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GUANGDONG AND HONG KONG UNIVERSITIES

"1+1+1" Joint Research Collaboration Scheme

粵港高校「1+1+1」聯合資助計劃

Research on Deep Statistical Learning Theory and Methods for Brain Imaging Data

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Project Overview

This project investigates advanced deep statistical learning theories and robust methodologies tailored for high-dimensional, complex brain imaging data.
Our research aims to bridge the gap between abstract statistical models and clinical neuroimaging applications, integrating advanced modeling, rigorous theoretical derivation, and localized medical evidence to enhance the precision of brain disease diagnosis and neurological insights.

Research Outputs

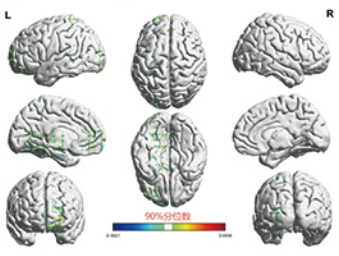
This project develops novel statistical learning algorithms and models that, while motivated by the intricate spatial and temporal dynamics of brain imaging, are broadly applicable to complex, high-dimensional biomedical datasets.

Representative Output 1: Image Regression Models via Tensor Decomposition

Background: Longitudinal brain imaging data and their rates of change reflect temporal regional variations highly correlated with disease risk.
Method & Application: We address the challenge of longitudinal analysis and high-dimensional features by proposing a novel image regression model. This model effectively incorporates tensor decomposition techniques and multilinear principal component analysis (MPCA) for efficient dimension reduction and feature extraction. The proposed low rank structure reshape model:

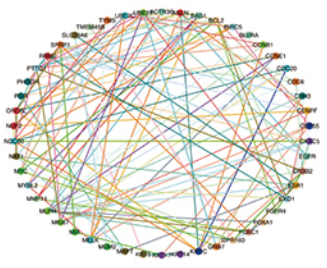
$$y_i = \alpha + \langle \mathcal{B}, \mathcal{X}_i \rangle + \gamma^T Z_i + e_i$$

This model effectively incorporates tensor decomposition techniques and MPCA for efficient dimension reduction.
We apply our method to a reading comprehension analysis and identify several brain regions of the left hemisphere (highlighted in green color) associated with character recognition ability.



Representative Output 2: Bayesian Structure Learning for Graphical Models With Symmetry Constraints

Background: Since cancer progression is driven by complex gene interactions rather than isolated genetic factors, and many genes exhibit similar expression patterns suggesting shared biological processes, we study utilizes "colored" graphical Gaussian models to reveal both conditional dependencies and symmetrical structures.
Method & Application: We apply the Stepwise Birth-Death (SBD) algorithm to a TCGA dataset of 772 breast cancer patients. The resulting network identifies a sparse structure with 127 edges, 15 vertex color classes, and 25 edge color classes. Notably, six key genes—ESR1, PGR, FOXA1, FOXC1, MYC, and MYBL2—do not share the same vertex color, indicating that each plays a distinct functional role in disease progression.



The project has generated **5 high-impact publications**, all published in leading SCI/EI journals and presented at competitive international conferences, demonstrating the rigor and relevance of our theoretical and methodological contributions.

Key Peer-Reviewed Papers:

- *Optimizing LVLMs with On-Policy Data for Effective Hallucination Mitigation.* IEEE/CVF WACV 2026. (Applies advanced optimization to large visual language models).
- *When Human Preferences Flip: An Instance-Dependent Robust Loss for RLHF.* AAAI 2026. (Enhances robustness in human-centric reinforcement learning).
- *Sequential Multiple Testing with Three Hypotheses.* IEEE ICASSP 2026. (Develops efficient statistical testing methodologies).
- *Light Wings: More Efficient Speculative Decoding via Linear Attention.* IJCNN 2026. (Innovates in deep learning efficiency).
- *Bayesian Structure Learning for Graphical Models With Symmetry Constraints.* Biometrical Journal 2025. (Contributes directly to graphical model structure learning).

Talent Development & Team Building

Our project prioritizes cultivating the next generation of researchers in the interdisciplinary field of statistical neuroimaging.

- **Talent Introduction:** The project successfully recruited Dr. Xinkai Zhou from Johns Hopkins University as an Assistant Professor of Statistics at BNBU, bringing world-class expertise to the team.
- **Team Expansion:** We hired Jie Liu and Shunyan Lyu as dedicated research assistants to facilitate project management and data analysis.
- **Student Training:** We are actively mentoring 10 PhD students and supporting 3 post-doctoral researchers, providing them with hands-on experience in advanced statistical modeling and medical data analysis.

Academic Exchanges & Conference Presentations

Active scientific exchange is a cornerstone of our project, fostering innovation and global collaboration.

Invited Lectures Hosted:

- **Prof. Melanie Burke** (University of Leeds)
  Topic: Dementia: Early Diagnosis and Modern Therapeutic Approaches
  Impact: Provided crucial clinical insights into dementia, linking mathematical modeling directly to patient care strategies.
- **Dr. Biao Cai** (City University of Hong Kong)
  Topic: Generalized Tensor Completion with Non-Random Missingness
  Impact: Advanced our methodological understanding of missing data handling, critical for complete brain imaging datasets.
- **Dr. Zaixu Cui** (Chinese Institute for Brain Research, Beijing)
  Topic: Connectional axis of structural connectivity development across healthy and ADHD youth
  Impact: Introduced recent advances in data analysis techniques of brain structural connectivity.

Team Conference Presentations:

- **Dr. Chuoxin Ma** (Contributed Oral Presentation)
  Title: Low-rank structure reshape for tensor regression in neuroimaging analysis
  Conference: 33rd International Biometric Conference (IBC 2026), Seoul, South Korea.

Newly Awarded Research Grants

Our team's excellence is recognized by securing prestigious competitive funding during the project's execution, totaling substantial research investment.

- **National Natural Science Foundation of China:** 300,000 RMB awarded to PI Yifan Chen for "Efficient Generative Pre-trained Transformer Architecture Compression Algorithm".
- **National Social Science Fund of China:** 200,000 RMB awarded to PI Yu Li for "Spatiotemporal Neural Representation of Chinese Character Reading Based on Multimodal Neuroimaging Fusion Technology".

Economic and Social Impact

The project translationally impacts both the economy and public health through the practical application of our research findings.

- **Economic Benefits:** The developed models and algorithmic software promote the localized medical and health technology industry, fostering innovation in domestic brain imaging diagnostic tools.
- **Social Impact:** Our tools will be directly integrated into clinical workflows for diagnostic support, enabling earlier prediction of disease progression, personalized treatment planning, and enhanced community-based public health services.