Diffusion Tensor Imaging tutorial

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DTI tutorial

This tutorial is an introduction to the advanced Diffusion MR capabilities of the Slicer3 software for medical image analysis.
Outline

This tutorial guides you through the process of loading diffusion MR data, estimating diffusion tensors, and performing tractography of white matter bundles.
The processing pipeline uses 9 image analysis modules of Slicer3.6

1. Data
2. Volumes
3. Diffusion Tensor Estimation
4. Diffusion Tensor Scalar Measurements
5. Editor
6. LabelMap Seeding
7. Fiber Bundles
8. Fiducials
9. Fiducial Seeding
The Diffusion MR tutorial dataset is composed of a **Diffusion Weighted MR scan** of the brain acquired with 12 gradient directions and 2 baseline.
DTI Processing Pipeline

- DWI Acquisition
- Tensor Calculation
- Scalar Maps
- 3D Visualization
Start Slicer3

Linux/Mac users
Launch the Slicer3 executable located in the Slicer3.6 directory

Windows users
Select Start → All Programs → Slicer3-3.6-2010-08-23→Slicer3
The **SlicerWelcome** module is the module displayed by default. This module gives an overview of the GUI of Slicer3, and data loading & saving functionalities.
Part 1:

Diffusion data loading and tensor estimation
Diffusion Tensor

\[ S_i = S_0 e^{-\frac{b_i}{D_g} T} \]

(Stejskal and Tanner 1965, Basser 1994)

\[ \mathbf{D} = \begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{zx} & D_{zy} & D_{zz} \end{bmatrix} \]
Tensor Calculation

Calculate the main directions of diffusivity and corresponding diffusion values in each voxel.

\[
\begin{bmatrix}
D_{xx} & D_{xy} & D_{xz} \\
D_{yx} & D_{yy} & D_{yz} \\
D_{zx} & D_{zy} & D_{zz}
\end{bmatrix}
\]

\[\lambda_1, \lambda_2, \lambda_3\]
Physical Interpretation

The diffusion tensor $D$ in the voxel $(I,J,K)$ can be visualized as an ellipsoidal isoprobability surface in which the principal axes correspond to the eigenvectors.
Loading the DWI volume

Select **File** → **Add Volume** from the File menu.
Loading the DWI volume

Browse to the location of the Diffusion tutorial dataset directory and select the file dwiDataset.nhdr

Click on **Apply** to load the volume
Loading the DWI volume

Left click on the menu **Modules** and select **All Modules** to display the list of **95 modules** available for image analysis and 3D visualization. Select the module **Volumes**.
Loading the DWI volume

Select the Active Volume `dwiDataset` and adjust the Window/Level Parameters

Slicer displays the anatomical views of the baseline volume of the diffusion dataset in the 2D Slice Viewer.
Tensor Estimation

Left click on the menu **Modules** and select the module **Diffusion Tensor Estimation**.
Tensor Estimation

Select the Input DWI Volume `dwiDataset`

Left click on OutputDTIVolume and select ‘Create New Diffusion Tensor Volume’

Left click on Output Baseline Volume and select ‘Create New Volume’

Left click on Otsu Threshold Mask and select ‘Create New Volume’
Tensor Estimation

Select the Tensor Estimation Algorithm **LS** (Least Squares), and click on **Apply** to estimate the tensors.
Tensor Estimation

Left click on **Output Baseline Volume** to display the list of volumes that have been computed by Slicer.
Tensor Estimation

Output DTI Volume is the volume of estimated tensors
Output Baseline Volume is the Baseline volume
Output Threshold Mask is the tensor mask (blue)
Tensor Estimation

Click on the link icon, left click on **Output Threshold Mask** and select **None**
Tensor Estimation

Select the module **Volumes** in the modules’ toolbar
Tensor Estimation

Select the **Active Volume ‘Output Baseline Volume’** and click on the tab **Display**.
Tensor Estimation

Adjust the Window/Level parameters of the baseline volume using the slider
Tensor Estimation

Browse through the baseline images, which correspond to the volumes that have been acquired without gradient.
Part 2: Scalar Measurements
Scalar Measurements

Select the category **Diffusion--> Utilities** from the list of modules, and left click on the **Diffusion Tensor Scalar Measurements module**.
Scalar Measurements

Select the Input DTI Volume Output DTI Volume
Select the Output Scalar Volume ‘Create New Volume’
Select the Operation Fractional Anisotropy, and click on Apply
Fractional Anisotropy Volume

Left click on the Slicer Viewer Menu icon, and select **Show label volume outlines**
Fractional Anisotropy Volume

Slicer displays the outline of the tensor mask overlaid on the Fractional Anisotropy volume.
Move the mouse over the Fractional Anisotropy map to explore the FA values which range from 0 to 1, and are displayed in the bottom corner of the active (Bg) window.
Part 3:
Region of Interest based Tractography
LabelMap Generation

Select the module **Editor** in the modules menu.

Select the Master Volume as ‘**Output Scalar Volume**’
Label Map Generation

Click 'Set' and select 'Create New' to create the seeding label map.
LabelMap Generation

Left click on the dropdown box and select **Discrete** and then select **Labels**.

Click **Apply**.
LabelMap Generation

Left click on the Slicer Viewer Menu icon, and select the label map Output Scalar Volume-label.
LabelMap Generation

Left click on the Slicer Viewer Menu icon, and select Don’t Show label volume outlines.
LabelMap Generation

Select the label 2 (pink), click on the icon **Paint**, set the radius to 2 and draw a region of interest within the corpus callosum in the sagittal view **on a set of 2 or 3 slices**.
LabelMap Seeding

Select the module **LabelMap Seeding** from the Modules’ menu.
LabelMap Seeding

Select the Input DTI volume ‘Output DTI Volume’

Select the Input Label Map ‘Output Scalar Volume - label’

Select Output Fiber Bundle ‘Create New Fiber Bundle’
LabelMap Seeding

In the Seed Placement Options tab, select **Use Index Space**.

In the Tractography Seeding Parameters tab, select the ‘Stopping Mode’ **Fractional Anisotropy**, and use the default parameters for the minimum and maximum tract length, stopping value, stopping track curvature and integration step length.

In the Label Definition tab, set ‘Seeding label’ to label 2, and click on **Apply**.
LabelMap Seeding

The tracts generated within the corpus callosum region appear in the 3DViewer.

The color map used represent the FA values along the tracts.
LabelMap Seeding

Select the module **FiberBundles**, and click on the tab **Tube** in the Display panel.

Check the visibility box to display the tubes.
LabelMap Seeding

Slicer displays the computed tracts as tubes colored with FA values.
Part 4:

Tractography on-the-fly
Fiducial Seeding

Select the module **Fiducials**
Fiducial Seeding

Set Fiducial List to Create New FiducialList
Fiducial Seeding

Left click on **Fiducial List** and select Rename
Fiducial Seeding

Enter the new name **Seed** and click on **Apply**
Fiducial Seeding

Click on the cross icon to add a fiducial to the list Seed
Fiducial Seeding

The fiducial **Seed-P** appears in the 3D Viewer.
Fiducial Seeding

Position the fiducial in the cingulum region located above the corpus callosum.
Fiducial Seeding

Check the box to select the ‘Seed-P’ fiducial: we will use this fiducial to drive the tractography.

Once selected, the fiducial Seed-P is displayed in pink letters in the 3D viewer.
Fiducial Seeding

Select the module **Fiducial Seeding**

Set the Output FiberBundleNode to **Create New FiberBundle**

**Important:** this step must be done first

Set the DTI Volume to **Output DTI Volume**

Select the Fiducial List **Seed**
Fiducial Seeding

Set the Stopping Mode to **Fractional Anisotropy** and set the tractography parameters to the values that we used for the corpus callosum:

- **Stopping Value**: 0.1
- **Stopping Track Curvature**: 0.8
- **Step Length**: 0.8 mm
- **Minimum Path Length**: 10 mm
- **Fiducial Stepping Size**: 1.5 mm
Fiducial Seeding

Slicer displays the tracts seeded from the Fiducial Seed-P. The tracts correspond to the region of the cingulum located above the corpus callosum.

For better visualization, uncheck the visibility box under **Tubes** in the **Fiber Bundles** module (Slide 42).
Fiducial Seeding

Move the fiducial Seed-P from the left cingulum to the corresponding region in the right cingulum in the coronal slice.
Fiducial Seeding

Slicer displays a portion of the right cingulum tracts which are seeded from the new position of the fiducial Seed-P.
Part 5:
Saving a DTI Scene
DTI Scene

Select the module Data

Slicer displays the list of volumes and models generated in this tutorial
Saving a DTI Scene

Select File→Save from the main menu
Saving a DTI Scene

Browse to a directory where you would like to save the data. Once you have selected a directory, select all the files that have been created during this tutorial and click on **Save Selected**.
Saving a DTI Scene

Select File→Close Scene to close the current DTI Scene.
Loading a DTI Scene

Select **File→Load Scene** and browse to the location where you saved the scene **SlicerScene1.mrml**
Loading a DTI Scene

Select the scene **SlicerScene1.mrml** and click on **Open**
Loading a DTI Scene

Select the module Data
Loading a DTI Scene

Slicer loads all the elements of the DTI Scene that were previously computed.
Conclusion

This tutorial guided you through some of the Diffusion MR capabilities of the Slicer3 software for studying the brain white matter pathways.

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Slicer Community

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