Spatial Analysis of Cerebral fMRI Data

Camille Gómez-Laberge
Andy Adler
Matthew J. Hogan

June 10th, 2008
CMBES: Montréal, Québec, Canada

The Ottawa Hospital
L'Hôpital d'Ottawa

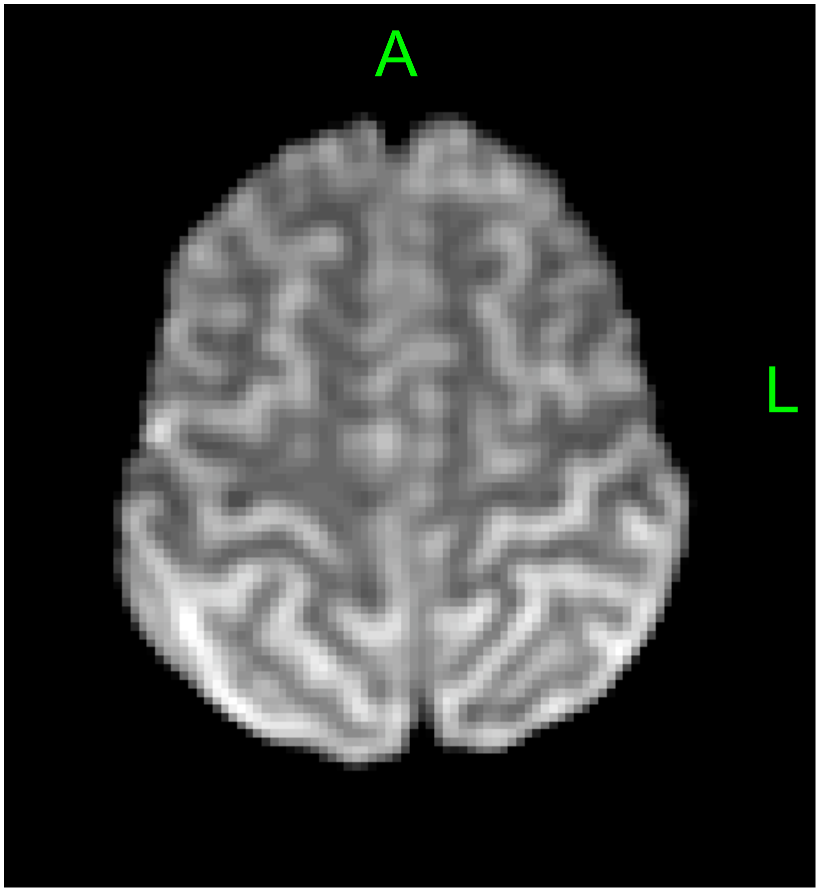
Carleton UNIVERSITY
Canada's Capital University

uOttawa
L'Université canadienne
Canada's university

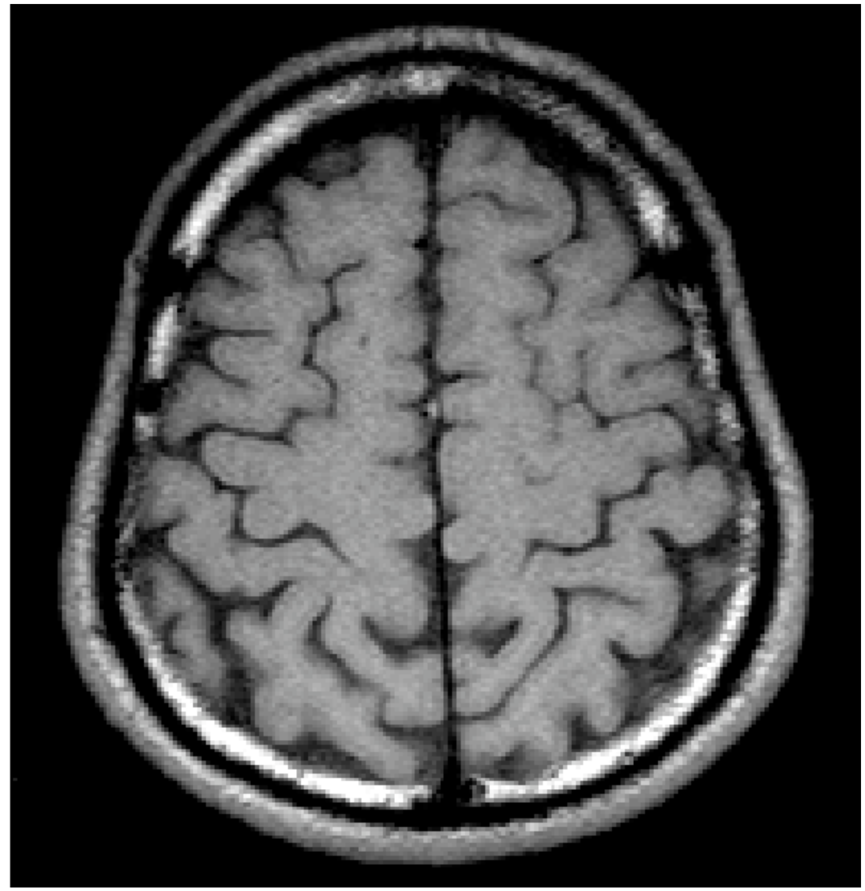
Neuroscience @ OHRI

- 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)

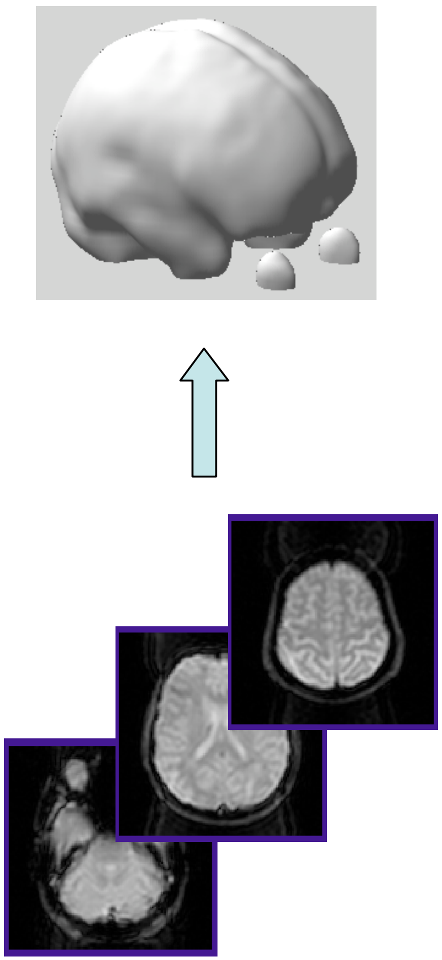

Axial T1 (anatomical)

fMRI Background

Why are these called “functional images”?

- Oxy-Hb is **dia**magnetic and deoxy-Hb is **para**magnetic
- 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

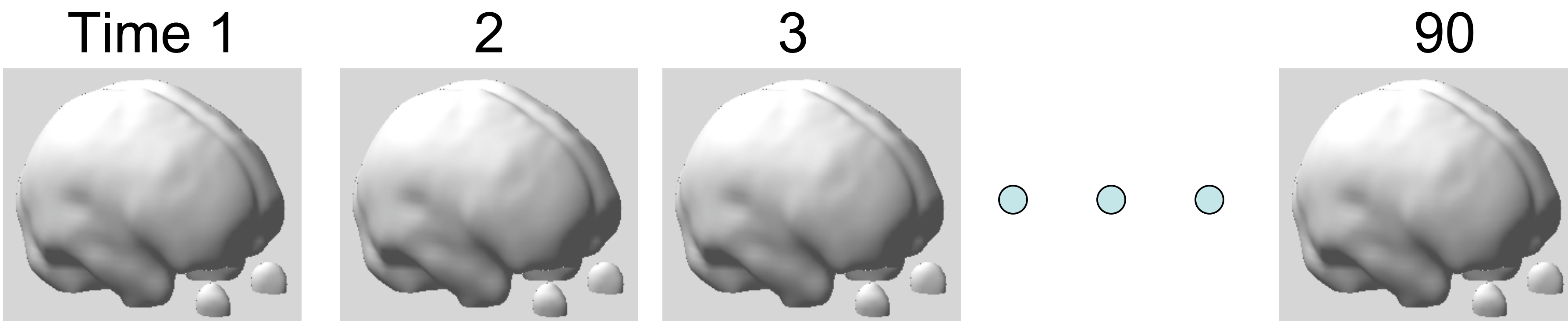


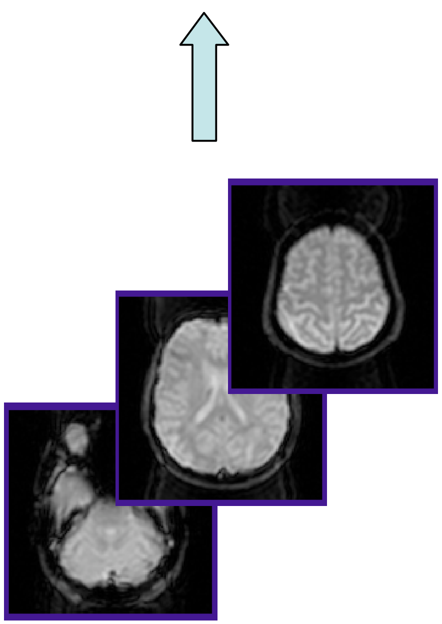
MRI method:

Echo Planar Imaging

- full 3D image / 2 seconds
- 250,000 voxels / image
- $1.5 \times 1.5 \times 5.0\ mm^3$ / voxel

Acquisition of fMRI Data

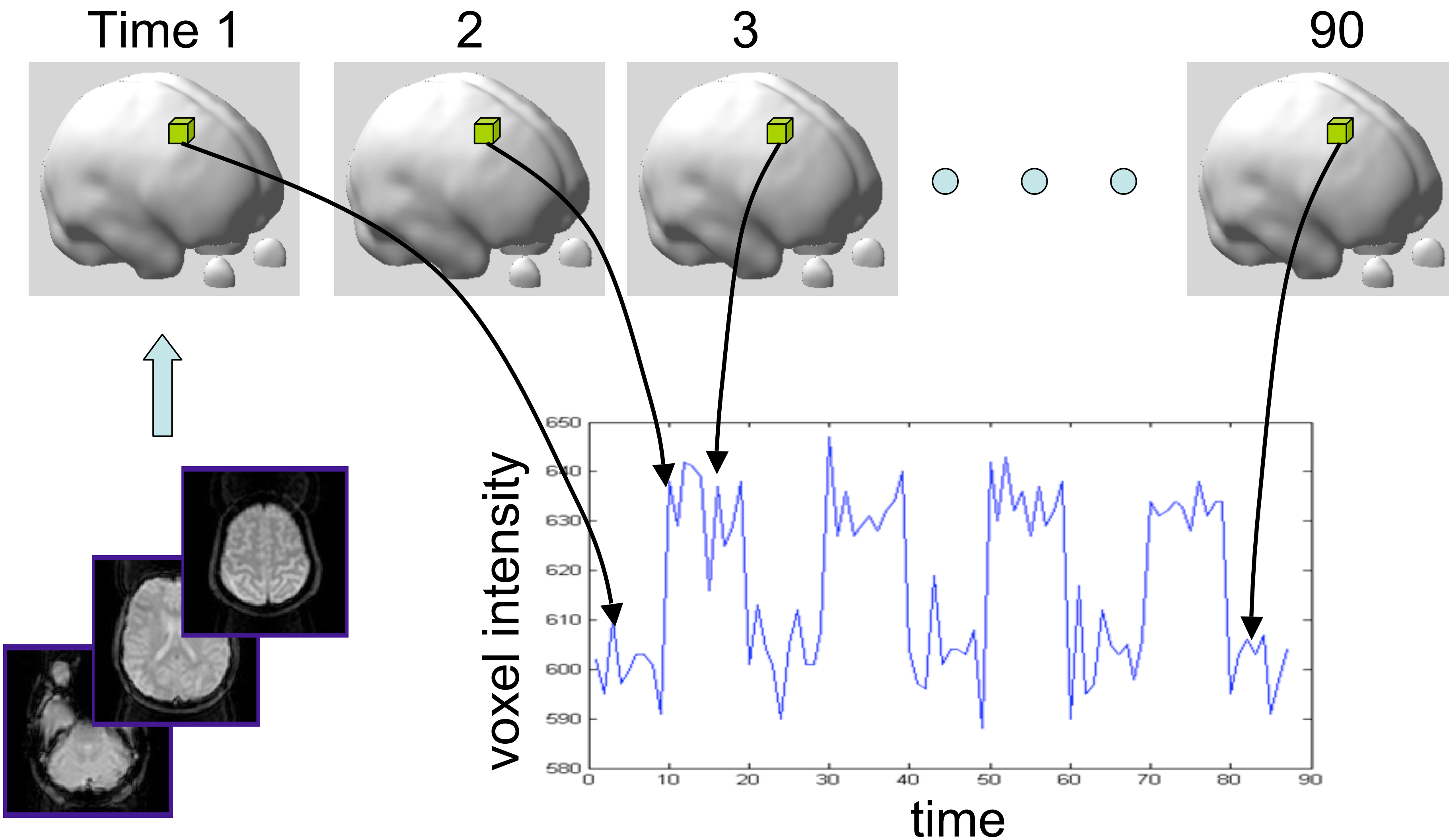




Echo Planar Imaging

- images in sequence, e.g., 90 images in 3 minutes
- analyse the time sequence for each voxel

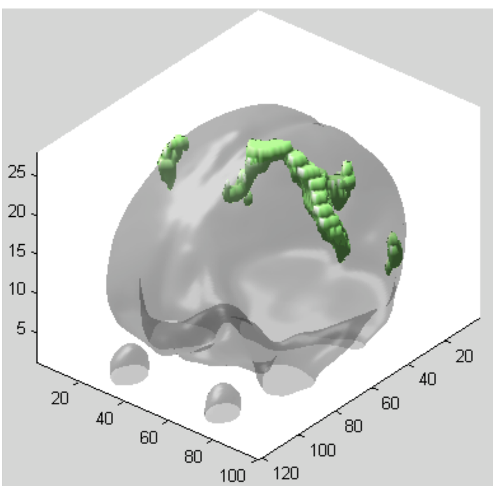
Acquisition of fMRI Data



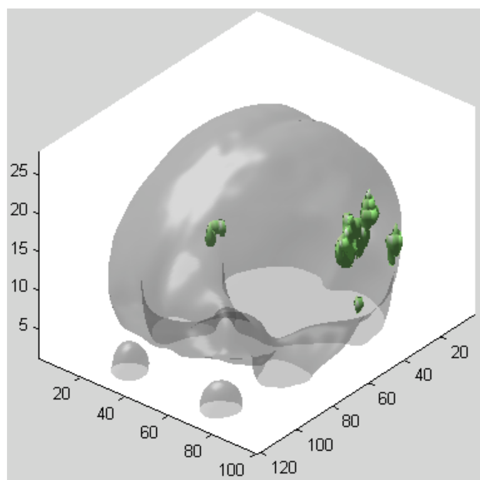
Analysis of fMRI Data

Temporal Analysis

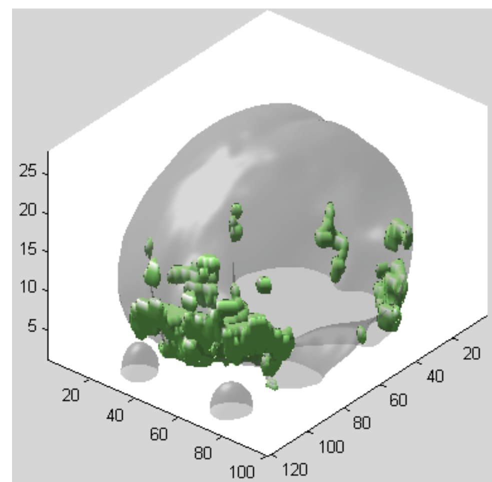
- Image is partitioned into **clusters** of correlated voxel time sequences
- Each cluster map shows the location of its member voxels over an anatomical model



Cluster 1

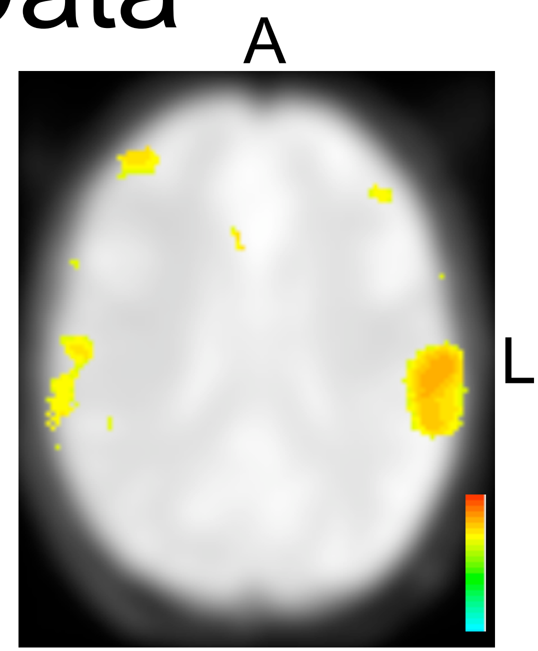


Cluster 2



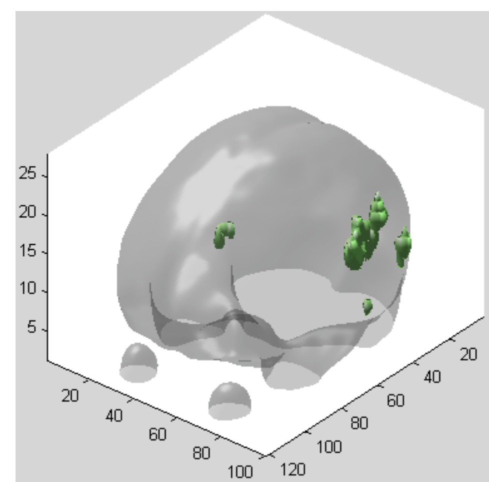
Cluster 3

Analysis of fMRI Data



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 = (1x3 + 0x4 + … + 0x8 + 1x9) / (2x14)
= 0.43

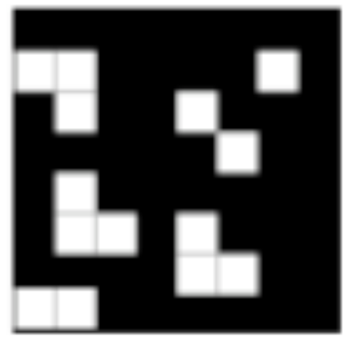
Cluster Contiguity

Further examples all with N = 14, l = 3

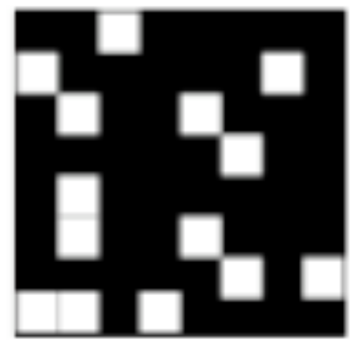
c = 1

c = 0.86

c = 0.43



c = 0.21



c = 0

Cluster Contiguity

Useful properties of *c*:

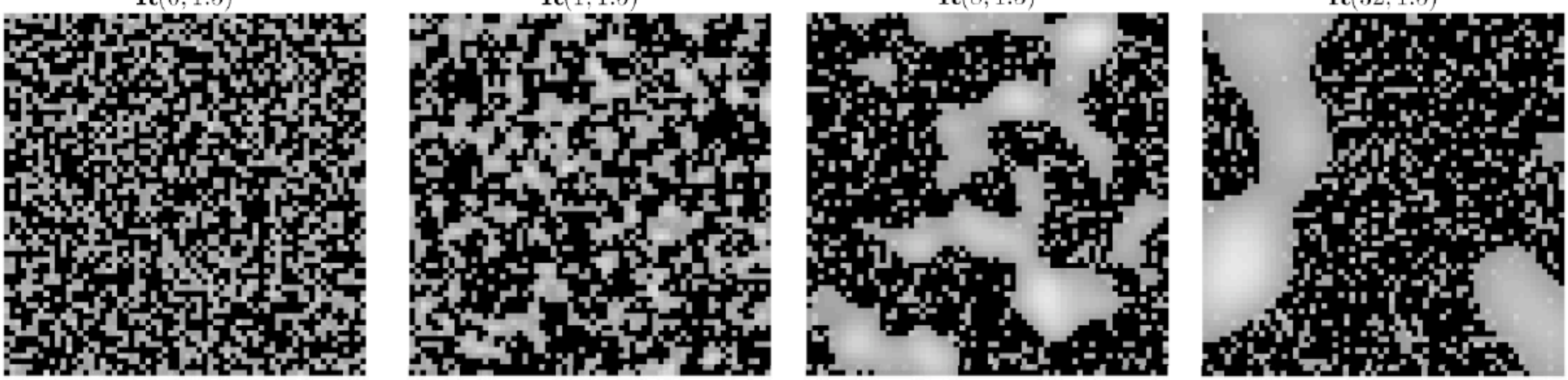
1. Mapped to the unit interval [0, 1]
2. Increases with group size
3. Decreases with number of free voxels
4. Invariant of geometry
5. Invariant of voxel size

Simulations

Synthesis model

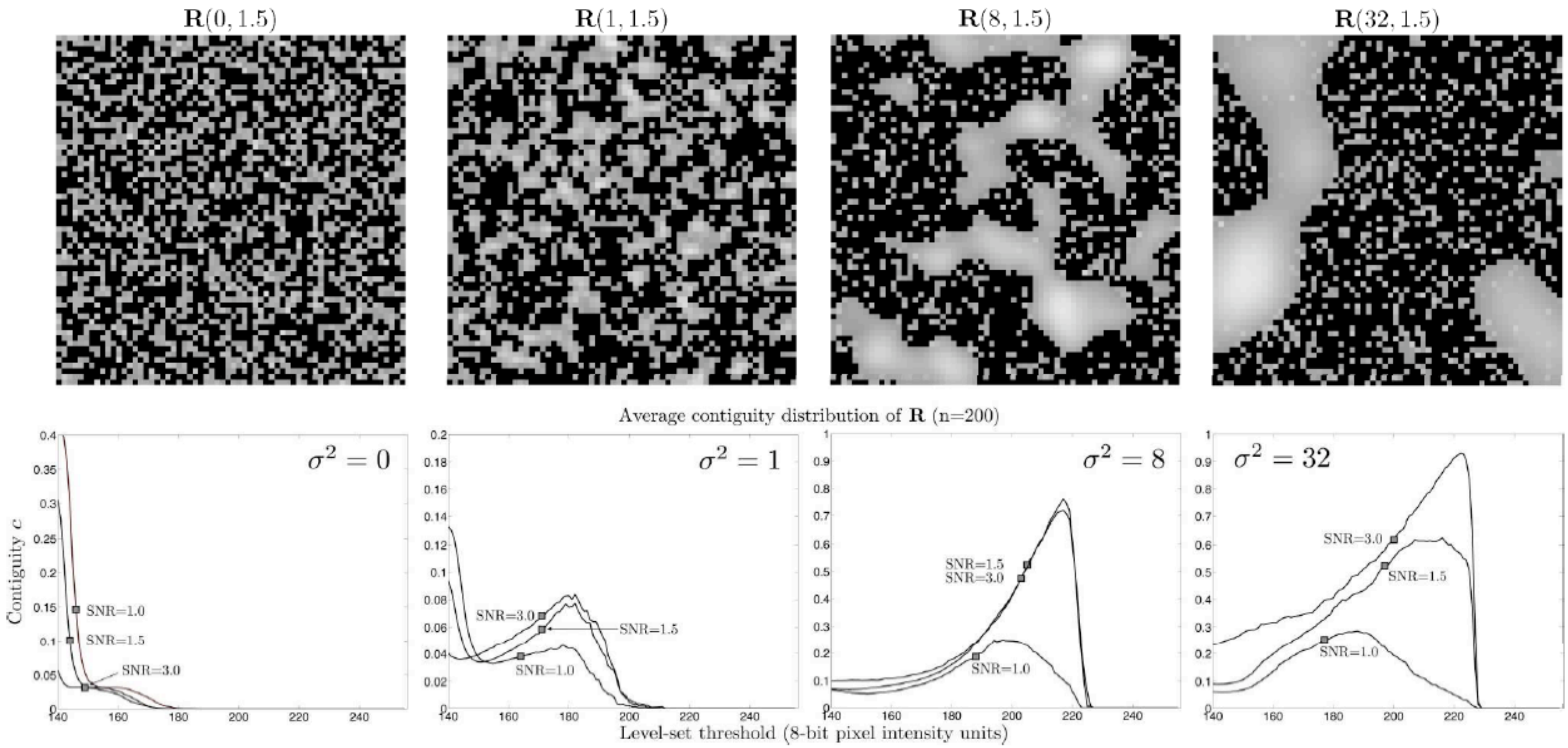
- Two-parameter GRF model $R(\sigma^2, SNR)$
- Generate 64x64 images with 8-bit pixels

$\mathbf{R}(0, 1.5)$ $\mathbf{R}(1, 1.5)$ $\mathbf{R}(8, 1.5)$ $\mathbf{R}(32, 1.5)$



Simulations

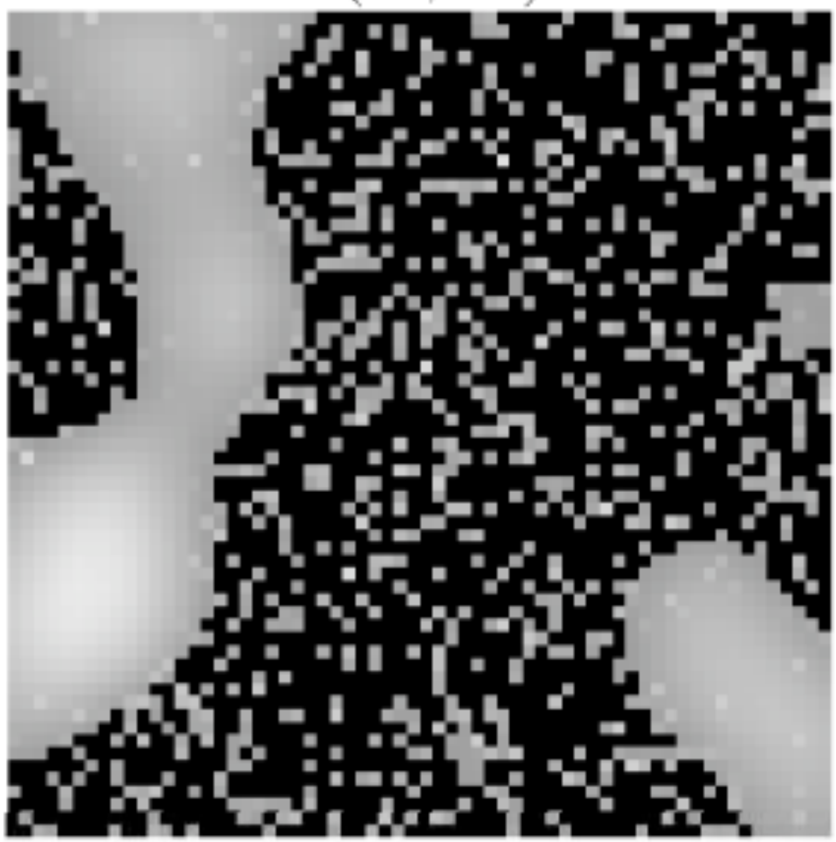
- 200 realisations for 12 parameter sets
- Plot average contiguity distribution per set

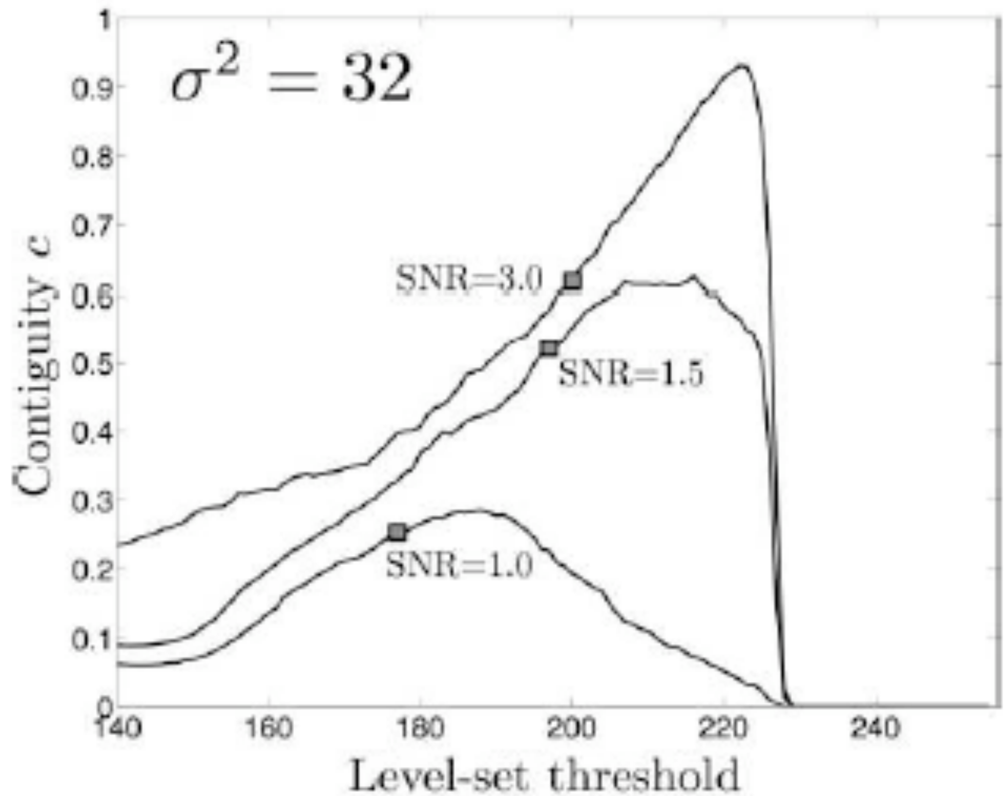


Simulations

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

$\mathbf{R}(32, 1.5)$

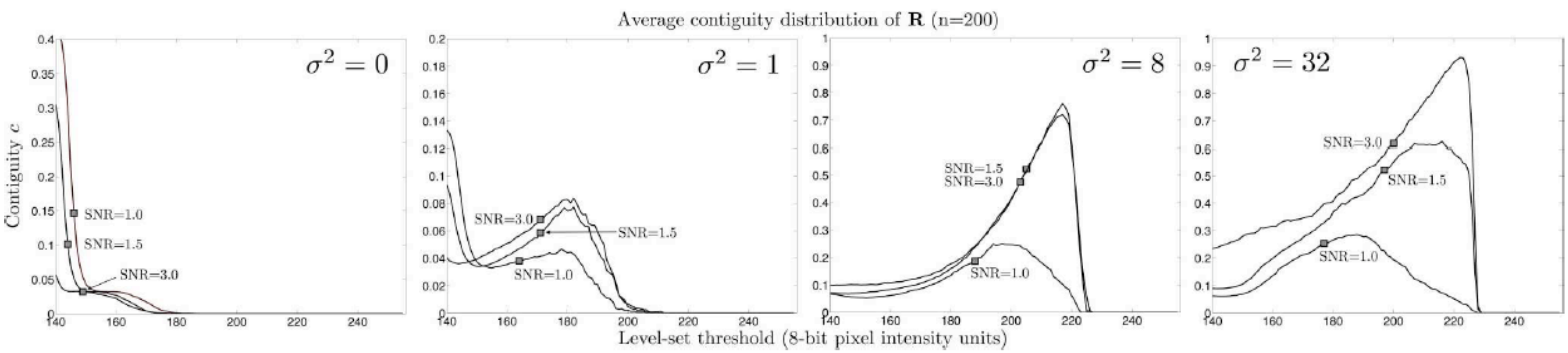




Results for Simulations

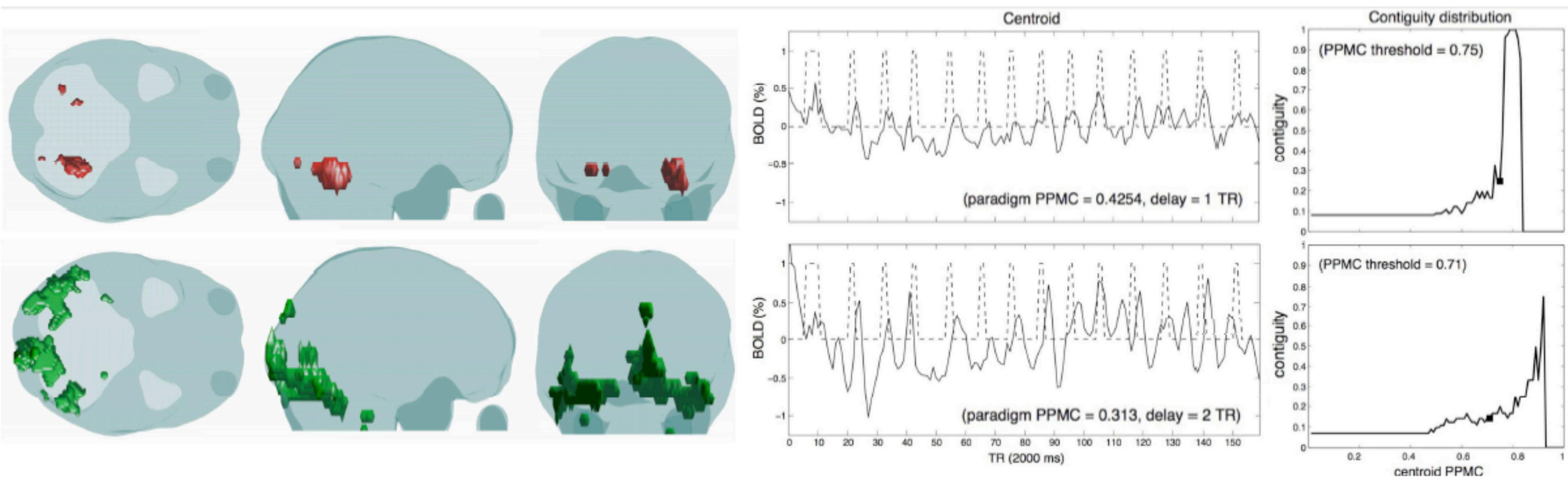
Graphs reveal that the contiguity

- 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



Adapted from: C. Gómez-Laberge *et al.*, *in press* IEEE Trans. Biomed. Eng., 2008.

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