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ARTIFICIAL INTELLIGENCE - A REVIEW ON DEEP LEARNING BASED BRAIN VOXEL CLASSIFICATION

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ABSTRACT

The Brain is key computational unit of Human beings and it is built of small volumetric units called Voxel. This is a Survey paper that explores how deep learning can be used in Brain Voxel classification from given functional magnetic resonance (fMRI) image data.

KEYWORDS: *Artificial Intelligence, Deep Learning, Neural Networks, Executive Function, CNN, Working Memory Voxel and Brain*

INTRODUCTION

Artificial Intelligence (AI) visualizes the Brain as a deep Neural Network. As per brain imaging concept, any stimuli carried towards the cell bodies and these input signals from dendrites are passed to neurons which produce an output signal through Axons. Since this simulates deep neural network signal flow and various analyses have proven effective results, recent research trend is to use Deep learning for Brain imaging and voxel classifications from input FMRI data.

In this aspect further sections summarize the basics of fMRI, Brain voxel classification approaches, deep learning usage in Voxel classification, tools used and a case study on deep learning architectures used in Brain Working Memory voxel classification domain.

FMRI, Voxel, Population Receptive Field (PRF)

The fMRI (functional Magnetic Resonance Imaging) uses BOLD (Blood Oxygen Level Dependent) contrast technique to measure brain activity. The fMRI scan record information from each brain voxel across time (Belliveau, 1991) in both resting and active states. For each stimuli activity, the fMRI records BOLD signal as variation or contrast in Blood Oxygen level from its original or baseline value. [3]

A Voxel is a single volumetric unit in the brain. Approximately 100,000 voxels are present in the human brain's cerebral cortex.

Population receptive field (pRF) is the group of neurons responding stimuli. The pRF mapping is processing of mapping voxel to the cortical field as a function of voxel parameters such as RF location and size.

FMRI Pre-Processing Tasks Prior to Voxel classification

The FMRI data has to be preprocessed before classification. Skull scripting or Brain extraction from given 3D fMRI medical image is first important pre-processing step. J.Kleesiek et al have used 3D CNN for skull scripting [2].

In [3] Fayyaz Ahmad and Iftikhar used SPM tool that can support fMRI preprocessing tasks such as smoothing with Gaussian kernel, realignment for movement correction and slice time correction activities and Contrast comparison. Few Other preprocessing steps include Data augmentation, Registration, Bias Field correction, Intensity Normalization- Z score computation in deep learning and Noise Reduction.

Voxel Encoding and Decoding

In the human brain, this process of mapping the activity or response in terms of stimuli is called Voxel Encoding. In [1] Encoding is defined as the mapping n-dimensional features related to subject's perception to each brain voxel. Same way Decoding is defined as mapping between n-dimensional dataset to 1-dimensional target**.** The Voxel encoding and decoding together called as Voxel classification

POPULAR VOXEL CLASSIFICATION APPROACHES

MVPA – Conventional Method of Voxel Classification

The Multivoxel Pattern Analysis (MVPA) is one of the multivariate decoding technique which classifies and predicts by deriving a brain pattern from input data. Multivariate regression approach is the Equivalent continuous output approach is [1]. The pyMVPA toolbox supports below pattern classification tasks

- **Pattern discrimination.** [4]- determine if predictor variable present in given fMRI dataset.
- **Pattern Localization** [4] – By seed selection method selects voxels carrying sufficient information to drive the classifier. Use Searchlight method to identify and group the correlated voxels and form a feature space and 'brain map'.
- **Pattern characterization** [4] **-**This will help to learn the complex relationship between multiple input stimuli, voxel activity, and response

Deep Learning Methods in Voxel Classification

Some Deep architectures used in voxel classification listed below

CNN

Deep Learning based. Convolution Neural networks (CNN) architectures emerged as powerful voxel encoding technique to model human Visual Processing, auditory and decision making system [3]. Using these encoders human brain activity can be predicted by training each hidden layer of CNN using low-level visual input called Pixels [1].

Visualization Models -The quality of CNN feature extraction, classification, and interpretation is proven accurate on MRI, fMRI, X-ray and CT images. Particularly for MRI and fMRI analysis the CNN models VGG16, VGG19, ResNet50, Inception, Inception-ResNet are suitable in terms of various dataset inputs, a number of layers, loss optimization, Training time, Bootstrapping and hybrid mechanisms. Following would be a general approach of building a Deep learning model

- Preprocessing the Input Dataset
- ROI Analysis
- Build and optimize a Deep model
- Classification and Prediction

The regression or classification Performance will be increased by using suitable GPU hardware and appropriate tuning of Deep architectures used.

In addition, CNN visualizations [5] help to understand and design classifiers. Max-patch, activation map, Guided Backpropagation, Salient maps, Autoencoders, heat maps, and Deconvolution are some visualization techniques that help fine tuning. Also, iterative training has been proved successful in optimizing memory during training in the unsupervised training of individual layers (Bengio et al., 2007)

DNN

Early studies on Voxel encoding assumed brain representations and receptive fields as 2D Gabor filter. Later the relationship between abstract feature space, activity space and BOLD signal established and led to the conclusion that any stimuli to Deep Neural networks (DNN) encoding model could predict BOLD response. [5]

In reverse mode, the decoders estimated the input stimuli from the brain activity response. In this method feature vs voxel, mapping is done as per complexity gradient. Ie voxels mapped to high-level features drive the final classification. Jack Gallant [6] established Voxel-Wise Modelling and Decoding a voxel encoding concept (VWMD) as seen in below diagram

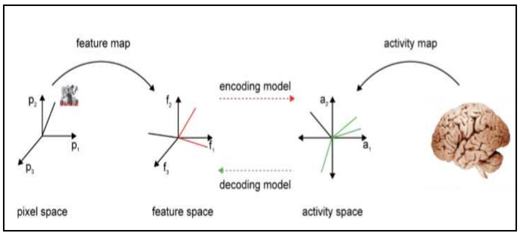

Figure 1: Reference from [6]

Auto Encoder – Nonlinear Feature Mapping Method

"Deep learning architectures combined with unsupervised feature learning backbone a low dimensional feature space which then mapped to high dimensional input data". [7]. Firat used Sparsed Auto encoder for learning low dimensional nonlinear feature mapping (NLFM) to classify fMRI data. Above concept was used in a Memory task. The voxels in temporal cortex memory were classified by above technique as 240 classes.

Case Study: Brain Working Memory Voxel Classification

In the human brain, the Working memory (a type of immediate memory) is responsible for Executive functions like Cognition, self-regulation, Planning and execution control. It is a Higher Order thinking control which is most important in a Daily life. The Brain's Prefrontal Cortex, posterior parietal cortex, and hippocampal system are key components of working memory. In this case study, we will highlight a few deep learning models used in Working Memory voxel classification.

Brodmann Index (BA)

In Brain, the visual cortex is located in the BA17, BA18, BA19 and the auditory cortex is located in BA41 and 42. BA 10 is also associated with Working memory and has a causal relationship with BA17 [3]. So voxel cluster covering BA10, BA17, BA19, BA 41, BA42 and BA47 as Voxel cluster ROI taken for Working memory and decision making an analysis.

Types of Human Working Memory

- Visual Working memory –A cognitive system that temporarily holds limited Visual information by capturing what is seen by the subject through Visual Cortex brain region.
- Auditory Working memory – A cognitive system that temporarily holds limited auditory information heard through auditory cortex brain region.

Visual Working Memory Voxel Classification

In [1] the subjects watch 5 movies which is visual stimulus and hence the voxels in Visual working memory are fired. The CNN is used to extract features from this video and classify fMRI brain voxels by transfer learning and parameter tuning the 7^{th} layer of CNN.

In [3] visual stimuli given to subjects by watching birds and an Artificial Neural network was used to classify the dominant visual voxels in the prefrontal brain.

In Visual Working Memory domain the LSTM (Long Short-Term Memory) was first introduced, later Hubel and Wiesel introduced CNN simulating human Visual cortex. Given a Visual Video Stimuli J. DOSHI [8] CNN was used to integrate separate experiences in working memory and form episodic memory. Similarly, in [7] Auto encoders are used for nonlinear feature mapping during memory encoding. Recently Hebb-Rosenblatt memory architecture and Short Term Attentive Working Memory model (STAWM) is introduced by combining CNN and Recurrent Neural Network (RNN) [9].

Auditory Working Memory Voxel Classification

In Auditory Working Memory Domain, the Restricted Boltzmann Machine [RBM] was used to model Auditory Cortex. CNN is used in building voxel wise cortical encoding model to replicate human auditory behavior and predict the auditory cortical response. [12], the main difference here is auditory stimuli. Compared to visual domain only a few works seen and it is growing deep learning domain.

Tools used for FMRI Voxel Classification

Fayyaz Ahmad and Iftikhar [3] used Statistics Toolbox in Matlab for fMRI analysis, Statistical parametric mapping (SPM) package and Brain Tutor. They visualized the most dominant voxel using MRIcorn Software. Tensor flow, Scikitlearn, Keras, python library is also widely used [12]

CONCLUSIONS

By this Literature survey, we understood Deep learning is apt technology for Brain Analysis use cases. We explored human Brain's structural and functional view in terms of Brodmann regions, fMRI basics, fMRI Preprocessing techniques, and Brain Voxel classification. Also, we have done a detailed review of deep learning architecture's usage in Brain functional encoding\decoding and Voxel classification. In specific the Working Memory brain function use case is reviewed in deep learning context in the last section.

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