Statistically Robust Means of Detecting and Categorizing BOLD Contrast in fMRI Data

Jae-min Lee and Jing Hu
Supervised by Dr. Gao

Electrical and Computer Engineering Department,
University of Florida

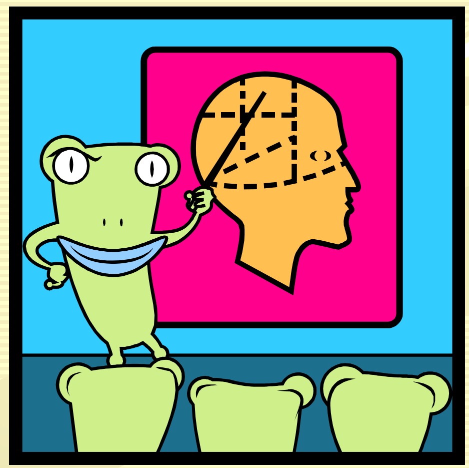
Outline

- System Design
- Challenges of fMRI data analysis
- Drawbacks of conventional techniques
- Proposed techniques for activation detection
- Brain mapping Examples
- Conclusions

Schematic System

MRI Scanning Room

Functional MRI

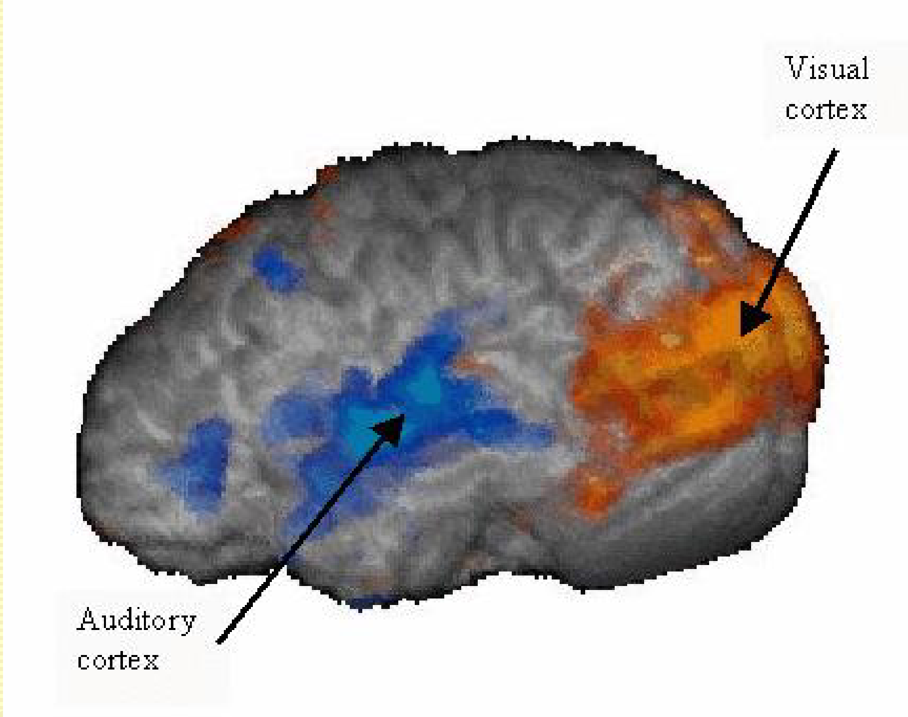


Research Goal

Apply several techniques from both linear and nonlinear dynamical systems analysis to evaluate fMRI data, identify statistically robust means of detecting and categorizing Blood Oxygenation Level Dependent (BOLD) contrast in fMRI images, which can give good estimation of brain activation.

Introduction of fMRI

- A technique for determining which parts of the brain are activated by different types of physical sensation or activity, such as sight, sound, utterance, or the movement of subject's finger.



- This "brain mapping" is achieved by setting up an advanced MRI scanner in a special way so that the increased blood flow to the activated areas of the brain shows up on Functional MRI scans.

Challenges of fMRI Data Analysis

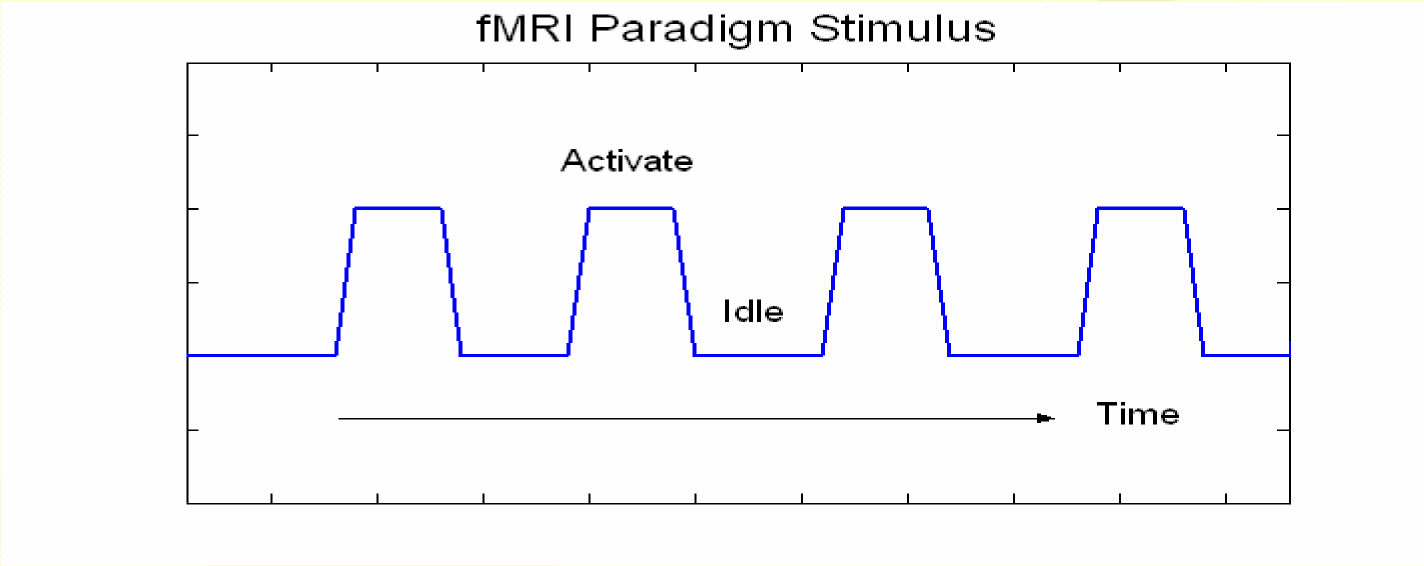
- **Do not have enough measurement**

  Typically get a few Gbytes of data per scanning session, but most of this is not relevant to neural activity (BOLD signal is weak).
- **Must make many decisions to make a brain map**

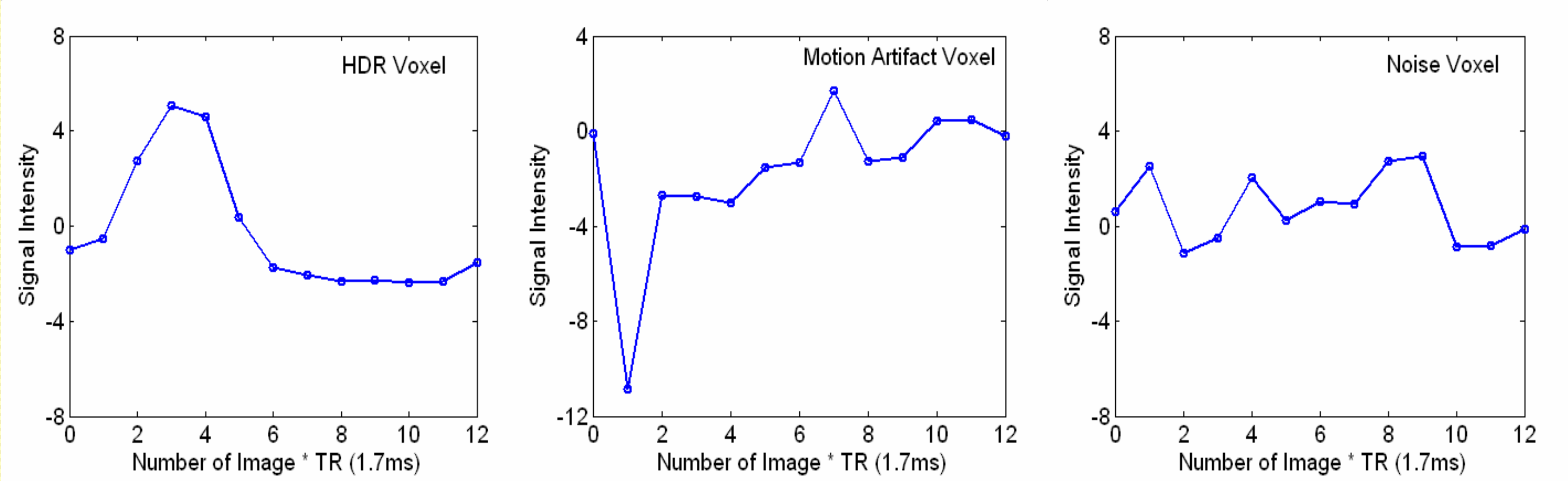
  Typically have $10^4 \sim 10^5$ voxels in the brain, if the chance of making a mistake in any one voxel is 1%, then expect 100 ~ 1000 errors in every brain map. This may be as big as the number of truly active voxels in the brain.
- **Thus, statistically robust means of activation detection is highly demanded**

Stimulus

Subjects have performed repeated trial experiments in which each trial consisted of various durations and rates of finger tapping paced by auditory cueing tones supplied through earphones.



Conventional Techniques for Activation Detection



Conventional techniques rely on predicting the BOLD response in terms of a global model. These responses are based on the Deconvolution Analysis. The deconvolution is computing each voxels' hemodynamic response function, and we assume that we know the input function (stimulus).

Conventional Techniques for Activation Detection (Cont')

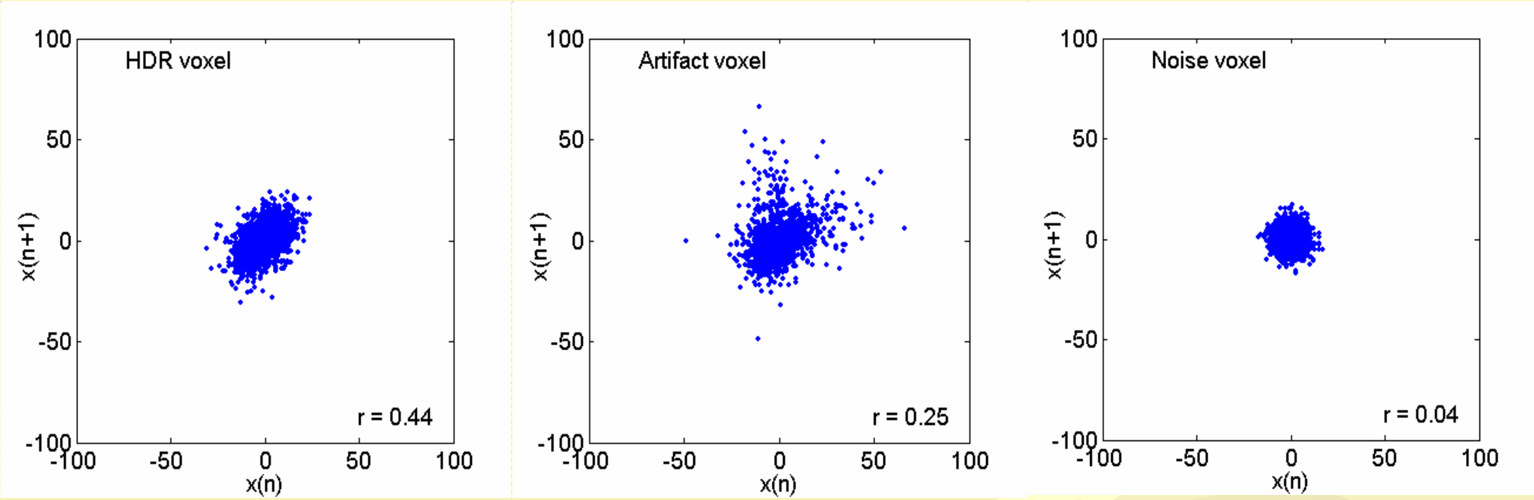
Drawbacks of the Deconvolution analysis:

- sensitive to event-related motion artifacts and noise, i.e., physiological pulsations (including cardiac and respiratory), instru-mental instability.
- we need to know prior knowledge of stimulus, assume that we know the input function (stimulus).

Proposed Techniques for Activation Detection

- Phase Space Plots
- Detrended Fluctuation Analysis
- Spatial-Temporal Correlation Analysis

Phase Space Plots



The abscissa plots the strength of magnetization recorded at individual points in the time series (X(n)), while the ordinate plots the strength recorded at the adjacent time point (X(n+1)).

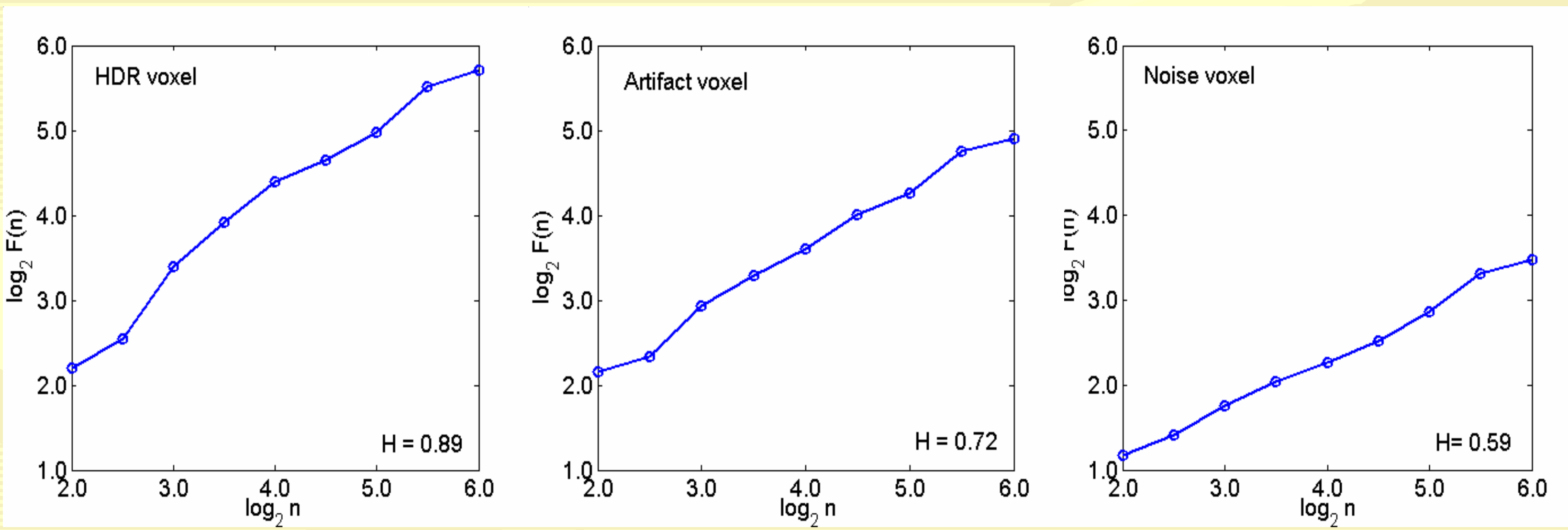
Detrended Fluctuation Analysis

The method is based on the random walk or integrated time series. The integrated time series is divided into boxes of equal length, *n*. In each box of length *n*, a least squares line is fit to the data (representing the trend in that box). The *y* coordinate of the straight line segments is denoted by $y_n(k)$. Next, we detrend the integrated time series, $y(k)$, by subtracting the local trend, $y_n(k)$, in each box. The root-mean-square fluctuation of this integrated and detrended time series is calculated by:

$$F(n) = \sqrt{\frac{1}{N}\sum_{k=1}^{N}[y(k) - y_n(k)]^2}$$

Detrended Fluctuation Analysis

This computation is repeated over all time scales (box sizes) to characterize the relationship between *F*(*n*), the average fluctuation, as a function of box size. Typically, *F*(*n*) will increase with box size *n*.



Spatial-Temporal Correlation Analysis (STCA)

Premises:

- fMRI data have intrinsic spatial and temporal correlation
- fMRI activation is more likely to occur in clusters of several contiguous voxels than in a single voxel

STCA (Cont')

STCA is performed with the joint time-courses of that voxel together with its neighboring voxels in both the same slice and the adjacent slices of the brain. We use a 3 X 3 X 3 cubic neighborhood, except possibly for the voxels at the edge of the brain. If the voxel of interest is part of the boundary of the brain, it will not have twenty-six voxels as neighbors. In such a case, we still run the STCA but with a fewer number of available neighboring voxels.

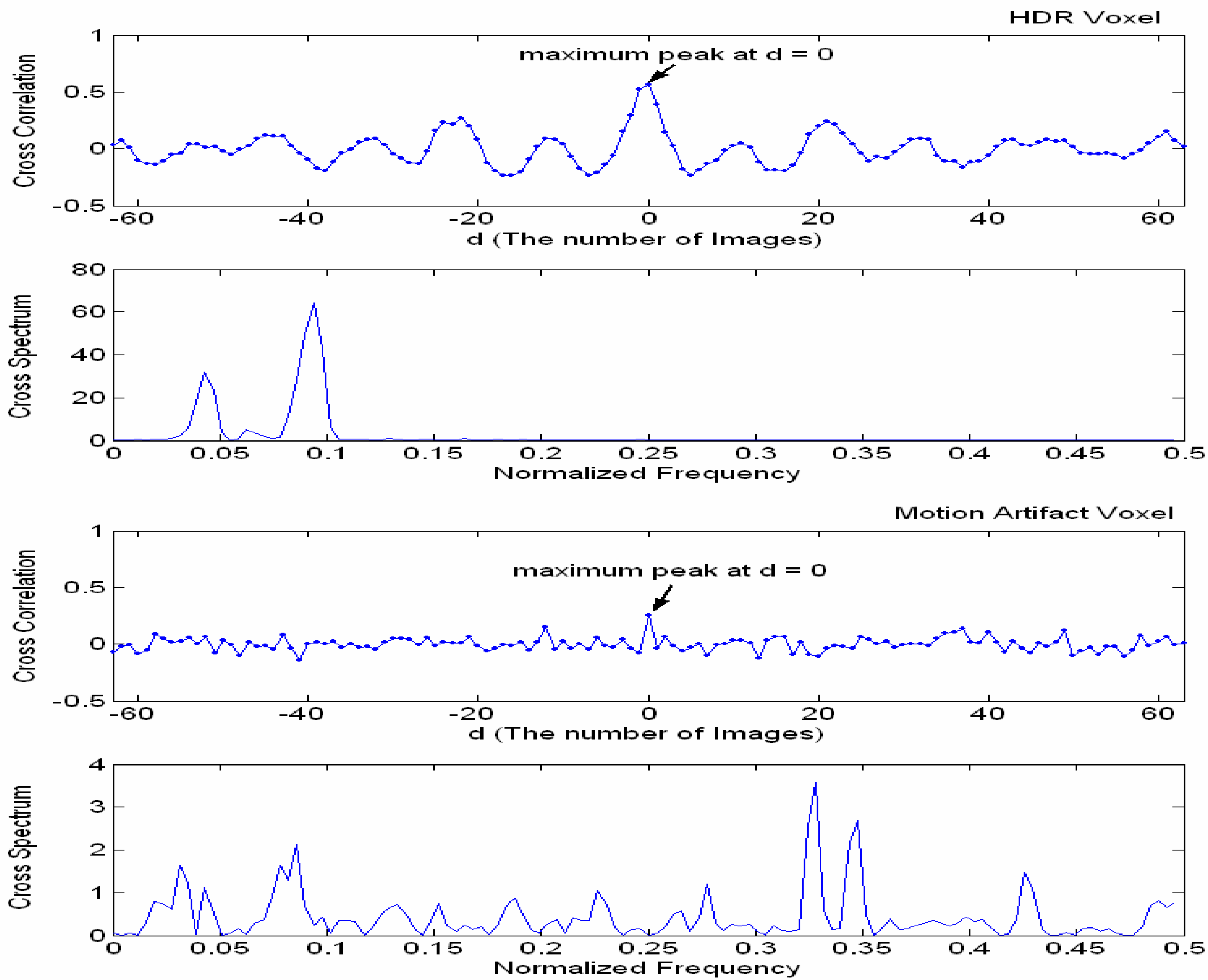
STCA (Cont')

Cross correlation is a standard method of estimating the degree to which two series are correlated. Consider two time series of voxel of interest and one of its neighbors, denoted by X(n) and Y(n), where n=0,1,2,...*N*-1, *N* is the length of the time series. The cross correlation R_{xy} at delay d (d can be chosen as –N+1, …, -1, 0, 1, …, *N*-1) is defined as:

$$R_{xy}(d) = \frac{\sum_{n=0}^{N-1} \{[x(n)-m_x][y(n-d)-m_y]\}}{\sqrt{\sum_{n=0}^{N-1} \{[x(n)-m_x]^2\}}\sqrt{\sum_{i=0}^{N-1} \{[y(n-d)-m_y]^2\}}}$$

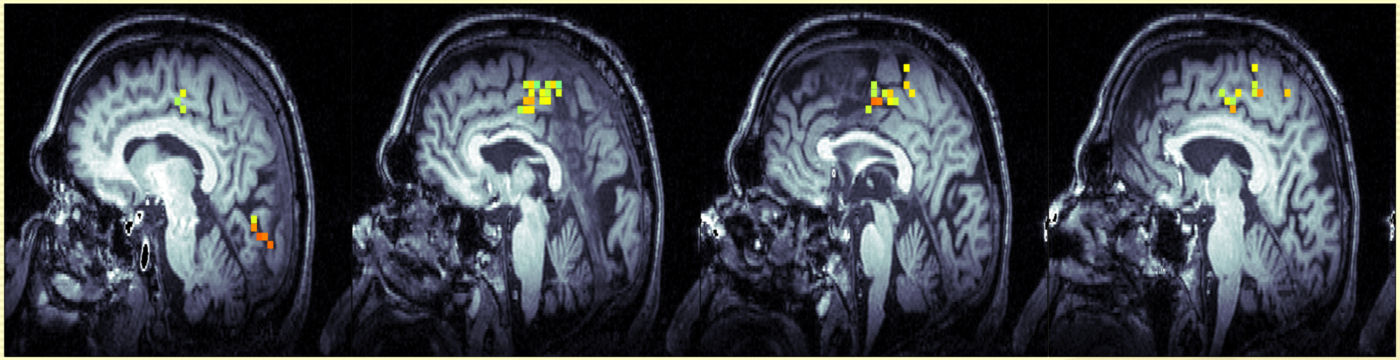
where *mx* and *my* are the means of the corresponding series. We also consider the Fourier transform of cross correlation, that is, cross spectrum.

STCA (Cont')

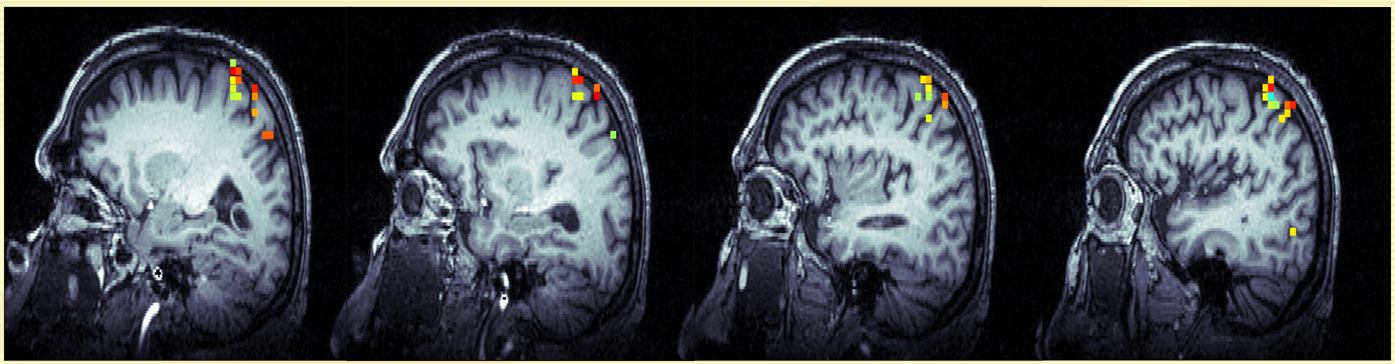

HDR Voxel
maximum peak at d = 0
Cross Correlation
1
0.5
0
-0.5
-60
-40
-20
0
20
40
60
d (The number of Images)
Cross Spectrum
80
60
40
20
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Normalized Frequency
Motion Artifact Voxel
maximum peak at d = 0
Cross Correlation
d (The number of Images)
Cross Spectrum
4
3
2
1
0
Normalized Frequency

Activation Brain Mapping

Supplementary Motor Area



Left Sensory Motor Area



Conclusions

- Challenges of fMRI data analysis
- Drawbacks of conventional techniques
- Our proposed techniques
  - Phase Space Plots
  - Detrended Fluctuation Analysis
  - Spatial-Temporal Correlation Analysis
- Our techniques can robustly detect brain activation

THANK YOU FOR YOUR ATTENTION

Any Questions or Suggestions?????