Modeling Brain Connectivity Using Multi-Modal Imaging Data

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Outline

1. Introduction
   - Functional MRI
   - Diffusion Tensor Image
   - Functional Connectivity

2. Objective

3. Model for fMRI

4. Simulation and Data Analysis

5. Summary
fMRI Data

- A 3-dimensional “volume” of the brain is collected over time.
- At each volumetric element (voxel), a discrete time series \( \{ y_t; t = 1, \ldots, T \} \) measuring Blood-Oxygen-Level-Dependent signals.
- The volume is very large, e.g., \( V \sim 0.2\text{million} \) many voxels.
- \( T \) is about a few hundreds.
Blood-oxygen-level dependence (BOLD)

- Oxygen consumption increases due to neuronal activity.
- The MRI measures the change in the ratio of oxy- and deoxyhemoglobin.
- **Indirect** measure of neuronal activity.
Diffusion Tensor Image (DTI)

- Local water diffusion depends on the structure of tissue.
- Water will travel more rapidly in the direction aligned with the internal structure, while slowly move perpendicular to the direction.
- DTI measures this difference.
“Temporal correlations between remote neurophysiological events”
- Karl Friston, 1993

- Two regions of the brain are functionally connected if their activities exhibit similar patterns
- Potential biomarker for certain diseases
- Used to discriminate between patients with Alzheimer’s disease and healthy controls (Wang et al, 2007)
- Used to discriminate between patients with schizophrenia and healthy controls (Lynall et al, 2010)
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To examine the combined effects of excessive alcohol use and HIV infection on structural and functional brain integrity, we use multi-modal MRI techniques.

Goal of this presentation is to propose Bayesian hierarchical models to combine the two types of brain data.

Structural connectivity is utilized as the expectation of prior distribution of the functional connectivity.
Spatio-Temporal Hierarchical Model

Consider that there are $P$ external stimuli, $C$ many ROIs, and $V_c$ many voxels in ROI $c$.

$$Y_{cv}(t) = \sum_{p=1}^{P} \beta^p_c X_p(t) + H_c(v) + d_c(t) + W_{cv}(t) + \epsilon_{cv}(t)$$

where $t = 1, \ldots, T$, $v = 1, \ldots, V_c$.

- $X_p(t)$ denotes time-varying covariate due to $p^{th}$ stimulus
- $\beta^p_c$ is an effect for the $p^{th}$ stimulus in ROI $c$
- $H_c(v)$ captures the spatial dependency in ROI $c$: separable, isotropy, and stationary.
- $d_c(t)$ is for functional connectivity
- $W_{cv}(t)$ is for temporal correlation - stationary
Spatio-Temporal Hierarchical Model

\[ Y_{cv}(t) = \sum_{p=1}^{P} \beta^p_c X_p(t) + H_c(v) + d_c + W_{cv}(t) + \epsilon_{cv}(t) \]

- \( H_c = \psi(\phi_c) \), \( \phi_c \) is a decaying parameter of exponential covariance function.
- \( d \sim MVN(0, \Sigma_d) \), where \( \Sigma_d \sim \text{Wishart}(\Sigma_{DTI}) \) where \( \Sigma_{DTI} \) comes from DTI.
- \( W \) is AR(1) process.
- \( \epsilon_{cv}(t) \sim N(0, \sigma) \)
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Data Generation and Estimation

- WinBUGS and R
- 5 ROIs, 50 voxels/ROI, T = 128
- Generate spatially and temporally correlated data given $\Sigma_d$, $\Sigma_{DTI}$, and other hyper parameters.
- Estimate $\Sigma_d$ using informative prior (random sample of $\Sigma_{DTI}$) and non-informative prior.
- A single chain with 2000 iterations after 1000 burn-in.
### Results from Simulations

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Results from Simulations

- Informative prior reduces about 10% of computational time, compared to non-informative prior.
- Informative prior saves more than 50% of MSE, compared to non-informative prior.
- Our approach allows us to easily draw inference about functional connectivity - single subject and/or multi-subjects.
Data Analysis

- Two working memory stimuli + instruction + rest = four stimuli.
- T = 147 and three ROIs of interest.
- Single subject out of 120 participants.
  1. HIV positive
  2. No history of alcohol/drug use
Regions of Interest
Results from Data Analysis

- Three regions of the brain are of interest: L dorsolateral prefrontal cortex (ROI 1), R precentral gyrus (ROI 2), and anterior cingulate cortex (ROI 3).
- Preliminary results indicates the functional connection between R precentral gyrus and anterior cingulate cortex based on hypothetical structural connectivity.

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Summary

- Spatio-Temporal Hierarchical Model
  1. takes into account local spatial correlation within ROI and global correlation between ROIs
  2. can use structural information to update functional connectivity.

- Structural information reduces computational burden and MSE.

- More simulations under different scenario - different non-informative priors.
Acknowledgments

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