3DSlicer
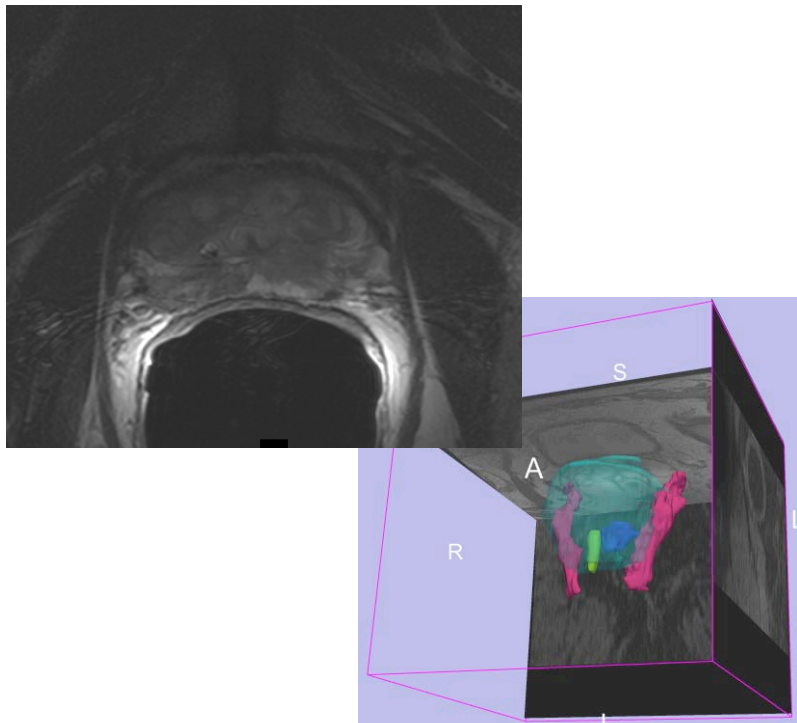
MR-guided prostate interventions with 3DSlicer and the NA-MIC Kit

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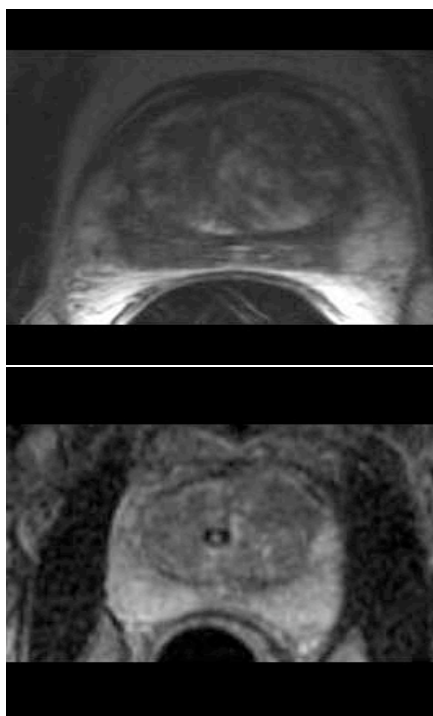Brigham and Women's Hospital

Harvard Medical School

Massachusetts General Hospital

Learning Objective

This tutorial will teach you how to perform the steps required for MR-guided prostate interventions using Slicer3.

In particular, you will learn how to:

- Register pre-operative and intra-operative prostate MR images using deformable
B-spline registration

- Incorporate models of the neurovascular bundle using image segmentation and model making

- Manually segment images

- Create 3D models from segmentations

Prerequisites

This tutorial assumes that you have already completed the tutorial **Data Loading and Visualization**. Tutorials for **Slicer3** are available at the following location:

- **Slicer3** tutorials

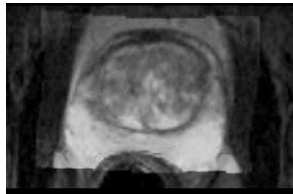   http://www.na-mic.org/Wiki/index.php/Slicer3.2:Training

Materials

This tutorial requires the installation of the **Slicer3** software and the tutorial dataset. They are available at the following locations:

- **Slicer3** download page (*Slicer 3.2*)

  http://www.slicer.org/pages/Downloads/

- Tutorial dataset (*MRGuidedProstateInterventions.zip*)
  http://wiki.na-mic.org/Wiki/index.php/IGT:ToolKit/
  Prostate-Planning

Disclaimer: *It is the responsibility of the user of Slicer to comply with both the terms of the license and with the applicable laws, regulations, and rules.*
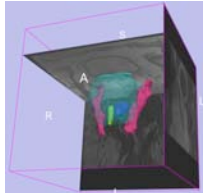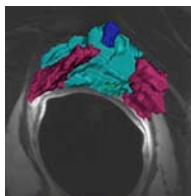

Overview

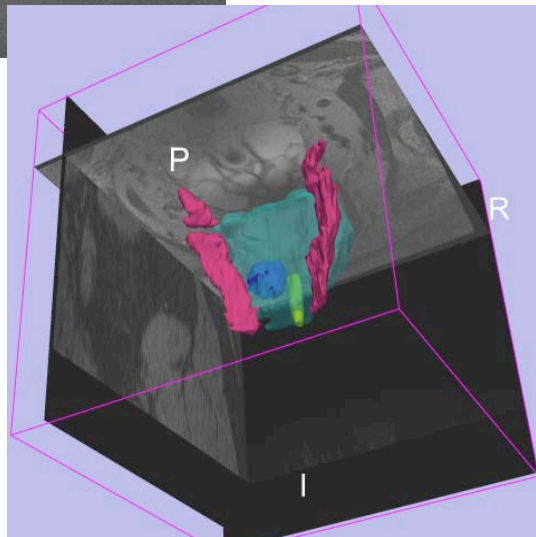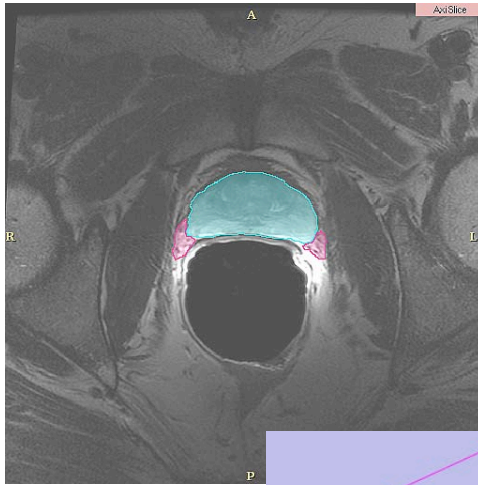1. MR-guided prostate interventions: clinical background

2. Registering pre-operative & intra-operative prostate MR images using deformable B-spline registration

3. Manual segmentation of images

4. Creating 3D models from segmentations

MR-guided prostate interventions: clinical background

Prostate cancer

- Prostate cancer has the second-highest mortality rate of all cancers in American men: one in six men will be diagnosed, and it kills one in thirty-five (American Cancer Society)

- **Diagnosis:**
  - Prostate specific antigen (PSA) level
  - Digital rectal exam
  - **Needle biopsy** (Gleason score)

- **(Some) Treatment options:**
  - "Watchful waiting"
 - **Brachytherapy**
  - External beam radiation therapy
  - Radical prostatectomy
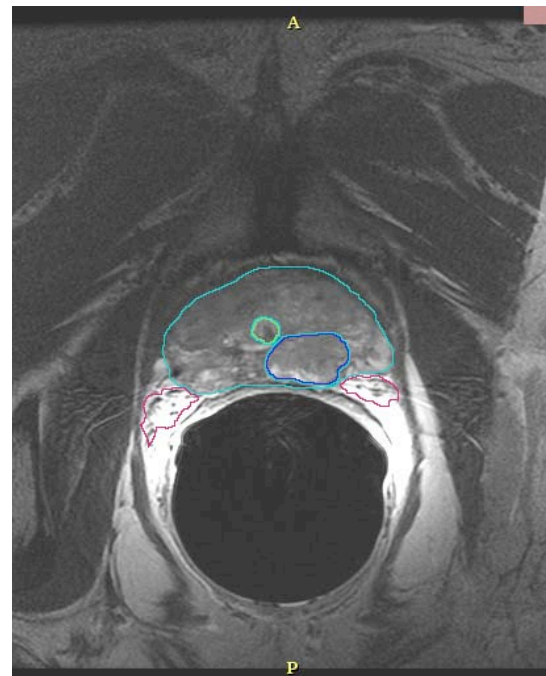
Guidance for biopsy/brachytherapy

3DSlicer

- ***Image guidance:***
    - allows specific locations within the prostate to be targeted
    - provides updates of the needle's current position and orientation

- Models can be used to highlight the prostate, the tumour, and structures to be avoided (such as the neurovascular bundle)

MR-guided prostate interventions

3DSlicer
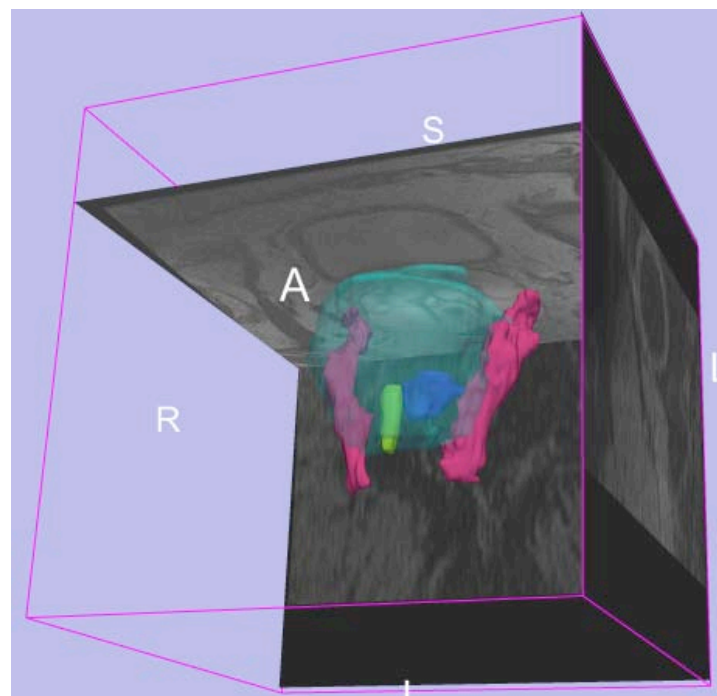
pre-operative

intra-operative

pre-operative
MR imaging
(high quality)

registration

intra-operative
MR imaging
(lower quality)

compensates for

– change in
patient position

– presence/
absence of
endorectal coil

(optional)
segmentation
model making
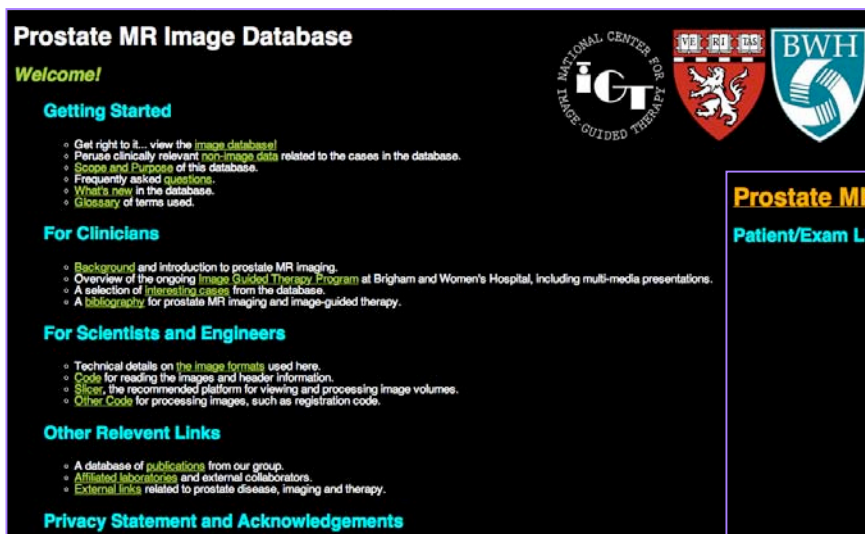
**Guidance based on
intra-operative
image fused with
higher quality pre-
operative image and
models of important
structures**

The Prostate MR Image Database

http://prostatemrimagedatabase.com

- Provides prostate MR images for a variety of clinical situations, including prostate cancer biopsy and brachytherapy
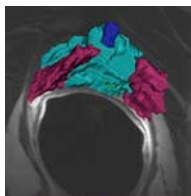
Overview

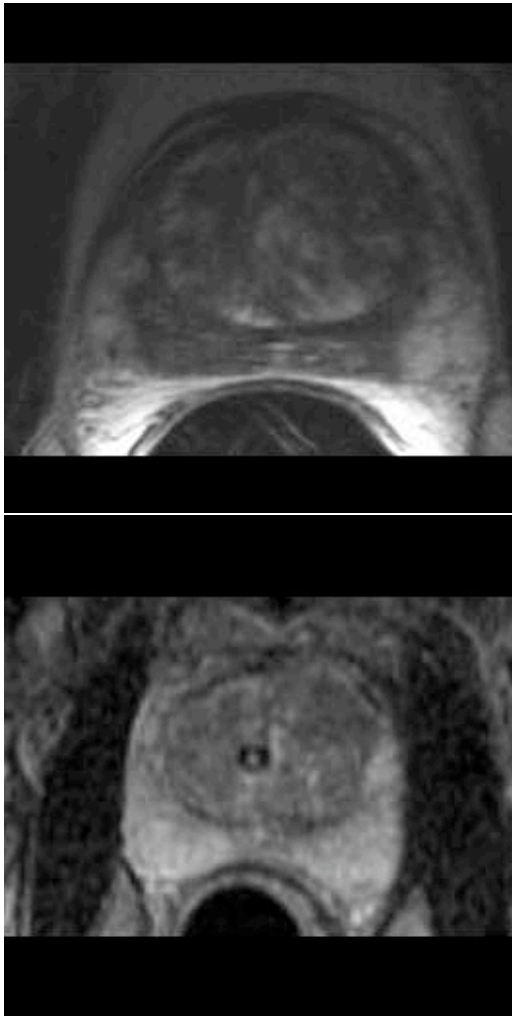1. MR-guided prostate interventions: clinical background

2. Registering pre-operative & intra-operative prostate MR images using deformable B-spline registration

3. Manual segmentation of images

4. Creating 3D models from segmentations

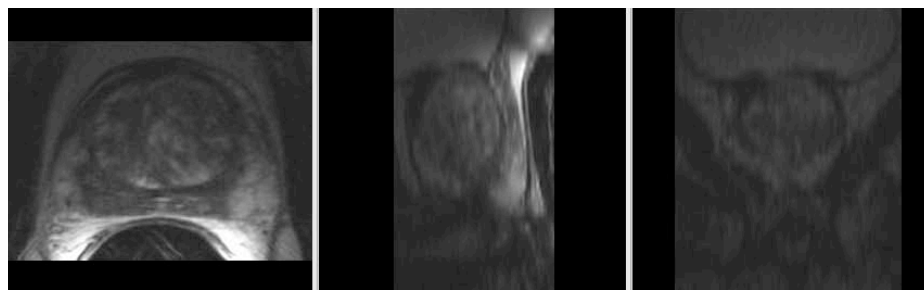# Registering pre-operative & intra-operative prostate MR images

Image Registration

- Image registration aligns two images together with the goal of making the corresponding anatomy overlap

Pre-operative

- T2 FSE at 1.5 T, endorectal coil
- pixel spacing:
  0.46875mm x 0.46875mm
- slice thickness: 3mm

Intra-operative

- T2 FSE at 0.5 T, body coil
- pixel spacing:
  0.9375mm x 0.9375mm
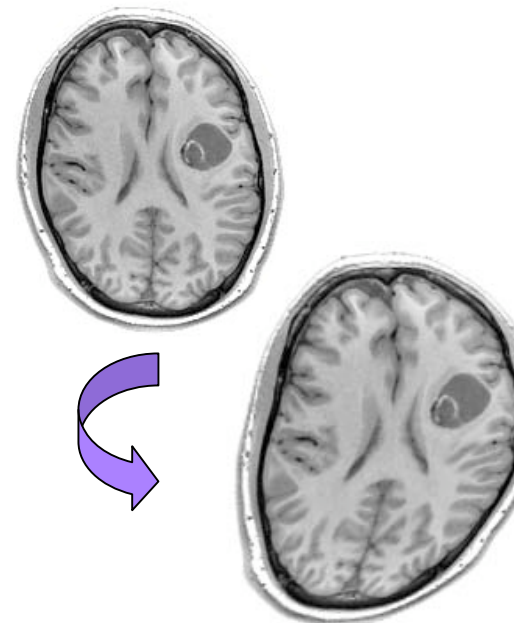- slice thickness: 5mm
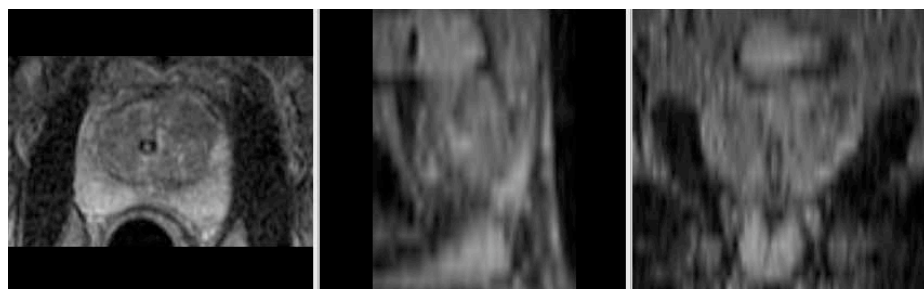
Three transformation models

Rigid	Affine	Non-rigid
• Translation • Rotation	• Translation • Rotation • Stretch • Shear	• Non-linear, e.g. spline-based, elastic/ fluid models

Deformable B–spline registration

3DSlicer

Transform

Fixed Image

Moving Image

B-spline grid

Control points

Pixel displacements
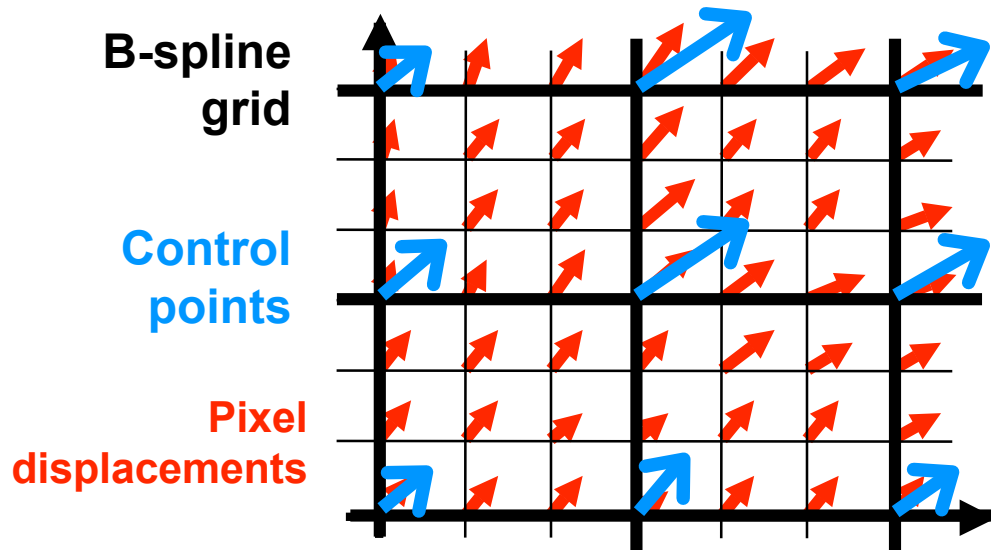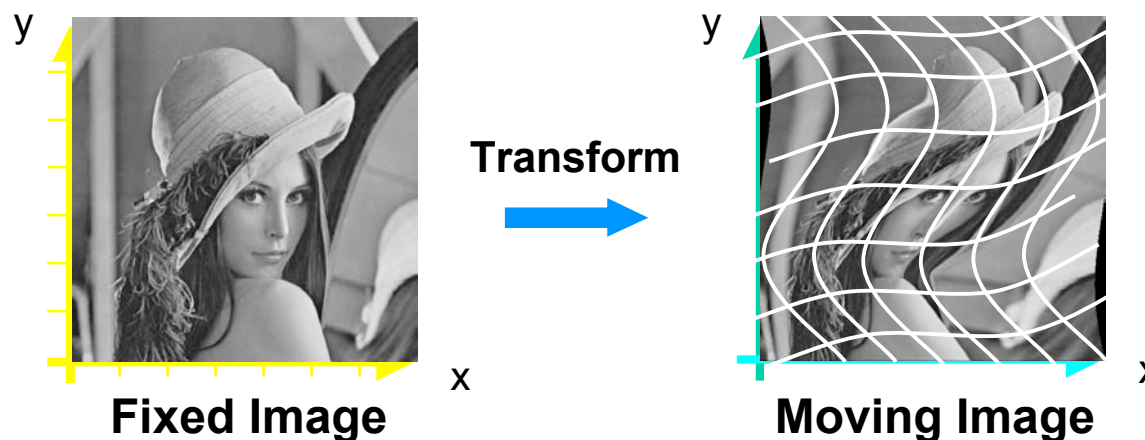
B-splines in Slicer3:

- Similarity measure: mutual information

- Optimizer: itkLBFGSB (limited memory Broyden Fletcher Goldfarb Shannon minimization with simple bounds)

Registration Steps

3DSlicer

- Load the image volumes

- Initial manual rigid transformation

  Initializes transform

- Automatic affine registration

  Initializes transform

- Automatic deformable B-spline registration

- Load the image volumes

- Initial manual rigid transformation

  Initializes transform

- Automatic affine registration

  Initializes transform

- Automatic deformable B-spline registration

Load the image volumes
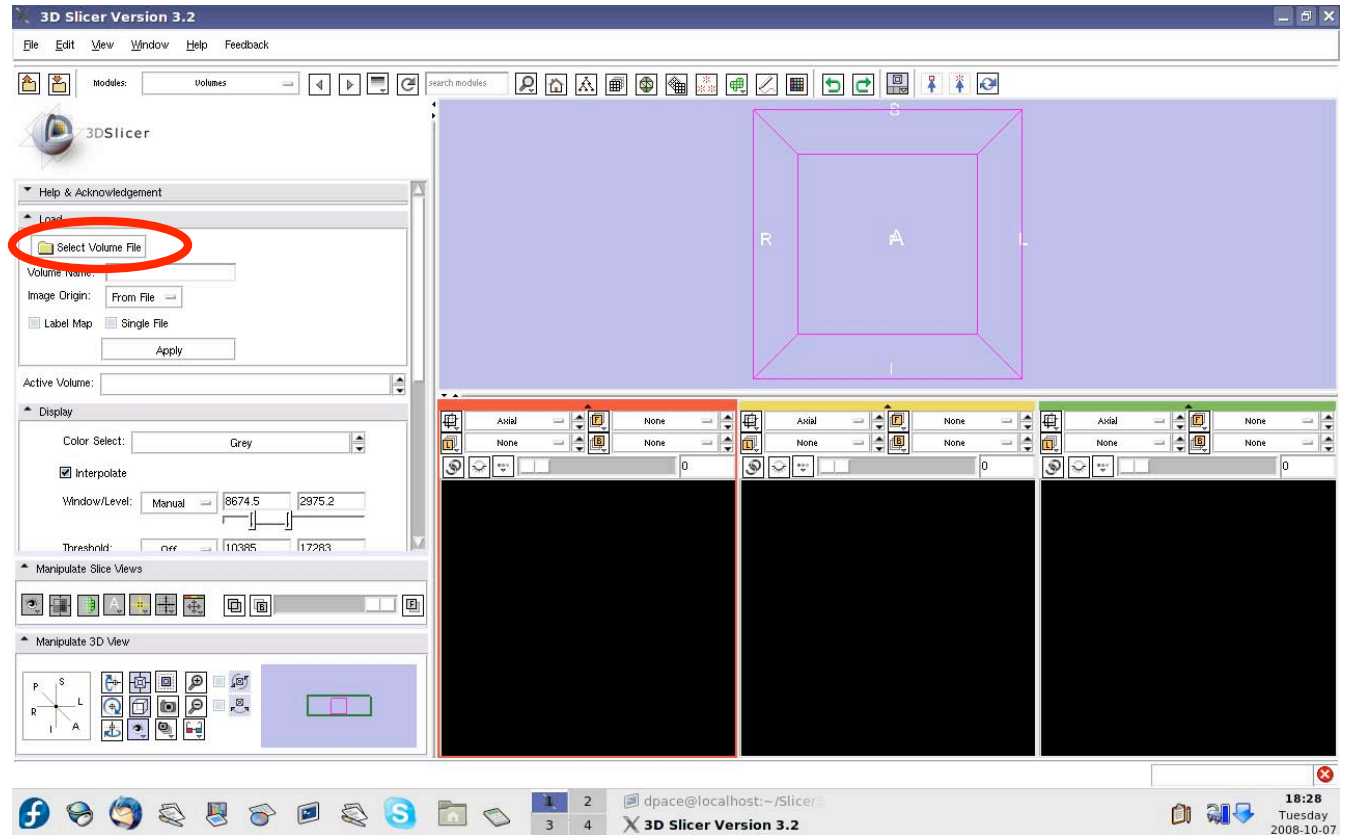
Load the pre-operative image

Open the Volumes Module
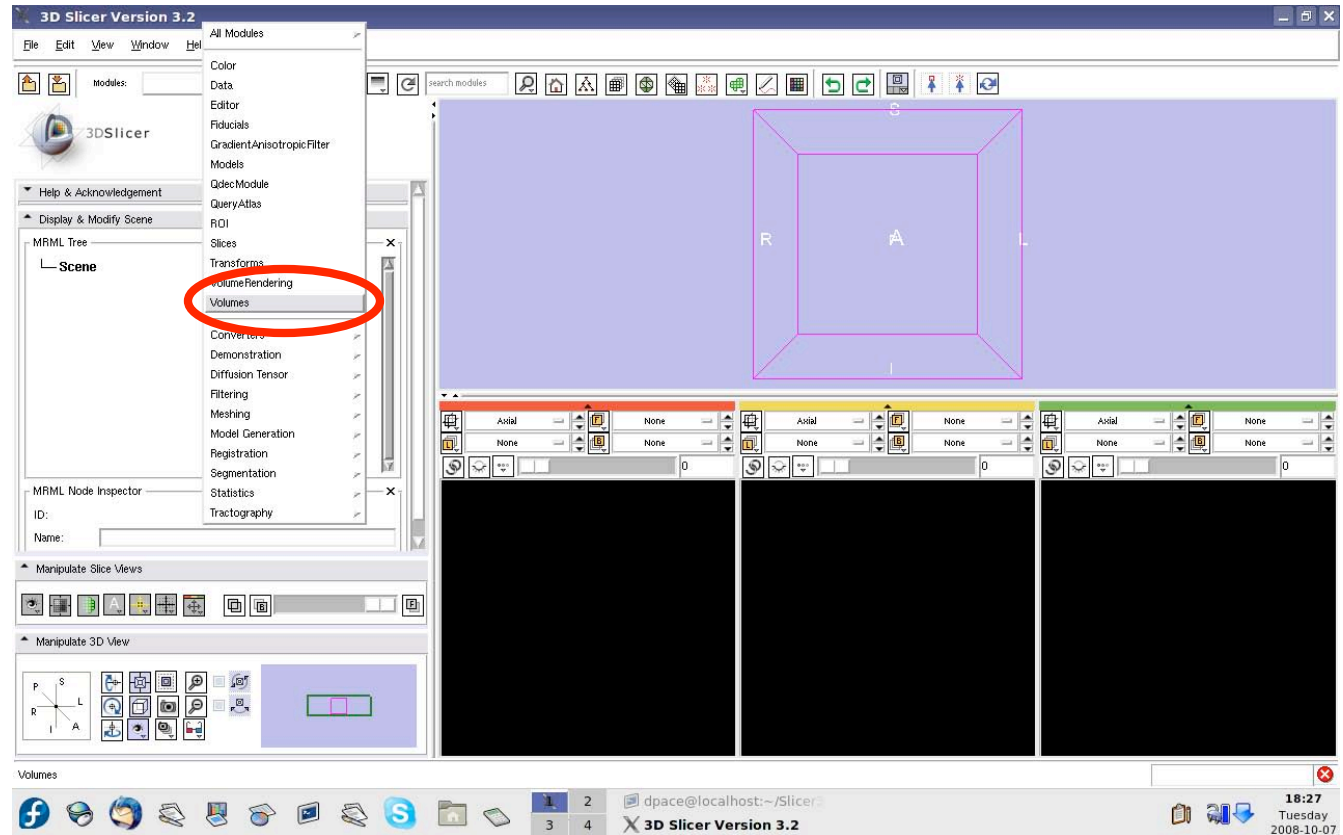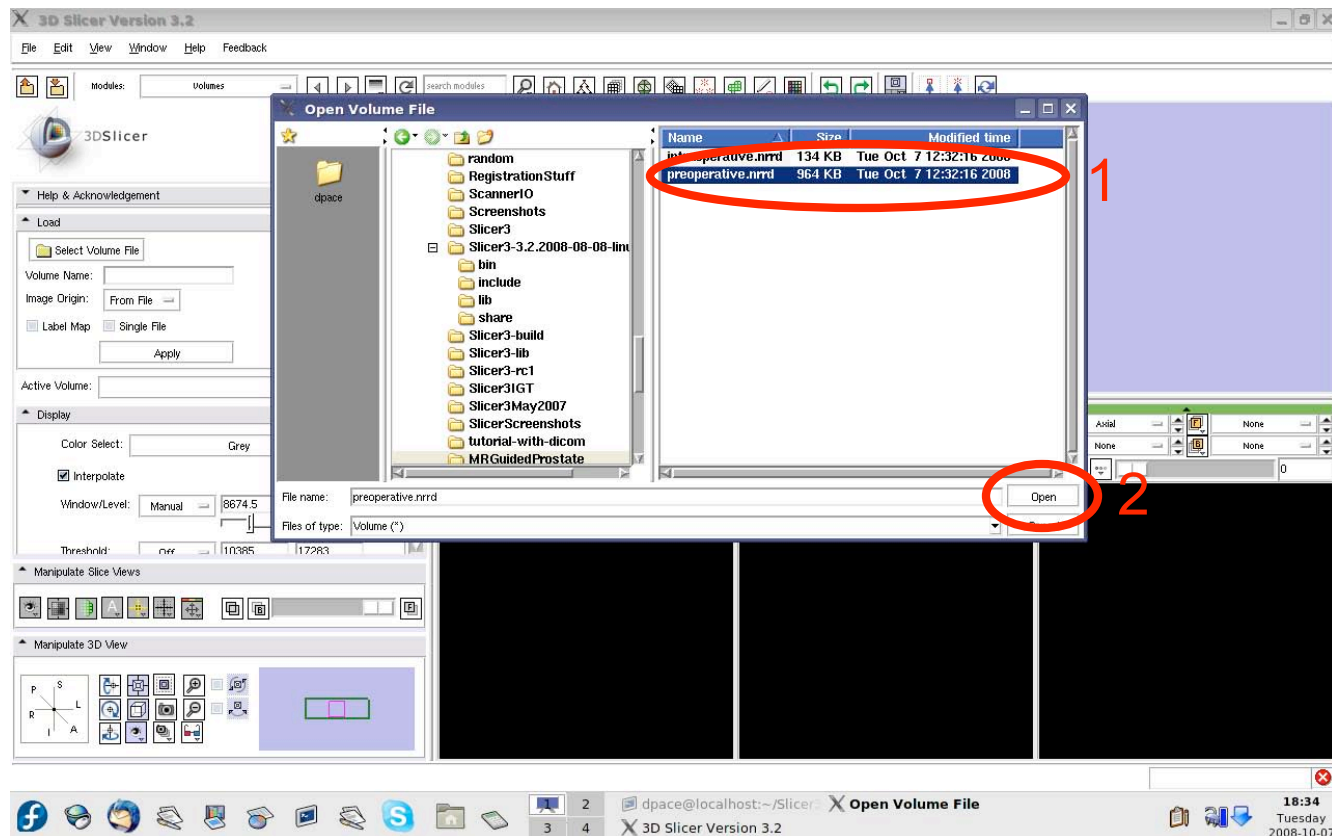
Load the image volumes

Click on "Select Volume File"

Load the image volumes

Select the pre-operative image: preoperative.nrrd
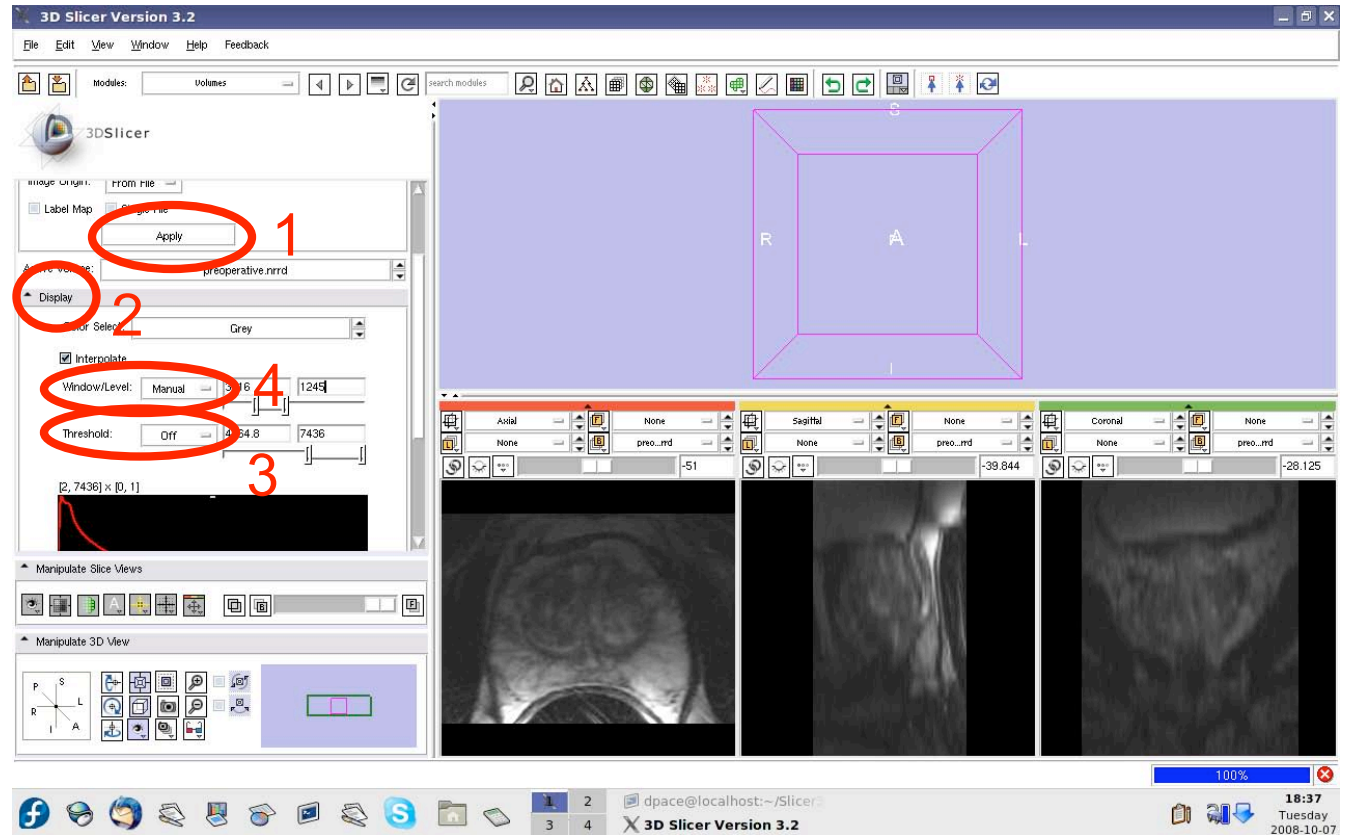
Click "Open"

Load the image volumes

Click "Apply"

Expand the Display tab

Turn thresholding off

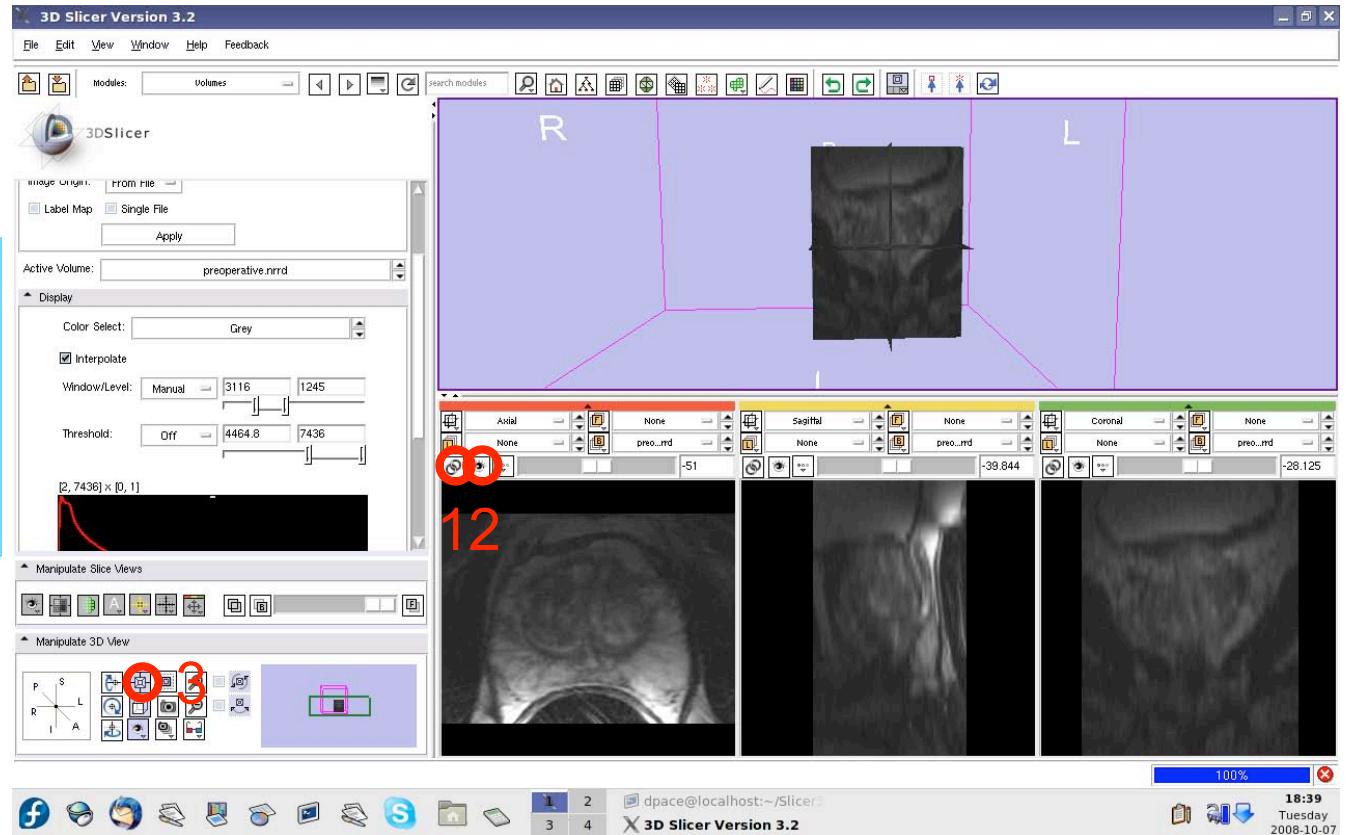Adjust the Window/Level sliders until you can see the image

Load the image volumes

Click on the slice control link button

Toggle the slice visibility to see the slices in the 3D viewer
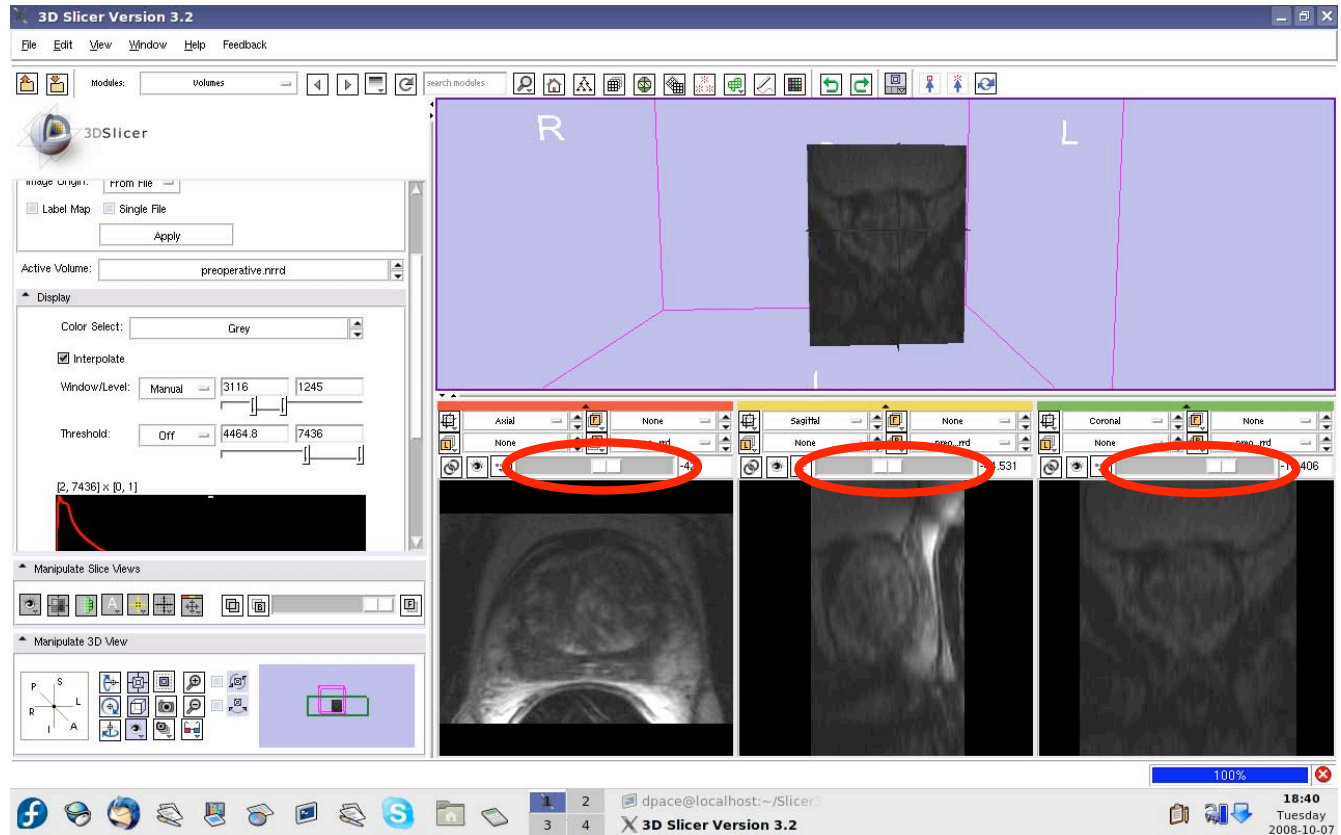
Center the 3D view on the scene and zoom in

Load the image volumes

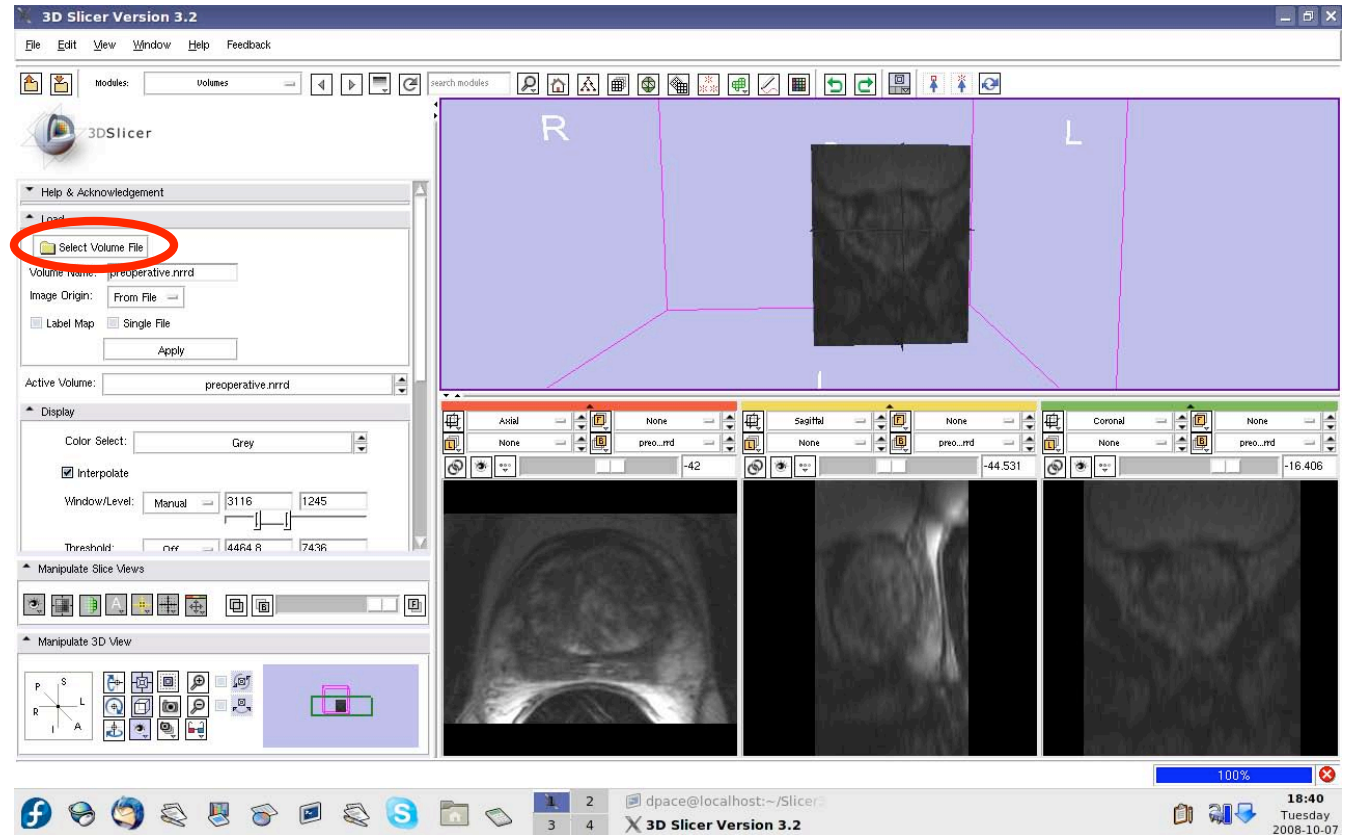**Use the slice selector sliders to explore the dataset**

Load the image volumes

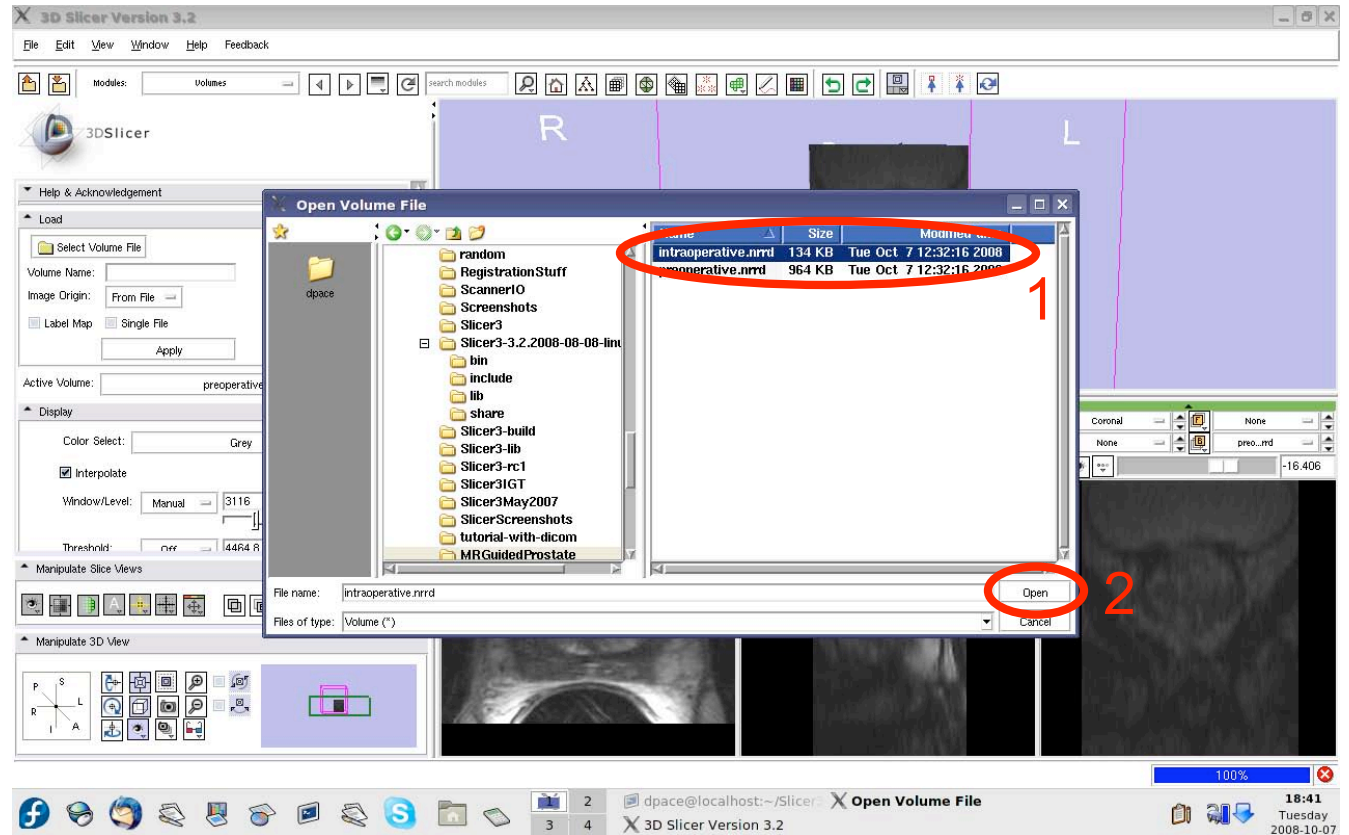**Load the intra-operative image**

Click on "Select Volume File"

Load the image volumes

Select the intra-operative image: intraoperative.nrrd
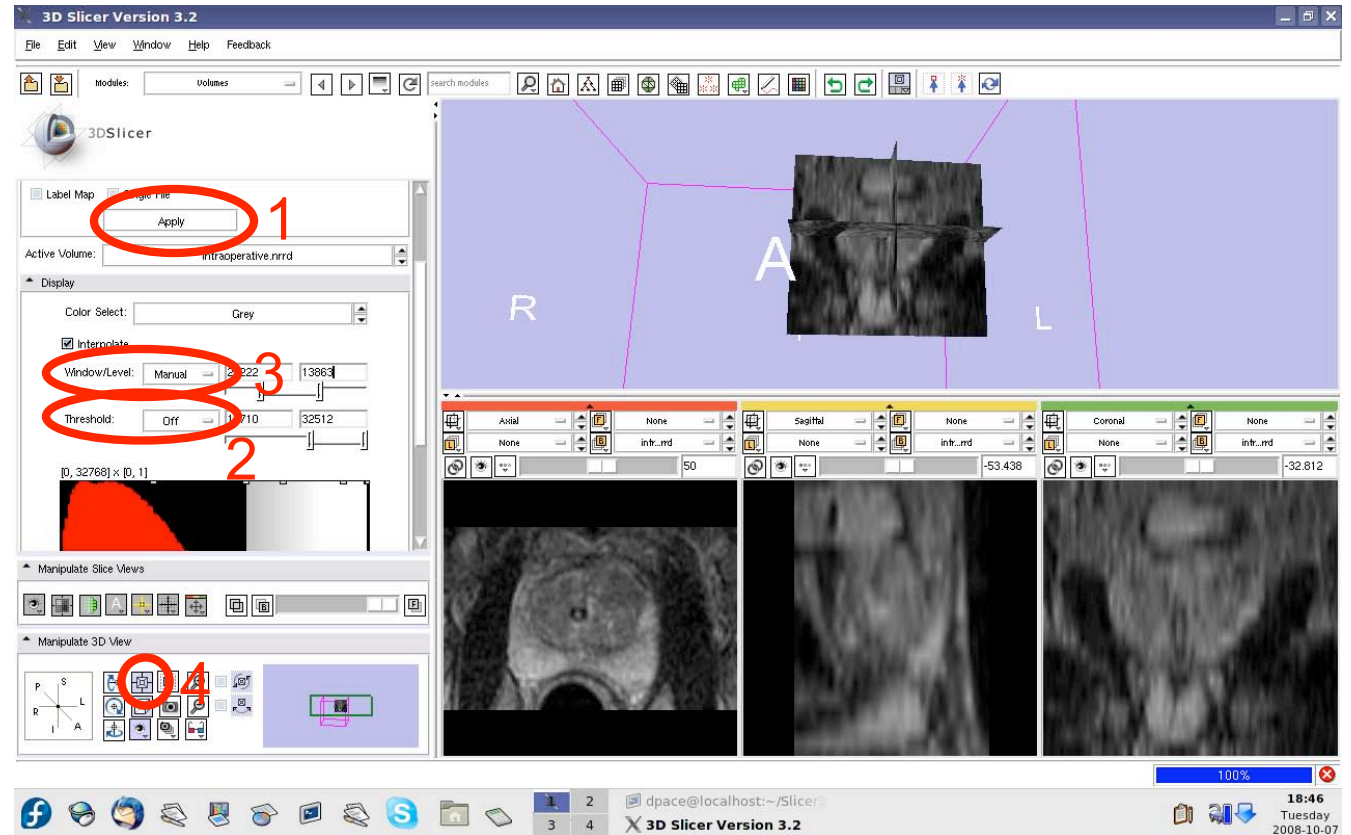
Click "Open"

Load the image volumes

Click "Apply"

Turn thresholding off

Adjust the Window/Level sliders until you can see the image
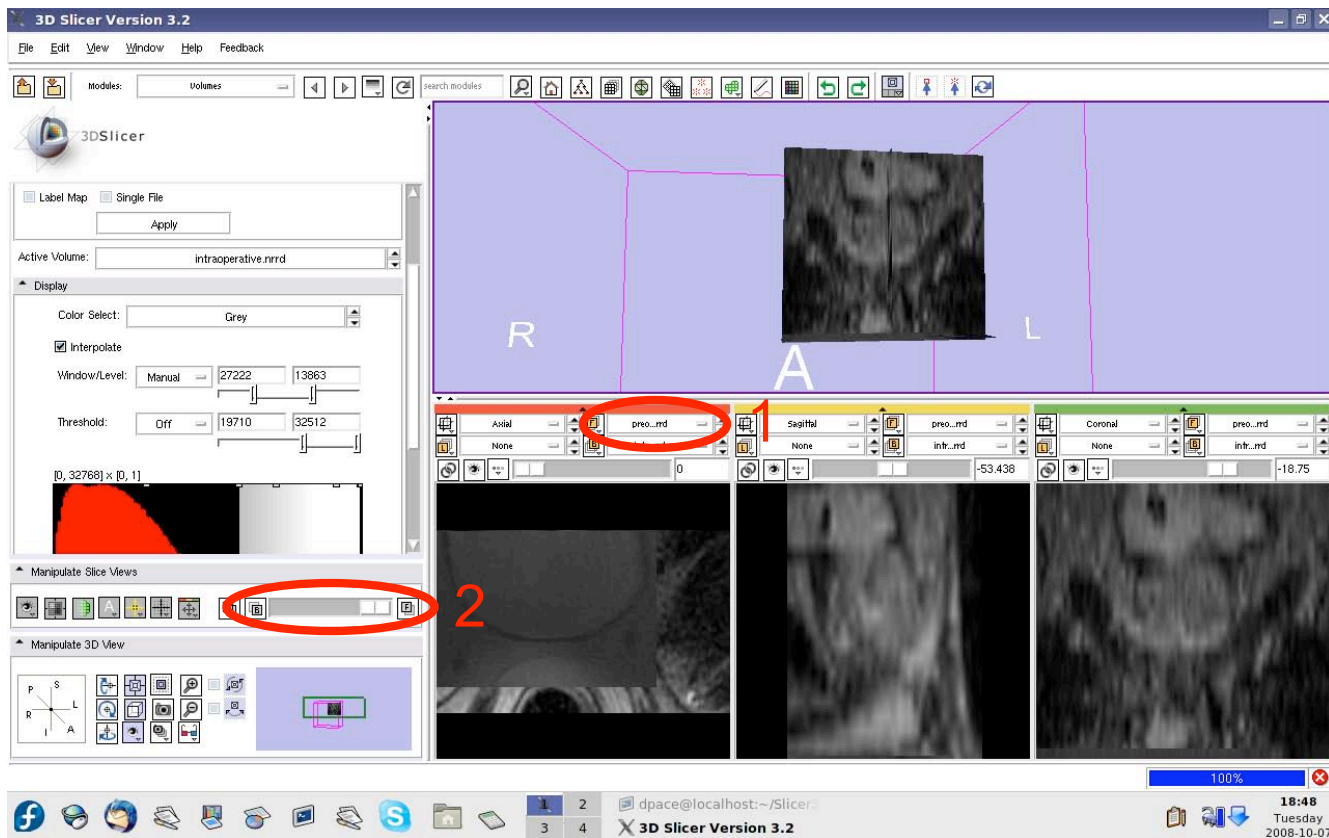
Center the 3D view on the scene

Load the image volumes

Note that the images are not aligned

Set the foreground to the pre-operative image

Scale between the foreground and background

Registration Steps

- Load the image volumes

- Initial manual rigid transformation

  Initializes transform

- Automatic affine registration

  Initializes transform

- Automatic deformable B-spline registration
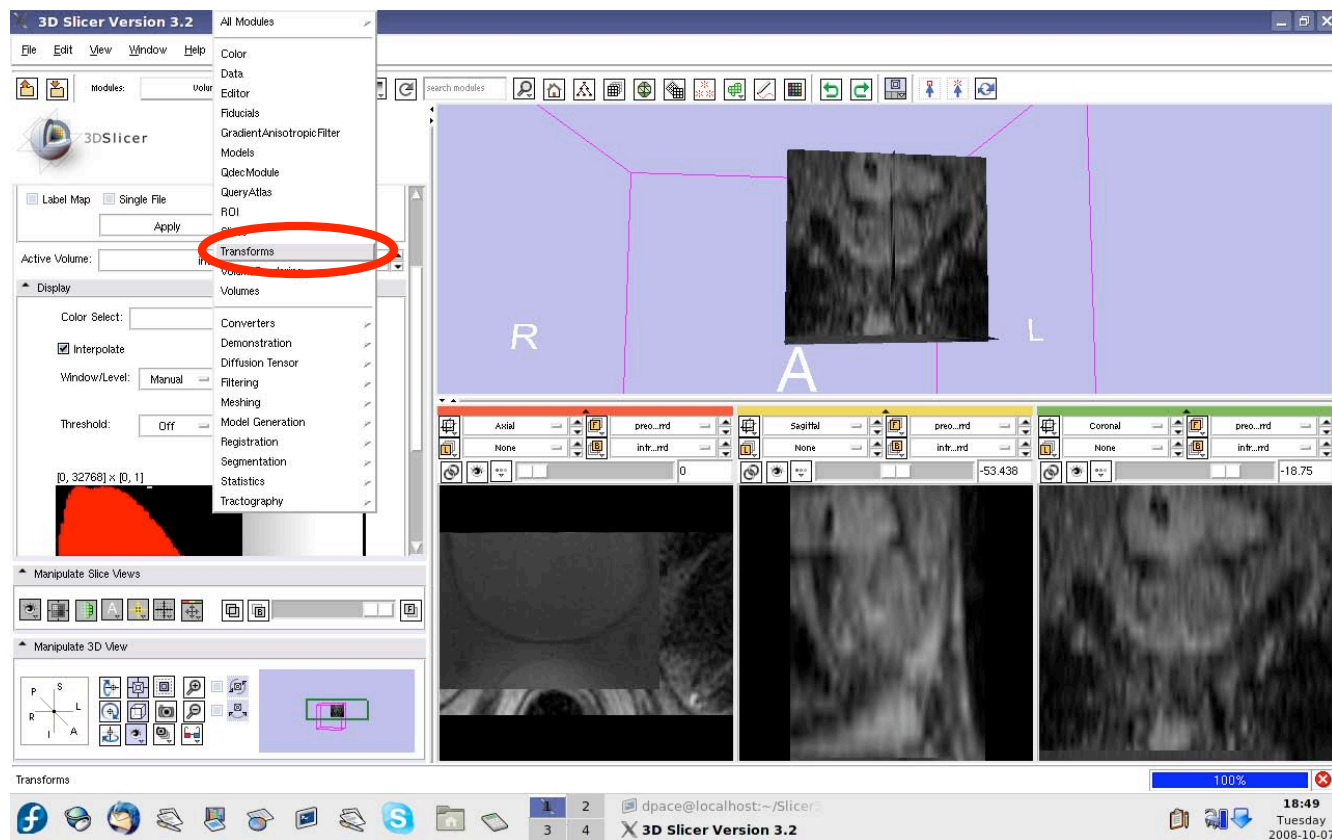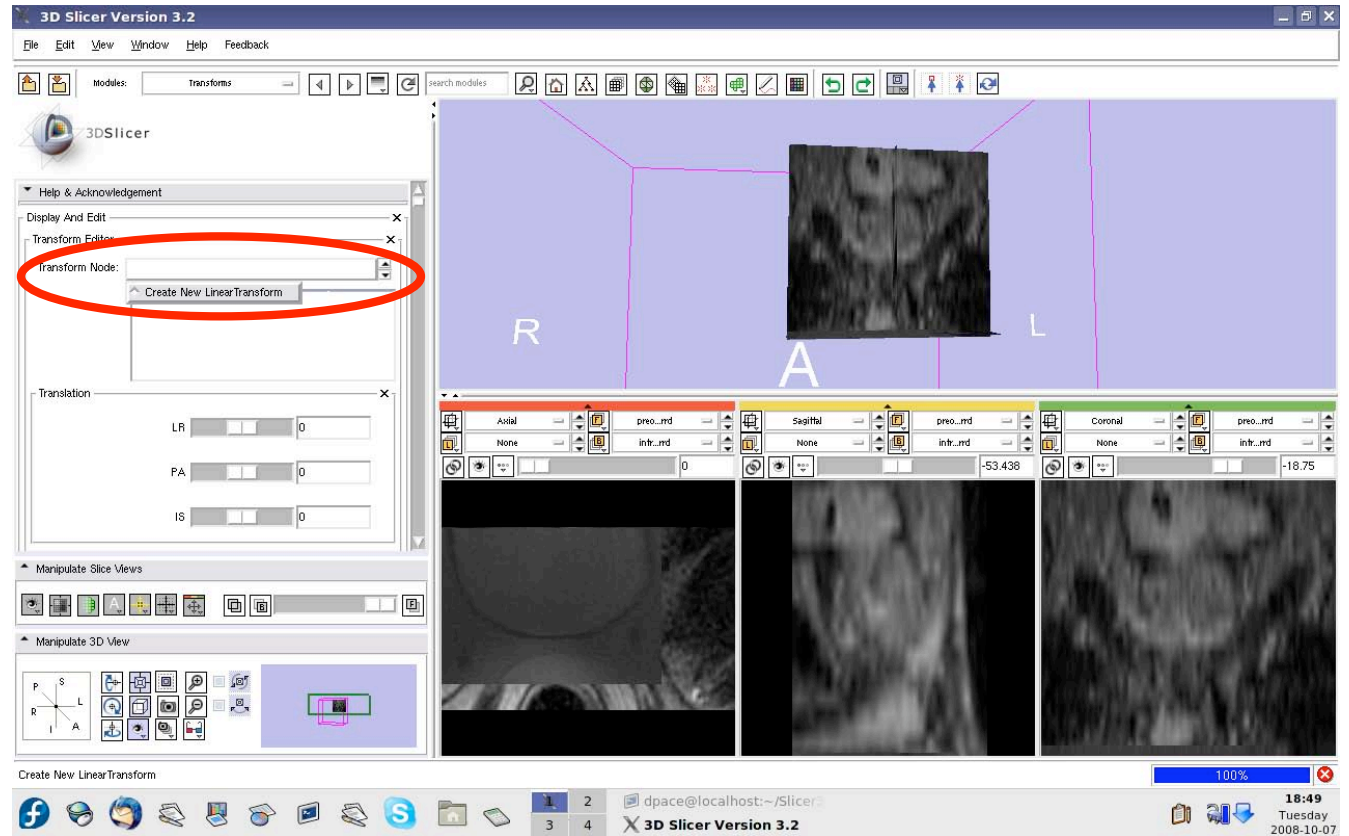
Manual rigid transformation

Open the Transforms module
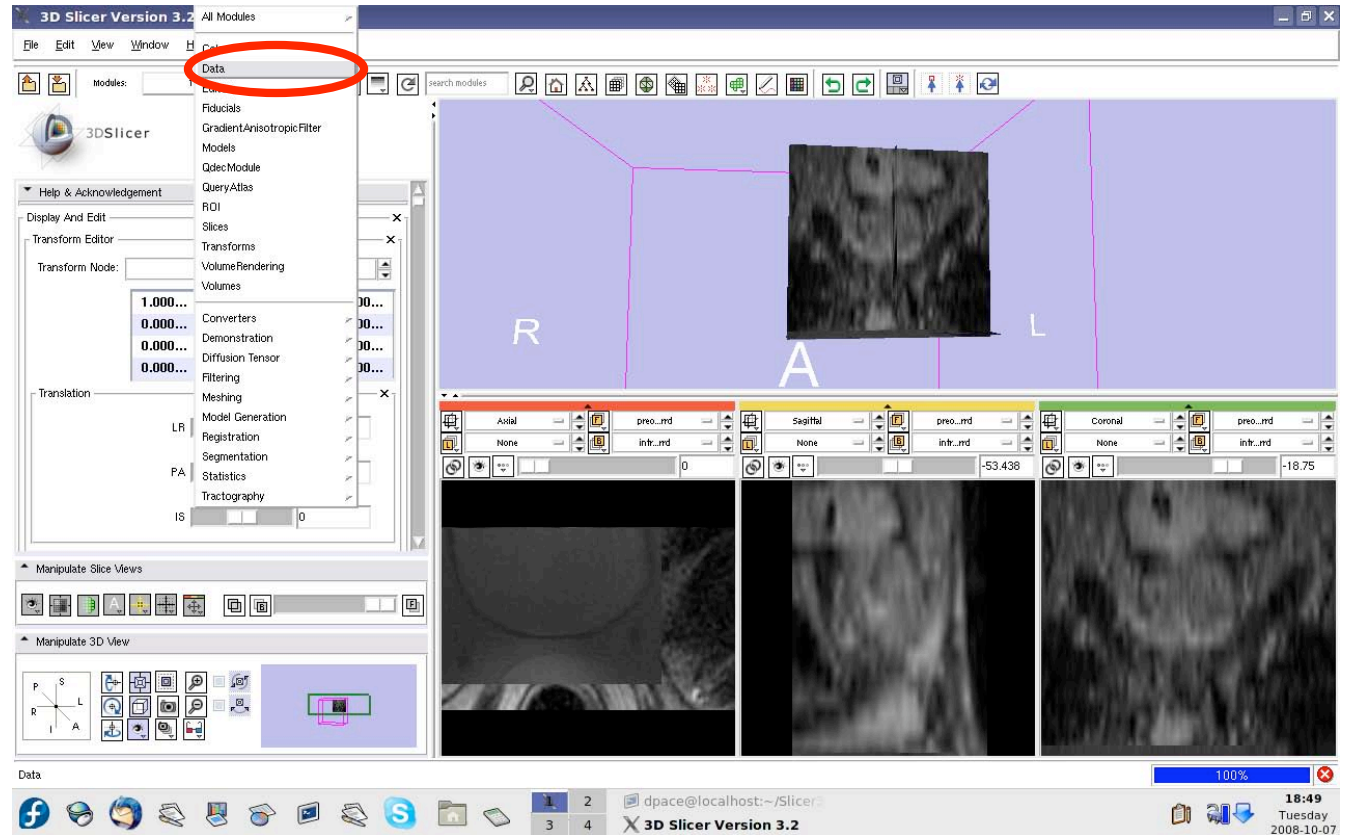
Manual rigid transformation

Create a new linear transform

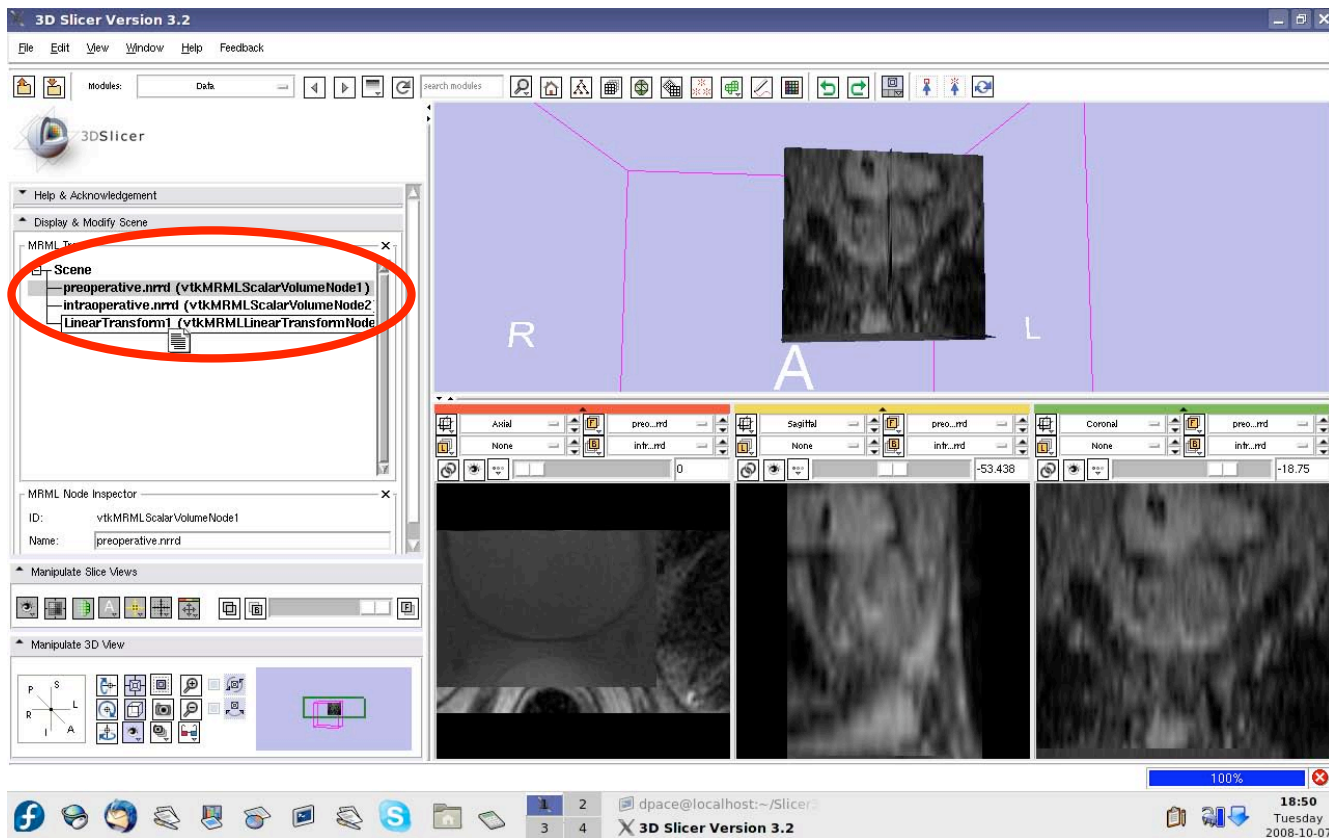# *Manual rigid transformation*

Open the Data module

Manual rigid transformation

Apply the manual rigid transformation to the pre-operative image

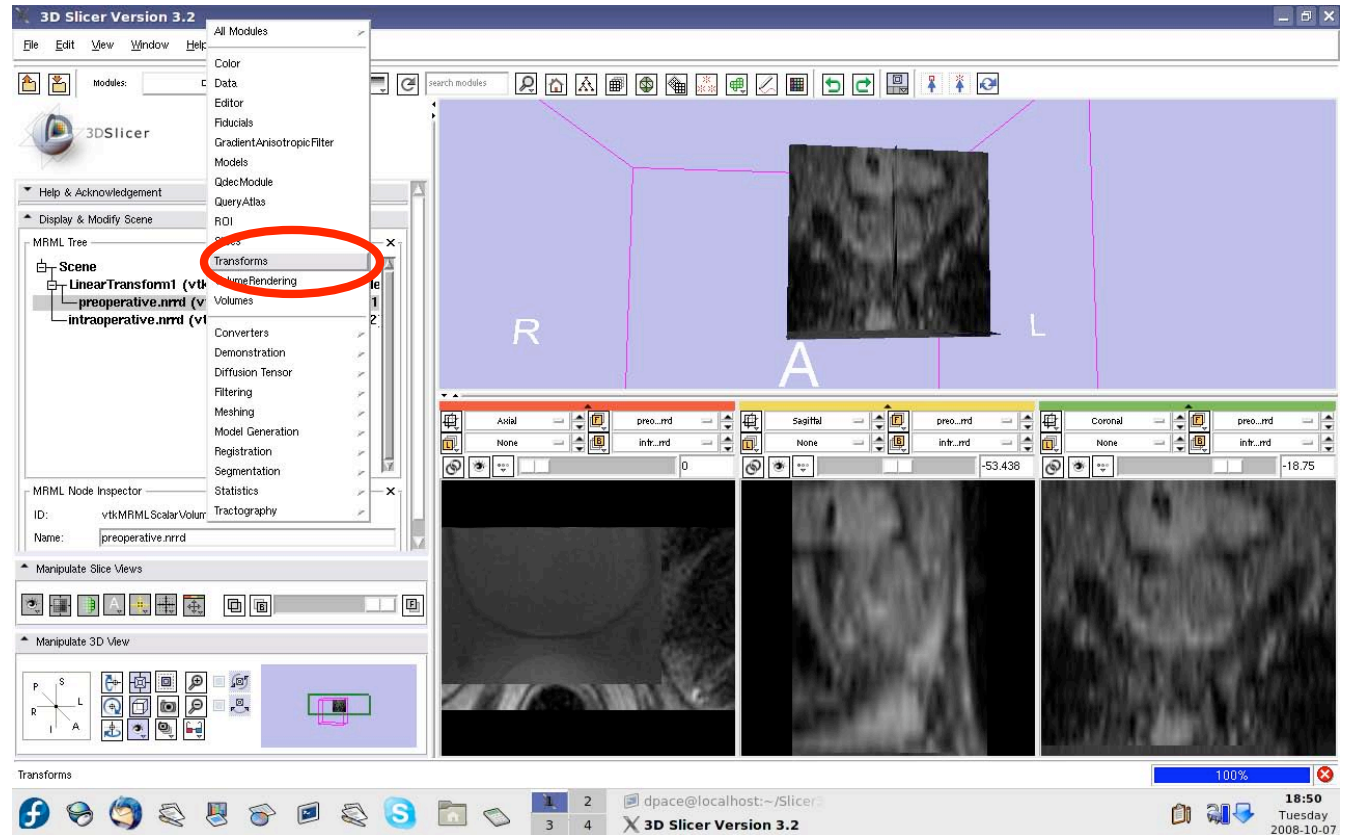Drag the pre-operative image under the Linear Transform1 node

Manual rigid transformation
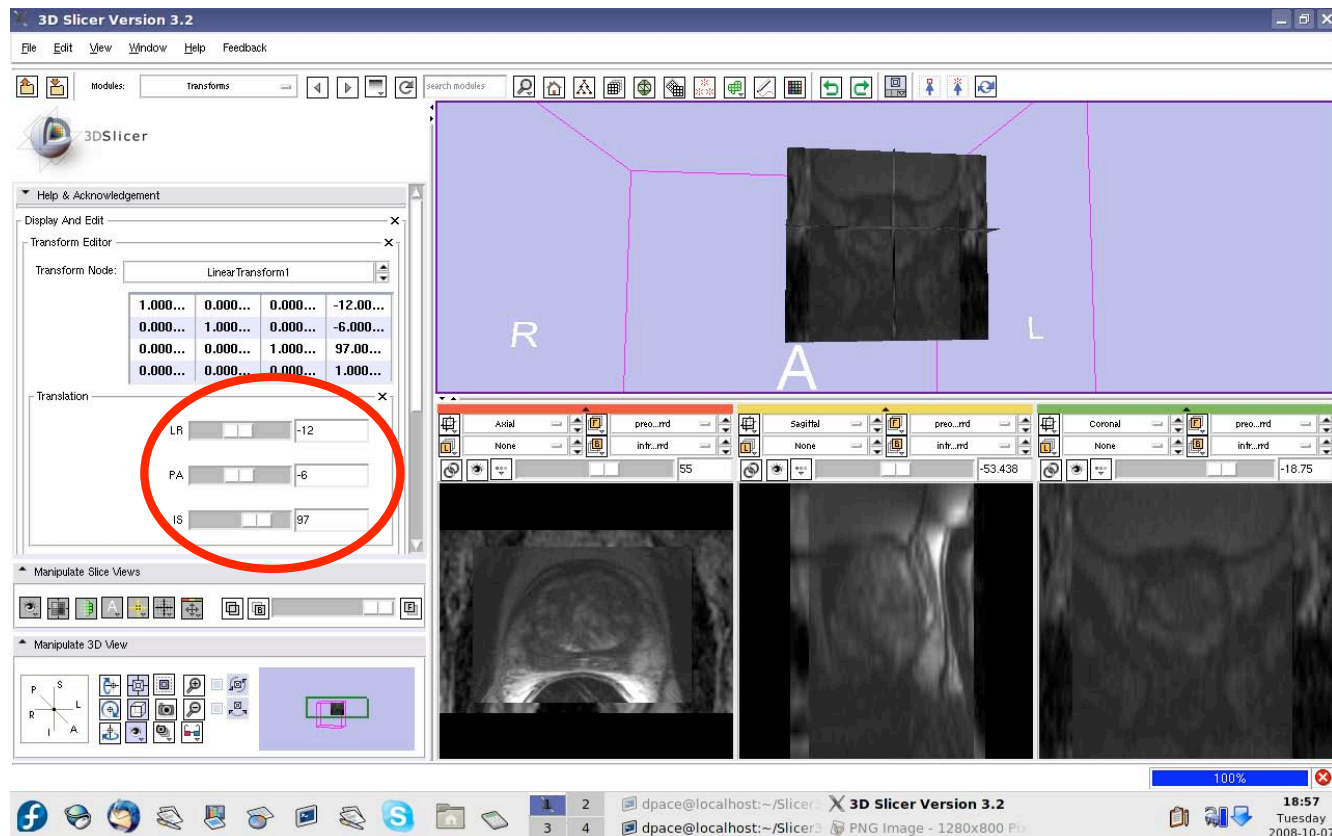
Open the Transforms module

Manual rigid transformation

Manually adjust the translation and rotation parameters to align the two image volumes
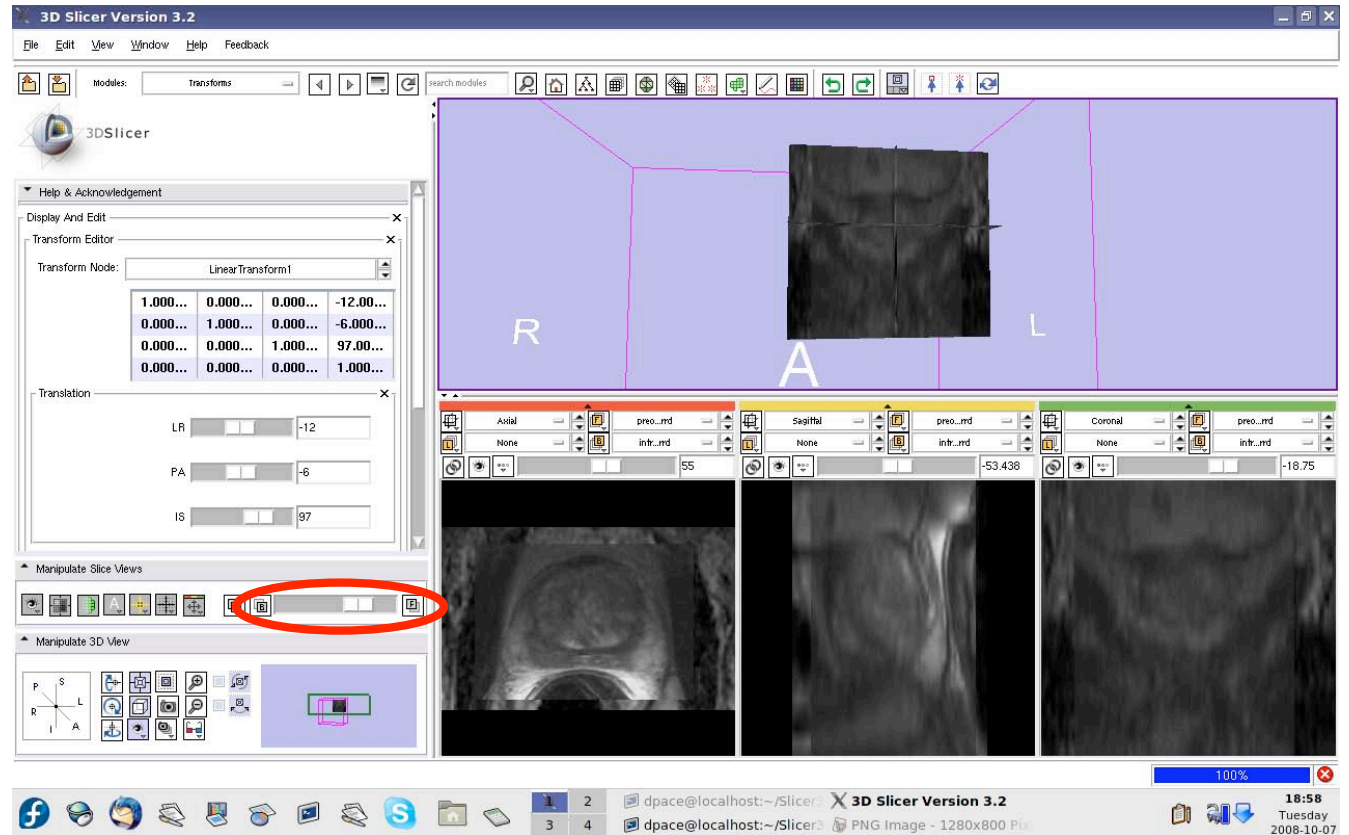
Recommended:
Trans. LR: -12
Trans. PA: -6
Trans. IS: 97
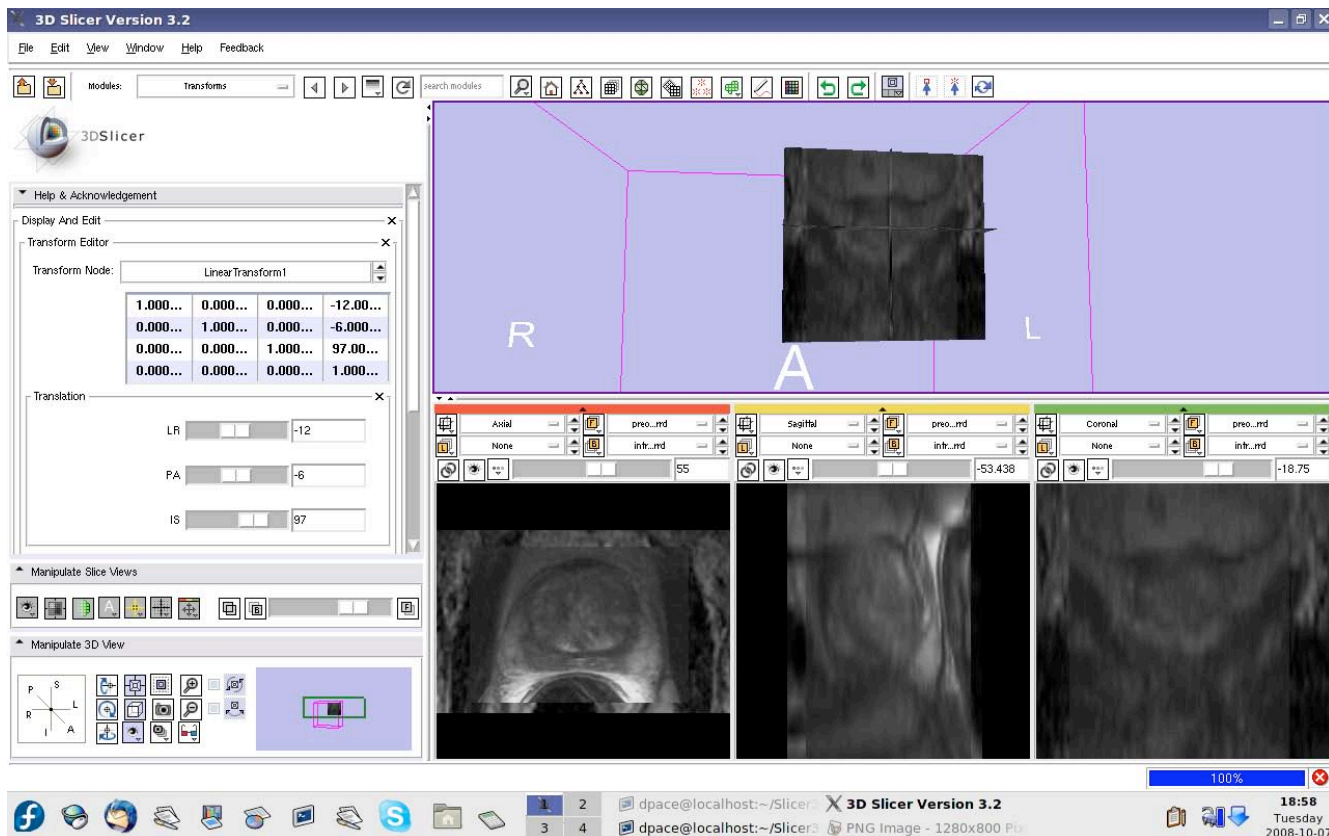**No rotation**

Manual rigid transformation

Scale between the foreground and background to evaluate the alignment

Manual rigid transformation

The initial transformation "pushes" the pre-operative image onto the intra-operative image, but Slicer's registration algorithm expects the inverse
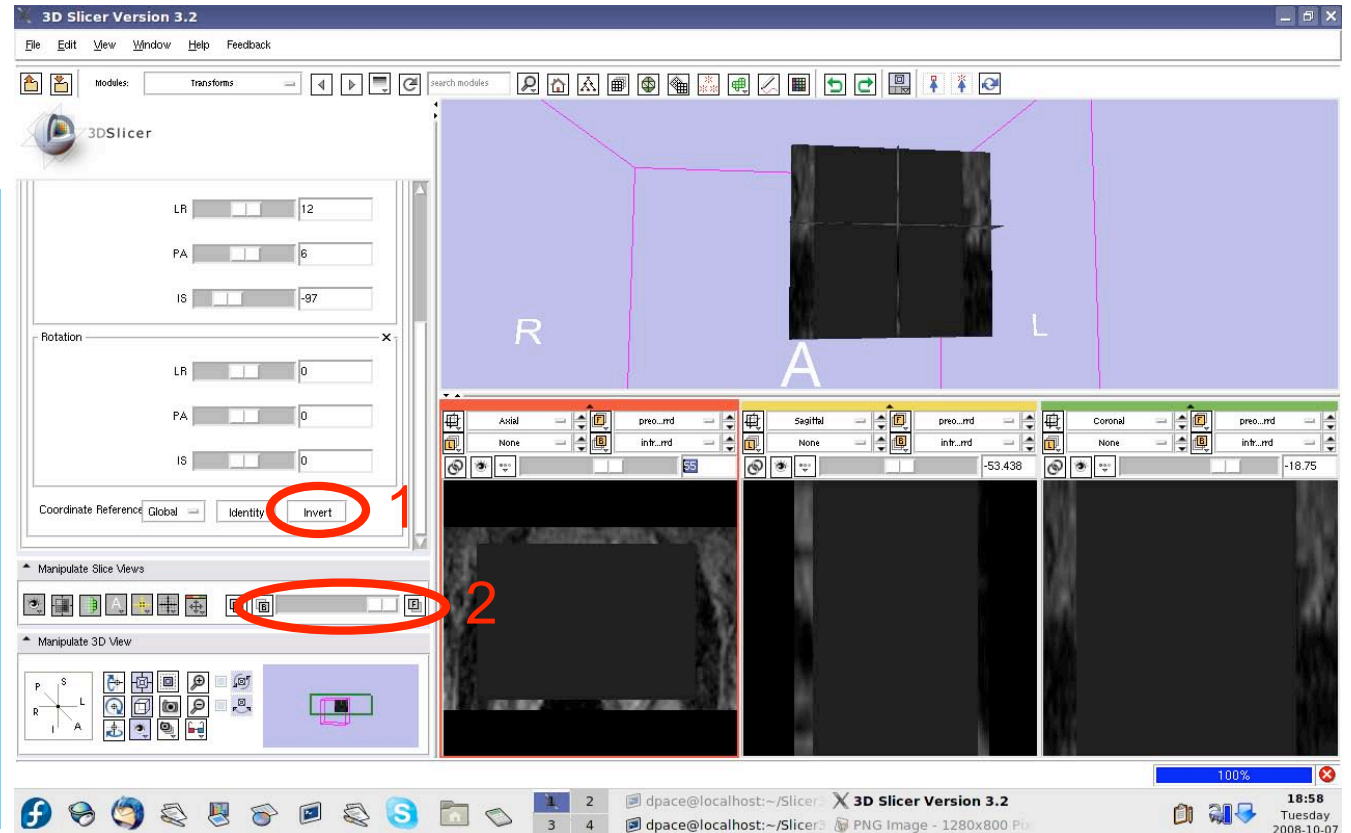
Manual rigid transformation

Click on the "Invert" button

Scale between the foreground and background - note that the two images are no longer aligned

- Load the image volumes
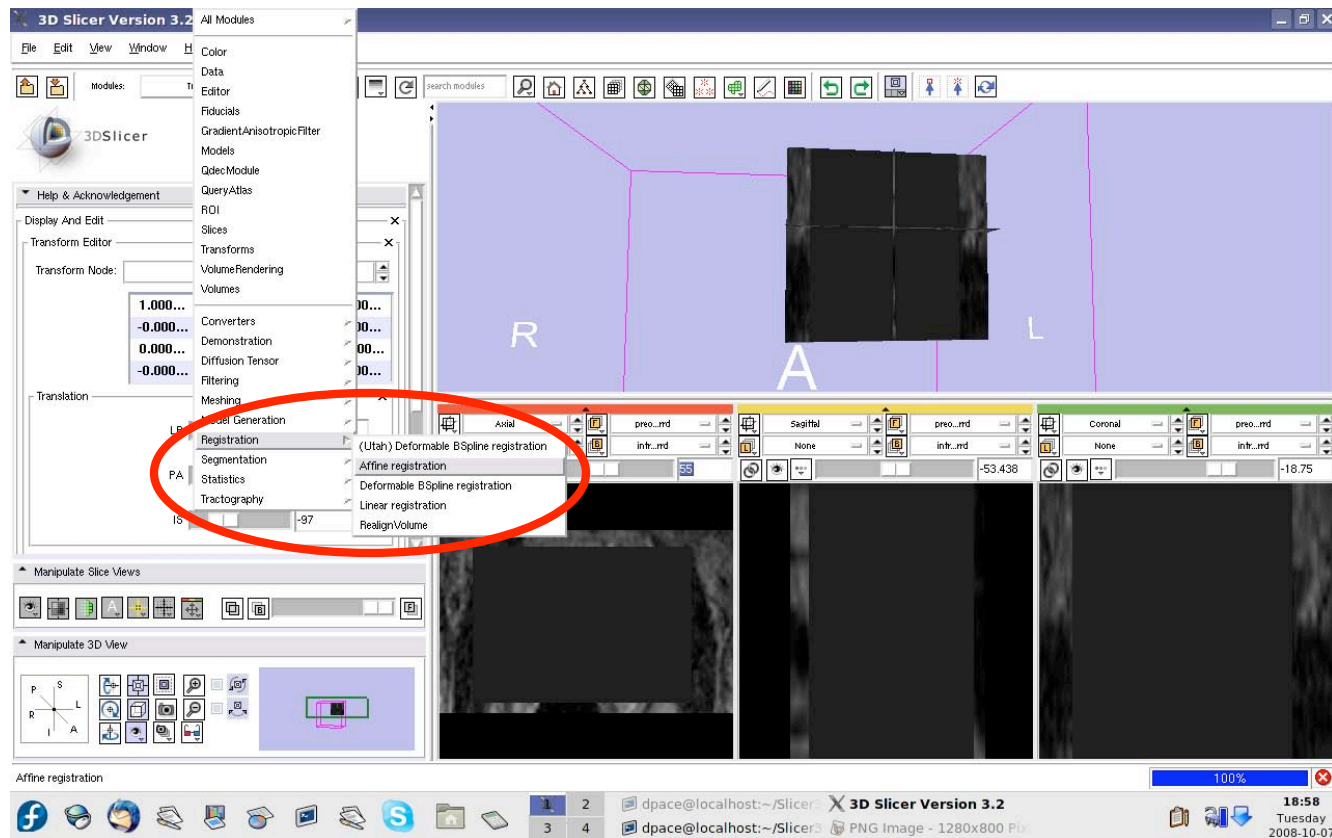
- Initial manual rigid transformation

  Initializes transform

- Automatic affine registration

  Initializes transform

- Automatic deformable B-spline registration

Affine registration

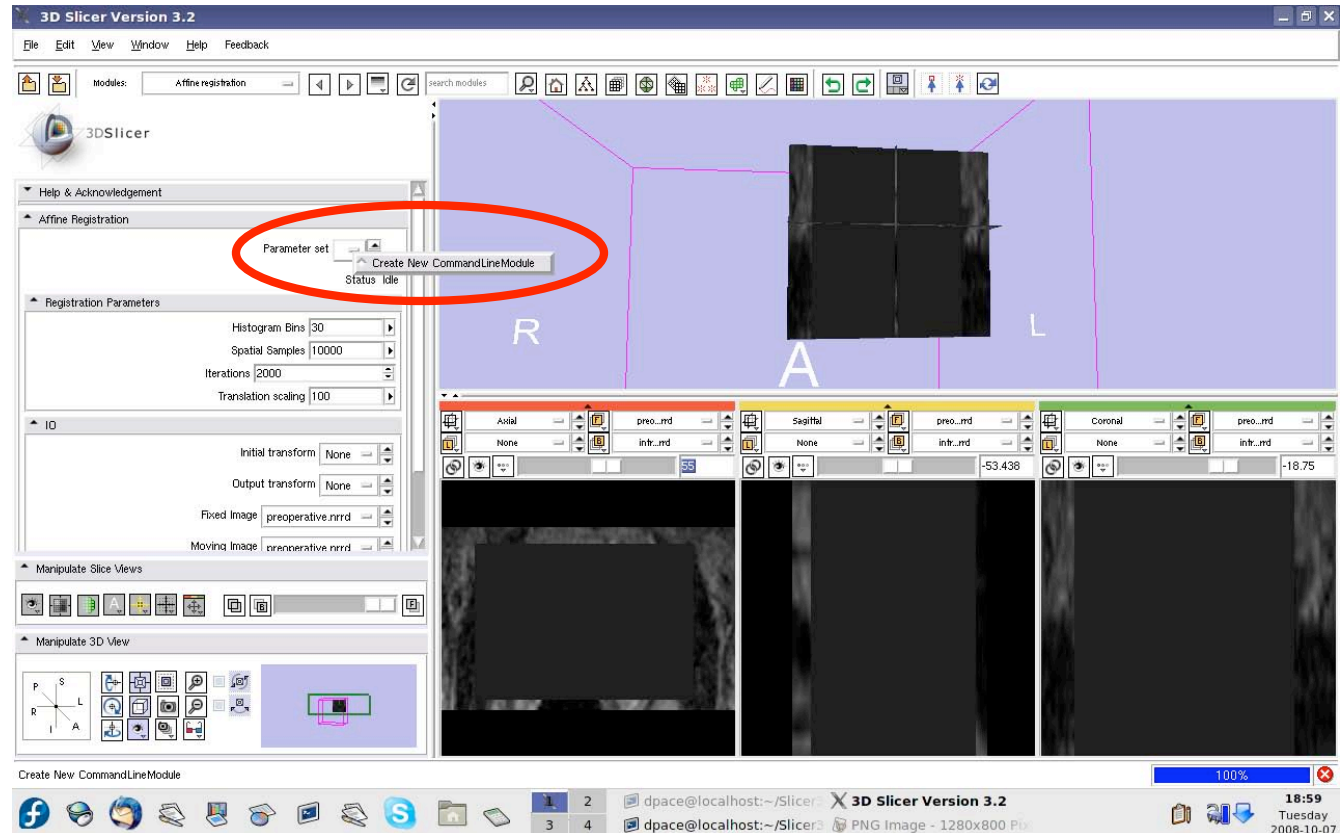**Perform the affine registration**

Open the Affine Registration module

Affine registration

Create a new affine registration transform
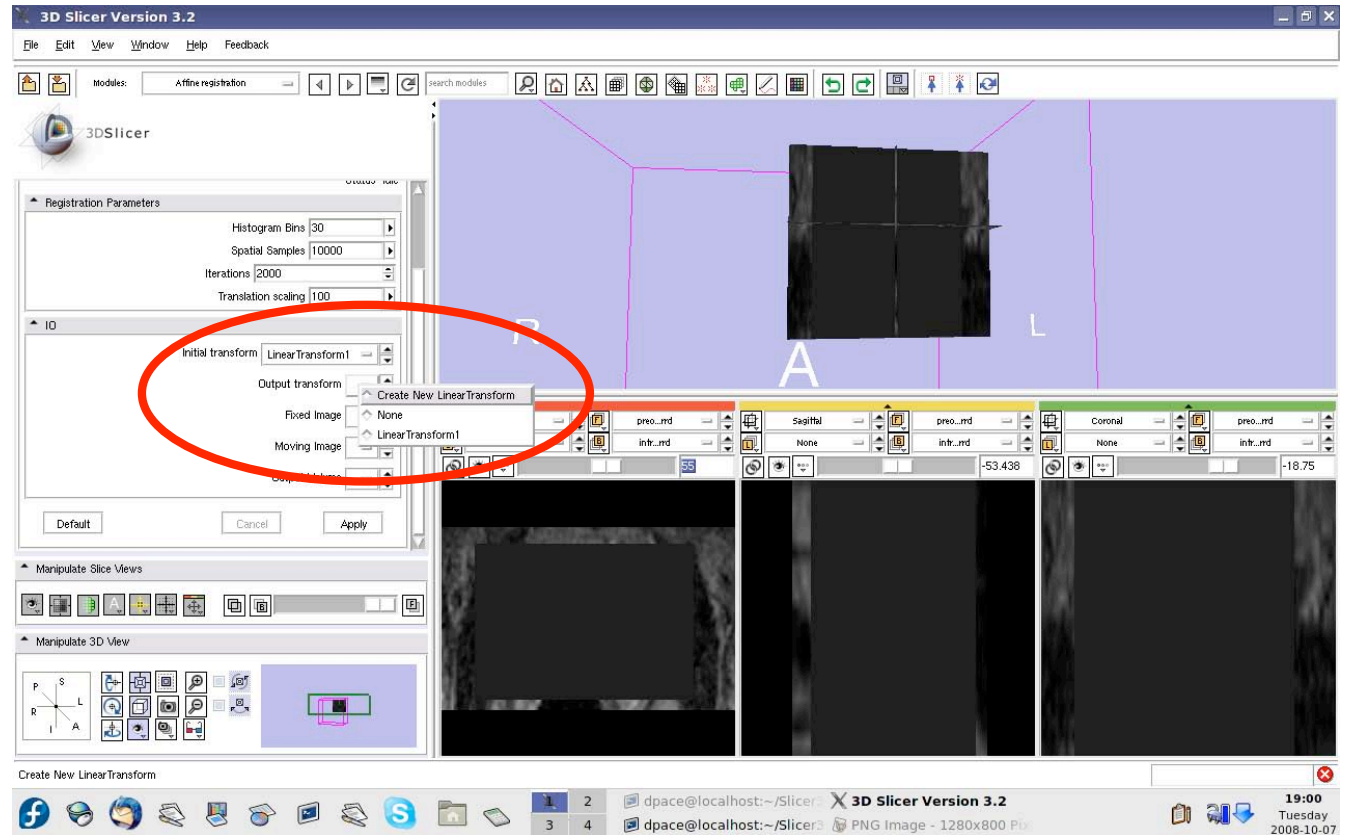
You do not need to change any of the registration parameters

Initial transform:
Linear Transform1
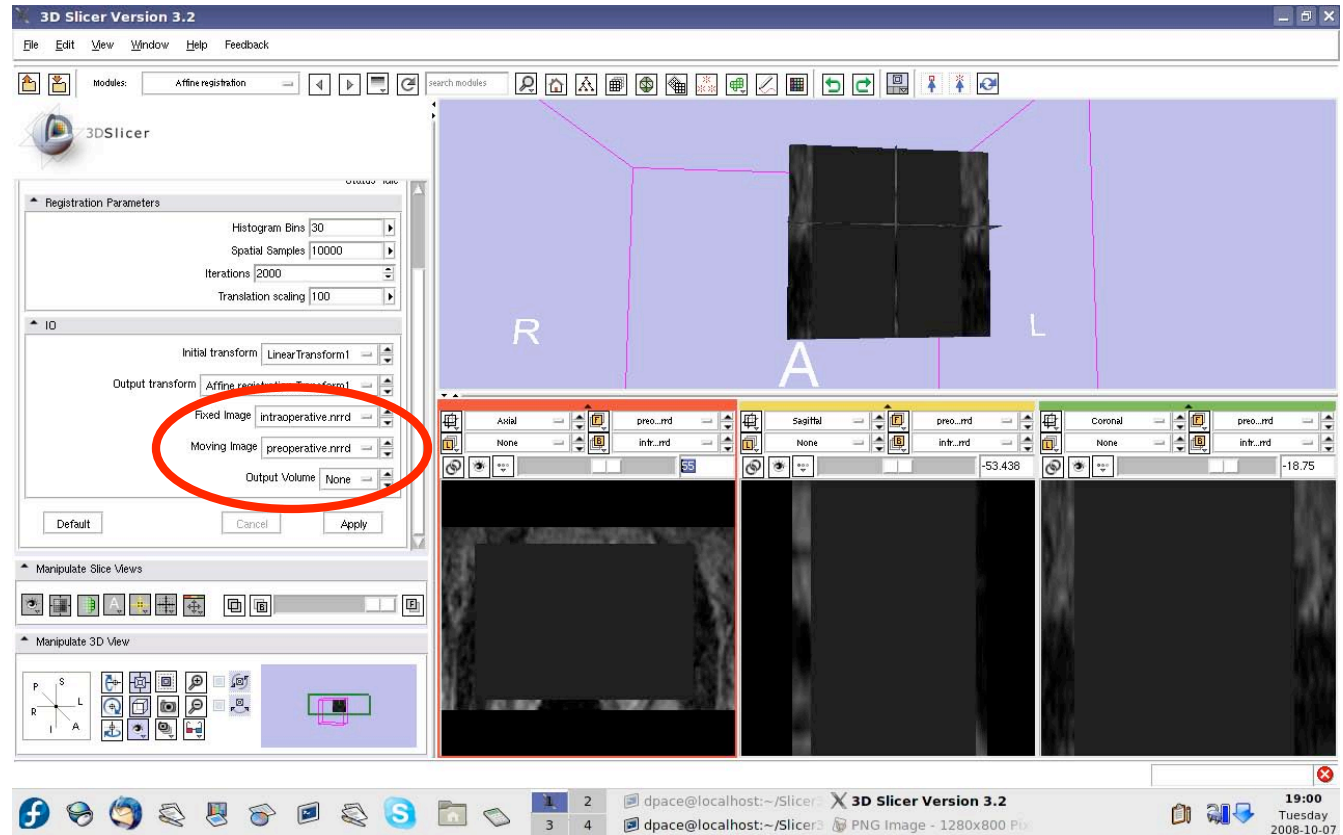
Output transform:
Create new linear transform

Affine registration

Fixed image:
intra-operative

Moving image:
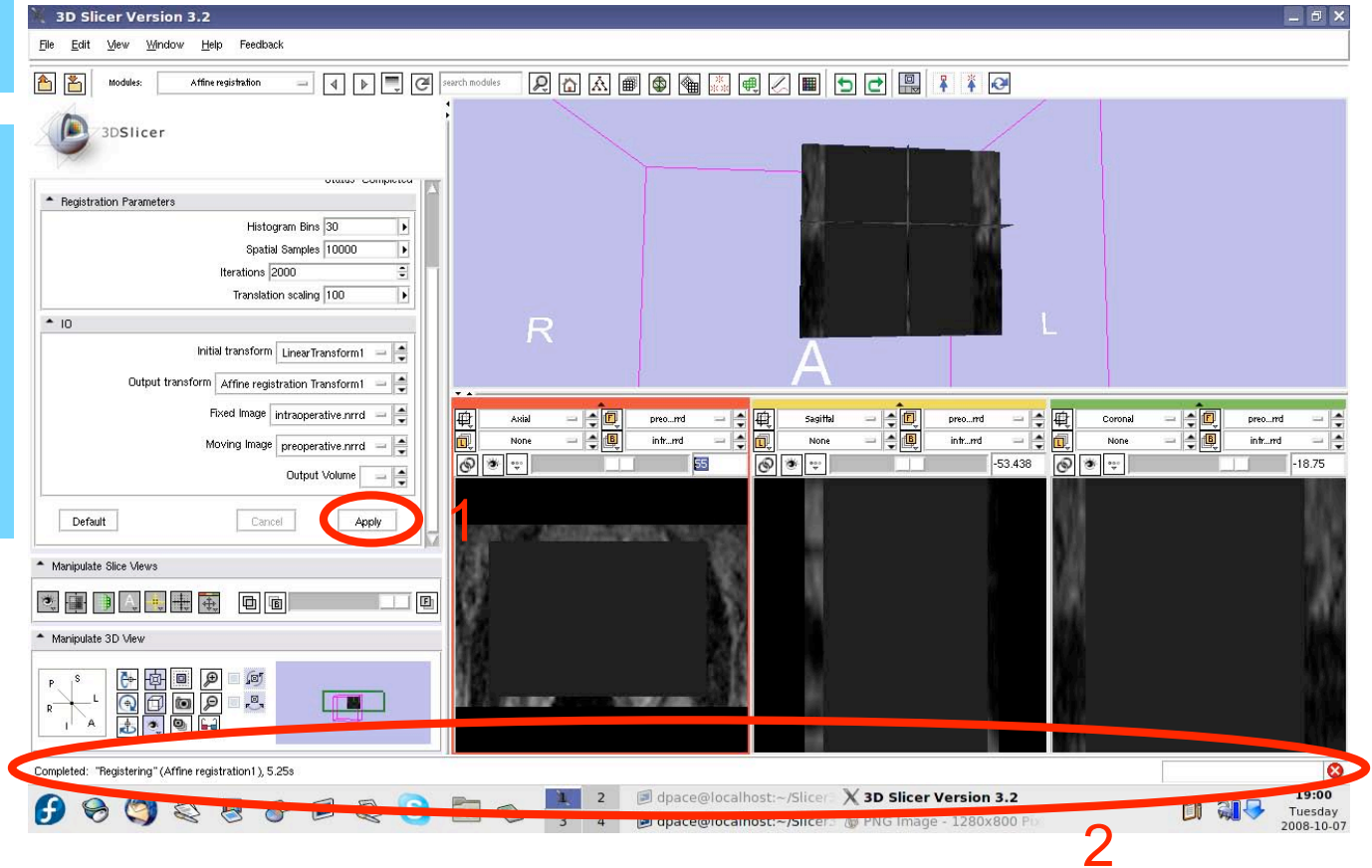pre-operative

Output Volume:
None

Affine registration

Click "Apply"
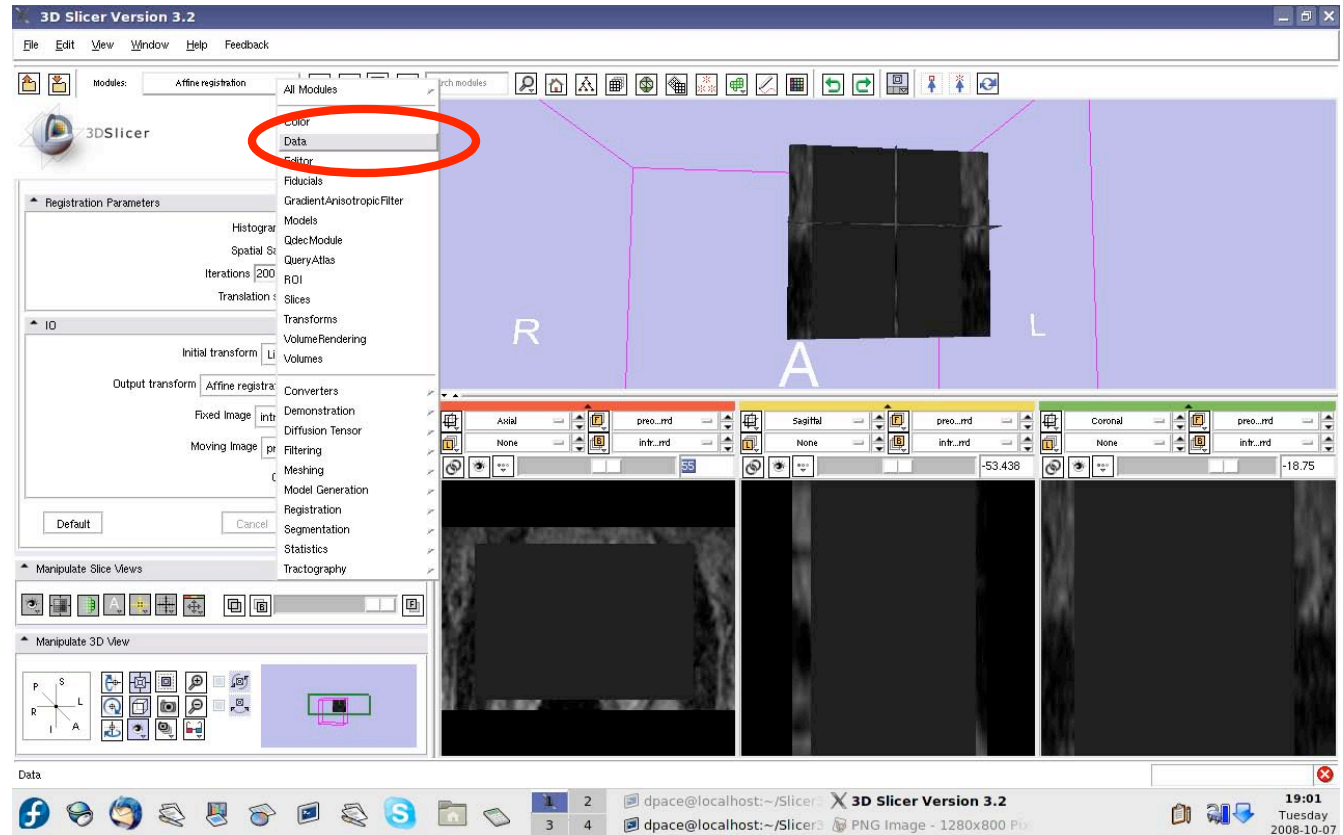
View the progress bar and wait until it says "Completed"

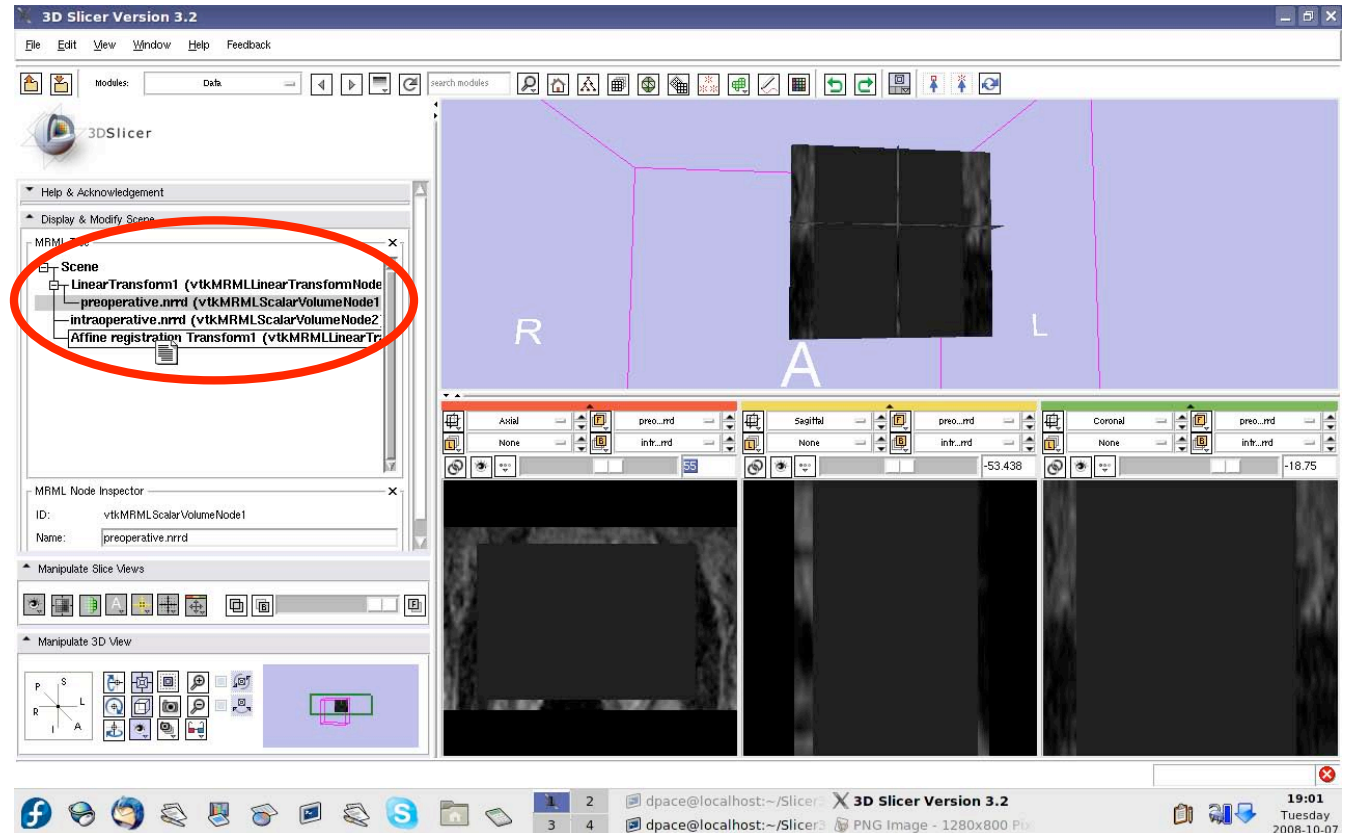# Affine registration

Evaluate the affine registration

Open the Data module

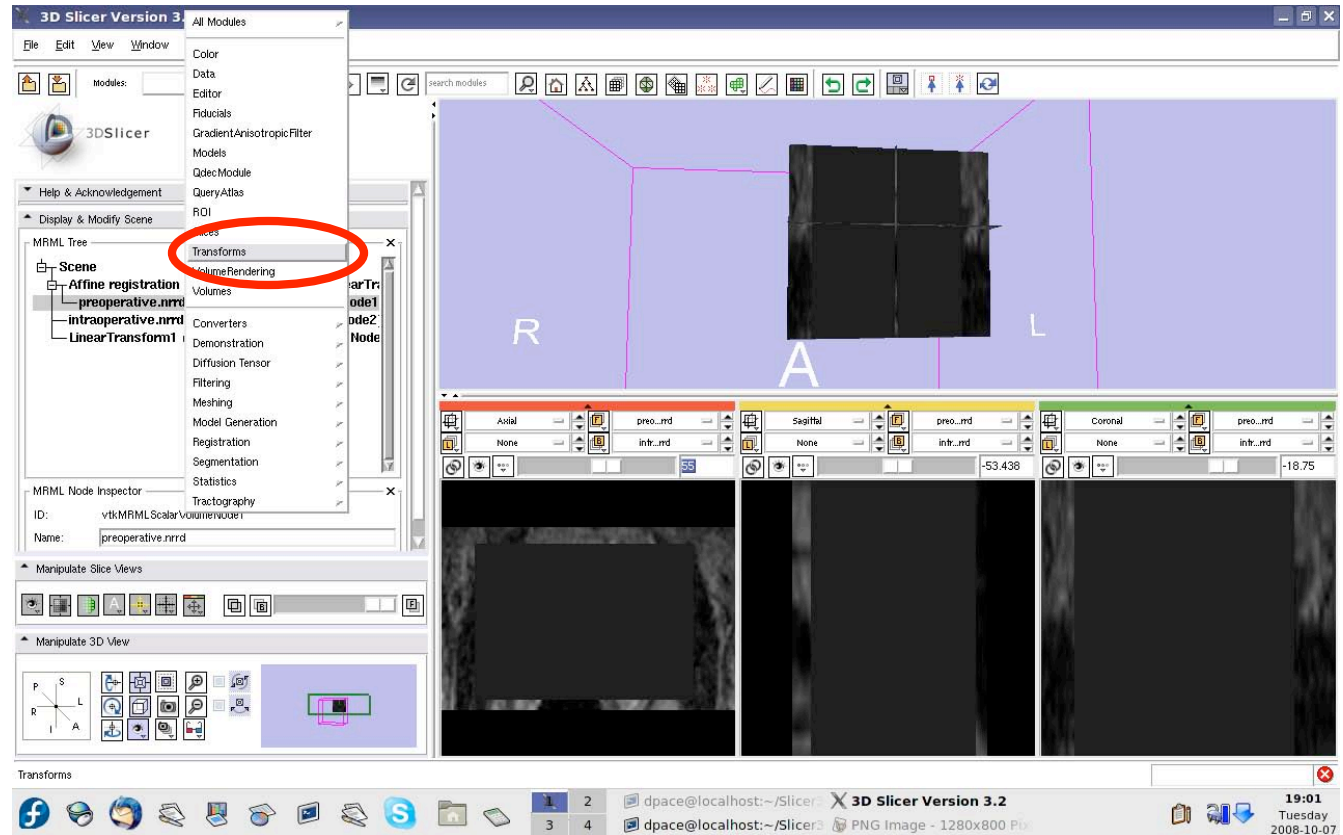**Drag the pre-operative image under the Affine registration Transform1 node**

Affine registration

In order to evaluate the affine registration, the transform must be inverted back
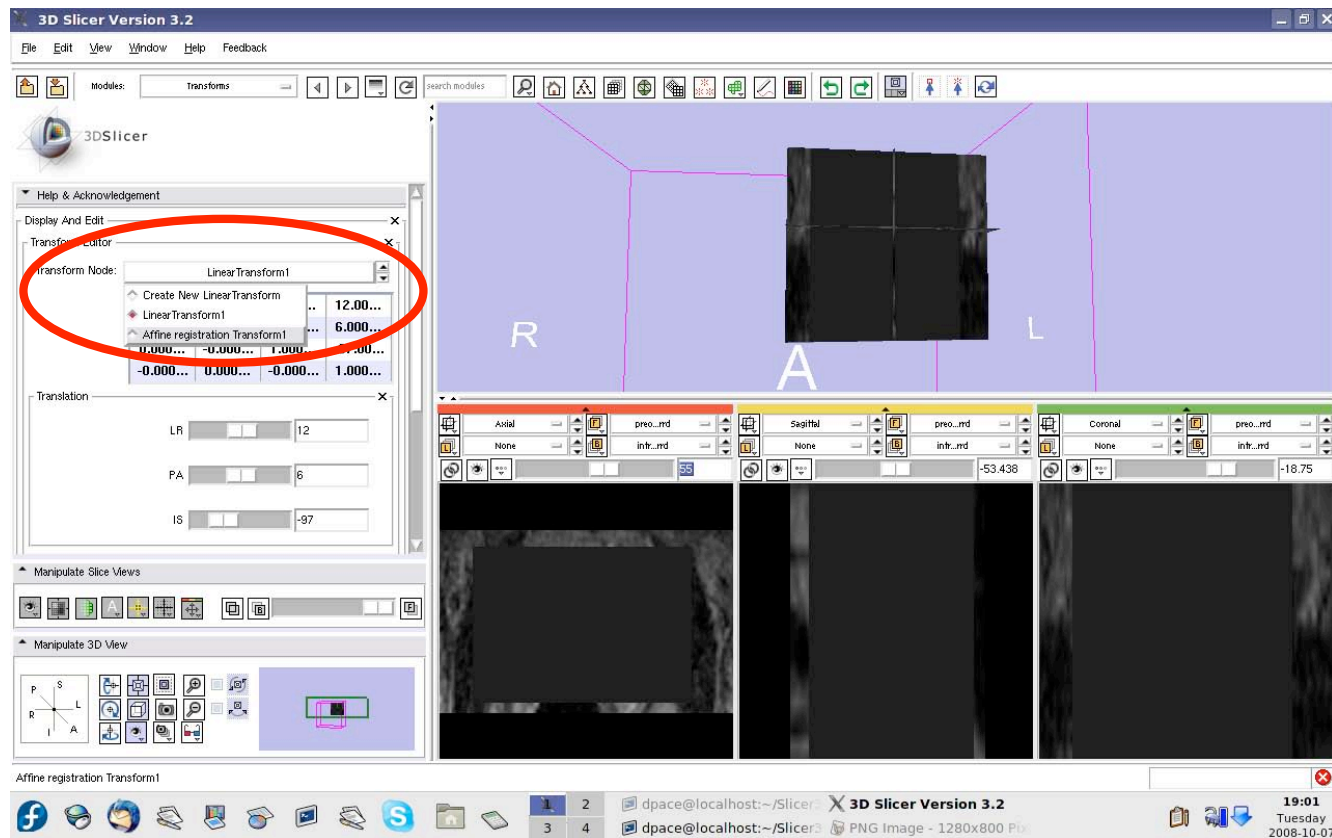
Open the Transforms module

Affine registration

Change the transform node to the affine registration transform

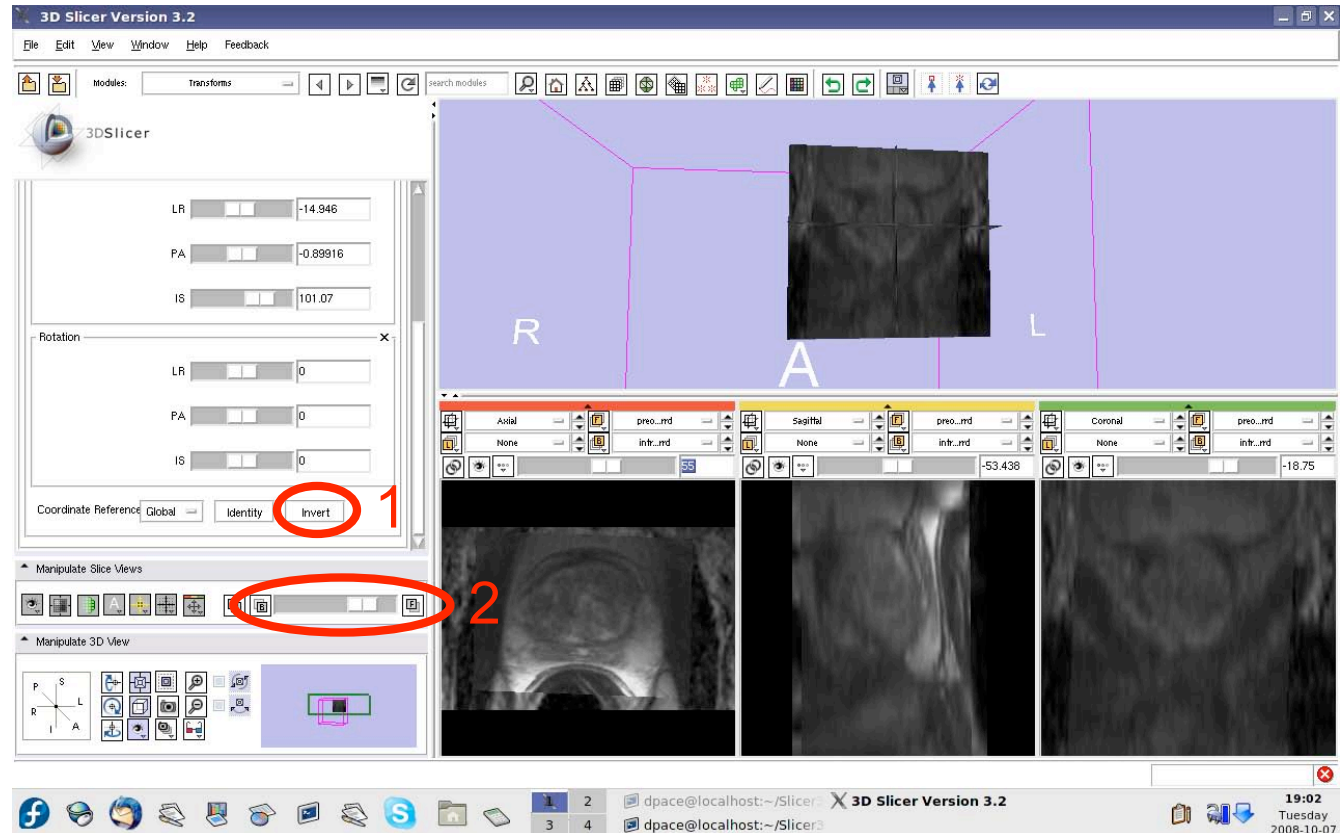Note that the affine transform is different from the rigid transform that we manually specified

Click on the "Invert" button

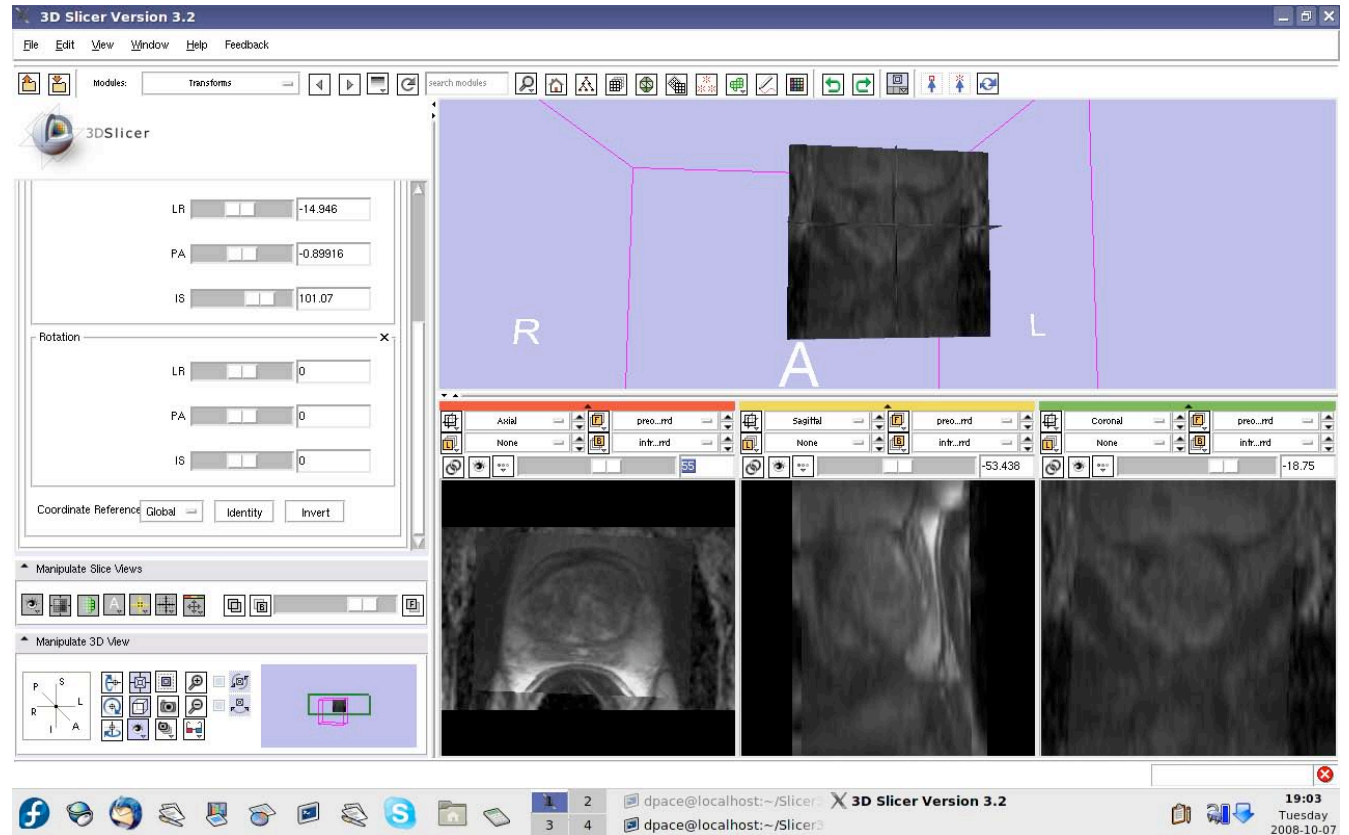**Scale between the foreground and background to evaluate the alignment**

Affine registration

Now that we've evaluated the affine transform, it must be inverted before it can be used to initialize the deformable B-spline registration
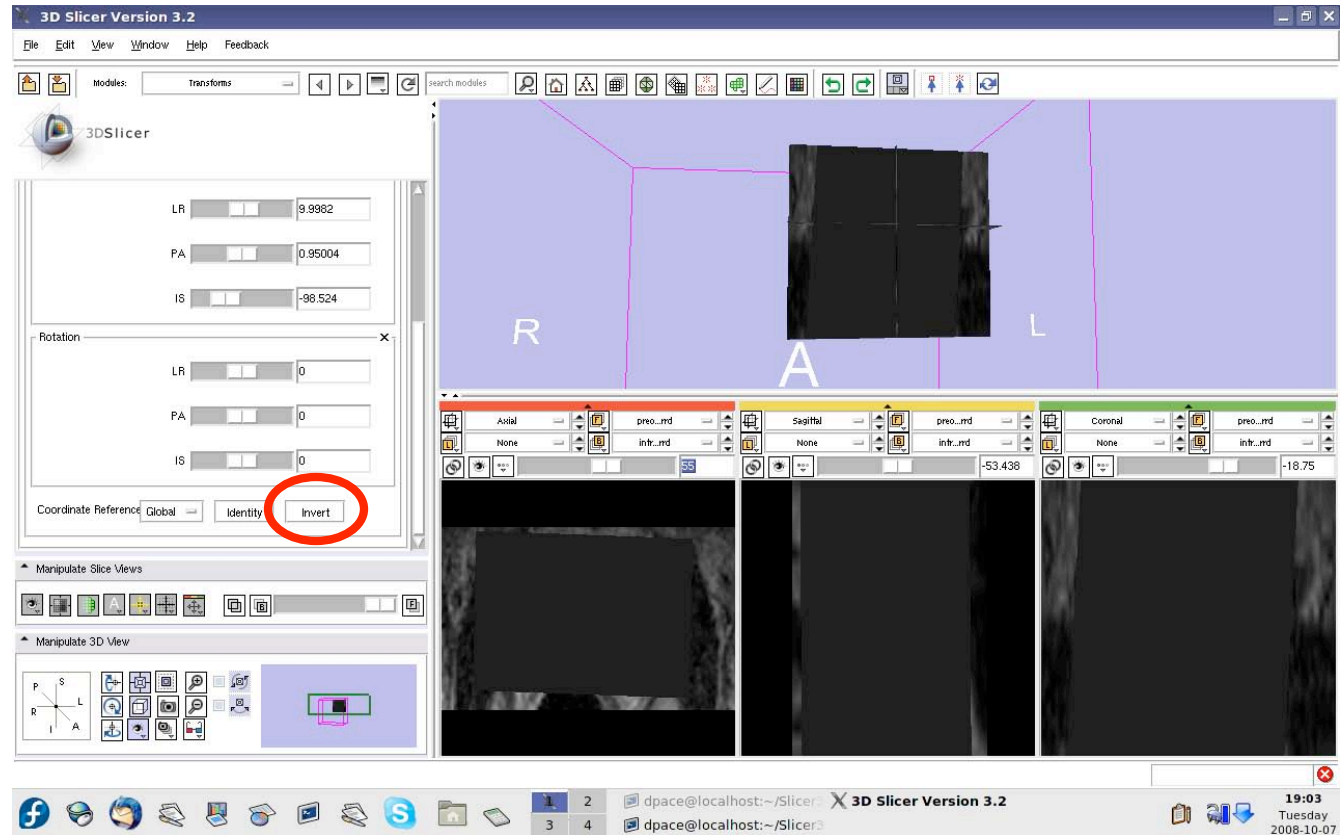
Affine registration

Click on the "Invert" button

We are back to the original transform given by the affine registration: note that once again, the images are not aligned

Registration Steps
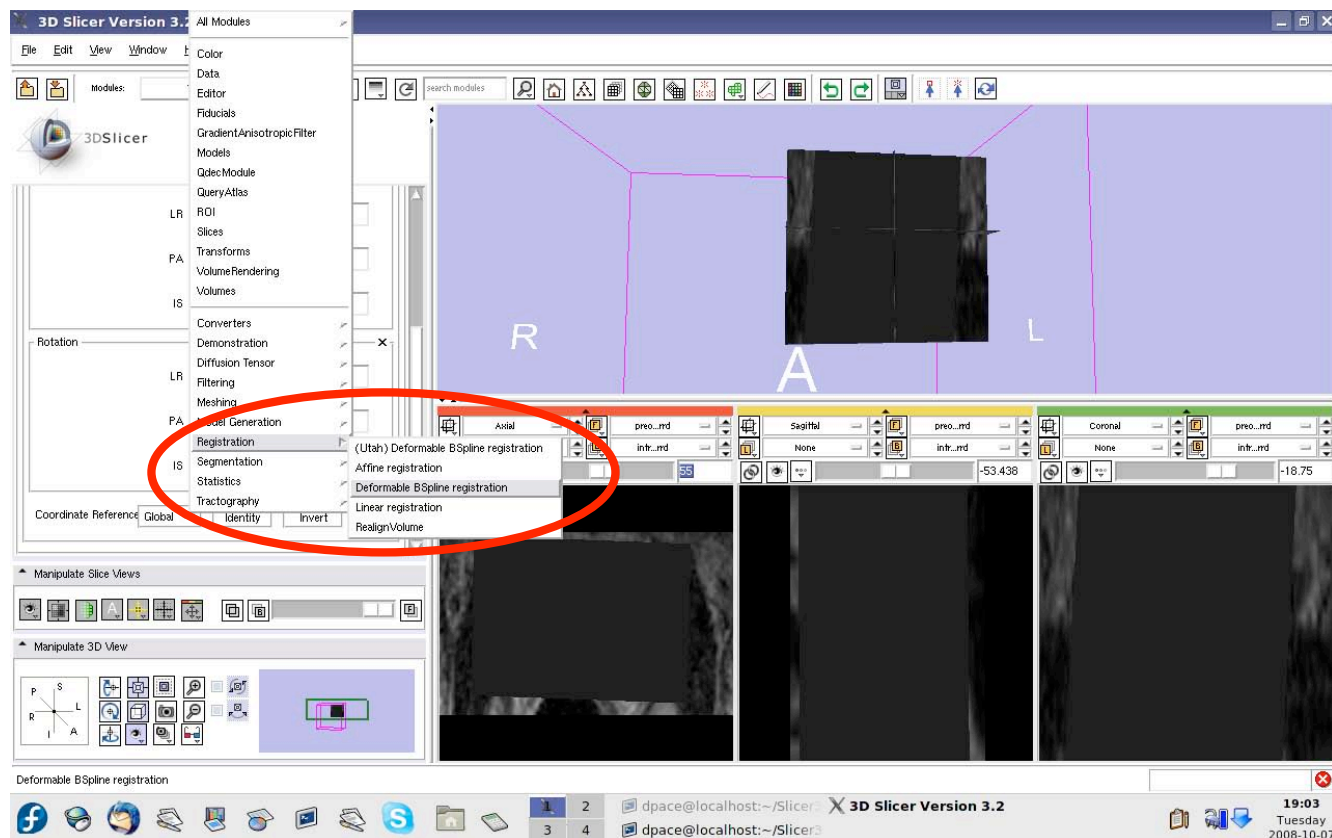
- Load the image volumes

- Initial manual rigid transformation

  Initializes transform

- Automatic affine registration

  Initializes transform

- Automatic deformable B-spline registration

Deformable B-spline registration

Perform the deformable B-spline registration
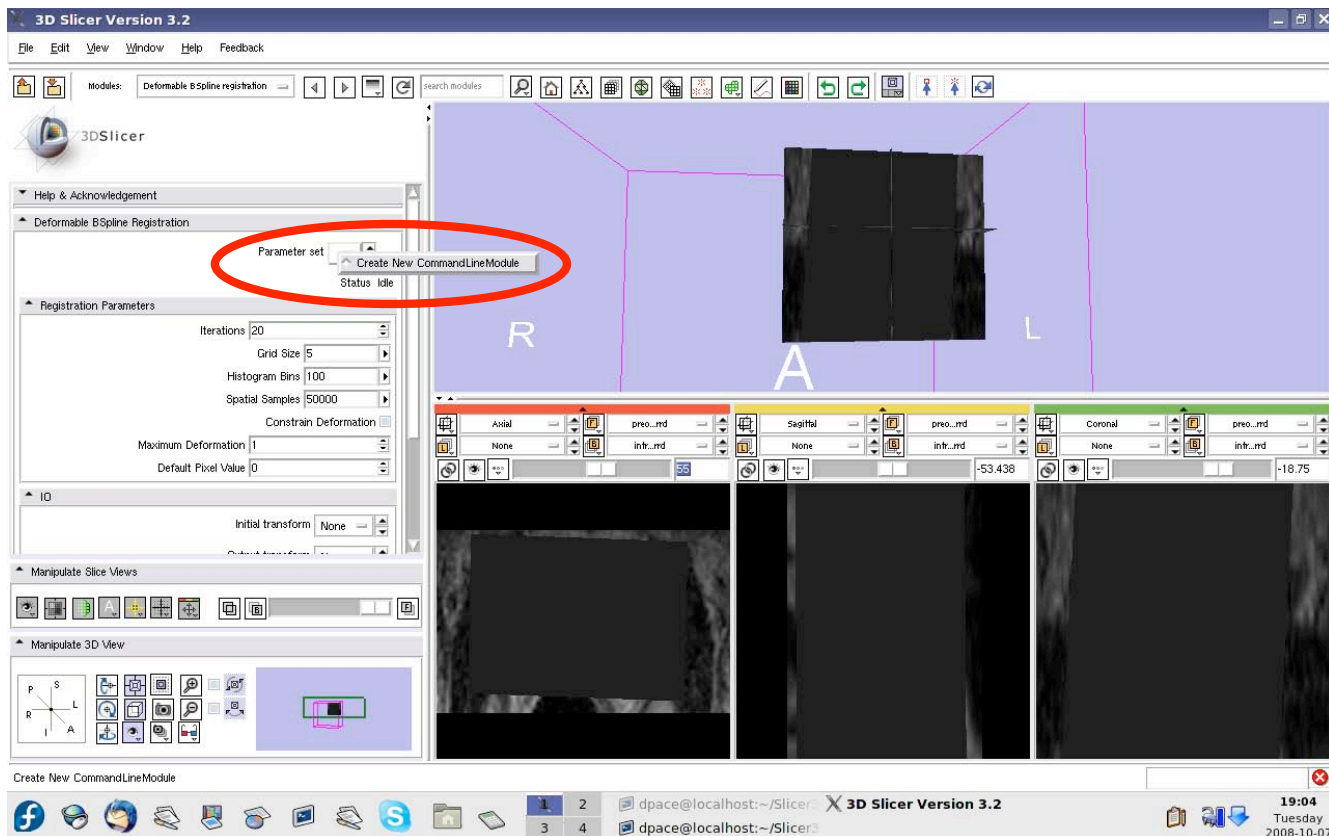
Open the Deformable Bspline Registration module

Deformable B-spline registration

Create a new deformable B-spline registration transform

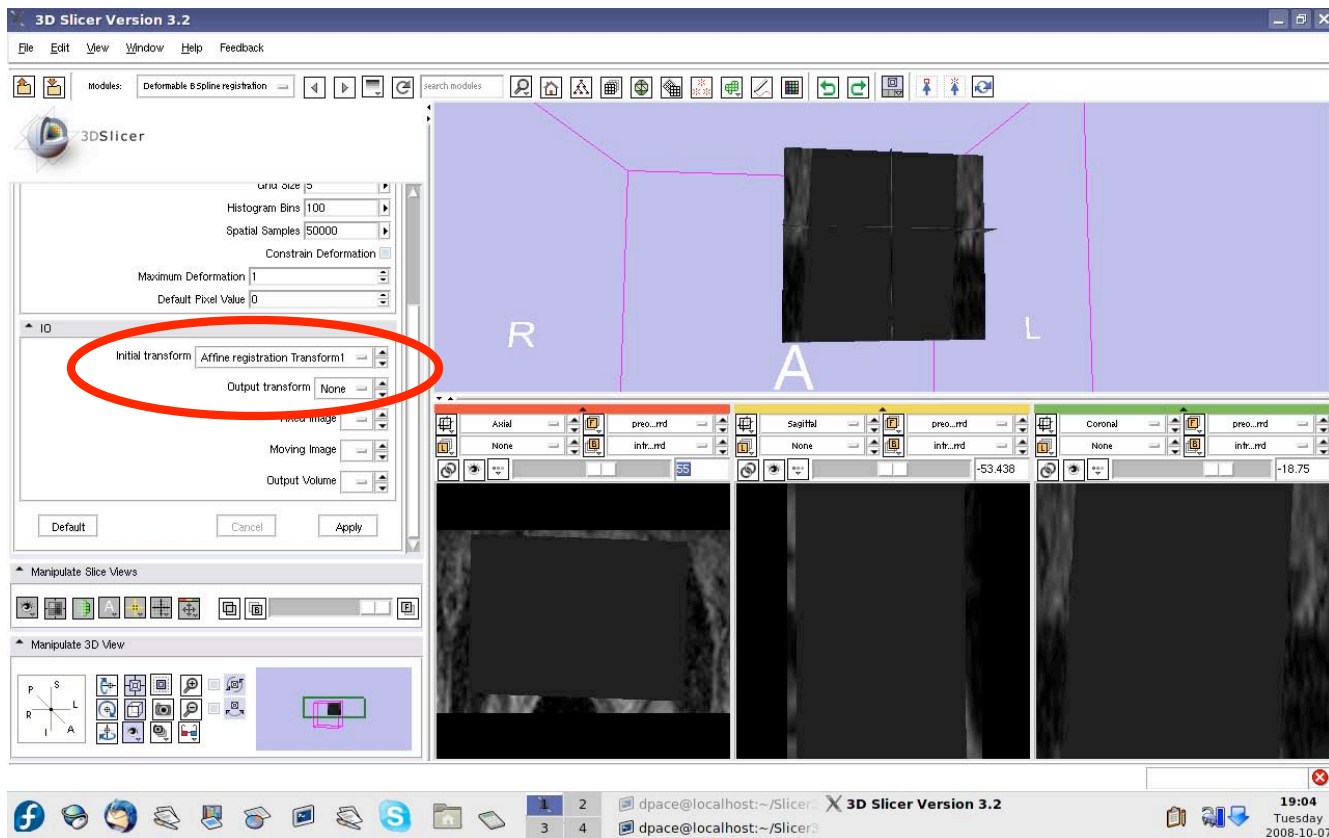You do not need to change any of the registration parameters

Deformable B‑spline registration

Initial transform:
Affine Registration Transform1
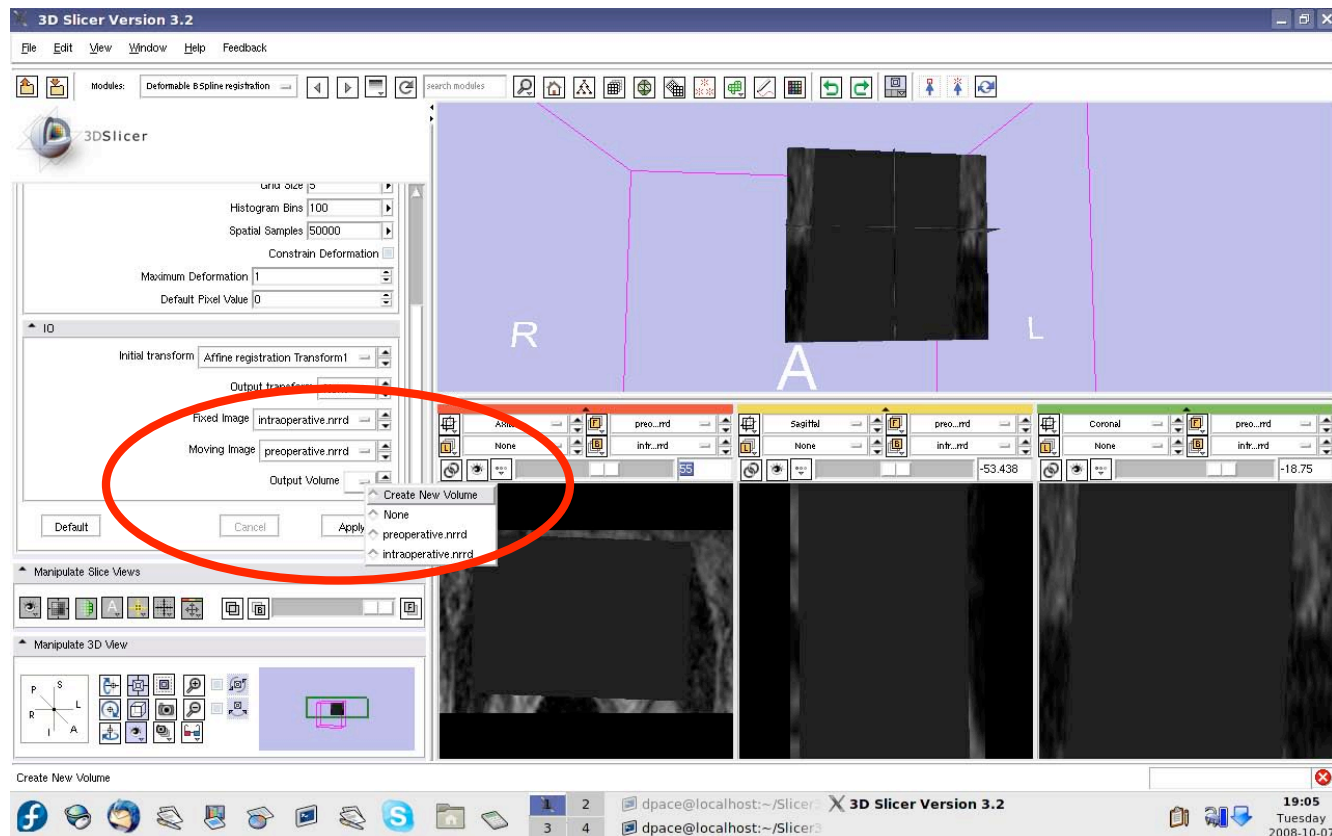
Output transform:
None

Deformable B-spline registration

Fixed image:
intra-operative

Moving image:
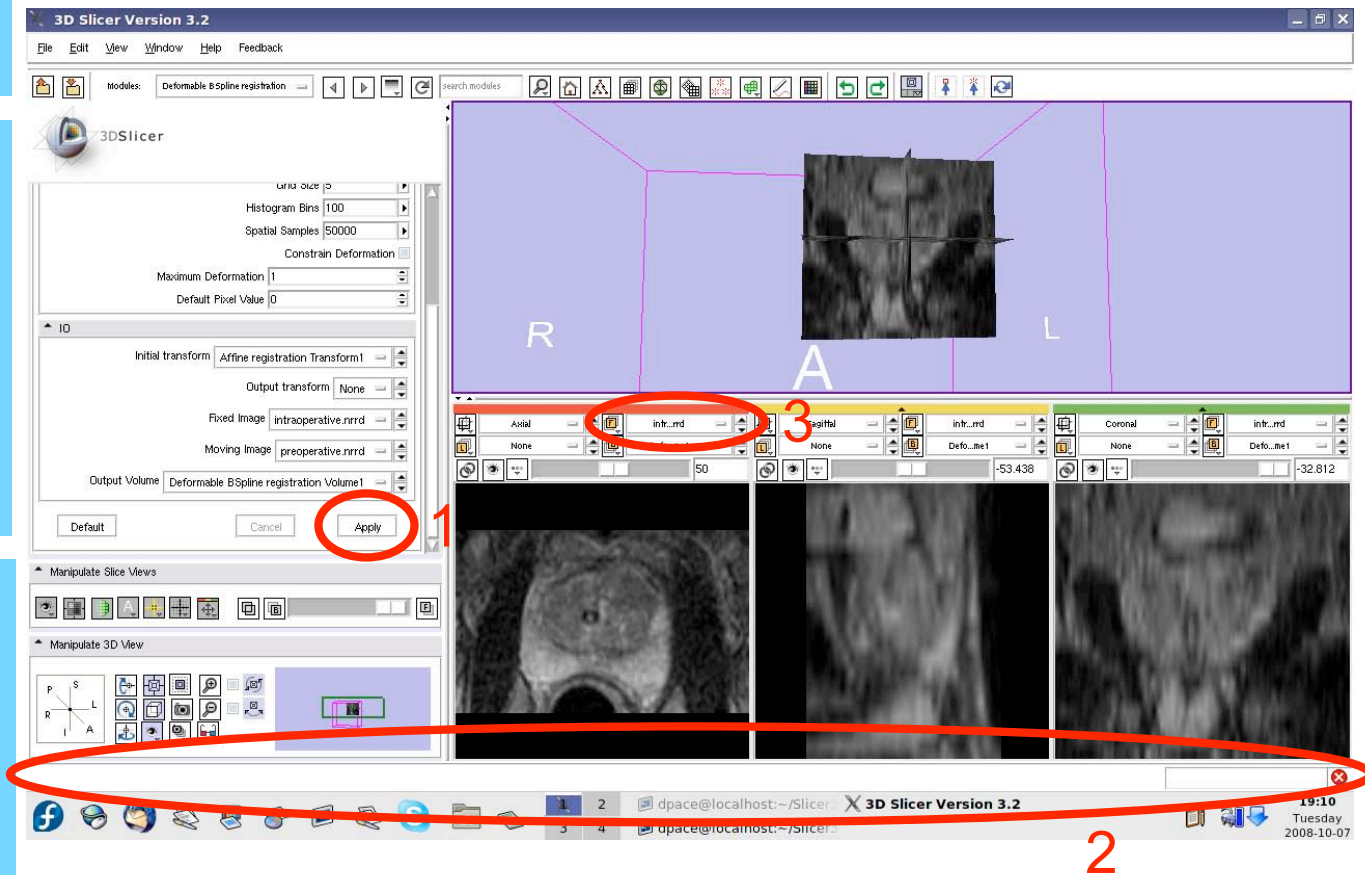pre-operative

Output Volume:
Create new volume

Deformable B-spline registration

Click "Apply"

View the progress bar and wait until it says "Completed"

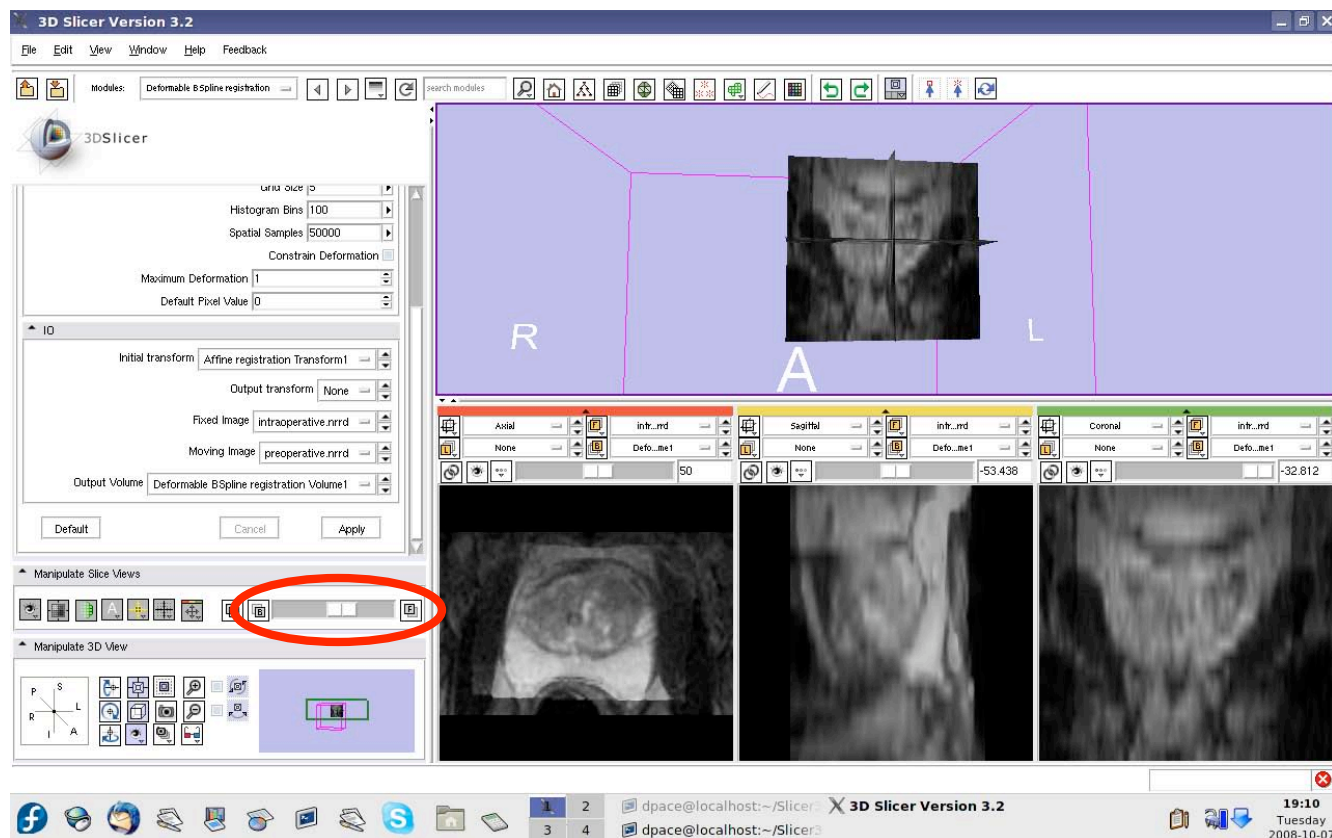Set the foreground to the intra- operative image

Deformable B-spline registration

Evaluate the deformable B-spline registration

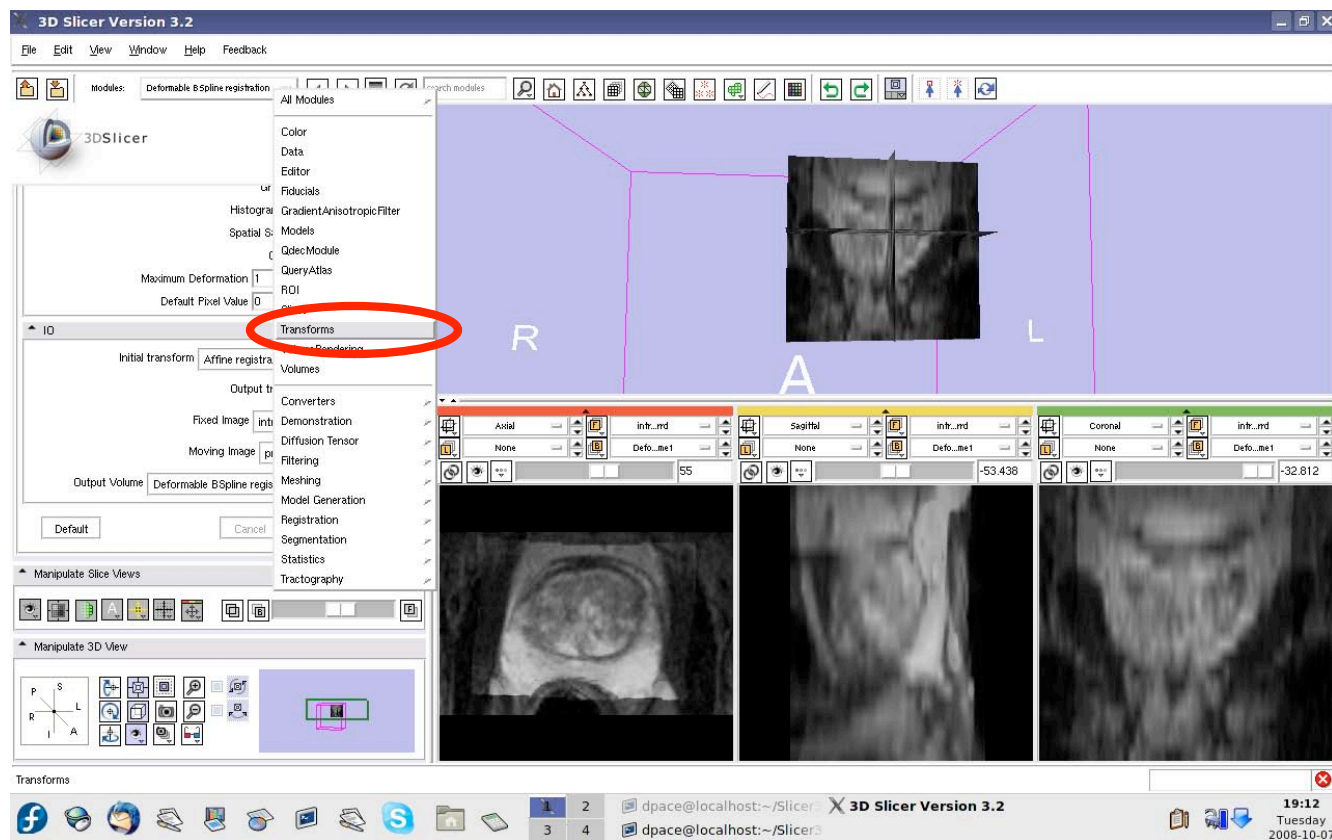Scale between the foreground and background to evaluate the alignment

Deformable B-spline registration

Compare the deformable B-spline registration results to the affine results

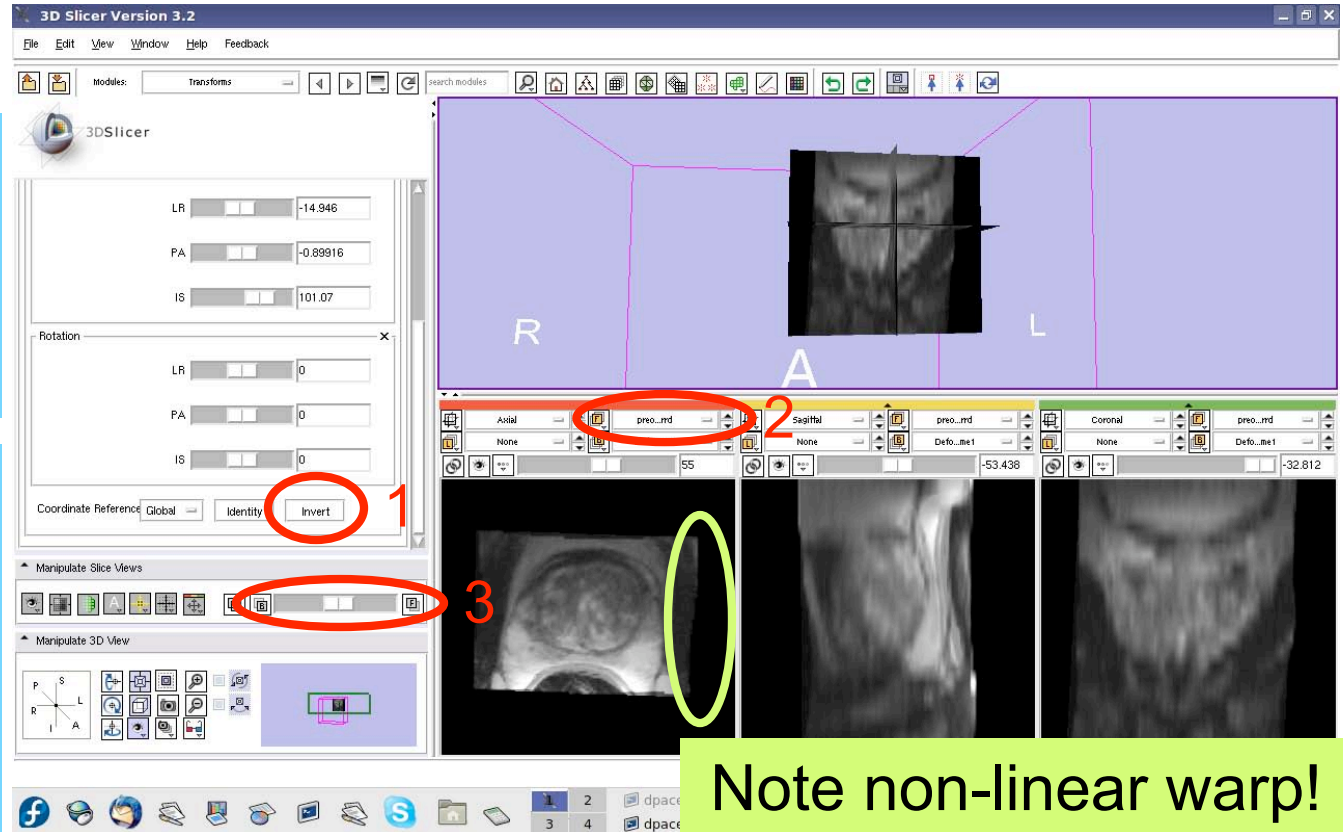The affine transform must be inverted back

Open the Transforms module

Deformable B-spline registration

Click on the "Invert" button

Set the foreground to the pre-operative image

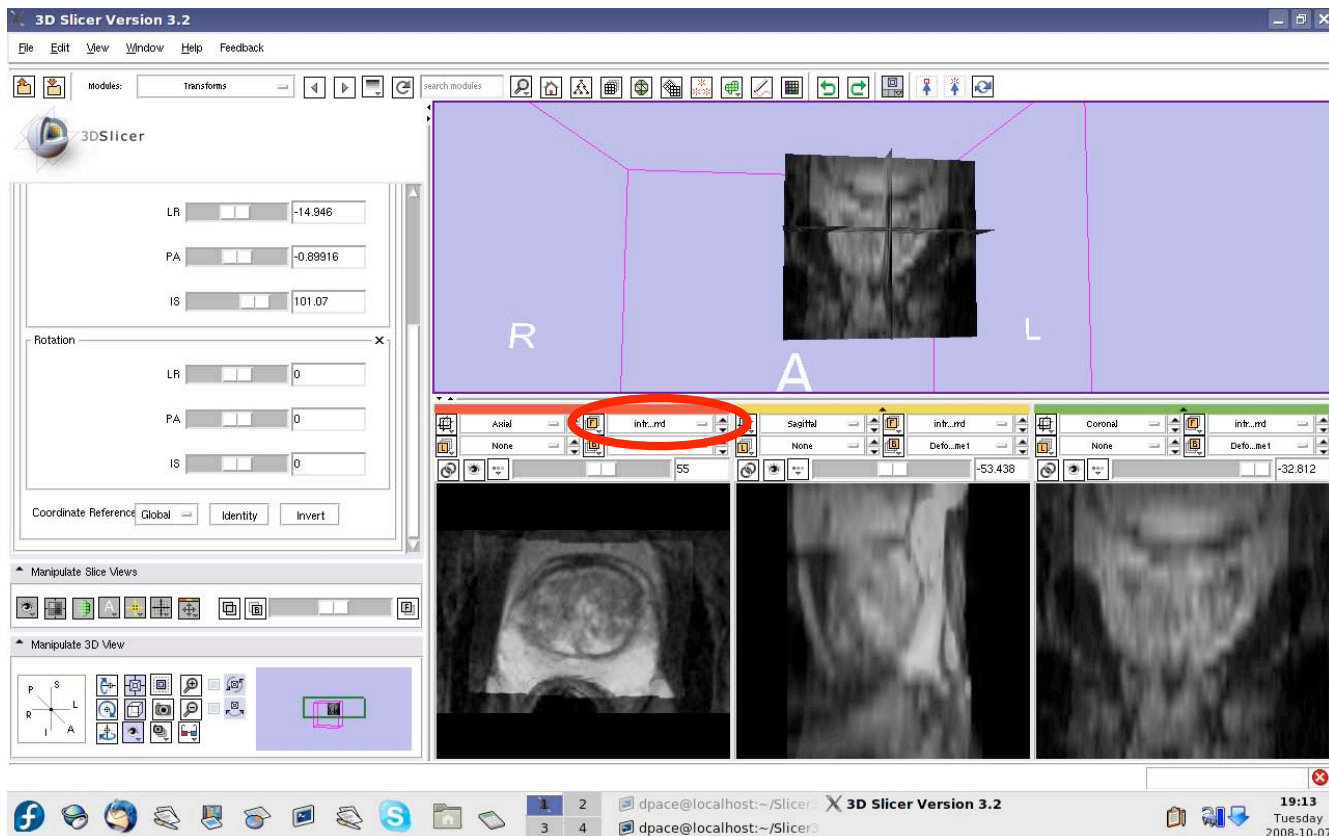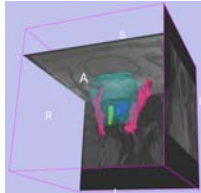Scale between the foreground and background to evaluate the alignment

Note non-linear warp!
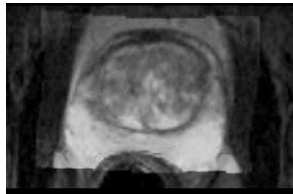
Deformable B-spline registration

Final results:

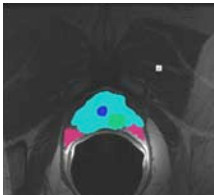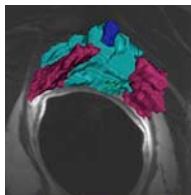Set the foreground back to the intra-operative image

3DSlicer

1. MR-guided prostate interventions: clinical background

2. Registering pre-operative & intra-operative prostate MR images using deformable B-spline registration
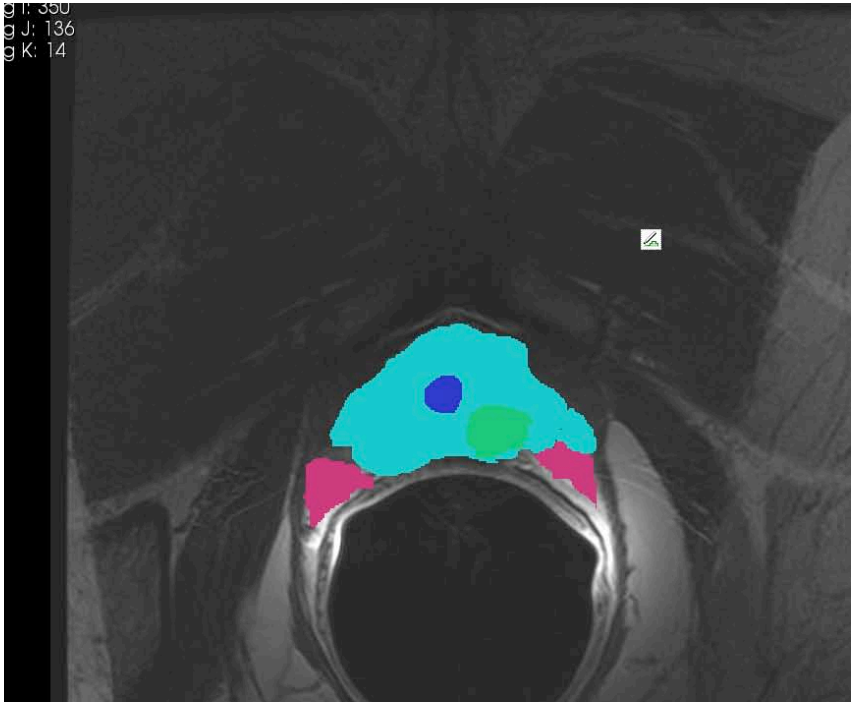

3. Manual segmentation of images

4. Creating 3D models from segmentations

Manual segmentation is the process of delineating the anatomical structures within an image

Manual Segmentation - Prostate
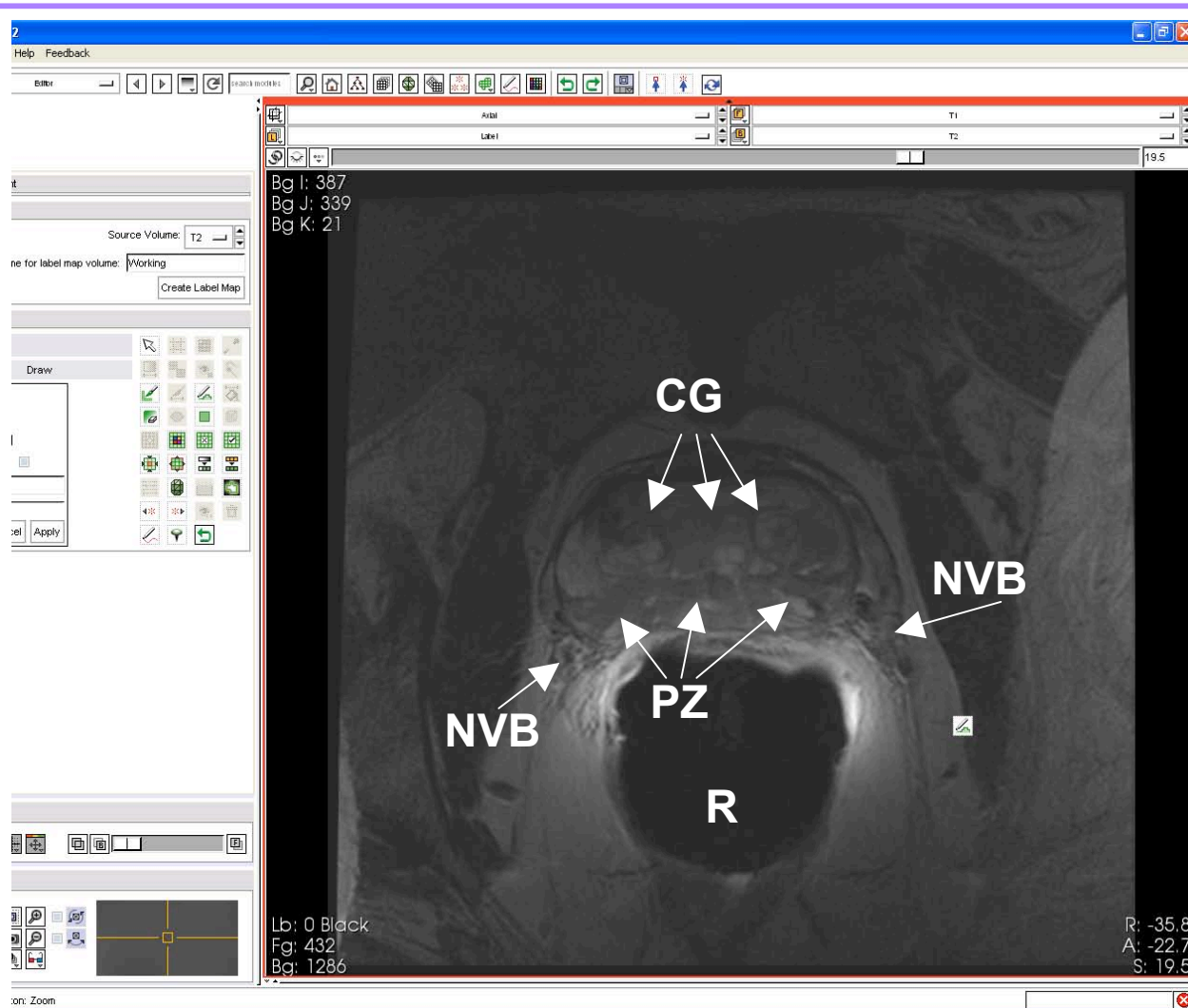
3DSlicer

Prostate MR dataset

T2-weighted axial image at 3.0 Tesla

Central gland, peripheral zone, neurovascular bundles and rectum shown

Prostate MR dataset
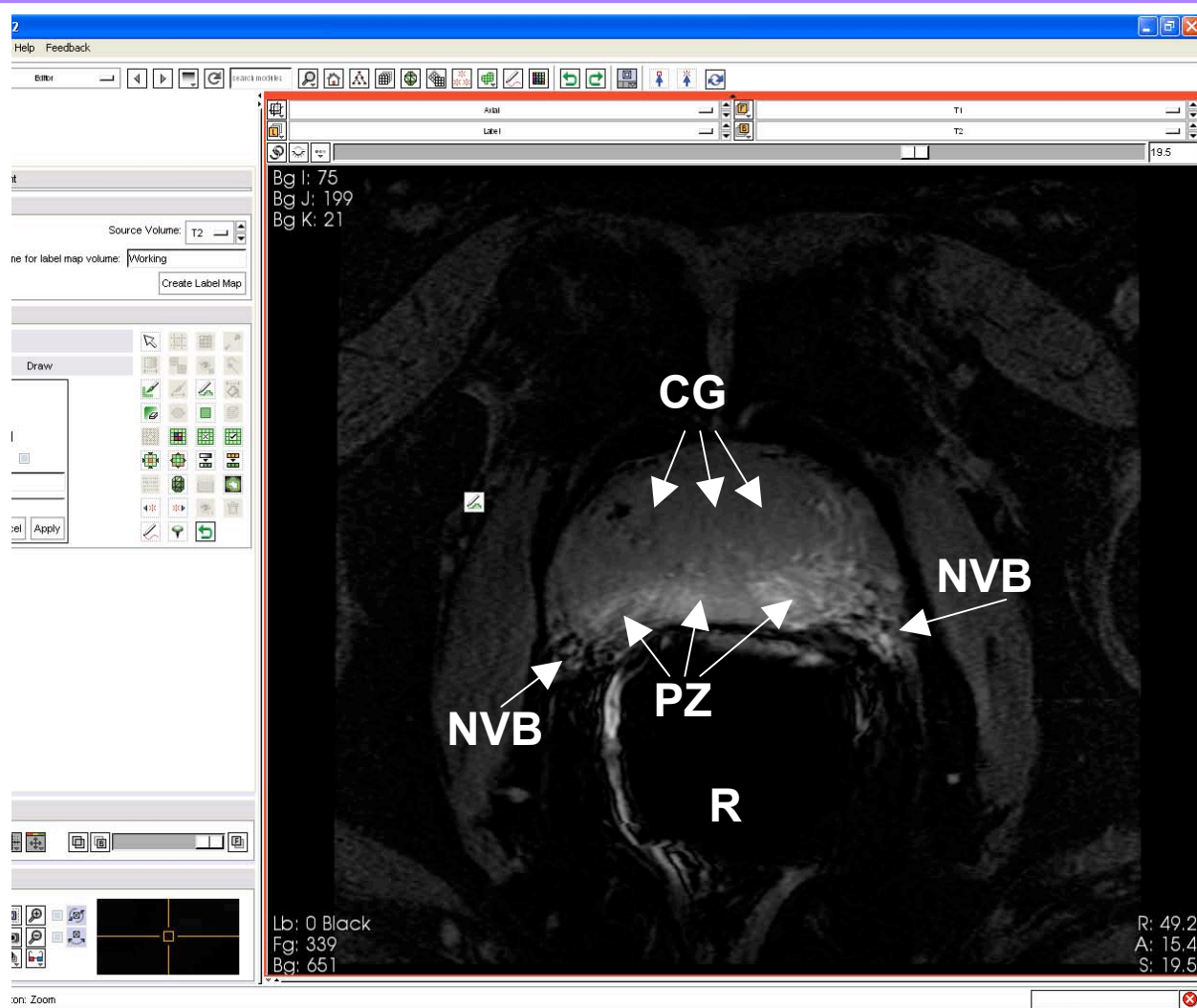
T1-weighted axial image at 3.0 Tesla

The T1 image can be used to complement T2 imaging visualization
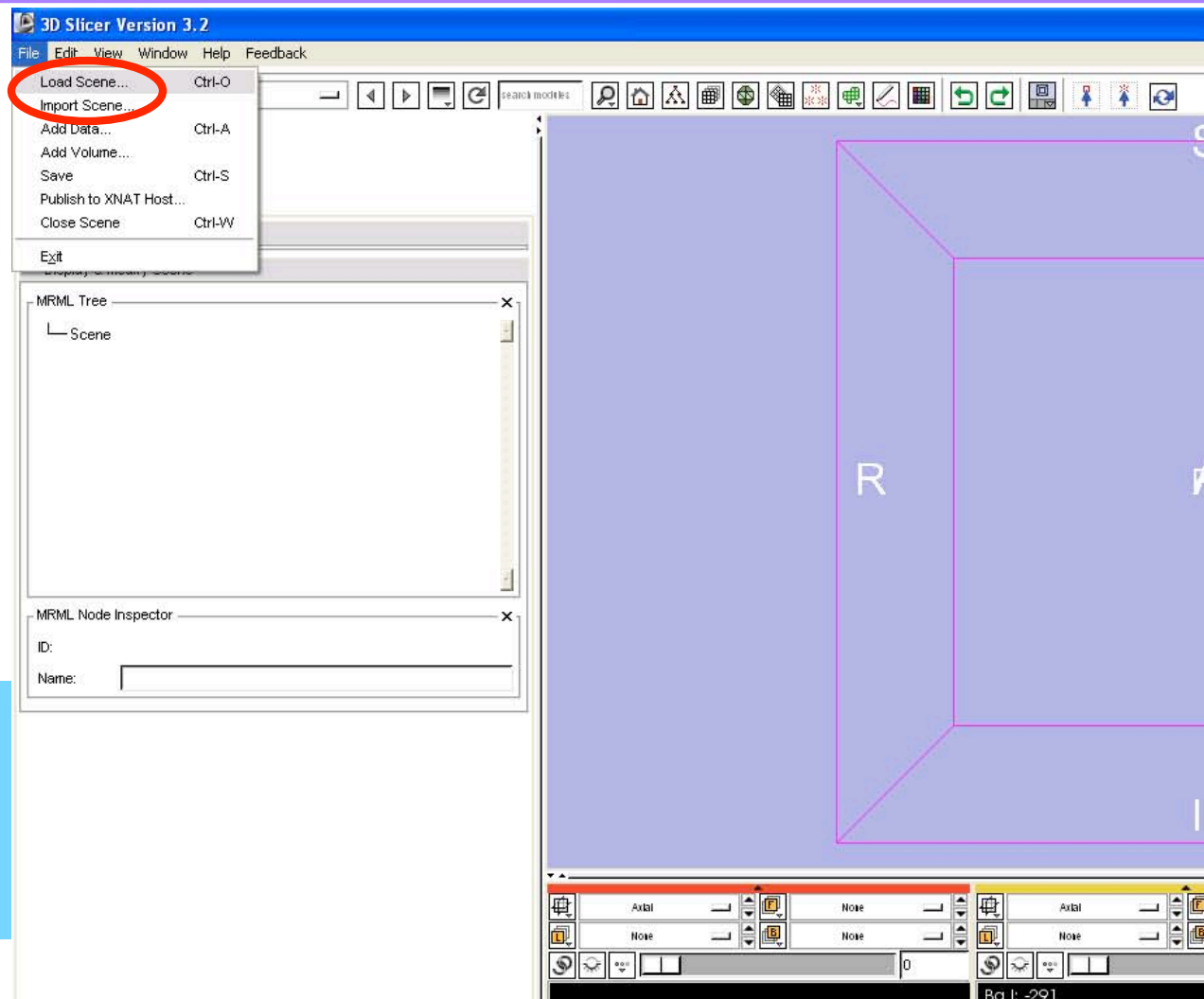
3DSlicer

Load the data

Sample segmentation data were previously saved in a scene file

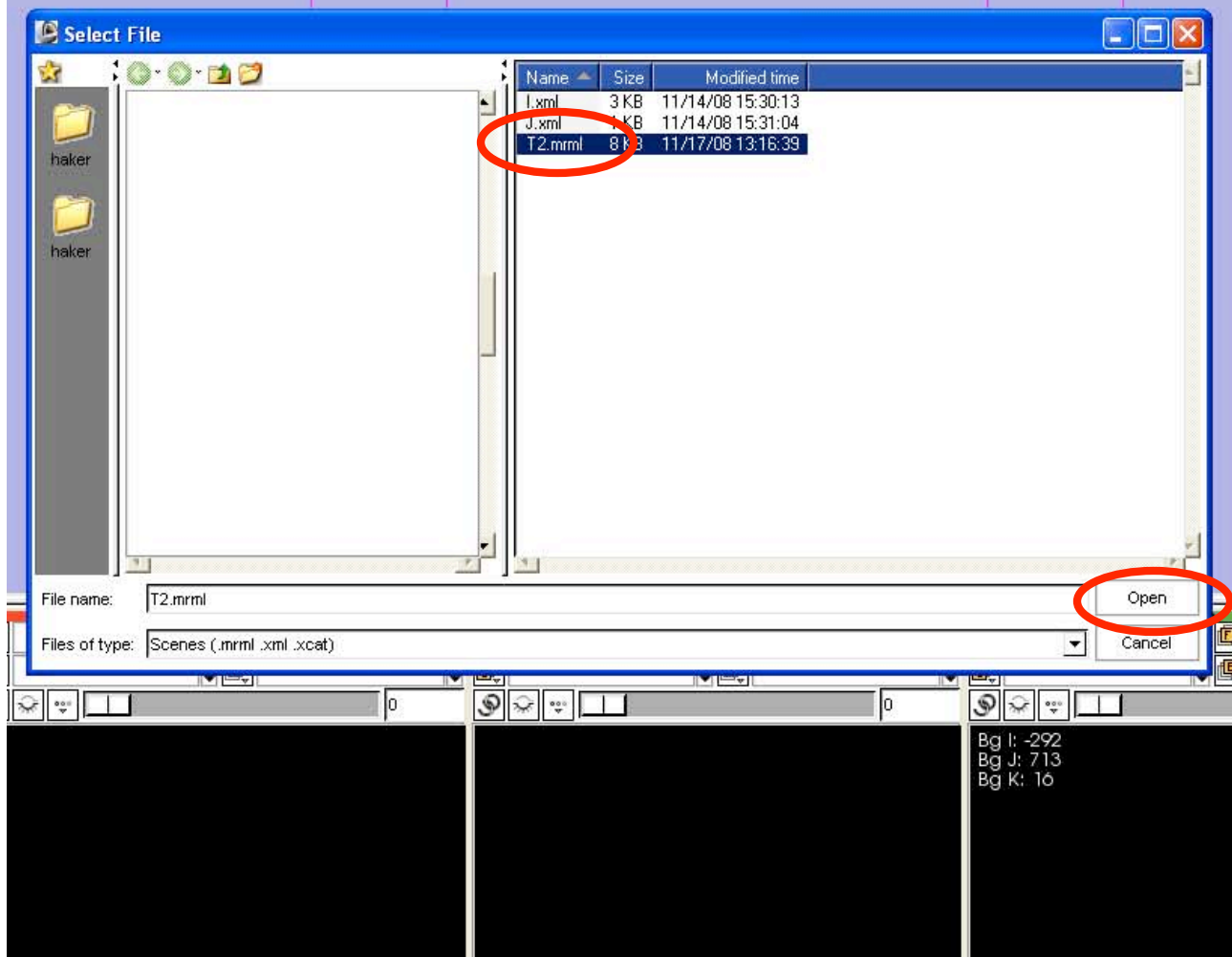Select "Load Scene" from the File menu

Manual Segmentation – Load

Select T2.mrml from the file selection menu and click "Open"

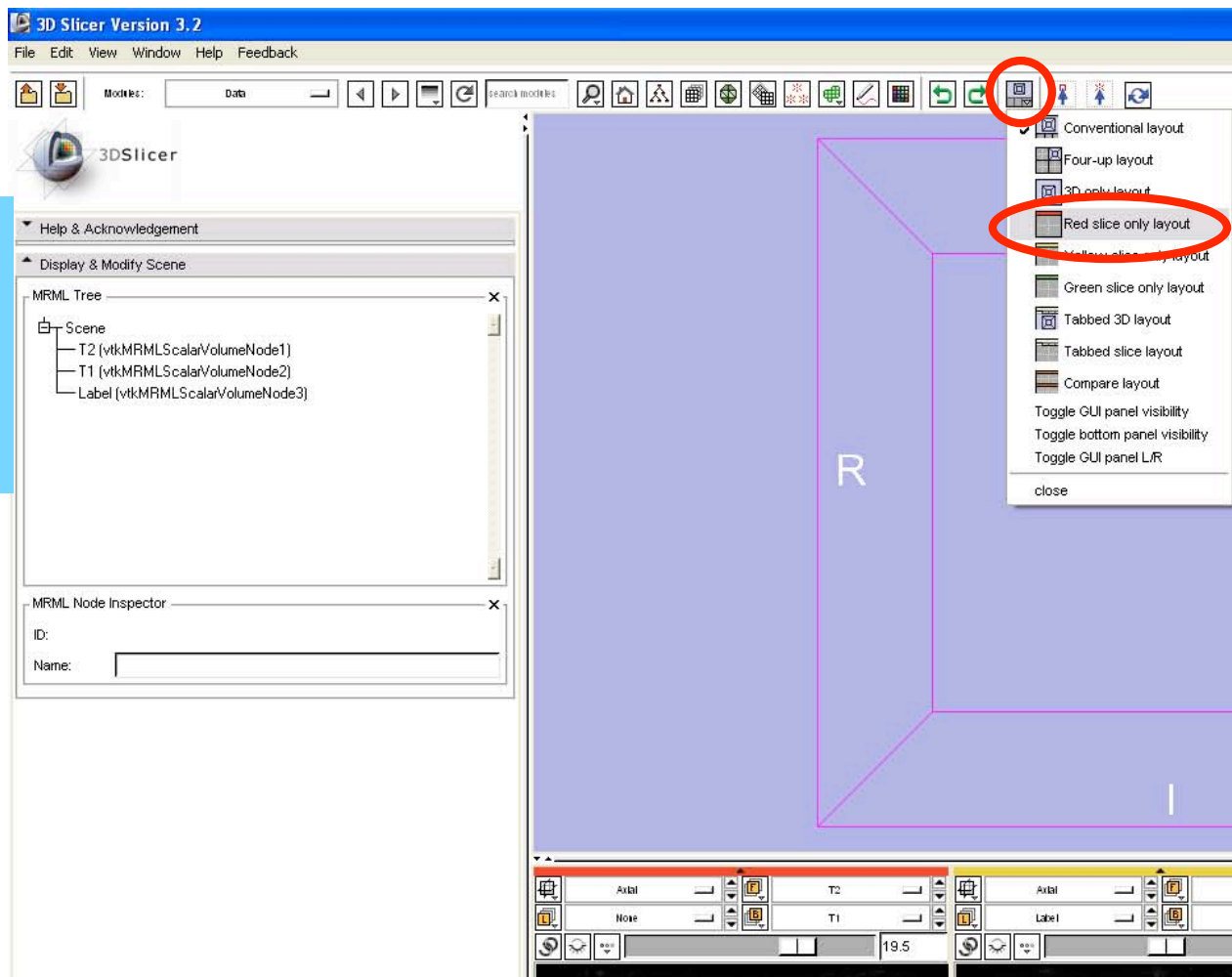This scene contains T2 and T1 MR, plus an example label map

Manual Segmentation – Layout

Select layout

Select the "Red slice only layout"

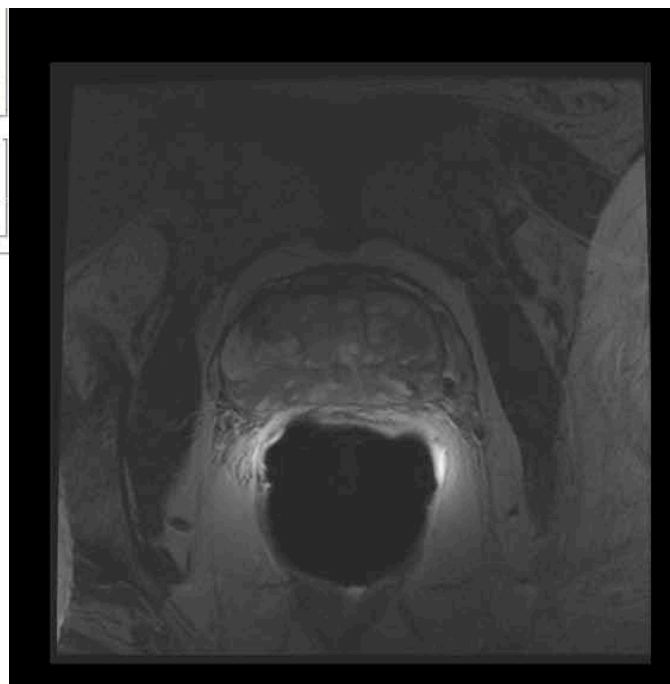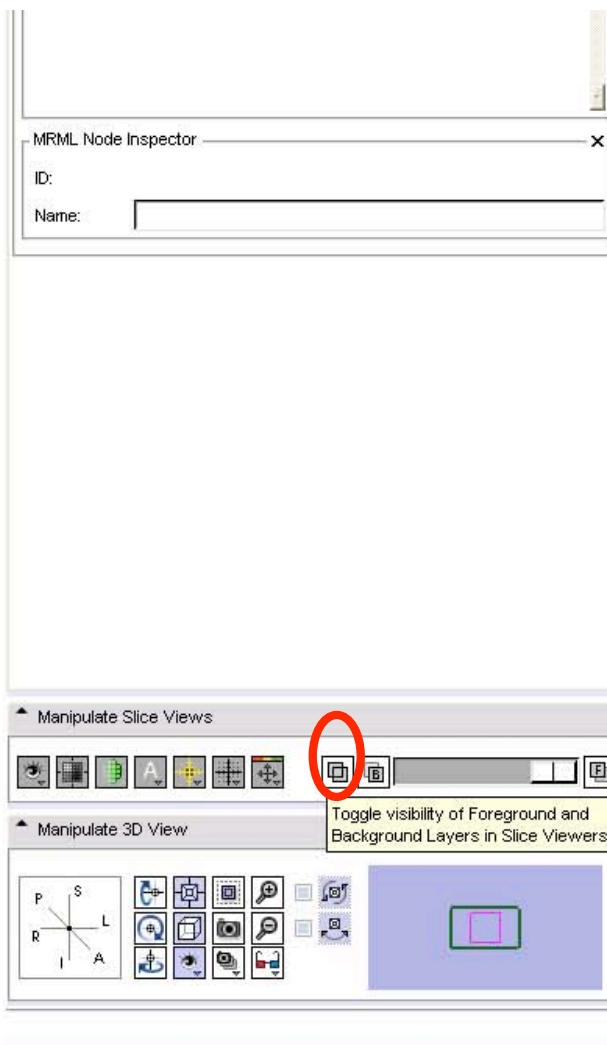This will display axial MR slices for the segmentation

Manual Segmentation – Visibility

Toggle visibility

Toggle visibility to foreground so that the T2-weighted image appears

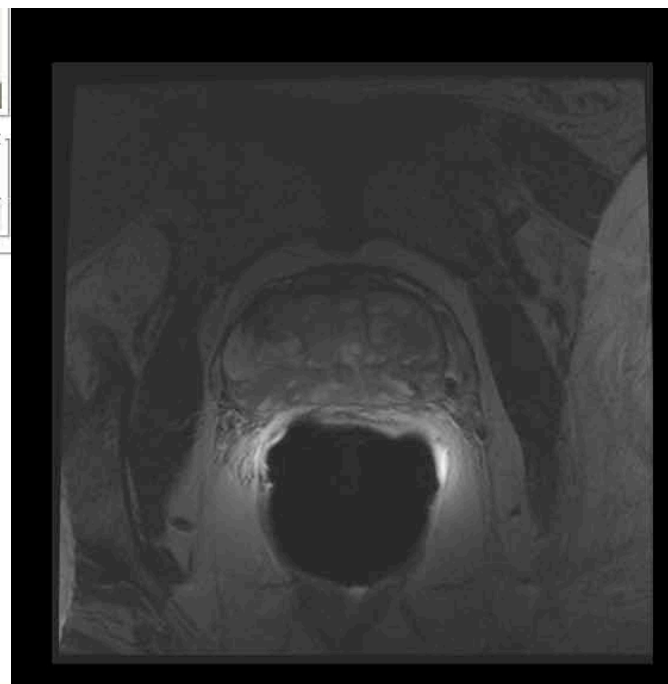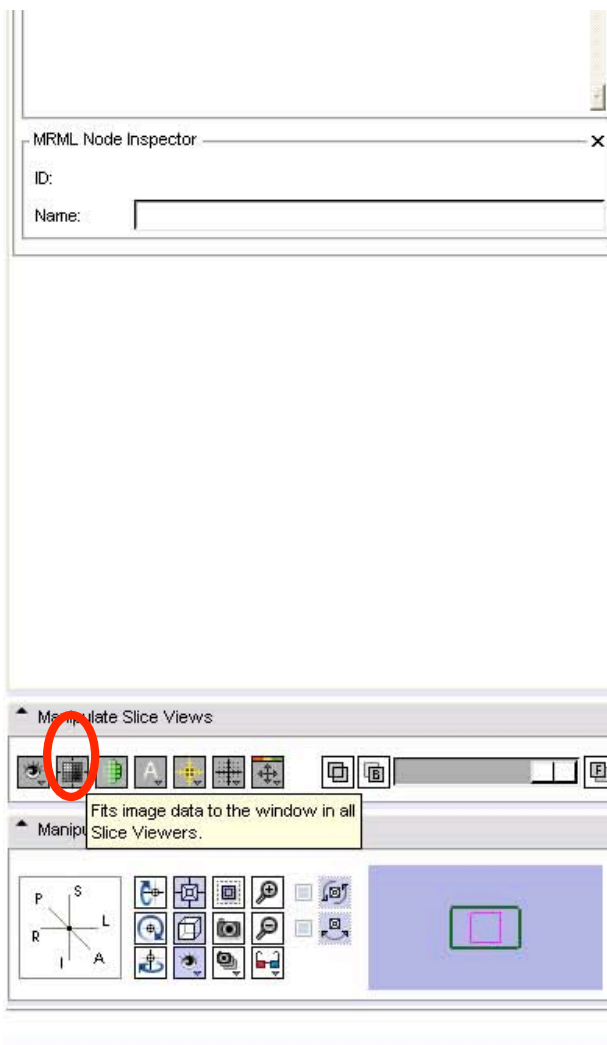The toggle allows for easy visualization of both the T1 and T2 images

Fit visible

The fit visible button zooms the image to fit the window

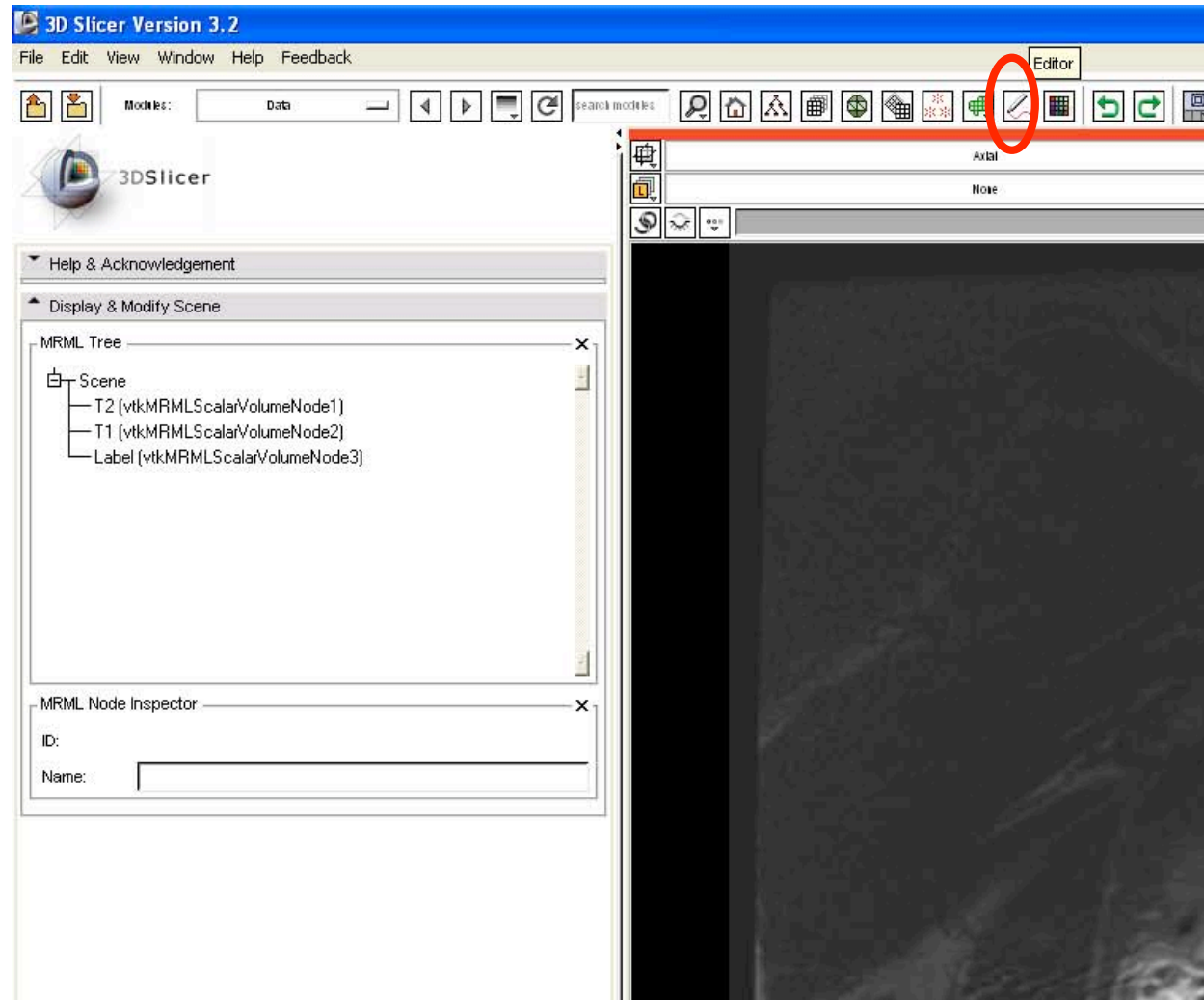This presents the maximum image size to aid in visualization

Manual Segmentation – Editor

Open the Editor module

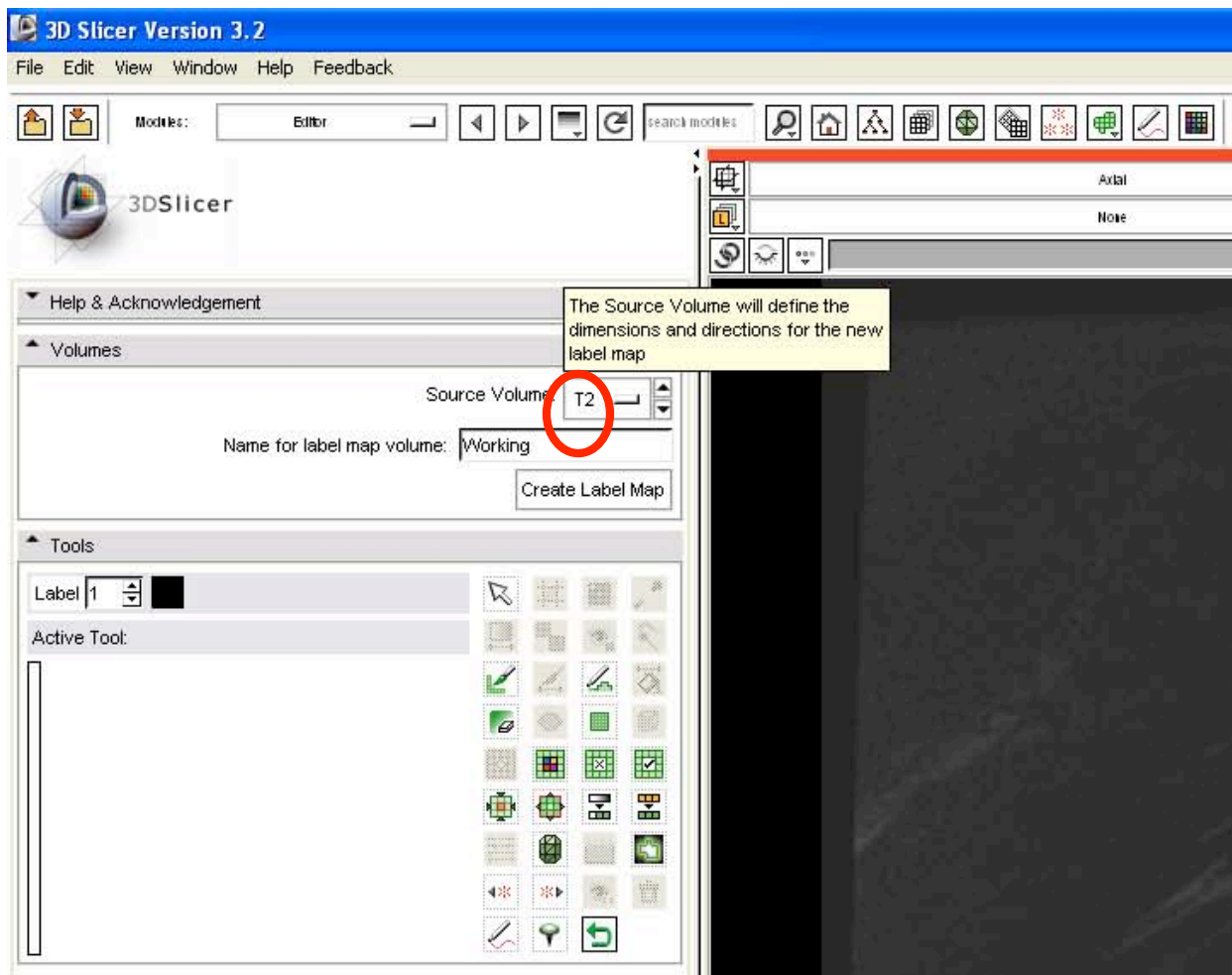The Editor module contains Slicer's drawing tools

Manual Segmentation – Source

Select the source volume

This is the volume you will be drawing on

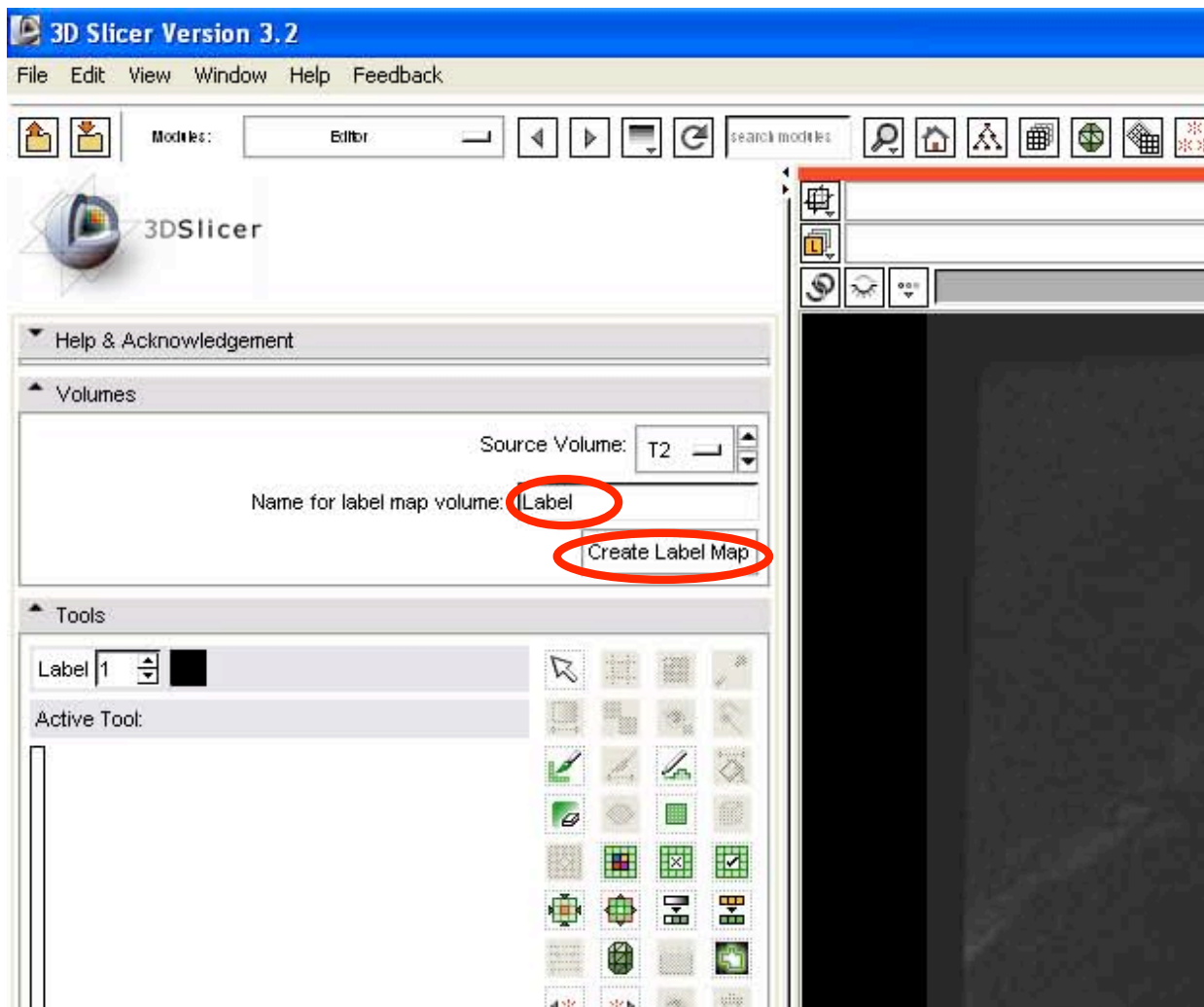Select the T2 volume for this demonstration

Manual Segmentation - Label Map

Enter a label map name

The label map will contain the segmentation results

Enter "Label" as the label map name
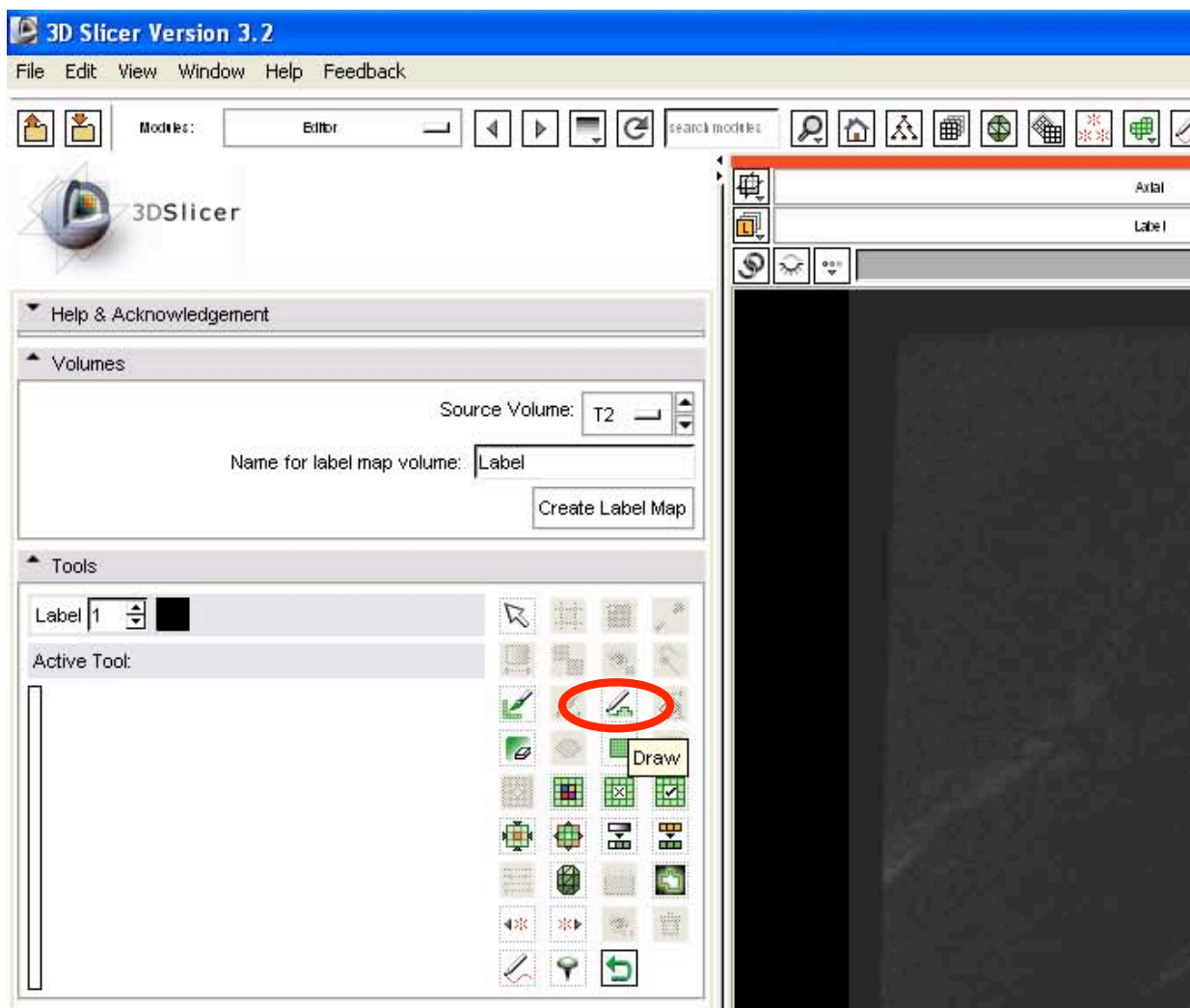
Press "Create Label Map"

Manual Segmentation - Draw

Select the draw tool

Click on the pencil icon

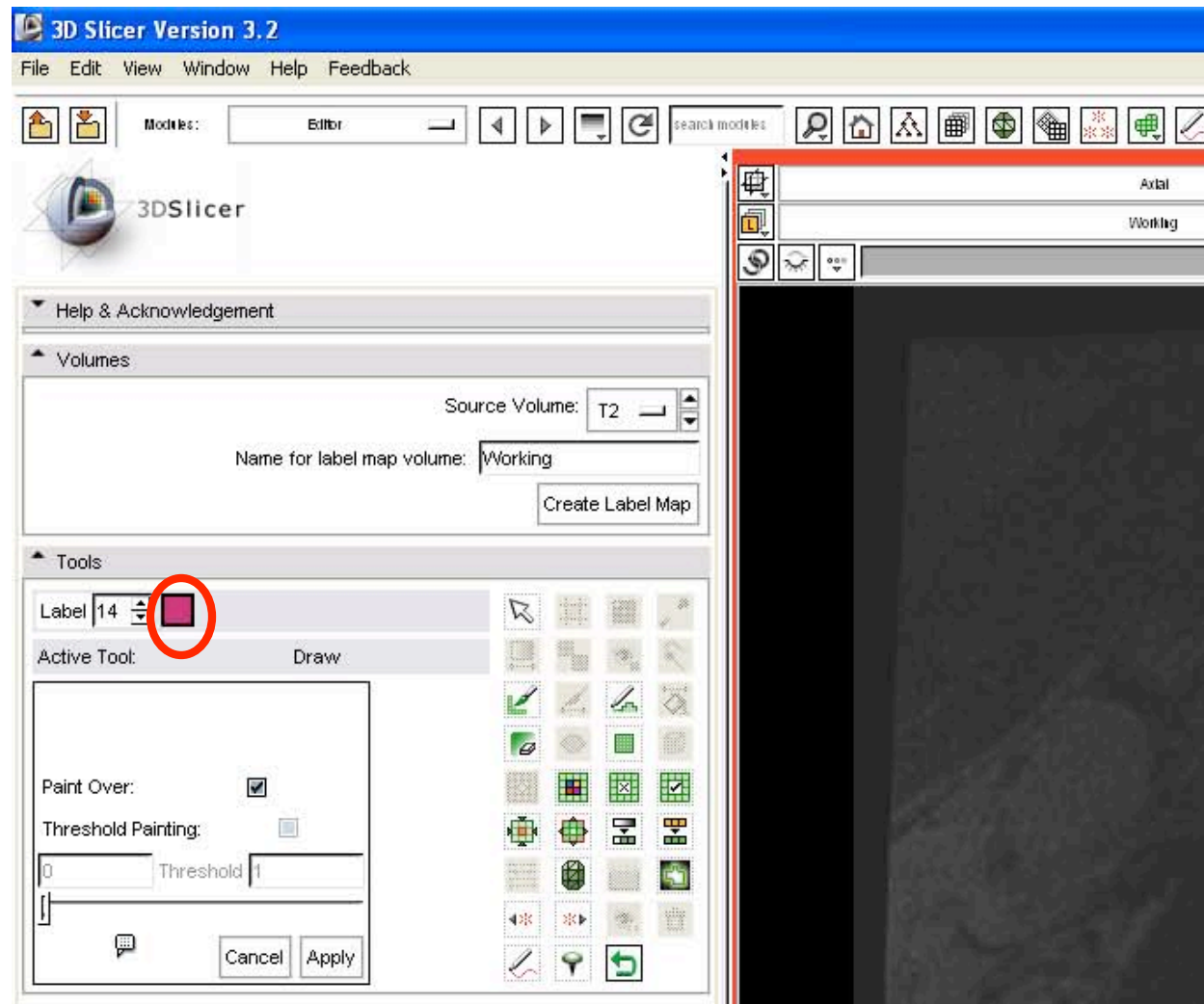The draw tool is used to contour regions of interest

Manual Segmentation - Color

Select color

Click on the color box for the pop-up color selector
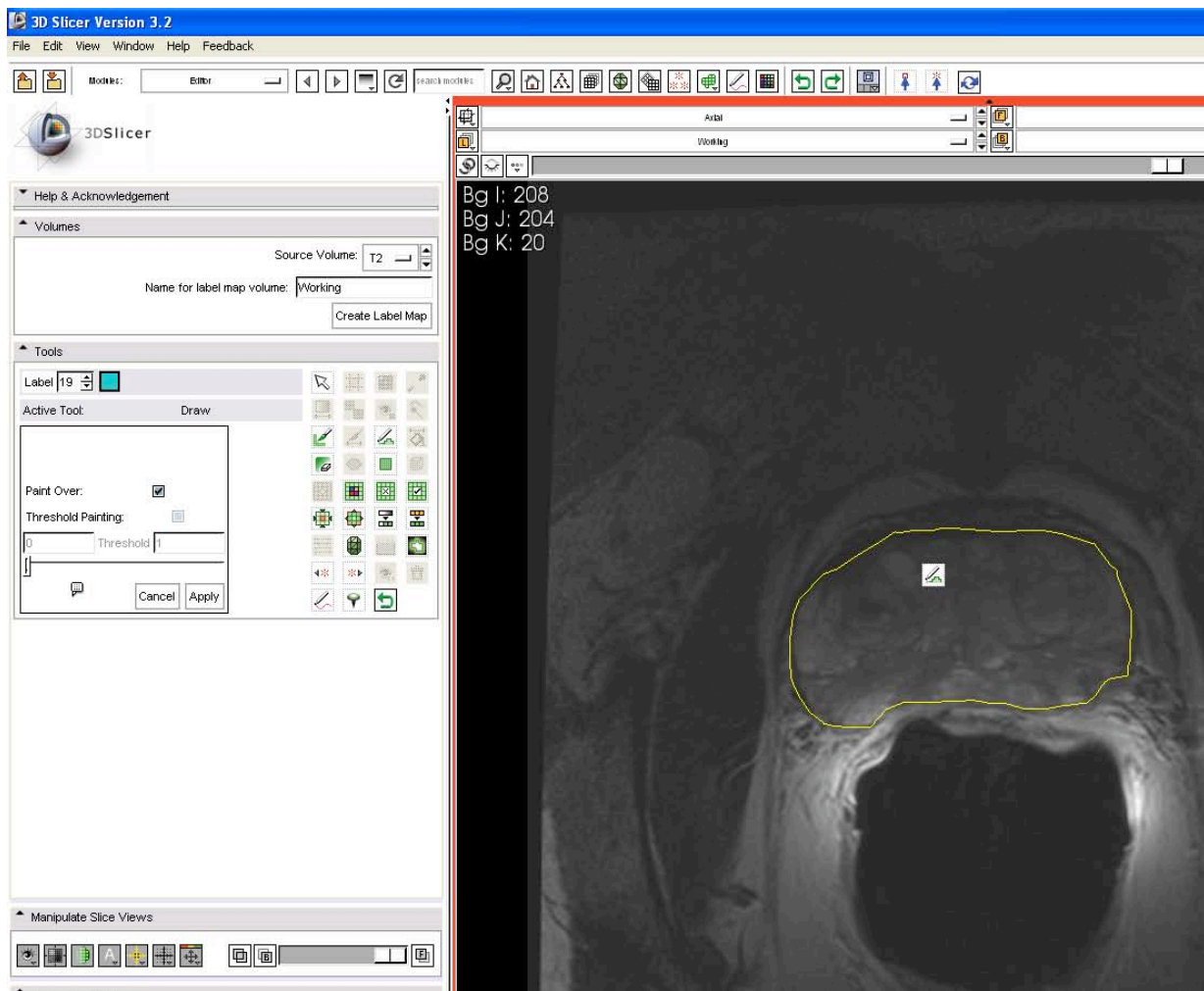
Use a different color for each anatomical region

Draw a closed contour

Contour the prostate

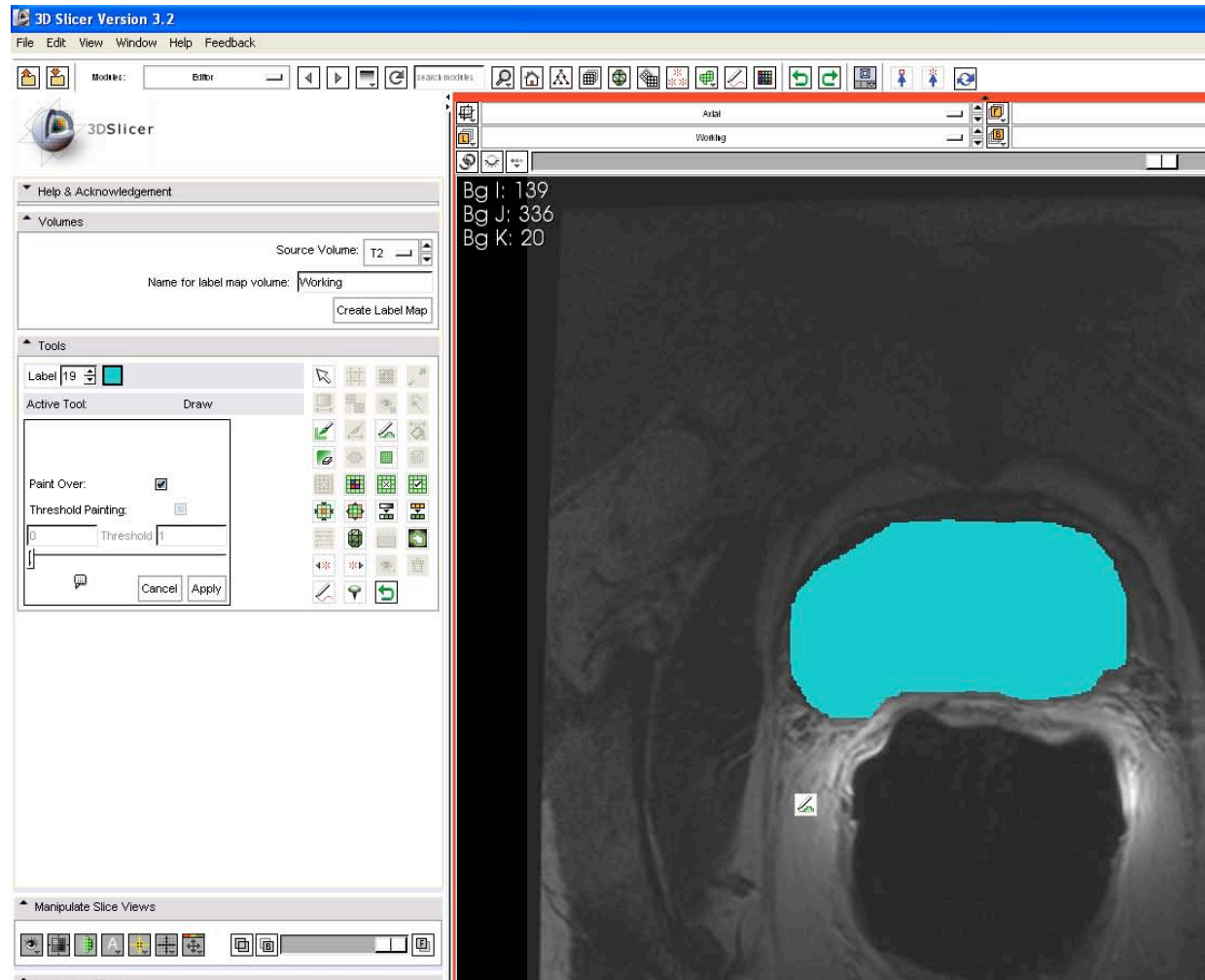Press the 'a' key to fill in the region when complete

Manual Segmentation - Contour

The contour is filled in when 'a' is pressed

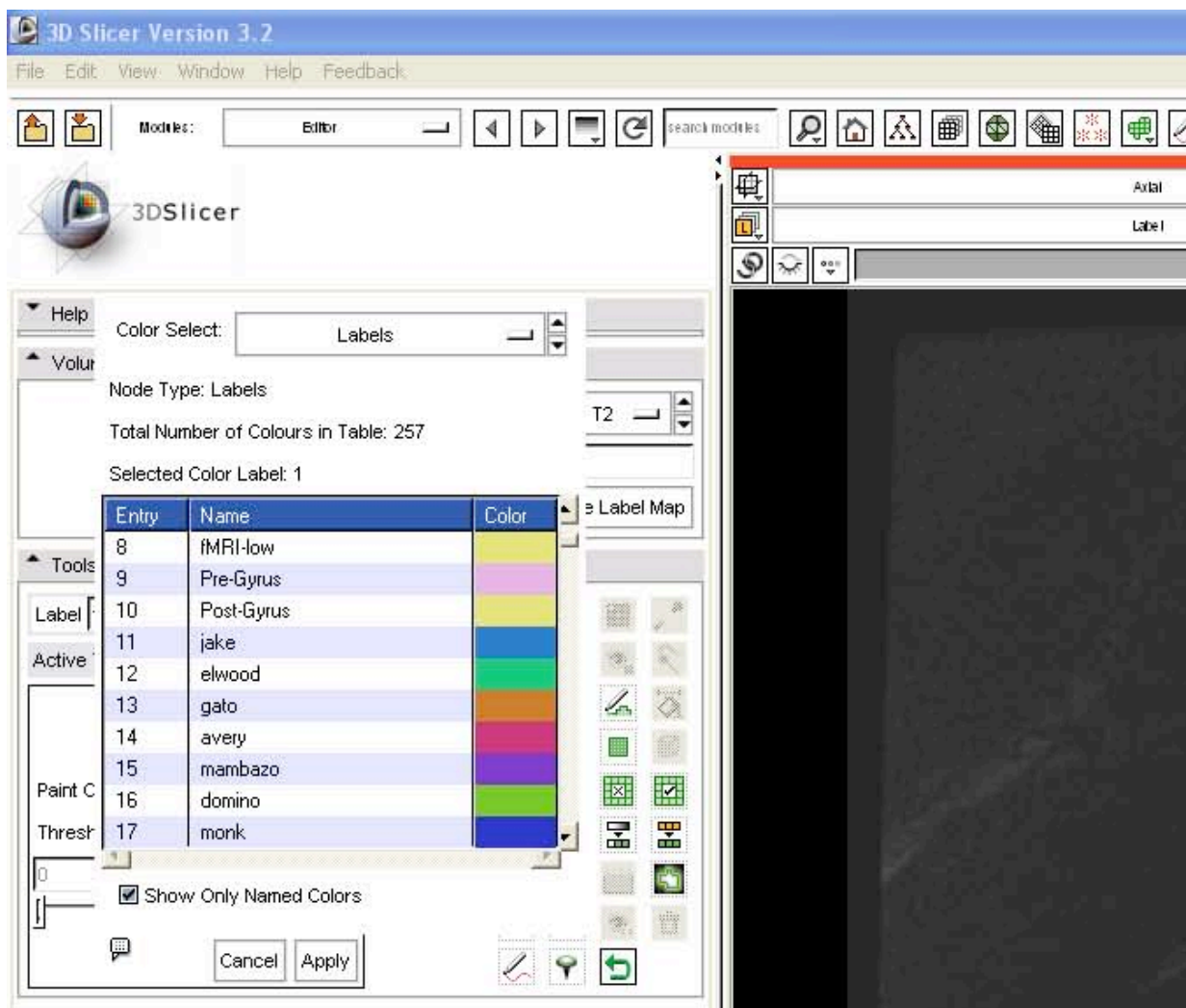Here the boundary of the prostate gland has been contoured

Manual Segmentation - Color

Select color

Change to a different color for another structure

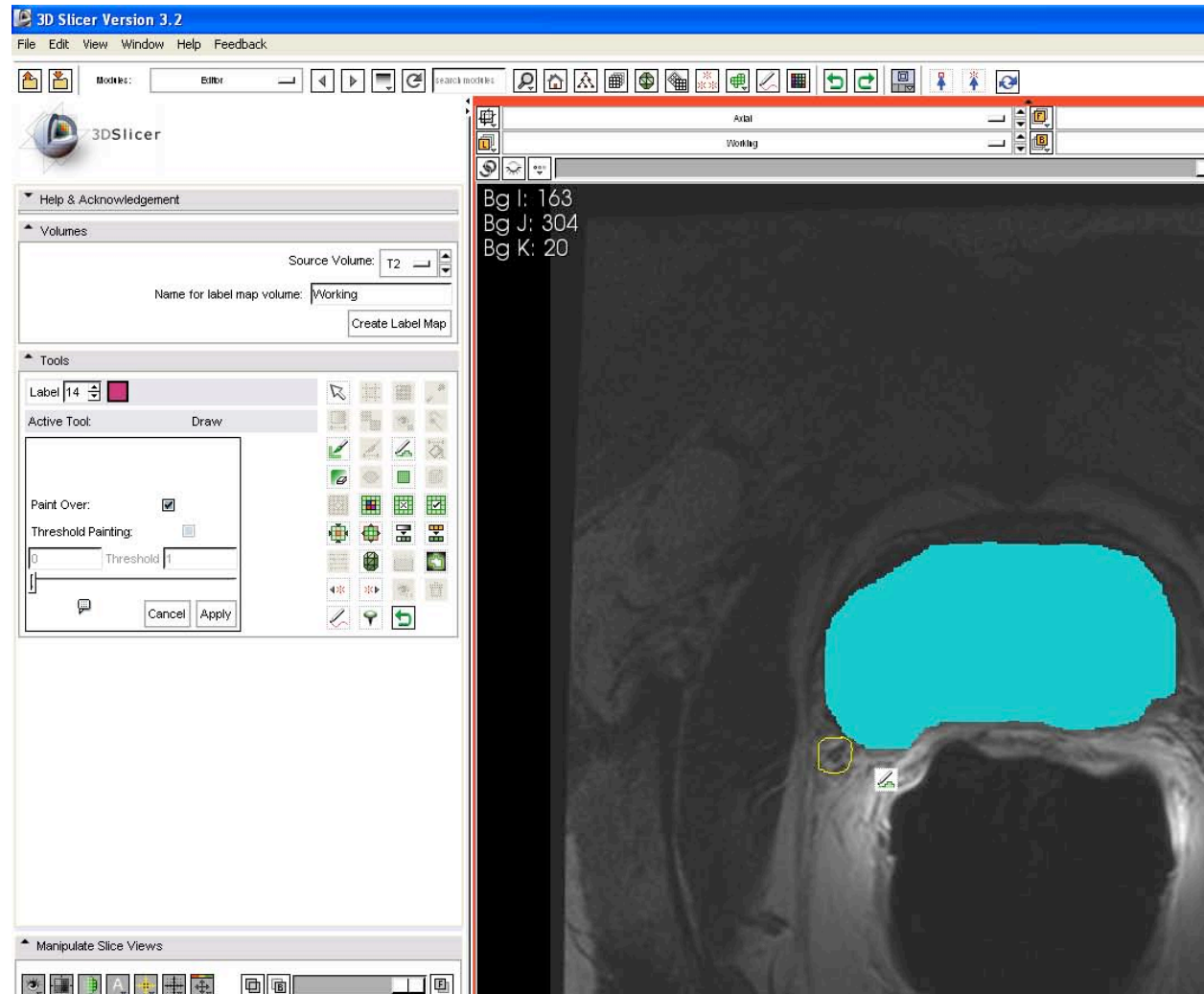Click on the color box for the pop-up color selector

Manual Segmentation - Contour

Draw a closed contour

Contour the right neurovascular bundle
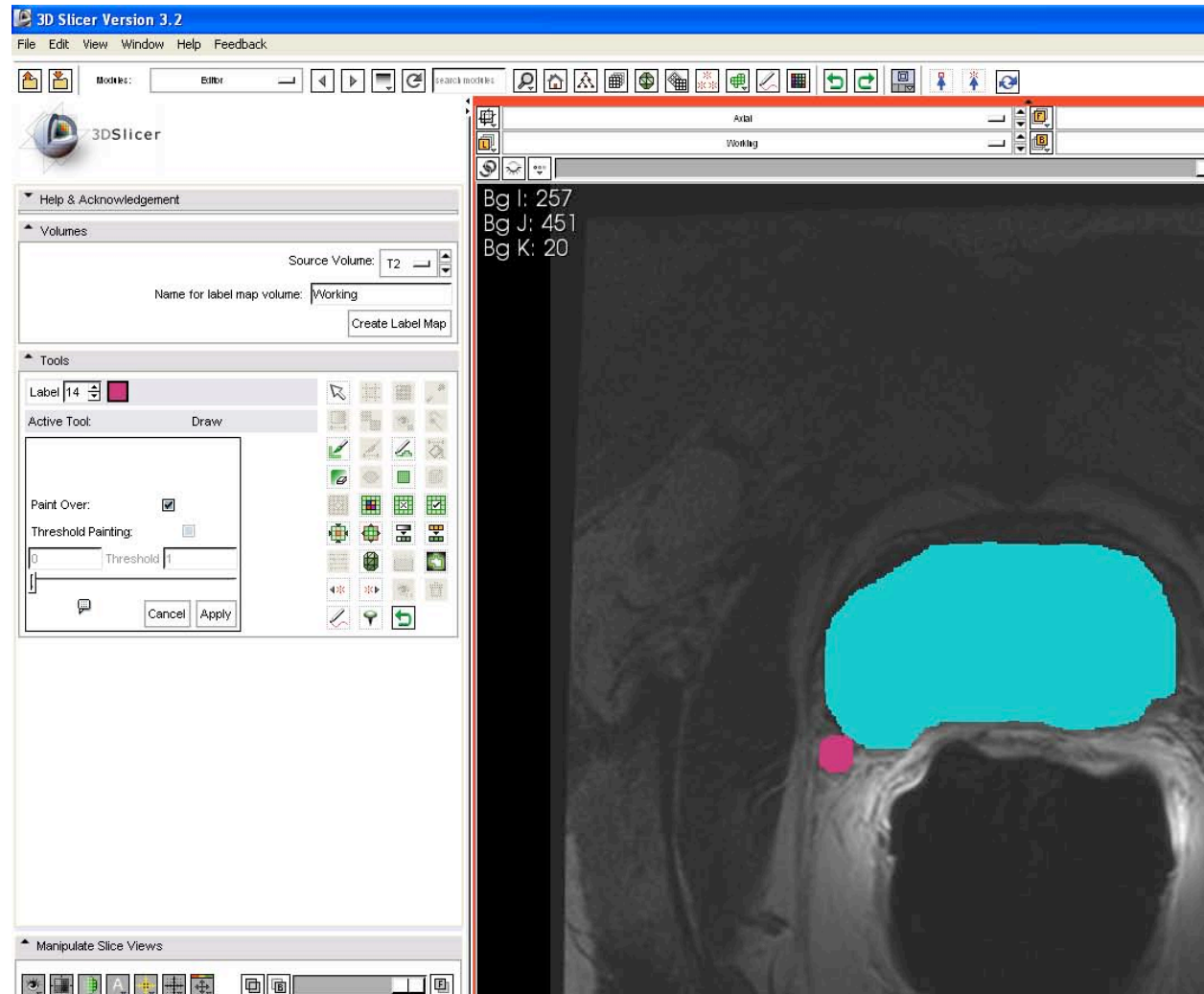
Press the 'a' key to fill in the region when complete

Manual Segmentation - Contour

The contour is
filled in when 'a'
is pressed

Here the right
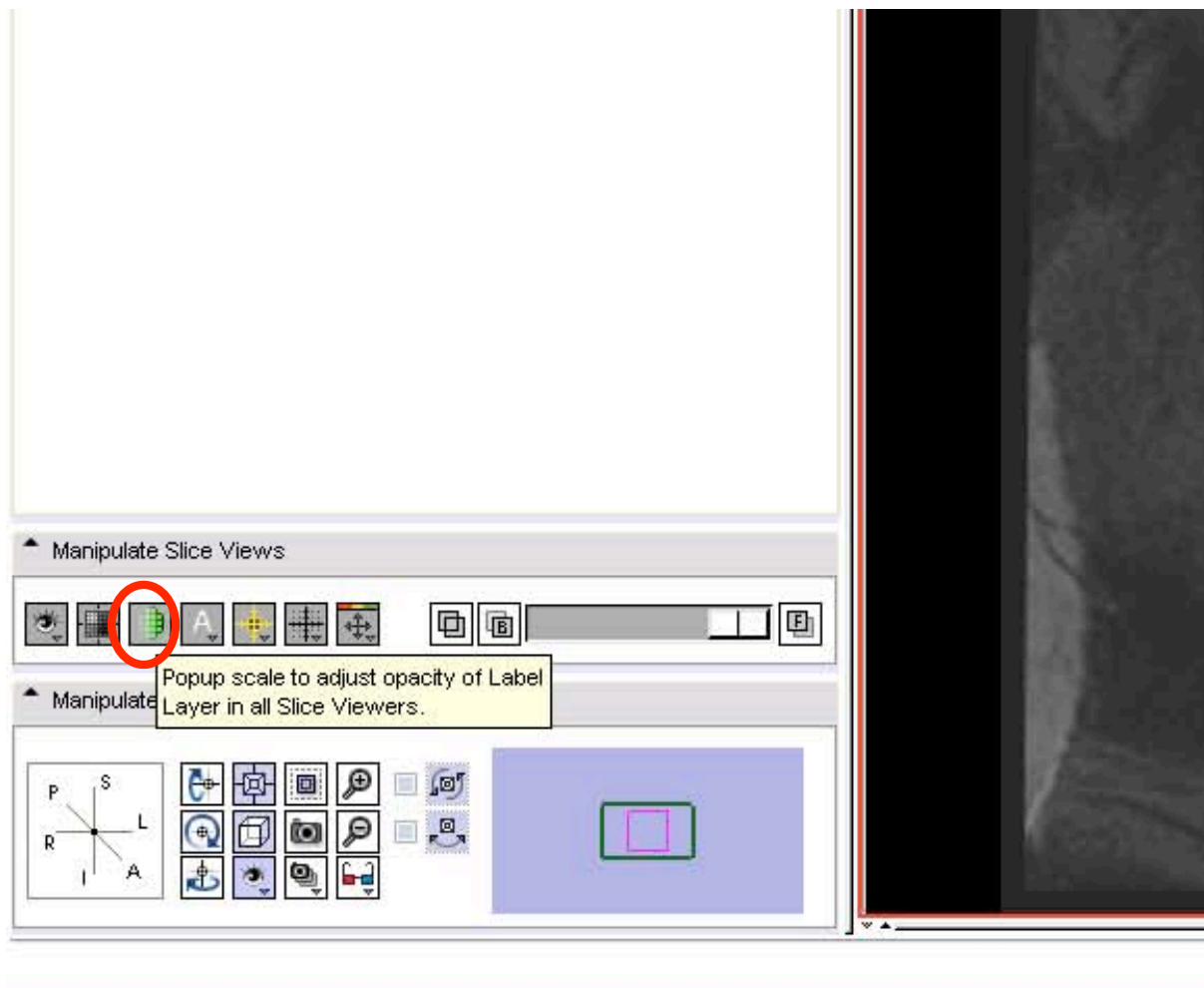neurovascular
bundle has
been contoured

Manual Segmentation - Opacity

Set label opacity

This allows you to see beneath the contoured regions

Select a value for the opacity using the pop-up slider

Manipulate Slice Views

Popup scale to adjust opacity of Label Layer in all Slice Viewers.

Manipulate

Now you can visualize the MR image and the selected regions at the same time
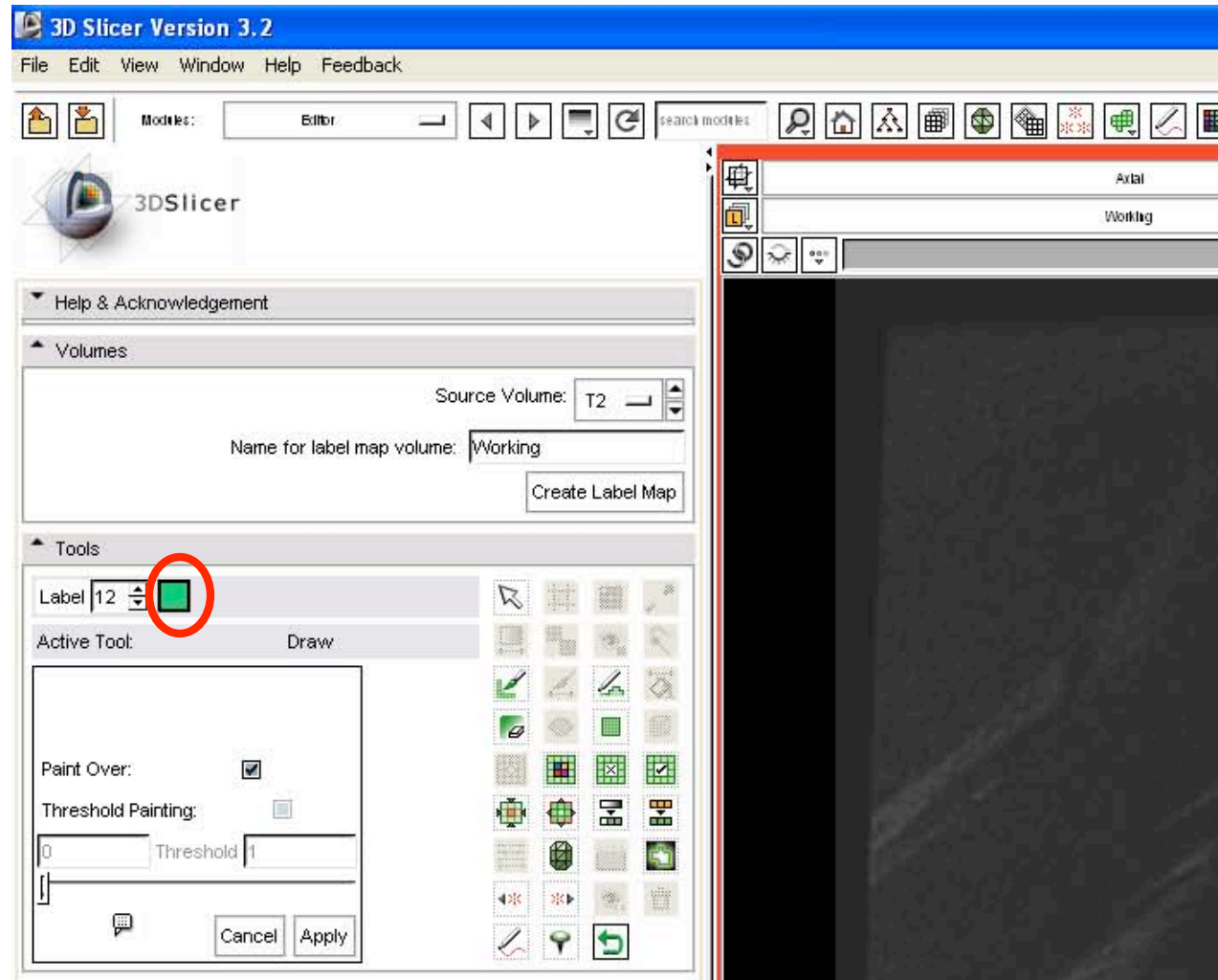
Manual Segmentation - Color

Select color

Change to a different color for another structure

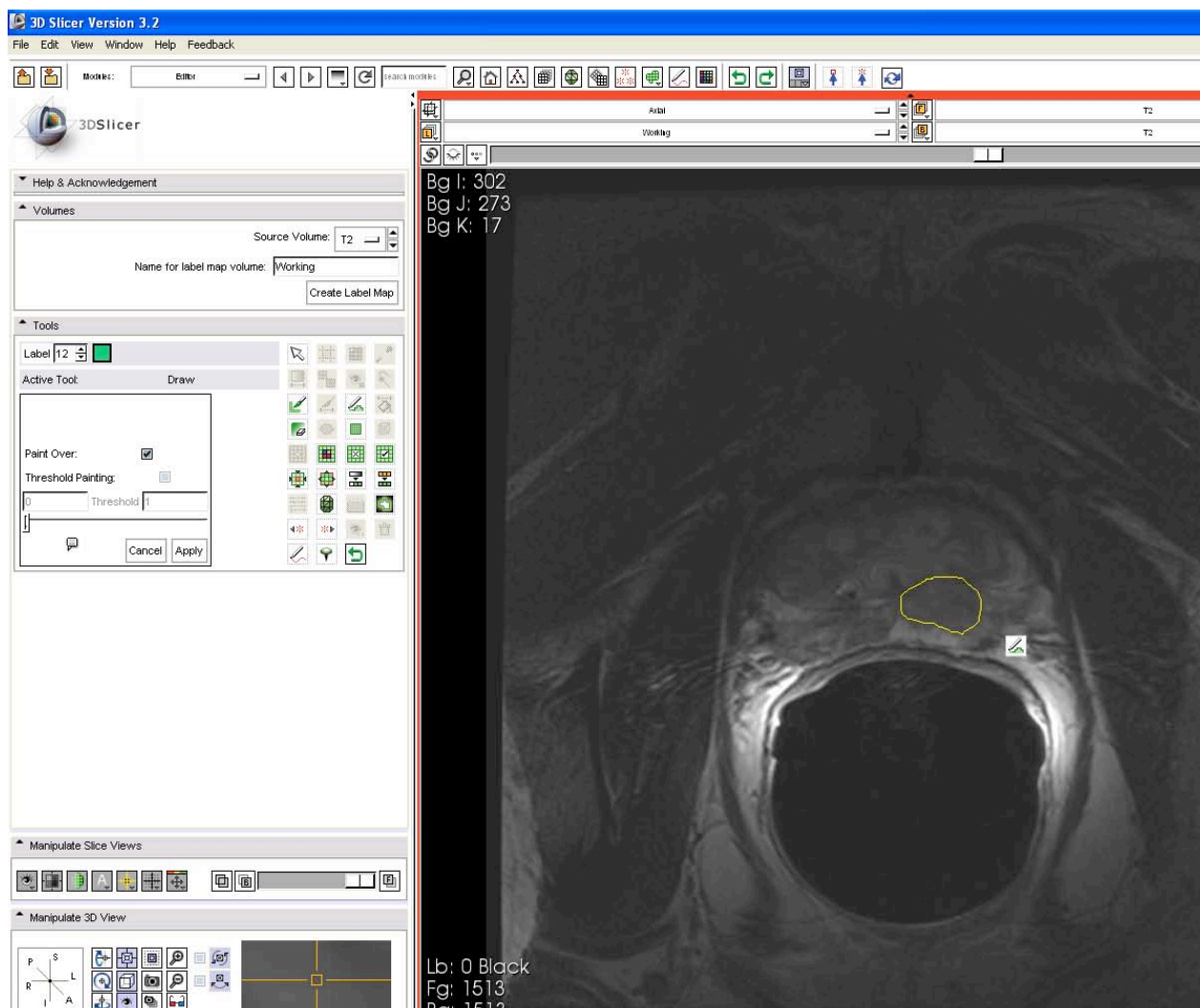Click on the color box for the pop-up color selector

Manual Segmentation - Contour

Draw a closed contour

Contour the tumour
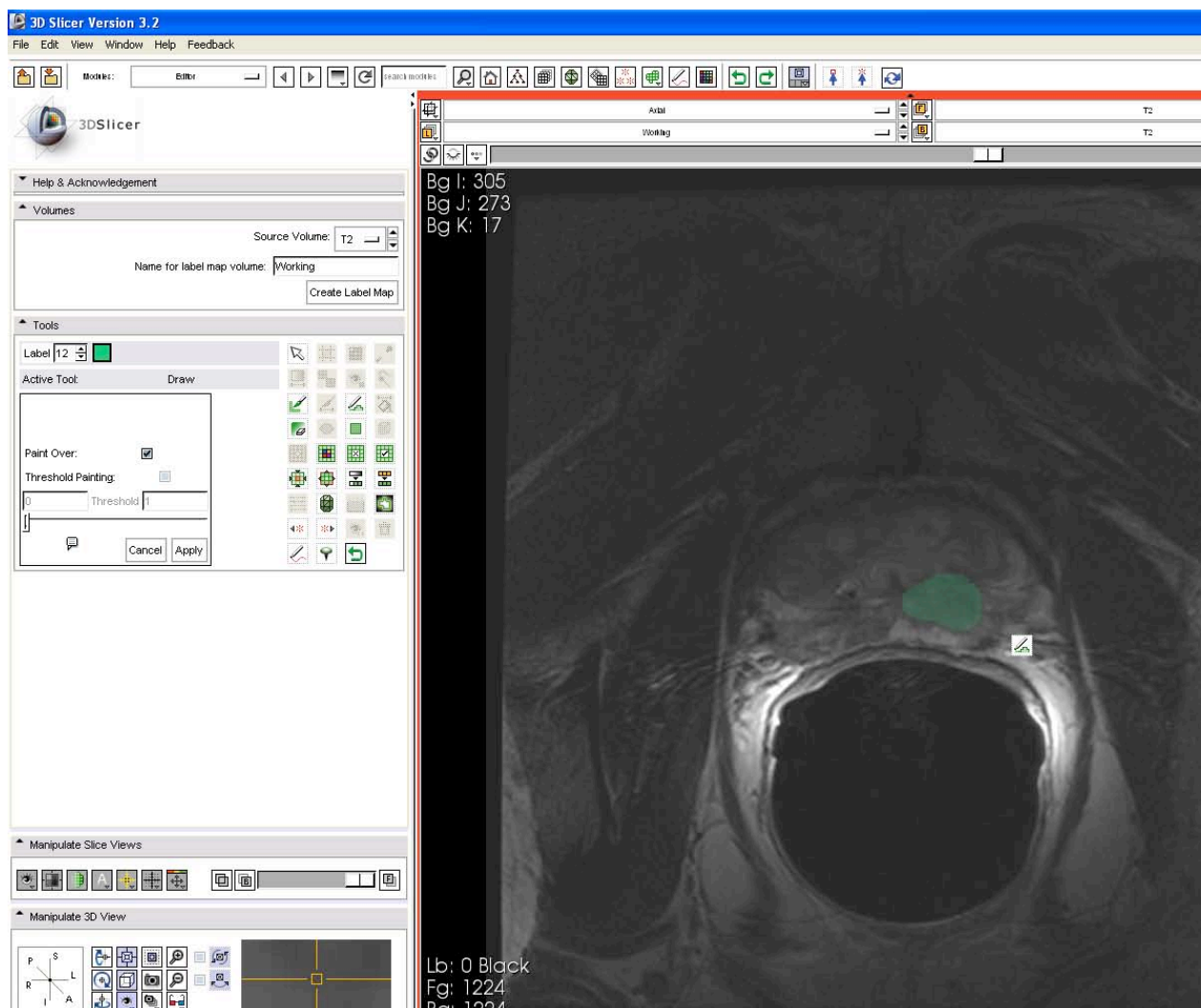
Press the 'a' key to fill in the region when complete

Manual Segmentation - Contour

The contour is filled in when 'a' is pressed
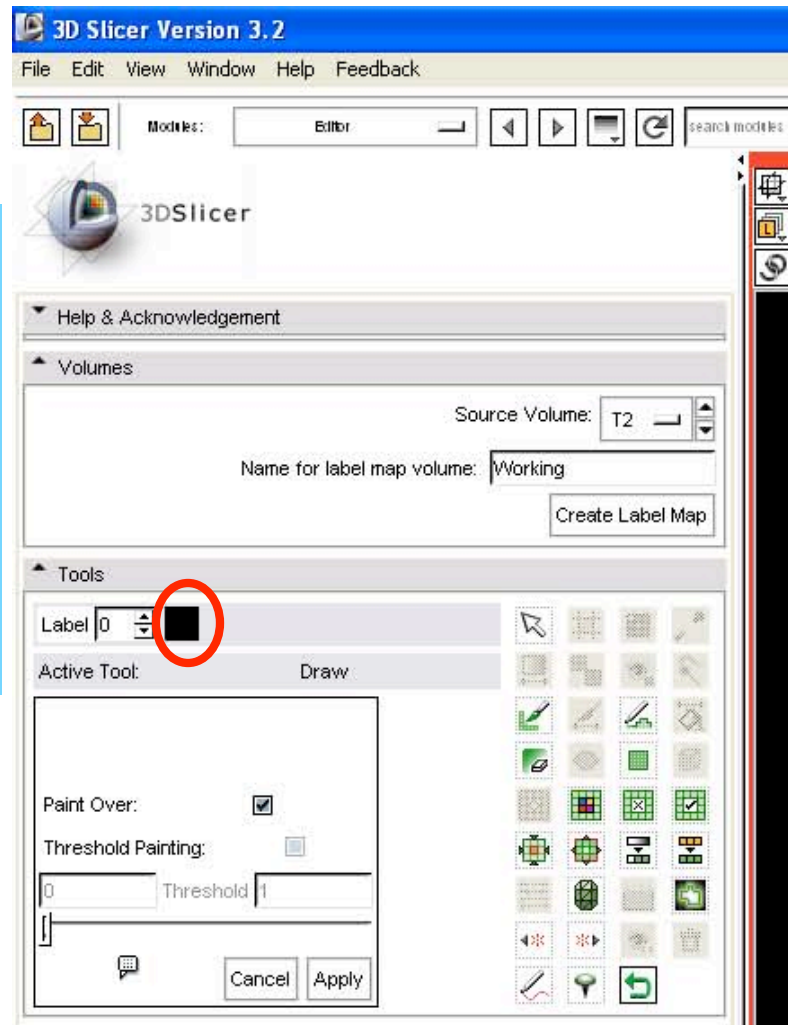
Here a suspected tumor has been contoured
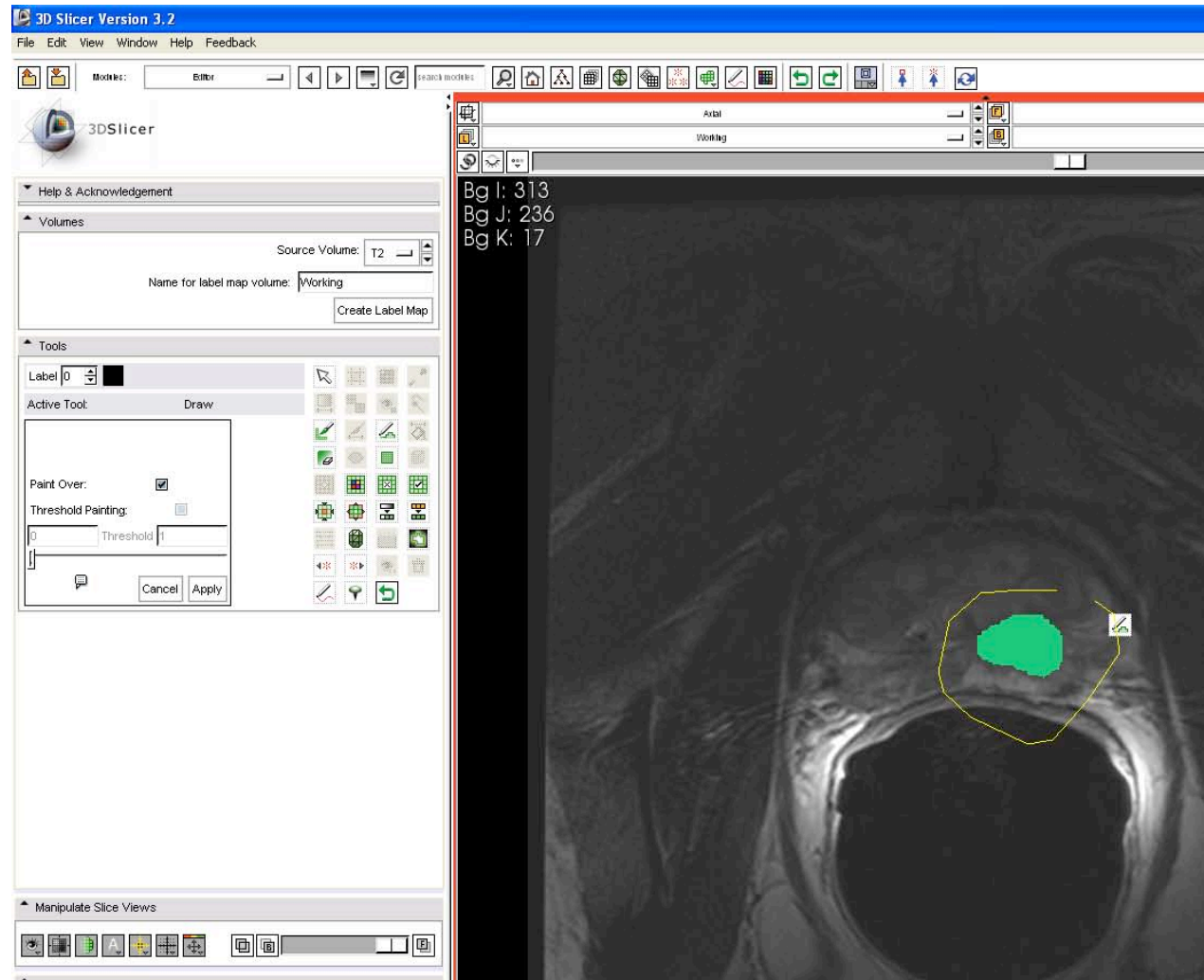
To erase, draw with black

Click on the color box for pop-up color selector and choose black (label zero)
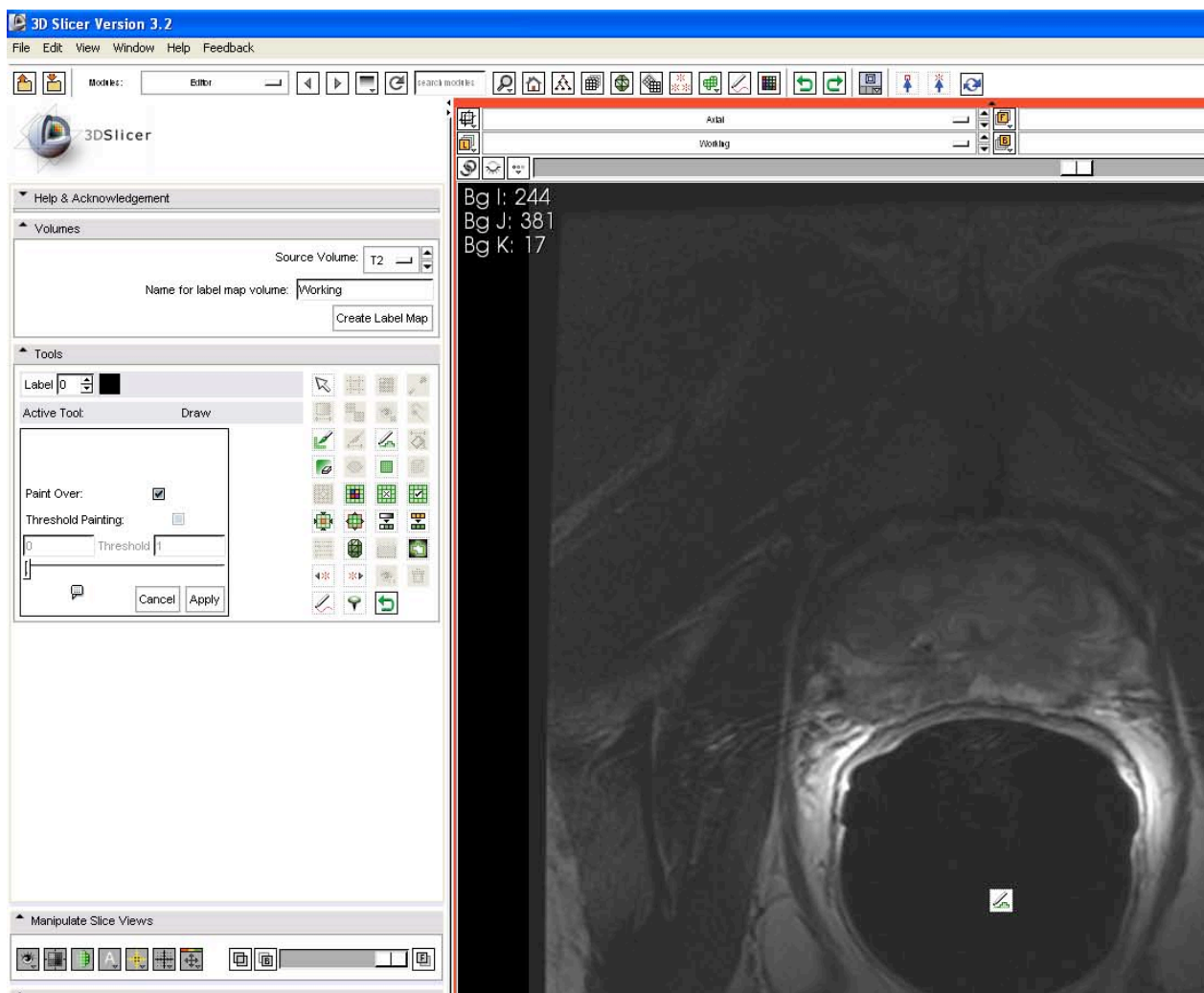
Manual Segmentation - Erase

Contour the region to be erased

Manual Segmentation - Erase
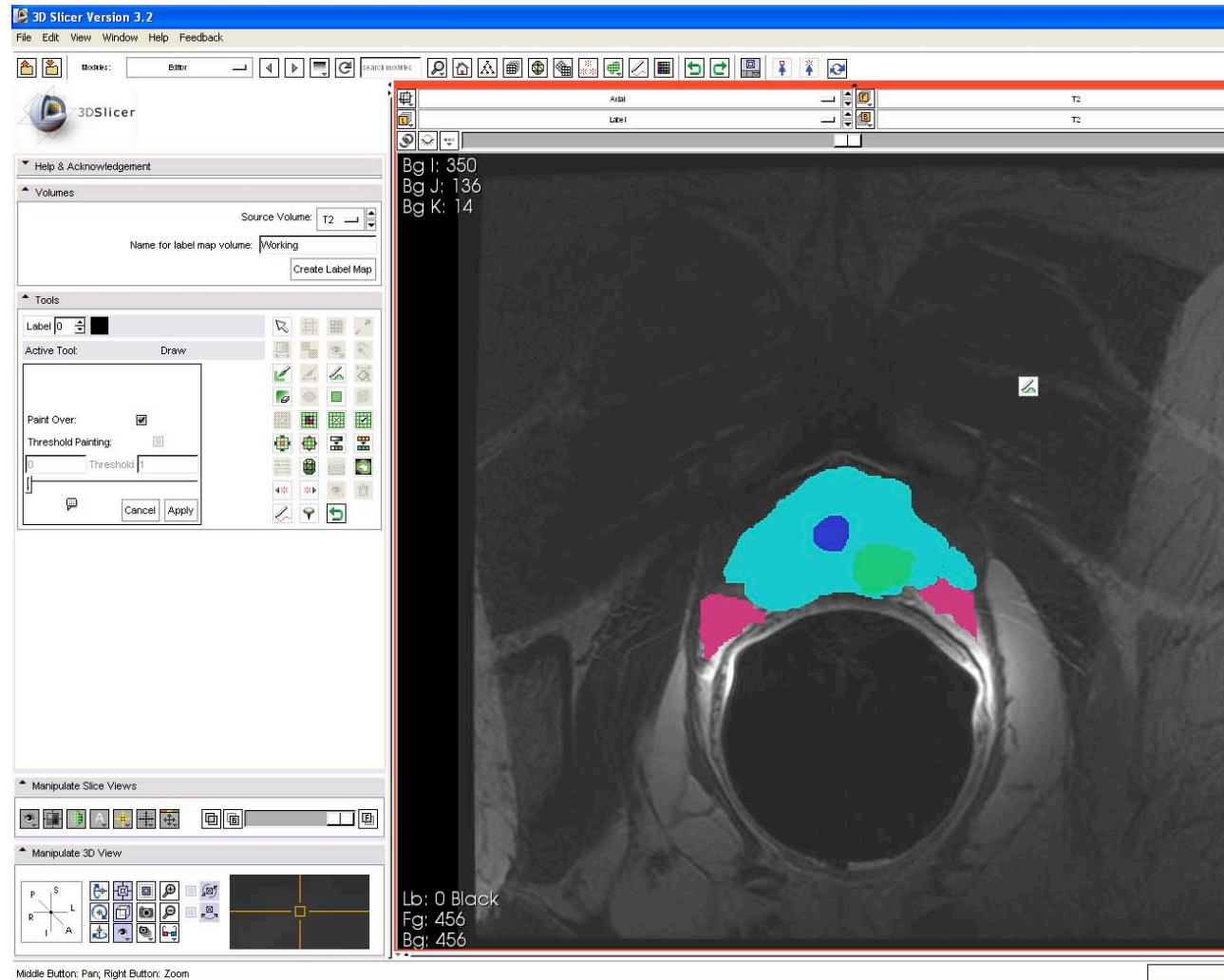
Press the 'a' key to erase the region when complete

Segment all slices in the volume

For each slice in the volume segment the prostate, both neurovascular bundles and the tumour: use a consistent color scheme.
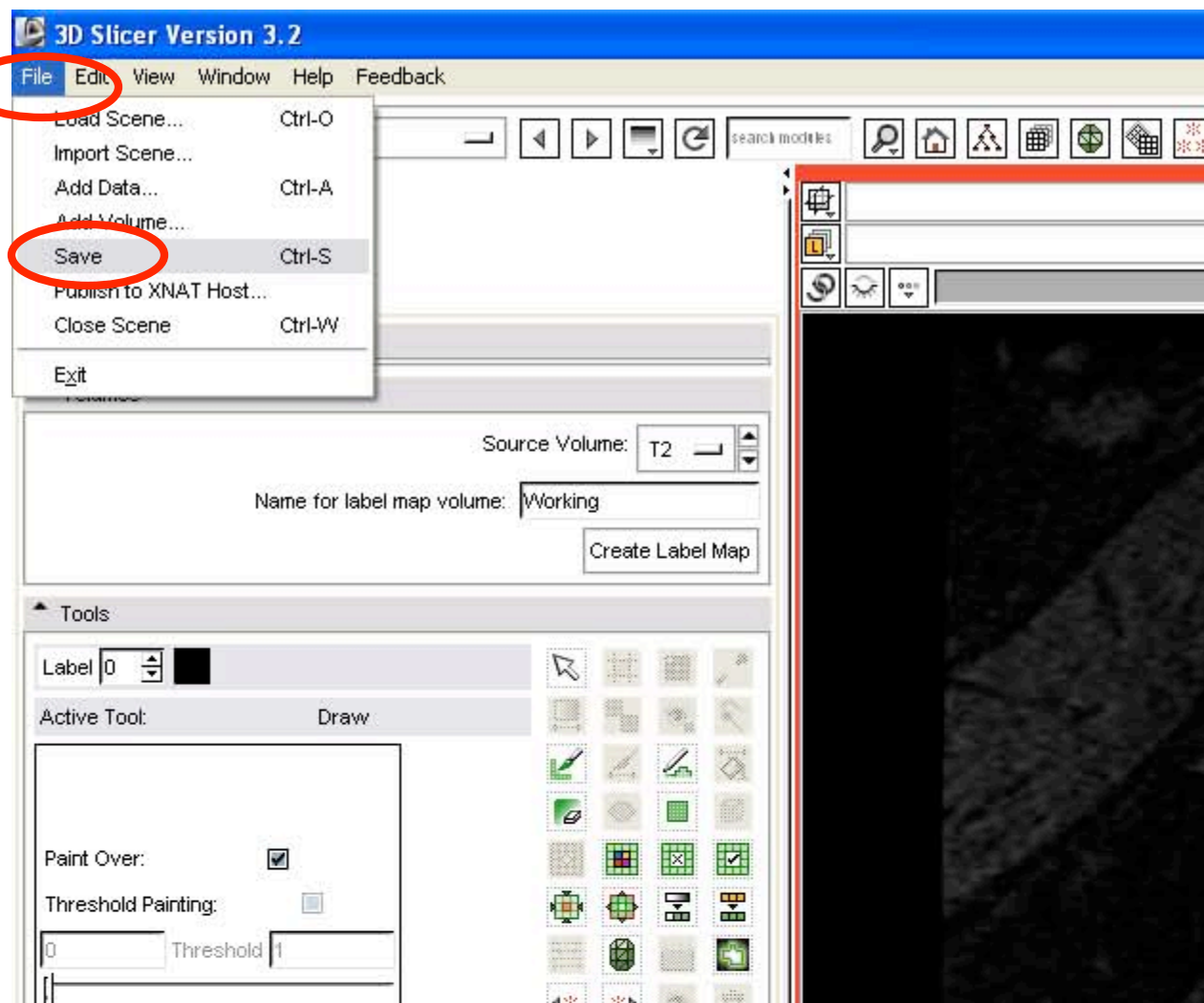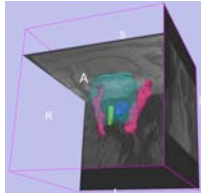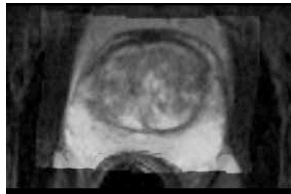
Manual Segmentation - Save

3DSlicer

Save the segmentation

Select "Save" from the File menu

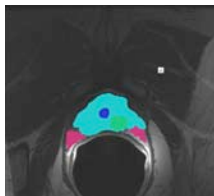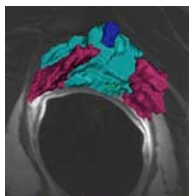Save the labels and current settings in a scene file

Overview

1. MR-guided prostate interventions: clinical background

2. Registering pre-operative & intra-operative prostate MR images using deformable B-spline registration
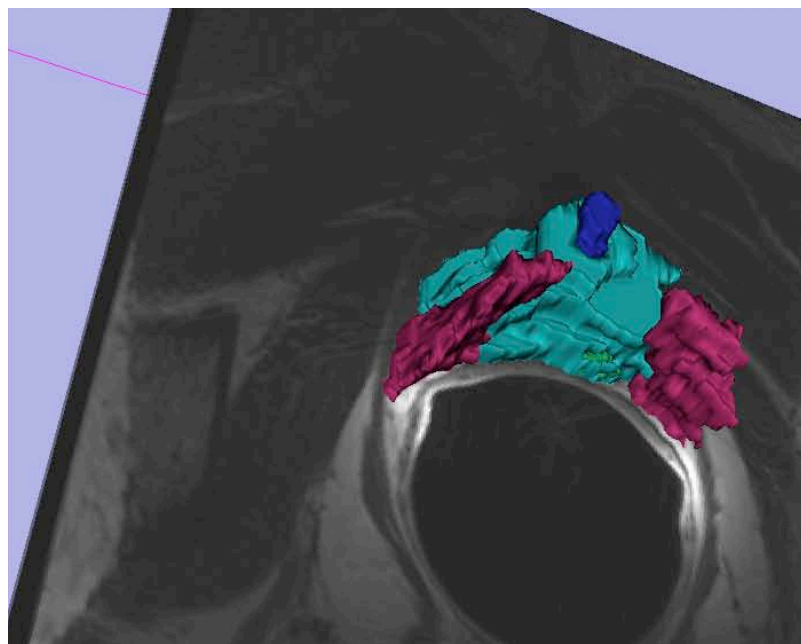
3. Manual segmentation of images

4. Creating 3D models from segmentations
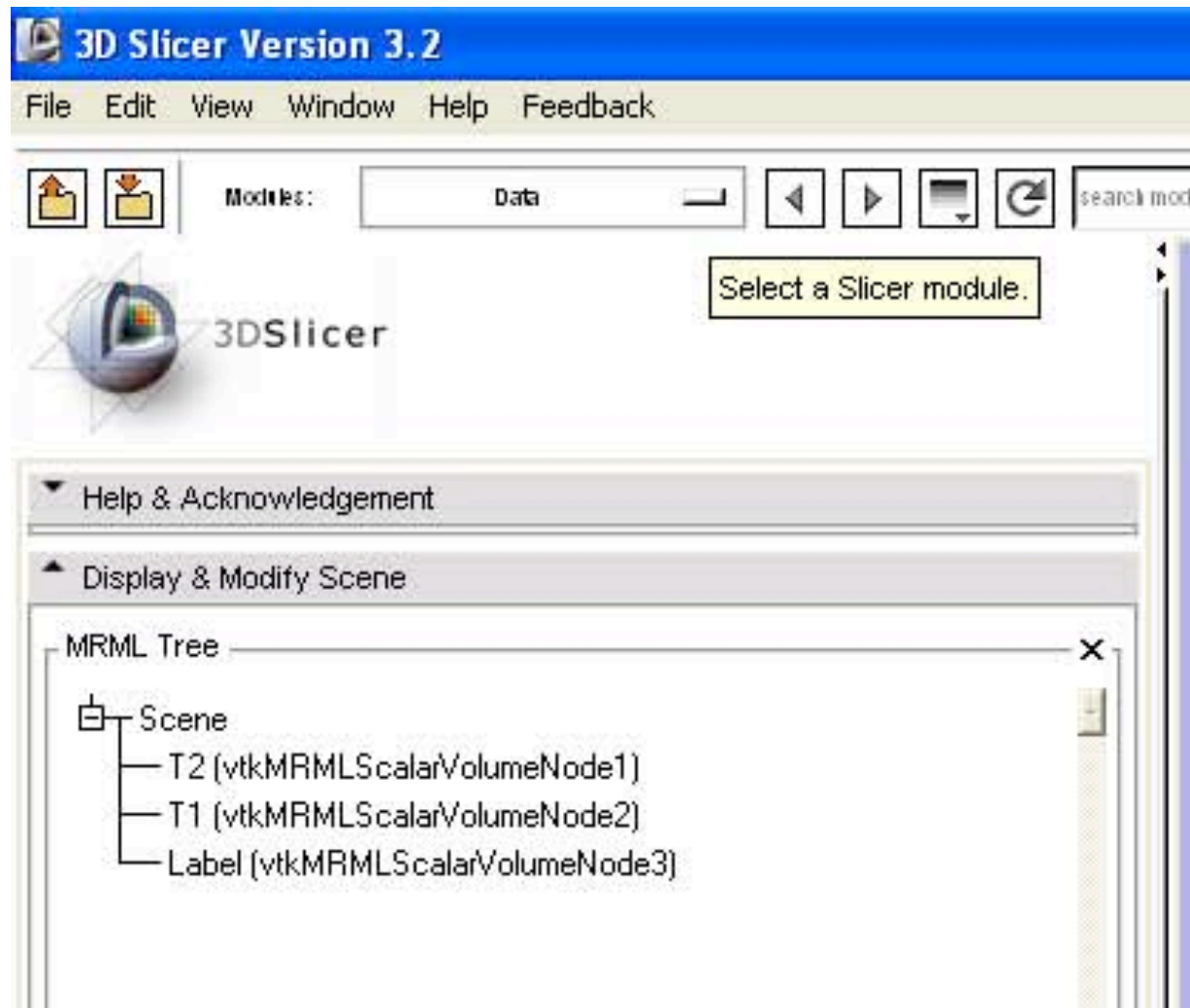
We can create 3D models of the anatomy to enhance our visualization

We will load the "Model Maker" module

The Model Maker module makes 3D triangulated surfaces from segmentations
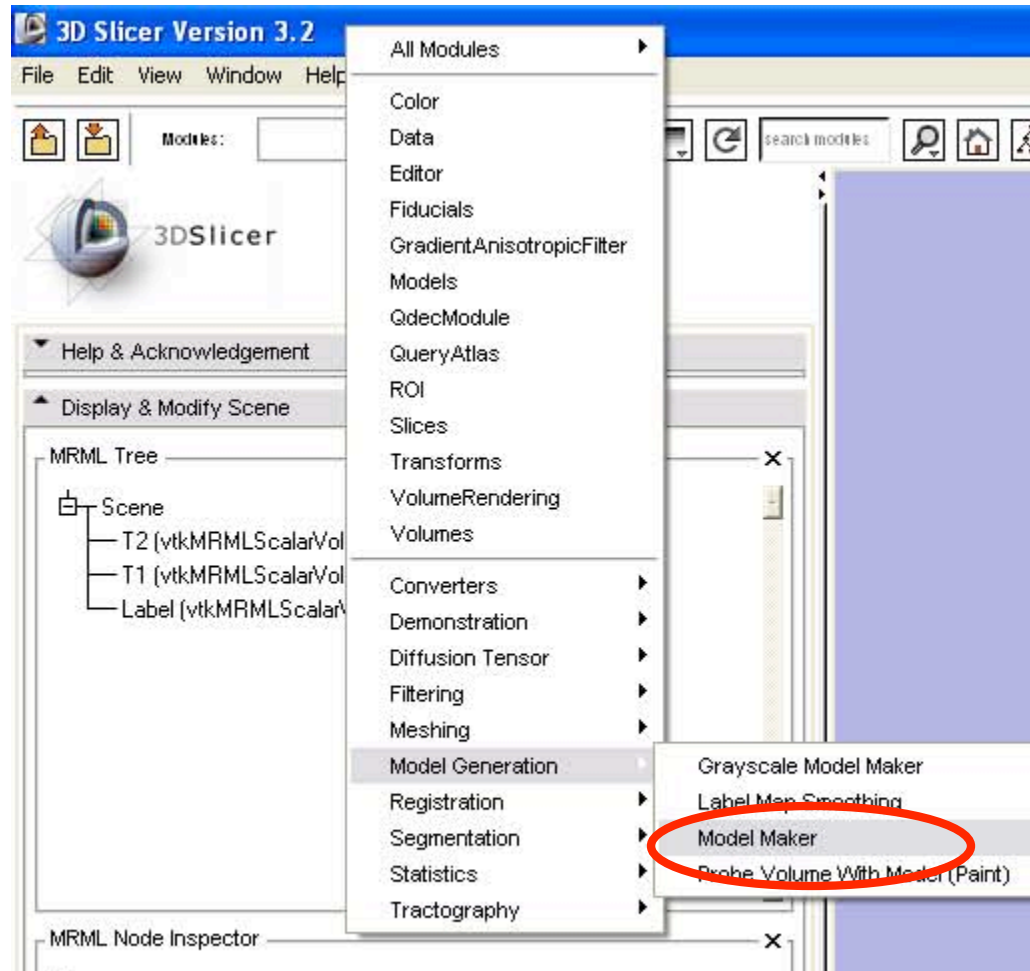
Open the Model Maker module

(Other model choices may apply for other applications)
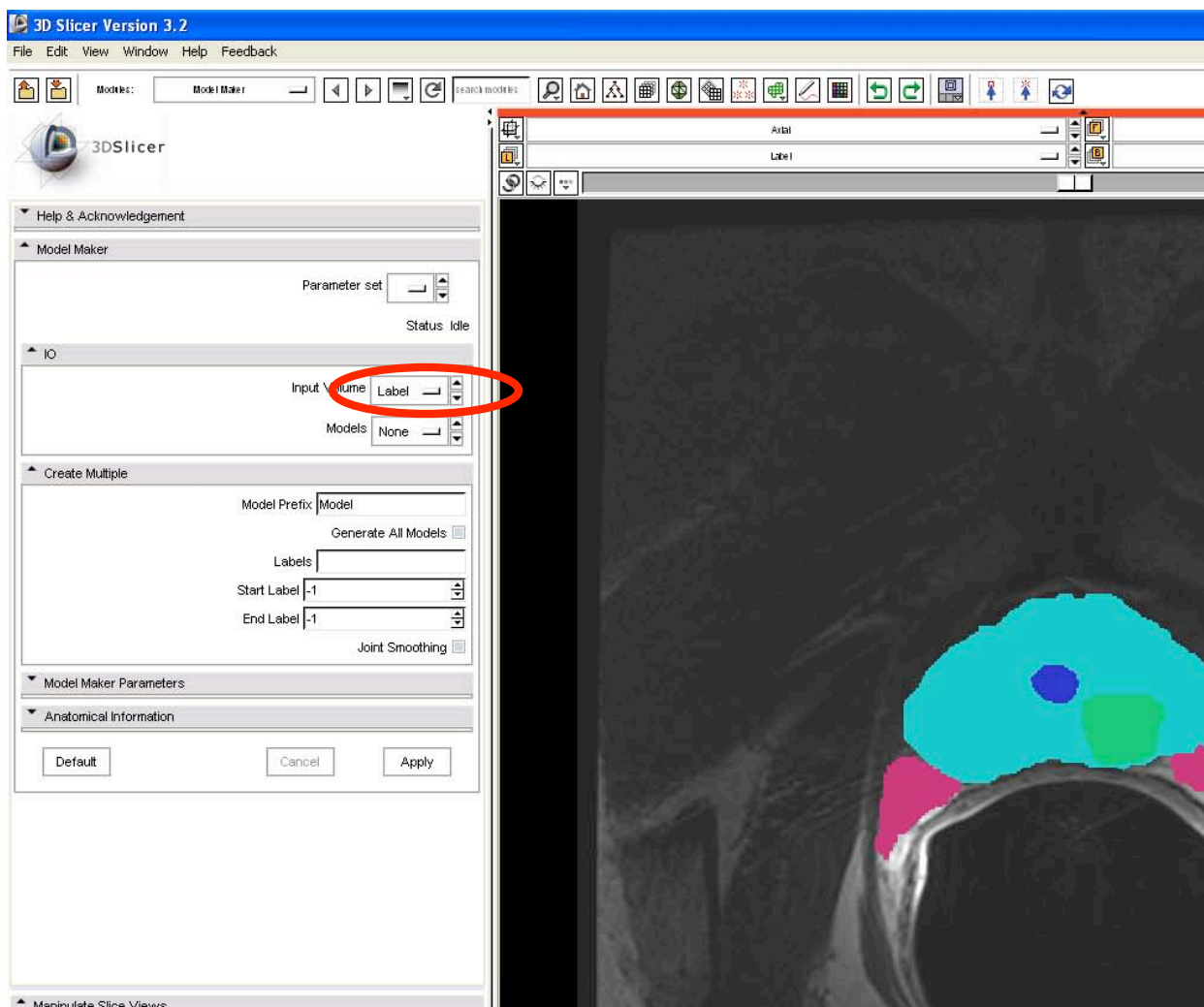
Creating Models - Input Volume

Choose the input volume

This is the volume called "Label" in this demonstration

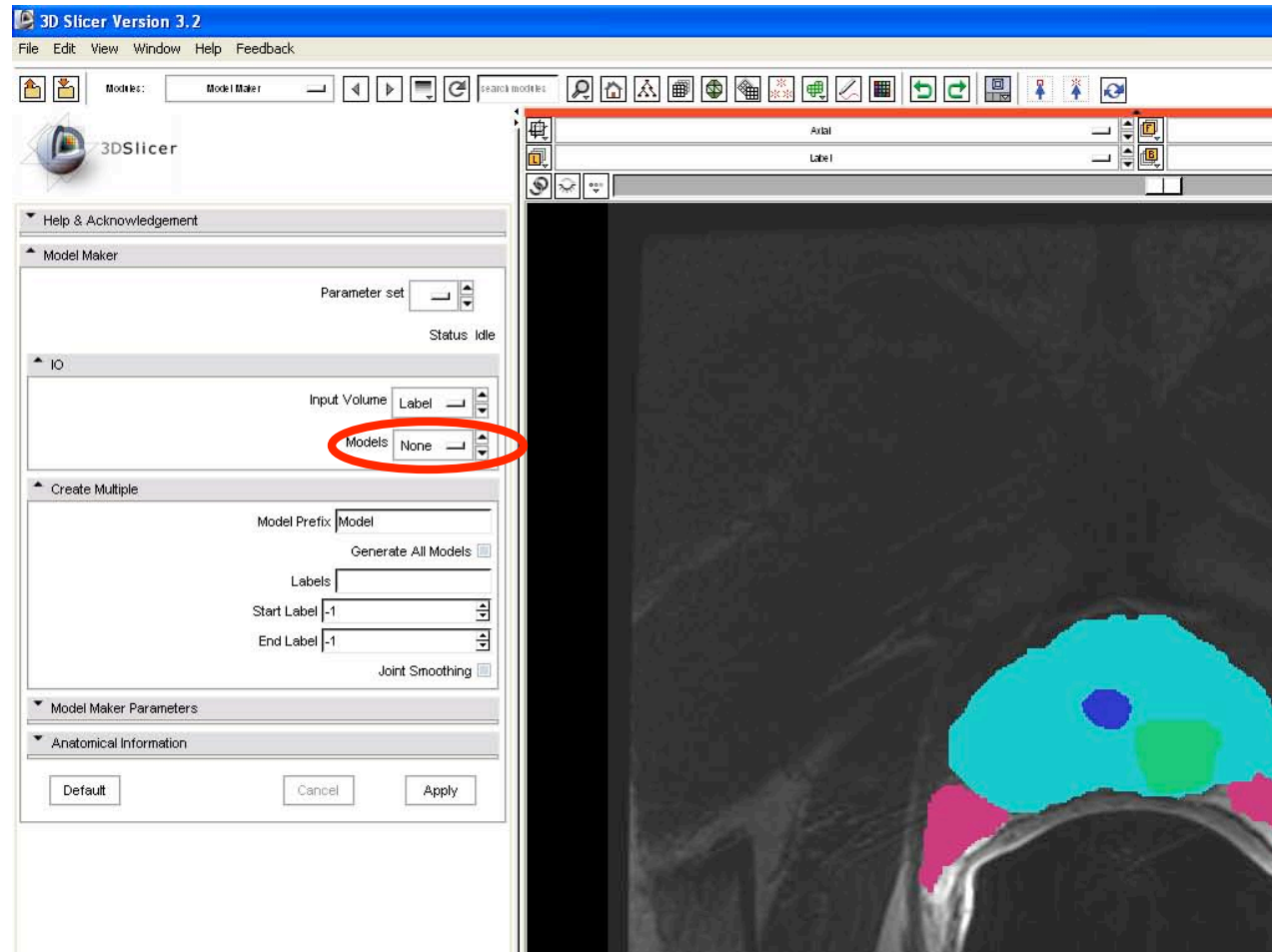Each label value in the label map can be made into a surface model
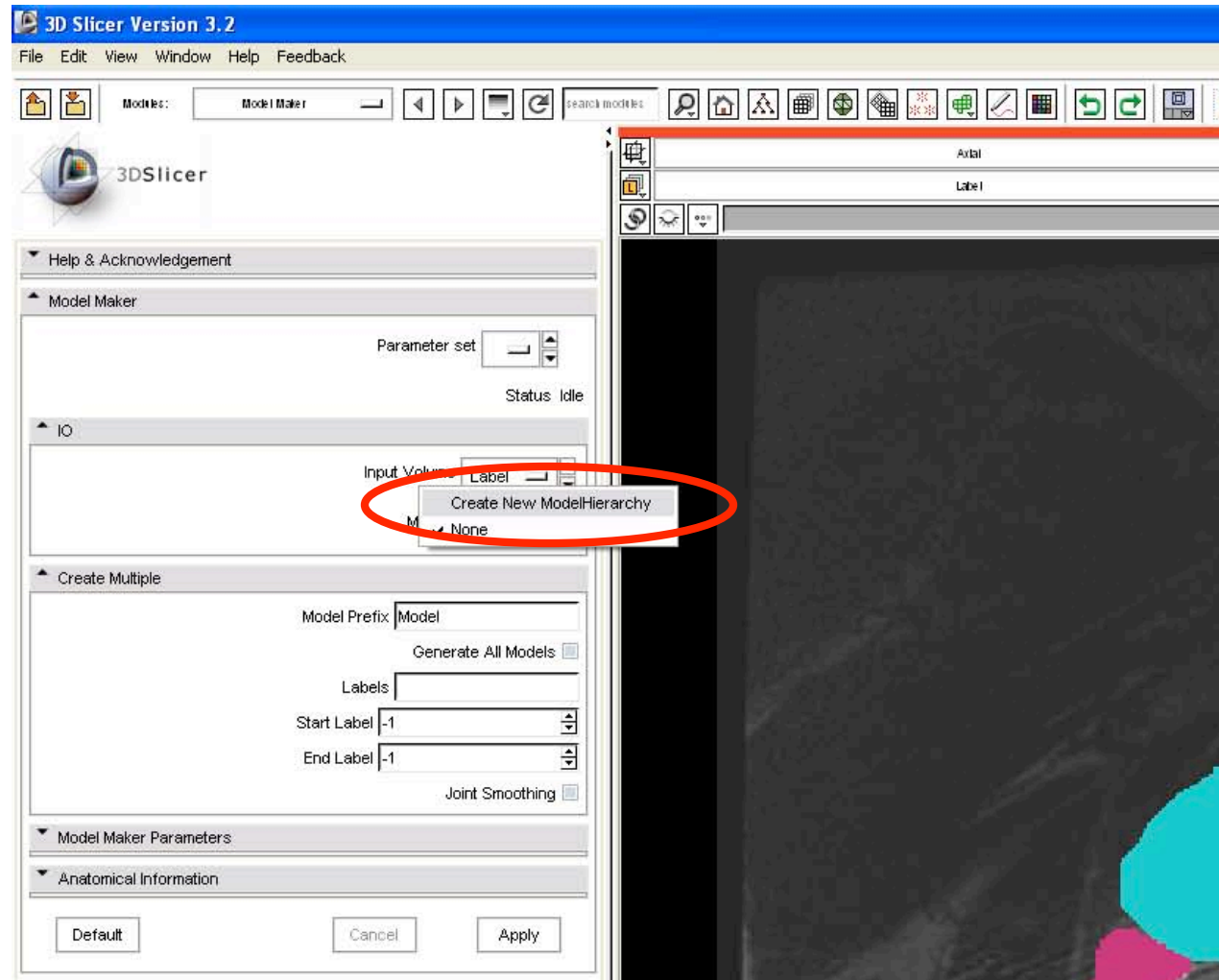
Create a new model hierarchy

Hierarchies can be used to organize 3D models into groups

Creating Models - Hierarchy

Select "Create New Model Hierarchy"
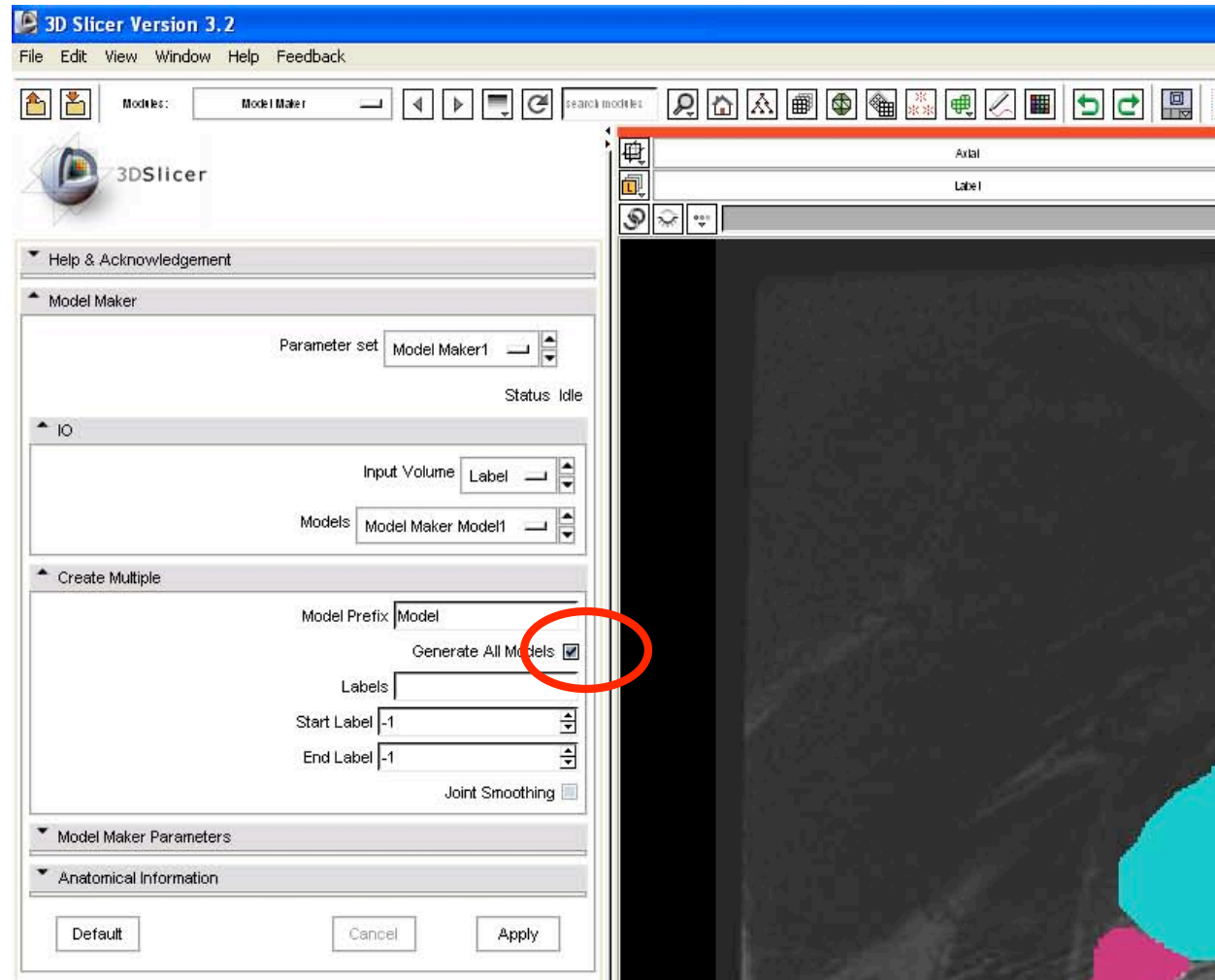
3DSlicer

Generate models

Check the box "Generate All Models" box

(You could also generate models individually for each label value)
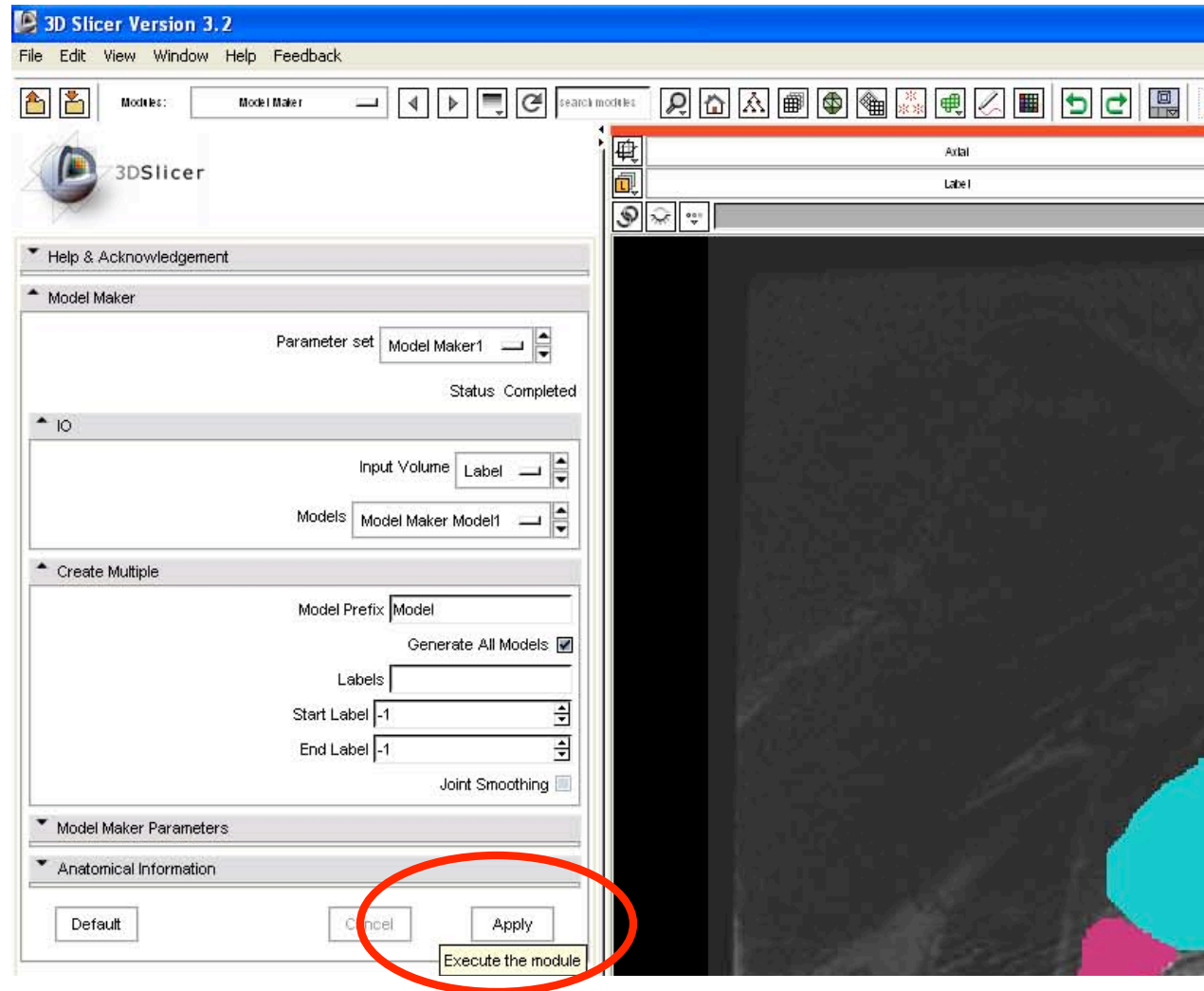
Creating Models - Apply

Press the "Apply" button

Slicer will create all the models
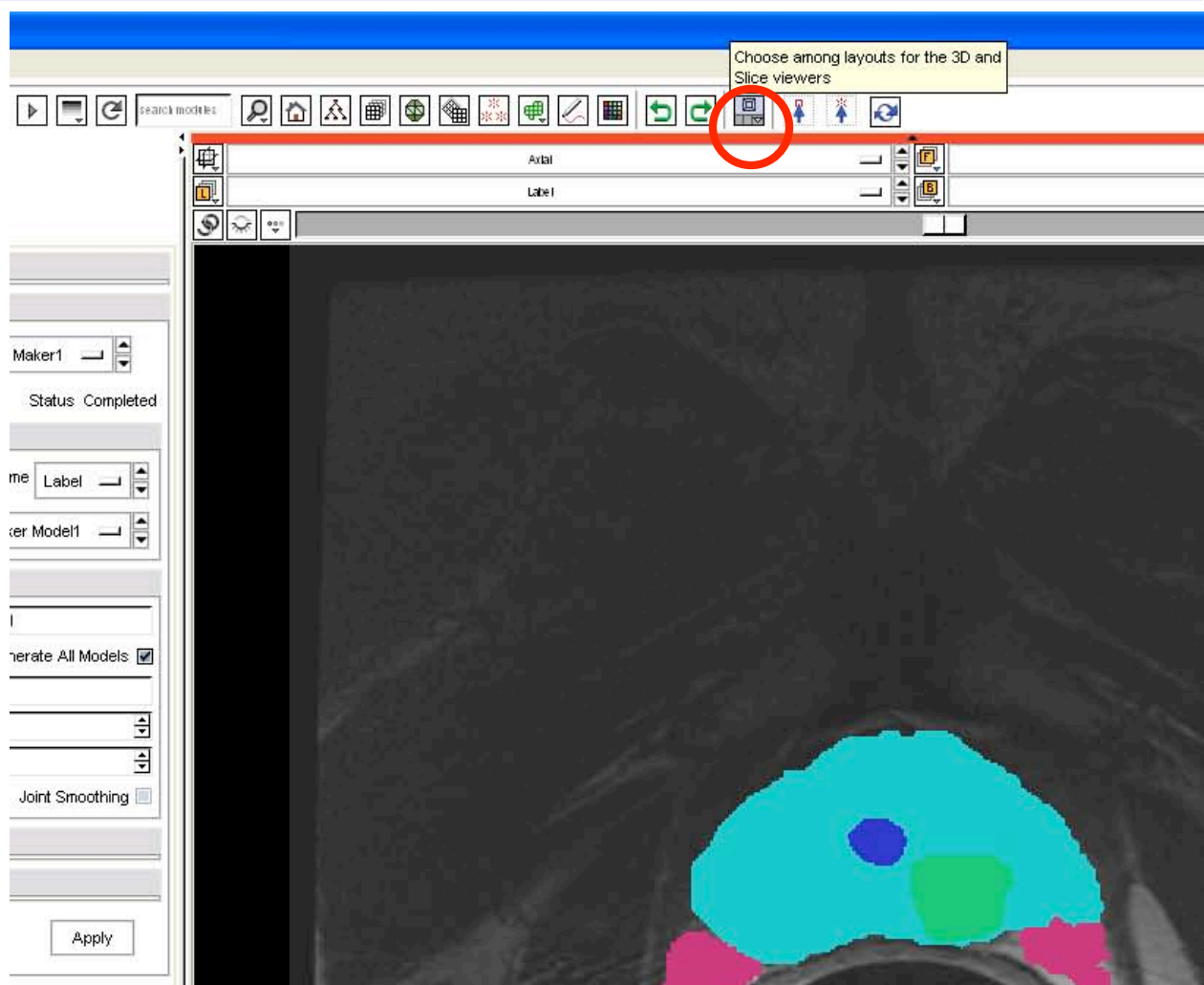
Creating Models - View

View the models in 3D

We can visualize both the models and the image slices in 3D

3DSlicer

Select "Conventional Layout"

This view allows for viewing both image slices and 3D space

3DSlicer
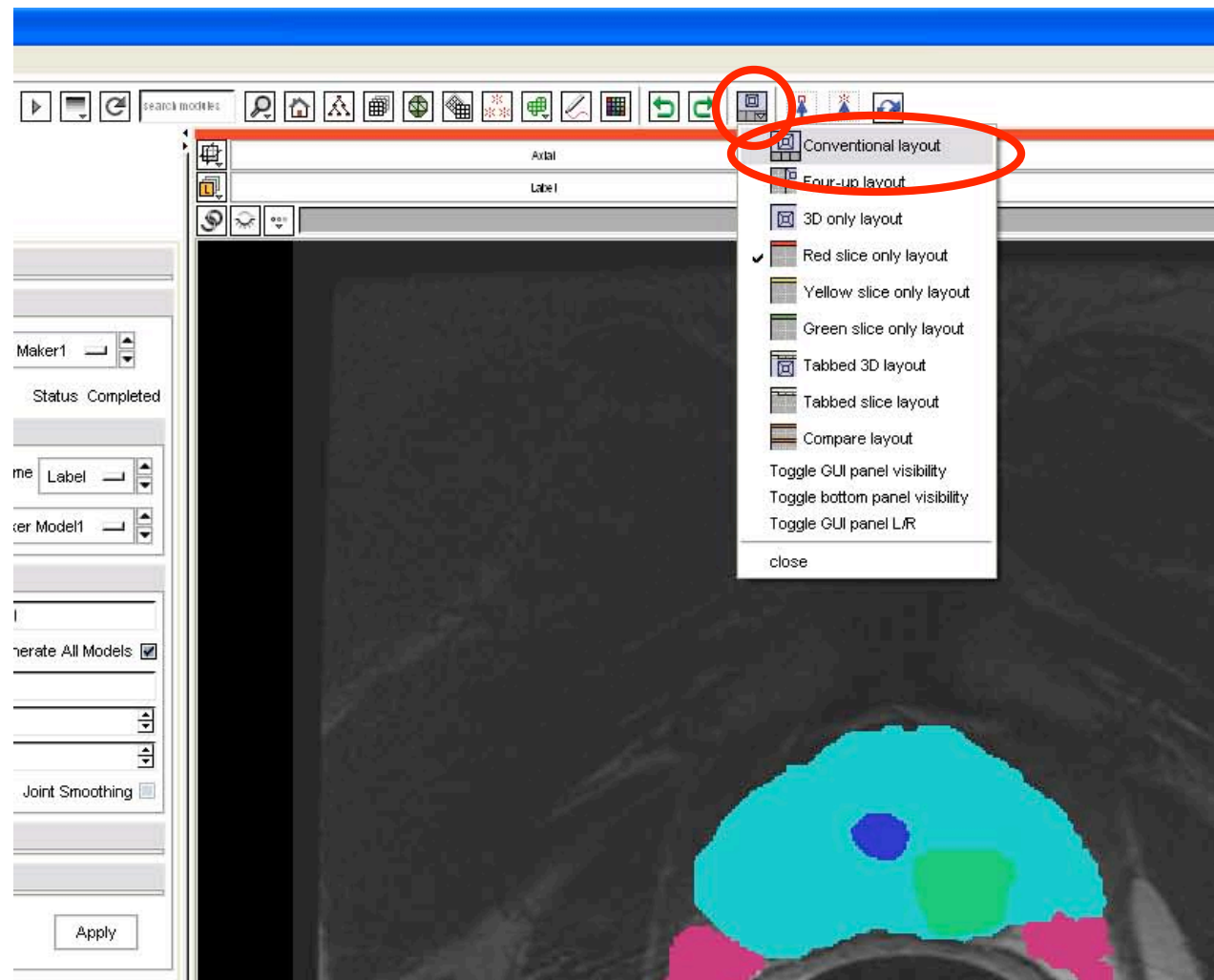
The 3D view appears

Surface structures appear colored by their label colors
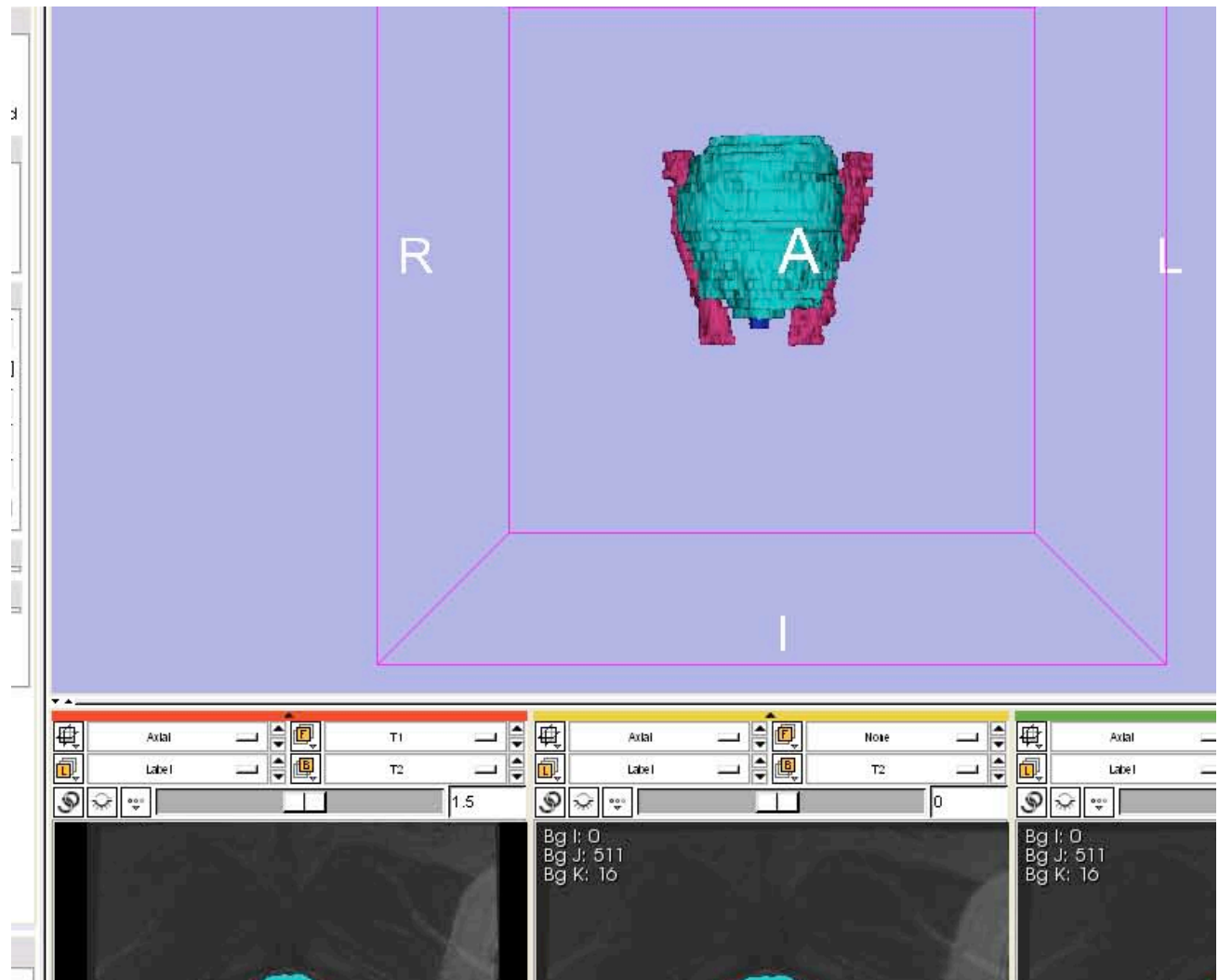
The mouse can be used to rotate the surfaces

The letters S/I A/P and R/L help with spatial orientation

View the cross-sectional slices by pressing the "eye" button above the slice(s)

3DSlicer

Save the models

The models need to be saved or they will be lost

Select "Save" from the "File" menu
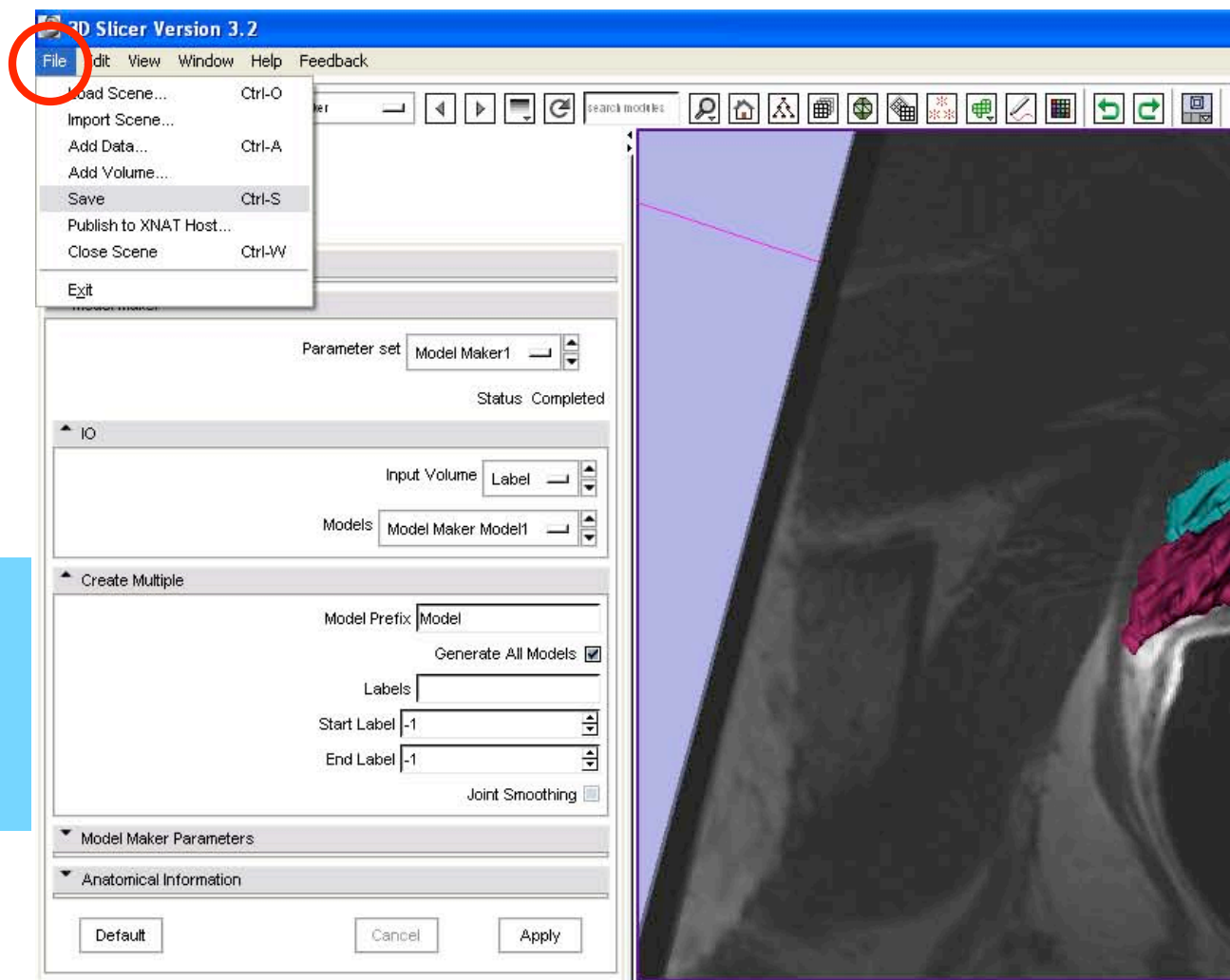
Make sure "Save" is checked next to the models and "Save Scene"
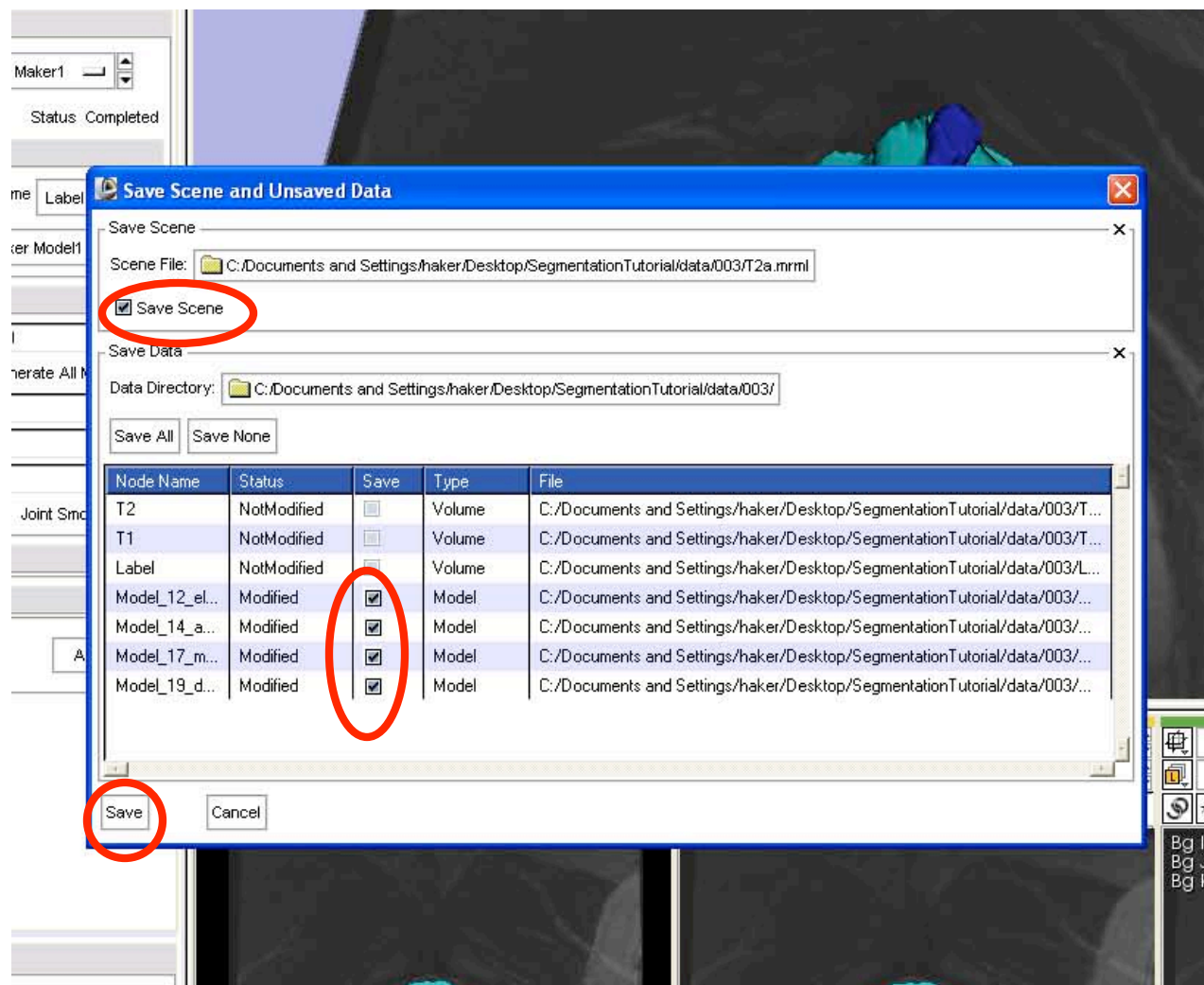
Conclusions

- The NA-MIC Kit can be used to perform the major computational steps in MR-guided prostate interventions

- Slicer3 provides an intuitive graphical user interface to interact with the data

- The NA-MIC Kit's open-source environment allows clinicians and researchers to share data and solutions to common problems

For more information

- For an example of using intraoperative MR for prostate interventions, see:

  Haker, S.J. *et al.*, Magnetic resonance-guided prostate interventions. Topics in Magnetic Resonance Imaging, 16(5):355-368 (2005).

- For a review of non-rigid image registration, see:

  Crum, W.R. *et al.*, Non-rigid image registration: theory and practice. The British Journal of Radiology, 77:S140-S153 (2004).

Acknowledgements

3DSlicer

National Alliance for Medical Image Computing
NIH U54EB005149

Neuroimage Analysis Center
NIH P41RR013218

Morphometry Biomedical Informatics Research Network
NIH U24RRO21382

Surgical Planning Laboratory (BWH)
Clare Tempany, Nobuhiko Hata, Ron Kikinis

National Center for Image Guided Therapy
NIH U41RR019703

NEDO Intelligent Surgical Instruments Project
Kiyo Chinzei