Spatial Analysis of Cerebral fMRI Data

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• Institute
  – Clinical & scientific study of the nervous system in health and sickness

• Our laboratory
  – Human brain imaging of ischemic stroke

• Me
  – Identification of brain space-time structure using functional MRI
fMRI Background

Axial EPI (functional)  Axial T1 (anatomical)
fMRI Background

Why are these called “functional images”?

• Oxy-Hb is diamagnetic and deoxy-Hb is paramagnetic
• Cerebral vasculature regulates flow of oxy-Hb to active neuronal tissue
• Following neural activity, concentration changes in deoxy-Hb affect local field magnitude
• Therefore, the image intensity varies in sympathy with brain function
• This phenomenon is known as the Blood Oxygenation Level-Dependent (BOLD) effect
Acquisition of fMRI Data

MRI method:
Echo Planar Imaging
- full 3D image / 2 seconds
- 250,000 voxels / image
- 1.5 x 1.5 x 5.0 mm$^3$ / voxel
Acquisition of fMRI Data

Echo Planar Imaging

- images in sequence, e.g., 90 images in 3 minutes
- analyse the time sequence for each voxel
Acquisition of fMRI Data
Analysis of fMRI Data

Temporal Analysis

• Image is partitioned into clusters of correlated voxel time sequences
• Each cluster map shows the location of its member voxels over an anatomical model
Spatial Analysis
• Neurological studies revealed the compartmental nature of CBF regulation and brain function
• However, spurious voxels also appear due to noise sources
• Can we distinguish these types by characterising the spatial structure of clusters?
Cluster Contiguity

We define contiguity as the quantity

\[ c = \frac{1}{GN} \sum_{k=l}^{m} g_k k \]

- \( N \) total number of (active) voxels
- \( G \) total number of groups
- \( k \) group size
- \( g_k \) number of \( k \)-groups

**Example**: 14 pixels on a 64 pixel image
Set \( l = 3 \) as the smallest group size
Then, the contiguity is

\[ c = \frac{(1 \times 3 + 0 \times 4 + \ldots + 0 \times 8 + 1 \times 9)}{2 \times 14} = 0.43 \]
Cluster Contiguity

Further examples all with $N = 14$, $l = 3$

$c = 1$
$c = 0.86$
$c = 0.43$
$c = 0.21$
$c = 0$
Cluster Contiguity

Useful properties of $c$:
1. Mapped to the unit interval $[0, 1]$
2. Increases with group size
3. Decreases with number of free voxels
4. Invariant of geometry
5. Invariant of voxel size
Simulations

Synthesis model

• Two-parameter GRF model $R(\sigma^2, SNR)$
• Generate 64x64 images with 8-bit pixels
Simulations

- 200 realisations for 12 parameter sets
- Plot average contiguity distribution per set
Simulations

Contiguity distribution: a cluster’s contiguity as a function of member voxel correlation coefficient threshold

\[ R(32, 1.5) \]
Results for Simulations

Graphs reveal that the contiguity
• is very sensitive to spatial covariance
• is sensitive to SNR
• the c-distribution can be summarised into one number (e.g., median, or AUC)
Results on fMRI Data

- Visually cued motor-task experiment on a 34-year-old healthy male volunteer
- Expected left sensorimotor cortex and right cerebellum were identified by two independent methods
- The contiguity of clusters shown below distinguish cerebellum from venous sinus

Conclusion

• We proposed a novel method for characterising the spatial distribution of fMRI data
• The motivation was that relevant information exists in the location of signal sources in the brain
• We have recently shown that contiguity and temporal cross-correlation form effective selection criteria for data-driven analysis of cerebral fMRI data