Application of Deep Learning to Brain Computer Interfaces

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Intro: What is a Brain -Computer Interface?

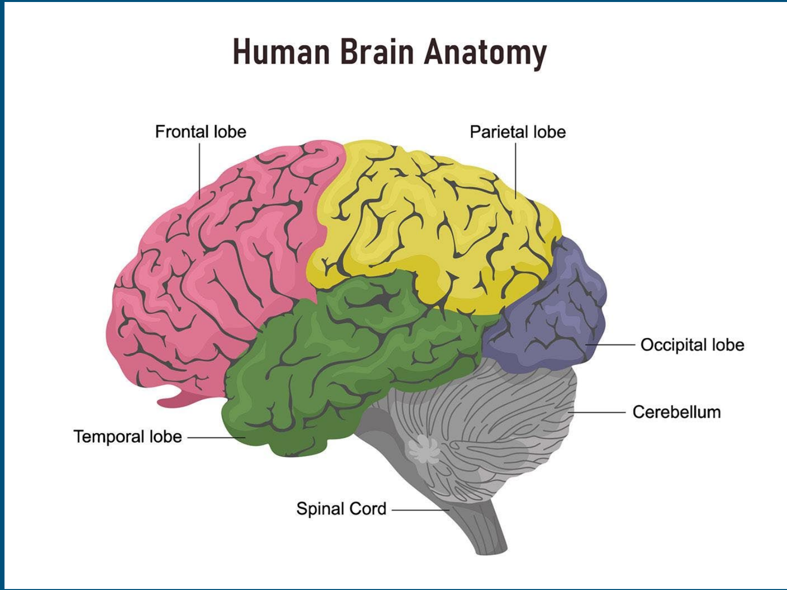
- Interprets brain activity into actions
- Medical: Neuro-rehabilitation
- Entertainment: Virtual Reality

Outline

- Background
  - The Brain
  - Electroencephalograms (EEG)
  - Deep Learning
  - Convolutional Neural Networks (CNN)
  - Brain-Computer Interface (BCI)
- Mental State Decoding
- Virtual Reality Neuro-Rehabilitation

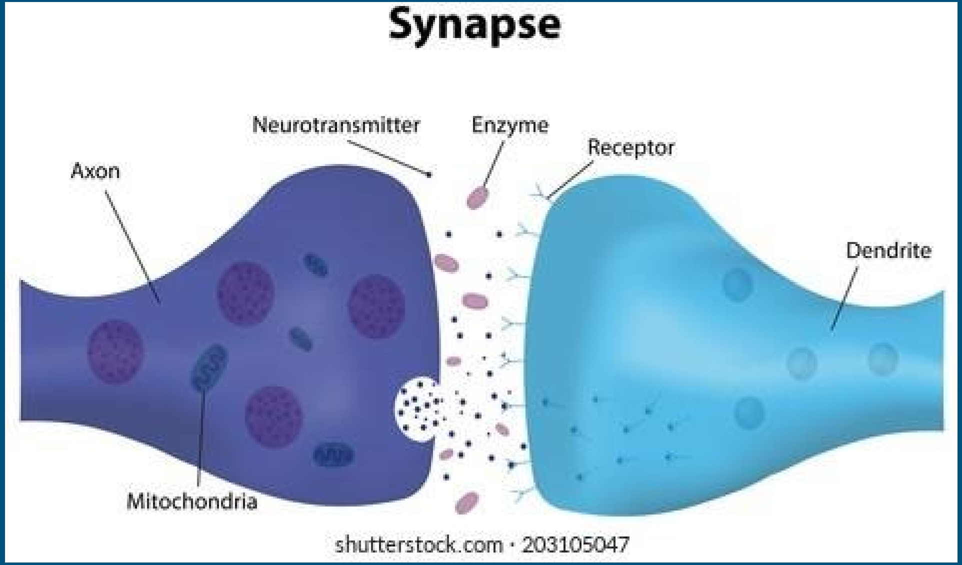
Background: The Brain

- Cerebrum, Cerebellum, Stem
- Frontal, Parietal, Temporal, Occipital
- Movement



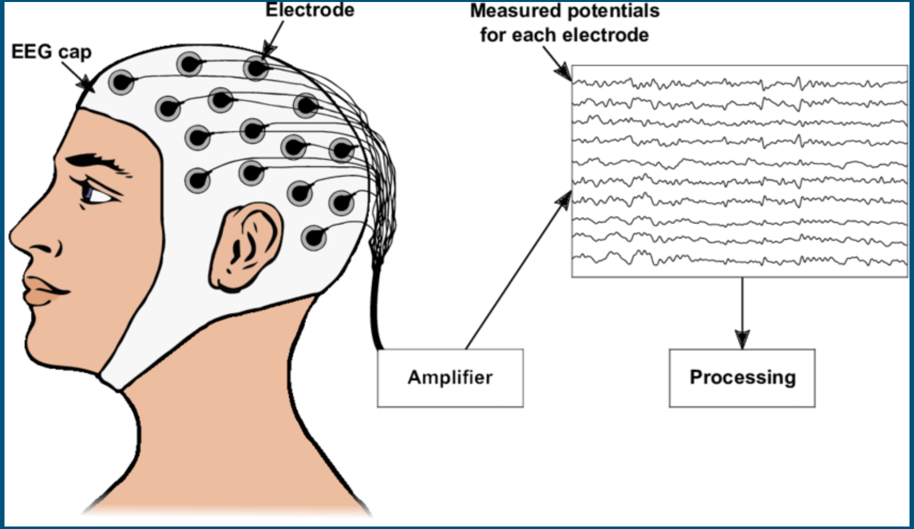
Background: The Brain

- 86 Billion Neurons
- Synapse
- Learning



Background: Electroencephalograms

- Measures brain activity
- Event-Related Potentials and/or Spectral Content



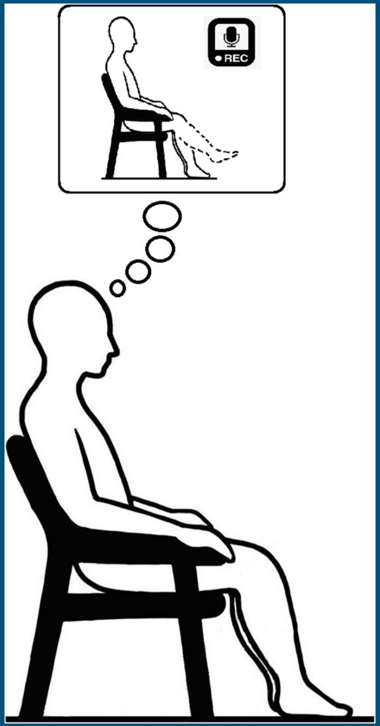
Background: Electroencephalograms

- Oscillation frequency categorized
- Area of brain and action performed

Band	Frequency (Hz)	Amplitude (μV)	Location	Activity
Delta	0.5–4 Hz	100–200	Frontal	Deep sleep
Theta	4–8 Hz	5–10	Various	Drowsiness, light sleep
Alpha	8–13 Hz	20–80	Posterior region of head	Relaxed
Beta	13–30 Hz	1–5	Left and right side, symmetrical distribution, most evident frontally	Active thinking, alert
Gamma	>30 Hz	0.5–2	Somatosensory cortex	Hyperactivity

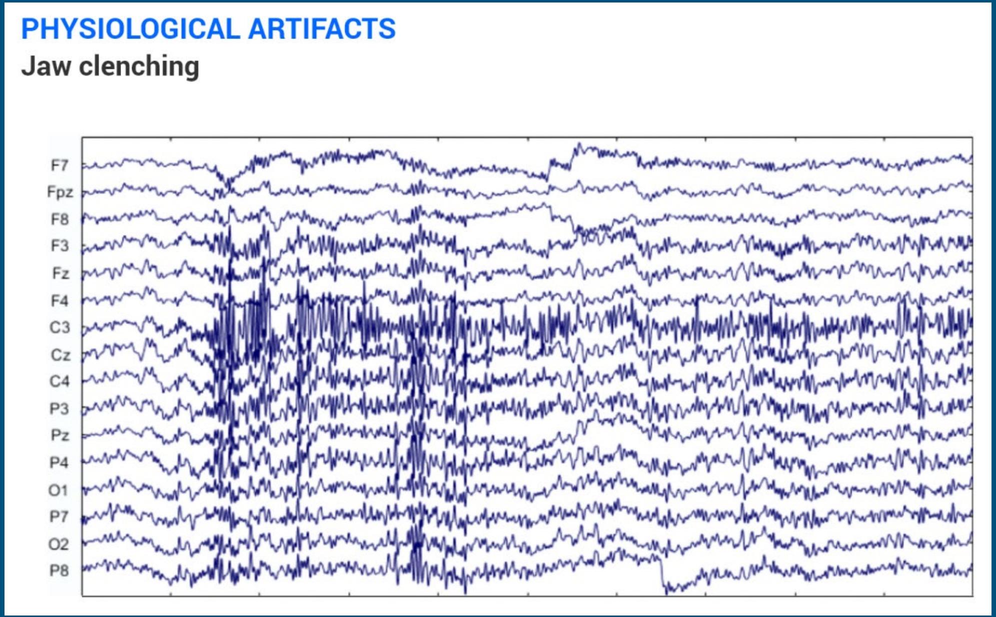
Background: Electroencephalograms

- Motor-Imagery Brain-Computer Interface (MI-BCI)
  - Sensorimotor Rhythms
- Alpha and Beta waves
- Can detect thinking about moving a muscle



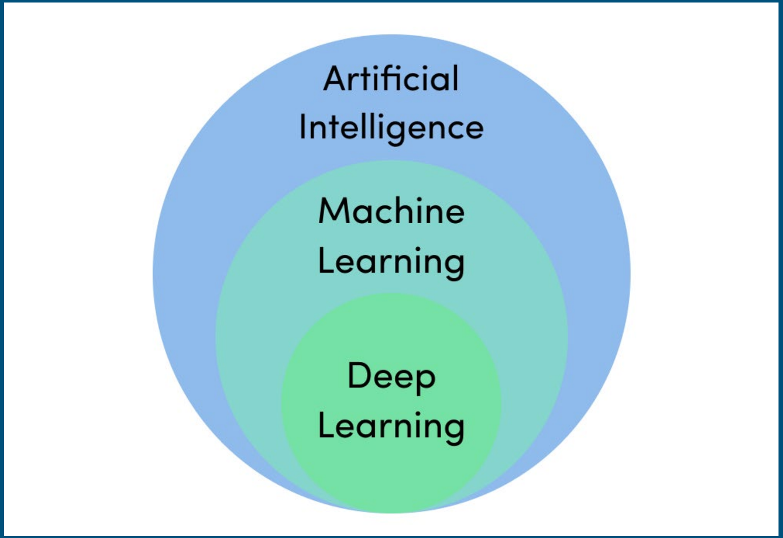
Background: Electroencephalograms

- Lots of variation;
  Hard to use clinically
- Artifacting
- Use Deep Learning
  to decipher



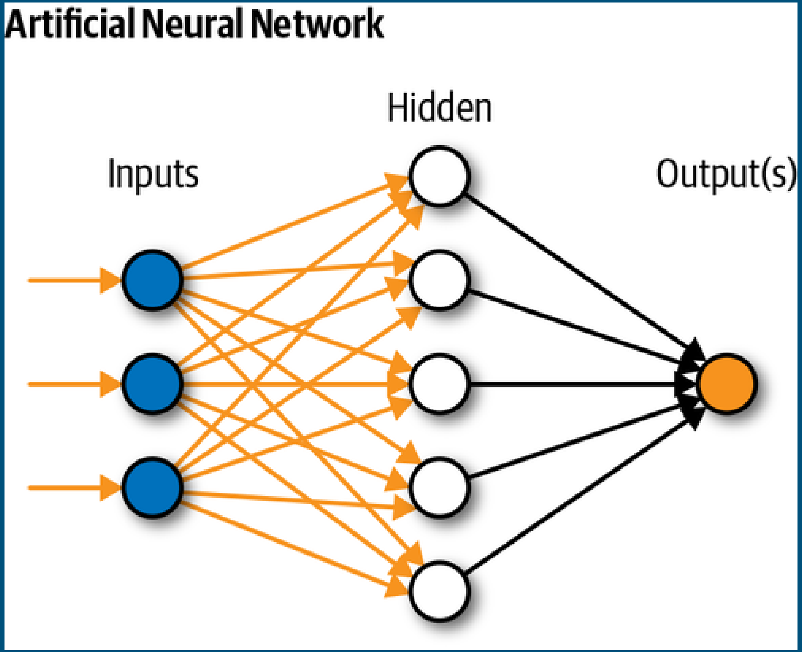
Background: Deep Learning

- Machine Learning method based on Artificial Neural Networks(ANN)
- Supervised, Semi-Supervised, Unsupervised



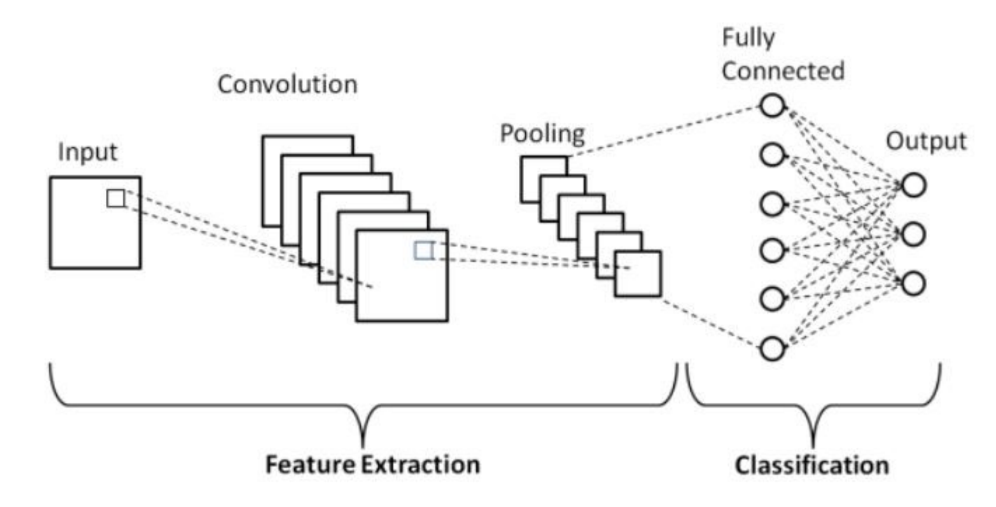
Background: Deep Learning

- ANN
- Data sent between nodes; Like neurons
- Transforms Data; Increasingly Abstract
- Convolutional Neural Networks



Background: Convolutional Neural Networks

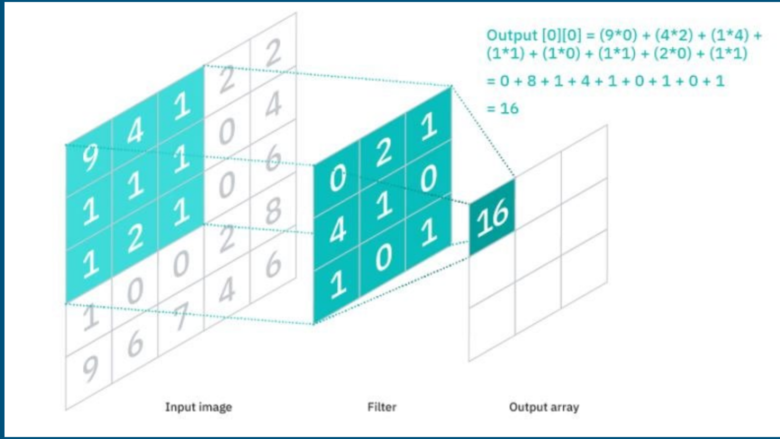
- Image Processing, Audio Processing, Speech Recognition,
- Convolutional, Pooling, Fully Connected



Background: Convolutional Neural Networks

Convolutional Layer

- Scanning input in search of a feature
- Applies weights and filter
- Produces output array using dot product operation
- Rectified Linear Unit (ReLU) Activation Function

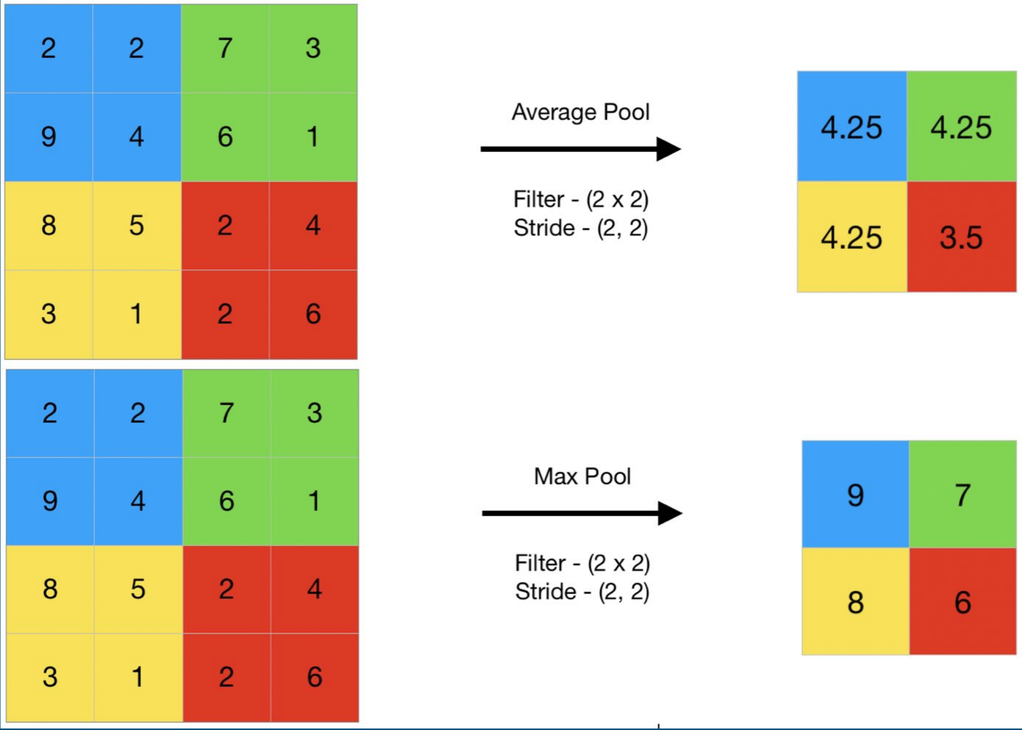


$$\mathbf{a} \cdot \mathbf{b} = \sum_{i=1}^{n} a_i b_i = a_1 b_1 + a_2 b_2 + \cdots + a_n b_n$$

Background: Convolutional Neural Networks

Pooling Layer

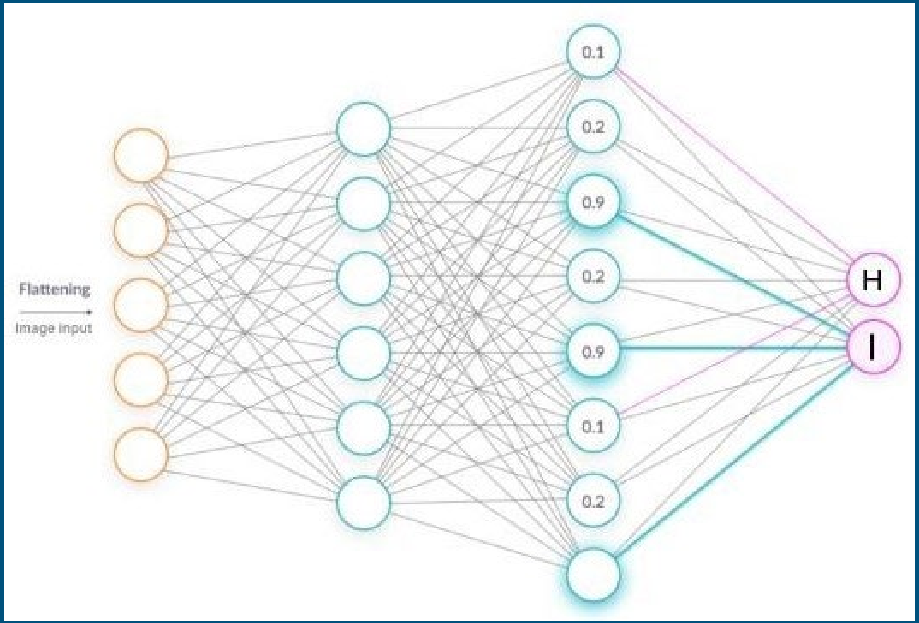
- Reduce complexity; Improve efficiency
- Average Pooling
- Max Pooling



Background: Convolutional Neural Networks

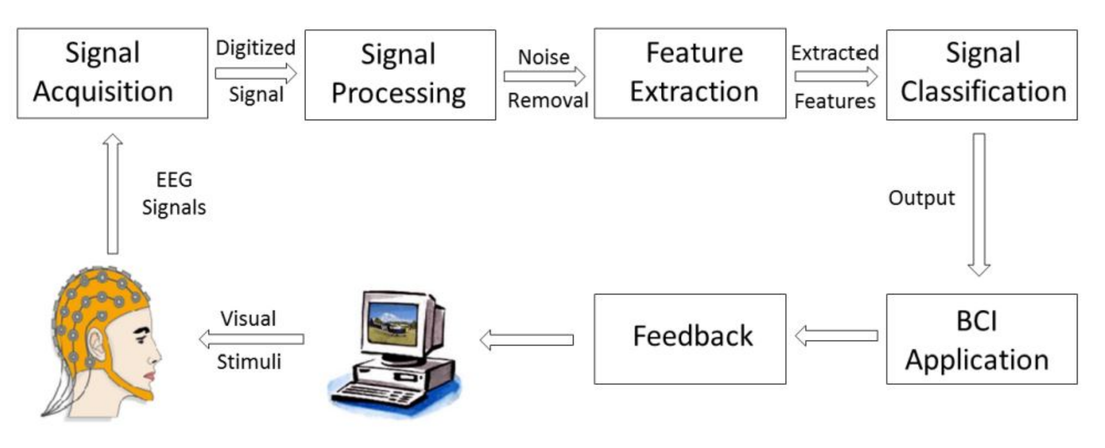
Fully Connected Layer

- Connects every output to Every input
- Softmax Activation Function
  - Classifies; between 0 and 1



Background: Brain -Computer Interface

1. Brain Activity Measurement
2. Pre-Processing
3. Feature Extraction
4. Classification
5. Translate into command



Mental State Decoding

Mental State Decoding

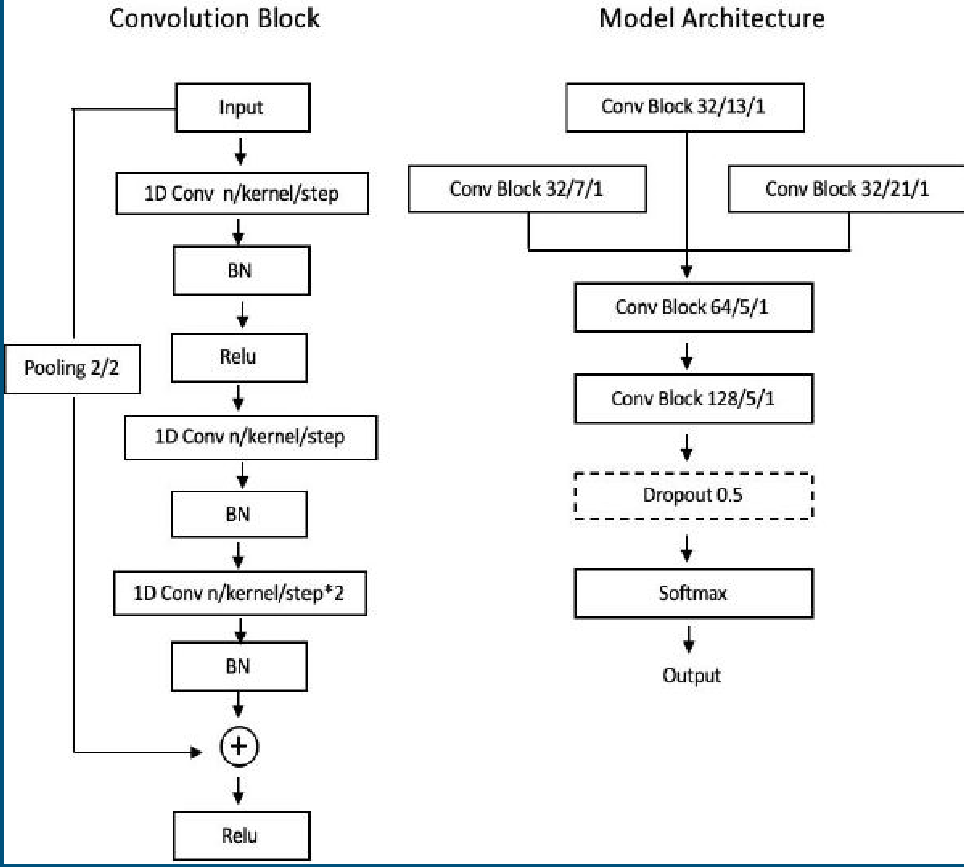
- Research conducted in 2019
  - DeepBlue Tech. Shanghai, China
- Predict Mental States
- Driver Fatigue
- EEG and Electrooculogram(EOG)

Mental State Decoding

- 5 participants;
  ~6 sessions each;
  25 hours of EEG recording
- Virtually driving a train for 30 minutes
  - 10 focused; 10 somewhat relaxed; 10 fully relaxed

Mental State Decoding

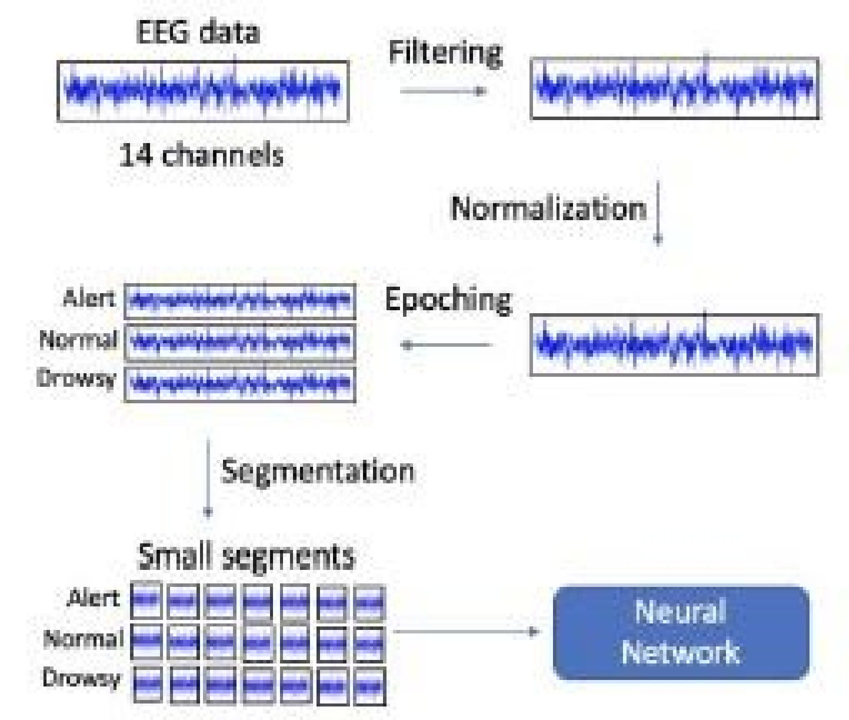
- Input; 5 Convolution blocks; Output
- ReLU
- Softmax



Mental State Decoding

- 14 electrodes; 0.2-43hz
- Data Normalization
- Alert, Normal, Drowsy

$$x_{i,j} = \frac{x_{i,j} - \overline{x}}{s}$$



Mental State Decoding

- 96.40% accuracy with traditional methods
  - k-Nearest Neighbor(kNN);
    Adaptive Neuro-Fuzzy Inference System(ANFIS);
    Support Vector Machine(SVM)
  - Universal Classifier > Subject Classifier
- 53.22% accuracy with proposed DL model
- Deep Learning needs more development

Table 1: Comparisons of the Prediction Accuracy with Traditional Methods.

Methods	Prediction Accuracy
kNN (Acl et al [12])	77.76%
ANFIS (Acl et al [12])	81.55%
SVM (Acl et al [12])	91.72%
Our proposed	96.40%

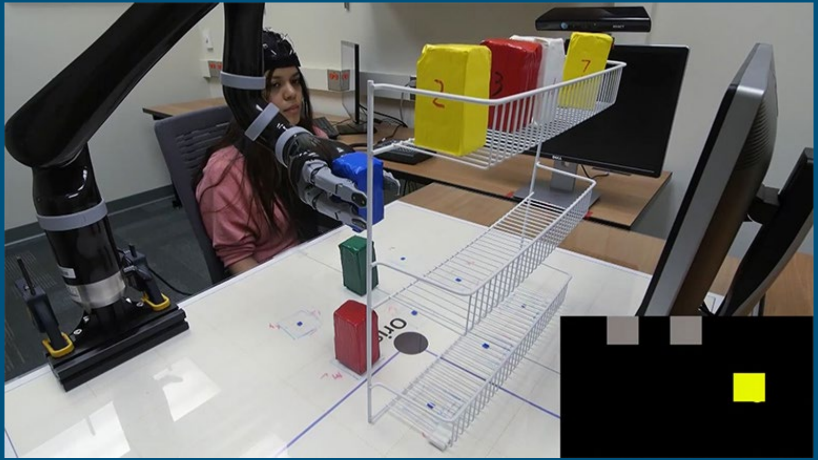
Table 2: Comparisons of the Prediction Accuracy with other Deep Learning Models.

Methods	Prediction Accuracy
EEGNet ([17])	51.01%
FBCSPShallowNet ([18])	49.17%
DeepConvNet ([18])	52.91%
Our proposed	53.22%

Virtual Reality Neuro - Rehabilitation

Virtual Reality Neuro -Rehabilitation

- BCI Neuro-Rehabilitation
- Neurons killed by Stroke
- Strengthening Motor Functions



Virtual Reality Neuro -Rehabilitation

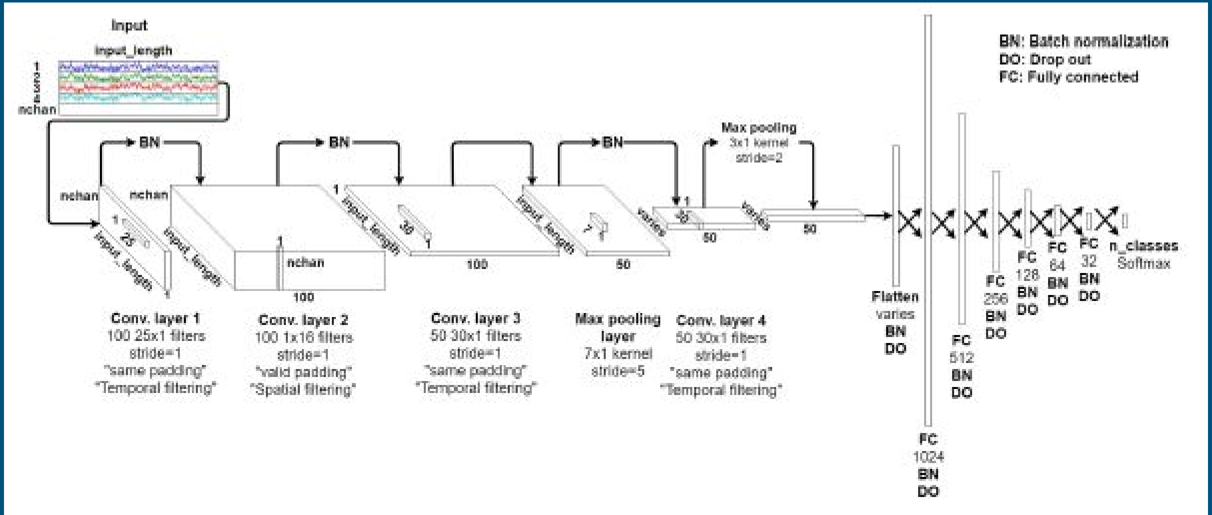
- Conventional therapy is monotonic
  - VR more enjoyable
- Motor-Imagery Brain-Computer Interfaces increase neuroplasticity
- Instant Brain Activity measurement

Virtual Reality Neuro -Rehabilitation

- Technical University of Denmark
- Catch Fruit; Kick Footballs
- No arm or leg graphics
- Positive feedback on success
- Three Data sets:
  2-class, 3-class, 4-class

Virtual Reality Neuro -Rehabilitation

- Every FC Layer and Convolutional Layer applies ReLU
- Max Pooling



Virtual Reality Neuro -Rehabilitation

- Global/Universal Classifier
- More Channels

  = Greater Accuracy

This work			6 [sec]	0.5 [sec]	
	64	global 2cl	85.94%	80.45%	CNN
		global 3cl	88.50%	84.08%	
		global 4cl	76.37%	72.28%	
	16	global 2cl	79.66%	72.81%	CNN
		global 3cl	84.13%	78.62%	
		global 4cl	65.96%	60.37%	

Left hand	Right hand	Overall
44.9±17.8% (77%)	75.6±11.4% (95.0%)	60.2±14.6% (87.0%)

Left hand	Right hand	Feet	Overall
38.6±22.0% (77.0%)	19.3±9.5% (30.0%)	100.0±0.0% (100.0%)	53.6±9.6% (70.0%)

Virtual Reality Neuro -Rehabilitation

- Participants found it fun and immersive
  - Slightly strenuous
- Results confirm clinical potential
- MI-BCI-VR systems recommended for MI stroke rehabilitation

Fun	Interesting	Strenous	Immersive	Discomfort
8.40±1.65 (10)	9.50±0.71 (10)	5.90±2.47 (10)	8.20±1.55 (10)	3.70±2.31 (7)

Conclusion

- Still in Development
- Potential has been shown
- EEG and DL issues

Questions?

Sources

1. Tamás Karácsony, John Paulin Hansen, Helle Klingenberg Iversen, and Sadasivan Puthusserypady. 2019. Brain Computer Interface for Neuro-rehabilitation With Deep Learning Classification and Virtual Reality Feedback. In Proceedings of the 10th Augmented Human International Conference 2019 (AH2019). Association for Computing Machinery, New York, NY, USA, Article 22, 1–8. DOI:https://doi-org.ezproxy.morris.umn.edu/10.1145/3311823.3311864
2. Dongdong Zhang, Dong Cao, and Haibo Chen. 2019. Deep learning decoding of mental state in non-invasive brain computer interface. In Proceedings of the International Conference on Artificial Intelligence, Information Processing and Cloud Computing (AIIPCC '19). Association for Computing Machinery, New York, NY, USA, Article 6, 1–5. DOI:https://doi-org.ezproxy.morris.umn.edu/10.1145/3371425.3371441