Convolutional Neural Networks for Seizure Prediction using Intracranial and Scalp Electroencephalogram

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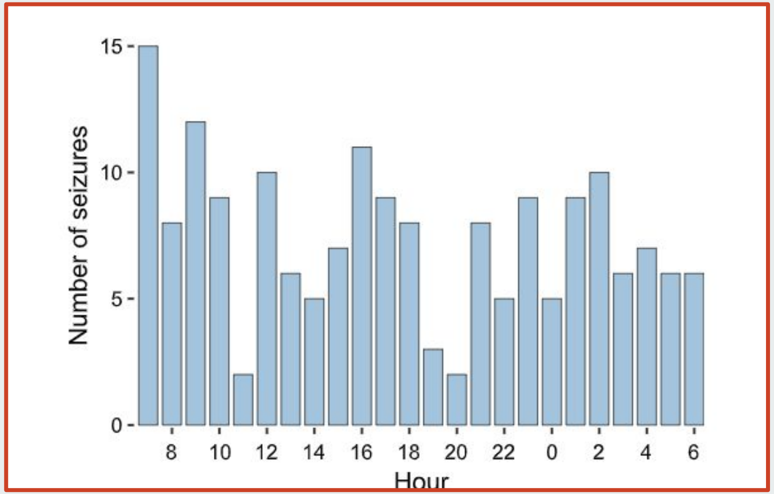


Background

- Abstract: Proposes generalized seizure convolutional neural network predictive model for iEEG and sEEG datasets
- 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

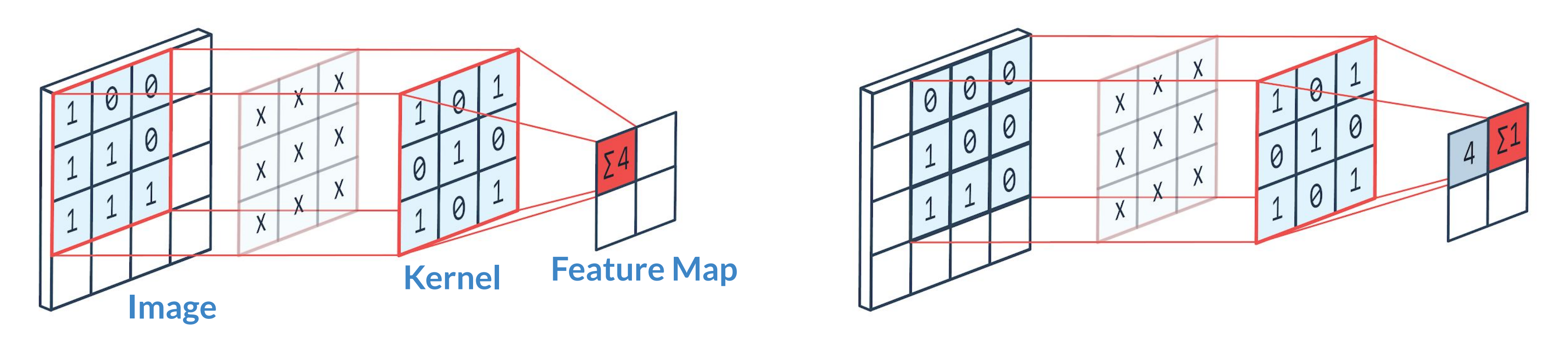
Table 1
Summary of the three datasets used in this work.

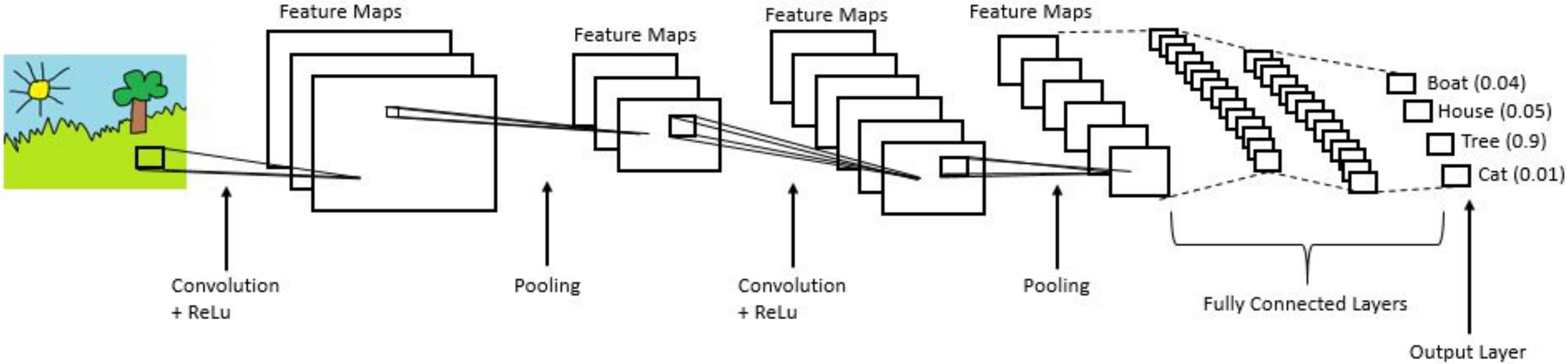
Dataset	EEG type	No. of patients	No. of channels	No. of seizures	Interictal hours
Freiburg Hospital	Intracranial	13 patients	6	59	311.4
Boston Children's Hospital–MIT	Scalp	13 patients	22	64	209
American Epilepsy Society Seizure Prediction Challenge (Kaggle)	Intracranial	5 dogs, 2 patients	16	48	627.7

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)




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

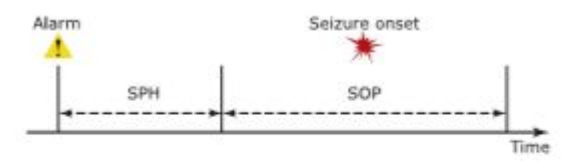
1. **Clean, convert and process input image data**
    a. Short time Fourier Transform (STFT) of input data
    b. **Convolutional network:**
        i. 3 convolution blocks w/rectified linear unit activation function and max pooling layer
            1. 1st convolution layer: w/ 16 n x 5 x5 kernel (where 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. **Batch normalization**
3. **2 fully connected neural network layers**
    a. 1st neuron: w/sigmoid activation, drop out rate of 0.5 & an output size of 256
    b. 2nd neuron: w/softmax activation function, drop out rate of 0.5 & output size of 2

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**
4. Leave-one-Out Cross-validation performed twice and average results w/ standard deviation were recorded

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	

network results are only marginally better than the random predictor's.

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	

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