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Domain Adaptation for Neurological Injuries

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Medical Motivation

Problem:
- Brain imaging methods - not always feasible or available.

EEG monitoring:

Advantages:
- Noninvasive.
- High time resolution.
- Inexpensive.

Disadvantages:
- Poor spatial resolution.
- Difficult to analyze.
EEG - How Does it Work?

- The nerve cells produce electrical signals.
- The electrodes detect and record the brain waves.
Project Goal

- Detect neurological injuries using EEG data.
- Develop general framework for similar tasks.
How to detect an injury?
How to detect an injury?
EEG - How Does it Work?

- MD: averaging over hundreds of trials. [D. Eytan et al., 2016].

Example:
EEG signal - subject 1, stimulus 3

The analysis is challenging.
EEG - How Does it Work?

- MD: averaging over hundreds of trials. [D. Eytan et al., 2016].

EEG signal - subject 1, stimulus 3
Average over 200 trials
Covariance Matrices as Features
[A. Barachant et al., 2012]

- The covariance matrix of $X$ is:

$$\Sigma_{xx} = E[(X - \mu_x)(X - \mu_x)^T]$$

- $\Sigma_{xx}$ is an SPD (Symmetric and Positive Definite) matrix: $\Sigma_{xx} \succ 0$.

- The set of all SPD matrices constitute a Riemannian manifold $\mathcal{M}$. 
Riemannian Geometry of SPD Matrices

The Riemannian geodesic distance:

$$\delta_R(P_1, P_2)$$
Riemannian Geometry of SPD Matrices

• We compute the Riemannian mean of a set, $\overline{P}$.

• Let $\mathcal{T}_P \mathcal{M}$ be the tangent space at the point $P \in \mathcal{M}$.

• Let $S_i \triangleq \text{Log}_P(P_i)$ be the logarithmic mapping from $P_i \in \mathcal{M}$ to $S_i \in \mathcal{T}_P \mathcal{M}$.
• 1 second trials.
• Down sampling to 1KHz.
• Exclusion of noisy trials and electrodes.
Single Subject

- 1 subject
- 3 stimuli:  
  - Right arm
  - Left arm
  - Light flash
- 150 trials
Two Subjects

Baseline

Different subjects
Different domains!
Domain adaptation

Colored by subjects
Colored by stimuli
- Right arm
- Left arm
- Light flash
Parallel Transport for Domain Adaptation

[O. Yair et al., 2019]

- Parallel Transport (PT) is a generalization of translation.

\[ \varphi(t) \]

\( \mathcal{M} \)
Parallel Transport for Domain Adaptation
[O. Yair et al., 2019]

1. Compute the centers $\overline{P}^{(1)}$ and $\overline{P}^{(2)}$.

2. Transport the points from $P^{(2)}$ to $\overline{P}^{(1)}$.

3. Project to the tangent plane.
Two Subjects

Baseline

Colored by subjects

PT

Colored by stimuli

- Right arm
- Left arm
- Light flash
Moments Alignment

1. Obtain the principal components of $Z^{(1)}$, $Z^{(2)}$ using SVD (Singular Value Decomposition).

2. Flip by the acute angle.

3. Rotate.
Two Subjects

Colored by subjects

Colored by stimuli
- Right arm
- Left arm
- Light flash

Baseline | PT | PT+Moments Alignment
EEG Data
[D. Eytan et al., 2016]

Raw data:
• 11 subjects.
• 64 EEG electrodes.
• Stimuli: somatosensory, auditory and visual.
• Synch disputes

After pre-processing:
• 37 electrodes.
• 80-500 repeated trials per stimulus for each subject.
Experimental Results

Baseline

Colored by subjects

PT

Colored by stimuli

- Right arm
- Light flash
- Emotionally-neutral word

PT+Moments Alignment
Classification Results

Total:
- Baseline - 63.2121%
- PT - 84.9394%
- PT and Moments Alignment - 94.9394%
Sick Subject - Results

- Expected deficit: left somatosensory.
  - Left arm
  - Light flash
  - Emotionally-neutral word
Sick Subject - Results

- Expected healthy areas: visual, auditory.
- Expected injured area: somatosensory.

<table>
<thead>
<tr>
<th>Known Label</th>
<th>Somatosensory</th>
<th>Visual</th>
<th>Auditory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Somatosensory</td>
<td>29 (9.7%)</td>
<td>0 (0.0%)</td>
<td>27 (9.0%)</td>
</tr>
<tr>
<td>Visual</td>
<td>71 (23.7%)</td>
<td>90 (30.0%)</td>
<td>2 (0.7%)</td>
</tr>
<tr>
<td>Auditory</td>
<td>0 (0.0%)</td>
<td>10 (3.3%)</td>
<td>71 (23.7%)</td>
</tr>
</tbody>
</table>

- Total accuracy: 63.3%
Summary

- Domain adaptation method using curved geometry.
- Single shot classification.
- Generic algorithm.
- [G. Maman et al., 2019].