



Optimizing MRI Pre-processing Pipelines: Tool Selection and Workflow Design

A practical guide for designing robust data processing pipelines

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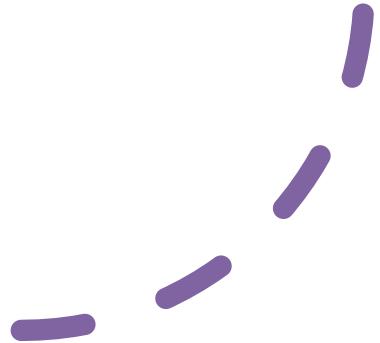
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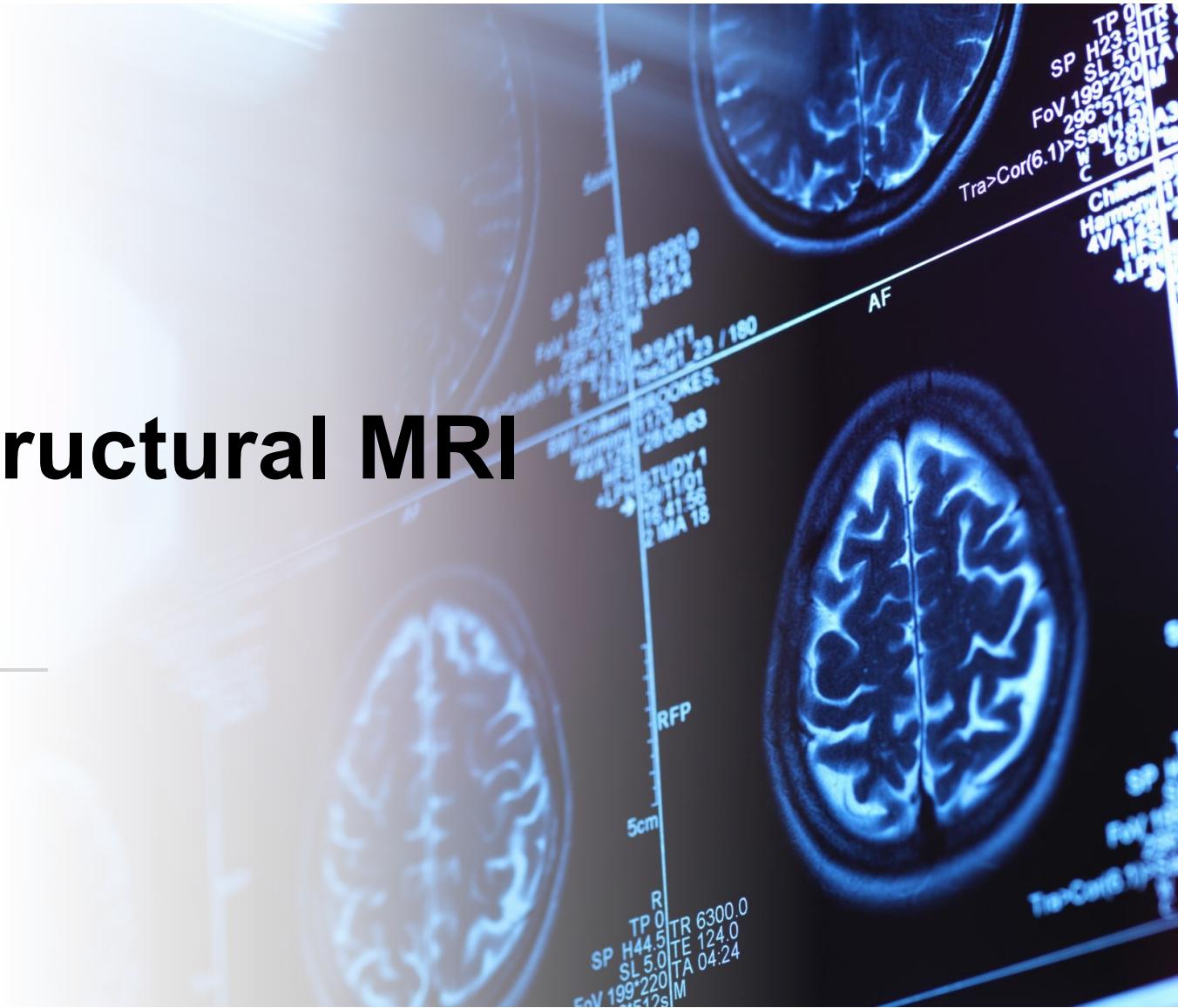
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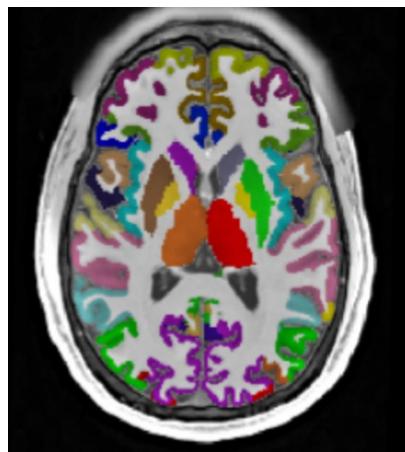
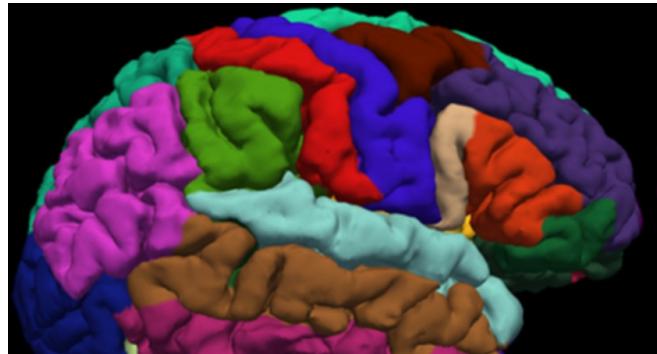
Overview

- **Goal:** Selecting optimal tools for MRI processing pipelines
 - Focus on two major modalities:
 - T1-weighted Structural MRI
 - Diffusion MRI
 - Emphasis on tailoring tools to research objectives
 - Hardware/software considerations
 - Summary



Part 1: T1 Structural MRI





Some Common Goals of T1w Image Processing

- Cortical reconstruction & thickness analysis
- Structural segmentation
- Tissue classification
- Registration
- Voxel-based morphometry (VBM)

Available Tools for Processing T1w MRI



Tool	Strengths	Use Case
FreeSurfer	Cortical surface parcellation	Longitudinal studies, cortical thickness analysis, subfield seg
FSL	HPC/GPU ready, FAST, MIST	basic morphometry, vertex analysis, atlases
SPM	Statistical analysis, segment, DARTEL, lots of toolboxes and templates	Statistical group analysis, tissue segmentation and normalization
ANTs	Powerful registration Syn	Custom template creation, image normalization
CAT12 (SPM toolbox)	VBM analysis	VBM pipelines with quality control

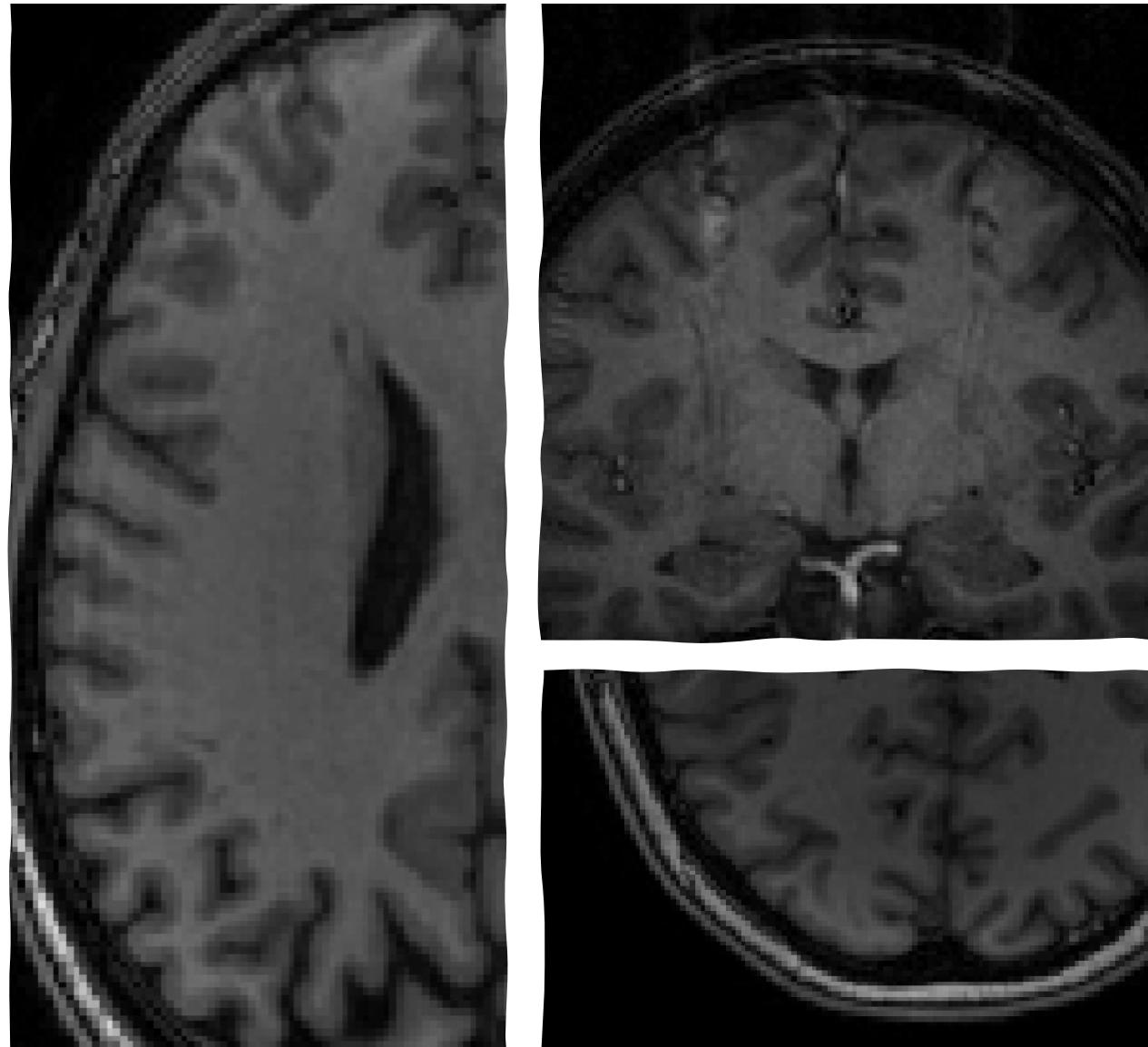
Sample T1 Pipeline

*Before any post-processing begins, determine if there are artifacts to be managed!

1. Check scan quality -- Artifacts

Artifact Type	Source	Description	Implications
Motion	Patient	Caused by head movement during scanning.	Blurring or ghosting of structures.
Field inhomogeneity	Scanner	Uneven magnetic field.	Variability in image brightness across the image.
Gibbs ringing	Scanner (reconstruction)	Undersampling or limited k-space acquisition.	Oscillating intensities at sharp edges.
Ghosting	Scanner (FOV-related)	Anatomy outside the field-of-view folds into the image.	Overlapping structures from outside FOV.

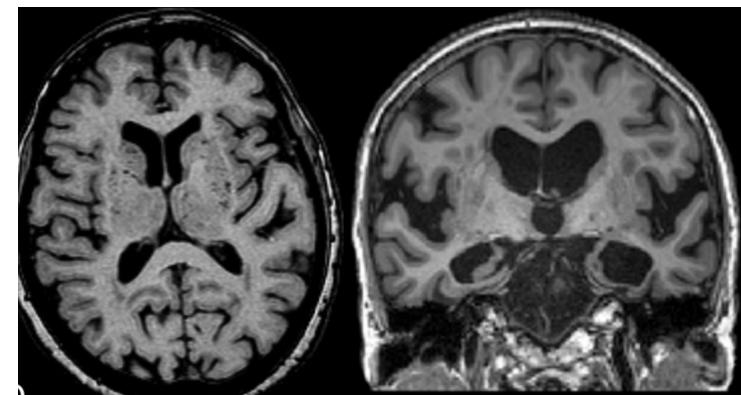
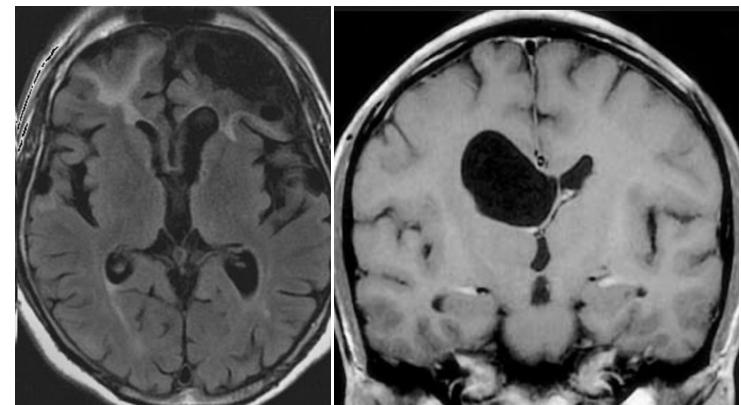
Some Artifacts from T1w



Sample T1 Pipeline

1. Check scan quality -- abnormal findings:

- Tissue loss due to stroke, surgery or Trauma
- Enlarged ventricles
- Hypointense signal in WM due to MS, PVS etc
- Hippocampal atrophy

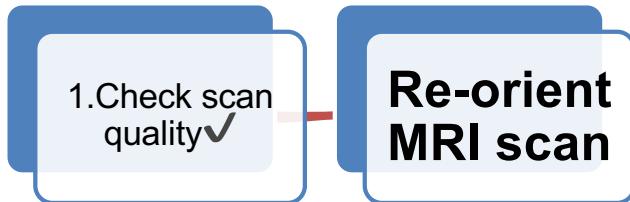


Sample T1 Pipeline

1. Check scan quality -- image quality metrics (MRIQC):

contrast-to-noise ratio (CNR)	how separated are the tissue distributions of GM and WM
signal-to-noise ratio (SNR)	tissue contrast to the background
EFC	ghosting and blurring
fwhm	spatial distribution of the image intensity, related to the blurring

Sample T1 Pipeline



Radiological vs Neurological

Axial vs Sagittal

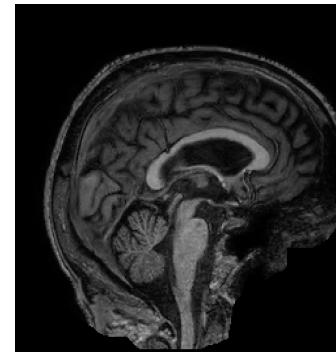
Storage order	Radiological
X voxel orientation	Right - Left
Y voxel orientation	Posterior - Anterior
Z voxel orientation	Inferior - Superior

Sample T1 Pipeline

1. Check scan
quality ✓

2. Re-orient MRI
scan ✓

**Crop
image**



Sample T1 Pipeline

1. Check scan quality ✓

2. Re-orient MRI scan ✓

3. Crop image ✓

Skull-stripping

mri_synthstrip from Freesurfer v7



default

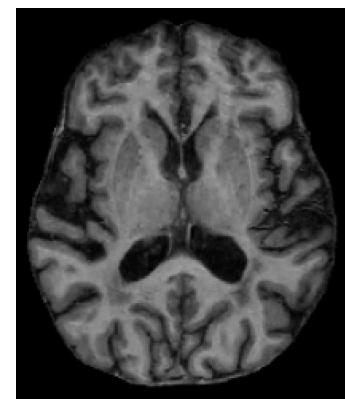
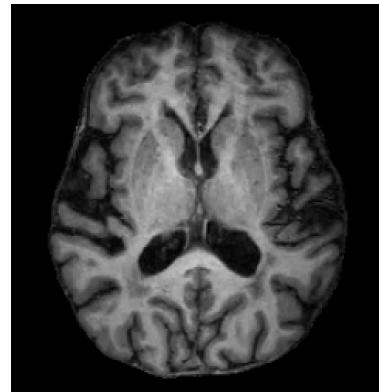


No-CSF

Sample T1 Pipeline



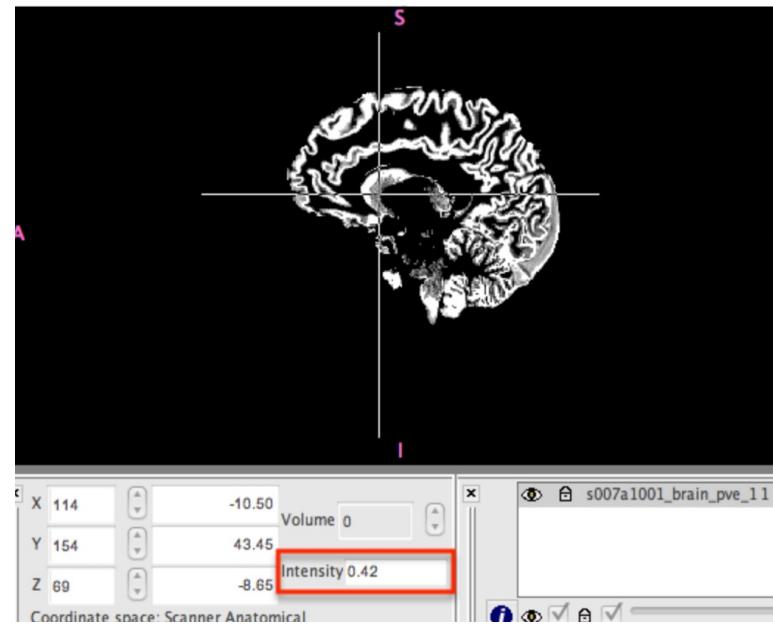
N4 vs N3



Sample T1 Pipeline



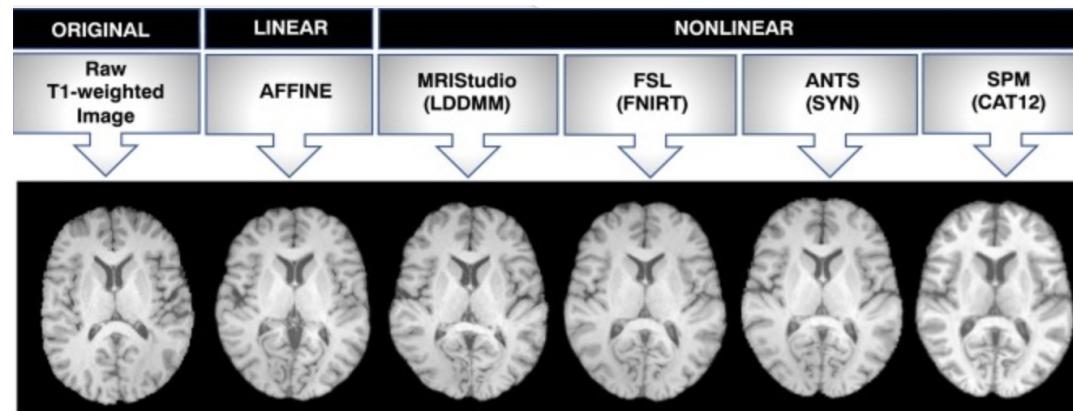
FSL FAST or SPM Segment



Sample T1 Pipeline



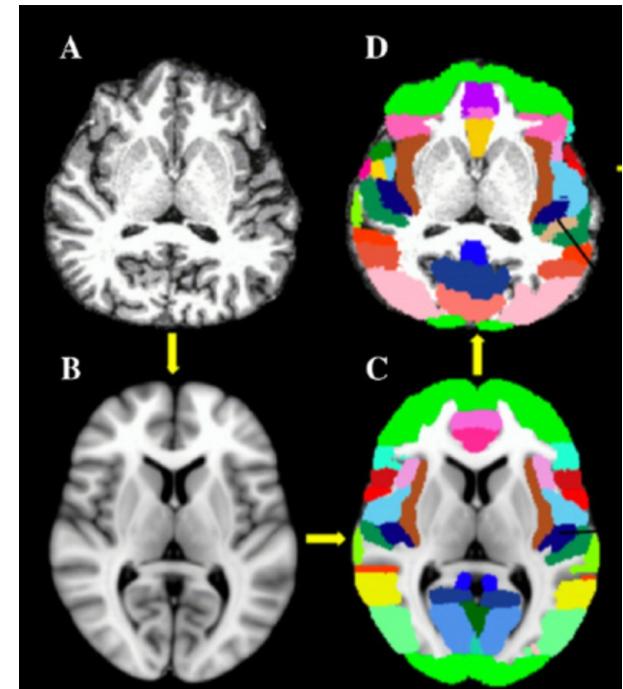
SyN (ANTs), FLIRT/FNIRT (FSL), DARTEL (SPM)



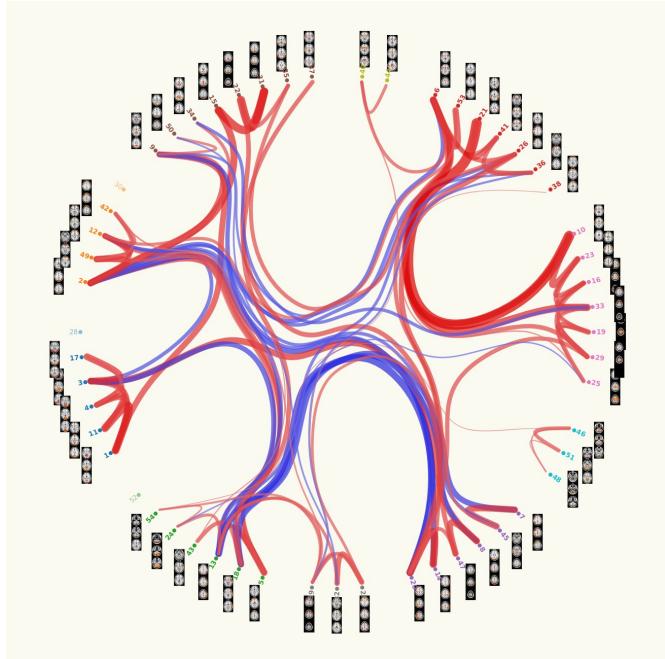
Sample T1 Pipeline



- Harvard-Oxford cortical and subcortical structural atlases
- Talairach atlas
- MNI structural atlas
- Probabilistic cerebellar atlas
- ...

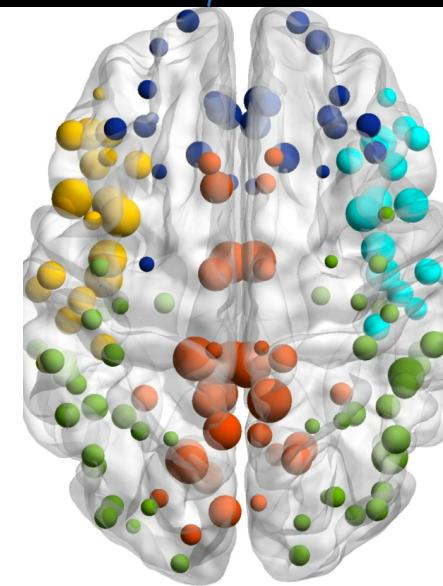
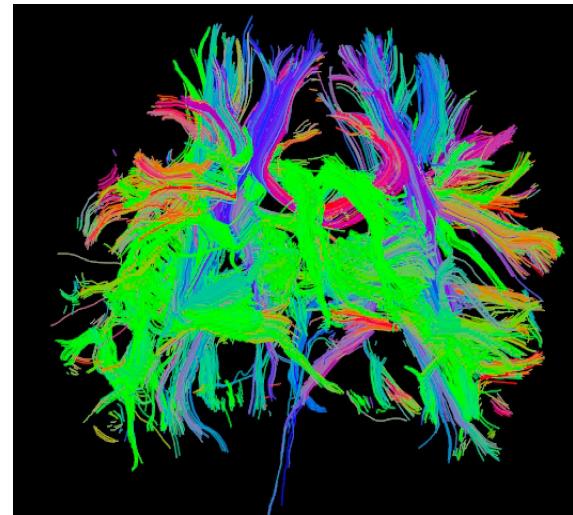


Part 2: Diffusion MRI



Some Common Goals of Diffusion Processing

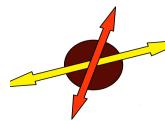
- Tensor (FA, MD, AD and RD)
- Fiber tractography
- Neurite Orientation Dispersion and Density Imaging (NODDI)
- Structural connectome
- Constrained Spherical Deconvolution (CSD)
- Diffusion Kurtosis Imaging (DKI)
- Diffusion Spectrum Imaging (DSI)
- ...



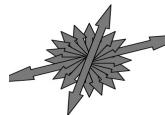
Diffusion Models



DTI / DKI



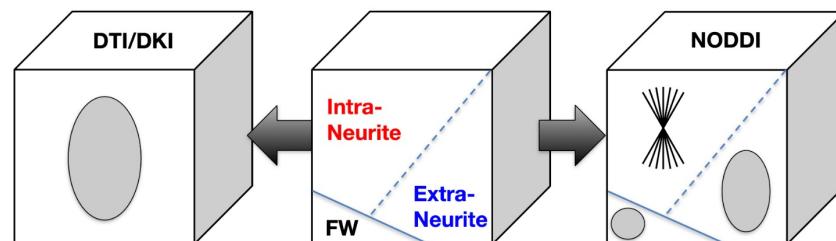
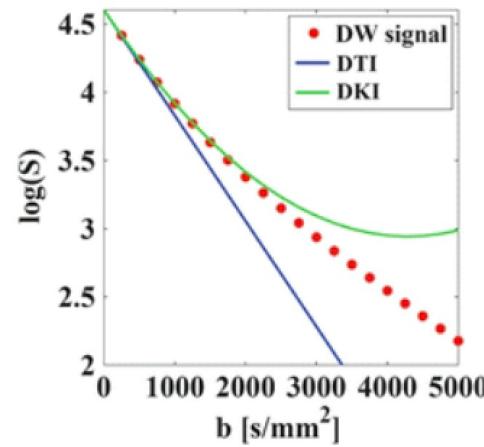
Ball-and-stick



ODF (CSD)



DSI



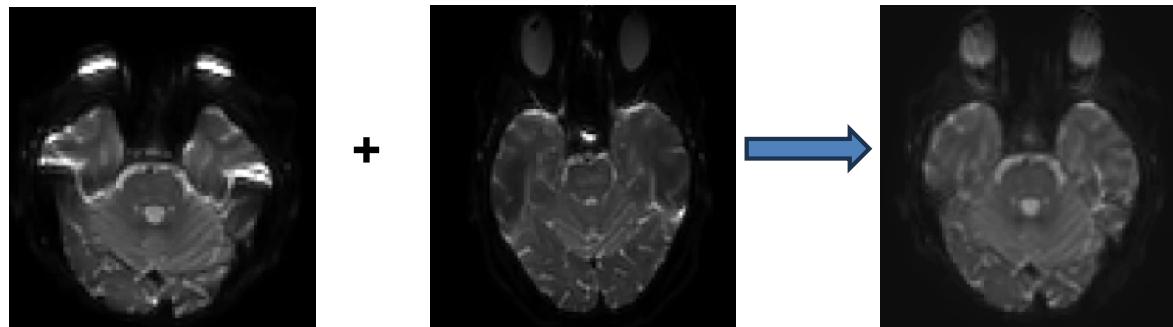
Available Tools for Processing Diffusion MRI

Tool	Strengths	Use Case
FSL	distortion correction (Topup/eddy), tractography, QC Preprocessing & standard DTI, TBSS, XTRACT	
MRtrix3	fixel analysis, CSD tractography	Advanced fiber modeling
DIPY	Python-based diffusion tools	Custom pipelines, denoise, CSD, DSI, DKI, RESTORE
DTI-TK	Spatial normalization	Custom atlas construction
AMICO	microstructure	NODDI
3D-Slicer	Visualization and processing	presentation and education
TrackVis	Track visualization and analysis	track analysis and visualization

Sample Diffusion Pipeline

1. Motion and distortion correction

- Reduce susceptibility artifacts (FSL Topup)



No Topup scan! No field map! → ??

Sample Diffusion Pipeline

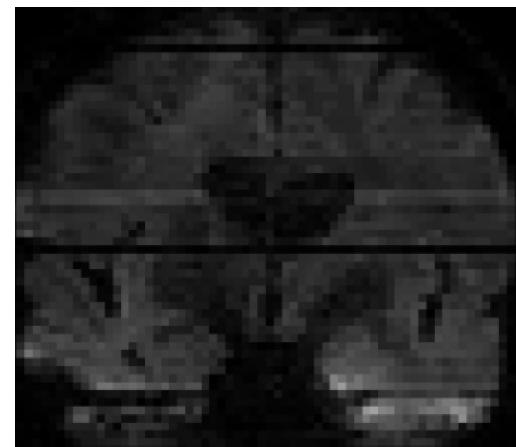
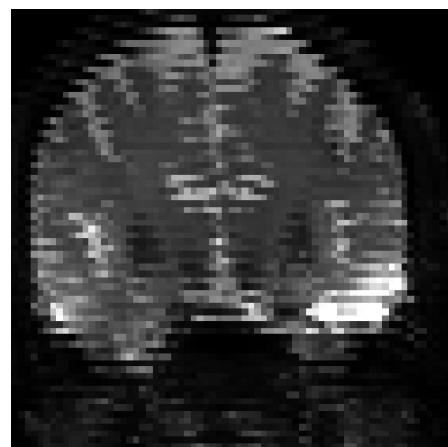
1. Motion and distortion correction

- Reduce motion artifacts (FSL eddy)

Intra-volume movement

Inter-volume movement

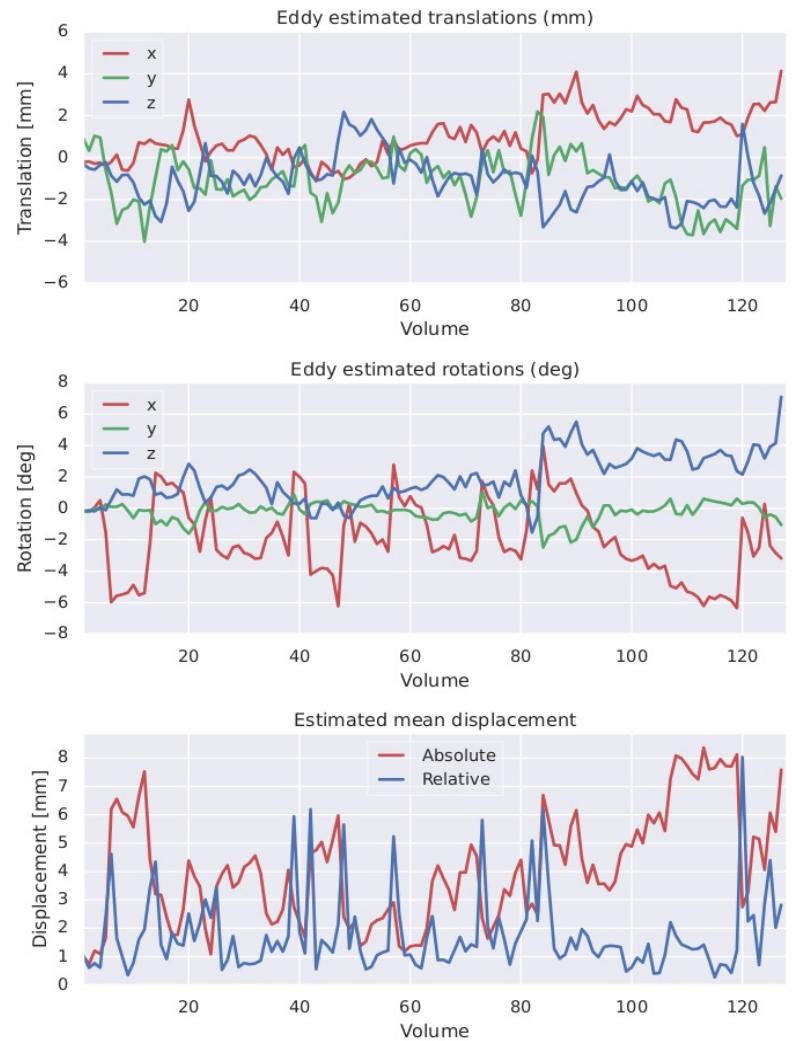
Outlier slices



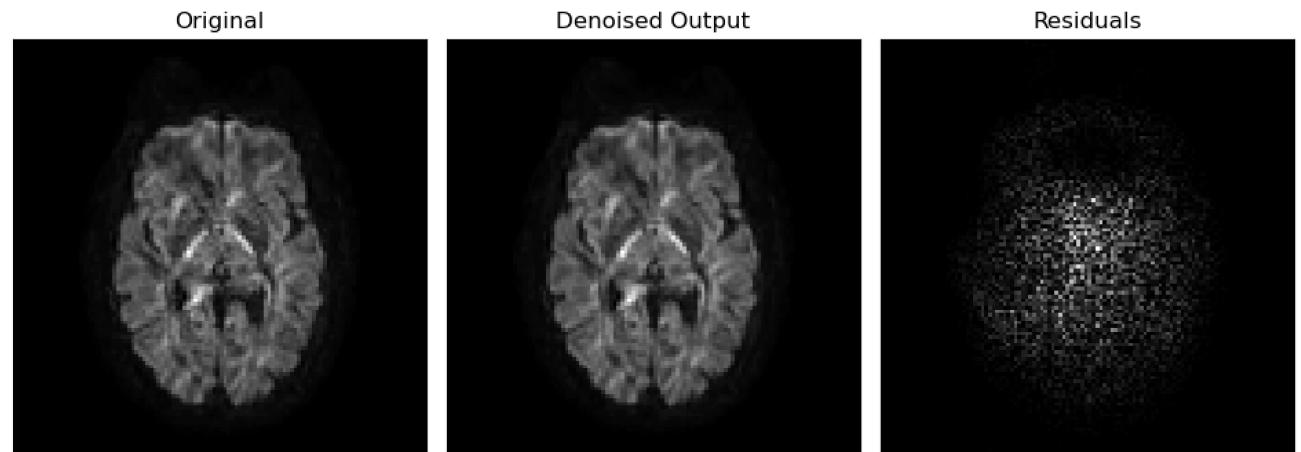
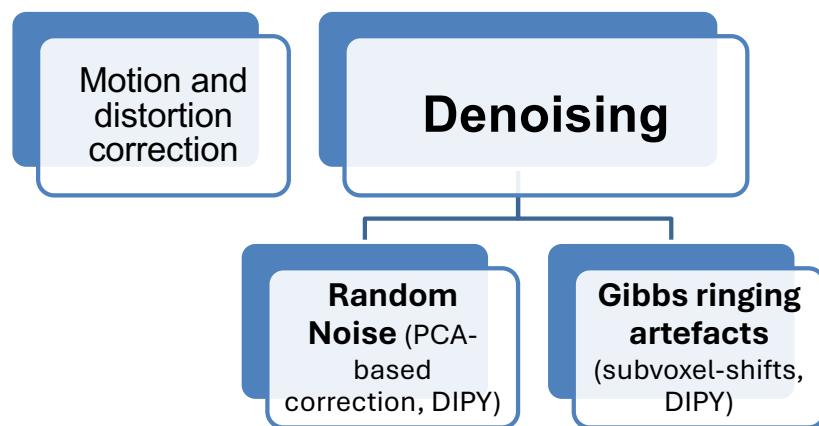
Sample Diffusion Pipeline

1. Motion and distortion correction

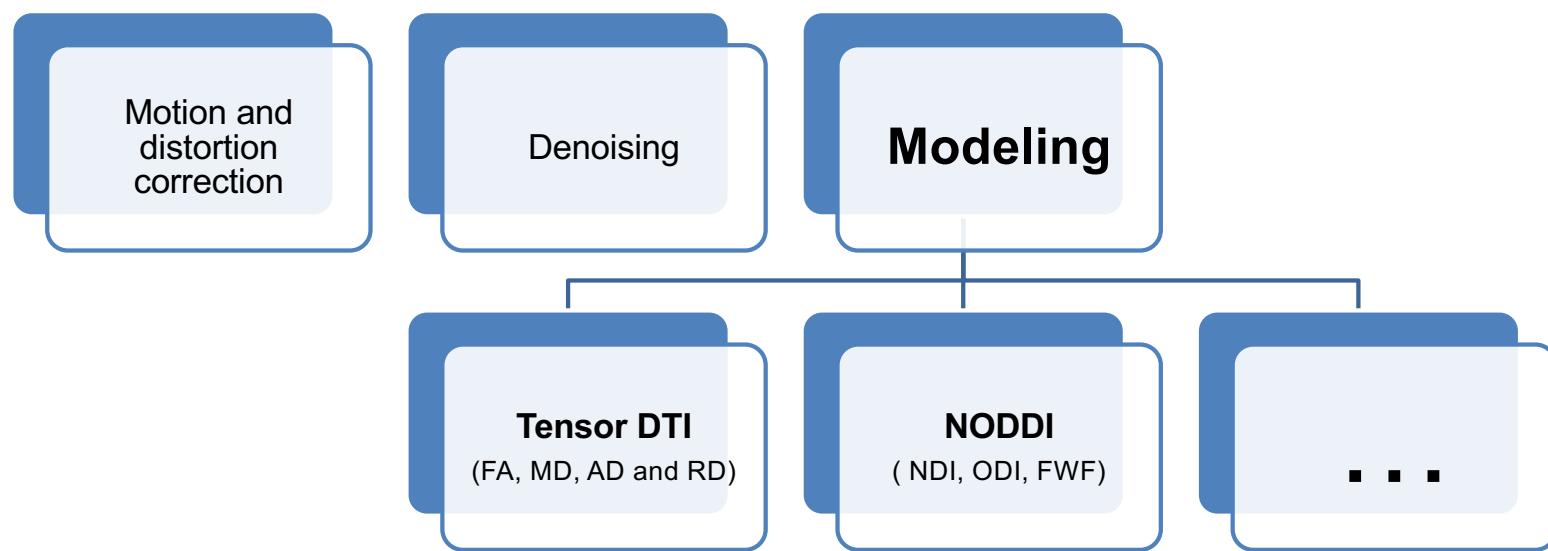
- Quality check artifact and movement after eddy (FSL eddy_quad)
- Exclude scans with mean displacement > 2 mm
- Check ghosting and bright/blank/half blank slices
- The quality of first B0 volume



Sample Diffusion Pipeline



Sample Diffusion Pipeline

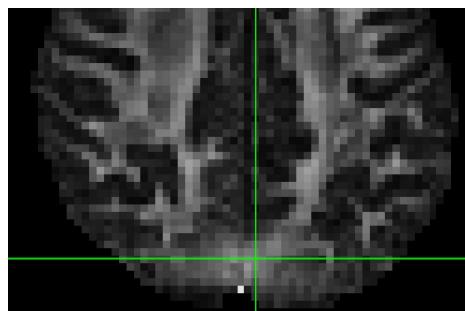
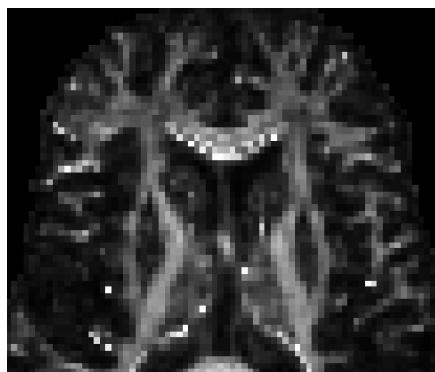


Check FA image

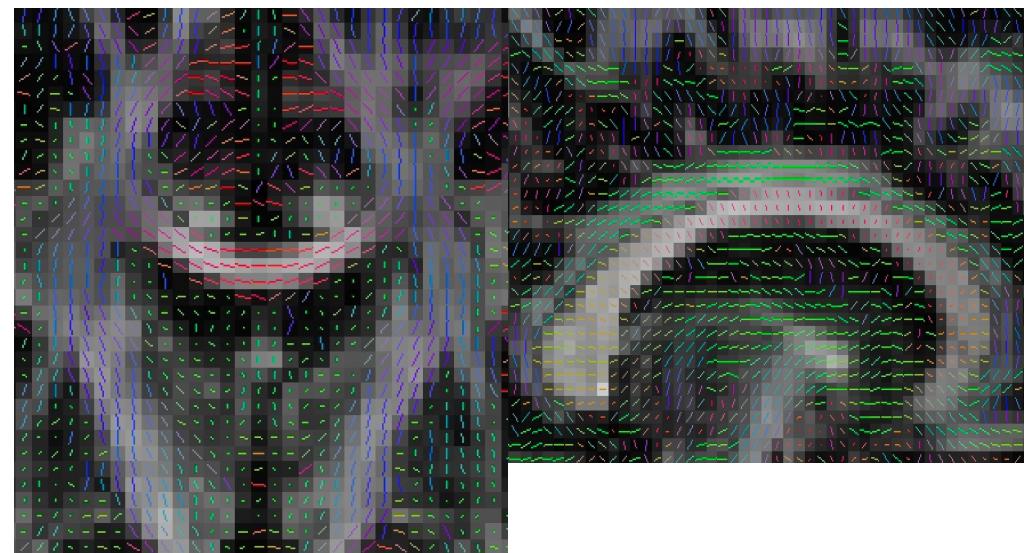
Motion and distortion correction

Denoising

Modeling

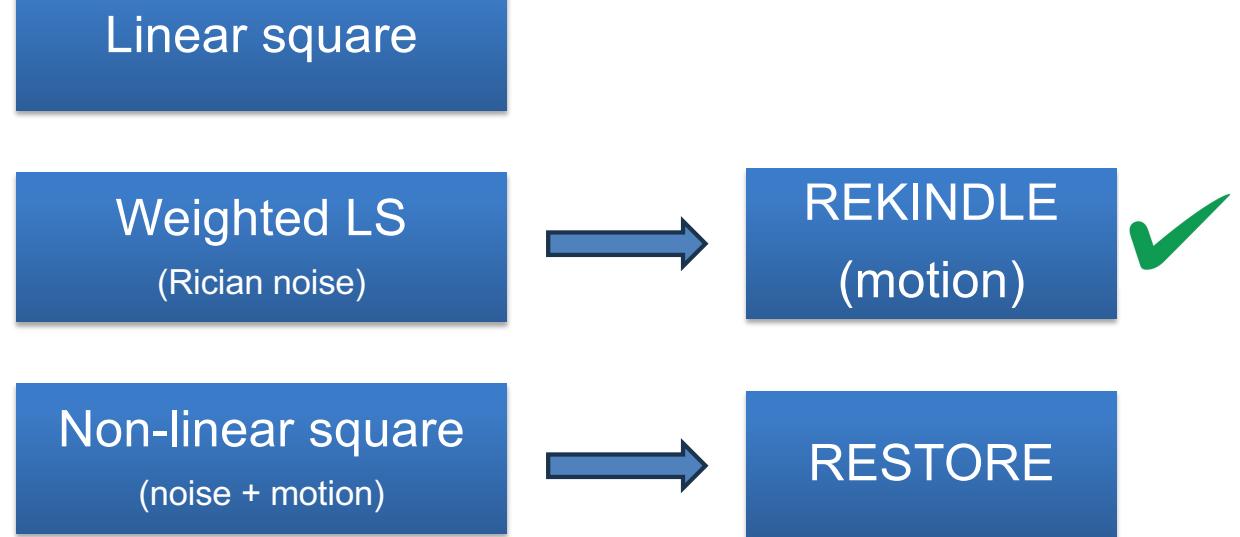


Abnormal FA

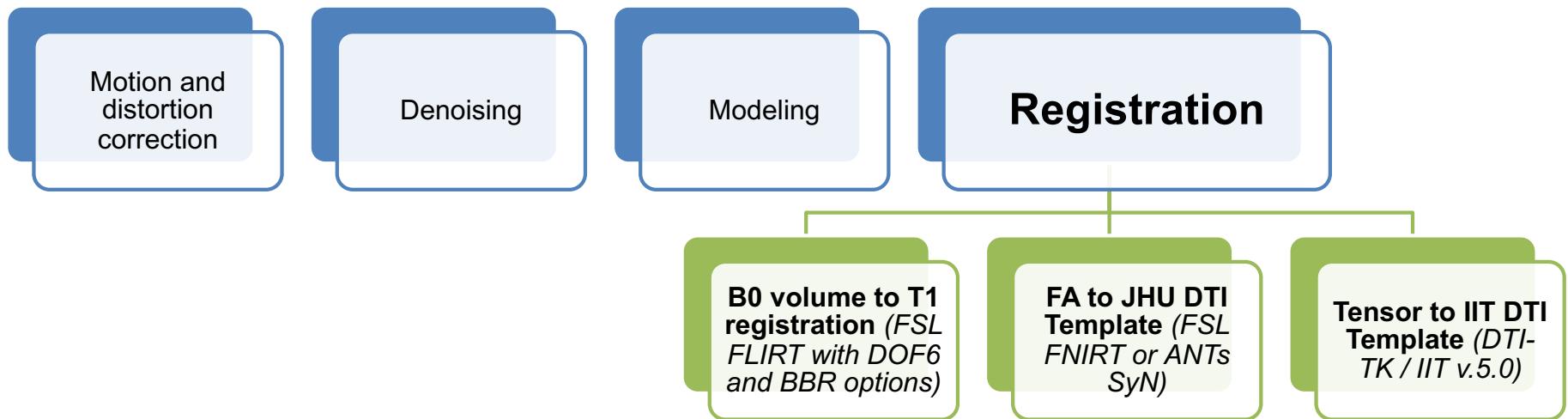


Fiber direction

Tensor Fitting

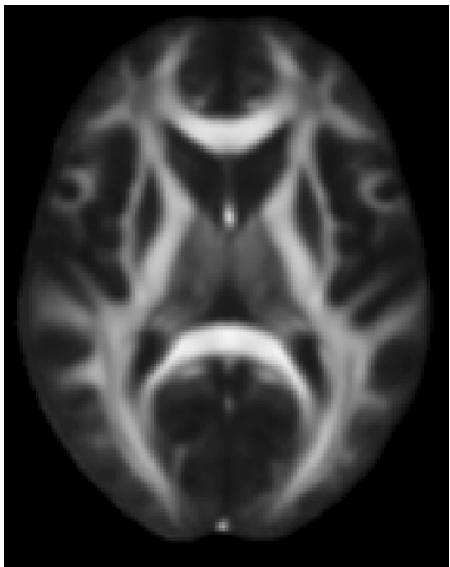


Sample Diffusion Pipeline

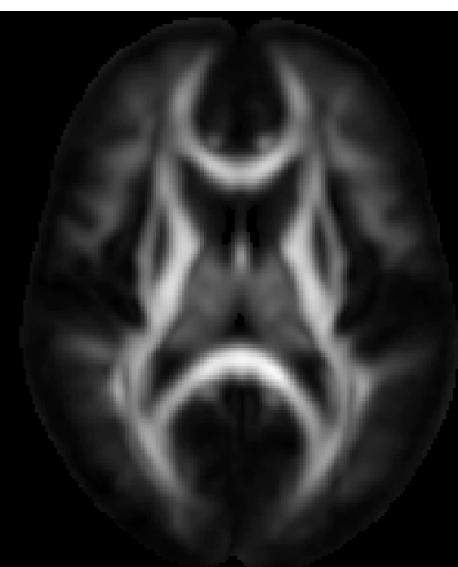


DTI brain templates

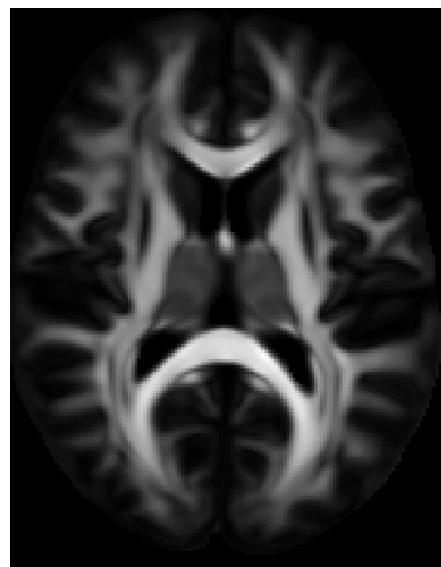
FMRIB58



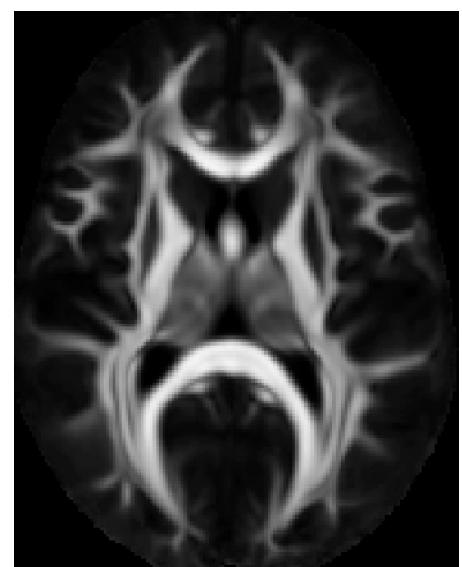
JHU-ICBM-81



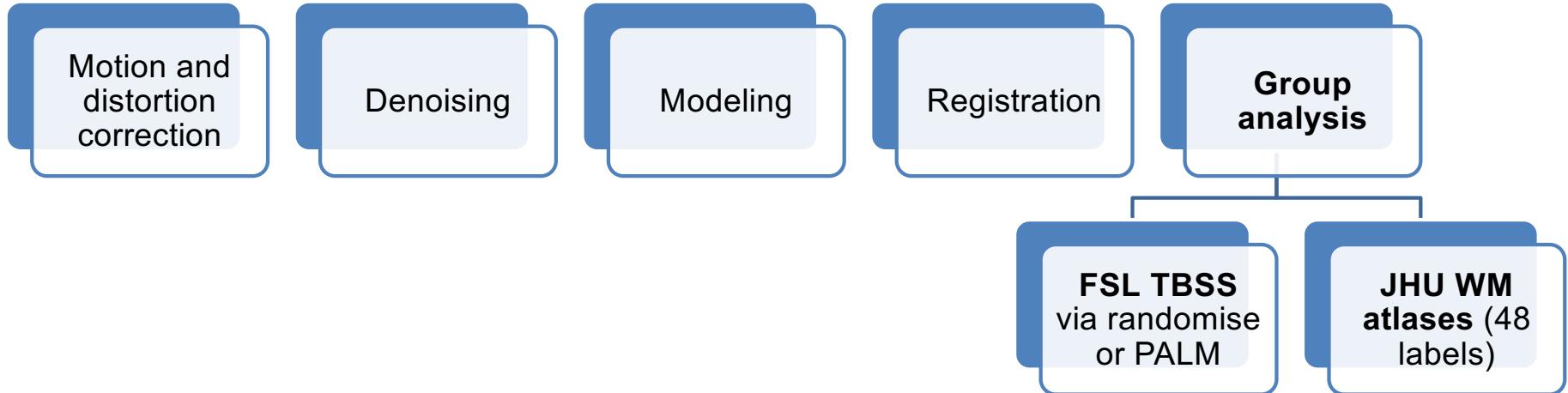
HCP1065



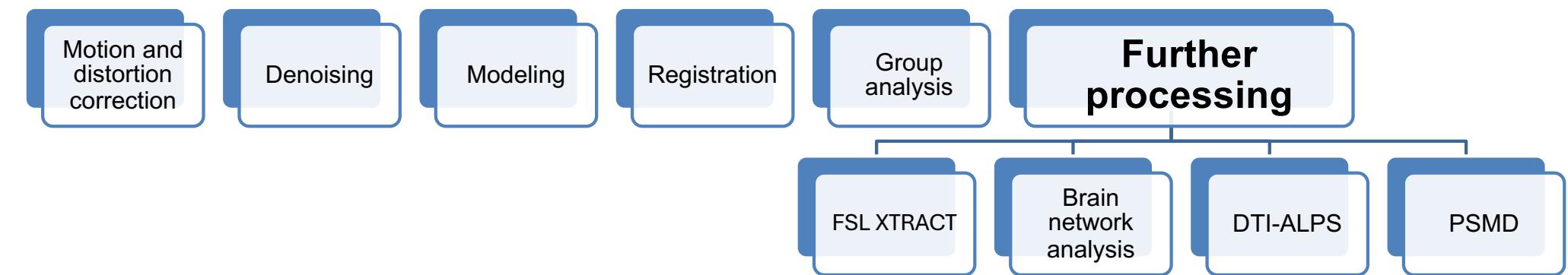
IIT



Sample Diffusion Pipeline



Sample Diffusion Pipeline



Hardware / Software Considerations



Single Powerful Desktop: only for small projects



HPC: command-line for automation and reproducibility, perfect for large project
fsl_sub (SGE and SLURM)



GPU: speeds up computing
FSL: eddy/bedpostx/probtrackx
Deep learning algorithms



Command-line and /or GUI



Programming languages
Linux shell scripts, Python, MATLAB ...



Operating System
Linux (Ubuntu LTS or Mac)

Summary - Choose the Right Tools Thoughtfully

- **No one-size-fits-all** — align tools with:
 - Study design (cross-sectional vs longitudinal)
 - Desired output (volumes, surface maps, tractography, etc.)
 - Data quality & resolution
 - Use GUI tools for QC and command-line for scalability
 - Combine tools to maximize strengths



Summary - Quality Check at Every Step

- **Raw Image QC:** Orientation, motion, artifacts (using MRIQC and manual inspection)
- **Skull stripping:** Visual confirmation
- **Segmentation:** Check for over/under-segmentation
- **Registration:** check alignment
- **Tractography:** Check for anatomically implausible tracts

Summary - Other tips

- Reduce motion from the source (on the scanner) as you can
- Combine all transforms into one to reduce blurring due to interpolation (FA → T1 → MNI).
- Always use same hardware, same OS and same software versions for one project
- Try on small scale → large scale implementing

Summary – File Format Issue!!

- **Volume:** .img/.hdr, nii, nii.gz, mgh/mgz, .mih/.mif, minc, par/rec, nrrd, etc
- **Surface:** gii, surface/curv/w/annot
- **Transform:** .mat (FSL/ITK), .xfm, .lta, m3d

FSL and Freesurfer are fully supporting each other!

Acknowledgements

Dr Willam Honer

Dr Donna Lang

Thank you!

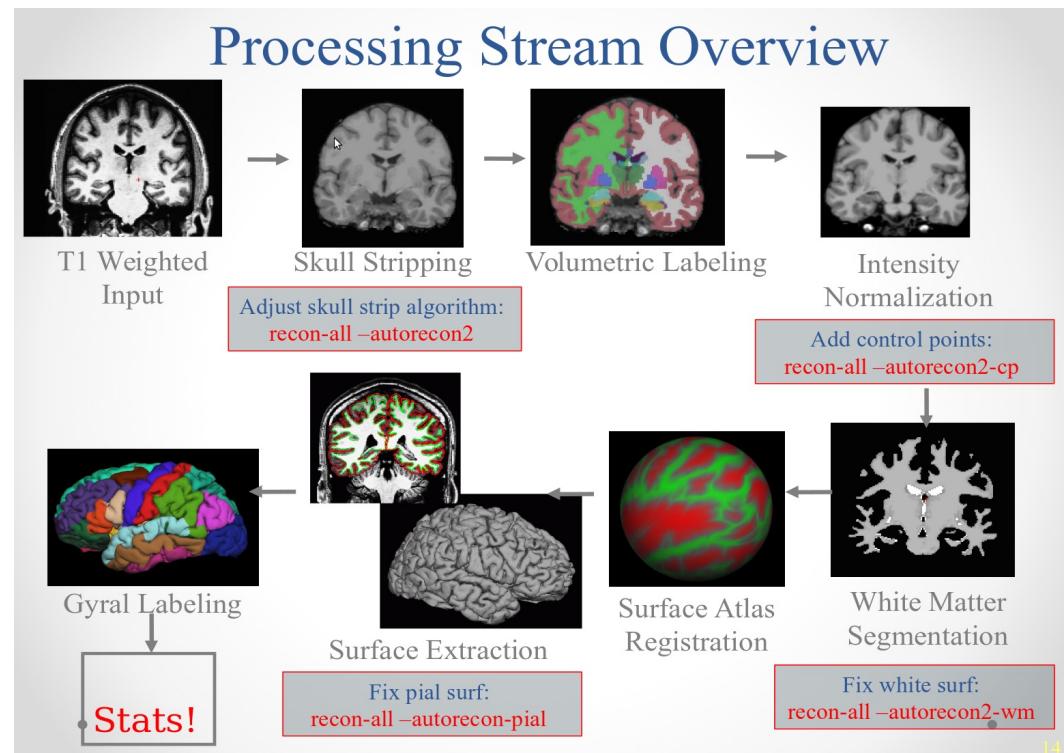
Questions?

Sample T1 Pipeline (FreeSurfer)

recon-all command (cross-section)

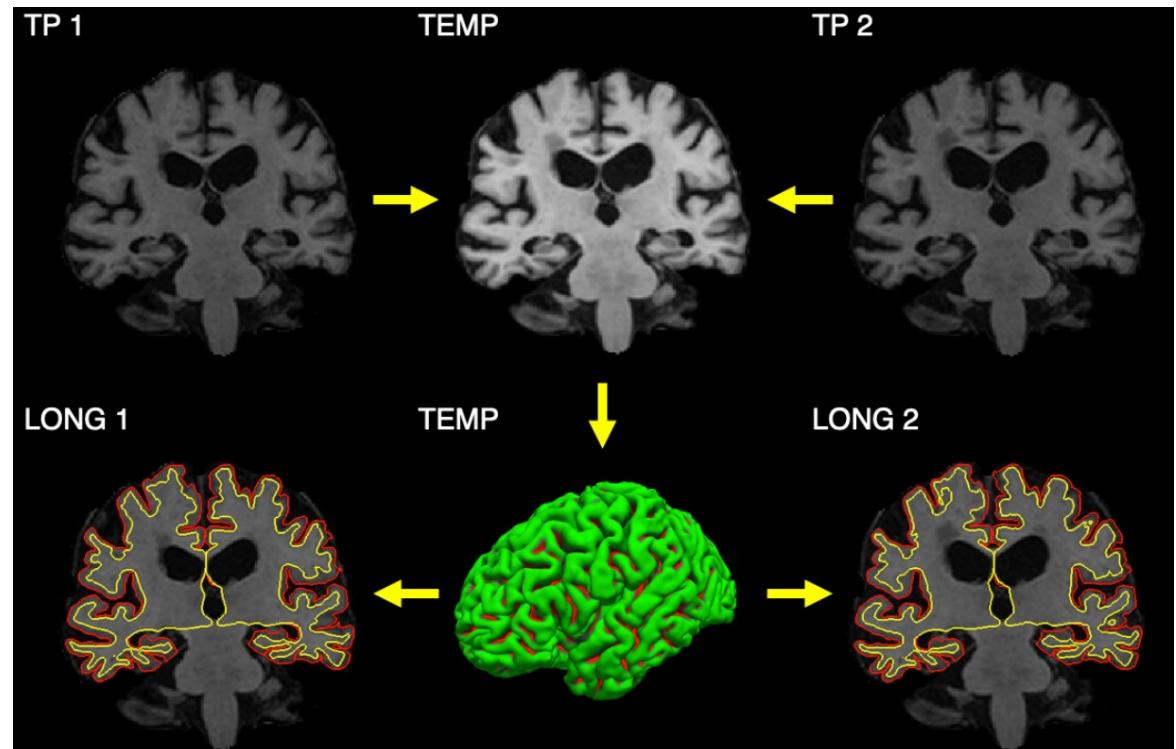
- cortical parcellation
- subcortical segmentation
- outputs: thickness, surface area, volume

T2 pial refinement
Hi-res



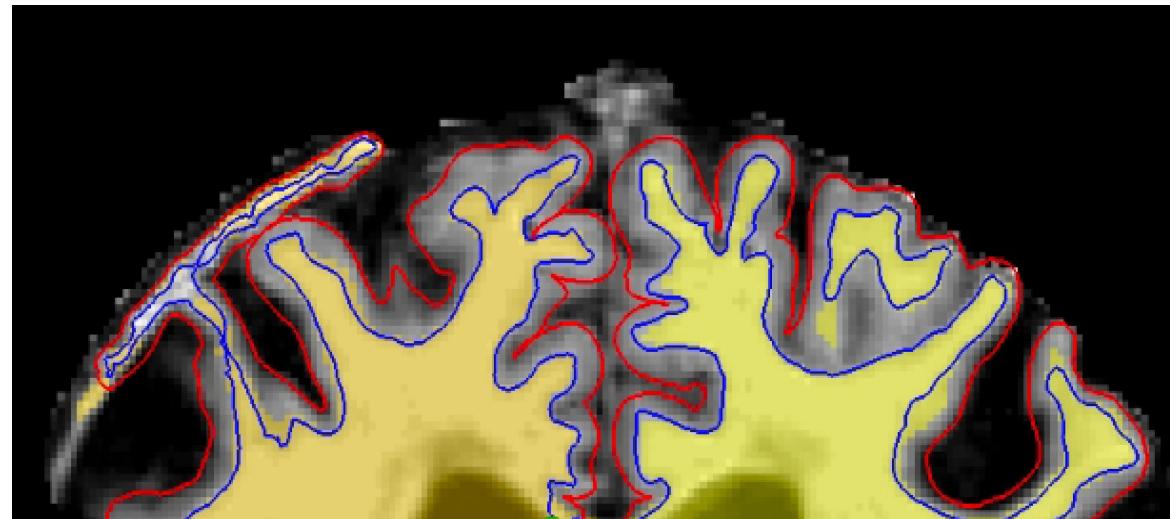
Sample T1 Pipeline (FreeSurfer)

- recon-all command (cross-section)
- **recon-all command (longitudinal)**



Sample T1 Pipeline (FreeSurfer)

- recon-all command (cross-section)
- recon-all command (longitudinal)
- **manual edits**
 - brain mask
 - pial and WM surfaces
 - subcortical segmentation



When: motion scans, patient group,
older adults

Sample T1 Pipeline (FreeSurfer)

- recon-all command (cross-section)
- recon-all command (longitudinal)
- manual edits
- **subfield segmentation**
 - Hippocampus, amygdala, thalamus and brainstem
- **surface based group analysis**
 - general Linear Model (GLM) / linear mixed effect (LME)
- **Other analysis: structural connectivity**

