Analysis of FMRI Data: Principles and Practice

Robert W Cox, PhD

Scientific and Statistical Computing Core

National Institute of Mental Health

Bethesda, MD

http://afni.nimh.nih.gov

Principles: Modeling

- Data analysis always takes place in the context of a mathematical model
- Model relates the properties of the system being observed to the numbers that are actually measured
  - Sometimes the model is implicit in the analysis algorithm, rather than being explicitly stated
  - Model also needs to take into account properties of the measurement system
- Models relating FMRI signals to neural changes are complex and tentative

Principles: Data Quality

- FMRI data are crappy:
  - Signal changes with neuronal activation are small (compared to noise), especially away from primary sensory areas
  - Signal is several level of indirection away from neuronal changes of interest
- Numerous other signal fluctuations of non-neural origin have similar or greater magnitude:
  - Ghosting, warping, head movement, scanner imperfections, heartbeat, breathing, long-term drifts, …

Conclusions from Principles

- It is better to explicitly state the mathematical model rather than implicitly rely on an algorithm
- It is a good idea to process FMRI data with more than one model, to see if results change significantly
- It is important to examine the processed data visually at each step in the analysis, to make sure that nothing bad has happened

Practice: Pattern Matching Models

- Looking for temporal (maybe spatial) patterns of signal changes that you expect
  - Based on the external stimulus and/or measured behavior
- Searching low dimensional “space” of pre-determined model to find best fit to data
- Then test fitted model parameters for statistical significance
  - Draw colors on top of significant voxels

Practice: Pattern Hunting Models

- Looking for common temporal (maybe spatial) patterns in the data
  - Fuzzy clustering tries to find voxel time series that "look alike" and then creates clusters of such similar voxels
  - Component analyses (PCA, ICA) try to find a small set of time series that when combined properly, explain "most" of the data in 10,000+ voxel time series
- These analyses are "exploratory" rather than for "hypothesis testing"
  - Difficult to assign statistical significance

Hemodynamic Model

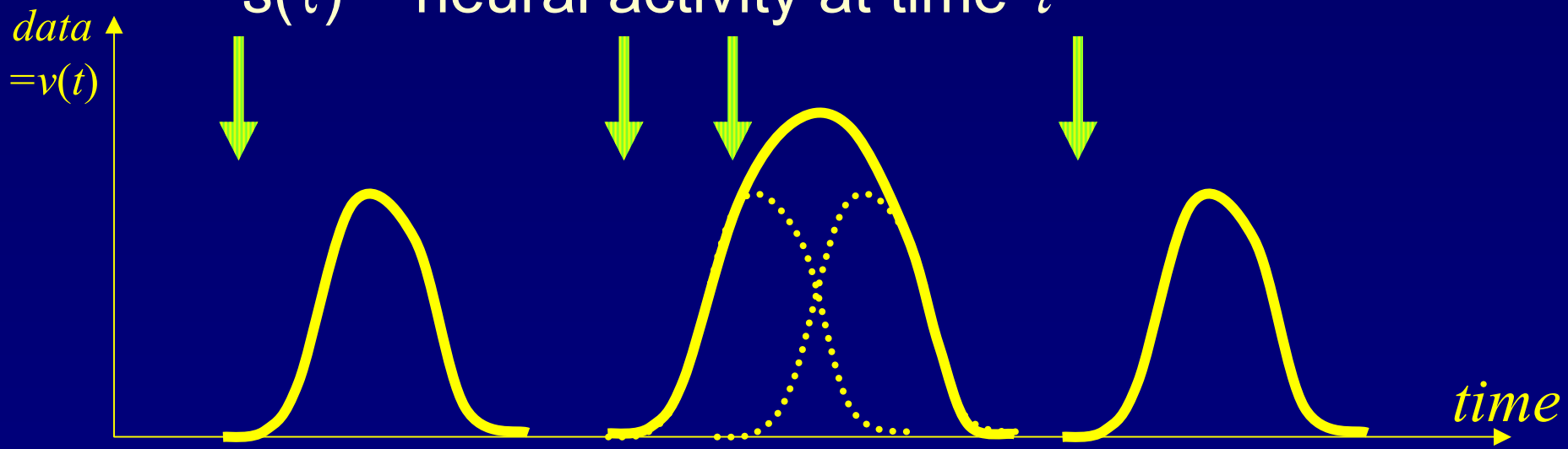
- Measured MRI value in each voxel is sum of:
  - Slowly drifting baseline
  - Hemodynamic response that is linearly proportional to "neural activity", delayed and blurred in time
  - Non-neural physiological "noise" due to respiration and blood flow pulsations through the cardiac cycle
  - White noise from random (thermal) currents in the body and the scanner
- Imaging is assumed perfect
  - Or at least is fixed up in preprocessing steps

Hemodynamic Equation

- Linear shift-invariant model for single voxel time series:

$$\text{data} = v(t) = \text{baseline}(t) + \sum_{\tau=0}^{t} h(t-\tau)s(\tau) + \text{noise}(t)$$

  - $h(t)$ = hemodynamic response at time t after neural activity
  - $s(\tau)$ = neural activity at time τ



Ways to Use This Model

- Assume $s(t)$ is known, and then
  - Assume $h(t)$ is known except for amplitude $\Rightarrow$ correlation method
  - Assume shape of $h(t)$ is also unknown $\Rightarrow$ deconvolution method
  - Assume several different classes of $s(t)$'s and correspondingly several different $h(t)$'s $\Rightarrow$ generic linear model
- Assume $h(t)$ is known, and find $s(t)$

  $\Rightarrow$ Wiener deconvolution
- Try to find both $h(t)$ and $s(t)$

  $\Rightarrow$ blind deconvolution

Further Considerations

- How many parameters to allow in unknown $h(t)$ depends on imaging TR, expected duration of response, and stimulus timing [event-related or blocked]
- Appropriate baseline model depends on duration of imaging run
  - May also include movement parameters
- Noise models can be simple or complicated:
  - Gaussian white noise
  - Gaussian colored noise [correlated in time]
  - Spatially correlated noise

Software Tools

- What package to use?
  - Sociological answer: the one your neighbors are using (so you can ask them for help)
- SPM: most widely used at present
- *AFNI*: flexible, customizable
  - and has the coolest logo

- FSL: newish package from Oxford
- Numerous other good packages out there
- Commercial products: MedX, Brain Voyager