Comparing connectivity-based groupwise parcellations generated from resting-state fMRI and DTI data: Preliminary results

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Introduction

Identification of functional/structural connections within the brain has potential to reveal the brain’s neural organisation in health and disease.

A critical stage in connectome analysis is the parcellation of the cerebral cortex into a set of subregions that can be used as the network nodes.
Motivation

• Traditional anatomical atlases are being replaced by functional/structural parcellations for network analysis
• Relationship between functional and structural connectivity is a hot topic, but direct comparison of parcellations is rare
• Compare parcellations derived from different data sources, but via the same parcellation framework
• Aim: Locate cortical subregions that have been consistently assigned to the same parcels across different parcellations/modalities
• Assess the performance of the parcellations in order to judge their potential for further analyses
Data acquisition and preprocessing

• Rs-fMRI and dMRI datasets of 50 unrelated subjects from the Human Connectome Project (HCP) [1]
• Preprocessed, de-noised, and ready to analyze [2]
• **Rs-fMRI**: Time-series normalized to unit-variance and zero-mean, and concatenated across different scans

![Images of brain scans]

• **dMRI**: Tractography matrix obtained on the native mesh via probabilistic tractography (see details in [3])

[3] Parisot et al. 2015, IPMI
Joint spectral decomposition\(^1\)

N-layer joint graph

\[
\begin{pmatrix}
W_{S_1} & C_{S_1S_2} & C_{S_1S_3} & \cdots & C_{S_1S_N} \\
C'_{S_1S_2} & W_{S_2} & & & \\
C'_{S_1S_3} & & W_{S_3} & & \\
\vdots & & \ddots & \ddots & \\
C'_{S_1S_N} & & & \ddots & W_{S_N}
\end{pmatrix}
\]

Joint spectral decomposition

Clustering

[Yu and Shi, 2003, ICCV]

Group parcellation

[Spectral matching
[Lombaert et al. 2013, IPMI]

Connectivity fingerprints

Joint spectral decomposition

Inter-cortical connections

Intra-cortical connections

[Spectral decomposition

[1] Arslan et al. 2015, IPMI

Spectral decomposition

Correlation

Spectral decomposition

[1] Arslan et al. 2015, IPMI

Inter-cortical connections

Intra-cortical connections
Parcellation setting

- Each subject is registered to the same standard cortical model
- Adjacency matrices and inter-cortical connections are weighted by different modalities

**rs-fMRI**
- Weight edges with resting-state fMRI correlations

**Diffusion**
- Weight edges with log-transformed tractography correlations

**All-1s**
- Weight edges with ones. No functional/structural information encoded.

COMPARE
Randomly pick 20 subjects from a set of 50

\[ K = 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200 \] per hemisphere

Repeat the process \( \times 100 \)

Clustering spatial coordinates of cortical vertices with k-means. No connectivity involved.
Evaluation

Quantitative assessment

- A probabilistic model of the task-fMRI signal [1]
  \[ y = \mu 1 + X\beta + \varepsilon \]
- **Goodness of fit**: Log-likelihood and Bayesian information criterion (BIC)
- **Reproducibility**: Dice index (requires pre-matching), adjusted rand index (invariant to permutation of labels)

Qualitative (visual) inspection

- Locate cortical areas that have been consistently assigned to the same parcels across different parcellations

  [link](https://github.com/bthirion/frontiers_2014)
**Goodness of fit**

Among the connectivity-driven parcellations, **Diffusion** consistently performs better than **RS-fMRI** for all parcellation resolutions.

**Geometric** and **All-1s** achieve the best fit, which is attributed to their tendency to generate more equally-sized parcels compared to the others.
Reproducibility

Among the connectivity-driven parcellations, RS-fMRI is more reproducible than Diffusion, for $K > 160$. Expectedly, All-1s is able to obtain the most similar parcellations, since the underlying model is almost identical for all groups. Due to anatomical variability across subjects, Geometric obtains the least similar parcellations.
Stable regions across parcellations
We compute a graphical model of the parcel stability across the parcellations ($N = 100$).

An edge between two vertices is weighted by the number of times they appear in the same parcel across parcellations.
We compute a graphical model of the parcel stability across the parcellations \((N = 100)\).
Stability graphs $\rightarrow$ cortical surface

• Transform stability graphs into degree (centrality) vectors and assign each vertex a stability score

$$D = \sum_{j} w_{ij}$$

• Scale into the range of $[0, 1]$ for better visualization as well as for a fair comparison across different resolutions and methods
Stable regions across parcellations

Resting-state fMRI
Stable regions across parcellations

Diffusion
Overlaps in stability might be due to a link between the structural and functional connectivity.

Without any functional/structural information, parcels seem to be randomly distributed across different resolutions.
Resting-state fMRI

Stability

Node centralities of the average correlation network
Diffusion MRI

Stability

Node centralities of the average correlation network
Mixed-effects analysis:

Functional variability

Task-fMRI image targeting the motor cortex

Within-parcel variability

Across-subject variability

\[ y = \mu 1 + X\beta + \epsilon \]
Conclusions and future work

• Rs-fMRI and dMRI-based parcellations generated by the same spectral clustering framework have been analyzed

• Connectivity-driven parcellations are more stable with varying $K$ compared to the reference model

• Stability is more prominent around the visual, insular and posterior cingulate cortex, and the temporal lobe

• Well-known tracts interconnect commonly found resting-state networks, especially the default mode network [1,2]

• Parcellations might be used in a prediction framework to see if they are functionally similar [3]

Thanks for your attention!

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Questions?
Literature

• Functional and structural organization of the brain network are likely to be linked [Hagmann et al., 2008, PLoS; Honey et al., 2009, PNAS; Bullmore and Sporns, 2009, Nat Rev Neurosci]

• Focus on the default mode network (DMN)
  – Structural connections between posterior cingulate and medial frontal cortex are related to the high functional connectivity [van den Heuvel et al., 2008, J. Neurosci]
  – Other parts of the DMN have been found to be interconnected by structural white matter tracts [Greicius et al., 2008, Cereb Cortex]

• Well-known tracts interconnect commonly found resting-state networks, including primary motor and visual network [van den Heuvel et al., 2009, HBM]
HCP functional contrasts

- *Faces-shape contrast* of the emotional protocol
- *Punish-reward contrast* of the gambling protocol
- *Math-story contrast* of the language protocol
- *Left foot-average contrast* of the motor protocol
- *Left hand-average contrast* of the motor protocol
- *Match-relation contrast* of the relational protocol
- *Theory of mind-random contrast* of the social protocol
- *Two back-zero back contrast* of the working memory protocol
Diffusion MRI

Stability

Homogeneity
Resting-state fMRI

Stability

Homogeneity