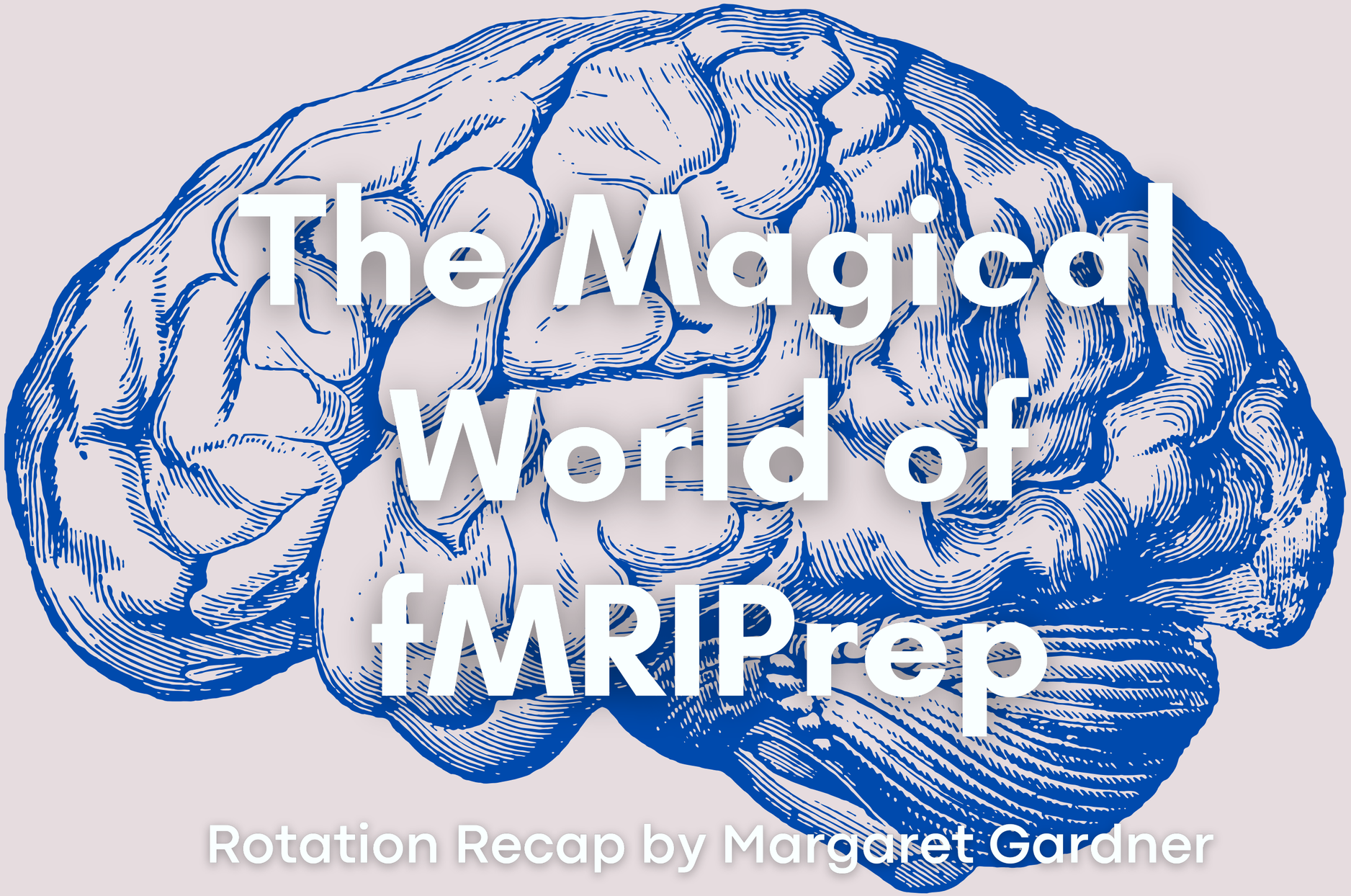


The Magical World of fMRIPrep

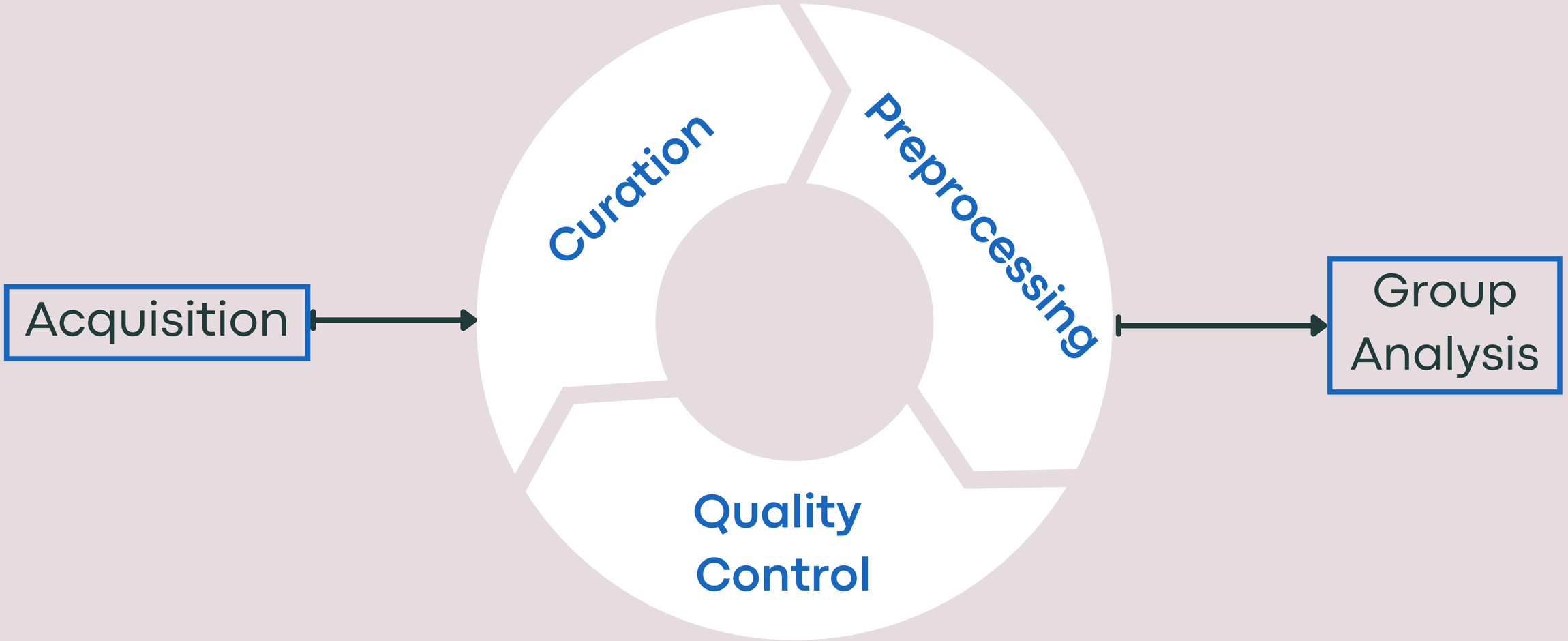
Rotation Recap by Margaret Gardner

Hi

My Objective:

Learn best-practice informatics
procedures for
reproducible & transparent
curation & analysis of fMRI data

fMRI Lifecycle



Day 2 Reward

n=125 subjects

anat = 125 subjects

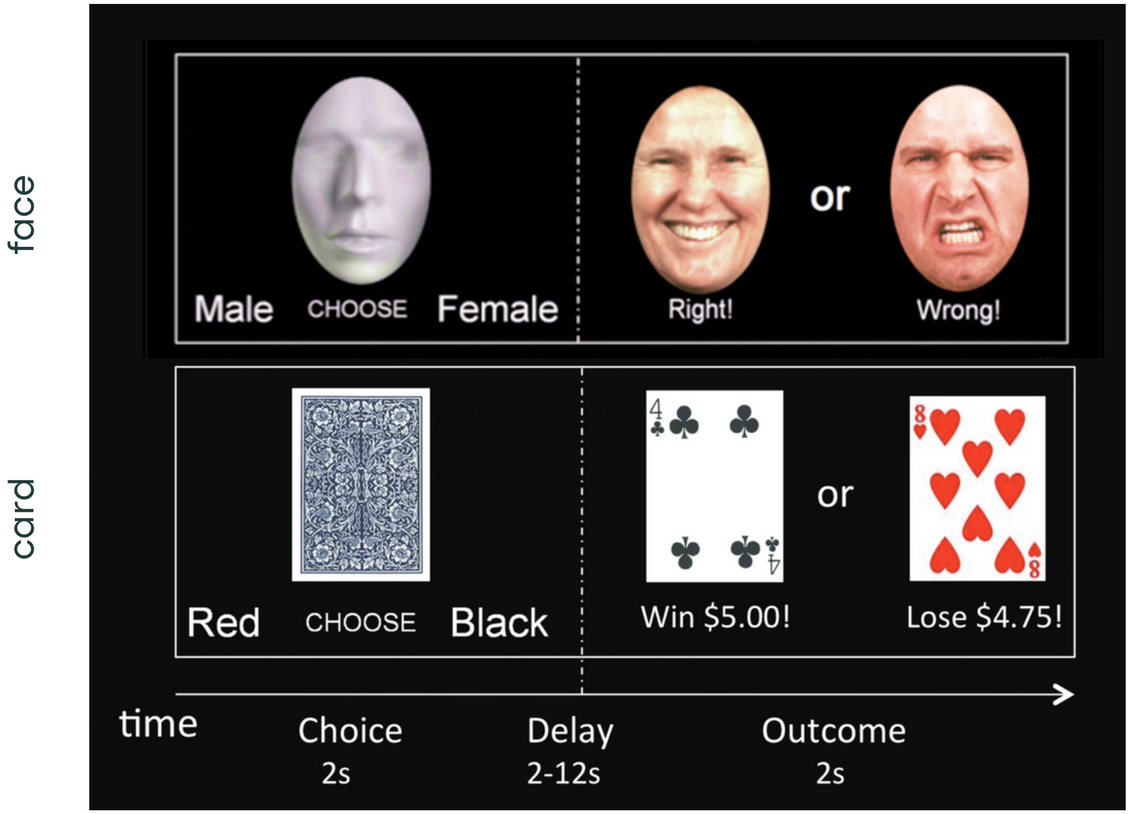
- T1w = 125
- T2w = 3

func = 125 subjects

- card run 01 = 124
- card run 02 = 124
- face run 01 = 123
- face run 02 = 124
- rest = 114

fmap = 124 subjects

dwi = 3 subjects



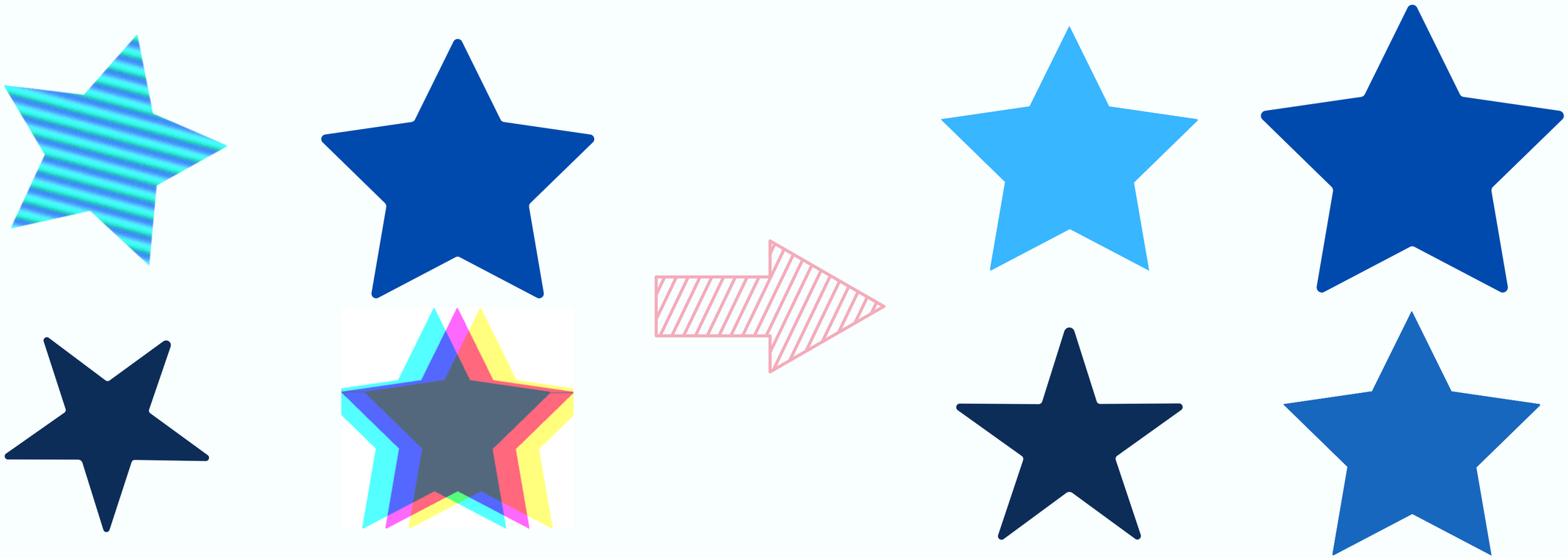
Adapted from Sharma et al, 2016 and Wolf et al, 2014

And now,

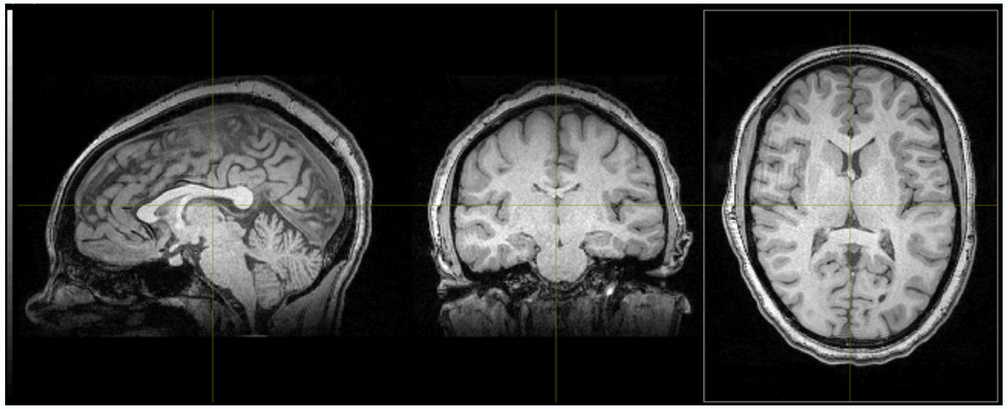
fMRIPrep

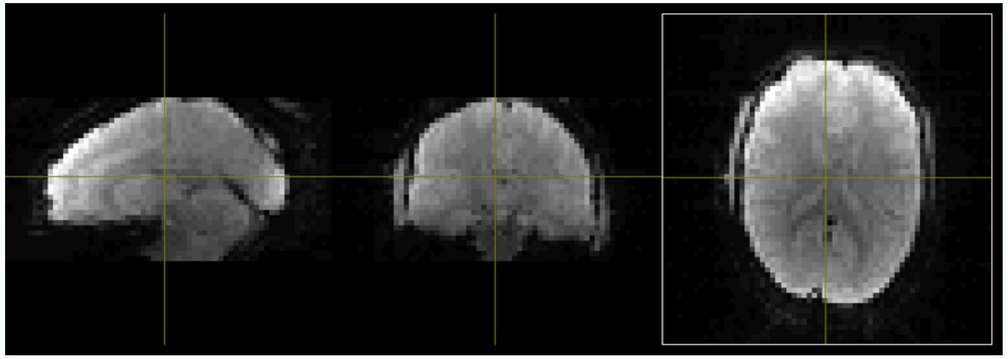
What is preprocessing?

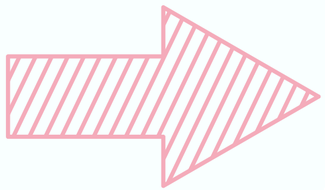
Cleaning up our data to more easily identify meaningful signal.

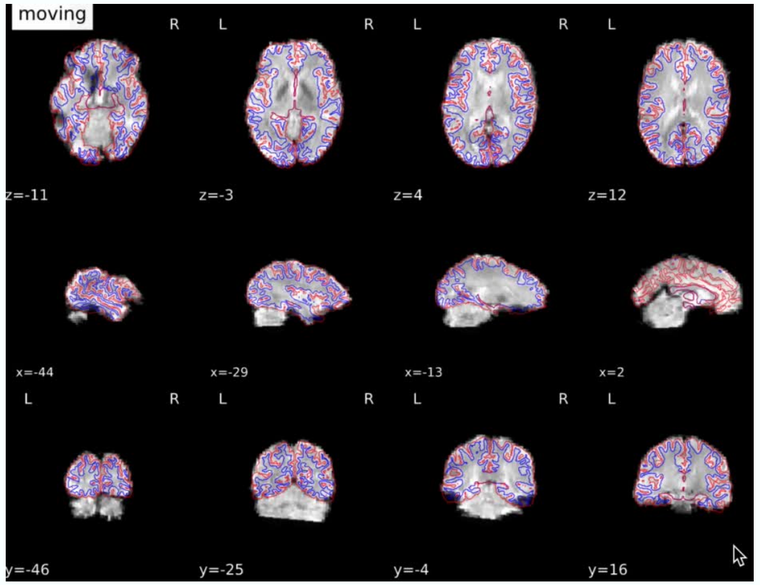


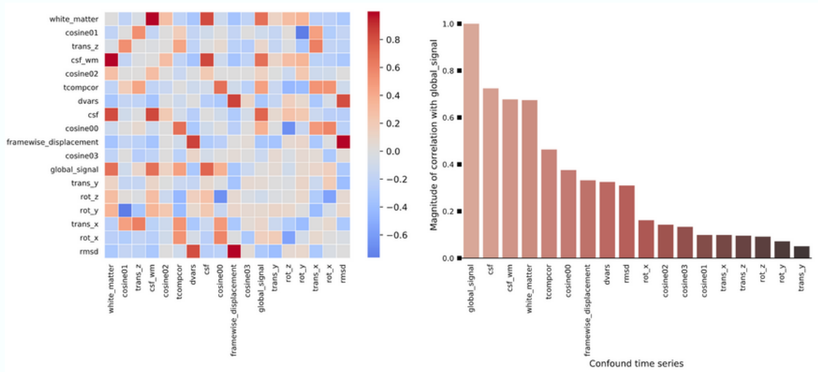
What is preprocessing?











Why fMRIPrep?

AFNI: environment for processing and displaying fMRI data

ANTs: set of tools to normalize data to standard spaces

FSL: popular set of tools for analyzing many types of MR data

---

FreeSurfer: program for analysis of (mostly) structural images, especially for surface analyses

---

tedana: Python library of tools for denoising multi-echo fMRI

It's a BIDS App!

- Can intelligently read info from BIDS inputs
- Can automatically adapt processing based on inputs
- Runs on Docker/Singularity, so it's all the subprograms (packages) are self-contained and reproducible

It uses NiPype!

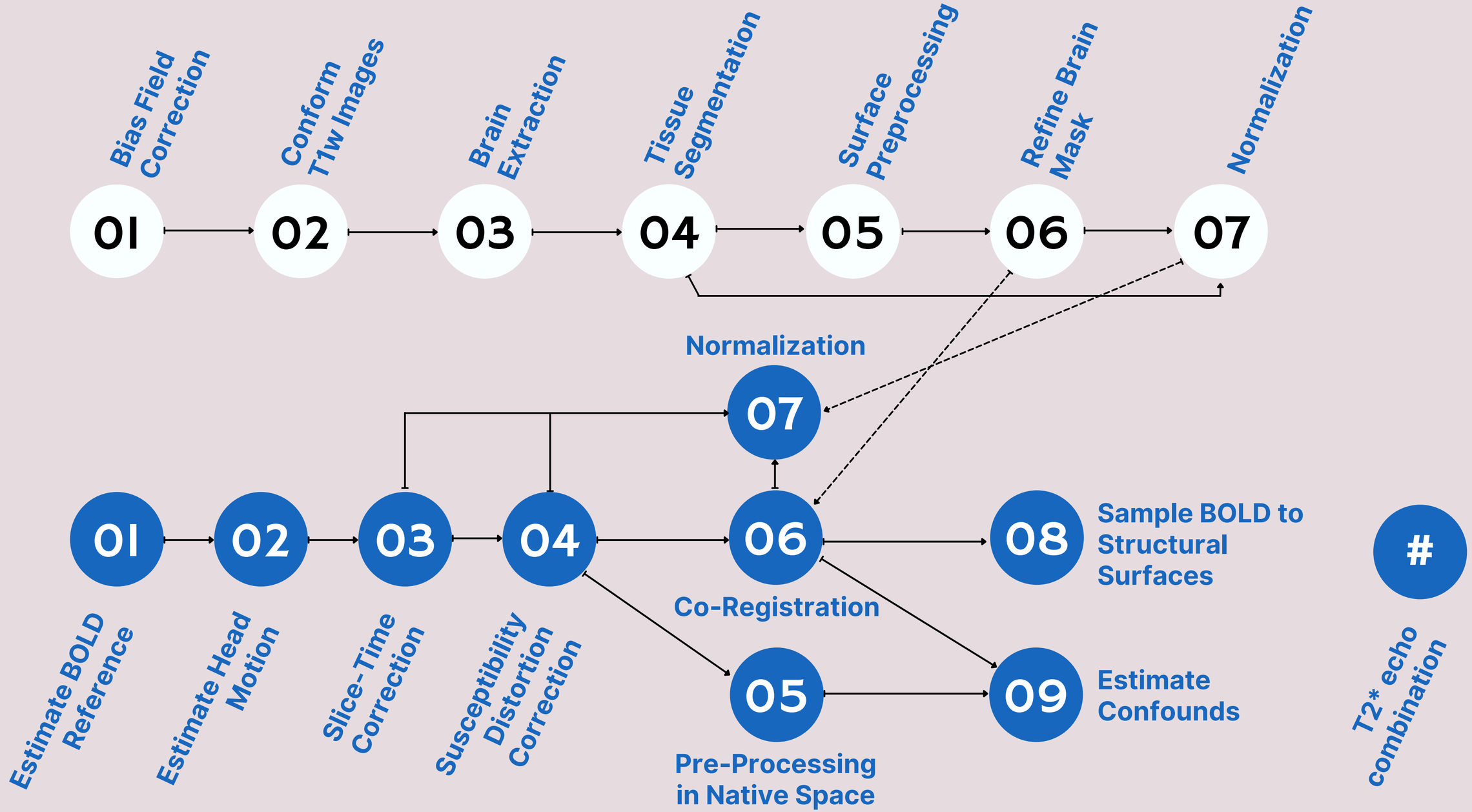
- Integrates scripts from different packages with Python

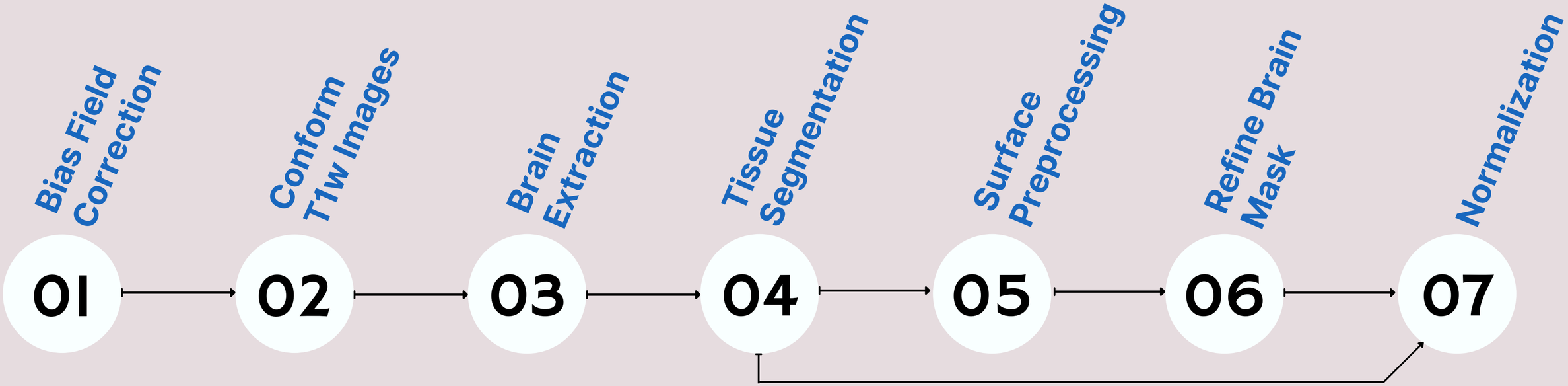
It gives you lots of options for subsequent processing!

- No spatial smoothing
- Calculates lots of confounds

It's transparent!

- Provides comprehensive visual QC reports automatically
- Boilerplate citation for manuscripts

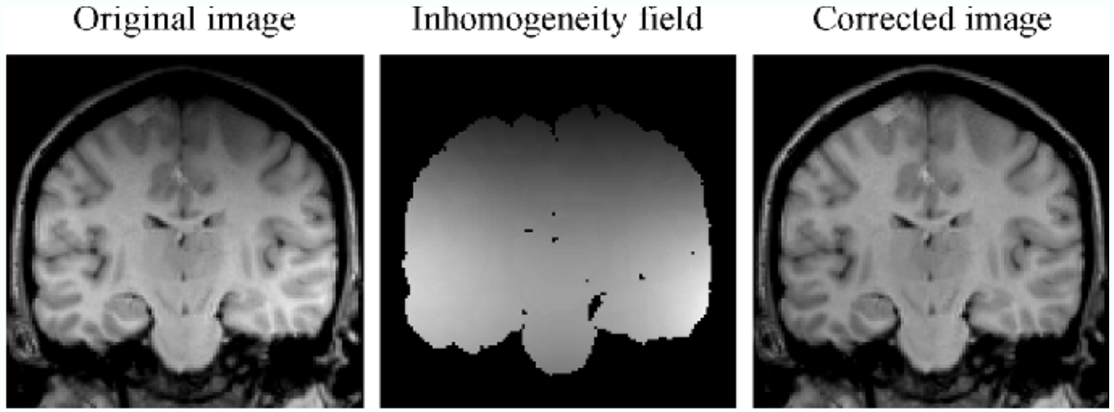

Bias Field Correction
Conform T1w Images
Brain Extraction
Tissue Segmentation
Surface Preprocessing
Refine Brain Mask
Normalization
01
02
03
04
05
06
07
Normalization
07
01
02
03
04
06
08
Sample BOLD to Structural Surfaces
Co-Registration
#
T2* echo combination
Estimate BOLD Reference
Estimate Head Motion
Slice-Time Correction
Susceptibility Distortion Correction
05
09
Estimate Confounds
Pre-Processing in Native Space



Structural Workflow

01

Bias Field Correction



Vovk U, Pernus F & Likar B, 2007

Identifies and corrects changes in voxel intensity caused by inhomogeneities in the magnetic field

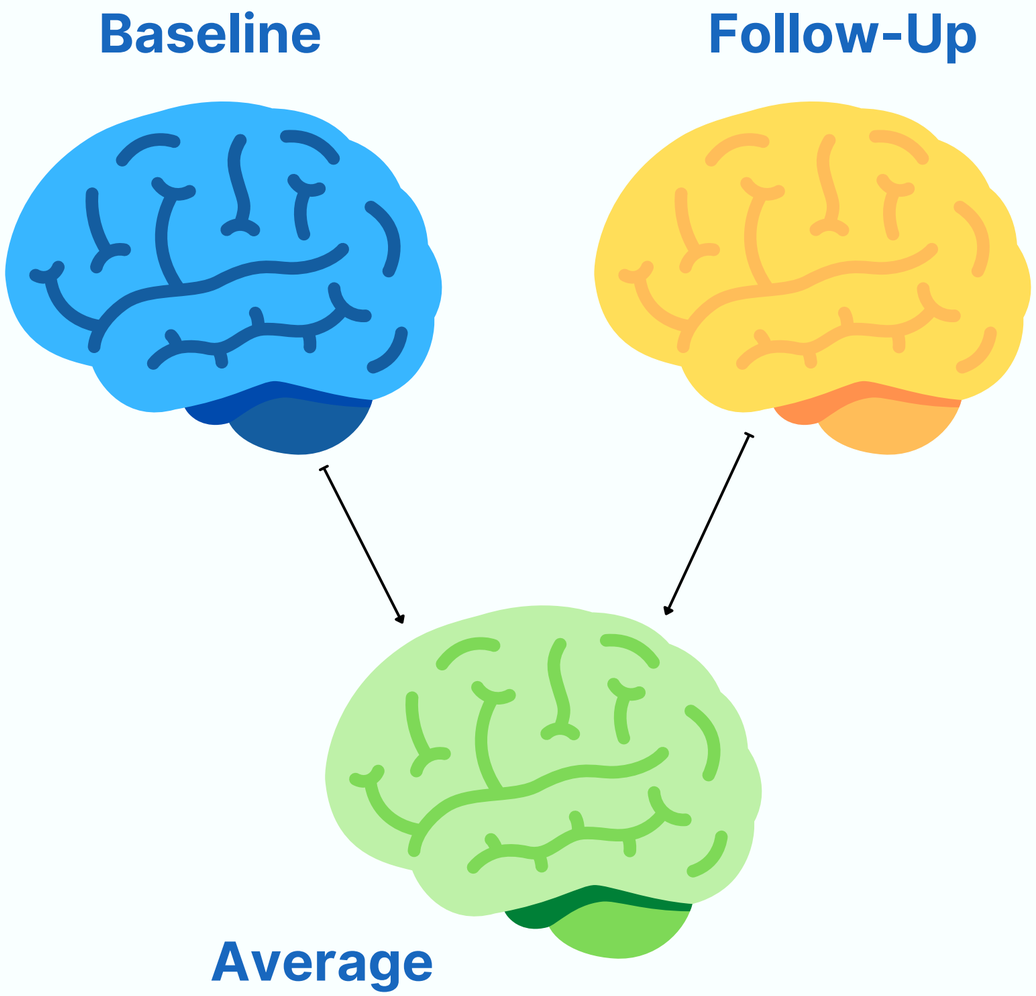
- Uses *N4BiasFieldCorrection* from ANTs

02

Conform TIw Images

Optional step to create a within-subject template for longitudinal studies in which you don't expect structural changes

- Uses *mri_robust_template* from FreeSurfer
- Can be helpful (i.e. more evenly distributing the transforms needed to normalize baseline and follow-up)
- Unbiased (all images averaged) or aligned to first image

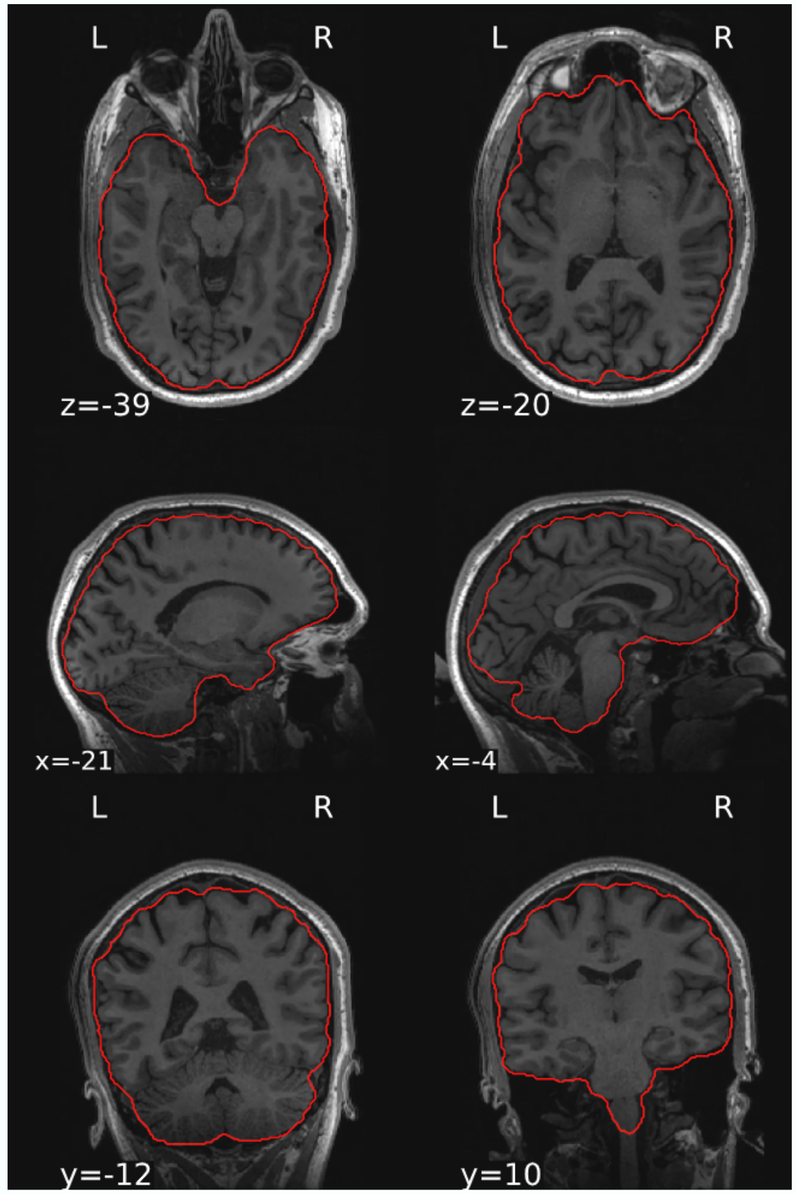


03

Brain Extraction

Removes all non-brain tissue

- Uses *antsBrainExtraction.sh* from ANTs
- Atlas-based - registers atlas whole-head image to T1w and applies atlas's brain mask to create subject's brain mask
- Sometimes referred to as "skull-stripping"



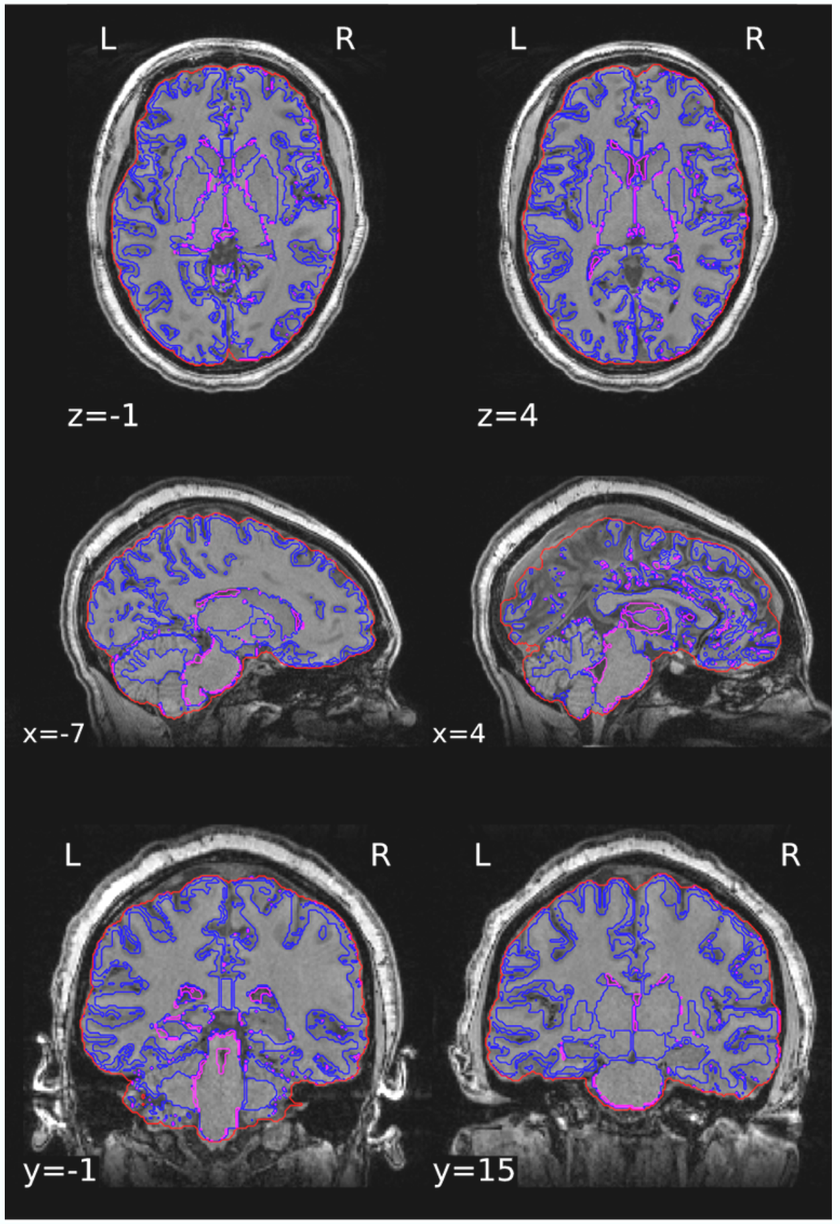
fMRIPrep Sample Report

04

Tissue Segmentation

Divides image into tissue types (white matter, gray matter, CSF)

- Uses *fast* from FSL
- Model classifies tissue based on the voxel's intensity and the intensity of neighboring voxels
- Reciprocally incorporates/assesses magnetic field inhomogeneity

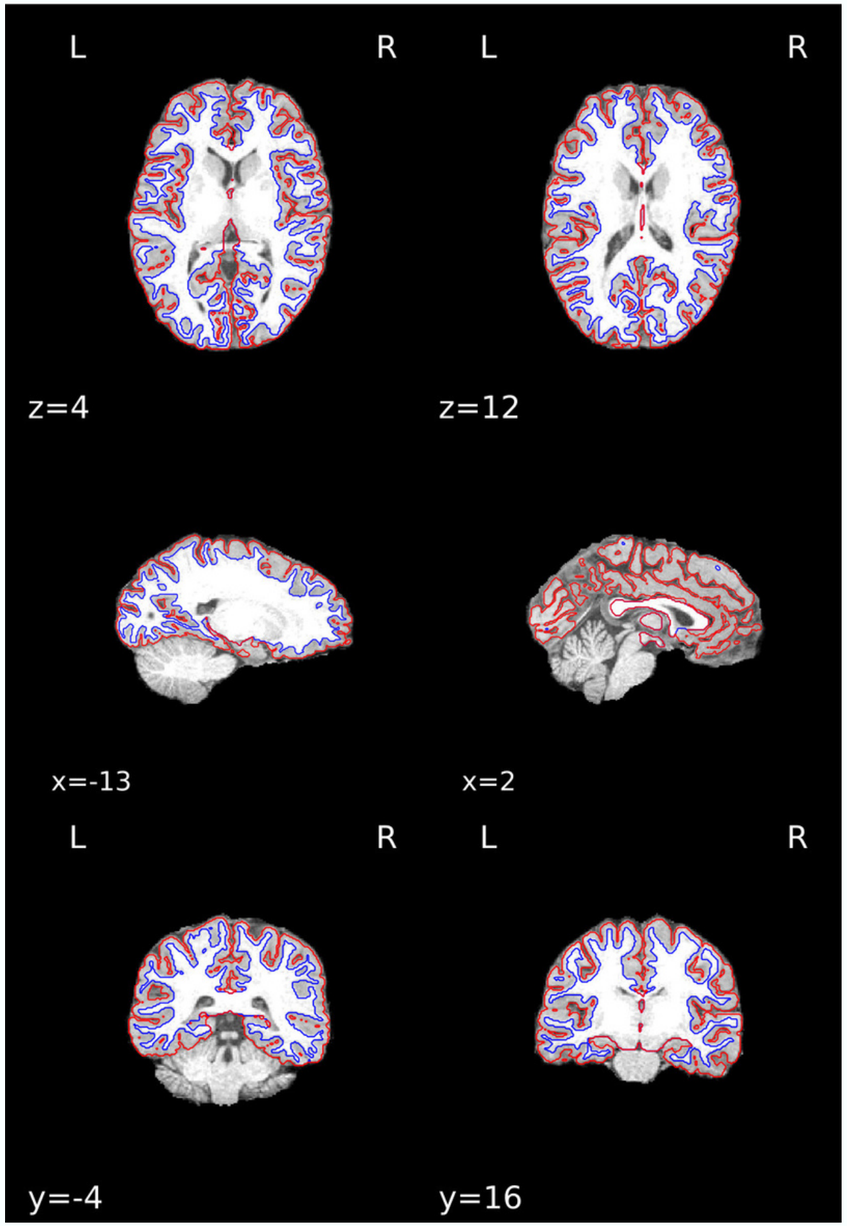


05

Surface Preprocessing

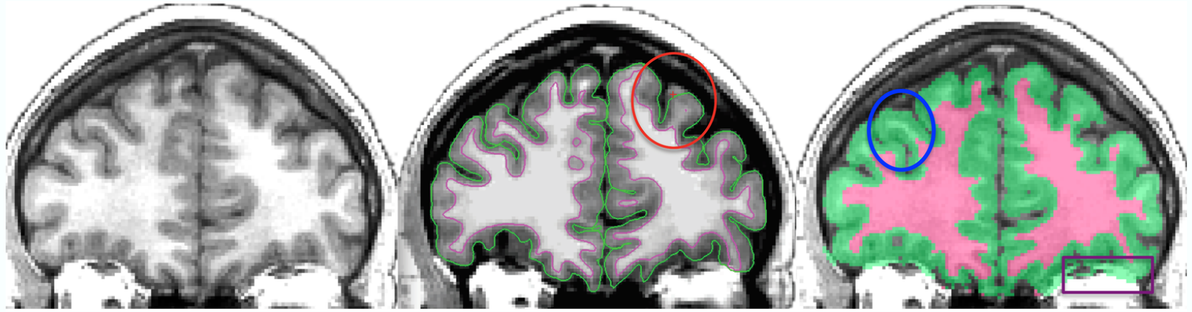
Optional assessment of boundary between white and gray matter (wm surface) and the cortical surface (pial surface)

- Uses *recon-all* from FreeSurfer
- Also calculates *.midthickness surfaces
- Saves surfaces in GIFTI format
- Uses T2w image if available



06

Refine Brain Mask



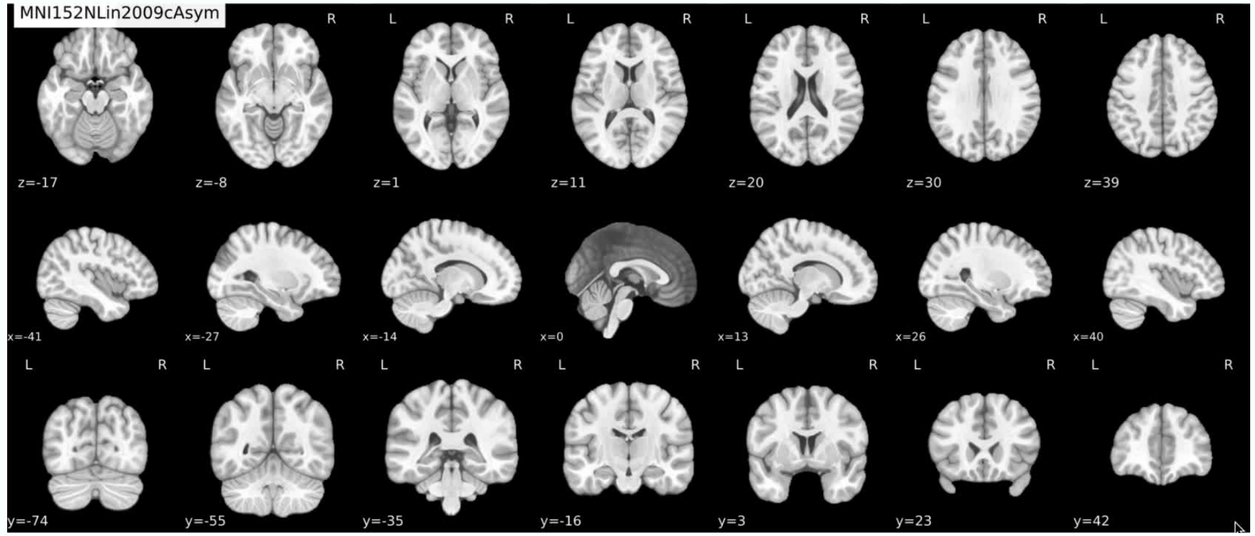
Klein et al, 2017

Cleans up the brain mask calculated by brain extraction based on the surface segmentation

- Uses a custom adaptation of Mindboggle's hybrid segmentation algorithm
- Unifies ANTs and FreeSurfer segmentations for the most accurate results

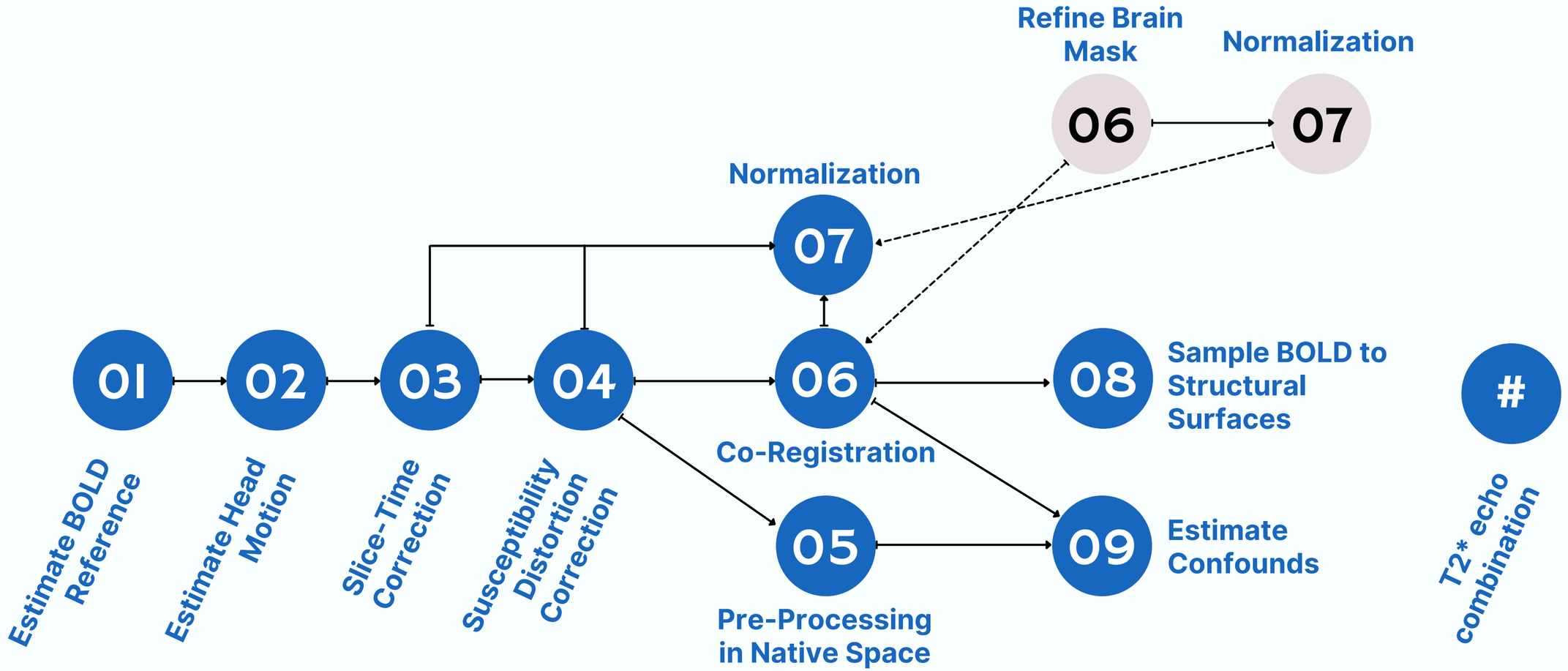
07

Normalization



Fits subject's anatomical image to a standard template so you can compare between individuals

- Uses *antsRegistration* from ANTs
- Non-linear resampling
- Can chose from standard or nonstandard templates ("spaces")
- Keeps original resolution (unless specified)



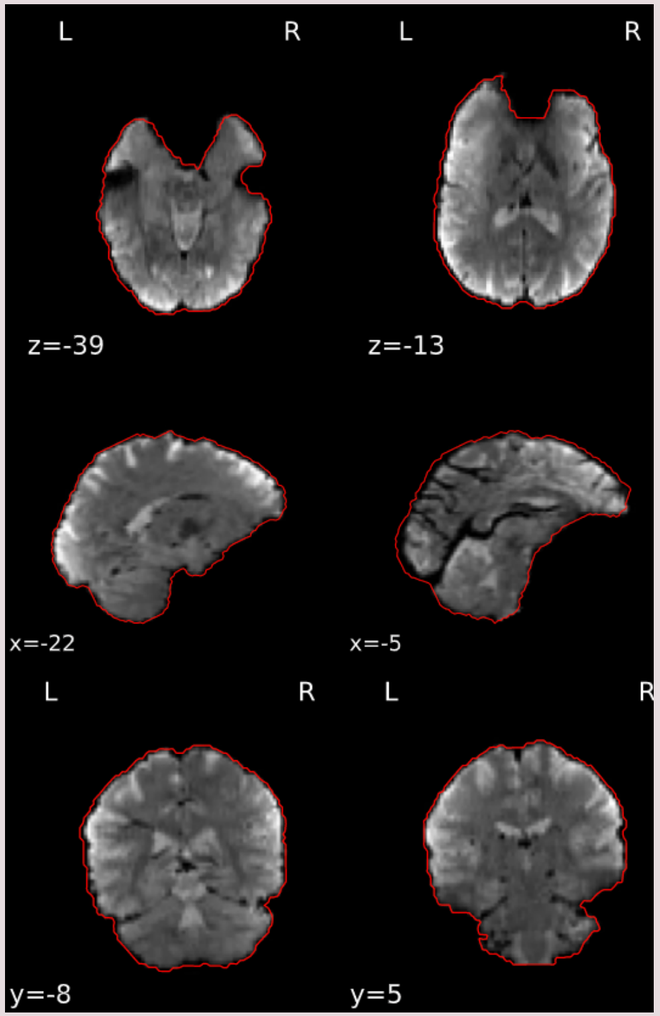
Functional Workflow

01

Estimate BOLD Reference

Creates a reference image from each functional run by averaging dummy scans or a motion-corrected subset of BOLD volumes

- Also creates BOLD run brain mask
- Uses sbref (single-band reference) if available



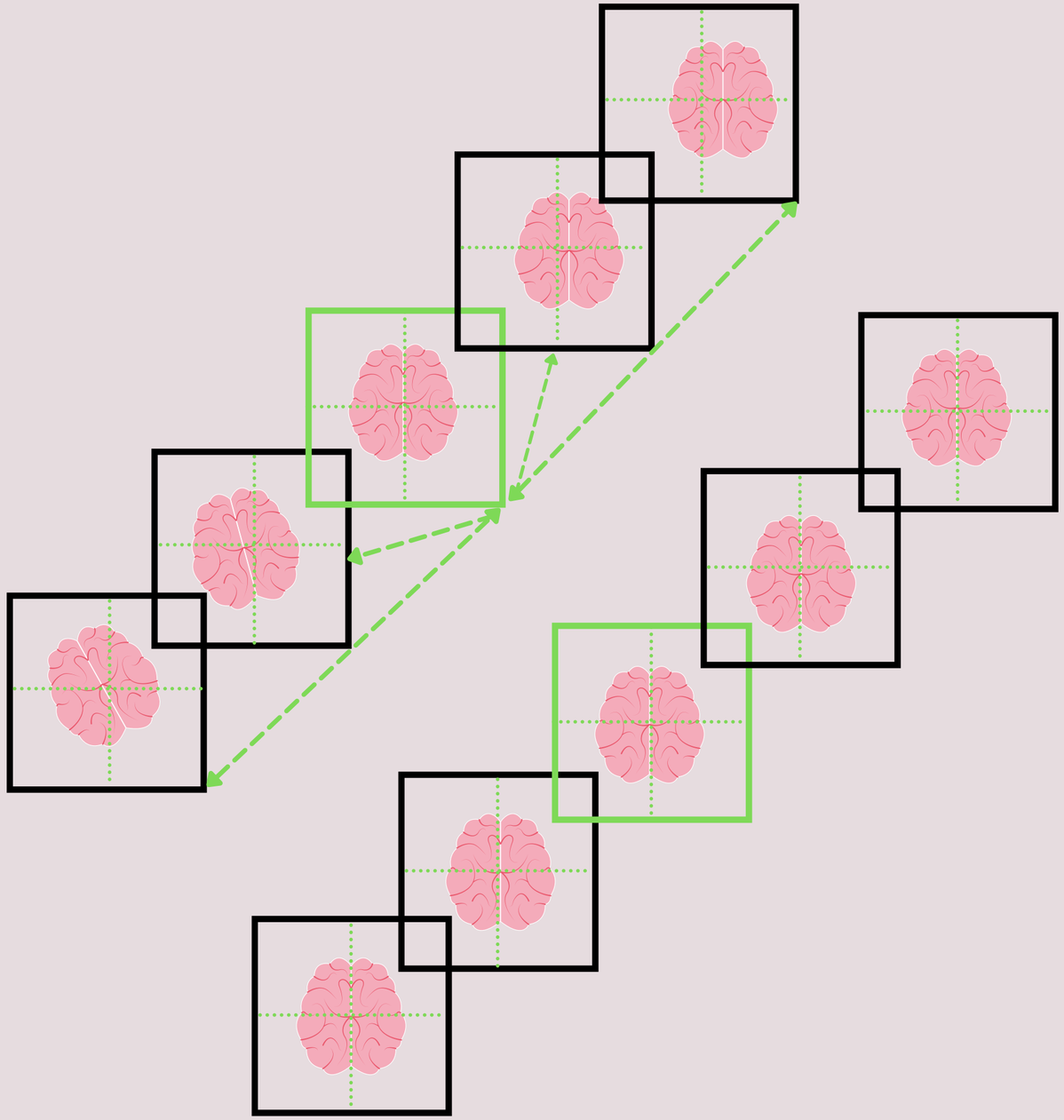
fMRIPrep Sample Report

02

Estimate Head Motion

Writes a rigid-body transform - steps needed to bring brain back into alignment with the reference image - for each volume

- Uses *mcflirt* from FSL
- Calculated from 6 motion parameters (3 rotations & 3 translations) per time-step

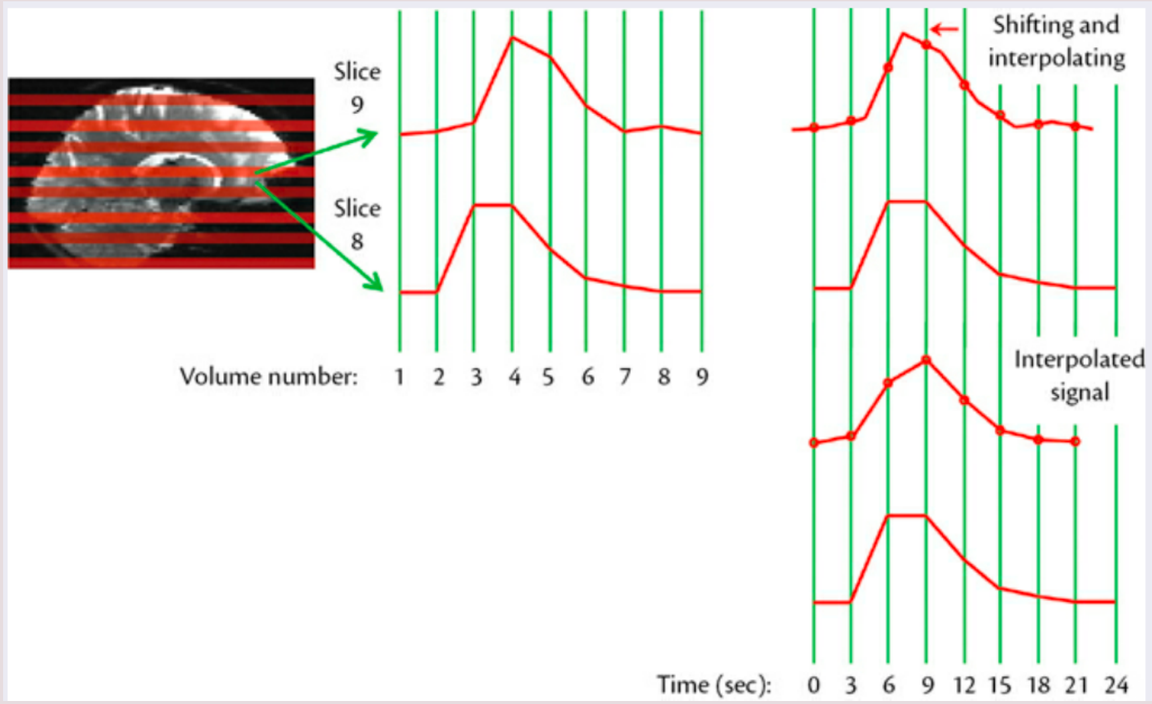


03

Slice Time Correction

Realigning 2D image slices to the middle TR (i.e. middle of that volume's acquisition)

- Uses *3dTShift* from AFNI
- Can be skipped



Jenkinson & Chappell, 2018

04

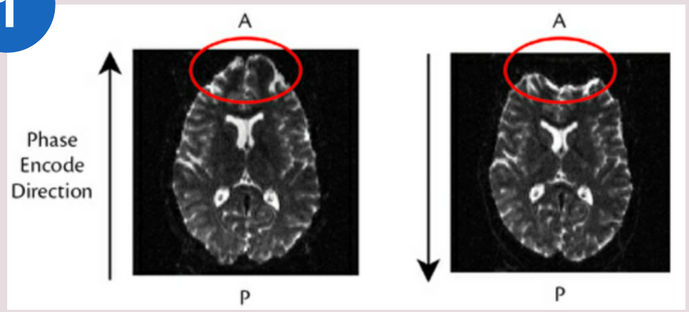
Susceptibility Distortion Correction

Correcting signal intensity noise caused by inhomogeneities in the magnetic field

- Calculates the fieldmap by:

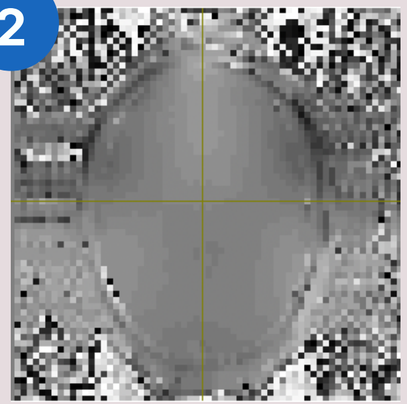
1. PE-Polar: Registering BOLD images acquired with opposite phase encoding directions to a reference and calculating voxel displacement
2. Direct: comparing echos in a double-echo sequence to reveal inhomogeneities
3. Fieldmap-less: Registering BOLD images to T1w to assess voxel displacement

1

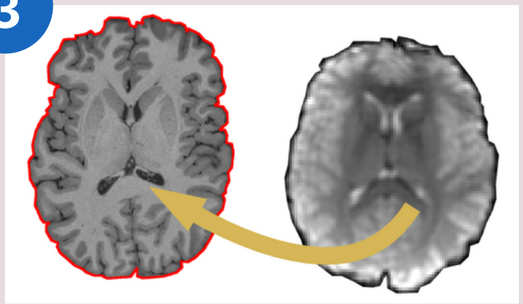


Jenkinson & Chappell, 2018

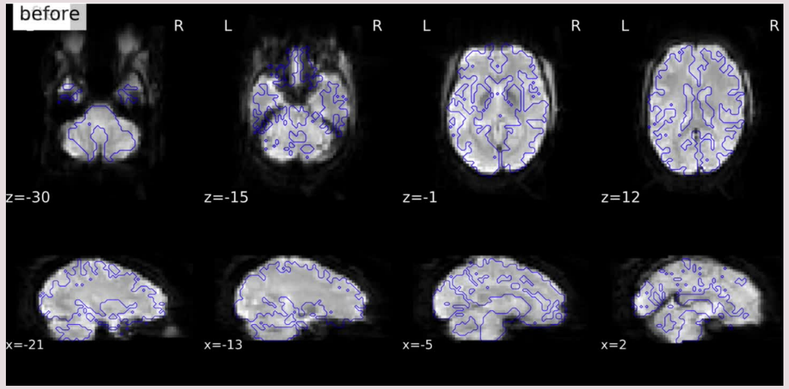
2



3



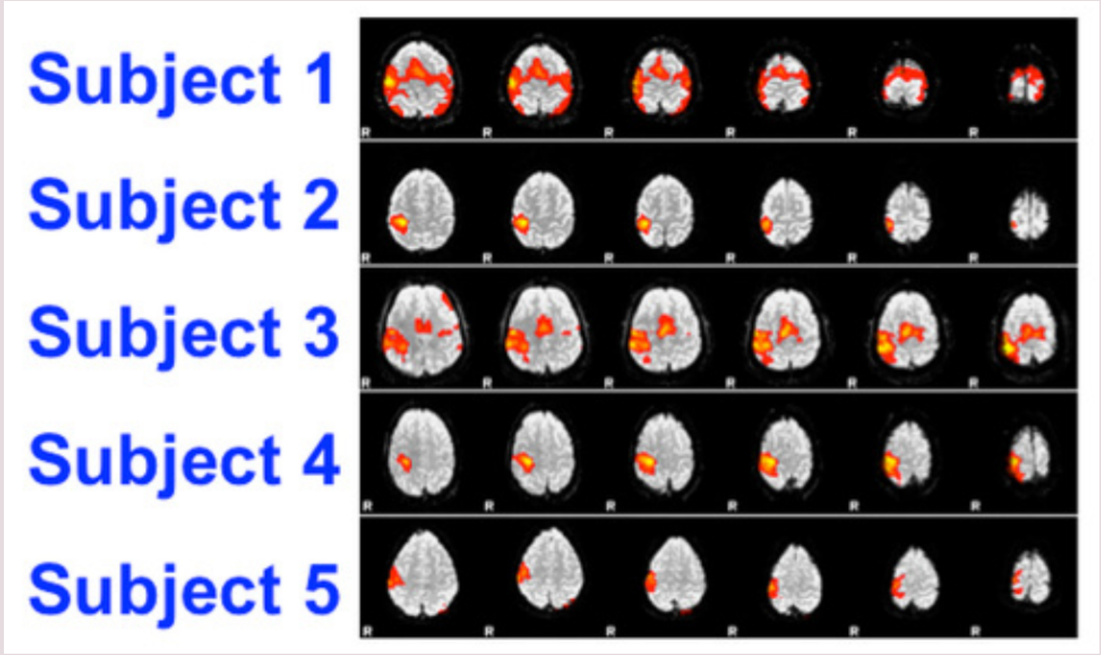
Adapted from Esteban et al, 2019



05

Pre-process BOLD in Native Space

Applying transforms calculated by motion correction, slice-timing correction, and signal distortion correction



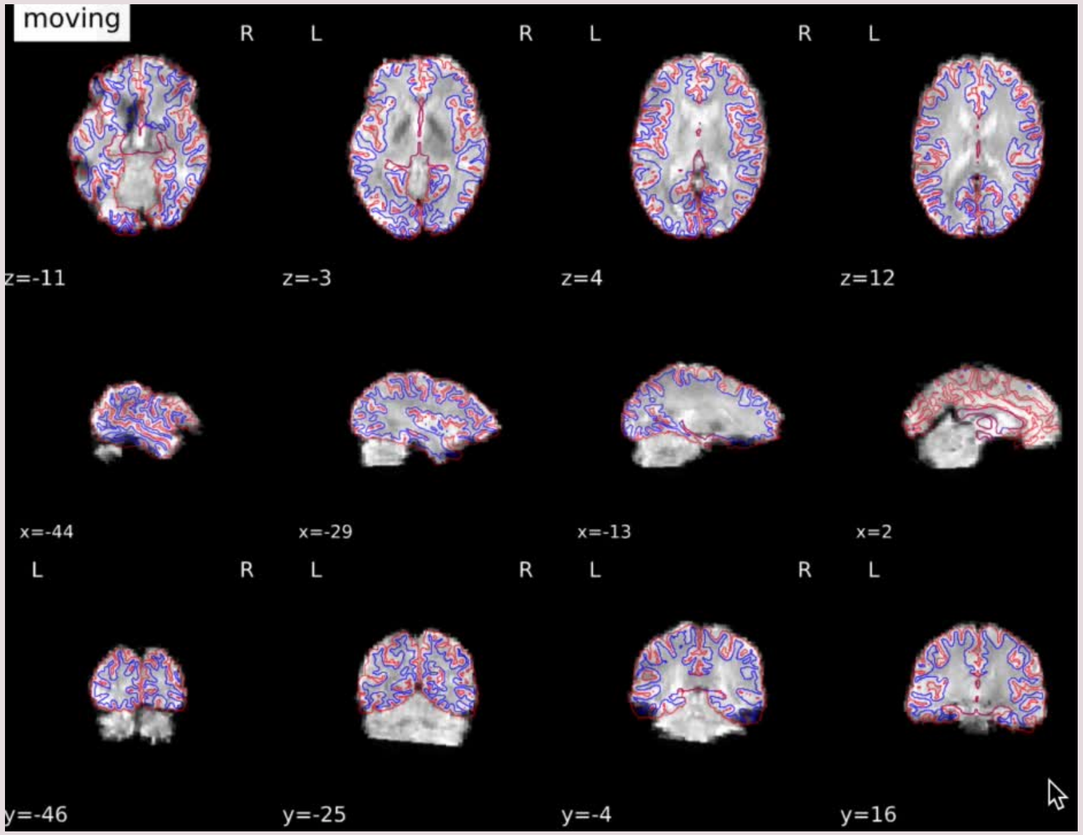
Adapted from MRI Questions.com

06

Co-Registration

Aligns the BOLD reference image to the T1w brain mask by maximizing it's intensity gradient across the white-matter boundary

- Uses *bbregister* from FreeSurfer or *FLIRT* from FSL



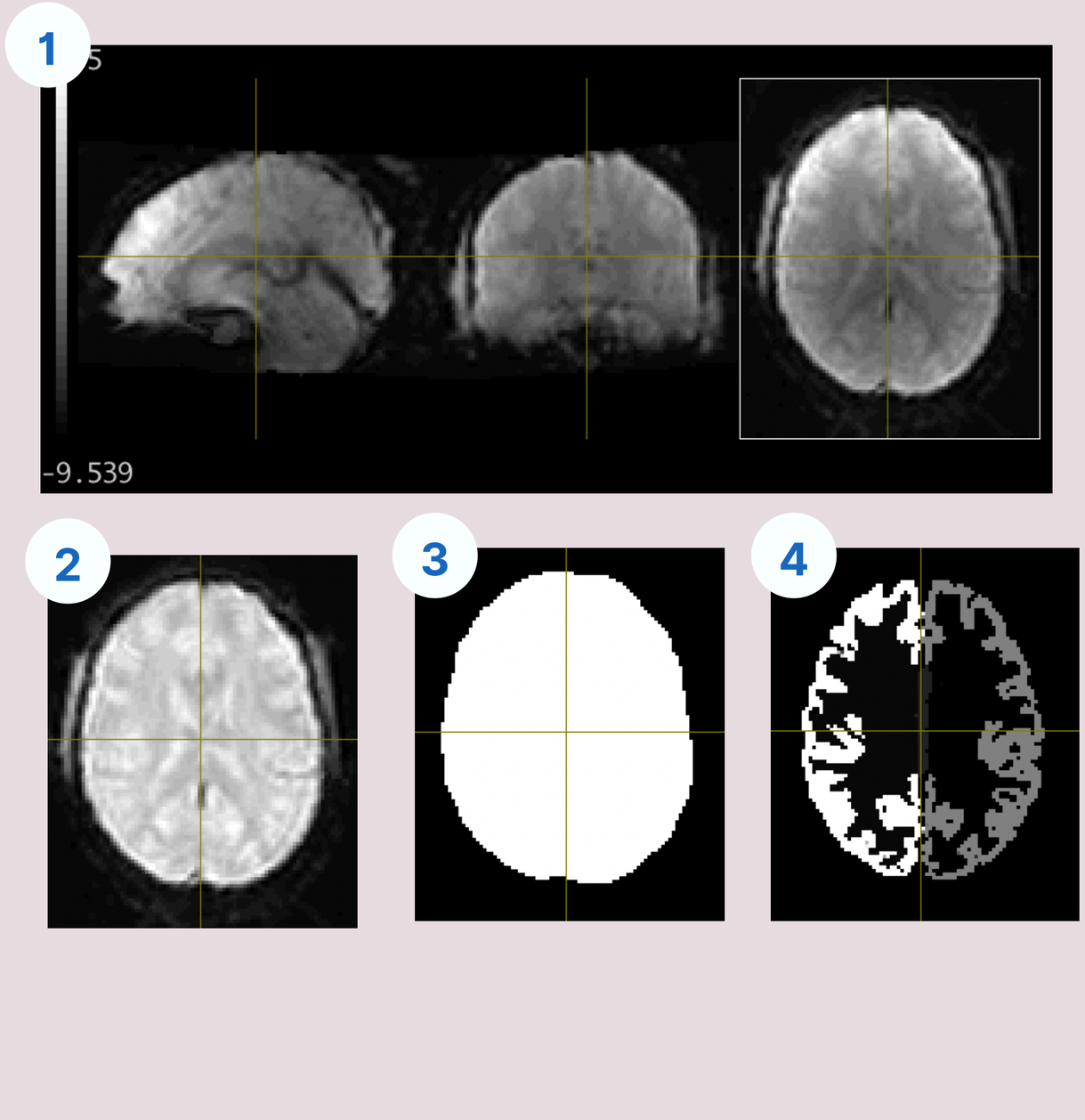
07

Normalization

Concatenates and applies all the transforms to map BOLD and T1w onto standard space

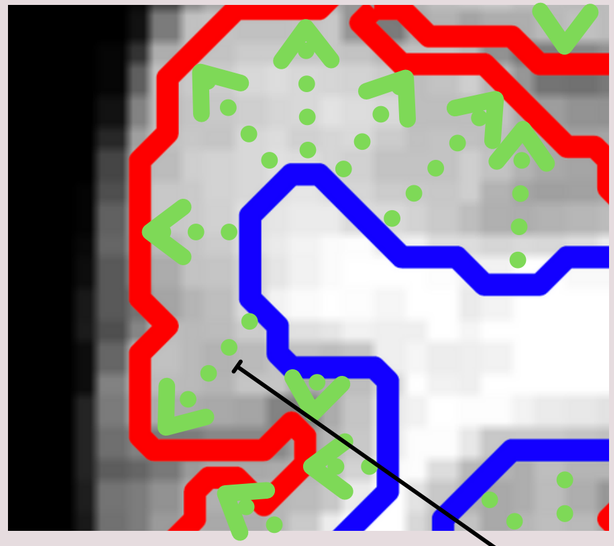
- Simultaneously applies the transforms calculated by Head Motion Estimation, Susceptibility Distortion Correction, Co-Registration, and T1w Normalization
- Outputs normalized:

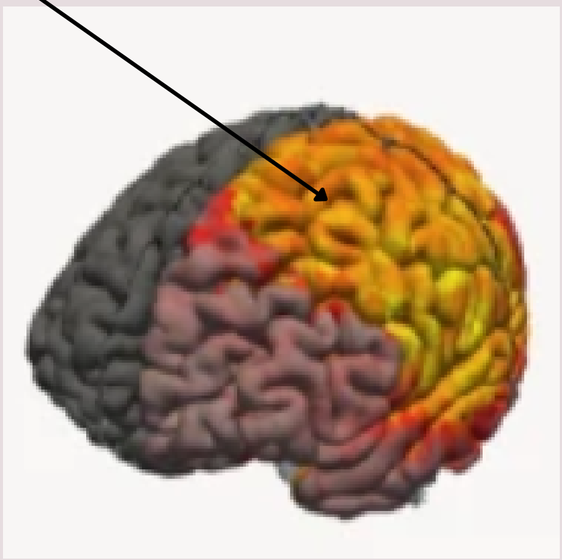
1. fMRI (BOLD) series
2. BOLD reference
3. T1w brain mask
4. FreeSurfer surfaces



08

Sample BOLD to Structural Surfaces





Adapted from Esteban et al, 2019

BOLD timeseries is aligned to the cortical surfaces by averaging across the cortical ribbon

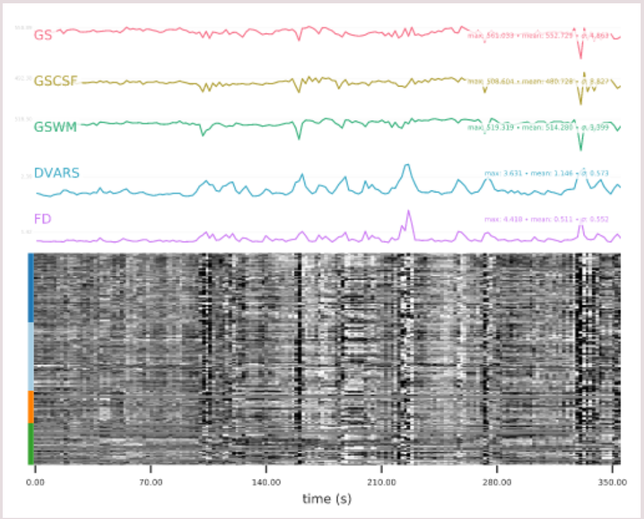
- Uses *mri_vol2surf* from FreeSurfer
- Calculated for native space and fsaverage (FreeSurfer's standard space)

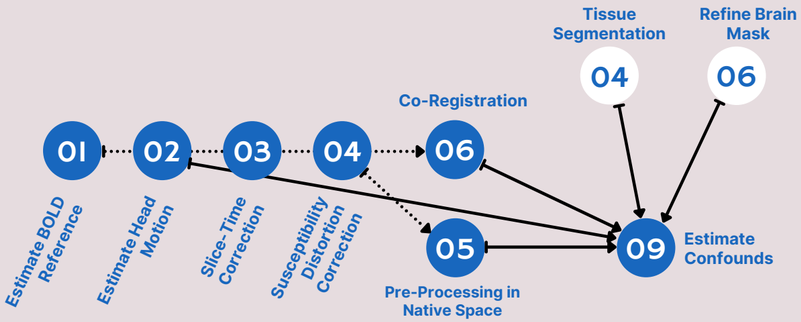
09

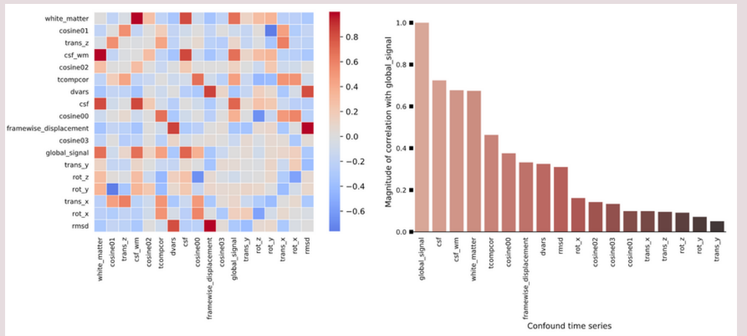
Estimate Confounds

Identifies many sources of potential noise in the signal that you can choose if/how to resolve:

- Mean signals (global and for each tissue type)
- Frame-wise Displacement
- 6 motion parameters
- Spike regressors
- Temporal and Anatomical CompCore
- DVARS
- ICA-AROMA





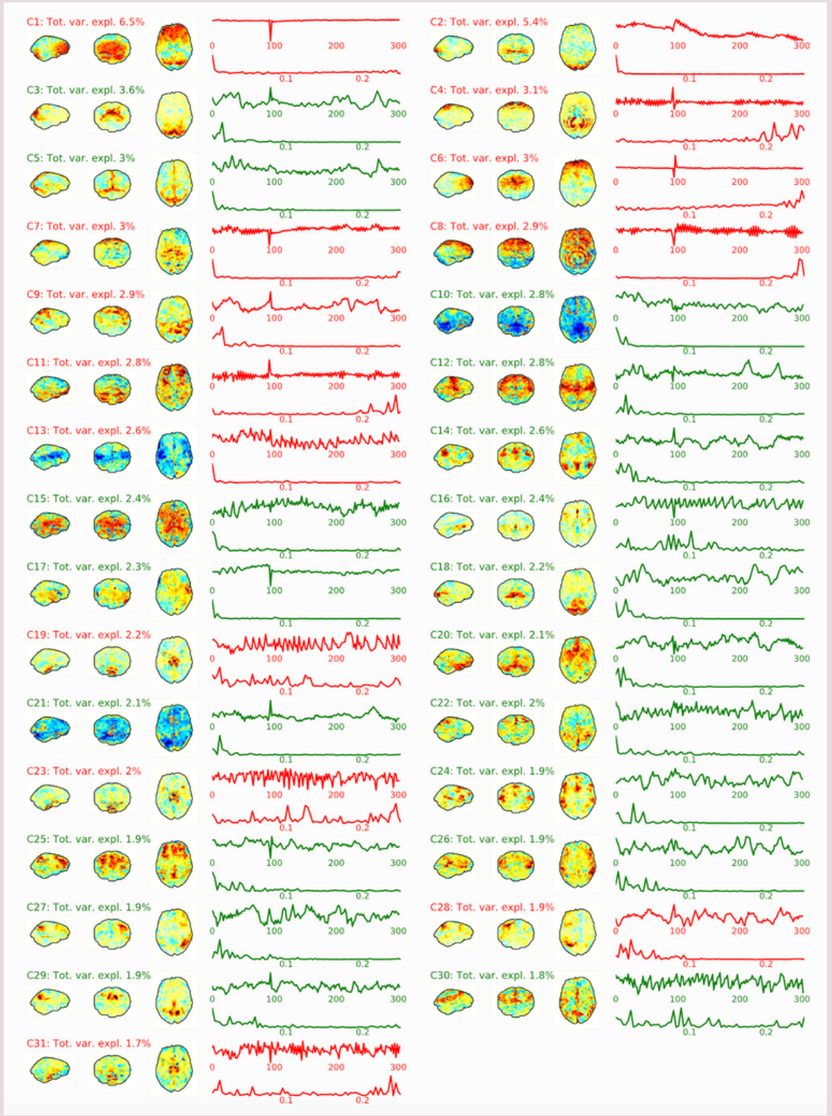


09

ICA-AROMA

Sub-workflow of Confound Regression that uses independent component analysis (ICA) to identify and remove signal caused by head motion

- Applies non-aggressive denoising to normalized BOLD data
- Calculated for both native space and normalized BOLD
- Provides confounds to run aggressive denoising if desired



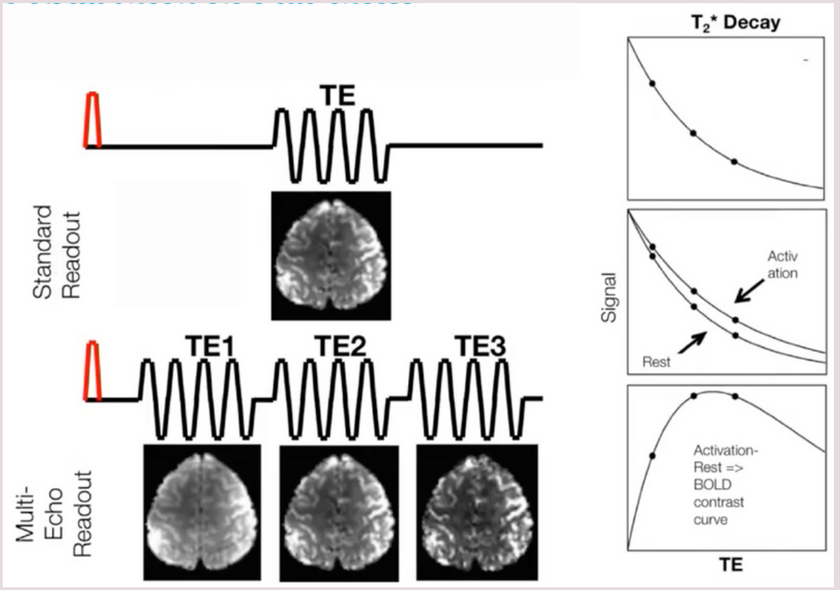
fMRIPrep Sample Report

#

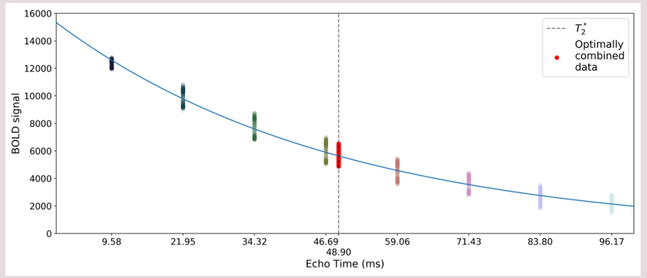
T2*-driven Echo Combination

Uses multi-echo data to create a T2* map then optimally combines echos into a single BOLD time series

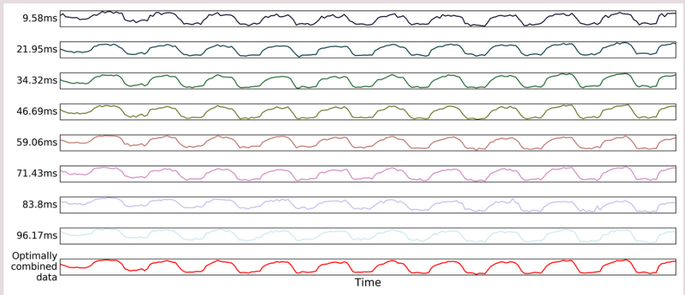
- Integration of part of tedana
- Estimates T2* for each voxel to create a map
- Uses a weighted average to compute BOLD at each voxel's optimum TE



Adapted from Kundu, P, 2017



tedana developers, Revision 4d5c6456



Thanks!

Tinashe Tapera
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Matt Cieslak
Azeez Adebimpe
Adam Pines
Dan Wolf
Ted Satterthwiate

and everyone for listening!

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