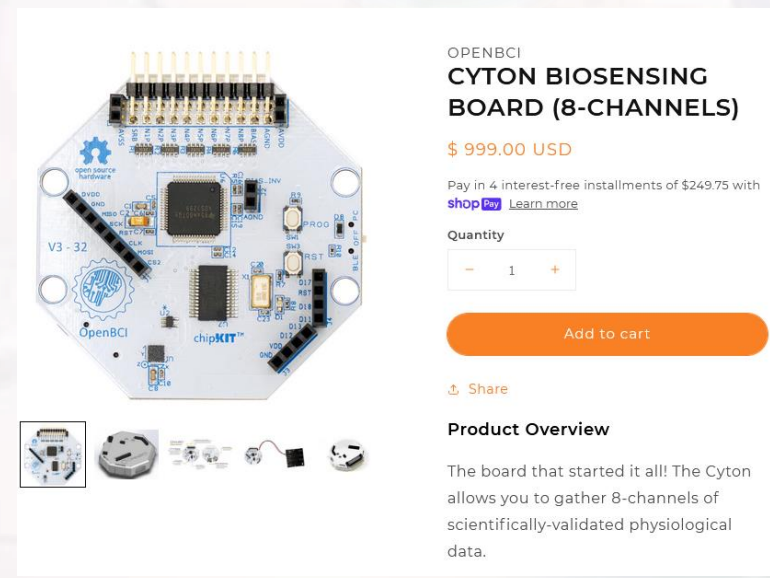
- 1 +

[Add to cart](#)

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**Product Overview**

This bundle includes a Cyton, Ultracortex, and additional electrodes & accessories for EEG, EMG, and ECG sensing. Available in 8 or 16 channels.



OPENBCI  
**CYTON BIOSENSING BOARD (8-CHANNELS)**

\$ 999.00 USD

Pay in 4 interest-free installments of \$249.75 with [shop Pay](#) [Learn more](#)

Quantity

- 1 +

[Add to cart](#)

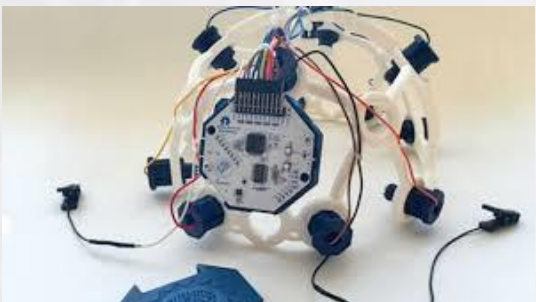
[Share](#)

**Product Overview**

The board that started it all! The Cyton allows you to gather 8-channels of scientifically-validated physiological data.

Cyton board  
8-channels  
Dry electrodes  
250 Hz  
Ultracortex Markup IV

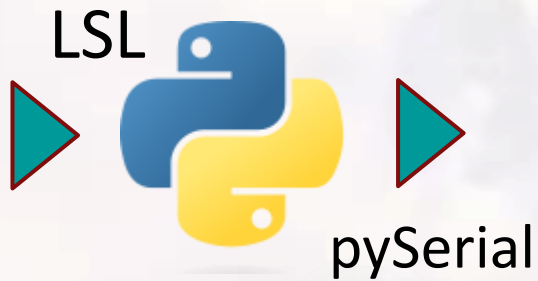
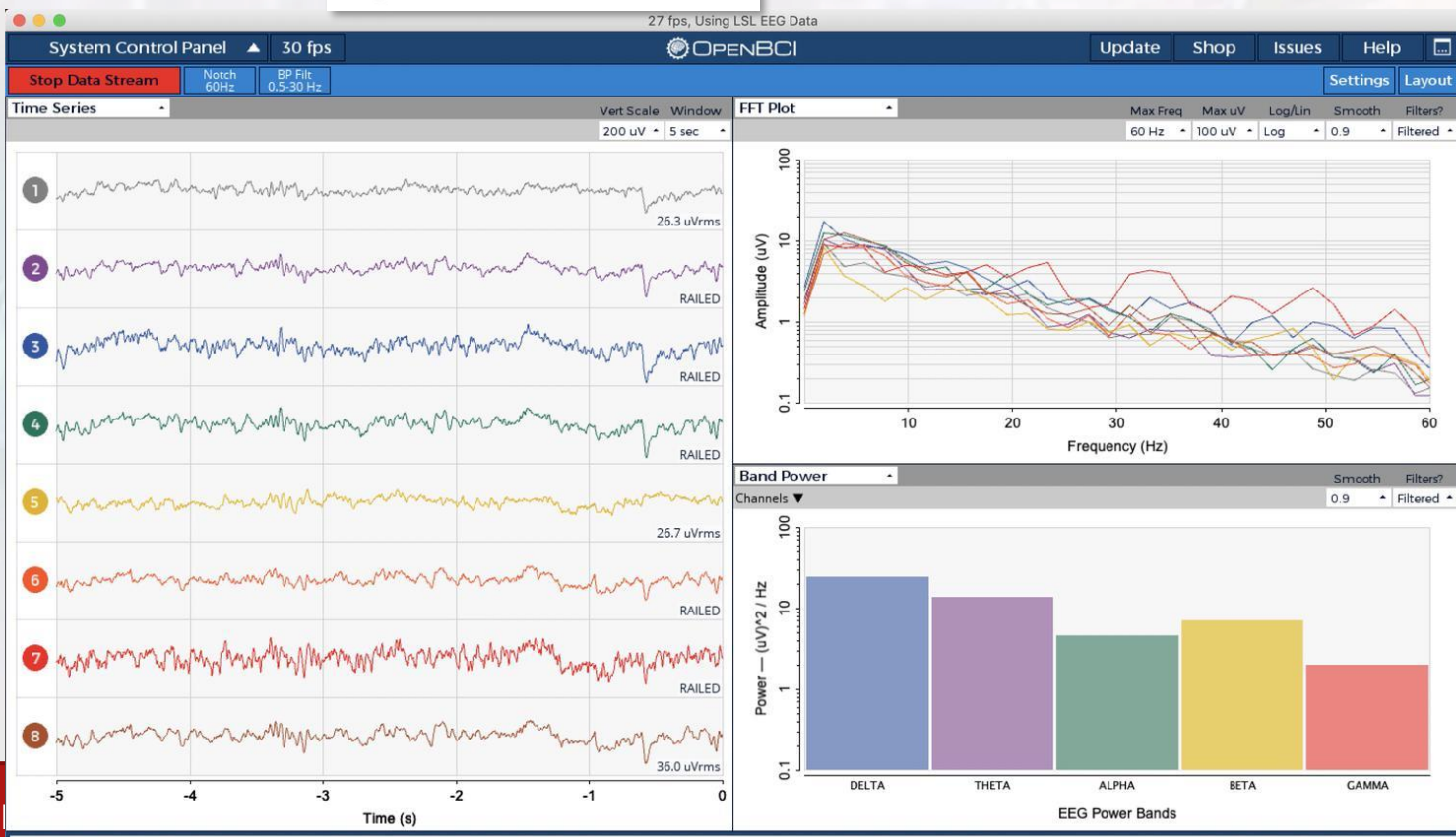
# OpenBCI



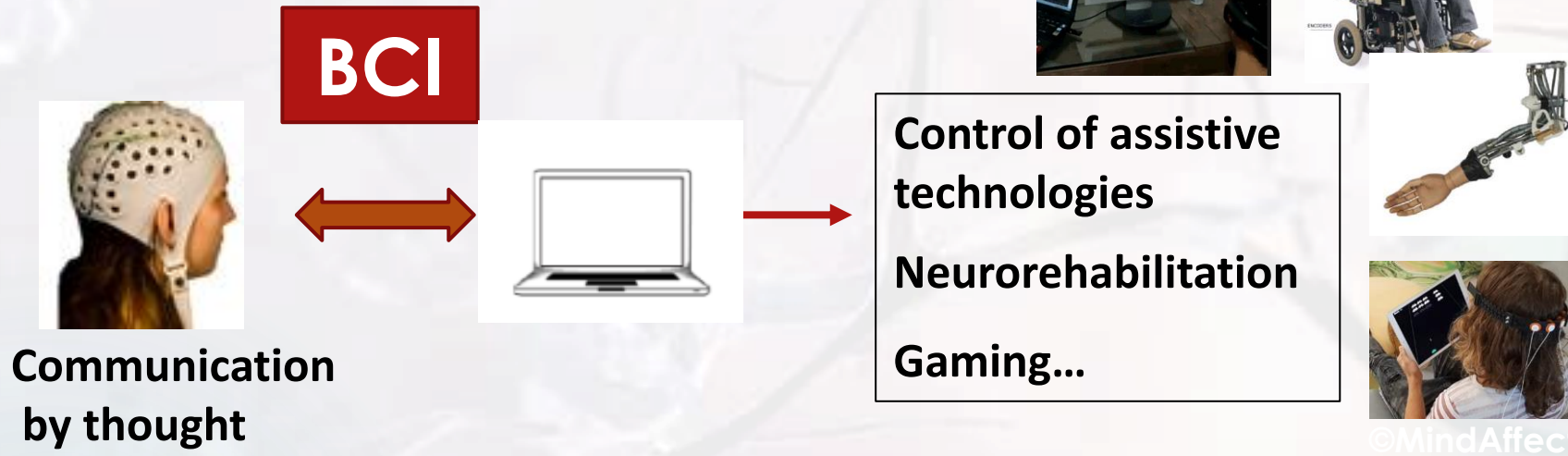
- Time series widget
- Frequency spectra
- Band power
- Networking: protocols to output data (Serial, LSL, OSC)



... Create your own widget with Processing



# Brain Computer Interface



Succeed in having a **common language** between the brain (seen through the EEG) and the computer

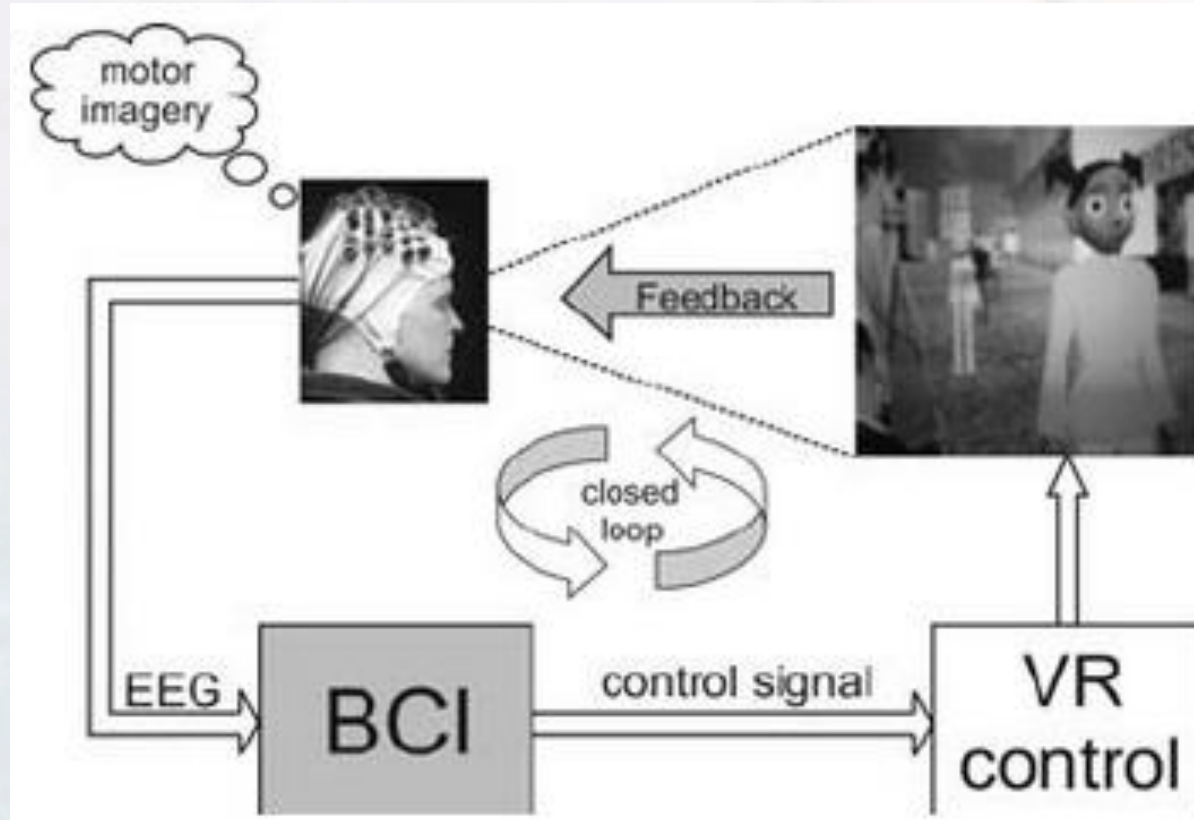
**Co-adaptation:** Human learning / BCI processing adjustment

Various technics based on different forms of electrical activities, **spontaneous** (wave rhythms linked to mental imagery) or **evoked** (by visual or acoustic stimuli) (ERP, P300)

# Active BCI: Mental imagery

- ▶ Mental tasks: motor-imagery of the limb, mental calculation or navigation
- ▶ **Active BCI** that employs the user's **endogenous** brain activity in the absence of any external stimulus (*Pfurtscheller & Da Silva, 1999*)
- ▶ Initially: communication for paralyzed people (yes/no)
- ▶ Today: **neurorehabilitation** of stroke patients – MI neurofeedback effective in reestablishing motor movements immediately after a stroke (*Mattia 2016, Pichiorri 2015*)

# Active BCI: Mental imagery



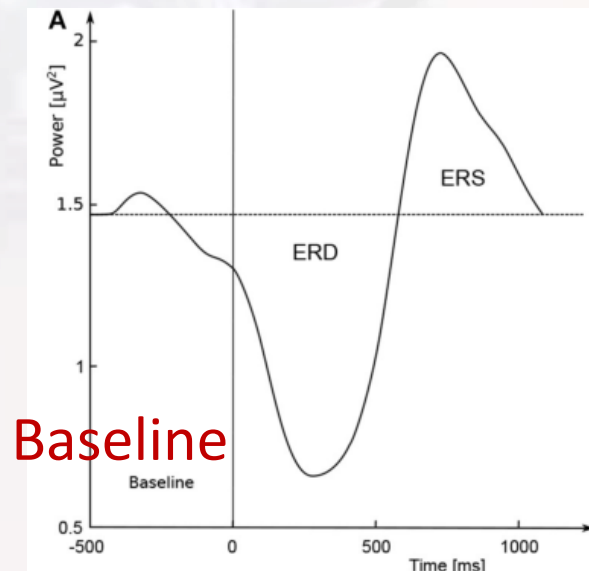
*(Pfurtscheller et al 2011)*

# Active BCI: Mental imagery

► Mental task will induce in specific cortical regions and in specific frequency bands:

1°) **Event-Related Desynchronisation** (ERD – while being performed)

2°) **Event-Related Synchronisation** (ERS – once the user has stopped)

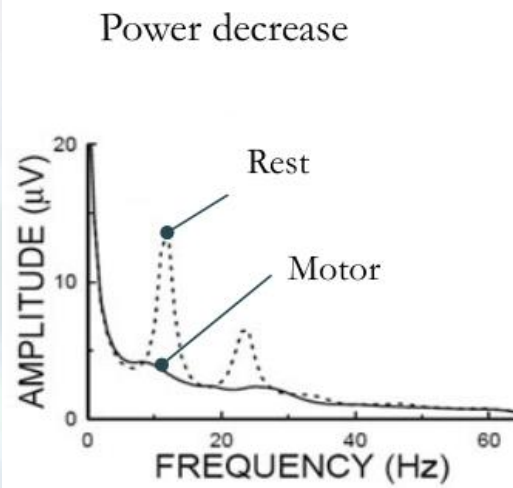


$t=0$  s start of the imagery movement  
(adapted from Lemm et al., 2009)

# Event-Related Desync/Synchronization

► Decrease or increase in synchrony of the underlying neuronal populations reflecting cortical activation and deactivation

(Pfurtscheller & Da Silva, 1999)



Desynchronization effect  
(Pfurtscheller et al, 1999)

Rest vs Motor



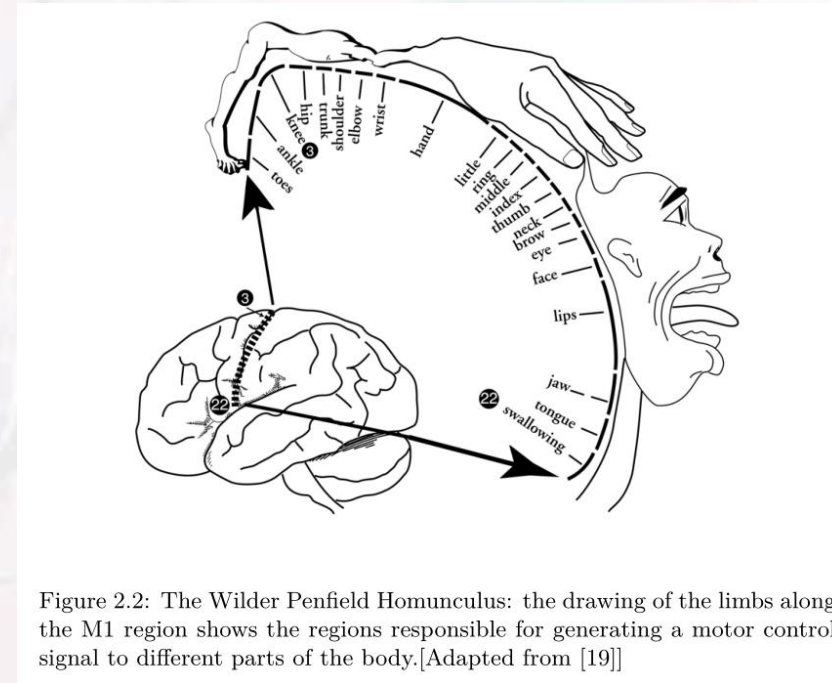
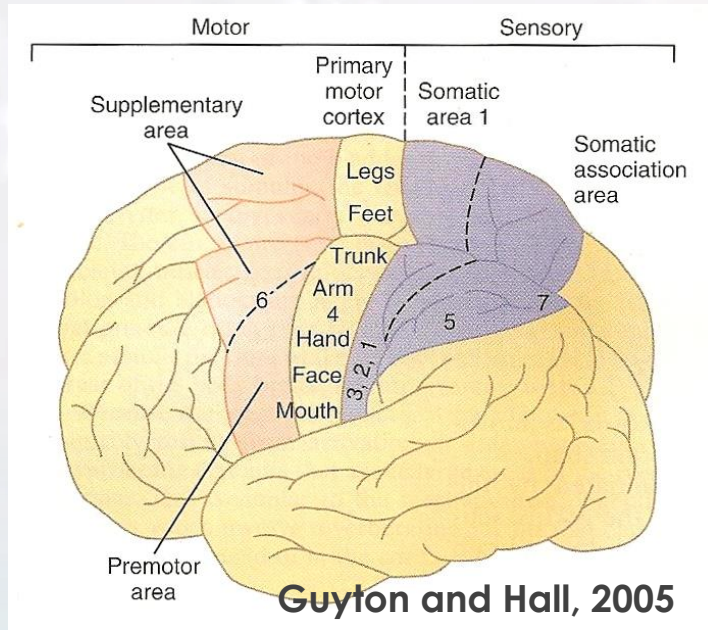
Clinical Neurophysiology  
Volume 110, Issue 11, 1 November 1999, Pages 1842-1857

Invited review  
**Event-related EEG/MEG synchronization and desynchronization: basic principles**  
G. Pfurtscheller<sup>a</sup> ✉, F.H. Lopes da Silva<sup>b</sup>

Neuronal networks become asynchronous during mental activity;  
**ERD** – correlated with mental **activity**;  
**ERS** – correlated with mental **inactivity**



# Motor-imagery



- ▶ The Primary Motor Cortex (PMC) is responsible for planning and executing movements
- ▶ Correspondence between the PMC areas and the various muscle groups

# Motor-imagery

- ▶ Movements tasks induce changes to brain activity (ERS/ERD)

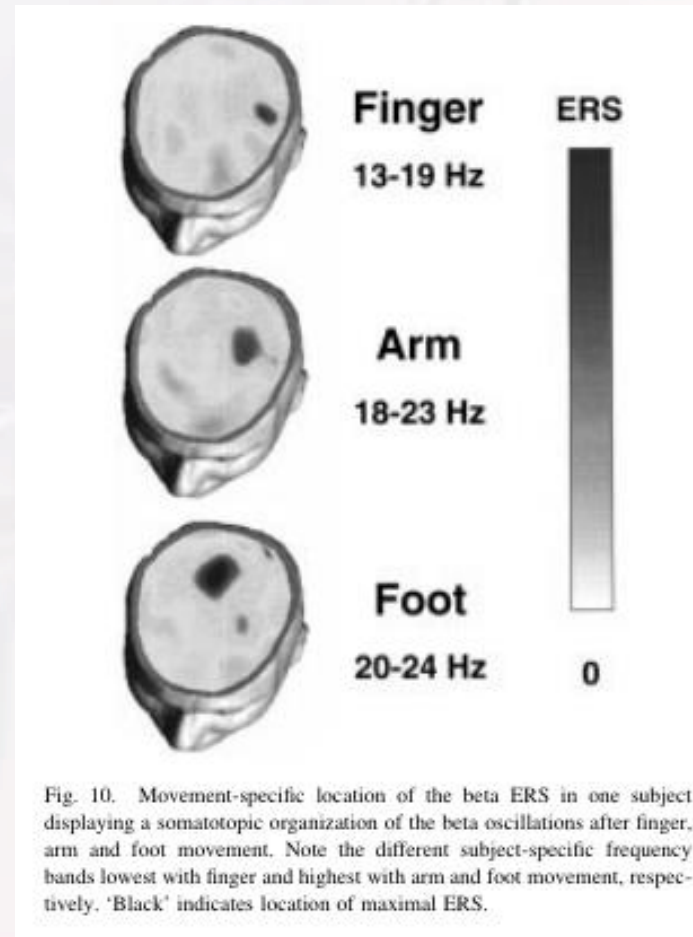
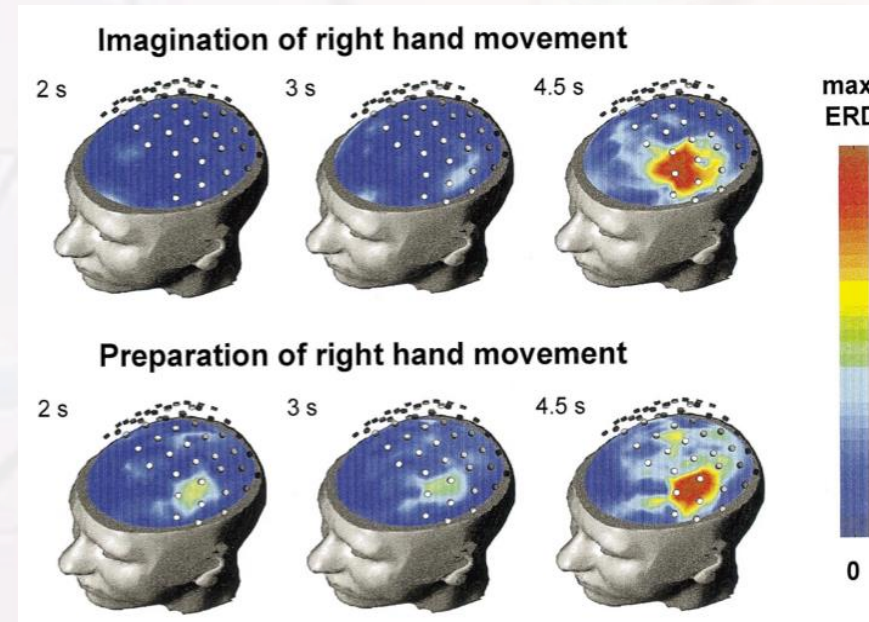
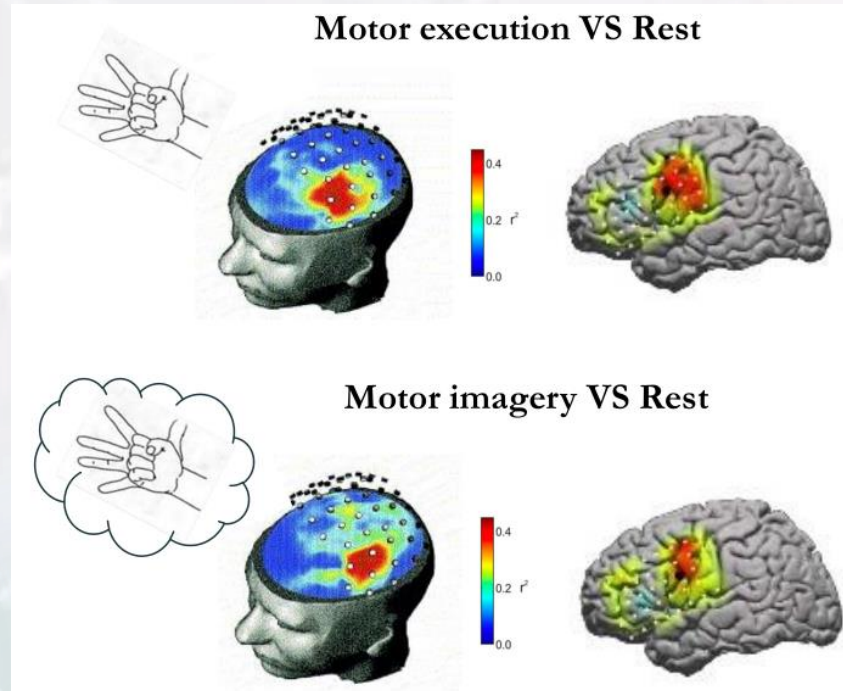


Fig. 10. Movement-specific location of the beta ERS in one subject displaying a somatotopic organization of the beta oscillations after finger, arm and foot movement. Note the different subject-specific frequency bands lowest with finger and highest with arm and foot movement, respectively. 'Black' indicates location of maximal ERS.

*Pfurstcheller & Da Silva, 1999*

# Motor-imagery



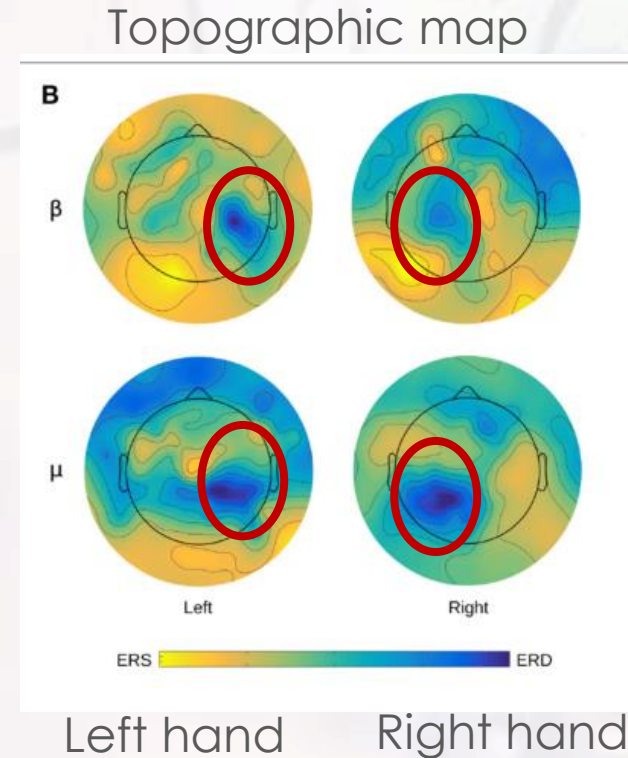
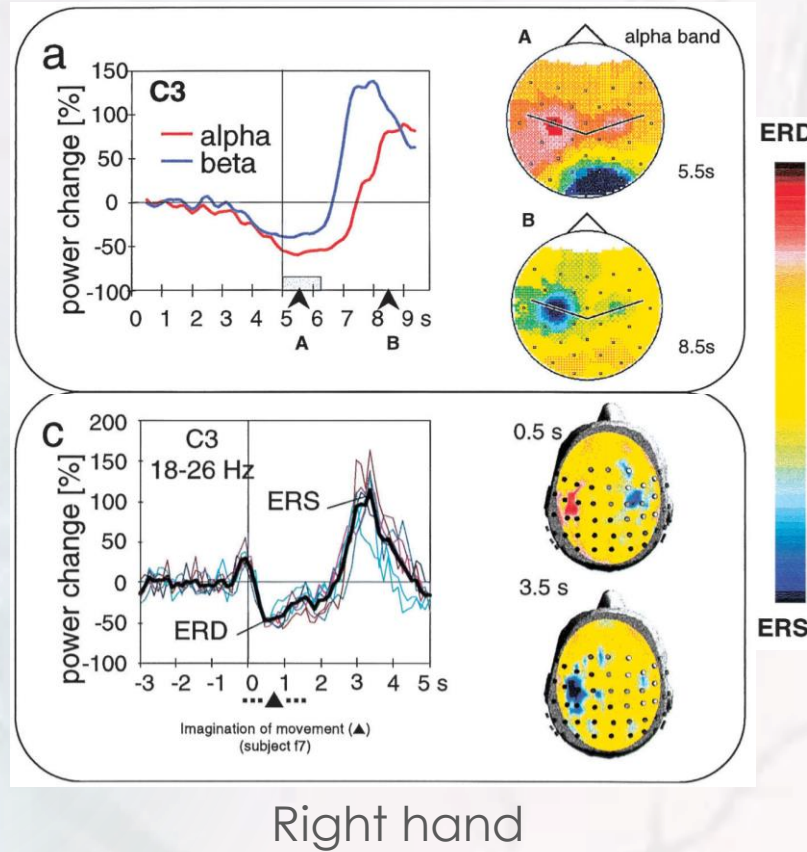
► Synchro and Desynchronisation of brain waves at motor cortex areas, whether by preparing the movement of the body or by imagining it

# Motor-imagery

- ▶ Movements tasks induce changes to brain activity visible in the EEG

$\alpha/\mu$   
8-12 Hz

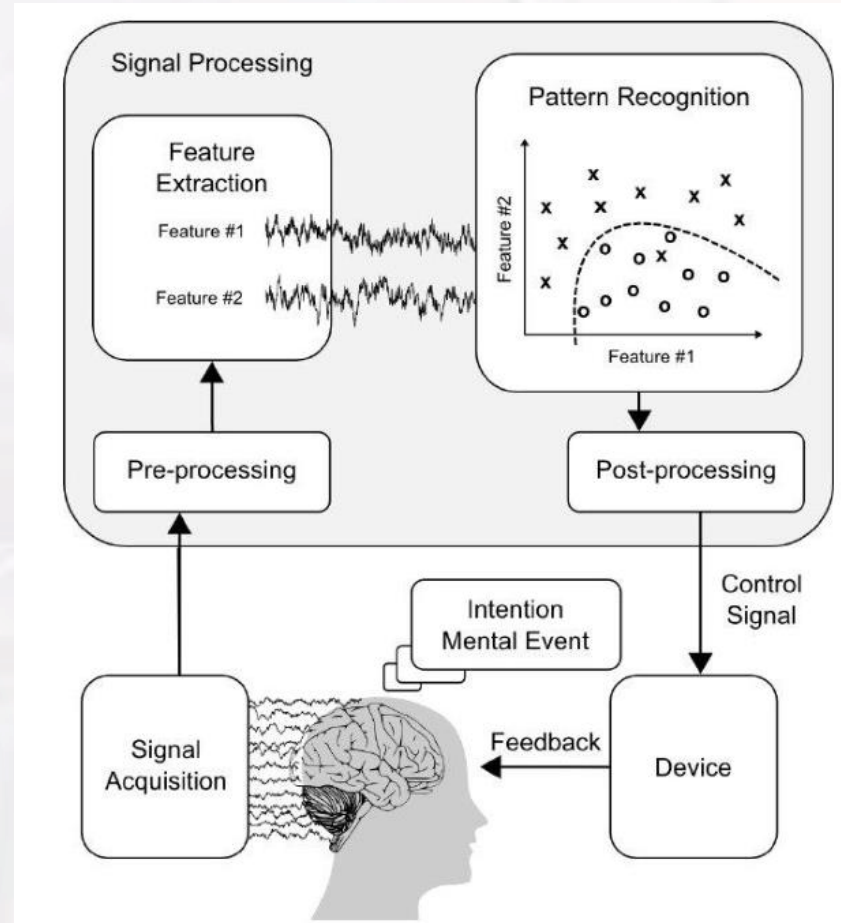
$\beta$   
18-26 Hz



- ▶ Features to be captured in BCI

*Pfurstcheller & Da Silva, 1999*

# Motor imagery



Hoffmann et al., 2006 : “A good feature extraction method should reduce the dimension of the input data as much as possible while keeping all the information necessary for classification.”

# Motor imagery: Graz protocol

## I- training the system

Series of MI-task (ex. Left/Right)  
[feature extraction to train a classifier]



## II- training the user

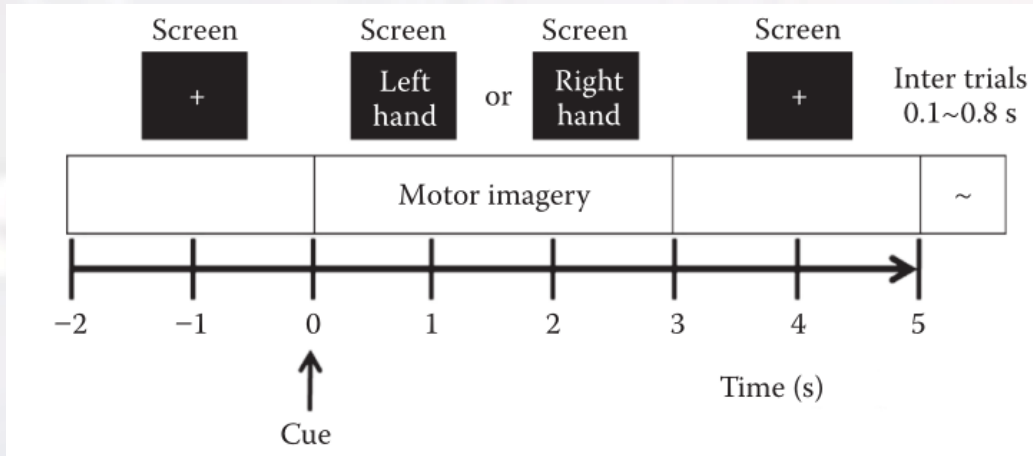
MI-task with feedback.

User goal: to develop effective strategies to increase system performance

*Pfurtscheller & Neuper, "Motor Imagery and Direct Brain-Computer Communication", 2001*

# Graz protocol

Offline

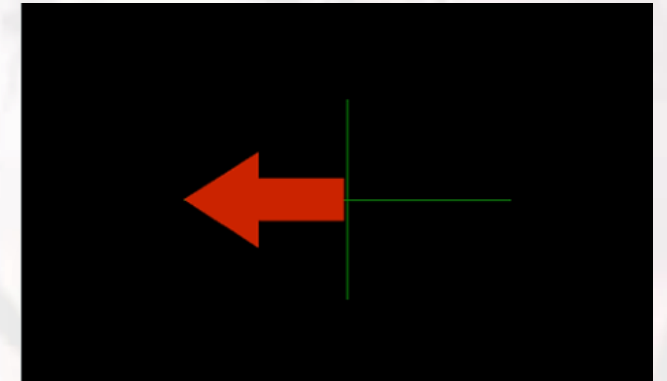


Multiple sessions, each of which multiple sequences (4-6 runs - fatigue > 6)

One run:

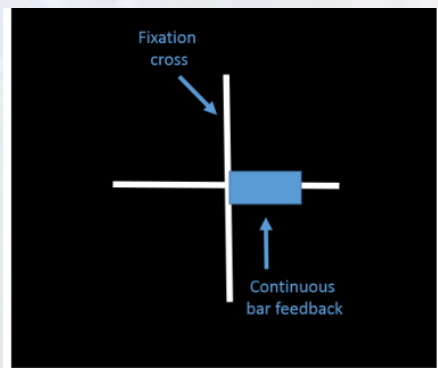
10-20 trials per class (Left/Right)

~ 7 min



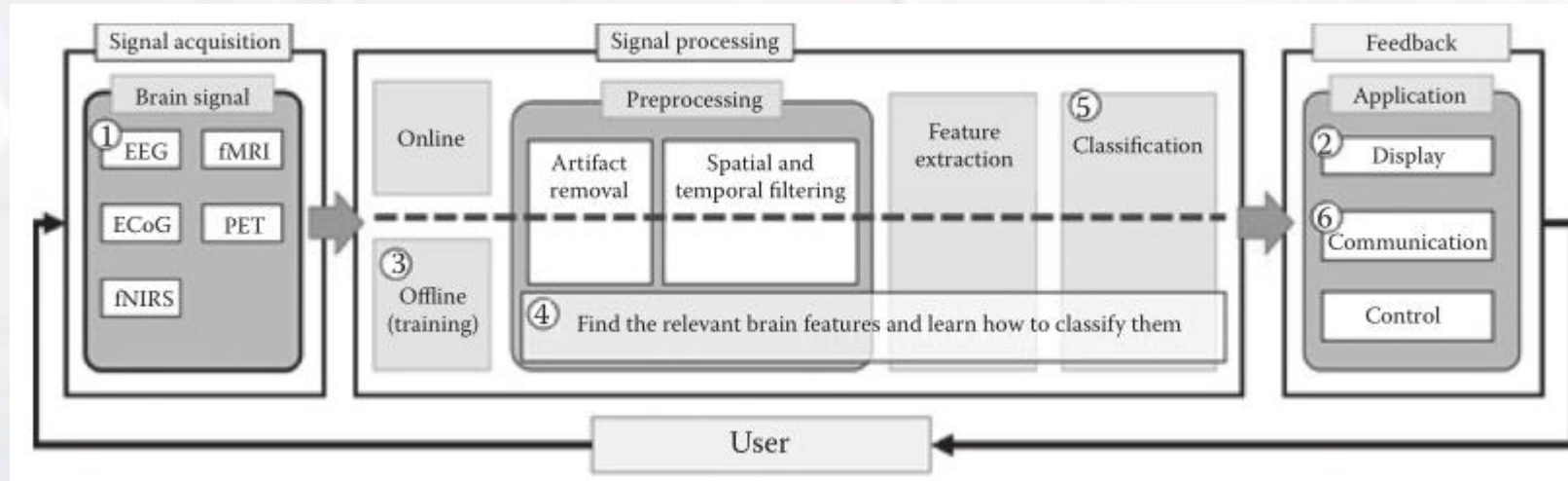
Indication of which MI task is to perform

Online



Feedback

# Motor imagery



- (1) an offline calibration stage, during which the system's settings are determined
- (2) an online operational stage, during which the system recognizes the user's brain activity patterns and translates them into application commands

*BCI research community is currently searching for solutions to help avoid the costly offline calibration stage*



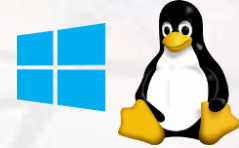
# OpenVibe



[openvibe.inria.fr](http://openvibe.inria.fr)

An open-source software platform

- Design, test and use BCIs
- Real-time EEG acquisition, processing and visualization
- Offline or batch analysis of large datasets

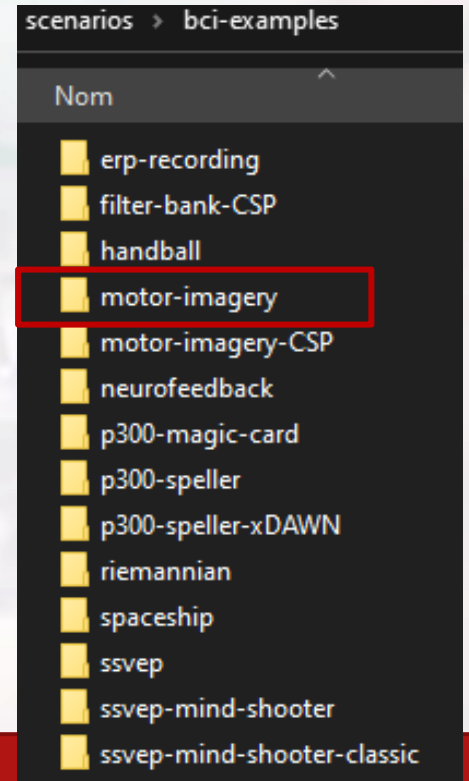


Wide EEG device compatibility (EGI, Brainamp, Biosemi,... C++ driver)

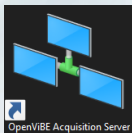
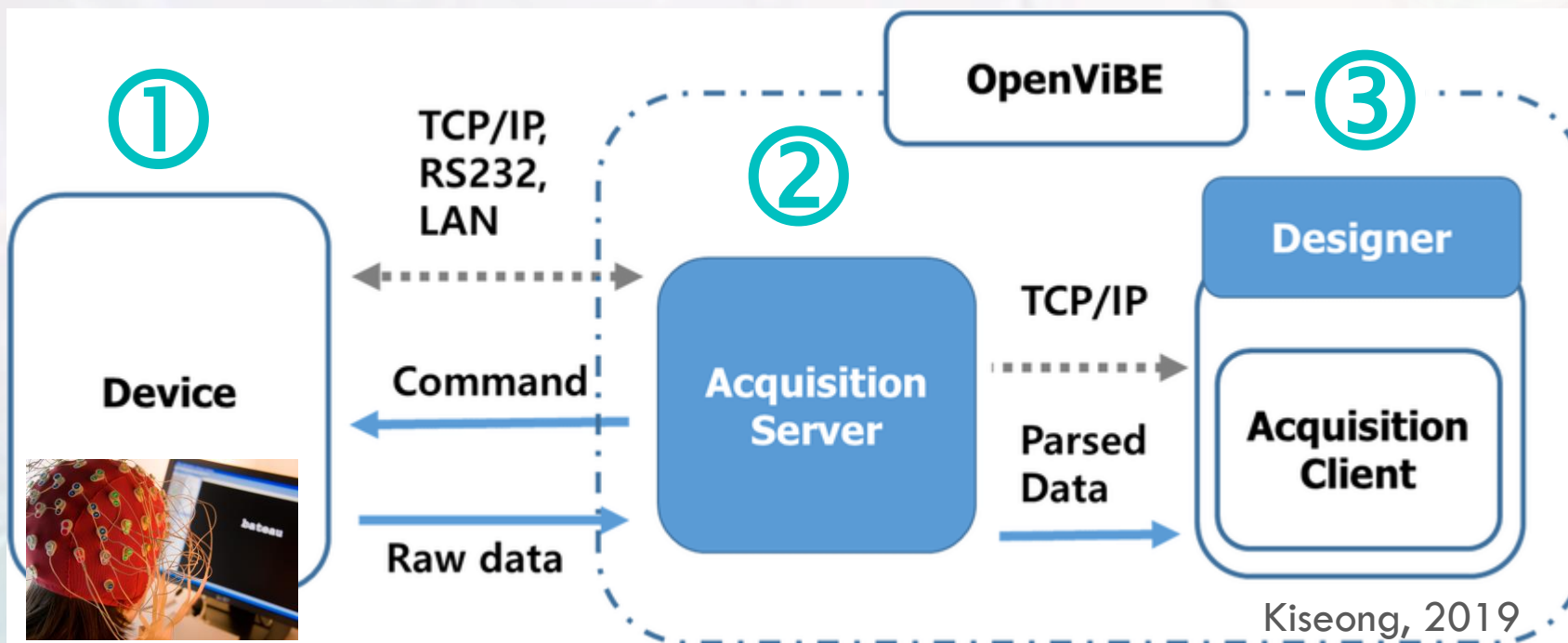
Compatibility with  & 

BCI paradigm demos available + tutorials

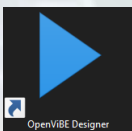
Visual programming (GUI boxes) + own plugin development in C++



# OpenVibe working flow

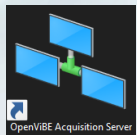
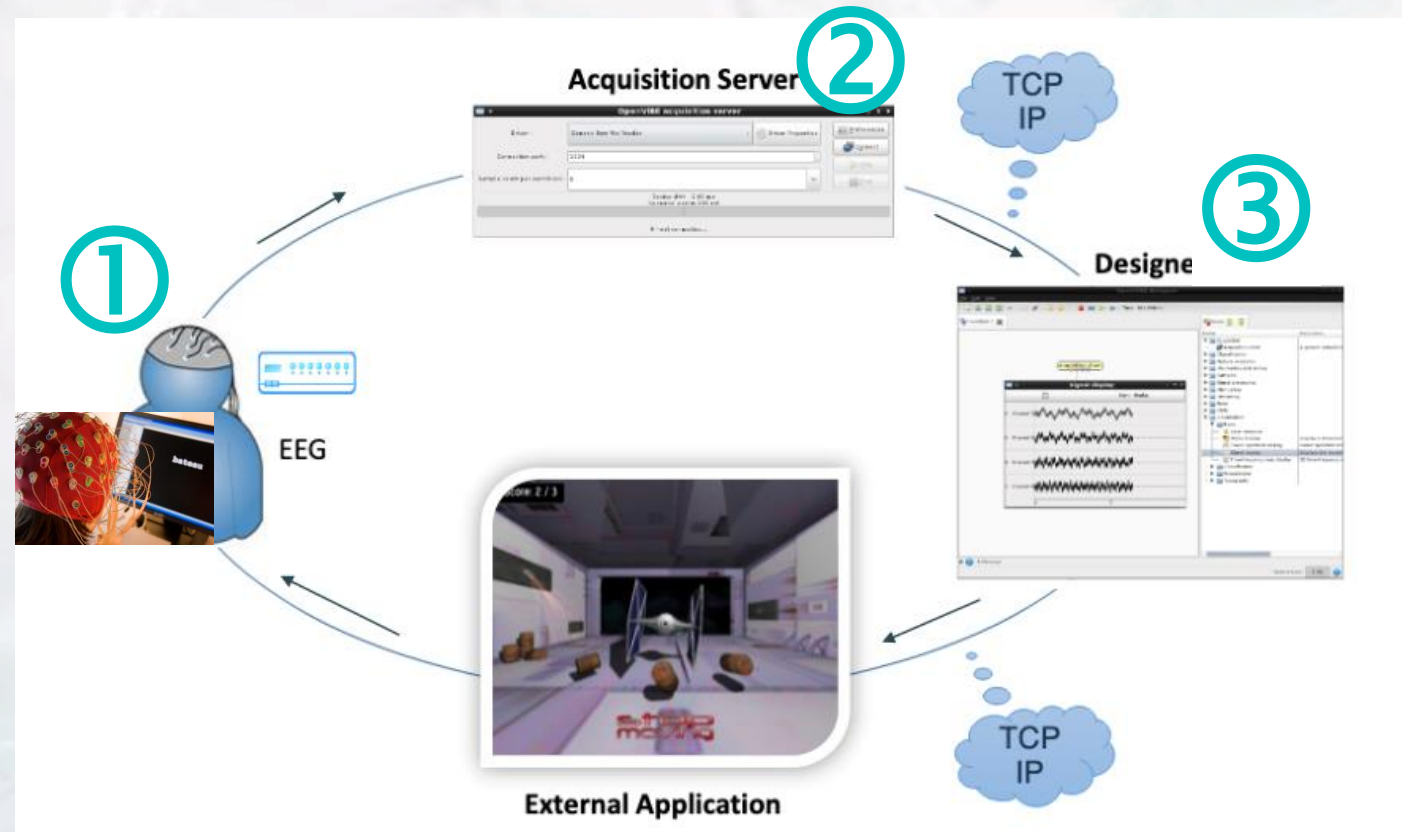


**Acquisition server:** Configuration to receive raw data depending on the device system

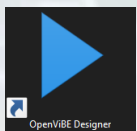


**Designer:** Define and Launch stimulation, online and offline data processing

# OpenVibe working flow



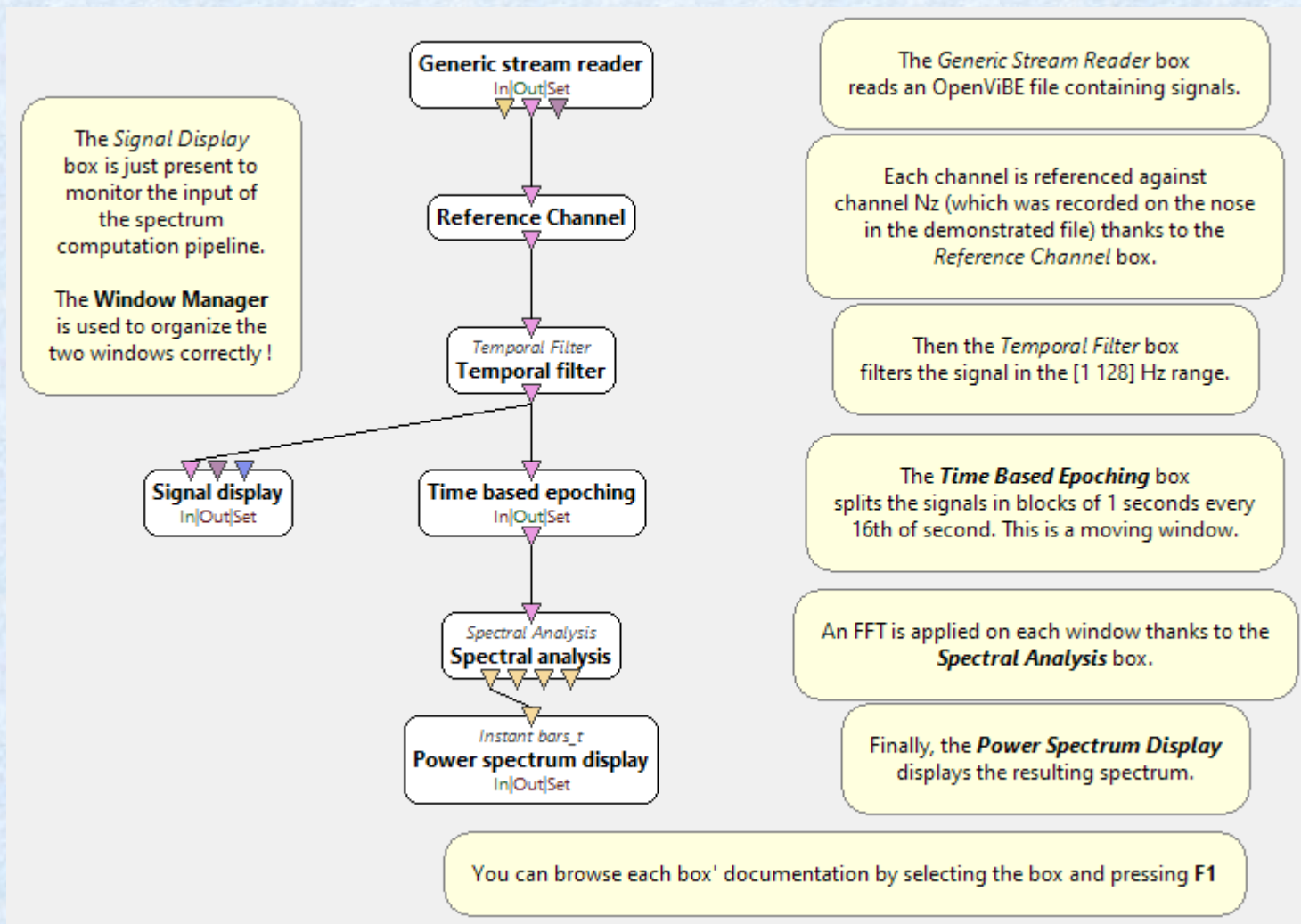
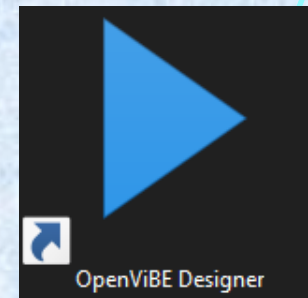
**Acquisition server:** Configuration to receive raw data depending on the device system



**Designer:** Define and Launch stimulation, online and offline data processing

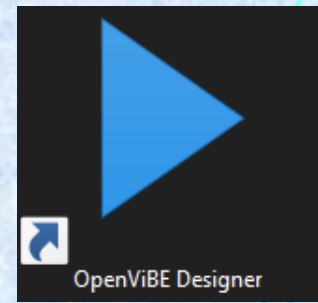
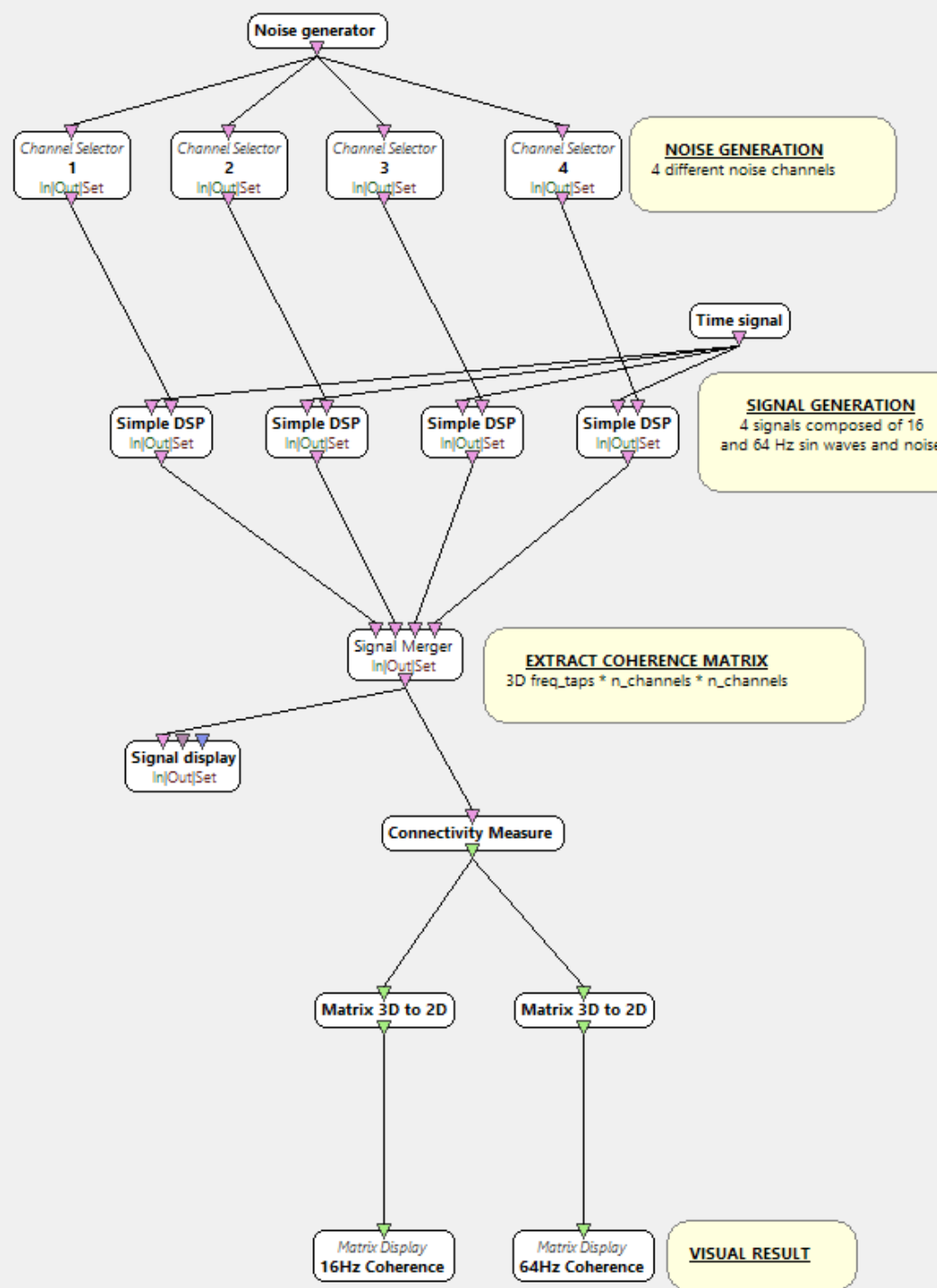
# OPENVIBE – BOX TUTORIALS

power-spectrum.xml



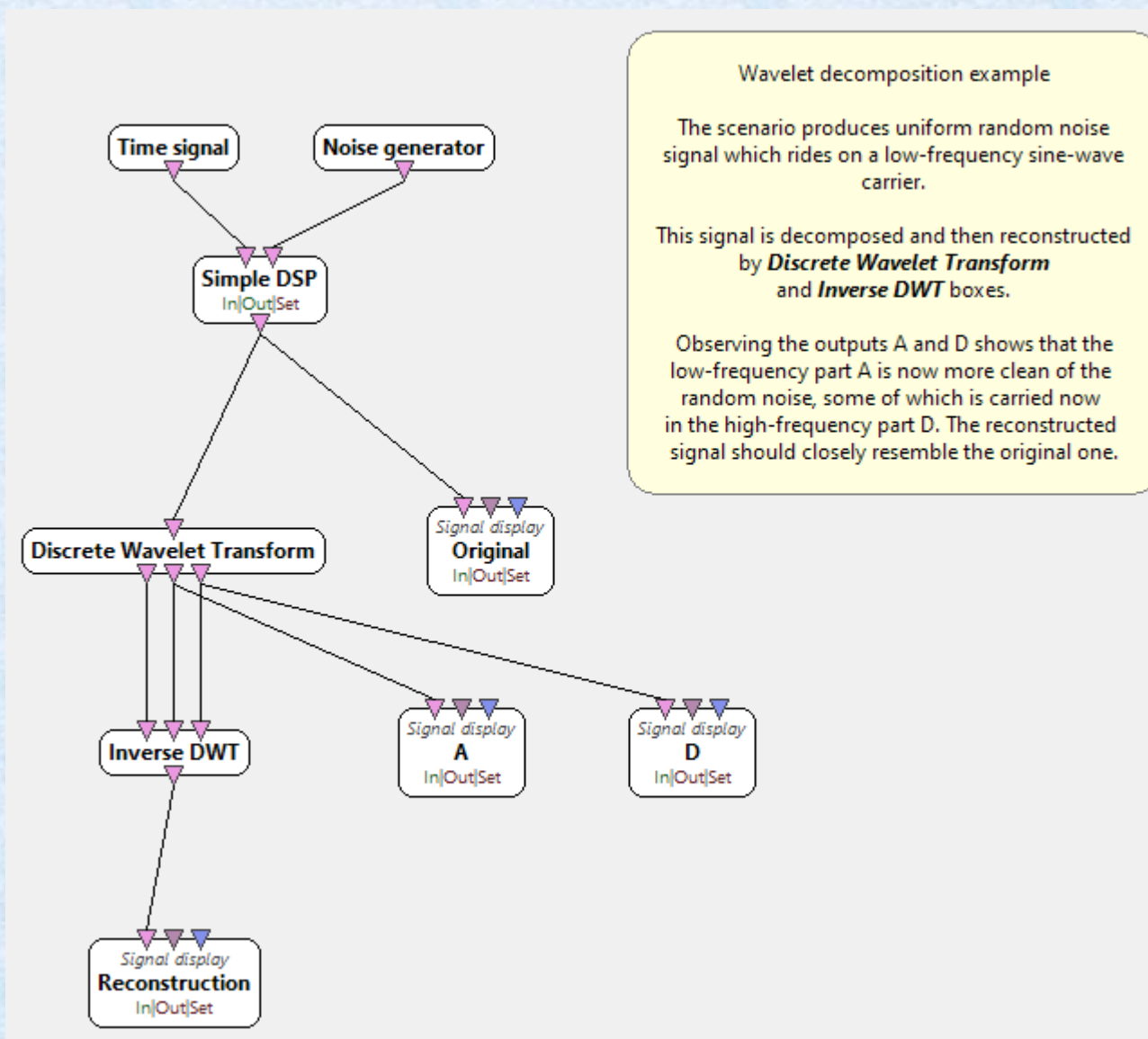
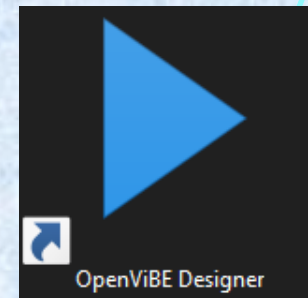
# OPENVIBE – BOX

connectivity\_measure.xml



# OPENVIBE – BOX TUTORIALS

wavelet-decomposition.xml



## Wavelet decomposition example

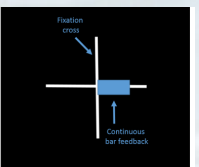
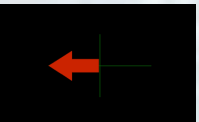
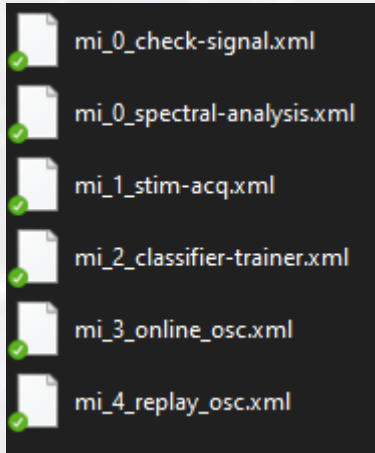
The scenario produces uniform random noise signal which rides on a low-frequency sine-wave carrier.

This signal is decomposed and then reconstructed by **Discrete Wavelet Transform** and **Inverse DWT** boxes.

Observing the outputs A and D shows that the low-frequency part A is now more clean of the random noise, some of which is carried now in the high-frequency part D. The reconstructed signal should closely resemble the original one.

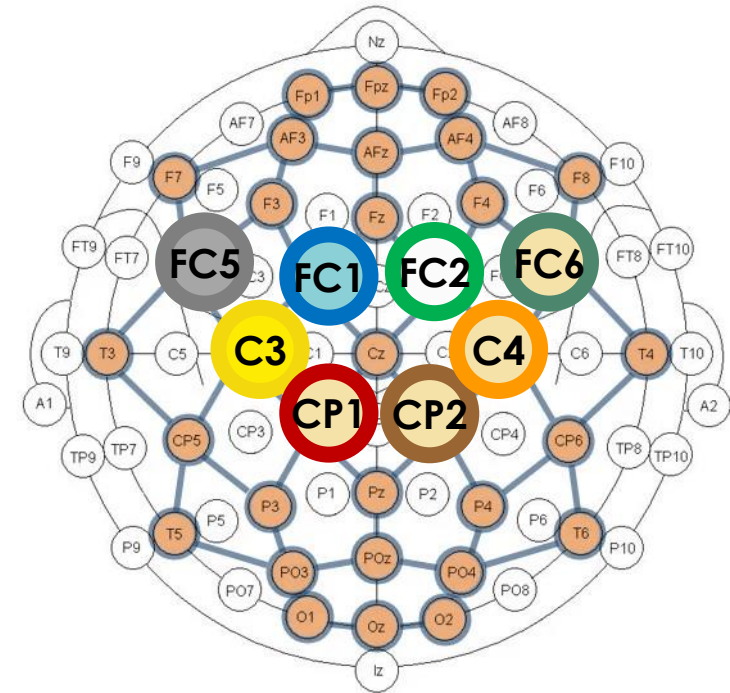
Artifact removal, PCA, Machine learning...

# Openvibe: Graz protocol + OpenBCI



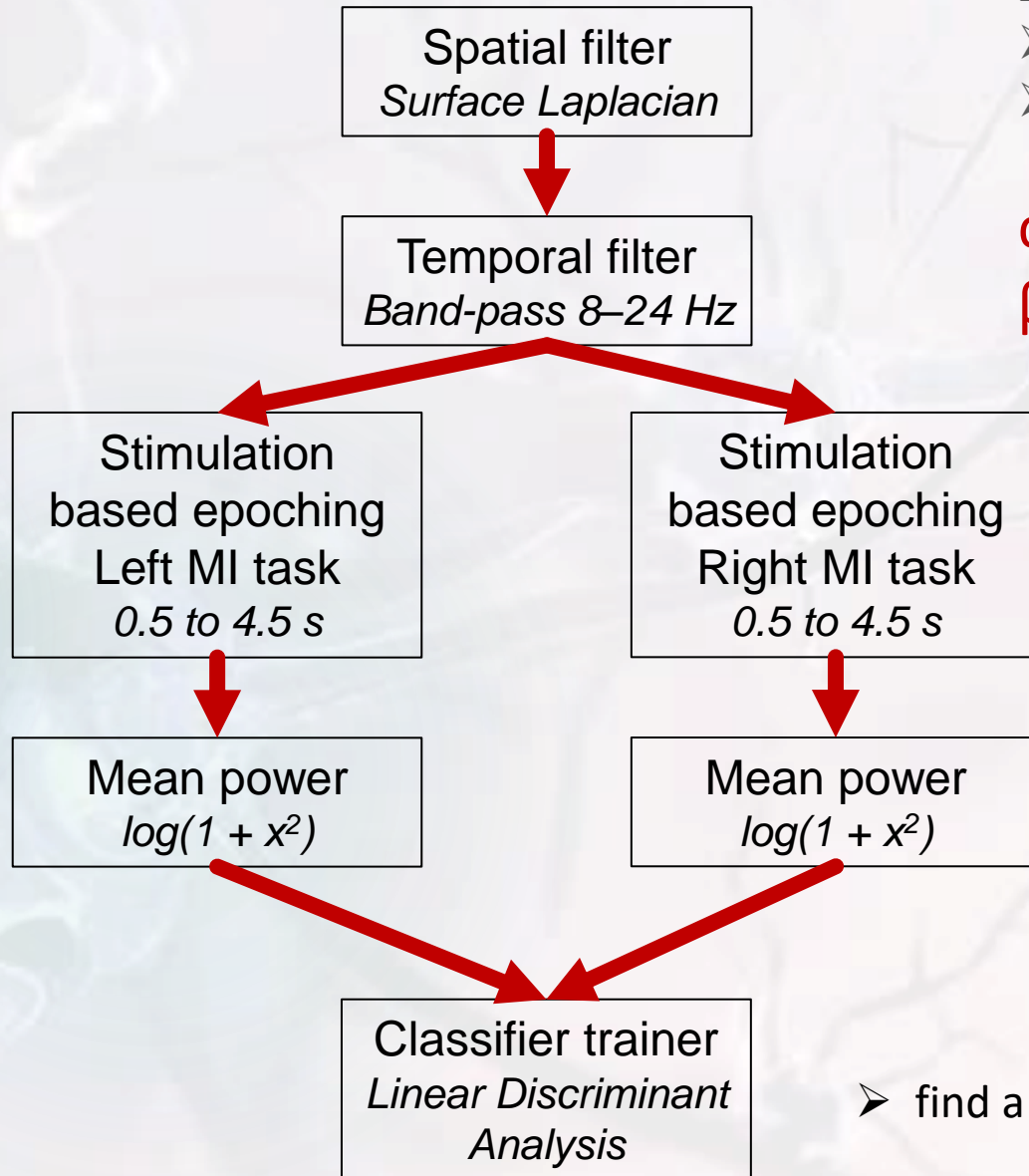
- mi\_1\_stim-acq: stimulation (L/R) while recording the training data set
  - mi\_2\_classifier-trainer: classifier parameters estimate
  - mi\_3\_online\_osc: classification in real time with feedback
- + send command by OSC to a [web app](#)

## Ultracortex Mark IV Node Locations (35 total)



Based on the internationally accepted **10-20 System** for electrode placement in the context of EEG research

# Motor imagery: data processing pipeline

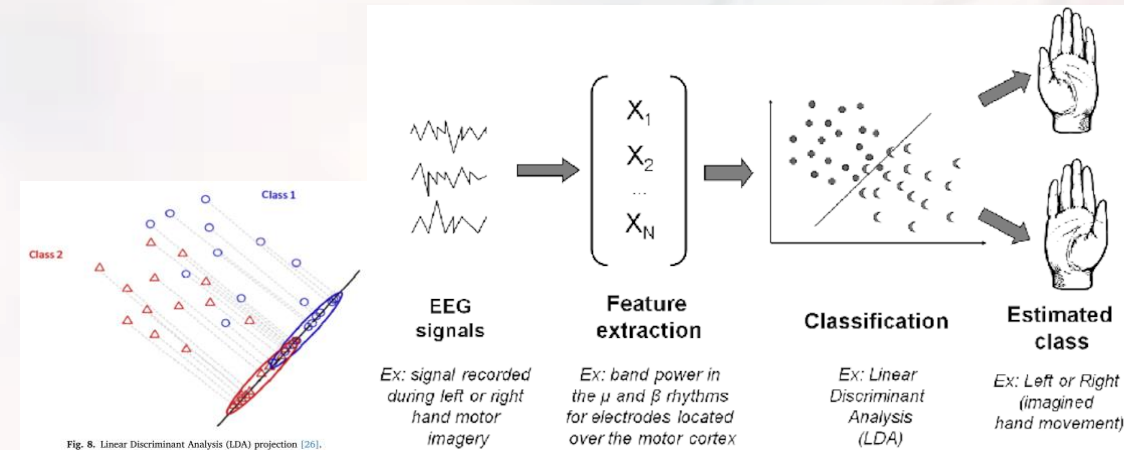


2 output channels:

- **Left side:** 3\*C3 – (FC5 + FC1 + CP1)
- **Right side:** 3\*C4 – (FC6 + FC2 + CP2)

$\alpha/\mu$ : 8-12 Hz

$\beta$ : 18-26 Hz

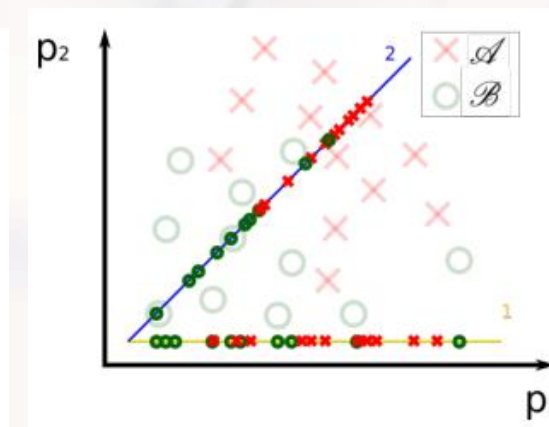
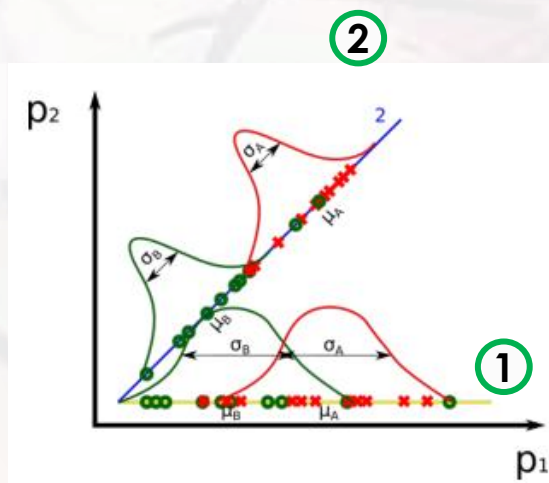
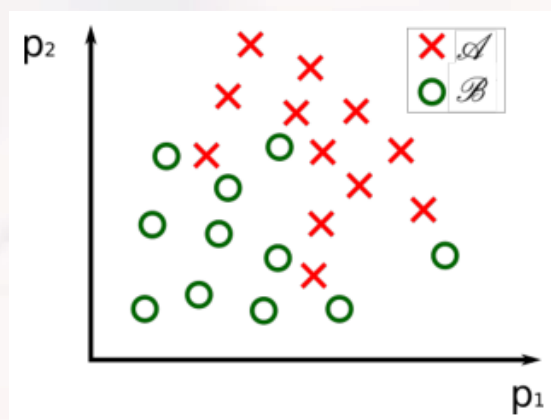
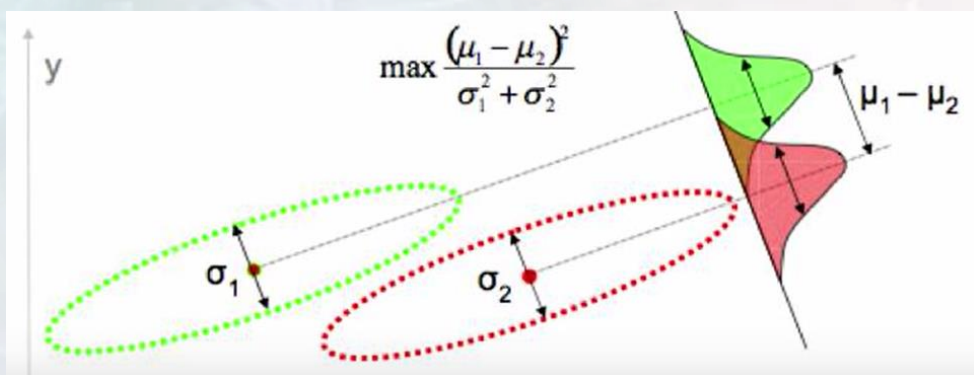


- find a linear discrimination of the two features



# Linear discriminant Analysis

- Find the projector line that gives:
  - maximum separation between means of projected classes
  - minimum variance within each projected class
- Solution: eigenvectors based on between-class and within-class covariance matrices



Example - Projector 2: best discriminant

# Openvibe: Graz protocol + OpenBCI

- Multiple sessions with Franziska
- Low classification accuracy by imagining the movement (60% with the Left class being better discriminated)

```
Cross-validation test accuracy is 55.836040% (sigma = 5.424622%)
Cls vs cls      1      2
Target 1:      58.5  41.5 %, 1020 examples
Target 2:      46.9  53.1 %, 1020 examples
Training set accuracy is 60.441176% (optimistic)
Cls vs cls      1      2
Target 1:      63.4  36.6 %, 1020 examples
Target 2:      42.5  57.5 %, 1020 examples
```

- By actually doing the movement: good accuracy (92%!) – classification based on the mu-beta features is very reliable

```
Classifier trainer> Cross-validation test accuracy is 92.354288% (sigma = 7.365529%)
Classifier trainer> Cls vs cls      1      2
Classifier trainer> Target 1:      97.1   2.9 %, 1020 examples
Classifier trainer> Target 2:      12.4  87.6 %, 1020 examples
Classifier trainer> Training set accuracy is 92.156863% (optimistic)
Classifier trainer> Cls vs cls      1      2
Classifier trainer> Target 1:      96.9   3.1 %, 1020 examples
Classifier trainer> Target 2:      12.5  87.5 %, 1020 examples
```

- ▶ Co-adaptation user/machine - substantial training to find the correct imagination strategy that leads to the most distinct ERD/ERS
- ▶ Currently it can only be used with a maximum of 3 or 4 different MI tasks to ensure maximal performances (classification accuracy)

# BCIs improvement

## « Illiterate users »

Most current systems do not properly establish this mutual understanding

- 10 to 30 % of users unable to control a BCI: “BCI illiteracy” or “BCI deficiency” phenomenon
- MI-BCI : even for not “illeterate”, performance rather low
  - 75% of classification accuracy for 2 class MI-BCIs
  - 20% reach 80 to 100%
- 2 main factors
  - (1) Signal processing (Stage I) – many studies over the last years
  - (2) The user-training role: mostly neglected – inefficient training protocol (instructions, training tasks, feedback and training environment)
- Controlling an BCI requires acquisition of specific skills = to generate stable and distinct brain activity patterns while performing the tasks
- Understand how the humain learn and how to adapt training process

# BCIs improvement

## Summary guidelines for designing more effective training protocols (C. Jeunet)

### **Training task**

Progression (increasing difficulty), adaptative user-specific  
Self-paced and asynchronous sessions  
Preparatory training tasks (meditation)

### **Feedback**

Visual with emotional connotations (smileys) – tactile is promising (channel much less saturated in interactive situations) / increase the quantity and quality of information (topography of cerebral activity...)

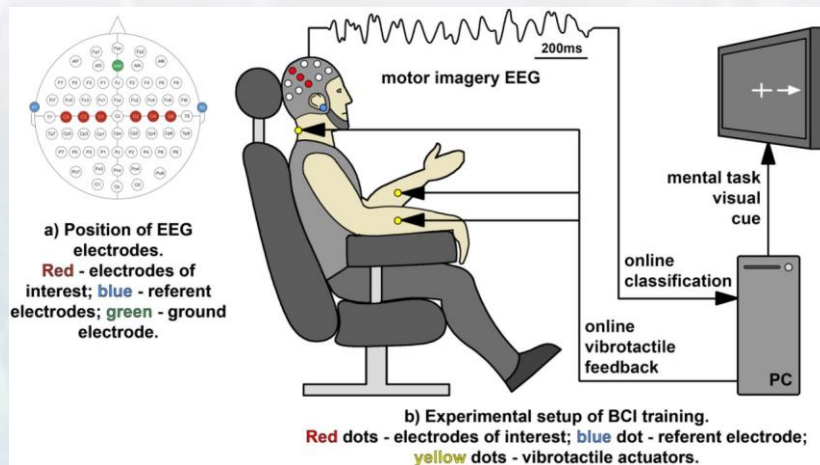
### **Training environment**

Improvement of user motivation & experience: gamified protocols (ex. ball-basket paradigm, spaceship that must avoid asteroids)  
Integration of virtual reality. Ex “Use the force” – allows users to levitate a spaceship by imagining moving their feet

# MI-based BCIs improvement


## Continuous Tactile Feedback for Motor-Imagery based Brain-Computer Interaction in a Multitasking Context

Camille Jeunet, Chi Vi, Daniel Spelmezan, Bernard N’Kaoua, Fabien Lotte, Sriram Subramanian




“Vibrotactile feedback during MI training induced significant enhancement of ERD activity only for non-dominant, left hand over contralateral motor cortex area measured in C4 electrode”

New Results

 Follow this preprint

## A BCI-based vibrotactile neurofeedback training improves motor cortical excitability during motor imagery

N. Grigorev, A. Savosenkov, M. Lukoyanov, A. Udoratina, N. Shusharina, A. Kaplan, A. Hramov, V. Kazantsev, S. Gordleeva

doi: <https://doi.org/10.1101/2021.02.28.433220> 

Now published in *IEEE Transactions on Neural Systems and Rehabilitation Engineering* doi: [10.1109/tnsre.2021.3102304](https://doi.org/10.1109/tnsre.2021.3102304) 