Spatial Graph Signal Interpolation with an application for Merging BCI Datasets with various Dimensionalities

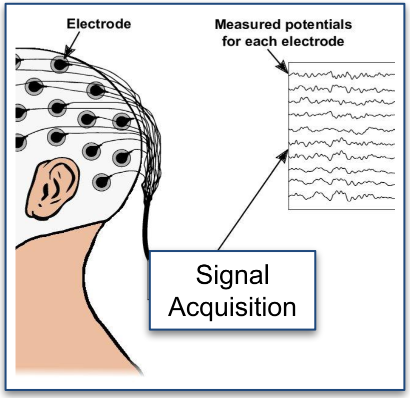
Yassine El Ouahidi
Lucas Drumetz
Giulia Lioi
Nicolas Farrugia
Bastien Pasdeloup
Vincent Gripon

ICASSP 2023

IMT Atlantique
Bretagne-Pays de la Loire
École Mines-Télécom
Région
BRETAGNE

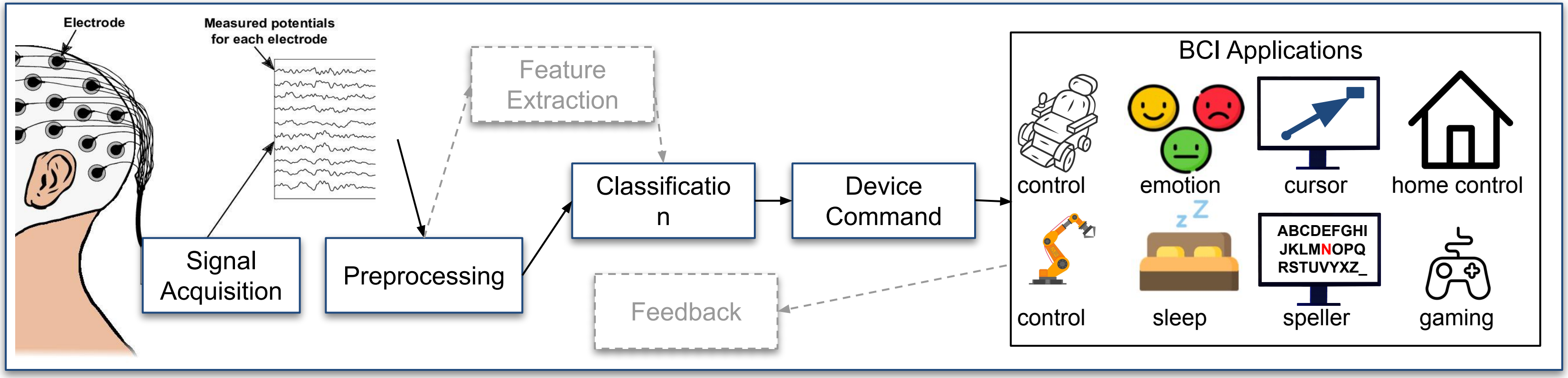
08/06/2023

Context - Brain Computer Interface (BCI)

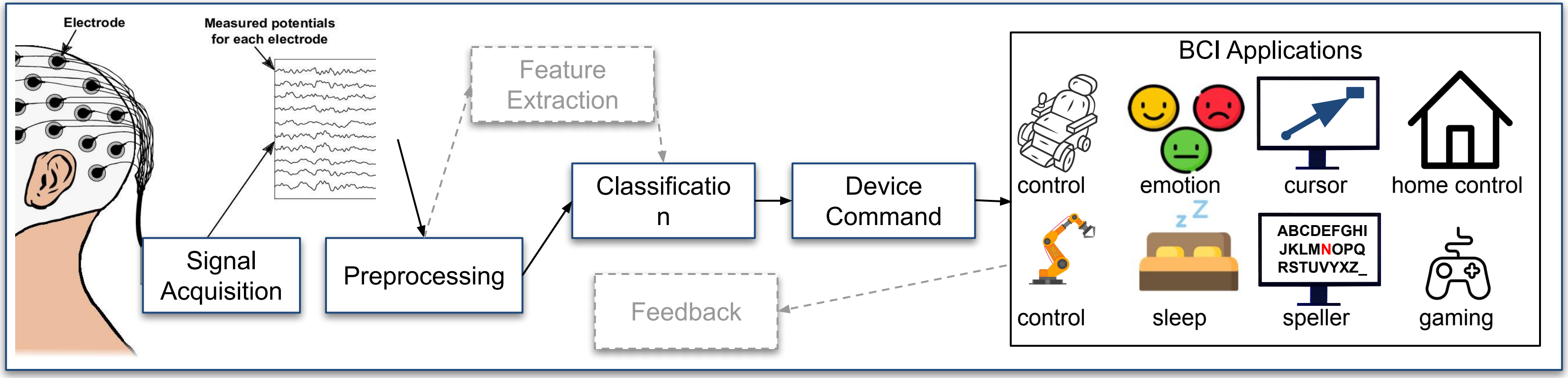


ElectroEncephaloGraphy
(EEG)

Context - Brain Computer Interface (BCI)



Context - Brain Computer Interface (BCI)

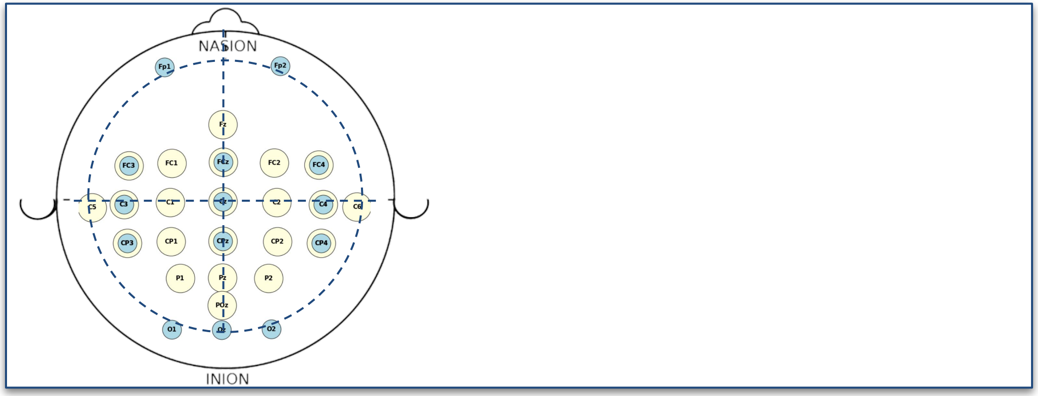


Challenges:

- Lack of big datasets.
- Small dataset with different recording setups.
  Electrodes layout, sampling frequency, filters, ...

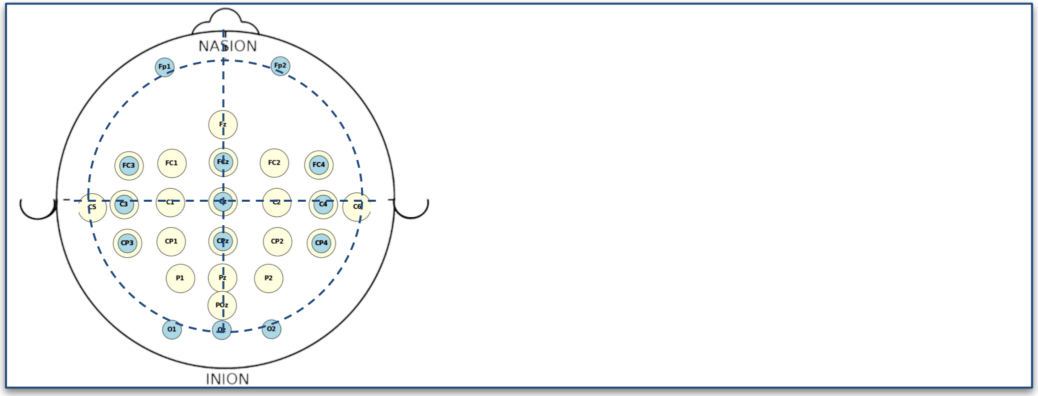
Context - Homogenize BCI datasets

However unifying the spatial aspect of the EEG setups remains a challenge.



Context - Homogenize BCI datasets

However unifying the spatial aspect of the EEG setups remains a challenge.

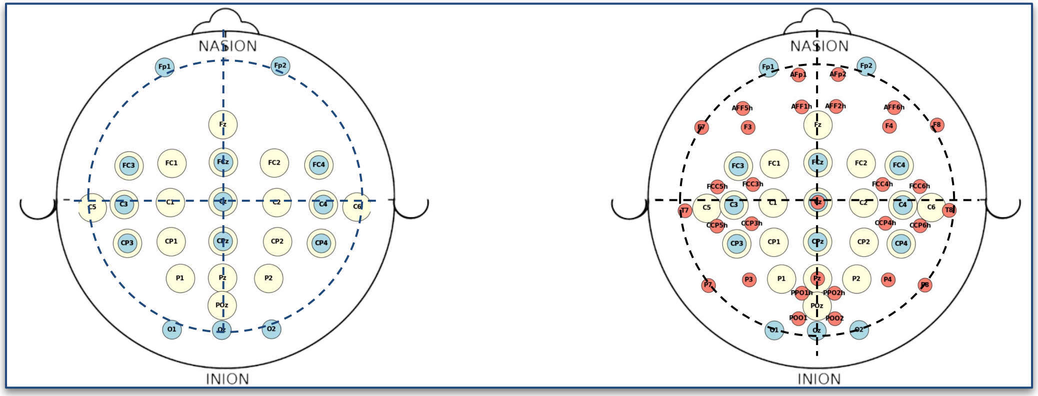


Few approaches have been proposed to unify the spatial aspect of the EEG setups.

- Reduce the spatial dimension:
  - Keeping the intersection
  - Dimension reduction methods (ex : PCA)

Context - Homogenize BCI datasets

However unifying the spatial aspect of the EEG setups remains a challenge.

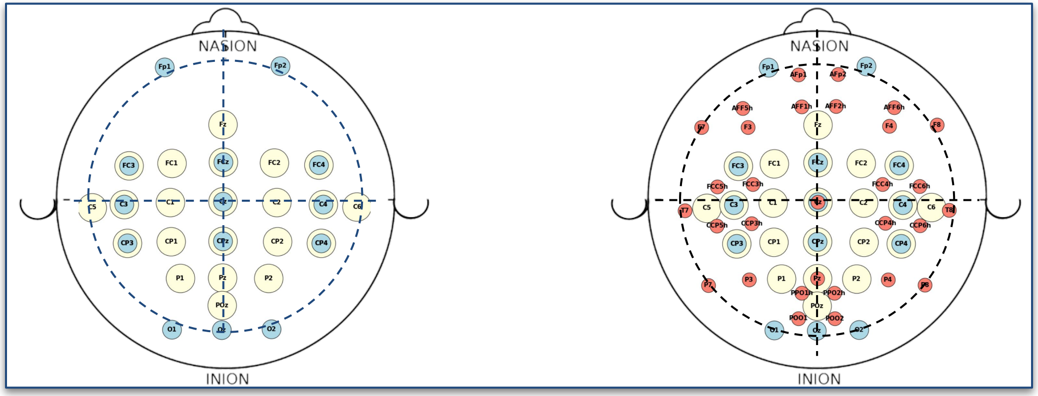


Few approaches have been proposed to unify the spatial aspect of the EEG setups.

- Reduce the spatial dimension:
  - Keeping the intersection
  - Dimension reduction methods (ex : PCA)
- Increase the spatial dimension
  - Riemannian geometry

Context - Homogenize BCI datasets

However unifying the spatial aspect of the EEG setups remains a challenge.



Few approaches have been proposed to unify the spatial aspect of the EEG setups.

- Reduce the spatial dimension:
  - Keeping the intersection
  - Dimension reduction methods (ex : PCA)

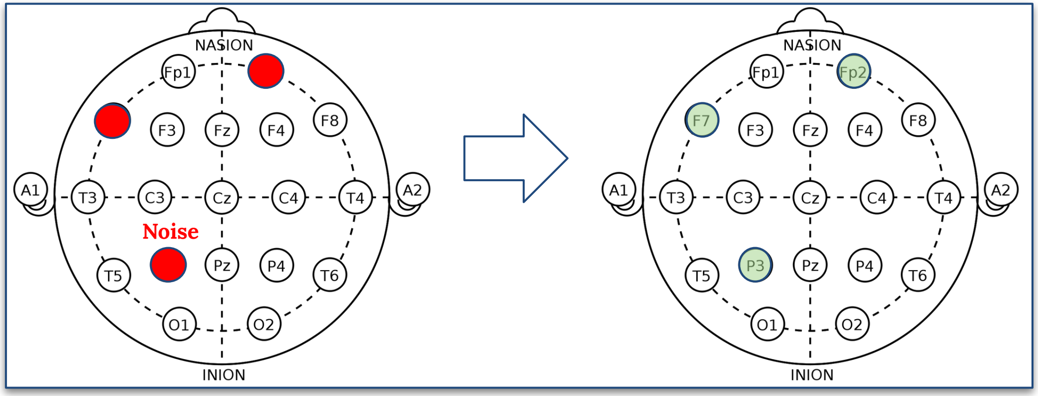
- Increase the spatial dimension
  - Riemannian geometry

No information loss

Context - Electrodes / Graph interpolation

Interpolating electrodes has been mainly used to recover signal from noisy electrodes

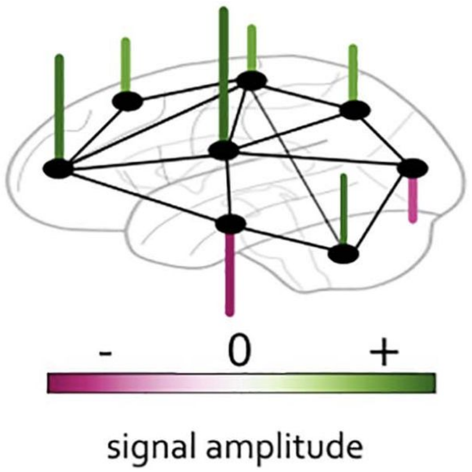
Mainly using is Spherical Spline [1]



[1] François Perrin,Jacques Pernier,O Bertrand, and Jean Francois Echallier, "Spherical splines for scalp potential and current density mapping," *Electroencephalography and clinical neurophysiology*, vo 72, no. 2, pp. 184–187, 1989

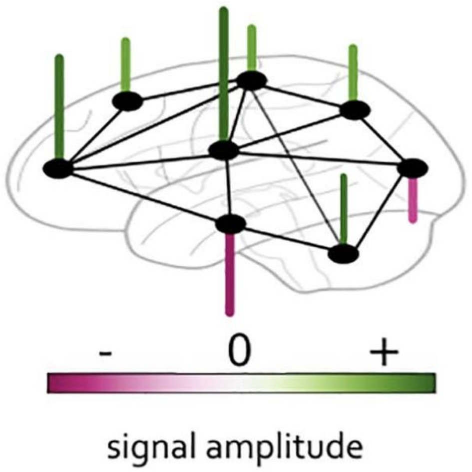
Scientific challenges

Our proposition: Interpolating spatial EEG using Graph Signal Processing



Scientific challenges

Our proposition : Interpolating spatial EEG using Graph Signal Processing

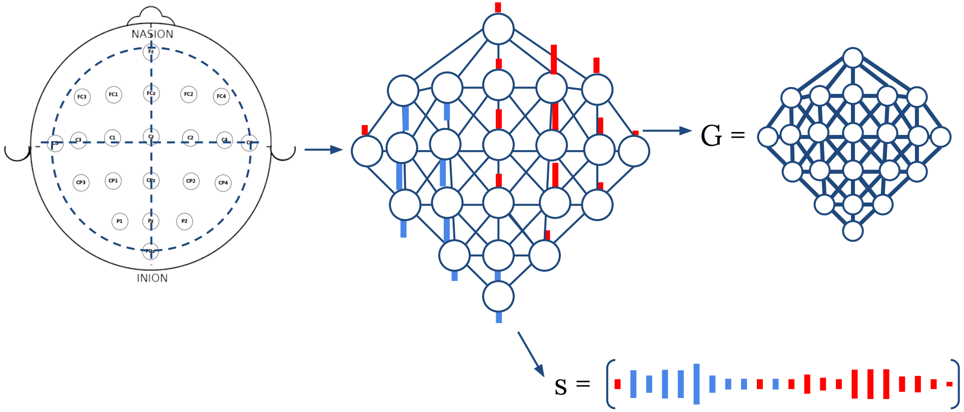


Research questions:

1) How to use GSP to interpolate electrodes?
   - Which graph?
   - Which interpolation criterion
2) Does unifying multiple EEG datasets with interpolation improve brain decoding?

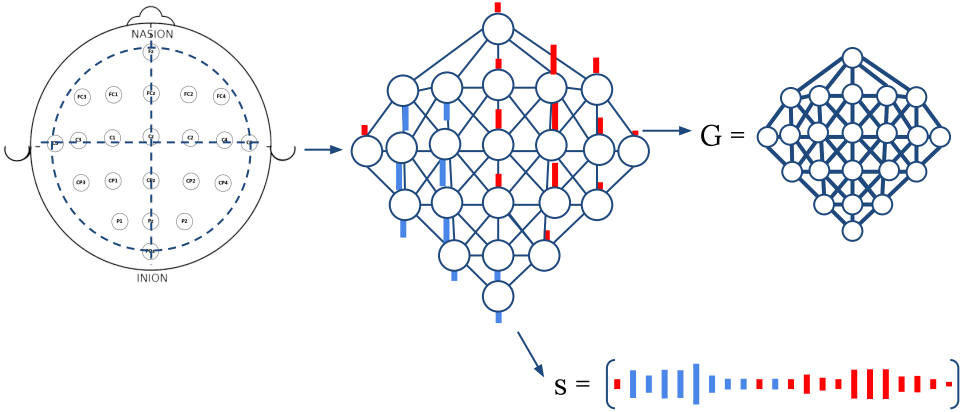
Methods

Few definitions:



Methods

Few definitions:



With D and W, the Degree and weights matrix of G, we have

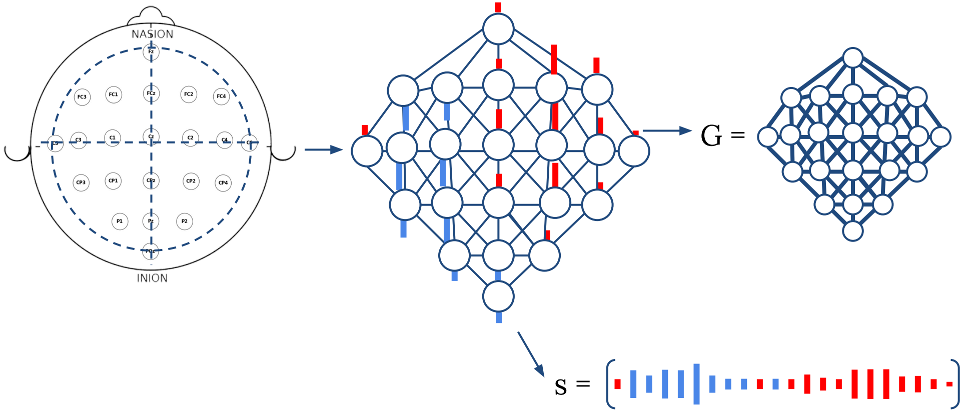
L = D-W , with L the Laplacian

Smoothness of the signal over the graph is defined by:

$$\sigma(\mathbf{s}) = \mathbf{s}^{\top}\mathbf{L}\mathbf{s} = \sum_{i=1}^{|\mathcal{V}|}\sum_{j=1}^{|\mathcal{V}|} W_{ij}(s_i - s_j)^2$$

Methods

Few definitions:



With D and W, the Degree and weights matrix of G, we have
L = D-W , with **L** the Laplacian

Smoothness of the signal over the graph is defined by :

$$\sigma(\mathbf{s}) = \mathbf{s}^\top \mathbf{L} \mathbf{s} = \sum_{i=1}^{|\mathcal{V}|} \sum_{j=1}^{|\mathcal{V}|} W_{ij}(s_i - s_j)^2$$

Interpolation problem formulation:

1) How to find SM? Which interpolation criterion?
2) How to build a Graph?

Methods

1 How to find $\mathbf{s}_{\mathcal{M}}$?

Interpolation criterion : **smoothness**

Minimizing $\sigma(\mathbf{s}) = \mathbf{s}^\top \mathbf{L} \mathbf{s} = \sum_{i=1}^{|\mathcal{V}|} \sum_{j=1}^{|\mathcal{V}|} W_{ij} (s_i - s_j)^2$

We found a closed form of $\sigma(\mathbf{s})$ that provides the optimal $\mathbf{s}_{\mathcal{M}}$

(A) $\mathbf{s}_{\mathcal{M}} = -\mathbf{L}_{\mathcal{M}}^{-1} \mathbf{L}_{\mathcal{M}\overline{\mathcal{M}}} \mathbf{s}_{\overline{\mathcal{M}}}$

Methods

1

How to found $\mathbf{s}_{\mathcal{M}}$?

Interpolation criterion : **smoothness**

Minimizing $\sigma(\mathbf{s}) = \mathbf{s}^\top \mathbf{L}\mathbf{s} = \sum_{i=1}^{|\mathcal{V}|}\sum_{j=1}^{|\mathcal{V}|} W_{ij}(s_i - s_j)^2$

We found a closed form of $\sigma(\mathbf{s})$ that provides the optimal $\mathbf{s}_{\mathcal{M}}$

(A) $\mathbf{s}_{\mathcal{M}} = -\mathbf{L}_{\mathcal{M}}^{-1}\mathbf{L}_{\mathcal{M}\overline{\mathcal{M}}}\mathbf{s}_{\overline{\mathcal{M}}}$

2

How to build G?

We learn G, from real data using gradient descent.

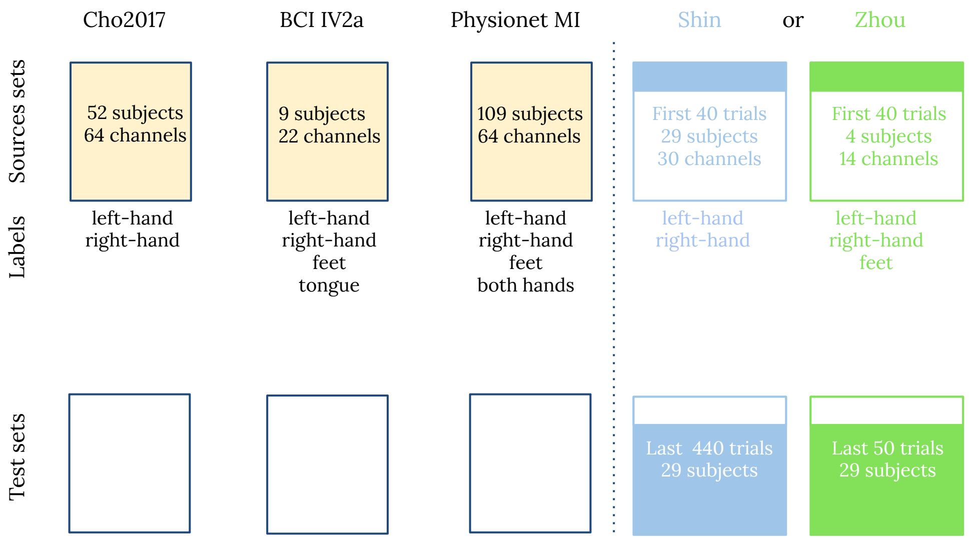
1) Initialize a connected graph G
2) Create virtual reconstruction problems
3) Reconstruct the signal using (A)
4) Update G based on the error of reconstruction
5) Repeat 2) to 4) until the error is low

Experiments

What is the added value brought by interpolated data?

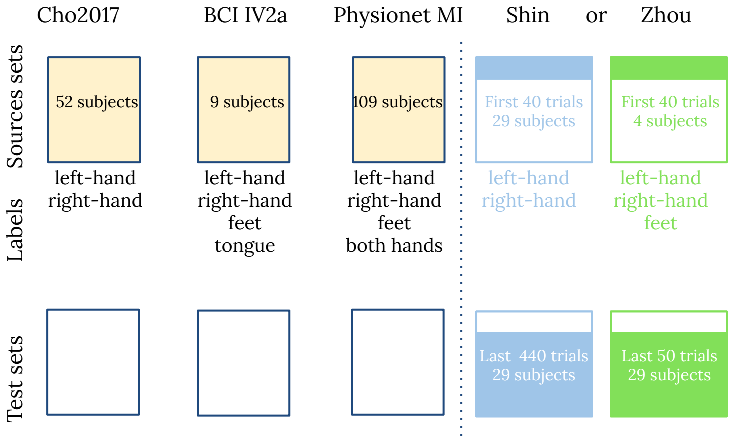
Does unifying multiple EEG datasets with interpolation improve brain decoding?

We experiment brain decoding on the following realistic setup:



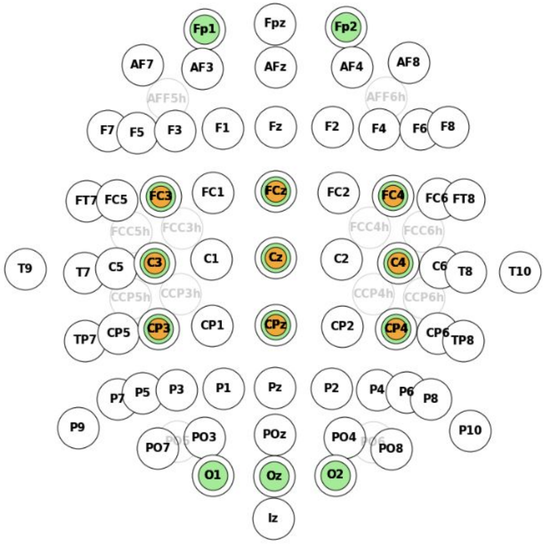
Results

Task : Brain decoding



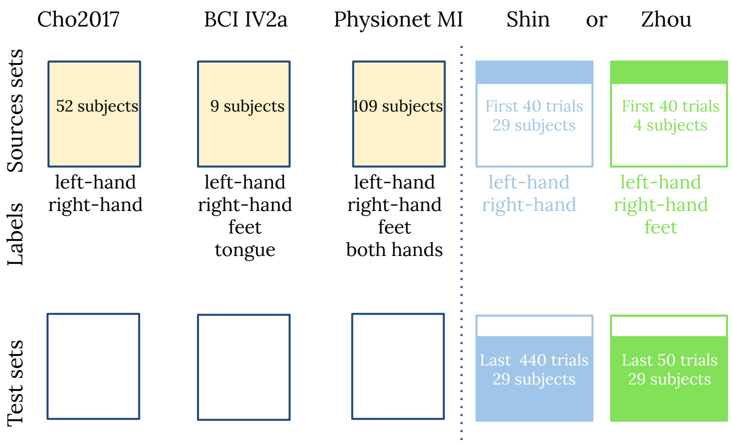
Classification accuracy

	Zhou	
	Acc	N
∩	<u>61.2 ± 2.0</u>	<u>9</u>
Dataset	56.2 ± 4.8	14
∪	46.4 ± 2.8	66



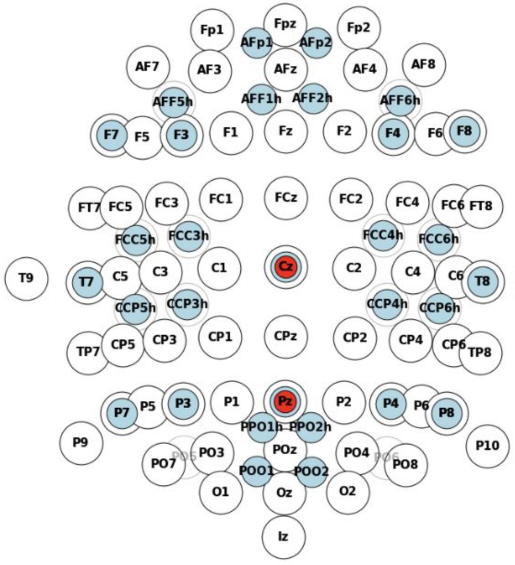
Results

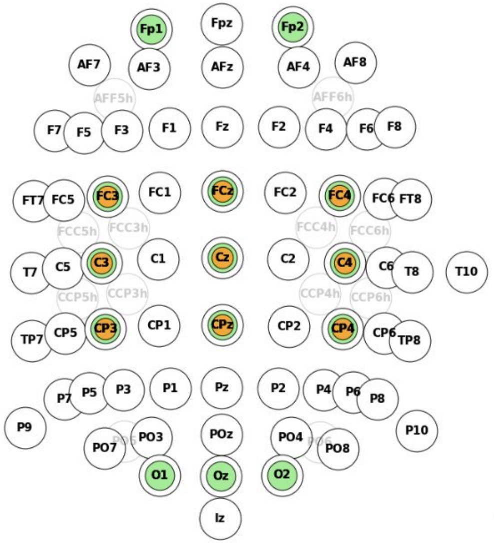
Task : Brain decoding



Classification accuracy

	Shin		Zhou	
	Acc	N	Acc	N
∩	53.2 ± 2.8	2	61.2 ± 2.0	9
Dataset	63.2 ± 2.3	22	56.2 ± 4.8	14
∪	62.3 ± 2.1	76	46.4 ± 2.8	66





Conclusions

- New and efficient electrode interpolation technique exploiting GSP tools
- Illustrated the interest of our method to homogenize datasets
    - Our code is open
    - Many more details in our paper!