Cerebral interface, open science carbon footprint

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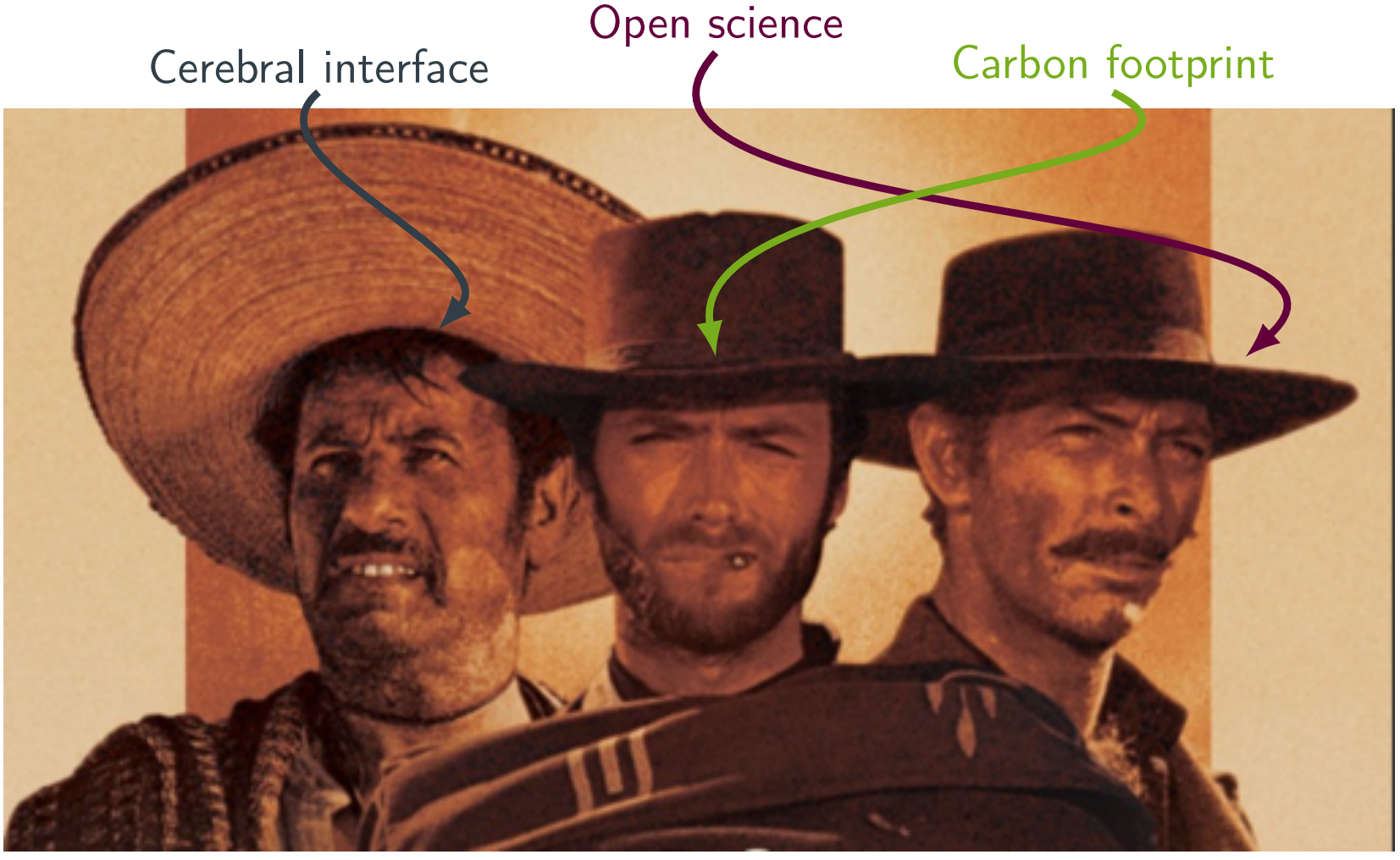
Cerebral interface

Open science

Carbon footprint


Cerebral interface
Open science
Carbon footprint

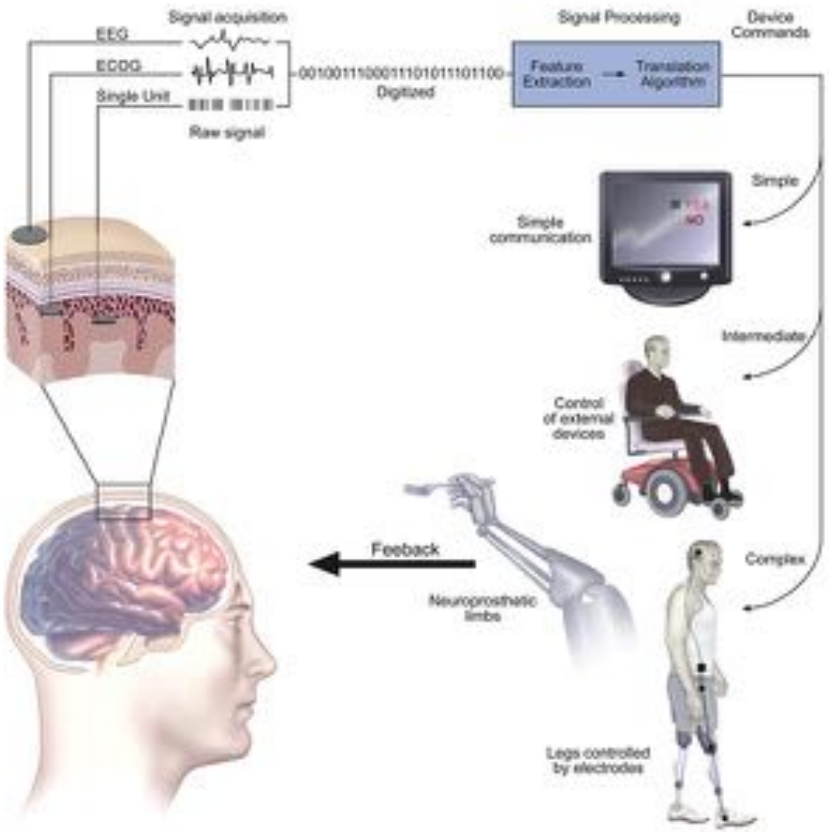
Brain-Computer Interface

BCI for non-muscular communication

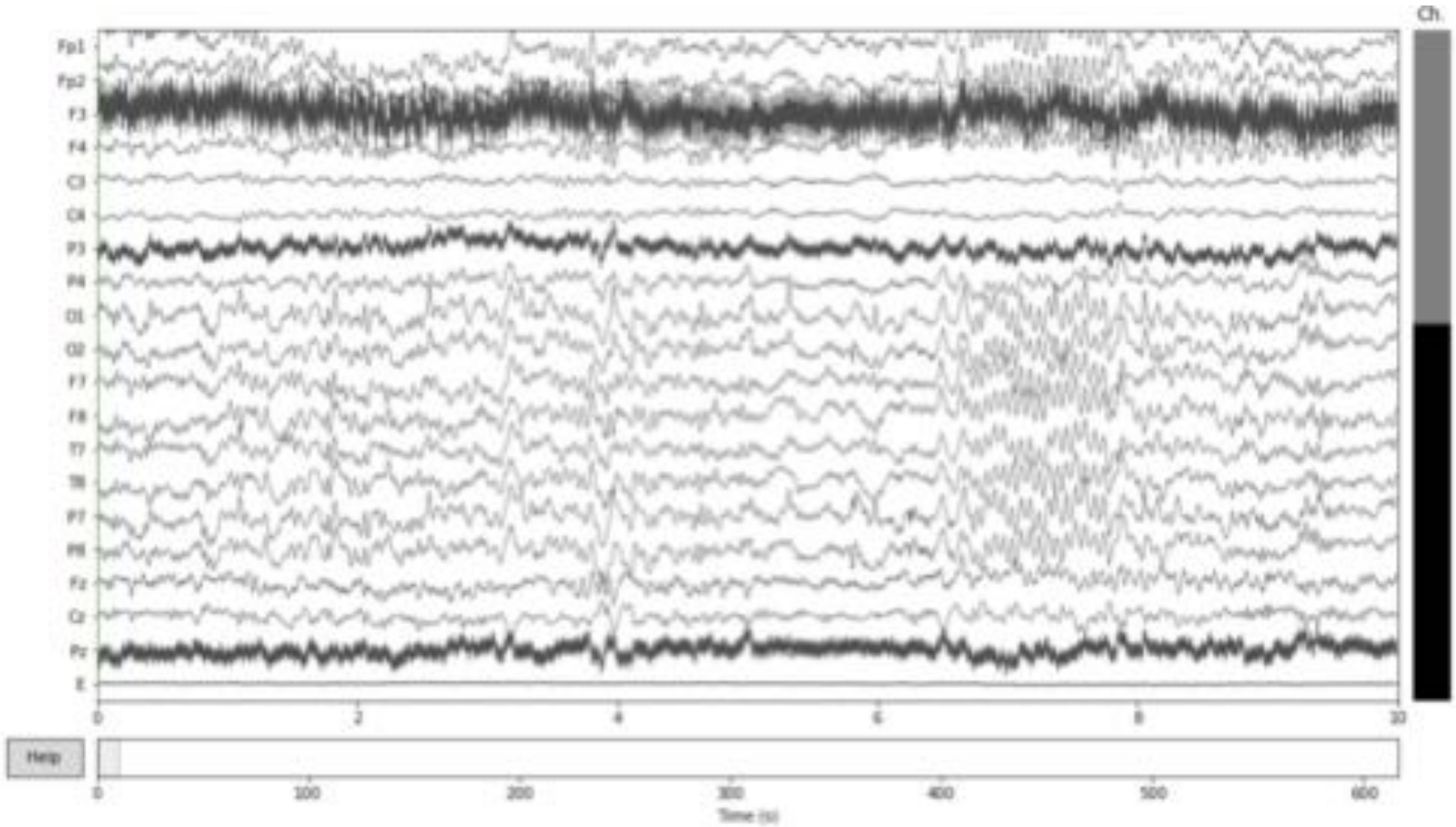
A challenging task:

1. Multivariate time series
2. Noise and artifacts
3. Human in the loop
4. Bulk of raw data
5. Few reference datasets

⇒Thrilling applications
⇒Supportive community



Sample EEG Recording



Geometric Approaches for Brain Signals

Manifold of symmetric positive-definite matrices (SPD)

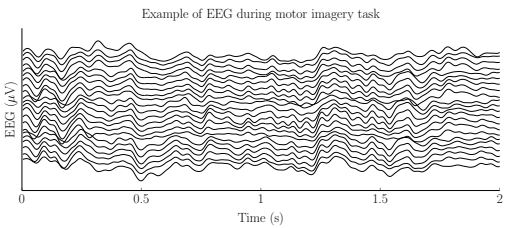
$$\mathcal{M}_C = \left\{\Sigma \in \mathbb{R}^{C\times C} : \Sigma = \Sigma^\intercal \text{ and } x^\intercal \Sigma x > 0, \forall x \in \mathbb{R}^C \backslash 0\right\}$$

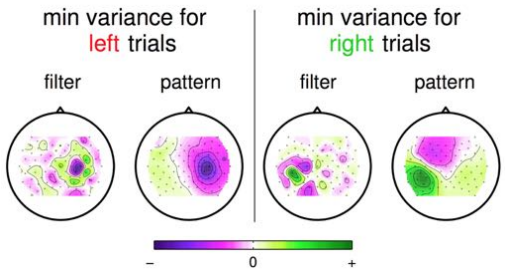
Context

Covariance matrix: $\Sigma = \frac{1}{N-1} X X^\intercal$

Brain-Computer Interface

EEG data $\rightarrow$ spatial filtering $\rightarrow$ classification





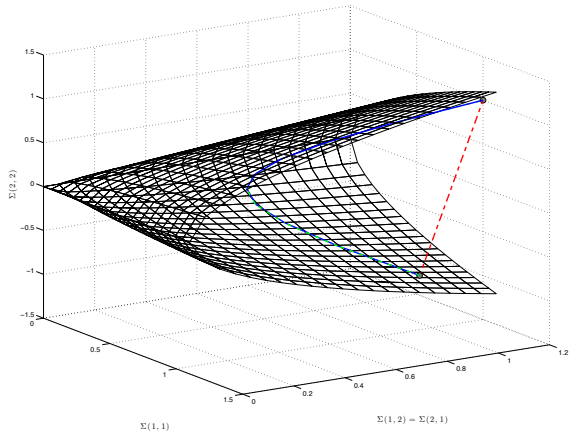
Manipulating Covariance Matrices

$X \in \mathbb{R}^{C \times N}$, C electrodes, N time samples

$\Sigma = \frac{1}{N} X X^\intercal$

- Affine-invariant (Fisher) distance

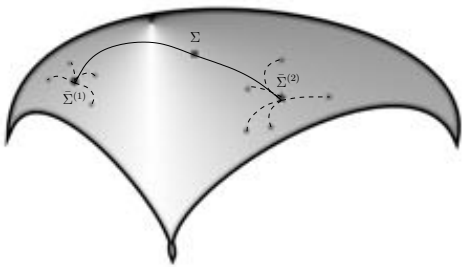
$$\delta(\Sigma_1, \Sigma_2) = \left\| \log(\Sigma_1^{-\frac{1}{2}} \Sigma_2 \Sigma_1^{-\frac{1}{2}}) \right\|_F$$



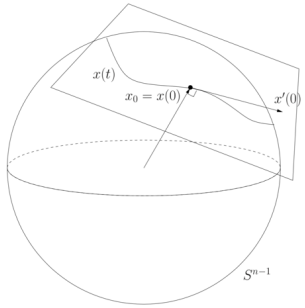
- Mean is $\bar{\Sigma} = \mu(\{\Sigma_i\}) = \arg\min_\Sigma \sum_{i=1}^{N} \delta^2(\Sigma_i, \Sigma)$

Simple Classifiers for EEG

Minimum Distance to Mean (MDM)



Tangent Space Classification



State-of-the-art results:

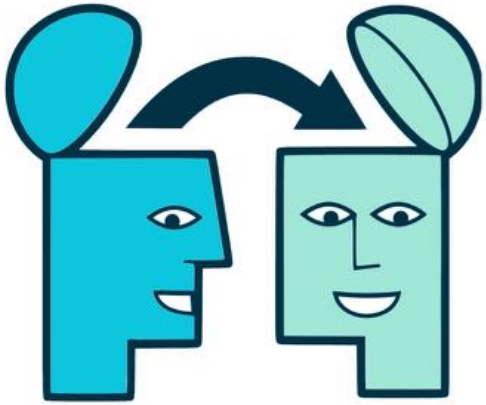
P300 - Brain Invaders		SSVEP - Exoskeleton		MI - BCI IV IIa	
Method	Acc. (std)	Method	Acc. (std)	Method	Acc. (std)
MDM	**89.04 (8.79)**	MDM	**89.85 (8.0)**	TSLDA	**70.2 (17.1)**
SWLDA	86.08 (10.05)	CCA	87.50 (15.1)	CSPLDA	65.1 (17.9)
XDAWN	86.26 (9.96)	FBCCA	87.40 (15.7)	SVM	63.2 (15.2)

Deep learning is not better than Riemannian approaches [Schirrmeister, 2017]

Open Problems

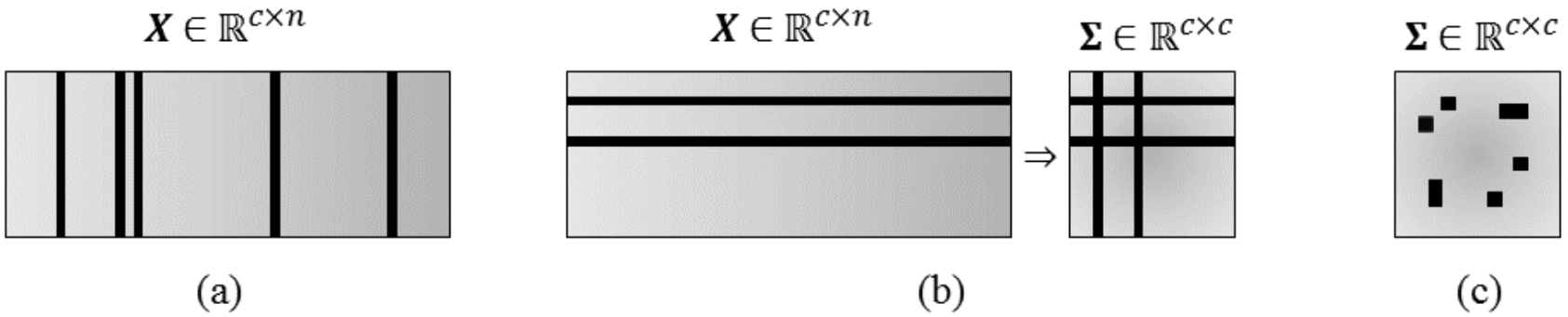
Missing Data

Transfer Learning



Practical Issues for Riemannian BCI

- Incapable of dealing with rank-deficient matrices
  $\Rightarrow$ Electrodes can get disconnected
  $\Rightarrow$ Signals can be corrupted and discarded



a Missing samples / observations in matrix X

b Missing variables / channels in matrices X and $\Sigma = \frac{1}{n} X X^\top$ (under the hypothesis that X is centered)

c Missing elements (at random) in the matrix Σ

Missing Data in EEG

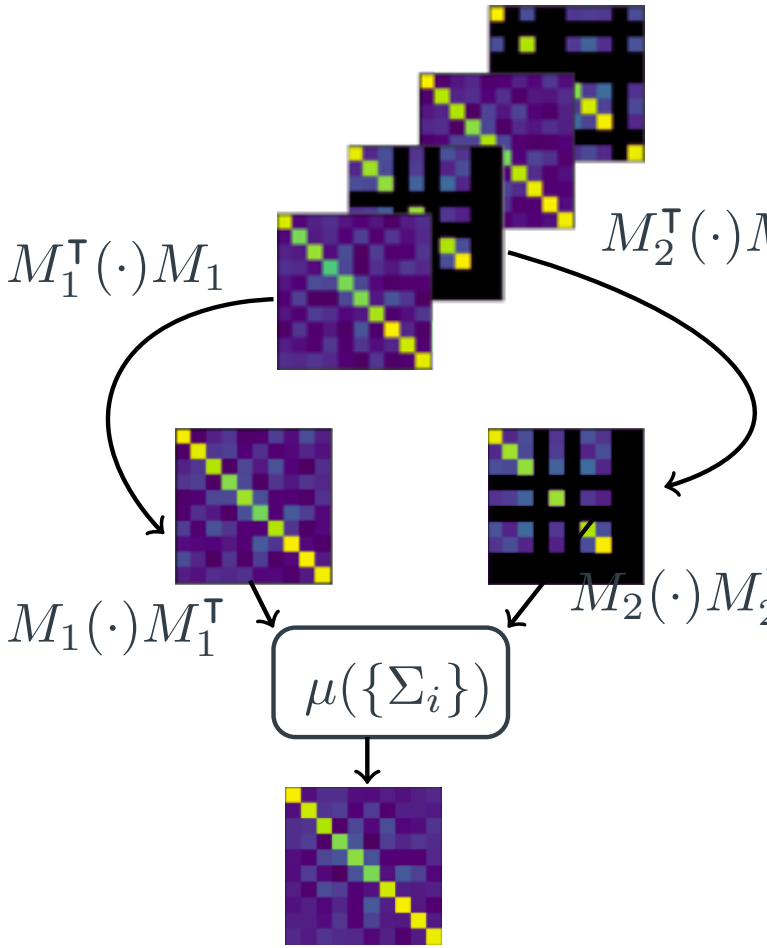
- Noisy/missing channel badly affects covariance
- Trusted information can be written as:

$$\hat{\Sigma} = M^\top \Sigma M$$

with M a matrix of mask

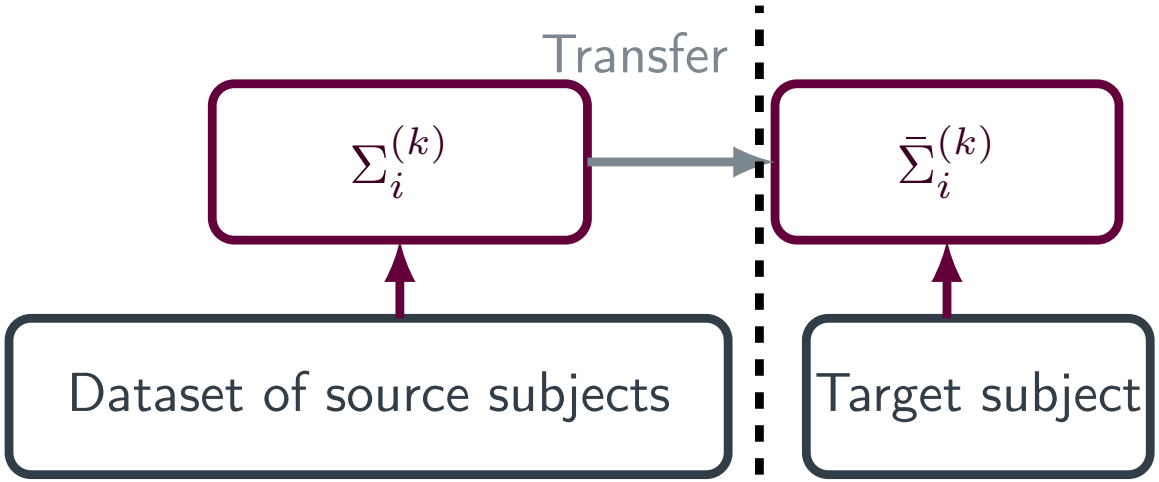
The masked Riemannian mean is defined as:

$$\bar{\Sigma} = \arg\min_{\Sigma} \frac{1}{2} \sum_{i=1}^{N} \delta^2(M_i^\top \Sigma_i M_i, M_i^\top \Sigma M_i)$$



Transfer Learning

- How to deal with inter-session and **inter-subject variabilities**?
  → Finding good examplar in database for new user
- Reducing (or even removing) the calibration phase
  → cross-subject transfer to address inter-subject variability



Open science

Why Open Source Matters

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

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

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

⇒ **Need for standard benchmark for any new paper**

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

MNE

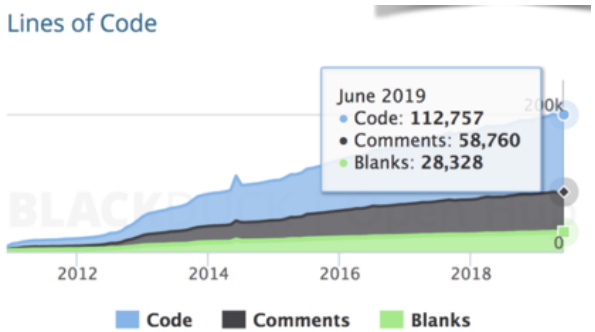
https://github.com/mne-tools/mne-python

History

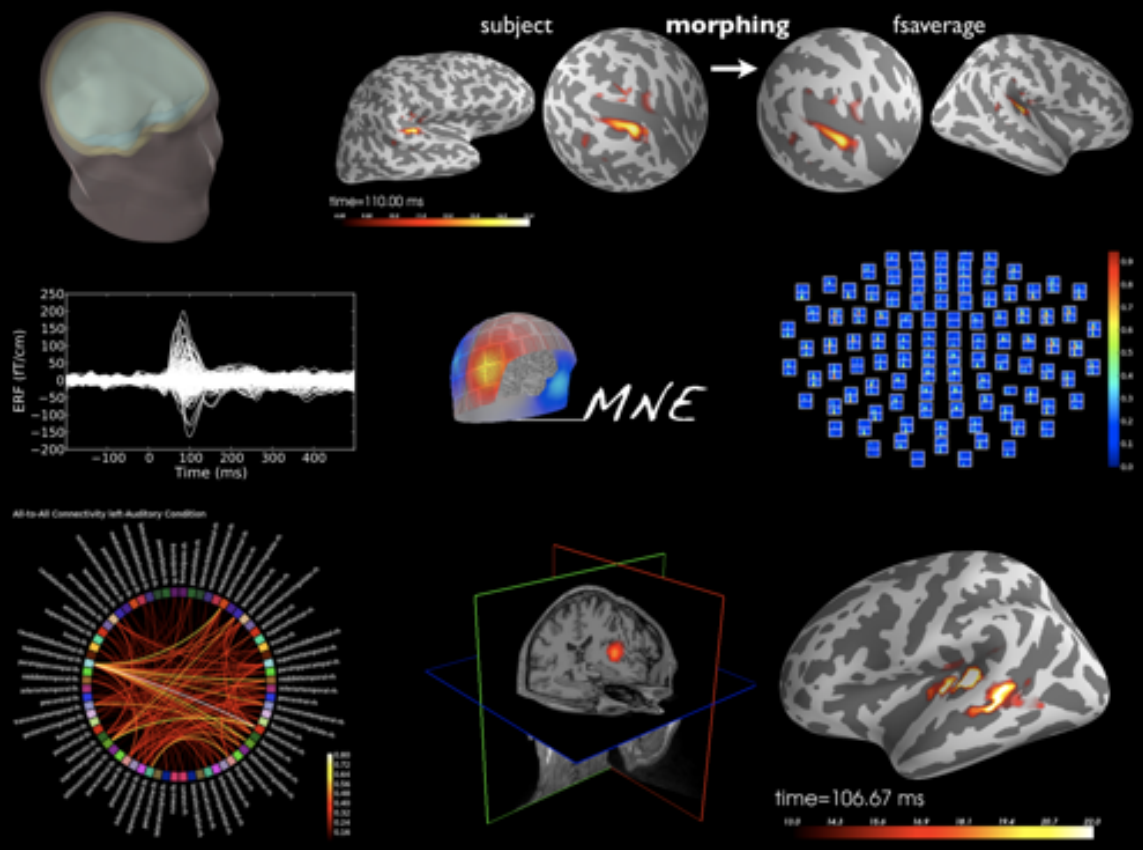
- based on C code developed for 18 years by Matti Hämäläinen
- Python started in 2010 at MGH, Boston

In a nutshell

- 236 contributors, 100k LOC
- mature codebase, large dev team
- $\sim$ 29 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

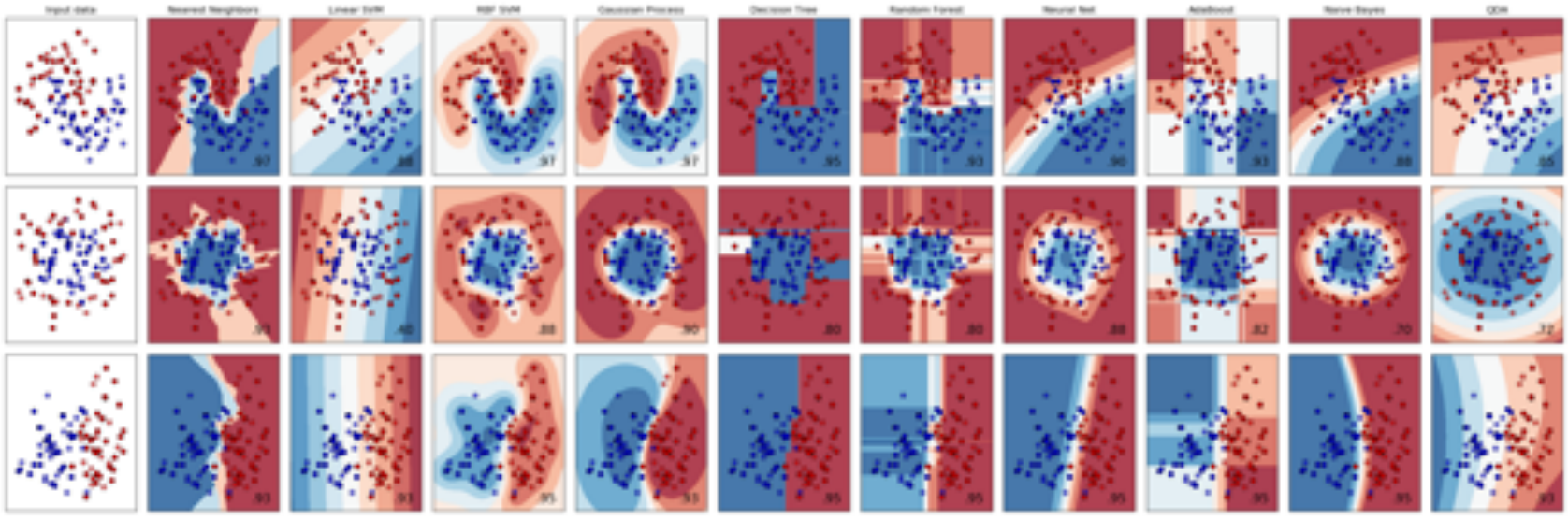
Scikit-learn – Accessible Machine Learning

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, diverse contributors

Easy as py:

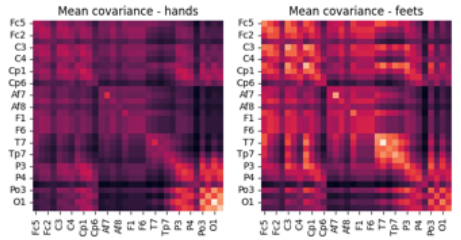
```
%      from sklearn import svm
       classifier = svm.SVC()
       classifier.fit(X train, Y_train)
       Y_test = classifier.predict(X_test)
```

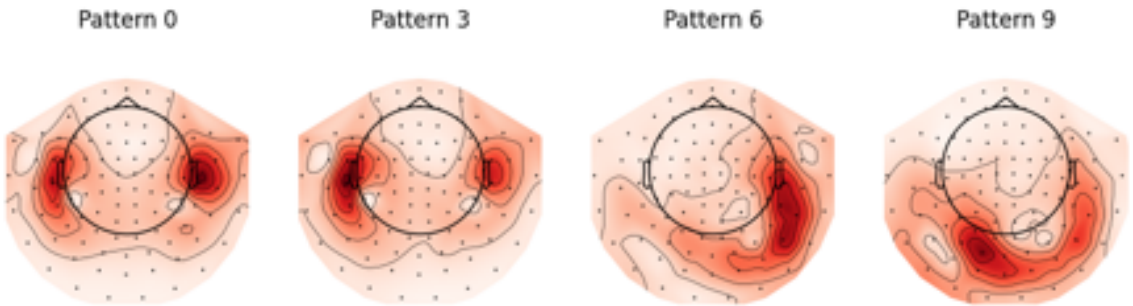

Input data
Nearest Neighbors
Linear SVM
RBF SVM
Gaussian Process
Decision Tree
Random Forest
Neural Net
AdaBoost
Naive Bayes
QDA
.97
.88
.97
.97
.95
.93
.90
.93
.88
.95
.90
.88
.90
.80
.80
.88
.82
.70
.72
.93
.91
.95
.93
.95
.95
.95
.95
.95
.93

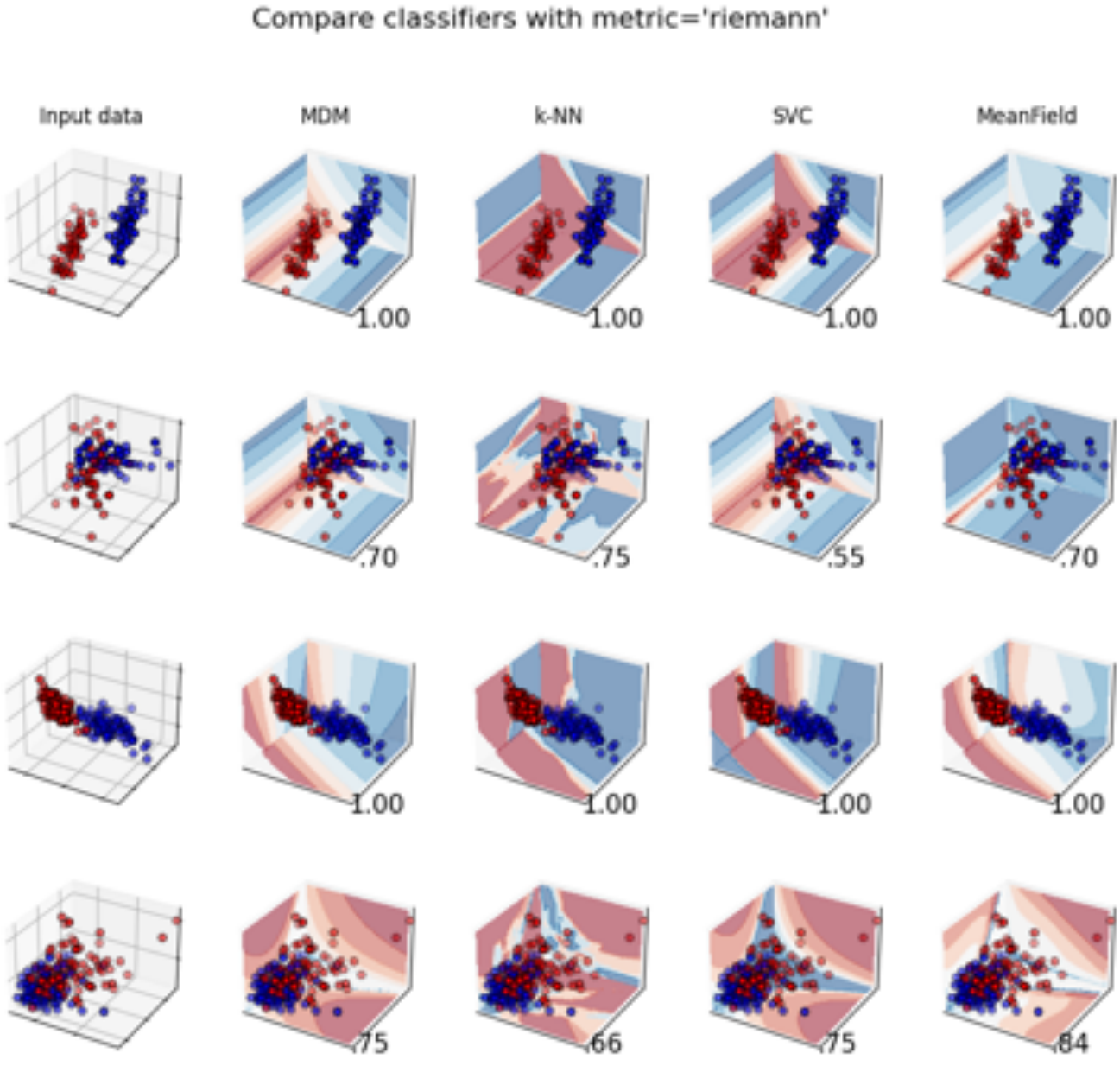
PyRiemann – Riemannian ML for All !

https://pyriemann.readthedocs.io

- **Scikit-learn compatible**
  ⇒High-level interface
  ⇒Wide machine learning models
- **Multivariate time series**
  ⇒Biosignals: MEG, EEG, EMG
  ⇒Radar, sensor networks, ...
- **Batteries included**
  ⇒Preprocessing, transfer learning
  ⇒Documentation, examples

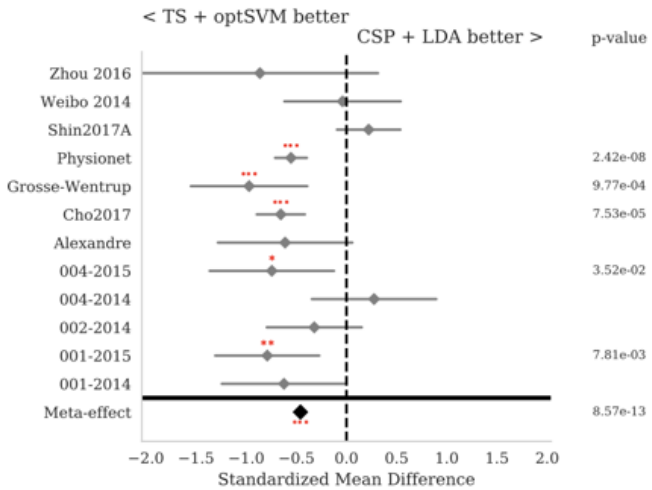




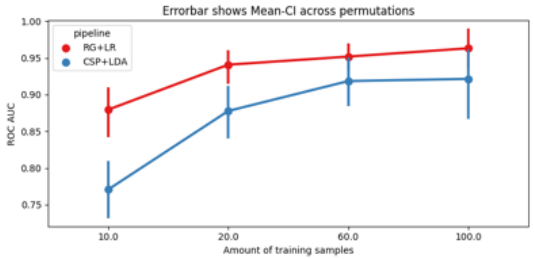

Compare classifiers with metric='riemann'
Input data
MDM
k-NN
SVC
MeanField
1.00
1.00
1.00
1.00
.70
.75
.55
.70
1.00
1.00
1.00
1.00
.75
.66
.75
.84

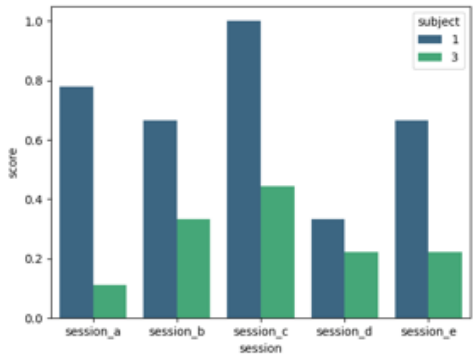
MOABB: Fair and Reproducible Benchmarks

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



Last Year Advances & Hot Topics





NeurIPS data competition `beetl.ai`
for transfer learning in BCI

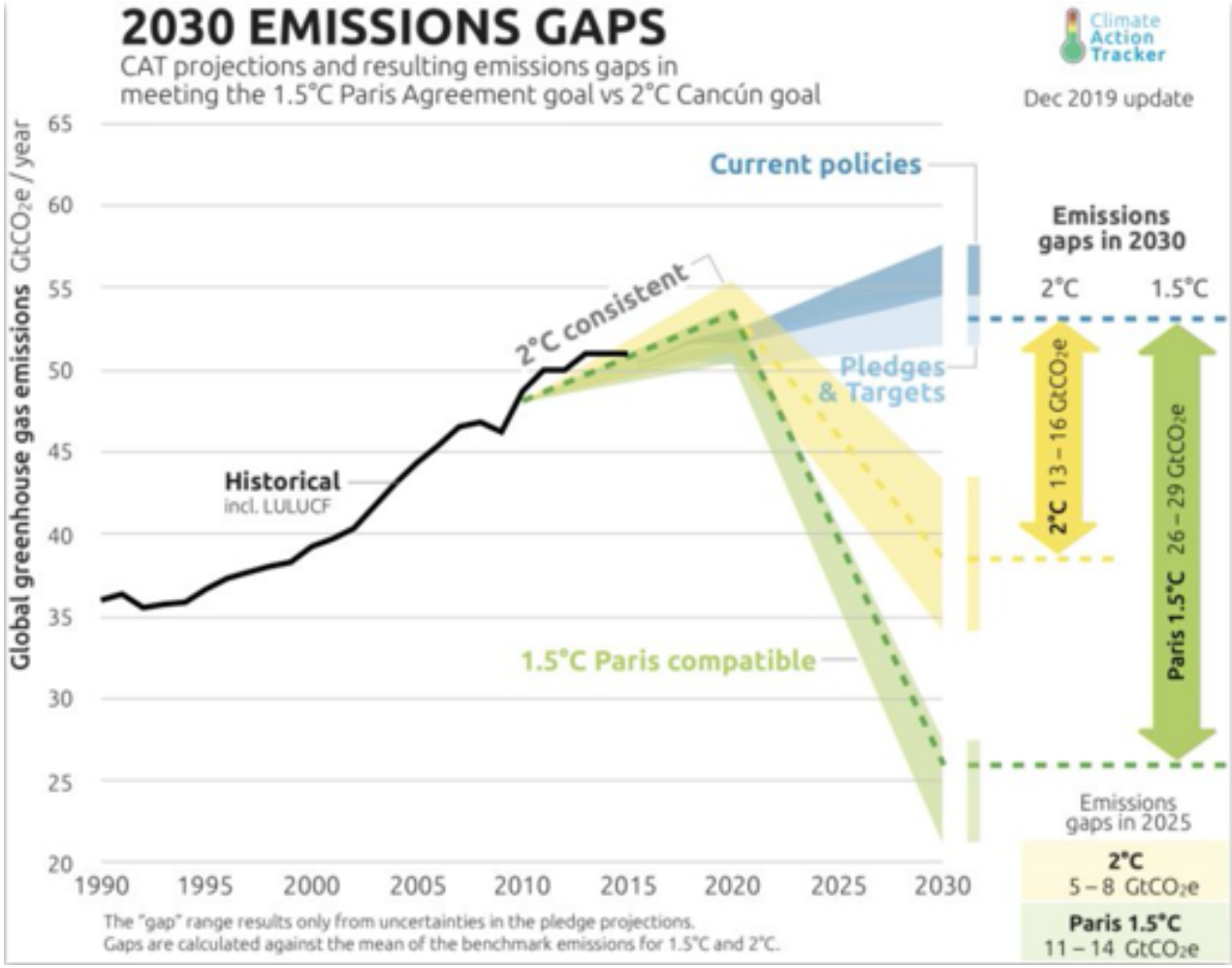
- Support latest python, MNE and sklearn version
- 10 new datasets
- Better download support with pooch
- Learning curves

Open for contributions and new paper in preparation!
Check `https://github.com/NeuroTechX/moabb`


Carbon footprint

Reducing Carbon Footprint

Climate change,
Biodiversity
preservation,
Sustainable world



Climate Impact of Research

Research is negligible in terms of GHG emission, actors with major impact should take action

- Scientists' voices have a special value in public discussion, call for congruence
- Academic liberty offers a safe space to discuss and propose solutions
- Leader role to play, to stimulate public and industrial sectors

[Lamb et al., 2020]

First Step: Evaluate

9 different coun-
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aving respectively
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idation is close to
data with a 5-fold
our opinion, to the
ed on multiple es-

l the requirements
LETTO (RIeman-
To cOnnectivity)
associated with an
take into account
to the competi-
prove our method
heory behind RG,

produce similar average patterns but this raises as well the question of their individual variability. We plan to study those questions in a long version of this draft.

6. ENVIRONMENTAL IMPACT

The approach taken in this submission does not require lengthy computation on GPU clusters or HPC, in order to reduce its environmental impact. The team members relied mainly on Slack, git and overleaf to communicate. As there is no direct estimation of the footprint of these services, we use the email scenario of The Shift Project report [26] as a surrogate. We estimate that this submission generated the equivalent of 62 gCO_2. The Shift Project made a contested estimation for the environmental impact of watching a video in HD on a streaming service [27]. The impact of our submission lies thus between streaming the theater-released version and the extended version of the *"Lord of the Ring"* trilogy.

Why Not Start Today?

EDUCATION

Ten simple rules to make your research more sustainable

Anne-Laure Ligozat[1,2]*, **Aurélie Névéol**[1], **Bénédicte Daly**[1], **Emmanuelle Frenoux**[1]

1 Université Paris-Saclay, CNRS, LIMSI, Orsay, France, **2** ENSIIE, Evry-Courcouronnes, France

Rule 2: Be informed

Rule 3: Prefer train over plane

Rule 5: Work collectively and reproducibly

Rule 7: Evaluate the impact of your research practices

...

Rule 1: Cherry-picking is allowed

Thank you !