Classification of Interictal Epileptiform Discharges by using Effective Connectivity

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EXPERIENCES
- Machine Learning and AI Student Ambassador (2017-Present)
- Research Assistant (2014-Present)
- Lecturer (2014)
- Teaching Assistant (2012)
- Lab Assistant (2013)

RESEARCH AREAS
- Machine Learning
- AI
- Biosignal Processing
- Data Analysis

EDUCATION
- Ph.D. in Electrical and Computer Engineering 2014-2019
- Bachelor in Mechatronics, Robotics, and Automation Engineering 2010-2012

Background
Background

The core facility at the Center of Advance Technology and Education (CATE) center continues to serve as a resource infrastructure for research and education with a strong foundation in computing, information processing, and the biosciences. Funded by the National Science Foundation (NSF) since 1993.

- Brain research with neuroscience applications
- Assistive technology research with a focus on visual impairment and motor disability
**Epilepsy** is a chronic disorder and is one of the most common neurological disorders affecting approximately 0.5 – 1% of the entire population. The major characteristic which defines the disorder is the recurrent unprovoked seizures.

Due to the **unpredictable occurrence of seizures**, the quality of life of epileptic patients might be greatly impacted by this uncertainty.
Introduction – Benefit of Epileptic Research

**Epileptic Diagnosis**
Conventionally, patients need to undergo various tests including hours of electroencephalogram recording. By using Machine Learning, diagnostic time can be reduced significantly.

**Epileptic Classification**
Epilepsy is classified into two broad types, generalized epilepsy and focalized epilepsy. The automatic detection of types of epilepsy will improve the diagnosis of the disease as well.

**Prediction of Seizures**
The occurrence of seizures affect the quality of life of epileptic patients greatly. Activities of daily living such as driving are considered dangerous for epileptic patients. The prediction of seizures provides a sufficient time for them to prepare.
Electroencephalogram (EEG): An electrophysiological monitoring method to record electrical activity produced from neurons of the brain. Sensors called electrodes are attached to your head and transfer the measured activity to the device.

Image Credit: http://www.medicalstudy.com
Approach – Why EEG?

- Non-Invasive
- High temporal resolution
- Cost-wise compare to other techniques
- No side effect

Image Credit: http://www.medicalstudy.com
Brain connectivity: refers to patterns of anatomical links of “Statistical Dependencies (Functional Connectivity)” or of “Causal Interaction (Effective Connectivity)” between groups of neurons.

Can be measured by various methods: **Coherence**, **Maximum Lagged Correlation**, **Phase Synchronization**, **Partial Directed Coherence**
**Approach – Effective Connectivity – Partial Directed Coherence (PDC)**

*PDC analysis is based on Granger causality concept*

**Granger Causality:** developed by Clive Granger and first applied in the economics studies. The concept works on the idea that, if the past values of $X_1$ contains information that help predicts $X_2$ beyond the past values of $X_2$ alone, then $X_1$ Granger-caused $X_2$ and not vice versa.
**Approach– Effective Connectivity – Partial Directed Coherence (PDC)**

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**Granger Causality based on Autoregressive Model**

**Univariate Autoregressive model**

\[ x(n) = \sum_{m=1}^{p} a(m)x(n - m) + e(n) \]

**Bivariate Autoregressive model**

\[
\begin{bmatrix}
    x_1(n) \\
    x_2(n)
\end{bmatrix} = \sum_{m=1}^{p} \begin{bmatrix}
    a_{11}(m) & a_{12}(m) \\
    a_{21}(m) & a_{22}(m)
\end{bmatrix} \begin{bmatrix}
    x_1(n - m) \\
    x_2(n - m)
\end{bmatrix} + \begin{bmatrix}
    e_1(n) \\
    e_2(n)
\end{bmatrix}
\]

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Approach—Effective Connectivity—Partial Directed Coherence (PDC)

**Modeling EEG with Multivariate Autoregressive Model**

**Multivariate Autoregressive model**

\[ X(n) = \sum_{m=1}^{p} A(m)X(n - m) + E(n) \]

- \( X(n) = \) 19 EEG Channels Data
- \( A(m) = \) Model Coefficients
- \( E(n) = \) Uncorrelated White Noise
- \( p = \) Model Order
**Partial Directed Coherence**

*Partial Directed Coherence*: a multivariate directional connectivity measure that shows interrelations between signals. The construction is based on the Fourier transform of the MVAR coefficient.

\[
\pi_{ij}(f) = \frac{A_{ij}(f)}{\sqrt{\sum_{k=1}^{K} |A_{kj}(f)|^2}}
\]

Value of PDC indicates the intensity of information flow between every channels of EEG.
Approach – Effective Connectivity – Surrogate Data Testing

**Surrogate Data Testing**

- The method is performed to test the significance between the connection
- Construction of surrogates are based on iAAFT method
- 100 surrogates are used to obtain the 95% level of significance
Approach – Effective Connectivity – Partial Directed Coherence (PDC)

| Electrode Labels | Fp1< | F7< | T3< | T5< | O1< | F3< | C3< | Fp2< | F2< | P2< | Fz< | Cz< | Pz< | Fp2< | T8< | T4< | T6< | O2< | F4< | C4< | P4< |
|------------------|------|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|-----|-----|-----|-----|
| Fp1<             |      |     |     |     |     |     |     |      |     |     |     |     |     |     |      |     |     |     |     |     |     |     |
| F7<              |      |     |     |     |     |     |     |      |     |     |     |     |     |     |      |     |     |     |     |     |     |     |
| T3<              |      |     |     |     |     |     |     |      |     |     |     |     |     |     |      |     |     |     |     |     |     |     |
| T5<              |      |     |     |     |     |     |     |      |     |     |     |     |     |     |      |     |     |     |     |     |     |     |
| O1<              |      |     |     |     |     |     |     |      |     |     |     |     |     |     |      |     |     |     |     |     |     |     |
| F3<              |      |     |     |     |     |     |     |      |     |     |     |     |     |     |      |     |     |     |     |     |     |     |
| C3<              |      |     |     |     |     |     |     |      |     |     |     |     |     |     |      |     |     |     |     |     |     |     |
| Fp2<             |      |     |     |     |     |     |     |      |     |     |     |     |     |     |      |     |     |     |     |     |     |     |
| F2<              |      |     |     |     |     |     |     |      |     |     |     |     |     |     |      |     |     |     |     |     |     |     |
| P2<              |      |     |     |     |     |     |     |      |     |     |     |     |     |     |      |     |     |     |     |     |     |     |
| Fz<              |      |     |     |     |     |     |     |      |     |     |     |     |     |     |      |     |     |     |     |     |     |     |
| Cz<              |      |     |     |     |     |     |     |      |     |     |     |     |     |     |      |     |     |     |     |     |     |     |
| Pz<              |      |     |     |     |     |     |     |      |     |     |     |     |     |     |      |     |     |     |     |     |     |     |
| Fp2<             |      |     |     |     |     |     |     |      |     |     |     |     |     |     |      |     |     |     |     |     |     |     |
| T8<              |      |     |     |     |     |     |     |      |     |     |     |     |     |     |      |     |     |     |     |     |     |     |
| T4<              |      |     |     |     |     |     |     |      |     |     |     |     |     |     |      |     |     |     |     |     |     |     |
| T6<              |      |     |     |     |     |     |     |      |     |     |     |     |     |     |      |     |     |     |     |     |     |     |
| O2<              |      |     |     |     |     |     |     |      |     |     |     |     |     |     |      |     |     |     |     |     |     |     |
| F4<              |      |     |     |     |     |     |     |      |     |     |     |     |     |     |      |     |     |     |     |     |     |     |
| C4<              |      |     |     |     |     |     |     |      |     |     |     |     |     |     |      |     |     |     |     |     |     |     |
| P4<              |      |     |     |     |     |     |     |      |     |     |     |     |     |     |      |     |     |     |     |     |     |     |

Frequency (Hz)
Approach—Challenges with EEG

- Low signal-to-noise ratio and noise from variety of sources: eye-blink, muscle spasm, power line frequency
- Sophisticated techniques are required for analysis
- Low spatial resolution
- Inverse problem from EEG is considered a difficult task
Python
Python

- Performance Increase
- Free
- Matlab-reminiscent code
- Assistive Community
- Shallow Learning Curve
- Various modules
- Prevalent Modality for data analysis
Community-driven module for EEG and MEG comprehensive data analysis tools

- Preprocessing
- Time-Frequency Analysis
- Statistical Testing
- Visualization
- Source Estimation
# Classification – Interictal Epileptiform Discharges (IEDs)

<table>
<thead>
<tr>
<th>Type</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interictal Spike</td>
<td><img src="image1.png" alt="Interictal Spike" /></td>
</tr>
<tr>
<td>Spike and Slow Wave Complex</td>
<td><img src="image2.png" alt="Spike and Slow Wave Complex" /></td>
</tr>
<tr>
<td>Repetitive Spike and Slow Wave complex</td>
<td><img src="image3.png" alt="Repetitive Spike and Slow Wave complex" /></td>
</tr>
</tbody>
</table>

**Types of IEDs**
Classification – Features Extraction

IS

SSC

RSS

Partial Directed Coherence Extraction
Classification – Features Transformation

IS → Surrogate Data Testing → SSC → RSS
Classification – Multilayer Perceptron Neural Network

Start

Input: Training Patterns
1 × 342 vectors

Nguyen-Widrow
Weight Initialization

Feedforward:
Each layer receives inputs and broadcasts outputs to next layer

Backpropagation of Error:
Each output and hidden unit computes the error information term and the weight correction term

Update Weights and Biases:
Each output and hidden unit updates its weights and bias with the inclusion of a momentum term

Stopping Condition:
If Mean Squared Error of weight changes < 0.0001

Output: Final Weights
Ready for testing new patterns

End
### Classification – Performance

#### Types of IEDs

![Waveform](image)

**Model I: Classification between two types of IEDs**

<table>
<thead>
<tr>
<th>Classification</th>
<th>F1 (%)</th>
<th>Acc (%)</th>
<th>Sen (%)</th>
<th>Spe (%)</th>
<th>Pre (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS vs. SSC</td>
<td>96.67</td>
<td>95.00</td>
<td>100.00</td>
<td>90.00</td>
<td>95.00</td>
</tr>
<tr>
<td>IS vs. RSS</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>SSC vs. RSS</td>
<td>76.67</td>
<td>85.00</td>
<td>80.00</td>
<td>90.00</td>
<td>75.00</td>
</tr>
<tr>
<td>Average</td>
<td>91.11</td>
<td>93.33</td>
<td>93.33</td>
<td>93.33</td>
<td>90.00</td>
</tr>
</tbody>
</table>

**Model II: Classification between all types of IEDs**

<table>
<thead>
<tr>
<th>Types of IED</th>
<th>F1 (%)</th>
<th>Acc (%)</th>
<th>Sen (%)</th>
<th>Spe (%)</th>
<th>Pre (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS</td>
<td>90.00</td>
<td>96.67</td>
<td>90.00</td>
<td>100.00</td>
<td>90.00</td>
</tr>
<tr>
<td>SSC</td>
<td>86.67</td>
<td>86.67</td>
<td>100.00</td>
<td>80.00</td>
<td>80.00</td>
</tr>
<tr>
<td>RSS</td>
<td>70.00</td>
<td>90.00</td>
<td>70.00</td>
<td>100.00</td>
<td>70.00</td>
</tr>
<tr>
<td>Overall Accuracy</td>
<td>86.87</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**F1: F1 score, Acc: Accuracy, Sen: Sensitivity, Spe: Specificity, Pre: Precision**

**Overall Accuracy: Correct Predictions / Number of Data Points**
Using Intel® Xeon Phi™ Cluster to Extract Functional Connectivity

- With the increase of data, extracting functional connectivity requires a high computational power. By using Intel® Xeon Phi™ Cluster, the computational time will be reduced significantly.

- Transforming functional connectivity into Eigen system domain and train with deep learning model to improve the precision and accuracy.