Scalable and Robust Tensor Decomposition of Resting Brain Networks in Stereotactic EEG

Jian (Andrew) Li, John C. Mosher, Dileep Nair, Jorge Gonzalez-Martinez, Richard M. Leahy

Motivation & Introduction

- Exploring dynamic functional connectivity (DFC) in resting-state brain signals is a rich area for studying brain networks.
- The most commonly used sliding window approach needs sufficient samples to obtain robust estimation of FC metrics. But longer window inevitably leads to over-smoothing of dynamic changes.
- PCA-based and ICA-based methods impose either orthogonality or independence constraint, which may not be proper for the identification of DFC as brain networks can spatially overlap and be temporally correlated.
- Canonical polyadic form / parallel factor analysis (CP) can capture the intrinsic interactions between different factors in higher dimensional space.
- Traditional widely used alternating least square (ALS) algorithm can not be scalable to large datasets and suffer from local minimum problem, especially in the case of over-factoring.

Methods

- CP Model
  \[
  \mathbf{X} = \sum_{r=1}^{R} \mathbf{a}_r \circ \mathbf{b}_r \circ \mathbf{c}_r + \mathbf{E}
  \]
- CP Decomposition
  \[
  \min_{\mathbf{X}, \mathbf{A}, \mathbf{B}, \mathbf{C}} \| \mathbf{X} - \sum_{r=1}^{R} \lambda_r \mathbf{a}_r \circ \mathbf{b}_r \circ \mathbf{c}_r \|_F, r = 1, \ldots, R
  \]
- Alternating Least Square (ALS) Algorithm
  \[
  \hat{\mathbf{A}} \leftarrow \text{argmin}_{\mathbf{A}} \| \mathbf{X}_1 - \mathbf{A} (\mathbf{C} \odot \mathbf{B})^T \|_F + \mu_1 F_1 (\mathbf{A})
  \]
  \[
  \hat{\mathbf{B}} \leftarrow \text{argmin}_{\mathbf{B}} \| \mathbf{X}_2 - \mathbf{B} (\mathbf{C} \odot \mathbf{A})^T \|_F + \mu_2 F_2 (\mathbf{B})
  \]
  \[
  \hat{\mathbf{C}} \leftarrow \text{argmin}_{\mathbf{C}} \| \mathbf{X}_3 - \mathbf{C} (\mathbf{B} \odot \mathbf{A})^T \|_F + \mu_3 F_3 (\mathbf{C})
  \]
- Scalable and Robust Sequential CP Decomposition

\[
\mathbf{X} \approx \mathbf{X}^{(r)} \approx \mathbf{X}^{(r+1)}
\]
Initializations for next iteration \( r + 1 \)

Results

<table>
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<tr>
<th>Subject</th>
<th>Type of Epilepsy</th>
<th># of Channels</th>
<th>Recording Name</th>
<th>Data Segment Time</th>
<th>Implantation Scheme</th>
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