COMPUTATIONAL TECHNIQUES FOR FUNCTIONAL BRAIN NETWORK ANALYSIS

ABSTRACT

Many natural and man-made systems are incredibly complex systems and they exhibit intricate interactions between the system components. Understanding of the structure and behavior of these complex systems has improved dramatically in the past decades due to the emergence of graph theoretical approaches. Graphs are simple models used for the representation of complex systems with a set of nodes that are connected to each other by links. Research on complex networks that focus on the modelling and analysis of complex social, technological, and biological systems as networks is becoming popular in recent years. Efficient computational techniques are needed to address various problems in complex network analysis. The human brain, one of the least understood complex systems in the universe is used throughout this study to illustrate the efficacy of the computational techniques proposed. The cognitive functioning of the brain is explored in many research studies in the recent past, which enable the understanding of the working mechanism by establishing a network model. The human brain consists of billions of interlinked neurons forming a massive complex connectome. This brain connectivity is studied in various ways using network theory namely anatomical/structural, functional, and effective connectivity. Devising efficient computational techniques to identify the integrative aspects of brain structure and function, specifically how the interactions among billions of neuronal elements result in cognition, which is one of the most challenging problems in

the field of computational neuroscience. Discovering interesting neural patterns from the neuroimaging or neurophysiological data poses many challenges that are to be addressed in the analysis of Functional Brain Networks (FBNs). This research addresses some of those challenges by applying efficient computational techniques on FBNs obtained using EEG data collected during different cognitive activities.

A complex system modelled as a network by considering its components as nodes and the relationships between them as edges may be dense or completely connected. Analysing the characteristics of such networks is much complicated due to the overhead involved in performing computationally expensive operations. To overcome this problem, removing the weak/insignificant connections from the dense or fully connected networks becomes essential using a process called thresholding. Various thresholding methods have been proposed in the literature to extract the influential subnetworks from the dense or complete networks. The limitations of these thresholding methods are analysed using the FBNs of EEG data.

A heuristic Branch-and-Bound based thresholding algorithm called Weighted Subgraph Extraction (WeSE) algorithm is proposed to overcome the limitations of the existing thresholding methods. It does not require any user specified threshold, ensures connectivity of all the nodes in a network, includes all the influential edges in resulting subnetwork, and supports various types of analysis. The proposed algorithm dynamically extracts the prominent connections between the nodes in the FBN and the resulting thresholded network brings the predominant connectivity patterns of the original network to light.

Many topological properties of complex networks are formulated based on the assumption that the information flows in the network along the shortest paths to optimize transportation costs. Hence, to identify and analyse the significant communication pathways of information exchange between various nodes in the network, a graph-theoretic approach using the concept of shortest path is proposed. A special weighted undirected network called Shortest Path Network is constructed using the thresholded network that portrays the information on the number of times the edges are used in information propagation. This network is further analysed to characterize the information dissemination to various nodes in the network. The shortest path based network analysis approach is used to study the FBNs of different cognitive load states to characterize the brain’s information communication patterns during these states.

Discovering the communities of nodes in a network with similar/common characteristics is essential for many applications to make useful decisions. An efficient pattern mining approach is proposed to analyse the common behavior of nodes in a network. It represents the influential subnetworks as sets of transactions by considering each node as a transaction, and the network features computed for each node as itemsets in each of these transactions. These features obtained are compactly stored into a graph data structure. Mining this graph enables the extraction of nodes with common characteristics. The proposed pattern mining approach is applied on FBNs of different cognitive load states to analyse the common behavior of various brain regions during these states.

The interactions among the entities/elements in many complex networks result in either positive or negative correlations. For instance, the FBNs constructed by applying linear measures include both positive and negative correlation values between the brain regions. The edges with negative correlation values are generally not considered for analysis owing to the difficulty in understanding the intricacies such as the origin and interpretation concerning the brain function. Graph theoretical approaches are proposed to explore the impact of negative correlations in the FBNs of different cognitive load conditions.

This research investigates applying various computational techniques for characterizing complex networks (FBNs) constructed using EEG data. The proposed WeSE algorithm overcomes the limitations of the existing thresholding methods by extracting the predominant connectivity patterns in the resulting influential subnetwork. Shortest path-based network analysis performed using the influential subnetwork helps to identify the information communication patterns of various nodes in the network. The pattern mining approach proposed to analyse the influential subnetwork identifies the communities of nodes with similar/common characteristics. The impact of negative connections in the network is analysed using graph theoretical approaches.