



Diffusion MRI Analysis: from images to tracts

Sonia Pujol, Ph.D.

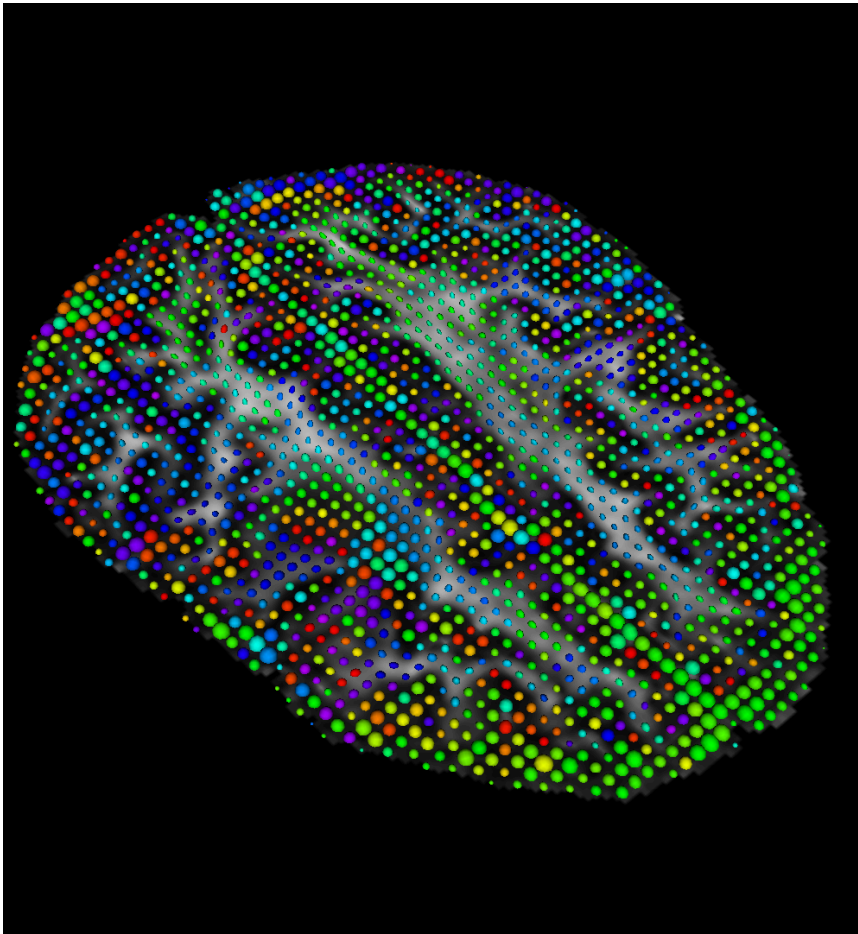
Surgical Planning Laboratory
Harvard University

Brain Anatomy



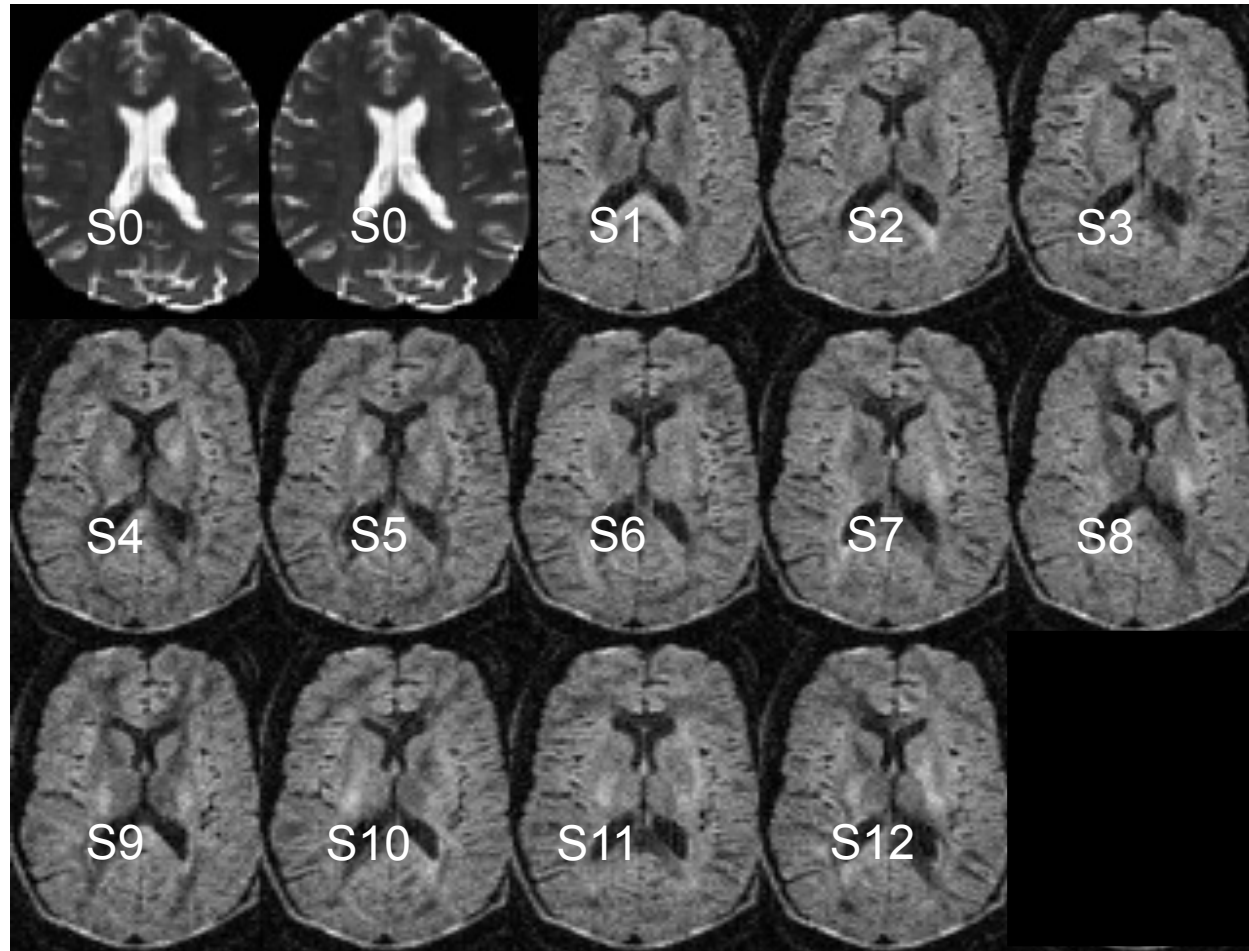
- White matter represents 45% of the brain, and is composed of myelinated nerve fibers

Diffusion MR Imaging



- First non-invasive window on white matter anatomy
- Measurement of the motion of water molecules using MRI techniques.
- Three-dimensional reconstruction of the trajectory of white matter bundles

Diffusion Weighted Imaging (DWI)

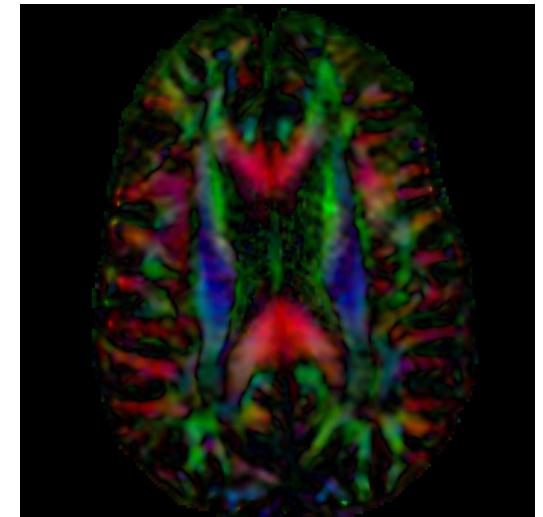
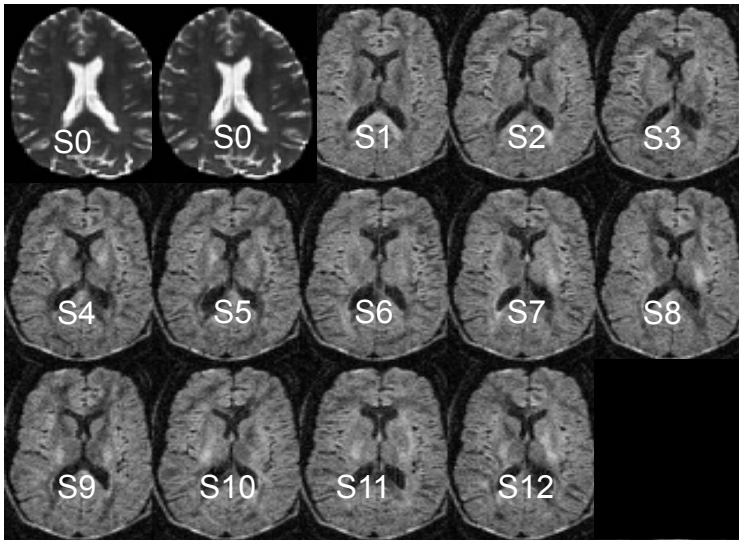


In this example, the DWI scan was acquired with 12 diffusion sensitizing gradient directions (S1-S12) and 2 non-diffusion sensitizing gradients (S0)

From DWI to DTI

DWI

DTI



DWI dataset acquired with
12 gradients and 2
baselines

DTI dataset

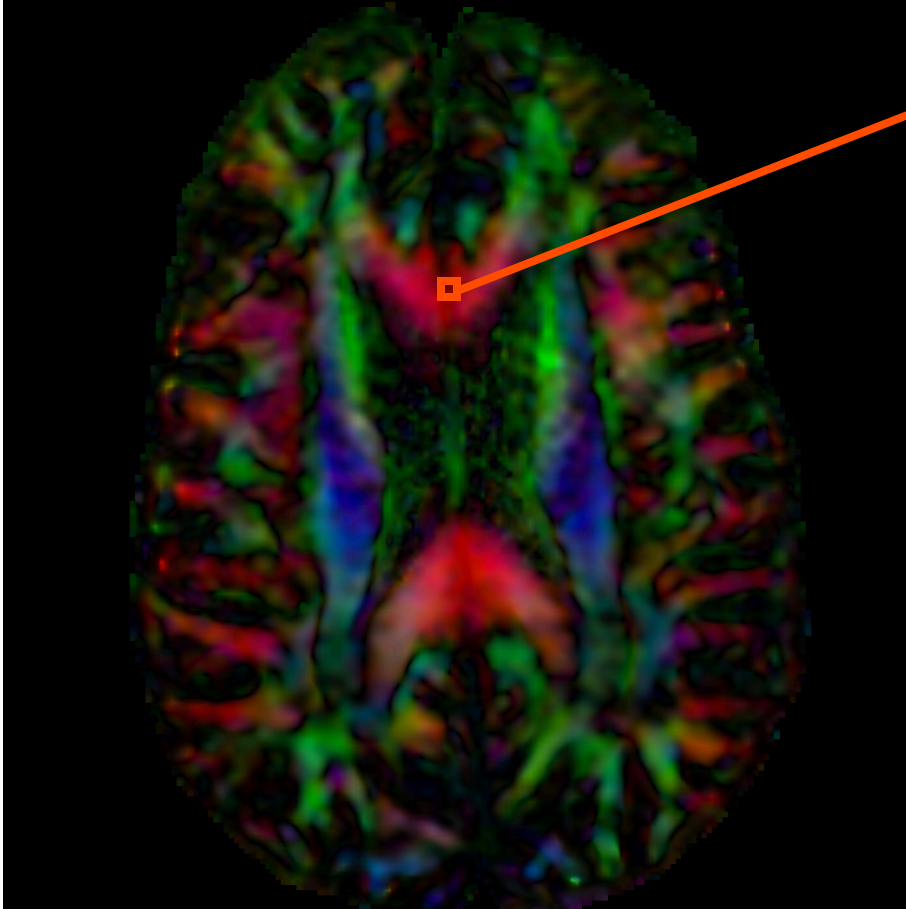
$$S_i = S_0 e^{-b \hat{g}_i^T \underline{D} \hat{g}_i}$$

Stejskal-Tanner (1965)

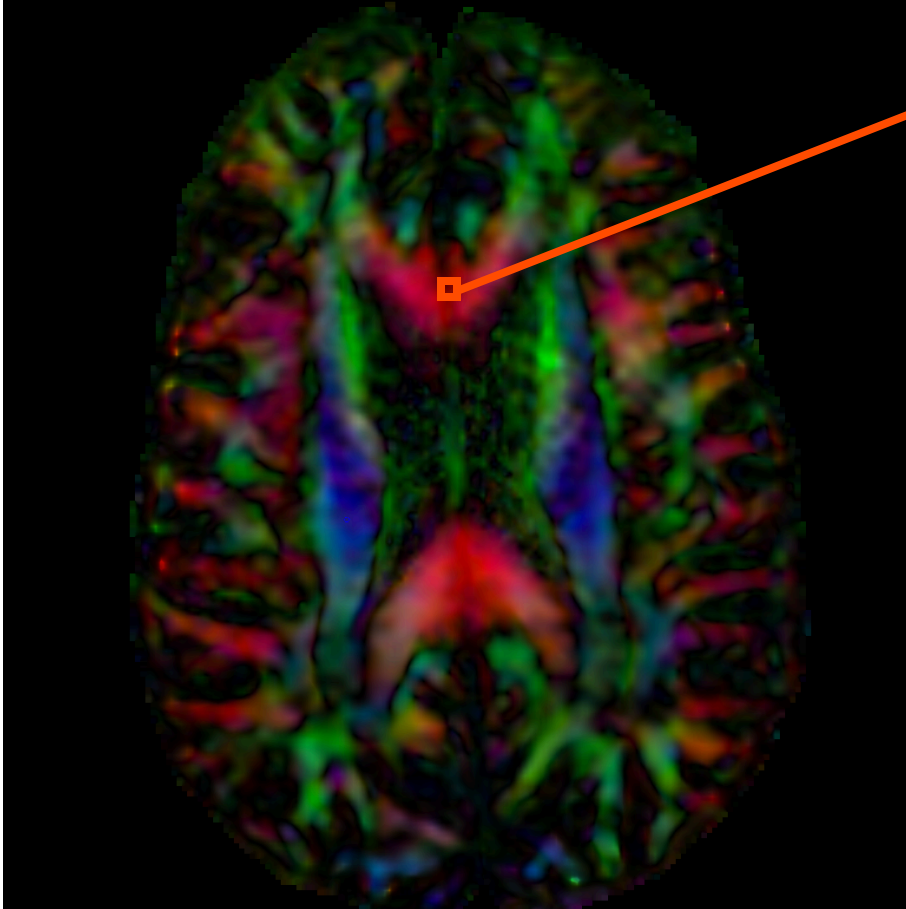
S_i : DWI volume acquired with
 i th gradient
 S_0 : Baseline volume

Diffusion Tensor Imaging

$$S_i = S_0 e^{-b \hat{g}_i^T \underline{D} \hat{g}_i}$$



Diffusion Tensor Imaging

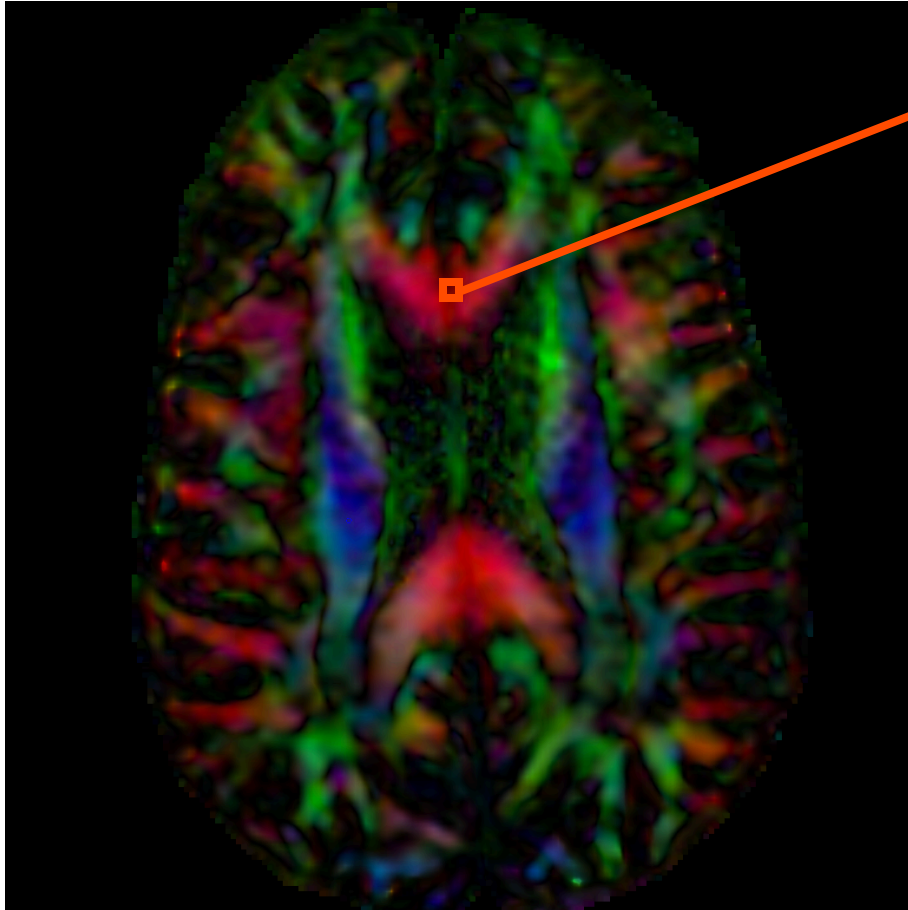


$$S_i = S_0 e^{-b \hat{g}_i^T \underline{D} \hat{g}_i}$$



$$\underline{D} = \begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{zx} & D_{zy} & D_{zz} \end{bmatrix}$$

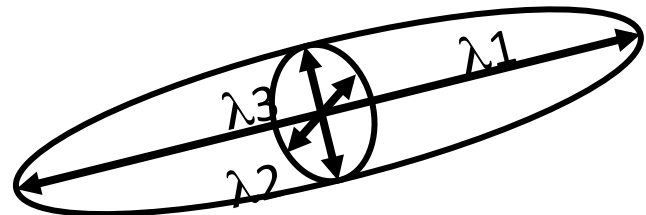
Diffusion Tensor Imaging



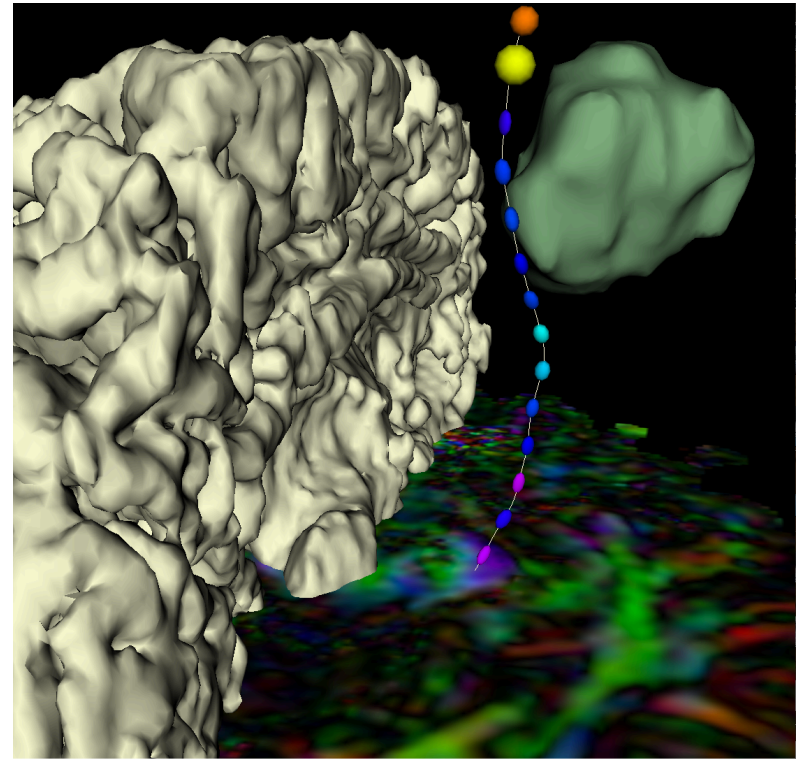
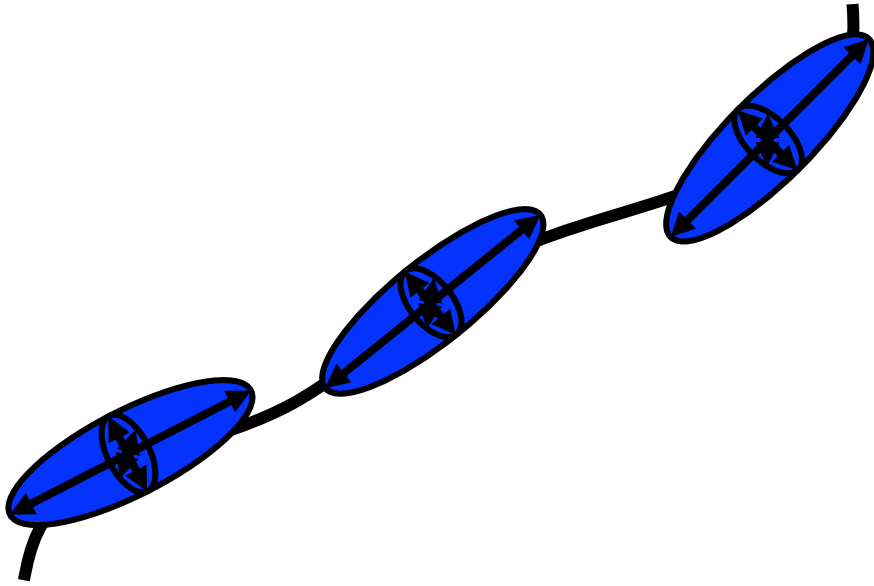
$$S_i = S_0 e^{-b\hat{g}_i^T \underline{D} \hat{g}_i}$$



$$\underline{\mathbf{D}} = \begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{zx} & D_{zy} & D_{zz} \end{bmatrix}$$



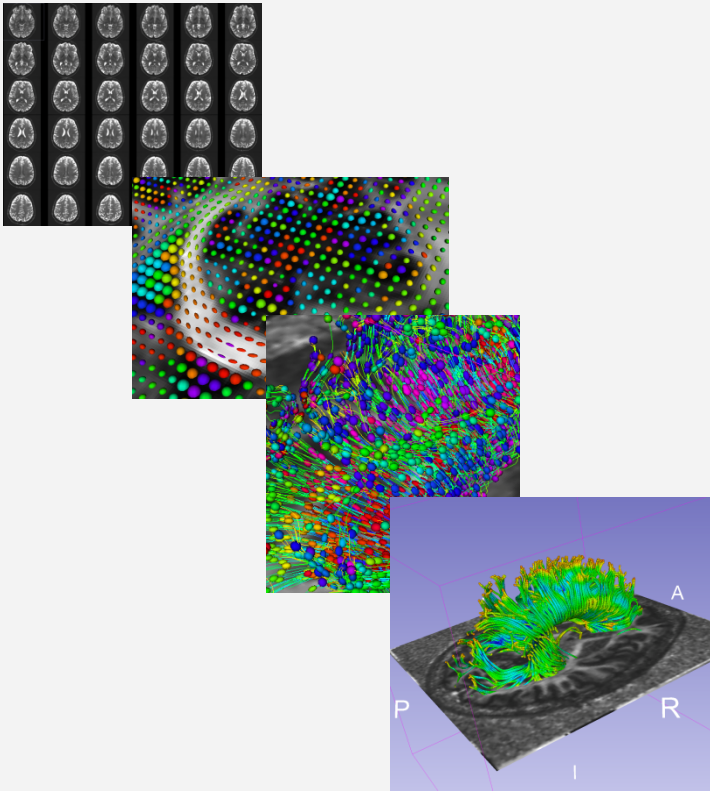
Tractography



DTI tractography provides 3D reconstruction of the trajectory of white matter pathways

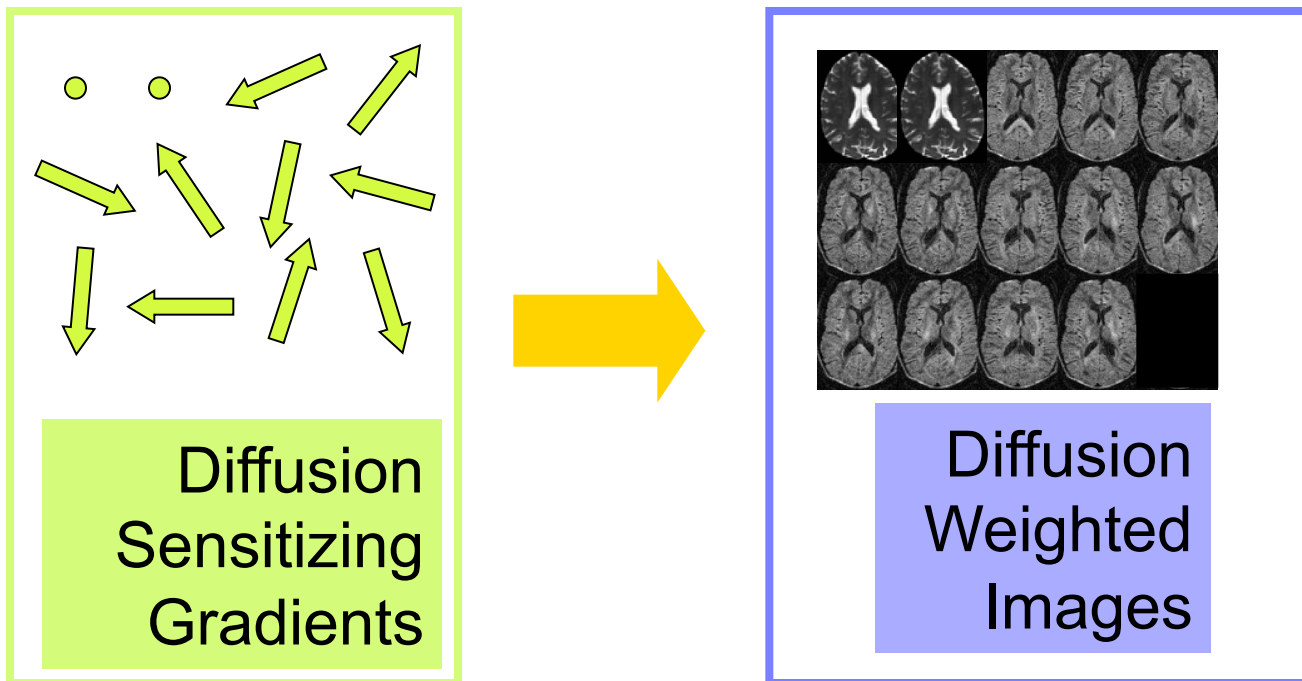
Tutorial Outline

This tutorial is an introduction to the fundamentals of Diffusion MRI analysis, from the estimation of diffusion tensors to the interactive 3D visualization of fiber tracts.



Tutorial Dataset

The tutorial dataset is a Diffusion Weighted MR scan of the brain acquired with 42 gradient directions and 7 baseline (Data source: Neuro Image Research and Analysis Lab, UNC)



Tutorial Software

The tutorial uses the 3D Slicer (Version 4.4.0r24272) software available at

http://www.na-mic.org/Wiki/index.php/3DSlicer_4.4_r24272

Disclaimer

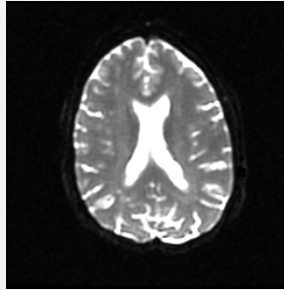
It is the responsibility of the user of 3DSlicer to comply with both the terms of the license and with the applicable laws, regulations and rules. Slicer is a tool for research, and is not FDA approved.

Learning Objectives

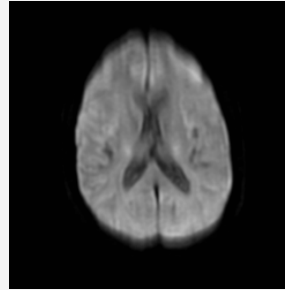
Following this tutorial, you'll be able to

- 1) Estimate a tensor volume from a set of Diffusion Weighted Images
- 2) Understand the shape and size of the diffusion ellipsoid
- 3) Reconstruct DTI tracts from a pre-defined region of interest
- 4) Interactively visualize DTI tracts seeded from a fiducial

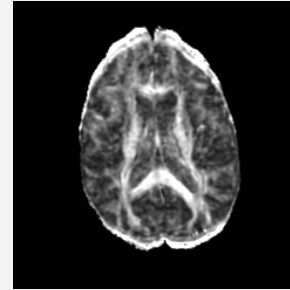
MR Diffusion Analysis Pipeline



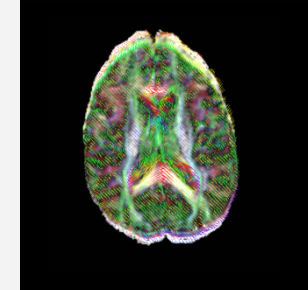
DWI
Acquisition



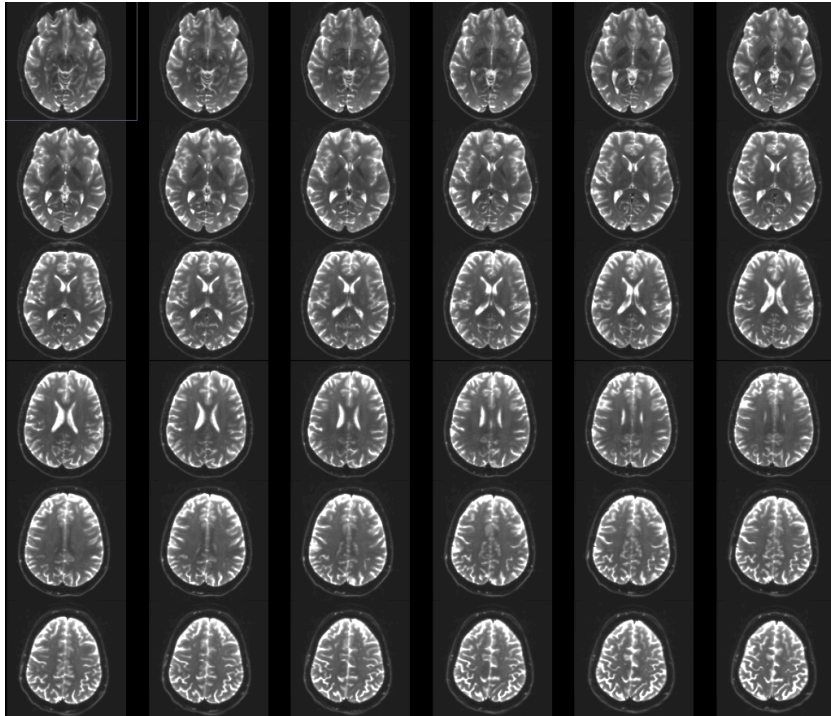
Tensor
Calculation



Scalar
Maps

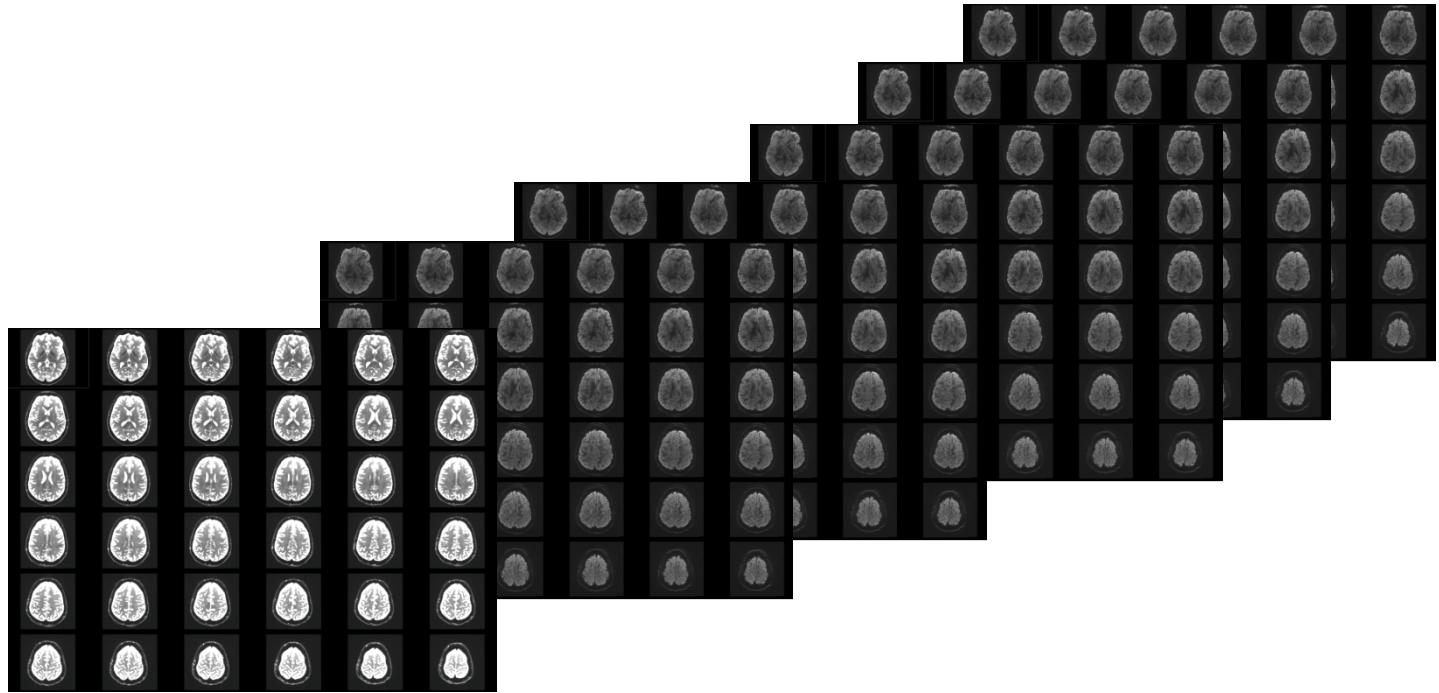


3D
Visualization



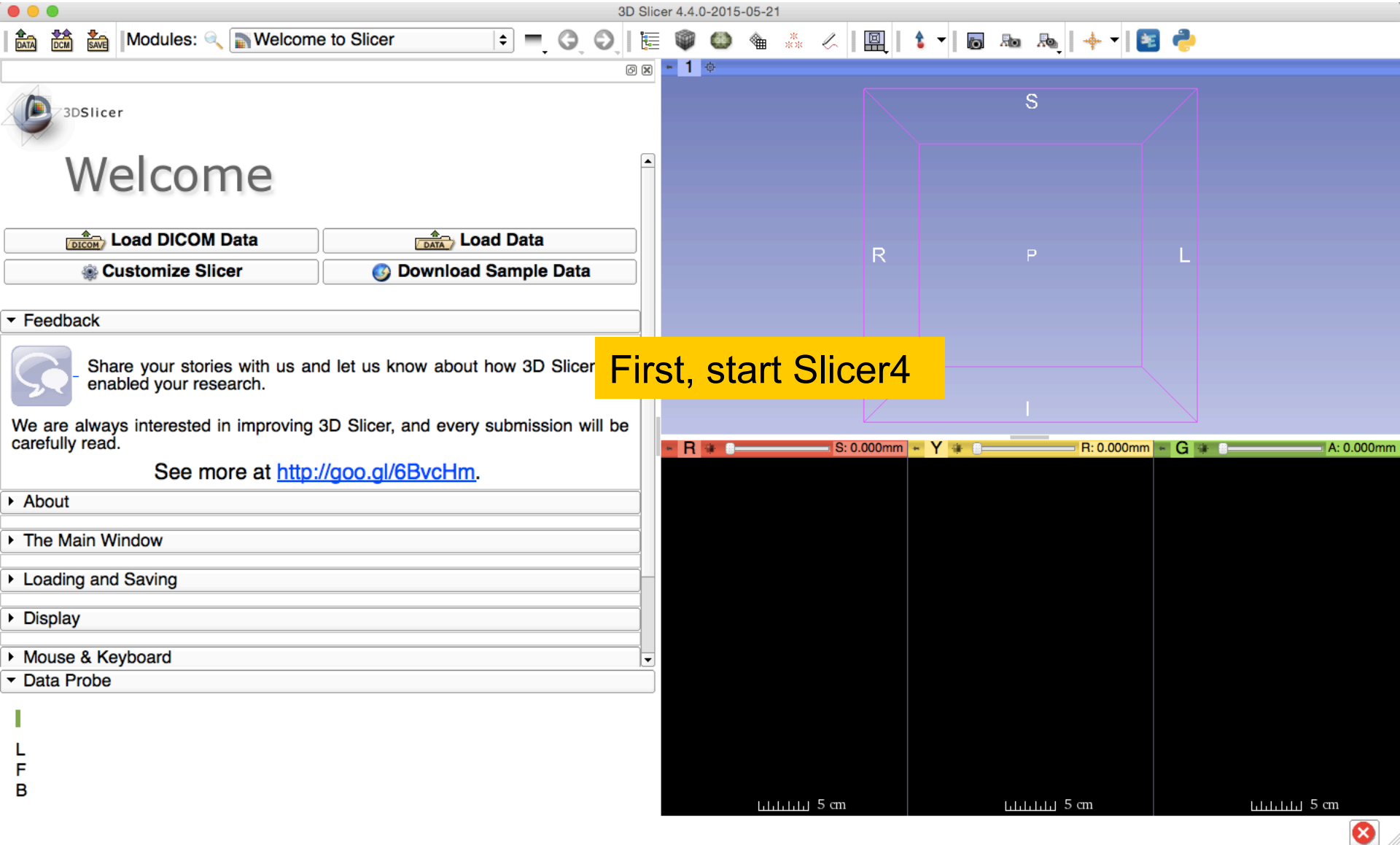
Part 1: From DWI images to Tensors

Understanding the DWI Dataset



The Diffusion Weighted Imaging (DWI) dataset is composed of a set of volumes acquired with 42 diffusion-sensitizing gradient directions, and 7 baseline image acquired without diffusion weighting.

Loading the DWI Dataset



Loading the DWI Dataset

The screenshot shows the 3D Slicer interface with a 'Load Data' dialog box open. The dialog box displays a file named 'dwi.nrrd' with a size of 26.1 MB, modified yesterday at 9:46 am. A red arrow points to the file name. A yellow callout box contains the following text:

In your files archive, locate the file **dwi.nrrd** in the dataset folder for this tutorial

The background shows the 3D Slicer interface with a 'Welcome' message and a 'Load Data' button. The main window displays a 3D view of a dataset with a purple bounding box and axes labeled S, P, L, and I. The bottom status bar shows 'R: 0.000mm', 'G', and 'A: 0.000mm'.

Loading the DWI Dataset

3D Slicer 4.4.0-2015-05-21

Modules: Welcome to Slicer

3DSlicer

Welcome

Load DICOM Data | Load Data

Customize Slicer

DiffusionMRI_tutorialData

Name	Date Modified	Size	Kind
dwi.nrrd	Yesterday 9:46 am	26.1 MB	Document

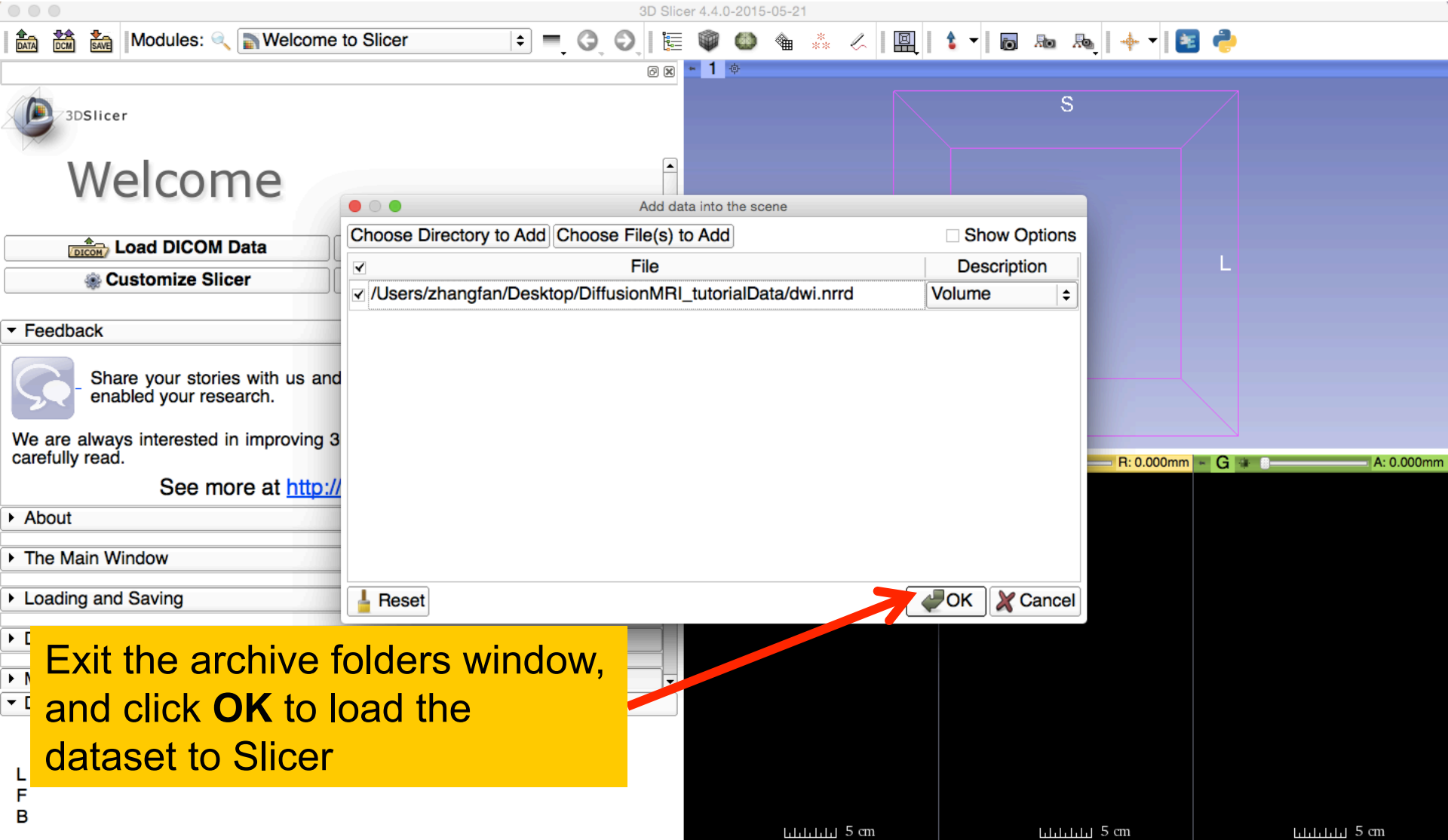
Drag and drop the file **dwi.nrrd** onto the viewer of the Slicer4 application

L
F
B

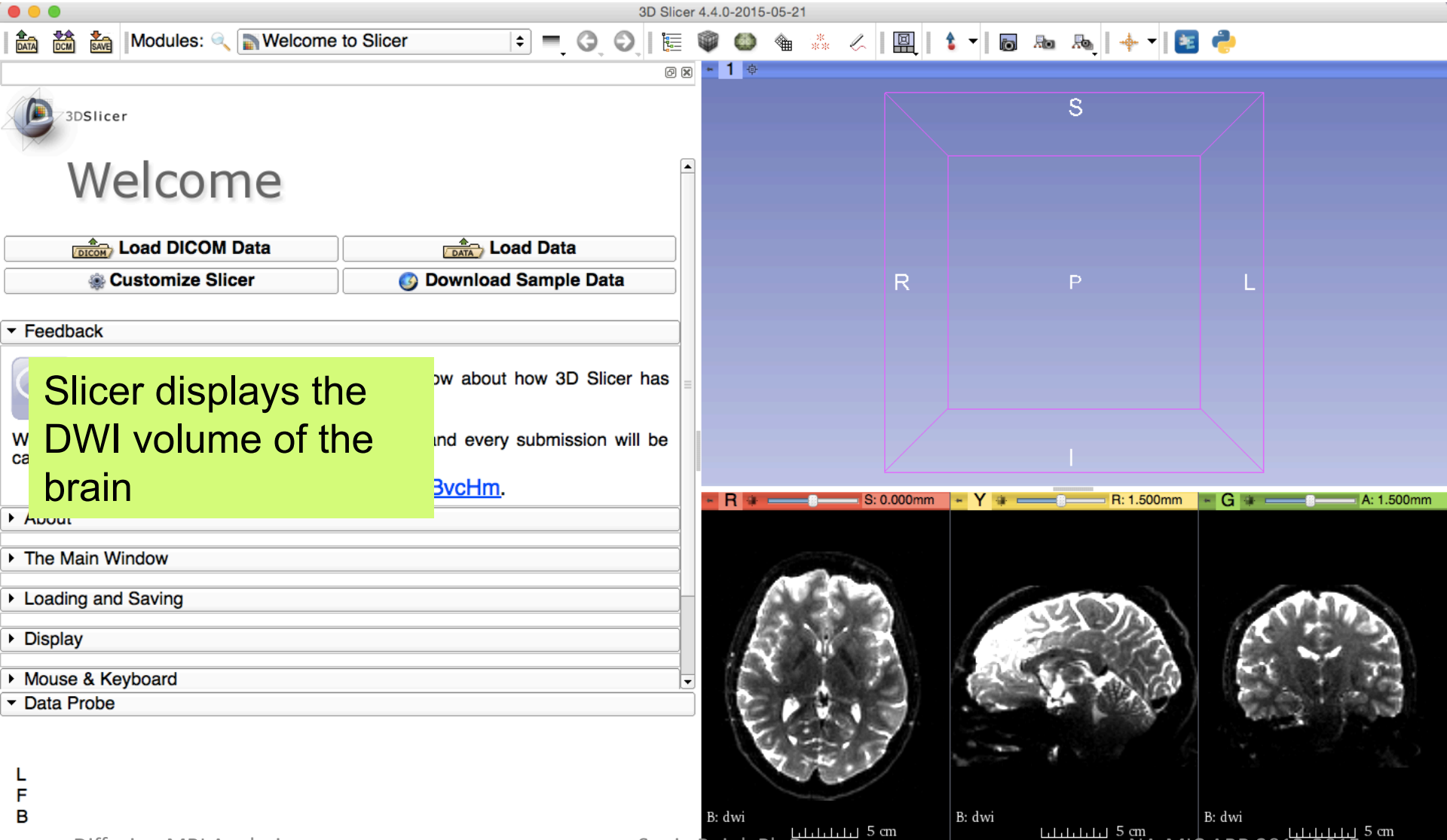
5 cm 5 cm 5 cm

A: 0.000mm

Loading the DWI Dataset



Loading the DWI Dataset



Loading the DWI Dataset

3D Slicer 4.4.0-2015-05-21

Modules: Welcome to Slicer

- All Modules
- Annotations
- Data
- DataStore
- DICOM
- Editor
- Markups
- Models
- Scene Views
- Subject Hierarchy
- Transforms
- View Controllers
- Volume Rendering
- Volumes**
- Welcome to Slicer

Wizards

- Informatics
- Registration
- Segmentation
- Quantification
- Diffusion
- IGT
- Filtering
- Surface Models
- Converters
- Endoscopy
- Utilities
- Developer Tools
- Legacy
- MultiVolume Support
- Unspecified
- BRAINS

Click on the **Modules** menu and select the module **Volumes**

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

Loading the DWI Dataset

3D Slicer 4.4.0-2015-05-21

Modules: Volumes

3DSlicer

Help & Acknowledgement

Active Volume: dwi

Volume Information

Display

Scalar Display

DWI Component: 10

Lookup Table: Gray

Interpolate:

Window Level editor presets:

W: 400 Auto W/L L: 283

Threshold: Off

-600 1390

Histogram

Data Probe

L
F
B

Diffusion MRI Analysis

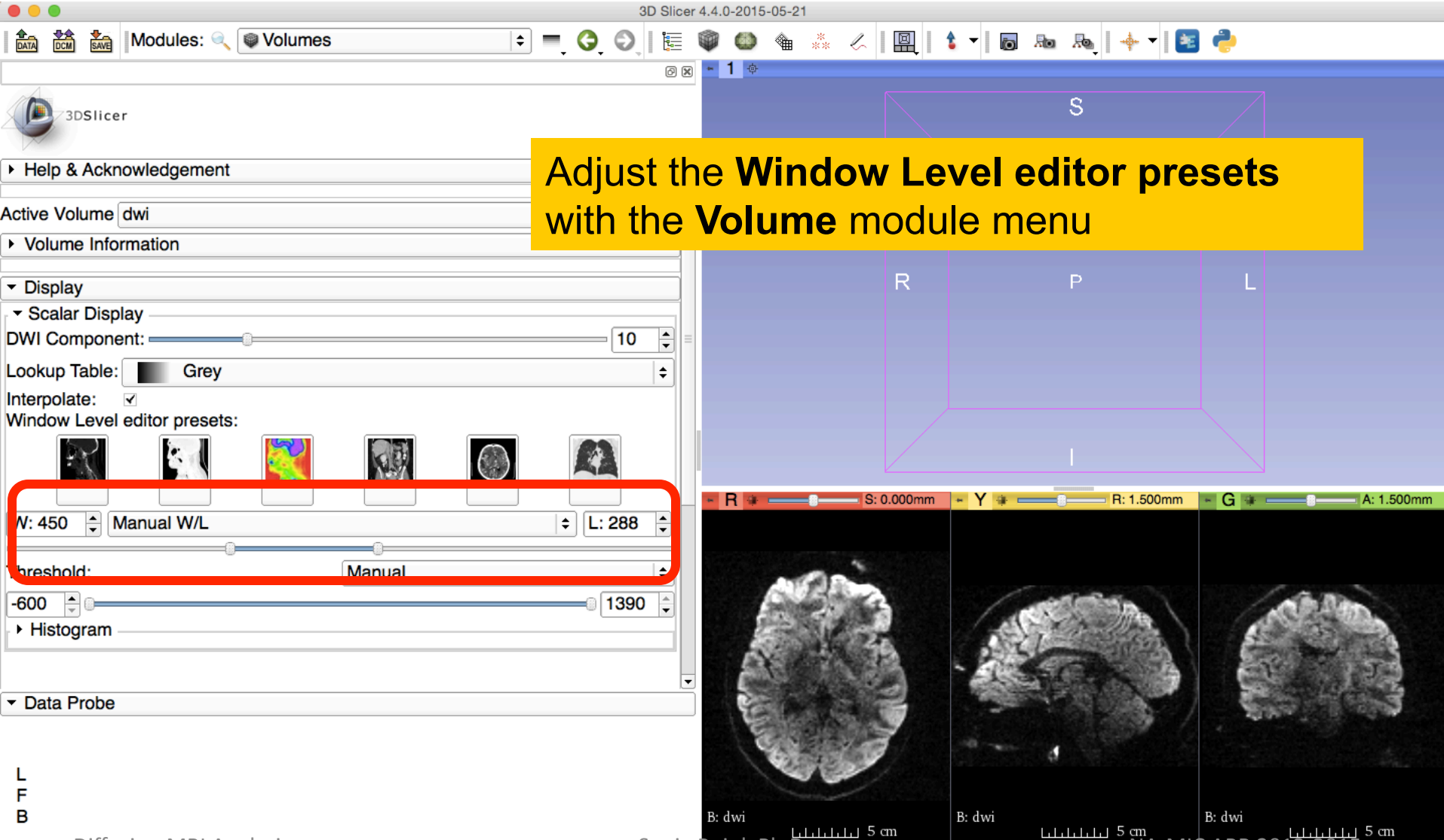
Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

The baseline image corresponds to the DWI Component #0. Select the DWI Component #10, which corresponds to the 10th diffusion sensitizing gradient

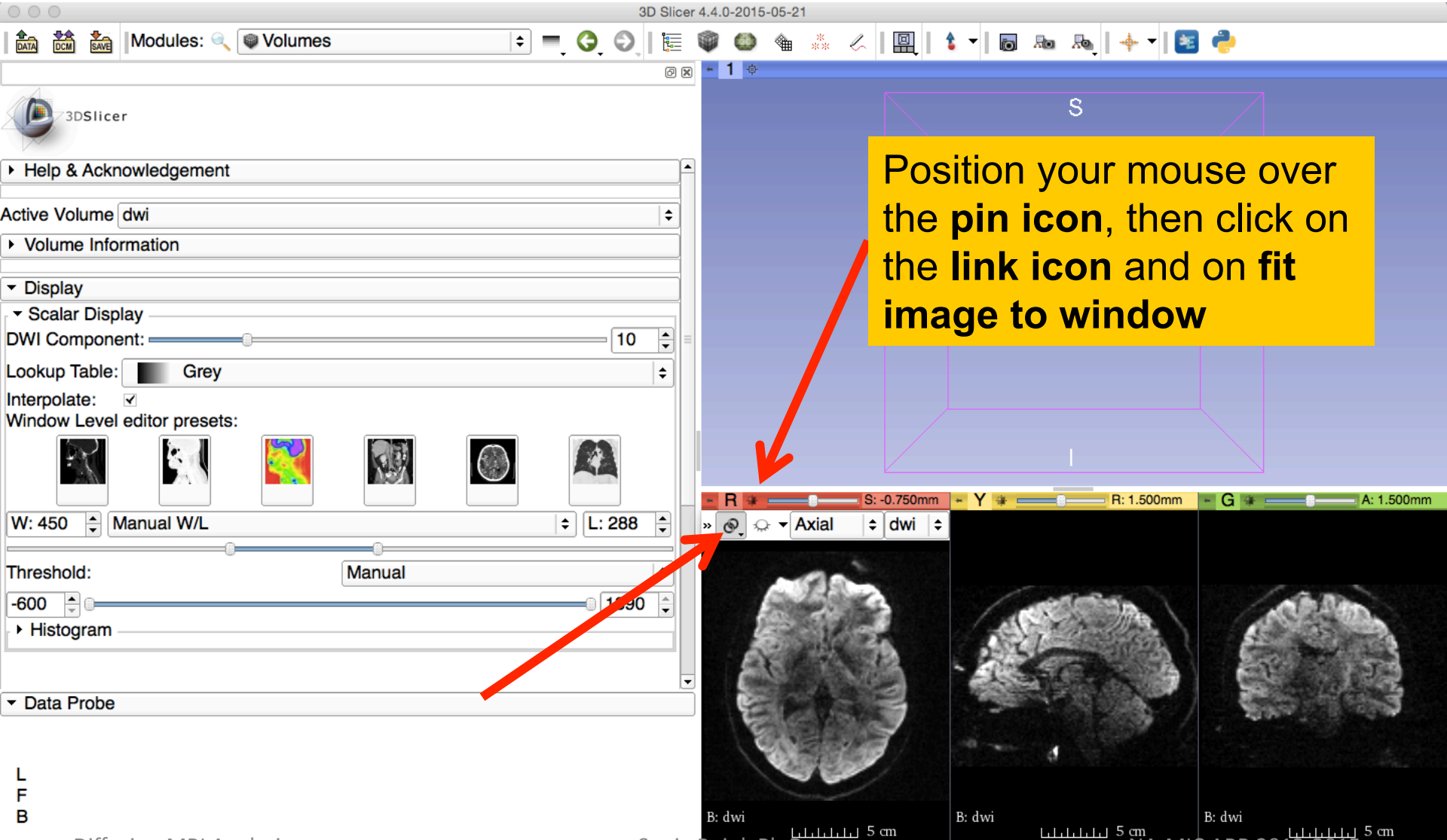
B: dwi 5 cm B: dwi 5 cm B: dwi 5 cm

Loading the DWI Dataset



Adjust the **Window Level editor presets** with the **Volume** module menu

Loading the DWI Dataset



Loading the DWI Dataset

3D Slicer 4.4.0-2015-05-21

Modules: Volumes

Active Volume: dwi

Volume Information

Display

Scalar Display

DWI Component: 10

Lookup Table: Grey

Interpolate:

Window Level editor presets:

- W: 4
- Three
- 600
- Hi

Data Probe

Slicer layout menu:

- Conventional
- Conventional Widescreen
- Conventional Quantitative
- Four-Up
- Four-Up Quantitative
- Dual 3D
- Triple 3D
- 3D only
- One-Up Quantitative
- Red slice only**
- Yellow slice only
- Green slice only
- Tabbed 3D
- Tabbed slice
- Compare
- Compare Widescreen
- Compare Grid
- Three over three
- Three Over Three Quantitative
- Four over four
- Two over Two
- Side by side
- Four by three slice
- Four by two slice
- Three by three slice

Click on the Slicer layout menu and select the **Red slice only** layout

L
F
B

B: dwi 5 cm

B: dwi 5 cm

B: dwi 5 cm

A: 1.500mm



Loading the DWI Dataset

3D Slicer 4.4.0-2015-05-21

Modules: Volumes

3DSlicer

Help & Acknowledgement

Active Volume: dwi

Volume Information

Disp

Sca

DWI C

Looku

Interp

Window Level editor presets:

W: 450 Manual W/L L: 288

Threshold: Manual

-600 1390

Histogram

Data Probe

Red RAS: (37.7, 52.5, -0.8) Axial Sp: 1.5

L None

F None

B dwi (39, 29, 47) 49 components

Diffusion MRI Analysis

Slicer displays the axial anatomical slice in the Viewer

R S: -0.750mm

5 cm

B: dwi

NA-MIC ARR 2012-2015

Sonia Pujol, Ph.D.

Creating a brain mask

The image shows the 3D Slicer software interface. The 'Modules' menu is open, and the 'Diffusion' sub-menu is selected. Within the 'Diffusion' sub-menu, 'Diffusion Weighted Volume Masking' is highlighted. A yellow callout box with a red arrow points to this option. The main window displays a brain MRI slice with a red arrow pointing to the same location. The interface includes a top toolbar, a left sidebar with various tool panels, and a central 3D view area. The title bar indicates the version '3D Slicer 4.4.0-2015-05-21' and the current slice position 'S: -0.750mm'. The bottom of the screen shows a scale bar and the text 'NA-MIC ARR 2012-2015'.

3D Slicer 4.4.0-2015-05-21

S: -0.750mm

Click on the Modules menu and select the module **Diffusion Weighted Volume Masking**

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

Creating a brain mask

3D Slicer 4.4.0-2015-05-21

Modules: Diffusion Weighted Volume Masking

3DSlicer

Help & Acknowledgement

Diffusion Weighted Volume Masking

Parameter set: Diffusion Weighted Volume Masking

IO

Input DWI Volume: dwi

Output Baseline Volume: baseline

Otsu Threshold Mask: dwi_mask

Otsu Omega Threshold Parameter: 0.05

Remove Islands in Threshold Mask:

Status: Completed 100%

Restore Defaults AutoRun Cancel Apply

Data Probe

L
F
B

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

5 cm

L: dwi_mask (100%)
B: baseline

S: 0.000mm

-select the Input DWI volume 'dwi'
-select Output Baseline Volume 'Create and Rename New Volume', and rename it 'baseline'
-select Output Threshold Volume 'Create and Rename new Volume', and rename it 'dwi_mask'
-uncheck Remove Islands in Threshold Mask
-set Otsu Omega Threshold Parameter 'WLS' to 0.05
-click on Apply.

Creating a brain mask

3D Slicer 4.4.0-2015-05-21

Modules: Diffusion Weighted Volume Masking

3DSlicer

Help & Acknowledgement

Diffusion Weighted Volume Masking

Parameter set: Diffusion Weighted Volume Masking

IO

Input Data: []

Output Data: []

Otsu Threshold: []

Otsu Omega Threshold Parameter: 0.05

Remove Islands in Threshold Mask:

Status: Completed

100%

Restore Defaults AutoRun [] Cancel Apply

Data Probe

L
F
B

Diffusion MRI Analysis

Slicer displays the brain mask

L: dwi_mask (100%)
B: baseline

5 cm

NA-MIC ARR 2012-2015

Creating a brain mask

3D Slicer 4.4.0-2015-05-21

Modules: Diffusion Weighted Volume Masking

- All Modules
- Annotations
- Data
- DataStore
- DICOM
- Editor**
- Markups
- Models
- Scene Views
- Subject Hierarchy
- Transforms
- View Controllers
- Volume Rendering
- Volumes
- Welcome to Slicer

Wizards

- Informatics
- Registration
- Segmentation
- Quantification
- Diffusion
- IGT
- Filtering
- Surface Models
- Converters
- Endoscopy
- Utilities
- Developer Tools
- Legacy
- MultiVolume Support
- Unspecified
- BRAINS

Parameter set: Diffusion Weig

Input DWI Volume dwi

Output Baseline Volume bas

Otsu Threshold Mask dwi

Otsu Omega Threshold Para

Remove Islands in Threshold

0.05

100%

Apply

Select the module Editor

L: dwi_mask (100%)
B: baseline

5 cm

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

Creating a brain mask

3D Slicer 4.4.0-2015-05-21

Modules: Editor

3DSlicer

Help & Acknowledgement

Create and Select Label Maps

Master Volume: baseline

Merge Volume: dwi_mask Set...

Edit Selected Label Map

Undo/Redo: [Undo] [Redo]

Active Tool: DefaultTool

Label: jake 1

Data Probe

L
F
B

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

5 cm

L: dwi_mask (100%)
B: baseline

S: 0.000mm

Set Master Volume to 'baseline'
Set Merge Volume to 'dwi_mask'

Creating a brain mask

3D Slicer 4.4.0-2015-05-21

Modules: Editor

Merge Volume: dwi_mask Set...

Per-Structure Volumes

Edit Selected Label Map

DilateEffect

Undo/Redo: [Undo] [Redo]

Active Tool: DilateEffect

Label: jake 1

Eight Neighbors

Four Neighbors

Apply

Data Probe

L
F
B

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

L: dwi_mask (100%)
B: baseline

5 cm

S: 0.000mm

Select the **Dilate Effect** tool and click on **Apply** 3 times

Creating a brain mask

3D Slicer 4.4.0-2015-05-21

Modules: Editor

Merge Volume: dwi_mask Set...

Per-Structure Volumes

Edit Selected Label Map

ErodeEffect

Active Tool: ErodeEffect

Label: jake 1

Eight Neighbors
 Four Neighbors

Apply

Data Probe

L
F
B

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

5 cm

L: dwi_mask (100%)
B: baseline

S: 0.000mm

Select Erode Effect tool and click on Apply once

Creating a brain mask

3D Slicer 4.4.0-2015-05-21

Modules: Editor

Merge Volume: dwi_mask Set...

Per-Structure Volumes

Edit Selected Label Map

Active Tool: ErodeEffect

Label: jake 1

Eight Neighbors
 Four Neighbors

Apply

Data Probe

L
F
B

Diffusion MRI Analysis

Slicer displays the edited brain mask

L: dwi_mask (100%)
B: baseline

5 cm

NA-MIC ARR 2012-2015

Creating a brain mask

3D Slicer 4.4.0-2015-05-21

Modules: Editor

Merge Volume: dwi_mask

Per-Structure Volumes

Edit Selected Label Map

Active Tool: ErodeEffect

Label: jake 1

Eight Neighbors
Four Neighbors

Apply

Data Probe

L
F
B

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

Change the label layer to **None** to make the mask invisible

None
dwi_mask
Rename Volume volume
baseline

5 cm

Estimating the tensor

3D Slicer 4.4.0-2015-05-21

Modules: Editor

- All Modules
 - Annotations
 - Data
 - DataStore
 - DICOM
 - Editor
 - Markups
 - Models
 - Scene Views
 - Subject Hierarchy
 - Transforms
 - View Controllers
 - Volume Rendering
 - Volumes
 - Welcome to Slicer
- Wizards
 - Informatics
 - Registration
 - Segmentation
 - Quantification
- Diffusion**
 - DWI to Full Brain Tractography
 - Tractography Display
 - Diffusion Data Conversion
 - Diffusion Tensor Images
 - Diffusion Weighted Images**
 - Diffusion Weighted Volume Masking
 - DWI Joint Rician LMMSE Filter
 - DWI Rician LMMSE Filter
 - DWI to DTI Estimation**
 - Resample Scalar/Vector/DWI Volume
 - Tractography
- IGT
- Filtering
- Surface Models
- Converters
- Endoscopy
- Utilities
- Developer Tools
- Legacy
- MultiVolume Support
- Unspecified
- BRAINS

Click on the Modules menu and select the module **DWI to DTI Estimation**

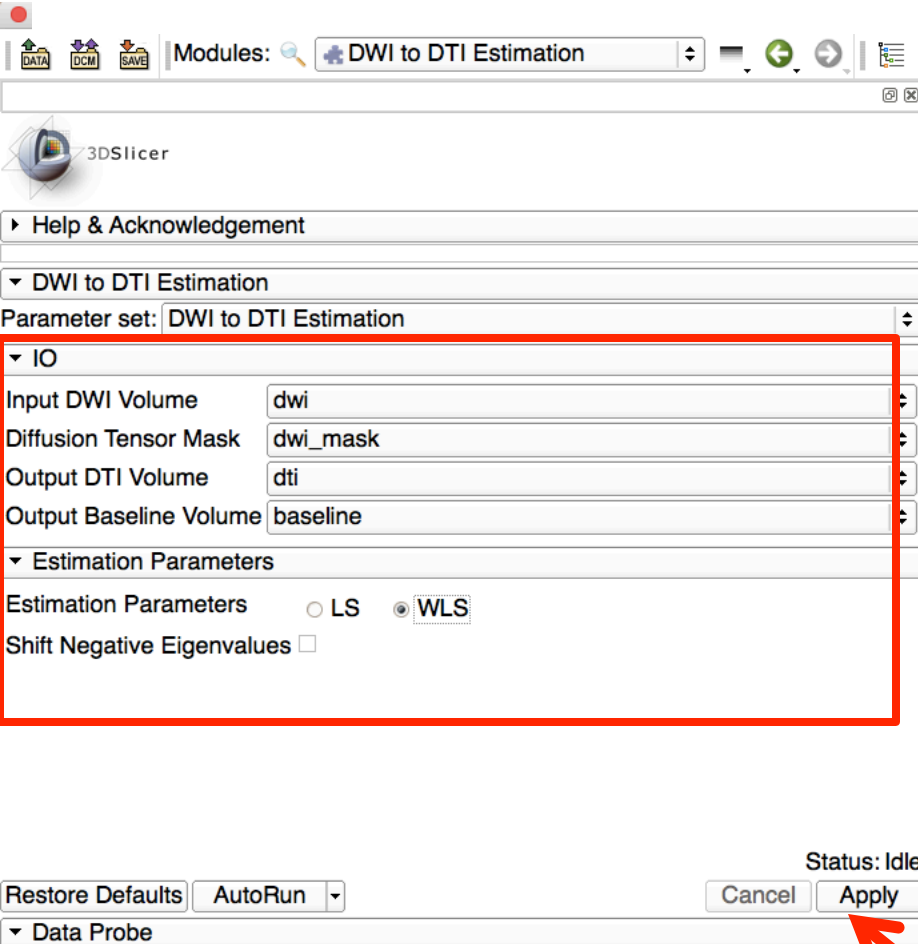
Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

5 cm

Estimating the tensor



- Select the module **DWI to DTI Estimation** in the modules menu:
- Set the **Input DWI volume** to 'dwi'
- Set the **Diffusion Tensor Mask** to 'dwi_mask'
- Select **Output DTI Volume 'Create and Rename New Volume'**, and rename it 'dti'
- Set **Output Baseline Volume** to 'baseline'
- Select the **Estimation Parameters 'WLS'** (Weighted Least Squares) and click on **Apply**.



Estimating the tensor

3D Slicer 4.4.0-2015-05-21

Modules: **DWI to DTI Estimation**

Position your mouse over the **pin icon** and select the volume **dti**

None
dwi
Output Baseline Volume
baseline
dwi_mask
dti
Rename cu DiffusionTensorVolume

Input DWI Volume: dwi
Diffusion Tensor Mask: dwi_mask
Output DTI Volume: dti
Output Baseline Volume: baseline

Estimation Parameters
Estimation Parameters: LS WLS
Shift Negative Eigenvalues:

Status: Completed
100%

Restore Defaults AutoRun Cancel Apply

L
F
B

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

Exploring the DWI Dataset

3D Slicer 4.4.0-2015-05-21

Modules: DWI to DTI Estimation

3DSlicer

Help & Acknowledgement

DWI to DTI Estimation

Parameter settings

IO

Input DWI Volume: []

Diffusion Tensor: []

Output DTI Volume: []

Output Basis: []

Estimation Method: []

Estimation Parameters: []

Shift Negative: []

Status: Completed

100%

Restore Defaults AutoRun [] Cancel Apply

Data Probe

L
F
B

Diffusion MRI Analysis

S: 0.000mm

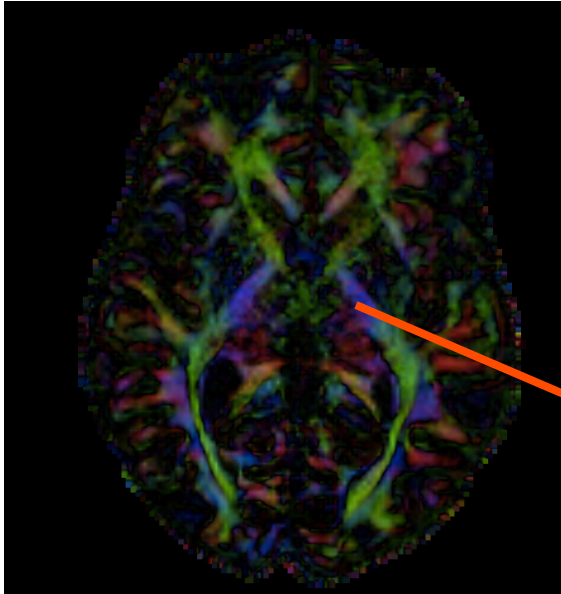
5 cm

NA-MIC ARR 2012-2015

B: dti

Sonia Pujol, Ph.D.

Diffusion Tensor Data



$$S_i = S_0 e^{-b \hat{g}_i^T \underline{D} \hat{g}_i}$$

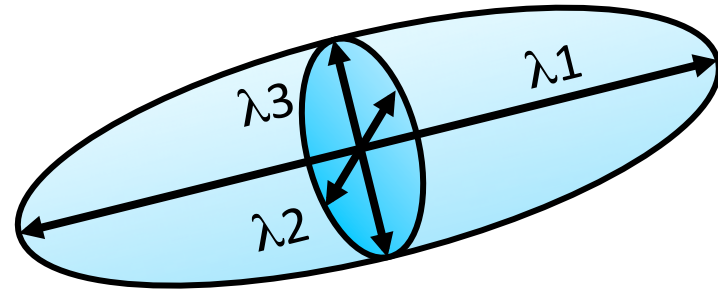
Stejskal-Tanner equation (1965)

$$\underline{\mathbf{D}} = \begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{zx} & D_{zy} & D_{zz} \end{bmatrix}$$

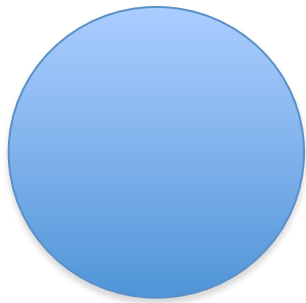
The diffusion tensor $\underline{\mathbf{D}}$ in the voxel (I,J,K) is a 3x3 symmetric matrix.

Diffusion Tensor

- The diffusion tensor \underline{D} in each voxel can be visualized as a diffusion ellipsoid, with the eigenvectors indicating the directions of the principal axes, and the ellipsoidal proportional to the square root of the eigenvalues defining the
- Scalar maps can be derived from the rotationally invariant eigenvalues λ_1 , λ_2 , λ_3 to characterize the size and shape of the diffusion tensor.

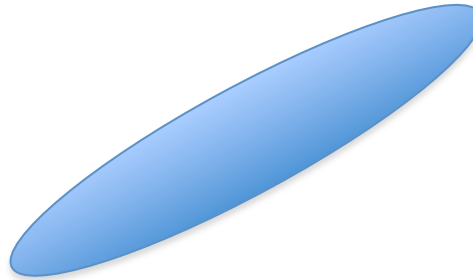


Diffusion Tensor Shape



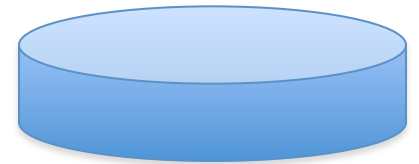
$$\lambda_1 = \lambda_2 = \lambda_3$$

Isotropic media
(Cerebrospinal
Fluid, gray matter)



$$\lambda_1 \gg \lambda_2, \lambda_3$$

Anisotropic media
(white matter)



$$\lambda_1 \sim \lambda_2 \gg \lambda_3$$

Exploring the DWI Dataset

3D Slicer 4.4.0-2015-05-21

Modules: **DWI to DTI Estimation**

3DSlicer

Help & Acknowledgement

DWI to DTI Estimation

Parameter set: DWI to DTI Estimation

IO

Input DWI Volume: dwi

Diffusion Tensor Mask: dwi_mask

Output DTI Volume: dti

Output Baseline Volume: baseline

Estimation Parameters

Estimation Parameters: LS DTI

Shift Negative Eigenvalues:

Status: Completed

100%

Restore Defaults AutoRun Cancel Apply

Data Probe

L
F
B

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

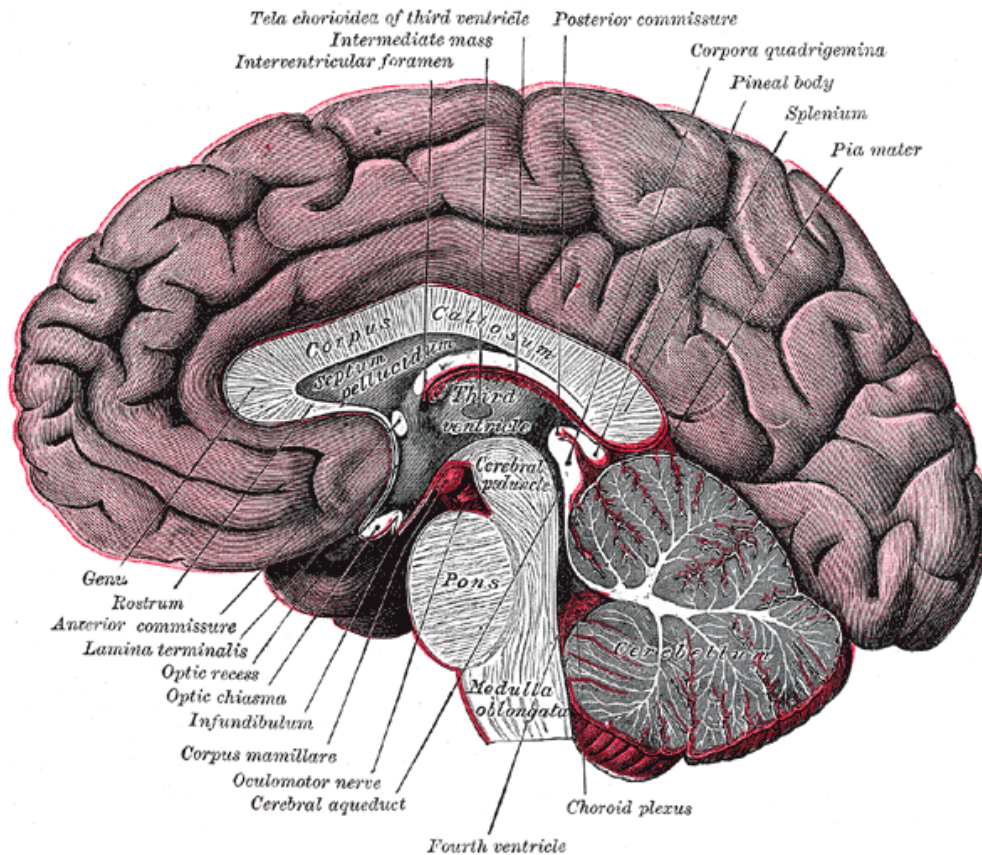
5 cm

S: 0.000mm

B: dti

Use the slider to browse through the dti volume, and try to locate the **Corpus Callosum**

Corpus Callosum



The corpus callosum is a broad thick bundle of dense myelinated fibers that connect the left and right hemisphere. It is the largest white matter structure in the brain

Image from Gray's Anatomy

Corpus Callosum

3D Slicer 4.4.0-2015-05-21

Modules: **DWI to DTI Estimation**

3DSlicer

Help & Acknowledgement

DWI to DTI Estimation

Parameter set: **Corpus Callosum**

IO

Input DWI Volume: dwi

Diffusion Tensor Mask: dwi_mask

Output DTI Volume: dti

Output Baseline Volume: baseline

Estimation Parameters

Estimation Parameters: LS WLS

Shift Negative Eigenvalues:

Image Courtesy of Dr. Alexandra Golby, Brigham and Women's Hospital, Boston, MA..

Status: Completed

100%

Restore Defaults AutoRun Cancel Apply

Data Probe

L
F
B

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

5 cm

NA-MIC ARR 2012-2015

Characterizing the Size of the tensor: Trace

$$\text{Trace}(D) = \lambda_1 + \lambda_2 + \lambda_3$$

- Trace(D) is intrinsic to the tissue and is independent of fiber orientation, and diffusion sensitizing gradient directions
- Trace(D) is a clinically relevant parameter for monitoring stroke and neurological condition (degree of structural coherence in tissue)
- Trace(D) is useful to characterize the size of the diffusion ellipsoid

Trace

The screenshot displays the 3D Slicer interface with the 'Modules' menu open. A yellow callout box at the top right contains the text: 'Click on the Modules menu and select the module Diffusion Tensor Scalar Measurements'. A red arrow points from this text to the 'Diffusion Tensor Scalar Measurements' option in the nested menu. The main window shows a brain slice with a color-coded DTI volume. The status bar at the bottom indicates 'S: 19.000mm' and 'B: dti'. The bottom left corner has 'Diffusion MRI Analysis' and 'BRAINS' text. The bottom right corner has 'NA-MIC ARR 2012-2015' and a close button.

3D Slicer 4.4.0-2015-05-21

Modules: DWI to DTI Estimation

All Modules

- Annotations
- Data
- DataStore
- DICOM
- Editor
- Markups
- Models
- Scene Views
- Subject Hierarchy
- Transforms
- View Controllers
- Volume Rendering
- Volumes
- Welcome to Slicer
- Wizards
- Informatics
- Registration
- Segmentation
- Quantification
- Diffusion**
 - DWI to Full Brain Tractography
 - Tractography Display
 - Diffusion Data Conversion
 - Diffusion Tensor Images
 - Diffusion Tensor Scalar Measurements**
 - Resample DTI Volume
 - Tractography Interactive Seeding
 - Tractography Label Map Seeding
 - Diffusion Weighted Images
 - Tractography
- IGT
- Filtering
- Surface Models
- Converters
- Endoscopy
- Utilities
- Developer Tools
- Legacy
- MultiVolume Support
- Unspecified
- BRAINS

Parameter set: DWI to DTI Estimation

Input DWI Volume: dwi

Diffusion Tensor Mask: dwi

Output DTI Volume: dti

Output Baseline Volume: baseline

Estimation Parameters

Shift Negative Eigenvalues

Restore Defaults AutoRun

Data Probe

S: 19.000mm

B: dti

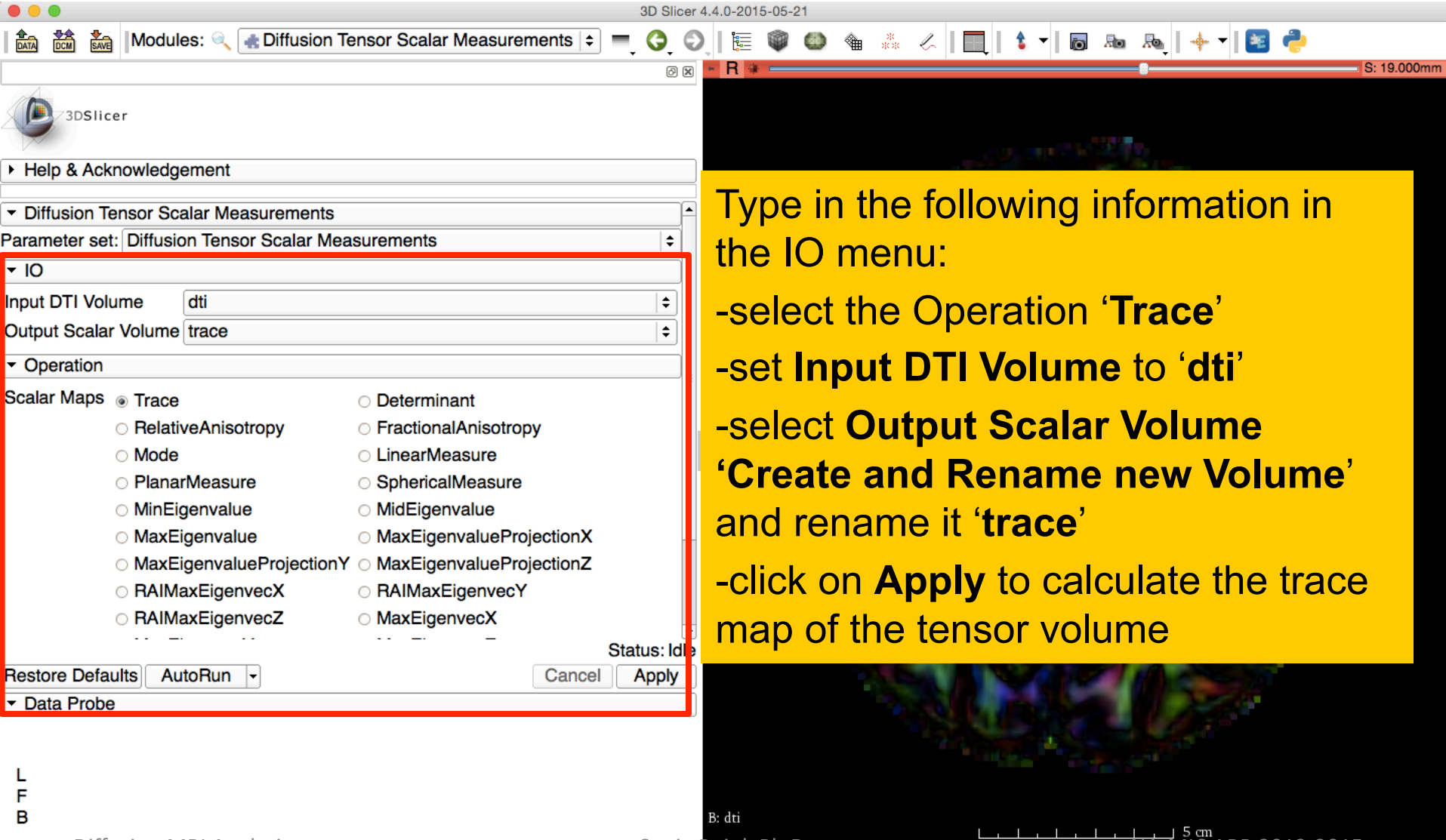
5 cm

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

Trace



Type in the following information in the IO menu:

-select the Operation **'Trace'**

-set **Input DTI Volume** to **'dti'**

-select **Output Scalar Volume**
'Create and Rename new Volume'
and rename it **'trace'**

-click on **Apply** to calculate the trace map of the tensor volume

Trace

3D Slicer 4.4.0-2015-05-21

Modules: Diffusion Tensor Scalar Measurements

3DSlicer

Help & Acknowledgement

Diffu

Param

IO

Input D

Output Scalar Volume trace

Operation

Scalar Maps

- Trace
- Determinant
- RelativeAnisotropy
- FractionalAnisotropy
- Mode
- LinearMeasure
- PlanarMeasure
- SphericalMeasure
- MinEigenvalue
- MidEigenvalue
- MaxEigenvalue
- MaxEigenvalueProjectionX
- MaxEigenvalueProjectionY
- MaxEigenvalueProjectionZ
- RAIMaxEigenvecX
- RAIMaxEigenvecY

Status: Completed

100%

Restore Defaults AutoRun Cancel Apply

Data Probe

L
F
B

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

B: trace

5 cm

S: 0.000mm

Trace

Position your mouse over the **pin icon** and then select the **'>>'** icon to display this table and fill in the following information:

- Select the volume **'trace'** in the Background viewer
- Select the volume **'dti'** in the Foreground viewer

Set the **opacity** of the **dti** volume to **0.40**

3D Slicer 4.4.0-2015-05-21

Modules: Diffusion Tensor Scalar Measurements

Volume Selection Table:

Volume Name	Opacity	View
None	1.00	Background
dti	0.40	Foreground
trace	1.00	Background

Foreground Viewer: F: dti (40%), B: trace

Background Viewer: trace

Scale: 5 cm



Trace

Position your mouse within the region of the Corpus Callosum and observe the trace values in the **Data Probe**

3D Slicer 4.4.0-2015-05-21

Parameter set: Diffusion Tensor Scalar Measurements

IO

Input DTI Volume: dti

Output Scalar Volume: trace

Operation

Scalar Maps

- Trace
- Determinant
- RelativeAnisotropy
- FractionalAnisotropy
- Mode
- LinearMeasure
- PlanarMeasure
- SphericalMeasure
- MinEigenvalue
- MidEigenvalue
- MaxEigenvalue
- MaxEigenvalueProjectionX
- MaxEigenvalueProjectionY
- MaxEigenvalueProjectionZ
- RAIMaxEigenvecX
- RAIMaxEigenvecY

Status: Completed

100%

Cancel Apply

Data Probe

Red RAS: (6.2, 6.7, 19.0) Axial Sp: 1.5

L None

F dti (60, 60, 60) ColorOrientation 0

B trace (60, 60, 60) 0.002111

Diffusion MRI Analysis

5 cm

NA-MIC ARR 2012-2015

tonia Pujol, Ph.D.

Trace

3D Slicer 4.4.0-2015-05-21

Modules: Diffusion Tensor Scalar Measurements

Note how the Trace values are fairly uniform in both white and gray matter, even if the tissues are different in structure.

Input DTI Volume: dti
Output Scalar Volume: trace

Operation

Scalar Maps

- Trace
- Determinant
- RelativeAnisotropy
- FractionalAnisotropy
- Mode
- LinearMeasure
- PlanarMeasure
- SphericalMeasure
- MinEigenvalue
- MidEigenvalue
- MaxEigenvalue
- MaxEigenvalueProjectionX
- MaxEigenvalueProjectionY
- MaxEigenvalueProjectionZ
- RAI_MaxEigenvecX
- RAI_MaxEigenvecY

Status: Completed
100%

Cancel Apply

Data Probe

Red RAS: (38.0, -21.2, 19.0) Axial Sp: 1.5

L None

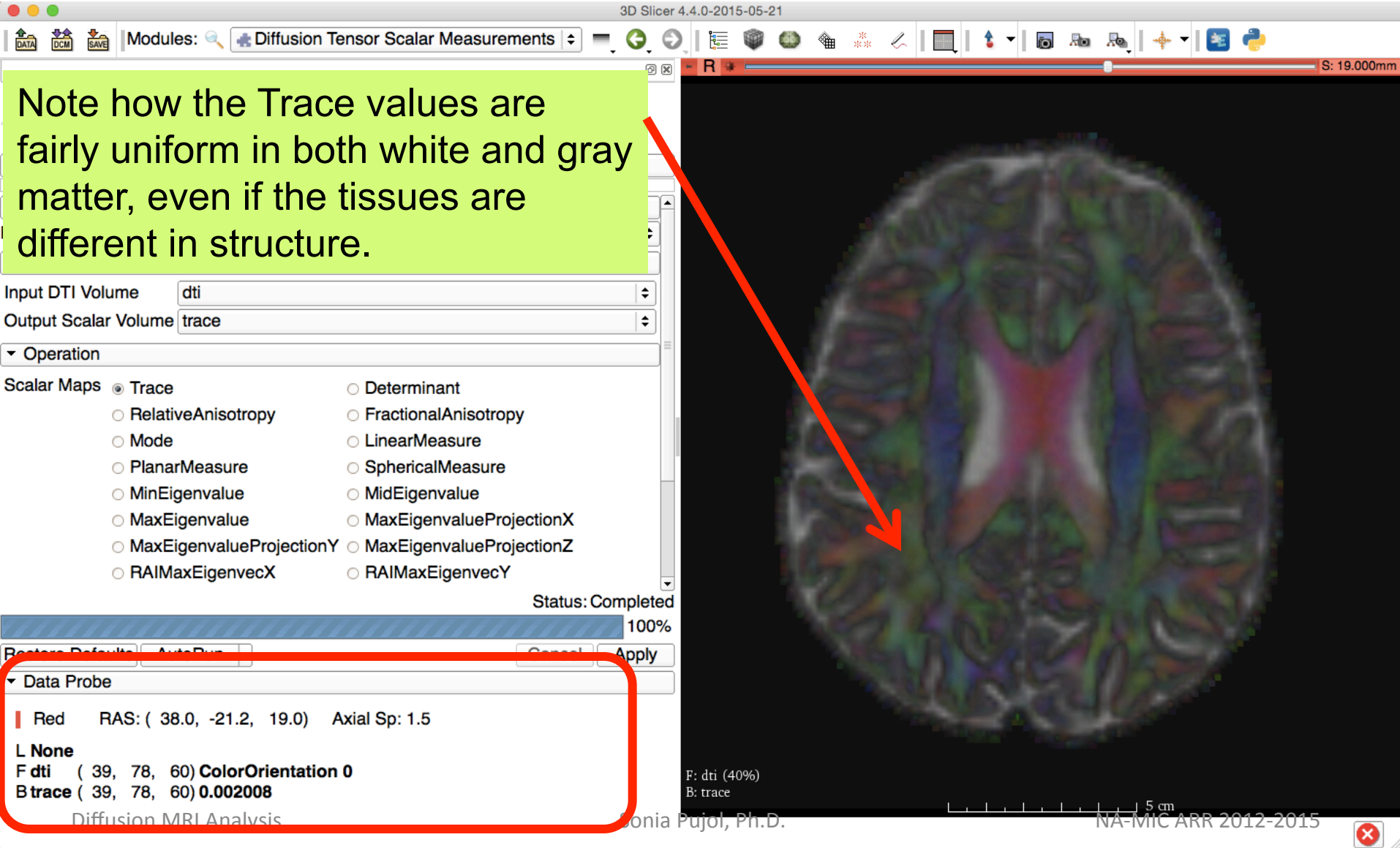
F dti (39, 78, 60) ColorOrientation 0

B trace (39, 78, 60) 0.002008

Diffusion MRI Analysis




5 cm

NA-MIC ARR 2012-2015

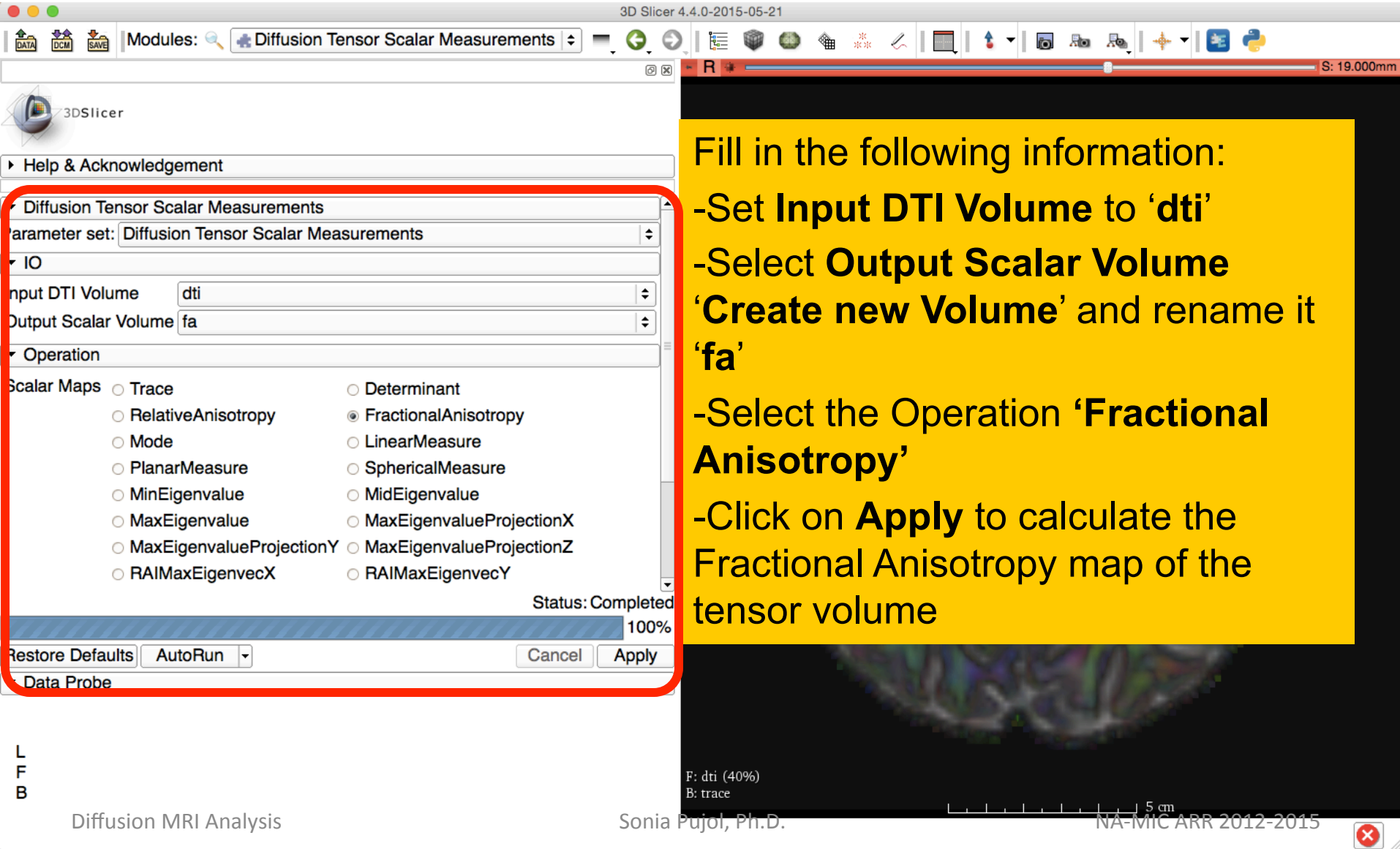


Scalar Maps: Fractional Anisotropy

$$FA(D) = \frac{\sqrt{(\lambda_1 - \lambda_2)^2 + (\lambda_1 - \lambda_3)^2 + (\lambda_2 - \lambda_3)^2}}{\sqrt{2} \sqrt{\lambda_1^2 + \lambda_2^2 + \lambda_3^2}}$$

- FA(D) is intrinsic to the tissue and is independent of fiber orientation, and diffusion sensitizing gradient directions
- FA(D) is useful to characterize the shape (degree of 'out-of-roundness') of the diffusion ellipsoid
- Low FA:   High FA: 

Fractional Anisotropy



3D Slicer 4.4.0-2015-05-21

Modules: Diffusion Tensor Scalar Measurements

3DSlicer

Help & Acknowledgement

Diffusion Tensor Scalar Measurements

Parameter set: Diffusion Tensor Scalar Measurements

IO

Input DTI Volume: dti

Output Scalar Volume: fa

Operation

Scalar Maps

- Trace
- RelativeAnisotropy
- Mode
- PlanarMeasure
- MinEigenvalue
- MaxEigenvalue
- MaxEigenvalueProjectionY
- RAImaxEigenvecX
- Determinant
- FractionalAnisotropy
- LinearMeasure
- SphericalMeasure
- MidEigenvalue
- MaxEigenvalueProjectionX
- MaxEigenvalueProjectionZ
- RAImaxEigenvecY

Status: Completed 100%

Restore Defaults AutoRun Cancel Apply

Data Probe

L
F
B

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

5 cm

NA-MIC ARR 2012-2015

F: dti (40%)
B: trace

S: 19.000mm

Fill in the following information:

- Set **Input DTI Volume** to 'dti'
- Select **Output Scalar Volume** 'Create new Volume' and rename it 'fa'
- Select the Operation '**Fractional Anisotropy**'
- Click on **Apply** to calculate the Fractional Anisotropy map of the tensor volume

Fractional Anisotropy

3D Slicer 4.4.0-2015-05-21

Modules: Diffusion Tensor Scalar Measurements

3DSlicer

Help & Acknowledgement

Diffu

Param

IO

Input D

Output Scalar Volume: fa

Operation

Scalar Maps

- Trace
- RelativeAnisotropy
- Mode
- PlanarMeasure
- MinEigenvalue
- MaxEigenvalue
- MaxEigenvalueProjectionY
- RAIMaxEigenvecX
- Determinant
- FractionalAnisotropy
- LinearMeasure
- SphericalMeasure
- MidEigenvalue
- MaxEigenvalueProjectionX
- MaxEigenvalueProjectionZ
- RAIMaxEigenvecY

Status: Completed

100%

Restore Defaults AutoRun Cancel Apply

Data Probe

L
F
B

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

5 cm

B: fa

S: 0.000mm

Fractional Anisotropy

3D Slicer 4.4.0-2015-05-21

Modules: Diffusion Tensor Scalar Measurements

3DSlicer

Help & Acknowledgement

Diffusion Tensor Scalar Measurements

Parameter set: Diffusion Tensor Scalar Measurements

IO

Input DTI Volume dti

Output Scalar Volume fa

Open Scalar

Position your mouse over the **pin icon** and click the **'>>' icon** to display this table. Set the background volume to **'fa'** and be sure the foreground volume is still set to **'dti'** with **opacity at 0.40**

Volume Name	Opacity	Background
dti	0.40	dti
fa	1.00	fa

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

5 cm

F: dti (40%)
B: fa

Fractional Anisotropy

Explore the FA values in the Corpus Callosum and in adjacent gray matter areas. Note how the FA values are high in the white matter areas, and low in gray matter regions

3D Slicer 4.4.0-2015-05-21

Modules: Diffusion Tensor Scalar Measurements

Output Scalar Volume: fa

Operation

Scalar Maps

- Trace
- RelativeAnisotropy
- Mode
- PlanarMeasure
- MinEigenvalue
- MaxEigenvalue
- MaxEigenvalueProjectionY
- RAIMaxEigenvecX
- Determinant
- FractionalAnisotropy
- LinearMeasure
- SphericalMeasure
- MidEigenvalue
- MaxEigenvalueProjectionX
- MaxEigenvalueProjectionZ
- RAIMaxEigenvecY

Status: Completed

100%

Cancel Apply

Data Probe

Red RAS: (7.7, 8.8, 19.0) Axial Sp: 1.5

L None

F dti (59, 58, 60) ColorOrientation 0

B fa (59, 58, 60) 0.890284

F: dti (40%)

B: fa

5 cm

NA-MIC ARR 2012-2015

Sonia Pujol, Ph.D.

Fractional Anisotropy

3D Slicer 4.4.0-2015-05-21

Modules: Diffusion Tensor Scalar Measurements

Change to Conventional view

Help & Acknowledgement

Diffusion Tensor Scalar Measurements

Parameter set: Diffusion Tensor Scalar Measurements

IO

Input DTI Volume: dti

Output Scalar Volume: fa

Operation

Scalar Maps

- Trace
- RelativeAnisotropy
- Mode
- PlanarMeasure
- MinEigenvalue
- MaxEigenvalue
- MaxEigenvalueProjectionY
- RAIMaxEigenvecX
- Determinant
- FractionalAnisotropy
- LinearMeasure
- SphericalMeasure
- MidEigenvalue
- MaxEigenvalueProjectionX
- MaxEigenvalueProjectionZ
- RAIMaxEigenvecY

Status: Completed

100%

Restore Defaults AutoRun Cancel Apply

Data Probe

Conventional

- Conventional Widescreen
- Conventional Quantitative
- Four-Up
- Four-Up Quantitative
- Dual 3D
- Triple 3D
- 3D only
- One-Up Quantitative
- Red slice only
- Yellow slice only
- Green slice only
- Tabbed 3D
- Tabbed slice
- Compare
- Compare Widescreen
- Compare Grid
- Three over three
- Three Over Three Quantitative
- Four over four
- Two over Two
- Side by side
- Four by three slice
- Four by two slice
- Three by three slice

L
F
B

Diffusion MRI Analysis

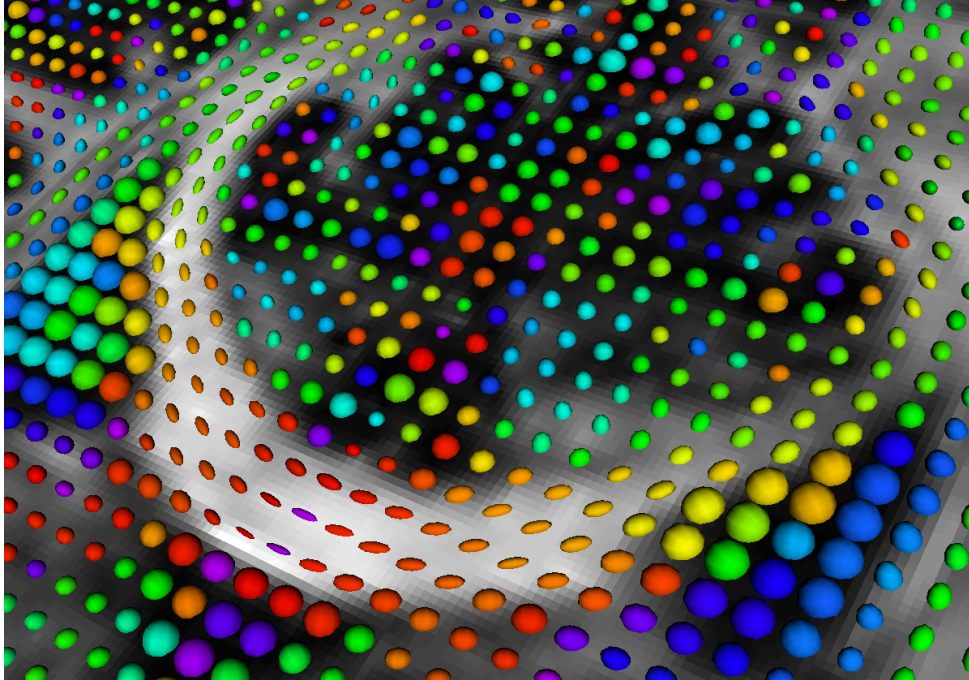
Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

F: dti (40%)
B: fa

5 cm

S: 19.000mm



Part 2: Visualizing the tensor data

3D Visualization: Glyphs

3D Slicer 4.4.0-2015-05-21

Modules: Diffusion Tensor Scalar Measurements

All Modules

- Annotations
- Data
- DataStore
- DICOM
- Editor
- Markups
- Models
- Scene Views
- Subject Hierarchy
- Transforms
- View Controllers
- Volume Rendering
- Volumes**
- Welcome to Slicer

Wizards

- Informatics
- Registration
- Segmentation
- Quantification
- Diffusion
- IGT
- Filtering
- Surface Models
- Converters
- Endoscopy
- Utilities
- Developer Tools
- Legacy
- MultiVolume Support
- Unspecified
- BRAINS

Completed: 100%

Apply

Click on the Modules menu and select the module **Volumes**

S

R P L

I

R S: 19.000mm Y R: 1.500mm G A: 1.500mm

F: dti (40%)
B: fa

5 cm

5 cm

5 cm

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

3D Visualization: Glyphs

3D Slicer 4.4.0-2015-05-21

Modules: Volumes

3DSlicer

Help & Acknowledgement

Active Volume: dwi

Volume Information

Display

Scalar Display

DWI Component: 10

Lookup Table: Grey

Interpolate:

Window Level editor presets:

W: 450 Manual W/L L: 288

Threshold: Manual

-600 1390

Histogram

Data Probe

L
F
B

Diffusion MRI Analysis

S. 19.000mm R: 1.500mm A: 1.500mm

Position the mouse over the **pin icon** and select the '**<<**' icon to display the axial slice toolbar. Set the **Foreground** to 'fa' and the **Background** to 'dti', with the **Foreground** opacity set to **1.00**

1.00 None
1.00 fa
1.00 dti

F: fa (100%)
B: dti

F: fa (100%)
B: dti

F: fa (100%)
B: dti

5 cm 5 cm 5 cm

3D Visualization: Glyphs

3D Slicer 4.4.0-2015-05-21

Modules: Volumes

Active Volume: dti

Scalar Display: Scalar Mode: ColorOrientation

Lookup table: Grey

Interpolate:

Window Level editor presets:

W: 255 Auto W/L L: 128

Threshold: Off

Glyphs on Slices Display: Red Yellow Green

Data Probe

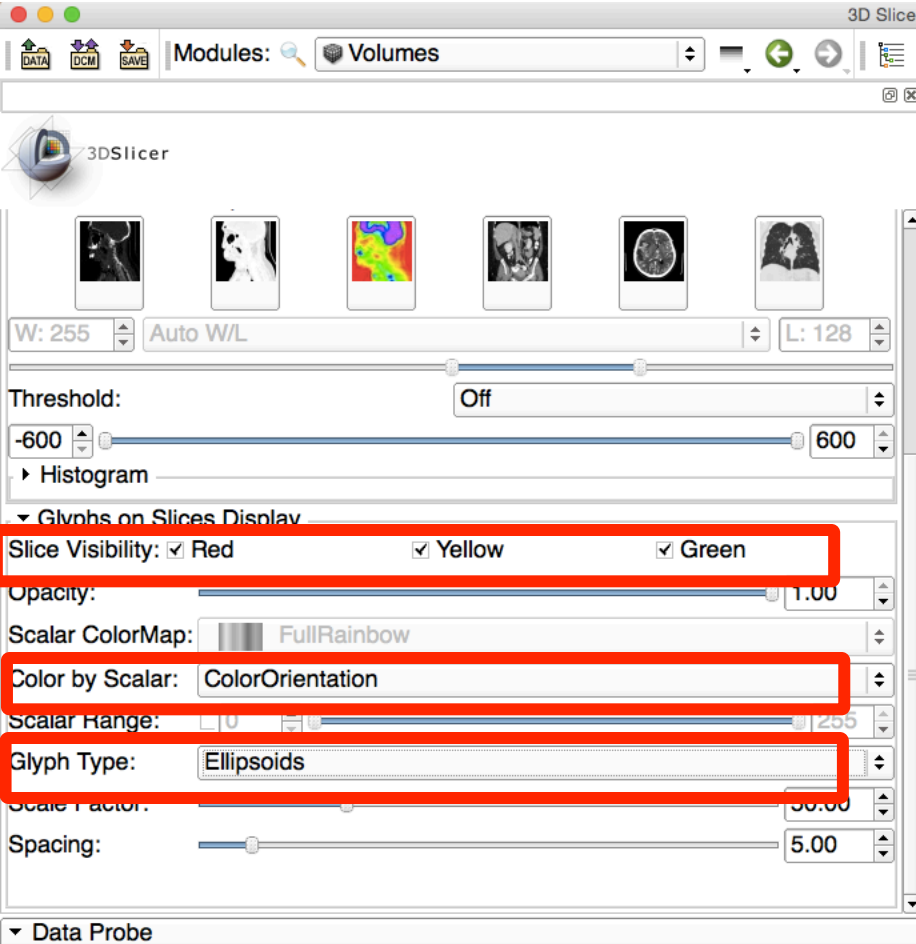
Set the **Active Volume** to 'dti' and the **Scalar Mode** to 'ColorOrientation'

R S: 19.000mm Y R: 1.500mm G A: 1.500mm

F: fa (100%)
B: dti

5 cm

3D Visualization: Glyphs

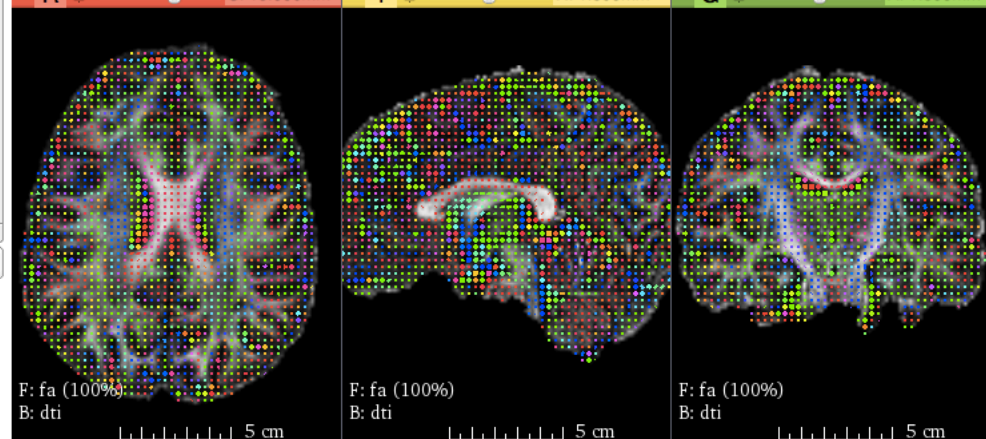


Scroll down the module panel and:

- Check off the option for **Red, Yellow, and Green Slice Visibility**

- Set the **Color by Scalar** parameter to **'ColorOrientation'**

- Set the **Glyph Type** to **'Ellipsoids'**



3D Visualization: Glyphs

The image shows the 3D Slicer 4.4.0-2015-05-21 interface. The main window displays a 3D view of a brain slice with glyphs (small colored dots) overlaid on the white matter tracts. A yellow text box in the 3D view states: "The glyphs appear in all 3 slice viewers".

The left sidebar shows the "Volumes" module with various settings for the Diffusion MRI Analysis:

- W: 255, L: 128
- Threshold: Off
- Scalar Range: -600 to 600
- Histogram
- ▼ Glyphs on Slices Display
 - Slice Visibility: Red, Yellow, Green
 - Opacity: 1.00
 - Scalar ColorMap: FullRainbow
 - Color by Scalar: ColorOrientation
 - Scalar Range: 0 to 255
 - Glyph Type: Ellipsoids
 - Scale Factor: 50.00
 - Spacing: 5.00
- ▼ Data Probe

The bottom of the interface shows three slice viewers (Axial, Sagittal, Coronal) displaying the glyphs on the slices. A red box highlights these three slice viewers. Each slice viewer shows the glyphs overlaid on the brain slice, with a 5 cm scale bar at the bottom. The slice viewers are labeled with their respective orientations: R (Right), S (Superior), V (Ventral), B (Bottom), G (Green), and A (Anterior).

Diffusion MRI Analysis

Sonia Raju, Ph.D.

NA-MIC ARR 2012-2015

3D Visualization: Glyphs

3D Slicer 4.4.0-2015-05-21

Modules: Volumes

3DSlicer

W: 255 Auto W/L L: 128

Threshold: Off

-600 600

► Histogram

▼ Glyphs on Slices Display

Slice Visibility: Red Yellow Green

Opacity: 1.00

Scalar ColorMap: FullRainbow

Color by Scalar: ColorOrientation

Scalar Range: 0 255

Glyph Type: Ellipsoids

Scale Factor: 50.00

Spacing: 5.00

▼ Data Probe

L
F
B

Diffusion MRI Analysis

Position your mouse over the **pin icon** select the **eye icon** to display the axial, coronal, and sagittal slices in the 3D viewer

R S: 19.000mm Y R: 1.500mm G A: 1.500mm

» Axial dti

F: fa (100%)
B: dti 5 cm

F: fa (100%)
B: dti 5 cm

F: fa (100%)
B: dti 5 cm



3D Visualization: Glyphs

The screenshot displays the 3D Slicer interface. The main 3D view shows a brain model with a grid of glyphs (small colored ellipsoids) overlaid on it. The glyphs are color-coded based on their orientation. The 3D view is labeled with 'A' (Anterior), 'L' (Left), 'R' (Right), and 'P' (Posterior). Below the 3D view, there are three 2D slice views: an axial slice (labeled 'R'), a sagittal slice (labeled 'Y'), and a coronal slice (labeled 'G'). Each slice view shows the brain model with the glyphs overlaid. The slice views are labeled with 'F: fa (100%)' and 'B: dti'. A 5 cm scale bar is visible in the bottom right of each slice view.

Control Panel (Left):

- W: 255, L: 128
- Threshold: Off
- Scalar Range: -600 to 600
- Histogram
- ▼ Glyphs on Slices Display
 - Slice Visibility: Red, Yellow, Green
 - Opacity: 1.00
 - Scalar ColorMap: FullRainbow
 - Color by Scalar: ColorOrientation
 - Scalar Range: 0 to 255
 - Glyph Type: Ellipsoids
 - Scale Factor: 50.00
 - Spacing: 5.00
- ▼ Data Probe



3D Visualization: Glyphs

3D Slicer 4.4.0-2015-05-21

Modules: Volumes

Zoom in to observe the glyphs.
The ellipsoids represent the diffusion tensors

Threshold: Off

0 0

► Histogram

▼ Glyphs on Slices Display

Slice Visibility: Red Yellow Green

Opacity: 1.00

Scalar ColorMap: FullRainbow

Color by Scalar: ColorOrientation

Scalar Range: 0 255

Glyph Type: Ellipsoids

Scale Factor: 50.00

Spacing: 5.00

▼ Data Probe

L
F
B

R S: 10.500mm Y R: -31.500mm G A: 13.500mm

F: fa (100%)
B: dti

5 cm

F: fa (100%)
B: dti

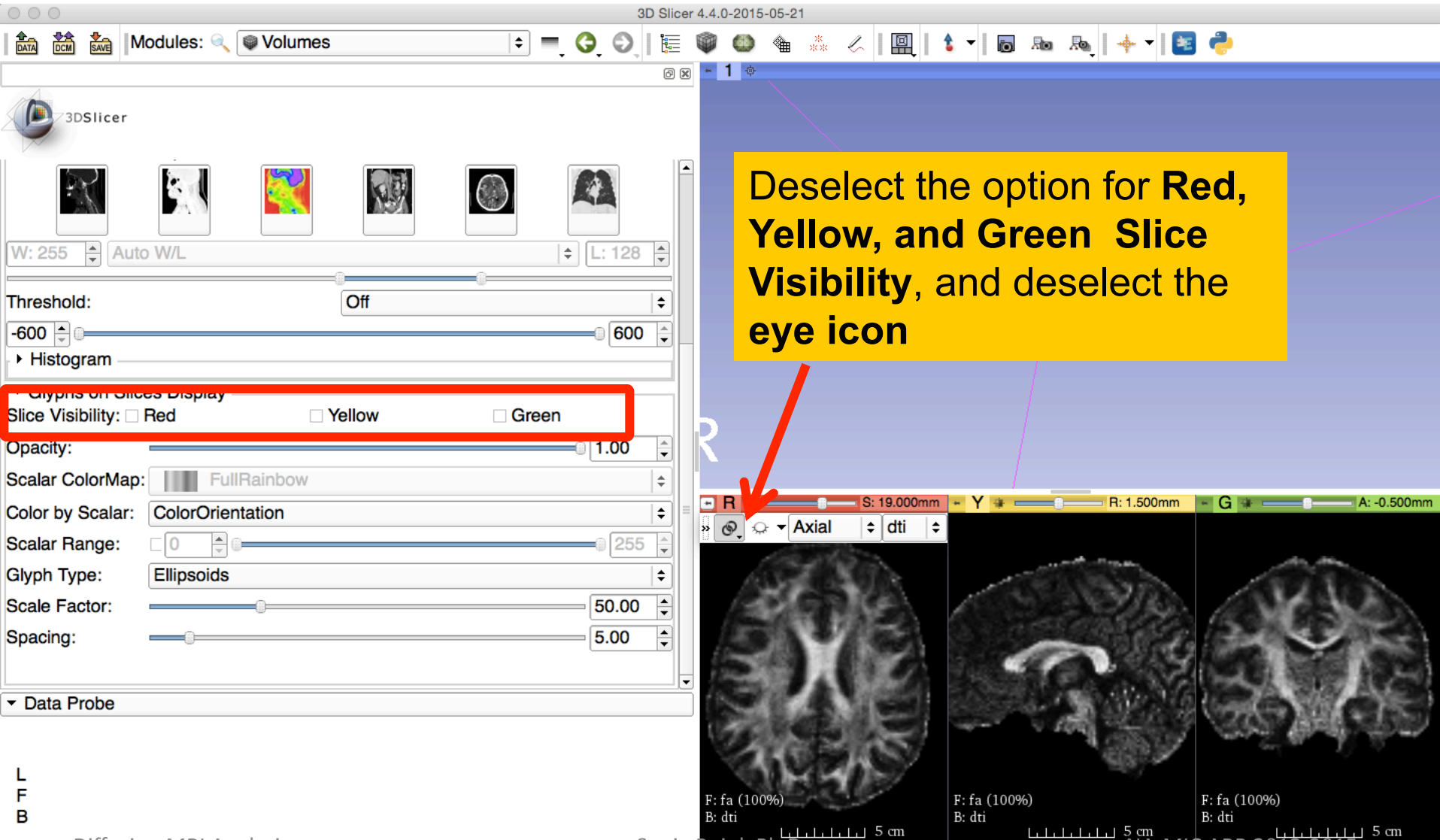
5 cm

F: fa (100%)
B: dti

5 cm



Diffusion MRI tractography



Diffusion MRI tractography

The image shows the 3D Slicer software interface. On the left is the 'Volumes' panel with various settings for the selected volume. On the right is a 3x3 grid of brain slices. A yellow text box is overlaid on the right side, and a red box highlights a portion of the slice grid.

3D Slicer 4.4.0-2015-05-21

Modules: Volumes

3DSlicer

W: 255 Auto W/L L: 128

Threshold: Off

-600 600

► Histogram

▼ Glyphs on Slices Display

Slice Visibility: Red Yellow Green

Opacity: 1.00

Scalar ColorMap: FullRainbow

Color by Scalar: ColorOrientation

Scalar Range: 0 255

Glyph Type: Ellipsoids

Scale Factor: 50.00

Spacing: 5.00

▼ Data Probe

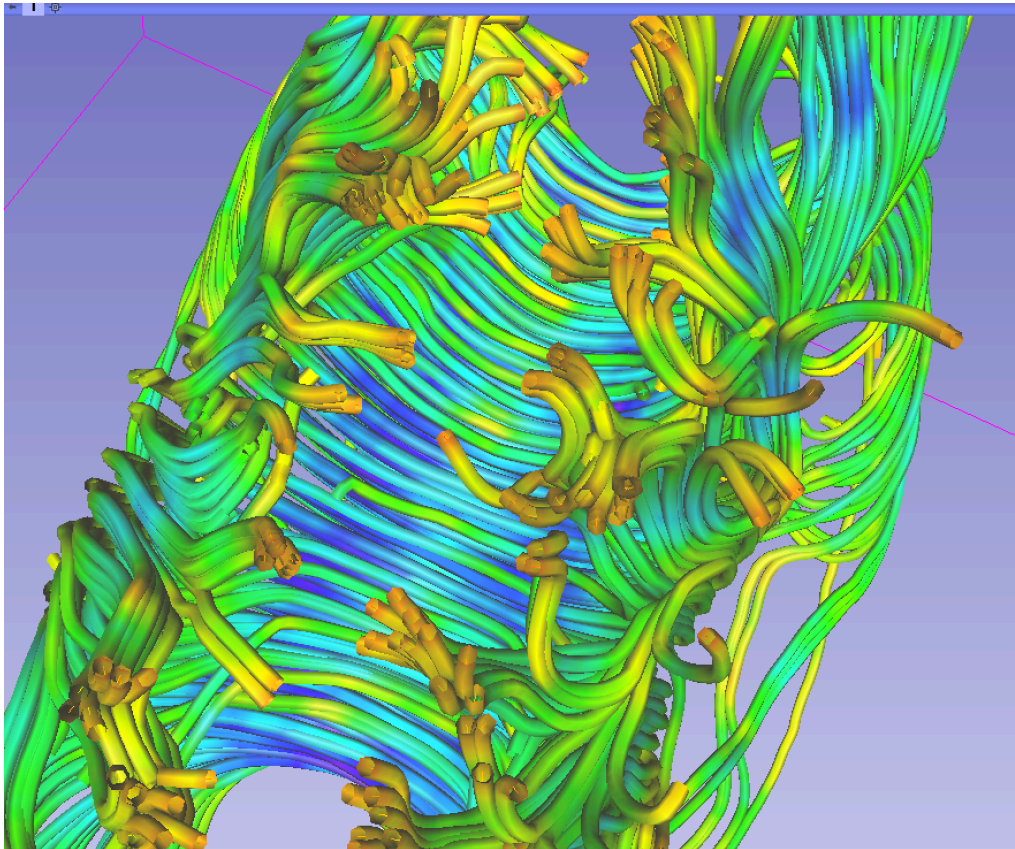
Position your mouse over the pin icon and change the Foreground to 'None' and the background to 'fa'

Axial 1.00 None 1.00 None 1.00 fa

L F B

B: fa 5 cm B: fa 5 cm B: fa 5 cm





Part 3: From tensors to tracts

DTI tractography

- Definition of a region of interest (ROI) for seeding tract in an FA map (Editor module)
- Single-tensor tractography (Tractography Interactive Seeding module)
- Fiducial-seeding tractography (Tractography Interactive Seeding module)

Diffusion MRI tractography

3D Slicer 4.4.0-2015-05-21

Modules: Volumes

- All Modules
- Annotations
- Data
- DataStore
- DICOM
- Editor**
- Markups
- Models
- Scene Views
- Subject Hierarchy
- Transforms
- View Controllers
- Volume Rendering
- Volumes
- Welcome to Slicer
- Wizards
- Informatics
- Registration
- Segmentation
- Quantification
- Diffusion
- IGT
- Filtering
- Surface Models
- Converters
- Endoscopy
- Utilities
- Developer Tools
- Legacy
- MultiVolume Support
- Unspecified
- BRAINS

W: 255 Auto W/L

Threshold: -600

► Histogram

▼ Glyphs on Slices Display

Slice Visibility: Red

Opacity: [Slider]

Scalar ColorMap: [Slider] Full

Color by Scalar: ColorOriented

Scalar Range: [Slider] 0

Glyph Type: Ellipsoids

Scale Factor: [Slider]

Spacing: [Slider]

▼ Data Probe

L
F
B

Select the module **Editor**

R

R S: 19.000mm Y R: 1.500mm G A: -0.500mm

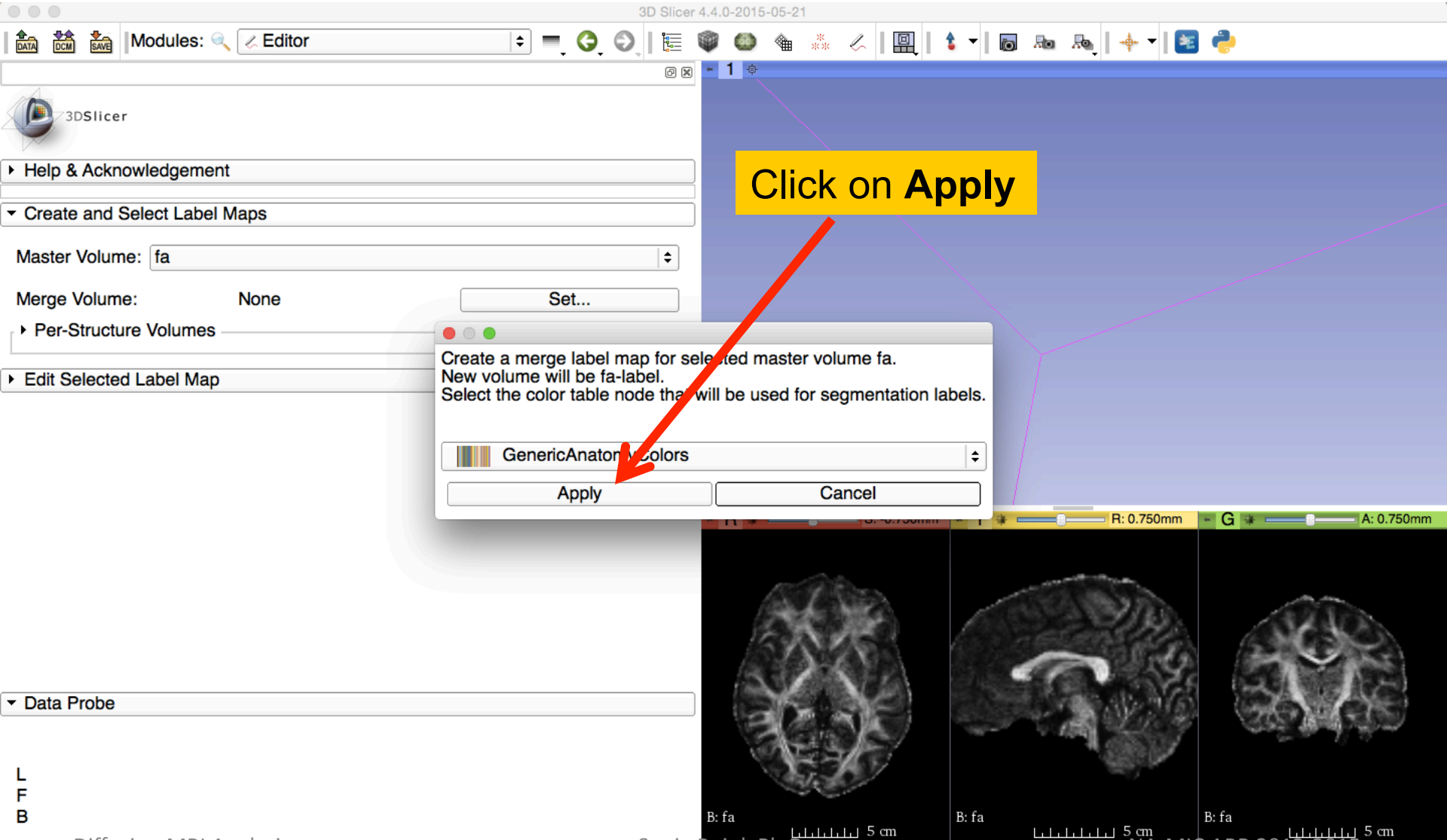
B: fa 5 cm B: fa 5 cm B: fa 5 cm

Diffusion MRI Analysis

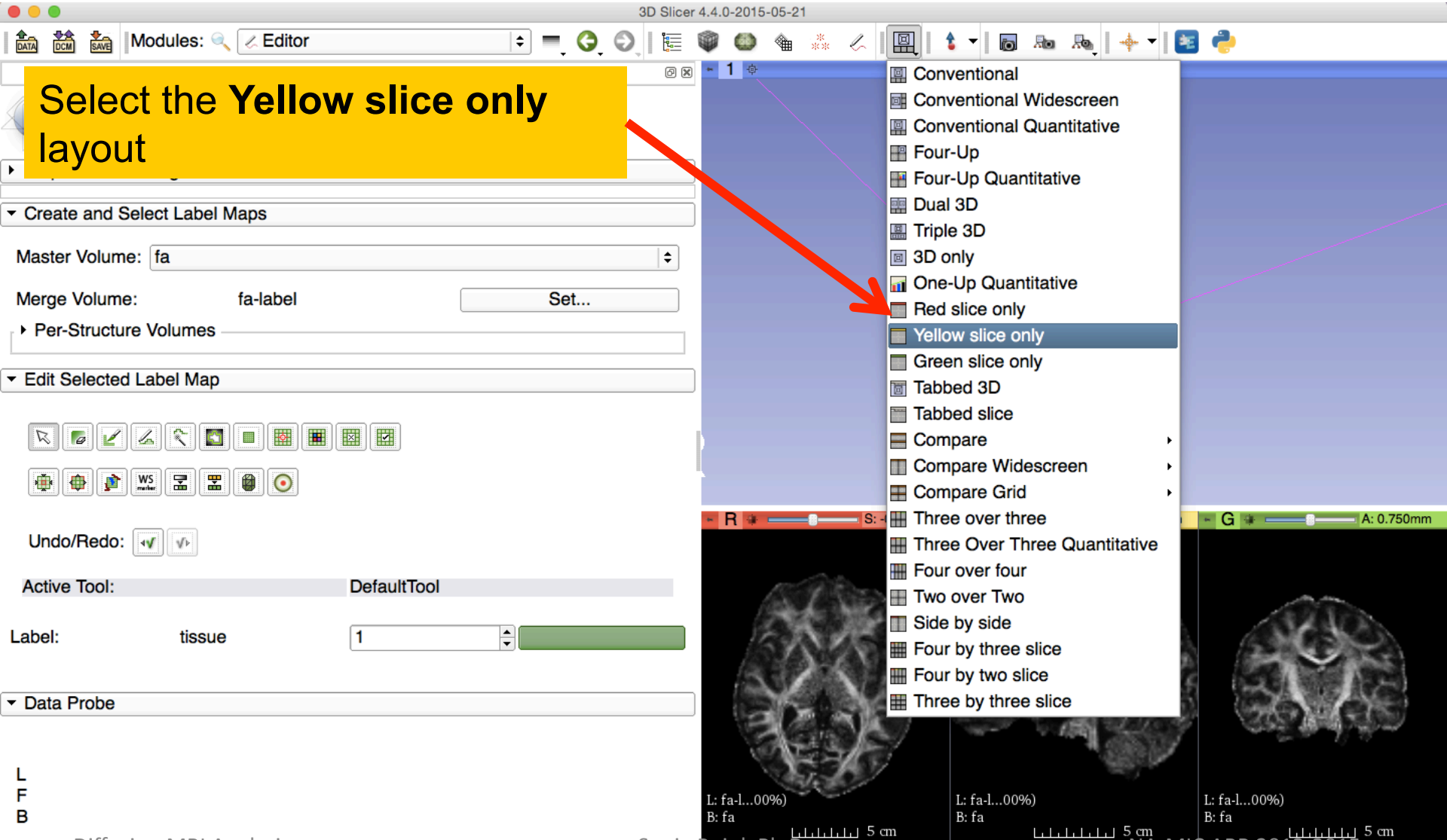
Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

Diffusion MRI tractography



Diffusion MRI tractography



Select the **Yellow slice only** layout



Diffusion MRI tractography

3D Slicer 4.4.0-2015-05-21

Modules: Editor

Fit to Screen Icon

Click on the **fit to screen** icon to adjust the dimensions of the yellow slice viewer to fit the screen

Master Volume: baseline

Active Tool: ErodeEffect

Label: jake 1

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

B: fa

5 cm

NA-MIC ARR 2012-2015

Diffusion MRI tractography

3D Slicer 4.4.0-2015-05-21

Modules: Editor

3DSlicer

Help & Acknowledgement

Create a

Master Volume

Merge Volume: dwi_mask Set...

Per-Structure Volumes

Edit Selected Label Map

DrawEffect

Undo/Redo:

Active Tool: ErodeEffect

Label: jake 1

Eight Neighbors

Data Probe

L
F
B

Diffusion MRI Analysis

B: fa

5 cm

NA-MIC ARR 2012-2015

R: 0.750mm

Select the DrawEffect tool

Diffusion MRI tractography

3D Slicer 4.4.0-2015-05-21

Modules: Editor

3DSlicer

Help &
Create
Master V
Merge V
Per-St
Edit Se

Outline the contour of the Corpus Callosum with the **DrawEffect tool** and press enter. Repeat this step with 3 adjacent sagittal slices

Active Tool: DrawEffect

Label: tissue 1

Paint Over
Data Probe

Yellow RAS: (1.5, 79.4, 12.2) Sagittal Sp: 1.5
L fa-label (63, 11, 55) background (0)
F None
B fa (63, 11, 55) 0.150501

Diffusion MRI Analysis

L: fa-label (100%)
B: fa

R: 1.500mm

5 cm

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

Diffusion MRI tractography

3D Slicer 4.4.0-2015-05-21

Modules: Editor

3DSlicer

Help & Acknowledgement

Create and Select Label Maps

Master Volume: fa

Merge

Pe

Edit

In the next section, we will seed tracts from this anatomical region of interest.

Undo/Redo: [Undo] [Redo]

Active Tool: DrawEffect

Label: tissue 1

Paint Over

Data Probe

L
F
B

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

5 cm

R: 1.500mm

L: fa-label (100%)
B: fa

Diffusion MRI tractography

The image shows the 3D Slicer software interface. The 'Modules' panel on the left is open to the 'Diffusion' category, with 'Tractography Interactive Seeding' highlighted. A yellow callout box with a red arrow points to this option. The main window displays a brain MRI slice with a green region of interest. The bottom status bar shows 'L: fa-label (100%)' and 'B: fa'. A scale bar at the bottom right indicates 5 cm.

3D Slicer 4.4.0-2015-05-21

Modules: Editor

- All Modules
- Annotations
- Data
- DataStore
- DICOM
- Editor
- Markups
- Models
- Scene Views
- Subject Hierarchy
- Transforms
- View Controllers
- Volume Rendering
- Volumes
- Welcome to Slicer
- Wizards
- Informatics
- Registration
- Segmentation
- Quantification
- Diffusion**
 - DWI to Full Brain Tractography
 - Tractography Display
 - Diffusion Data Conversion
 - Diffusion Tensor Images
 - Diffusion Tensor Scalar Measurements
 - Resample DTI Volume
 - Tractography Interactive Seeding**
 - Tractography Label Map Seeding
 - Diffusion Weighted Images
 - Tractography
- IGT
- Filtering
- Surface Models
- Converters
- Endoscopy
- Utilities
- Developer Tools
- Legacy
- MultiVolume Support
- Unspecified
- BRAINS

Master Volume: fa

Merge Volume:

Per-Structure Volumes

Edit Selected Label Map

Undo/Redo:

Active Tool:

Label: tissue

Paint Over

Data Probe

R: 1.500mm

5 cm

L: fa-label (100%)
B: fa

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

Labelmap Seeding: Step1: I/O

3D Slicer 4.4.0-2015-05-21

Modules: Tractography Interactive Seeding

Change to Conventional view

Conventional
Conventional Widescreen
Conventional Quantitative
Four-Up
Four-Up Quantitative
Dual 3D
Triple 3D
3D only
One-Up Quantitative
Red slice only
Yellow slice only
Green slice only
Tabbed 3D
Tabbed slice
Compare
Compare Widescreen
Compare Grid
Three over three
Three Over Three Quantitative
Four over four
Two over Two
Side by side
Four by three slice
Four by two slice
Three by three slice

Input DTI Volume: dti
Input Fiducials, Model or Label Map: fa-label
Output Fiber Bundle: corpusCallosum
Enable Seeding Tracts:

-Set the Input DTI Volume to 'dti'
-Set the Input Label Map to 'fa-label'
-Set Output Fiber Bundle to 'Create and Rename New Fiber Bundle' and rename it 'corpusCallosum'
-Uncheck Enable Seeding Tracts

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

Step 2: Seeding parameters

3D Slicer 4.4.0-2015-05-21

Modules: Tractography Interactive Seeding

Enable Seeding Tracts

Label Map Options

Use index Space

Seed Spacing 2.00

Random Grid

Linear Measure Start Threshold 0.30

ROI Labels 1

Write Fibers To Disk

Output Directory /Applications

File Prefix

Tractography Seeding Parameters

Minimum Path Length 20.000mm

Maximum Path Length 500.000mm

Stopping Criteria Fractional Anisotropy

Stopping Value 0.15

Stopping Track Curvature 0.70

Integration Step Length 0.500mm

Enabling Options

Data Probe

R S: 0.000mm Y R: 1.500mm G A: 1.500mm

L: fa-l...00%)
B: fa

L: fa-l...00%)
B: fa

L: fa-l...00%)
B: fa

5 cm 5 cm 5 cm

Select **Use index Space**
Set **Stopping Criteria** to
FractionalAnisotropy
Set **Stopping Value** to 0.15

Step 3: Generate Tracts

3D Slicer 4.4.0-2015-05-21

Modules: Tractography Interactive Seeding

Parameters: FiducialSeedingParameters

Presets: Slicer4 Interactive Seeding Defaults

Input DTI Volume: dti

Input Fiducials, Model or Label Map: fa-label

Output Fiber Bundle: corpusCallosum

Enable Seeding Tracts

Use index Space

Seed Spacing: 2.00

Random Grid

Linear Measure Start Threshold: 0.30

File Prefix:

Data Probe:

L
F
B

Diffusion MRI Analysis

S: 0.000mm V: R: 1.500mm G: A: 1.500mm

L: fa-l...00%)
B: fa

L: fa-l...00%)
B: fa

L: fa-l...00%)
B: fa

5 cm 5 cm 5 cm

The tracts generated in the corpus callosum area appear in the 3D viewer.

Check **Enable Seeding Tracts**



Step 4: Tract editing

3D Slicer 4.4.0-2015-05-21

Modules: Tractography Interactive Seeding

- All Modules
 - Annotations
 - Data
 - DataStore
 - DICOM
 - Editor
 - Markups
 - Models
 - Scene Views
 - Subject Hierarchy
 - Transforms
 - View Controllers
 - Volume Rendering
 - Volumes
 - Welcome to Slicer
- Wizards
- Informatics
- Registration
- Segmentation
- Quantification
- Diffusion**
 - DWI to Full Brain Tractography**
 - Tractography Display**
 - Diffusion Data Conversion
 - Diffusion Tensor Images
 - Diffusion Weighted Images
 - Tractography
- IGT
- Filtering
- Surface Models
- Converters
- Endoscopy
- Utilities
- Developer Tools
- Legacy
- MultiVolume Support
- Unspecified
- BRAINS

Enable Seeding Tracts

Label Map Options

Use index Space

Seed Spacing

Random Grid

Linear Measure Start Threshold

ROI Labels

Write Fibers To Disk

Output Directory

File Prefix

Tractography Seeding Parameters

Minimum Path Length

Maximum Path Length

Stopping Criteria

Stopping Value

Stopping Track Curvature

Integration Step Length

Enabling Options

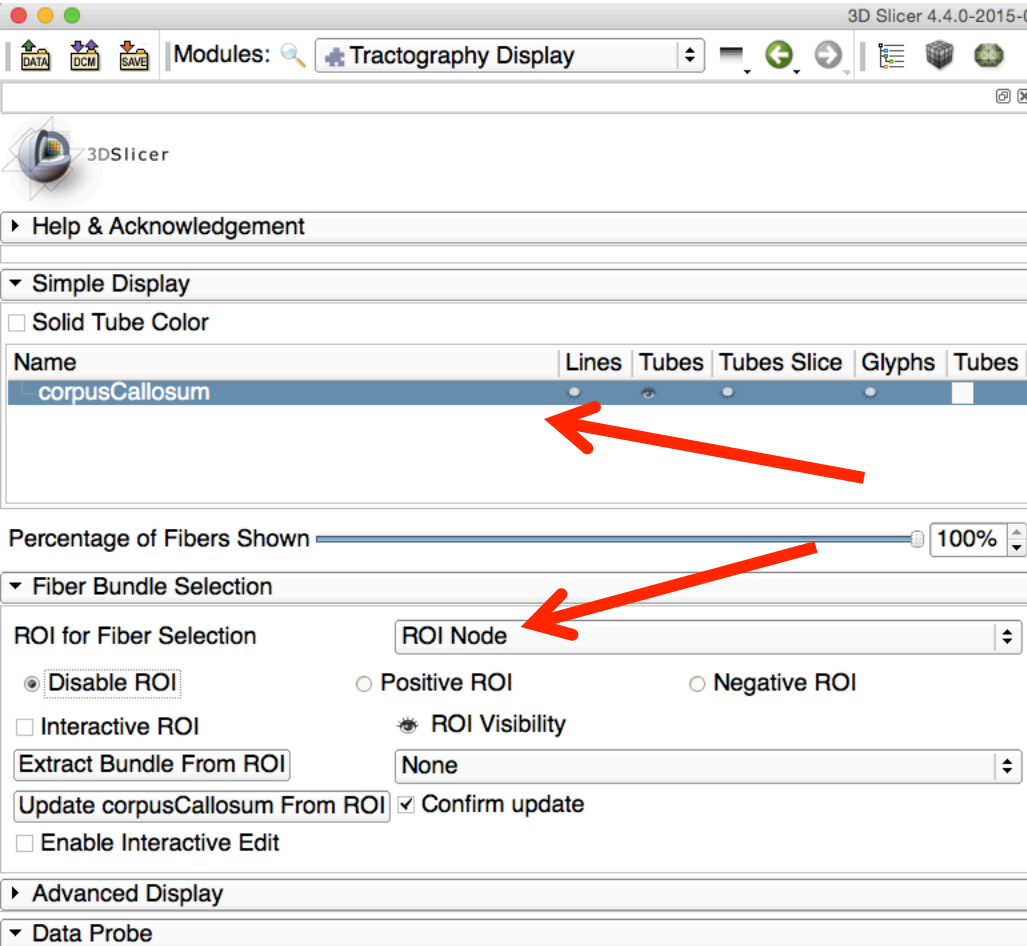
Data Probe

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

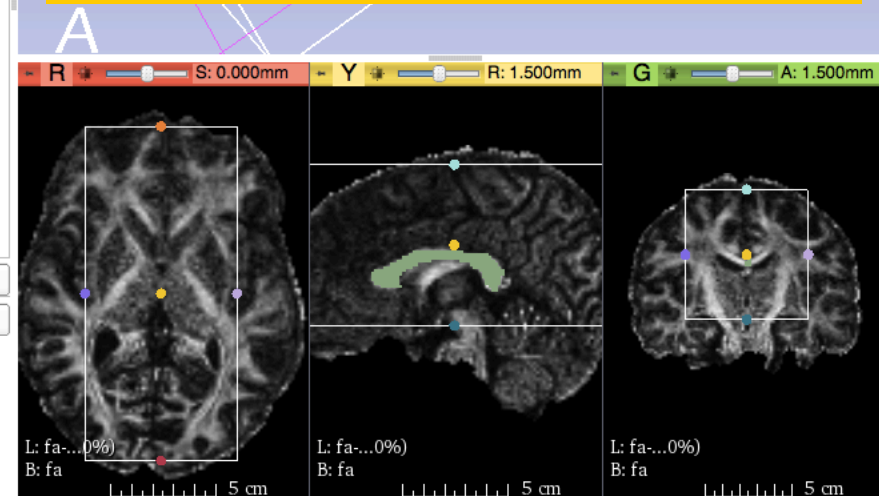
NA-MIC ARR 2012-2015

Step 4: Tract Editing



Select the fiber
corpusCallosum

In the Fiber Bundle Selection
tab, select **ROI for Fiber
Selection** to **'Create New'**



Slicer creates the ROI ROI Node



Step 4: Tract Editing

3D Slicer 4.4.0-2015-05-21

Modules: Tractography Display

3DSlicer

Help & Acknowledgement

Simple Display

Solid Tube Color

Name

corpusCallosum

Percentage of Fibers Shown 100%

Fiber Bundle Selection

ROI for Fiber Selection ROI Node

Disable ROI Positive ROI Negative ROI

Interactive ROI ROI Visibility

Extract Bundle From ROI None

Update corpusCallosum From ROI Confirm update

Enable Interactive Edit

Advanced Display

Data Probe

L
F
B

Adjust the ROI frame to include the tracts to be removed

R P
A

R S: 0.000mm Y R: 1.500mm G A: 1.500mm

L: fa-...0%) B: fa 5 cm

L: fa-...0%) B: fa 5 cm

L: fa-...0%) B: fa 5 cm



Step 4: Tract Editing

3D Slicer 4.4.0-2015-05-21

Modules: Tractography Display

3DSlicer

Help & Acknowledgements

Simple Display

Solid Tube Color

Name	Lines	Tubes	Tubes Slice	Glyphs	Tubes
corpusCallosum	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Percentage of Fibers Shown: 100%

Fiber Bundle Selection

ROI for Fiber Selection: ROI Node

Disable ROI

Positive ROI

Negative ROI

Interactive ROI

ROI Visibility

Extract Bundle From ROI: None

Update corpusCallosum From ROI: Confirm update

Enable Interactive Edit

Advanced Display

Data Probe

L
F
B

R S: 0.000mm Y R: 1.500mm G A: 1.500mm

L: fa-...0%
B: fa

L: fa-...0%
B: fa

L: fa-...0%
B: fa

5 cm 5 cm 5 cm



Step 4: Tract Editing

3D Slicer 4.4.0-2015-05-21

Modules: Tractography Display

3DSlicer

Help & Acknowledgem

Simple Display

Uncheck ROI Visibility

Solid Tube Color

Name	Lines	Tubes	Tubes Slice	Glyphs	Tubes
corpusCallosum	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Percentage of Fibers Shown: 100%

Fiber Bundle Selection

ROI for Fiber Selection: ROI Node

Disable ROI Positive ROI Negative ROI

Interactive ROI ROI Visibility

Extract Bundle From ROI: None

Update corpusCallosum From ROI: Confirm update

Enable Interactive Edit

Advanced Display

Data Probe

L
F
B

R S: 0.000mm Y R: 1.500mm G A: 1.500mm

L: fa-...0%)
B: fa

L: fa-...0%)
B: fa

L: fa-...0%)
B: fa

5 cm 5 cm 5 cm



Tractography Interactive Seeding

3D Slicer 4.4.0-2015-05-21

Modules: Tractography Display

- All Modules
 - Annotations
 - Data
 - DataStore
 - DICOM
 - Editor
 - Markups
 - Models
 - Scene Views
 - Subject Hierarchy
 - Transforms
 - View Controllers
 - Volume Rendering
 - Volumes
 - Welcome to Slicer
- Wizards
 - Informatics
 - Registration
 - Segmentation
 - Quantification
 - Diffusion
 - DWI to Full Brain Tractography
 - Tractography Display
 - Diffusion Data Conversion
 - Diffusion Tensor Images
 - Diffusion Tensor Scalar Measurements
 - Resample DTI Volume
 - Tractography Interactive Seeding**
 - Tractography Label Map Seeding

ROI for Fiber Selection

- Disable ROI
- Interactive ROI
- Extract Bundle From ROI
- Update corpusCallosum From
- Enable Interactive Edit

Advanced Display

Data Probe

Percentage of Fibers Shown: 100%

Tubes Slice Glyphs Tube

Tractography Display

Select the module **Tractography Interactive Seeding**

Diffusion Tensor Scalar Measurements

Resample DTI Volume

Tractography Interactive Seeding

Tractography Label Map Seeding

S: 0.000mm R: 1.500mm G: A: 1.500mm

L: fa-...0%) B: fa

L: fa-...0%) B: fa

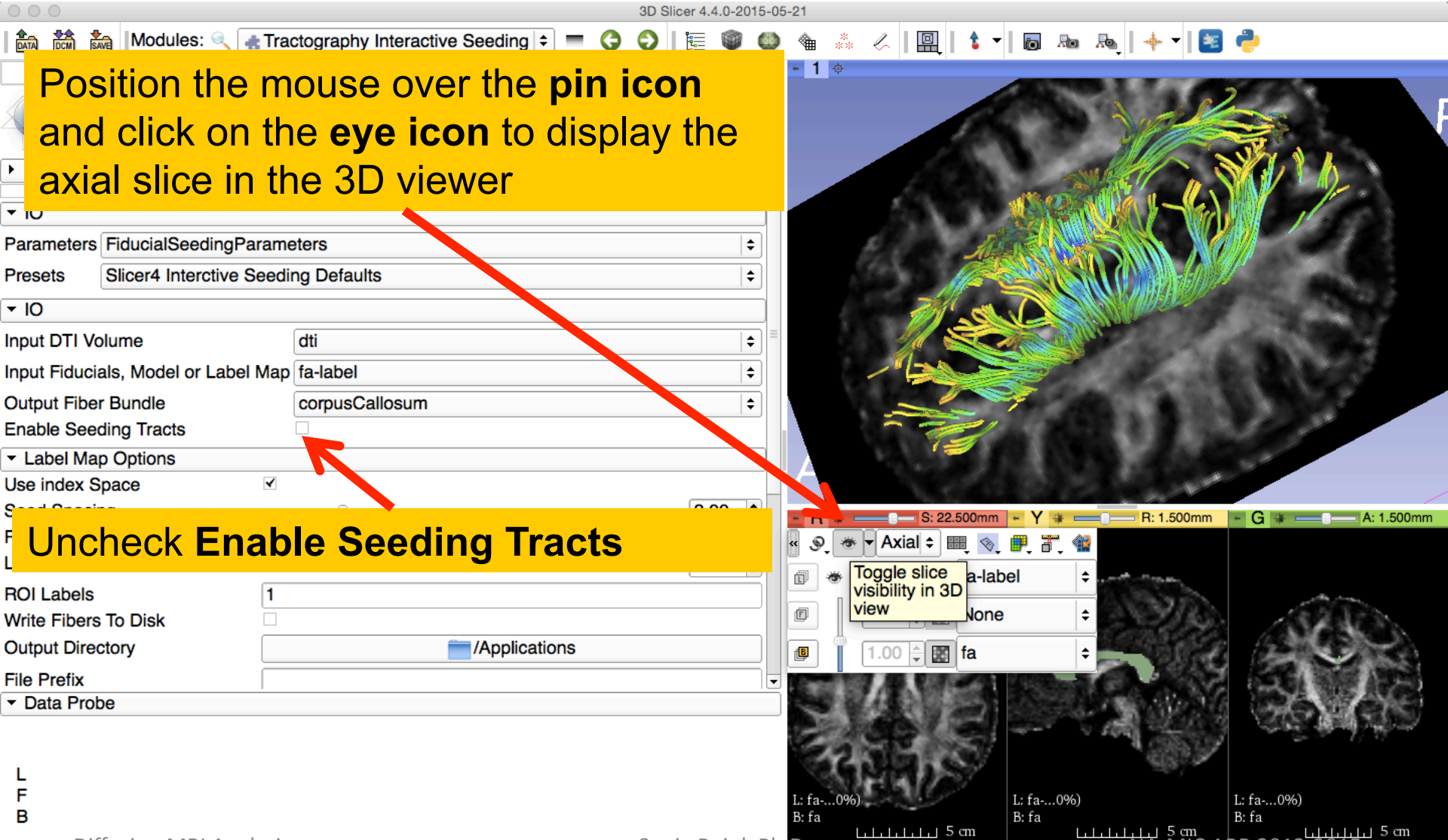
L: fa-...0%) B: fa

5 cm 5 cm 5 cm

Tractography Results

Position the mouse over the **pin icon** and click on the **eye icon** to display the axial slice in the 3D viewer

Uncheck **Enable Seeding Tracts**



Fiducial Seeding

3D Slicer 4.4.0-2015-05-21

Modules: **Tractography Interactive Seeding**

- All Modules
- Annotations
- Data
- DataStore
- DICOM
- Editor
- Markups
- Models
- Scene Views
- Subject Hierarchy
- Transforms
- View Controllers
- Volume Rendering
- Volumes
- Welcome to Slicer

Wizards

- Informatics
- Registration
- Segmentation
- Quantification
- Diffusion
- IGT
- Filtering
- Surface Models
- Converters
- Endoscopy
- Utilities
- Developer Tools
- Legacy
- MultiVolume Support
- Unspecified
- BRAINS

Parameters: FiducialSeeding

Presets: Slicer4 Interactive

Input DTI Volume

Input Fiducials, Model or Lab

Output Fiber Bundle

Enable Seeding Tracts

Label Map Options

Use index Space

Seed Spacing

Random Grid

Linear Measure Start Threshold

ROI Labels

Write Fibers To Disk

Output Directory

File Prefix

Data Probe

2.00

0.30

S: 0.000mm

R: 1.500mm

G: A: 1.500mm

L: fa-...0%)
B: fa

5 cm

L: fa-...0%)
B: fa

5 cm

L: fa-...0%)
B: fa

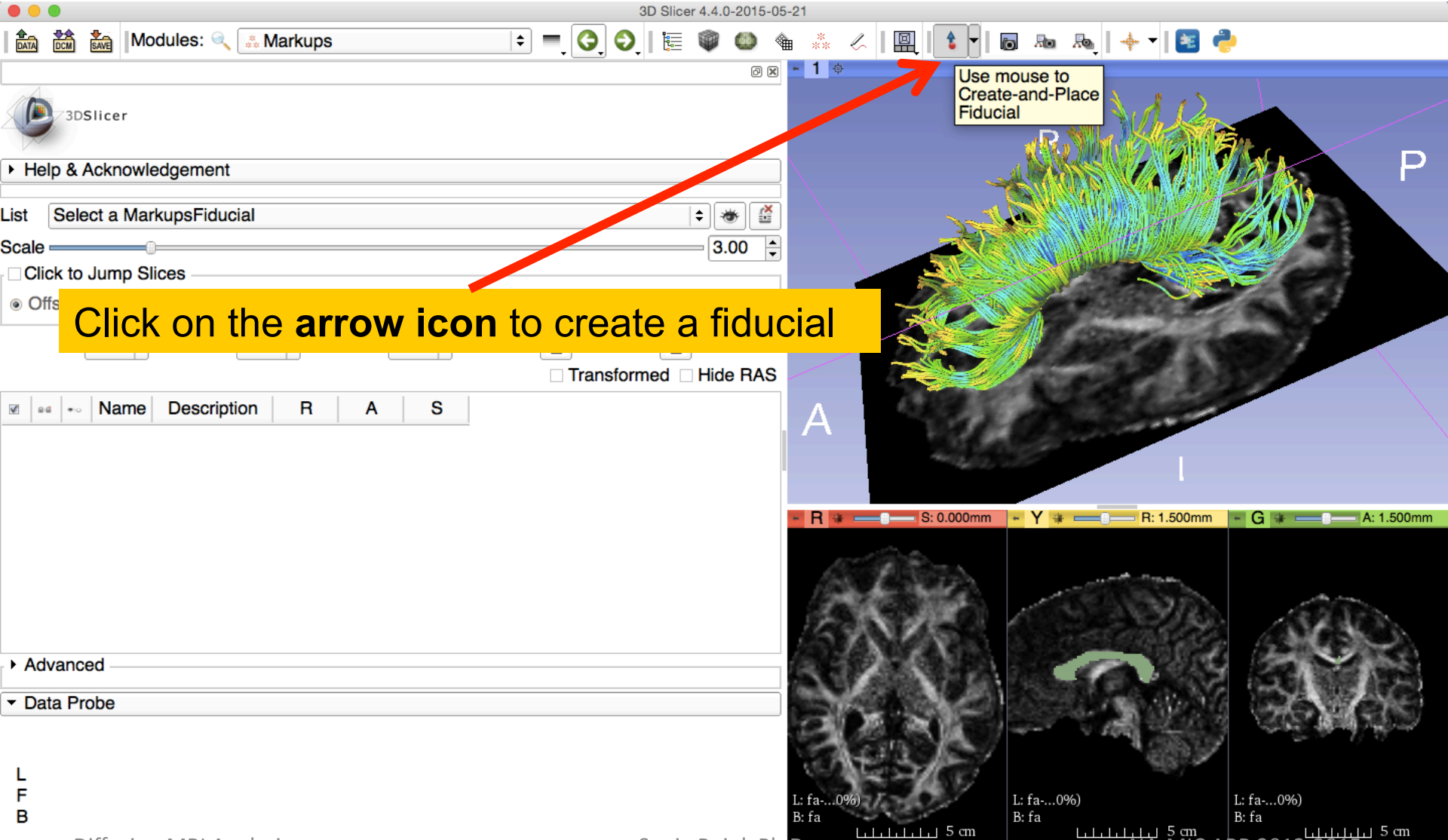
5 cm

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

Fiducial Seeding



Fiducial Seeding

3D Slicer 4.4.0-2015-05-21

Modules: Markups

3DSlicer

Help & Acknowledgement

List F

Sc

Position the fiducial in the left cingulum of the coronal slice

Transformed Hide RAS

	Name	Description	R	A	S
1	F-1		-3.137	1.500	23.736

Advanced

Data Probe

L
F
B

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

Fiducial Seeding

3D Slicer 4.4.0-2015-05-21

Modules: Markups

3DSlicer

Help & Acknowledgement

List F

Sc

Double click on the fiducial and change the name to **LeftCingulum**

Transformed Hide RAS

	Name	Description	R	A	S
1	LeftCingulum		-3.137	1.500	23.736

Advanced

Data Probe

L
F
B

Diffusion MRI Analysis

S: 22.500mm Y R: 1.500mm G A: 1.500mm

L: fa-...0%)
B: fa

L: fa-...0%)
B: fa

L: fa-...0%)
B: fa

5 cm 5 cm 5 cm

NA-MIC ARR 2012-2015

Fiducial Seeding

3D Slicer 4.4.0-2015-05-21

Modules: **Tractography Interactive Seeding**

3DSlicer

Help & Acknowledgement

IO

Parameters: FiducialSeedingParameters

Presets: Slicer4 Interactive Seeding Defaults

IO

Input DTI Volume: dti

Input Fiducials, Model or Label Map: F

Output Fiber Bundle: Cingulum

Enable Seeding Tracks:

Seed Placement Options

Fiducial Region Size: 2.50mm

Fiducial Seeding Step Size: 1.00mm

Seed Selected Fiducials:

Max Number of Seeds: 100

Data Probe

L
F
B

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

5 cm

5 cm

5 cm

leftcingulum

Fiducial Seeding

3D Slicer 4.4.0-2015-05-21

Modules: Tractography Interactive Seeding

3DSlicer

Help & Acknowledgement

IO

Part of the left cingulum appears in the 3D viewer.

Move the Left Cingulum fiducial to explore the spatial relationship between the left cingulum and the corpus callosum

2.50mm

1.00mm

R S: 3.500mm Y R: 1.500mm G A: 1.500mm

L F B

L: fa-...0%) B: fa

L: fa-...0%) B: fa

L: fa-...0%) B: fa

5 cm

5 cm

5 cm

Fiducial Seeding

3D Slicer 4.4.0-2015-05-21

Modules: Tractography Interactive Seeding

- All Modules
- Annotations
- Data
- DataStore
- DICOM
- Editor
- Markups
- Models
- Scene Views
- Subject Hierarchy
- Transforms
- View Controllers
- Volume Rendering
- Volumes
- Welcome to Slicer

Wizards

- Informatics
- Registration
- Segmentation
- Quantification
- Diffusion
- IGT
- Filtering
- Surface Models
- Converters
- Endoscopy
- Utilities
- Developer Tools
- Legacy
- MultiVolume Support
- Unspecified
- BRAINS

Parameters: FiducialSeeding

Presets: Slicer4 Interactive

Input DTI Volume

Input Fiducials, Model or Lab

Output Fiber Bundle

Enable Seeding Tracts

Seed Placement Options

Fiducial Region Size: 2.50mm

Fiducial Seeding Step Size: 1.00mm

Seed Selected Fiducials

Max Number of Seeds: 1

Data Probe

L
F
B

Diffusion MRI Analysis

Sonia Pujol, Ph.D.

NA-MIC ARR 2012-2015

Cingulum

F. Cingulum

R S: 3.500mm Y R: 1.500mm G A: 1.500mm

L: fa-...0%)
B: fa

L: fa-...0%)
B: fa

L: fa-...0%)
B: fa

5 cm 5 cm 5 cm

Fiducial Seeding

3D Slicer 4.4.0-2015-05-21

Modules: Markups

3DSlicer

Help & Acknowledgement

List F

Scale 3.00

Click to Jump Slices

Offset Centered Show Slice I

	Name	Description	R	A	S
1	LeftCingulum		-4.691	1.500	24.513
2	RightCingulum		10.855	1.500	26.068

Transform

Position a second fiducial in the right cingulum of the coronal slice

Double click on the name and change it to **RightCingulum**

R S: 3.500mm Y R: 1.500mm G A: 1.500mm

L: fa-...0%) B: fa

L: fa-...0%) B: fa

L: fa-...0%) B: fa

5 cm 5 cm 5 cm



Fiducial Seeding

3D Slicer 4.4.0-2015-05-21

Modules: Markups

3DSlicer

Help & Acknowledgement

List F

Scale

Click to Jump Slices

Offset Centered

	Name	Description
1	LeftCingulum	
2	RightCingulum	

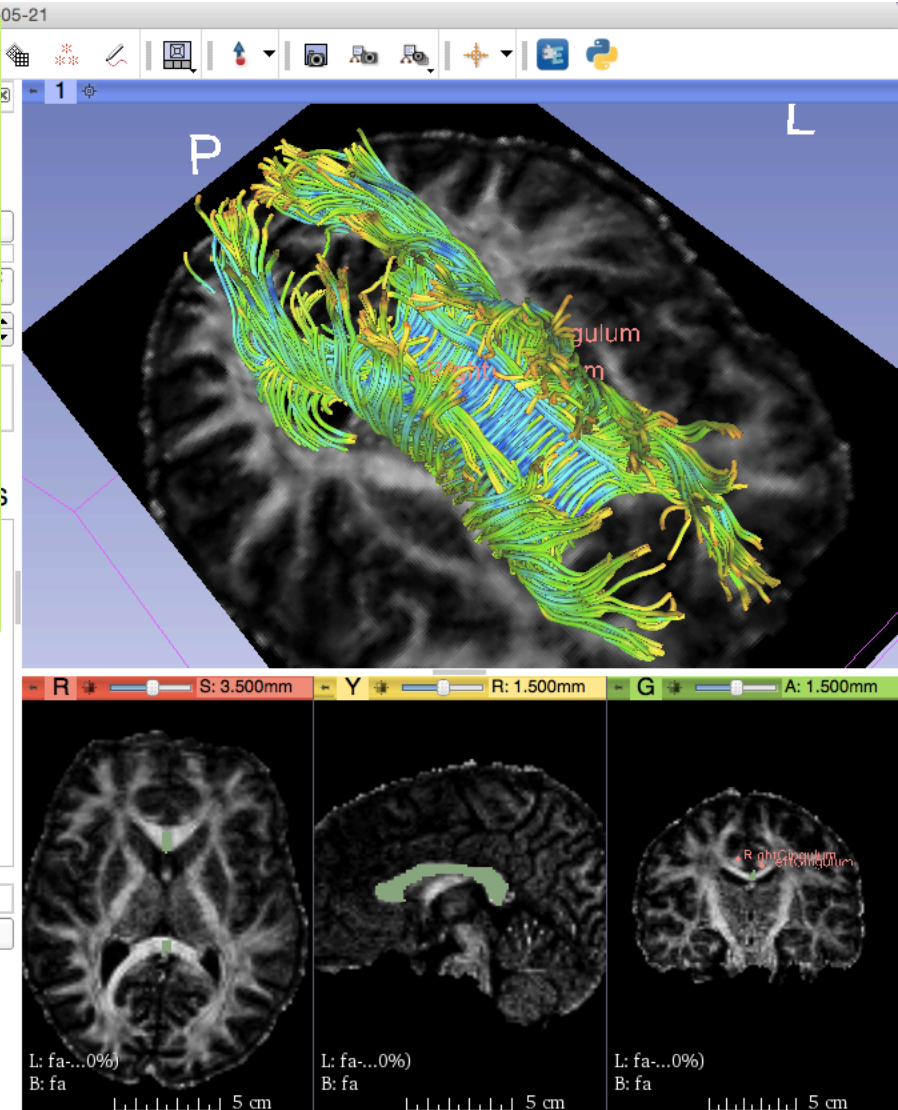
Advanced

Data Probe

L
F
B

Part of the left and right cingulum appear in the 3D viewer.

Move the fiducials to explore the spatial relationship between the left and right cingulum, and the corpus callosum



Fiducial Seeding

Click on the arrow icon to create a new fiducial, and position it in the 3D viewer

	Name	Description	R	A	S
1	LeftCingulum		-4.691	1.500	24.513
2	RightCingulum		9.301	1.500	27.622
3	F-3		36.616	-6.073	-5.171

3D Slicer 4.4.0-2015-05-21

Modules: Markups

3DSlicer

Offset Centered Show Slice Intersections

Transformed Hide RAS

Advanced

Data Probe

L
F
B

Diffusion MRI Analysis

S: -16.500mm Y R: 1.500mm G A: 1.500mm

L: fa-...0%)
B: fa

L: fa-...0%)
B: fa

L: fa-...0%)
B: fa

5 cm 5 cm 5 cm

NA-MIC ARR 2012-2015

Fiducial Seeding

3D Slicer 4.4.0-2015-05-21

Modules: **Markups**

3DSlicer

Help & Acknowledgement

List **F**

Scale **3.00**

Click to Jump Slices

Offset Centered Show Slice Intersections

Transformed Hide RAS

	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Name	Description	R	A	S
1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	LeftCingulum		-4.691	1.500	24.513
2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	RightCingulum		9.301	1.500	27.622
3	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	F-3				-6.937

Move the fiducial F-3 in the 3D viewer to explore the dti dataset

Advanced

Data Probe

L
F
B

3D viewer showing brain slices and streamlines. Labels: P, L, F-3, R, Y, G, S, R, A.

3D viewer showing brain slices and streamlines. Labels: L: fa-...0%), B: fa, 5 cm.

Tractography 'on-the-fly'

3D Slicer 4.4.0-2015-05-21

Modules: **Markups**

3DSlicer

Help & Acknowledgement

List: **F**

Scale: **3.00**

Click to Jump Slices

Offset Centered Show Slice Intersections

Transformed Hide RAS

	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Name	Description	R	A	S
1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	LeftCingulum		-4.691	1.500	24.513
2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	RightCingulum		9.301	1.500	27.622
3	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	F-3		37.546	-3.799	-6.937

Advanced

Data Probe

L
F
B

P L

F-3

R S: -16.500mm Y R: 1.500mm G A: 1.500mm

L: fa-...0%)
B: fa

L: fa-...0%)
B: fa

L: fa-...0%)
B: fa

5 cm 5 cm 5 cm

DTI Analysis

3D Slicer 4.4.0-2015-05-21

Modules: Data

3DSlicer

Help & Acknowledgement

Display & Modify Scene

Nodes

- Scene
 - View1
 - Red
 - Yellow
 - Green
 - Default Scene Camera
 - dwi
 - baseline
 - dwi_mask
 - dti
 - fa
 - trace
 - fa-label
 - All Annotations
 - ROI Node
 - ROI List
 - corpusCallosum
 - F
 - Cingulum

Scene Model: Transform

- Display MRML ID's
- Show Hidden nodes

Data Probe

Volume

Select the module **Data** to display the list of elements that have been generated in this tutorial

P L

R S: -16.500mm Y R: 1.500mm G A: 1.500mm

L: fa-...0%)
B: fa

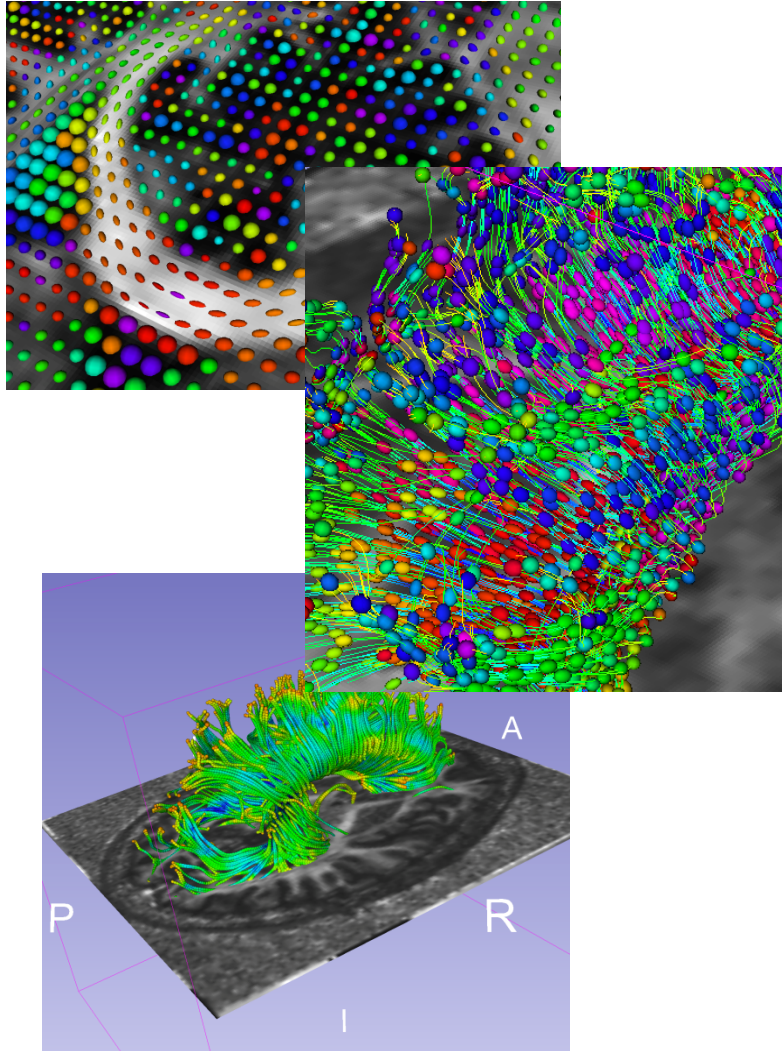
L: fa-...0%)
B: fa

L: fa-...0%)
B: fa

5 cm 5 cm 5 cm



Conclusion



This tutorial guided you through the different steps of a Diffusion MR analysis pipeline, from tensor estimation to 3D tracts visualization, for exploring and studying the 3D architecture of the brain white matter.

Acknowledgments



- National Alliance for Medical Image Computing (NA-MIC)

NIH U54EB005149



- Neuroimage Analysis Center (NAC)

NIH P41RR013218

- Fan Zhang, University of Sydney