Classification of Neuro-Psychological disorders from raw EEG data using Non linear parameters and neural networks[1]

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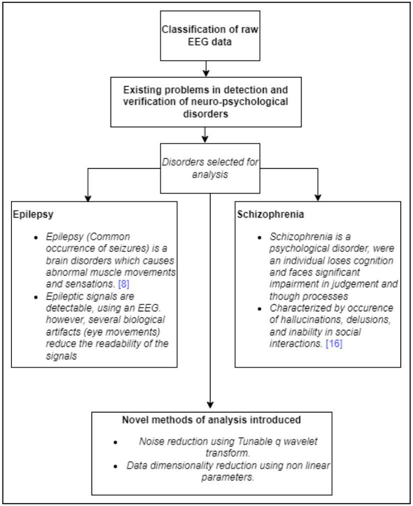


Figure: Motivation

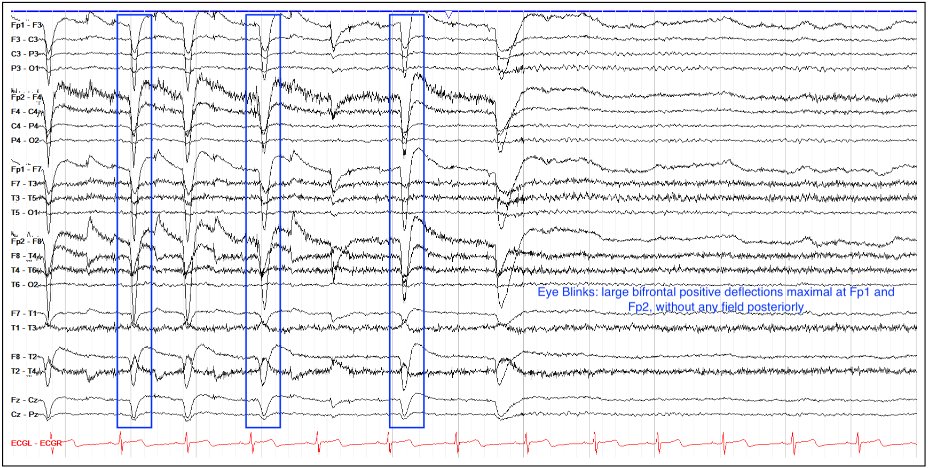


Figure: A normal EEG (with eye movement artifacts/Bell's phenomenon[12])

Motivation III

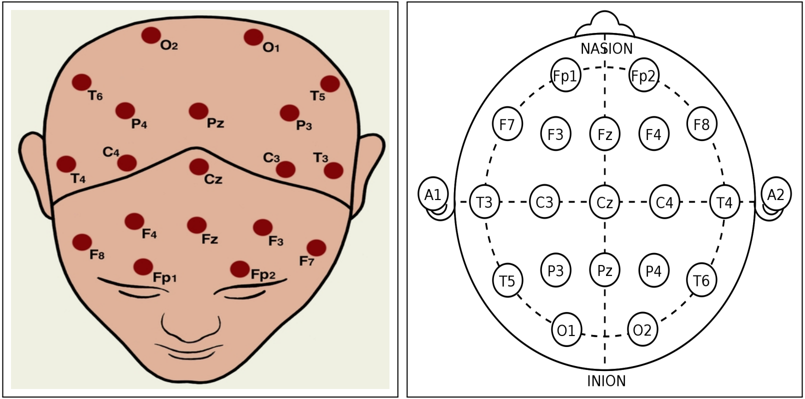


Figure: 10 - 20 System

Method of analysis

The method of analysis done is as follows,

1. Obtaining a data set which contains EEG data that can be used for classification
2. Denoising the data using a Tunable Q wavelet transform (TQWT) algorithm
3. Calculating Non linear features on each data vector/Creating visual heat maps based on the computed non linear features.
4. Performing Classification using various techniques (KNNs, SVMs, CNNs etc)

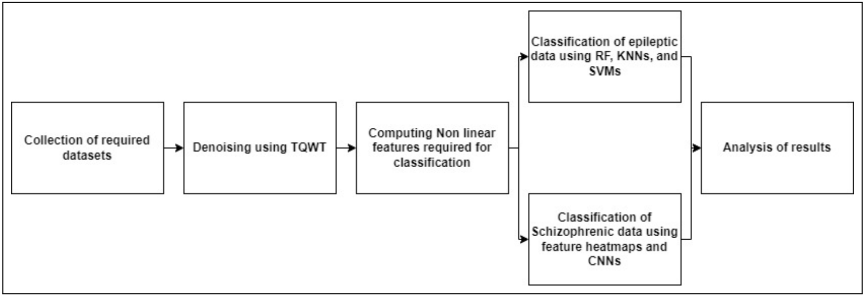


Figure: Method of analysis

Bonn Dataset

- The well established epilepsy data set, provided for public access by *University of Bonn, Germany* [7].
- The bonn dataset contains EEG data for epileptic and non epileptic candidates.
- The dataset features are shown tabulated below.

Sets	Subjects				
	Patient Stage	Electrode Type	Num. of Cases	Num. of Data	Length of Segments
Set A	Eye Open	Surface	5	100	4097
Set B	Eye Close	Surface	5	100	4097
Set C	Seizure Free	Intracranial	5	100	4097
Set D	Seizure Free	Intracranial	5	100	4097
Set E	Seizure Activity	Intracranial	5	100	4097

Figure: Description of the dataset

[13]

The Dataset II

Samples from the Bonn Dataset

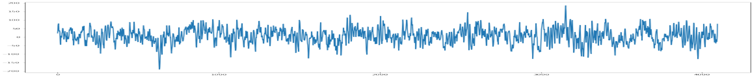


Figure: A normal EEG sample from the data set (Set A)

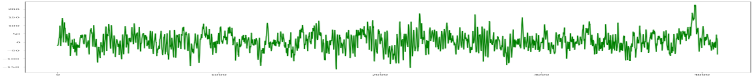


Figure: A normal EEG sample from the data set (Set B)

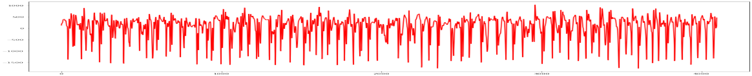


Figure: An epileptic (ictal) EEG sample from the data set (Set E)

The Dataset III

MV Lomonosov dataset

- This dataset is a publicly hosted schizophrenia dataset by *MV Lomonosov moskow state university.*
- The dataset consisted of two sets with two labels
  - Healthy Adults (39)
  - Adults experiencing symptoms of Schizophrenia (45)
- The data was in standard ASCII in .eea format.
- Each file contained numerical values, which 7680 data entries based on starndard 10-20 placement.

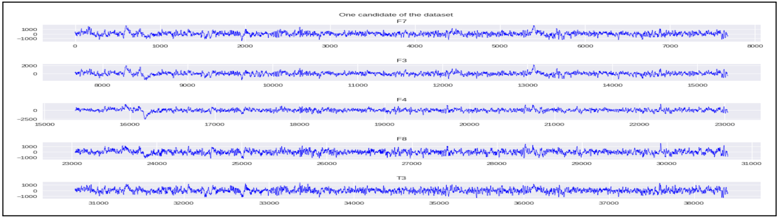


Figure: One candidate of the set

TQWT

- Tunable Q wavelet transform is a modified wavelet transform method developed by selesnick[16]
- It uses a specific Q factor for multi-resolution analysis.
- For the present use, A python implementation of the program developed by Hajek-Lellmann [1] was used.
- The parameters of the algorithm q and r are set to be 6 and 5 respectively.

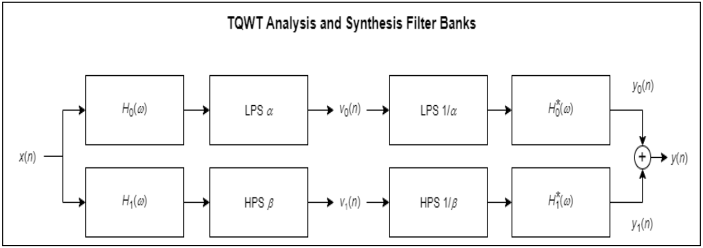


Figure: TQWT

[6]

Decomposition

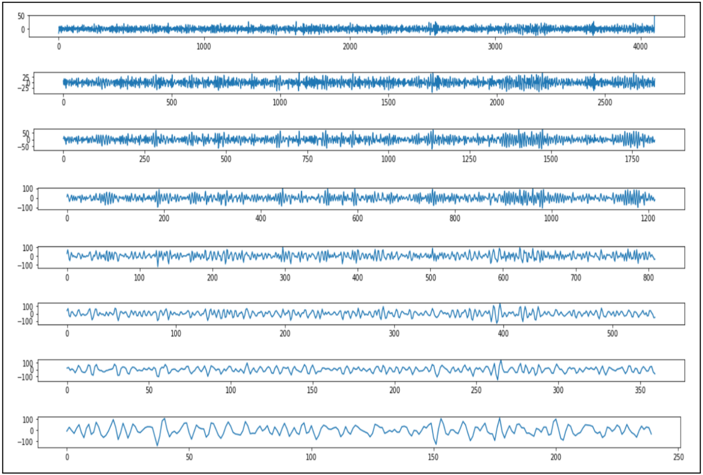


Figure: Decomposition into different Subbands using TQWT of a sample

Chaos related Features I

Lyapunov Exponent

$$|\delta \mathbf{Z}(t)| \approx e^{\lambda t} |\delta \mathbf{Z}_0|$$

$$\lambda(x_o) = \lim_{n \to \infty} \frac{1}{n} \sum_{i=0}^{n-1} \ln |f'(x_i)|$$

Hurst Exponent

$$\left(\frac{R}{S}\right)_s = Ks^H$$

$R = Re\ scaled\ Range$
$S = Standard\ Deviation$

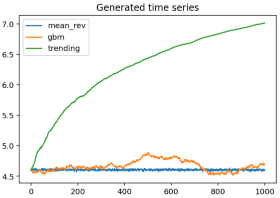


Figure: Different types of time series

Chaos related Features II

Sample Entropy

A: 01010101010101010101
B: 01101000110111100010

Figure: Two Series with different Entropy

$$SampEn = -ln\frac{A}{B}$$

$A =$ *Total number of vector pairs*
$B =$ *Total number of template matches*

Detrended Fluctuation Analysis

$$X_t = \sum_{i=1}^{t}(x_i - \langle x \rangle)$$

$$F(n) = \sqrt{\frac{1}{N}\sum_{t=1}^{N}(X_t - Y_t)^2}$$

The selected statistical features are then calculated and plotted. [15]

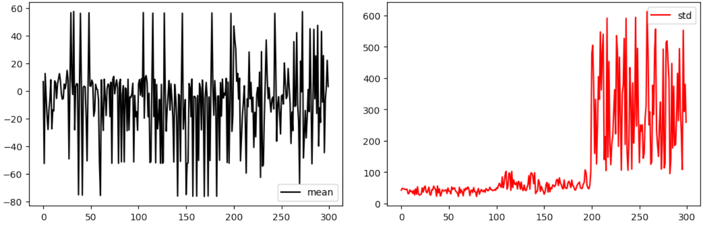


Figure: Mean and Standard deviation

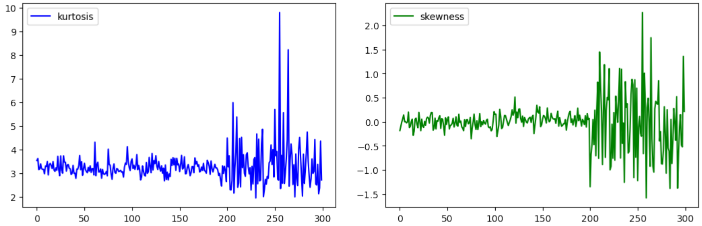


Figure: Kurtosis and Skewness

The selected Non linear dynamic features are calculated and then plotted..

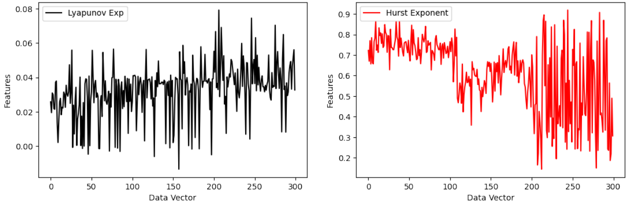


Figure: Lyapunov Exponent and Hurst Exponent

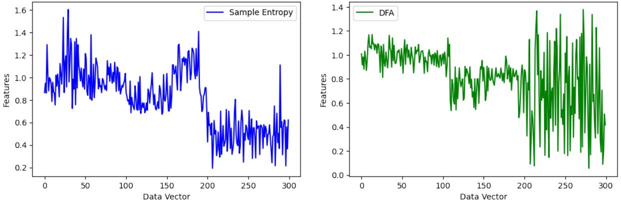
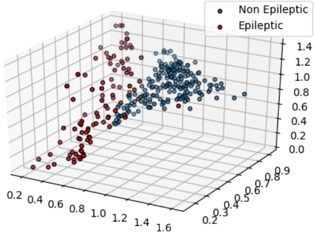
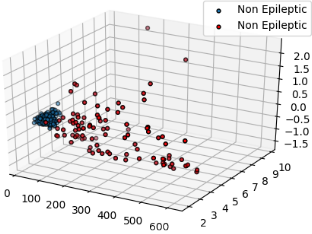


Figure: Sample Entropy and Detrended Fluctuation Analysis (DFA)

Chaos related features



(a) NLD Features



(b) Statistical Features

Creation of heat maps with Non linear features

A Novel Method

- A novel method[2]was explored for schizophrenia classification.
- The idea of creating heatmaps using Non linear features was first proposed by Kutepov, Ilya E et al. [11]
- The 10 - 20 system is mapped into a 4×4 system which represents a top view of the brain .
- This inherently acts as a dimensionality reduction technique, reducing the dimension of the crucial information required for classification significantly.

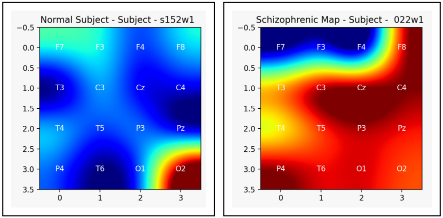


Figure: Normal and Schizophrenic Brain activity

[2]Submitted to *Student Journal of Physics*

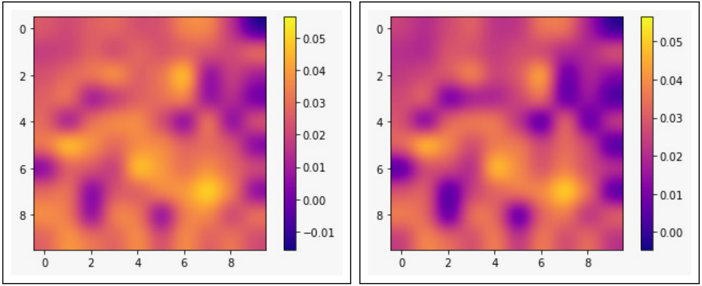


Figure: Before (Left) and After (Right) applying TQWT

For Epilepsy data classification

- For Epilepsy data vector classification, different supervised learning models were used. For this analysis, Random Forest Classifiers[5], K nearest neighbours[4] and Support Vector Machines (SVMs)[3] were used and then their accuracy is tested.
- For implementing these classifiers a custom classification pipeline was built using SciKit Learn package and both statistical as well as Non linear parameters were used as essential features for classification.

For Schizophrenia data classification

- For Schizophrenia classification, a much more sophisticated Convolutional neural network (CNN) architecture was designed based on the heatmaps created and used as a classifier.

Data Augmentation

- When the training data for a neural network is minimal, data augmentation techniques are used for increasing the training pool. [8]
- For enriching the data pool, symmetry of the heatmap can be ignored.
- Vertically and horizontally the images can be flipped or can be zoomed in. This was done using Tensorflow Keras package. [2]
- The input shape is then changed to (224,224,3) for maintaining uniformity.

CNN Architecture

- The CNN architecture was then designed, based on the input data shape.
- The network takes input using a 'MobilenetV2' layer which is specifically designed for deep neural networks in mobile systems. [14]
- The final layer consisted of one neuron with a sigmoid activation function.
- The optimizer was set to be gradient descent and loss as binary crossentropy.

Data augmentation and CNN architecture II

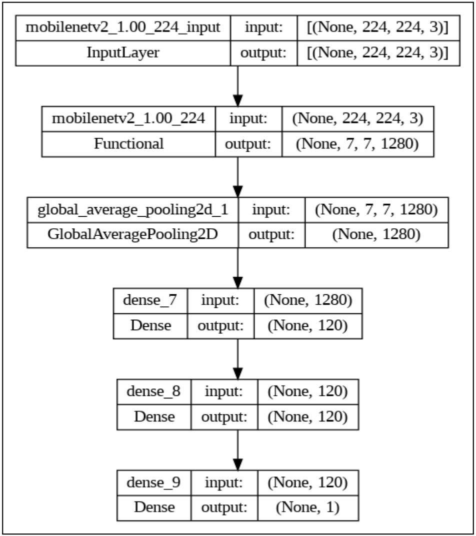


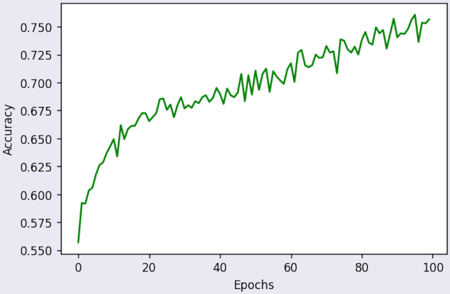
Figure: Architecture of the network *(Plotted using Keras plot utility)*

Classification Accuracy for Epileptic data

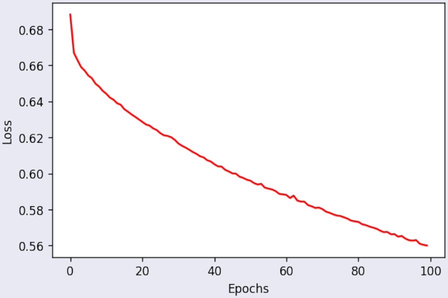
Accuracy		RF	KNN	SVM
Statistical Features		99.0%	98.3%*	97.7%
NLD Features	**Training**	95.4%	100%†	100%
	Testing	94.0%	89.0%†	91.0%

- $^{*}k = 3$ for Statistical Features
- $^{\dagger}k = 1$ for NLD Features

CNN metrics



(a) Accuracy



(b) Loss

Figure: CNN Metrics

Final accuracy - 75.6**%**

TQWT

Tunable q wavelet transform involves tuning a specific q factor for multi-resolution spatial analysis. It is based on modifying DWT (discrete wavelet transform)

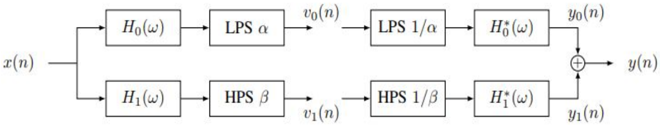


Figure: LP HP filter

Appendix 2 - 10-20 placement system

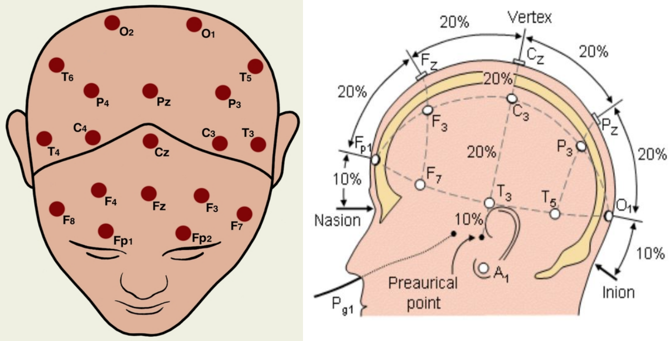


Figure: 10-20 Placement system

Appendix 3 - Previous work done in Schizophrenia classification

- Previous work indicates the use of hybrid CNN/LSTM classifiers [17] use of support vector machines (SVMs) [9]
- A list of classifiers that have been implemented is documented by Sun et al. shown in (figure), (extracted from [[17]])

Author (year)	EEG dataset	Rest/task	Sampling rate	Channels	Features	Classifier	Accuracy
Bose et al., 2016[16]	57 schizophrenia patients and 24 normal subjects	Rest	256	23	Absolute power analysis	SVM	83.33%
Johannesen et al., 2016[53]	40 schizophrenia patients and 12 healthy controls	Task	1024	60	Morlet continuous wavelet transform	SVM	87%
Jeong et al., 2017[54]	30 schizophrenia patients and 15 controls	Task	1024	14	Mean subsampling technique	SKLDA	Over 98%
Piryatinska et al., 2017[55]	45 boys suffering from schizophrenia and 39 healthy boys	Rest	128	16	ϵ-complexity of a continuous vector function	RF	85.3%
Chu et al., 2017[56]	10 normal and 17 markedly ill schizophrenic patients	Task	256	31	ApEn	SVM	81.5%
Alimardani et al., 2018[57]	26 subjects with schizophrenia and 27 patients with BMD	Rest	250	22	DB-FFR	NN	87.51%
Alimardani et al., 2018 [58]	23 bipolar disorder and 23 schizophrenia subjects	Rest	250	21	SSVEP SNR	KNN	91.30%
Phang et al., 2019[59]	45 schizophrenia patients and 39 healthy controls	Rest	128	16	Vector-autoregression-based directed connectivity (DC), graph-theoretical complex network (CN)	DNN-DBN	95%
Phang et al.,2019[60]	45 schizophrenia patients and 39 healthy controls	Rest	128	16	Directed connectivity measures (VAR coefficients and PDCs) and topological CN measures	MDC-CNN	91.69%
Oh et al.,2019[14]	14 healthy subjects and 14 SZ patients	Rest	250	19	-	CNN	98.07%
Present work	54 patients with schizophrenia and 55 healthy controls	Rest	500	60	FuzzyEn	CNN + LSTM	99.22%

Figure: List of previous work compiled by Sun et al.

Random Forest

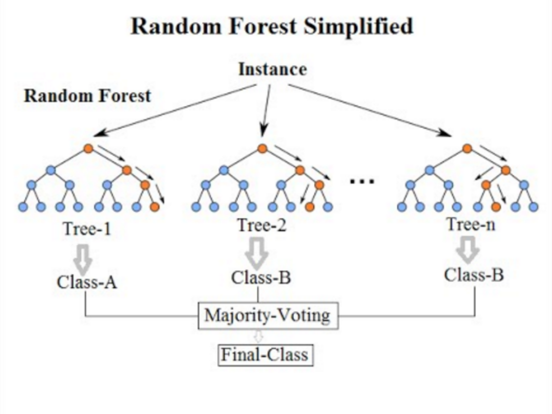
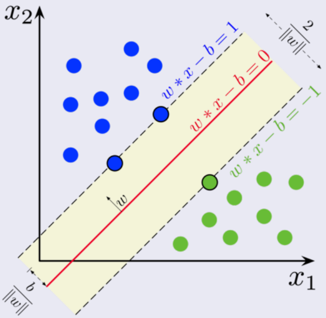


Figure: Random Forest[5]

KNNs and SVMs

- Support Vector Machines
- K Nearest Neighbour



(a) SVM[3]

(b) KNN[4]

Classification method

A **Convolutional Neural Network** is used for classification. These are neural networks specifically designed for image analysis[10] with reduced number of weights that take exploit translational in variance. The network takes the heat maps as image input and classifies them on basis of Schizophrenic or Non-Schizophrenic.

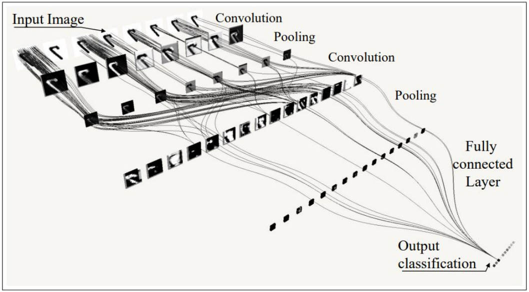
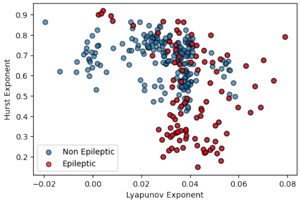
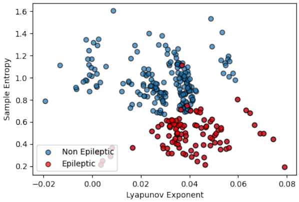


Figure: An example of a convoluted neural network

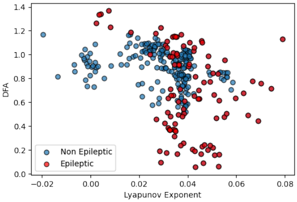
Appendix 6 - Additional plots



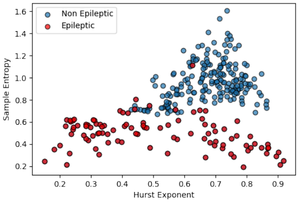
(a) Lyapunov-Hurst

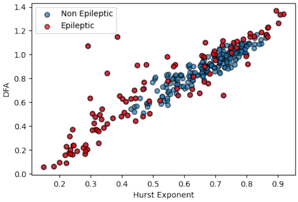


(b) Lyapunov-Entropy

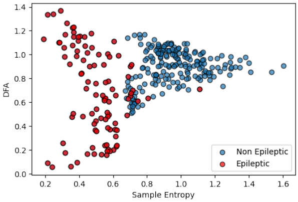


(c) Lyapunov-DFA





(e) Hurst-DFA



(f) Entropy-DFA

(e) Hurst-Entropy

- Module: tf.keras — tensorflow core v2.4.1.
- File:SVM margin.png - Wikimedia Commons, Mar 2022.
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In *2018 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, pages 856–860, 2018.

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IEEE Transactions on Signal Processing, 59:3560–3575, 0.

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Scientific Reports, 11, 02 2021.