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COMPUTER SCIENCE PROJECT

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Project Description

Title: Automatic Identification of Neuropsychiatric Disorders from Brain Networks Using Deep Learning

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Abstract

The brain is the most complex system in the human body. Similar to our social network, different regions or areas of the brain interact with each other in a massive complex network. Many neuropsychiatric diseases or disorders have been associated with disruptions or abnormality in the brain connectivity networks such as Alzheimer's disease, schizophrenia (SZ), major depressive disorder, epilepsy, attention-deficit hyperactivity disorder (ADHD). Recently there is an active research leveraging on human brain connectivity as biomakers for clinical diagnosis of brain disorders.

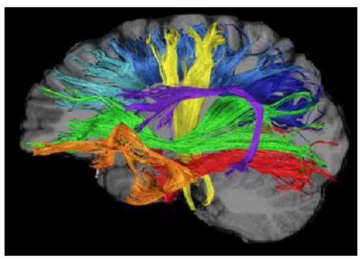
Motivated by these neuroscience findings, this research exploits the altered patterns in brain functional connectivity as discriminative features and utilizes machine learning algorithms to automatically differentiate neuropsychiatric patients from normal subjects. Recent innovations in deep neural networks (DNN) have achieved remarkable success in classifying objects and images with near-human performance, which is potentially applicable to classifying brain connectivity maps. The main goal is to develop an DNN-based computer-aided automatic system for identifying neuropsychiatric disorders from human brain connectomme. The expected outcome of this project is a software tool to support medical practitioners in the decision making for pre-screening or diagnosis of brain disorders, e.g., estimating a probability that a subject potentially develops neural diseases based on their brain connectivity patterns.

This project research theme will cover several final year student projects related to development of brain connectomic classification system using various state-of-the-art deep learning algorithms. The developed system consists of two components: (1) Extraction of brain connectivity maps or graphs from neuroimaging data such as functional MRI (fMRI) and electroencephalogram (EEG). (2) Automatic classification of neuropsychiatric patients based on the extracted brain maps or graphs using deep learning methods. We will focus on schizophrenia, a complex and heterogeneuous mental disorders that impairs multiple cognitive domains including memory, attention, language and execution function. Student groups are free to choose other brain disorders to work on.

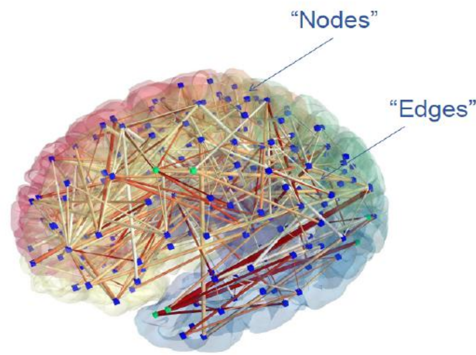
Keywords: Brain connectomics, brain networks, deep neural networks, classification, computer-aided diagnosis, neuroimaging, fMRI, EEG, neuropsychiatric diseases.

1. Introduction & Background

Brain networks: Study of human brain connectome has become an important research in neuroscience, which provides insights into the function of the brain in health and diseases [1]. The USA National Institutes of Health has recently initiated the **Human Connectome Project** as part of ambitious scientific endeavor to map the human brain (after genetic mapping) https://www.youtube.com/watch?v=i2W570VgV6I. Distinct brain regions are connected functionally or anatomically with each other. This inter-regional interactions can be represented as a network or graphs . As shown in Figure 1, each brain region is represented by a node in a network, and the connections between regions by the edges that link pairs of nodes.



DTI of white matter fiber tracts of the brain



Distinct brain regions (nodes) are connected (via edges) as a network

Figure 1: Graphical representation of brain connectivity networks.

Modeling Brain Networks from Neuroimaging data: The connectivity in brain networks can be quantified through statistical dependencies between distinct brain regions, called the *functional connectivity*. One popular measure is the cross-correlations between neuroimaging signals measured over brain regions, e.g., electroencephalogram (EEG) and functional magnetic resonance imaging (fMRI) time series [1], [2], as shown in Figure 2. Then, a connectivity map (a 2-D matrix) can be formed from the correlation values between every pairs of brain regions. Finally, a brain network graphs can be constructed by binarizing the correlation maps.

Abnormal/Altered brain connectivity in Neuropsychiatric disorders: Alterations in the brain connectivity patterns have been associated with various neuropsychiatric disorders and are potentially useful as biomarkers for clinical applications. For example, schizophrenia (SZ) has been regarded as a dysconnectivity disorder characterized by abnormal structural and functional brain connectivity networks at both microscopic and macroscopic levels [3, 4, 5]. Analysis of functional connectivity, the statistical dependencies between signals (fMRI or EEG) from spatially distant brain regions, has revealed dysconnectivity in schizophrenic brain networks especially between the frontal regions [4]. EEG studies reported SZ-related aberrant synchronization of neural oscillatory at both the low and high frequencies [6, 7]. See a review [8] on the clinical application of brain connectivity analysis.

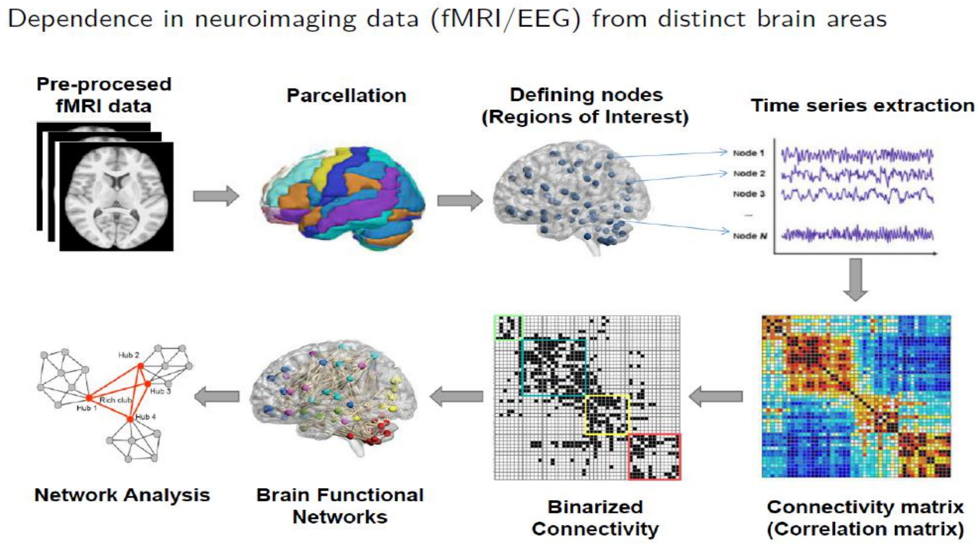


Figure 2: Brain network construction from neuroimaging data

Application of Machine Learning in Identifying Brain Disorders: There is growing interest in applying machine learning algorithms for automatic detection and classification of neuropsychiatric disorders. This is potentially useful in developing diagnostic tool to assists medical practitioners in medical decision making. For example, traditional machine learning algorithms have been employed for automated classification of altered brain activity in SZ using EEG and fMRI data, such as support vector machine (SVM) [9], kernel discriminant analysis (KDA) [10] and adaptive boosting [11]. Recent advances in deep learning techniques have been shown to be promising for neuroscience applications [12]. Deep neural networks (DNNs) have been used to classify brain connectivity of autism spectrum disorder (ASD) with encouraging accuracy [13,14]. Convolutional neural networks have been recently used for functional connectivity-based classification of mild cognitive impairment [15] and prediction of neurodevelopment [16]. In our recent work [17], we developed a multi-domain CNN for classfying SZ from EEG connectivity patterns.

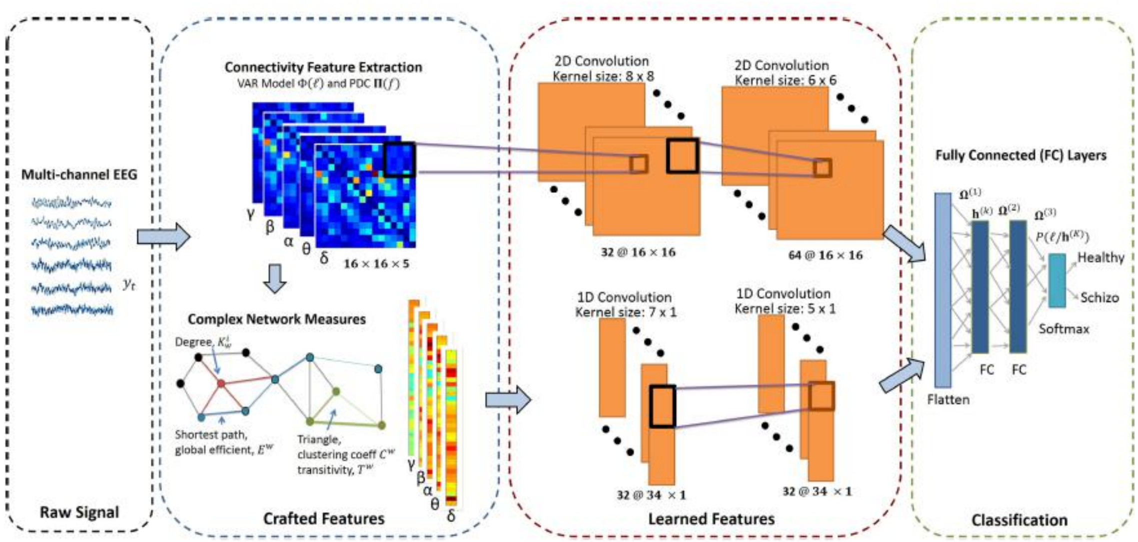


Figure 3: Mutli-domain Multi-Domain Connectome CNN for Identifying Schizophrenia From EEG Connectivity Patterns [17]

Application of deep learning techniques to classifcation of abnormal brain networks in neuropsychiatric disorders is at its early stage, and various novel techniques of DNN are yet to be explored, which potentially improve the classification perfomance of existing methods.

2. Objectives

To research, design and develop an automatic classification system for neurospychiatric disorders such as schizophrenia (SZ) based on brain connectivity patterns.

a) To extract brain functional connectivity (association) maps from neuroimaging signals such as fMRI and EEG, and identify differences in the connectivity maps between patient groups from healthy control (HZ).

b) To design a deep neural network architecture to extract features or/and classify the functional connectivity maps into patient or healthy groups, using one or fusion of the following deep neural network approaches:

    i. Convolutional neural networks (CNNs)

    ii. Recurrent neural networks (RNNs) (e.g., Long short term memory networks)

    iii. Autoencoders (AEs)

    iv. Generative adversarial networks (GANs)

    v. Transfer learning

3. Scopes

Automatic brain connectomic classification system using deep learning approaches

a) Identify a classification problem related to a particular type of neurospychiatric disorders with abnormal brain connectivity

b) Extract functional connectivity features from neuroimaging data (fMRI/EEG)

c) Design an deep neural network architecture for binary classification of patients and healthy group. The choice of DNN architecture could include (**select one or combination of several methods**)

    i. Convolutional neural networks (CNNs) - Classifying 2-dimensional connectivity matrices

    ii. Recurrent neural networks (RNNs) - Classifying sequential brain connectivity patterns

    iii. Autoencoders (AEs) - Extracting high-level features in an supervised manner from the connectivity maps, which is then used for classification

iv. Generative adversarial networks (GANs) - Train a discriminator and generator to differentiate patients and healthy control connectivity maps

v. Transfer learning - Use DNN model trained on large image datasets (e.g. GoogLeNet) to classify connectivity maps.

d) Evaluate classification performance on a provided or publicly available dataset.

e) Design and implement a prototype diagnostic software with GUI to visualize the connectivity maps, to perform classification and output results (e.g. probability of brain disorders)

Schizophrenia EEG/fMRI dataset will be provided. Students are also free to choose other neuropsychiatric disorder and other public neuroimaging dataset they are interested to analyze.

4. Approaches

To start, each team has to decide on a particular scope as aforementioned, according to their choice of DNN architecture to be developed (3.a). The selected scope should fulfil all the objectives in the project description.

Once the type of scope and problem is determined, each team then work to complete the following:

a) Project management plan

b) Project design and prototype

c) Project progress report

d) Project proposal with literature review

e) Prototype development

f) Final report

5. References

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