Quantitative and Functional Imaging

BME 4420/7450

**Project #7: Functional brain mapping**

The goal of this project is to measure the BOLD signal due to two sets of stimuli: **speech (meaningless letter combinations, e.g., ‘tog’)** and **music (chord sequences played on a piano).** In both cases, the BOLD signal is the difference in image intensity during periods of stimulation and rest (i.e., silence). As in the previous projects, you are free to get your results in some other way—these procedures are just one (not necessarily optimal) method. Matlab commands are given in *italics* for easy reference. Use *help <command>* (for example, *help meshgrid*) or the Matlab Help pages for more details on any Matlab function.

1. Load the data file p**roj7wordsData.mat** into your Matlab workspace. There are two variables in the file:

image\_3d An array (64 x 64 x 216) of **pixel values for 216 time points in a functional MRI study.**

sound\_v A 1D array (216 elements) giving the state of the stimulus at each time point. If the stimulus is audible at time n, then sound\_v(n) = 1 (otherwise, sound\_v(n) = 0).

The indices of the array image\_3d are (row, column, timeIndex). The individual images (the pages of the 3D array) are given in time order, i.e., image\_3d(:,:,1) is the first image, image\_3d(:,:,2) is the second, and so on.

1. Smooth **the images** to improve the signal-to-noise ratio (SNR). **Use the *conv2* function to average pixel intensity in a 4x4 neighborhood of each pixel (*conv2* performs a two-dimensional convolution of the image with a 4x4 square function).** Do this for each time point (i.e., each page of the 3D array):

*for time = 1:nTimes*

*image\_m = squeeze(image\_3d(:, :, time));*

*smoothImage\_m = conv2(image\_m, ones(4), 'same');*

*image2\_3d(:, :, time) = smoothImage\_m;*

*% Insert code here to display both the original and smoothed*

*% images (in one figure):*

***end***

1. **Make a binary mask (a matrix of 1’s and 0’s) showing where the mean image intensity (mean over all times) is at least 10% of the maximum pixel intensity. Call this matrix ‘headMask\_m’.**
2. Transform the 1D array sound\_v so it has mean value equal to zero and unit norm (i.e., the square root of the sum of the squared elements equals 1). Call this vector ‘normSound\_v’.
3. Calculate the **correlation coefficient of** the signal with **normSound\_v** for each **pixel** in the head (as defined by your headMask\_m). First initialize the matrix of correlation values:

*rWord\_m = zeros(nRows, nCols);*

Then for each pixel in the **head** (at position row, col) calculate the correlation coefficient:

*data\_v = squeeze(image2\_3d(row, col, :));*

*% Insert code here to transform the data\_v to have zero mean*

*% and unit norm. Call this vector normData\_v:*

*% Calculate the correlation coefficient of normData\_v and*

*% normSound\_v:*

*rWord\_m(row, col) = sum(normData\_v .\* normSound\_v);*

Display the **correlation coefficient map in a new figure**. If you use the default colormap, the **auditory areas of the cortex should appear red** (i.e., have the **largest correlation coefficients**).

1. Prompt the user of your program to define a region of interest (ROI) covering the activated auditory cortex in the left hemisphere. Use *roipoly* to define the ROI. The output of *roipoly* is a binary mask with 1’s inside the ROI—name this matrix ‘leftRoiMask\_m’. Repeat for the right hemisphere, calling this mask ‘rightRoiMask\_m’. Calculate roiSignal\_v**, the signal as a function of time summed over pixels in the combined (left + right) region of interest:**

*title('Define left hemisphere region of interest...')*

*[leftRoiMask\_m, xLeft\_v, yLeft\_v] = roipoly;*

*line(xLeft\_v, yLeft\_v, 'LineWidth', 3, 'Color', 'k')*

*title('Define right hemisphere region of interest...')*

*[rightRoiMask\_m, xRight\_v, yRight\_v] = roipoly;*

*line(xRight\_v, yRight\_v, 'LineWidth', 3, 'Color', 'k')*

*roiMask\_m = rightRoiMask\_m + leftRoiMask\_m;*

*roiSignal\_v = zeros(nTimes, 1);*

*% Insert code here to calculate roiSignal\_v at each*

*% time point:*

Transform roiSignal\_v to have zero mean and unit norm. Call this ‘normRoiSignal\_v’. Plot this along with normSound\_v for comparison. **How well does the ROI signal follow the ideal response given by normSound\_v?**

1. Calculate the **mean value** **of roiSignal\_v** while the stimulus (sound) is on. Call this ‘meanStim’. Similarly, find the mean value of roiSignal\_v while the stimulus is off. Call this ‘meanRest’.
2. Calculate the standard deviation of roiSignal\_v around its mean values (i.e., the standard deviation relative to meanStim during stimulation and relative to meanRest during rest). Using your values of meanStim, meanRest, and noiseStd calculate and display the contrast-to-noise ratio (CNR) of the BOLD measurement.
3. Find the ‘center of activation’ in each hemisphere. This is **analogous to a center-of-mass calculation in mechanics**: the center of activation is the weighted average of all pixel positions in the ROI (weighted by the correlation coefficient). For example, the center of activation of a uniform disk of correlation coefficients is just the center of the disk. If the disk has higher correlation coefficients on one side, then the center of activation would be on that side of the disk’s center. Use the ***meshgrid* command** to generate coordinate matrices [cols\_m, a matrix with all rows equal to 1:nCols, gives the column number of each image pixel and rows\_m, a matrix with all columns equal to transpose(1:nRows), gives the row number of each image pixel]. Find the weighted average of the row and column positions in the left hemisphere ROI:

*[cols\_m, rows\_m] = meshgrid(1:nCols, transpose(1:nRows));*

*wordLeftCenterRow = sum(sum(leftRoiMask\_m.\*rows\_m.\*rWord\_m)) / ...*

*sum(sum(leftRoiMask\_m .\* rWord\_m));*

*wordLeftCenterCol = sum(sum(leftRoiMask\_m.\*cols\_m.\*rWord\_m)) / ...*

*sum(sum(leftRoiMask\_m .\* rWord\_m));*

Repeat the calculation for the right hemisphere (i.e., calculate wordRightCenterRow and wordRightCenterCol).

1. Repeat steps 1-9 for a second stimulus (‘chords’ as opposed to ‘words’).
2. Compare the positions of the centers of activation for the two stimuli. Show the locations of the Word and Chord activation centers in each hemisphere on an image of the brain. Is one shifted with respect to the other?

Graduate credit/undergraduate extra credit

1. There are several sources of signal variance that reduce the activation CNR. One of these is the slow change over time in scanner sensitivity—this is termed scanner drift. One way to reduce its effect is to model and subtract the drift from the signal. Estimate the signal drift in your ROI by fitting the signal during the ‘stimulus off’ blocks with a straight line (using *polyfit*, for example). Subtract this linear component (trend) from the signal at all time points (i.e., during stimulation and rest). Compare the activation CNR (for chords and words) before and after this ‘detrending’ operation. Does detrending improve CNR?

# Questions

1. Why does the signal increase when the subject hears the sound (words or chords)?
2. What is the contrast-to-noise ratio of the BOLD measurement for each stimulus? What are some strategies (beside step #12) that you could use to improve this?
3. Studies have shown that speech, like all sounds, is processed by the ‘primary’ auditory cortex, but unlike other stimuli, the information is then fed to a neighboring area farther back (i.e., posterior) in the temporal lobe. Are your measurements of the centers of activation consistent with this model? If the primary auditory area detects the frequency and timing of sounds, what do you think the neighboring area might do? The ‘words’ used in our experiment are comprised of standard English phonemes (i.e., sounds, for example ‘vos’), but have no meaning.
4. [Grad/extra credit] What activation CNR did you measure for each stimulus after removing the linear trend in signal? Did this step improve the CNR? Why does your result make sense?

# Assignment

Create a Word document that includes

1. A figure of an original and smoothed image.
2. A figure showing the ‘word’ correlation coefficient map with your ROIs (use the *line* command to show the border of your region).
3. A figure showing the ‘chord’ correlation coefficient map with your ROIs.
4. Your plots of ROI signal intensity versus time for both stimuli.
5. A figure showing the location of the center of Word and Chord activations in each hemisphere. Display these as dots (or crosses) on a single, unsmoothed image of the brain.
6. [Grad/extra credit] Your plots of ROI signal intensity versus time after trend removal (both stimuli).
7. Your answers to the questions above.
8. Your Matlab code.

Please submit your report (one per group) on Brightspace by Thursday, December 1.