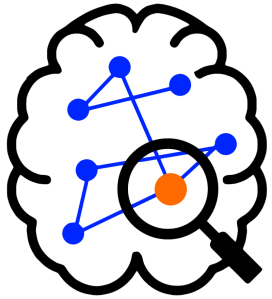

Graz'24 Workshop 2 - Sept. 9th 2024

HappyFeat: an interactive and efficient BCI framework for clinical applications

Arthur Desbois

Inria Paris, NERV team, Paris Brain Institute (ICM)

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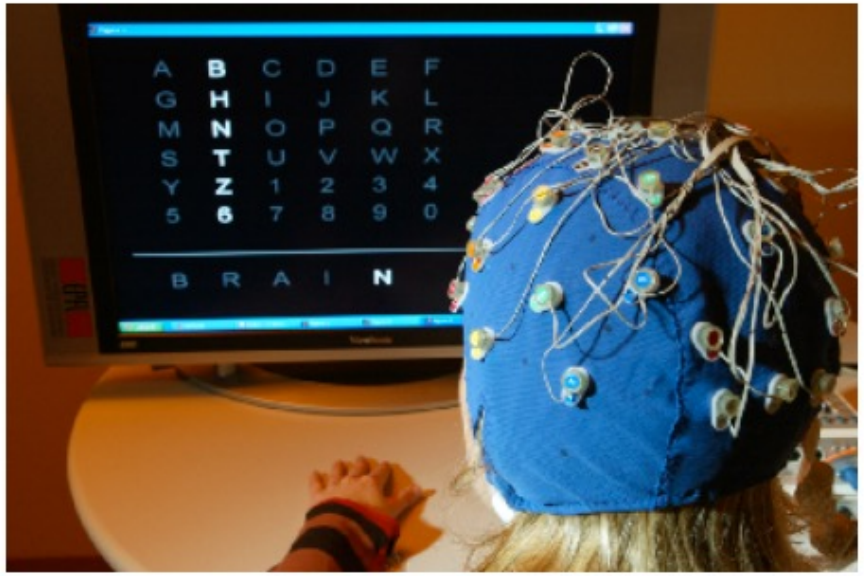
1. Context

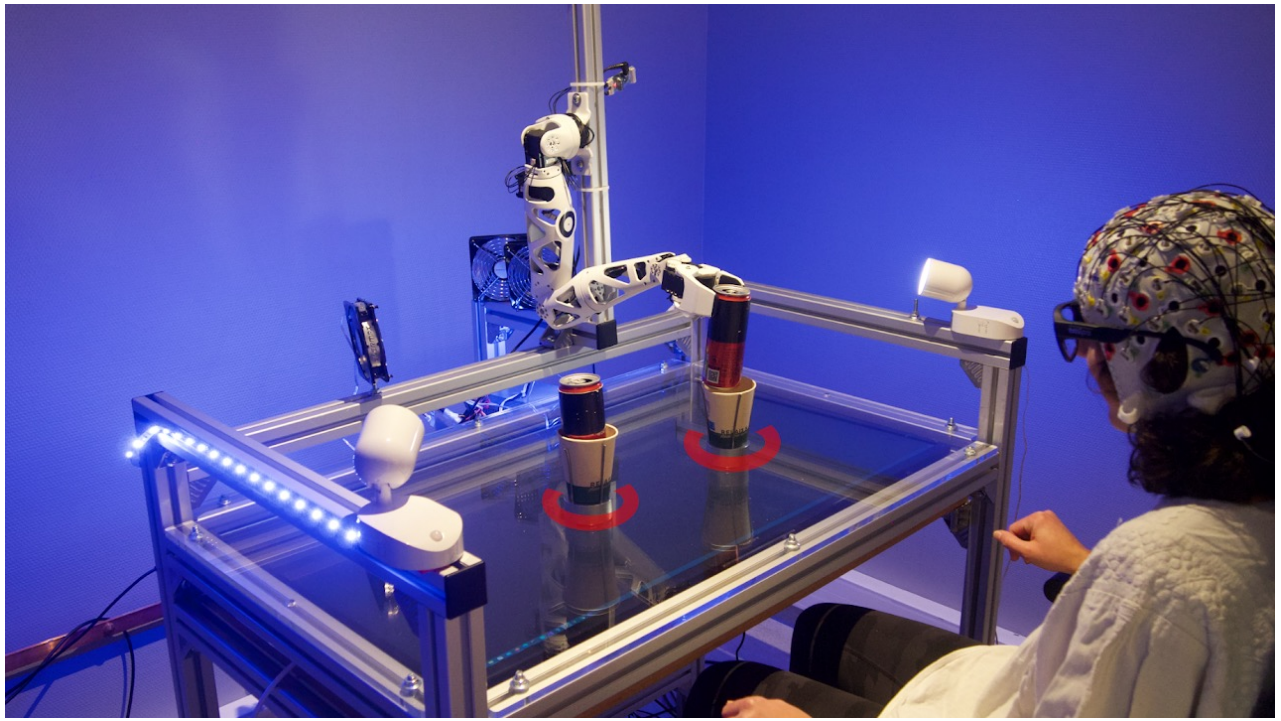
- What is BCI? What are we looking for?
- Feature-based classification vs. BCI variabilities



http://mmspg.epfl.ch/research

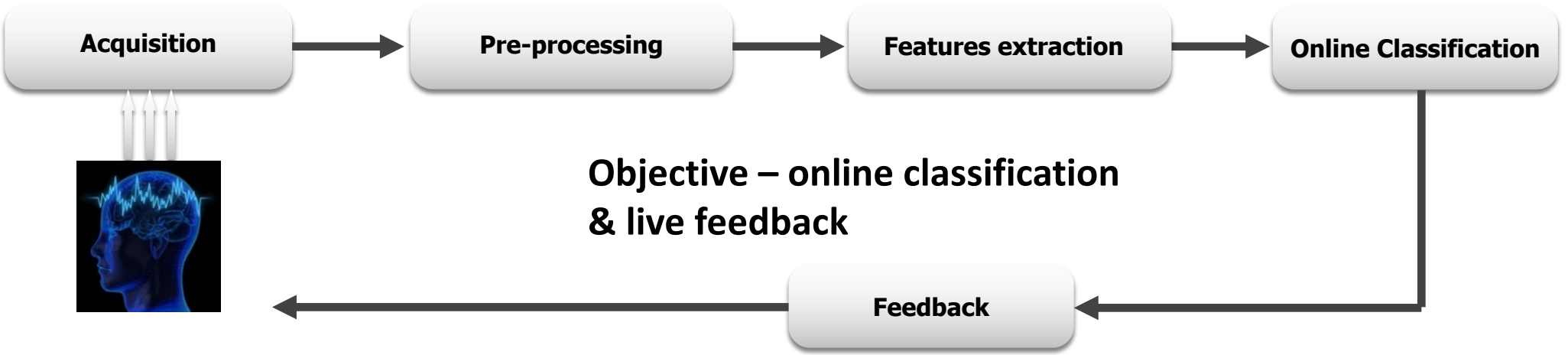
SSVEP – Inria/Hybrid

What is “BCI”?

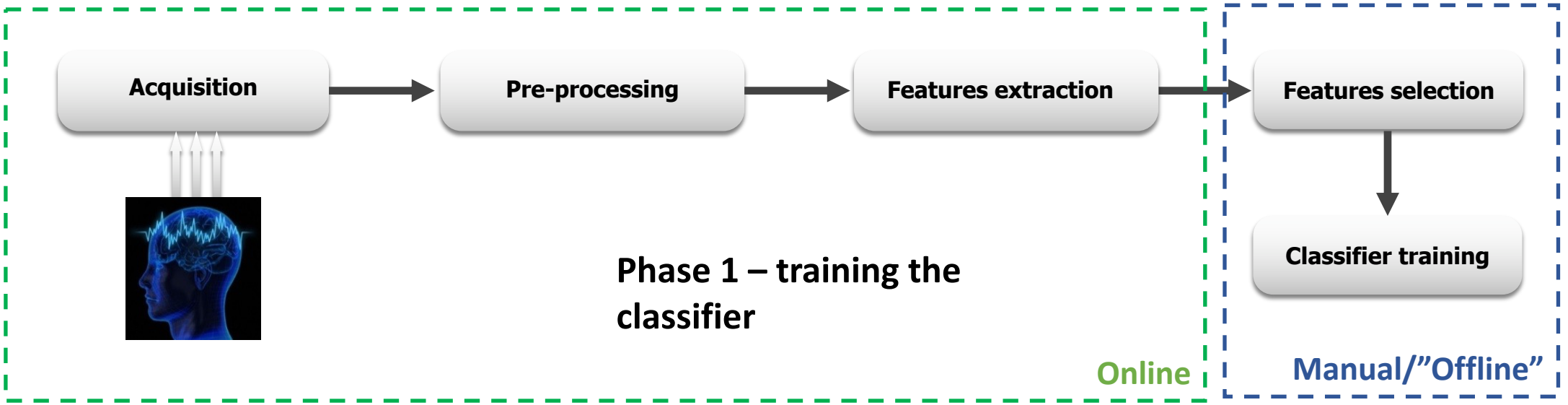


Protocole BRACCIO – Venot et al., ICM/NERV

What is “BCI”?

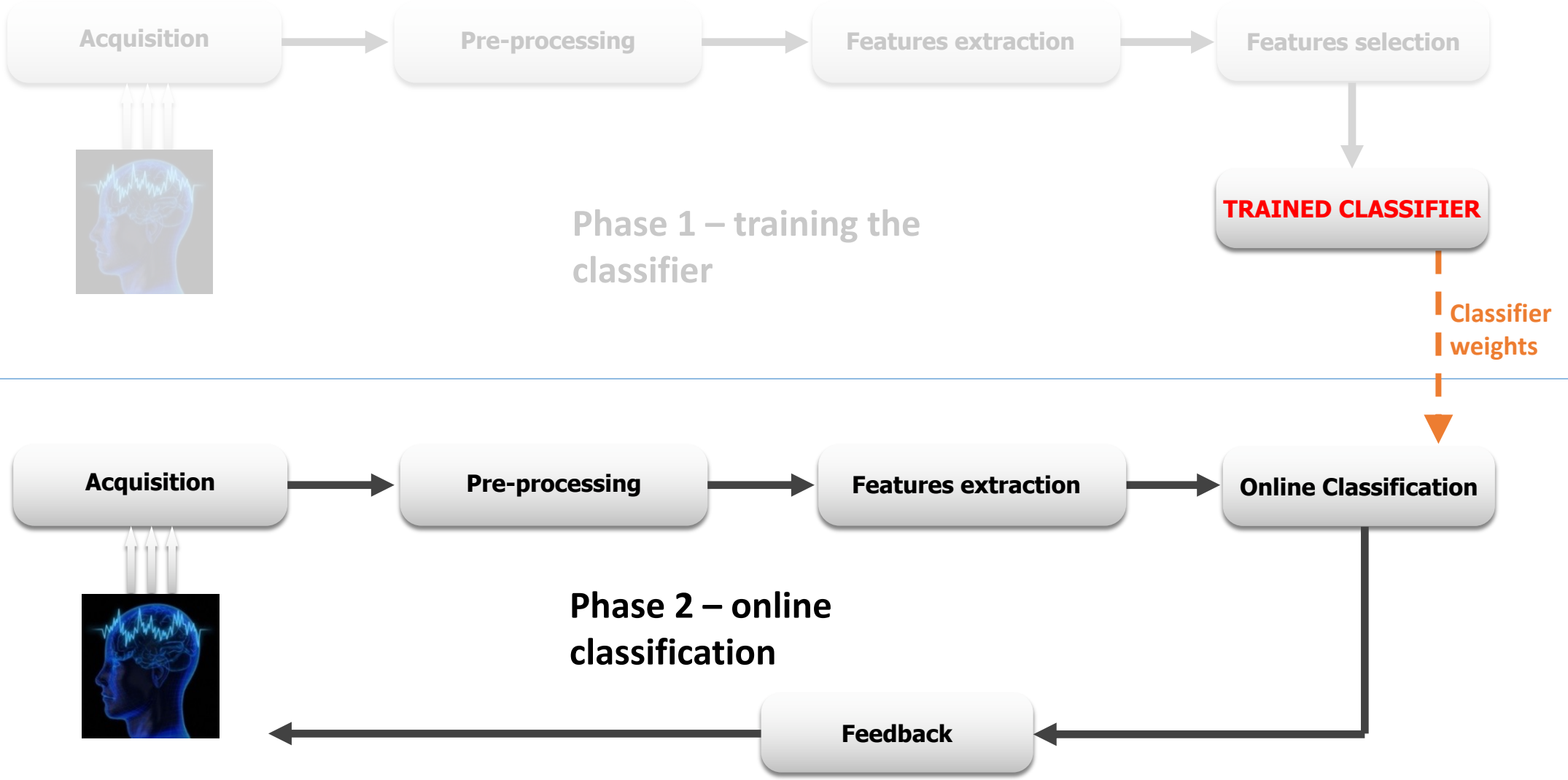

Acquisition
Pre-processing
Features extraction
Online Classification
Objective – online classification
& live feedback
Feedback

What is “BCI”?


Acquisition
Pre-processing
Features extraction
Features selection
Classifier training
Phase 1 – training the classifier
Online
Manual/”Offline”

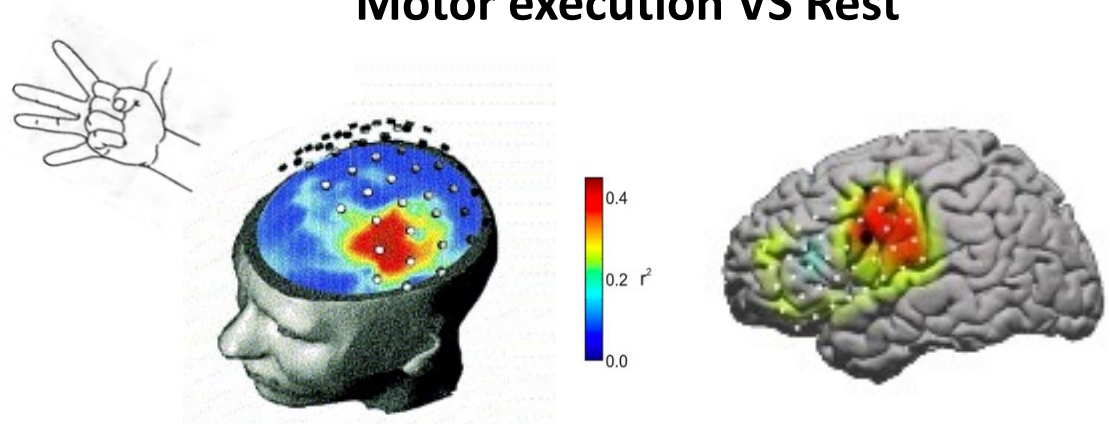
Acquisition
Pre-processing
Features extraction
Online Classification
Objective – online classification & live feedback
Feedback

What is “BCI”?

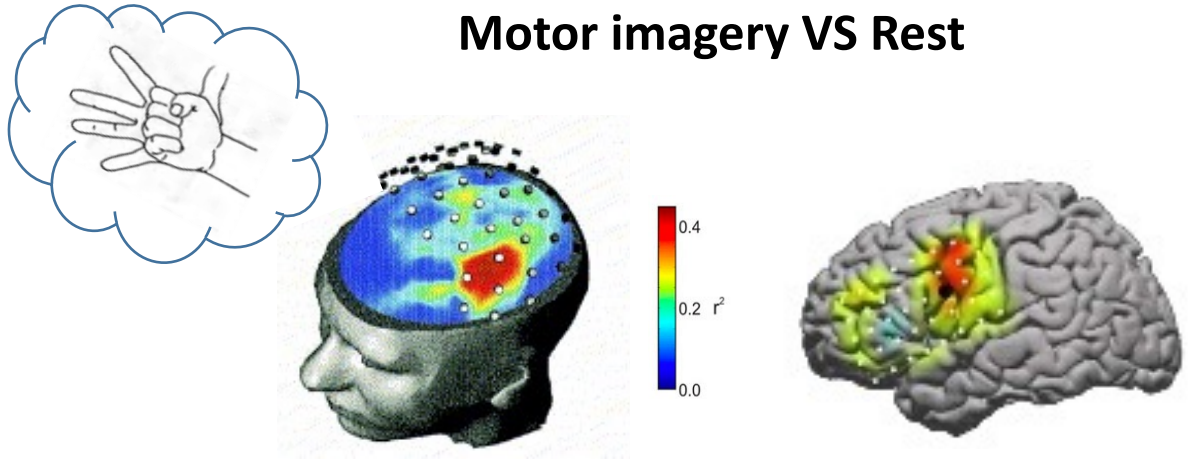

Acquisition
Pre-processing
Features extraction
Features selection
TRAINED CLASSIFIER
Phase 1 – training the classifier
Classifier weights
Acquisition
Pre-processing
Features extraction
Online Classification
Phase 2 – online classification
Feedback

Motor Imagery - Observations

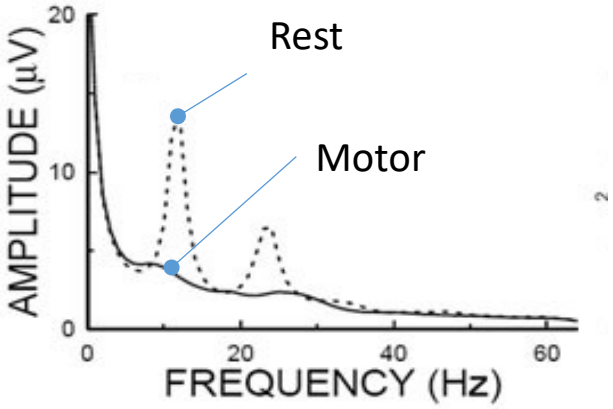
Motor execution VS Rest



Motor imagery VS Rest



Spectral Power Decrease

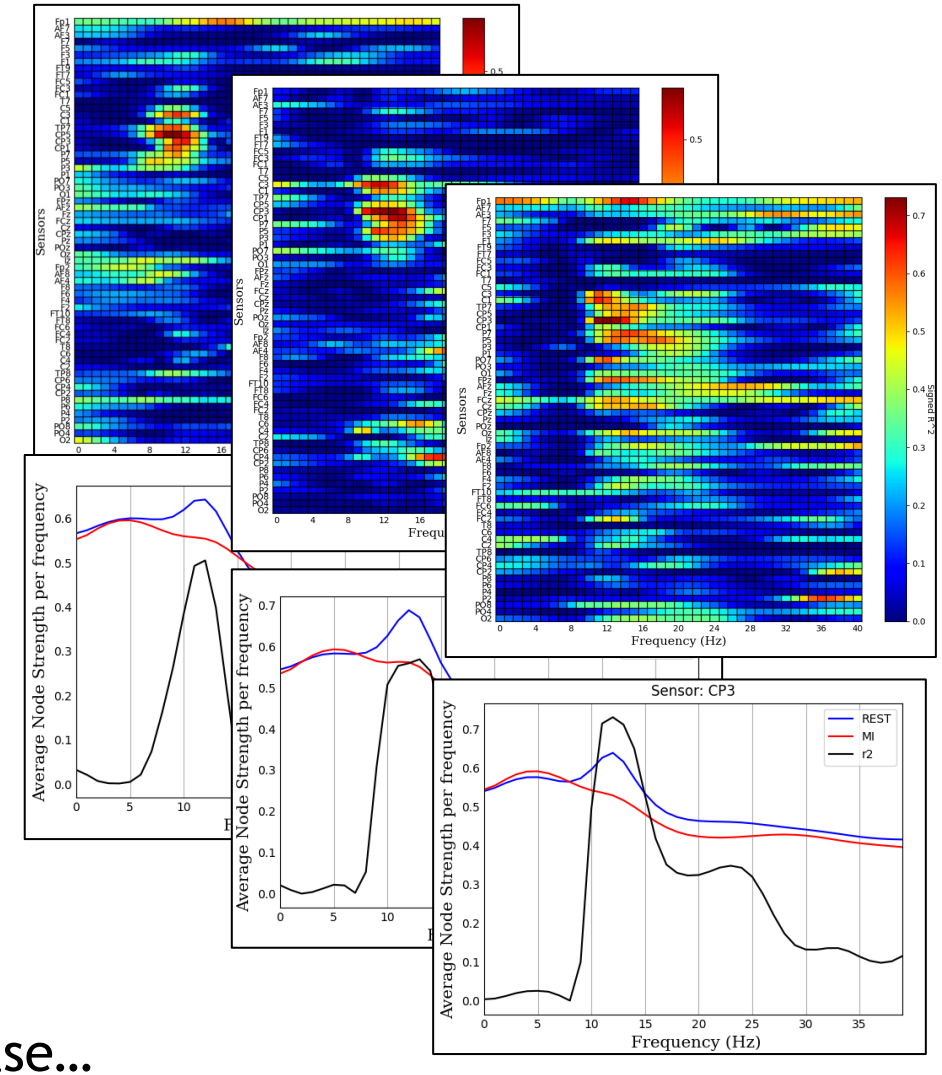


Desynchronization effect
(Pfurtscheller et al, 1999)

BCI in clinical settings - Feature selection

- **Features of interest (FOI)**
  - Selecting adequate FOIs is a **crucial step for BCI performance**.
  - After EEG signals acquisition, an **analysis phase** is needed to select best FOIs.
    - ➔ Scientific softwares (i.e., MATLAB)
    - ➔ Manual step, expertise needed
  - If this analysis phase is too long, a lot can change in the meantime:
    - EEG sensors impedances
    - Subject's brain behaviors
    - Subject's attention & motivation

➔ Signal characteristics might be very different between Acq/Training phase and Online phase…



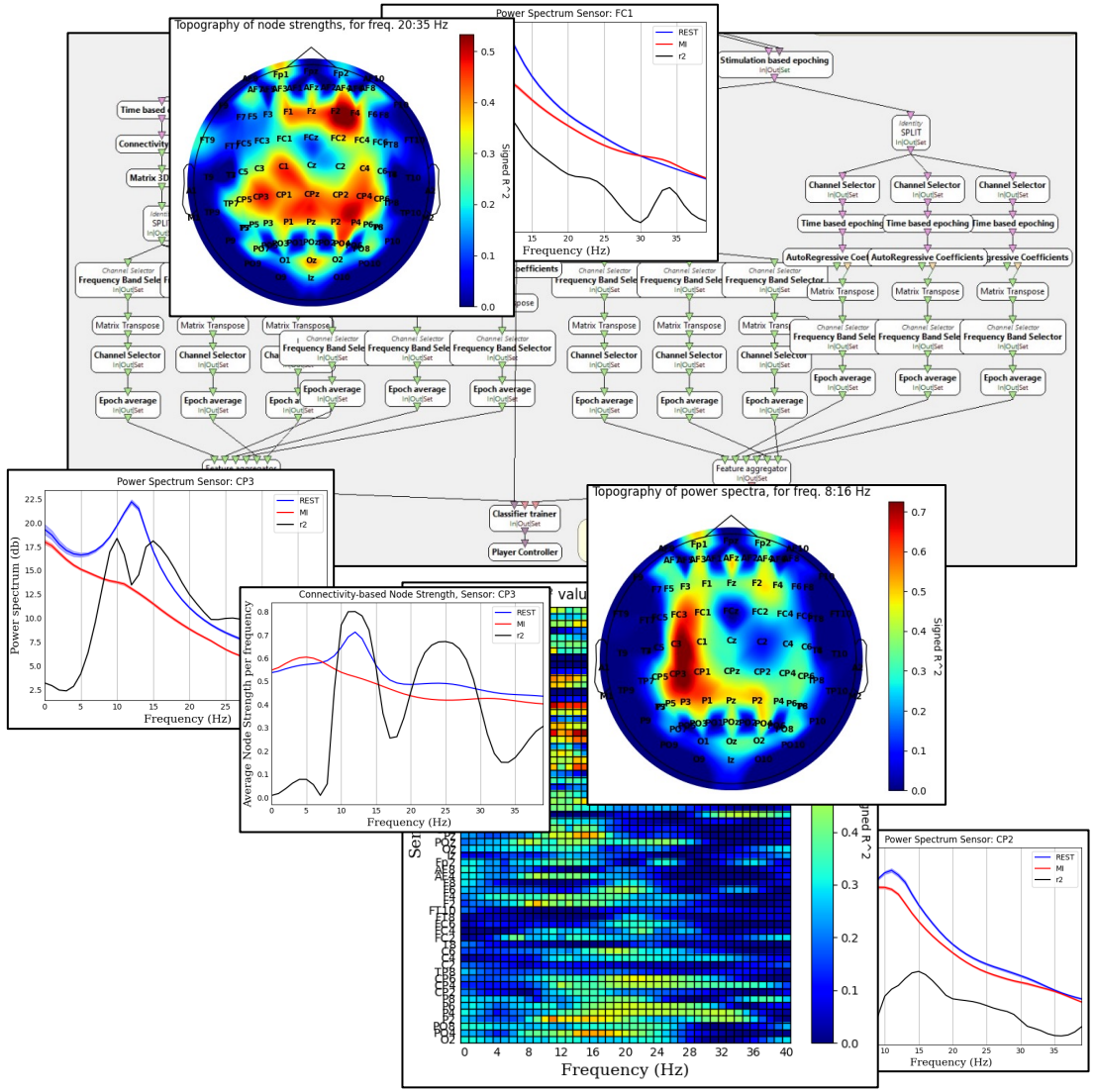
BCI in clinical settings – Feature selection

The “analysis phase” involves many manipulations. An example:

- Setting up “**feature extraction**” pipelines (e.g. OpenViBE)
- Finding FOIs through **visualization** (e.g. with Matlab, Python, etc.)
- Setting up & running **training** pipelines (e.g. OpenViBE)

- … and maybe **going again** through those steps **multiple times** until “correct” features have been found, or to account for inter-run variability

➔ **Tedious, error-prone, hard to achieve in a limited time**



HappyFeat

Python-based framework for facilitating MI pipelines

Main focus:

Making Feature Selection

& Classif. Training phases

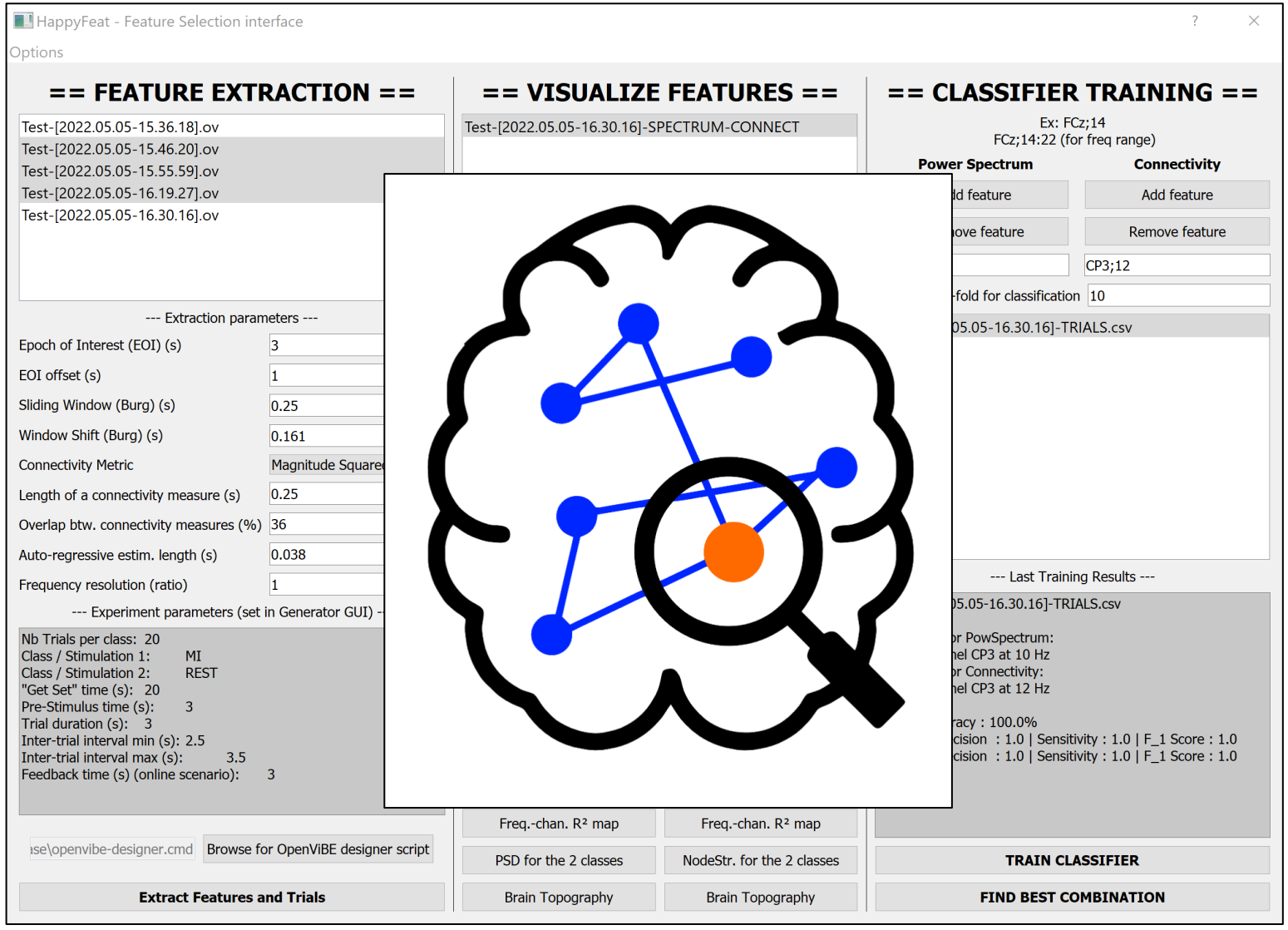
easy & fast

Analyze your data,

select your Features

& train your classifier

in less than 5 minutes!



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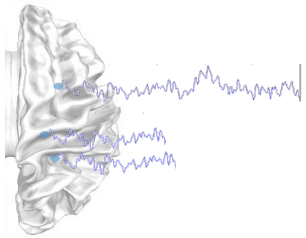
Key-Features

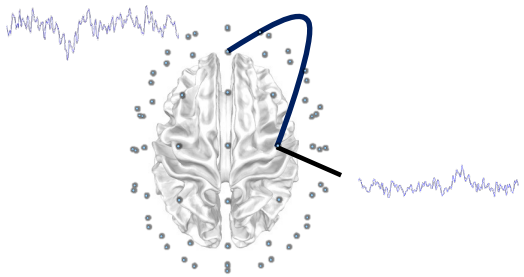
Unified, dashboard-like GUI

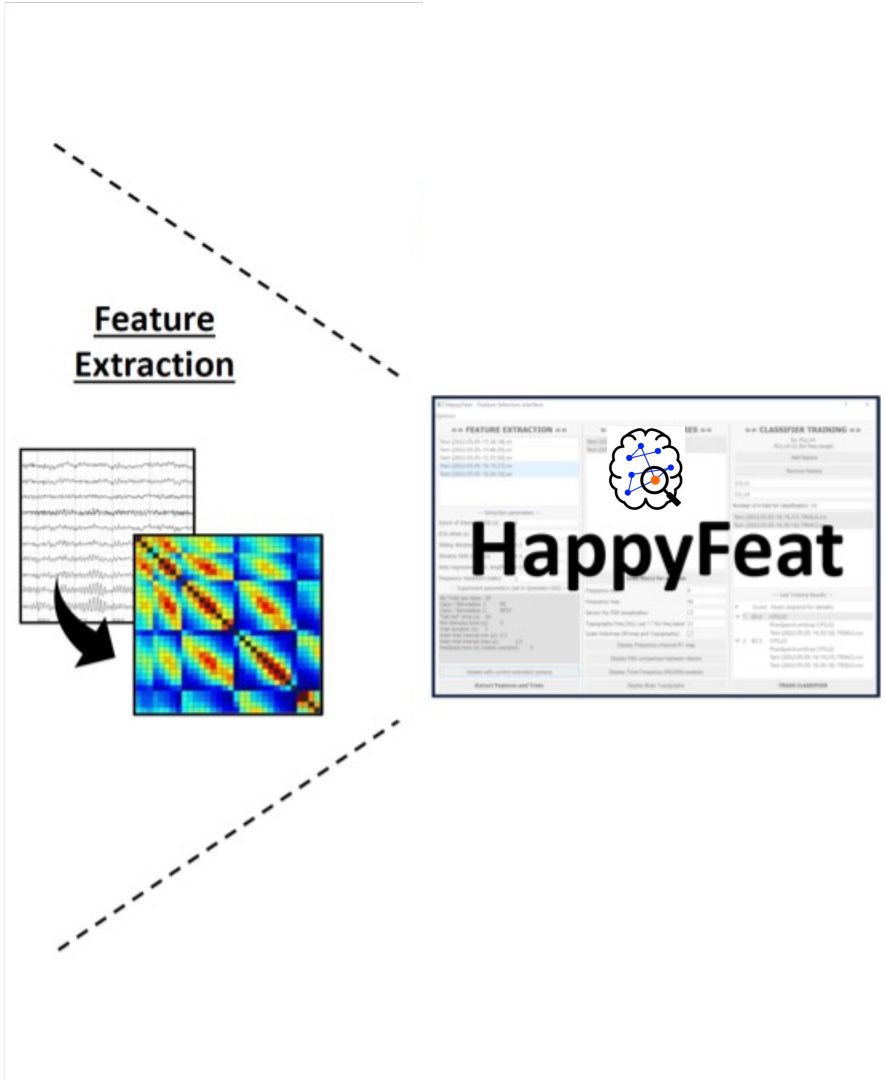
Key-Features

- Classical **local measures**

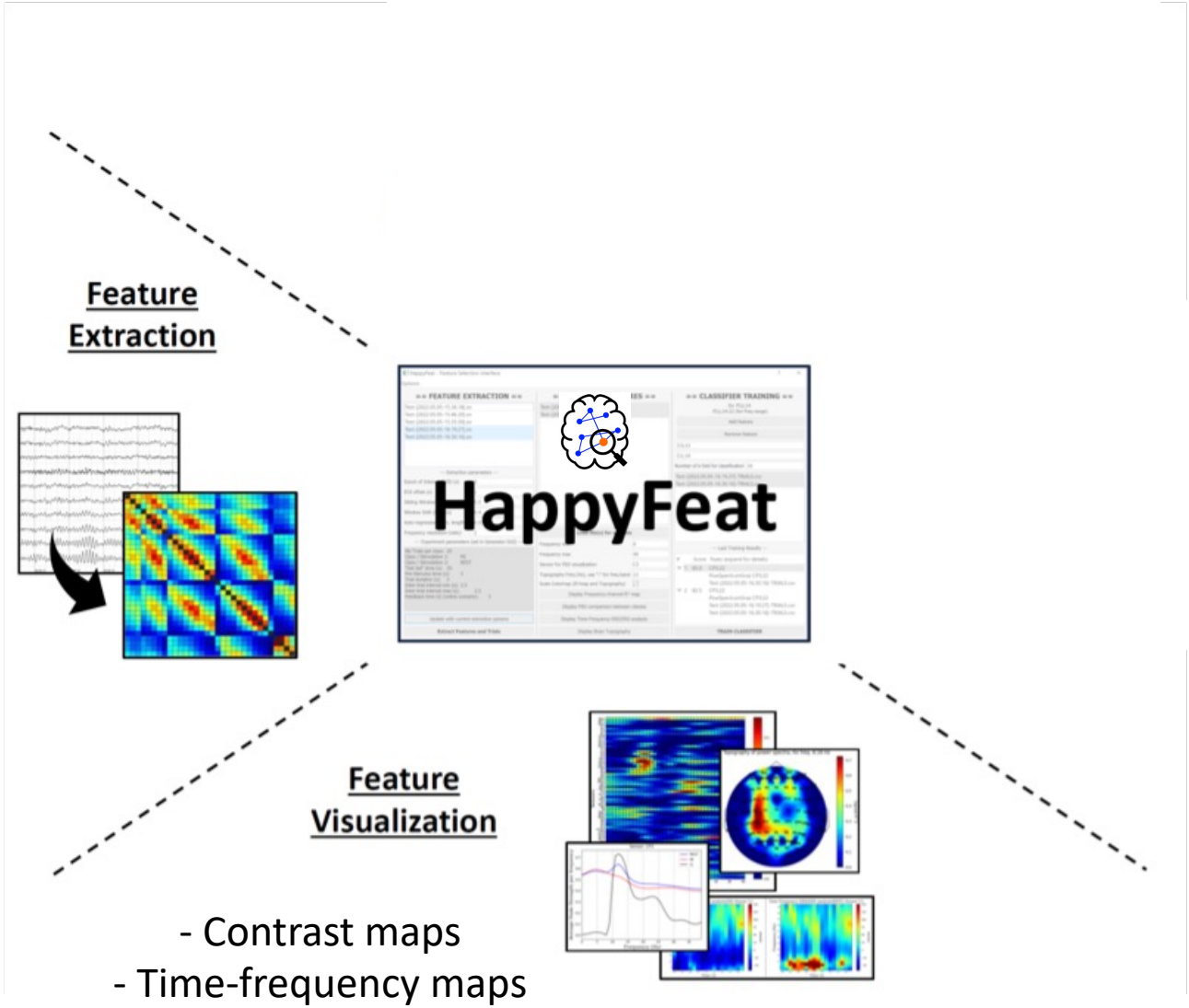


- Novel **network-based** approaches



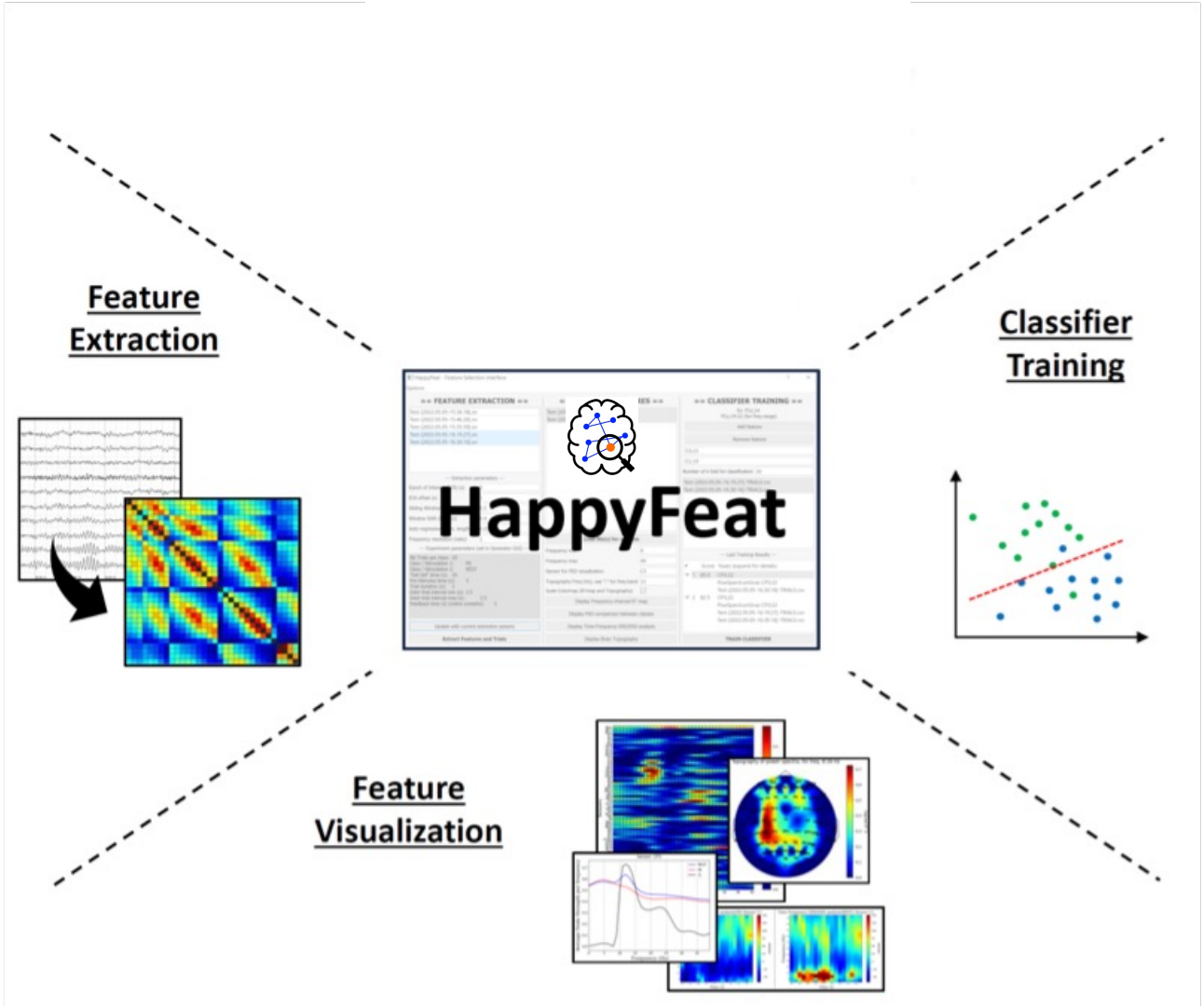


Key-Features



- Contrast maps
- Time-frequency maps
- Topographies

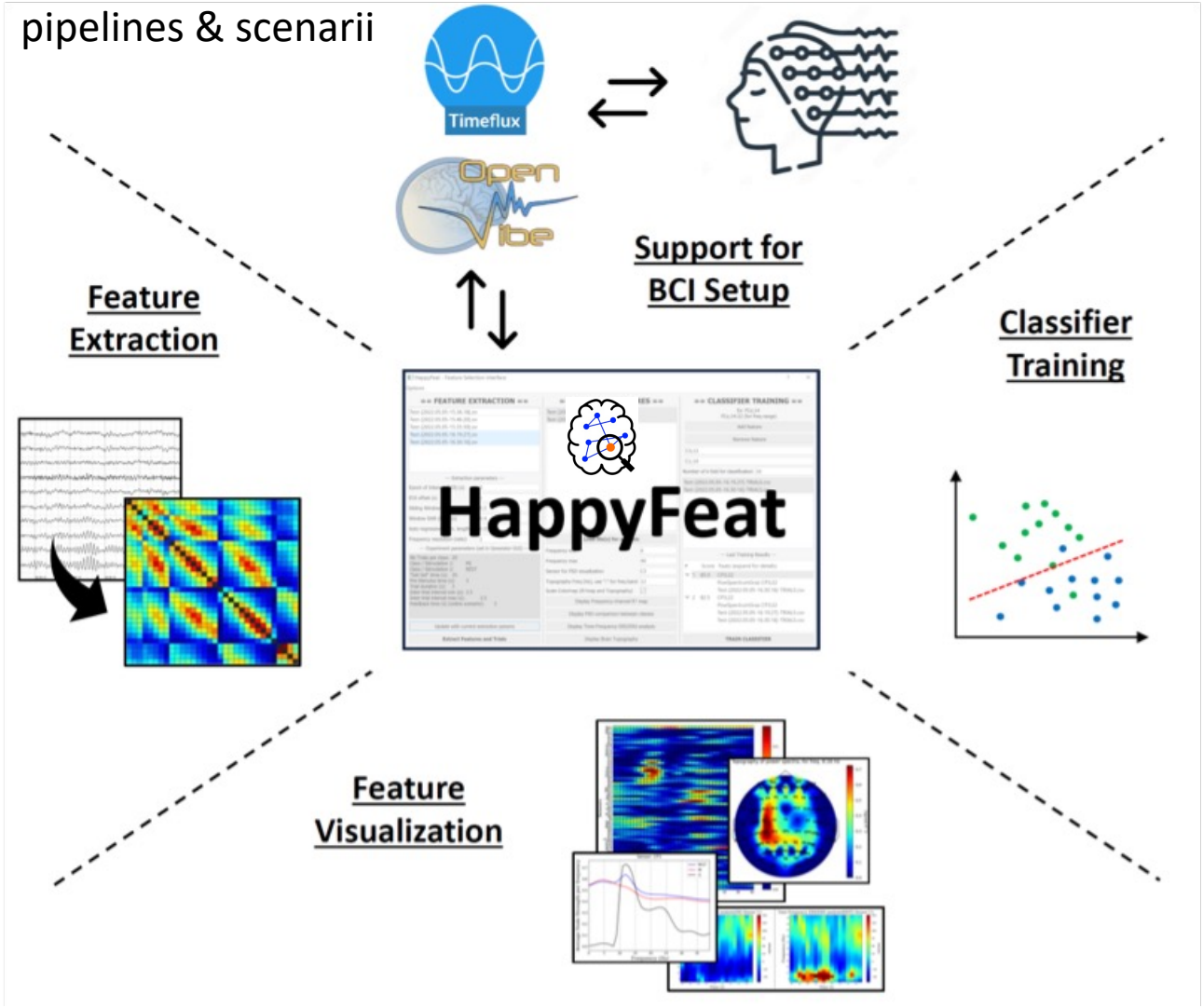
Key-Features



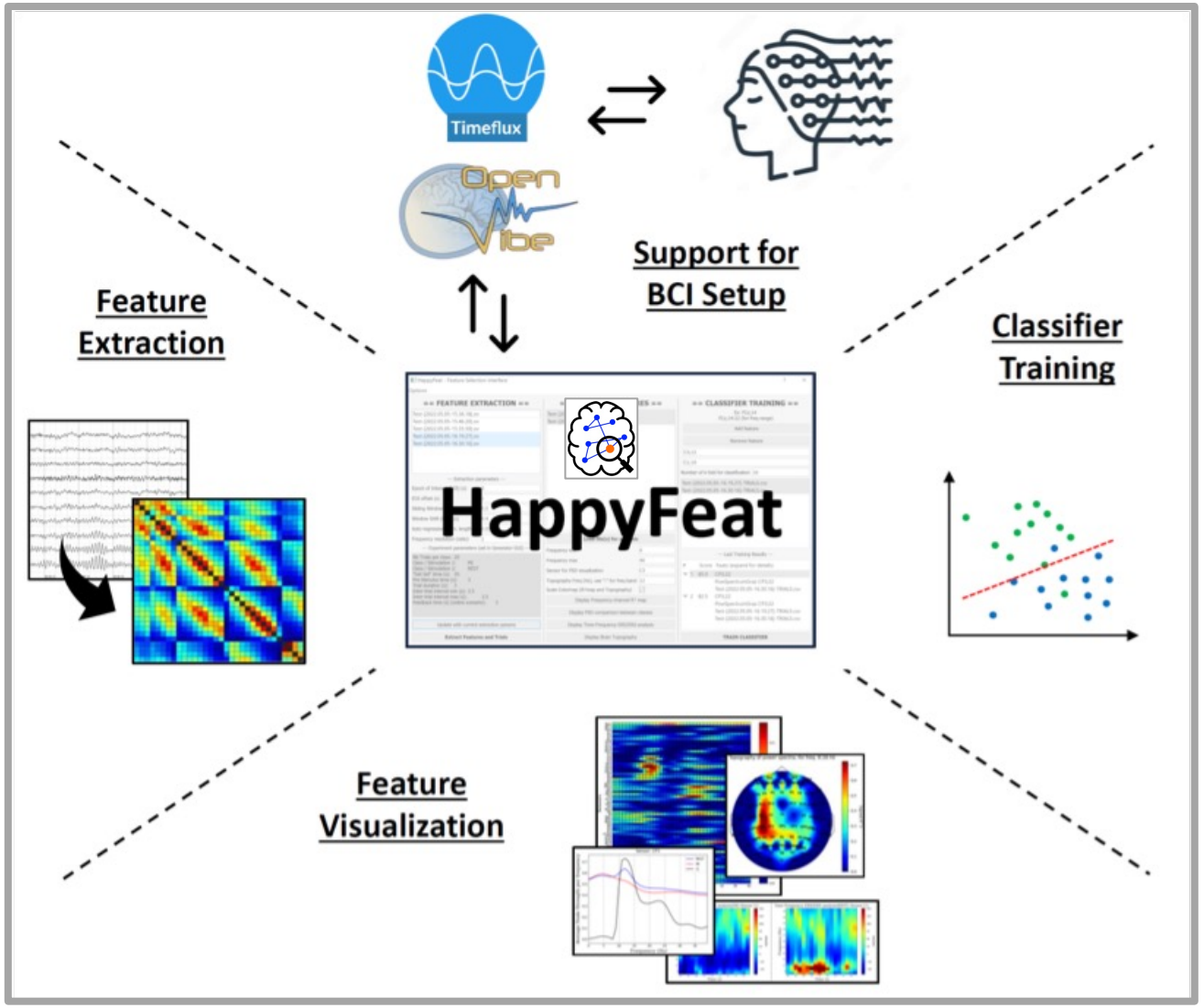
Tool for the decision

Key-Features

Automatic manipulation of pipelines & scenarii



Key-Features



Workspace to ensure **reproducibility** and **replicability** of all the manipulations

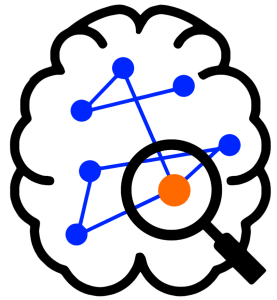
HappyFeat – Main Concepts

- **Key feats & mechanisms:**
  - **Clean, risk-free environment**

    ➔ avoid unnecessary & error-prone manipulations.
  - **Trial-and-error oriented workflow**

    ➔ all steps can be repeated quickly & as many times as needed
  - **Unified "dashboard" GUI + Workspace management system**
  - **Direct link with BCI software(s)**: OpenViBE (TimeFlux in the near future!)

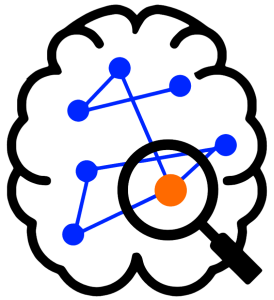
    ➔ no scenario edition/manipulation necessary: everything is **automated**!



- **Two main use cases:**
  - **Make BCI pipelines smoother/easier to use** and allow **reproducibility** of exps.
  - **Prospective works** & **comparison of alternative features of interest** (connectivity, networks…)

HappyFeat – Main Concepts

- **Efficient processing pipelines**
  - Available features for classif.: *Spectral Power (PSD)*, *Connectivity-based network metrics*
  - … It's also possible to train the classifier using **a fusion of both features.**
- **Feature extraction**
  - Easy access to all experiment & signal processing parameters.
  - Use **pre-recorded signals** or **on-the-fly during acquisition phase.**



- **Assisting feature selection: Visualization, AutoFeat**
  - Viz: R^2 maps, PSD comparison across trials, time/freq. ERD/ERS analysis, brain topography
  - Select features manually using visualization tools…

    ….or a set of the channel/freq couples with the highest R^2, **automatically**

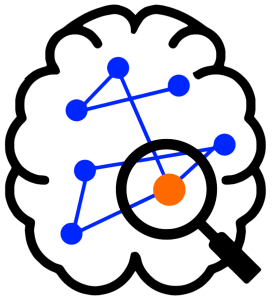
HappyFeat – Main Concepts

- **Classifier training**
  - **Run as many training attempts as needed**, using different features, in only a few clicks.
  - Concatenate trials from multiple recorded sessions
  - Automatically **try different feature combinations** with one click

- **Onwards to online classification**
  - Automatically generate/update the

    “online classification” OpenViBE / TimeFlux scenario

    using selected classification feats. and trained classifier.



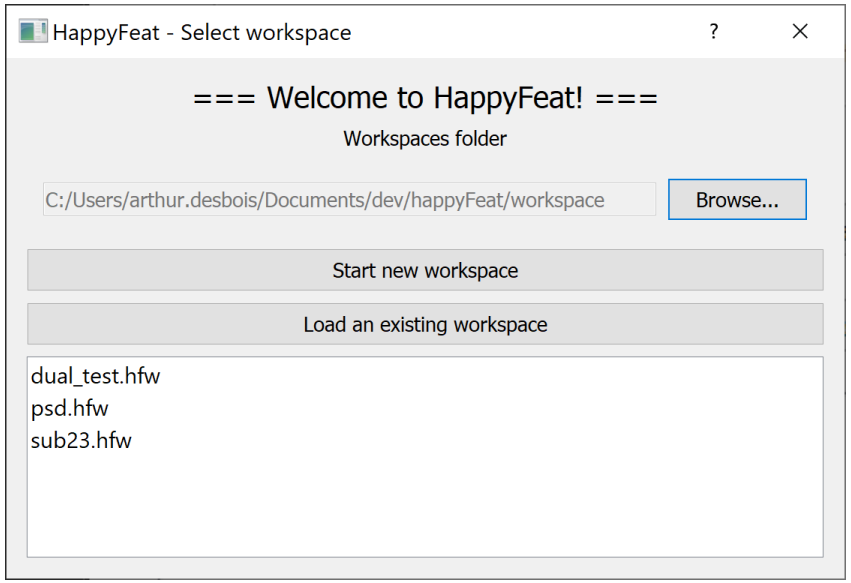
HappyFeat - Typical use case

1. **Workspace creation/selection**

- Create a new environment (file tree, configuration, data structures) for the experiment/analysis

  Ex: **sub23_session01**

- … or select an already existing one.



➔ All user settings & manipulations are saved and available in the workspace for future usage or sharing:

- Extraction parameters (spectral analysis, list of processed files…)
- Training attempts (runs & features used, training accuracy…)

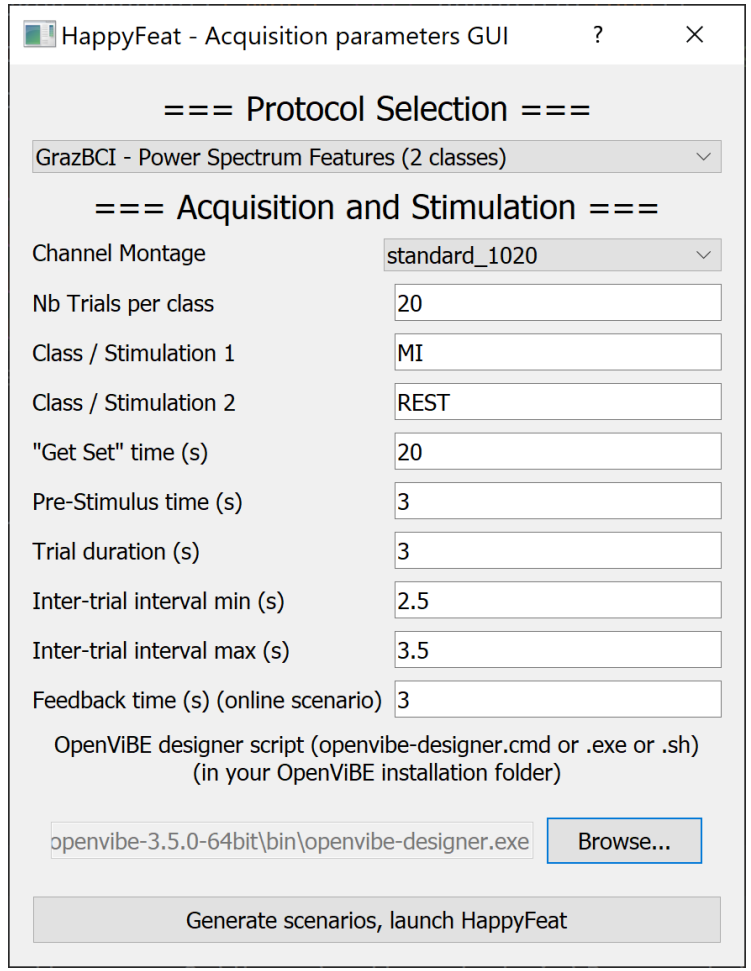
HappyFeat - Typical use case

1. Workspace creation/selection

- When creating a new workspace:
  - the feature type (PSD, Connectivity…) is chosen
  - experimental/acquisiton parameters are entered (electrode montage, stimulation names, experimental layout…)

➔ This step allows to automatically set up the OpenViBE acquisition scenario.

These experimental parameters are also important for the different processing steps of HappyFeat.



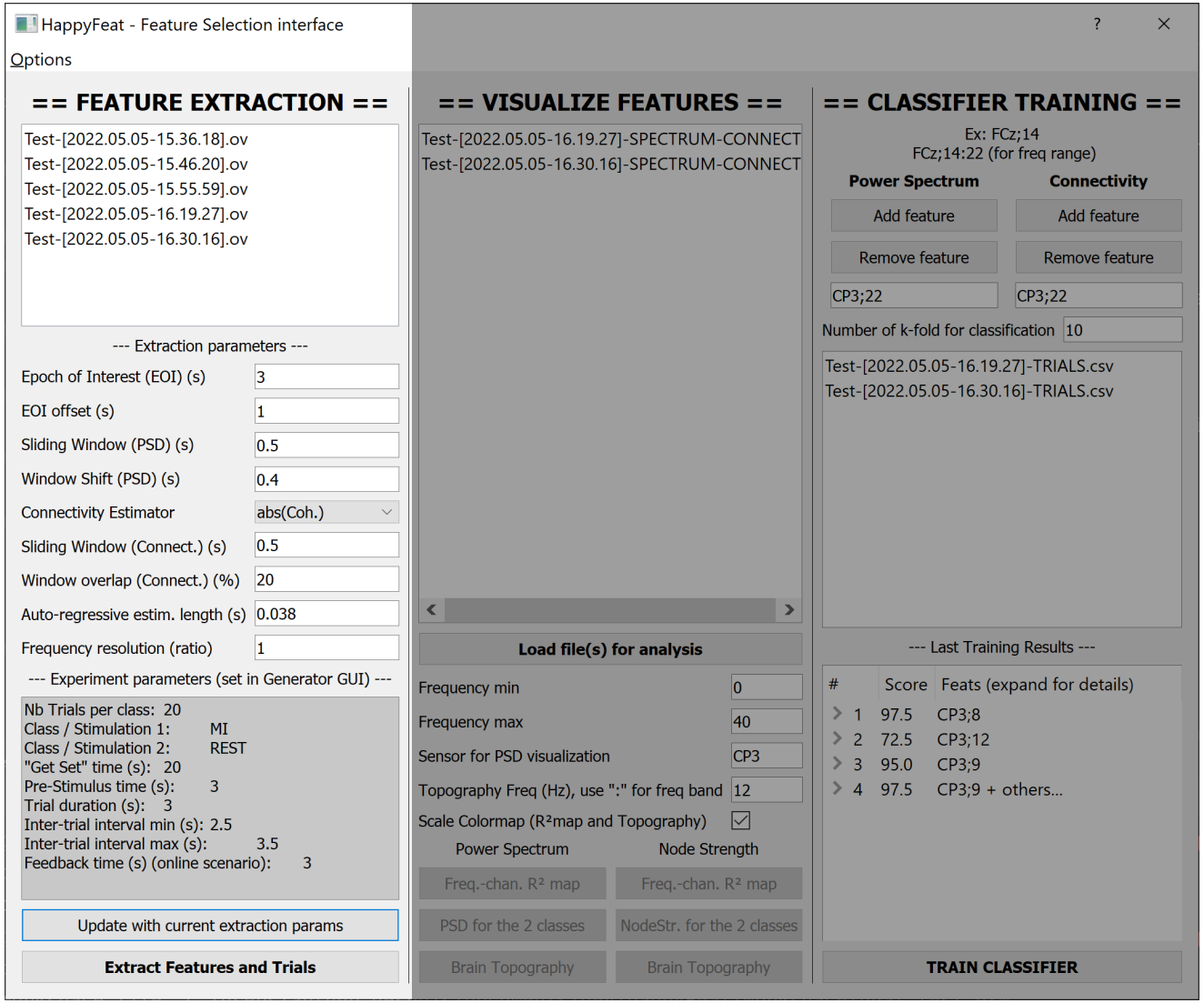
HappyFeat - Typical use case

1. Workspace creation/selection
2. **Feature Extraction**

- Files in the “signals” folder of the workspace are listed in the left panel
- Select one or multiple files…
- Enter the parameters for feature extraction…
- Press the button!

💡 Along the **workspace** mechanism, HappyFeat also uses **work sessions** to keep track of extraction parameters.

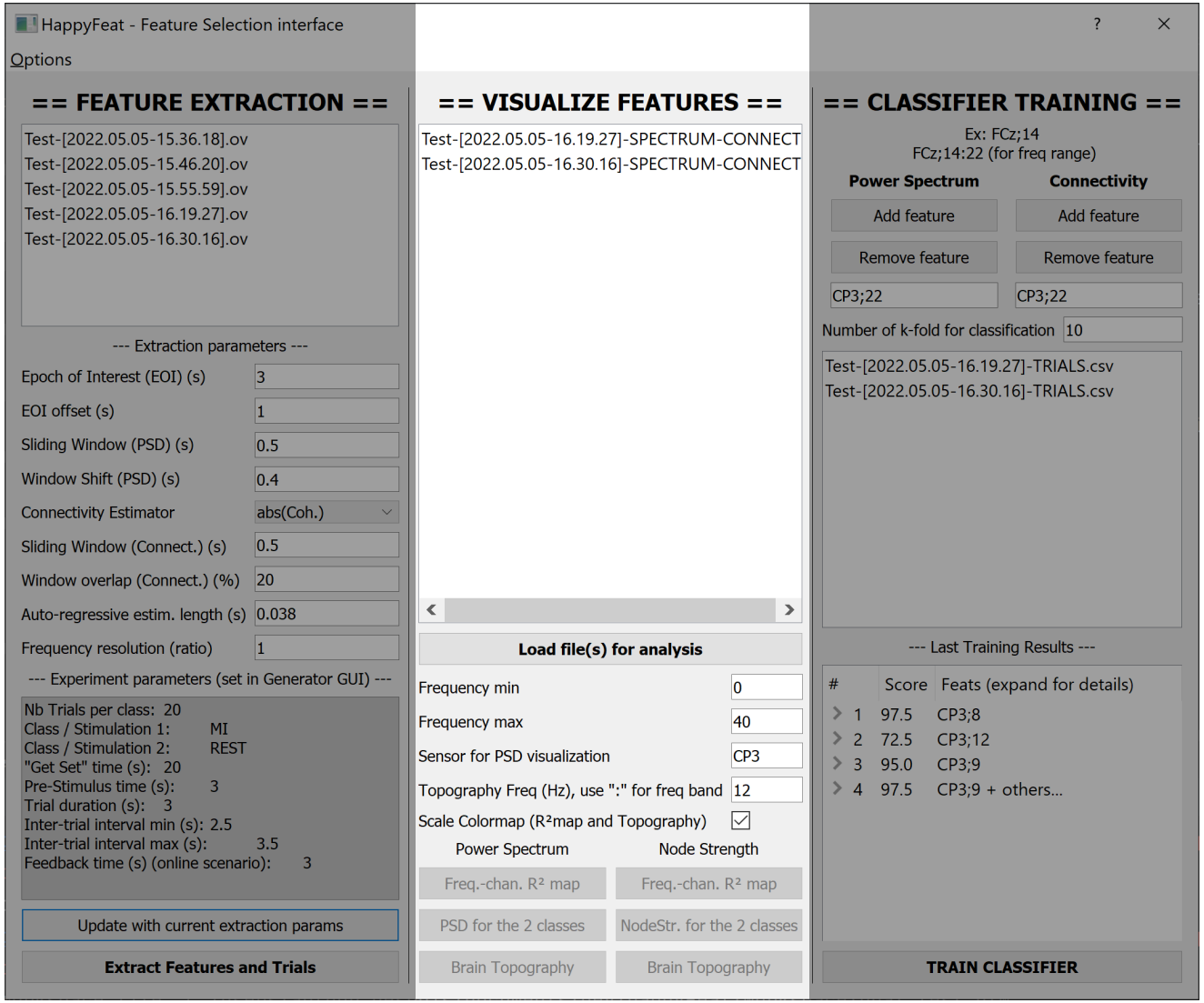
Therefore, all steps realized with a set of extraction parameters (which files have undergone extraction + training attempts) are stored and can be recovered.



HappyFeat - Typical use case

1. Workspace creation/selection
2. Feature Extraction
3. **Analysis & Feature Selection**

- “Extracted” files (runs) appear in the central panel.
- Select which runs to analyze…



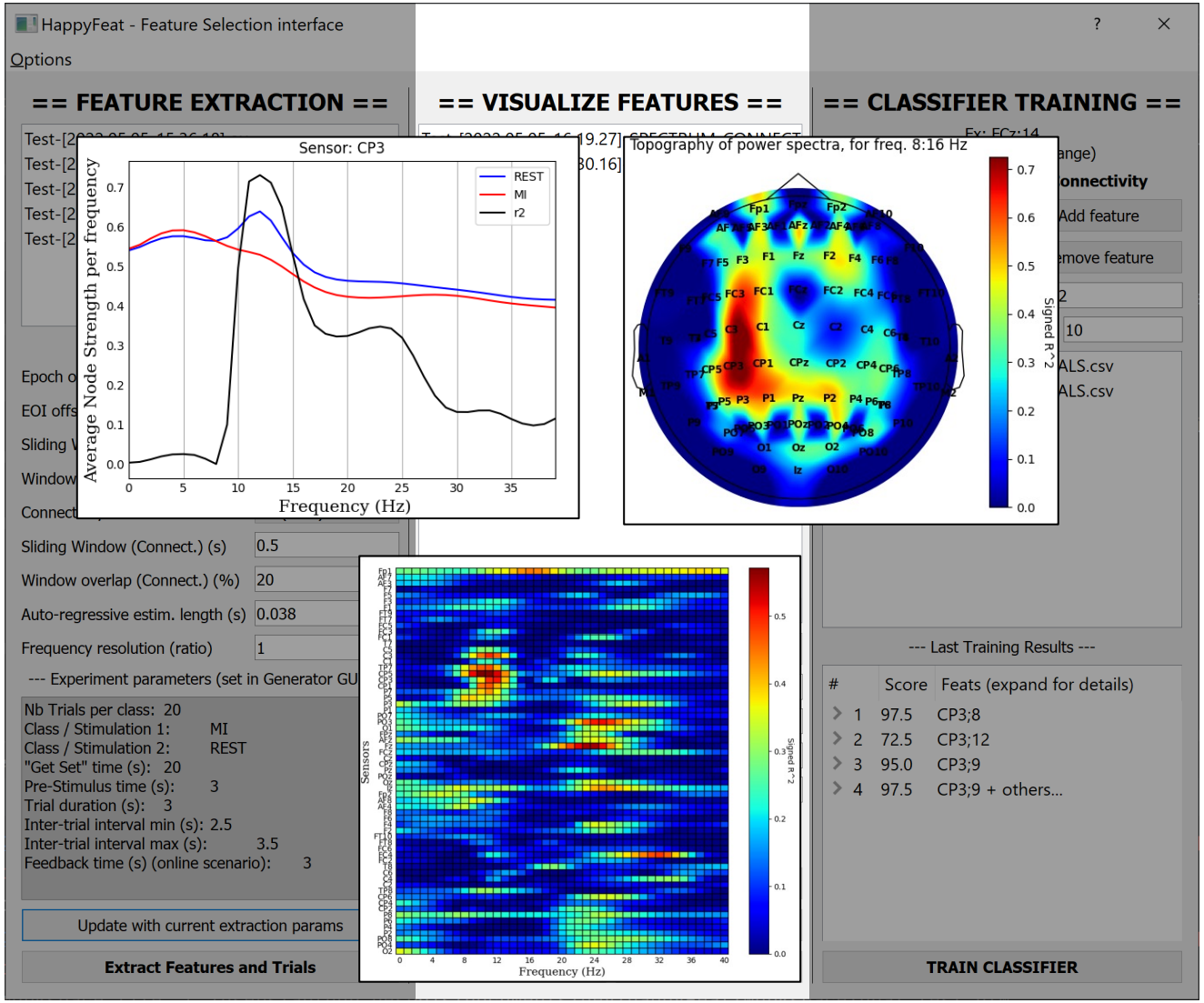
HappyFeat - Typical use case

1. Workspace creation/selection
2. Feature Extraction
3. **Analysis & Feature Selection**

- "Extracted" files (runs) appear in the central panel.
- Select which runs to analyze…

- And use the different **visualization tools** to select adequate features:
  - Channel/frequency R^2 map
  - Per-channel metric comparison
  - Per-frequency R^2 topography

- More coming soon…



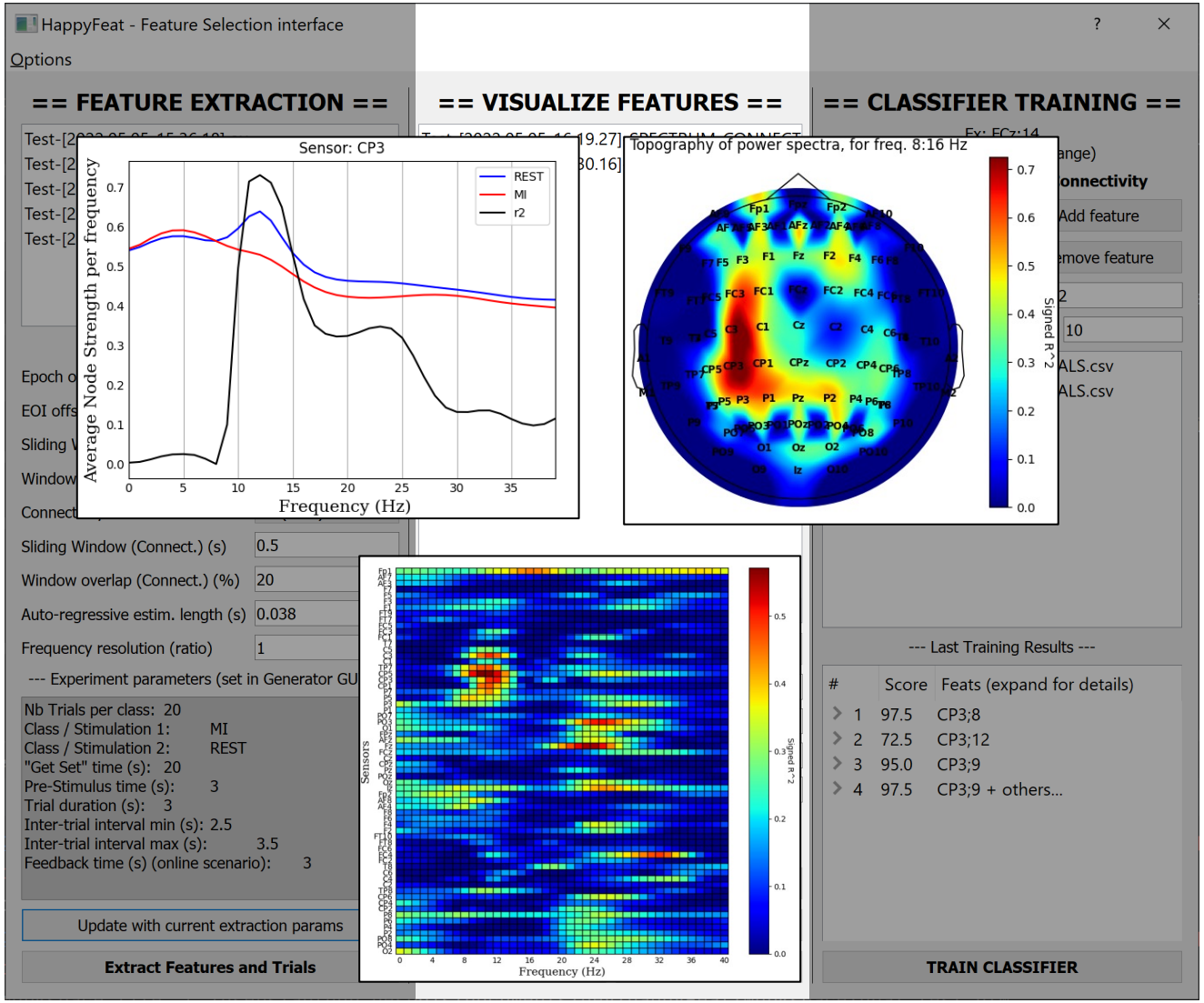
HappyFeat - Typical use case

1. Workspace creation/selection
2. Feature Extraction
3. **Analysis & Feature Selection**

- "Extracted" files (runs) appear in the central panel.
- Select which runs to analyze…

- And use the different **visualization tools** to select adequate features.

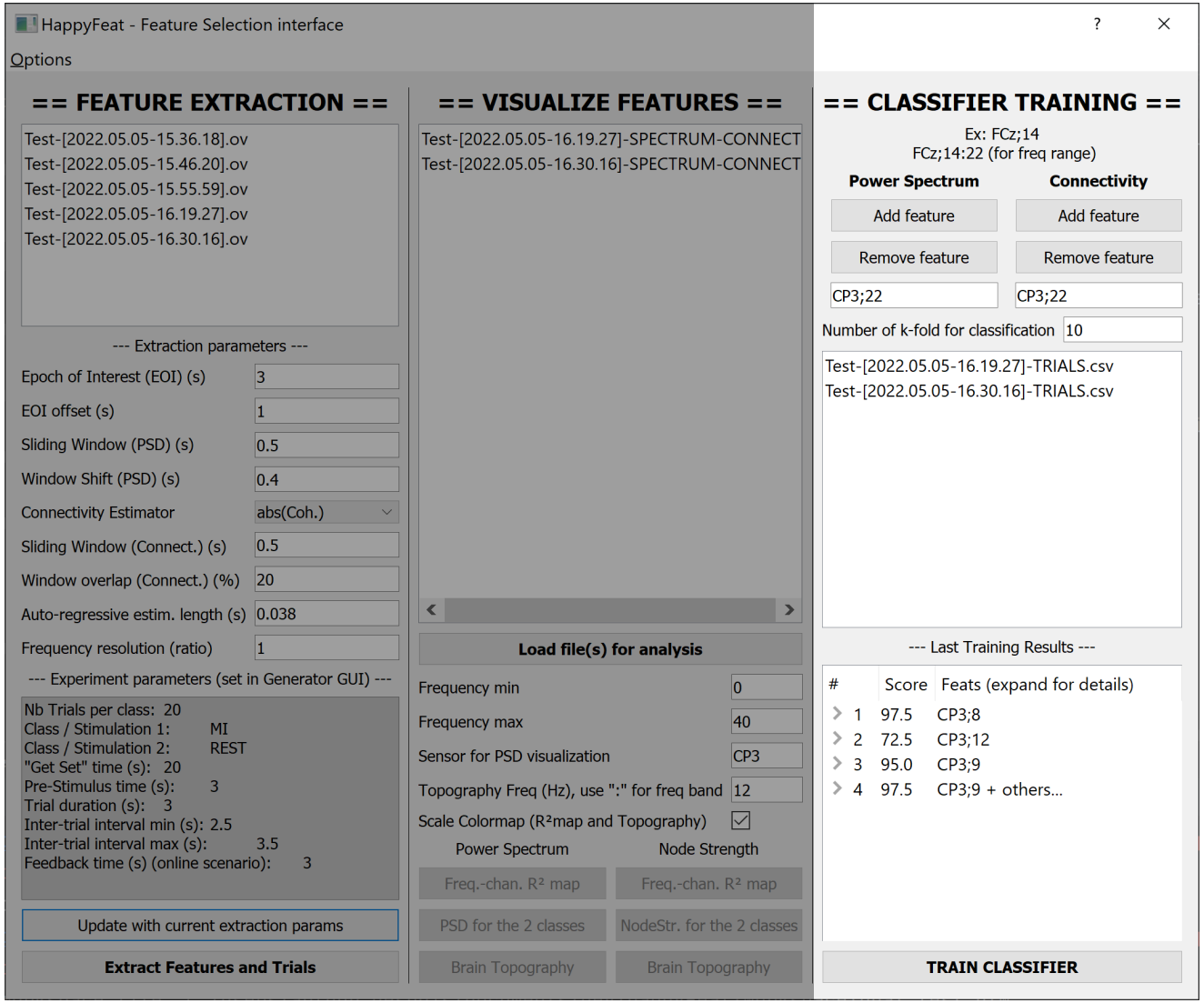
- … or use the "**AutoFeat**" mechanism to automatically select a set of (channel/frequency) pairs with the highest R2



HappyFeat - Typical use case

1. Workspace creation/selection
2. Feature Extraction
3. Analysis & Feature Selection
4. **Classifier training**

- “Extracted” files (runs) also appear in the right panel.
- Select one or multiple runs…
  … their trials will all be used for training.
- Select one or multiple feature(s) of interest (channel;frequency)
- Click the button!



HappyFeat - Typical use case

1. Workspace creation/selection
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3. Analysis & Feature Selection
4. **Classifier training**

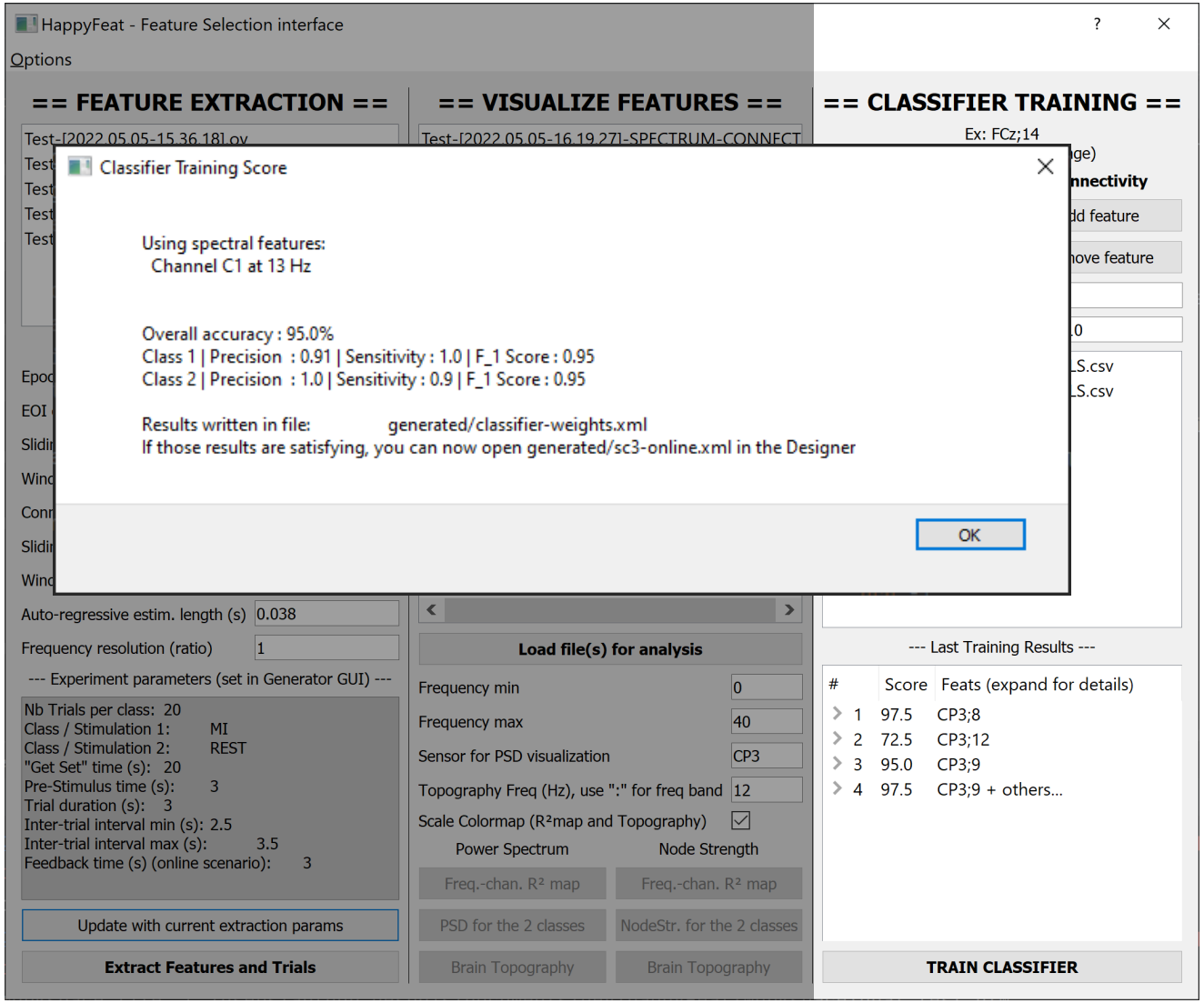
- "Extracted" files (runs) also appear in the right panel.
- Select one or multiple runs…
  … their trials will all be used for training.

- Select one or multiple feature(s) of interest (channel;frequency)

- Click the button!

➔ A training accuracy is provided

➔ All previous training results are available (displayed in the GUI, and classif. weights in the workspace)



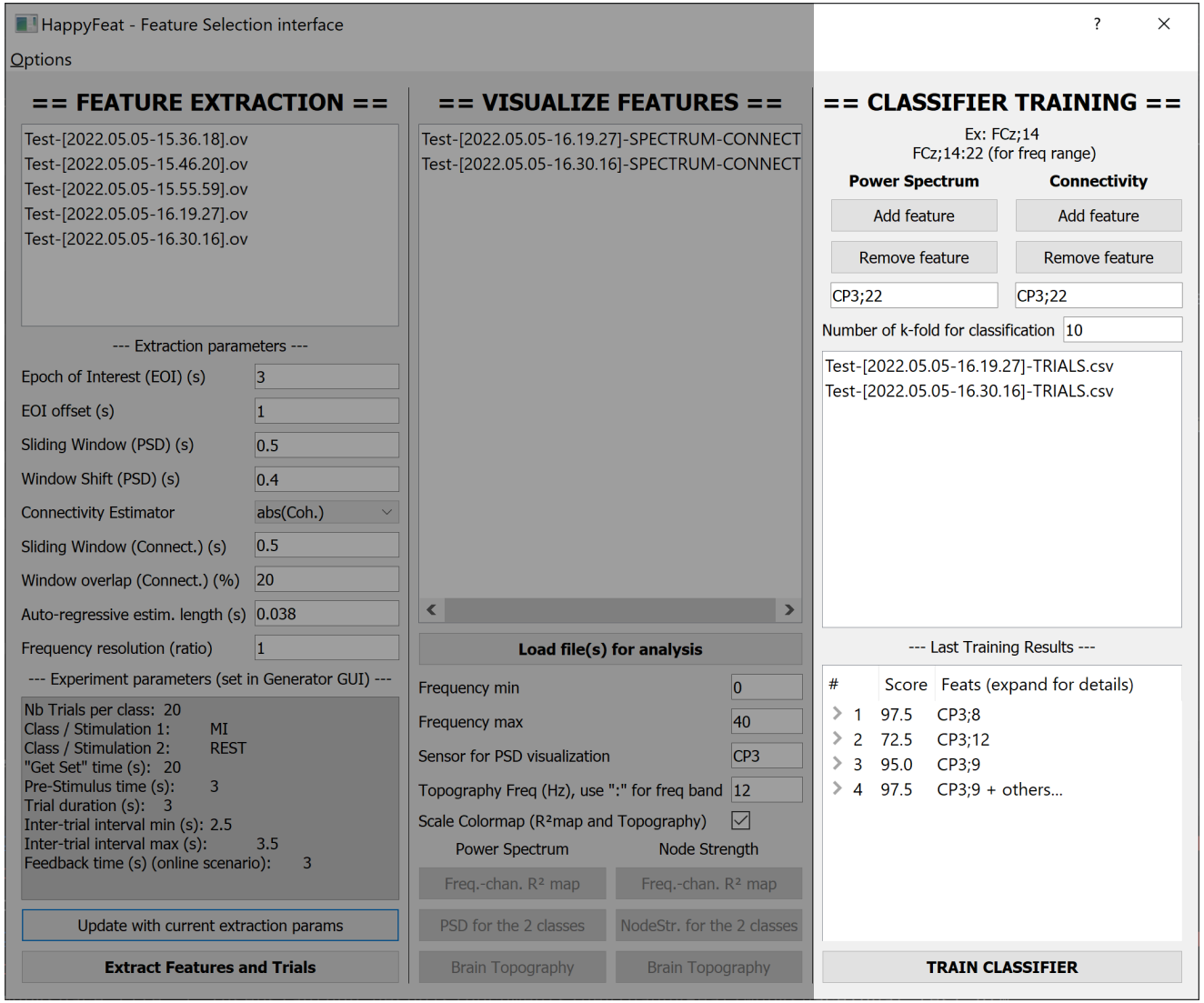
HappyFeat - Typical use case

1. Workspace creation/selection
2. Feature Extraction
3. Analysis & Feature Selection
4. Classifier training
5. **Online classification**

A satisfactory set of classification features has been found!

➔ Generate a **ready-to-use** OpenViBE (soon TimeFlux) scenario

- trained classifier
- selected classif.features



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Current limitations & future works

- **Current limitations**
  - Only one type of classification algo. proposed (LDA)
  - Pipelines are “fixed”:
    - − trading OpenViBE’s high level of flexibility…
    - + …for a high comfort of pipeline settings customization
    - + & “trial-and-error” workflow
  - Only three types of pipelines/feature types:
    - Power Spectrum Density
    - Connectivity (coherence & its variants)
    - Dual (mixing PSD & Connectivity)

➔ In project (*long term!*) for more “**prospective power**”:
allow the user to choose btw. 1 and 3 feature-types & network metrics to mix as they see fit (MSC/node strength + Imag(Coh)/Laterality + …)

Current limitations & future works

- **Future works**
  - **Fully autonomous 100% Python version**, without OpenViBE (in progress: *T. Venot*)
    - − No acquisition/online possibilities
    - − Obviously slower… (no C++ optimizations! … or maybe via pybind?)
    - \+ More portable, all types of platforms supported (MacOS!)
    - \+ Other (more flexible) formats for I/O and work files (CSV, EDF…)
    - \+ **Directly use great OS packages (MNE, scikit-learn…)**
    - \+ **Research oriented app** ➔ integrating NERV's works on graphs

Current limitations & future works

- **Future works**
  - *2024 internship in progress*: allowing other BCI softwares: **Timeflux**
    - − Slower… (no C++ optimizations! … or maybe?)
    - + More portable, all types of platforms
    - + TimeFlux also 100% Python, easier communication between softwares
  - **Tutorials using MOABB datasets**
  - **General GUI improvements**
    - « Click & play » philosophy for feature selection

HappyFeat - Tech details…

Version 0.2.0 (since June 2024!)

PyPi package / github repo

Testers, feedback & contributions are welcome (via github issues and PR…)

Full list of dependencies:

- **Python 3.9**
  - shutils>=0.1.0
  - Mne==1.5.1
  - Numpy==1.26.4
  - Pandas==2.2.1
  - PySide2==5.15.2.1
  - statsmodels>=0.13.1
  - scipy>=1.7.1
  - spectrum>=0.8.0
  - Matplotlib==3.8.4

- **OpenViBE v3.6.0**

HappyFeat – Conclusion

- **Available online:**

  github: https://github.com/Inria-NERV/happyFeat
  PyPI: https://pypi.org/project/happyfeat/
  documentation: https://happyfeat.readthedocs.io/

- **To be continued…**
  - + + **flexibility** (pipeline options, mixing metrics…)
  - + + **network metrics** (based on connectivity) (and associated viz. tools)
  - + + **classification algorithms options**
  - Fully autonomous Python version, “sandbox” for research purposes
  - Support for other BCI SW (starting with TimeFlux)
  - GUI & general interactivity improvement

Stay tuned!

Useful links

github.com/Inria-NERV/happyFeat

https://doi.org/10.1016/j.simpa.2023.100610

Thanks for your attention!

BCI Motor Imagery with OpenViBE in X-Men: First Class

Thanks for your attention! Any questions?

Graz'24 - WS2 - Sept. 9th 2024

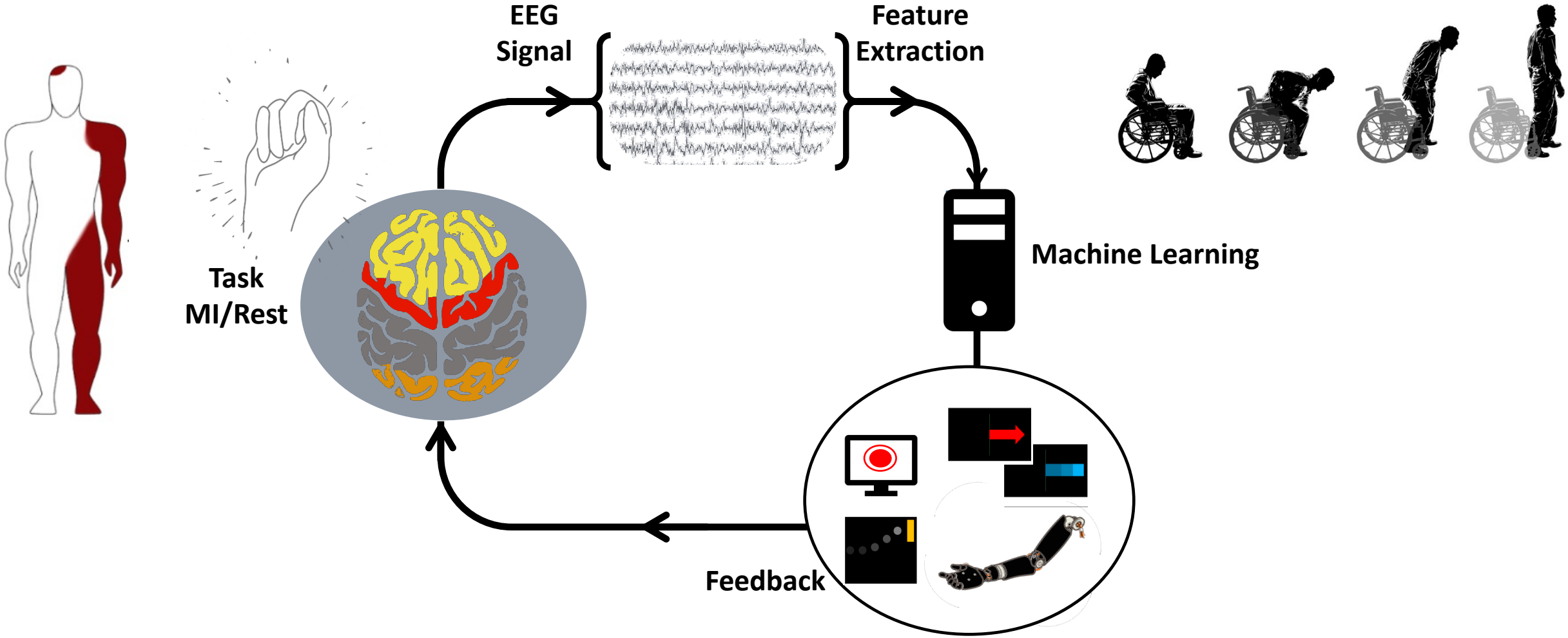
HappyFeat: an interactive and efficient BCI framework for clinical applications

Additional material

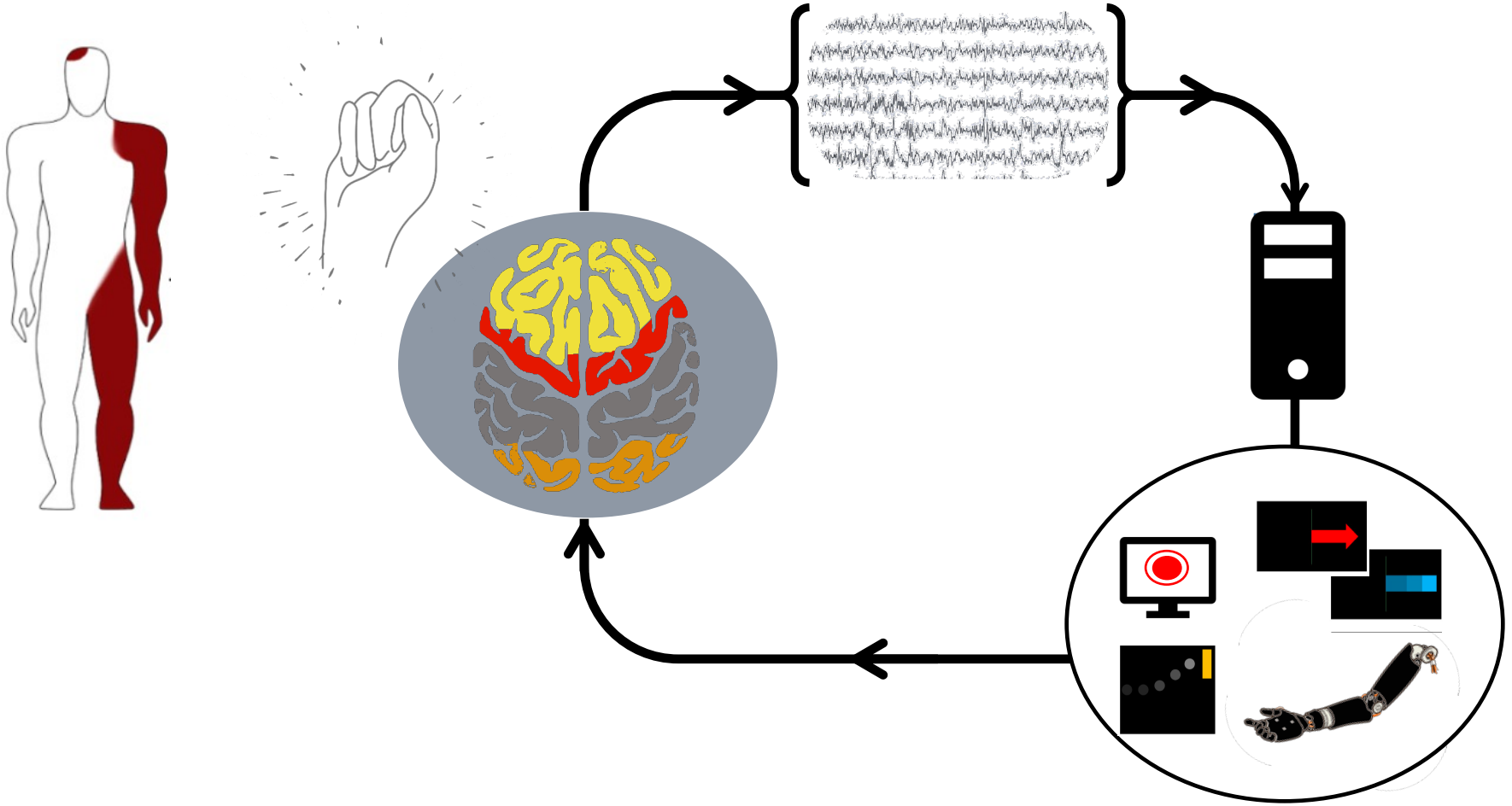
Arthur Desbois

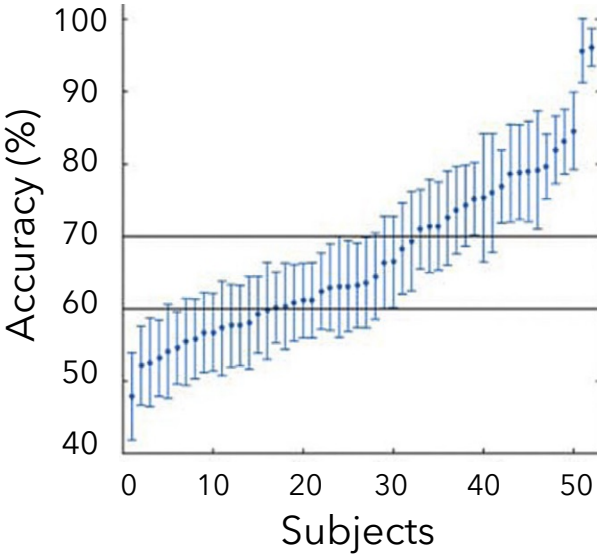
Inria Paris, NERV team, Paris Brain Institute (ICM)

Context - What is a “BCI”?



Context - Variabilities in BCI





Adapted from (Ahn & Jun, 2015)

Current BCIs fail to detect the mental intentions in ~30% of users – **BCI inefficiency**

Context – Variabilities in BCI

- **Sources of variabilities**
  - Data acquisition (eg EEG sensors impedances)
  - Tiredness
  - Brain signatures (eg spatial shifts)

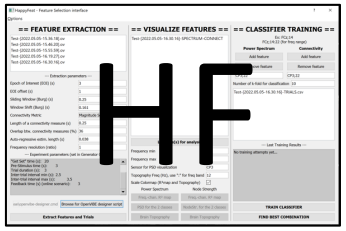
➔ Need to reduce the calibration time

➔ Need to identify the features that best capture the patients' intent

HappyFeat is a software aiming to simplify the use of BCI pipelines
in **clinical settings by non-expert users** by
assisting the extraction and the selection of the classification features.

HappyFeat - How? (with openvibe)

1. **Workspace creation/selection**

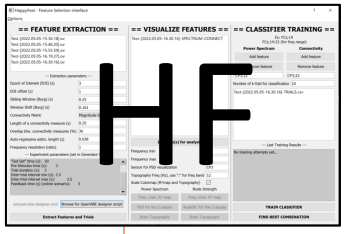


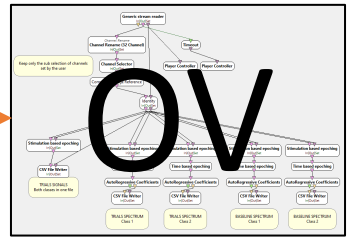
- Create a new environment (file tree, configuration, data structures) for the experiment/analysis
- … or select an already existing one.
- All user settings & manipulations are saved and available in the workspace for future usage or sharing:
  - Extraction parameters (spectral analysis, list of processed files…)
  - Training attempts (runs & features used, training accuracy…)

HappyFeat - How? (with openvibe)

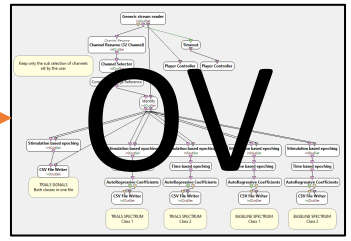
1. Workspace creation/selection
2. **MI Pipeline / “Feature type” selection**

- Selecting btw. multiple “template” scenarios depending on the use case (power spectrum, connectivity type…)
- Edit basic/common parameters (acquisition, extraction, training…)

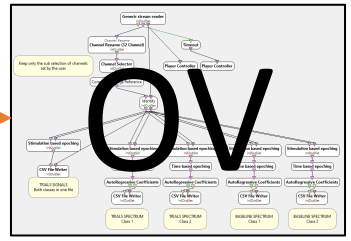




Extraction scenario



Training scenario

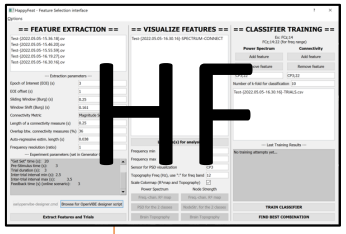


Online classif. scenario

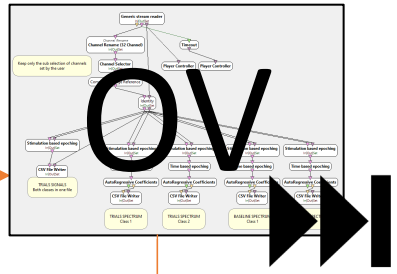
HappyFeat - How? (with openvibe)

1. Workspace creation/selection
2. MI Pipeline / “Feature type” selection
3. **Feature Extraction**

- **Select signal files**, and **extraction parameters** (lengths and overlap of windows, FFT size…)
- **Run** the generated extraction OpenViBE scenario (**in the background**) for all selected signal files:
  - ➔ **Extract metadata** (sampling freq, electrodes…)
  - ➔ Cut the signal to **regions of interest** (MI trials & baseline portions), **generate CSV file** with only these chunks (for the training step)
  - ➔ Apply a **signal processing** pipeline (PSD computation, connectivity measure…) to the signal chunks of interest, **generate CSV files for future analysis**
- **Runs in an autonomous thread:**
  You can do visualizations and training attempts for signals already processed in the meantime.



Extraction scenario



Signal 1 (.ov)

- Spectral Power (class 1) CSV
- Spectral Power (class 2) CSV
- Trials CSV
- Metadata CSV

Signal 2 (.ov)

- Spectral Power (class 1) CSV
- Spectral Power (class 2) CSV
- Trials CSV
- Metadata CSV

…

HappyFeat - How? (with openvibe)

1. Workspace creation/selection
2. MI Pipeline / “Feature type” selection
3. Feature Extraction
4. **Analysis, Feature Selection**

- Select one or multiple signals & load their spectral/connectivity data (CSV work files generated during “Feature Extraction”)

- Use different **Visualization Tools** to help find & select **features of interest** (FOIs) for training

  ➔ Frequency/channel R^2 map

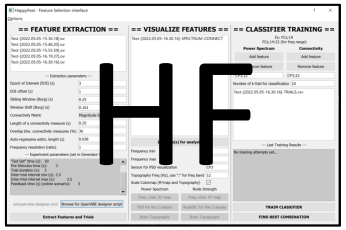
  ➔ PSD (or connect. metric) comparison btw. the 2 conditions (MI/REST) for a given electrode

  ➔ Time/frequency ERD/ERS analysis for each condition

  ➔ R^2 mapped as a brain topography for a given frequency (or range)

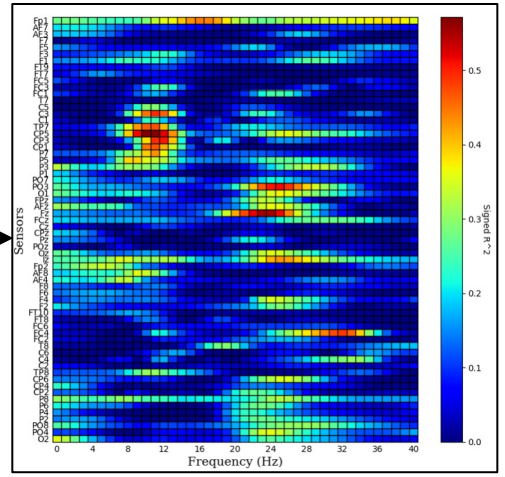
Combine as many visualization windows as you need

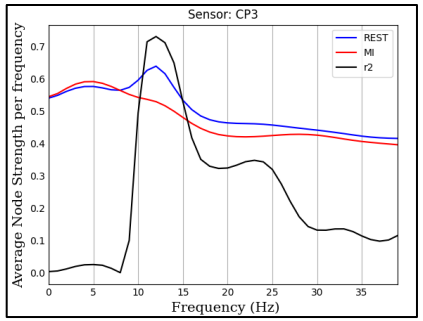
A “Dual metric” pipeline allows to show (for ex.) R^2 maps for both Power Spectrum and Connectivity in parallel

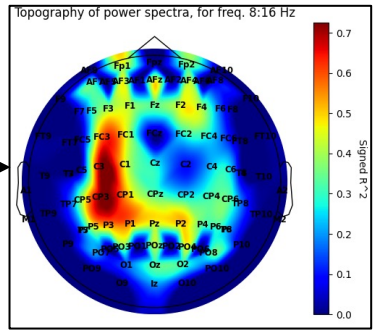


Signal 1
(.ov)

- Spectral Power (class 1) CSV
- Spectral Power (class 2) CSV
- Trials CSV
- Metadata CSV







HappyFeat - How? (with openvibe)

1. Workspace creation/selection
2. MI Pipeline / “Feature type” selection
3. Feature Extraction
4. Analysis, Feature Selection
5. **Classifier Training**

- Set one or more **Features of Interest** (Electrode/Freq.)

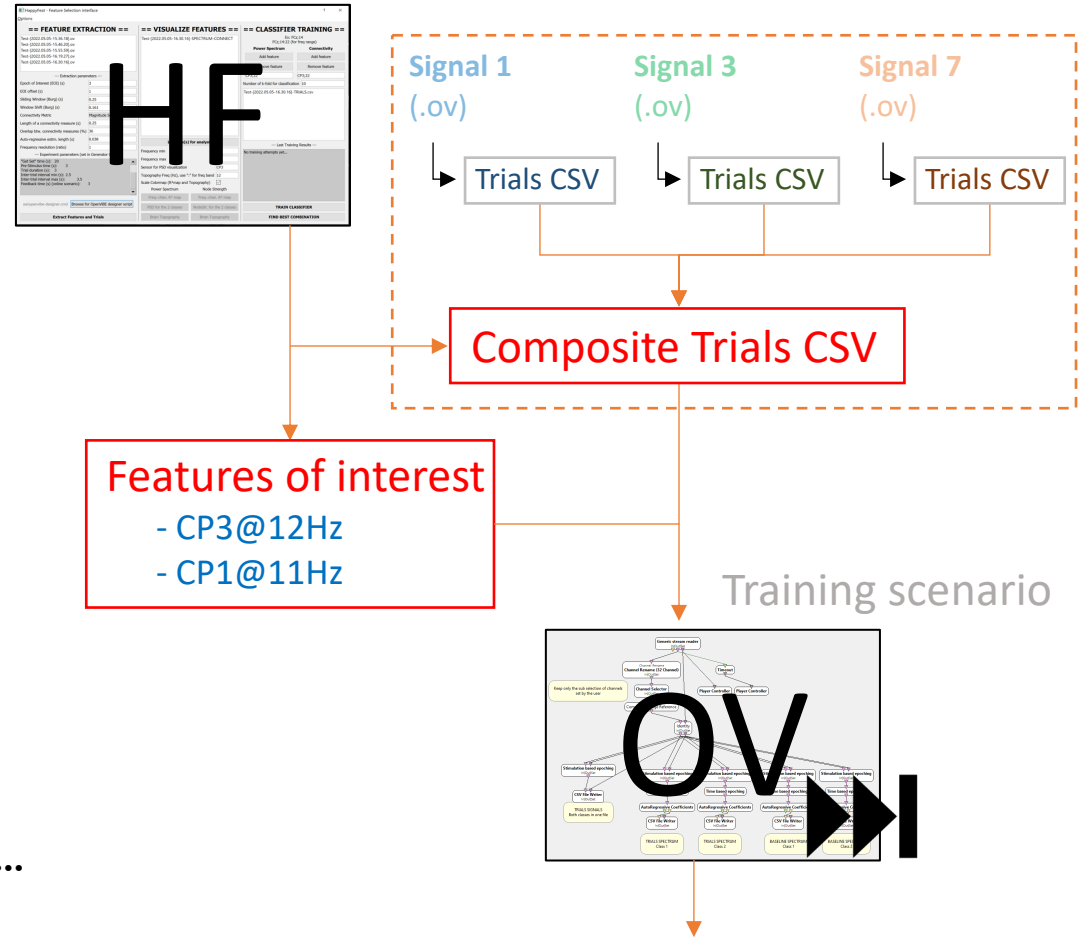
- **Select file(s)** with which you want to train your classifier
  If > 1 file : their trials **are automatically concatenated**

- **Run the Classifier Training scenario**
  (Auto. generated in step 1 + auto. edited with FOIs)
  ➔ Classification **ACCURACY** + **WEIGHTS**

Disappointing results? (“My accuracy is 50% ☹”)
Maybe try again with other features. **It only takes a few seconds…**

Satisfying results?! (“OMG 95%”)
Good news! The “Online Classification” scenario has already been automatically been updated with:

- Classifier training weights
- Features of interest used for training



Training accuracy “**score**”
+ Classifier **Weights**
+ **Online scenario updated**