CONVERGENT BRAIN CONNECTOME ANALYSIS WITH BRAIN GRAPH TRANSFORMERS

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ABSTRACT

Modern neuroscience has increasingly recognized the intricate complexity of the brain's wiring structure and its functional dynamics. Neuroimaging studies are now embracing a network-based model of the brain, abstracting it as an interconnected web of Regions of Interest (ROIs), linked either by anatomical tracts or functional associations. This connectome perspective facilitates our understanding of neural disorders and the complex nature of brain-behavior relationships.

Traditional brain connectome analysis, requiring extensive feature engineering and using shallow models, often falls short in capturing complex network structures [1]. Recently, deep models such as Graph Neural Networks (GNNs) have been shown promising in brain connetome analysis by learning graph representations [2], but GNNs' efficacy is challenged by the dense real-velued edges in brain networks. Concurrently, the Graph Transformer (GT) architecture has emerged as a powerful tool, with recent applications in brain connectome analysis [3, 4, 5]. Nevertheless, an in-depth and systematic study of GTs' compatibility with brain connectome analysis remains under-explored. Moreover, existing studies focus solely on individual-level interpretations over important network connections via attention mechanisms, overlooking the potential to identify shared connectome patterns among subjects with similar functionalities, disorders, or behavioral traits.

In this work, we present a pioneering exploration at the intersection of GT and the unique requirements of brain connectome analysis. Building on this, we suggest a set of general recipes for effective GT designs and propose a plug-and-play interpretability mechanism, which can capture the group-level connectome patterns across subjects. In summary, our key contributions are three-fold:

- **In-Depth Analysis of Compatibility between GT and Brain Connectome Analysis:** We illustrate that the fundamental design of GT, particularly the attention mechanism, can adaptively navigate through densely connected networks, thereby prioritizing predictive connections of brain networks. We also suggest that GT naturally accommodates the structural and positional intricacies of brain networks with the design of positional encoding, among which connection profiles consistently outperform other positional attributes in terms of predictive performance.
- **A Novel Mask-based Interpretability Mechanism:** We develop a novel mask-based interpretability mechanism that identifies brain connectome patterns shared across groups. Accompanying this paradigm, a series of case studies further reveal that the extracted patterns are indicative of certain brain circuits linked to various clinical outcomes and behavioral traits such as neural disorders and cognitive development. Such correlations hold the potential to aid in clinical decision-making processes and enhance the comprehension of brain functionality.
- **Extensive Validation Across Studies, Datasets, and Clinical Tasks:** We conduct extensive experiments on multi-modality brain connectome datasets constructed from various neuroimaging studies with various clinical prediction tasks, ranging from demographics to behavioral traits and neural disorders. The results demonstrate the convergent prediction power and interpretability of GT for brain connectome analysis.

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