

JOURNAL PAPER: A BENCHMARK FOR BRAIN NETWORK ANALYSIS WITH GRAPH NEURAL NETWORKS

Hejie Cui[†] Wei Dai[‡] Yanqiao Zhu[§] Xuan Kan[†] Antonio Aodong Chen Gu[†] Joshua Lukemire[†]
Liang Zhan[¶] Lifang He[◇] Ying Guo[†] Carl Yang^{†*}

[†] Emory University, [‡] Stanford University, [§] UCLA, [¶] University of Pittsburgh, [◇] Lehigh University

Human brains are at the center of complex neurobiological systems in which neurons, circuits, and subsystems interact to orchestrate behavior and cognition. Recent studies in neuroscience show that interactions between brain regions are key driving factors for neural development and disorder analysis [1, 2]. Mapping the connectome of the human brain using structural or functional connectivity has become one of the most pervasive paradigms for neuroimaging analysis. Recently, Graph Neural Networks (GNNs) motivated from geometric deep learning have attracted broad interest due to their established power for modeling complex networked data.

In the literature, functional and structural connections are widely acknowledged as valuable information resources for brain investigation [3]. However, they mainly experiment with their proposed models on specific private datasets. Due to the ethical issue, the datasets used are usually not publicly available, and the details of imaging preprocessing are not disclosed, rendering the experiments irreproducible for other researchers. There has not yet been a systematic study of how to design effective GNNs for brain network analysis.

To bridge this gap, we present BrainGB, a benchmark for brain network analysis with GNNs, published in IEEE-TMI in 2023 [4]. The overview of BrainGB is demonstrated in Fig. 1. We conduct experiments on four datasets across cohorts and modalities and recommend a set of recipes for effective GNN designs on brain networks. Our contributions are four-fold:

- A *unified, modular, scalable, and reproducible* framework is established for brain network analysis with GNNs to facilitate reproducibility. It is designed to enable fair evaluation with accessible datasets, standard settings, and baselines to foster a collaborative environment within computational neuroscience and other related communities.
- We summarize the preprocessing and construction pipelines for functional and structural brain networks to bridge the gap between the neuroimaging and ML communities.
- We decompose the design space of interest for GNN-based brain network analysis into four modules: (1) node features, (b) message-passing mechanisms, (c) attention mechanisms, and (d) pooling strategies. Different combinations based on these four dimensions are provided as baselines,

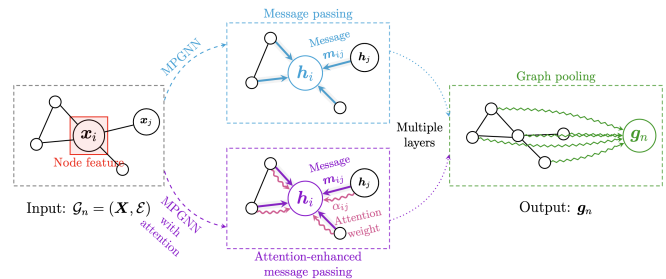


Fig. 1. An overview of our BrainGB framework for brain network analysis with graph neural networks.

- and the framework can be easily extended to new variants.
 - We conduct various experiments and suggest a set of general recipes for effective GNN designs on brain networks.
- To support open and reproducible research on GNN-based brain network analysis, we host the BrainGB website at <https://braingb.us> with models, tutorials, examples, as well as an out-of-box Python package. We hope that this work will provide useful empirical evidence and offer insights for future research in this novel and promising direction.

1. REFERENCES

- [1] Xiaoxiao Li, Yuan Zhou, Nicha Dvornek, Muhan Zhang, Siyuan Gao, Juntang Zhuang, Dustin Scheinost, Lawrence H Staib, Pamela Ventola, and James S Duncan, “Braingnn: Interpretable brain graph neural network for fmri analysis,” *Med Image Anal*, vol. 74, 2021.
- [2] Farzad V Farahani, Waldemar Karwowski, and Nichole R Lighthall, “Application of graph theory for identifying connectivity patterns in human brain networks: a systematic review,” *Front. Neurosci.*, vol. 13, pp. 585, 2019.
- [3] Luigi A Maglanoc, Tobias Kaufmann, et al., “Multimodal fusion of structural and functional brain imaging in depression using linked independent component analysis,” *Hum Brain Mapp*, vol. 41, pp. 241–255, 2020.
- [4] Hejie Cui, Wei Dai, Yanqiao Zhu, Xuan Kan, Antonio Aodong Chen Gu, Joshua Lukemire, Liang Zhan, Lifang He, Ying Guo, and Carl Yang, “BrainGB: a benchmark for brain network analysis with graph neural networks,” *IEEE Transactions on Medical Imaging*, 2022.

*Corresponding author: Carl Yang <j.carlyang@emory.edu>