Artificial Intelligence – Deep Learning ased Cognitive Ontology Model

F. Catherine Tamilarasi, J. Shanmugam

Abstract: Neuro Imaging and Artificial Intelligence (AI) are two big technology oceans. Machine learning and Deep learning are subfields of AI with numerous customized tools facilitating a statistically driven Neuro Image data analysis and accurate disease prediction. This paper suggests a Cognitive Ontology model driven by Machine and Deep learning based analysis on functional Magnetic Resonance Image (fMRI) data.

Key Words: Artificial Intelligence, Deep Learning, Neural Networks, Machine learning, Scikit learn

I. INTRODUCTION

The main objective of the 4D fMRI image data analysis is brain function decoding. This necessitates the analysis and interpretation of the fMRI brain voxels that results in a model which can predict brain's cognitive behaviour for different set of input stimuli. This paper discusses some of latest techniques used in cognitive analysis in light of Machine learning and Deep Learning and propose a Cognitive Ontology model.

A. Cognitive Ontology

- Cognition is 'thought process' to do a task such as Memory, attention and planning etc.
- Cognitive study is the study of thought, learning, and mental organization.
- As per Neuroscience the "Default Mode Network" (DMN)" is defined as a brain's baseline rest condition and is composed of set of interconnected brain regions (denoted by Brodmann Area) and is responsible for different cognitive states.
- "An ontology is a (formal), explicit specification of a shared conceptualisation" – General definition
- Combining above definitions the 'Cognitive Ontology' is defined as a mapping between Cognition, Cognitive science and Neuro science. [4]

B. AI in Cognitive Analysis

In Current decade the Artificial Intelligence (AI) has taken upper hand in Cognitive Analysis. The human brain by default has cognitive abilities such as Visual Processing, Auditory Processing, Long-term\short-term\working memory, Sustained\selective\divided attention, Logic and reasoning. From birth till end of life the human brain learns these abilities by every day human experience. Hence, they are called cognitive skills. Lack of one or more of these skills will result in neurological diseases such as Autism, ADHD, Alzheimer etc. Till last decade the diagnosis of such diseases and recovery was based on human intervention.

But in current decade the statistical techniques of Machine learning and Deep learning has become a boon to cognitive neuroscience facilitating accurate diagnosis, prediction and disease classification. As it is known machine learning based analysis is suitable for very high dimensional and sparse data. In this context in neuro image analysis, different input modalities like EEG\MEG (Electro\Magneto encephalography), fMRI (functional Magnetic Resonance Imaging) are catering high dimensional data for the complex brain function analysis. At the Outset the scope of paper in rest of chapters is limited only to the analysis of fMRI data and the related tools, packages and frameworks based on Python. Also out of many available Neuro Imaging formats below key Neuro image formats are used for analysis.

- Nifti - Neuroimaging Informatics Technology Initiative.
- DICOM- DICOM File format.

C. Aim of Study

Most of the fMRI experiments done with objective of modeling one of the brain's cognitive functions mentioned in previous section by finding the statistical relationship between the respective input stimuli and the corresponding brain evoked potential (response). But eventually there is one to many relationships between stimuli and neural response ie, for every single stimulus, it is found that a group of neurons in different brain regions interactively respond and oxygenated blood flow in all such evoked neurons. This BOLD (Blood Oxygen Level Dependent) and hRF (hemodynamic response) are the key fMRI phenomenon. So it is concluded that the general goal in most of the fMRI researches to identify Neural encoding model for each human cognitive function. Existing models also validate ensemble of various deep learning and machine learning algorithms combinations. This study in addition explores if usage of Ontology would improve the classification metrics.

II. PROPOSED MODEL AND METHODOLOGY

A. Deep learning based Cognitive Ontology Model

In last decade the Neuro image analysis research domain was independent and statistically driven. But the current decade researches are well integrated with usage of machine and deep learning algorithms enabling detection, general Prediction and classification of various neurological diseases [6]. As on today there is significant research outputs in Neuro Imaging fMRI analysis, Deep learning and Ontology and Semantic web.

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But only few papers discuss on the 'Ontology and Semantic web' application on both Neuro Imaging and Deep learning [7]. This paper proposes a model integrating above three domains namely "Deep learning driven Neuro Image Cognitive ontology model". The main hypothesis is Introduction of ontology based model would provide better interoperability and knowledge Inference resulting in improved Accuracy and Prediction compared with current fMRI classification methods.

B. Datasets and Experimental Set up

There are many sources of getting neuro Image data. Out of huge fMRI available data sources, listed below are key sources of getting fMRI datasets.

a) OpenfMRI Project

This is a recognized data repository and recommended for academic research. It has open and public domain access for all neuro imaging MRI and EEG datasets for human brain. It contains raw fMRI datasets without pre-processing and can be downloaded from below path https://openfmri.org/dataset/

Once the Non pre-processed dataset is downloaded below Pre-processing steps done for localization and Anatomical standardization Motion correction via Volume Registration –This means each slice from time series data is spatially mapped to a location in the Anatomical reference by using map-slice –to –volume approach. This process helps to localize the fMRI signal in a common Talaraich Coordinate space.

1) Affine Transformation – This includes rotate, translate and isotropic scaling of given image and fits it in scanner RAS+ coordinates corresponding to the voxel coordinates
2) slice acquisition timing correction –This is a temporal interpolation done to correct the temporal offset introduced when slices are converted to 2D image.
3) Voxel wise linear detrending – used to remove low frequency signal intensity drift.
4) Mask Data-Masking is a process of extracting voxels in a particular region of Interest defined by a Masker.

b) Connectomes Project

The fMRI scan image taken from different scan machines requires extensive pre-processing as mentioned in [2]. In order to narrow down scope and focus research goals, for proposed model the systematically pre-processed fMRI dataset is downloaded from below path and used .http://preprocessed-connectomes-project.org/datasets.html

Most of the existing researches use the two publicly available ADHD-200 and Autism Brain Imaging Data Exchange ABIDE (http:// fcon_1000.projects.nitrc.org/indi/abide/) multi-site datasets many models has been developed and tested. ABIDE classification research results using (3D patch sampling +Autoencoder+CNN) combination yield 64 [5] and that using Graph CNN yield 70.86 respectively [8]. The proposed model use ADHD-200 and ABIDE datasets and aim for higher prediction and classification accuracy.

C. Feature Extraction Process

Deep architecture: Recently Automatic Feature extraction has been proven by Convolutional Neural Network (CNN) models. Feature Vectors can be obtained by Automatic feature extraction techniques such as Automated Anatomical Labeling (AAL) segmentation and Temporal Mesh Model. [8]. For the given proposal the Automatic feature extraction would be first explored using Basic CNN. Then the improvement in extraction performance would be tested using the Inception Recurrent CNN(IRCNN) and Graphic CNN(G-CNN) deep architectures. Voxel classification: In fMRI the voxels are the features. A known constraint in fMRI data is high feature sample ratio. ie each fMRI sample would contain min 3000 to 4000 voxels. This warrants dimensionality reduction and feature extraction techniques. Eliminating redundant voxels is done using techniques such as Independent Component Analysis (ICA), Principle component Analysis (PCA), Search Light Analysis, Identifying Region of Interest(ROI), Multivariate Pattern Analysis (MVPA), Correlation Analysis and Covariance Analysis. For the given proposal the Voxel classification and feature extraction would be explored based on one of the above techniques.

D. Extraction of Region of Interest (ROI) from Dataset

In ROI Analysis, from the pre-processed fMRI data the features or Voxels related to particular cognitive function of Interest is segregated. The key rationale used in Voxel selection are Activity (Voxels evoked for particular task), Accuracy (Voxels with High prediction accuracy), Search Light (Voxels and neighboring voxels in three dimension with High prediction accuracy), ANOVA (Voxels showing mean value shift as per stimuli) and Stability. (Voxels showing consistently evoking behaviour). [2]. For the proposed model, the cognitive function "executive functioning" is the research area planned for Cognitive Ontology. Hence the corresponding Brodmann area BA10 and associated brain region "Pre-Fontal Cortex" is selected as the Region of Interest [3]. Below table highlights the key DMN brain regions and highlighted is the ROI selected for this Proposal. The ROI Voxels selected in such a way that it should drive the classifier.

TABLE 1. Core regions associated with the brain's default network

REGION	ABREV	INCLUDED BRAIN AREAS
Ventral medial prefrontal cortex	vMPFC	24, 10 m/ 10 r/ 10 p, 32ac
Posterior cingulate/retosplenial cortex	PCC/Rsp	29/30, 23/31
Inferior parietal lobule	IPL	39, 40
Lateral temporal cortex†	LTC	21
Dorsal medial prefrontal cortex	dMPFC	24, 32ac, 10p, 9
Hippocampal formation††	HF+	Hippocampus proper,EC, PH

E. Transfer Learning Approach

Since most of fMRI is high dimensional and limited data, it is optimal to use Pre-trained deep learning models and customize it. Keras supports transfer learning concept by making available ImageNet pre-trained models such as Xception, VGG16, VGG19, ResNet50, InceptionV3, InceptionResNetV2, MobileNet, DenseNet and MobileNetV2. For our proposed model the CNN is used as feature descriptor and the transfer learning approach is explored using pre-trained CNN models such as VGG16, VGG19, ResNet50, Inception, Inception-ResNet and Inception Recurrent CNN(IRCNN). The model providing best classification accuracy would be selected. For example, Brodmann Area 'BA 10' is associated with Brain Region 'Pre-Frontal Cortex' and is responsible for cognitive state called "Executive Functioning". Below table high lights BA10 and DMN brain regions. Our proposal aims to covert the Features learnt from CNN to Cognitive Ontology.

III. TOOLS AND TECHNOLOGIES FOR IMPLEMENTATION OF PROPOSAL

The given model is based on 4 domains namely Neuro Imaging, Machine learning, deep learning and Semantic Web Ontology. This section lists the domain-wise tools used to develop the model

A. Neuro Imaging

Nilearn -Nilearn is a python based package for neuro Image analysis. It is used to analyze the fMRI image pixels otherwise called brain voxels. The 4D fMRI image data is first converted as a 3D Voxel Array and then as feature vector or 2 dimensional feature matrices

B. Machine Learning

The fMRI by itself is a high dimensional Image data as it is representation of complex brain data. In addition, depending on nature of input stimuli the complexity of evoked brain neurons results in a complex encoding model. So compared with conventional statistical methods Machine learning based computational models and libraries speed up Inductive learning and predictive Analysis. Below are some of the Python based Machine learning libraries with inbuilt fMRI analysis functions. [1]

- Scikit –learn- Scikit-learn is a python based library that contain all the Machine learning algorithms in a reusable function format that can be imported as per application requirement. Algorithms used for tasks such as pre-processing, feature selection, dimensionality reduction, classification, regression, prediction, and clustering are made available as inbuilt function for users.

C. Deep Learning

fMRI encoding aims to identify features impacted by given input stimuli and the associated voxel classification. Hubel and Wiesel demonstrated Deep Learning Convolutional Neural Network (CNN) through the hierarchical representation of human Visual cortex. This concept along with invention of advanced GPU architectures facilitated Deep learning libraries Automatic feature extraction, Image Segmentation, data augmentation and Image registration. Below are Python based Deep learning libraries with inbuilt fMRI analysis functions.

- Keras -Keras is a python based Deep learning library with inbuilt functions used to build a CNN. The core data structure of keras is inbuilt as 'model'. Using this 'model' object we can build our CNN layer by layer. These algorithms are used for tasks such as pre-processing, automatic feature selection, dimensionality reduction, classification, regression, prediction, and clustering.
- Niftynet -Niftynet is an Open source CNN based Deep learning platform used for Medical Image Analysis.

D. Ontology

Ontological Engineering is part of Artificial Intelligence. The Neuro Imaging Ontology is a growing research domain that aims to integrate, automate and reuse neuro imaging data across different modalities, standardization and comparison across multi- centers. In current proposal the fMRI brain data would be semantically annotated as fMRI Ontology using W3C Semantic web standards namely Resource Description Framework (RDF) data model, The SparqL query language, RDF schema and OWL standards (Ontology web language).

- Protégé -Protégé is an Open source tool containing above four technologies integrated in it. It is used for building intelligent Ontologies.

IV. CONCLUSION

In this paper we understood Deep learning is apt technology for Brain Analysis use cases. A detailed review done on Neuro Imaging fMRI, deep learning architectures, Ontology tools their usage in Brain functional encoding\decoding and Voxel classification. Also a prototype and approach proposed for the modeling Cognitive executive functions use case using above technologies. Future work is to implement the same and validate the experimental results.

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