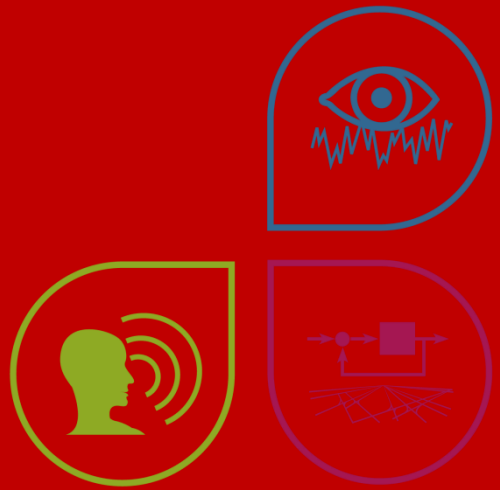
Marco Congedo

Centre National de la Recherche Scientifique

Université Grenoble Alpes

Grenoble INP



How Riemannian Geometry transformed BCI?

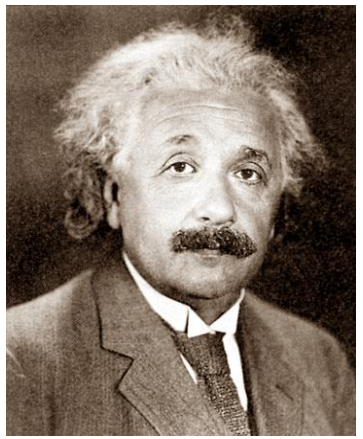
Bernhard Riemann
1826-1866

Elwin Bruno
Christoffel
1829-1900

Gregorio Ricci
Cubastro
1853-1925

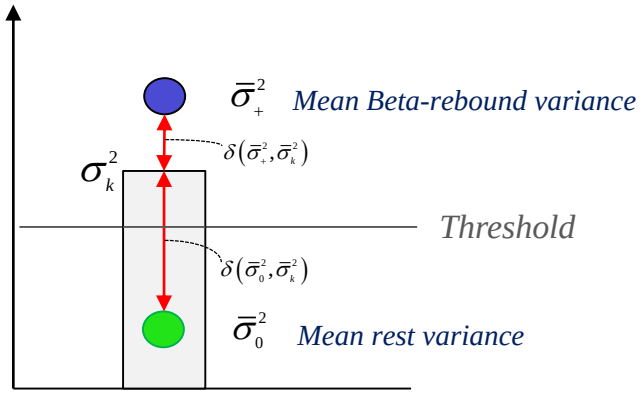
Tullio Levi-Civita
1873-1941

Albert Eninstein
1879-1955



Riemannian Geometry in BCI: a Short History

1977
Vidal
UCLA

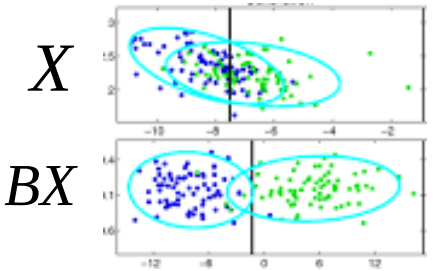


1995
Only six research groups

Introduction of the Fukunaga-Koontz transform

2000
Ramoser et *al.*
UTG

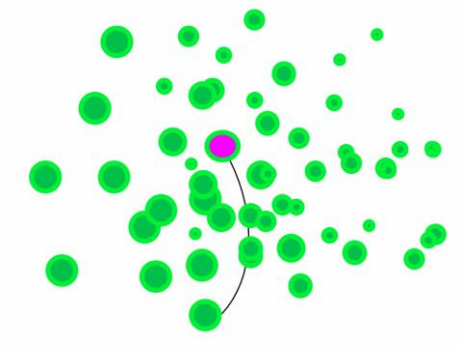
$$\lambda_i b_i = \left(C_1^{-1} C_2 \right) b_i$$



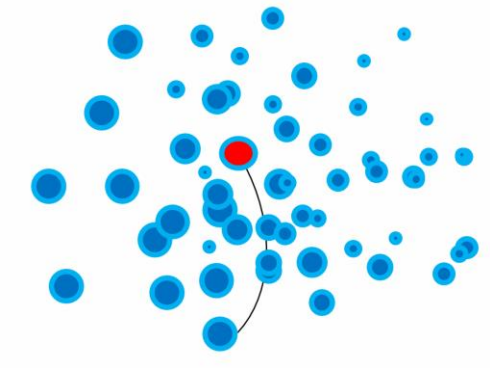
2010
Barachant et *al.*
UGA

Introduction of Riemannian Geometry

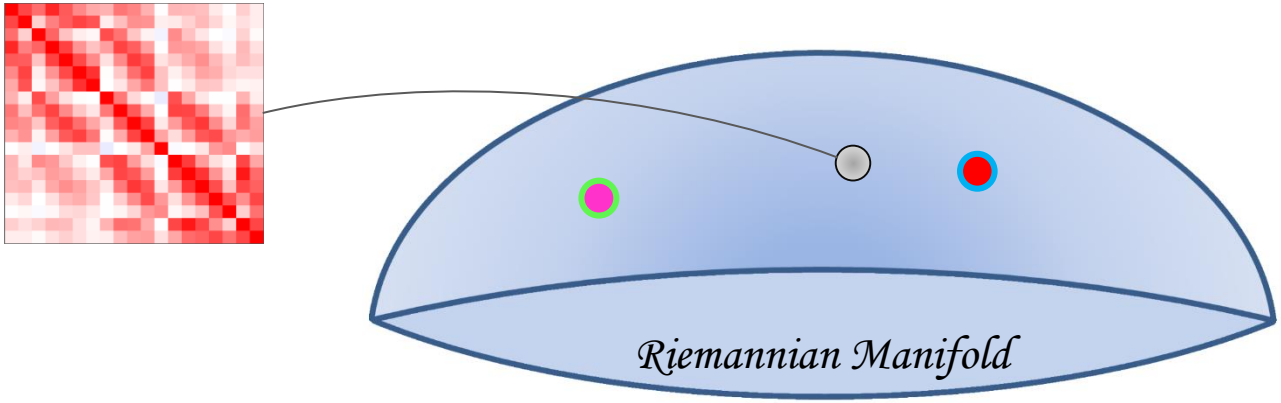
Minimum Distance to Mean (MDM) Classifier



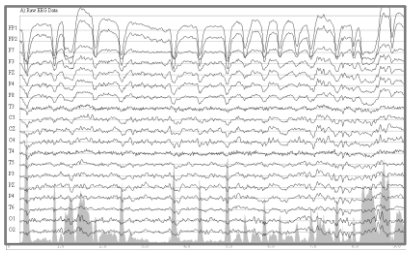
Class 1

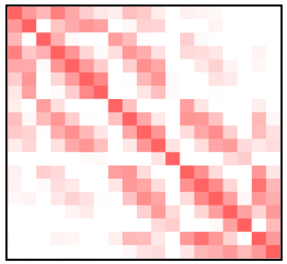


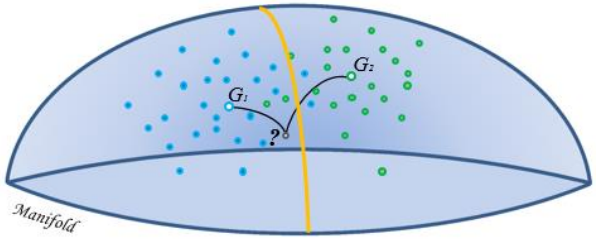
Class 2



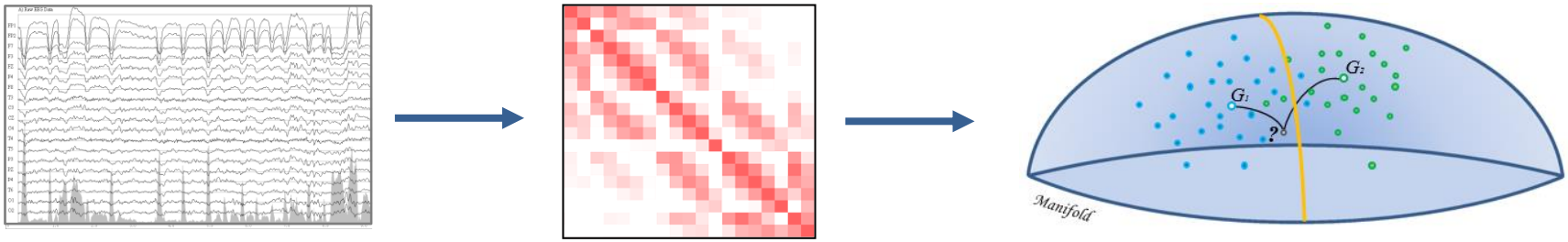
ML on Manifold



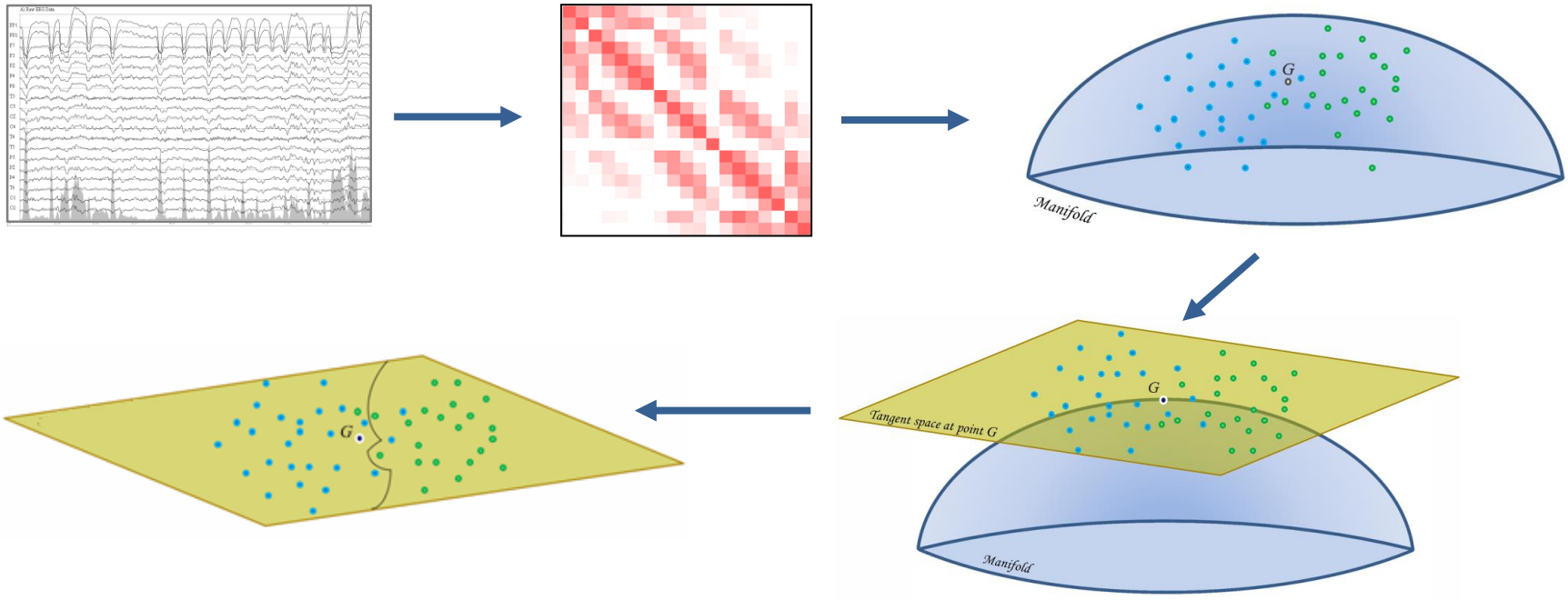




ML on Manifold



ML on Tangent Space



2012
Barachant et *al.*
UGA

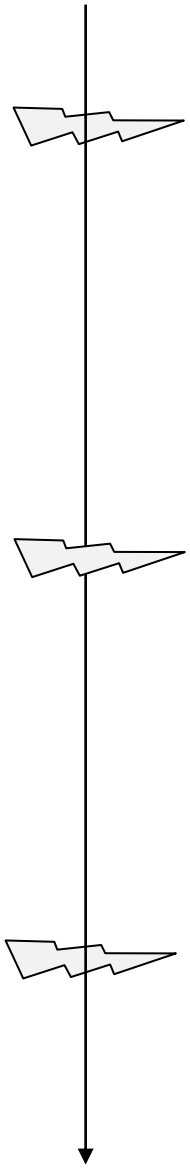
Riemannian MDM and TS classification
(seminal paper)

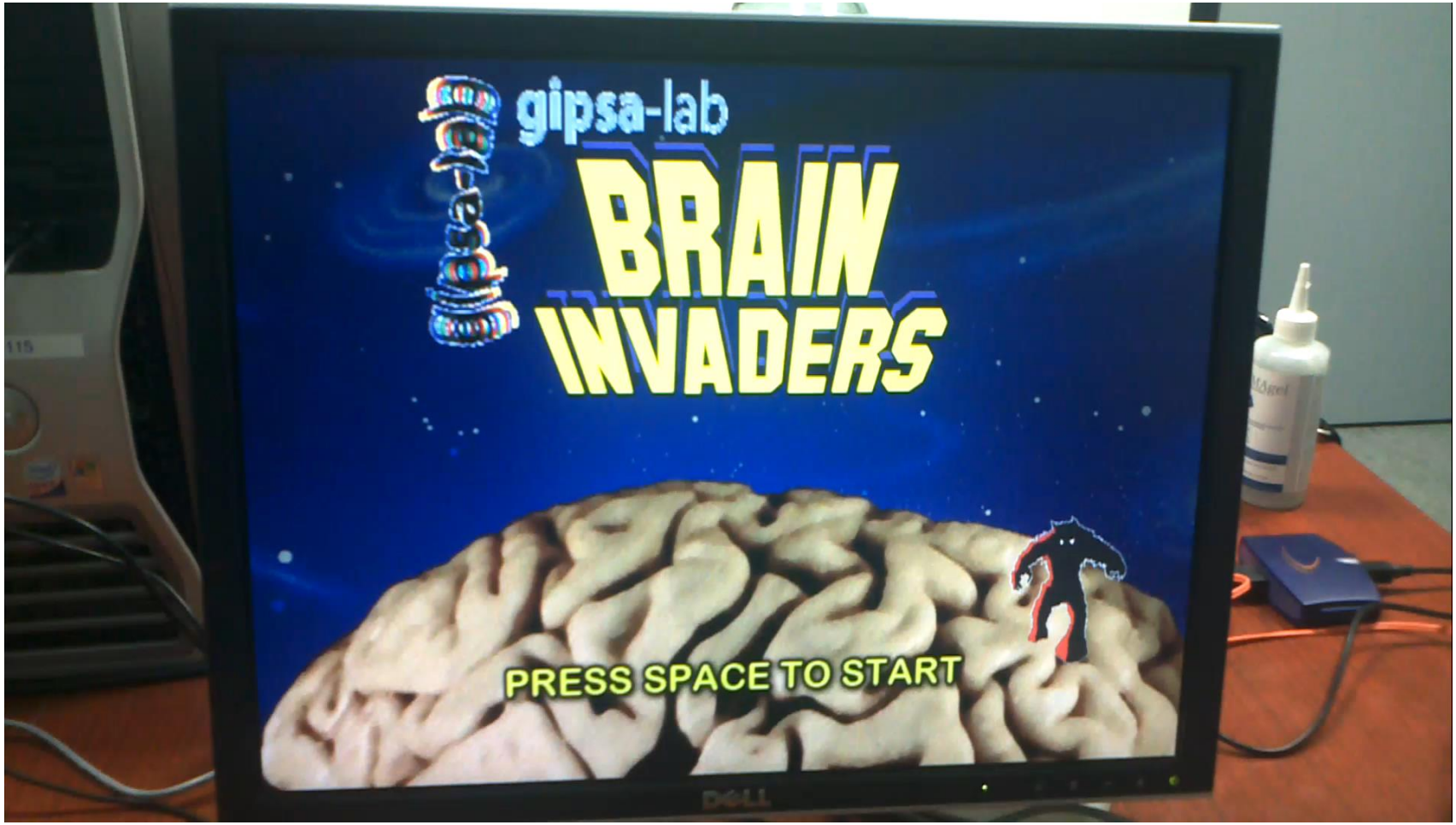
2013
Barachant et *al.*
UGA

First *Transfer Learning* attempts

2014
Barachant & Congedo
UGA

First working demonstrator of *calibration-less* BCI
« Brain Invaders »




gipsa-lab
BRAIN
INVADERS
PRESS SPACE TO START

2013
F. Yger and
S. Chevallier

Indipendent groups in the BCI field
start contributing and confirming efficacy

2014
Barachant.
UGA

Riemannian Geometry wins an international
competition (over 301 participants)

2015
Korczowski et *al.*
UGA

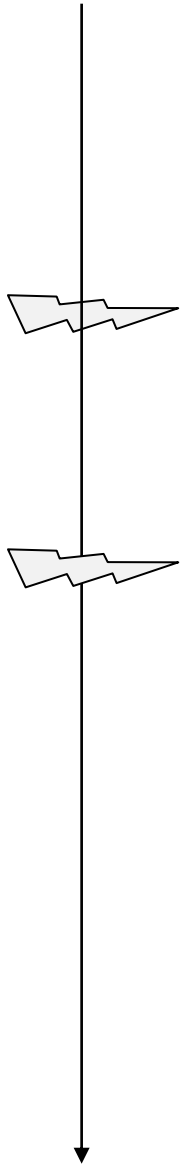
First working demonstrator of a *multi-user* BCI

2015
Barachant

Riemannian Geometry wins two more international
Competition (over 311 & 452 participants)

2016
Barachant

Riemannian Geometry wins two more international
Competition (over 688 & 7 participants)



2017
Congedo et al.
Yger et al.

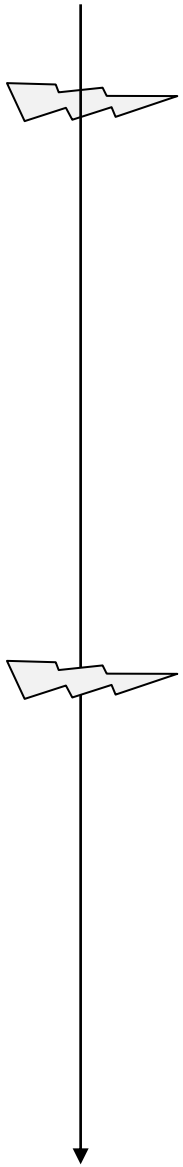
First comprehensive reviews on Riemannian Geometry for BCI.

2018
Zanini et *al.*
UGA

Unsupervised Transfer Learning

2019
Rodrigues et al.
UGA

Riemannian Procrustes Analysis (RPA): Semi-supervised Transfer Learning



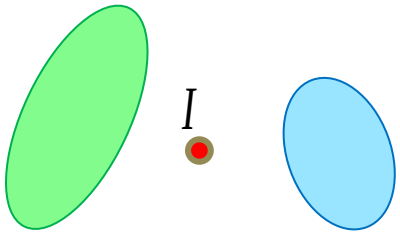
Riemannian Procrustes Analysis (RPA)

unsupervised

supervised

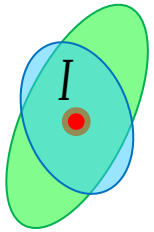
Original Data

$$C_k$$



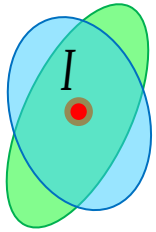
Recentering

$$C_k \leftarrow G^{-1/2} C_k G^{-1/2}$$



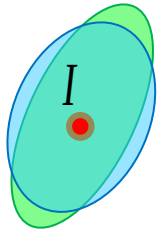
Streching

$$C_k \leftarrow C_k^p$$

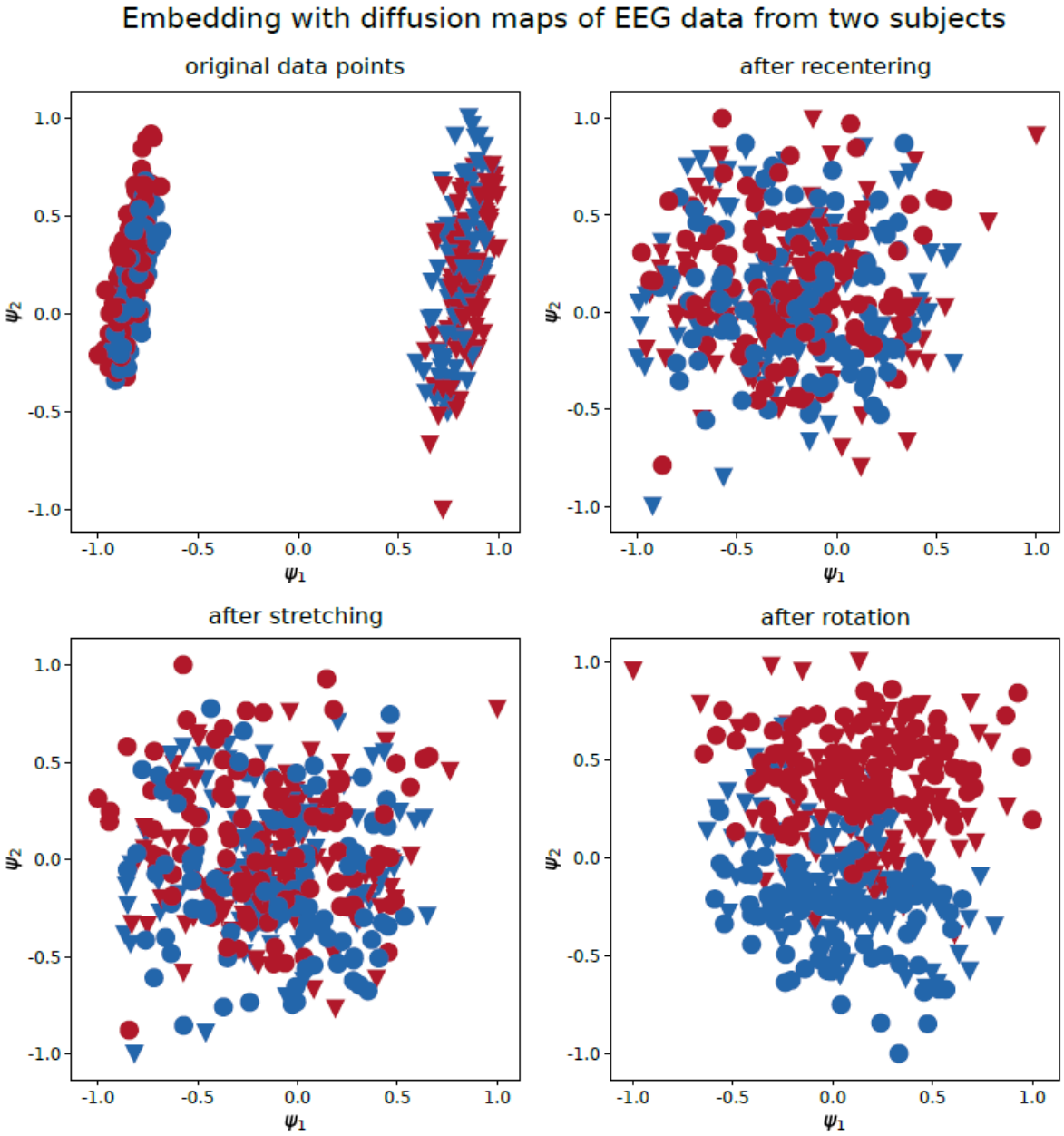


Rotation

$$C_k \leftarrow U C_k U^T$$



Real Data Example



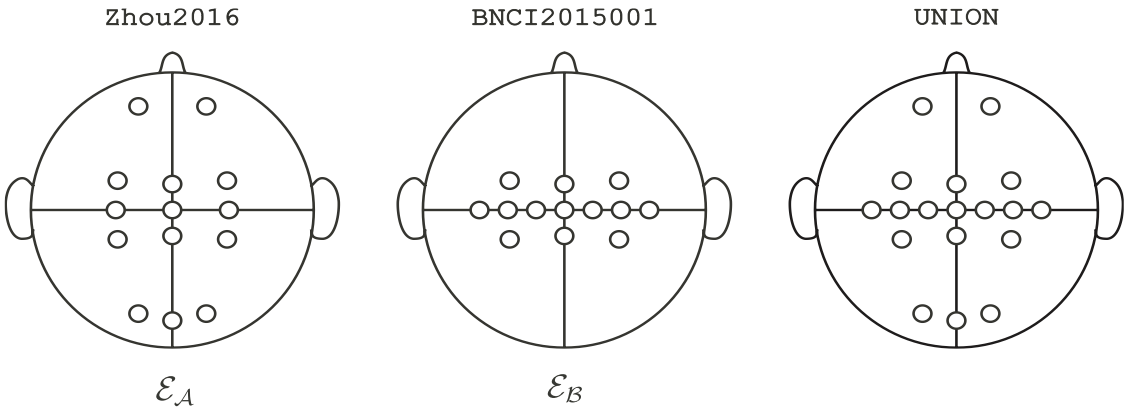
Cho2017 (MI, 40 ss, 23 elec., 2 classes).

Visualization: Spectral Embedding

ψ_1 ψ_2 are the eigenvalues of the Laplacian

2021
Rodrigues et al.
UGA

RPA for heterogeneous domains



(14 electrodes) (13 electrodes) (18 electrodes)

$$T(C_{RPA}) = UP \begin{pmatrix} \left(G^{-1/2} C_k G^{-1/2}\right)^p & 0 \\ 0 & I \end{pmatrix} P^T U^T$$

Code for Riemannian geometry

(**Julia –** Python – R – Matlab – C++ – Delphi)

https://sites.google.com/site/marcocongedo/science/code-resources

P300-BCI Data

https://sites.google.com/site/marcocongedo/science/EEG-data

7 *Databases*

273 *Subjects*

1446 *Sessions*

BCI in Virtual Reality and on a PC

Description: Visual P300 BCI experiment on PC and virtual reality (passive head-mounted display) (2018)
Subjects: 21
Sessions: 2
Electrodes: 16 wet Silver/Silver Chloride electrodes
EEGMachine: g.tec g.USBamp
Sampling Rate: 512 sps
Database ID: *VR.EEG.2018-GIPSA*

Brain Invaders Multi-User Cooperation vs. Competition

Description: Multi-User Brain Invaders: Cooperation versus Competition condition (2015)
Subjects: 44
Sessions: 2
Electrodes: 32 wet Silver/Silver Chloride electrodes
EEGMachine: g.tec g.USBamp
Sampling Rate: 512 sps
Database ID: *bi2015b*

Brain Invaders Multi-User flash duration

Description: Brain Invaders calibration-less P300-based BCI with modulation of flash duration (2015)
Subjects: 50
Sessions: 3
Electrodes: 32 wet Silver/Silver Chloride electrodes
EEGMachine: g.tec g.USBamp
Sampling Rate: 512 sps
Database ID: *bi2015a*

Brain Invaders Solo vs. Multi-User Collaboration

Description: Multi-User Brain Invaders in Solo versus Collaboration condition (2014)
Subjects: 38
Sessions: 3
Electrodes: 32 wet Silver/Silver Chloride electrodes
EEGMachine: g.tec g.USBamp
Sampling Rate: 512 sps
Database ID: *bi2014b*

Brain Invaders dry electrodes

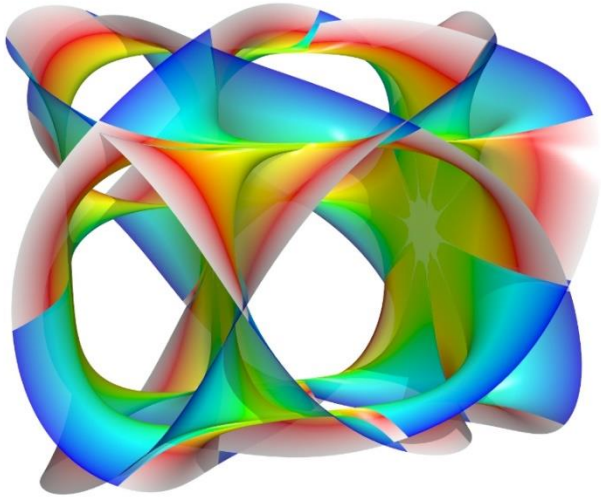
Description: Brain Invaders calibration-less P300-based BCI with dry electrodes (2014)
Subjects: 71
Sessions: up to three per participant
Electrodes: 16 metal dry electrodes
EEGMachine: g.tec g.USBamp
Sampling Rate: 512 sps
Database ID: *bi2014a*

Brain Invaders Adaptive vs. Non-Adaptive

Description: First Brain Invaders dataset of a BCI working without calibration (2013)
Subjects: 24
Sessions: 8 for subjects 1-7, one for the remaining.
Electrodes: 16 wet Silver/Silver Chloride electrodes
EEGMachine: g.tec g.USBamp
Sampling Rate: 512 sps
Database ID: *BI.EEG.2013-GIPSA*

Building Brain Invaders

Description: First Brain Invaders BCI dataset (2012)
Subjects: 25
Sessions: 2
Electrodes: 16 wet Silver/Silver Chloride electrodes
EEG Machine: TMSI Porti
Sampling Rate: 128 sps
Database ID: *BI.EEG.2012-GIPSA*



Collaborators @GIPSA-lab

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Post-Doc: A. Barachant, P. Zanini

PhD Students: L. Korczowski, F. Bouchard, P.L.C. Rodrigues, A. Bleuzé