GRAZ BCI 2024 Workshop

Riemannian decoding

Summary

- What is the riemannian manifold ?
- What are the advantages ?
- Common usage

Riemannian manifold

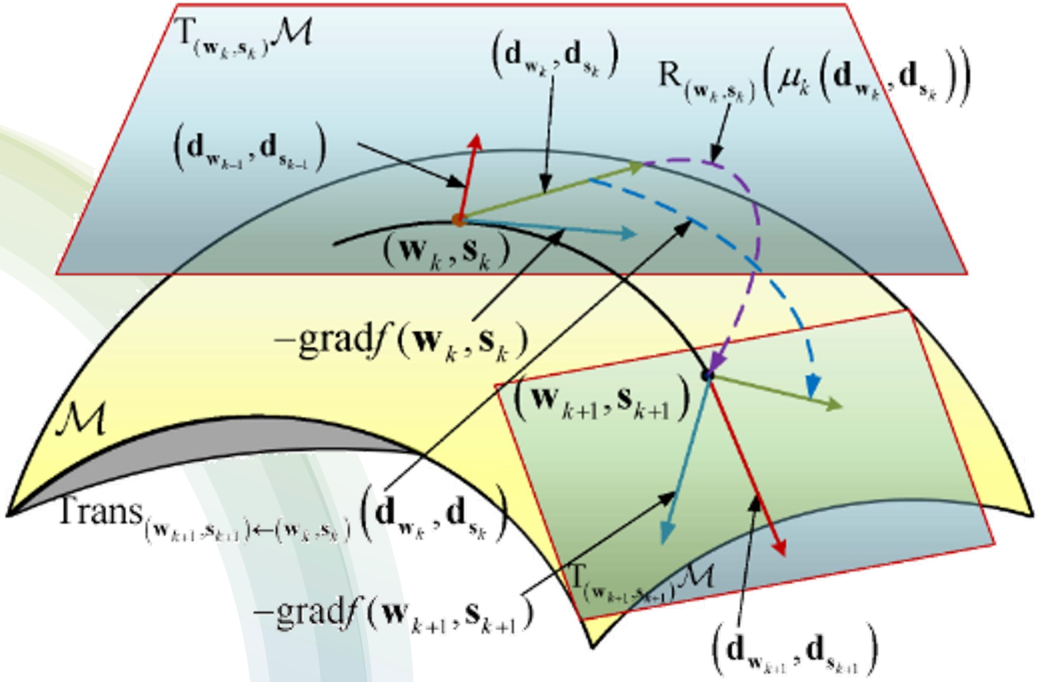
Riemannian manifold

- SPD : symmetric positive definite

Definition 1.1. A matrix $\mathbf{A} \in \mathbb{R}^{n\times n}$ is deemed Symmetric Positive Definite (SPD) if it holds that $\mathbf{A} = \mathbf{A}^T$ and $\mathbf{x}^T\mathbf{A}\mathbf{x} > 0$ for all non-zero vectors $\mathbf{x} \in \mathbb{R}^n$. The eigenvalues of such a matrix $\mathbf{A}$, denoted by $\lambda(\mathbf{A})$, are guaranteed to be positive.

Riemannian manifold

Geometric plan of tangent plan, riemannian manifold and geodesic



Equation to go from manifold to tangent space

$$\log(\mathbf{A}) = \mathbf{U}\mathrm{diag}(\log(\lambda_1), \ldots, \log(\lambda_n))\mathbf{U}^T$$

Equation to go from tangent space to manifold

$$\exp(\mathbf{A}) = \mathbf{U}\mathrm{diag}(\exp(\lambda_1), \ldots, \exp(\lambda_n))\mathbf{U}^T$$

Affine invariant metric

$$\delta_A(P_1, P_2) = \left\| \mathrm{Log}(P_1^{-1/2} P_2 P_1^{-1/2}) \right\|_F$$

Log-euclidian metric

$$\delta_L(P_1, P_2) = \| \mathrm{Log}(P_1) - \mathrm{Log}(P_2) \|_F$$

I.E Tibermacine & al. Riemannian Geometry-Based EEG Approaches: A Literature Review. In arXiv, 2024, 10.48550/arXiv.2407.20250

The advantages

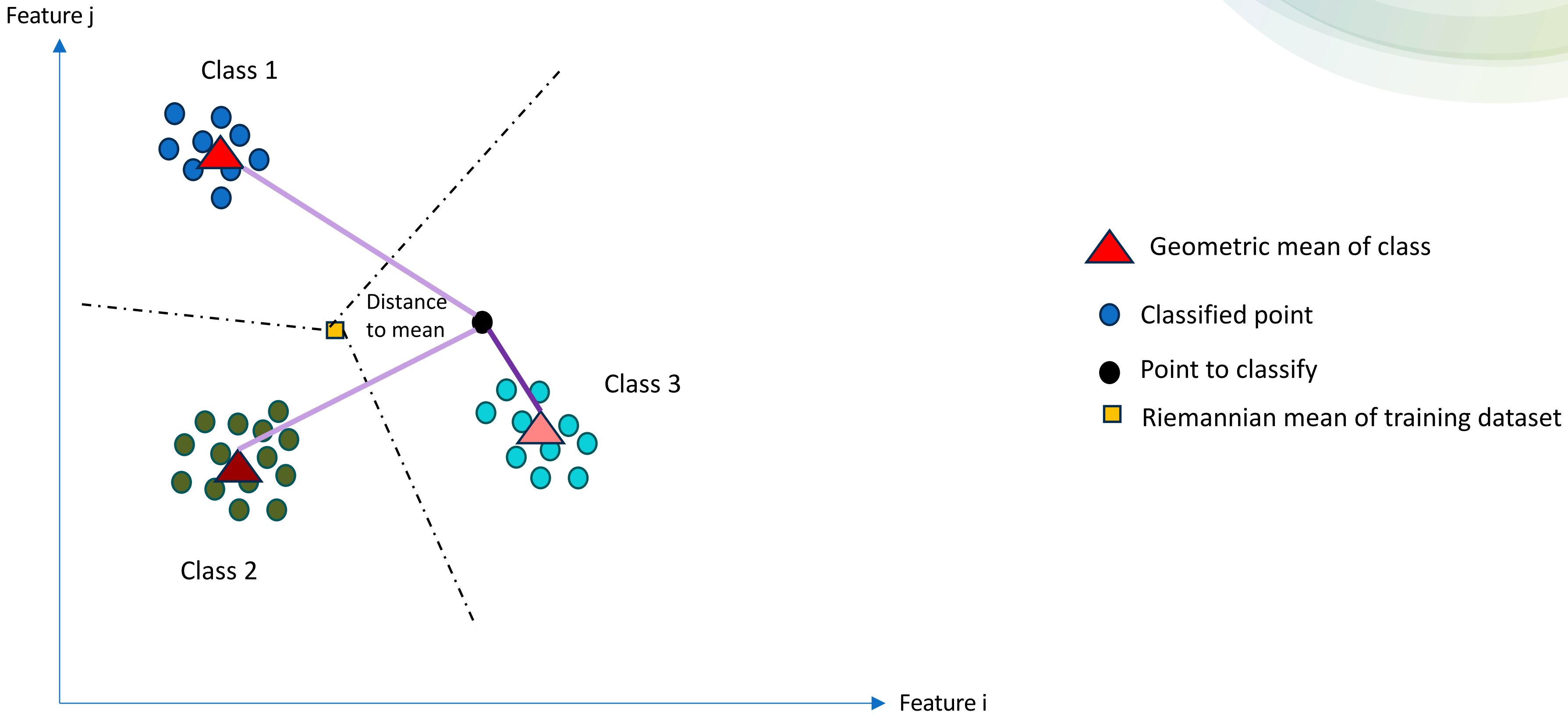
The advantages

- Reduces noises
- Retrieves high statistical information
- Helps to extract new features, to create Riemannian classifiers or to perform transfer learning
- Improved accuracy classification in a lot of competitions and different paradigms
- Contains information of power spectrum and how components vary together over time (useful for connectivity)

-I.E Tibermacine & al. Riemannian Geometry-Based EEG Approaches: A Literature Review. In arXiv, 2024, 10.48550/arXiv.2407.20250
-G. Xu *et al*., "Attentional State Classification Using Amplitude and Phase Feature Extraction Method Based on Filter Bank and Riemannian Manifold," in *IEEE TNSRE*, vol. 31, pp. 4402-4412, 2023, doi: 10.1109/TNSRE.2023.3329482

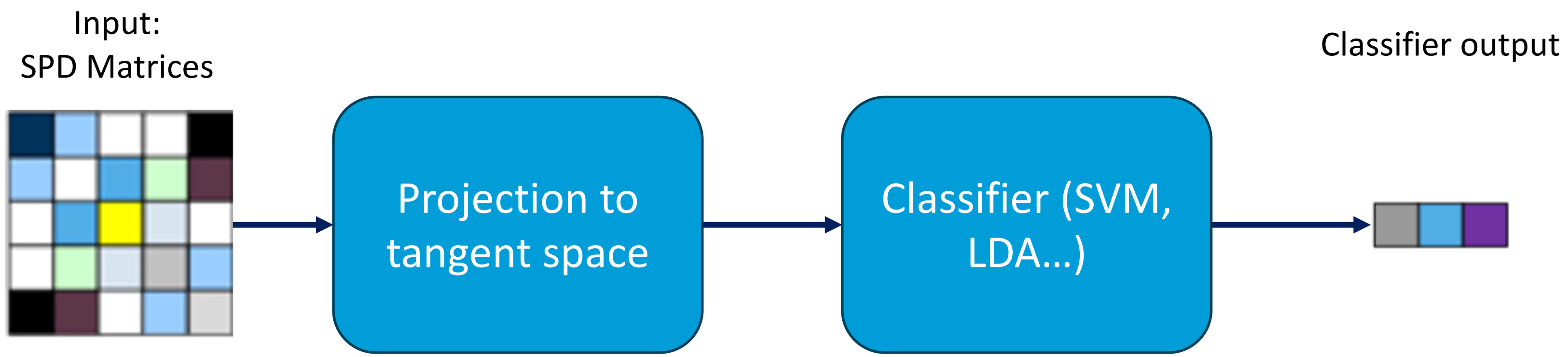
Common Riemannian usage

Minimum Distance to Mean

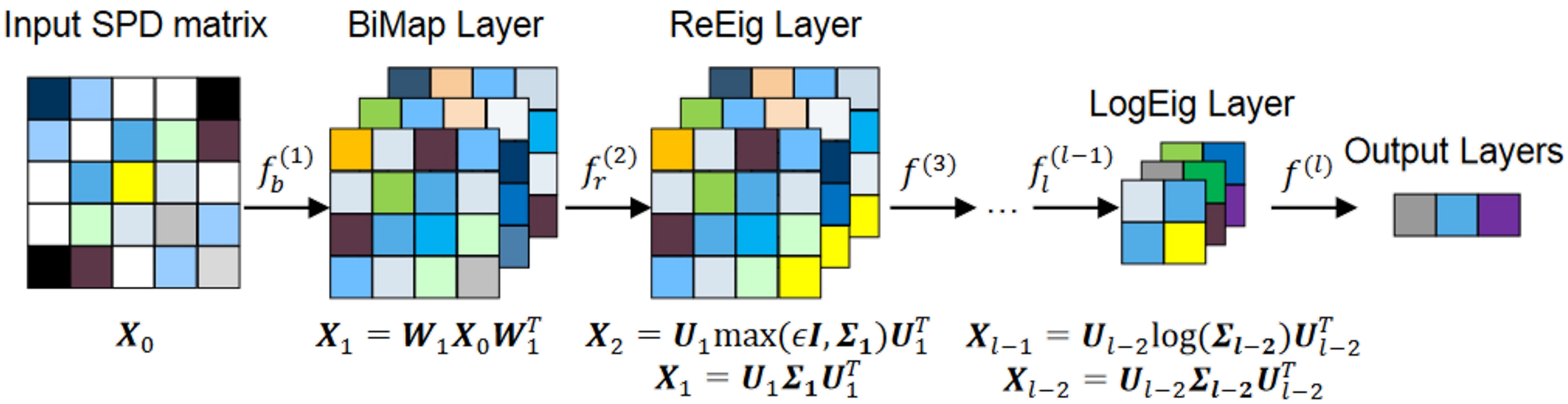


E. Kalunga & al. Transfer Learning for SSVEP-based BCI using Riemannian similarities between users. 26th European Signal Processing Conference (EUSIPCO 2018), Sep 2018, Rome, Italy. pp.1685-1689, ⟨10.23919/EUSIPCO.2018.8553441⟩. ⟨hal-01911092⟩

Riemannian space + Tangent space + classifier

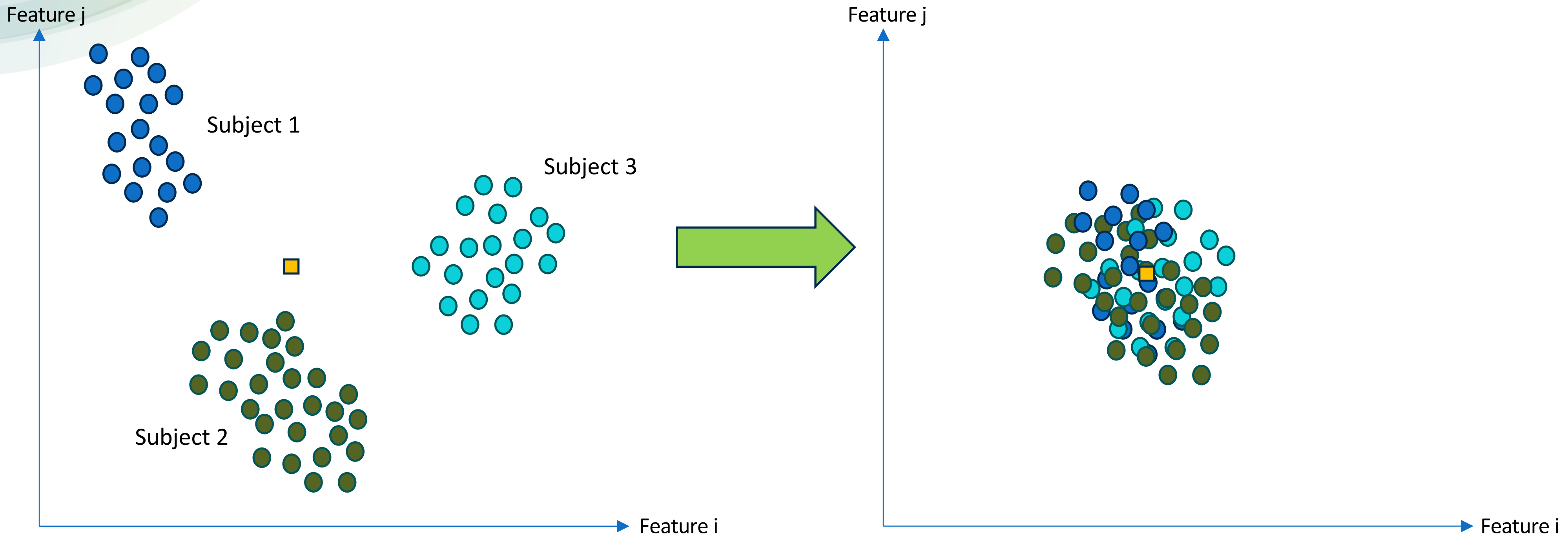


SPDNet



[10] Z. Huang and L. Van Gool. A riemannian network for SPD matrix learning. In AAAI, page 9, 2017

Spatial recentering

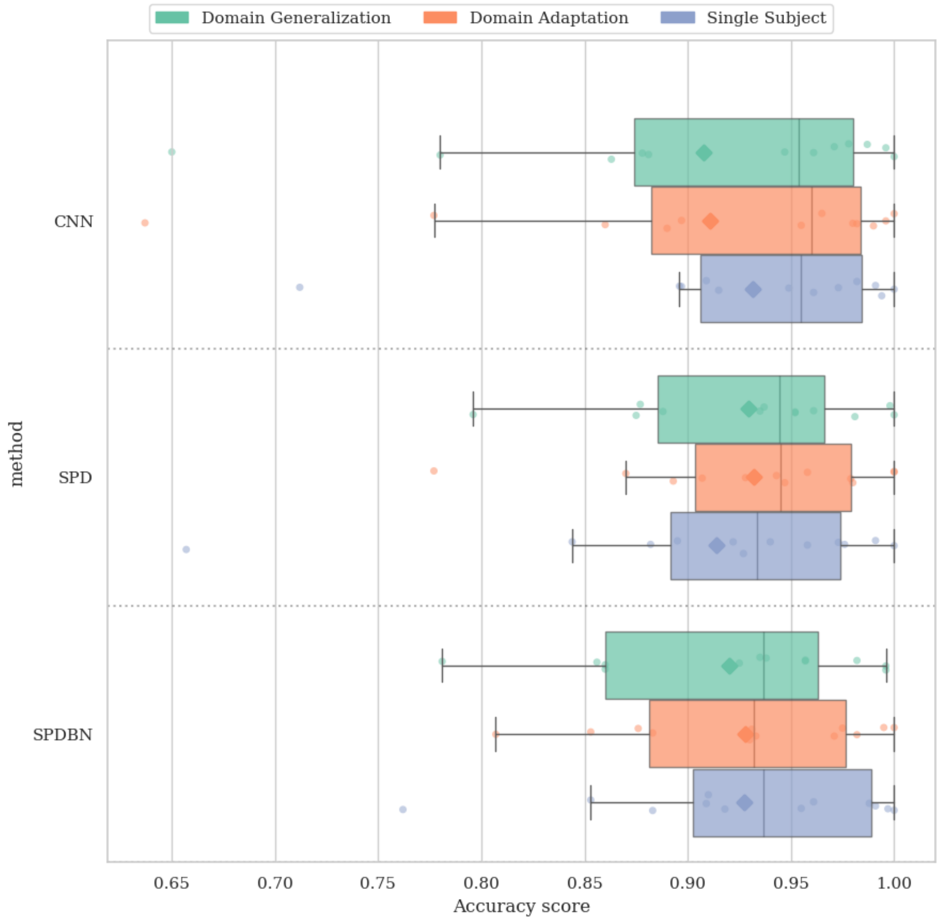


Riemannian mean of training dataset

P.L.C Rodrigues & al. Riemannian Procrustes Analysis : Transfer Learning for Brain-Computer Interfaces. IEEE Transactions on Biomedical Engineering, 2018, 66 (8), pp.2390 - 2401. ⟨10.1109/TBME.2018.2889705⟩. ⟨hal-01971856⟩

Results

- 2 SPDNet and a CNN on a BurstCVEP dataset (12 participants)
- 3 different method
- Recentered data
- ~ 93% accuracy
- Riemannian DeepLearning algorithms seems more consistent than CNN



Thanks for listening !