Convolutional Neural Networks for Seizure Prediction using Intracranial and Scalp Electroencephalogram

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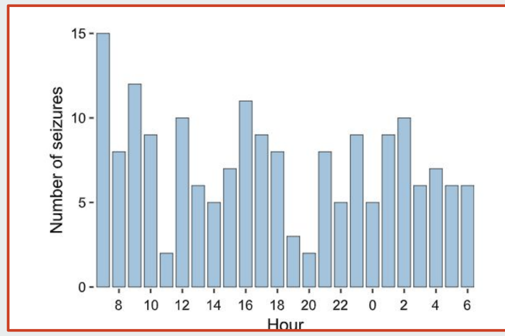


Hi my name is Daniella Pombo

Today I will be presenting on a study on Convolutional Neural Networks for Seizure Prediction using Intracranial and Scalp Electroencephalogram
Which was produced by these scientists from China and Australia
And was published in May 2018 by Neural Network Journal

This graph demonstrates a subset of the analyzed patient population w/ frequent seizures & as you can see, patient can have a large amount of seizures w/ in one day

So what is a seizure:

Defined as a temporary event of abnormal, uncontrollable neurological electrical activity that produces neurological and physical symptoms such as physical convolution and thought disruption

Seizure frequency, characteristics and symptoms are patient specific and change per patient over time

Therefore, it is crucial that science begins to create biomedical devices that *can detect the onset of seizures to assist w/ precautionary measures and treatments to insure the safety and longevity of patients w/ seizures*

Purpose

- Propose generalized seizure convolutional neural network predictive model for iEEG and sEEG datasets

The purpose of this research study is to propose a generalized seizure convolutional neural network predictive model for Intracranial EEG also referred to as iEEG and Scalp EEG denoted sEEG

> *What the scientists specifically mean by generalized is an algorithm w/ minimum feature engineering techniques as previous seizure predictive algorithms required a large amount of feature engineering per patient and thus is not applicable for a larger period of time per patient and for a larger sample of seizure patient.*

EEG's output is depicted here, as the EEG's electrode pick up the electrical signals from the brain and produce graphical images to indicate their brain waves of the patient. Therefore EEG's data is an image HxWXD (high, width, dimension) matrix of pixel values

Here is an example of partially processed EEG image data that this study uses.

Background

- Materials:
  - Datasets: Freiburg Hospital Dataset, CHB MIT dataset, American Epilepsy Society Seizure Prediction Challenge (Kaggle)
  - Python 2.7, Tensorflow 1.4.0
- Seizure predictive algorithms' accuracy and success metrics are compared to a random chance predictor

Table 1
Summary of the three datasets used in this work.

Dataset	EEG type	No. of patients	No. of channels	No. of seizures	Interictal hours
Freiburg Hospital	Intracranial	13 patients	6	59	311.4
Boston Children's Hospital–MIT	Scalp	13 patients	22	64	209
American Epilepsy Society Seizure Prediction Challenge (Kaggle)	Intracranial	5 dogs, 2 patients	16	48	627.7

Materials include

Python 2.7 and Tenserflow

Datasets…

Which intotal comprise 28 patient and 5 dogs

171 seizures

1148.1 hrs of recordings

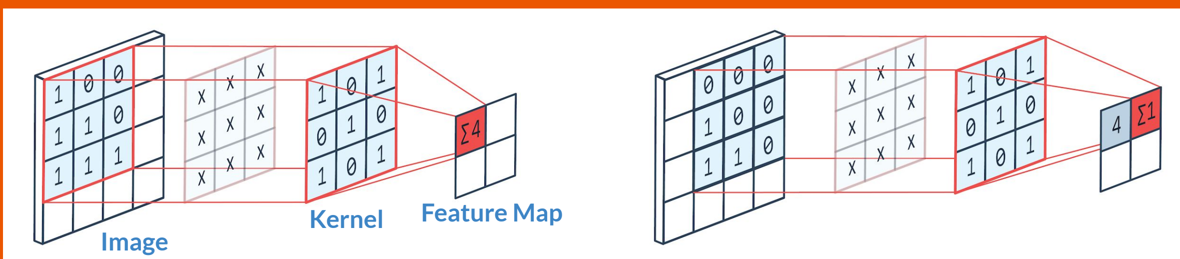
Something to keep in mind is that seizure predictive algorithms have an accuracy metric that is created by comparing their outputs to a random chance predictor: they must prove that their algorithm is better predicting a seizure in comparison to predicting the seizure by chance.

- For seizures less than 30 min from previous seizure = consider them as only one seizure and use the onset of the leading seizure as on the onset of the combines seizures
- Note: Kaggle data has iEEG data from 5 dogs and 2 patients

Convolutional Neural Networks (CNN)

Convolution: mathematical operation on 2 functions that produces an another which expresses how the shape of one function affects/modifies the other

- *CNN*: deep learning algorithm used for images
  - **Image Dimensionality Reduction**:
    - Allows for use of multilayer neural network
    - ***Kernel***: a HxWxD matrix that functions as a filter for image dimensionality reduction
    - ***Convolutional Operation***: used to extract high level, features from input image via dot(kernel, image)



As I am an applied math major I enjoying learning and talking about the mathematics behind these algorithms,

Therefore, w/in mathematics a convolution is the operation on 2 functions which produces a 3rd that describes how one of the functions affects and modifies the other. Therefore the result describes the connection and affect one function has on the other.

CNN: deep learning algorithm used for images

Tat was inspired by the visual cortex

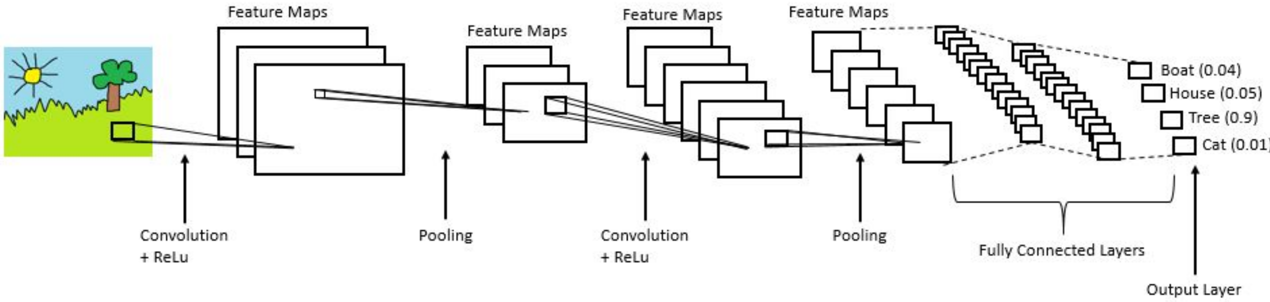
in which retains all the crucial spatial and temporal features of an image

Its main component is the image dimensionality reduction

Which allows for the use of a multilayer neural network as raw EEG data would not be properly processed and interpreted by a neural network as is

The image reduction is created by applying a dot product to the image and the kernel which the kernel is a matrix that actions as a filter to the image and carries out the convolutional operation.

The dot product results in the feature map.


Feature Maps
Feature Maps
Feature Maps
Feature Maps
Boat (0.04)
House (0.05)
Tree (0.9)
Cat (0.01)
Convolution
+ ReLu
Pooling
Convolution
+ ReLu
Pooling
Fully Connected Layers
Output Layer

MLA Seizure Predictive Algorithm Procedure & Implementation

Implementation

1. **Clean, convert and process input image data**
   a. Short time Fourier Transform (STFT) of input data
   b. Convolutional network:
      i. 3 convolution blocks w/ batch normalization, rectified linear unit activation function and max pooling layer
         1. 1st convolution layer: w/ 16 n x 5 x5 kernel (where n is number of EEG channels), stride 1x2x2
         2. 2nd colutionan layer: w/ 32 convolution kernels, kernel size 3x3, stride of 1x1 and max pooling over 2x2 region
         3. 3rd colutionan layer has 64 convolution kernels, kernel size 3x3, stride of 1x1 and max pooling over 2x2 region
2. **2 fully connected neural network layers**
   a. 1st layer: w/sigmoid activation, drop out rate of 0.5 & an output size of 256
   b. 2nd layer: w/softmax activation function, drop out rate of 0.5 & output size of 2

mplementation of generalized seizure predictive CNN is composed of 3 main parts

> *1st is the data preprocessing and convert which is started via Short time Fourier Transform (STFT) which takes a raw EEG data and converts it into a 2d Matrix that has a frequency vs time axis*
>
> *Then the convolutional operations are applied w/ 3 convolutional blocks computed of batch normalization, rectified linear unit function and max pooling layer*

Convolutional network w/ 3 convolution blocks w/ rectified linear unit activation function and max pooling layer

2 fully connected neural network layers

> *1st layer is composed of Sigmoid activation w/drop out rate 0.5 & output size 256*
>
> *2nd layer is composed of Softmax activation function w/drop out rate 0.5 and output size 2*

MP: reps max pooling layers

rectified linear unit activation function and max pooling layer

Features extracted by the 3 convolution blocks are flattened to connected to 2 followed connected layer

Procedure

$$P \approx 1 - e^{-\mathrm{FPR}\cdot\mathrm{SOP}} .$$

$$p = \sum_{i \geq m} \binom{M}{i} P^i (1-P)^{M-i} .$$

Random Chance Predictor

1. Compute predicted seizures
2. Compare to nonspecific random chance predictor
   a. **P** = approximation of the probability of alarm in an SOP given the FPR
   b. **p** = probability of predicting at least m of M independent seizures by chance
      i. Calculated for each patient
3. **If $p < 0.05$, can conclude prediction method is “significantly better” in comparison to the random predictor**

1. Leave-one-Out Cross-validation performed twice, then recorded average results w/ standard deviation

- SOP: seizure occurrence period, during the period of a seizure onset (the seizure event) which is before the SPH (seizure prediction horizon)
- FPR: “defined as the number of false alarms per hour”

Results

- CHB-MIT: Sensitivity 81.2% w/ FPR 0.16/h

Patient	No. of seizures	Interictal hours	Sensitivity (%)	FPR (/h)	p
Pat1	7	17	85.7 ± 0.0	0.24 ± 0.00	<0.001
Pat2	3	22.9	33.3 ± 0.0	0.00 ± 0.00	<0.001
Pat3	6	21.9	100 ± 0.0	0.18 ± 0.00	<0.001
Pat5	5	13	80 ± 20	0.19 ± 0.03	0.010
Pat9	4	12.3	50 ± 0.0	0.12 ± 0.12	0.067
Pat10	6	11.1	33.3 ± 0.0	0.00 ± 0.00	0.025
Pat13	5	14	80 ± 0.0	0.14 ± 0.00	<0.001
Pat14	5	5	80 ± 0.0	0.40 ± 0.00	0.004
Pat18	6	23	100 ± 0.0	0.28 ± 0.02	<0.001
Pat19	3	24.9	100 ± 0.0	0.00 ± 0.00	<0.001
Pat20	5	20	100 ± 0.0	0.25 ± 0.05	<0.001
Pat21	4	20.9	100 ± 0.0	0.23 ± 0.09	<0.001
Pat23	5	3	100 ± 0.0	0.33 ± 0.00	<0.001
Total	64	209	81.2 ± 1.5	0.16 ± 0.00	

Patient	No. of seizures	Interictal hours	Sensitivity (%)	FPR (/h)	p
Pat1	4	23.9	100 ± 0.0	0.00 ± 0.00	<0.001
Pat3	5	23.9	100 ± 0.0	0.00 ± 0.00	<0.001
Pat4	5	23.9	100 ± 0.0	0.00 ± 0.00	<0.001
Pat5	5	23.9	40 ± 0.0	0.13 ± 0.00	0.032
Pat6	3	23.8	100 ± 0.0	0.00 ± 0.00	<0.001
Pat14	4	22.6	50 ± 0.0	0.27 ± 0.00	0.078
Pat15	4	23.7	100 ± 0.0	0.02 ± 0.02	<0.001
Pat16	5	23.9	80 ± 0.0	0.17 ± 0.13	0.001
Pat17	5	24	80 ± 0.0	0.00 ± 0.00	<0.001
Pat18	5	24.8	100 ± 0.0	0.00 ± 0.00	<0.001
Pat19	4	24.3	50 ± 0.0	0.16 ± 0.00	0.033
Pat20	5	24.8	60 ± 0.0	0.04 ± 0.00	<0.001
Pat21	5	23.9	100 ± 0.0	0.00 ± 0.00	<0.001
Total	59	311.4	81.4 ± 0.0	0.06 ± 0.00	

- Freiburg: Sensitivity: 81.4% w/ FPR 0.06/h

- American: Sensitivity 75% and FPR 0.21/h

Participant	No. of seizures	Interictal hours	Sensitivity (%)	FPR (/h)	p
Dog1	4	80	50 ± 0.0	0.19 ± 0.02	0.053
Dog2	7	83.3	100 ± 0.0	0.04 ± 0.03	<0.001
Dog3	12	240	58.3 ± 0.0	0.14 ± 0.09	<0.001
Dog4	14	134	78.6 ± 0.0	0.48 ± 0.07	<0.001
Dog5	5	75	80 ± 0.0	0.08 ± 0.01	<0.001
Pat1	3	8.3	100 ± 0.0	0.42 ± 0.06	0.009
Pat2	3	7	66.7 ± 0.0	0.86 ± 0.00	0.693
Total	48	627.7	75 ± 0.0	0.21 ± 0.04	

- Sensitivity: “defined as percentage of seizures correctly predicted divided by the total number of seizures”
- Freiburg: Sensitivity: 81.4% (48/59 seizure successfully predicted) w/ FPR 0.06/h

- CHB-MIT: Sensitivity 81.2% w/ FPR 0.16/h
- American: Sensitivity 75% and FPR 0.21/h

Conclusion:

1. Generalized CNN is good approach for iEEG and sEEG data sets
2. Perfect prediction is not yet available: Current predictions can, at minimum, provide for precautionary warnings for seizures

Future:

- FDA defines *International Medical Device Regulators Forum (IMDRF) software "as a medical device as software intended to be used for one or more medical purposes that perform these purposes without being part of a hardware medical device" (FDA).*
    - Reviewed through **premarket pathway Clearance 510K**
        - *Any updates/modifications to software as medical device must go through approval process*
        - **Was not designed for AI and MLA**
            - FDA has proposed and requested enhancements on premarket approval specifically for AI and ML software as Medical Devices (SaMD)
- Currently any medical devices w/ AI and ML have to go through a long outdated pre approval process for pre market integration and modifications

Resources

- https://www.fda.gov/medical-devices/software-medical-device-samd/artificial-intelligence-and-machine-learning-software-medical-device#transforming
- https://towardsdatascience.com/batch-normalization-in-neural-networks-1ac91516821c
- https://medium.com/@amarbudhiraja/https-medium-com-amarbudhiraja-learning-less-to-learn-better-dropout-in-deep-machine-learning-74334da4bfc5
- https://peltarion.com/knowledge-center/documentation/modeling-view/build-an-ai-model/blocks/2d-convolution-block
- https://medium.com/data-science-bootcamp/understand-the-softmax-function-in-minutes-f3a59641e86d
- https://towardsdatascience.com/a-comprehensive-guide-to-convolutional-neural-networks-the-eli5-way-3bd2b1164a53
- https://buzzrobot.com/whats-happening-inside-the-convolutional-neural-network-the-answer-is-convolution-2c22075dc68d
- https://peltarion.com/knowledge-center/documentation/modeling-view/build-an-ai-model/blocks/2d-convolution-block
- https://www.hopkinsmedicine.org/health/treatment-tests-and-therapies/electroencephalogram-eeg
- https://www.medicaldevice-network.com/digital-disruption/ai/tech-watch-machine-learning-healthcare/
- https://www.sciencedirect.com/science/article/pii/S0893608018301485?via%3Dihub
- https://www.sciencedirect.com/science/article/abs/pii/S0893608018301485?via%3Dihub
- http://clik.dva.gov.au/ccps-medical-research-library/sops-grouped-icd-body-system/e-g/epileptic-seizure-f050-7803
- https://medium.com/@RaghavPrabhu/understanding-of-convolutional-neural-network-cnn-deep-learning-99760835f148