INTERNATIONAL SOCIETY FOR
ISMRM
MAGNETIC RESONANCE IN MEDICINE

DECLARATION OF CONFLICT OF INTEREST OR RELATIONSHIP

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I have no conflicts of interest to disclose with regard to the subject matter of this presentation.

Toronto!

Artifacts in fMRI

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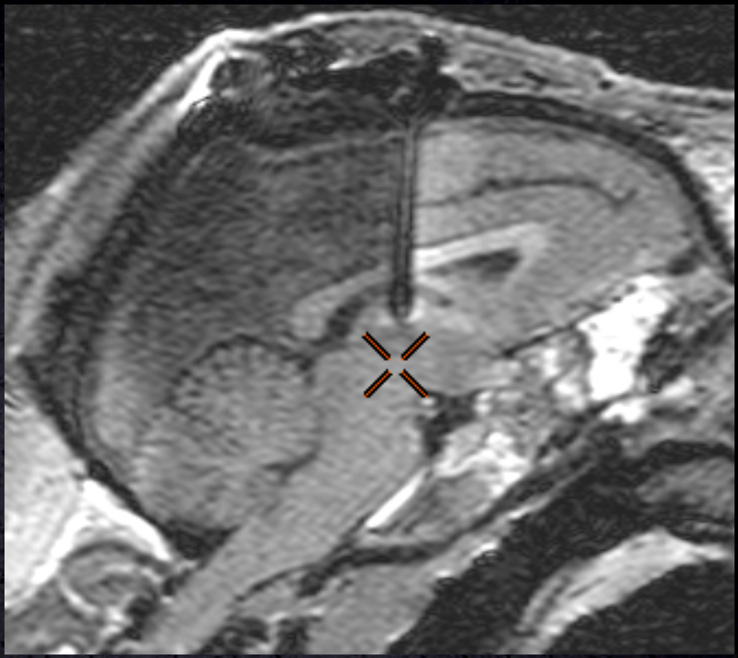
THE UNIVERSITY of WISCONSIN MADISON

What I can tell you about:

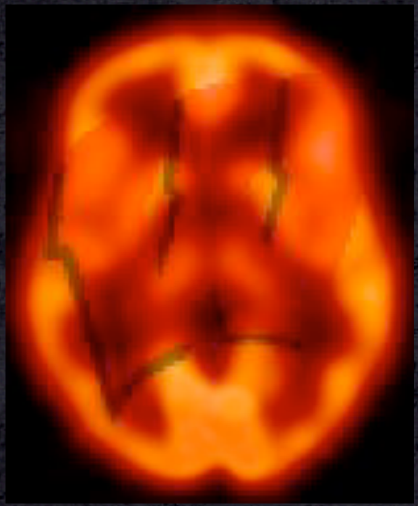
- PET imaging
- Radionuclide production
- PET data analysis
- fMRI data analysis
- Coregistration
- Morphometry measures



Not so much:
MRI physics, pulse sequences, data acquisition

What is an Artifact?

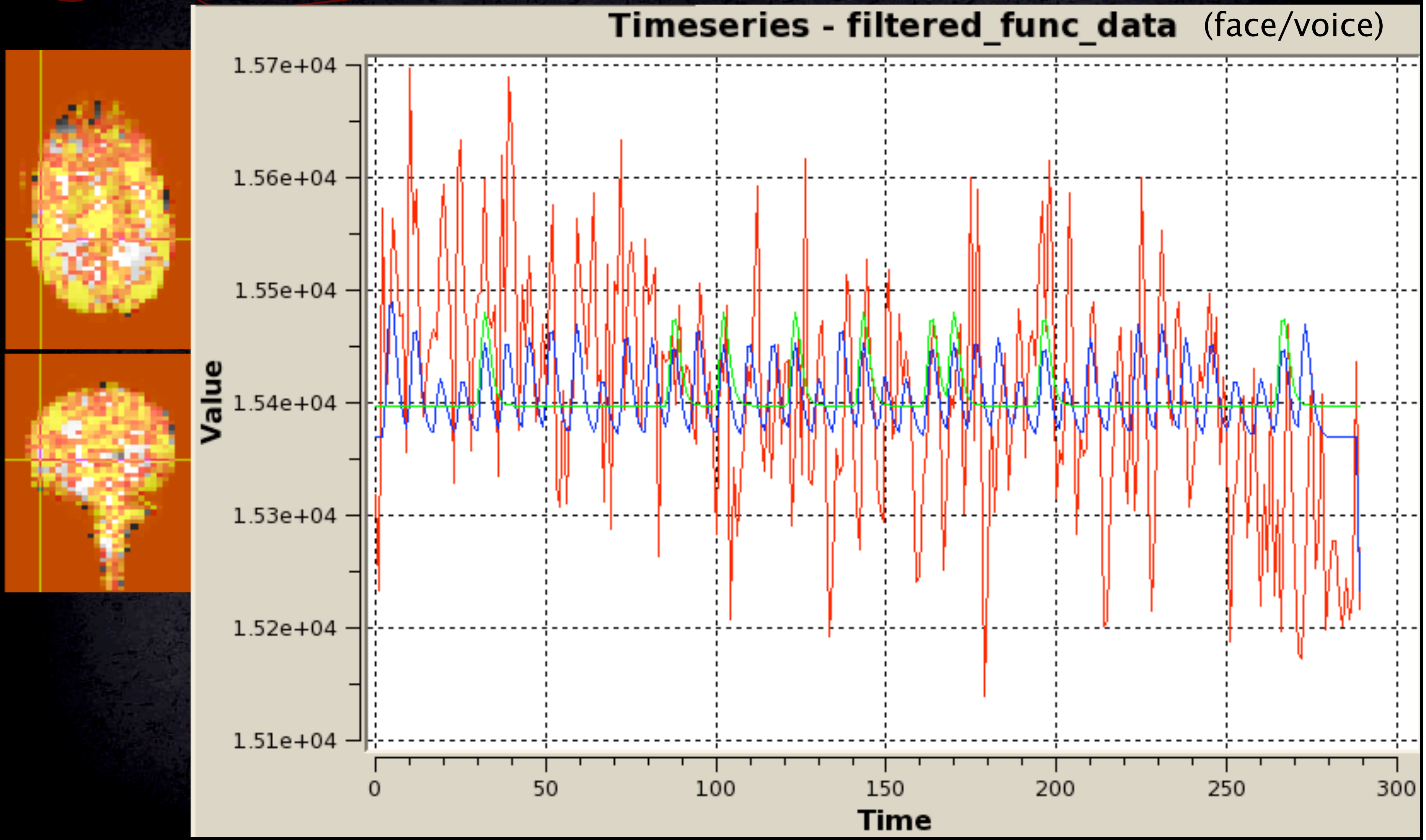
To neuroscientists, this brain looks funny.



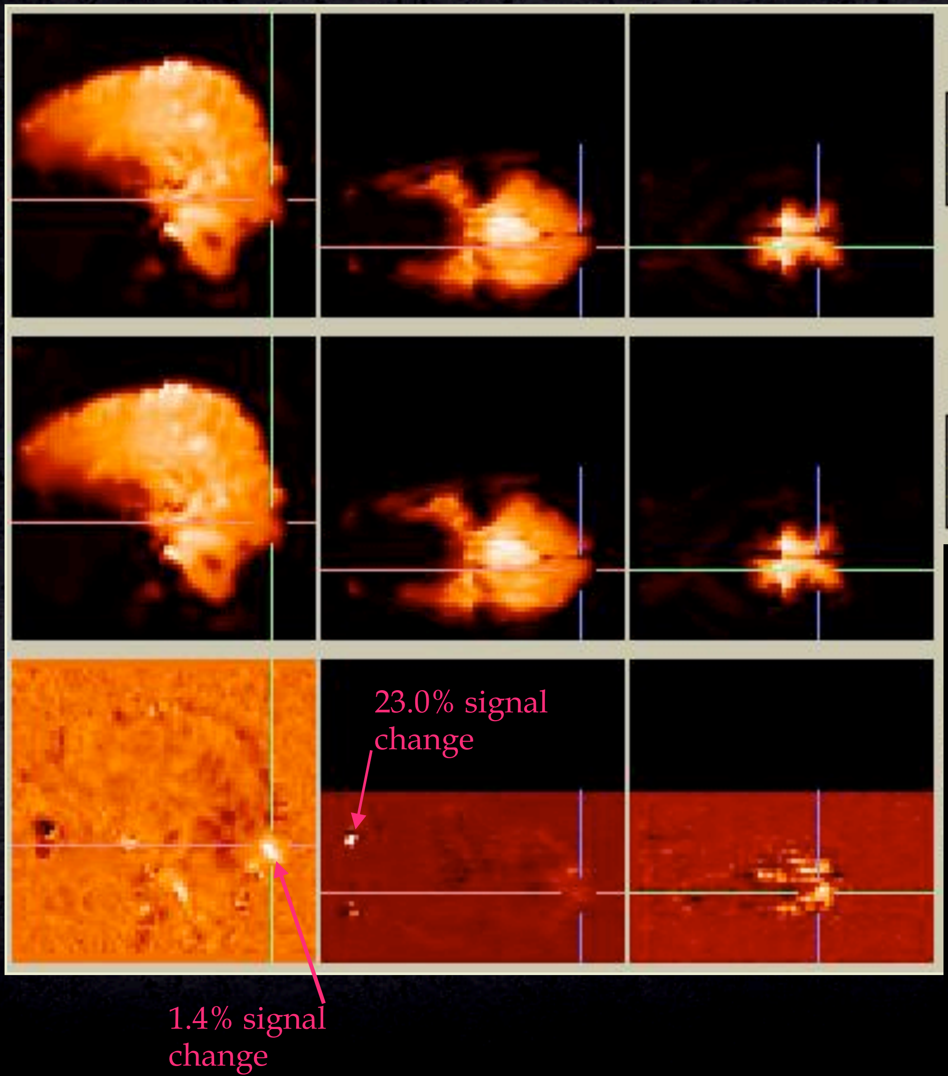
To Wisconsin Badger fans, the brain obscures the logo.

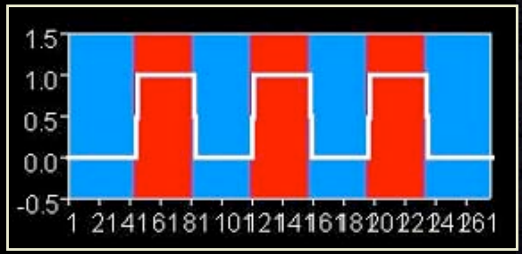
An artifact is anything that prevents you from seeing what you want to see.

What is the Signal?

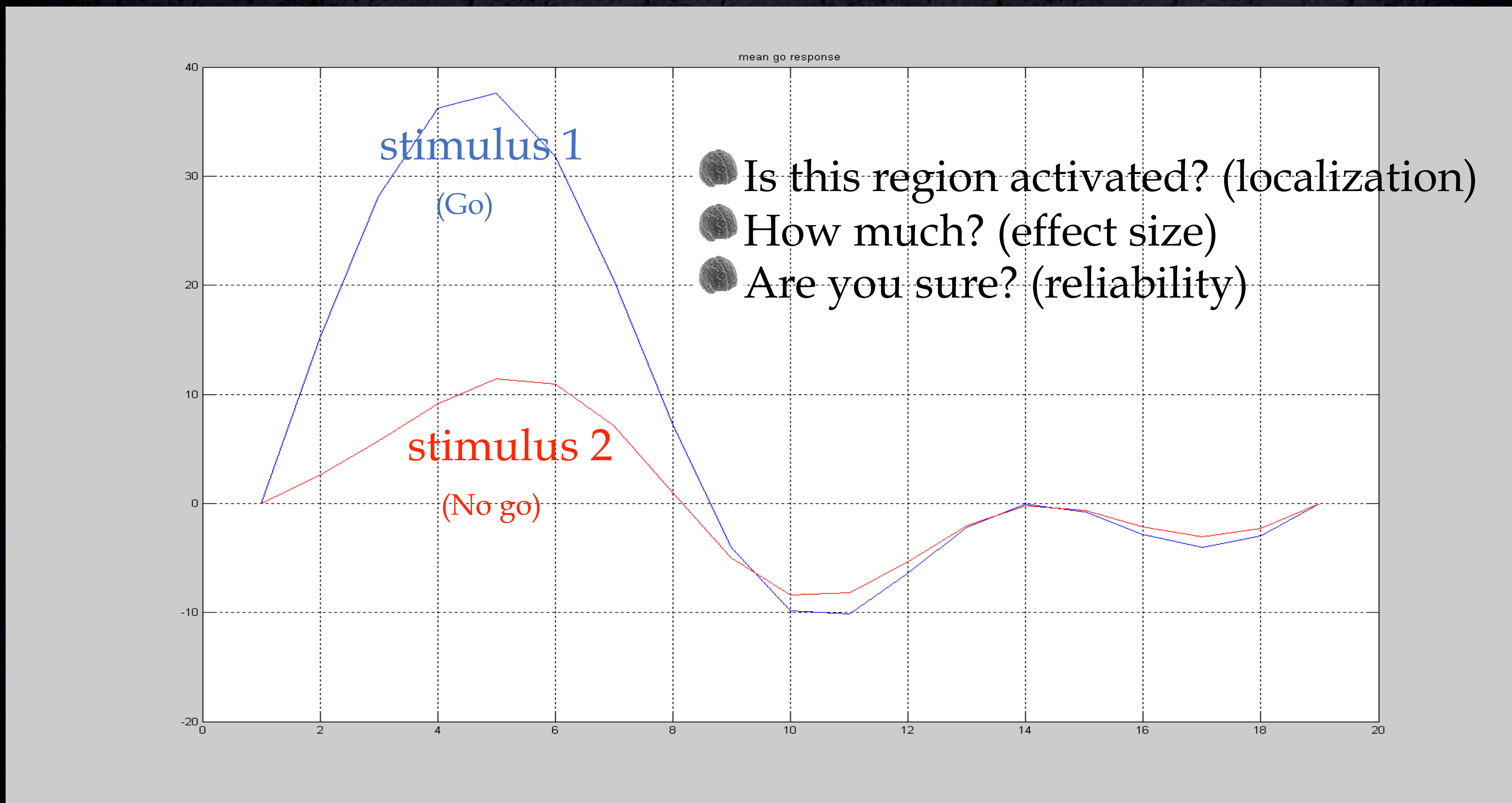


What is the goal?





Big-picture goal

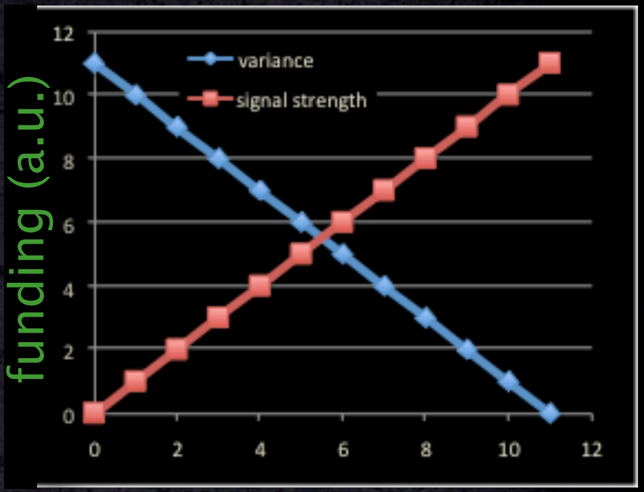


Artifact Sources

$$t = \frac{\text{effect}}{\text{variance}}$$

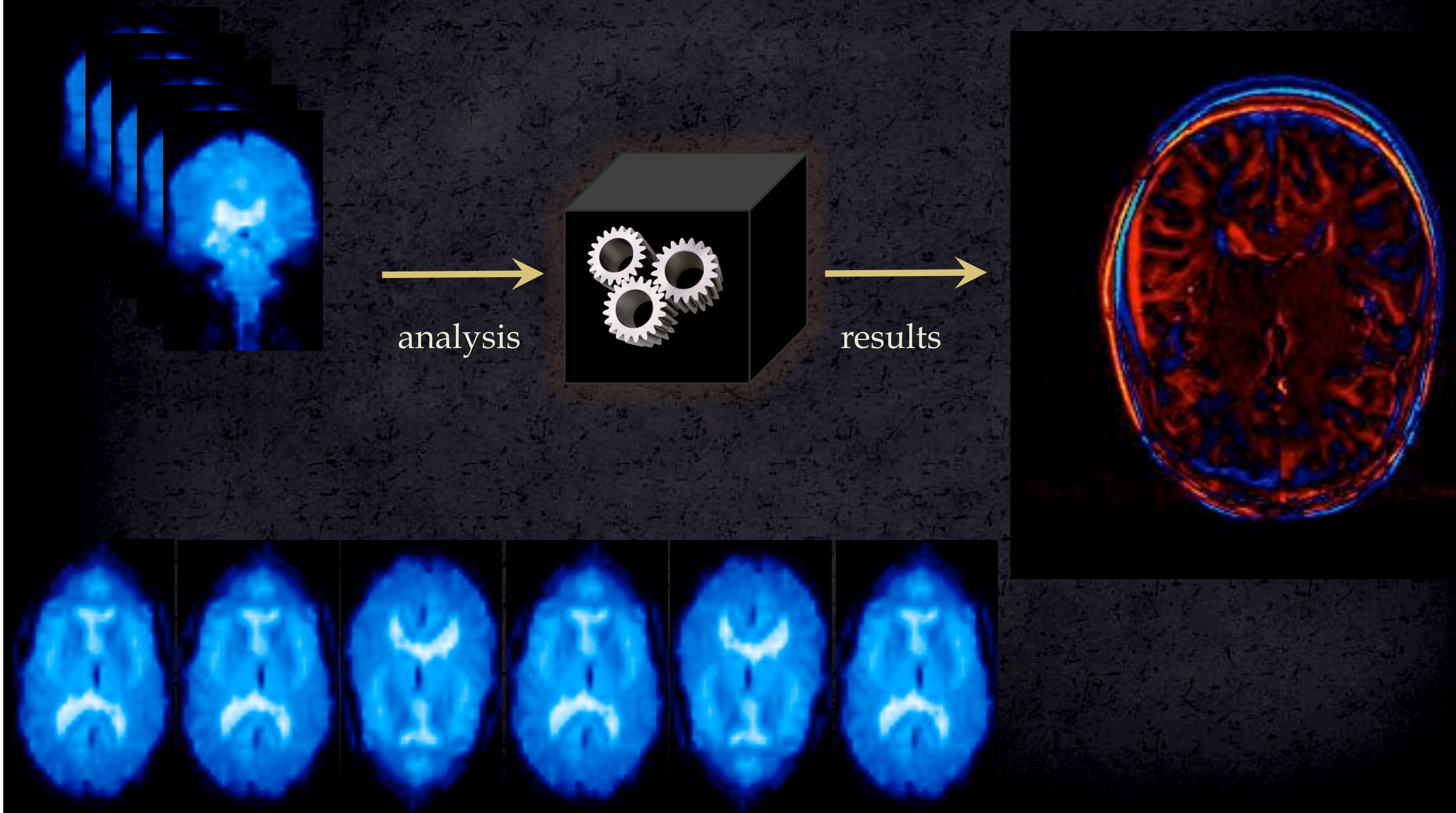
- Physiological
  - cardiac, respiratory motion
  - subject movement
  - poor intersubject alignment
  - B-field susceptibility (dropout)
  - foreign objects
- Scanner
  - SNR
  - B-field inhomogeneity
  - detector coil sensitivity
  - reconstruction tradeoffs
  - slice-timing (2D) effects

A Scientific Experiment



- Before
  - measure twice, cut once
- During
  - look at your data. with your eyes.
- After
  - pre-processing: modeling and removing variance
  - data analysis: modeling and discovering signal

The single biggest artifact source



Being Clever Ahead of TIme

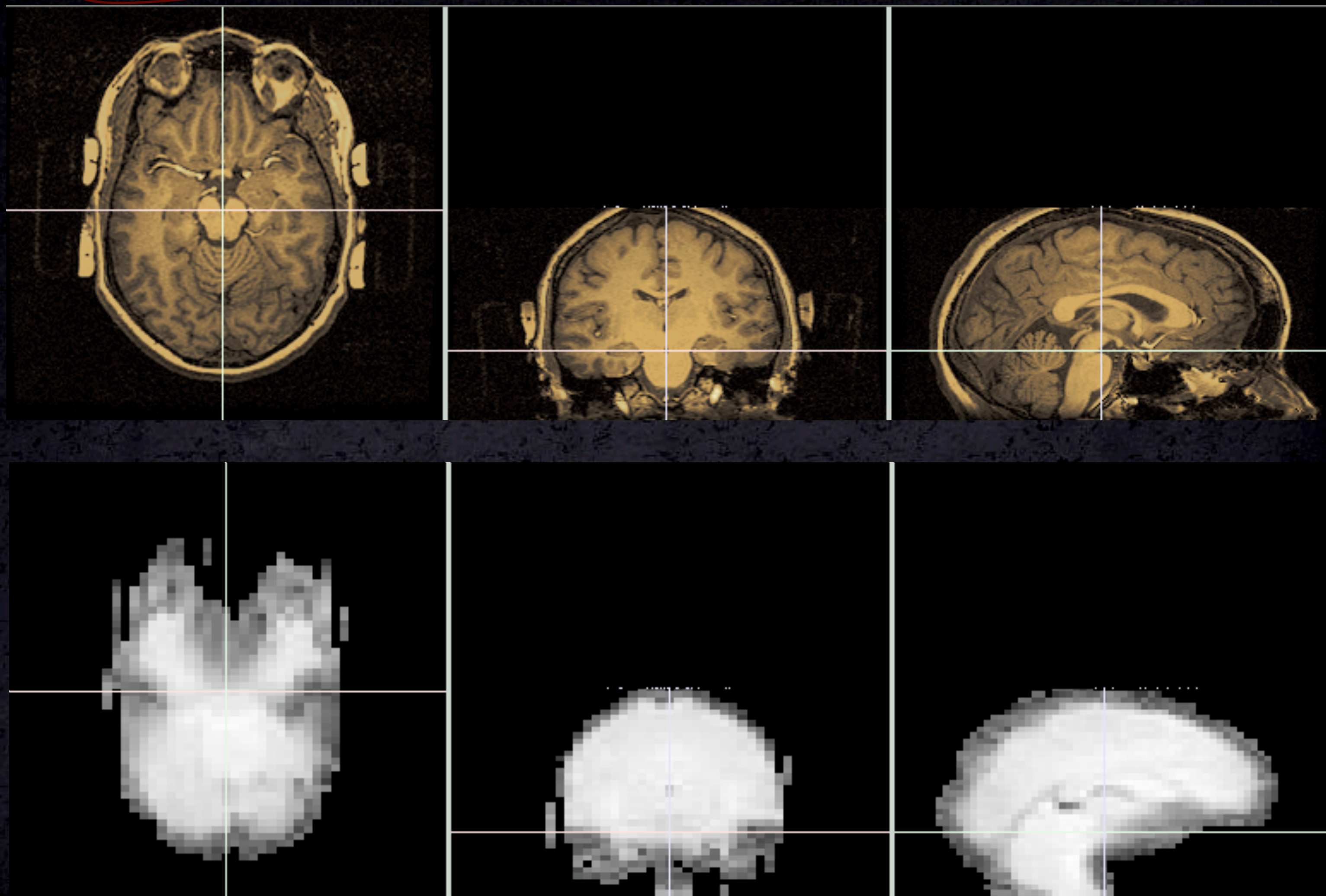
- Before
  - Learn a package
    - provides an orderly introduction to analysis.
  - Software programming skills
  - File format conversion
  - Experimental paradigm
    - event-related paradigms can isolate stimulus, HR
  - Acquisition sequence
  - Collect enough data
    - multispectral anatomicals (T1, T2, PD, ...)
    - field map
    - physiological (cardiac, respiratory, skin conductance, eye tracking)
    - estimator for HRF (e.g. motor response)

Post-hoc Corrections

- Some folks call it image processing...
  - spatial registration
  - field map correction
  - slice time correction
  - motion correction
  - smoothing- spatial, temporal

- These corrections are ignorant of the experimental model.

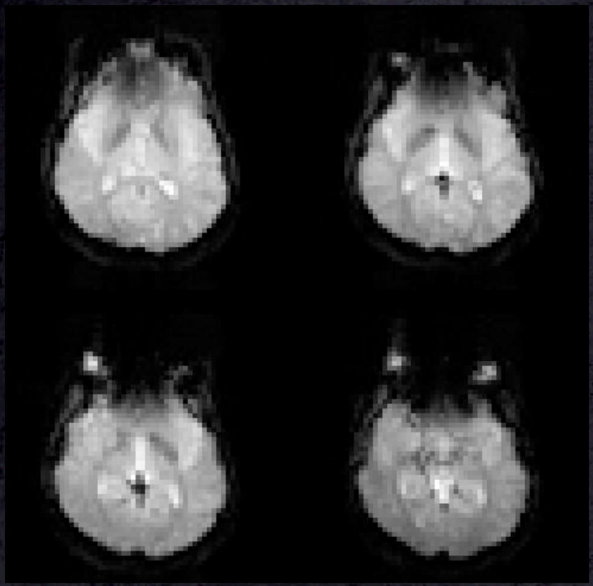
EPI Dropout (susceptibility) artifact

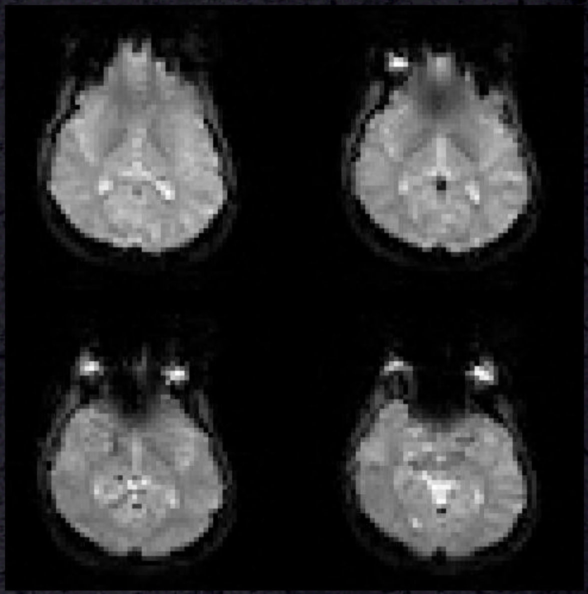


phase dispersion => signal loss

EPI susceptibility artifact

clever ahead of time: optimize acquisition parameters

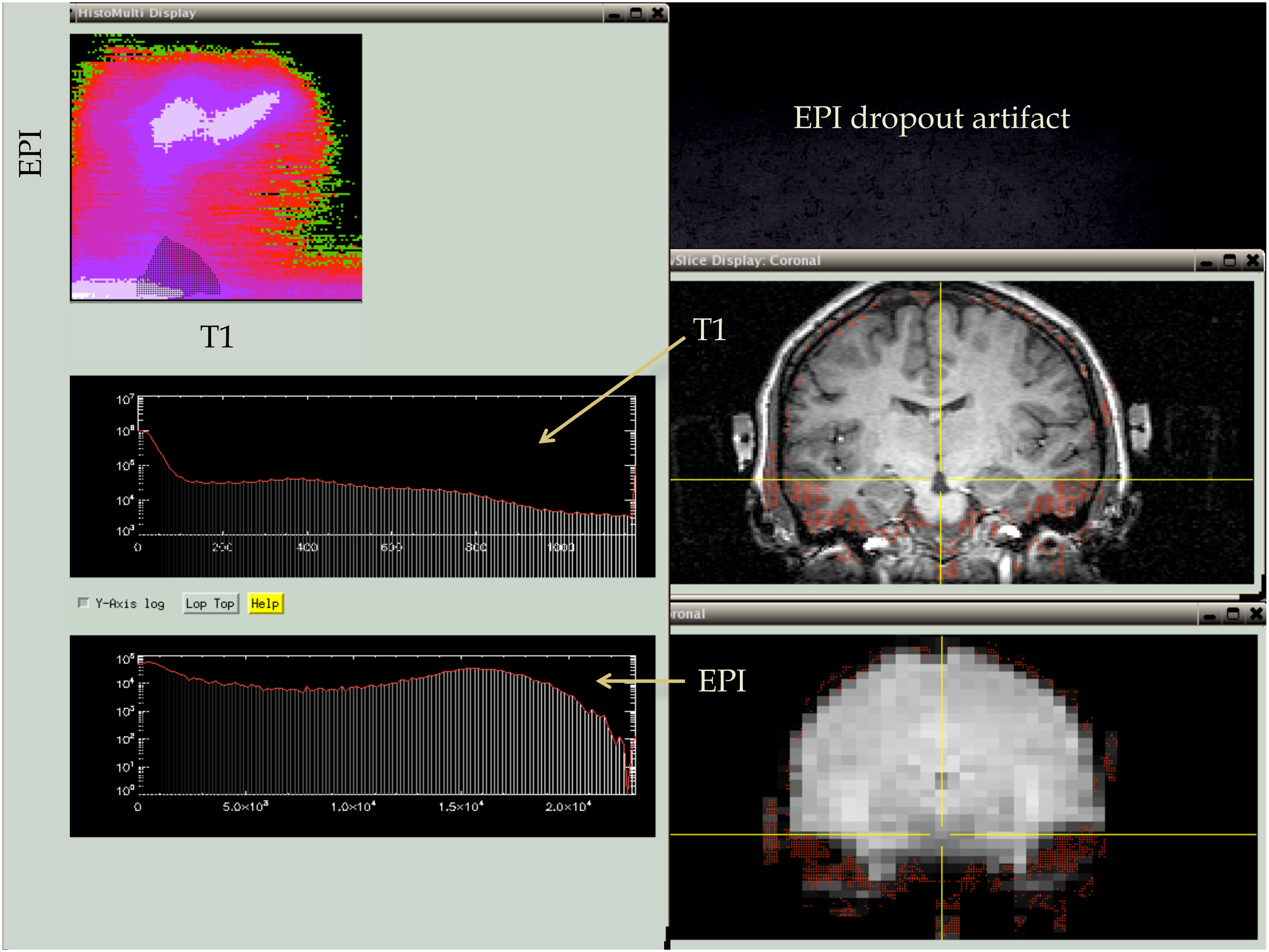




TE = 30 ms
4mm thick slices

TE = 20 ms
2mm thick slices

courtesy of Andy Alexander


EPI dropout artifact
HistoMulti Display
EPI
T1
Y-Axis log
Lop Top
Help
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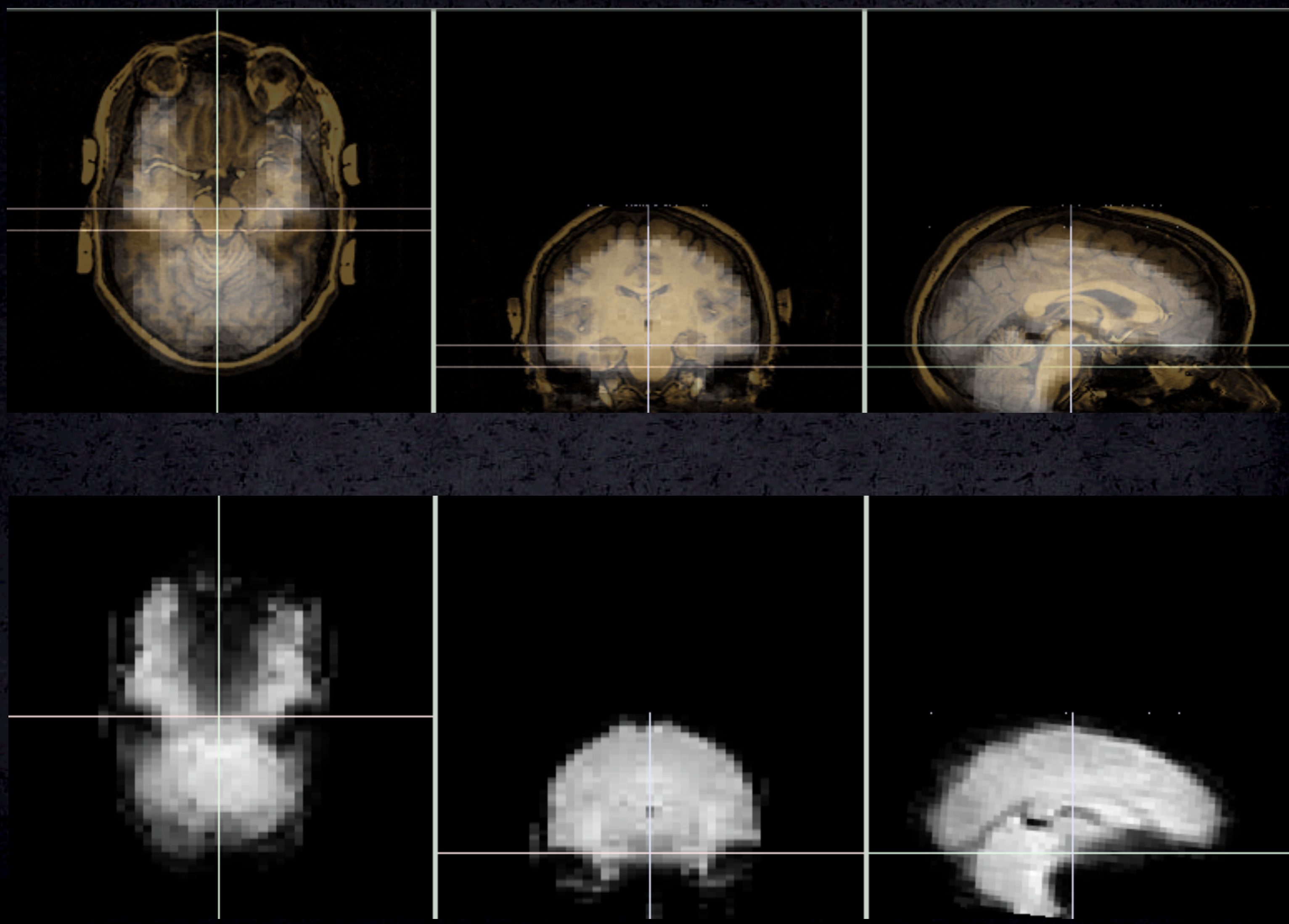
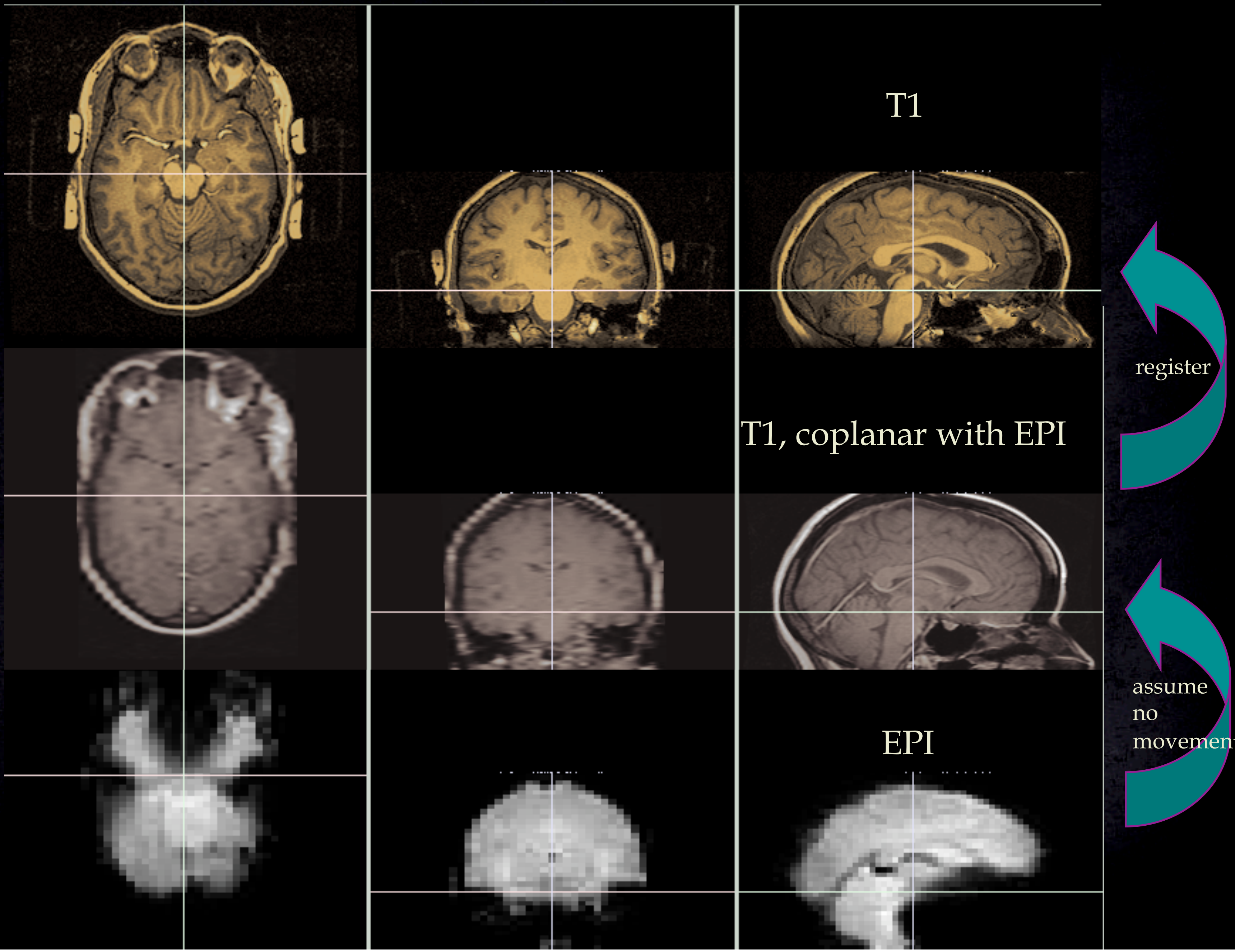
5.0×10³
1.0×10⁴
1.5×10⁴
2.0×10⁴

EPI registration - tread carefully

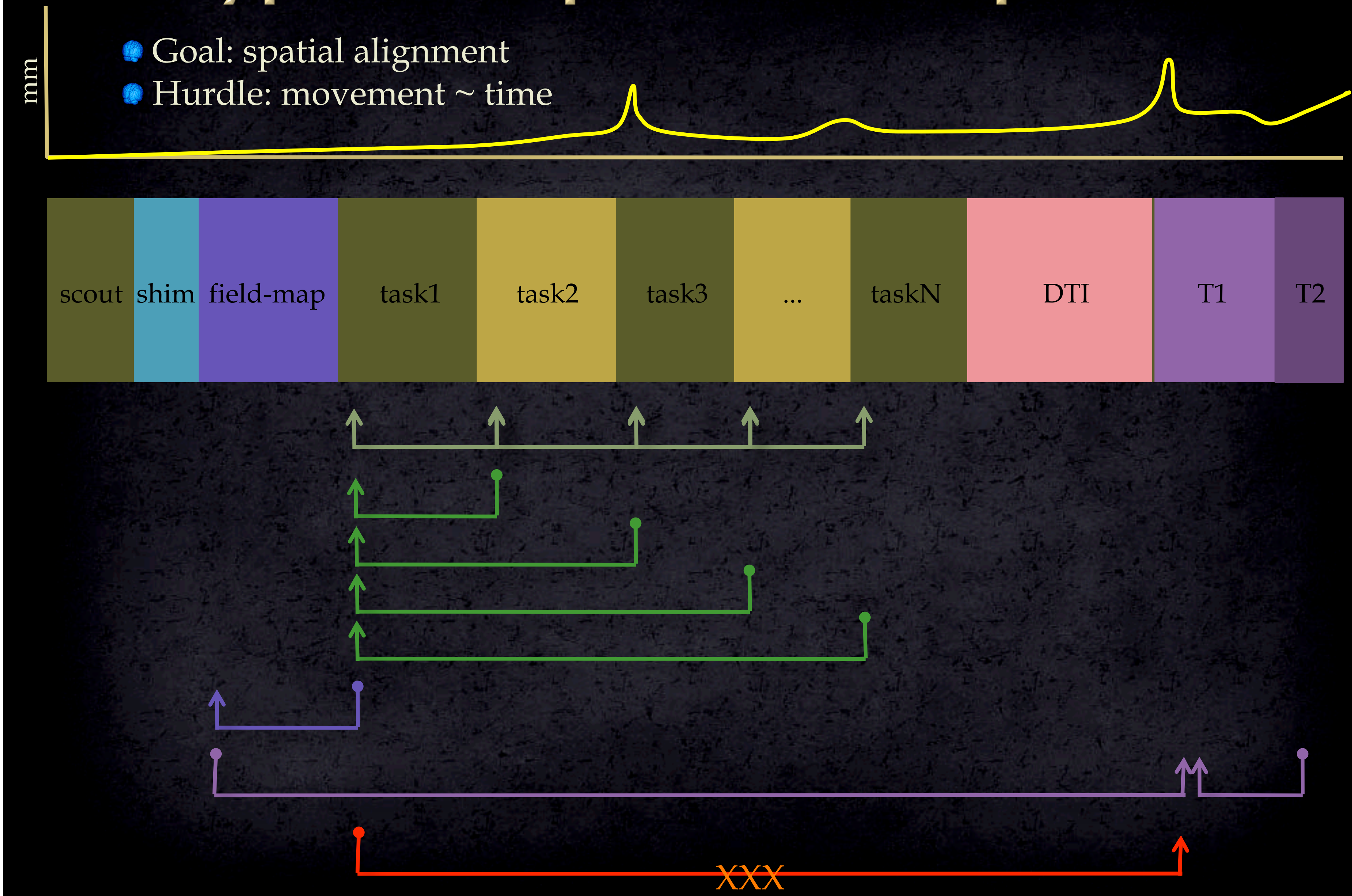


EPI registration: indirect approach

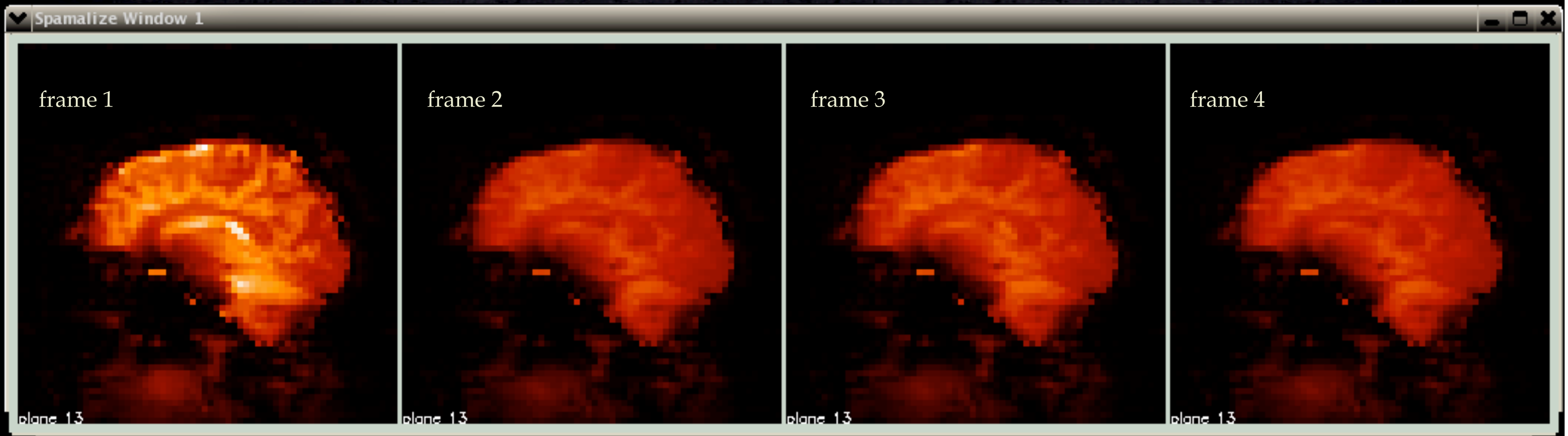


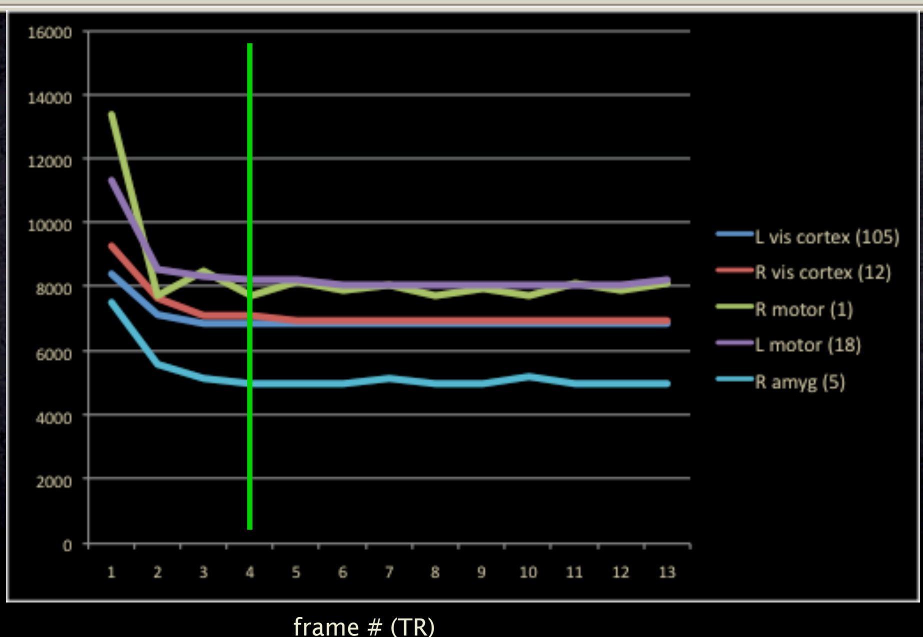
Typical acquisition sequence

- Goal: spatial alignment
- Hurdle: movement ~ time



Off to a bad start





Remove first 3-5 frames:

- delete from series

or

- mark via GLM software

or

- assign to a unique condition

Field Map Correction

- The magnetic field is not uniform, leading to misplaced signal, since recording/reconstruction assumes a uniform gradient.
- 3T => worse

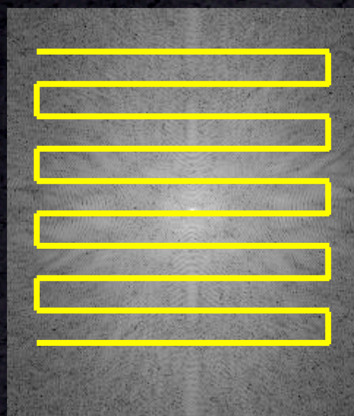
- Nonuniformities are object-dependent.
- Largest source of B_0 inhomogeneity:
  air-tissue interfaces => susceptibility differences

- Different acquisition sequences may have different affect.
  - EPI data (Gradient Echo) most affected (fMRI, DTI)
  - Spin Echo affected little

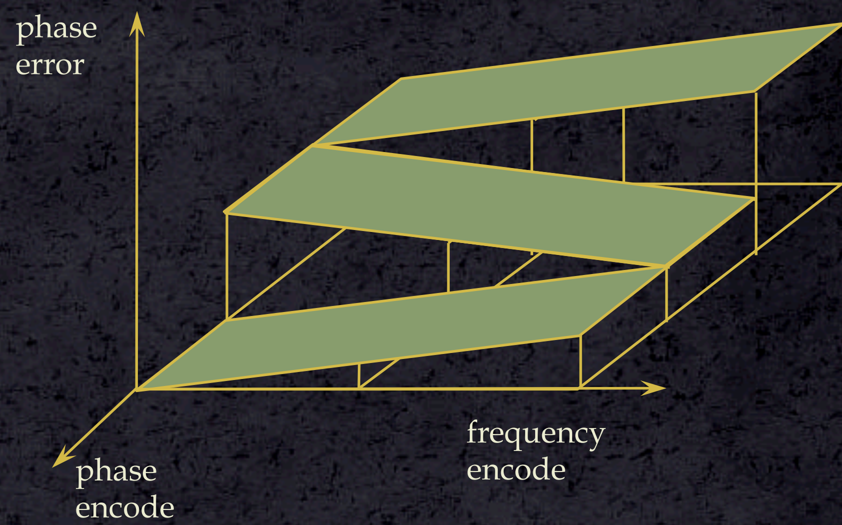
- Luckily, this can be modeled and corrected...
  - But, a seperate measurement is required.
  - 2 scans with different TEs (e.g. 8, 11 msec), minimal distortion.

B-Field Distortion

The Cause: EPI Phase Error Accumulation



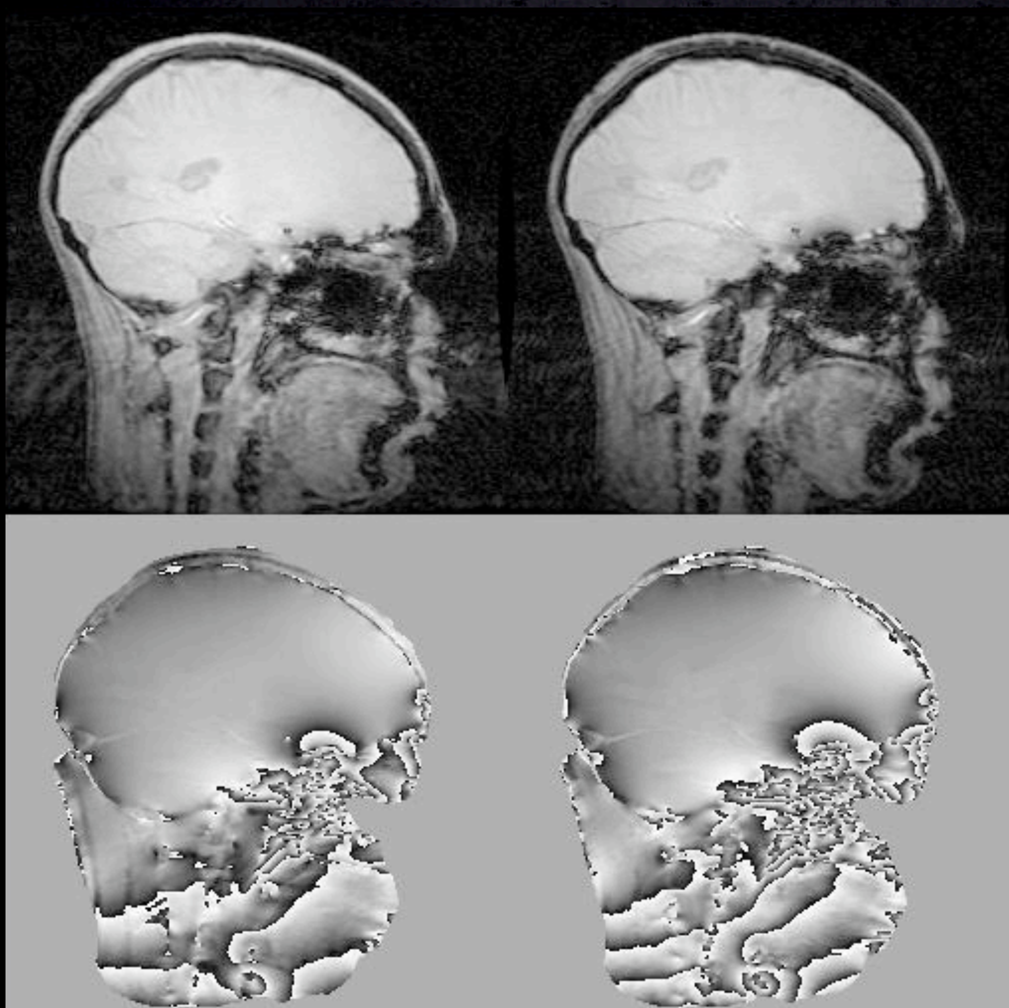
k-space



- For a linear field offset, phase error accumulates linearly.
- Cummulative phase errors cause a shift in position

courtesy of John Ollinger, Andy Alexander

Distortion (Fieldmap) Correction



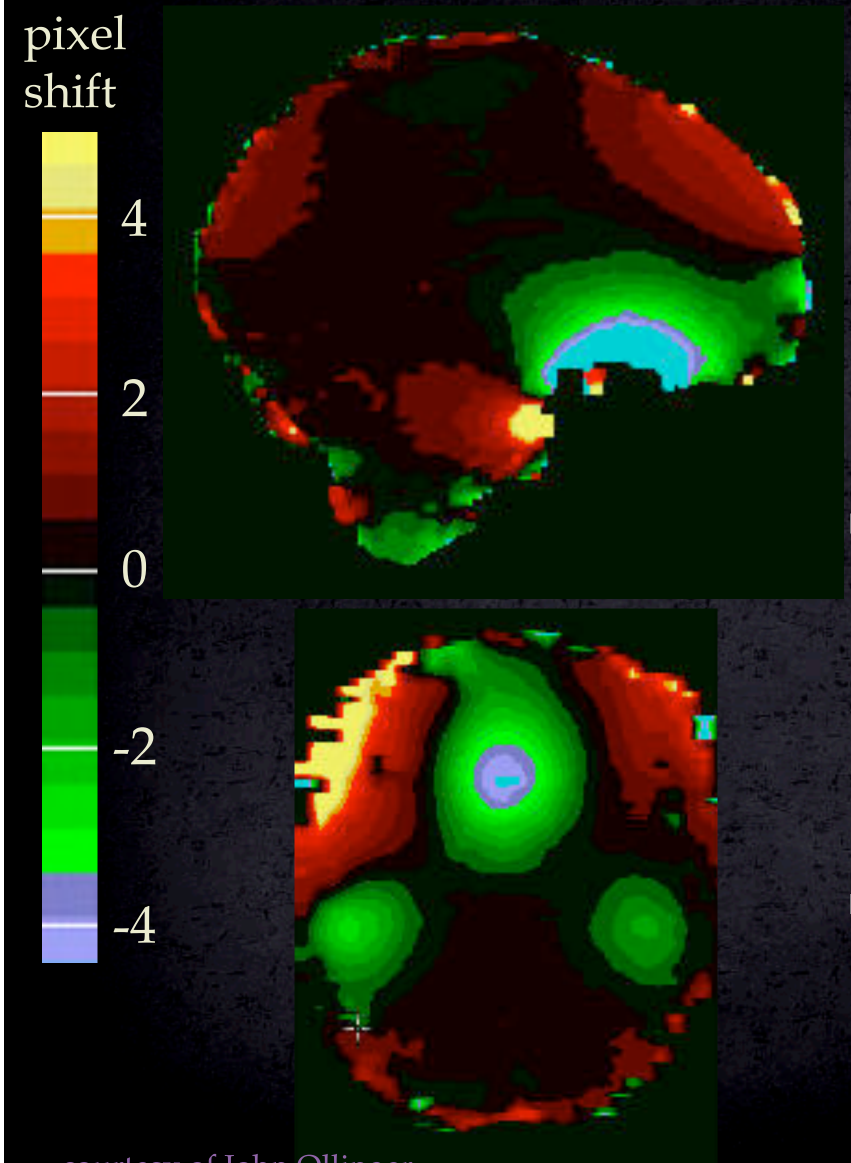
TE=7ms TE=10ms

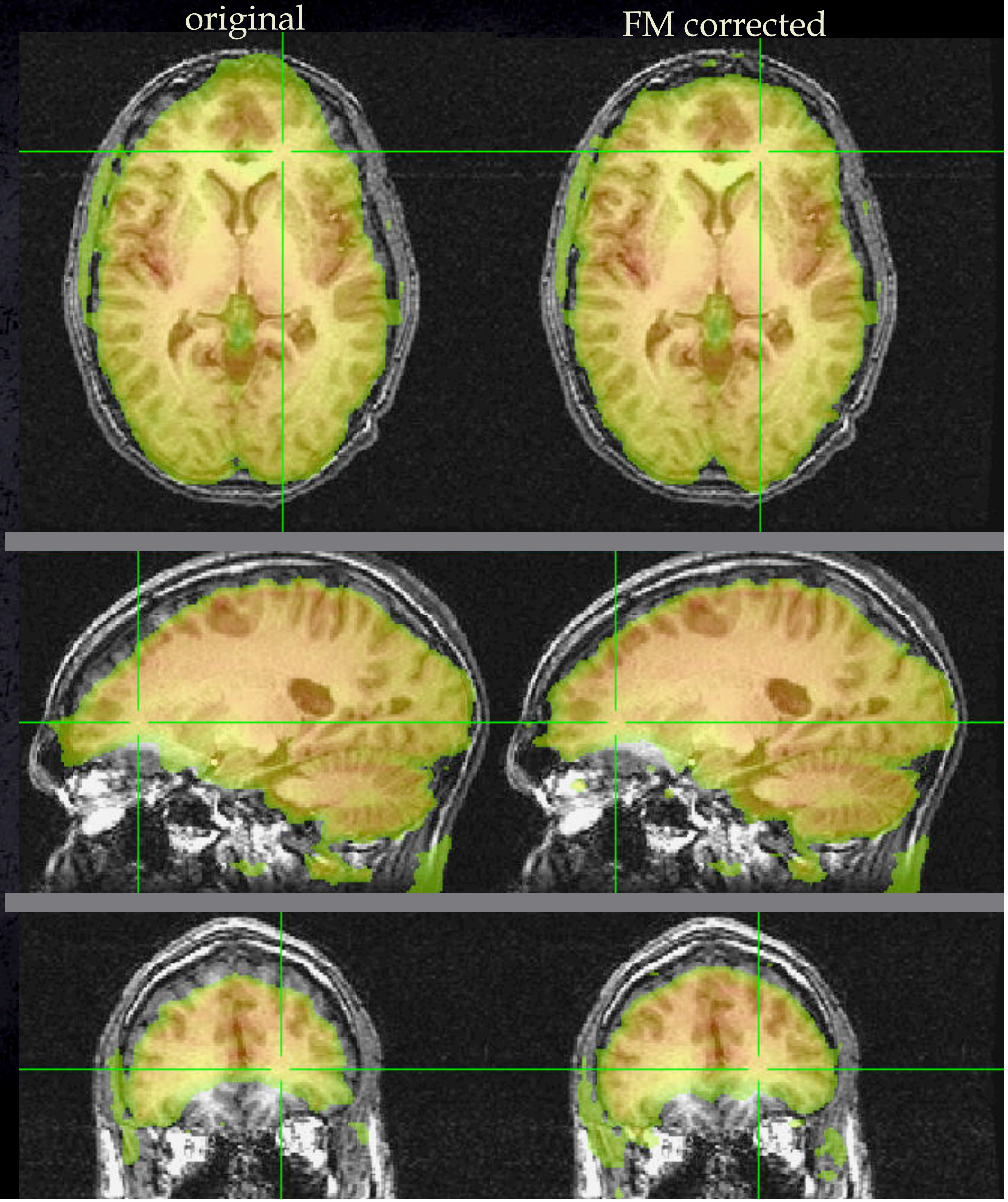
- Strategy: Collect two gradient echo images at short but different echo times.
- Unwrap the phase.
- Phase-difference proportional to the pixel-offset along the phase-encode axis.
- Resample the EPI image to correct for the offset.

Peter Jezzard and Stuart Clare, "Sources of distortion in functional MRI data", *Human Brain Mapping*, 8:80-85, 1995.

courtesy of John Ollinger

Field Map Correction





courtesy of John Ollinger

Field Map Correction

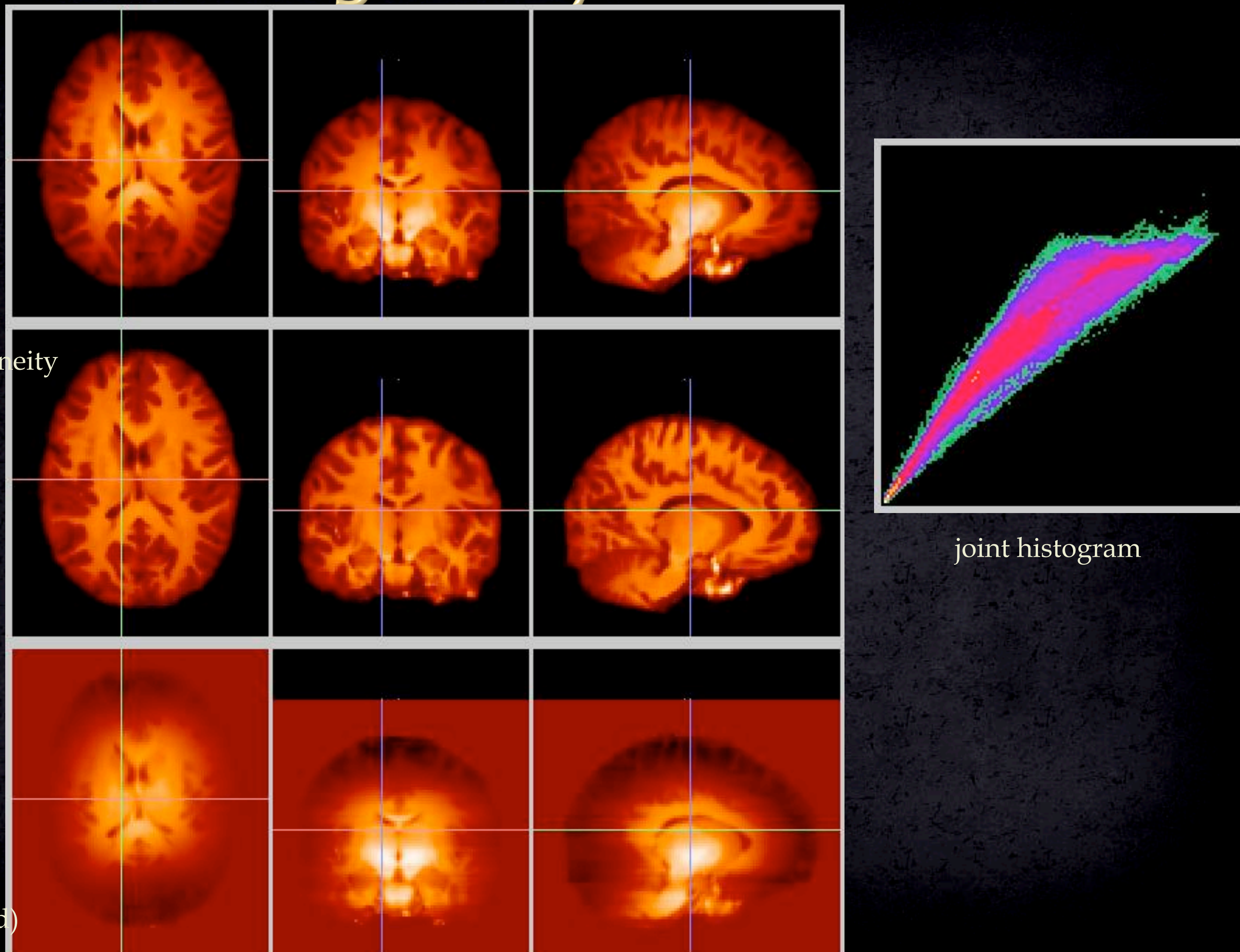
- Magnitude of correction depends on the magnitude of the susceptibility artifact, which depends on the size of the sinuses.
    - Larger in men than women.
    - Larger in adults than children

- Although the magnitude of the correction is often small, it can reduce confounds between gender, age and susceptibility.

- It cannot recover missing data from the dropout region.

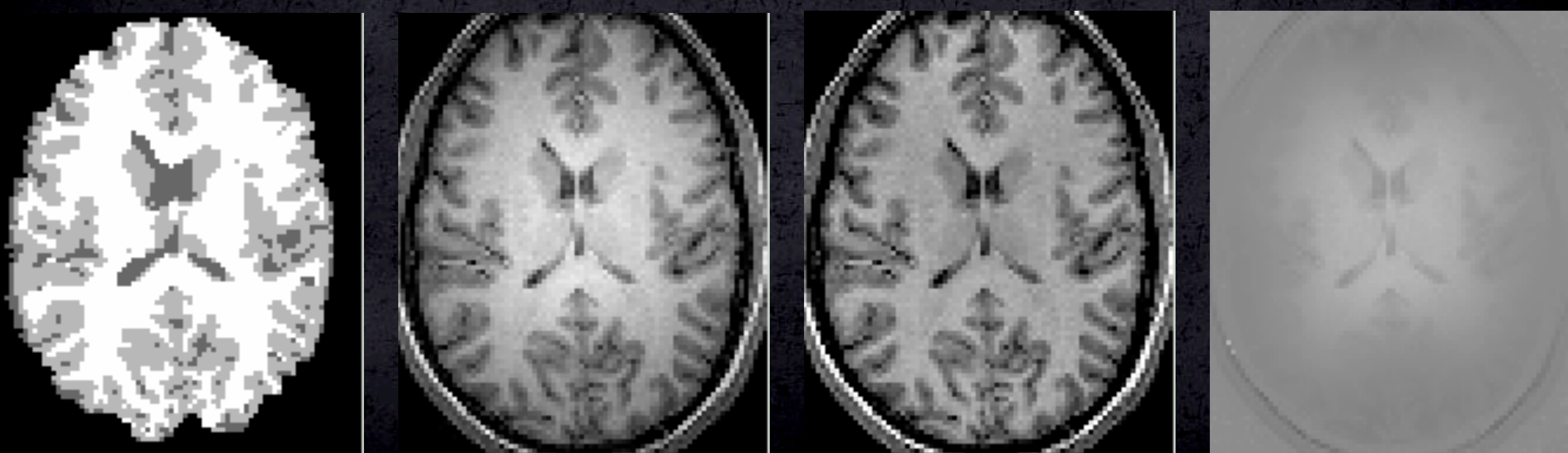
courtesy of John Ollinger

Inhomogeneity Correction

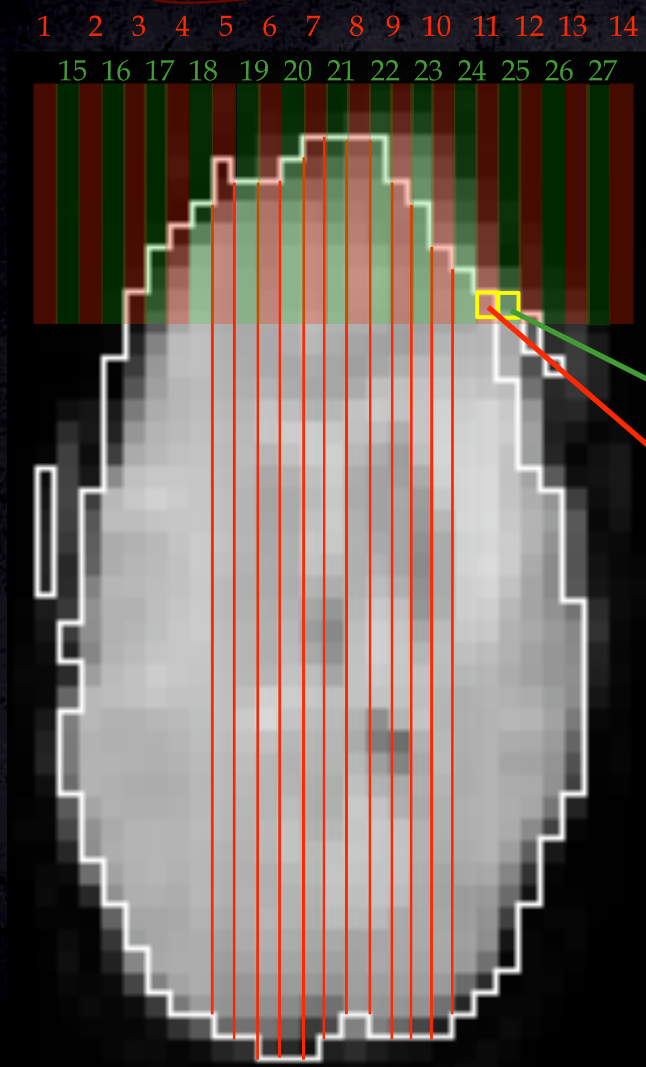


Inhomogeneity Correction

- Increase gradient magnetic field strength.
- Decrease echo time.
- Smaller pixels (better resolution).
- Phase encoding.
- Postprocessing.

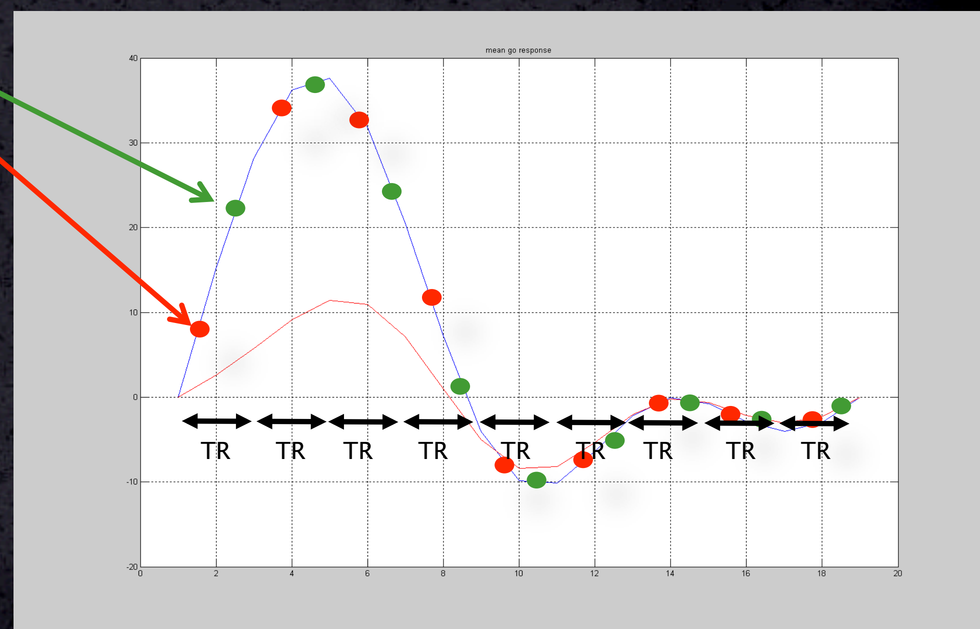


Slice-time Correction



Make all slices appear to have been acquired at the same time.

A "reference" HRF should look the same in all slices.

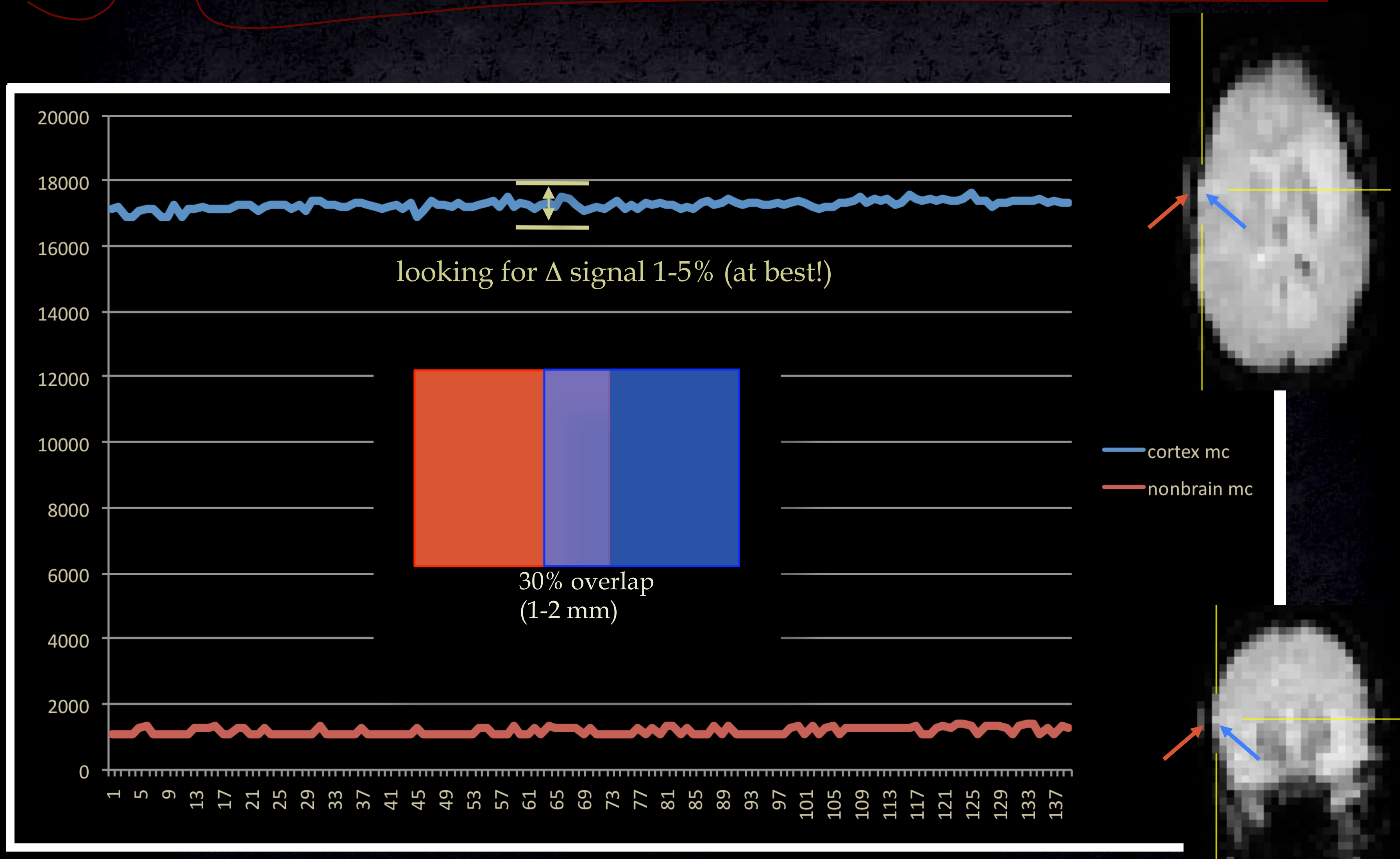


More important for longer TR.
Usually best prior to motion correction.

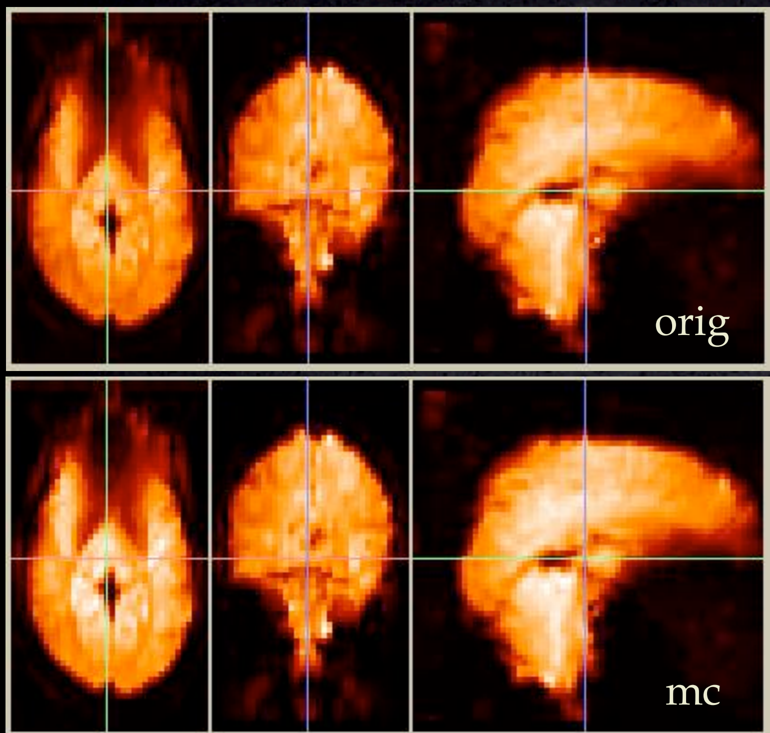
Motion Artifacts

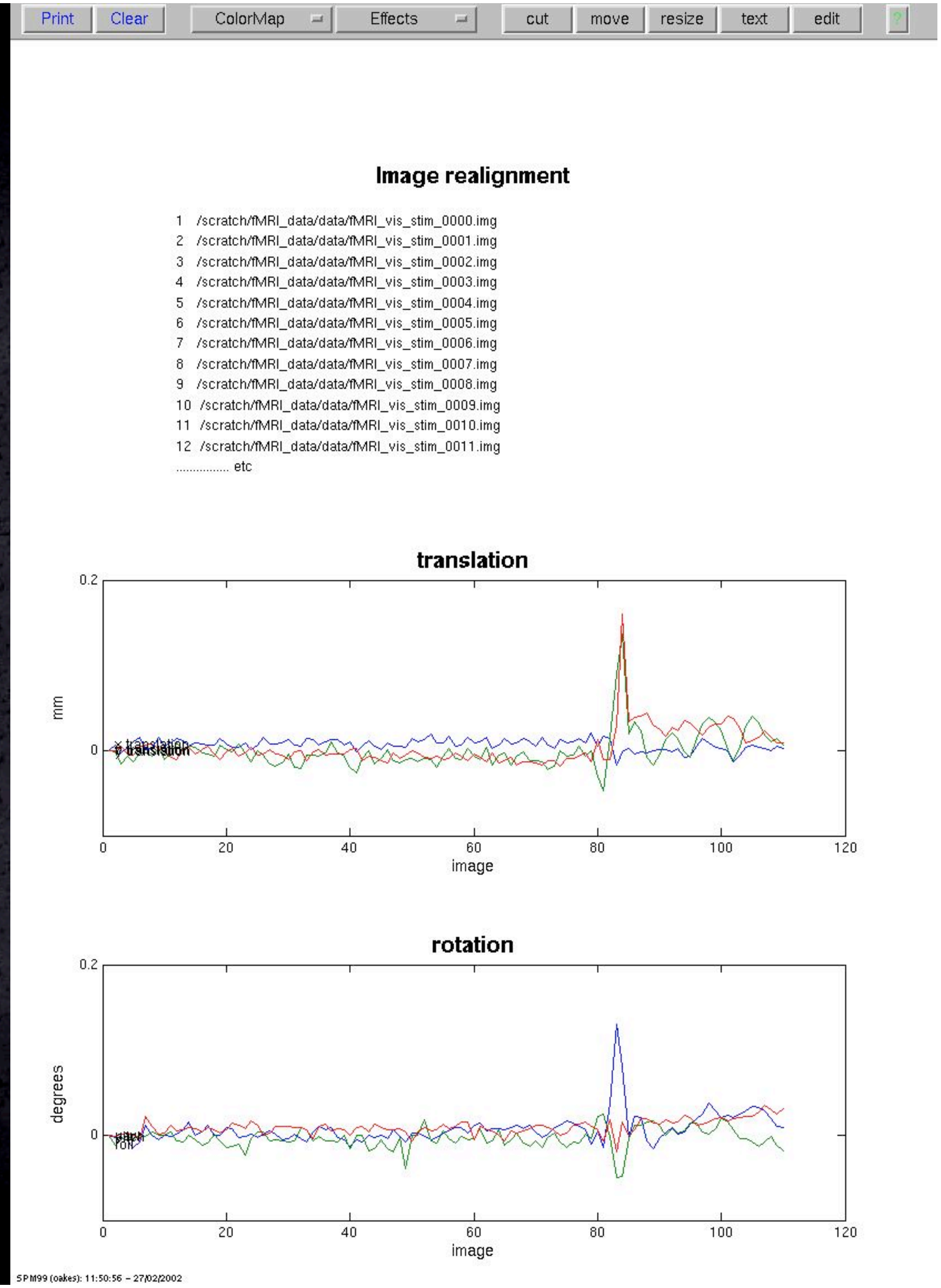
- Sources
  - Subject motion
  - Peripheral movement (changes B-field)
  - Respiration, cardiac
- Magnitude / Importance
  - a significant fraction of the fMRI signal!
- Model
  - framewise 3D volumetric
    - rigid body (translation, rotation)
    - ignores intraframe motion
  - assumes only small movement
- Correlation between motion, stimulus
  - correcting motion can attenuate activation signal
  - motion estimates can be incorporated into GLM

Motion Correction: Magnitude

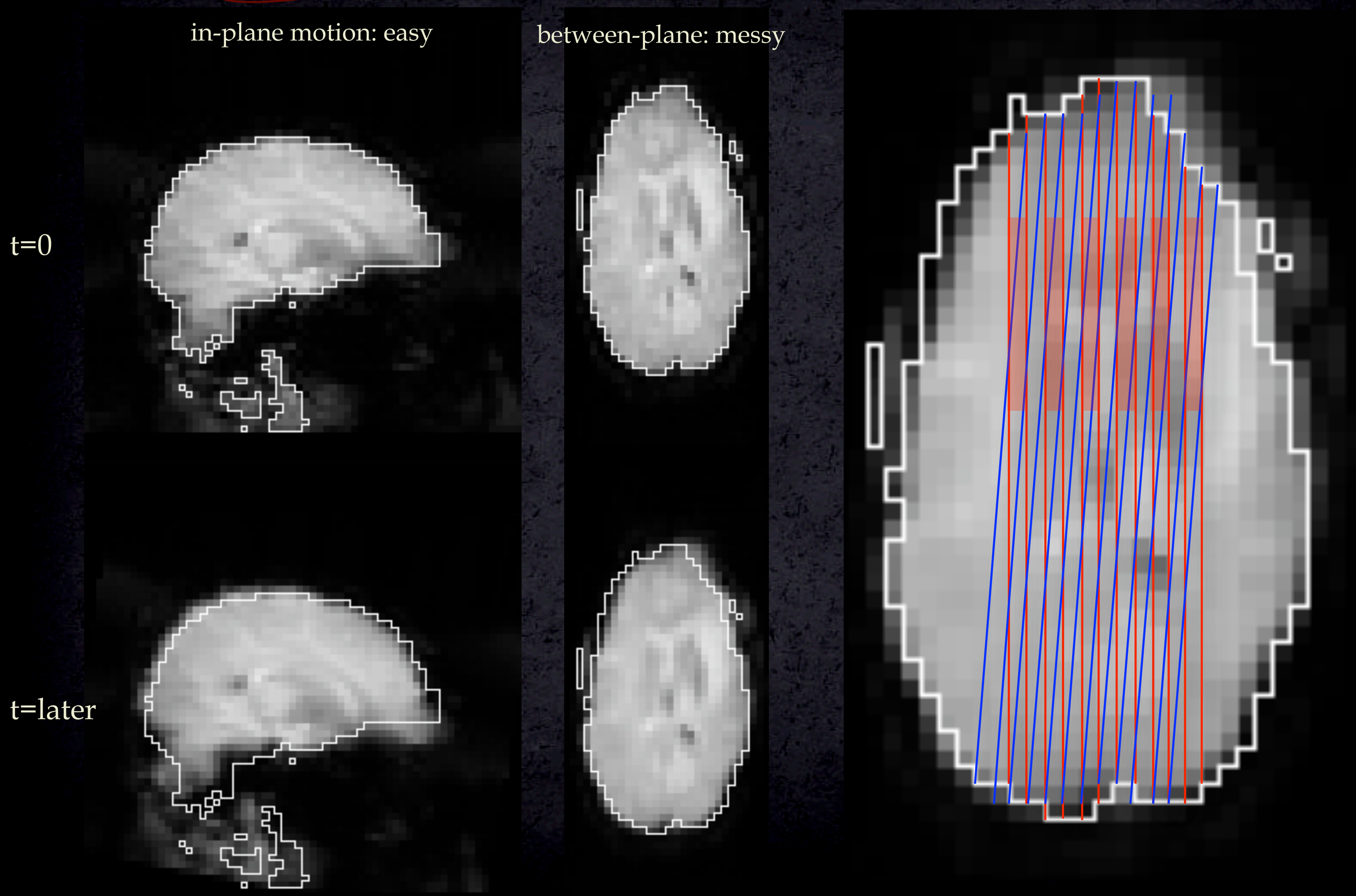


Motion Correction

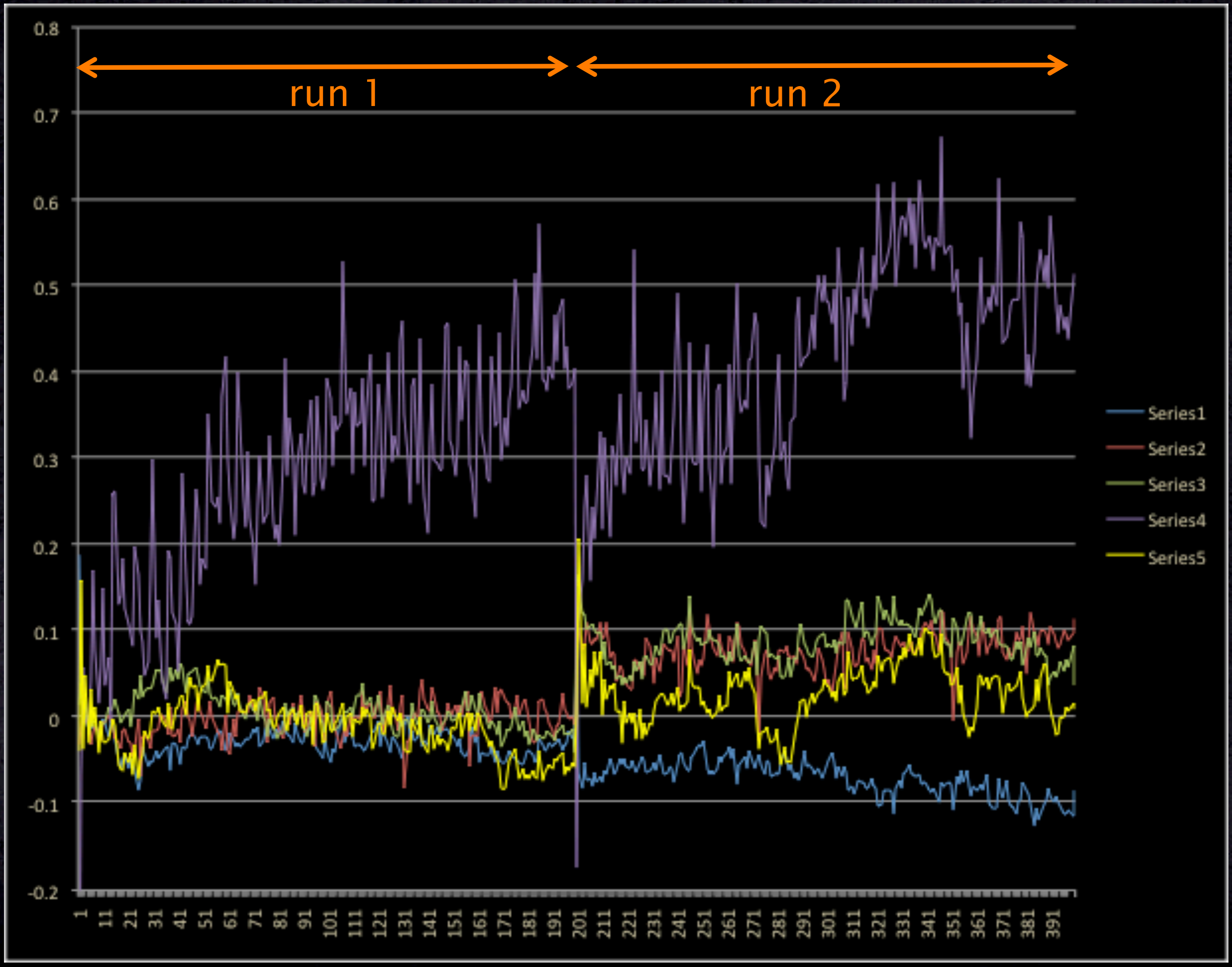




Motion Correction: Subject Motion

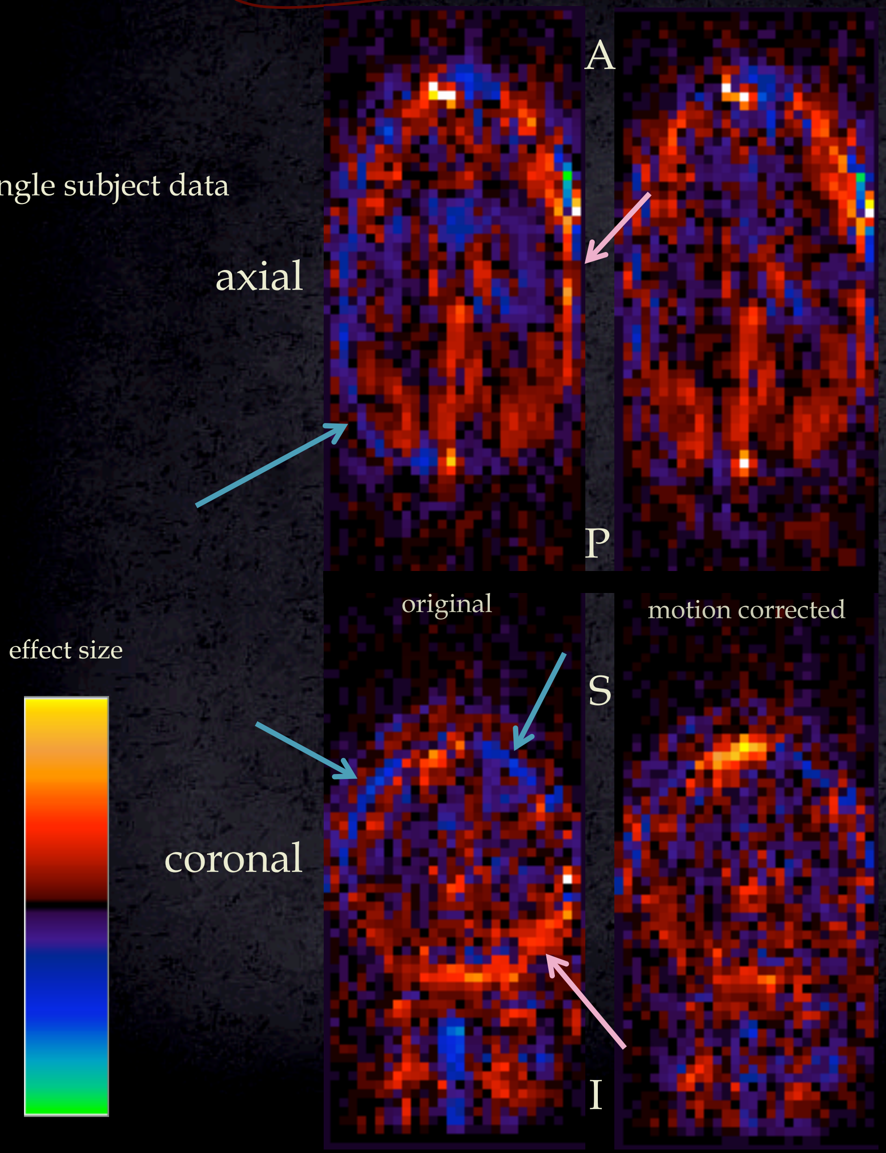


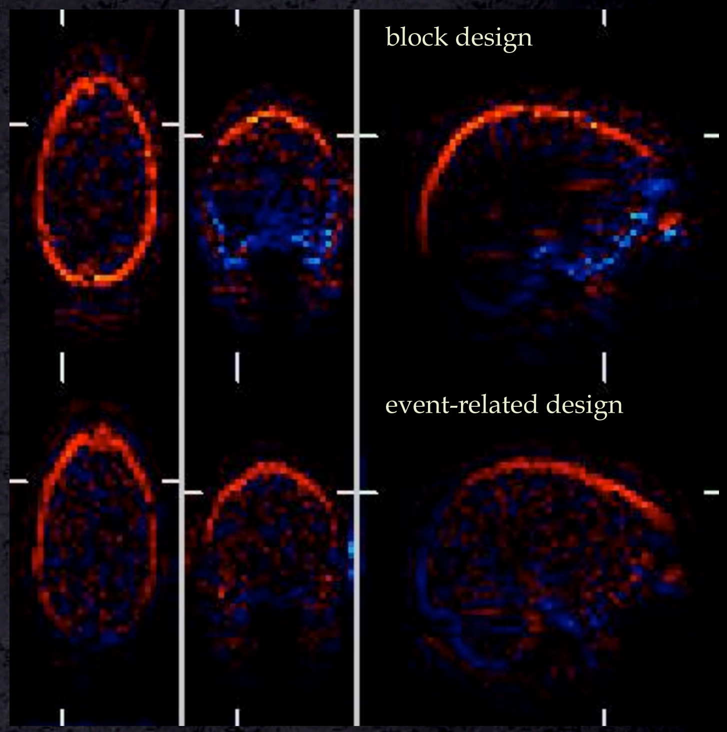
Combining scan runs



Motion Artifact: Typical pattern

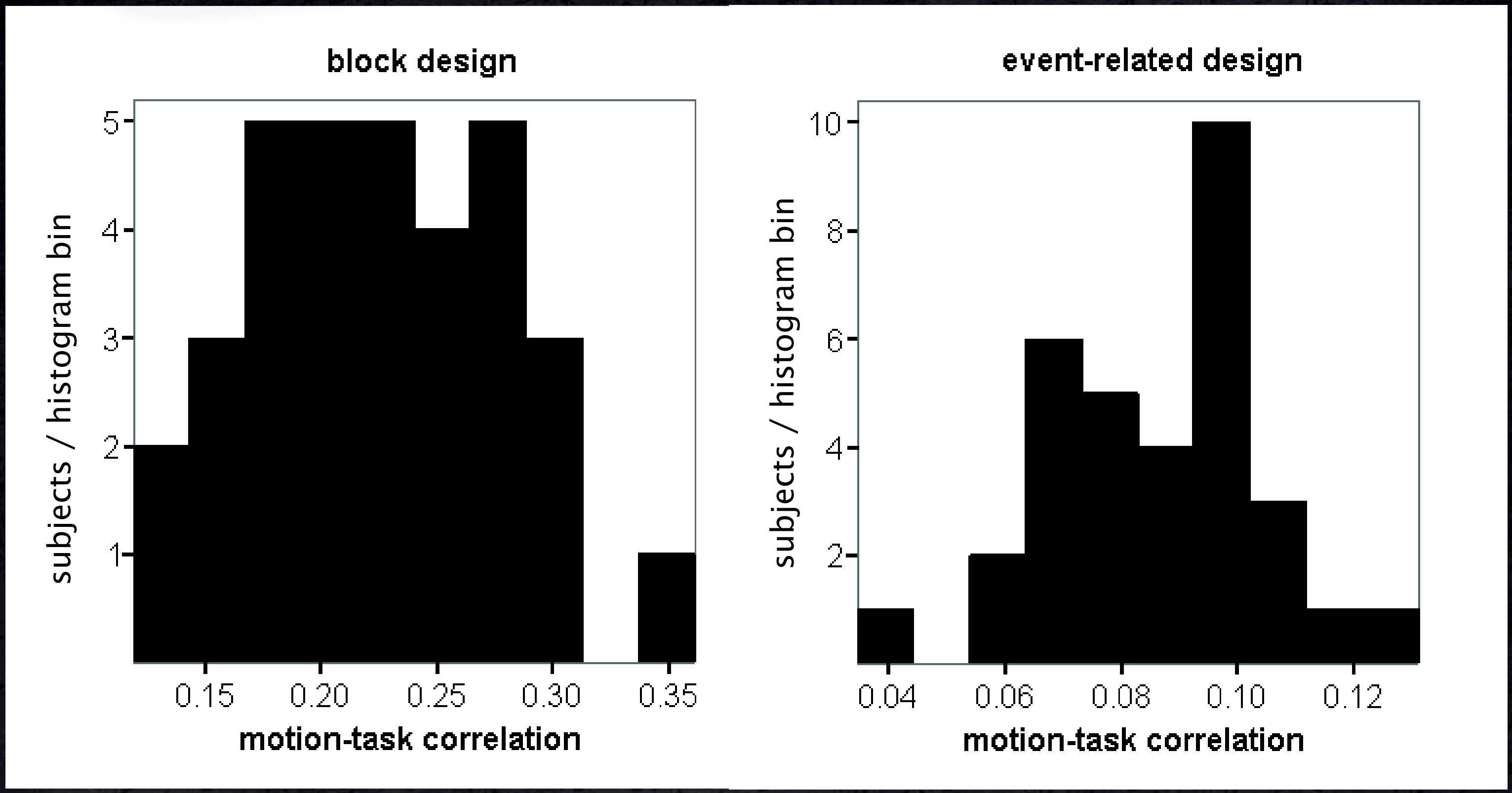
Single subject data





Phantom (simulated) data

Motion Correlated with Stimulus



Johnstone T et al., "Motion Correction and the Use of Motion Covariates in Multiple-Subject fMRI Analysis", ***Hum Brain Mapp*** **27:779 –788, 2006.**
Birn RM et al., "Event-related fMRI of tasks involving brief motion", *Hum Brain Mapp* 7:106 – 114, 1999.

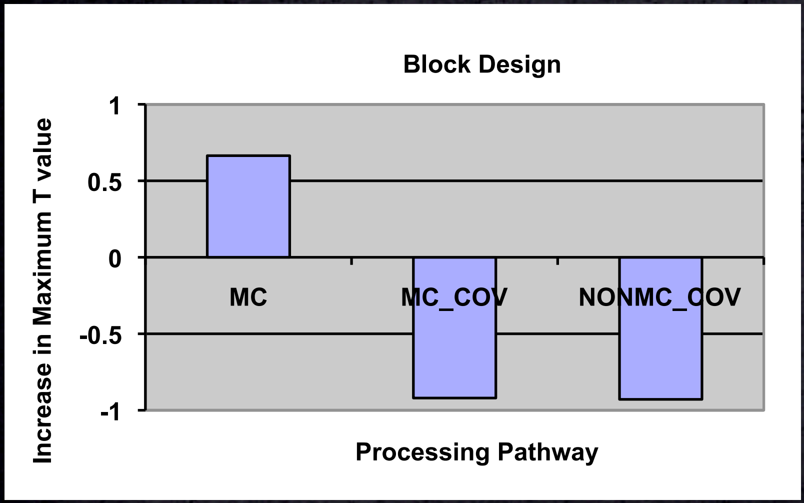
Motion Parameters:

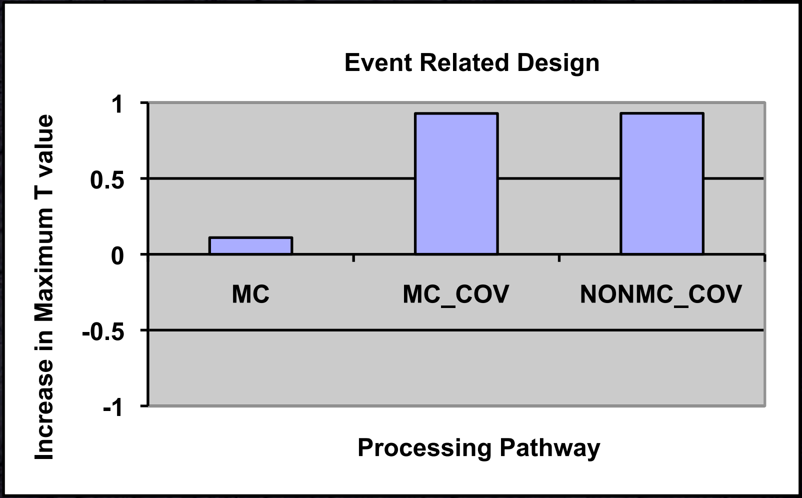
How can we use this information for Good?

- Apply motion correction: reslice each 3D volume
  - "standard" aproach
  - loss of sensitivity if motion correlated with activation
- Use parameters as covariates in GLM
  - may increase sensitivity
  - more flexible data analysis
  - small loss of degrees of freedom in GLM

Motion Parameters as GLM Covariates

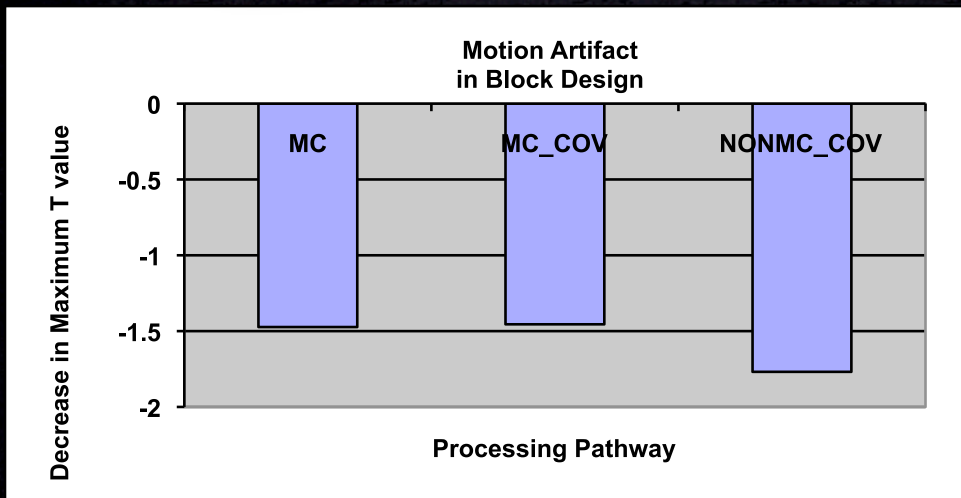
- Block design:
  - if motion correlated with stimulus, "standard" reslice best
- Event-related design:
  - motion parameters in GLM usually work well.

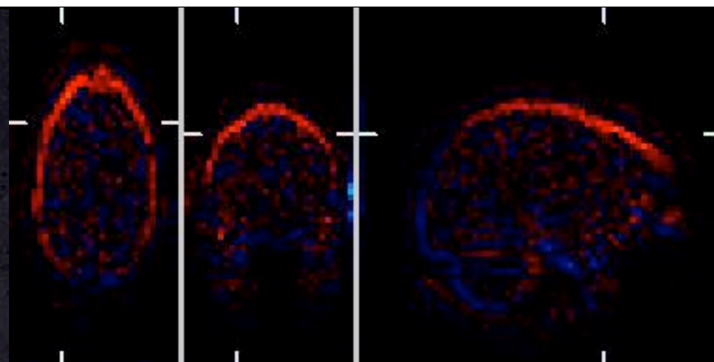




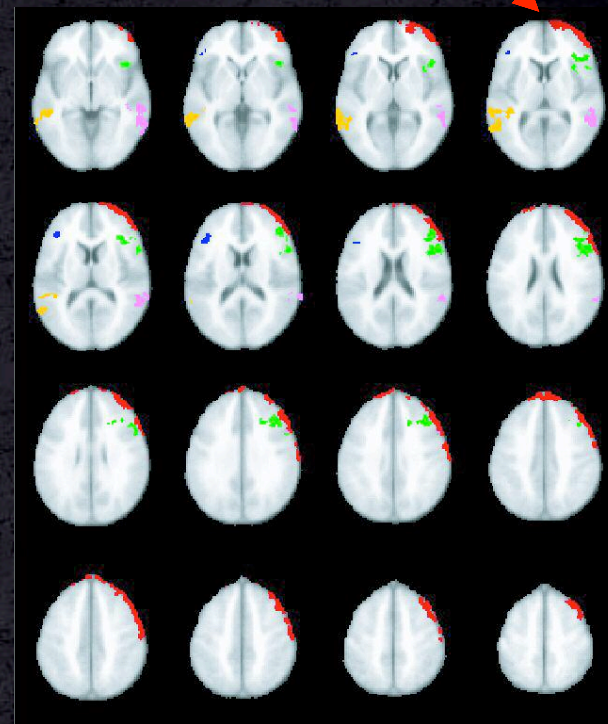
T Johnstone et al., "Motion Correction and the Use of Motion Covariates in Multiple-Subject fMRI Analysis", ***Hum Brain Mapp*** **27:779 –788, 2006.**

Motion Correction at Work

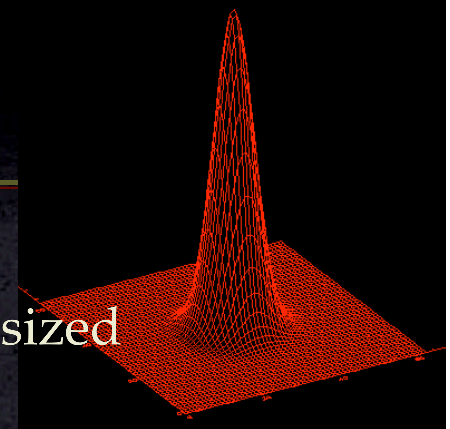




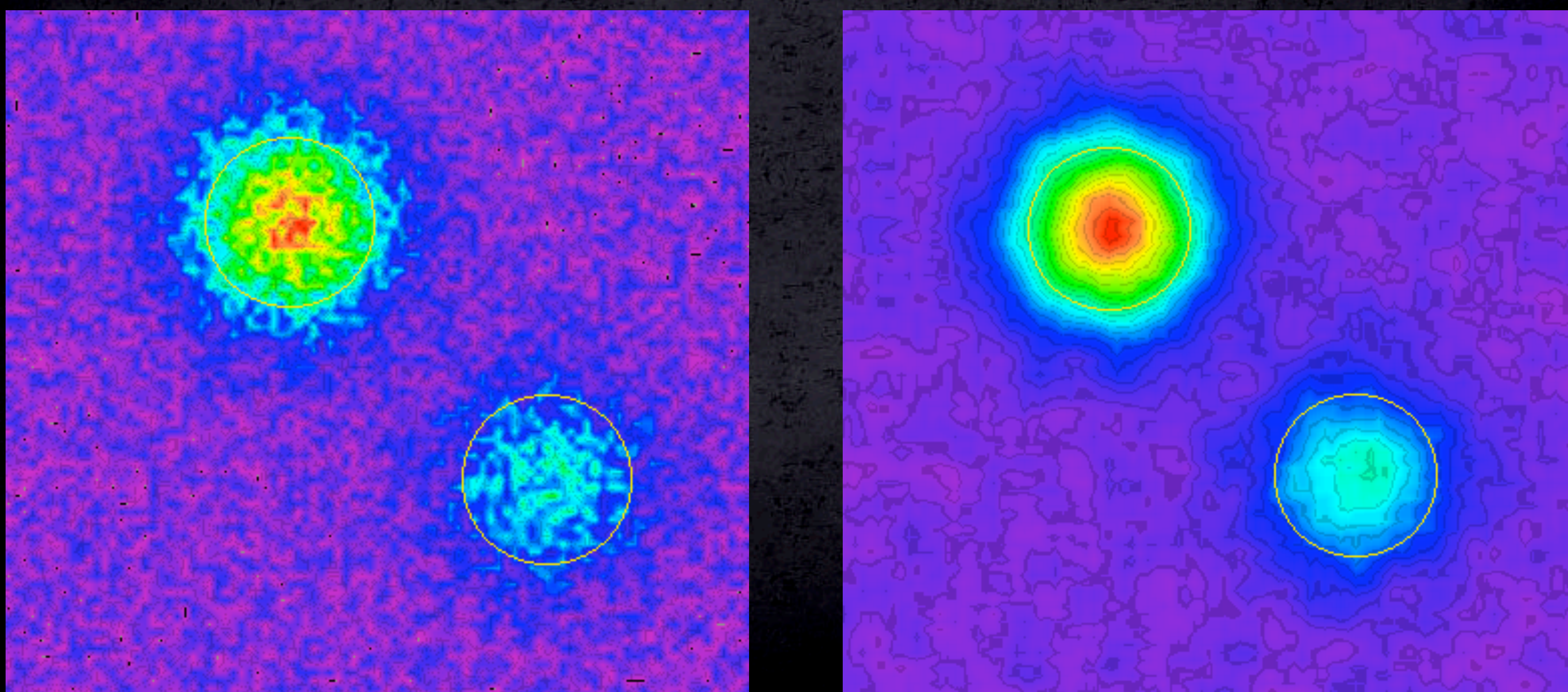
motion artifact



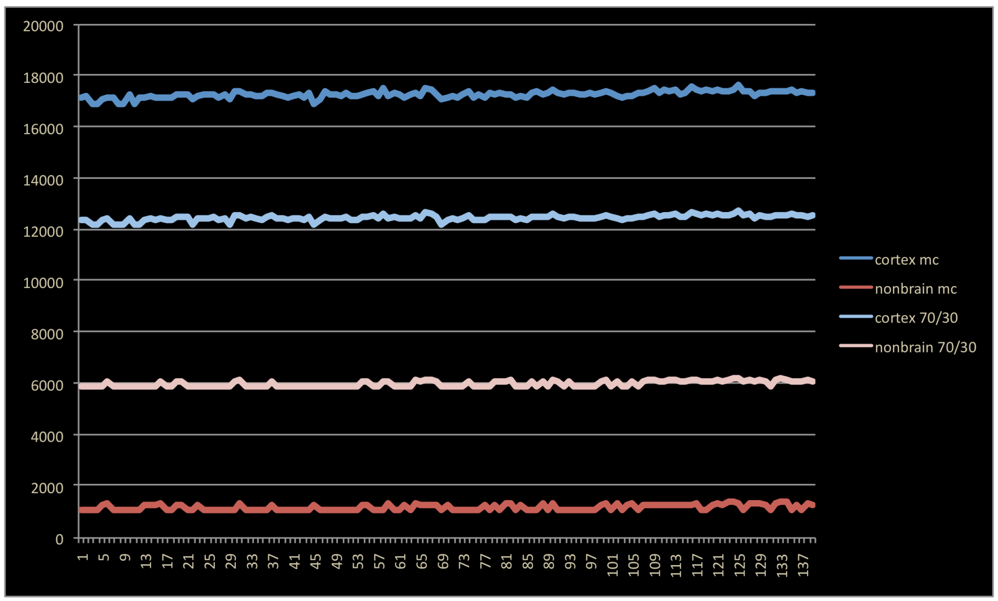
Smoothing - spatial



- Increase S:N
  - Objects similar in size to smoothing kernal emphasized
  - matched filter theorem
- Manage imperfect registration
- Fulfill “Gaussian random field” assumption



Smoothing



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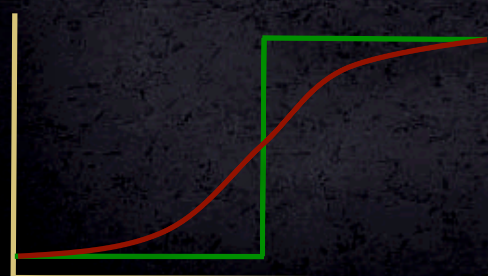
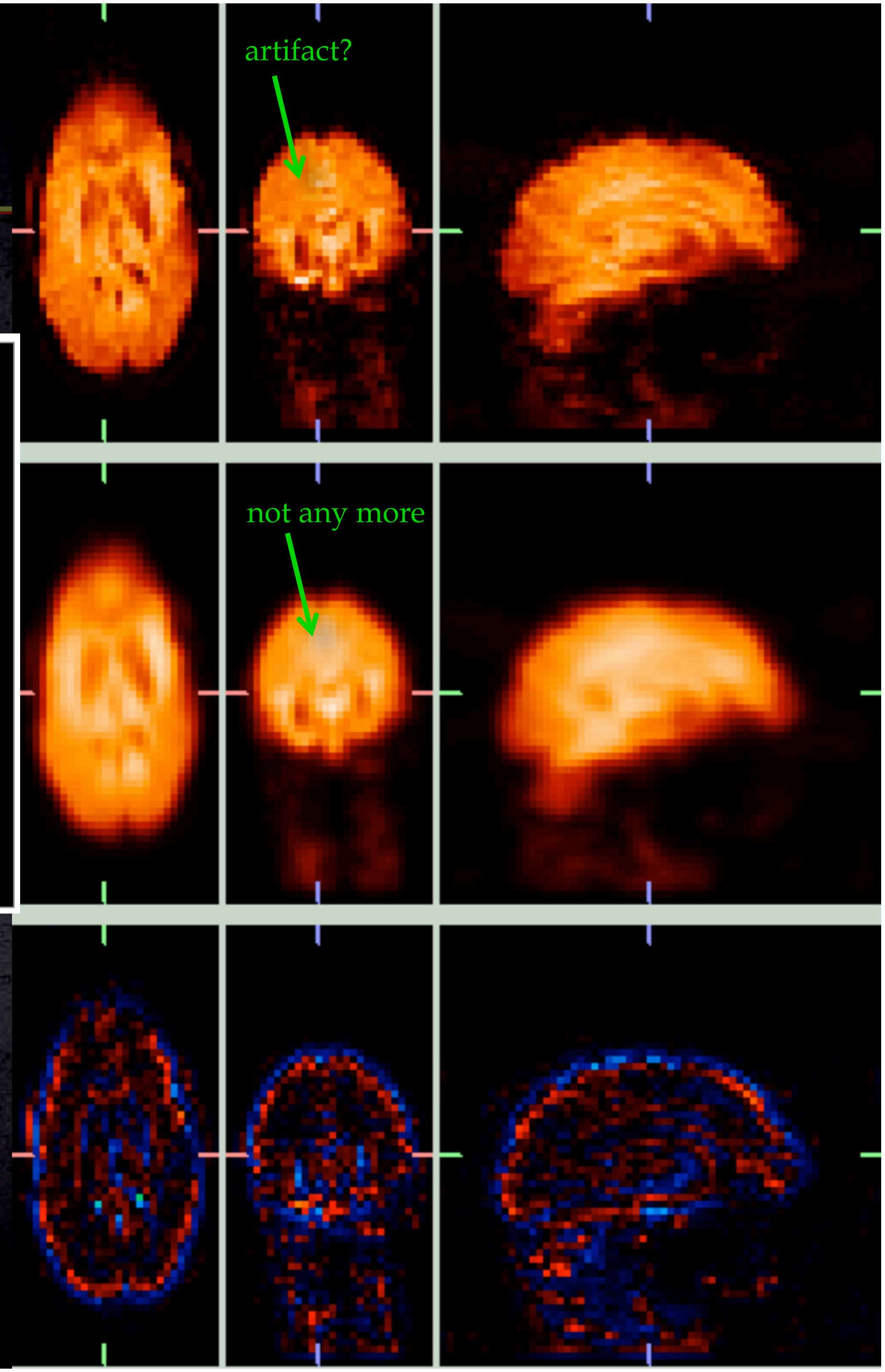
cortex mc
nonbrain mc
cortex 70/30
nonbrain 70/30





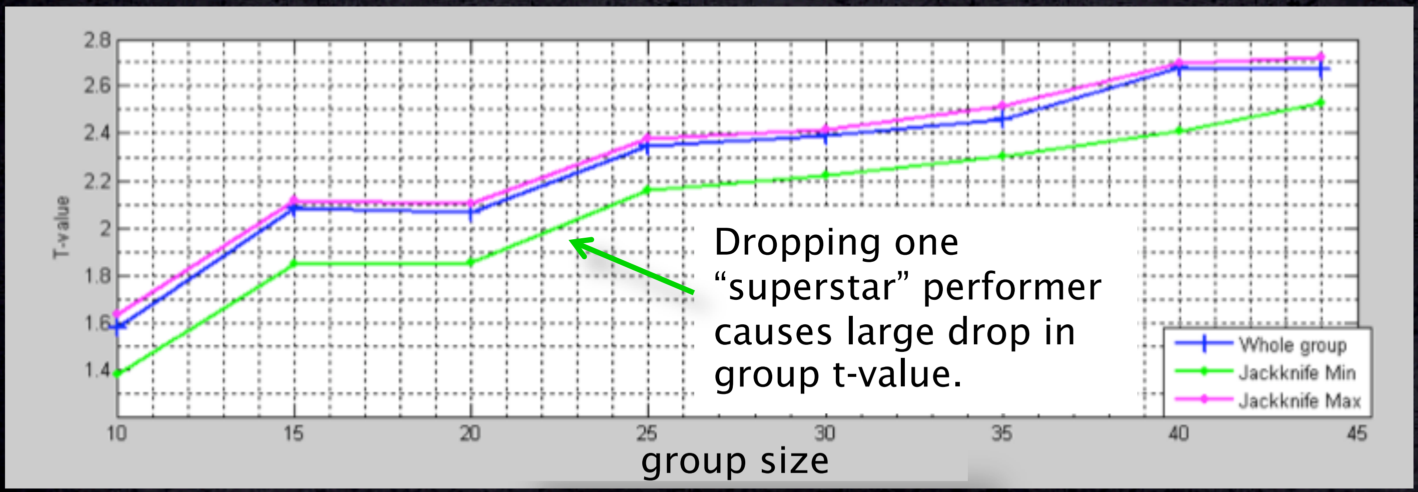
artifact?
not any more

Smoothing – when?

- EPI time series
  - Spatial smoothing removes small (uninteresting) clusters
  - Mild temporal smoothing beneficial:
    - trend removal
    - high-pass filter
    - most versatile if left until GLM stage
- Parameter estimate (cluster) maps
  - more versatile for analysis
  - changes fitted results

Group-wise artifacts

- Multi-subject or 2cnd-level analysis
- subject-to-subject variance dominates
- most analysis assume:
  - similar within-subject variance
  - similar data acquisition, analysis



from work by Pradeep Chilakamarri

Software Recommendations

- fMRI - specific
  - AFNI, FSL, SPM have largest market share, similar results
  - Two- step procedure for selecting software:
    - Find the smartest person in your lab.
    - Use what they use.
- Scripting
  - bash
    - fast, easy, universal
    - idiosyncratic, hard to distribute
  - Python
    - versatile, extensible, good for distribution
    - mostly universal, moderate learning curve
  - Matlab, IDL
  - sed & awk? You don't need my advice.
- Other handy tools:
  - R http://www.r-project.org/
  - fmristat http://www.math.mcgill.ca/keith/fmristat/
  - NiPy http://neuroimaging.scipy.org/