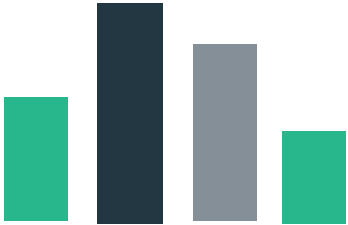


MOABB

Benchmark your BCI algorithms on a rich collection of Motor Imagery, ERP, SSVEP and c-VEP datasets

Workshop 2: Designing Brain-Computer Interfaces, from theory to real-life scenarios

Pierre Guetschel
Data-Driven NeuroTechnology Lab, Radboud University, Donders Institute, Nijmegen, Netherlands
Currently affiliated with META, Paris, France

September 9 — 9th Graz BCI Conference 2024

Radboud University Radboudumc

Mother Of All BCI Benchmarks (MOABB)

- Python library
- to compare/benchmark
- classification algorithms
- used for Brain-Computer Interfaces (BCI).

Design Philosophy

Reproducible research in BCI built on a rich Python ecosystem to design FAIR benchmarks with the help of a community.

(Un)reproducible Research in BCI

MOABB

Design Philosophy

Reproducible research in BCI built on a rich Python ecosystem to design FAIR benchmarks with the help of a community.

Why open source matters

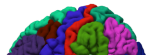
MOABB

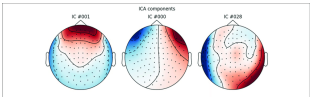
Reproductibility issues

Freesurfer Popular software for extracting features from MRI
→ Software variation lead to different conclusions

ICA Popular matrix factorization problem
→ Different results with different machines

eigs/eigsh Popular solver for eigenvalues decomposition
→ Solvers can lead to different outcome





Neurophysiological analysis is complex, require advanced processing
⇒ **Need for collective efforts to build open science**

Why Do We Need MOABB?

MOABB

Reproducible research in BCI has a long way to go...

- Unavailable code
- Exotic data format/data structure/language/toolboxes
- Preprocessed data (including errors)

No comprehensive benchmark of BCI algorithms
Huge waste of time for everyone

⇒ **MOABB aims to be the standard benchmark for any new paper**

- Comprehensive benchmark of popular BCI algorithms
- Extensive list of freely available EEG datasets
- Ranking algorithms with fair evaluations

Built on a rich ecosystem

MOABB

Design Philosophy

Reproducible research in BCI built on a rich Python ecosystem to design FAIR benchmarks with the help of a community.

MNE

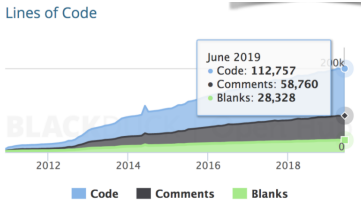
https://github.com/mne-tools/mne-python

History

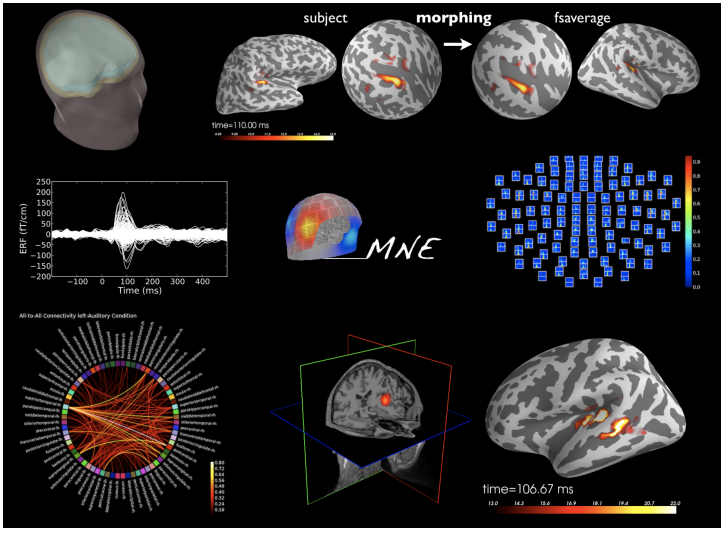
- based on C code developed for 18 years by Matti Hämäläinen
- Python started in 2010 at MGH, Boston

In a nutshell

- 361 contributors, 280k LOC
- mature codebase, large dev team
- $\sim$ 33 years of efforts (COCOMO)



$\Rightarrow$BSD licensed (commercial use ok)
$\Rightarrow$Mac / Linux / Windows


subject
morphing
fsaverage
time=110.00 ms
ERF (fT/cm)
Time (ms)
MNE
All-to-All Connectivity left-Auditory Condition
time=106.67 ms

Scikit-learn – accessible machine learning

MOABB

http://scikit-learn.org

- **Machine learning for all**
  ⇒No specific application domain
  ⇒No requirements in machine learning
- **High-quality Pythonic software library**
  ⇒Interfaces designed for users
- **Community-driven development**
  ⇒BSD licensed, very diverse contributors

Easy:

```
1 from sklearn.svm import SVC
2 classifier = SVC()
3 classifier.fit(X train, Y_train)
4 Y_test = classifier.predict(X_test)
```

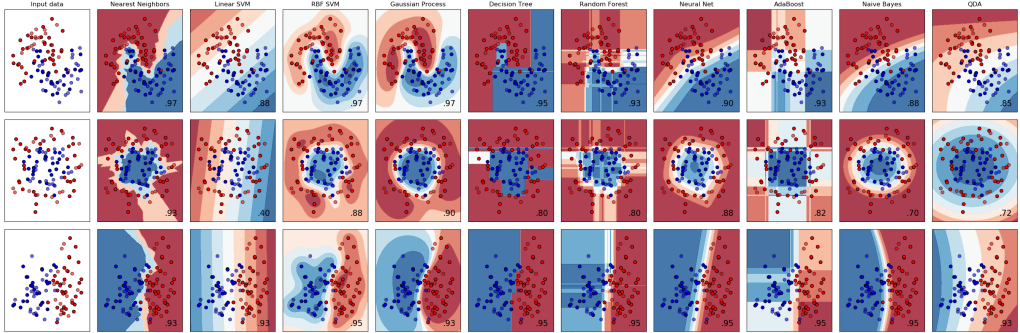


Figure: Comparison of several Scikit-learn classifiers on synthetic datasets.

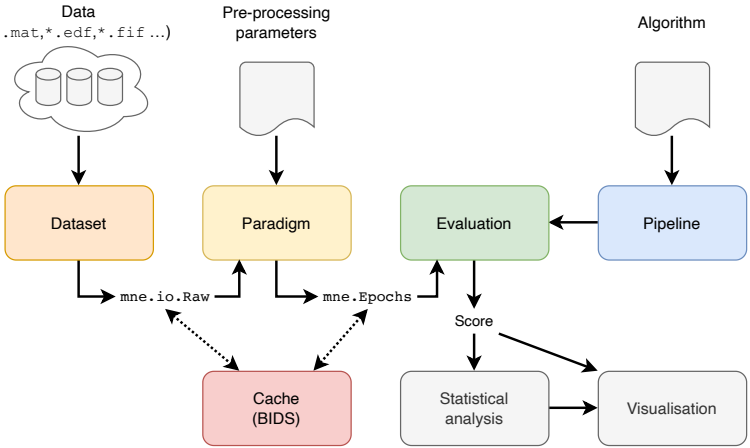
Framework Architecture

MOABB

Design Philosophy

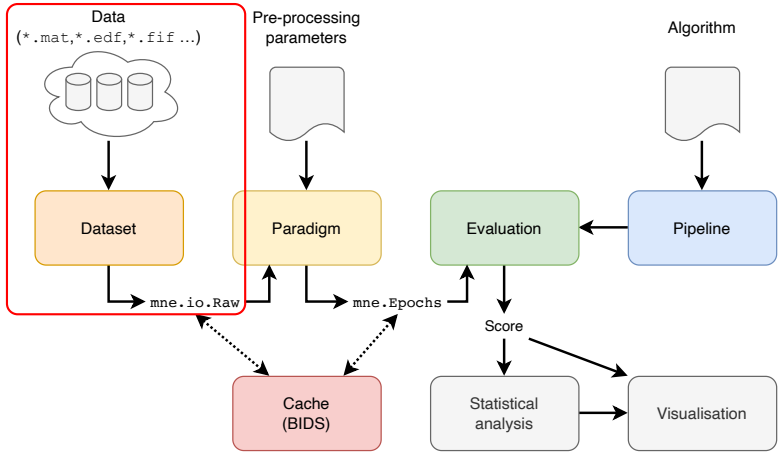
Reproducible research in BCI built on a rich Python ecosystem to design FAIR benchmarks with the help of a community.

MOABB Architecture



⇒All the components of MOABB

MOABB Architecture: Datasets



Dataset

- Stored locally, converted in MNE format
- Pick only subjects you need

MOABB Architecture: Datasets

- Wrapper around any data format (`.mat`, `.edf`, `.fif`, etc.);
- 16 Motor Imagery, 16 ERP, 7 SSVEP and 1 c-VEP datasets available;
- Only public datasets;
- Only un-processed datasets.

Dataset list

MOABB Architecture: Datasets

MOABB

Dataset list

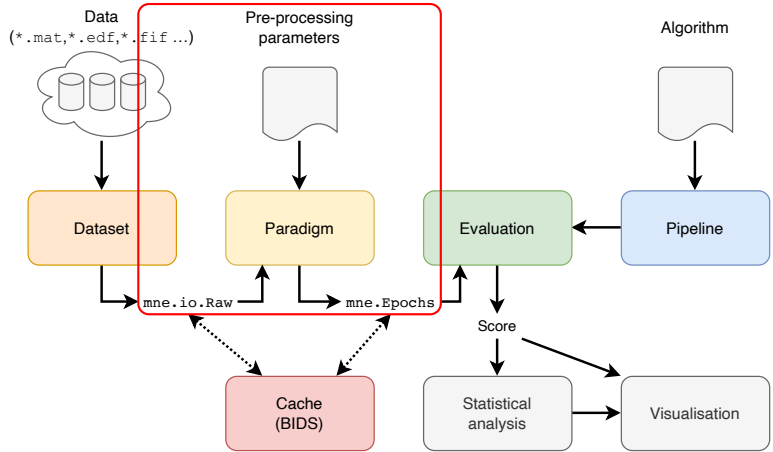
- Wrapper around any data format (`.mat`, `.edf`, `.fif`, etc.);
- 16 Motor Imagery, 16 ERP, 7 SSVEP and 1 c-VEP datasets available;
- Only public datasets;
- Only un-processed datasets.

```
1 from moabb.datasets import BNCI2014_001
2 dataset = BNCI2014_001()
3 data = dataset.get_data(subjects=[1, 2])
4
5 data  # dict[int, dict[str, dict[str, mne.io.Raw]]]
```

Returns nested dictionary containing:

- subjects,
  - sessions of the subjects,
    - and runs within the sessions.

MOABB Architecture: Paradigm



Paradigm

- Motor Imagery, P300, SSVEP, c-VEP
- Preprocessing

MOABB Architecture: Paradigm

```python
from moabb.paradigms import MotorImagery
paradigm = MotorImagery(fmin=1, channels=['C3', 'C4'])
X, labels, metadata = paradigm.get_data(dataset)

X          # numpy.ndarray
labels     # list[str]
metadata   # pandas.DataFrame
```

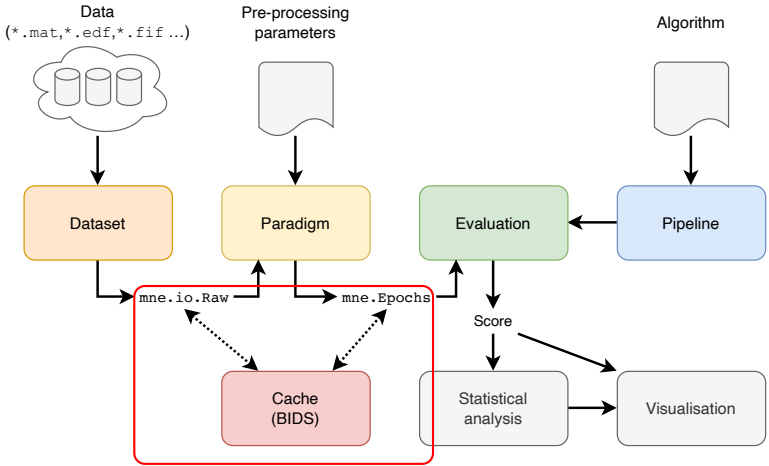
MOABB Architecture: Paradigm

```python
from moabb.paradigms import MotorImagery
paradigm = MotorImagery(fmin=1, channels=['C3', 'C4'])
X, labels, metadata = paradigm.get_data(dataset)

X          # numpy.ndarray
labels     # list[str]
metadata   # pandas.DataFrame
```

Alternatively, you can get MNE epochs:

```python
epochs, _, _ = paradigm.get_data(dataset, return_epochs=True)

epochs     # mne.Epochs
```

MOABB Architecture: Cache ★new★



Cache

- Disk cache: **raw** (`.edf`) or **pre-processed** (`_epo.fif` or `.npy`)
- In **BIDS** format for easy export.

MOABB Architecture: Cache ★new★

MOABB

Time for one subject of Zhou2016

Without cache 3.8 seconds

Raw 1.4 seconds

```
data = dataset.get_data(
    cache_config={'save_raw': True, 'use': True})
```

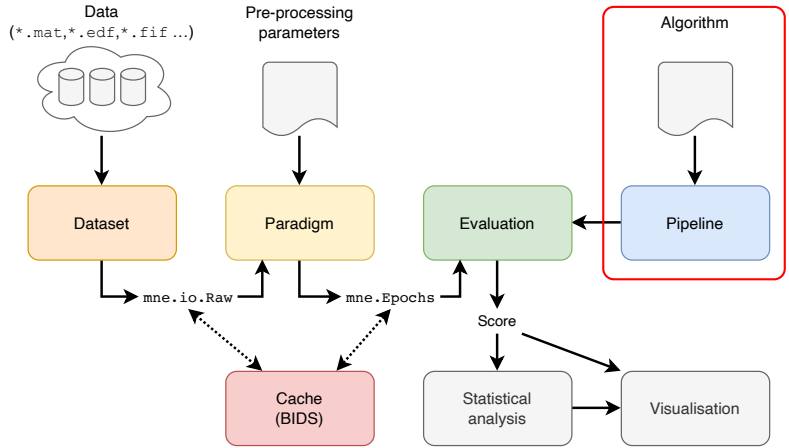
Epochs 0.8 seconds

```
epochs, _, _ = paradigm.get_data(
    dataset,
    return_epochs=True,
    cache_config={'save_epochs': True, 'use': True})
```

Numpy array 0.6 seconds

```
X, _, _ = paradigm.get_data(
    dataset,
    cache_config={'save_array': True, 'use': True})
```

MOABB Architecture: Pipelines



Pipelines

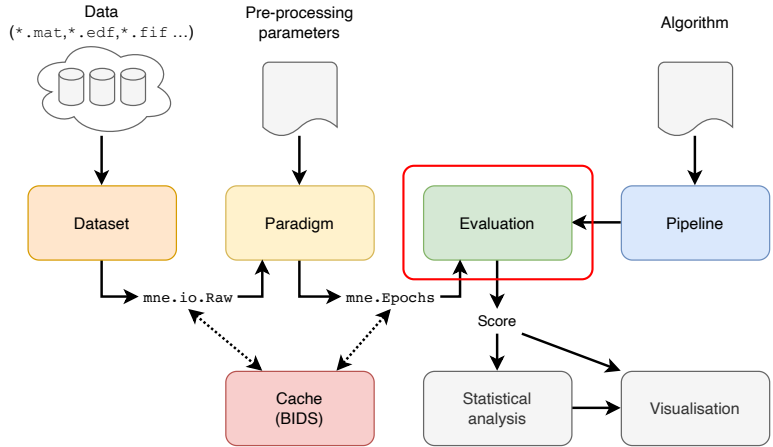
- All steps required for obtaining a prediction
- Scikit-learn style

MOABB Architecture: Pipelines

A Scikit-learn pipeline example:

```python
from moabb.pipelines.features import LogVariance
from sklearn.svm import SVC
from sklearn.pipeline import make_pipeline
classifier = make_pipeline(
    LogVariance(),  # step 1
    SVC(),          # step 2
)

classifier  # sklearn Pipeline
```

MOABB Architecture: Evaluations

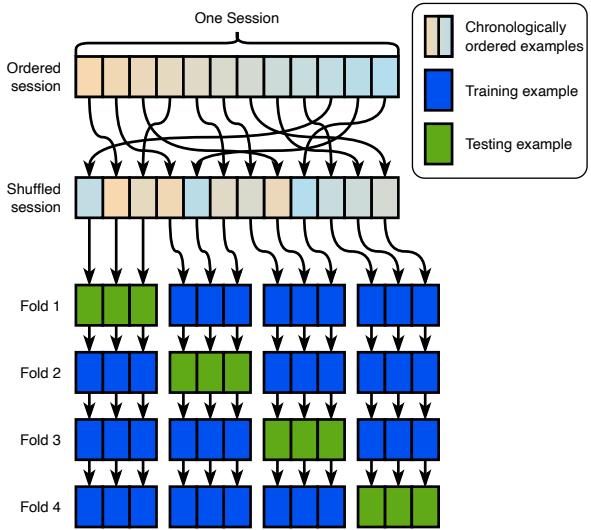


Evaluations

- Defines a scoring method (AUC, accuracy, ...)
- within or across session, across-subject, ...

MOABB Architecture: Evaluations – Within-Session

- Within-session,
- Shuffled,
- 5-folds cross-validation.

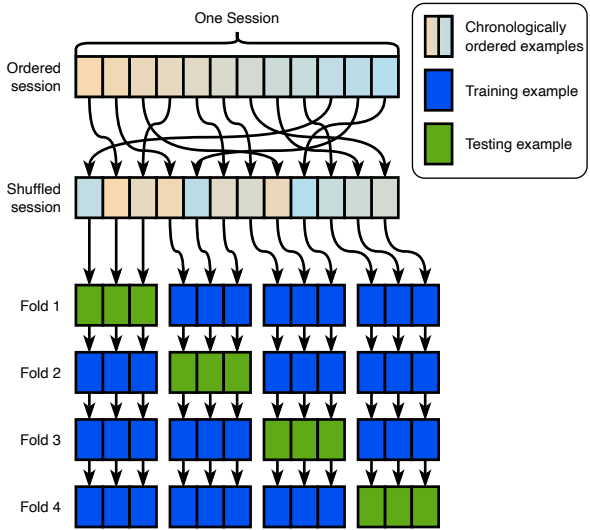


MOABB Architecture: Evaluations – Within-Session

- Within-session,
- Shuffled,
- 5-folds cross-validation.

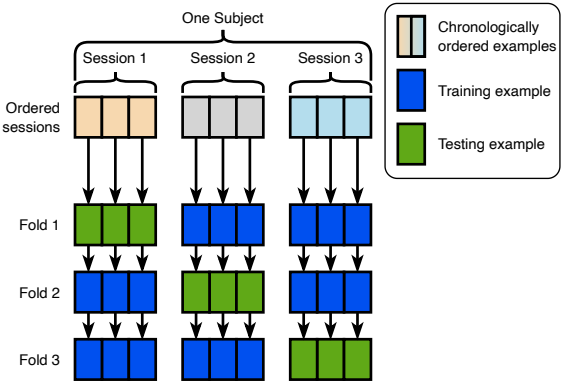
Arriving soon:

- Within-session,
- Pseudo-online evaluation,
- (respecting chronological aspect of data).



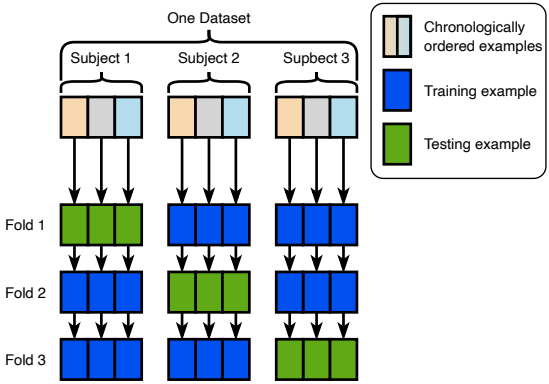
MOABB Architecture: Evaluations – Cross-Session

- Within-subject,
- Leave-one-session-out cross-validation.



MOABB Architecture: Evaluations – Cross-Subject

- Within-dataset,
- Leave-one-subject-out cross-validation.



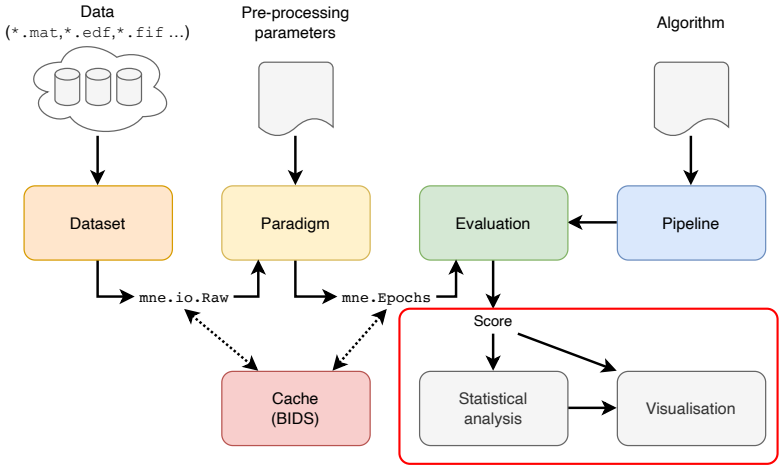
MOABB Architecture: Evaluations

```python
from moabb.evaluations import WithinSessionEvaluation
evaluation = WithinSessionEvaluation(
    paradigm=paradigm, datasets=[dataset])
results = evaluation.process({'AM+SVM': classifier})

results  # pandas.DataFrame
```

Results are easy to save as .csv

```python
results.to_csv('my_results.csv')
```

MOABB Architecture: Results

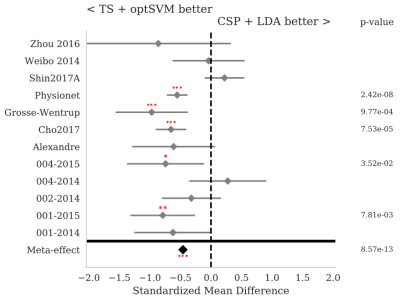


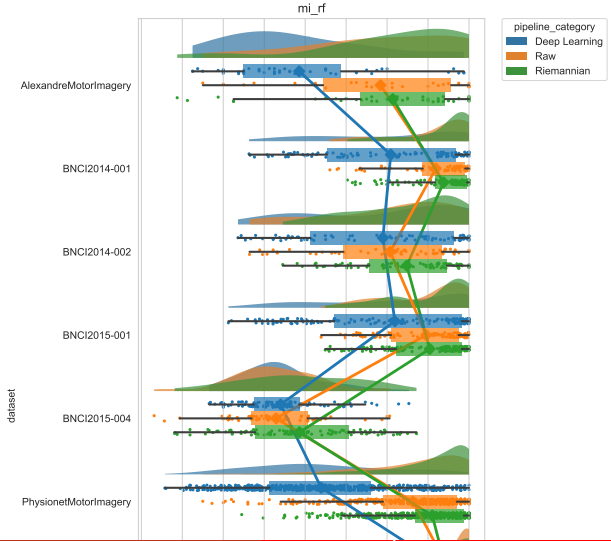
Results

- Statistics & visualization
- Results are store in a DataFrame

Fair and Reproducible Benchmarks

1. Load multiple datasets
2. Apply pipelines
3. Run meta-analysis and plot





Community of MOABB

MOABB

Design Philosophy

Reproducible research in BCI built on a rich Python ecosystem to design FAIR benchmarks with the help of a community.

An NTX Community Project

MOABB

Maintainers:

Sylvain Chevallier

Bruno Aristimunha

Igor Carrara

Pierre Guetschel

Sara Sedlar

Founders:

Alexander Barachant

Vinay Jayaram

Contributors:

How To Get Started or Contribute

Getting-started tutorial

Check the github and the documentation

- `https://github.com/NeuroTechX/moabb`
- `https://neurotechx.github.io/moabb/`

Discuss during Office Hours or on Gitter

- `https://github.com/NeuroTechX/moabb/issues/191`
- `https://gitter.im/moabb_dev/community`

Possible contributions:

- Add new datasets,
- Add working examples and use cases,
- Help on character-level decoding of ERP and c-VEP,
- ...

Thank you !