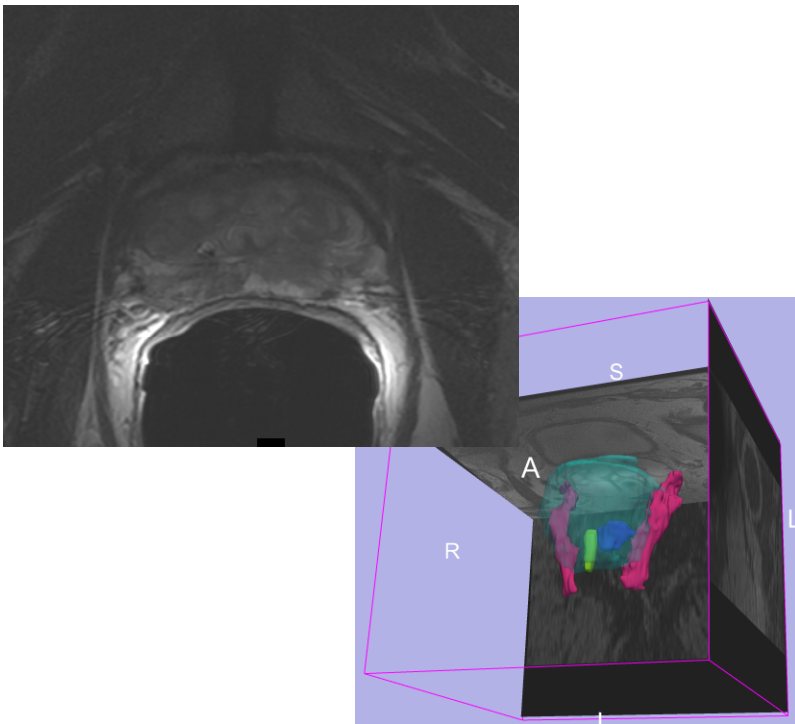


## MR-guided prostate interventions with 3DSlicer and the NA-MIC Kit



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Sota Oguro, M.D.

Steve Haker, Ph.D.

Surgical Planning Laboratory

Brigham and Women's Hospital

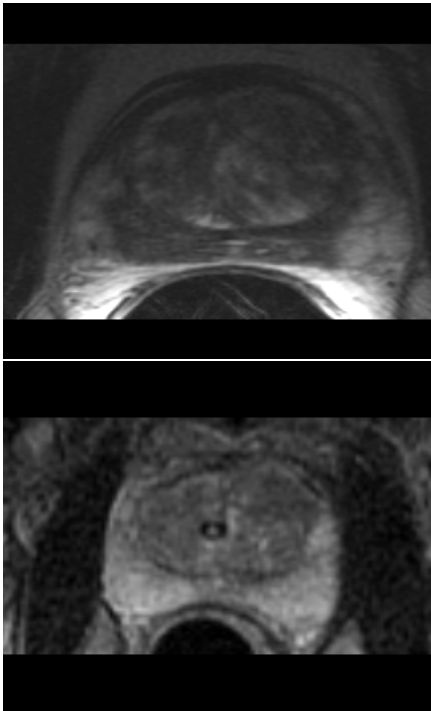
Harvard Medical School

Massachusetts General Hospital

# Learning Objective

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***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

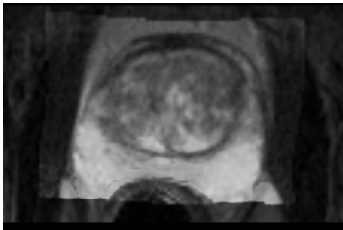
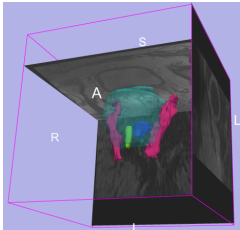
<http://www.na-mic.org/Wiki/index.php/Slicer3.2:Training>



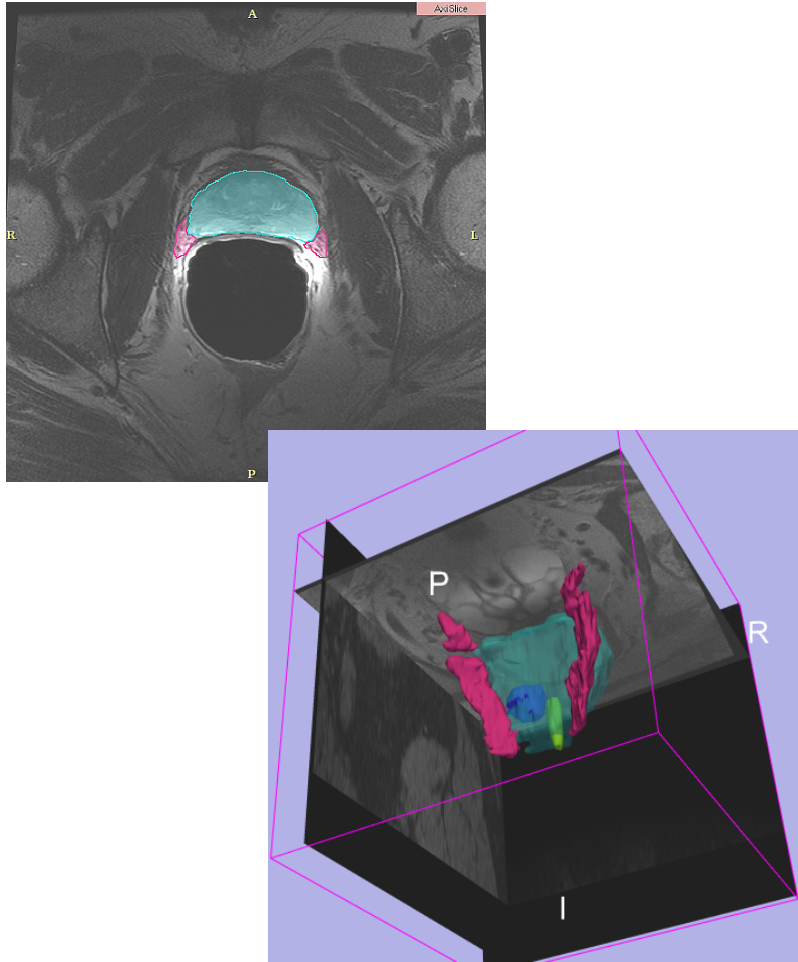
This tutorial requires the installation of the **Slicer3** software and the tutorial dataset. They are available at the following locations:

- **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.*



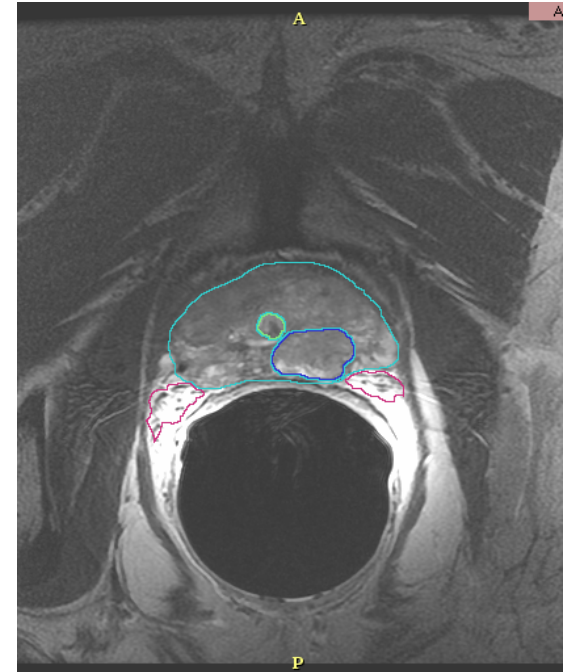
1. MR-guided prostate interventions: clinical background
2. Registering pre-operative & intra-operative prostate MR images using deformable B-spline registration
3. Manual segmentation of images
4. Creating 3D models from segmentations



# MR-guided prostate interventions: clinical background

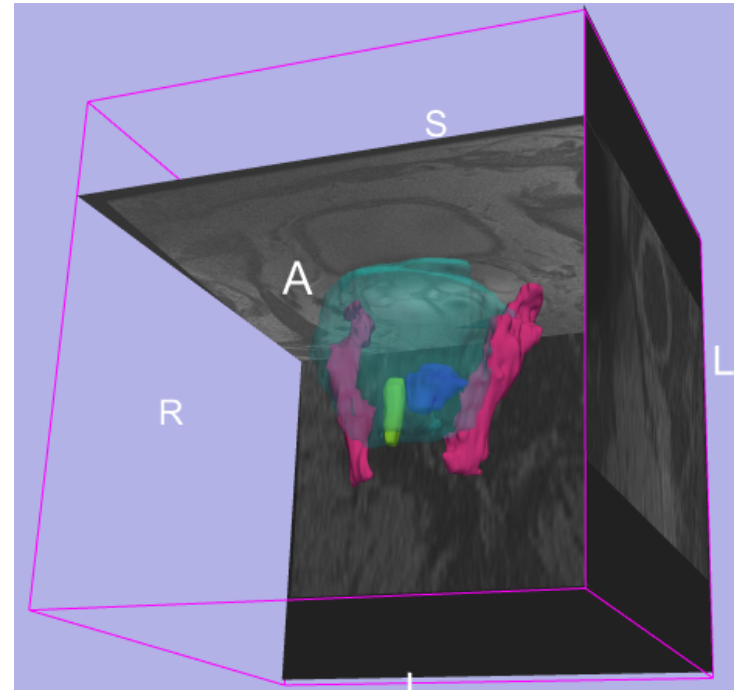
# Prostate cancer

- 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

- **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*

---

## *pre-operative*

pre-operative  
MR imaging  
(high quality)

(optional)  
segmentation  
model making

## *registration*

---

- compensates for
- change in patient position
  - presence/absence of endorectal coil

## *intra-operative*

intra-operative  
MR imaging  
(lower quality)

**Guidance based on  
intra-operative  
image fused with  
higher quality pre-  
operative image and  
models of important  
structures**



# The Prostate MR Image Database

<http://prostatemrimage database.com>

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



**Prostate MR Image Database**

Welcome!

**Getting Started**

- Get right to it... view the [image database!](#)
- Browse clinically relevant [top-image data](#) related to the cases in the database.
- [Scope and Purpose](#) of this database.
- [Frequently asked questions](#).
- [What's new](#) in the database.
- [Glossary](#) of terms used.

**For Clinicians**

- [Background](#) and introduction to prostate MR imaging.
- Overview of the ongoing [Image Guided Therapy Program](#) at Brigham and Women's Hospital, including multi-media presentations.
- A selection of [interesting cases](#) from the database.
- A [bibliography](#) for prostate MR imaging and image-guided therapy.

**For Scientists and Engineers**

- Technical details on the [image formats](#) used here.
- [Code](#) for reading the images and header information.
- [Slicer](#), the recommended platform for viewing and processing image volumes.
- [Other Code](#) for processing images, such as registration code.

**Other Relevant Links**


- A database of [publications](#) from our group.
- [Alliance](#) (sponsors and external collaborators).
- [External links](#) related to prostate disease, imaging and therapy.

**Privacy Statement and Acknowledgements**

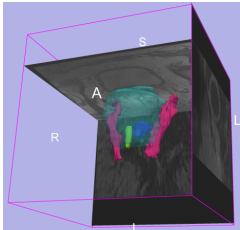


**Prostate MR Image Database**

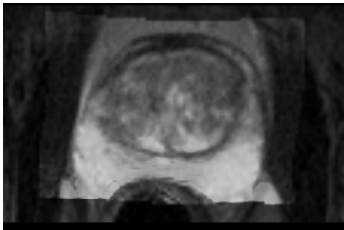
Patient/Exam List

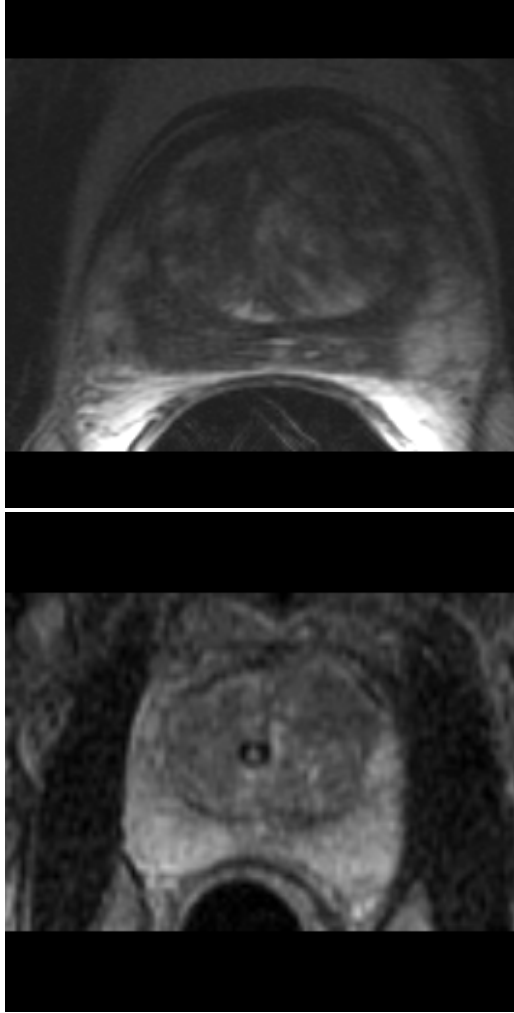


Patient	Exam	Exam Description	Number Of Series	Exam Date	View	Download
000001	00001	PROSTATE BIOPSY	2	Day 42	View	Download
000001	00002	PROSTATE	5	Day 1	View	Download
000002	00001	BRACHYTHERAPY	1	Day 59	View	Download
000002	00002	PROSTATE	5	Day 1	View	Download
000003	00001	BRACHYTHERAPY	1	Day 255	View	Download
000003	00002	PROSTATE STAGING	5	Day 1	View	Download
000004	00001	PROSTATE BX	2	Day 36	View	Download
000004	00002	PROSTATE	9	Day 1	View	Download
000005	00001	BRACHYTHERAPY	2	Day 114	View	Download
000005	00002	PROSTATE	5	Day 1	View	Download
000006	00001	BRACHYTHERAPY	1	Day 148	View	Download
000006	00002	PROSTATE	5	Day 1	View	Download
000007	00001	PROSTATE BX	2	Day 1	View	Download
000008	00001	BRACHYTHERAPY	1	Day 93	View	Download
000008	00002	PROSTATE	5	Day 1	View	Download
000009	00001	BRACHYTHERAPY	1	Day 72	View	Download
000009	00002	PROSTATE W/ SPEC	4	Day 1	View	Download
000010	00001	BRACHYTHERAPY	2	Day 77	View	Download



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

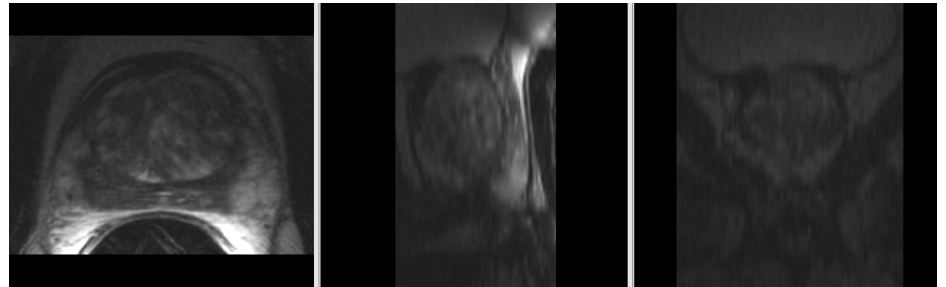
# Image Registration

---

- 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



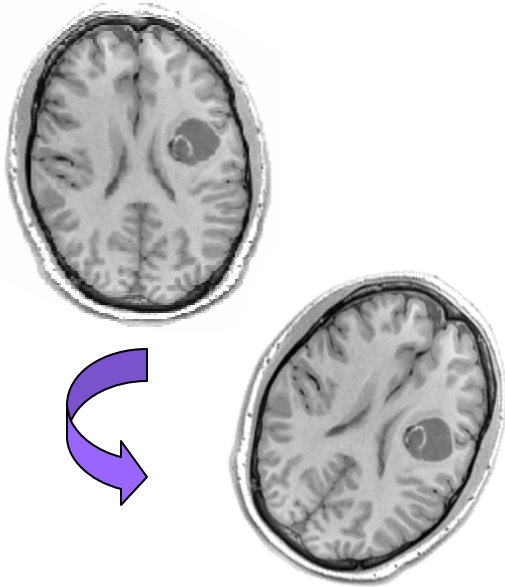
## Intra-operative

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



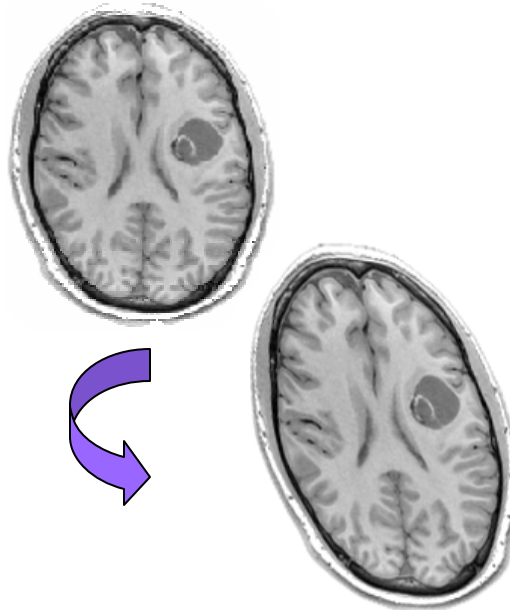
# Three transformation models

## Rigid



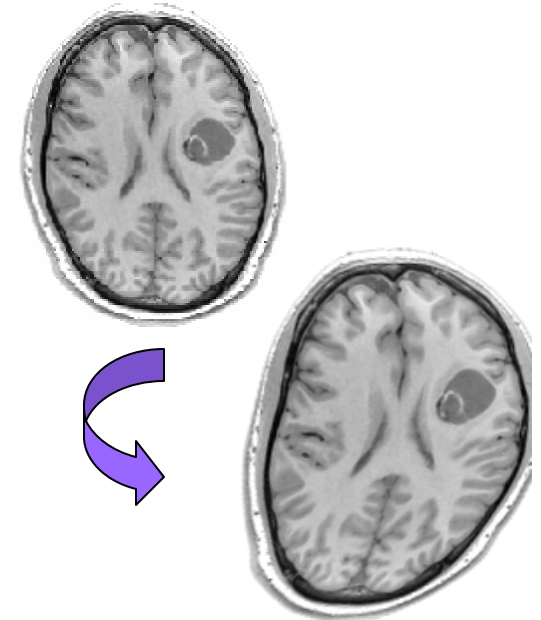
- Translation
- Rotation

## Affine



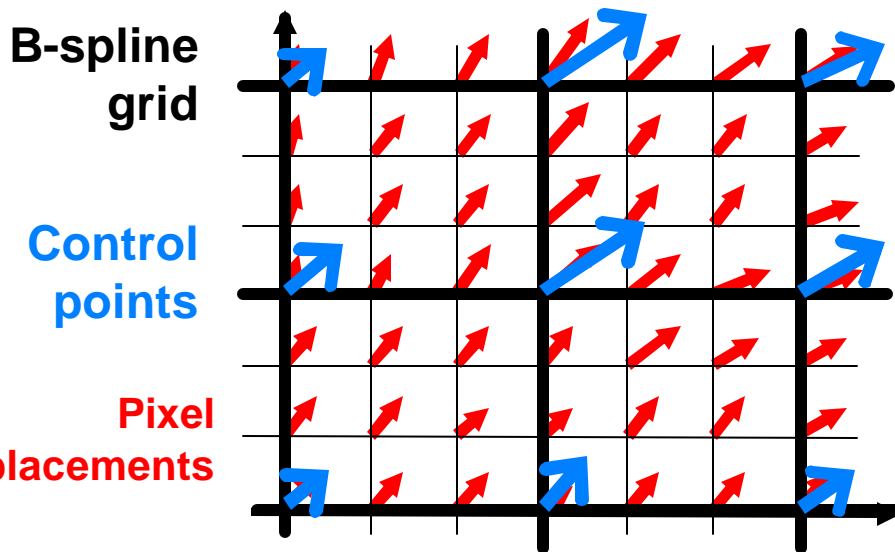
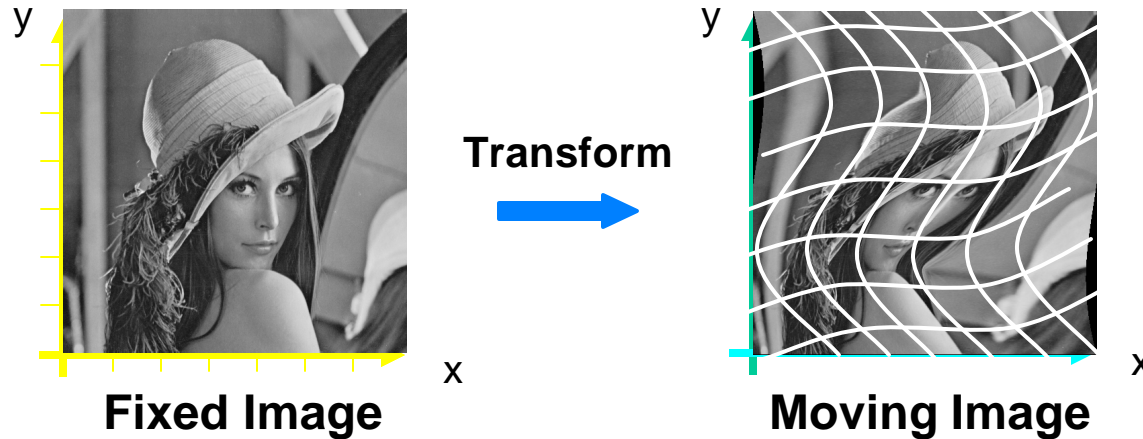
- Translation
- Rotation
- Stretch
- Shear

## Non-rigid



- Non-linear, e.g. spline-based, elastic/ fluid models

# Deformable B-spline registration

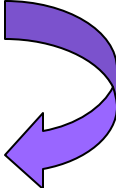



## ***B-splines in Slicer3:***

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

# Registration Steps

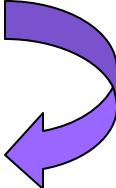

---

- Load the image volumes
- Initial manual rigid transformation  *Initializes transform*
- Automatic affine registration
- Automatic deformable B-spline registration  *Initializes transform*



# Registration Steps

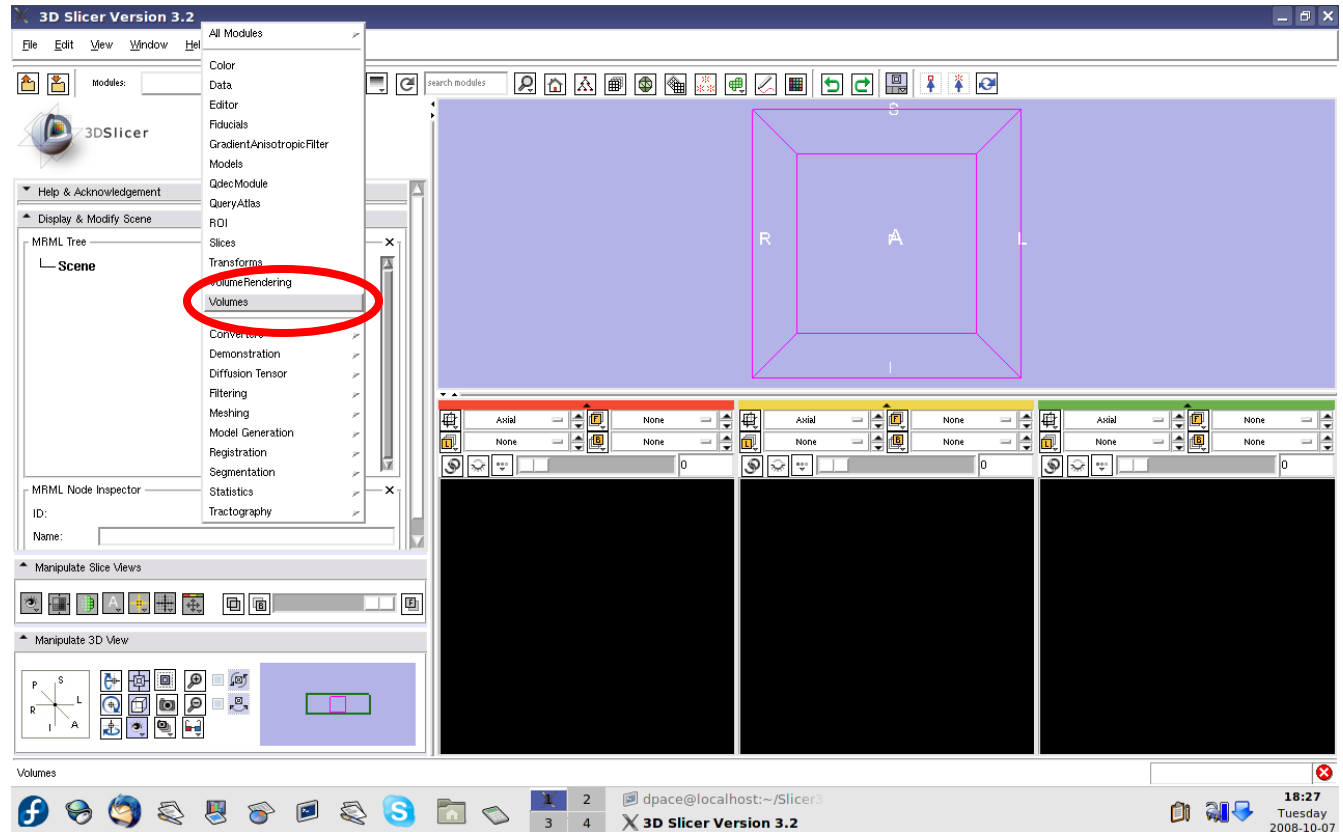
---

- Load the image volumes
- Initial manual rigid transformation  *Initializes transform*
- Automatic affine registration
- Automatic deformable B-spline registration  *Initializes transform*

# Load the image volumes

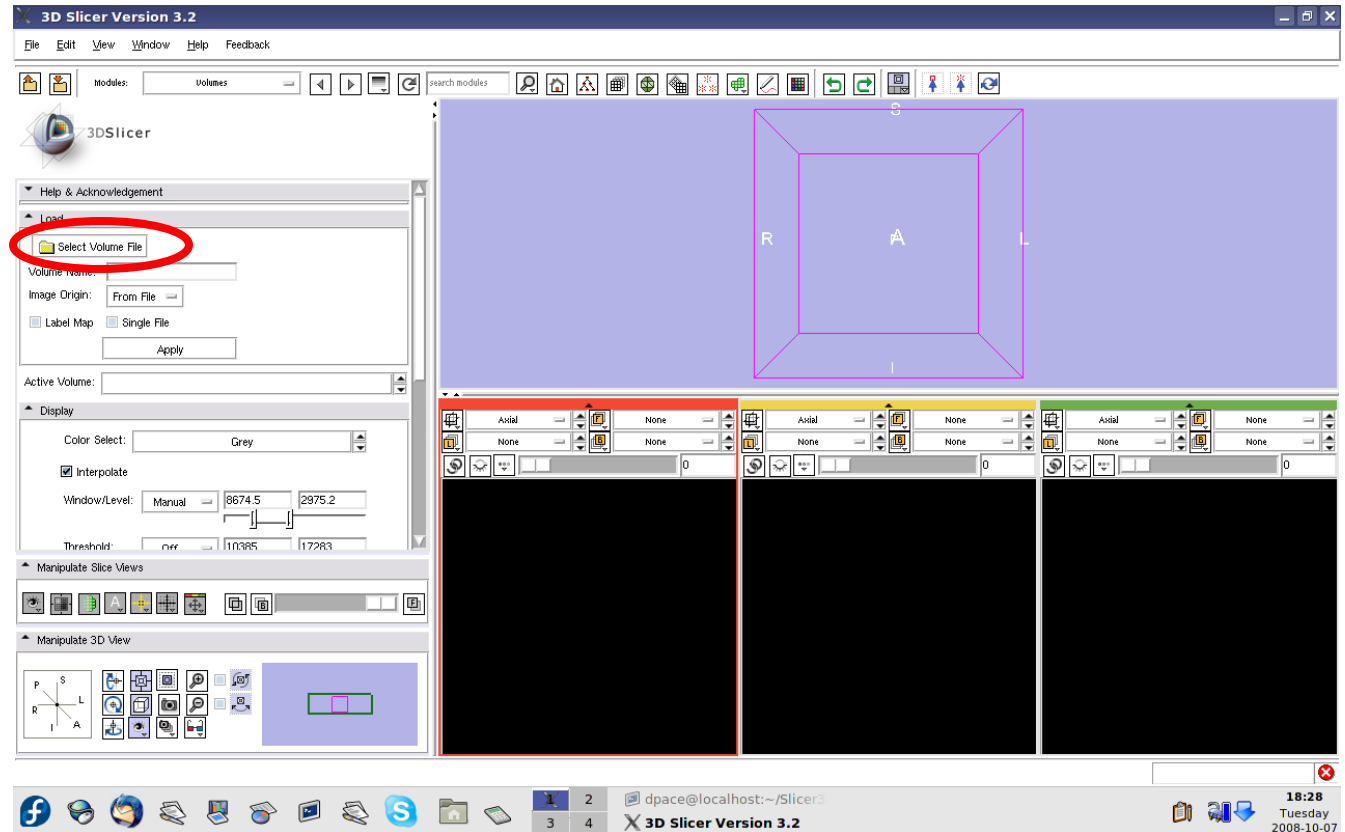
**Load the  
pre-operative  
image**

Open the  
Volumes  
Module



# Load the image volumes

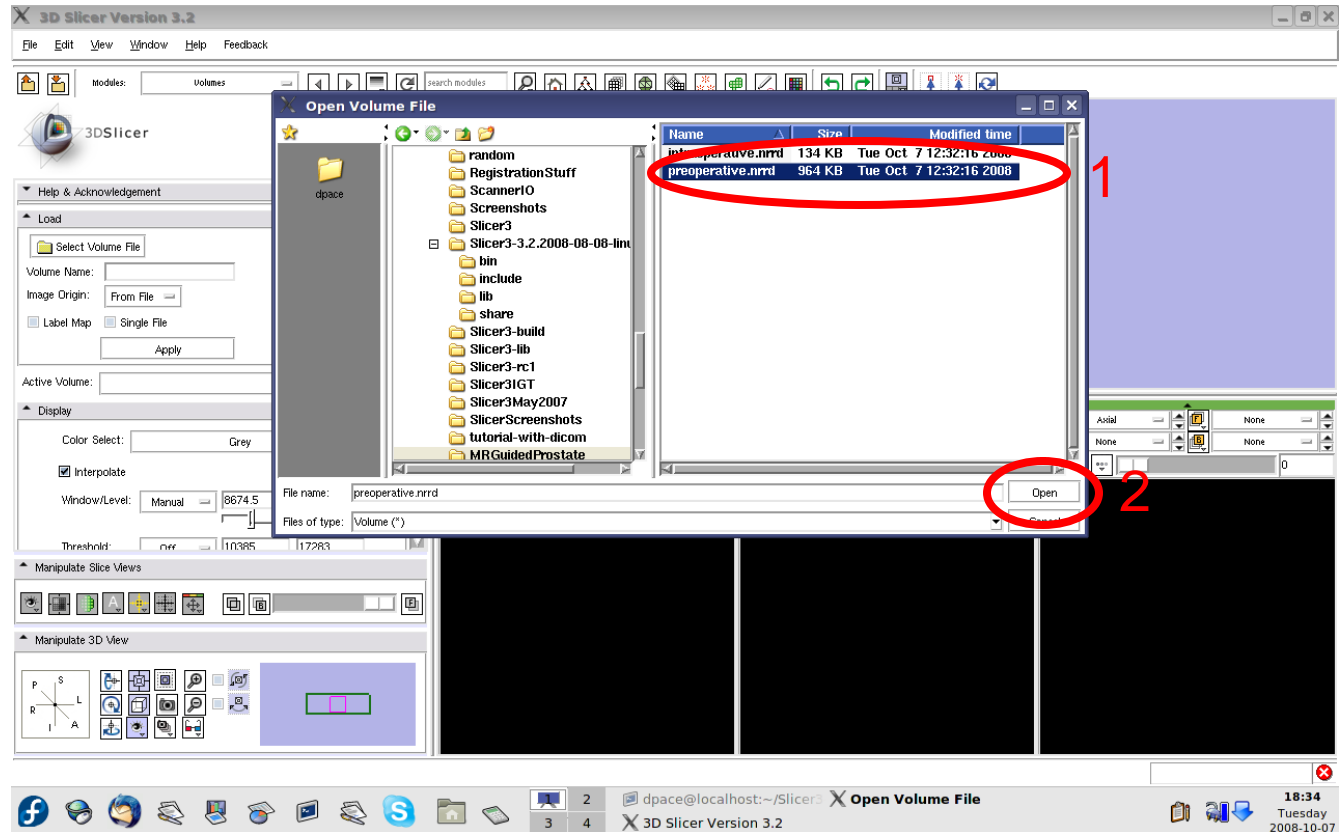
Click on “Select Volume File”



# Load the image volumes

Select the  
pre-operative  
image:  
preoperative.nrrd

Click “Open”



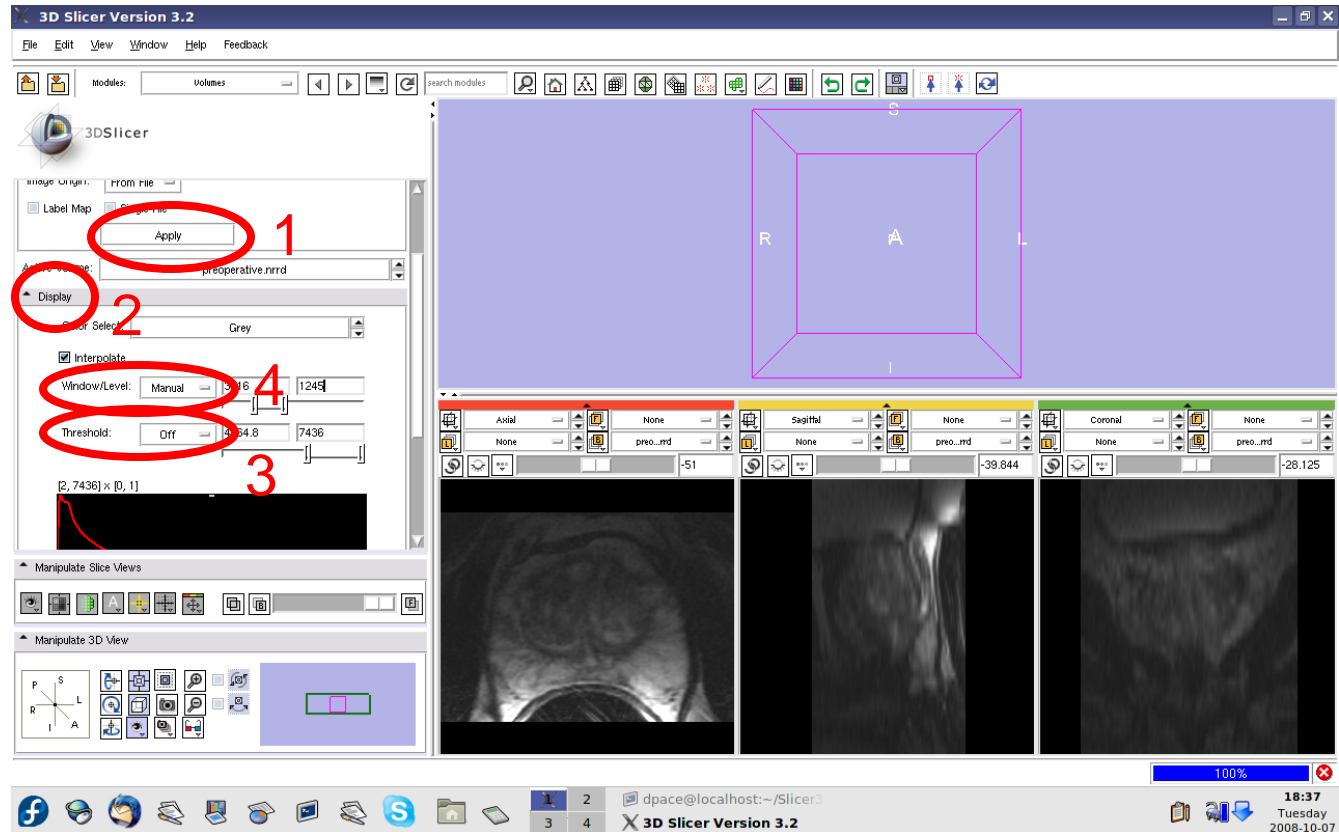
# Load the image volumes

Click “Apply”

Expand the Display tab

Turn thresholding off

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

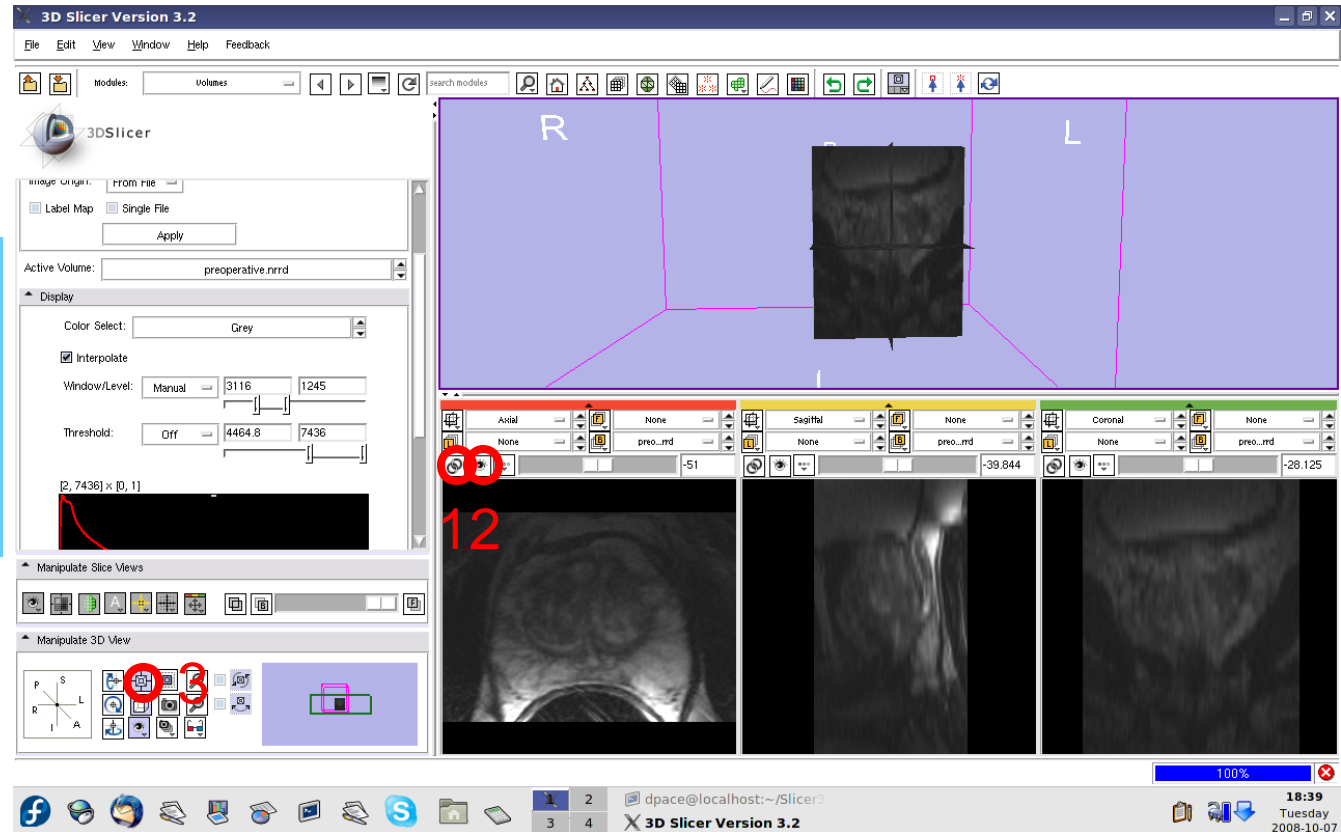


# Load the image volumes

Click on the slice control link button

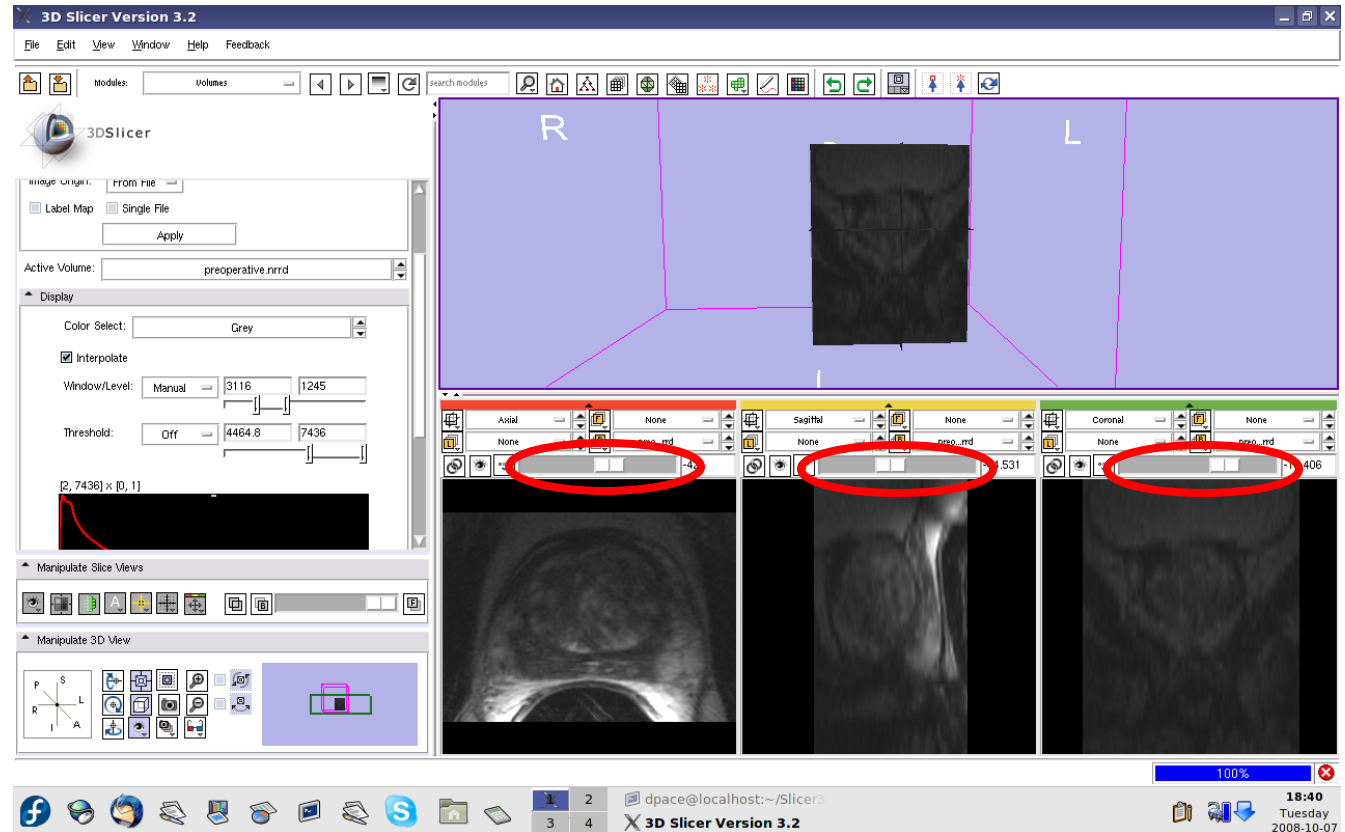
Toggle the slice visibility to see the slices in the 3D viewer

Center the 3D view on the scene and zoom in



# Load the image volumes

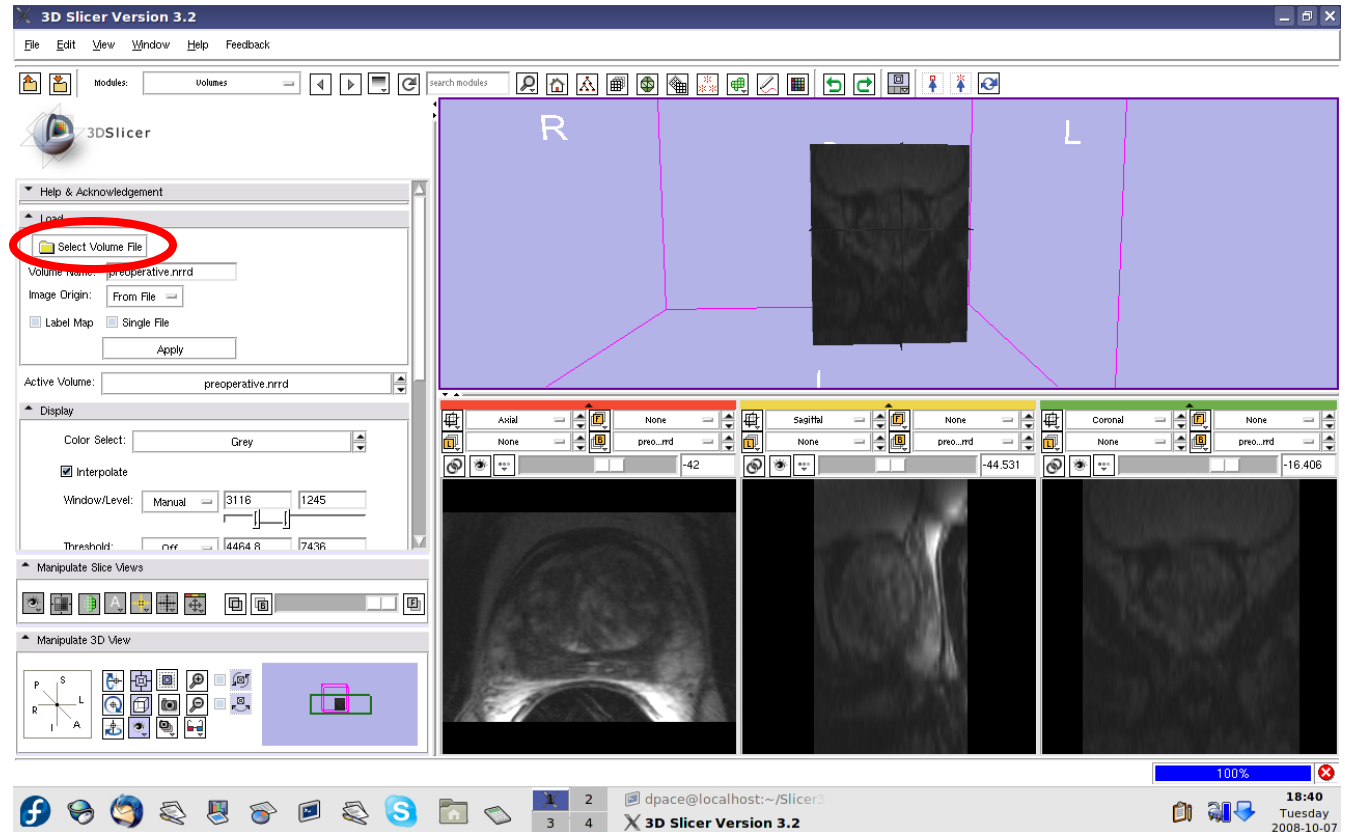
Use the slice selector sliders to explore the dataset



# Load the image volumes

## Load the intra-operative image

Click on “Select  
Volume File”

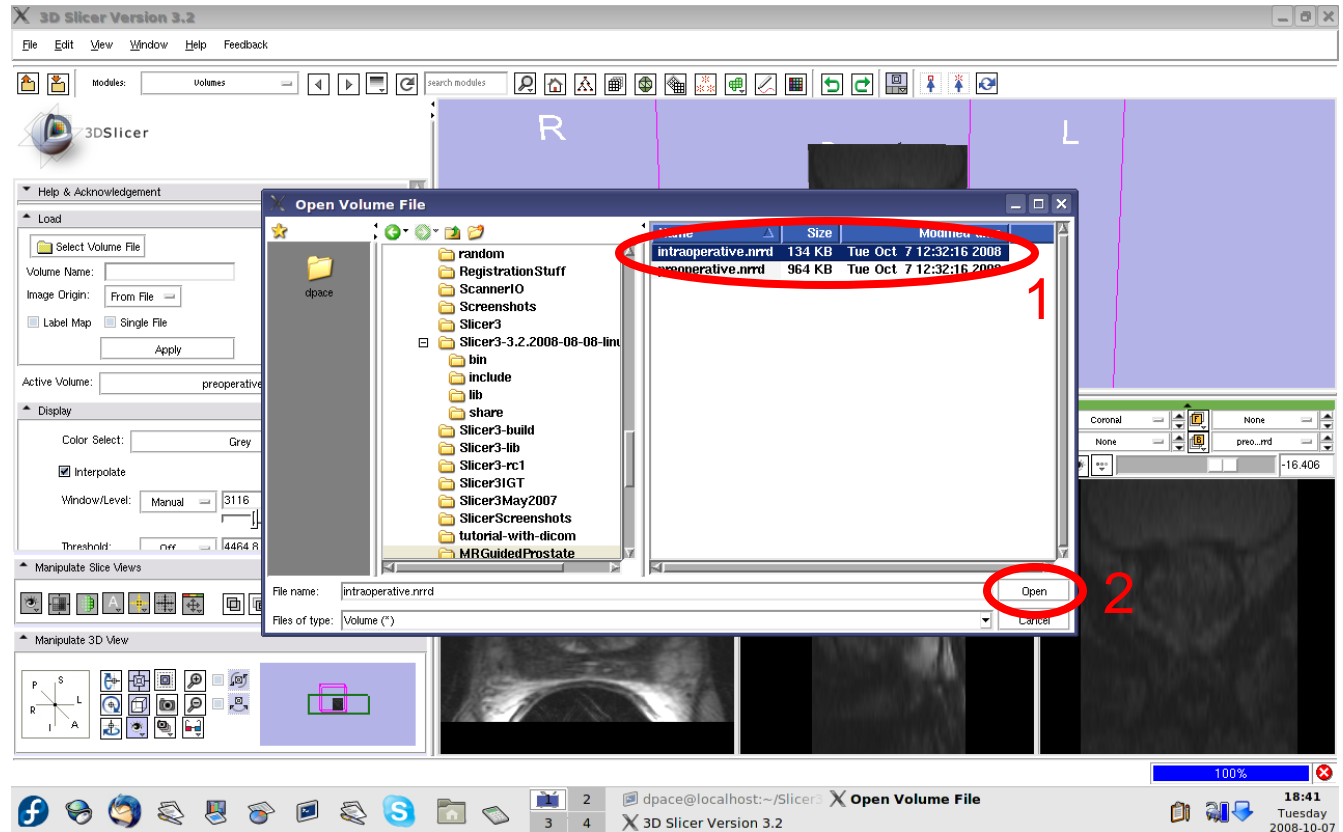




# Load the image volumes

Select the  
intra-operative  
image:  
intraoperative.nrrd

Click “Open”



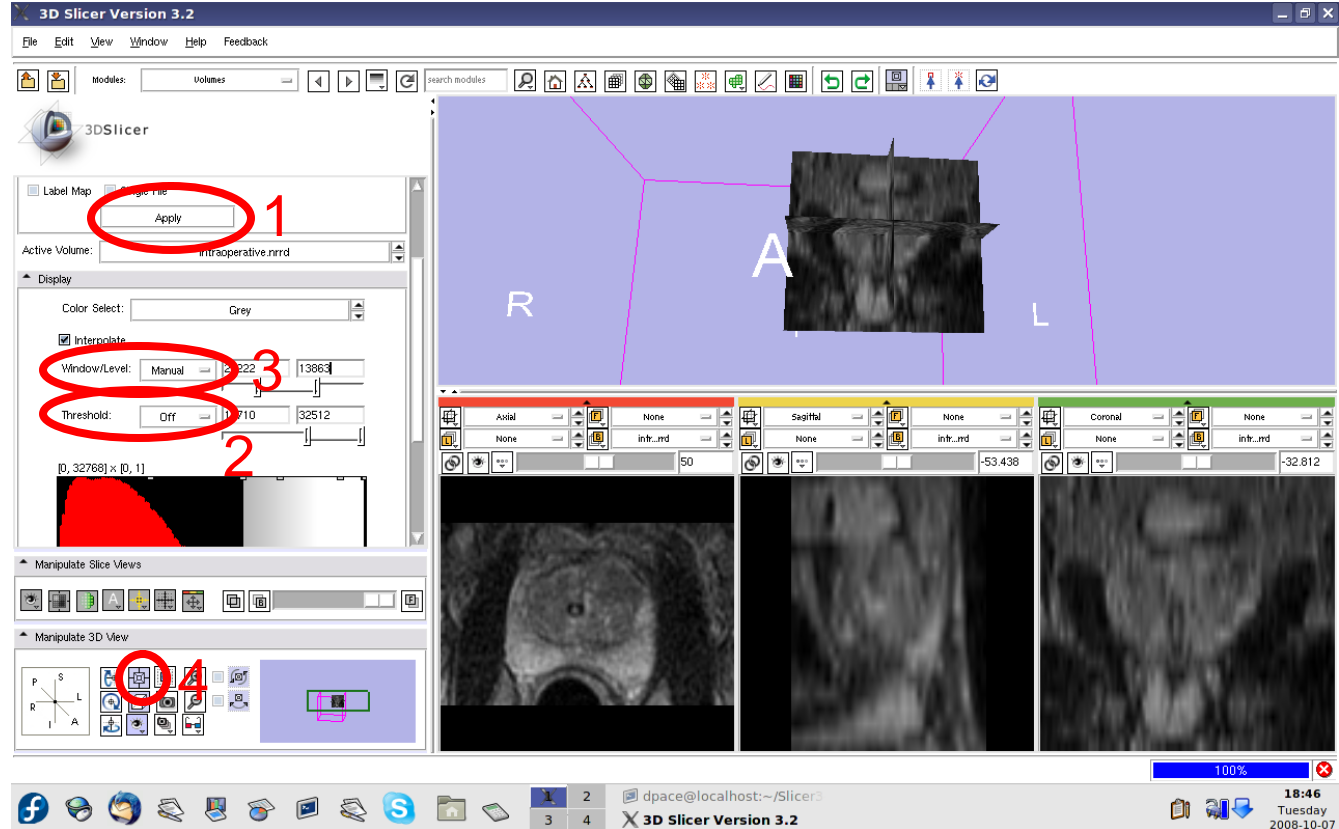
# Load the image volumes

Click “Apply”

Turn  
thresholding off

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

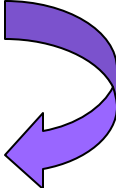

Center the 3D  
view on the  
scene





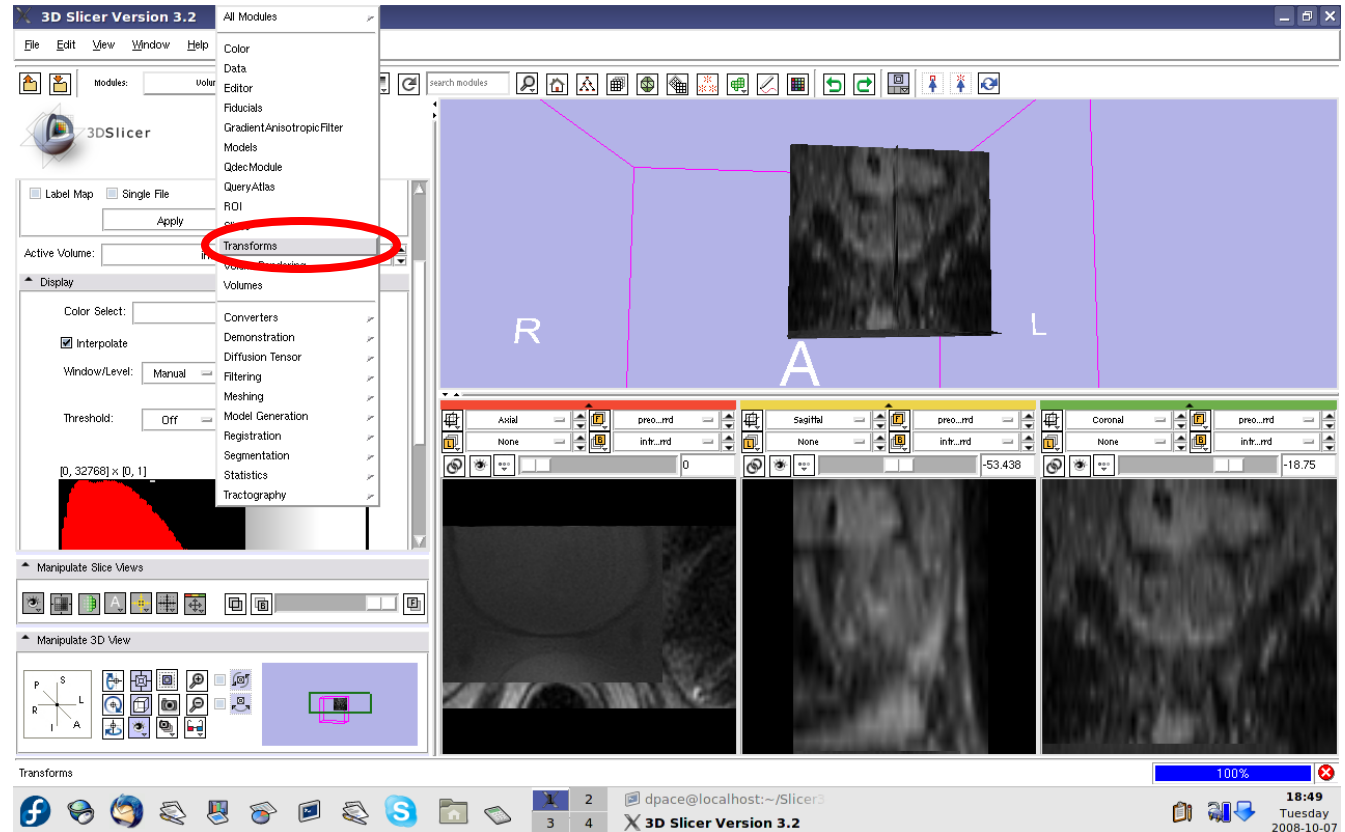
# Registration Steps

---

- Load the image volumes
- Initial manual rigid transformation  *Initializes transform*
- Automatic affine registration
- Automatic deformable B-spline registration  *Initializes transform*

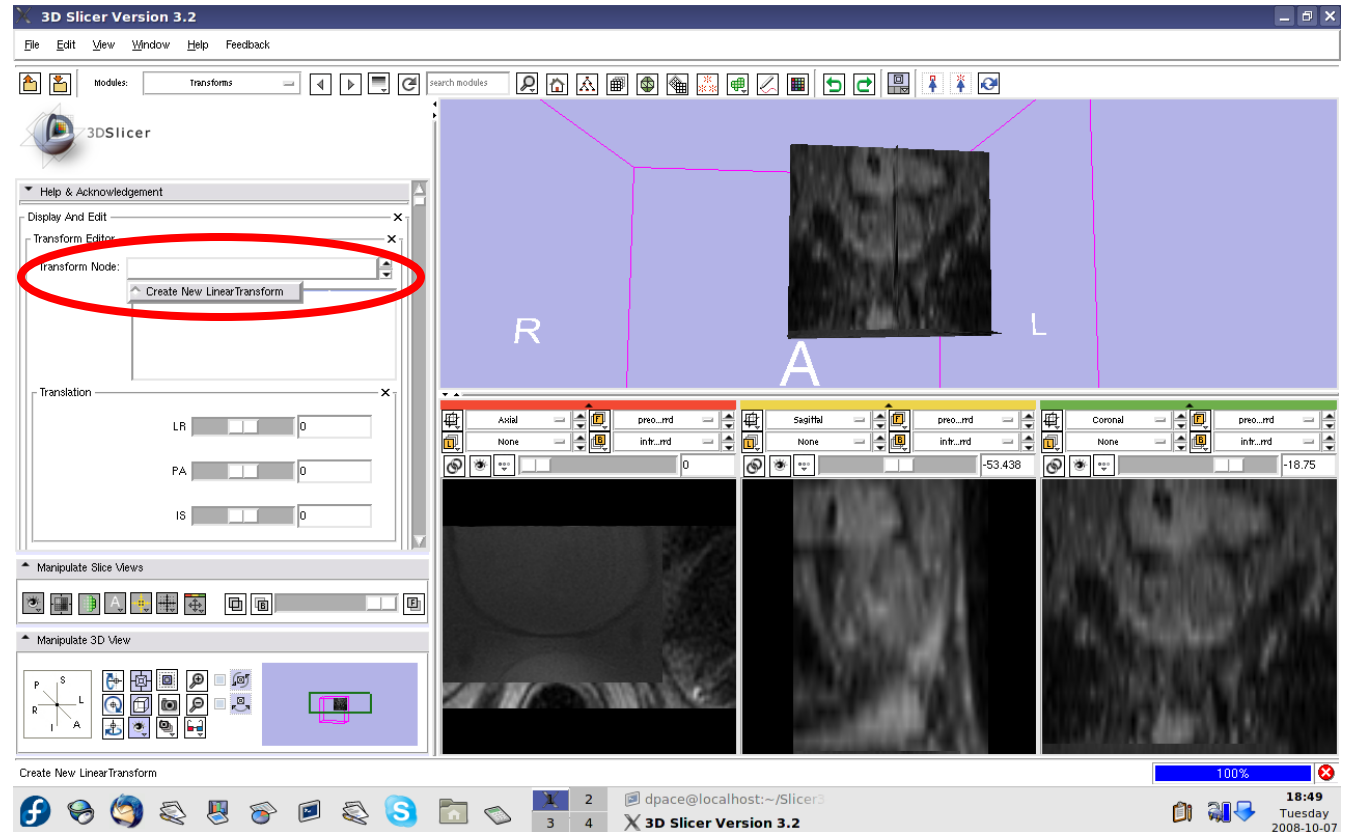
# Manual rigid transformation

Open the  
Transforms  
module



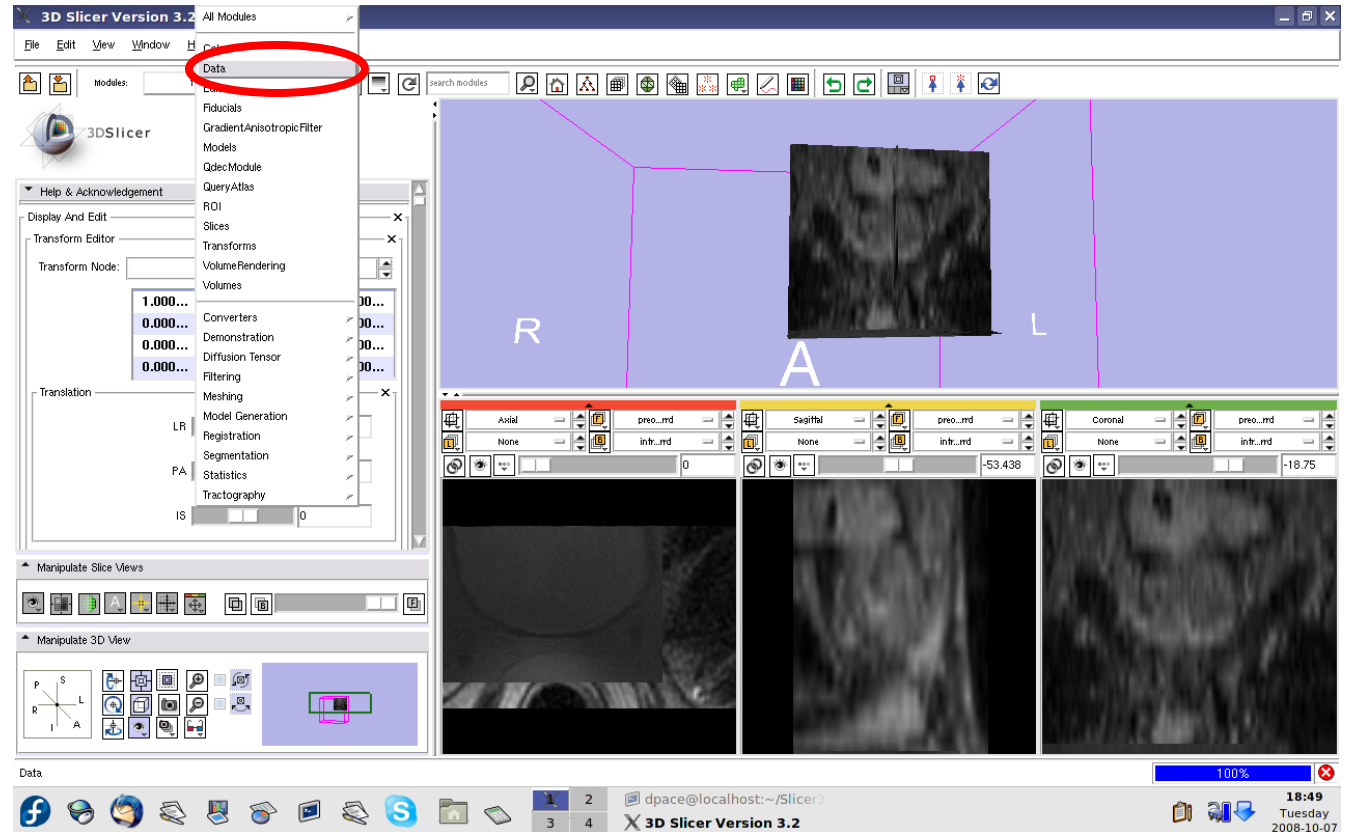
# Manual rigid transformation

Create a new linear transform



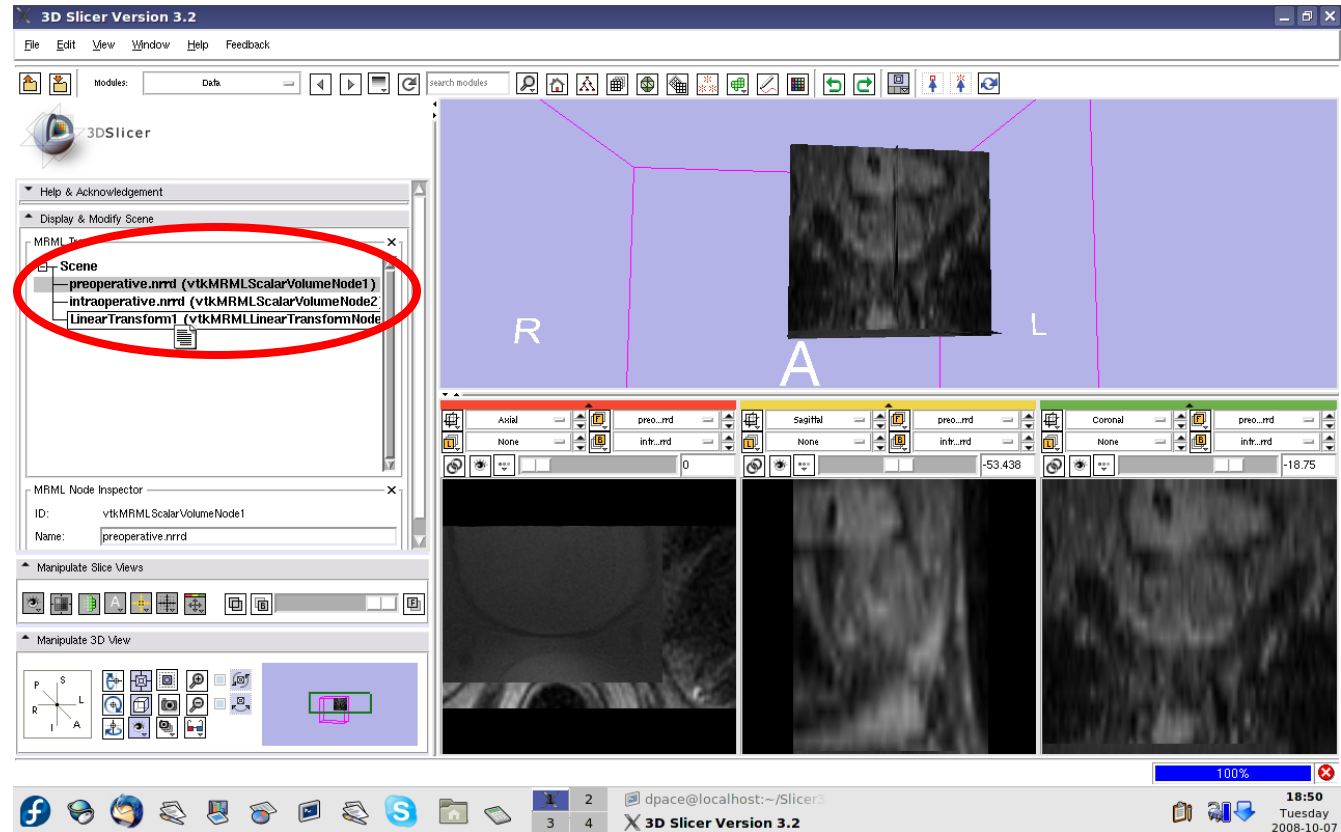
# Manual rigid transformation

Open the Data module



**Apply the manual rigid transformation to the pre-operative image**

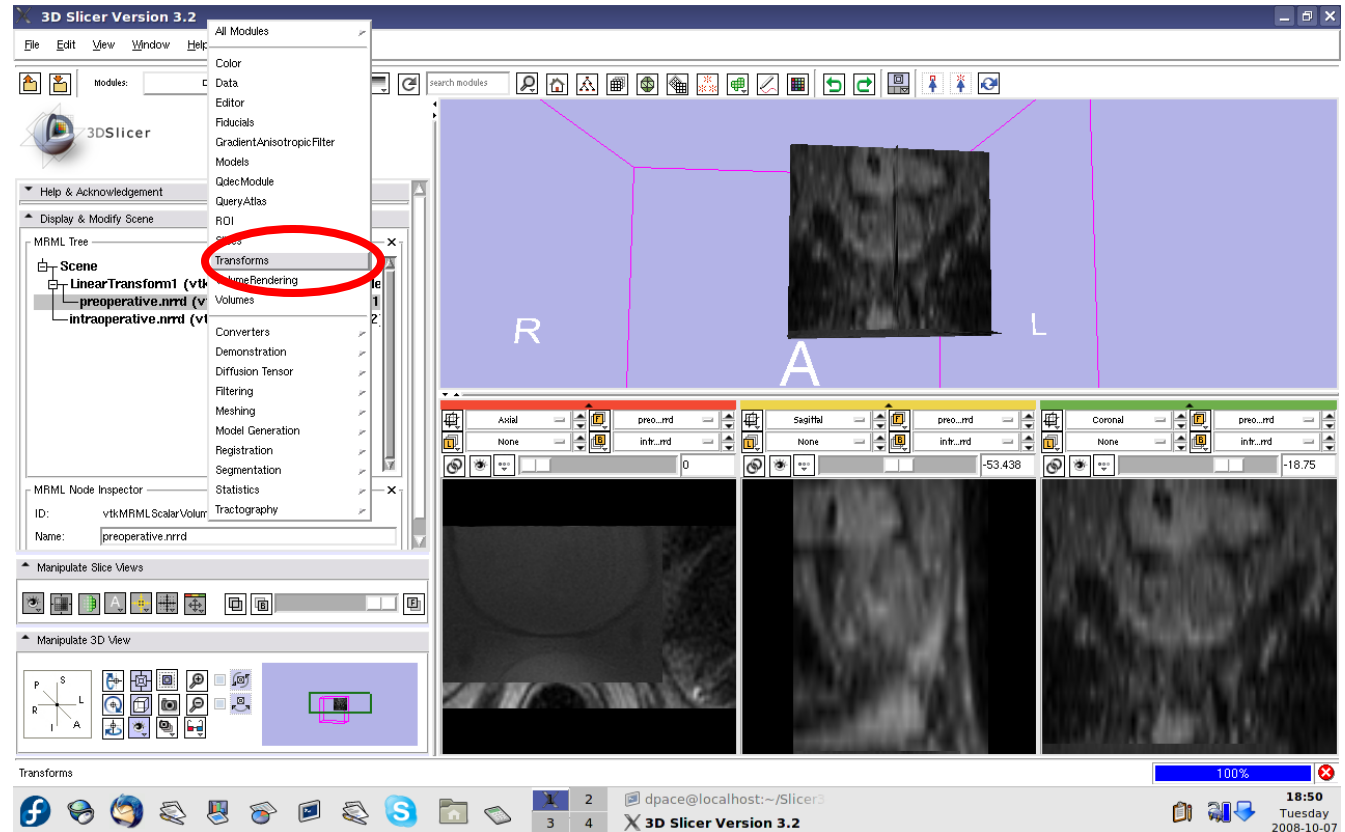
Drag the pre-operative image under the Linear Transform1 node





# Manual rigid transformation

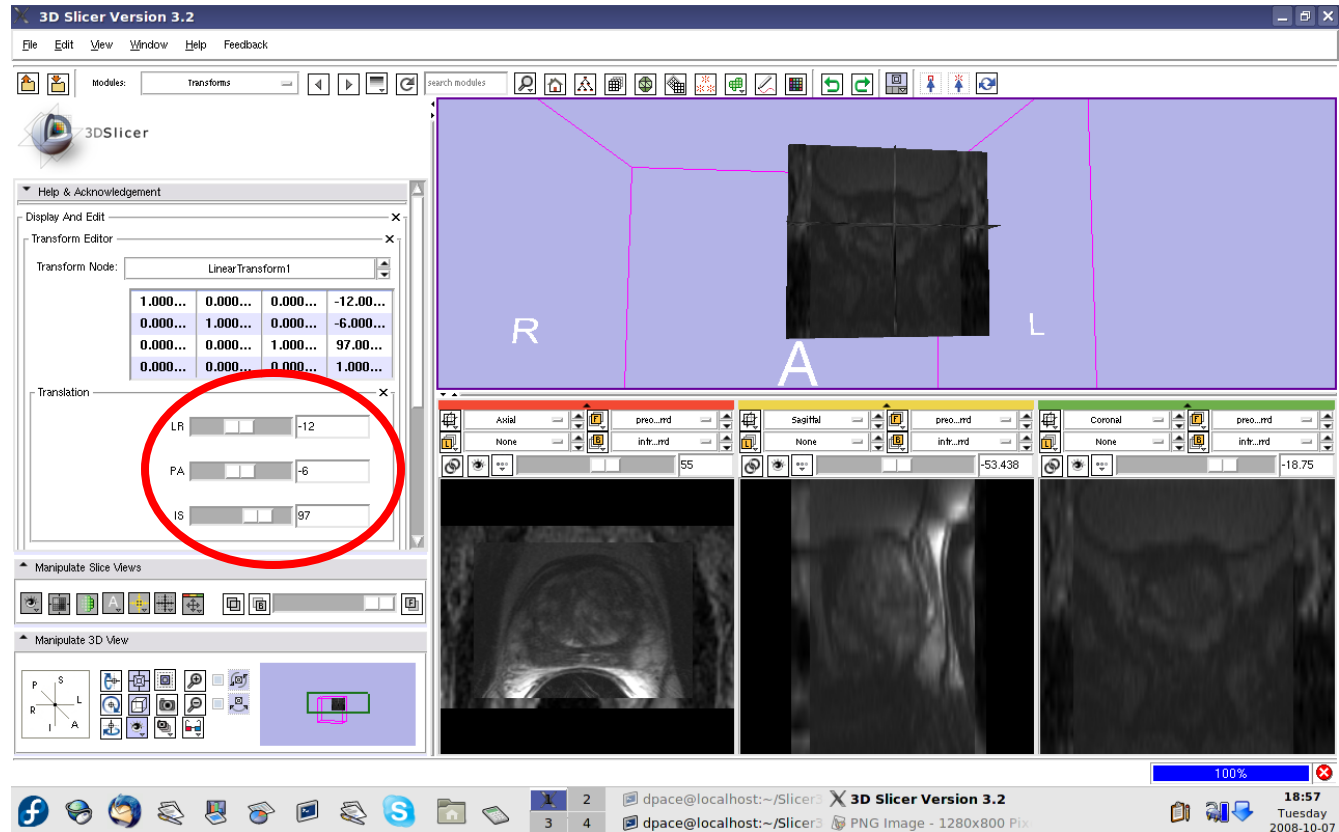
Open the  
Transforms  
module



# Manual rigid transformation

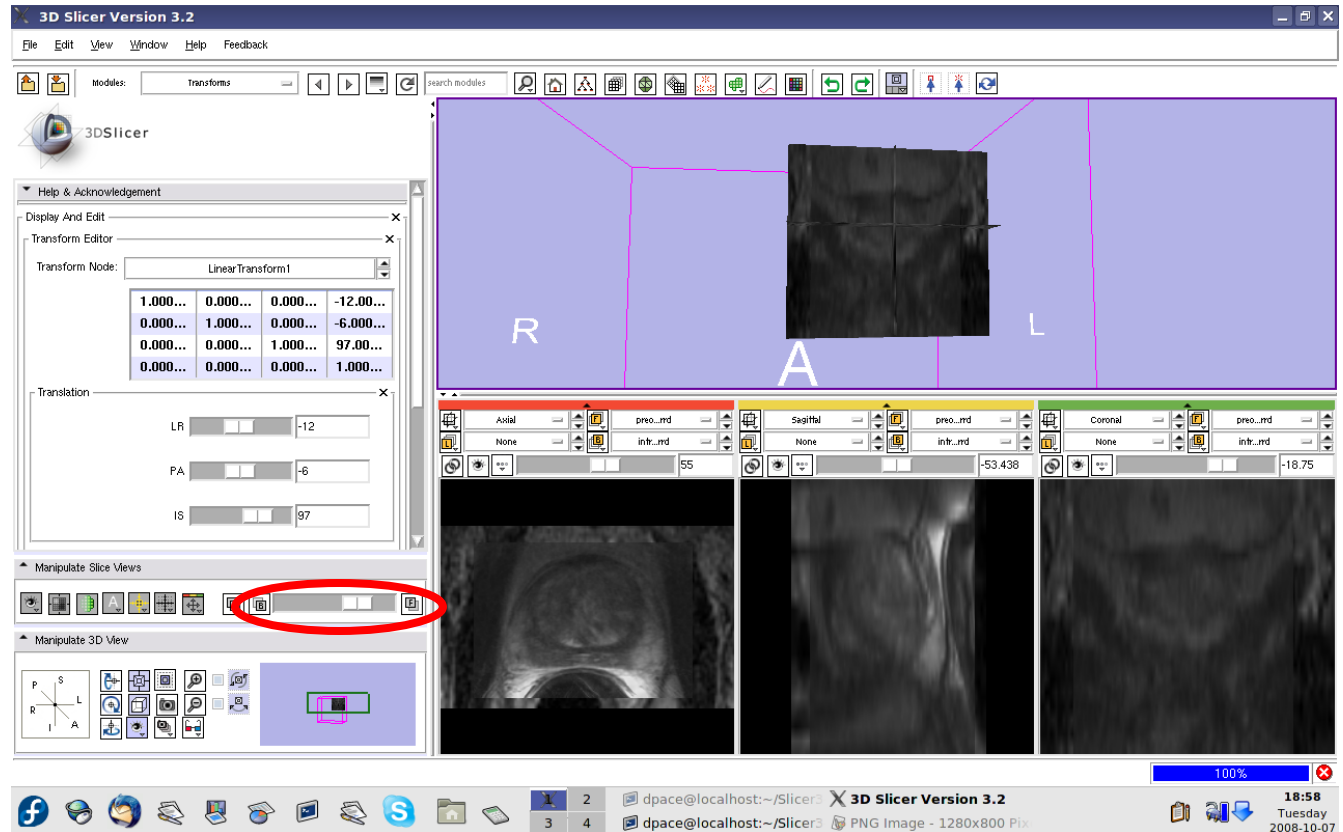
Manually adjust the translation and rotation parameters to align the two image volumes

**Recommended:**  
**Trans. LR: -12**  
**Trans. PA: -6**  
**Trans. IS: 97**  
**No rotation**



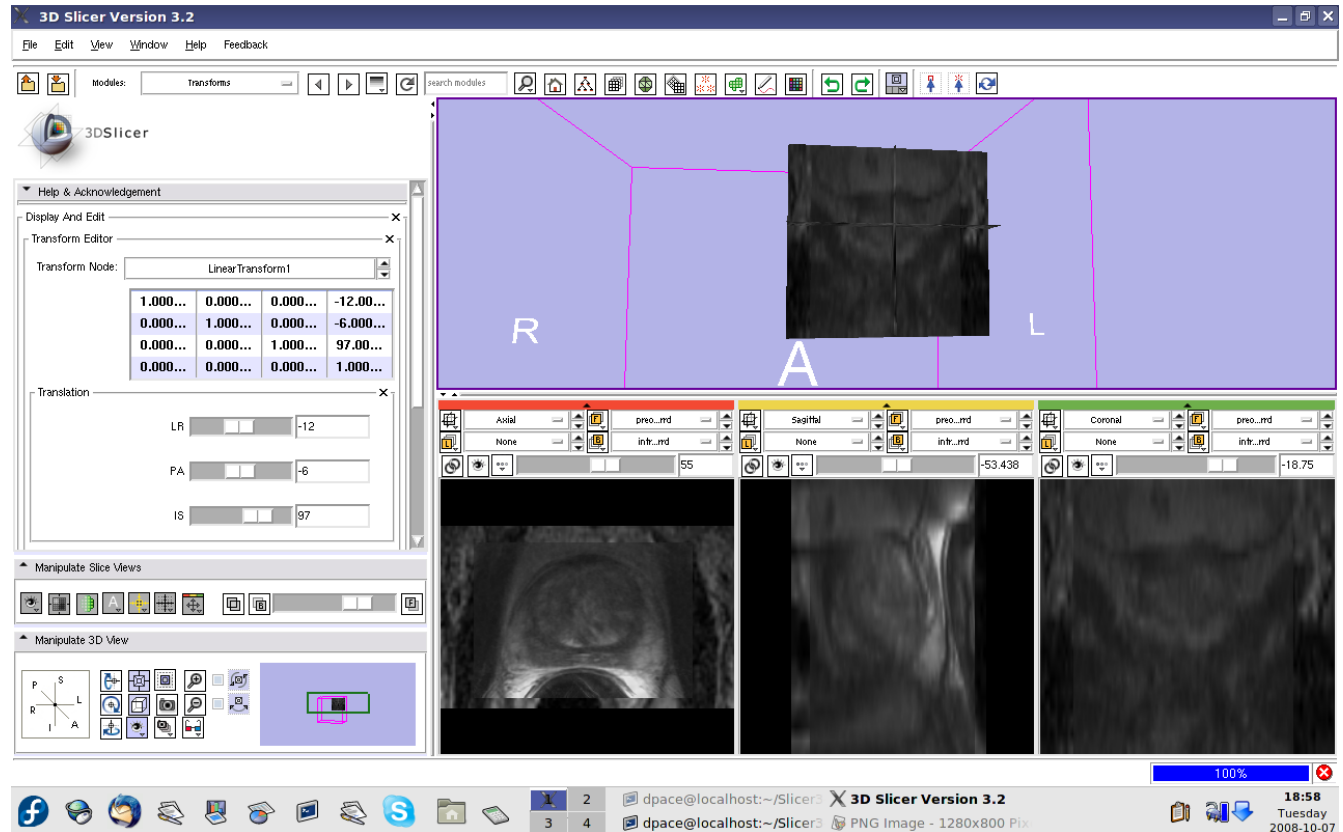
# Manual rigid transformation

Scale between the foreground and background to evaluate the alignment



# Manual rigid transformation

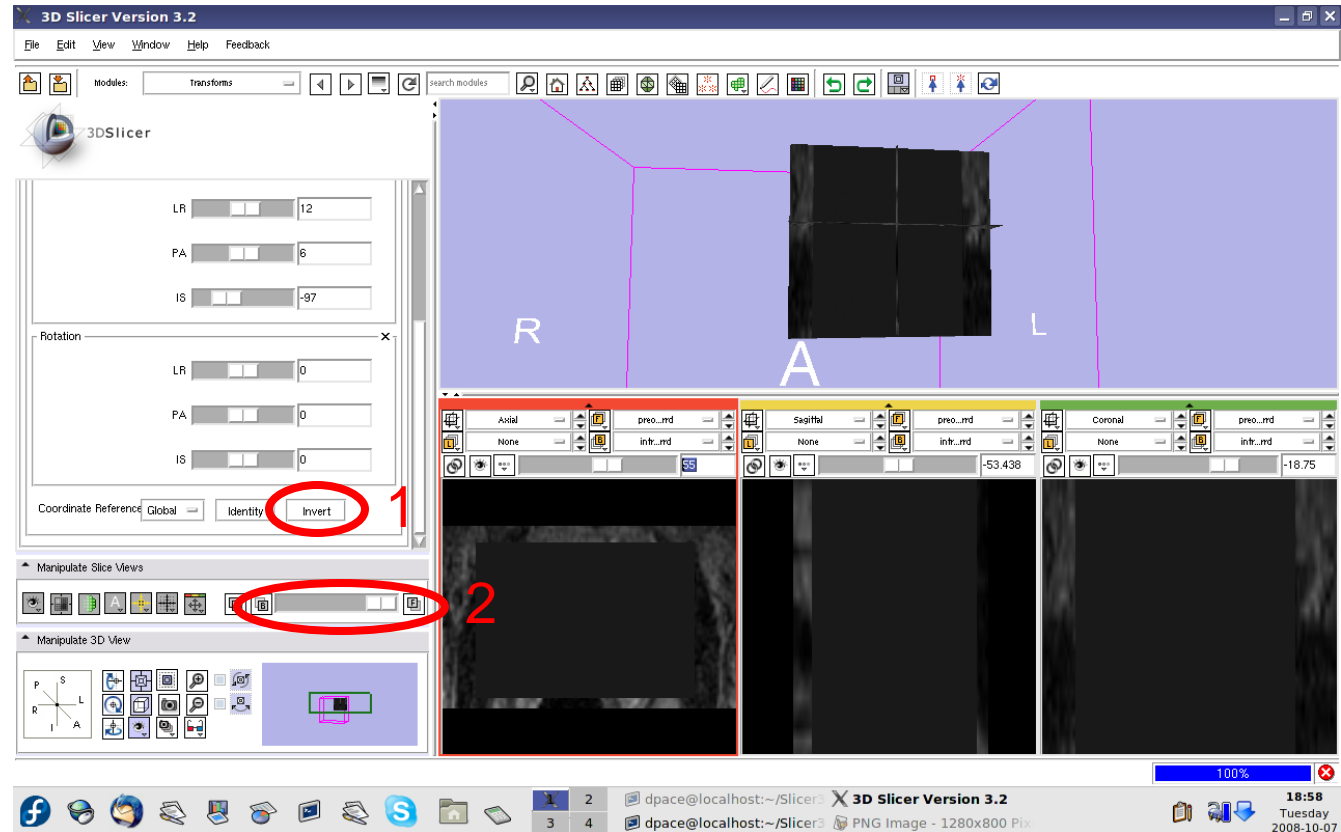
The initial transformation “pushes” the pre-operative image onto the intra-operative image, but Slicer’s registration algorithm expects the inverse



# Manual rigid transformation

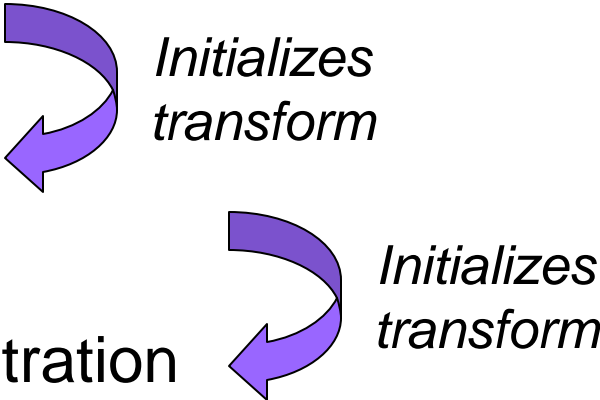
Click on the  
“Invert” button

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



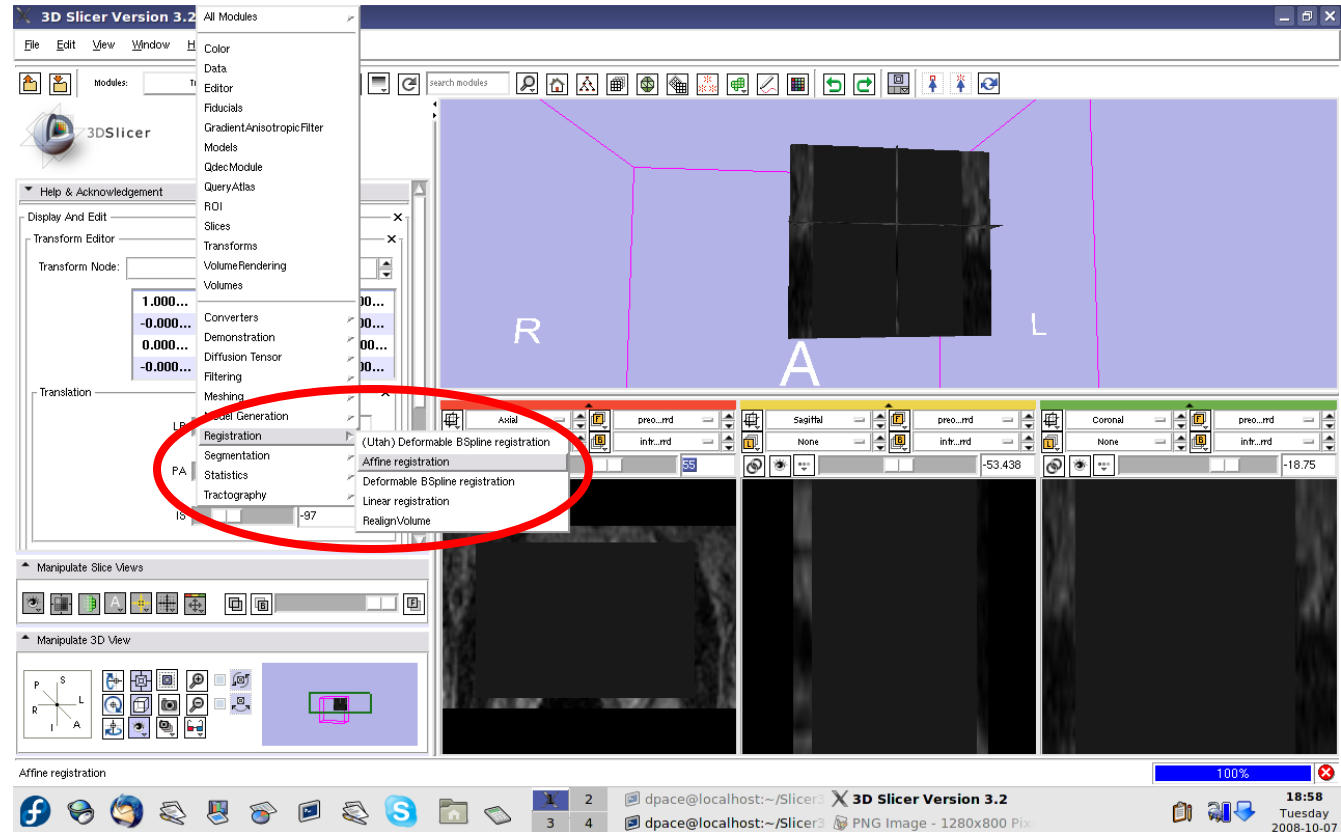
# Registration Steps

---

- Load the image volumes
  - Initial manual rigid transformation
  - Automatic affine registration
  - Automatic deformable B-spline registration
- 
- Initializes transform*
- Initializes transform*

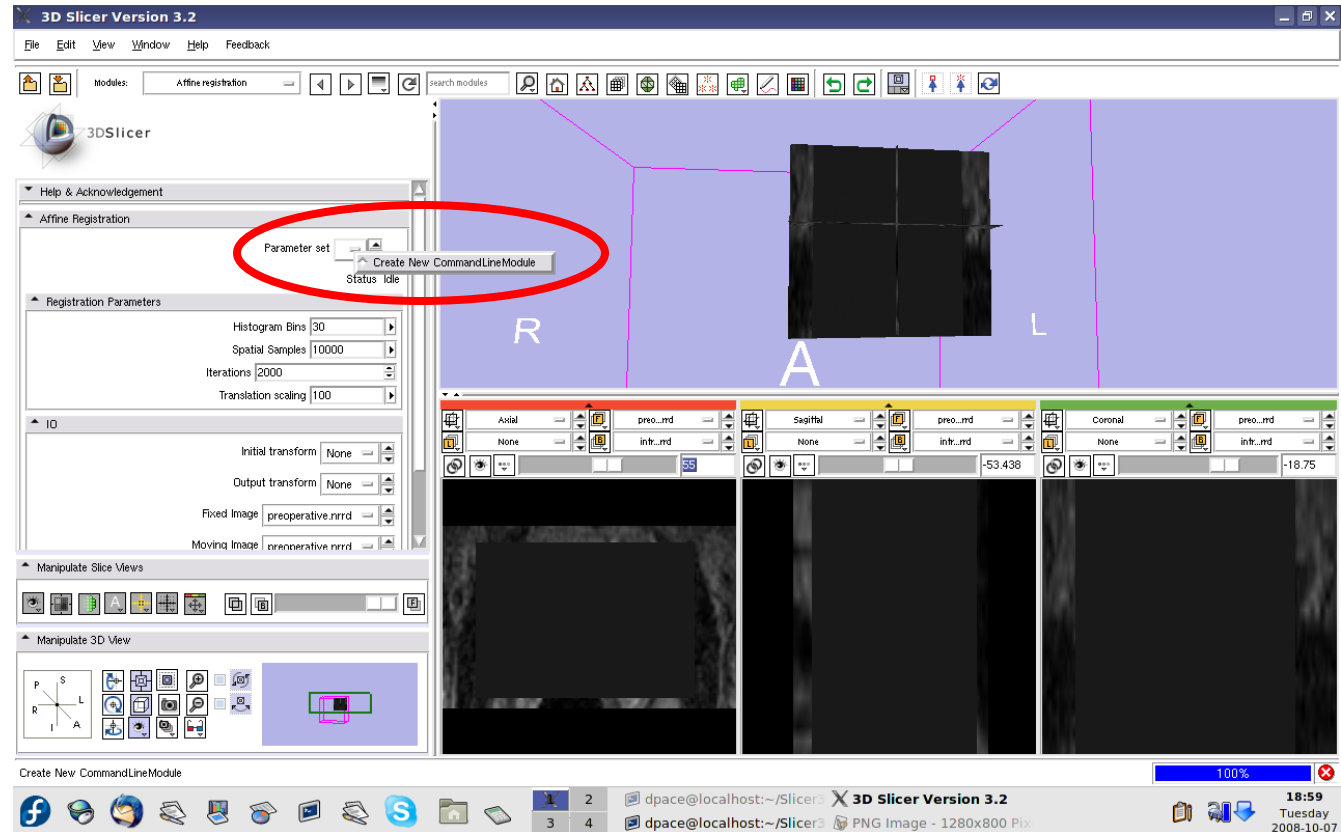
**Perform the  
affine  
registration**

Open the Affine  
Registration  
module



Create a new affine registration transform

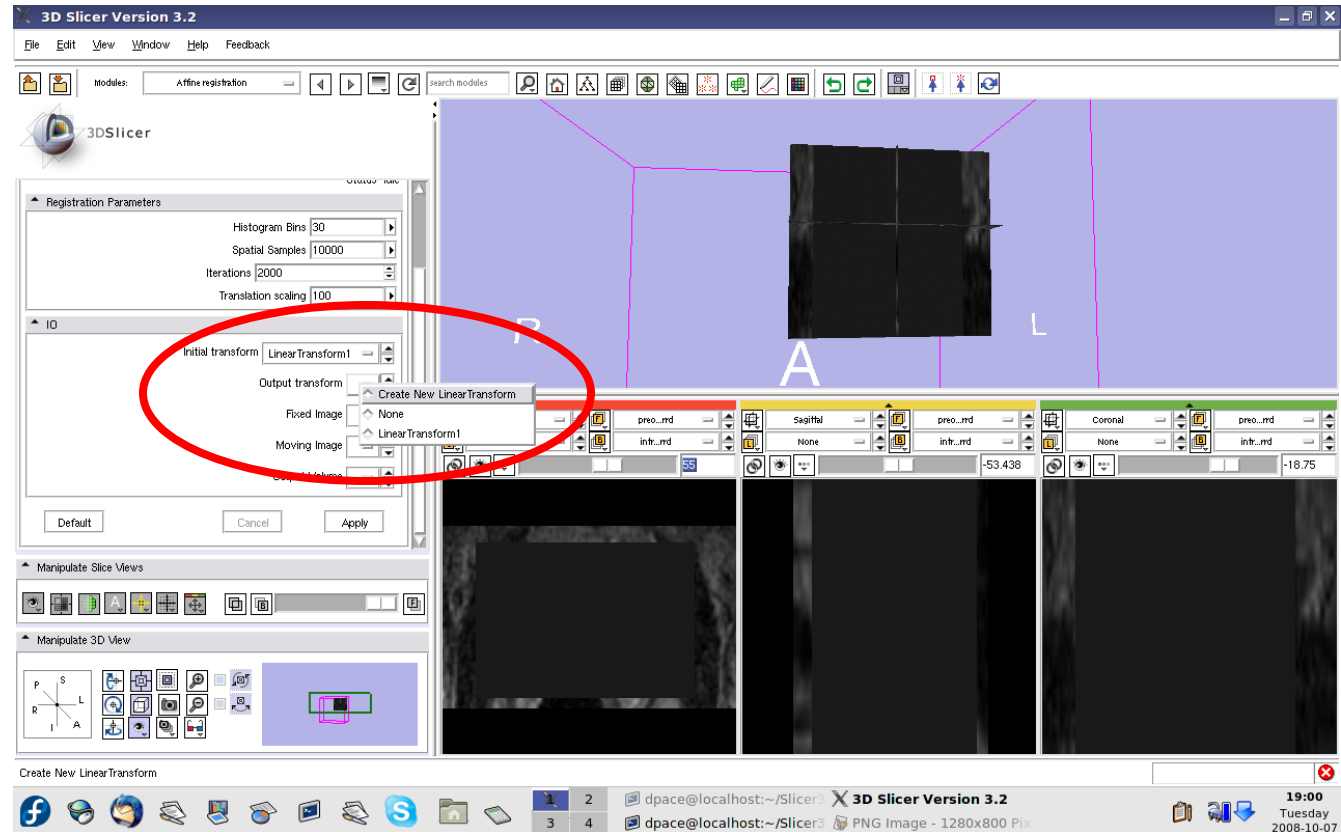
You do not need to change any of the registration parameters





**Initial  
transform:  
Linear  
Transform1**

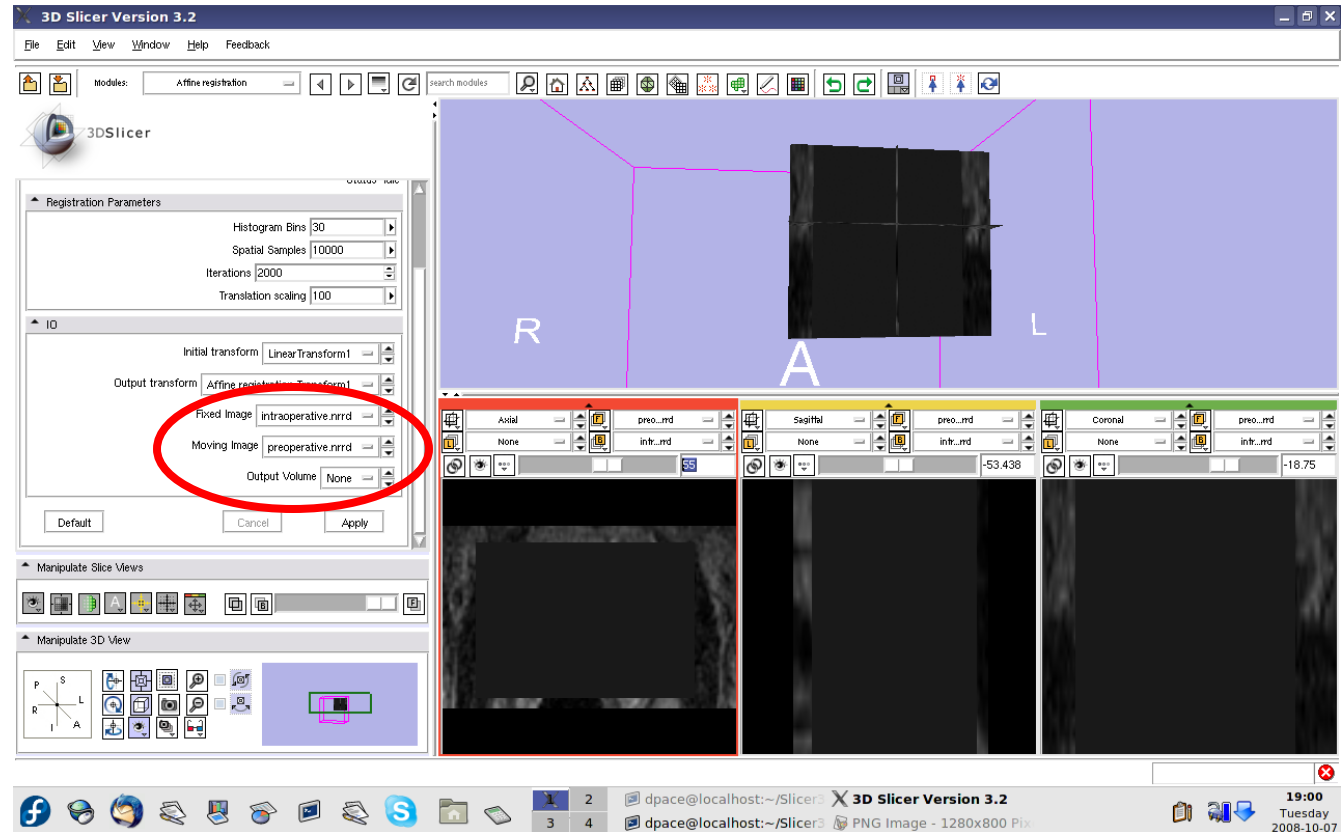
**Output  
transform:  
Create new  
linear transform**



**Fixed image:**  
intra-operative

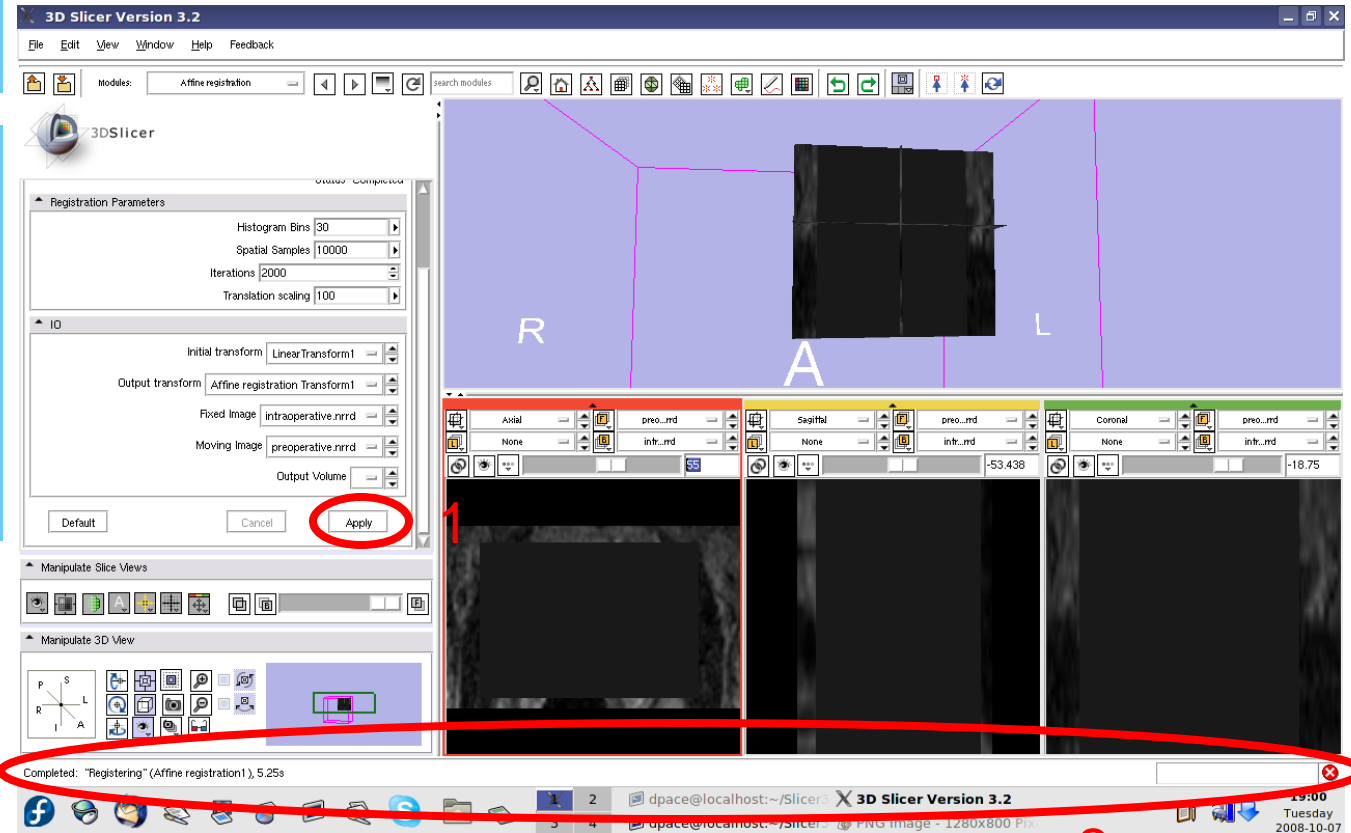
**Moving image:**  
pre-operative

**Output  
Volume:**  
None



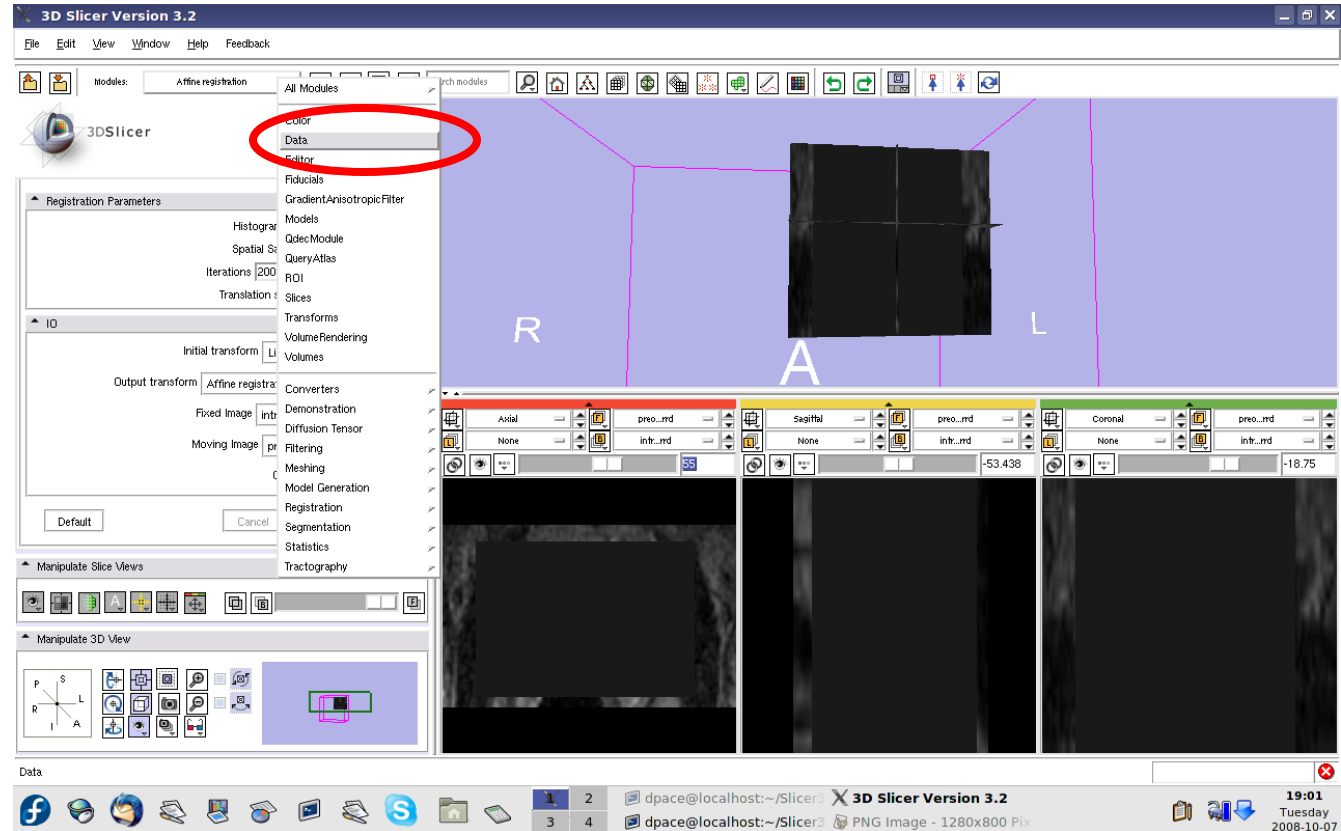
Click “Apply”

View the progress bar and wait until it says “Completed”

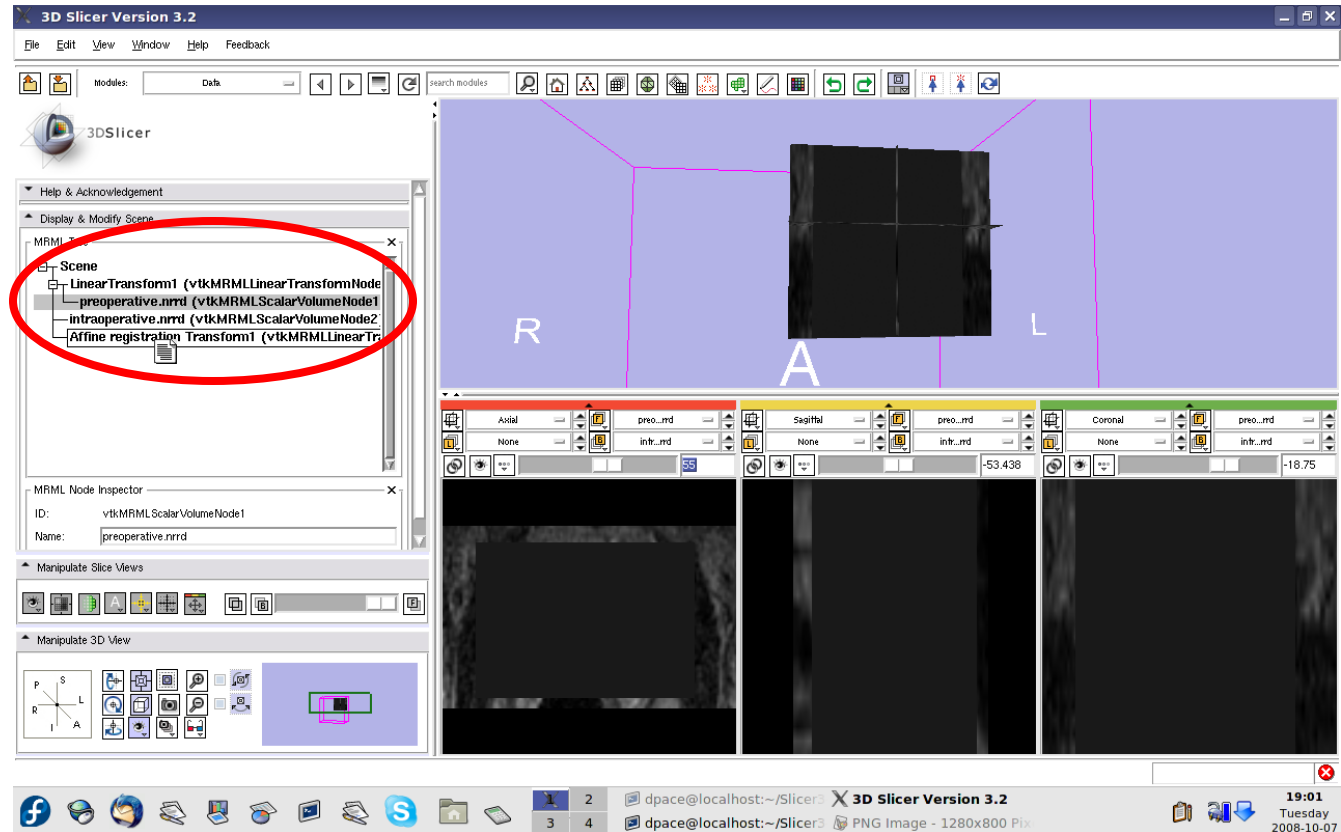


## Evaluate the affine registration

Open the Data module

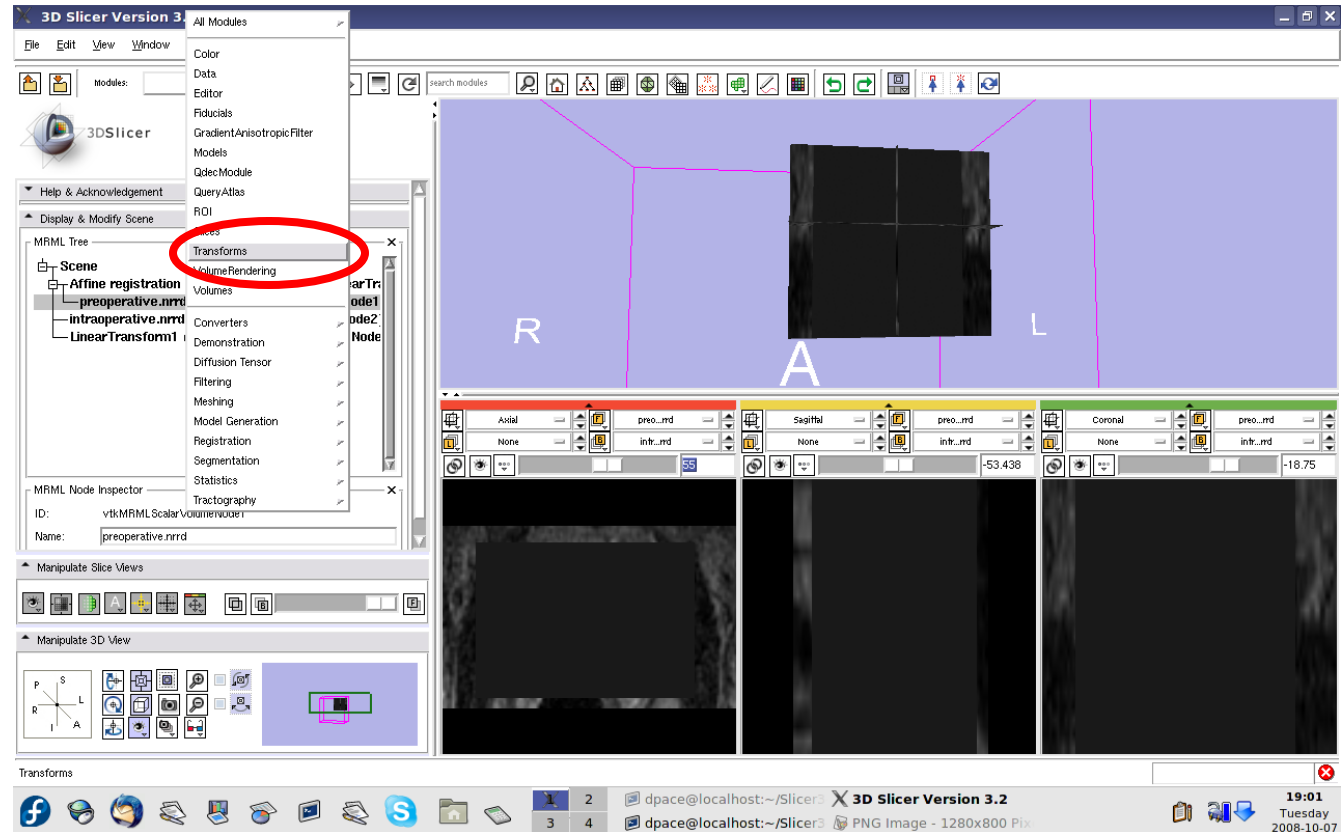


Drag the pre-operative image under the Affine registration Transform1 node



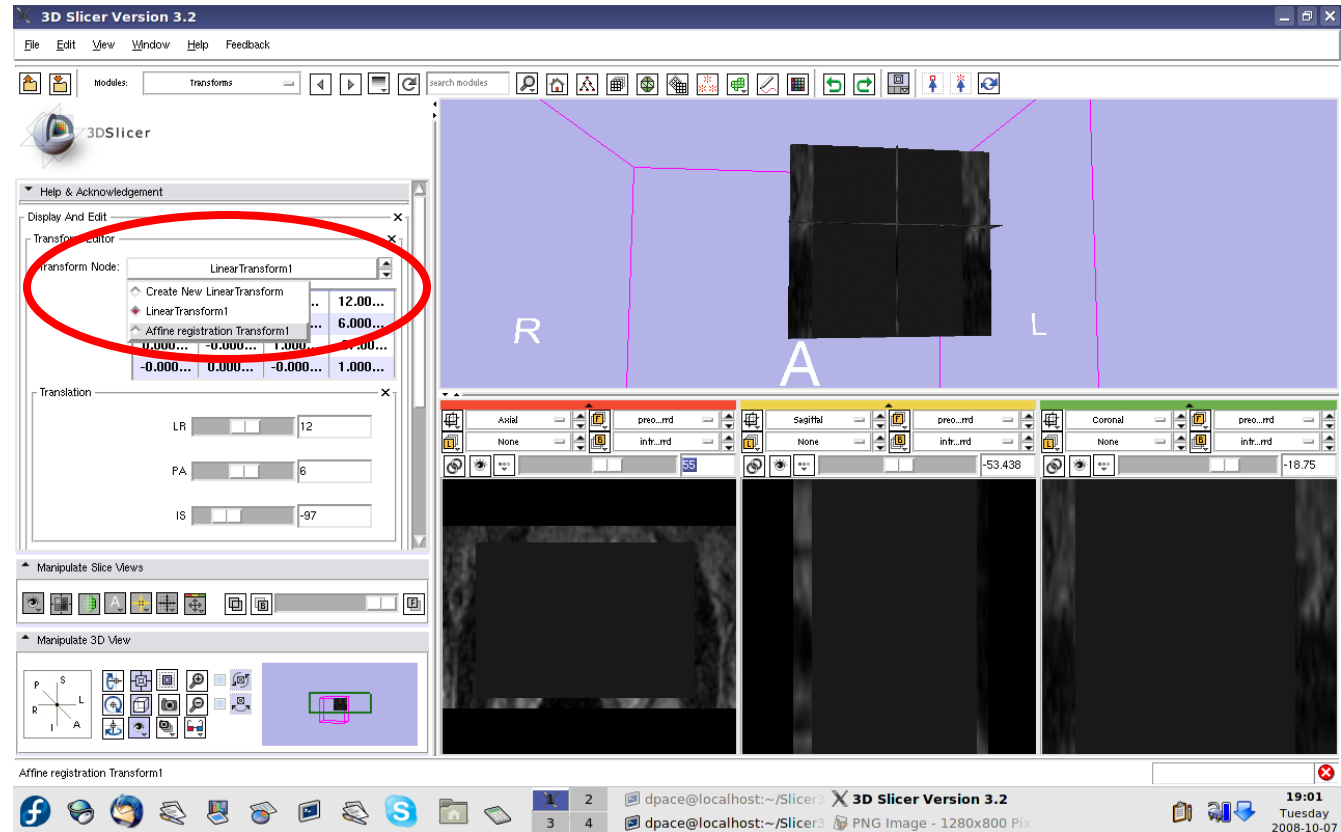
In order to evaluate the affine registration, the transform must be inverted back

Open the Transforms module



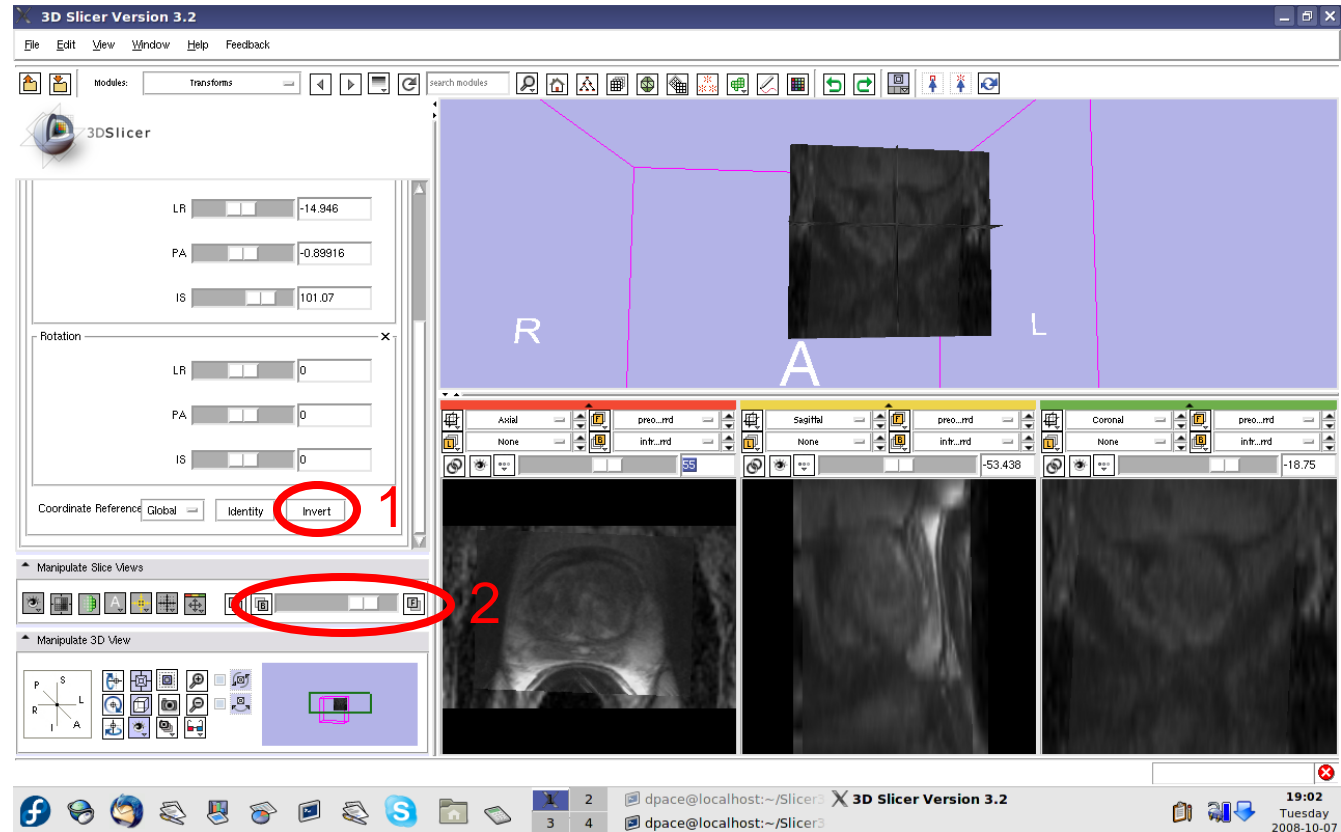
Change the transform node to the affine registration transform

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



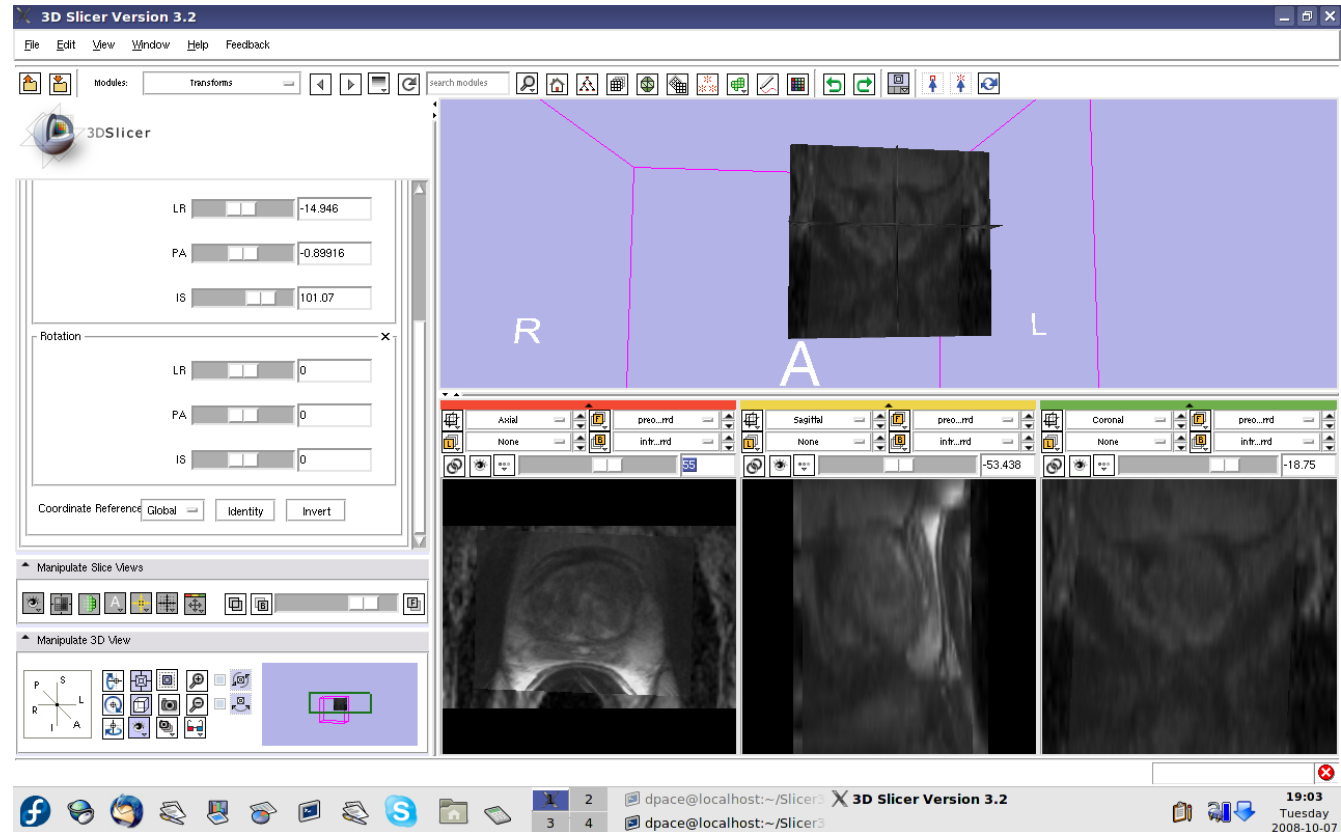
Click on the  
“Invert” button

Scale between  
the foreground  
and background  
to evaluate the  
alignment



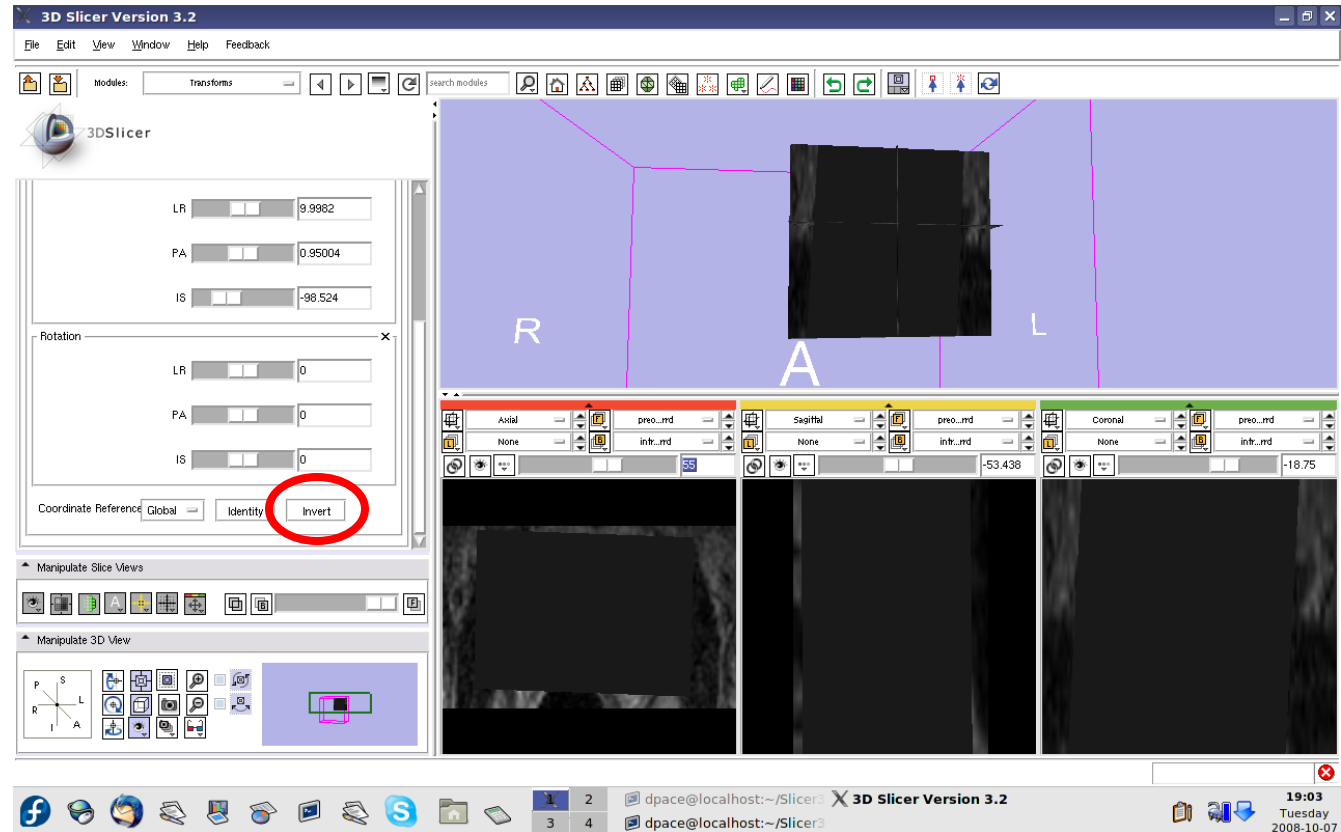


Now that we've evaluated the affine transform, it must be inverted before it can be used to initialize the deformable B-spline registration



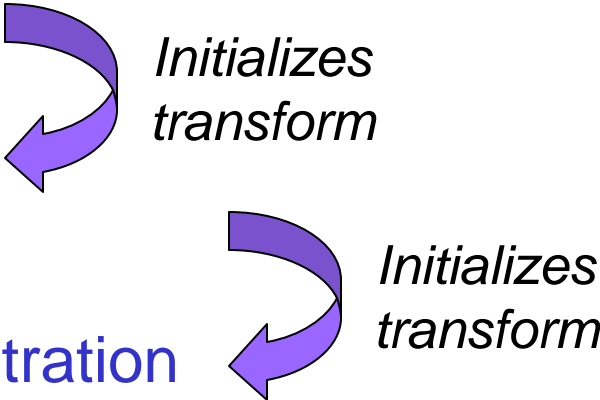
Click on the  
“Invert” button

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



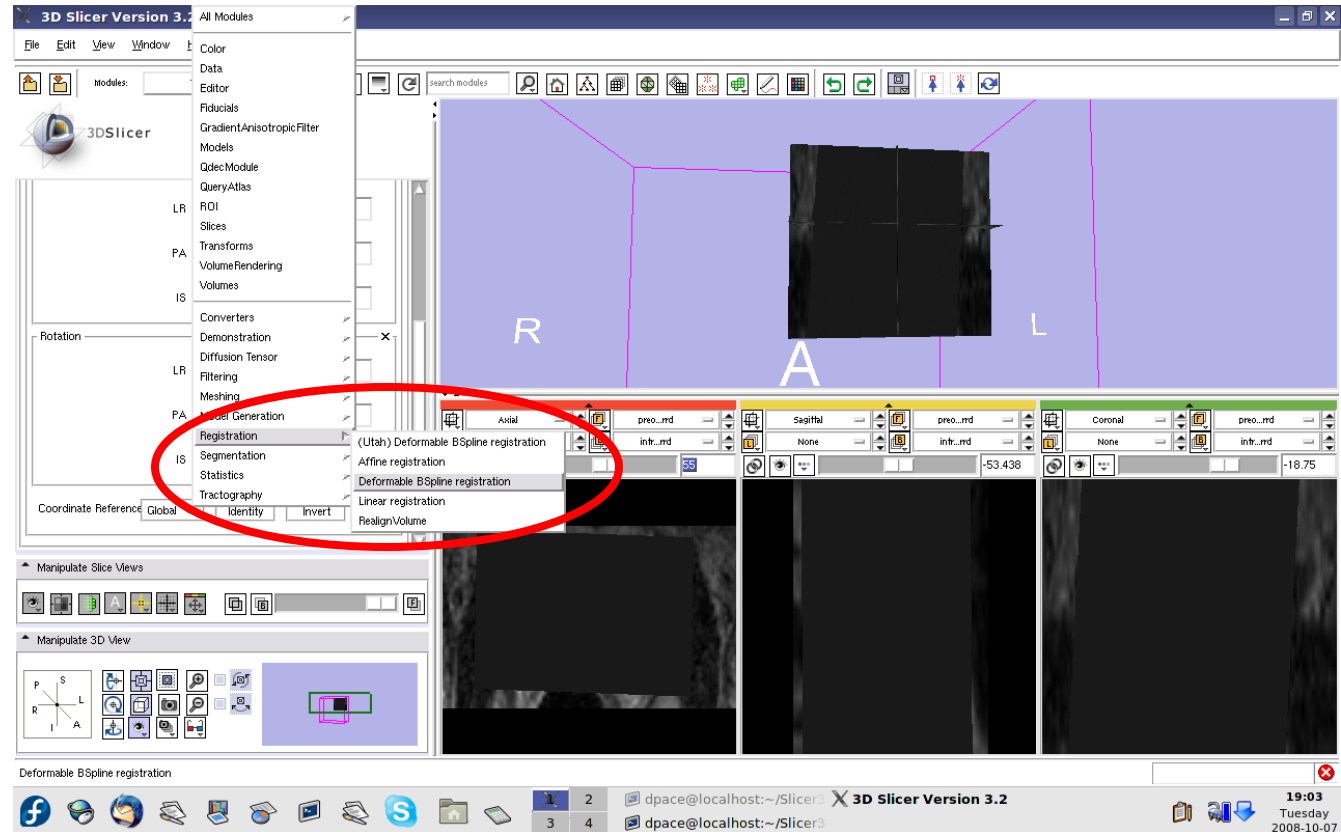
# Registration Steps

---

- Load the image volumes
  - Initial manual rigid transformation
  - Automatic affine registration
  - Automatic deformable B-spline registration
- 
- Initializes transform*
- Initializes transform*

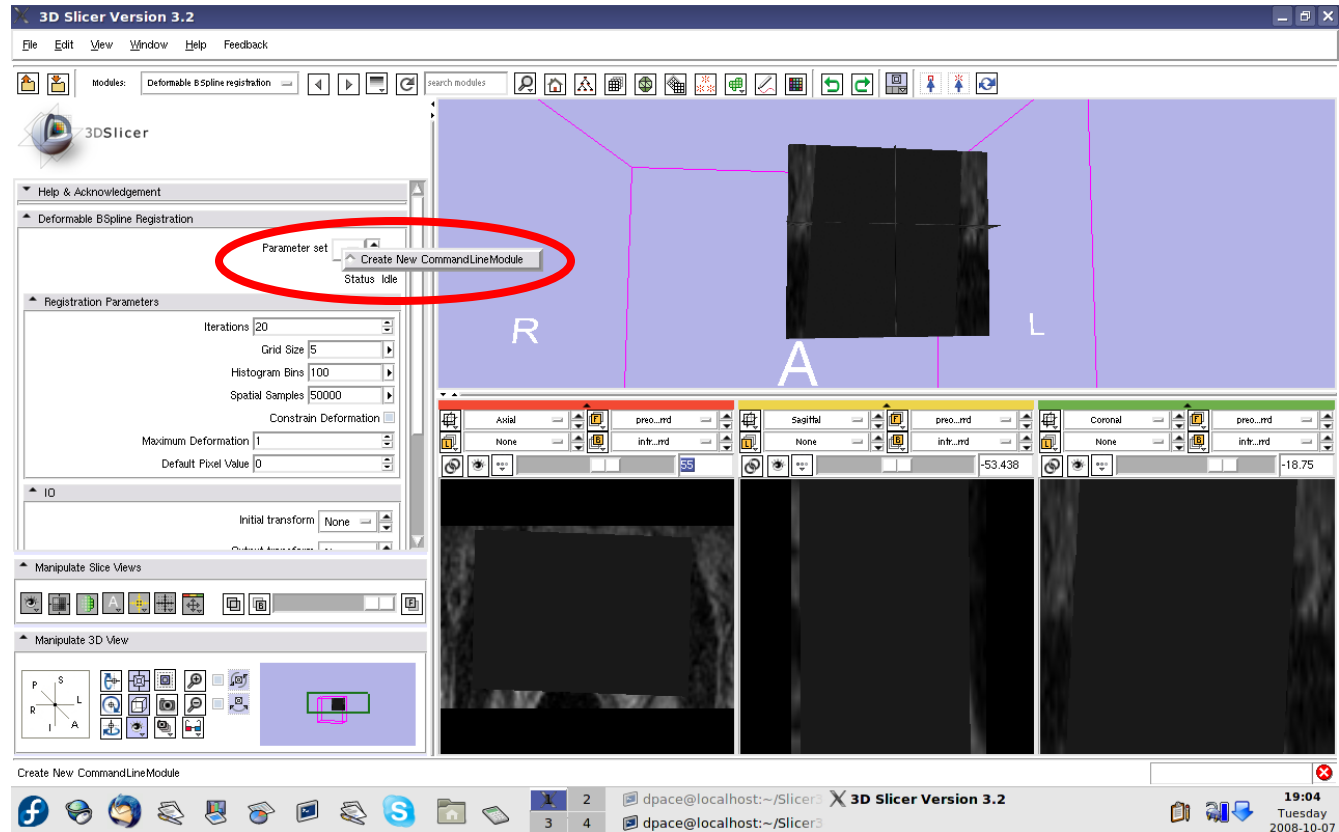
## Perform the deformable B-spline registration

Open the Deformable B-spline Registration module



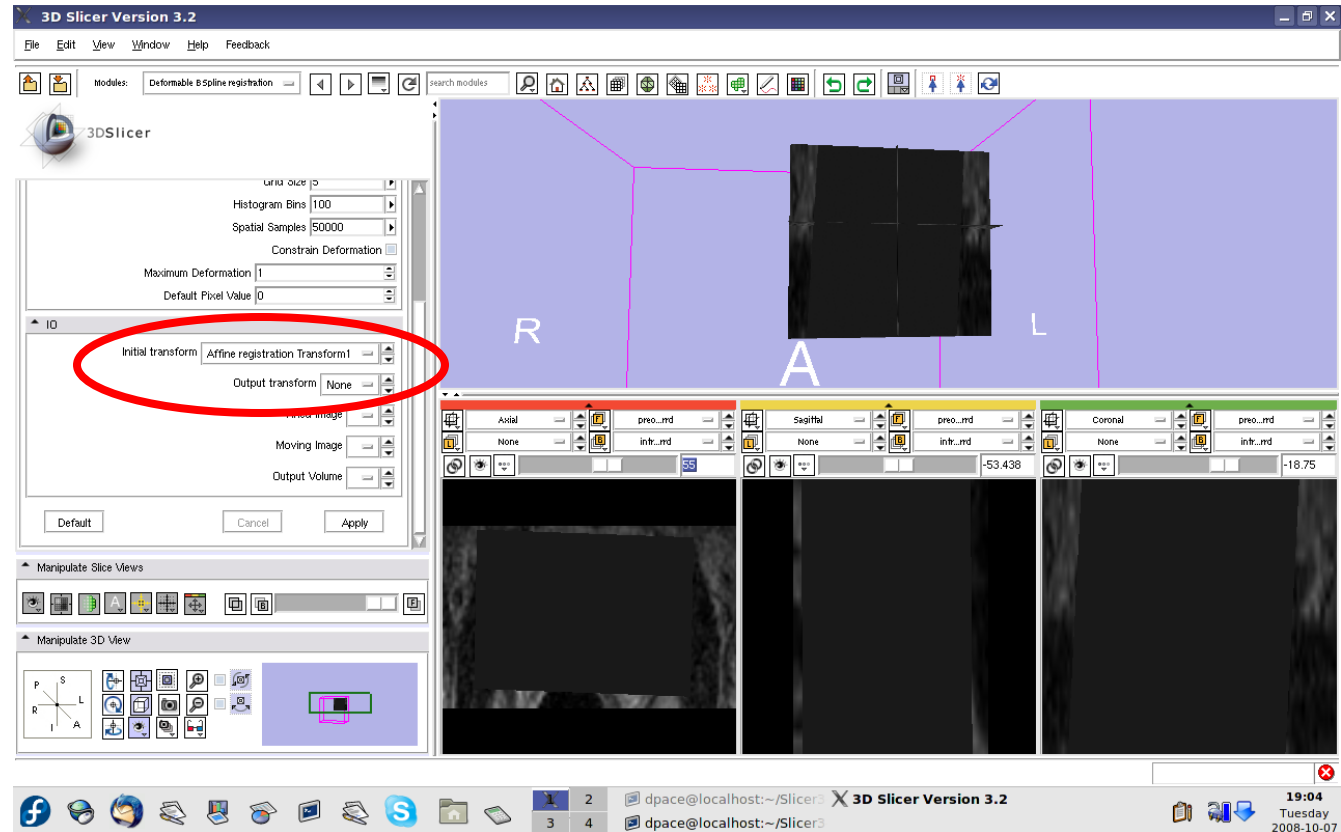
Create a new deformable B-spline registration transform

You do not need to change any of the registration parameters



**Initial transform:**  
Affine  
Registration Transform1

**Output transform:**  
None

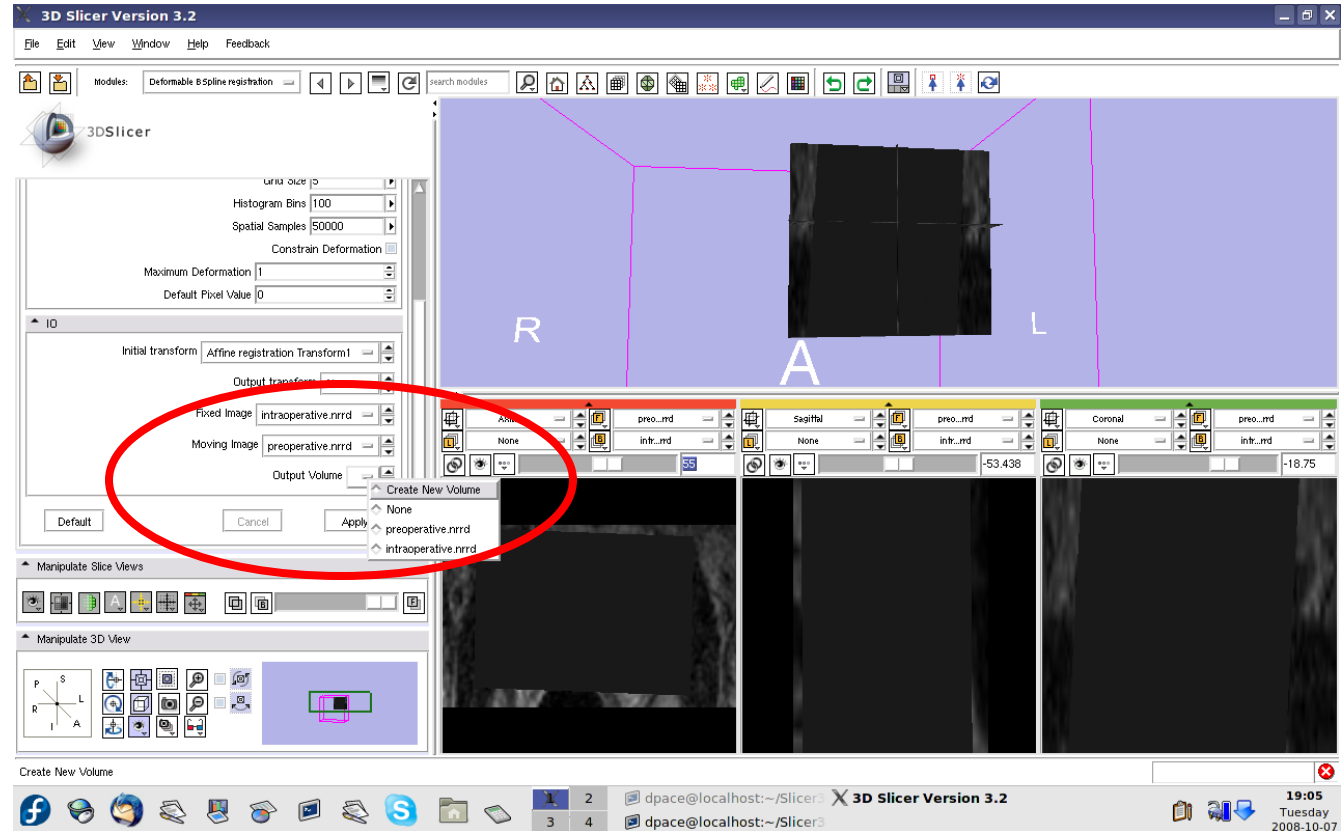


# Deformable B-spline registration

**Fixed image:**  
intra-operative

**Moving image:**  
pre-operative

**Output Volume:**  
Create new volume

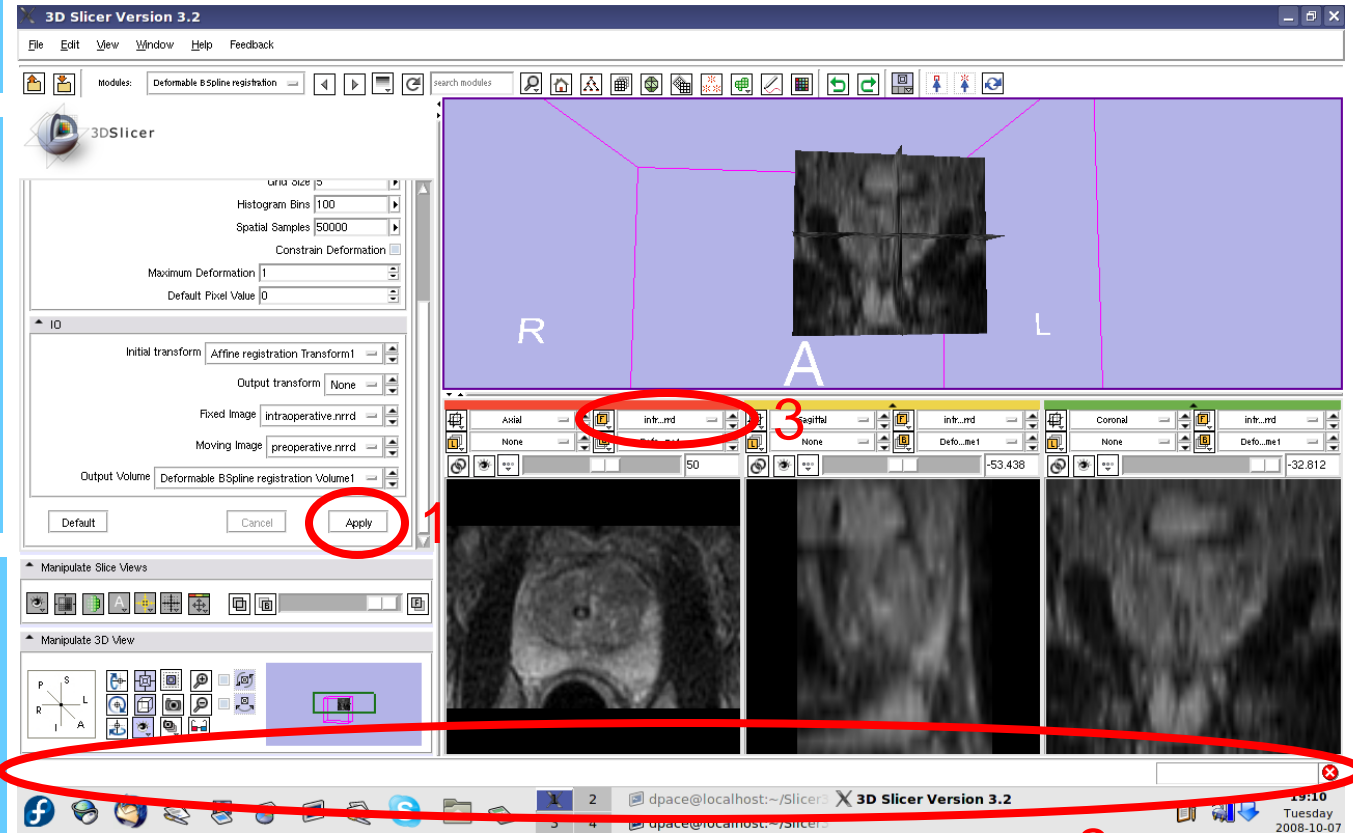


# Deformable B-spline registration

Click “Apply”

View the progress bar and wait until it says “Completed”

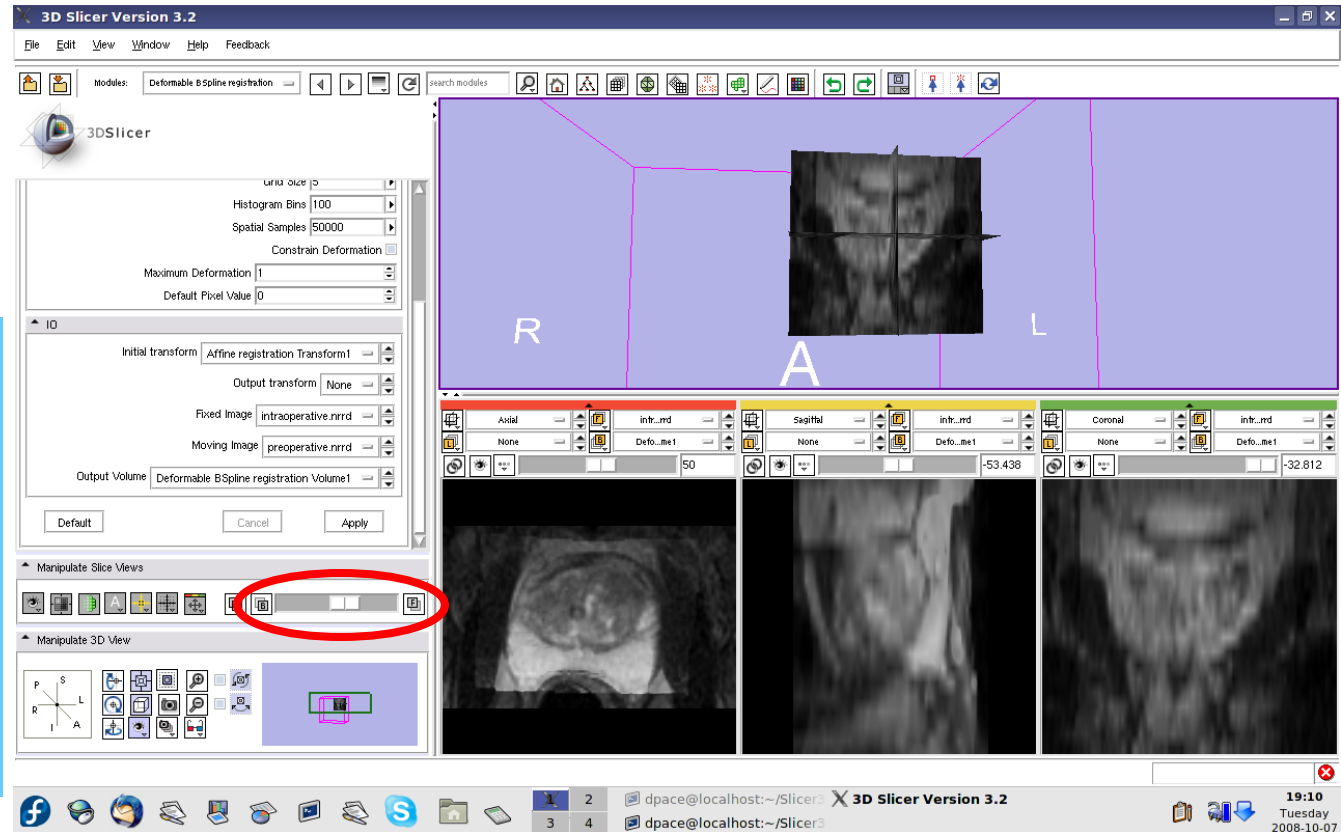
Set the foreground to the intra-operative image





## Evaluate the deformable B-spline registration

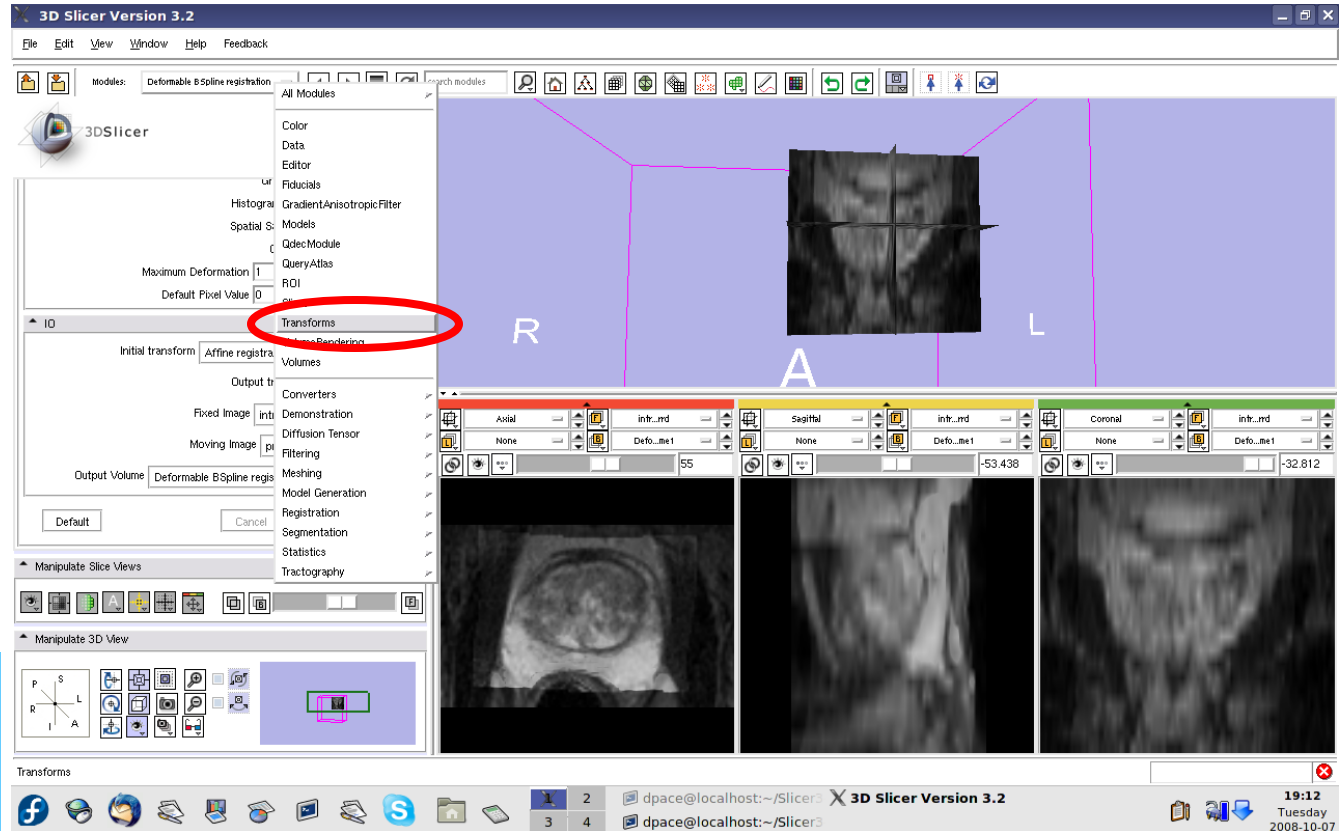
Scale between the foreground and background to evaluate the alignment



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

The affine transform must be inverted back

Open the Transforms module

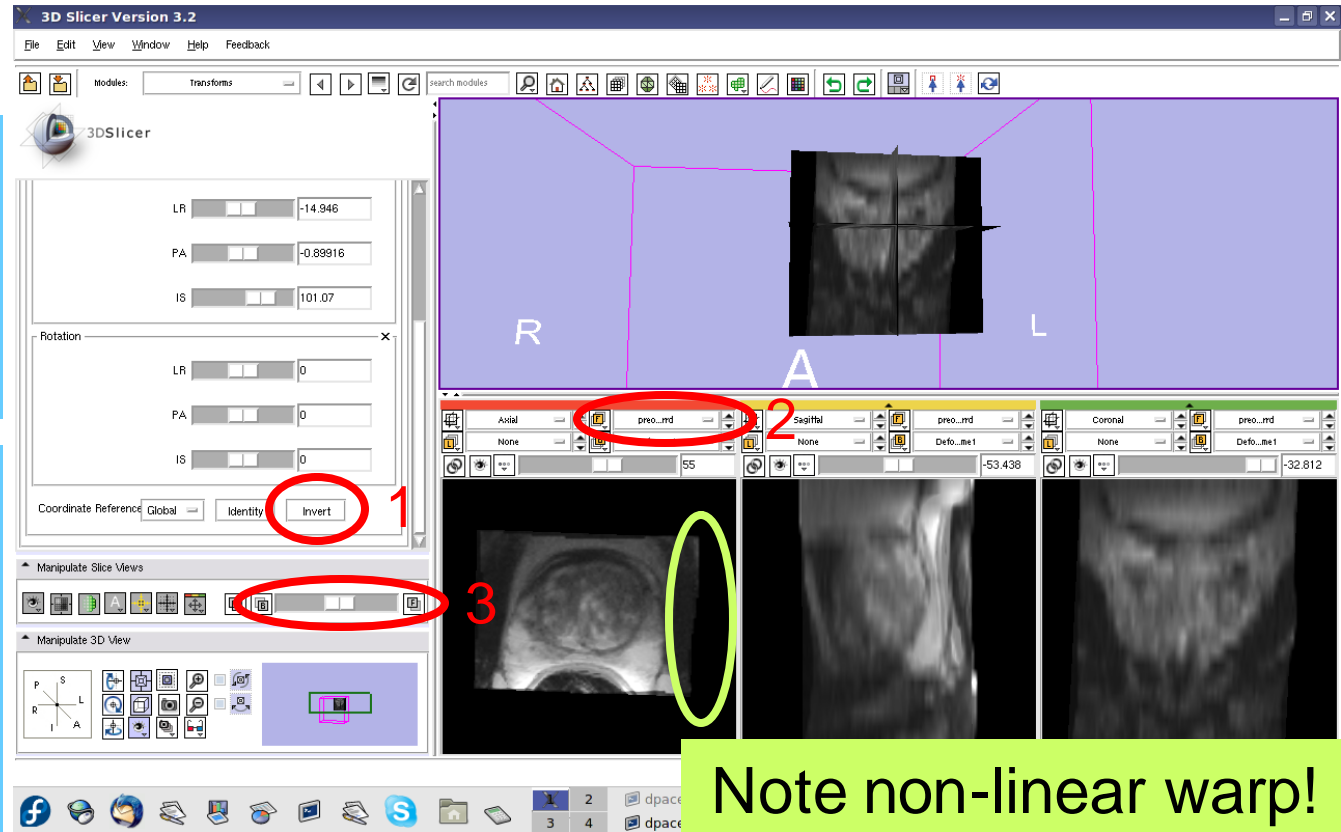


# Deformable B-spline registration

Click on the “Invert” button

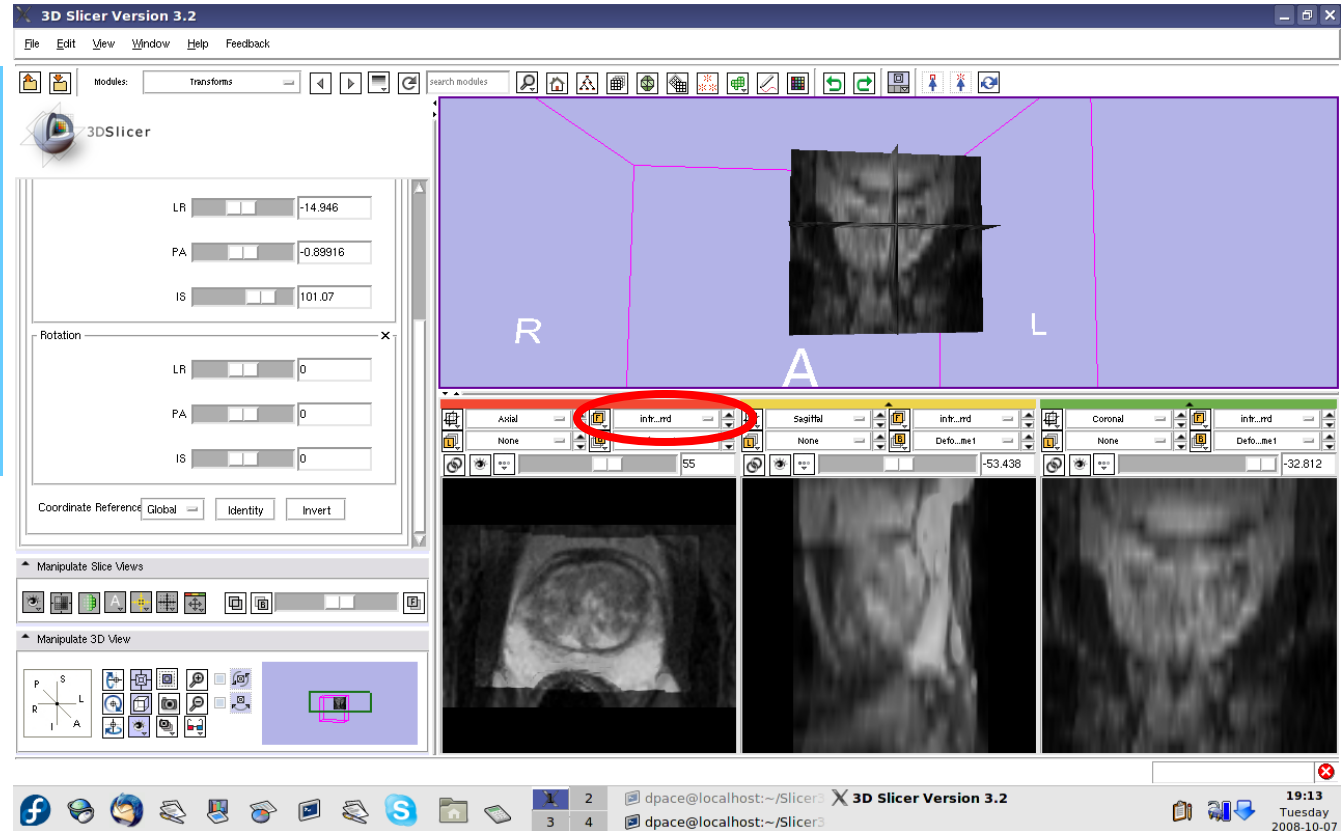
Set the foreground to the pre-operative image

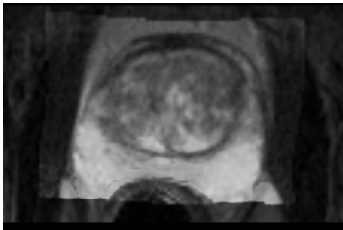
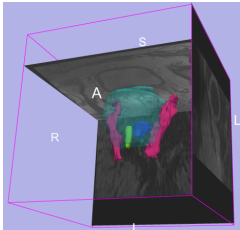
Scale between the foreground and background to evaluate the alignment



## Final results:

Set the foreground back to the intra-operative image

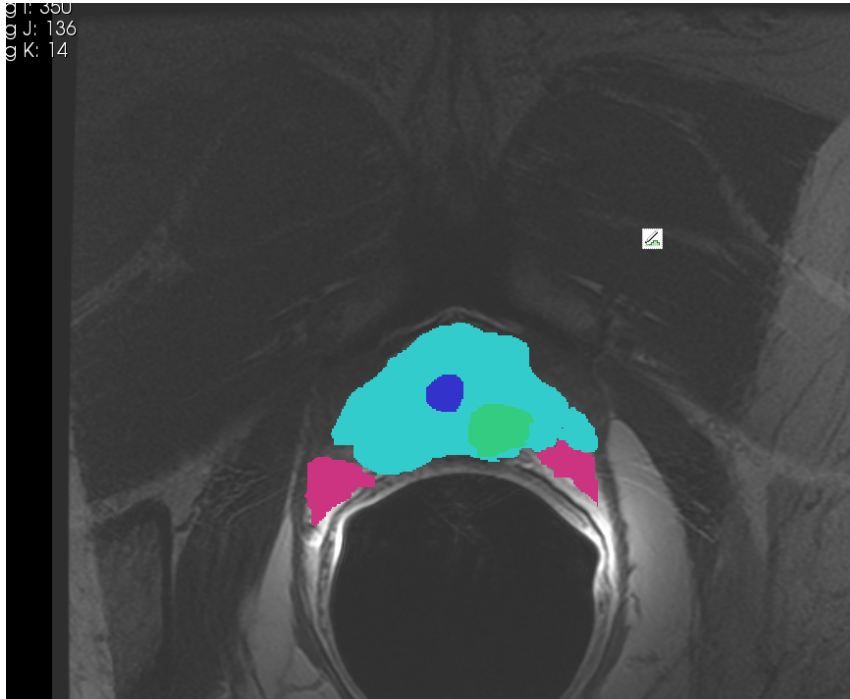




1. MR-guided prostate interventions: clinical background
2. Registering pre-operative & intra-operative prostate MR images using deformable B-spline registration
3. Manual segmentation of images
4. Creating 3D models from segmentations

# Manual Segmentation

---

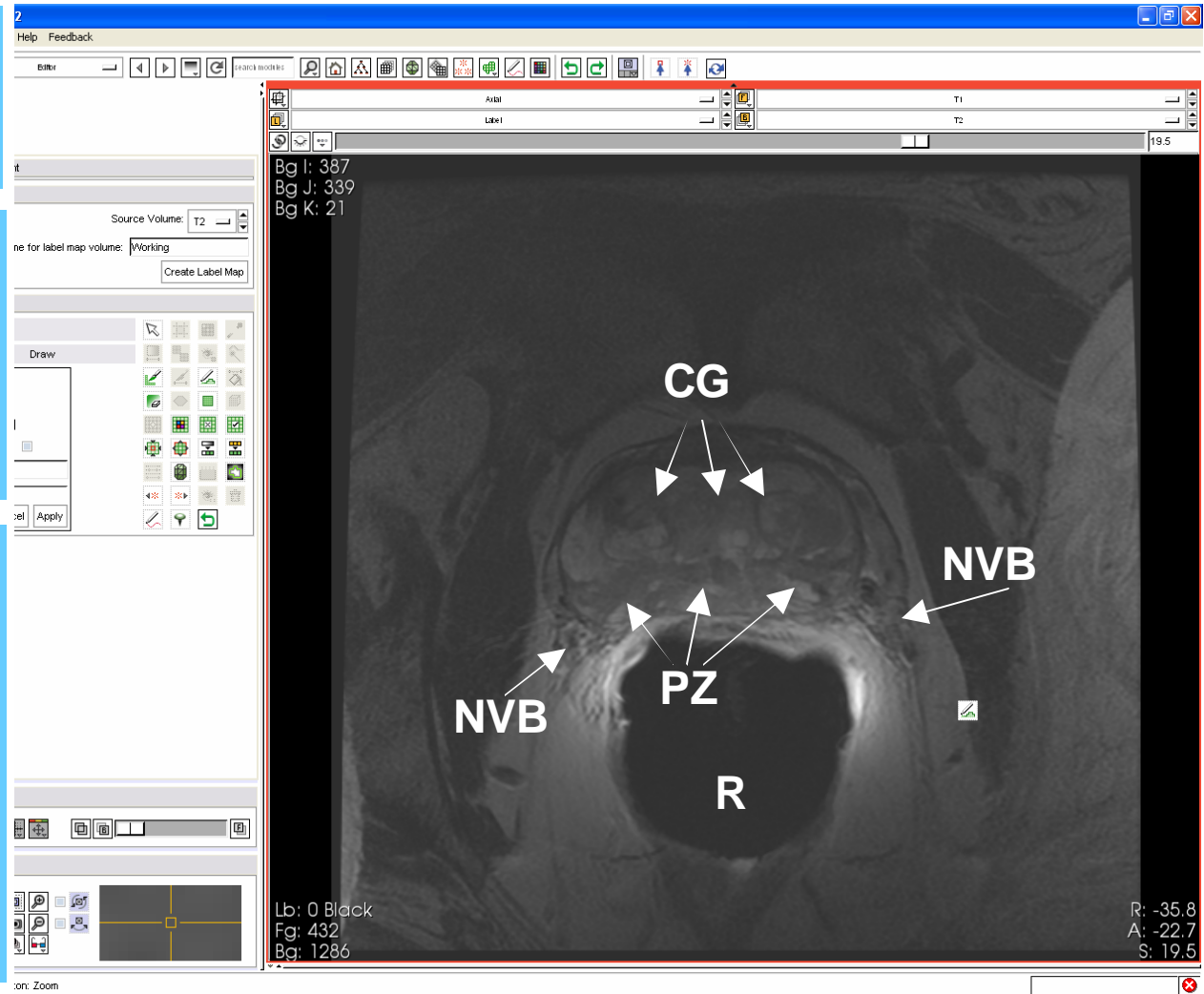


Manual segmentation  
is the process of  
delineating the  
anatomical structures  
within an image

Prostate MR  
Dataset

T2-weighted  
axial image at  
3.0 Tesla

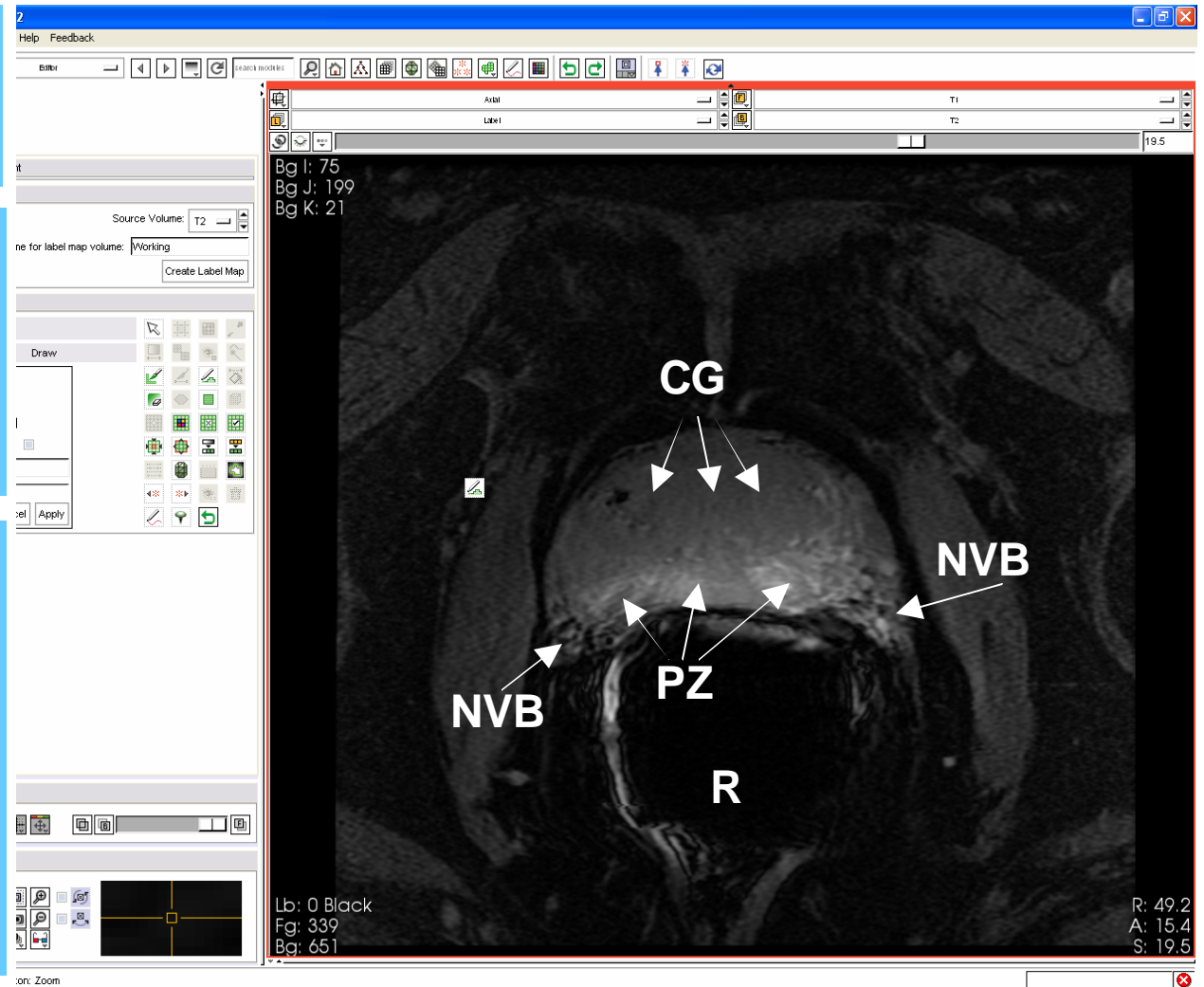
Central gland,  
peripheral zone,  
neurovascular  
bundles, rectum  
shown



Prostate MR  
Dataset

T1-weighted  
axial image at  
3.0 Tesla

T1 image can  
be used to  
complement T2  
imaging  
visualization



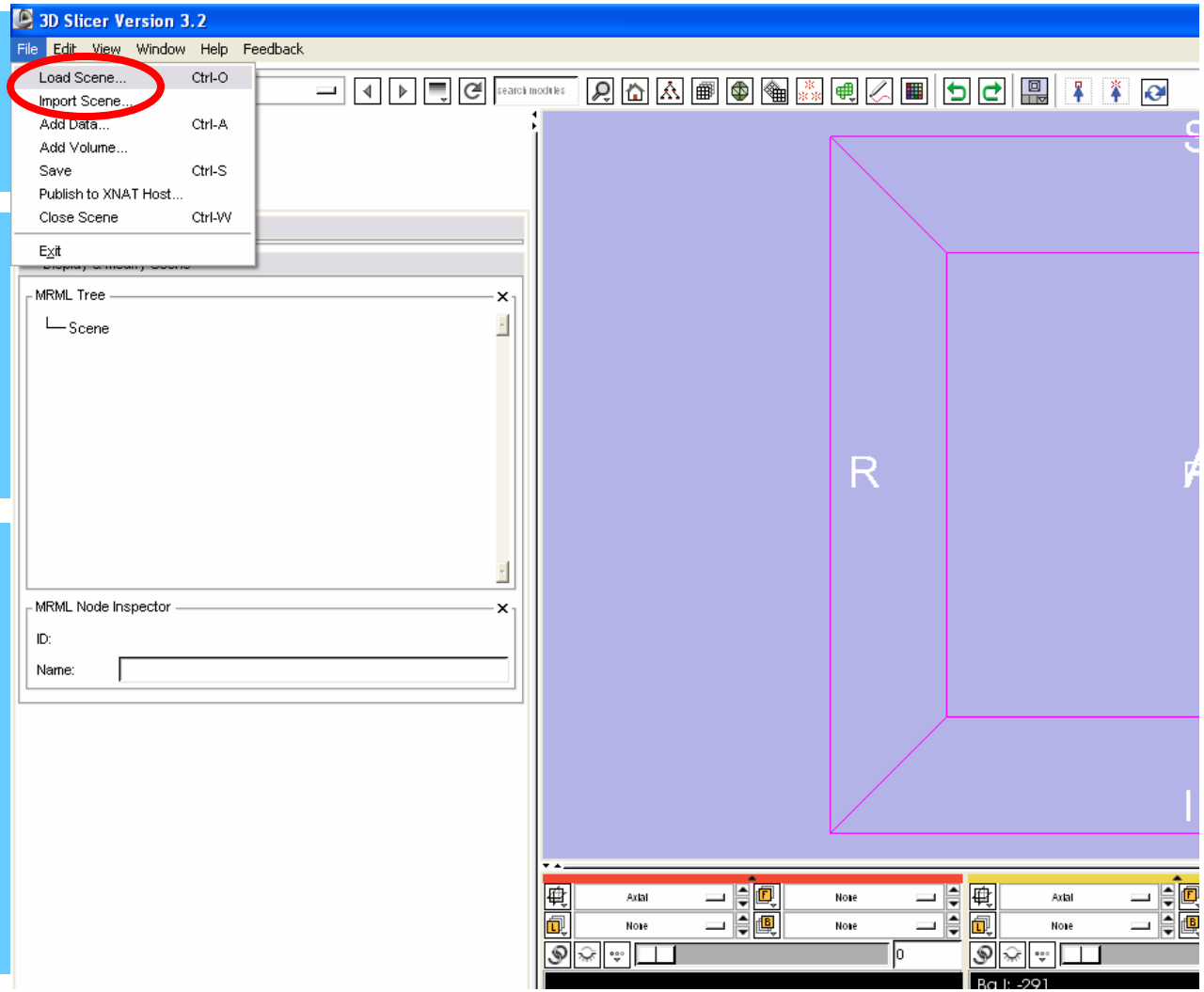


# Manual Segmentation - Load

Load the Data

Segmentation data are saved in a scene file

Select “Load Scene” from the File Menu

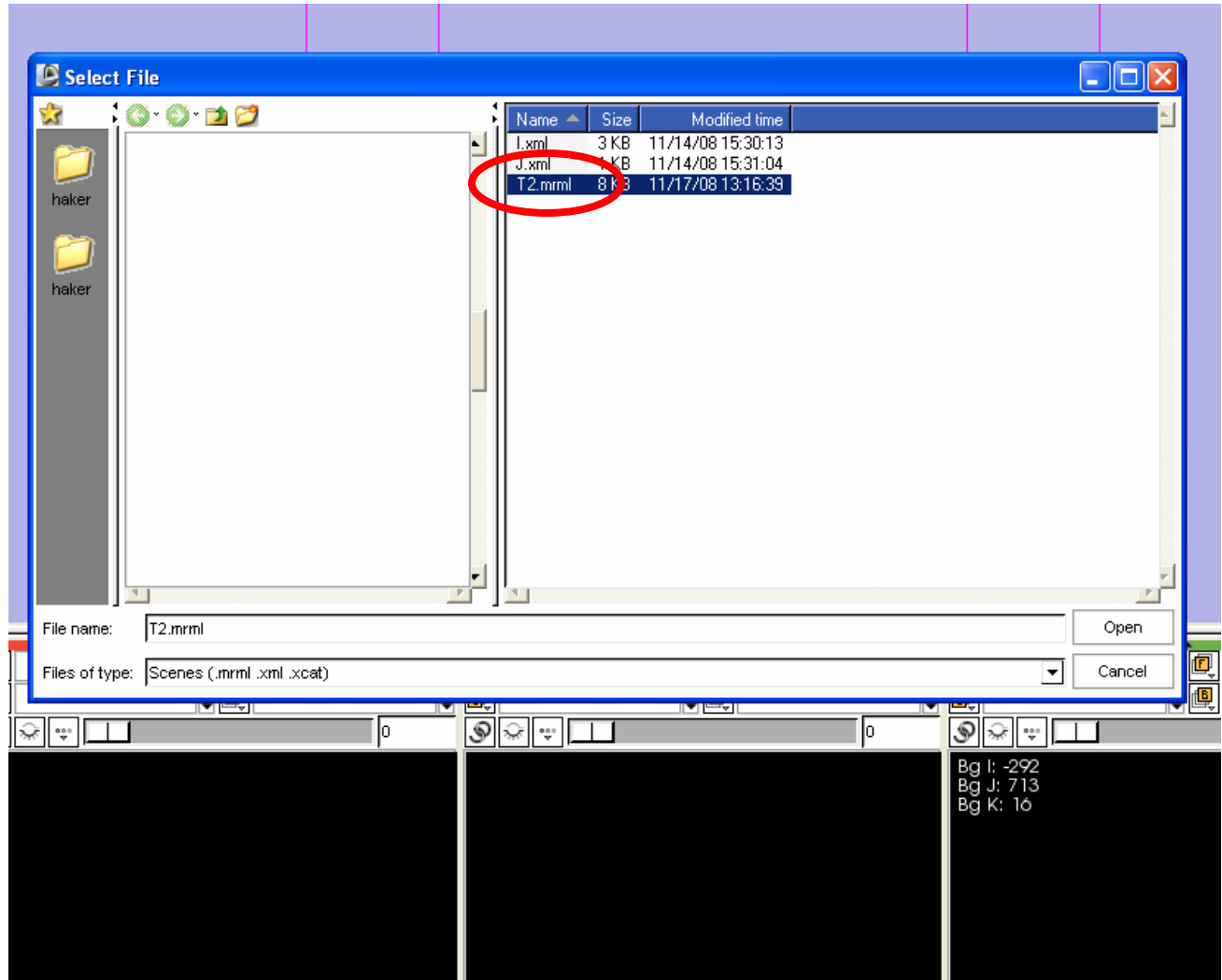


# Manual Segmentation - Load

Load the Data

Select T2.mrml  
from the file  
selection menu

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

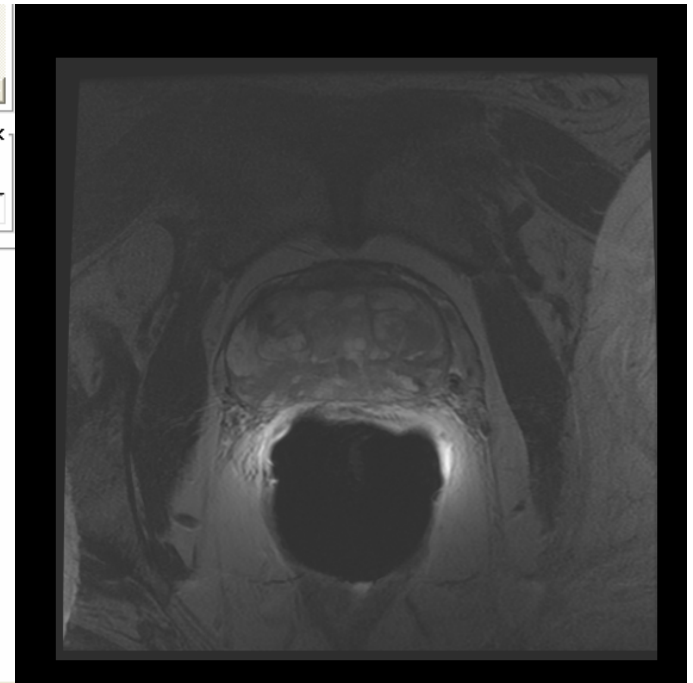
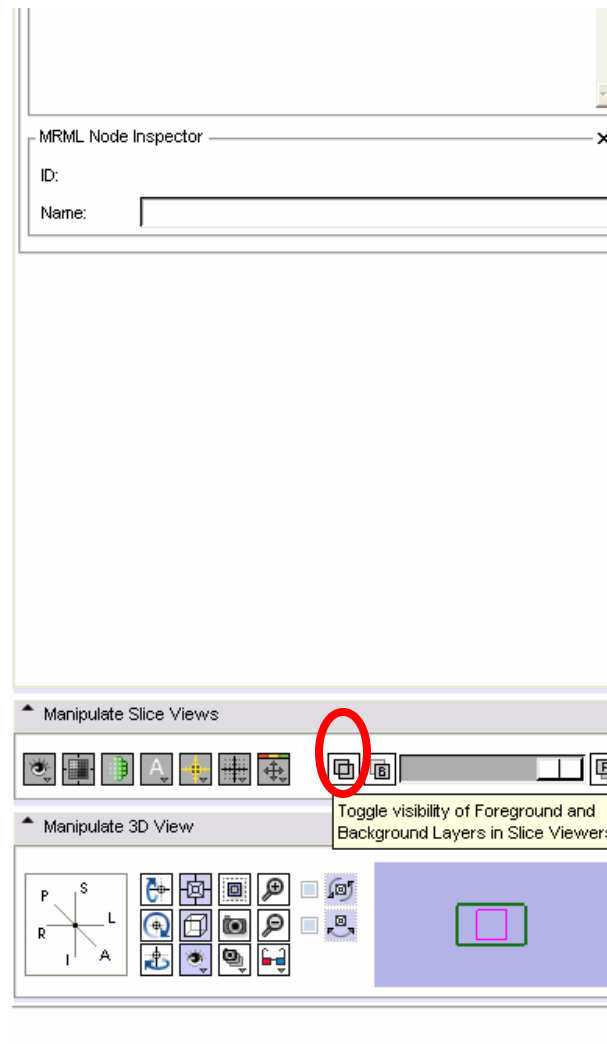




Toggle Visibility

Toggle layer visibility so T2-weighted image appears

The toggle allows for easy visualization of both T1 and T2 imaging

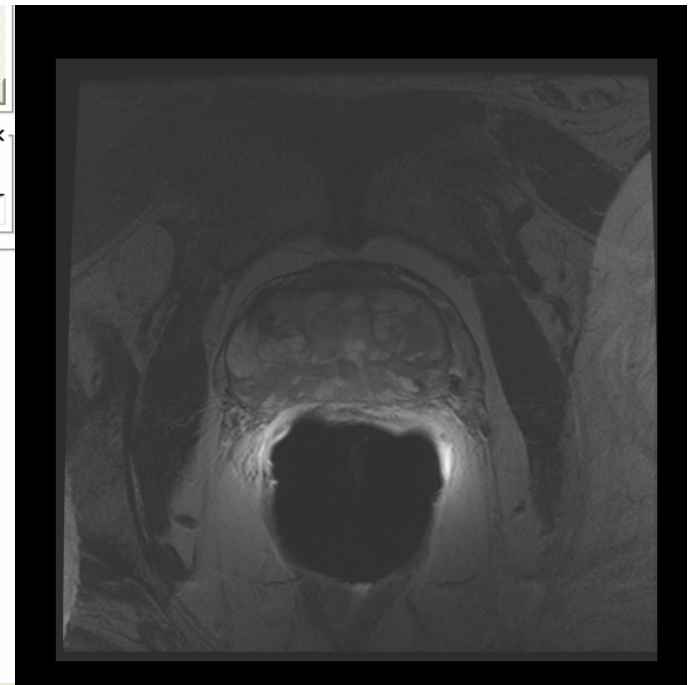
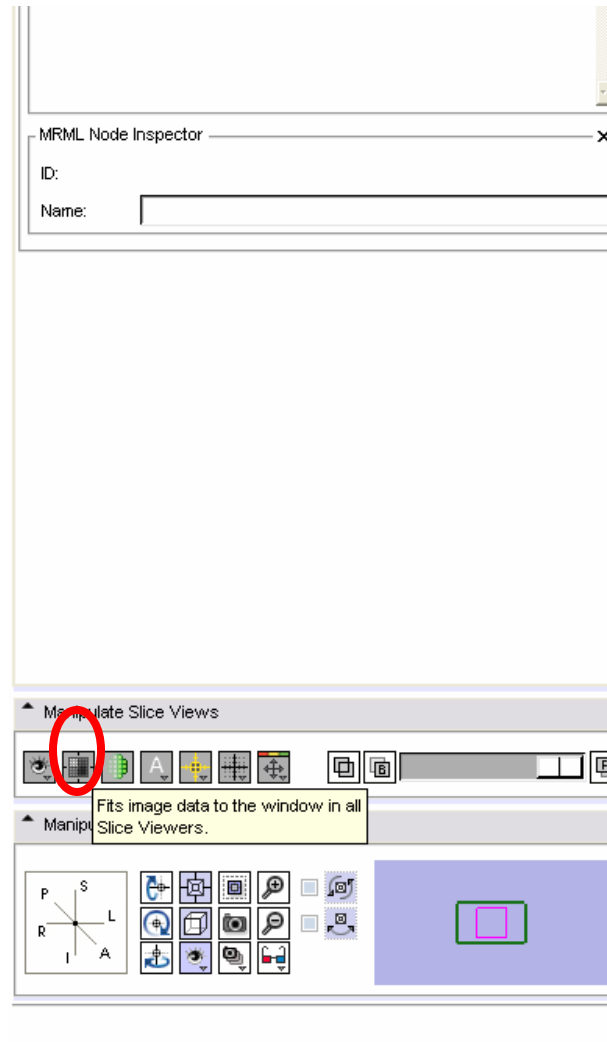


# Manual Segmentation - Visibility

## Fit Visible

This button zooms the image to fit the window

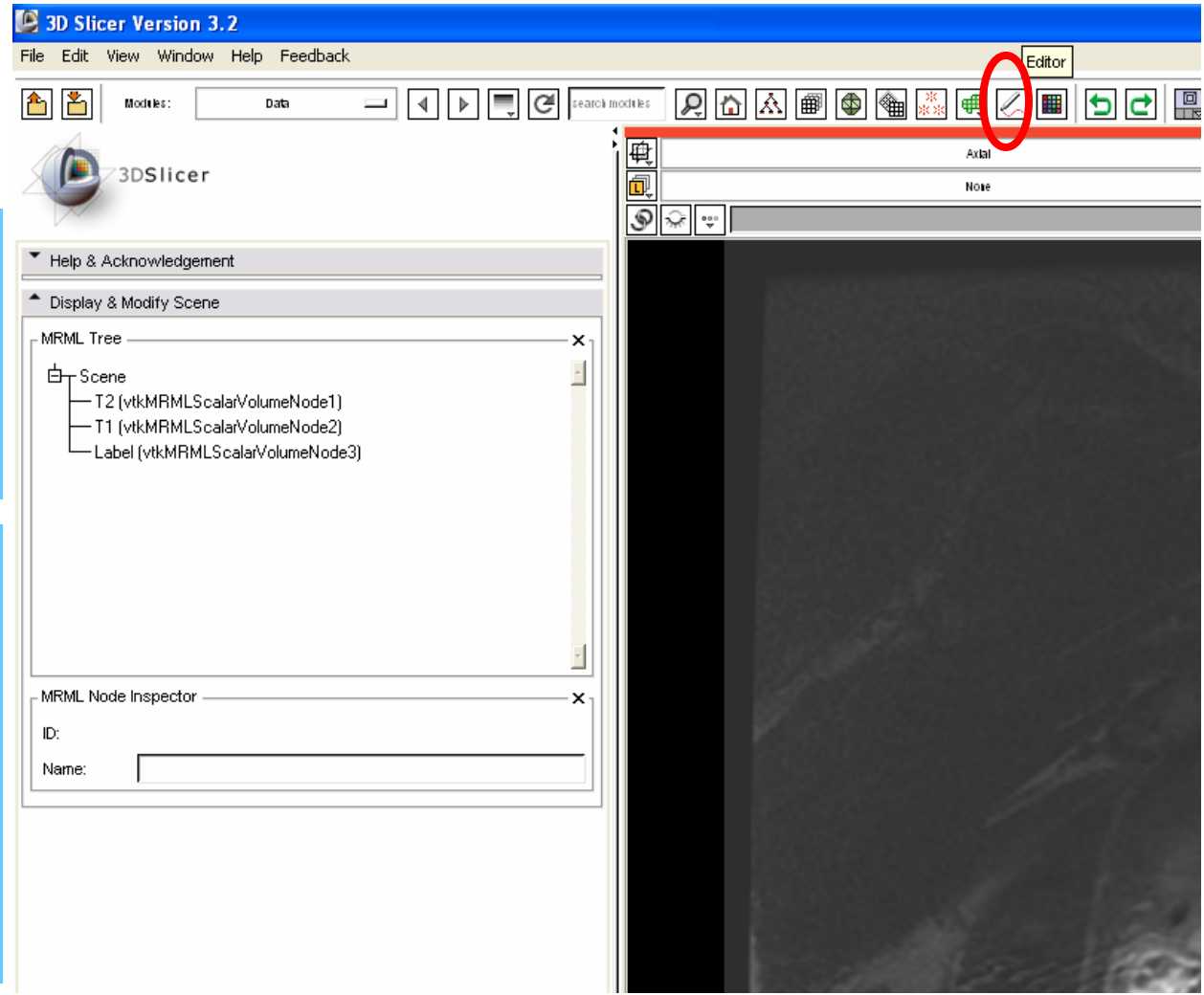
Presents maximum image size to aid in visualization



Select Editor  
Module

Click the pencil  
icon on the main  
toolbar

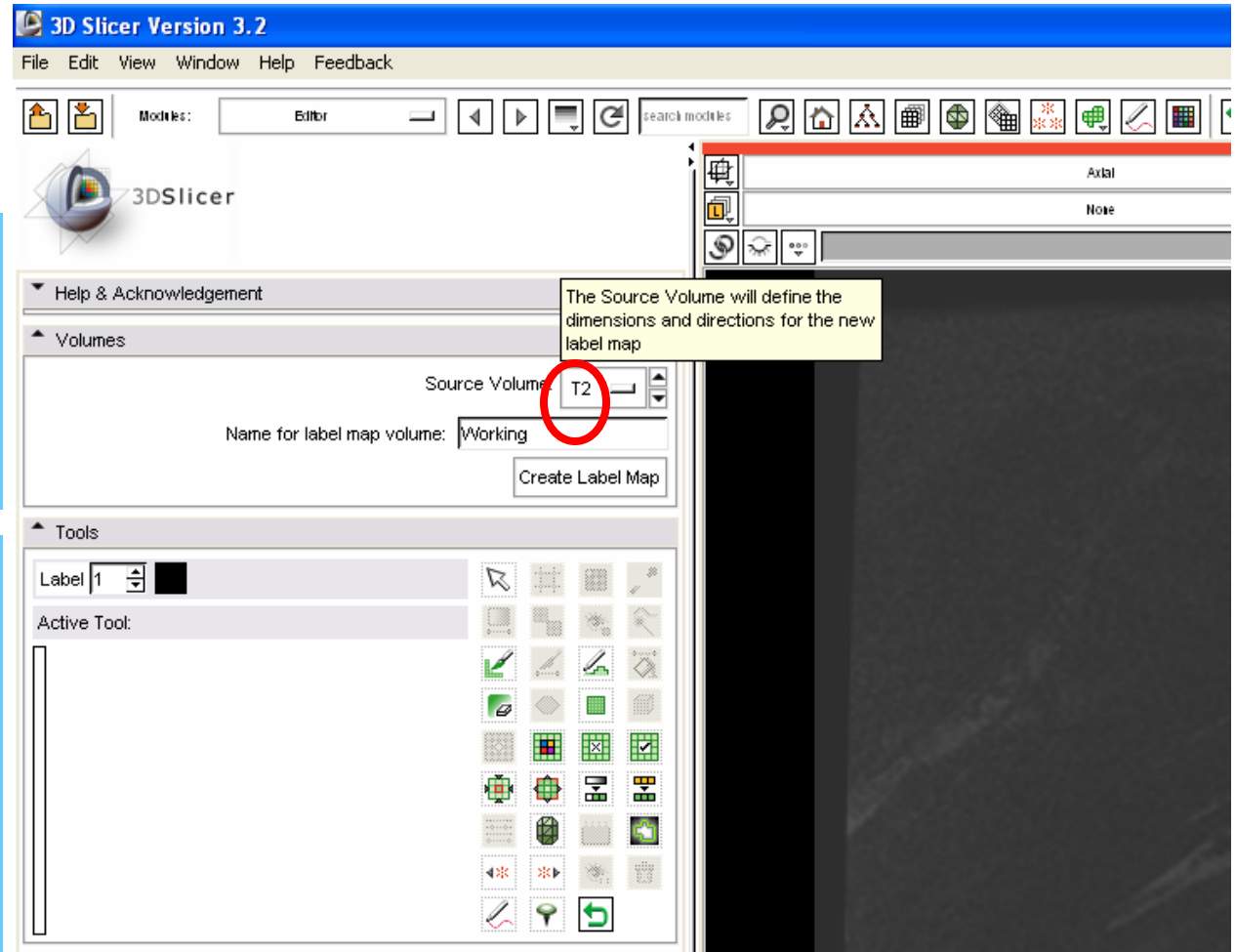
The Editor  
Module contains  
the drawing  
tools



Select Source Volume

This is the volume you will be drawing on

Select the T2 volume for this demonstration



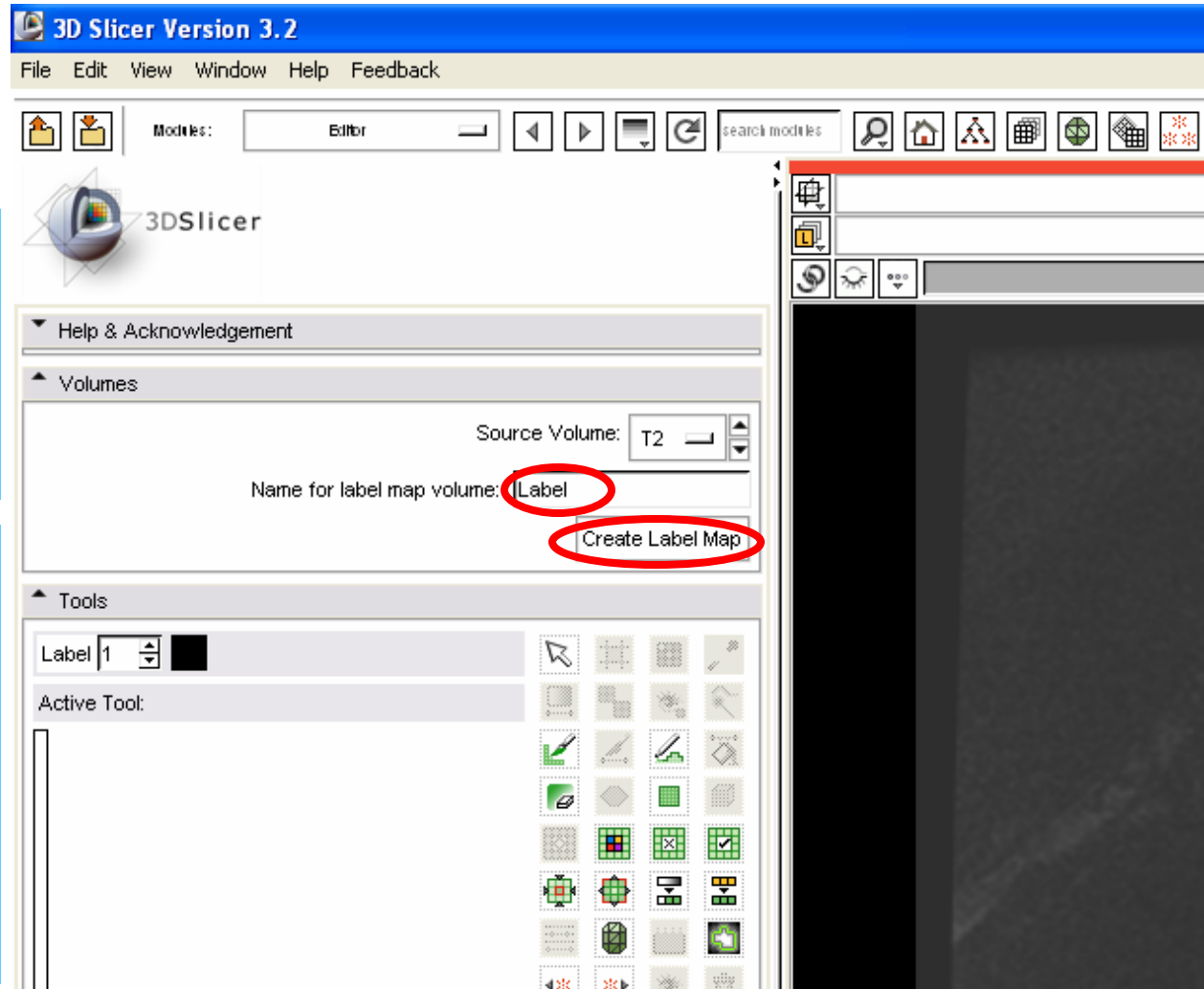


# Manual Segmentation – Label Map

Enter a Label Map name

The label map will contain the segmentation

Press “Create Label Map” to create new map

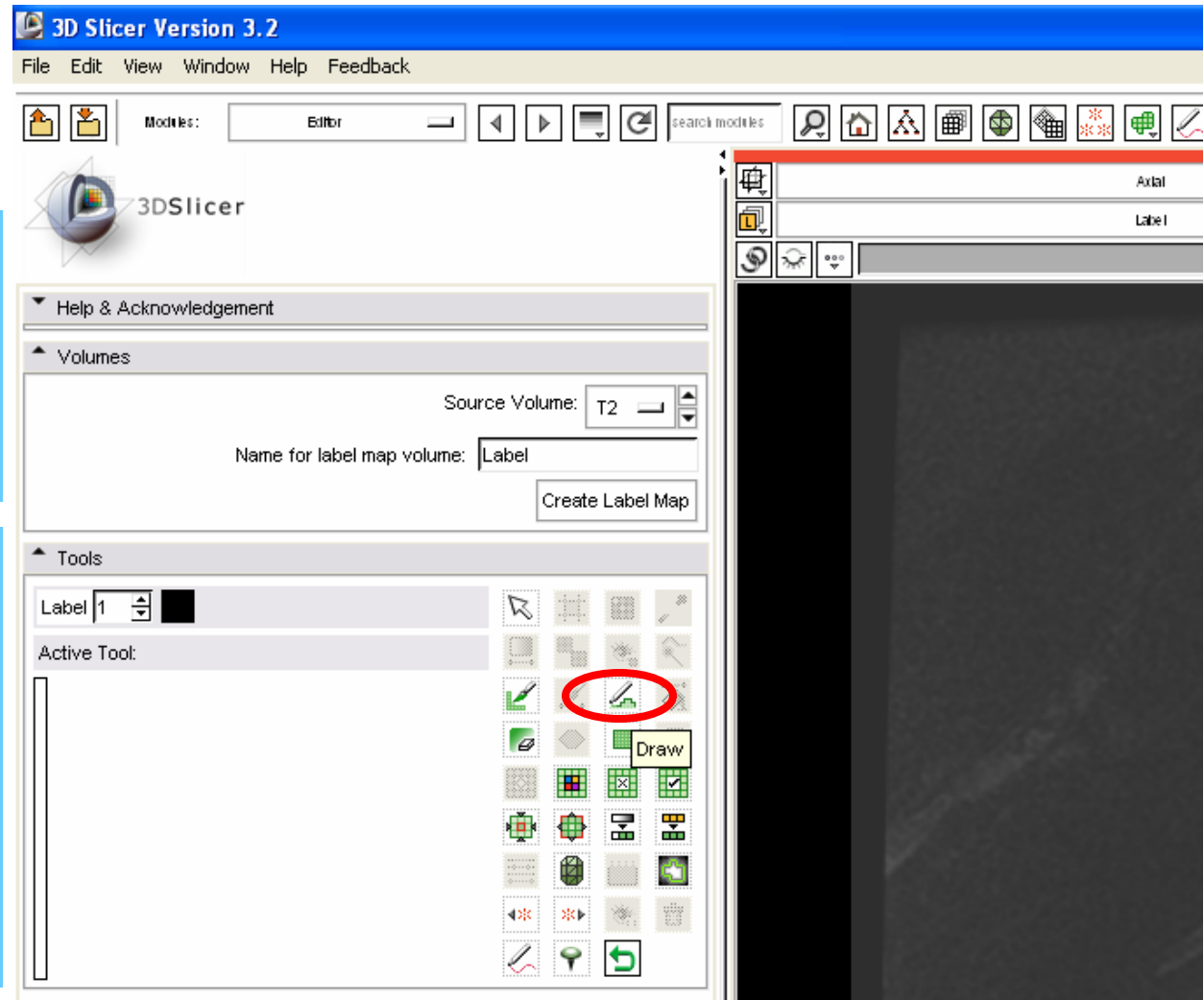




Select Draw Tool

Click on the pencil icon

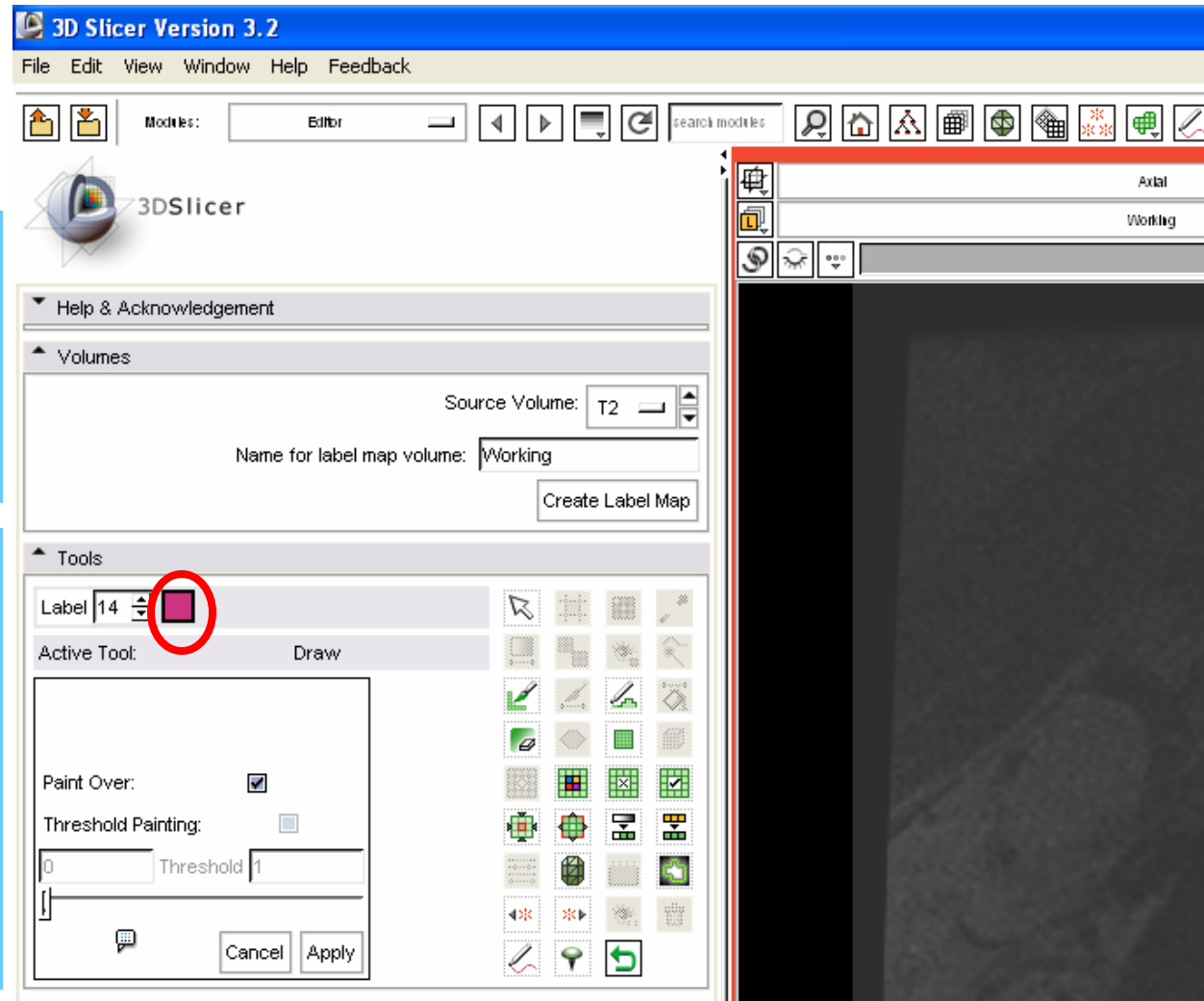
The draw tool is used to contour regions of interest



Select Color

Click on the color box for pop-up color selector

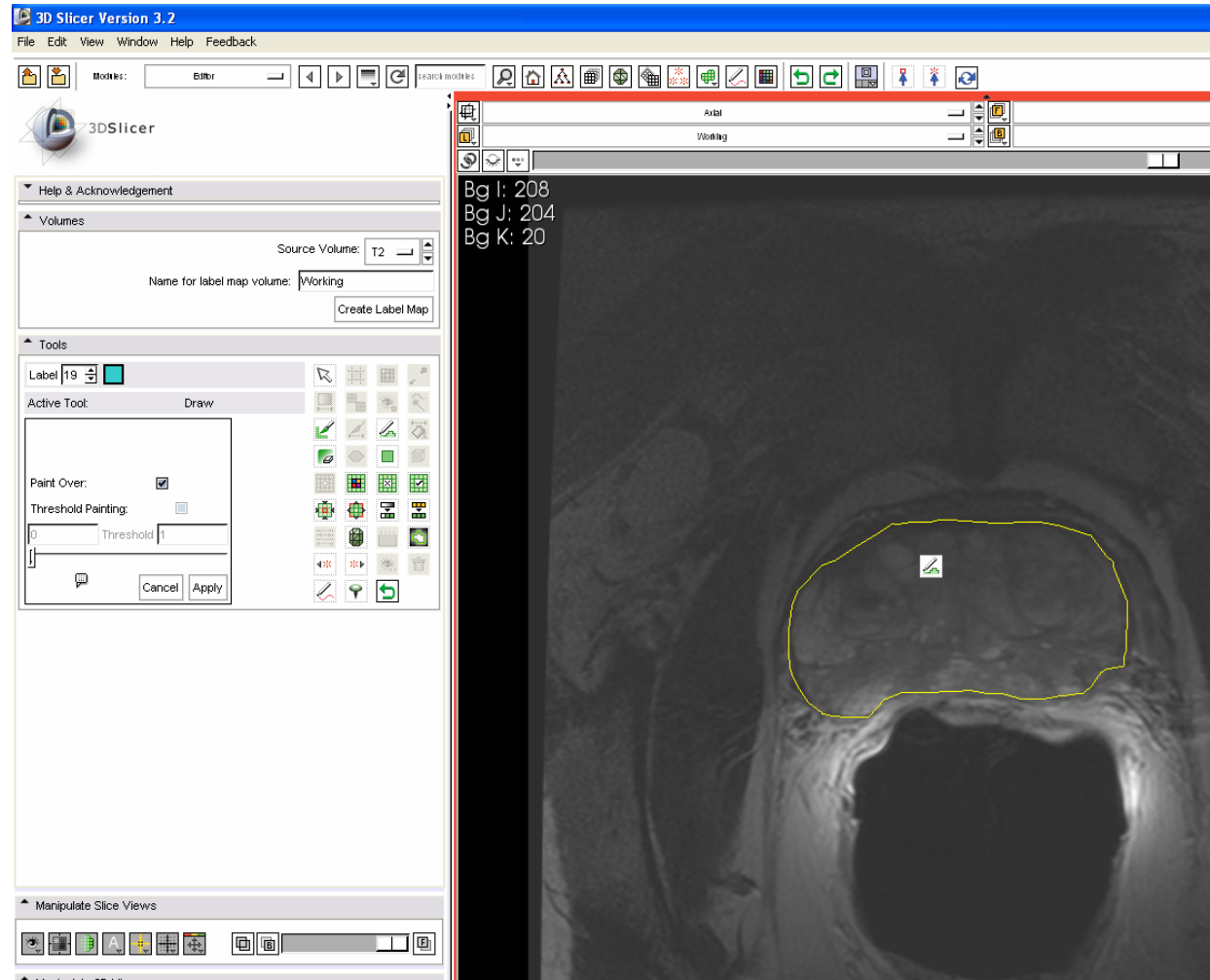
Use a different color for each anatomical region



Draw a closed contour

Contour the desired region

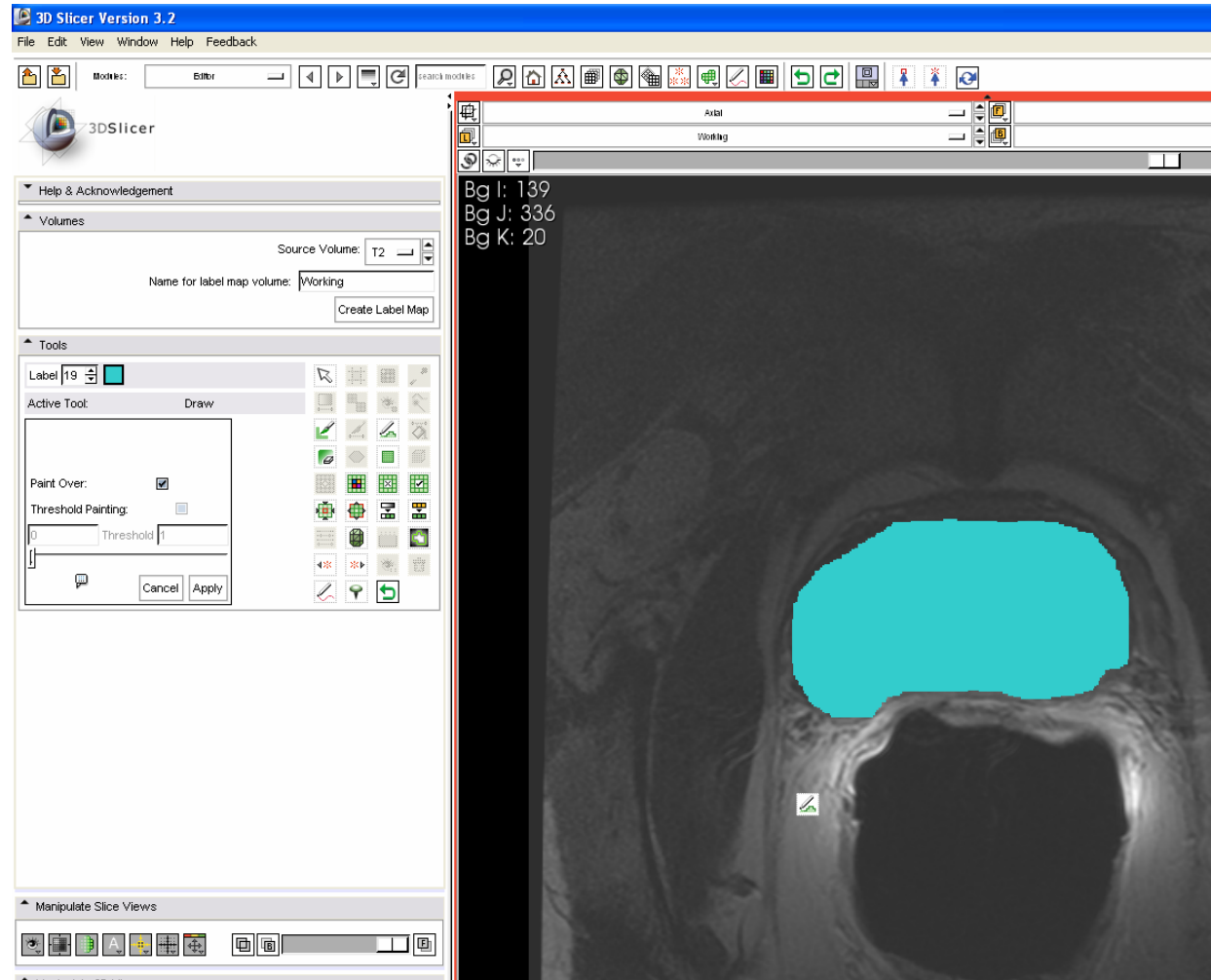
Press the 'a' key to fill in the region when complete



Draw a closed contour

Contour is filled in when 'a' is pressed

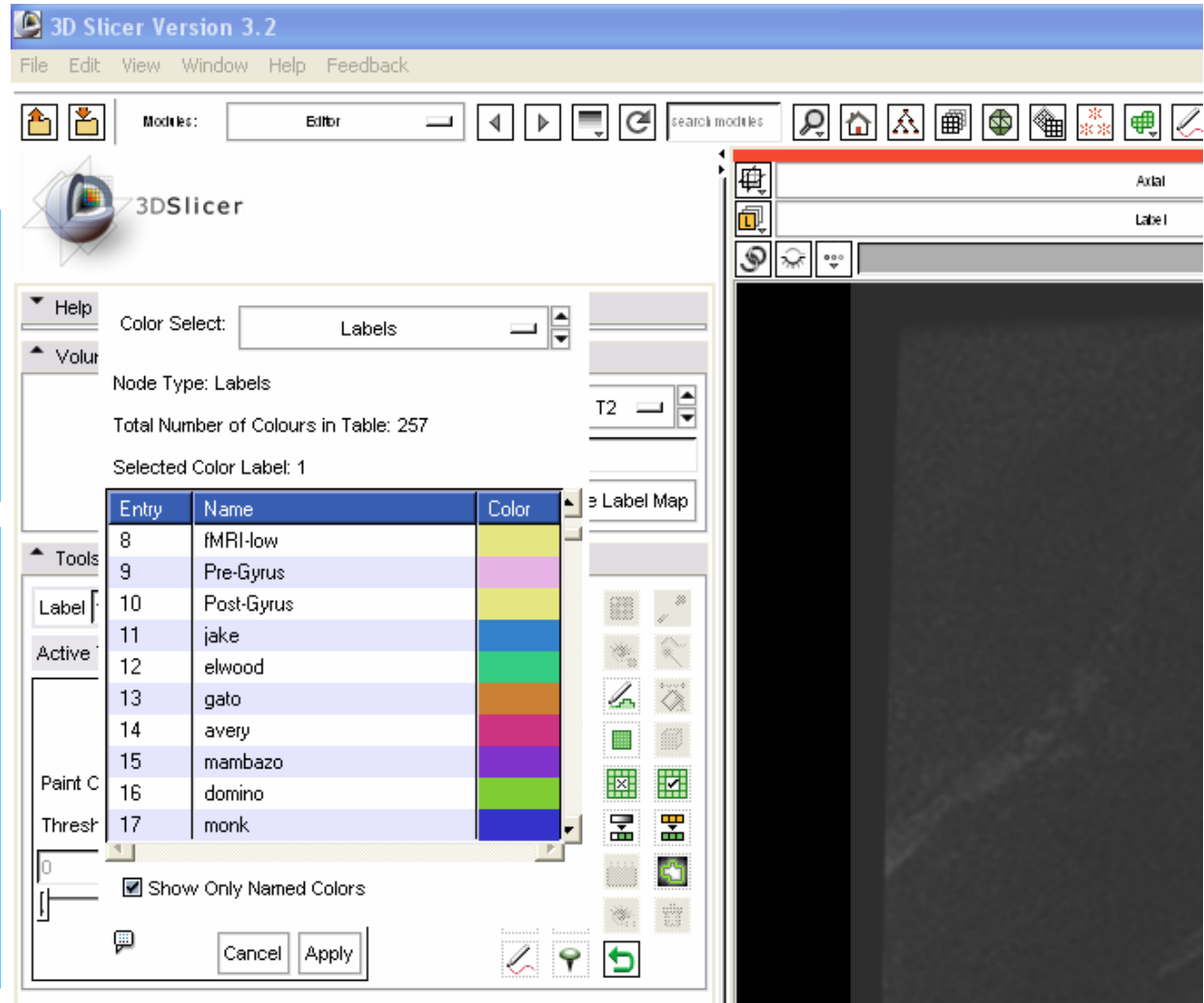
Here, the boundary of the prostate gland is being contoured



Select Color

Change to different color for another structure

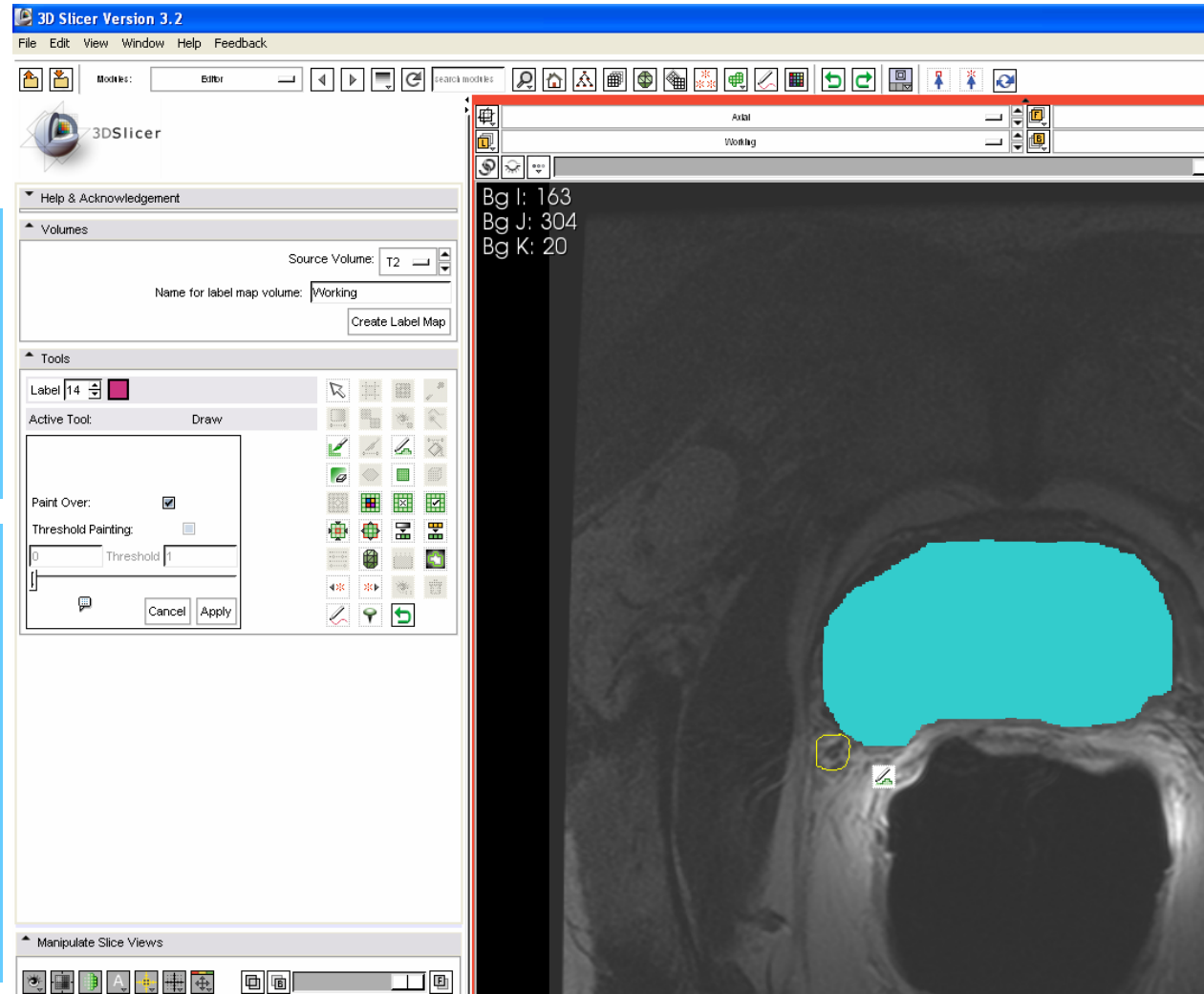
Click on the color box for pop-up color selector



Draw a closed contour

Contour the desired region

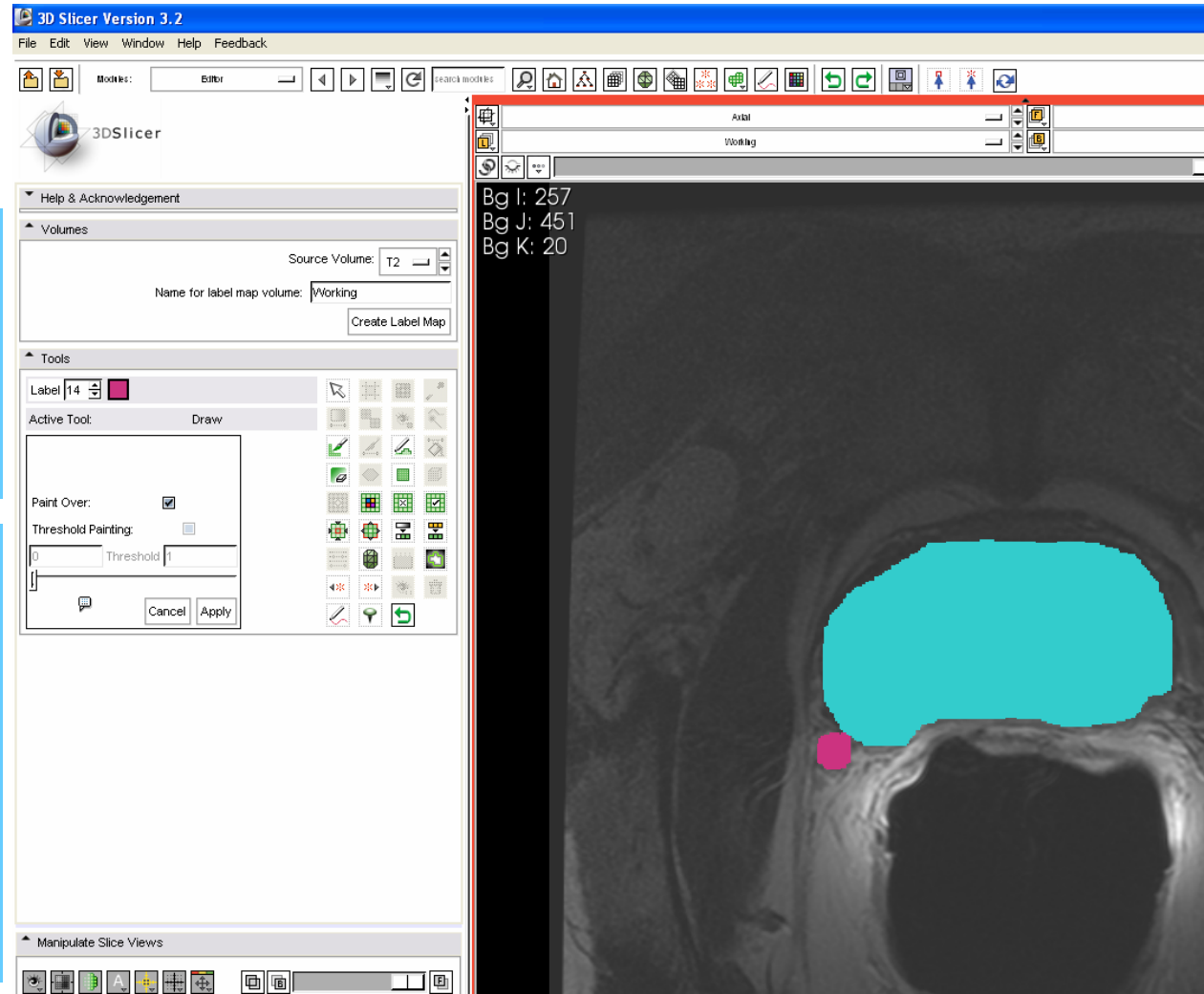
Press the 'a' key to fill in the region when complete



Draw a closed contour

Contour is filled in when 'a' is pressed

Here the right NVB has been contoured

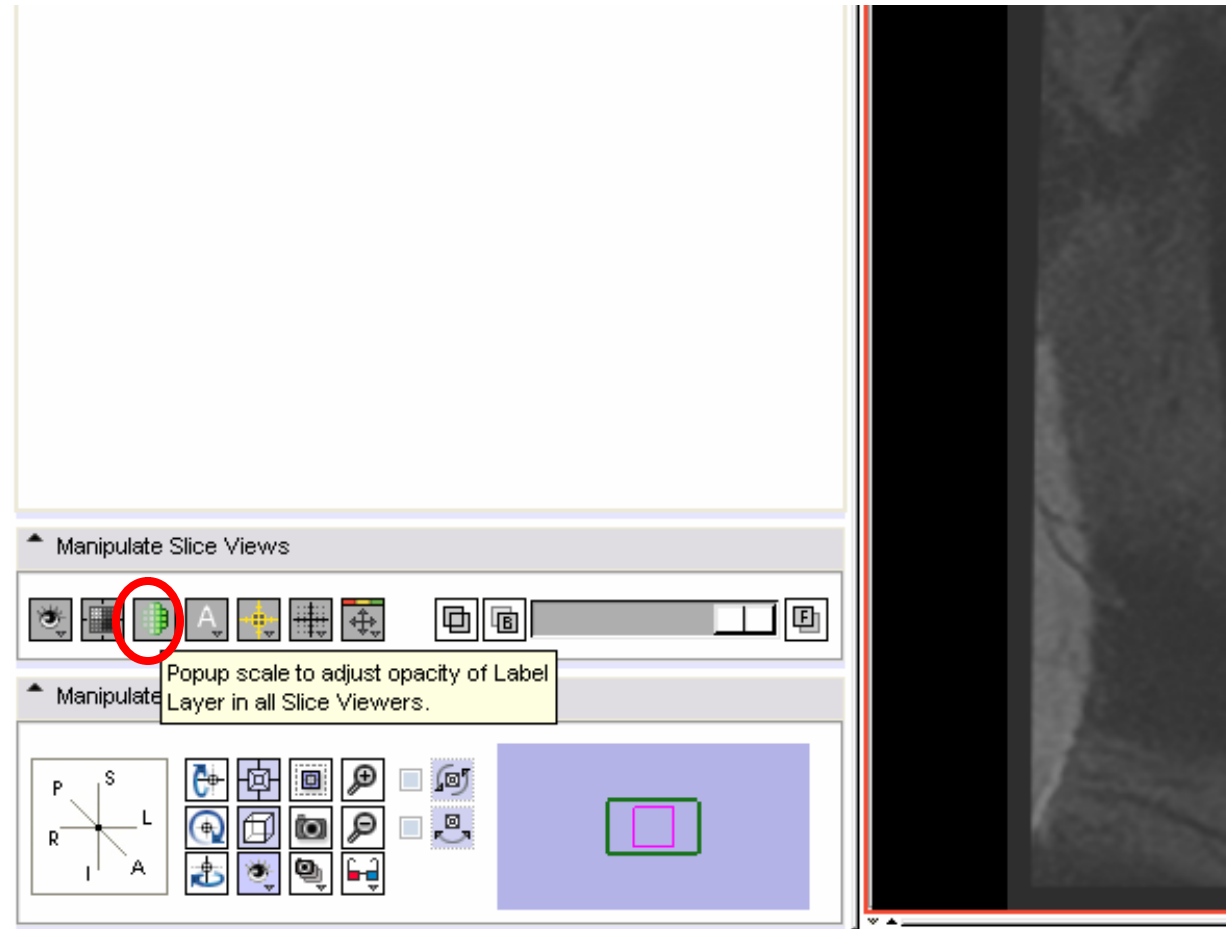


# Manual Segmentation – Opacity

Set Label Opacity

Allows for seeing beneath contoured regions

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

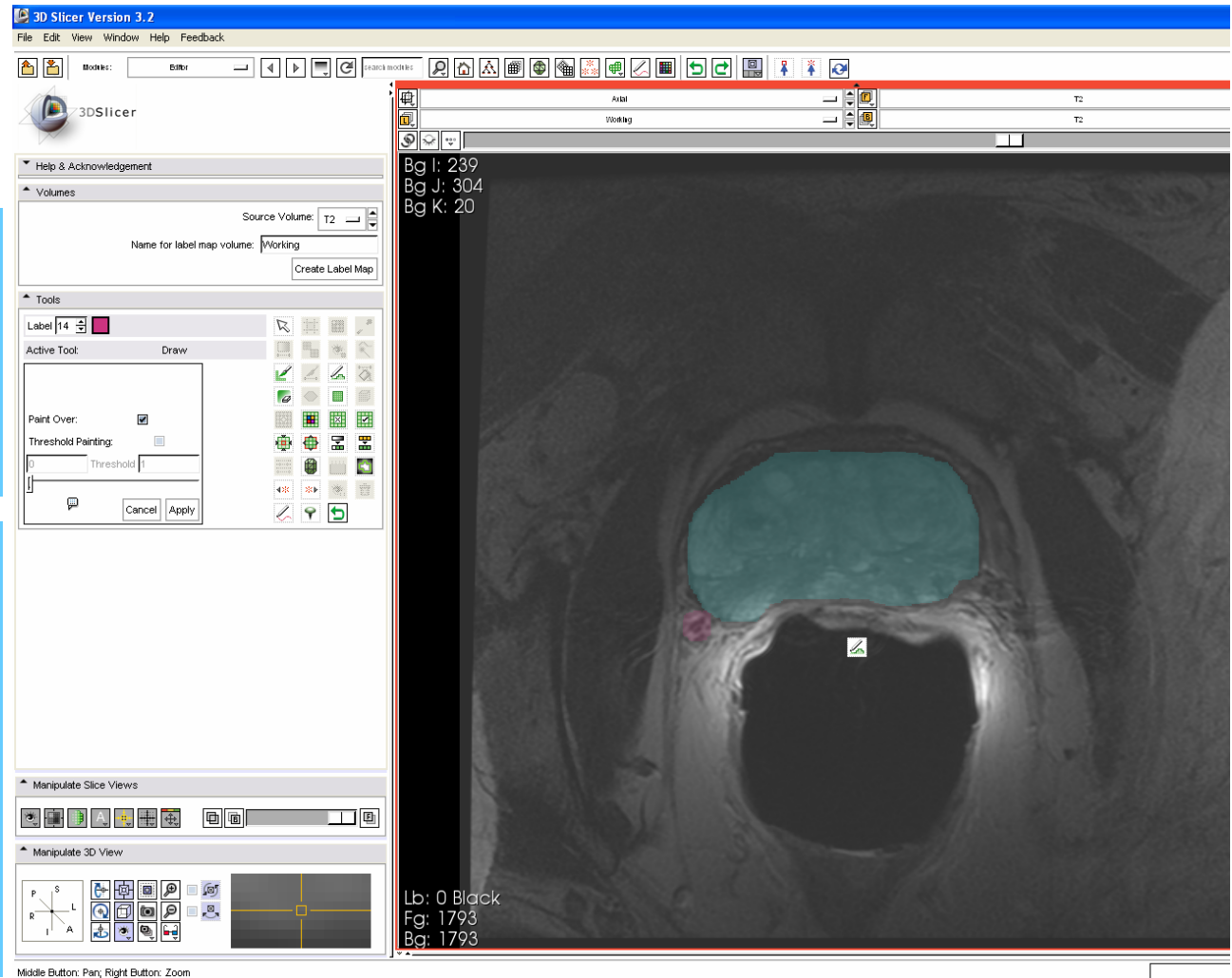




## Set Label Opacity

Allows for seeing beneath contoured regions

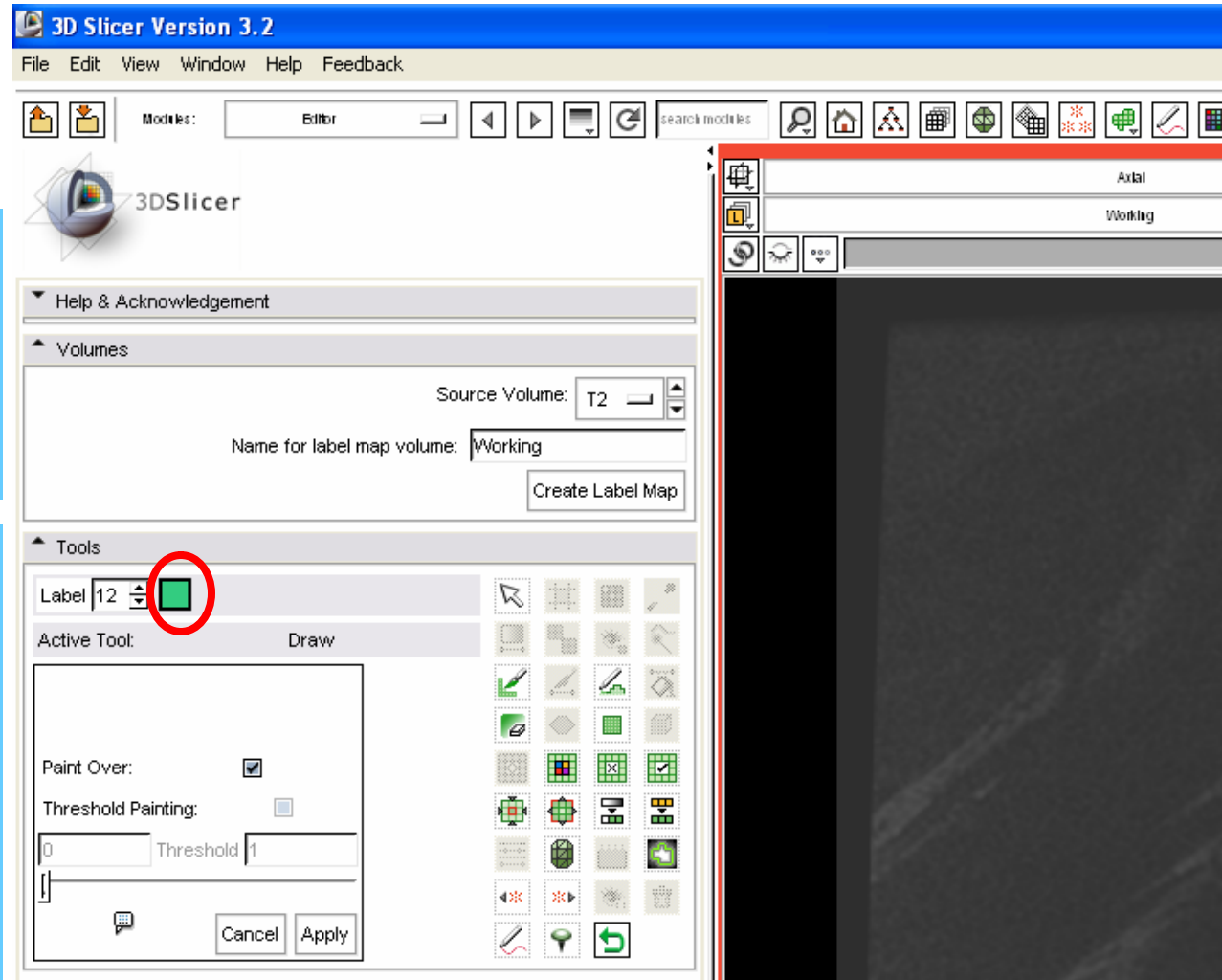
Can visualize MR structure and selected regions at the same time



Select Color

Change to different color for another structure

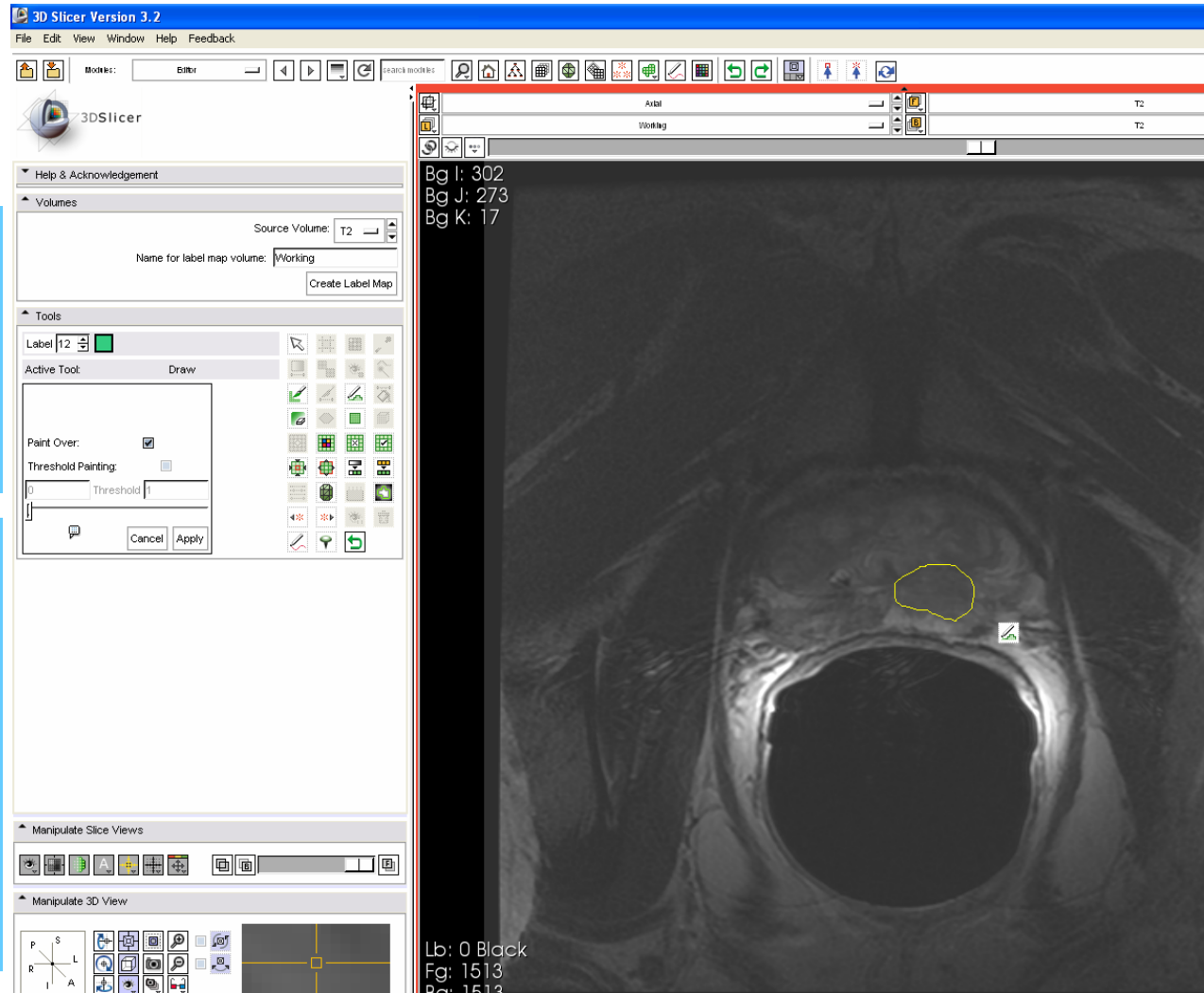
Select a color for tumor segmentation



Draw a closed contour

Contour the desired region. In this case, tumor

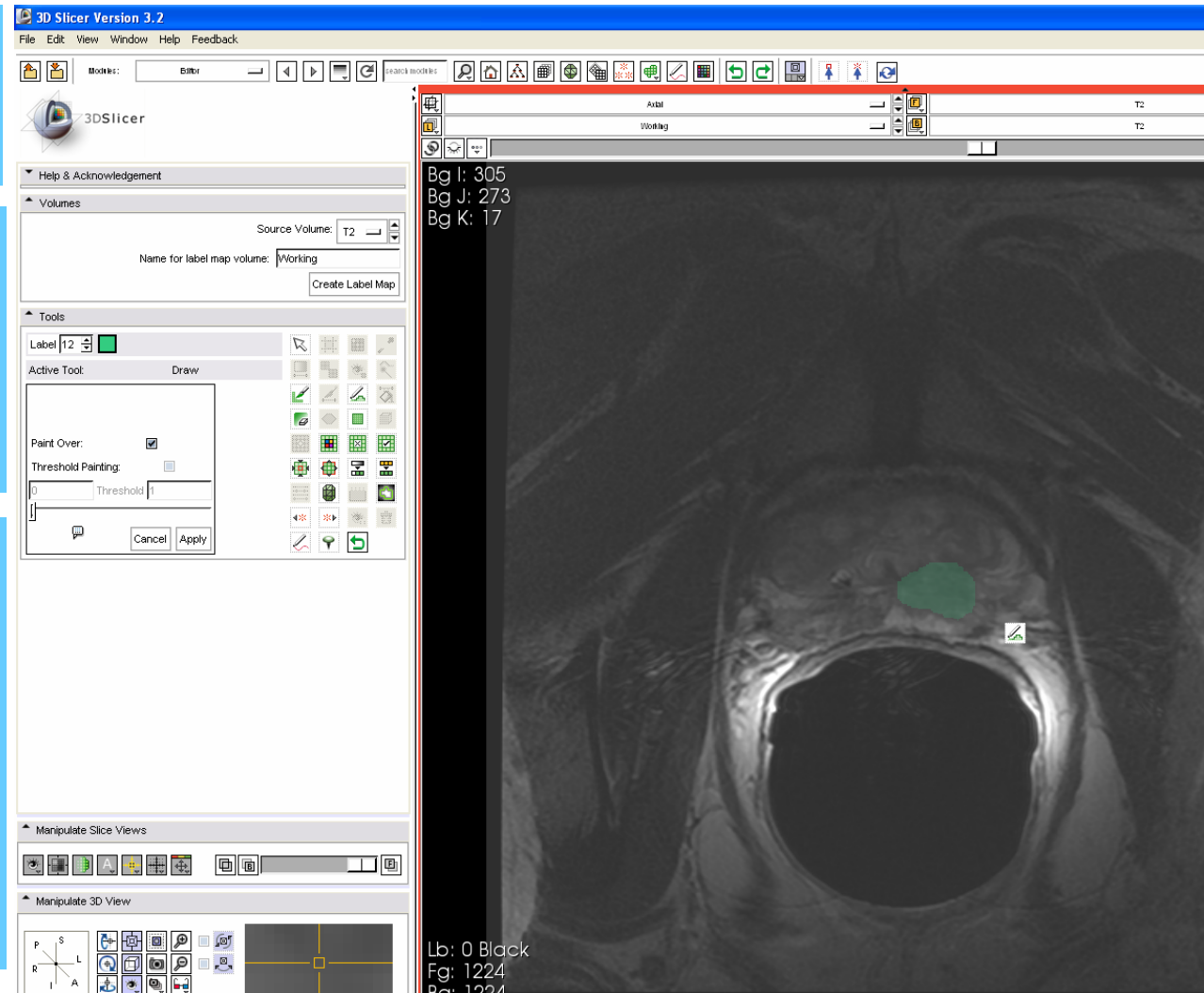
Press the 'a' key to fill in the region when complete



Draw a closed contour

Contour is filled in when 'a' is pressed

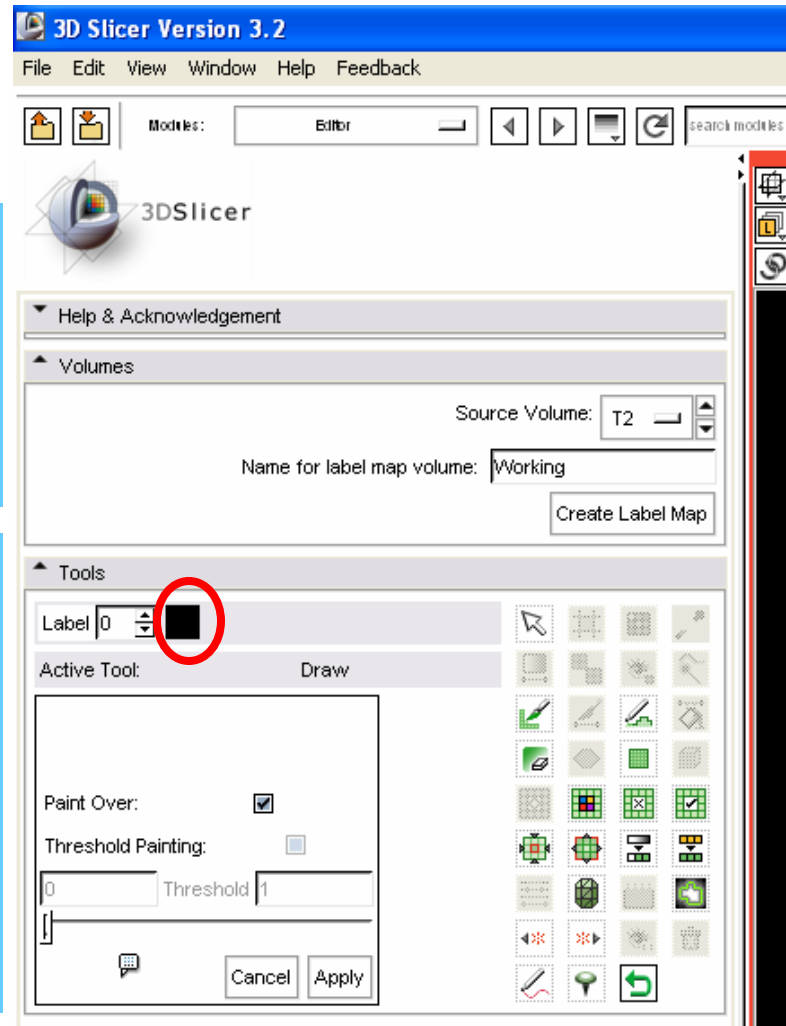
Here a suspected tumor is contoured



Select black as color to draw

Black is label zero.

Draw a closed contour in black to erase a region



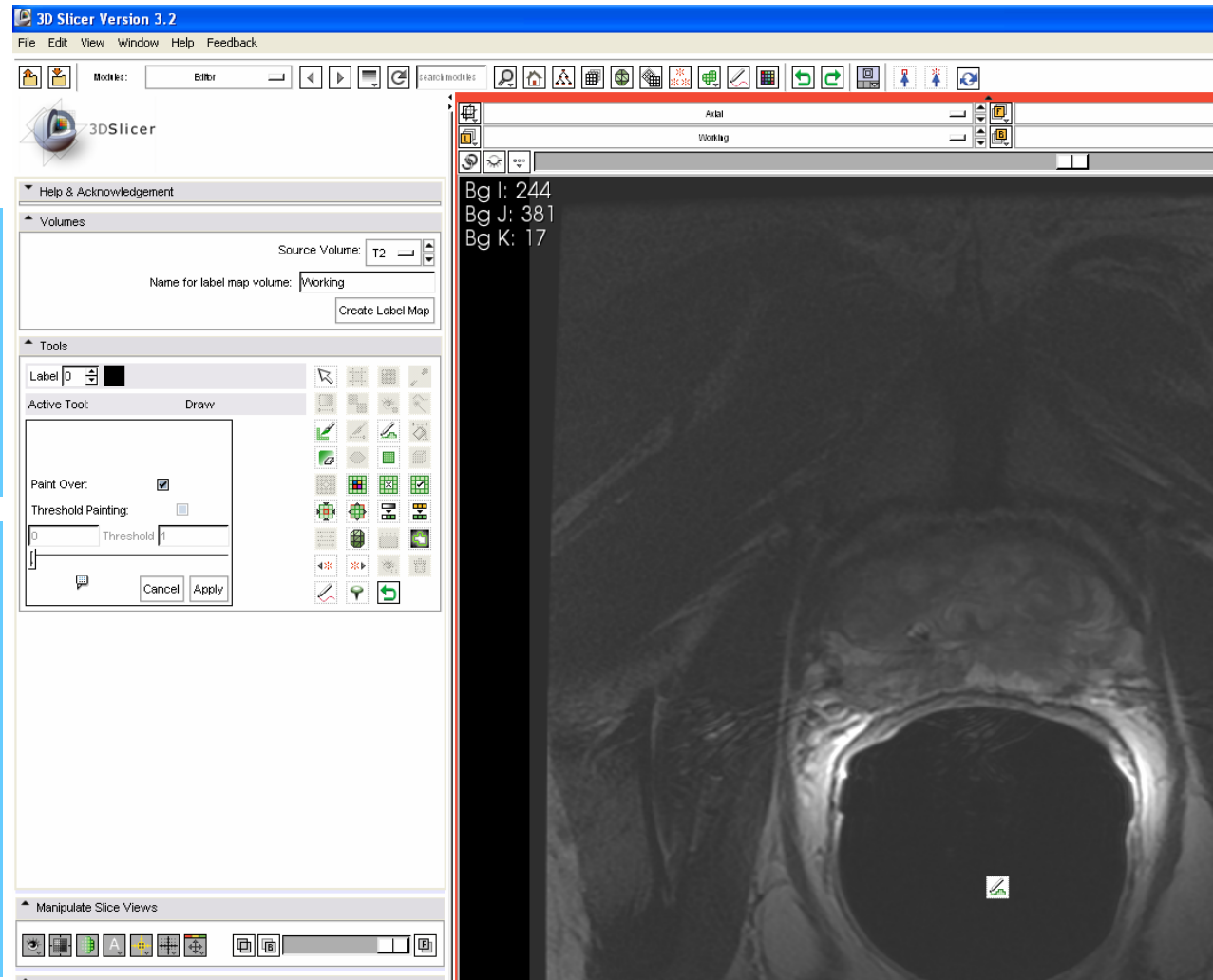


# Manual Segmentation – Erase

Select black as color to draw

Contour the region to erase

Press the 'a' key to erase the region when complete

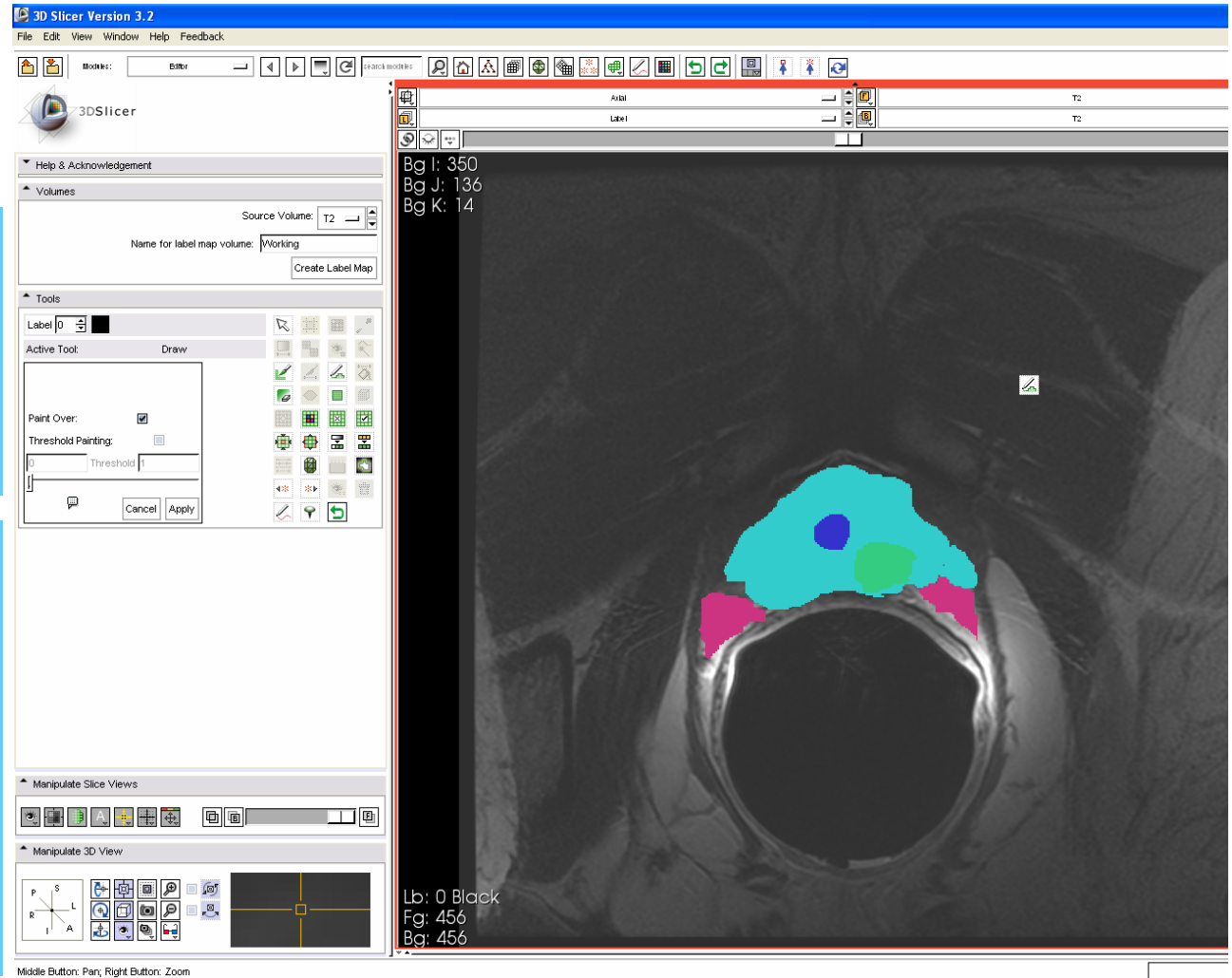


# Manual Segmentation – Result

Segment all slices in volume

Use consistent color scheme

3D models can be made from each labeled region



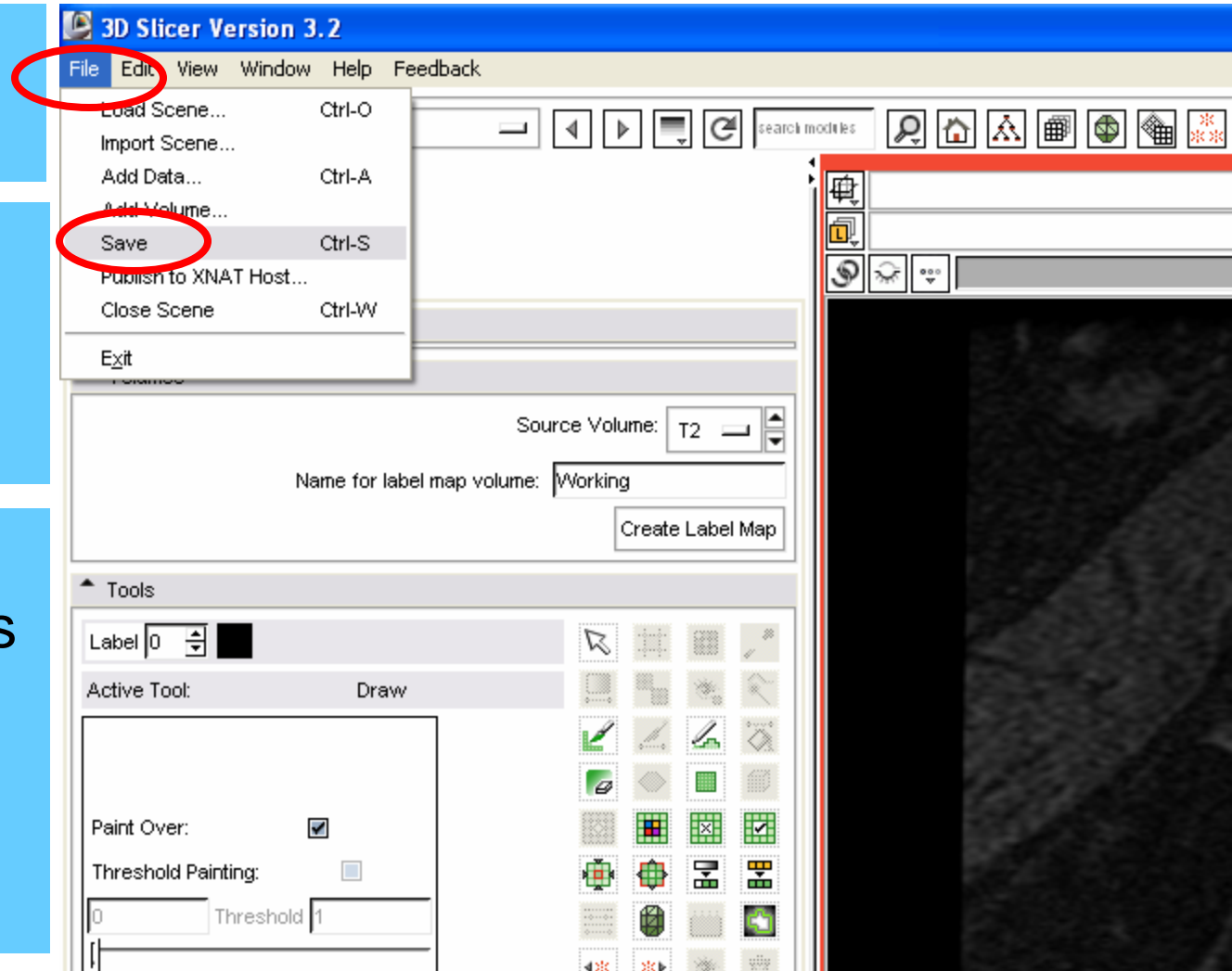


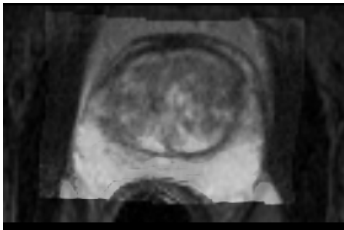
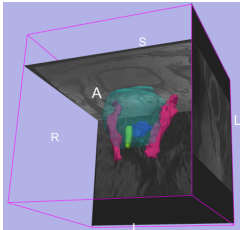
# Manual Segmentation – Save

Save  
Segmentation

Select “Save”  
from File menu

Can save labels  
and image  
settings in a  
scene file





1. MR-guided prostate interventions: clinical background
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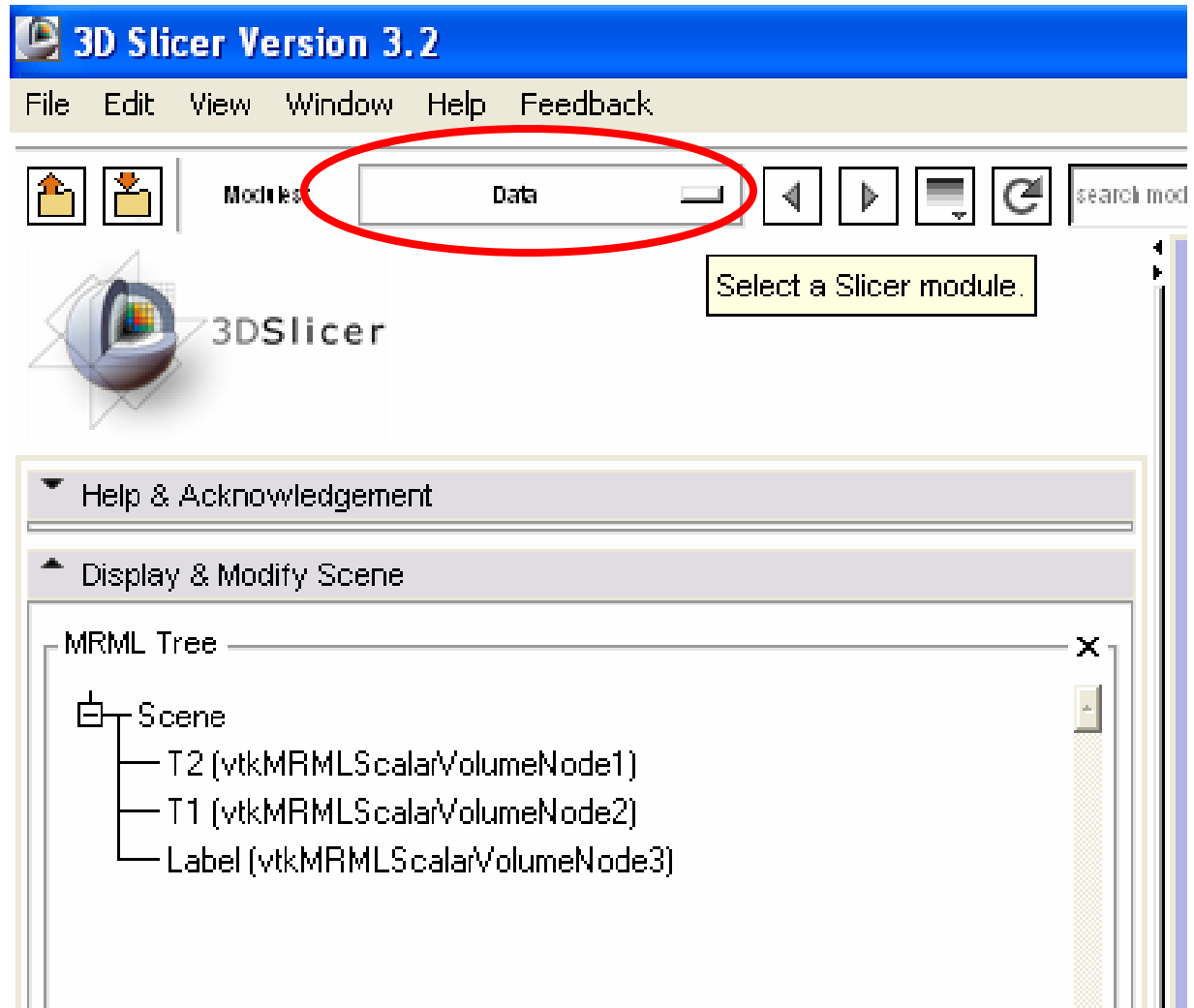


# Creating Models –Select Module

Select Module to Load

We will load the “Model Maker” module

Model Maker Module makes 3D triangulated surfaces from segmentations

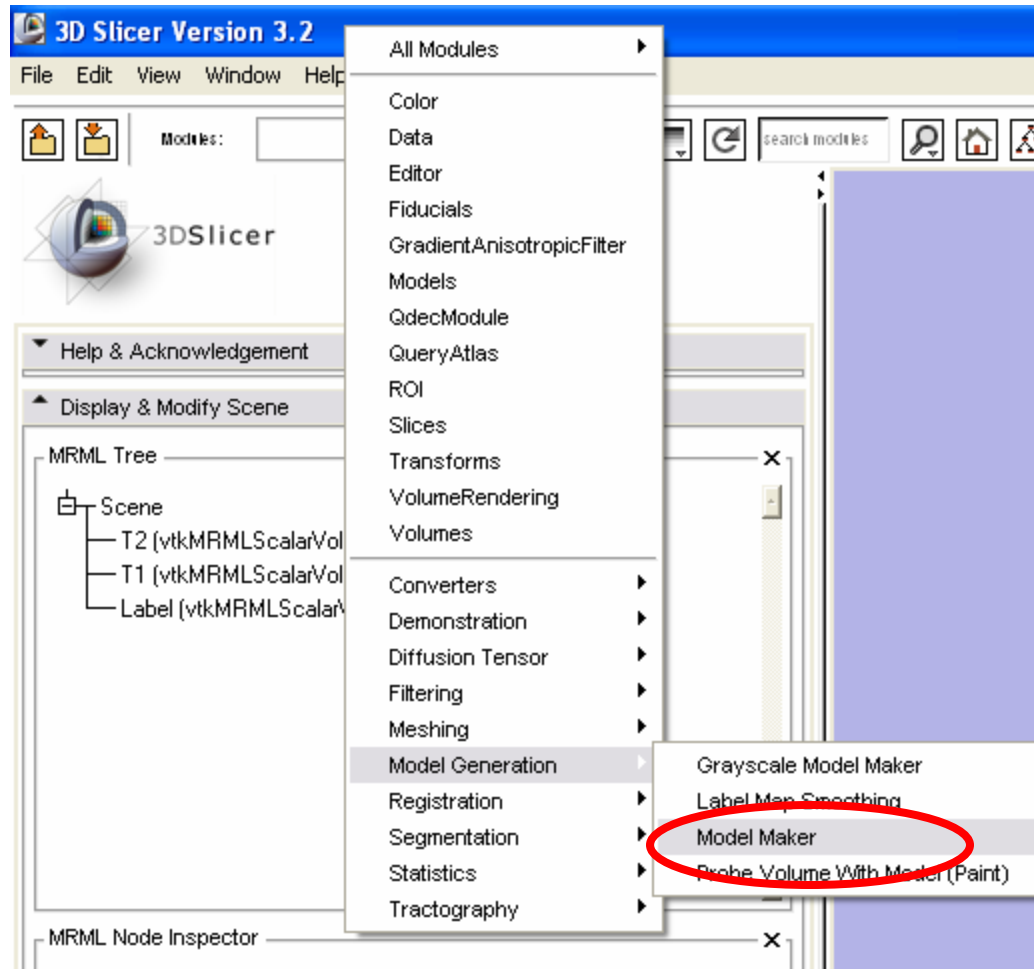


# Creating Models –Select Module

Select Module  
to Load

“Model Maker”

Other model  
choices may  
apply for other  
applications

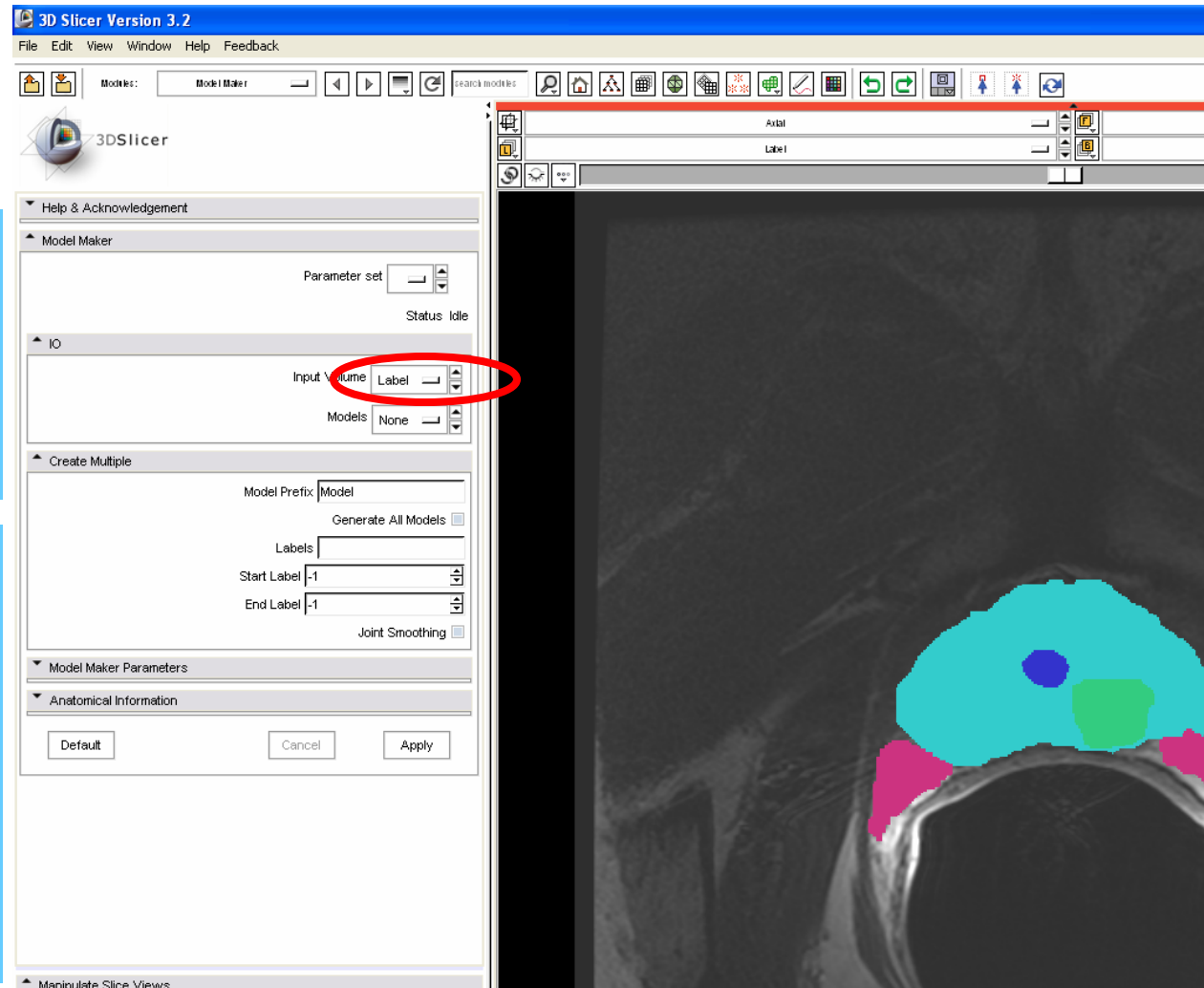


# Creating Models – Input Volume

Choose Input Volume

This is the volume called “Label” in this demo

Each label value in the label map can be made into a surface

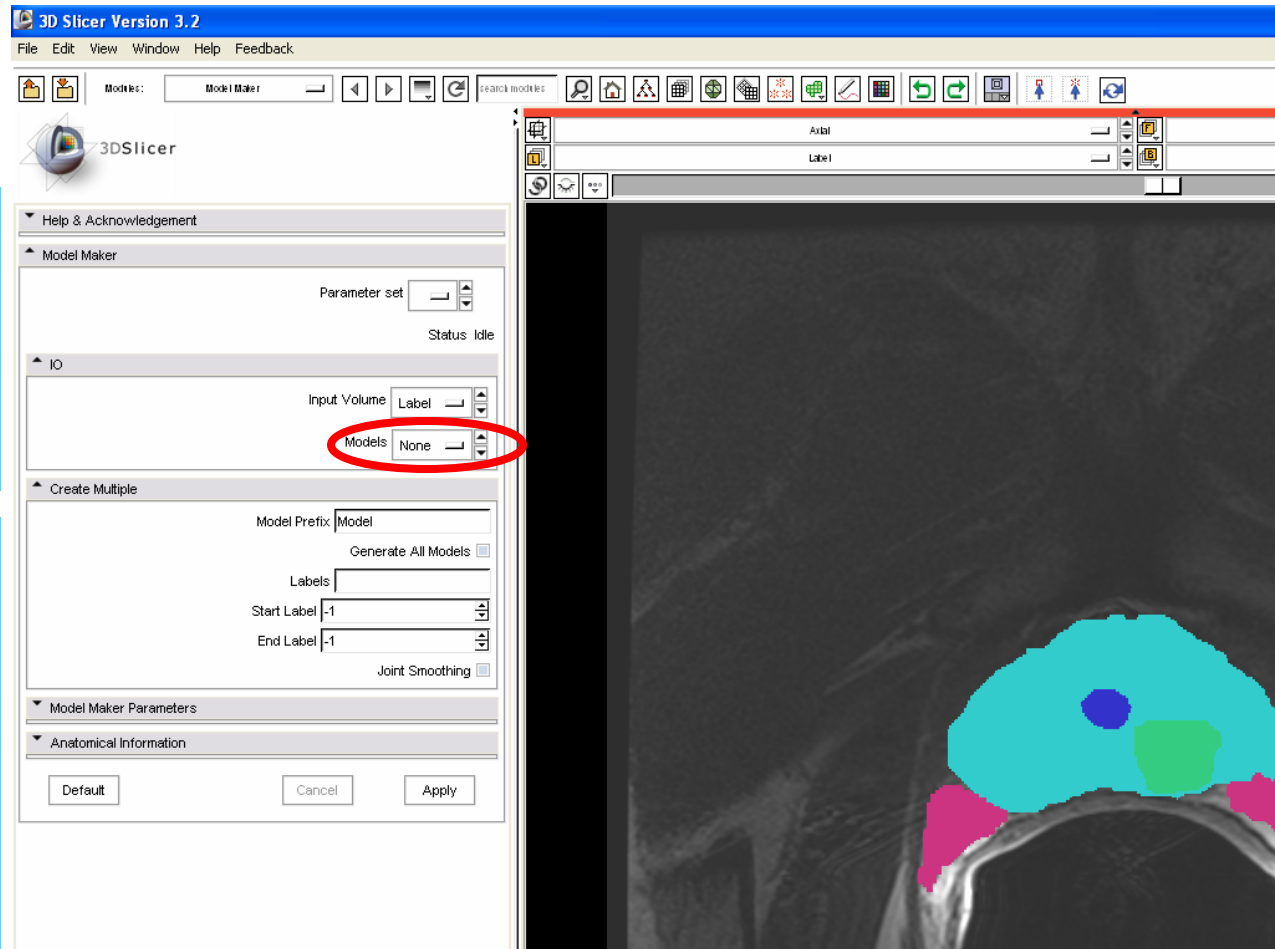


# Creating Models – Hierarchy

Create a Model Hierarchy

Under “Models” menu

Hierarchies can be used to organize 3D models into groups

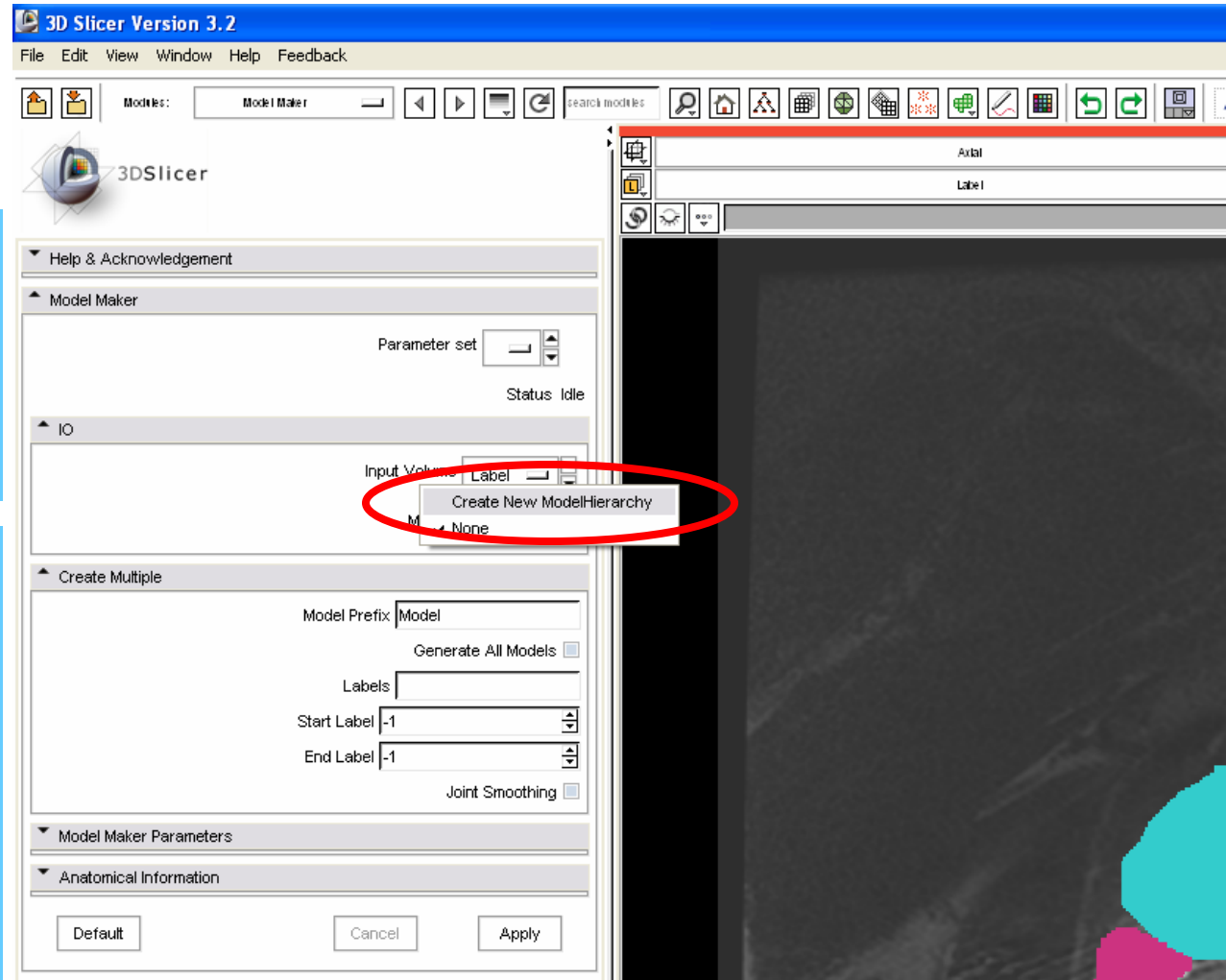


# Creating Models – Hierarchy

Create a Model Hierarchy

Select “Create New Model Hierarchy”

Hierarchies can be used to organize 3D models into groups



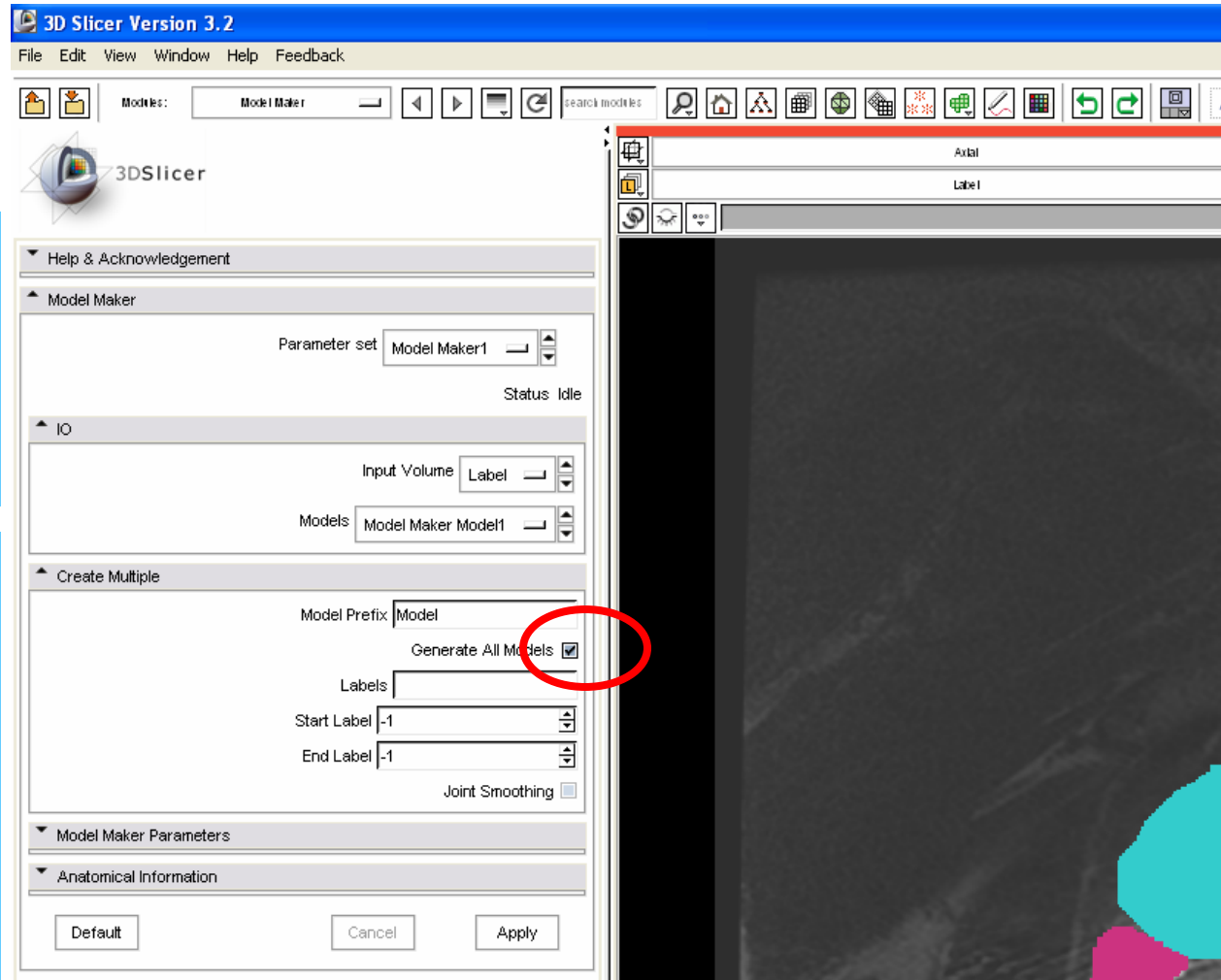


# Creating Models – Generate

Generate Models

Check the box “Generate All Models”

You could also generate models individually for each label value

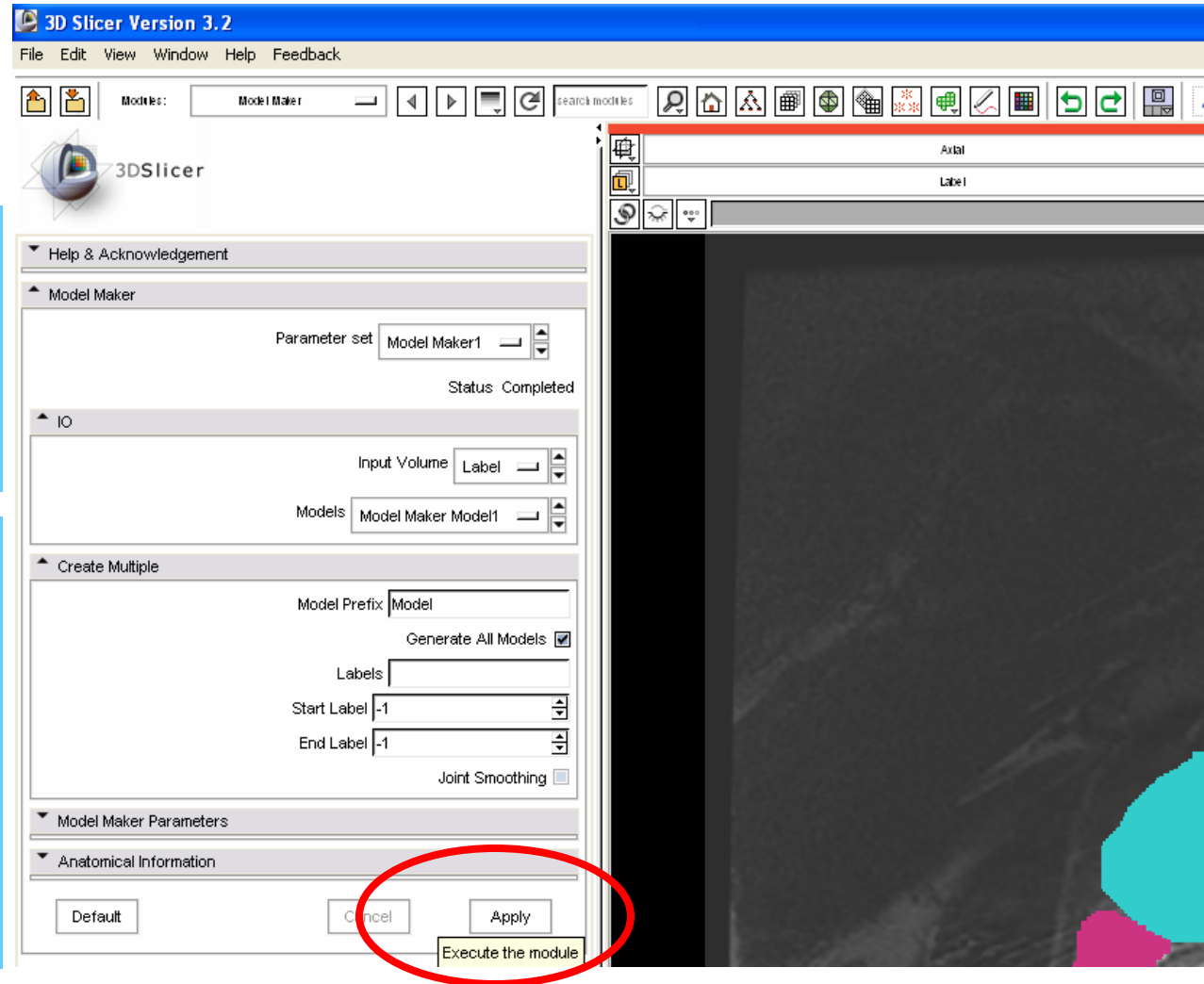




Generate Models

Press the “Apply” Button

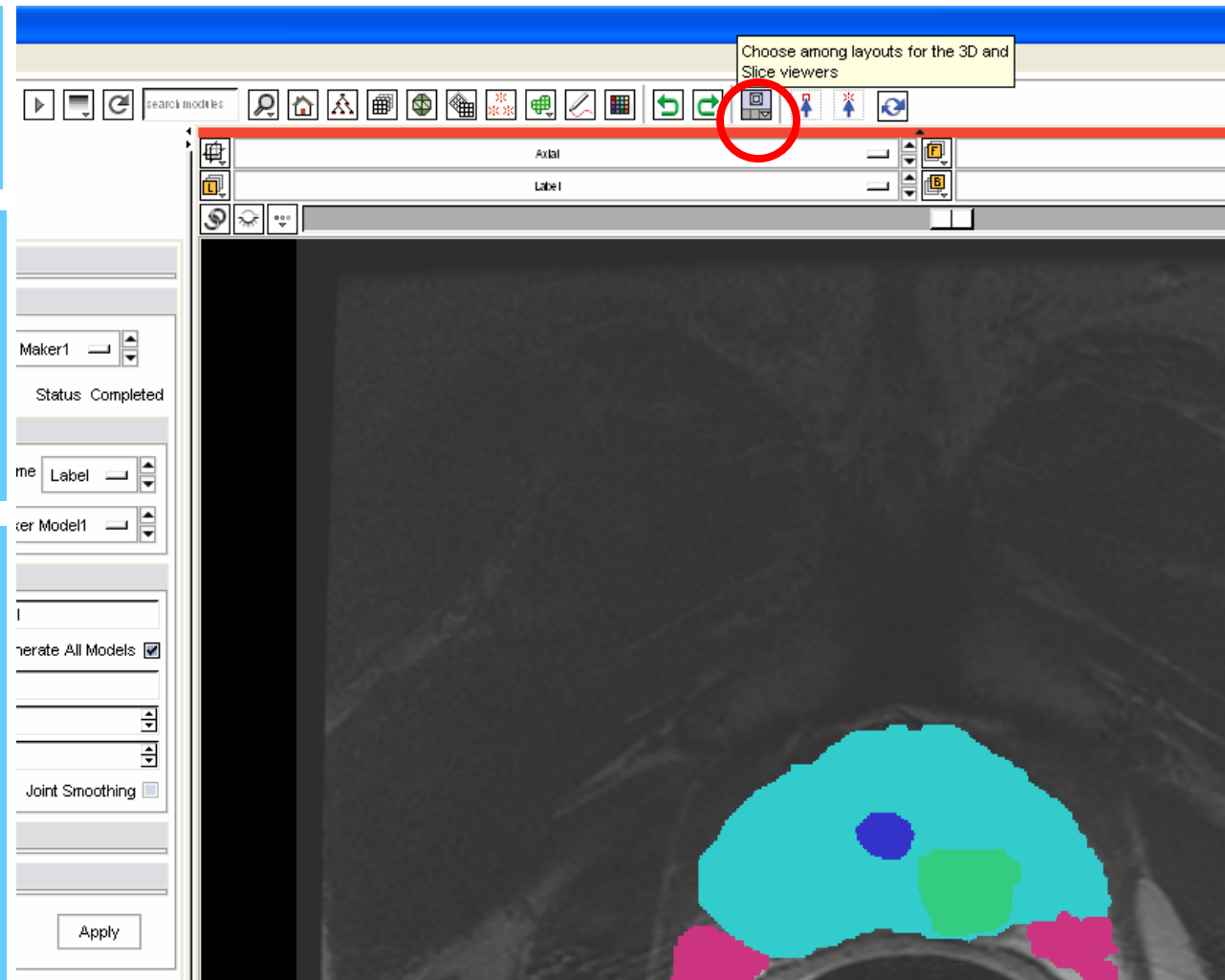
Slicer will create all the models



View the models  
in 3D

Change from  
Single Slice  
View

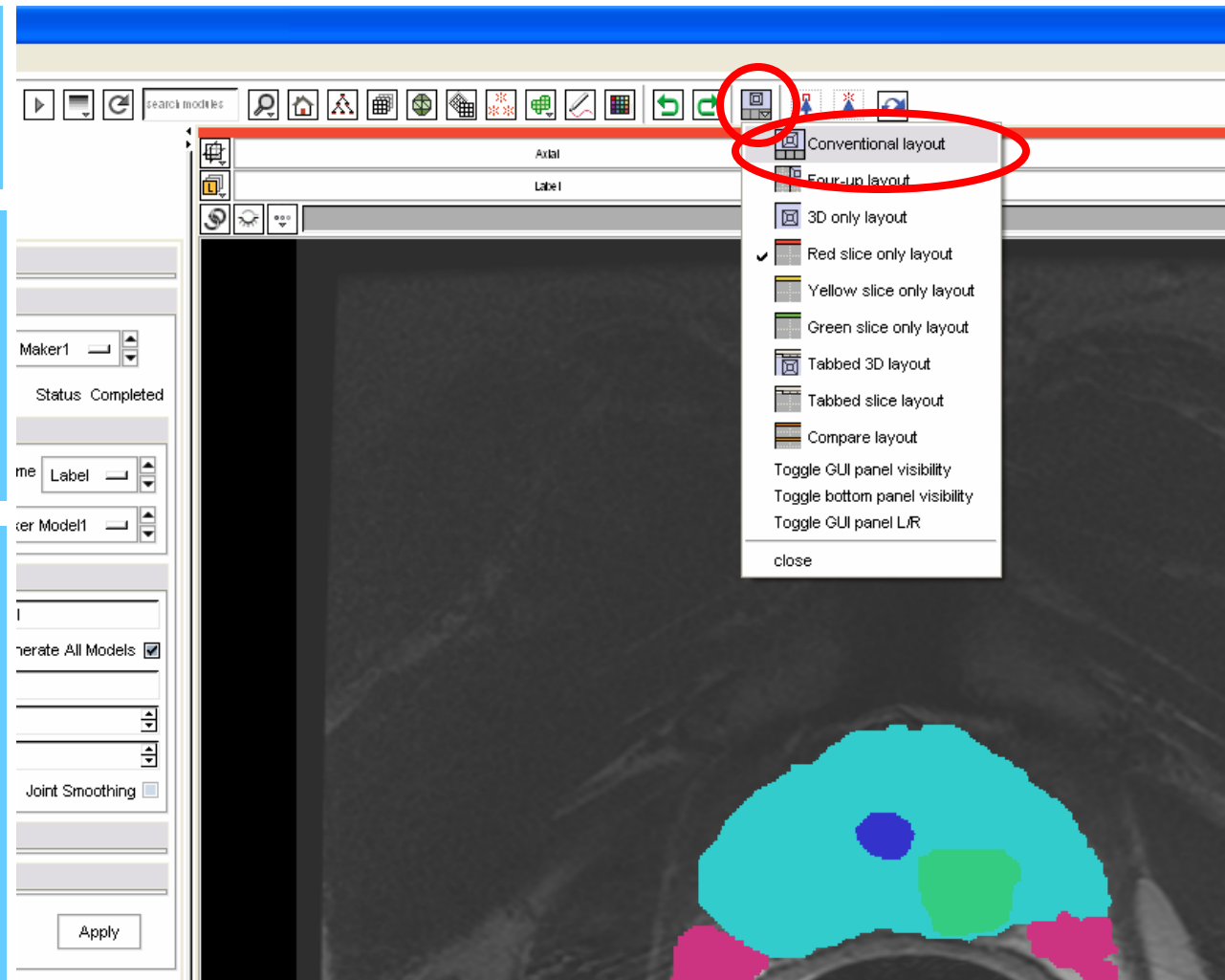
We can  
visualize both  
the models and  
image slices in  
3D



View the models  
in 3D

Select  
“Conventional  
Layout”

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

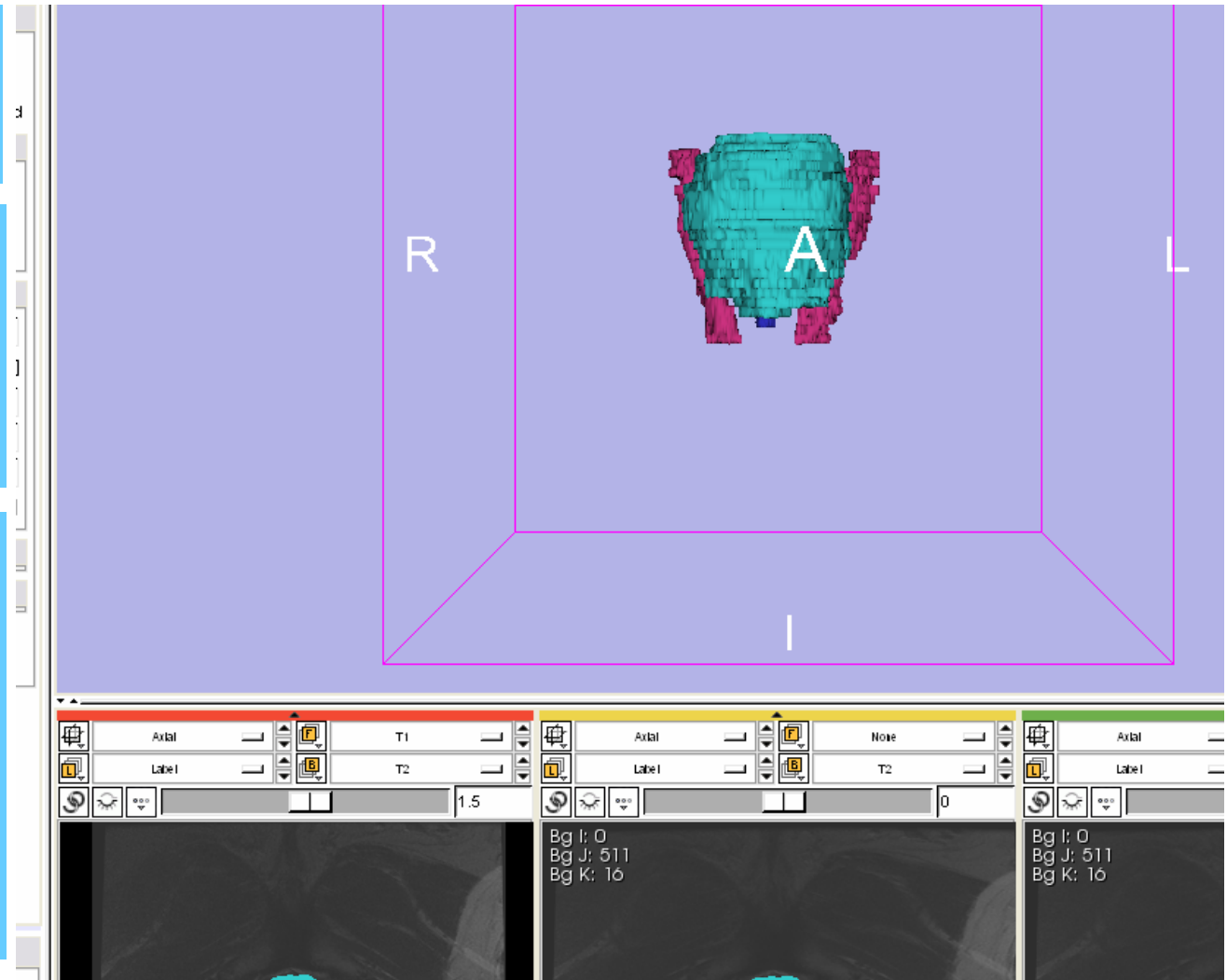


# Creating Models – View

View the models  
in 3D

3D View  
appears

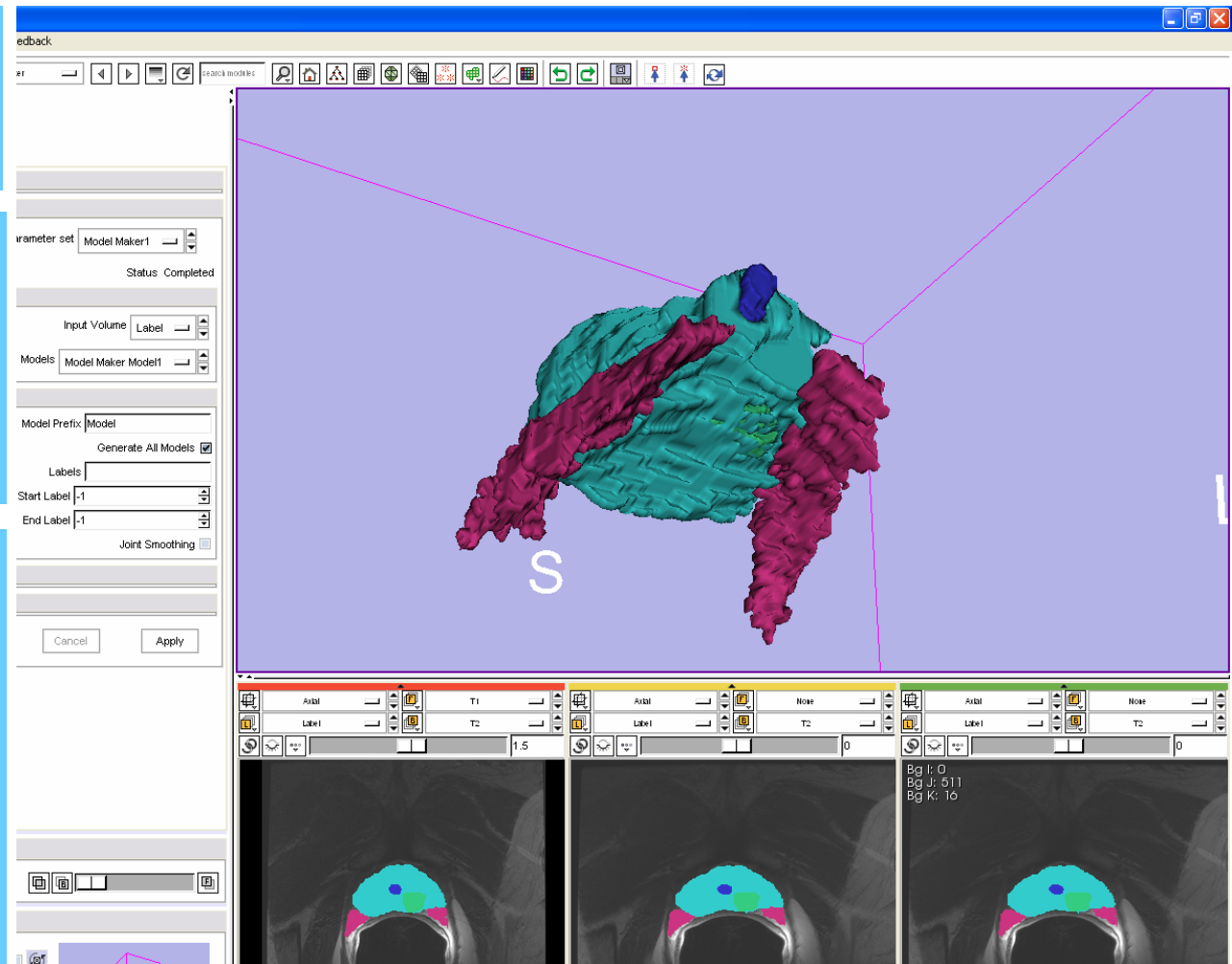
Surface  
structures  
appear colored  
by their label  
colors



View the models  
in 3D

Mouse can be  
used to rotate  
surface

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



# Creating Models – View

View the models  
in 3D

View cross-  
sectional slice

Press the “eye”  
button above  
the slice(s) to  
view

Parameter set: Model Maker1

Status: Completed

Input Volume: Label

Models: Model Maker Model1

Model Prefix: Model

Generate All Models:

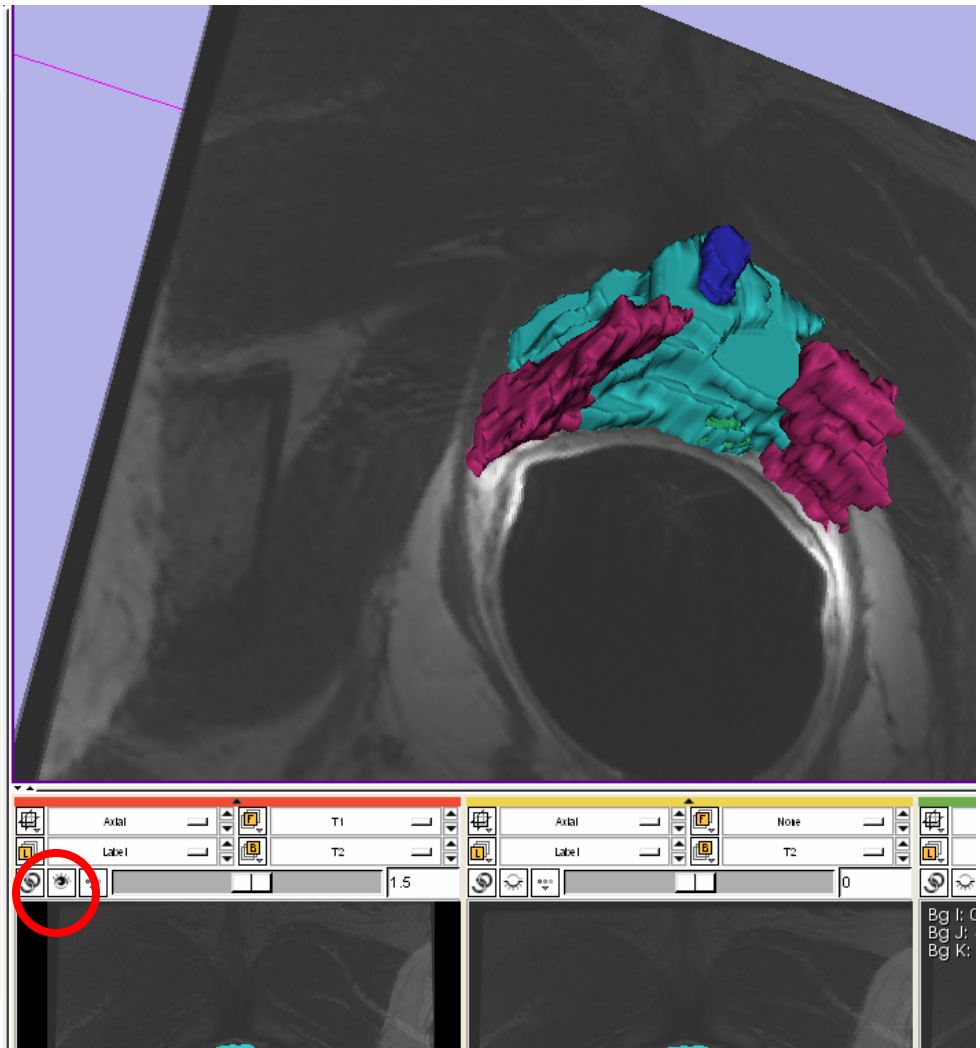
Labels:

Start Label: -1

End Label: -1

Joint Smoothing:

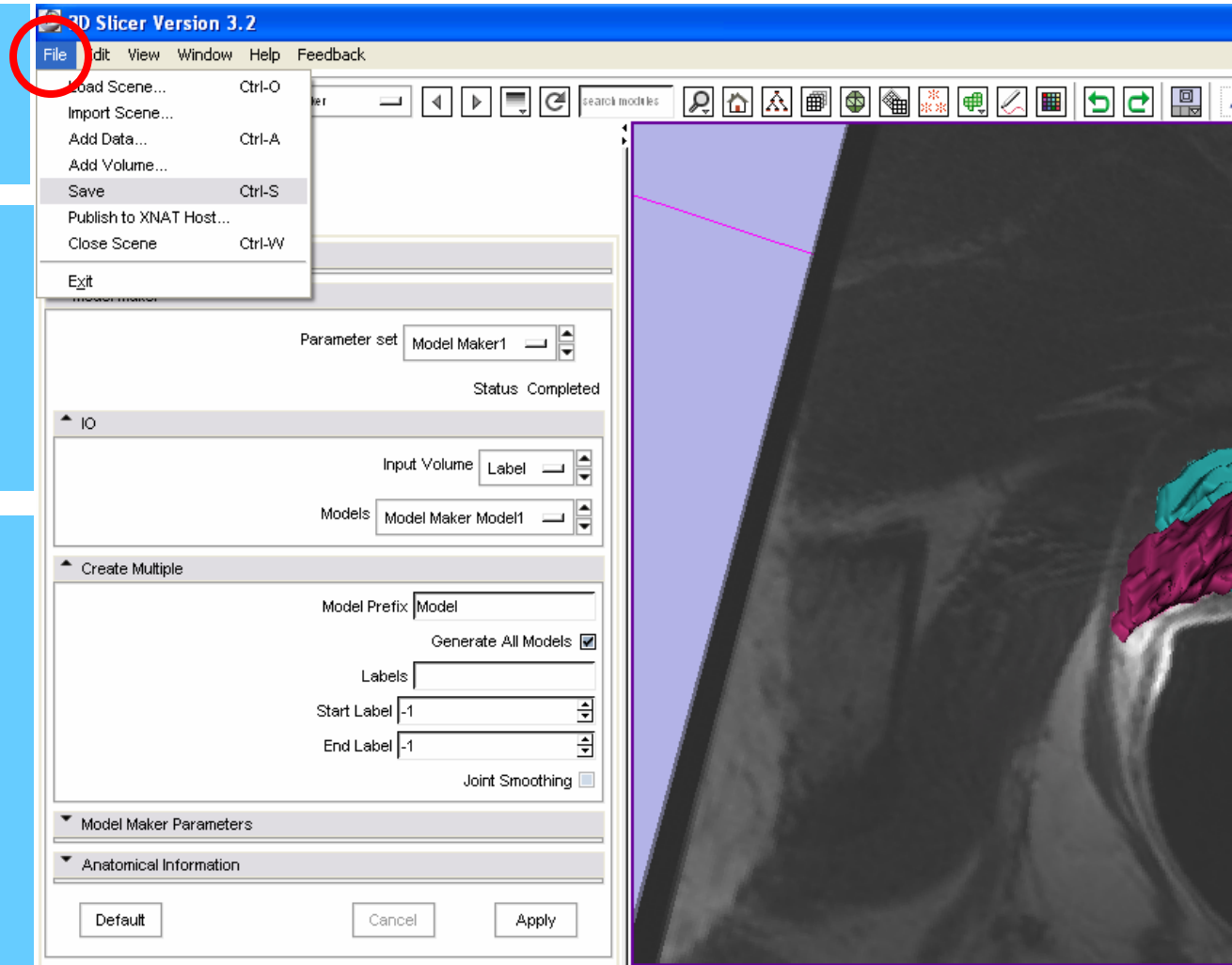
Cancel Apply



Save the models

Models need to be saved or they will be lost

Select “Save” from the “File” menu

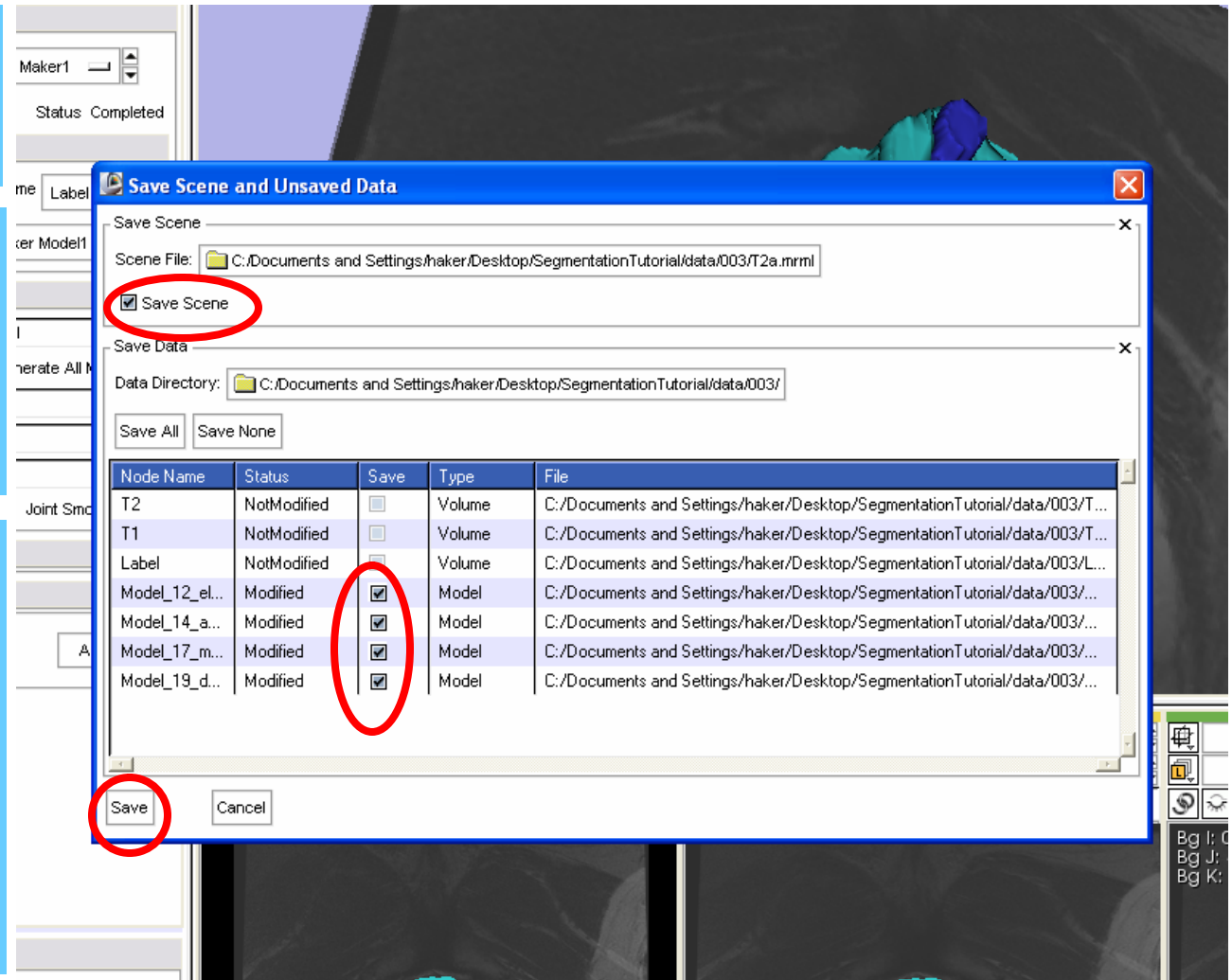


# Creating Models – Save

Save the models

Models need to be saved or they will be lost

Make sure “Save” is checked next to models and “Save Scene”







# Conclusions

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- 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*

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- 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

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Clare Tempany, Nobuhiko Hata, Ron Kikinis



**National Center for Image Guided Therapy**  
NIH U41RR019703



**NEDO Intelligent Surgical Instruments Project**

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