Preprocessing Diffusion Tensor Imaging data

Turku PET Centre Brain Imaging Course 4.-5.10.2017
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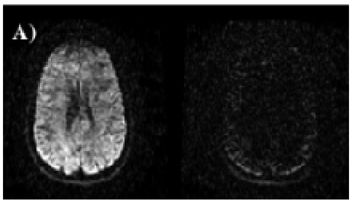
Outline

- Why should I do DTI preprosessing
- Optimizing diffusion-imaging sequences
- Preprosessing tools (and tools I use)
- Tensors

Why should I do DTI preprosessing

Artefacts: Head motion

diffusion of protons: ~10 µm
subject motion: ~ millimetre



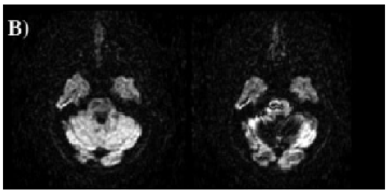
severe ghosting (shifted image duplications)
signal attenuation

Image: Liu B et al. Comparison of quality control software tools for diffusion tensor imaging 2015 (33), 3, 276-285

Why should I do DTI preprosessing

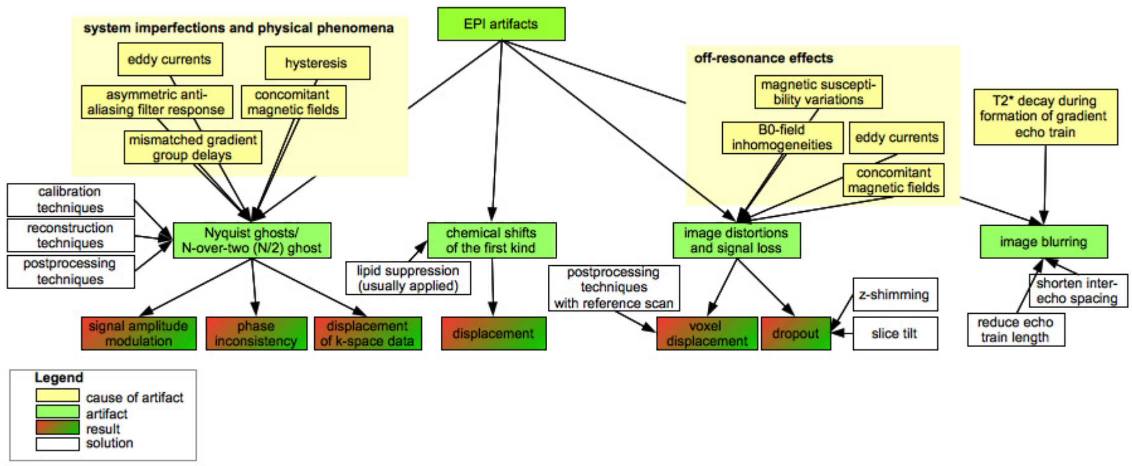
Artefacts: Cardiac pulsation

- source of bulk tissue motion.
- variable over regions of the brain.
- Signal dropout



synchronize the volume acquisition with the cardiac cycle
increase the experiment duration considerably.

Image: Liu B et al. Comparison of quality control software tools for diffusion tensor imaging 2015 (33), 3, 276-285



Chapter 16.1.4 of Bernstein et al (2004) *Handbook of MRI pulse sequences*

Optimizing diffusion-imaging sequences

- question under study & analysis of the data
- brain anatomic coverage
- specific anatomic structure

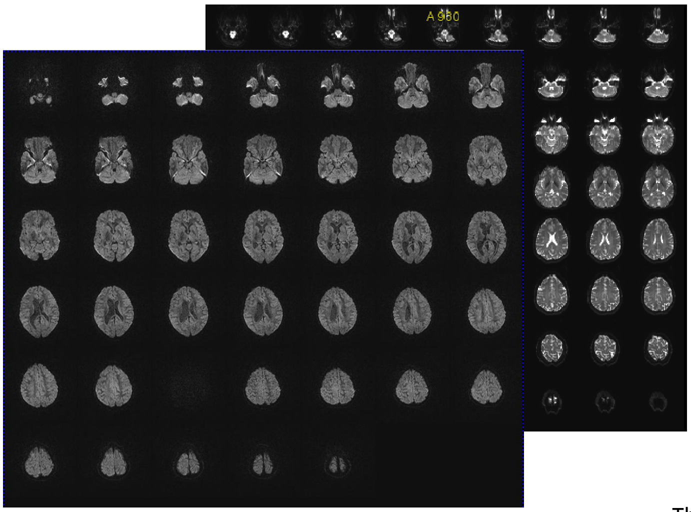
- MRI hardware configuration (vendor, field strength, coils, software)
- scanning time available
- axial slices with no gap between slices
- voxel size
- additional sequences

Imaging sequence

- Diffusion tensor estimation:
  - high b-values (e.g., 1000s/mm2) along at least 6 non-collinear diffusion encoding directions & one image with b-value (b = 0s/mm2)
  - high b-value (e.g., 1000s/mm2) along 60 non-collinear diffusion encoding directions & one image with b-value (b = 0s/mm2)
  - Super high b-value (e.g., 3000s/mm2) and high b-value (e.g., 1000s/mm2) along 60 non-collinear diffusion encoding directions & 10 images with b-value (b = 0s/mm2)

Imaging sequence: one direction

high b-value (e.g., 1000s/mm2) along 60 non-collinear diffusion encoding directions & one image with b-value (b = 0s/mm2)



Thanks for the case:
Jani Saunavaara

Imaging parameters

TR:

- The TR is long in order to reduce T1 effects and improve signal

TE:

- short TE
- Is using twice-refocused spin echo pulse longer is OK.

BW:

- low bandwidth to increase SNR
- high bandwidth low spatial distortion

Imaging parameters

Parallel imaging (phased-array head coils)

- Sensitivity Encoding (SENSE),
- Array Spatial Sensitivity Encoding Technique (ASSET)
- Generalized Autocalibrating Partially ParallelAcquisition (GRAPPA)

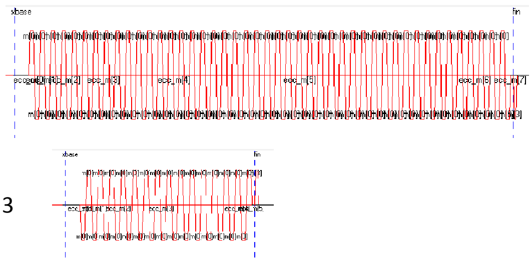
Imaging parameters

Parallel imaging → reduce the echo train →

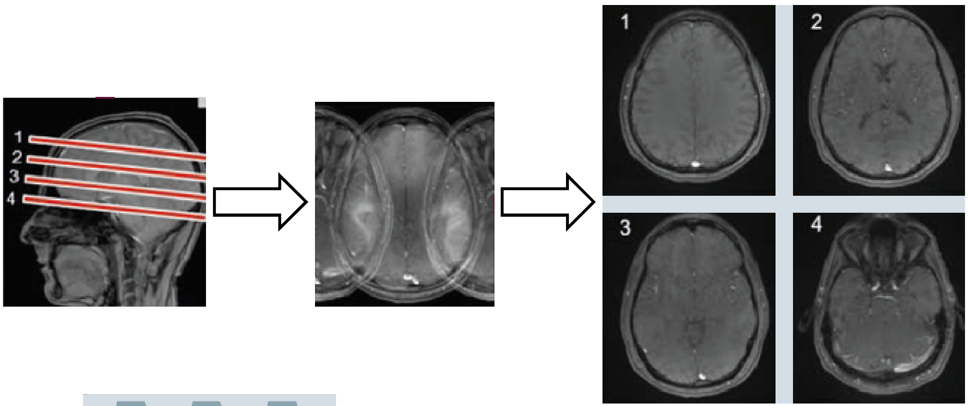
- lower sensitivity to motion
- reduced susceptibility to geometric artifacts
- reduced blurring

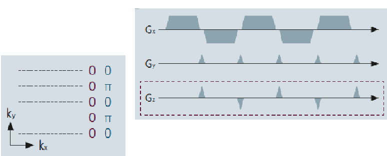
No Sense

Sense 3



- Simultaneous Multi-Slice Excitation / HyperBand / Multi-band SENSE



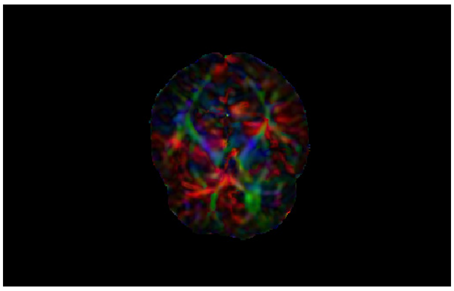


TA:6:48 (2x2x2); TR 5500 ms; TE 90 ms;
64 slices 2b values 68 dir

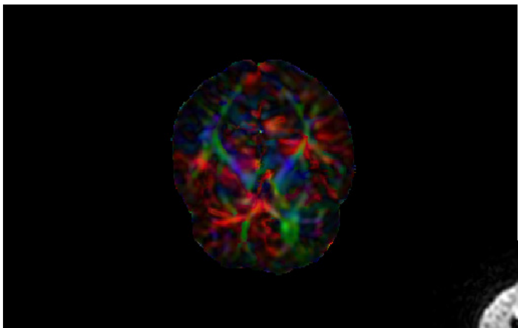
DTI preprosessing

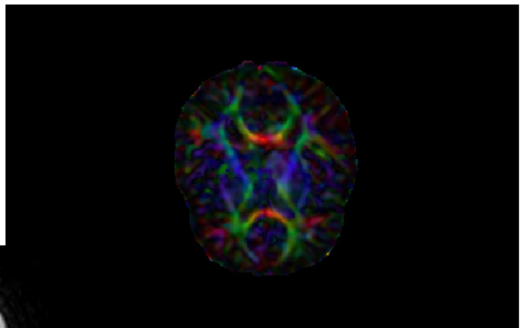
Exclude:

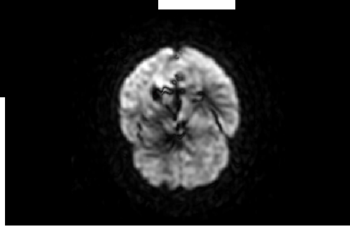
- Limit the analysis to regions without artifacts
- single slice
- affected subject
- gradient volume



DTI preprosessing







Patient was excluded from the study.

DTI tools

Table 2 | A list of the main workflow steps implemented by the common DTI tools*.

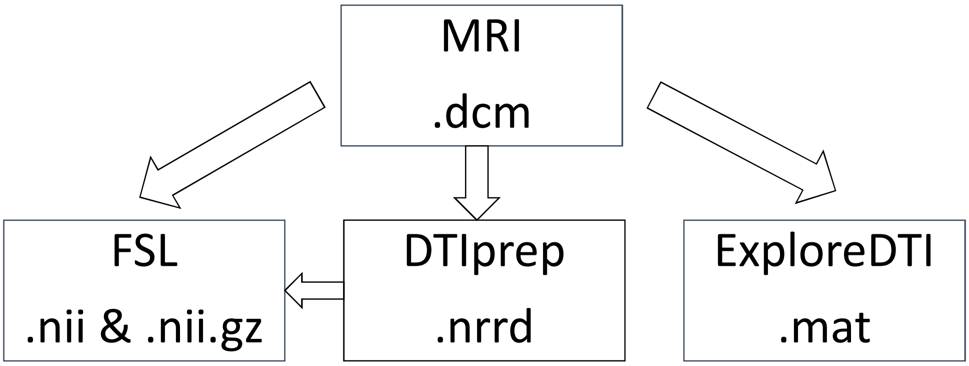
Steps \ Software	Quality control and preprocessing			Processing and visualization				Quantitative analysis			
	Outlier detection	Motion and eddy current correction/ B-matrix rotation	Skull stripping	Tensor estimation	Scalar maps	Glyphs	Tractography (deterministic/ probabilistic)	ROI	Histogram	VBA	TBSS
3D Slicer	✗	✓/✓	✓	✓	✓	✓	✓/✓	✓	✗	✗	✗
AFNI	✗	✓/✗	✓	✓	✓	✓	✓/✓	✓	✓	✓	✗
BioImage Suite	✗	✗/✗	✓	✓	✓	✓	✓/✗	✓	✗	✗	✗
BrainVoyager QX	✗	✗/✗	✗	✓	✓	✓	✓/✗	✗	✗	✓	✗
Camino	✓	✗/✗	✗	✓	✓	✓	✓/✓	✗	✗	✗	✗
Dipy	✗	✗	✗	✓	✓	✗	✓/✗	✗	✗	✗	✗
DoDTI	✗	✓/✗	✗	✓	✓	✓	✓/✗	✗	✗	✗	✗
DTIStudio	✓	✗/✗	✗	✓	✓	✓	✓/✗	✓	✗	✗	✗
ExploreDTI	✓	✓/✓	✗	✓	✓	✓	✓/✓	✓	✗	✗	✗
Freesurfer	✗	✓/✓	✓	✓	✓	✗	✗/✓	✓	✗	✓	✗
FSL	✗	✓/✗	✓	✓	✓	✓	✗/✓	✓	✓	✓	✓
JIST	✓	✓/✓	✗	✓	✓	✗	✓/✗	✗	✗	✗	✗
MedINRIA	✗	✗/✗	✗	✓	✓	✓	✓/✗	✓	✓	✗	✗
MRtrix	✗	✗	✓	✓	✓	✗	✓/✗	✗	✗	✗	✗
SATURN	✗	✗/✗	✗	✓	✓	✓	✓/✗	✓	✗	✗	✗
SPM and toolboxes	✗	✓/✓	✓	✓	✓	✗	✗/✗	✗	✗	✓	✓
TrackVis	✗	✗/✗	✗	✓	✓	✗	✓/✗	✓	✓	✗	✗
TORTOISE	✓	✓/✓	✗	✓	✓	✗	✗/✗	✓	✗	✗	✗

**To the best of our knowledge at the date of submission, based on information gathered from the software manuals, main webpages, and published papers.*

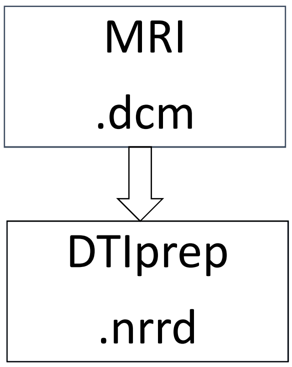
Soares J et al. A hitchhiker's guide to diffusion tensor imaging. Frontiers in neuroscience 2013 (7)

Programs I use

- DTIprep (module in Slicer)
- AFNI tools (gradient flips)
- FSL (tensors, tbss, tractography)
- ExploreDTI
- Brain Connectivity Toolbox (BCT) & Network Based Statistic Toolbox (NBS), Matlab



DTIPrep




```
/Applications/Slicer.app/Contents/lib/Slicer-4.4/cli-
modules/DWIConvert --conversionMode DicomToNrrd --
inputDicomDirectory $a --outputDirectory $b --outputVolume
data.nrrd  --smallGradientThreshold 0.2 ;
```

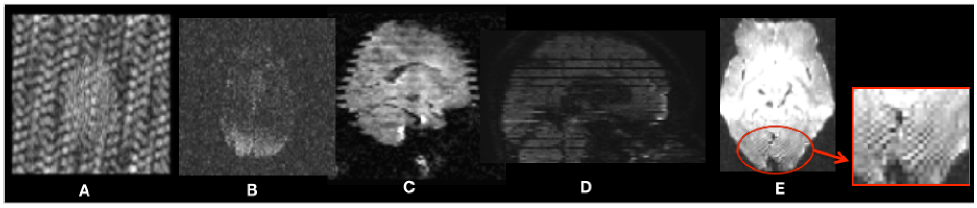
DTIprep

1. Image information checks (ensuring correct image dimensions, spacing, and orientation).
2. Diffusion information checks (ensuring correct diffusion gradient orientations, gradient b-values).
3. **Rician noise removal on rawDWI volumes**
4. **Inter-slice brightness artifact detection via normalized correlation analysis between successive slices within a single DWI volume.**
5. **Interlaced correlation analysis for detection and removal of "venetian blind" artifacts and motion within a single DWI volume.**
6. **Co-registration to an iterative average over all the baseline images.**
7. **Eddy-current and motion artifact correction, including appropriate gradient direction adjustments.**
8. **Residual motion detection to ensure all DWI volumes are well registered.**
9. Reconstruction of the DTI data and computation of DTI property maps.
10. Directional artifact detection/correction.

Oguz et al. DTIPrep: quality control of diffusion-weighted images. Frontiers in neuroinformatics, volume 8, January, article 4, 2014

```
~/DTIprep --DWINrrdFile file.nrrd --check --xmlProtocol
/Users/FSL/Documents/My project/my protocol.xml --outputFolder
${save here} ;
```

Artifacts



. (A) An electromagnetic interference-like artifact, (B) severe signal loss in the anterior and middle regions, (C) venetian blind artifact, (D) inter-slice and intra-slice intensity artifact, and (E) checkerboard artifact.

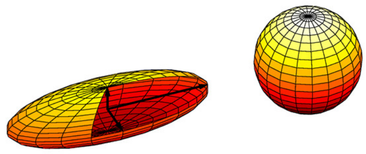
DTIPrep: quality control of diffusion-weighted images. Frontiers in neuroinformatics 2014 (8) 4 Oguz et al.

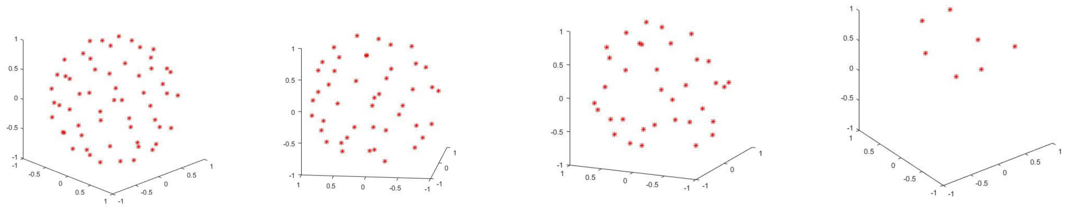
After DTIprep

- Diffusion tensor estimation:
  - high b-value (e.g., 1000s/mm2) along 60 non-collinear diffusion encoding directions & one image b-value (b = 0s/mm2)

  If we lose?
  - Image with b-value (b = 0s/mm2)
  - If we lose directions b-value (e.g., 1000s/mm2)

Gradient volumes





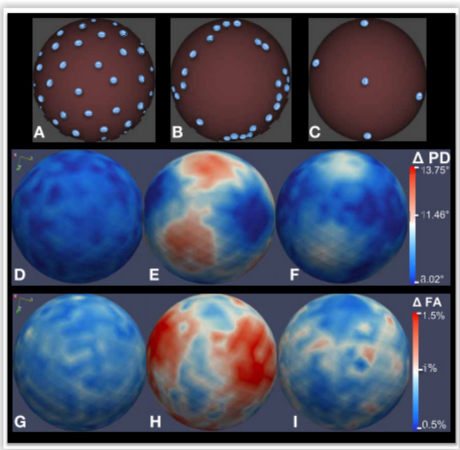
57 44 34 6

Gradient volumes

DWI acquisition schemes

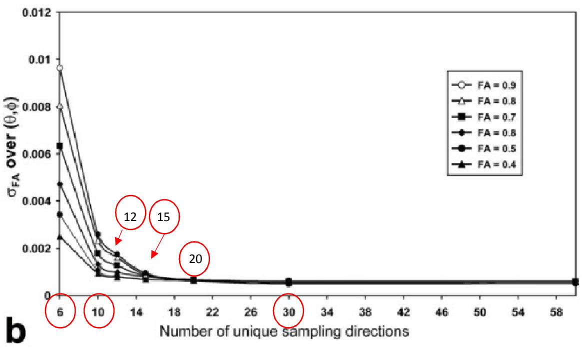
A) 42-direction quasi-uniform,
B) Phillips 32-direction non-uniform
C) 6-direction uniform.
D–F) Estimated error distribution in principal direction of diffusion computation.
G–I) Estimated error distribution in FA computation as a percentage of true FA.

200,000 MC simulation were performed for this experiment, with a true FA value of 0.4 and SNR = 10.



DTIPrep: quality control of diffusion-weighted images. Frontiers in neuroinformatics 2014 (8) 4 Oguz et al.

Number of diffusion gradient volumes



Variation in the estimated FA as a function of tensor orientation (SNR 15)

Magn Reson Med. 2004 Apr;51(4):807-15.
The effect of gradient sampling schemes on measures derived from diffusion tensor MRI: a Monte Carlo study.
Jones DK.

Number of diffusion gradient volumes

20 unique sampling orientations: necessary for a robust estimation of anisotropy

30 unique sampling orientations were required for a robust estimation of tensor orientation and mean diffusivity

Jones DK. The effect of gradient sampling schemes on measures derived from diffusion tensor MRI: a Monte Carlo study. Magn Reson Med 2004;51:807–15

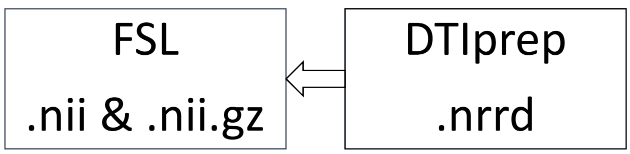
Eddy current and other corrections

- **Eddy currents** induced within conductors by changing gradient and RF fields.

Couse:

- unwanted time-varying gradients
- shifts in the main magnetic field (**B0**).

= geometric image distortions



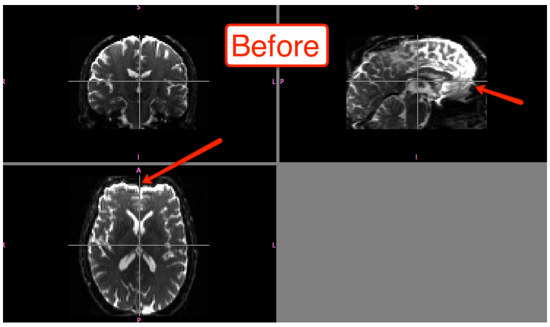

```
/Applications/Slicer.app/Contents/lib/Slice
r-4.4/cli-modules/DWIConvert --
conversionMode NrrdToFSL --inputVolume $e -
-outputVolume data_Qced.nii --outputBValues
data.bvals --outputBVectors data.bvecs --
smallGradientThreshold 0.2 ;
```

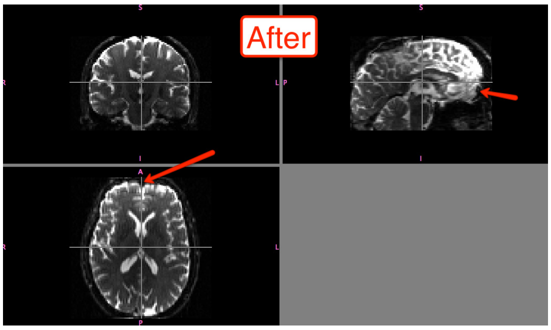
Field map corrections

- EPI images often exhibit substantial signal dropout and spatial distortion in regions where the magnetic field is inhomogenous (for the brain, this means the fontal cortex and medial temporal lobe). We can not recover the lost signal, but we can attempt to undistort our images if we collect field maps (that measure the field inhomogeneity).

- SPM fieldmap toolbox (Field map from scanner required)
- FSL fugue (Field map from scanner required)
- **FSL topup**

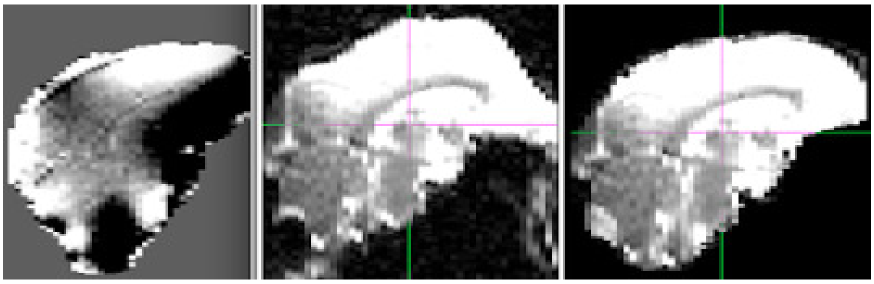
Field map corrections





http://andysbrainblog.blogspot.fi/2014/08/dti-analysis-steps-1-2-distortion.html

Field map corrections



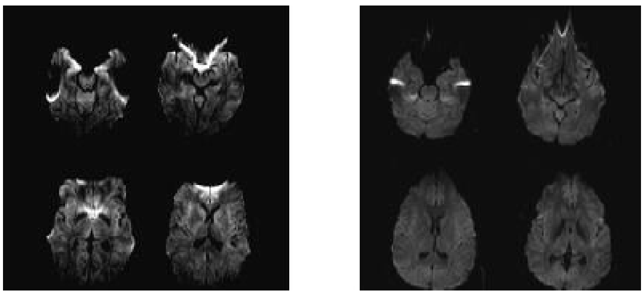
Field map   Original data   Corrected data

http://www.diffusion-imaging.com/2012/03/dti-preprocessing-distortion-correction.html

Top-up

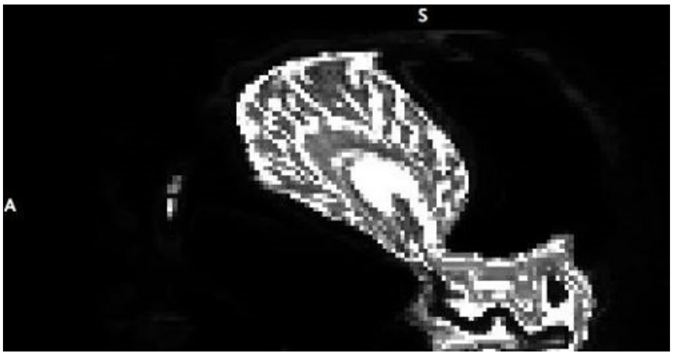
acqparams.txt
0 -1 0 0.0665
0 1 0 0.0665

-1 AP
1 PA
Readout time



Left: Fat shift direction A; Susceptibility artifacts shifted to Post
Right: Fat shift direction P; Susceptibility artifacts shifted to Ant.

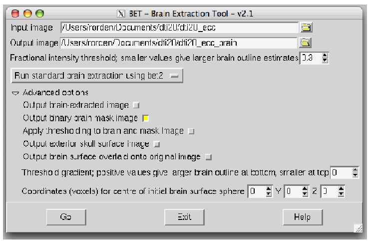
FM correction failed




```
fslreorient2std data_QCed.nii data.nii ;
```

Tensors

- bet2 data.nii brain -f 0.4 -g 0 -m ;



- dtifit -k data.nii -m brain_mask.nii.gz -r flipped_y.bvecs -b row.bvals -o <basename> ;

DTIfit, Output

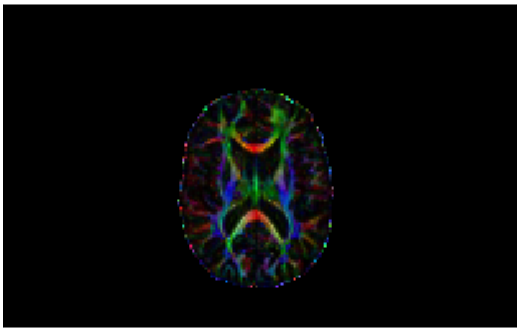
Outputs of dtifit

<basename>_V1 - **1st eigenvector**
<basename>_V2 - 2nd eigenvector
<basename>_V3 - 3rd eigenvector
<basename>_L1 - 1st eigenvalue
<basename>_L2 - 2nd eigenvalue
<basename>_L3 - 3rd eigenvalue
<basename>_MD - mean diffusivity
<basename>_FA - fractional anisotropy
<basename>_MO - mode of the anisotropy (oblate ~ -1; isotropic ~ 0; prolate ~ 1)
<basename>_S0 - raw T2 signal with no diffusion weighting

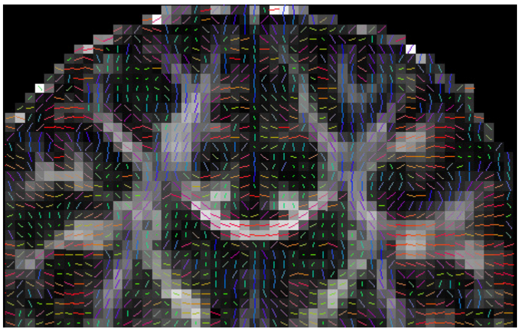
optional output
<basename>_sse - Sum of squared error
<basename>_tensor - tensor as a 4D file in this order

Is my data OK? Original data

RGB (FA-modulated)

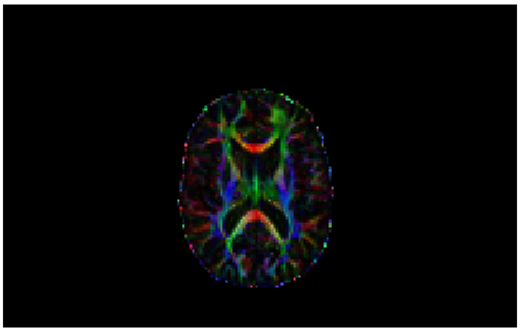


Glyps

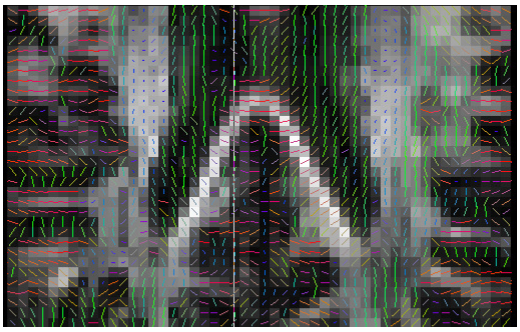


Is my data OK?
Original data

RGB (FA-modulated)



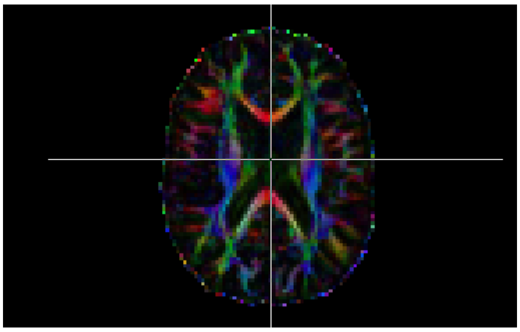
Glyps (axial slice)



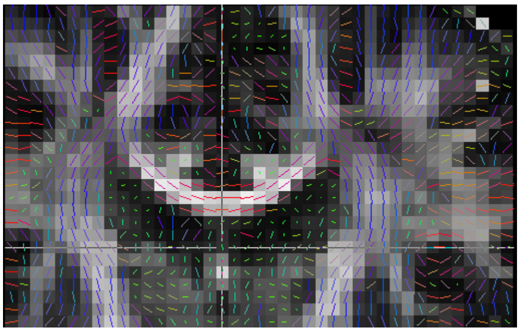
- 1dDW_Grad_o_Mat -in_grad_cols data.bvecs -in_bvals data.bvals -flip_y -keep_b0s -out_grad_rows flipped_y.bvecs -out_bval_row_sep row.bvals;

Is my data OK?
Corrected data

RGB (FA-modulated)

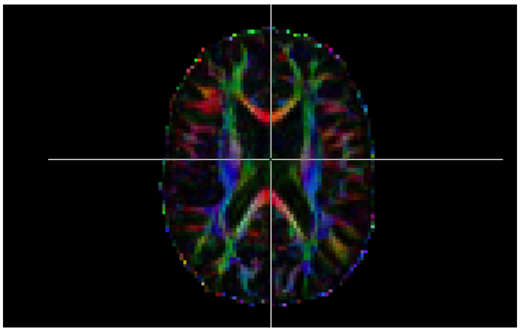


Glyps

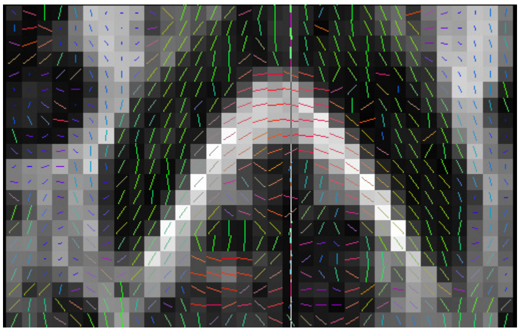


Is my data OK?
Corrected data

RGB (FA-modulated)



Glyps



After preprosessing

- **BEDPOSTX**
- **PROBTRACKX - probabilistic tracking with crossing fibres**