Slicer3 Training Tutorial

Centerline Extraction of Coronary Arteries in 3D Slicer using VMTK based Tools

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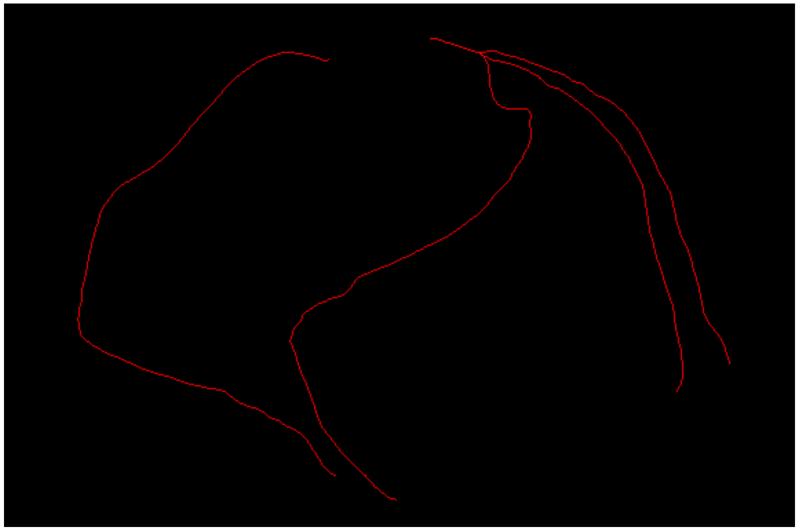
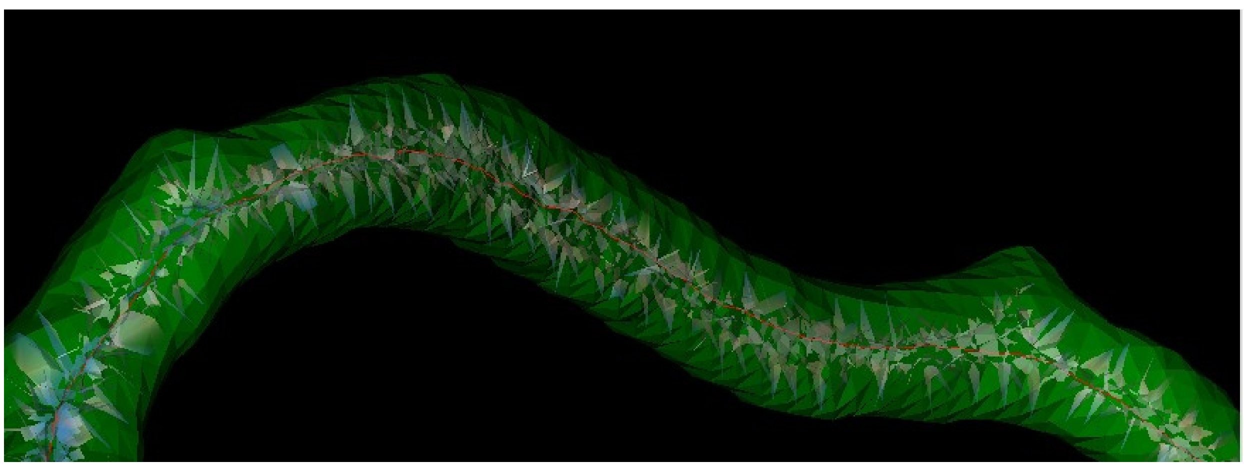
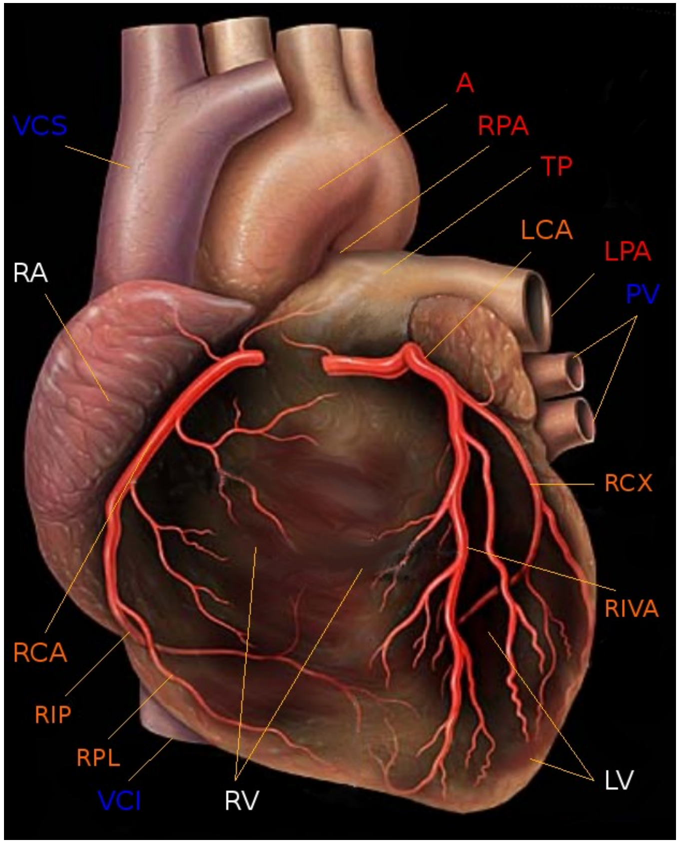
Learning Objective



Guiding you step by step through the process of centerline extraction of Coronary Arteries in a cardiac blood-pool MRI using VMTK based Tools.



Background



Human Heart with Coronaries, Author: Patrick J. Lynch (1999), Creative Commons License

Coronary heart disease (CHD) is the leading cause of death in high-income countries and one of the main causes of death worldwide*.

The primary cause for CHD is atherosclerosis of the coronary arteries and is called coronary artery disease (CAD).

The extraction of the central lumen line (centerline) of coronary arteries is helpful for visualization purposes, stenosis quantification or further processing steps.

* WHO Fact Sheet 310: http://www.who.int/mediacentre/factsheets/fs310/en/index.html

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 3.5 Nightly Build****)

http://slicer.org/pages/Special:SlicerDownloads

- Unzipped **Tutorial MRI data** (3 files)

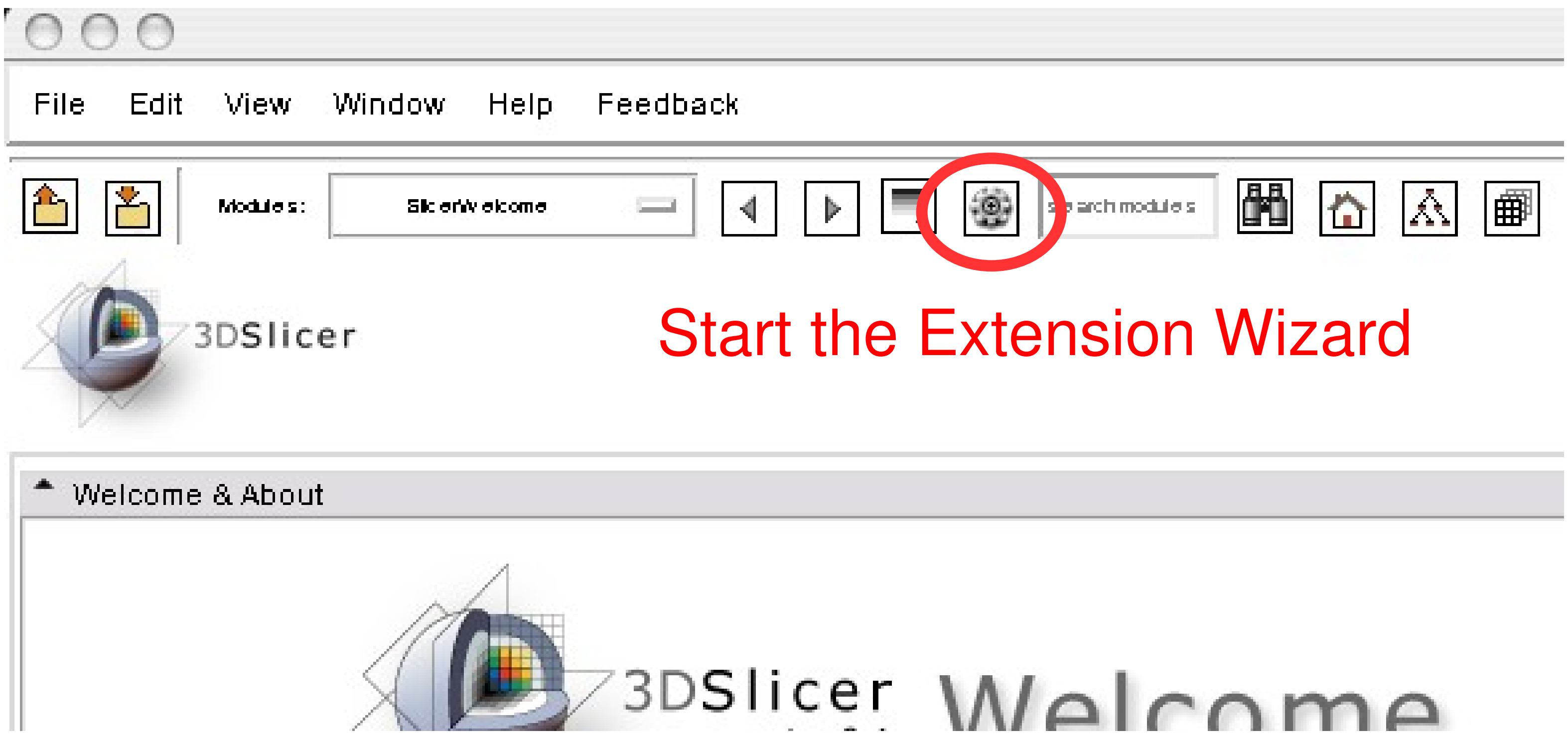
http://www.na-mic.org/Wiki/index.php/File:TutorialVMTKCoronariesCenterlinesMRI_Data_Winter2010AHM.zip

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.*

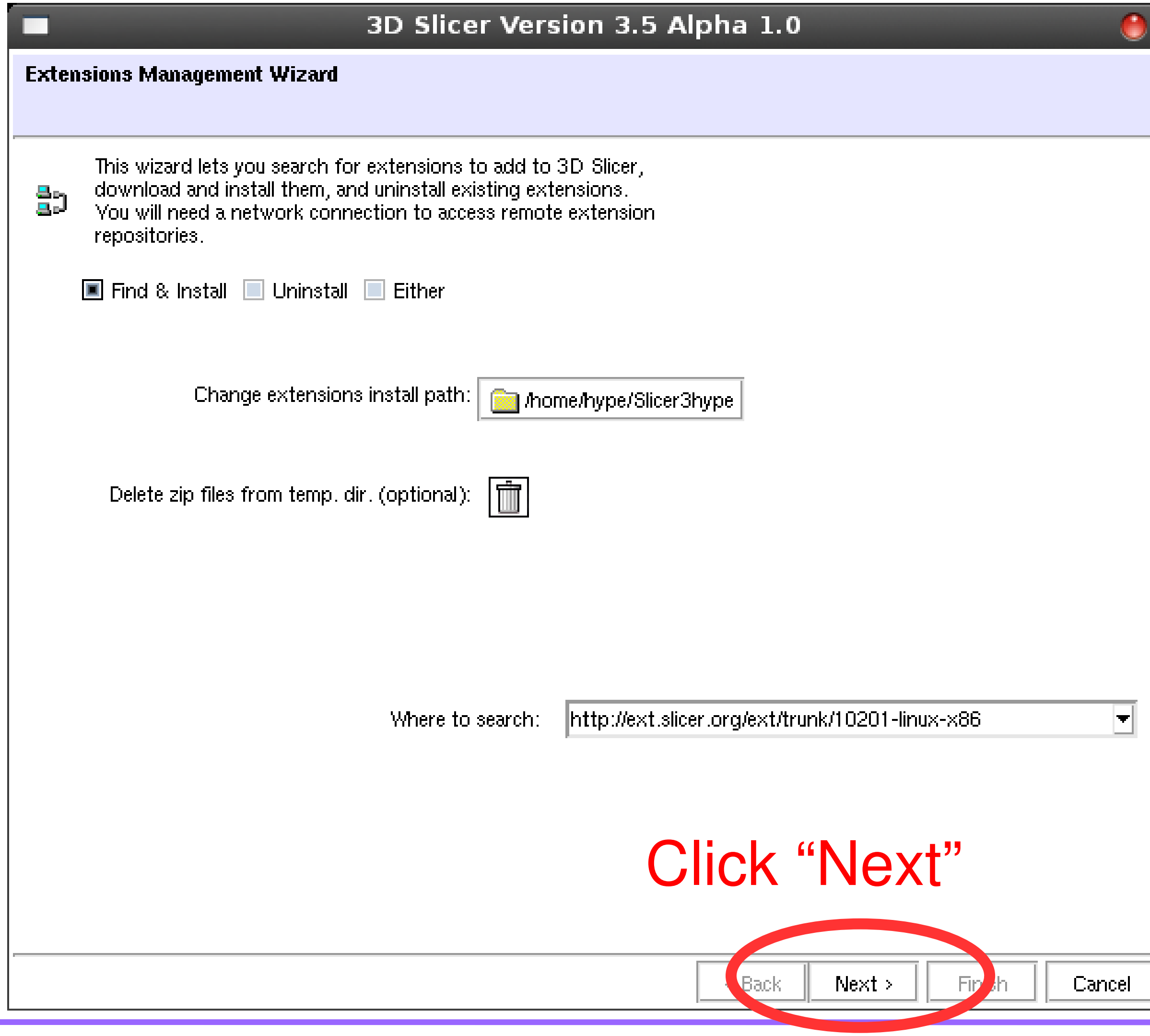
* or a Snapshot after December 2009, the Slicer3 extension system has to work properly

Overview

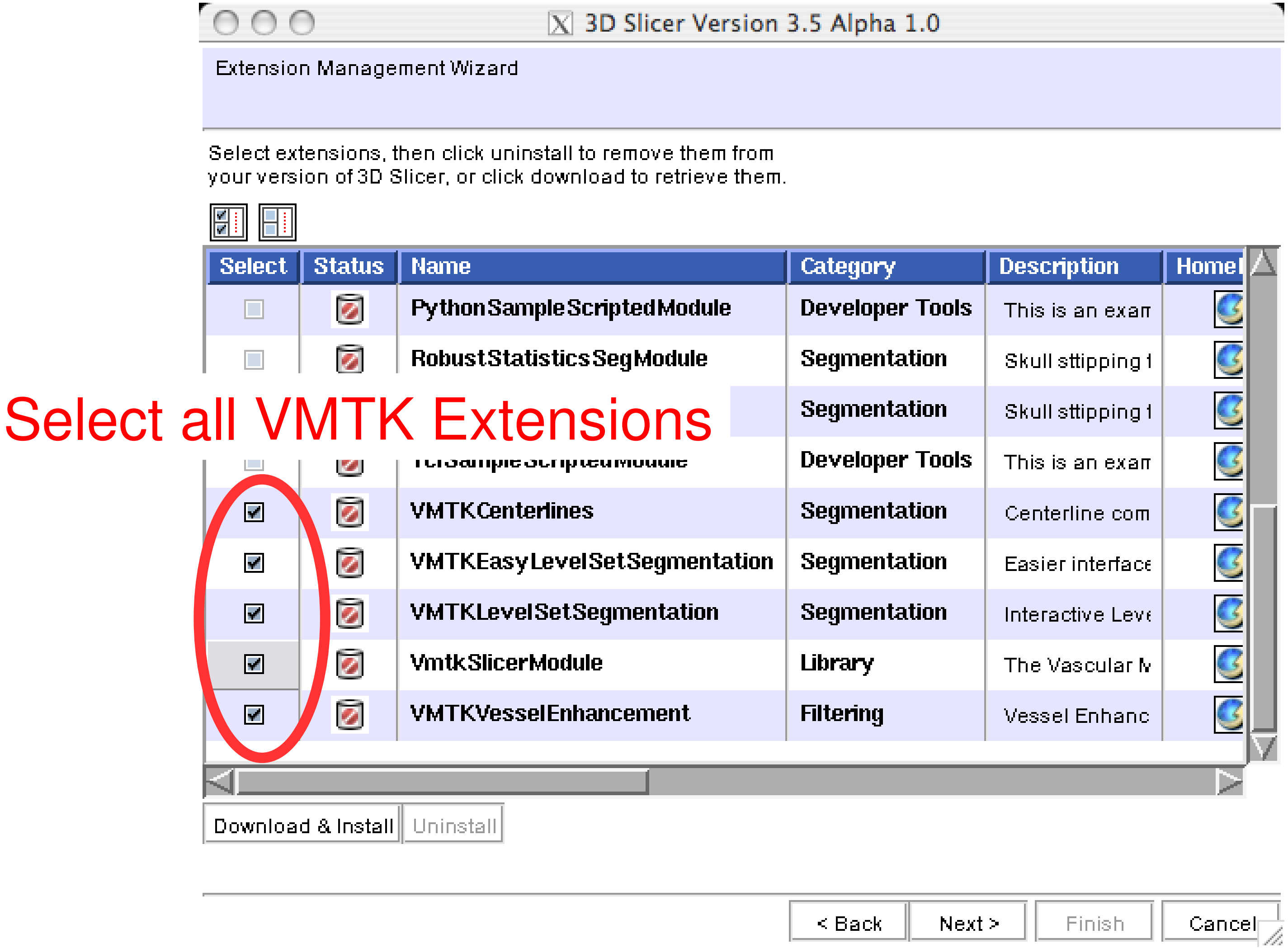
Installing VMTK in 3D Slicer



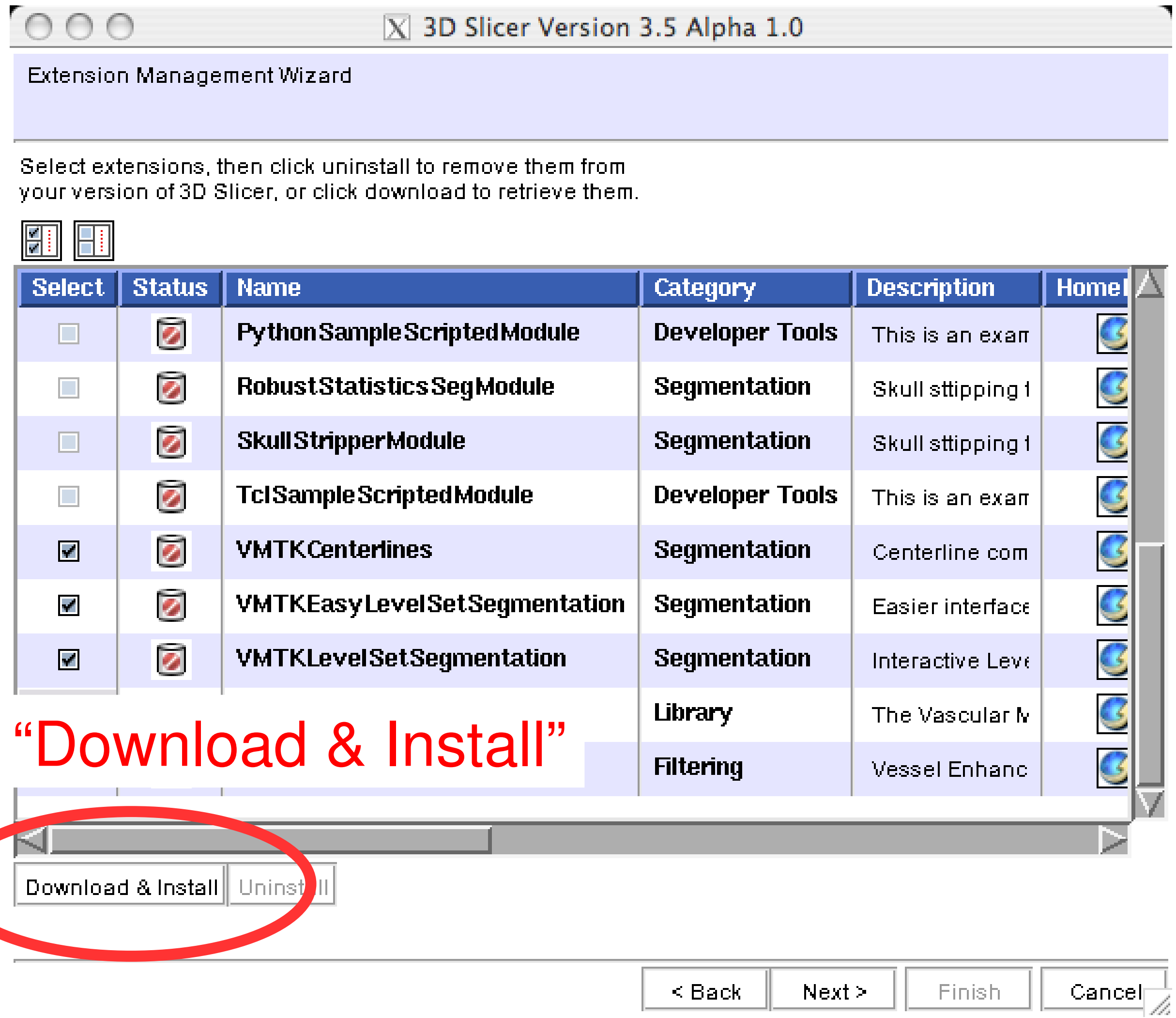
Installing VMTK in 3D Slicer



Installing VMTK in 3D Slicer

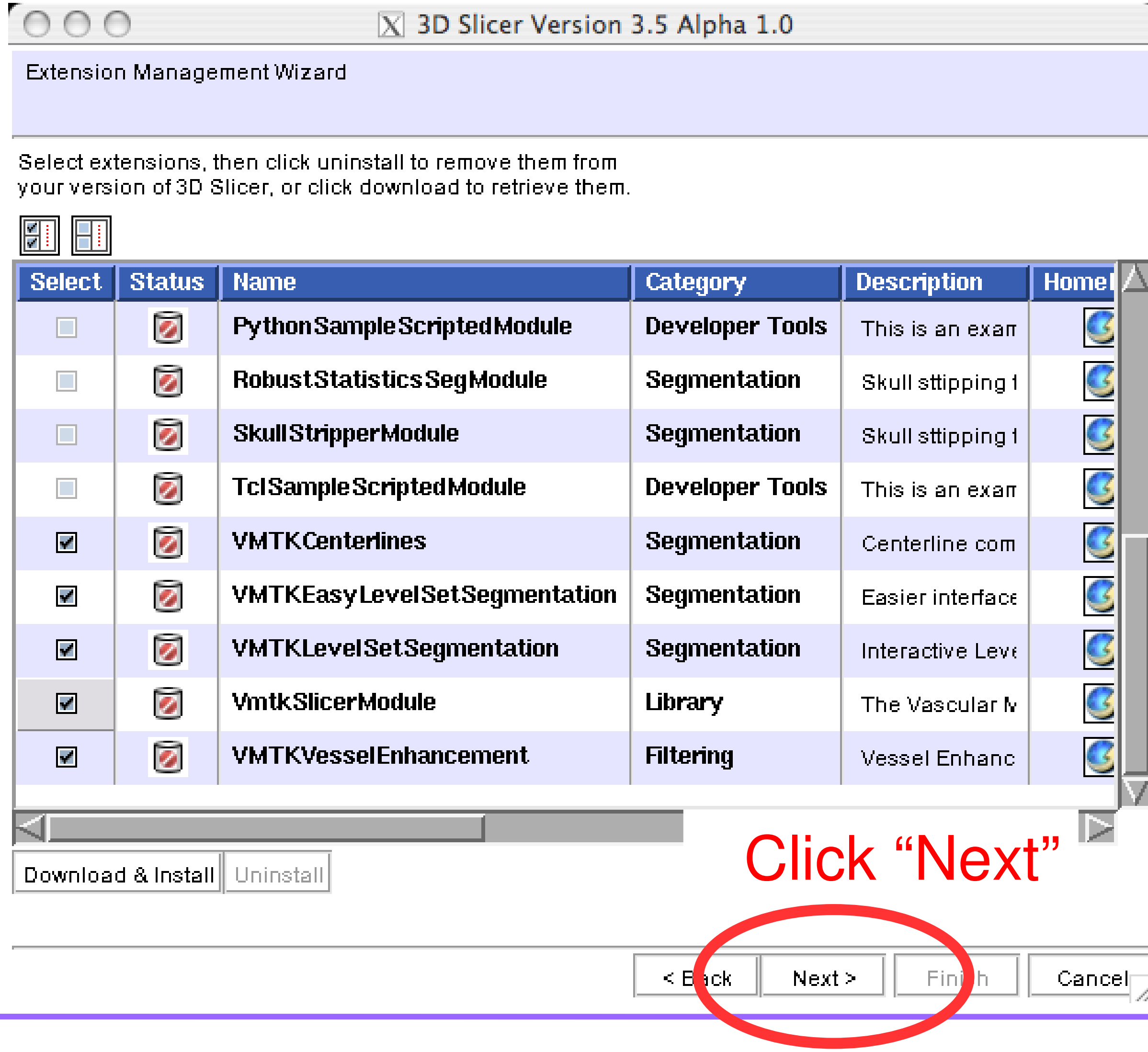


Installing VMTK in 3D Slicer



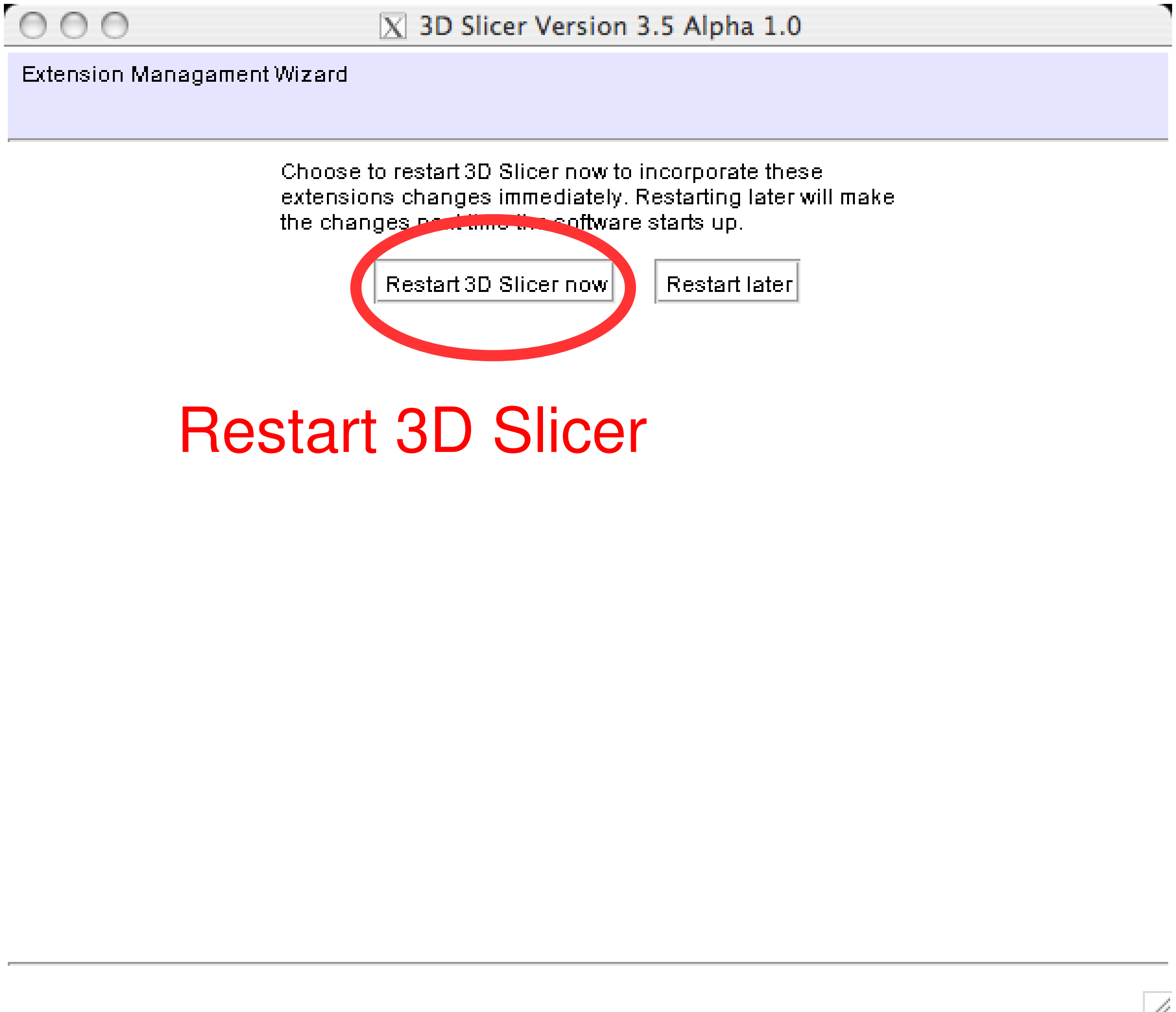
Click "Download & Install"

Installing VMTK in 3D Slicer



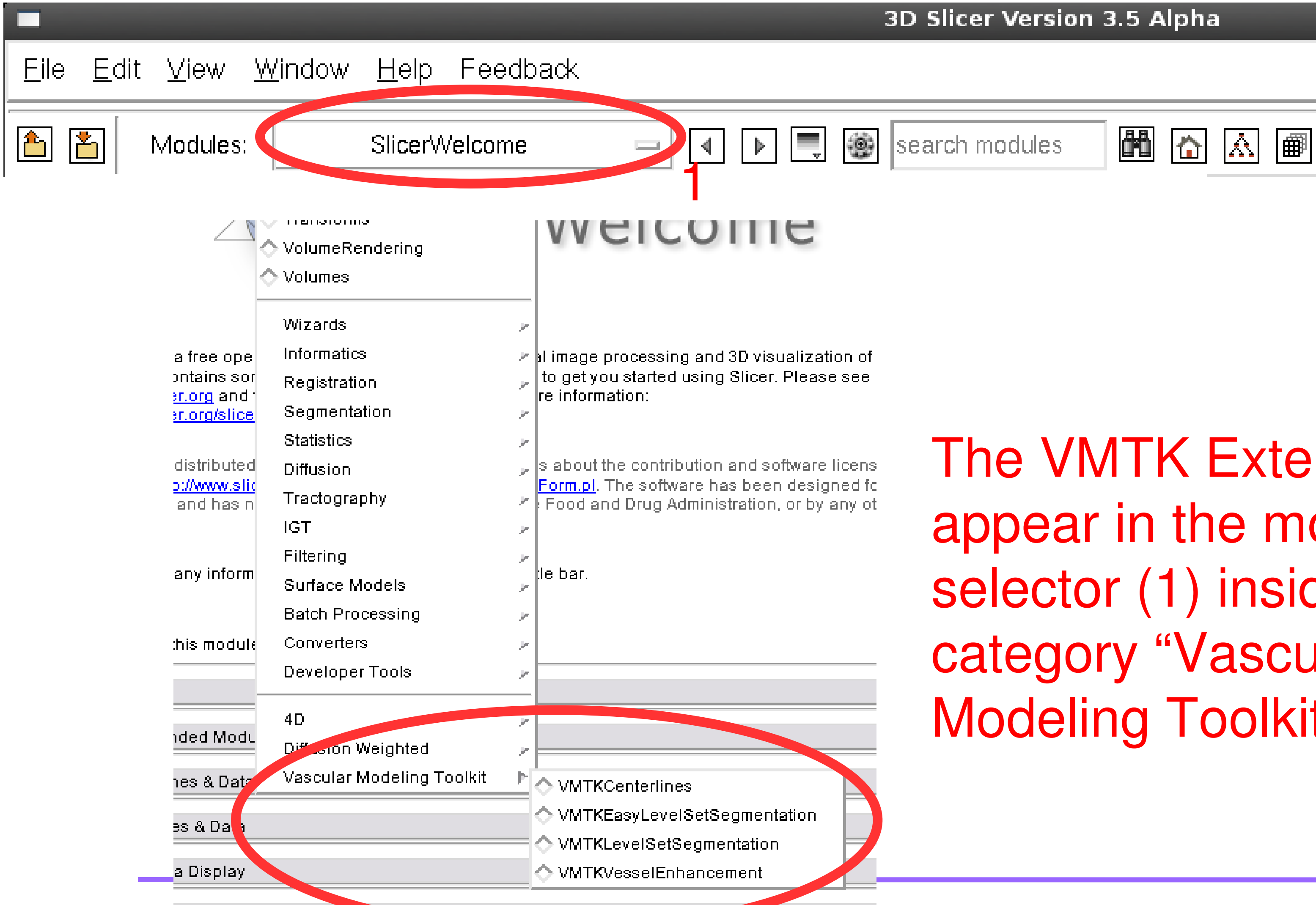
Click “Next”

Installing VMTK in 3D Slicer



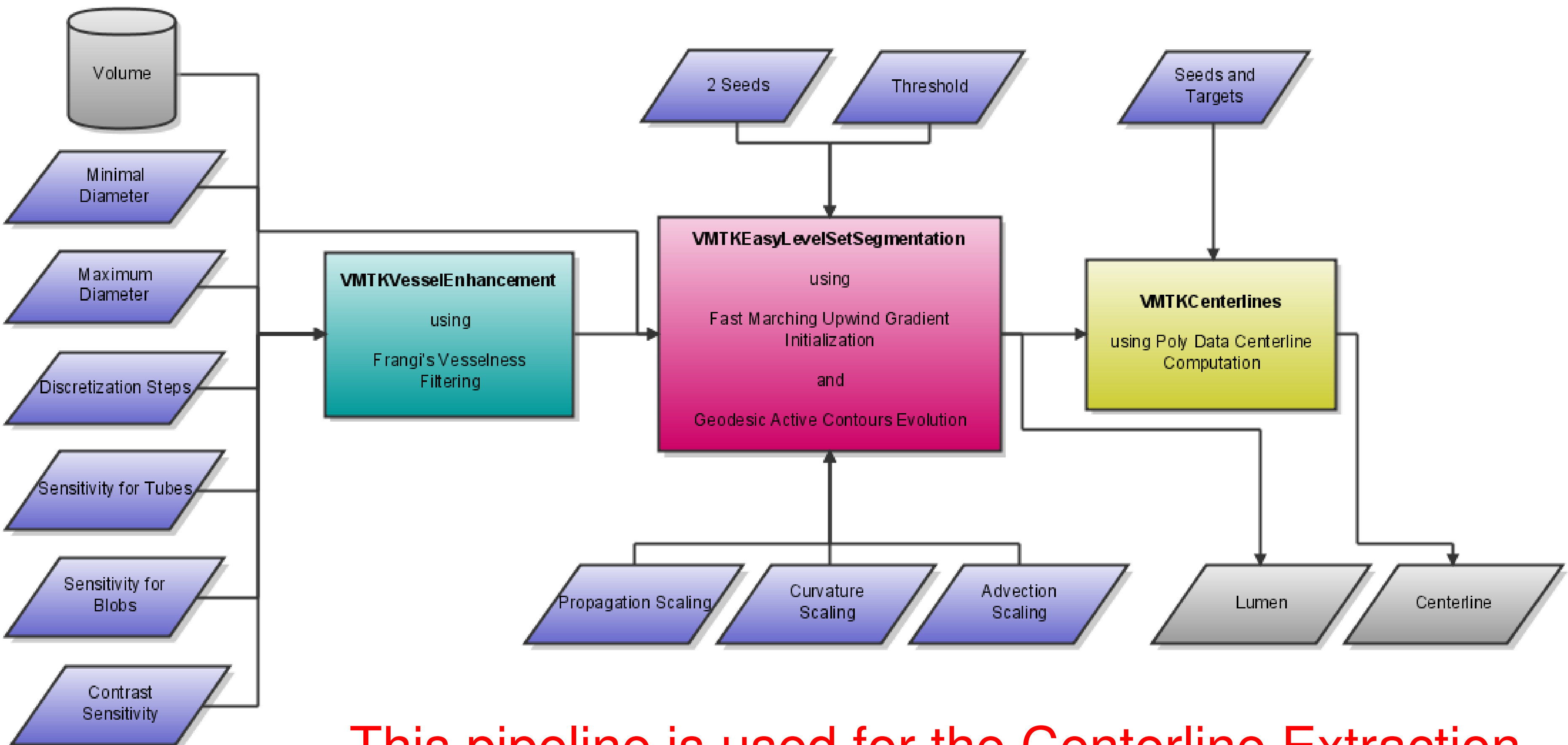
Restart 3D Slicer

Installing VMTK in 3D Slicer



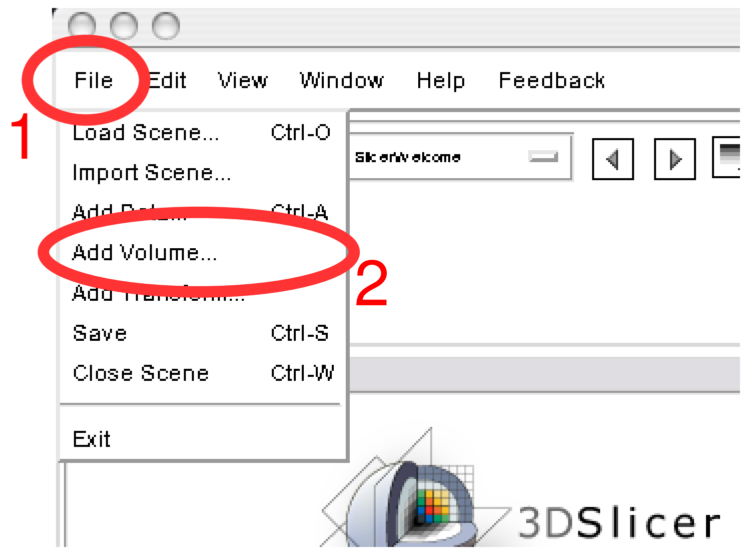
The VMTK Extensions appear in the modules selector (1) inside the category “Vascular Modeling Toolkit”

The Pipeline



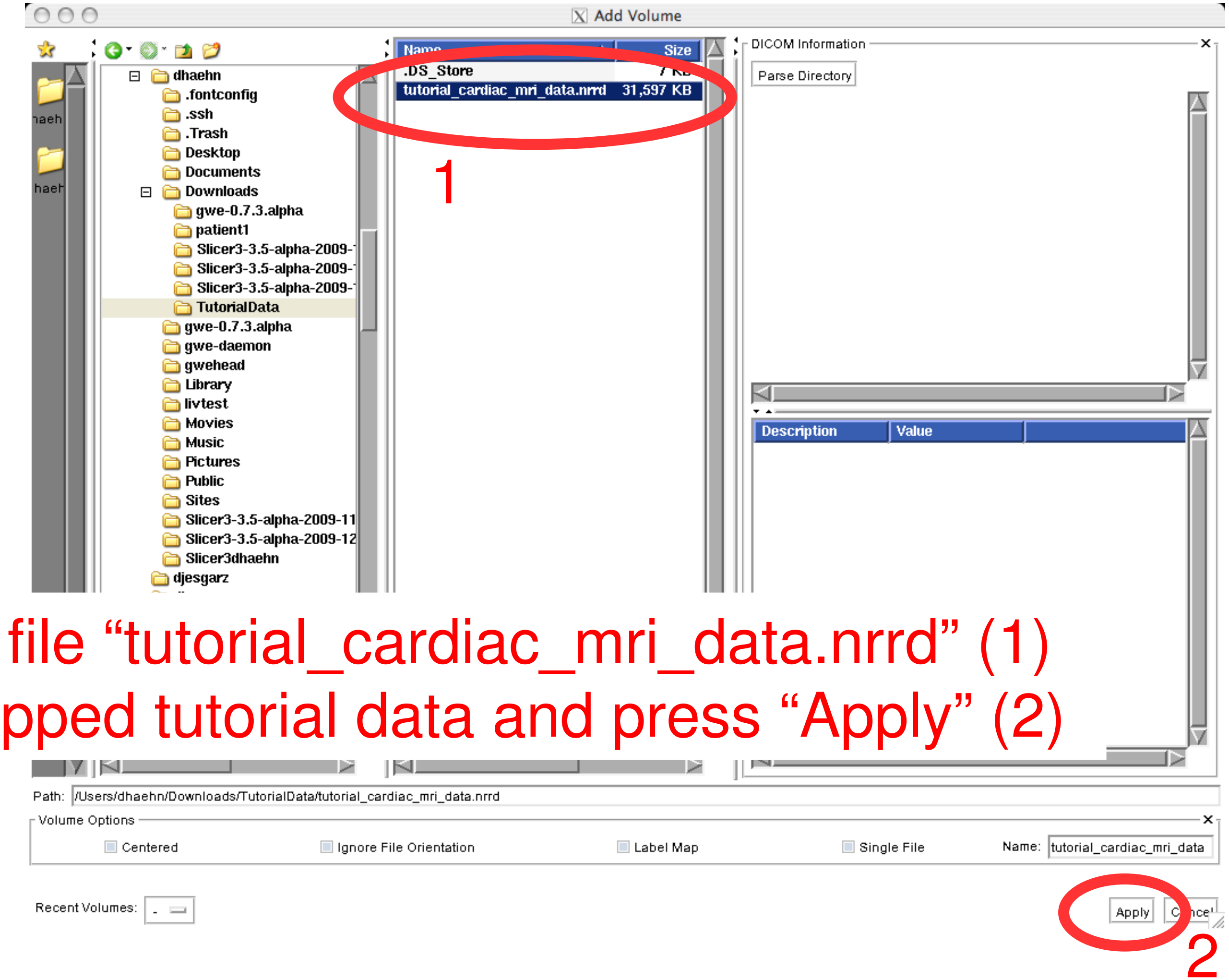
This pipeline is used for the Centerline Extraction.

Loading Data



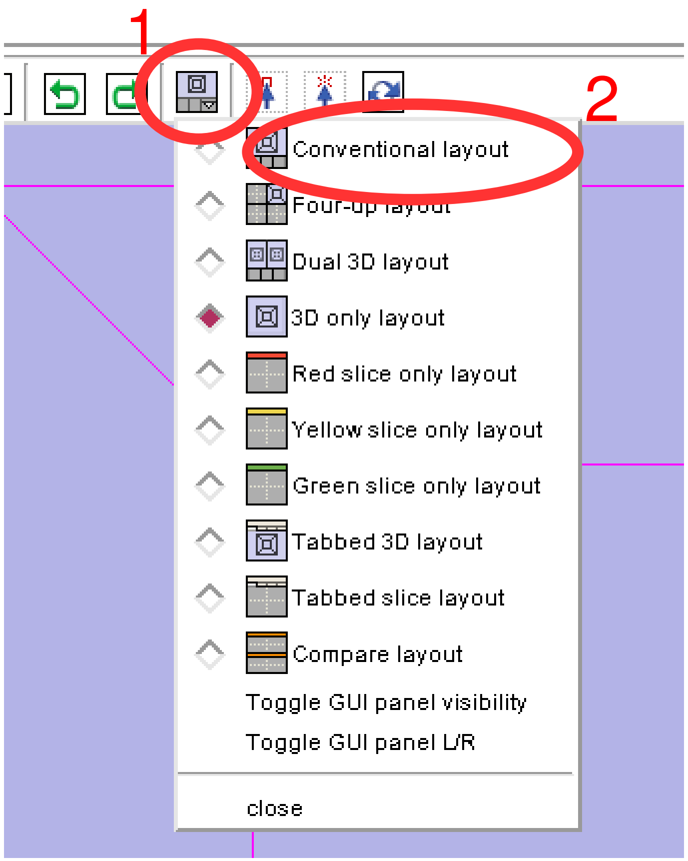
To load the tutorial data, choose the “File” menu (1) and select “Add Volume...” (2)

Loading Data



Select the file "tutorial_cardiac_mri_data.nrrd" (1) of the unzipped tutorial data and press "Apply" (2)

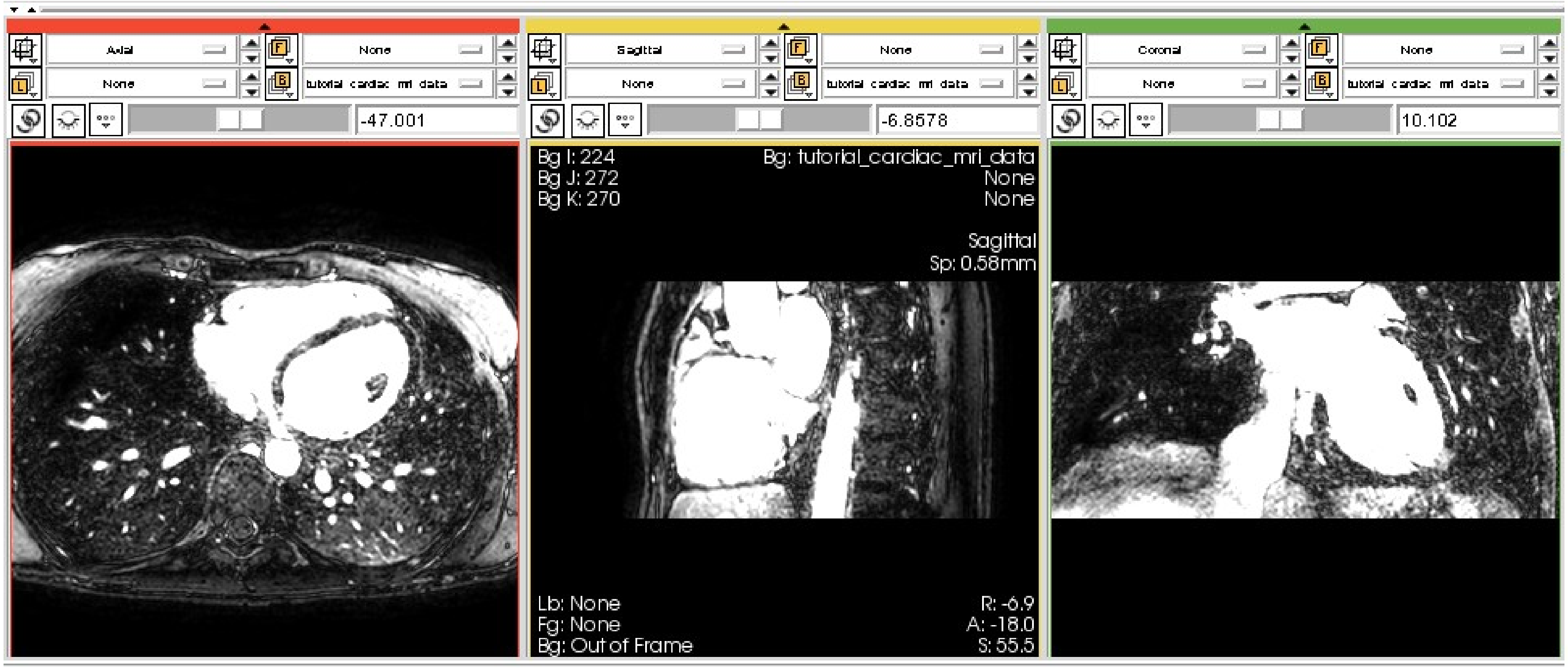
Loading Data



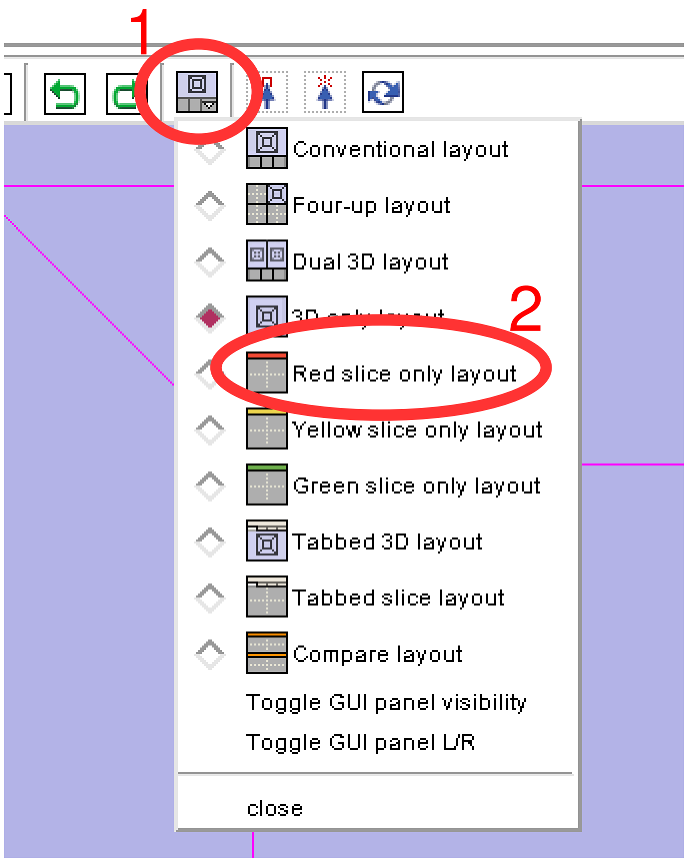
Use the layout selector (1) to switch to the “Conventional layout” (2)

Loading Data

The 2D slice viewers show the loaded volume.

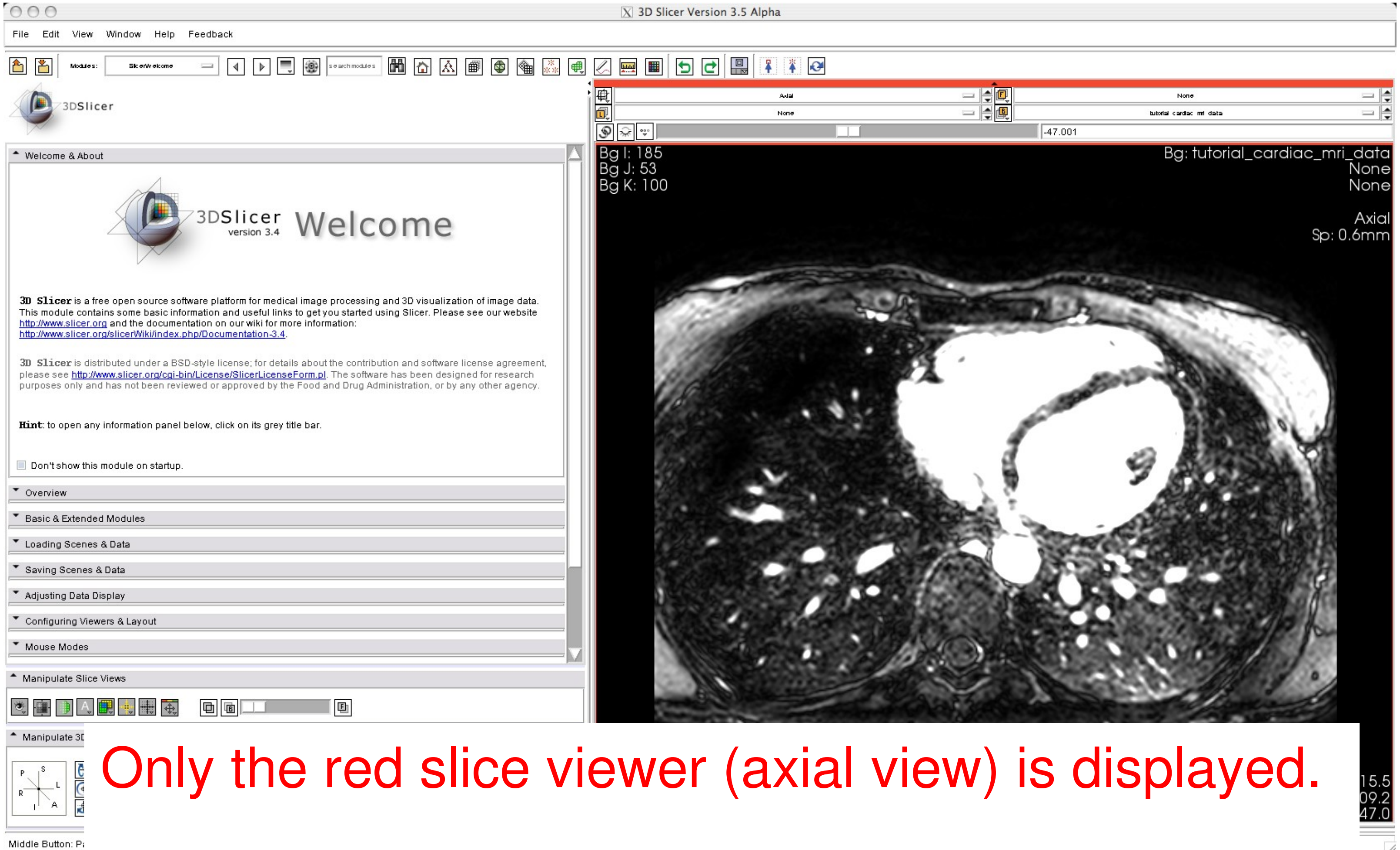


Loading Data



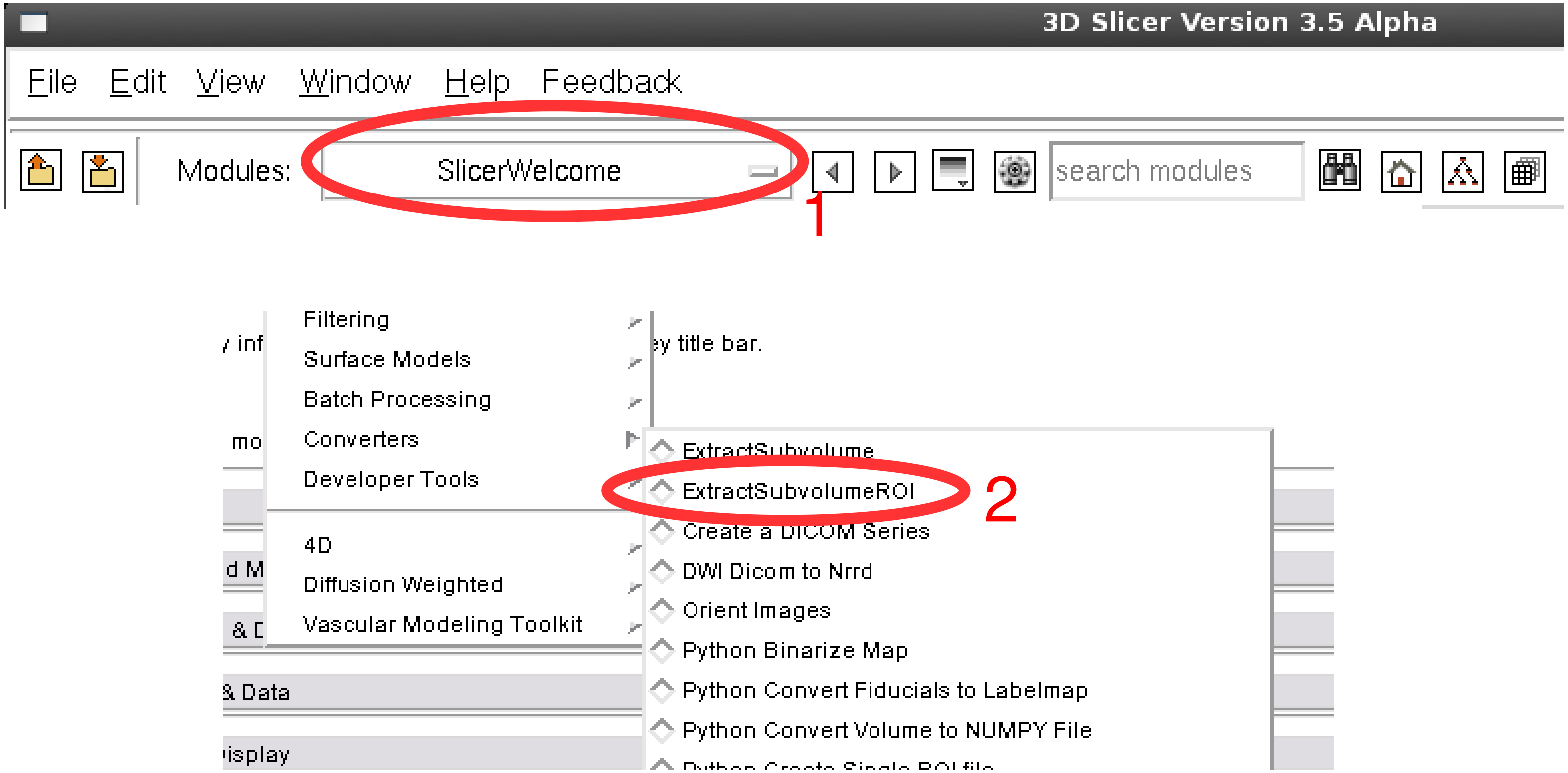
Use the layout selector (1) to switch to the “Red slice only layout” (2)

Loading Data



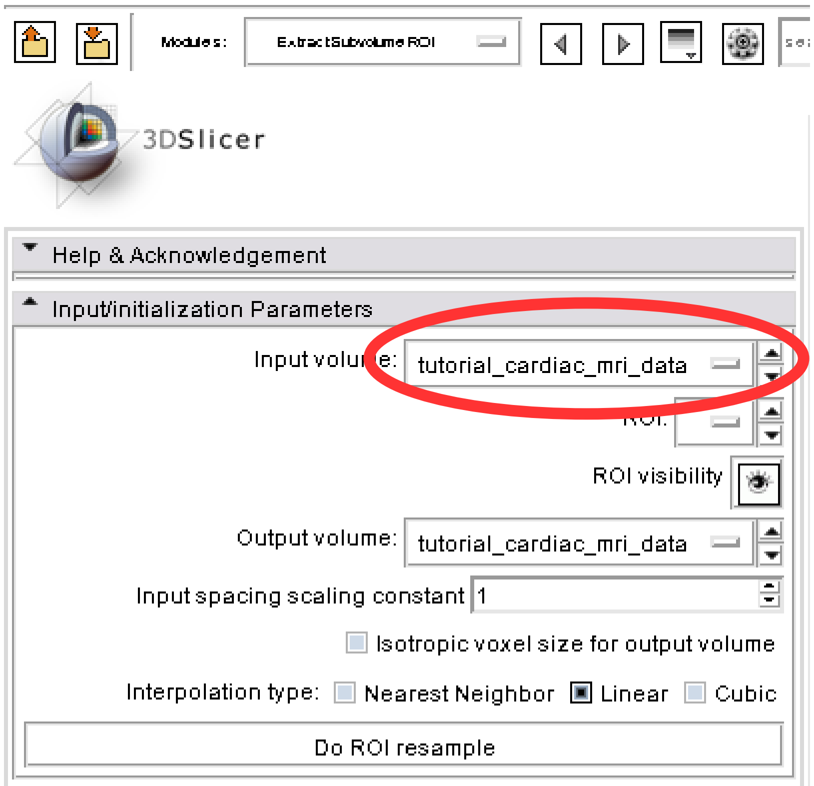
Only the red slice viewer (axial view) is displayed.

Extracting the ROI



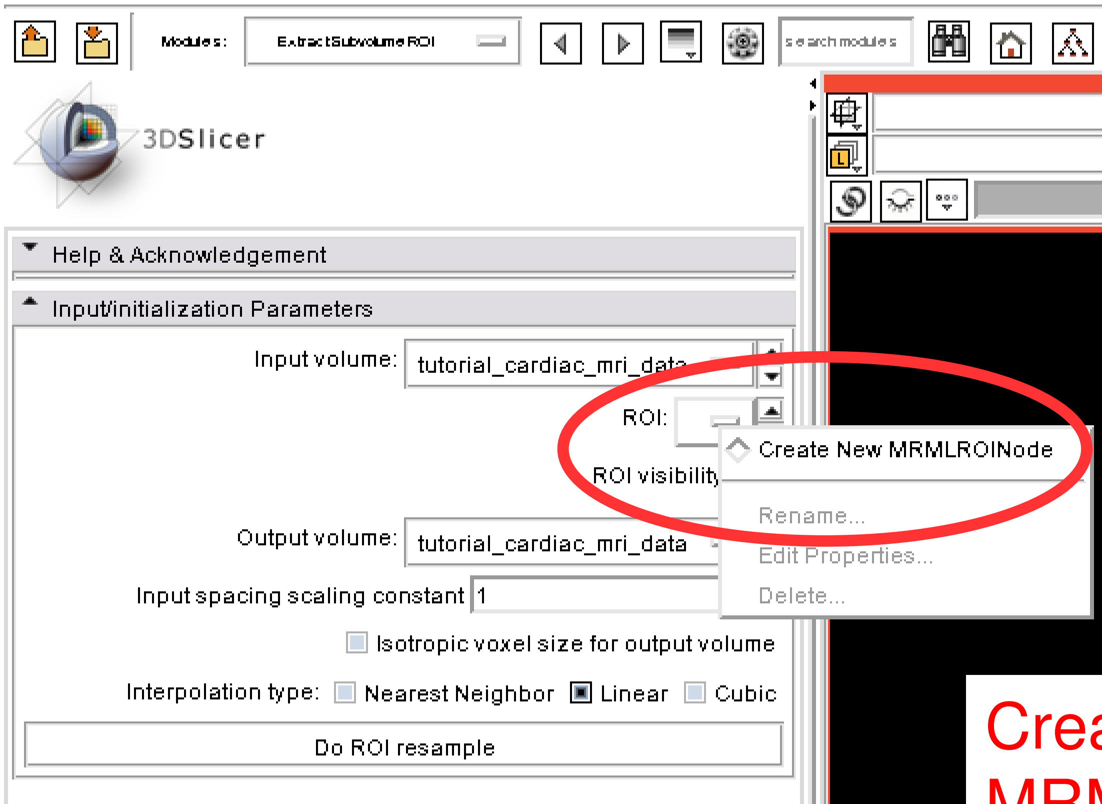
Use the modules selector (1) to start the "ExtractSubvolumeROI" (2) module

Extracting the ROI



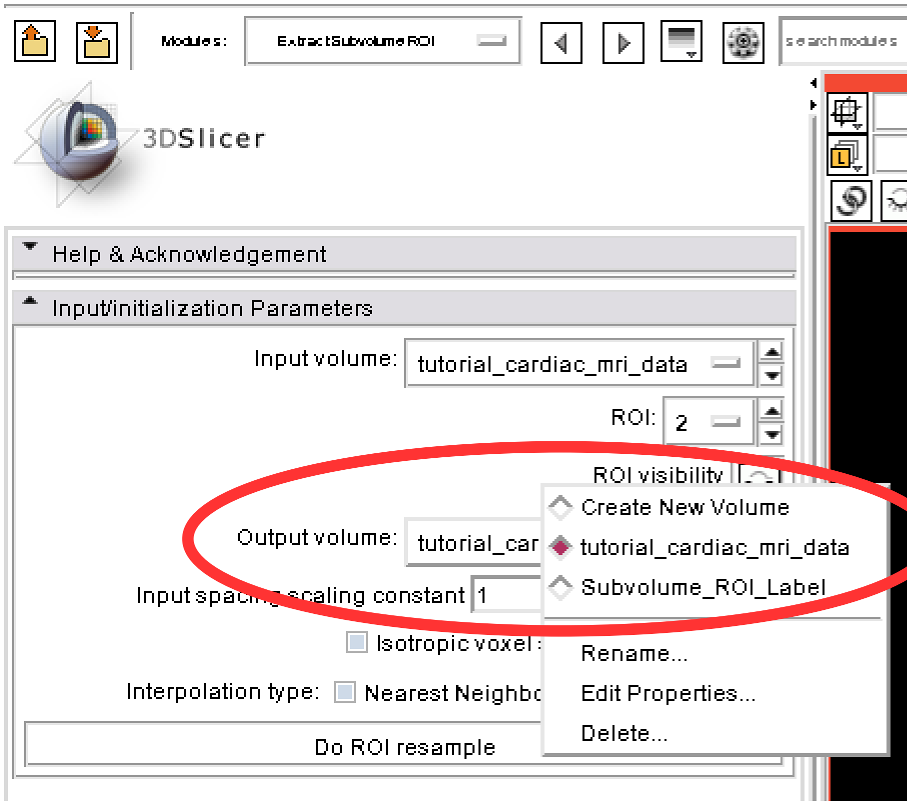
This panel now appears. Be sure that the “Input volume” is the loaded tutorial data.

Extracting the ROI



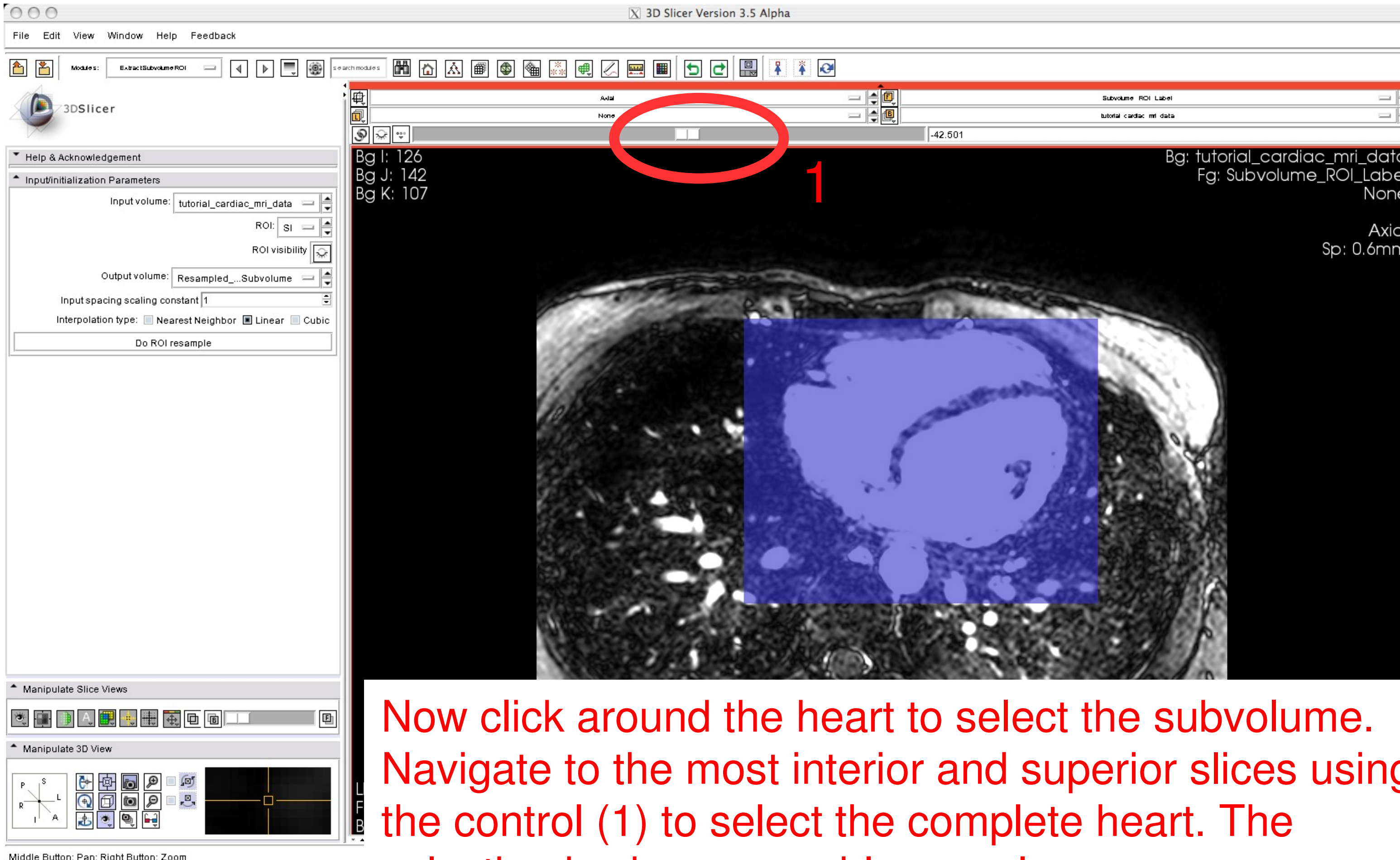
Create a new MRMLROINode

Extracting the ROI



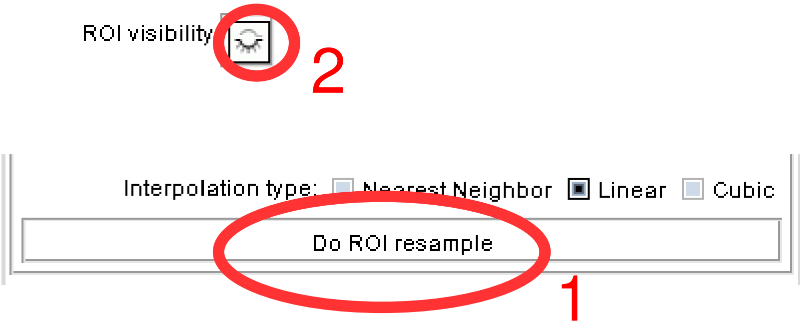
Create a new Volume as "Output volume"

Extracting the ROI



Now click around the heart to select the subvolume. Navigate to the most interior and superior slices using the control (1) to select the complete heart. The selection is shown as a blue overlay.

Extracting the ROI

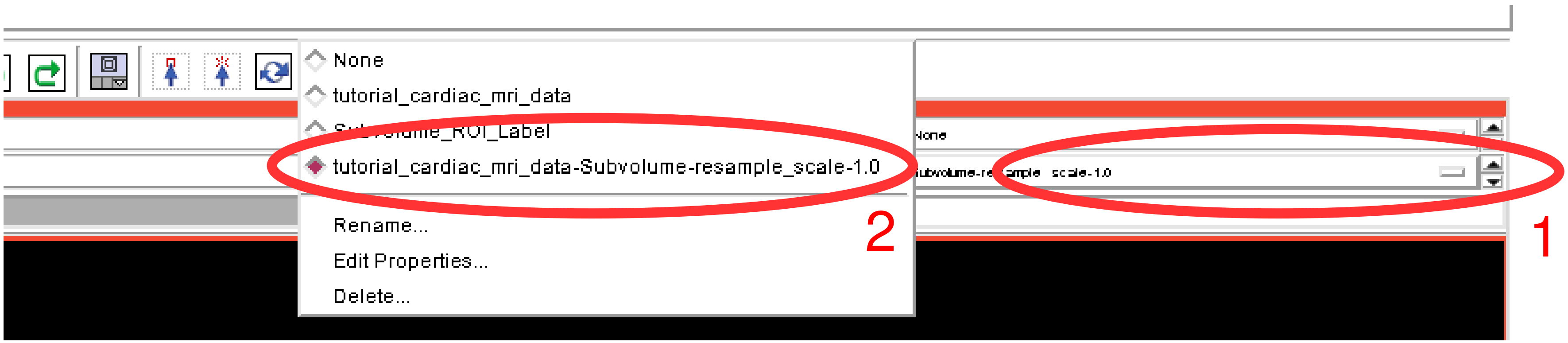


Click “Do ROI resample” (1) to extract the subvolume and click toggle the “ROI visibility” (2) to hide the blue overlay

Extracting the ROI

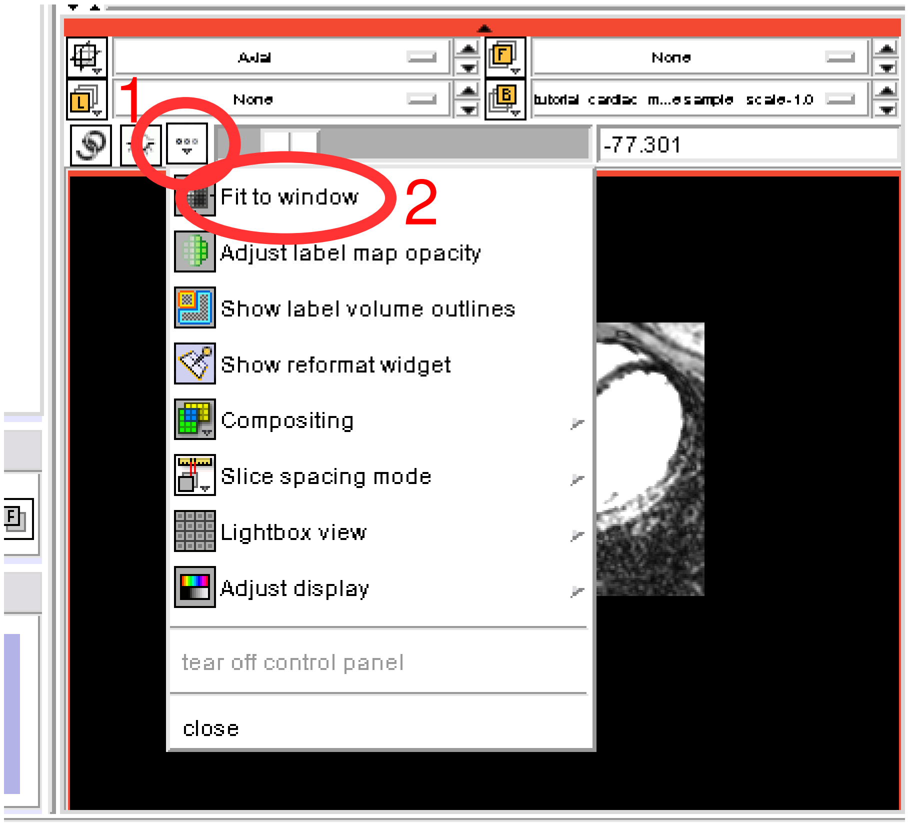
You can also directly load the prepared "tutorial_cardiac_mri_data-Subvolume-resample_scale-1.0.nrrd" file of the unzipped tutorial data to get the extracted subvolume (see the "Loading Data" section).

Extracting the ROI



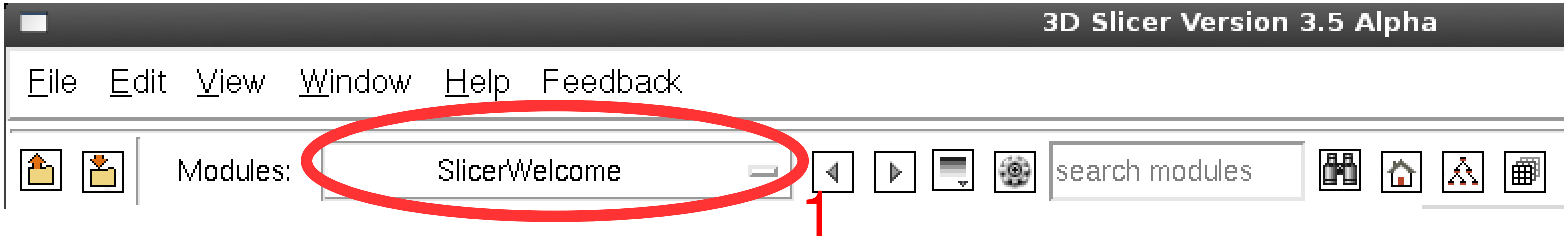
Select the extracted subvolume (2) in the red slice viewer by using the volume selector (1)

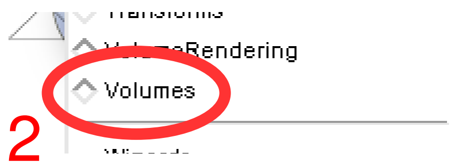
Extracting the ROI



Fit the volume to the window by using the options icon (1) and selecting “Fit to window” (2)

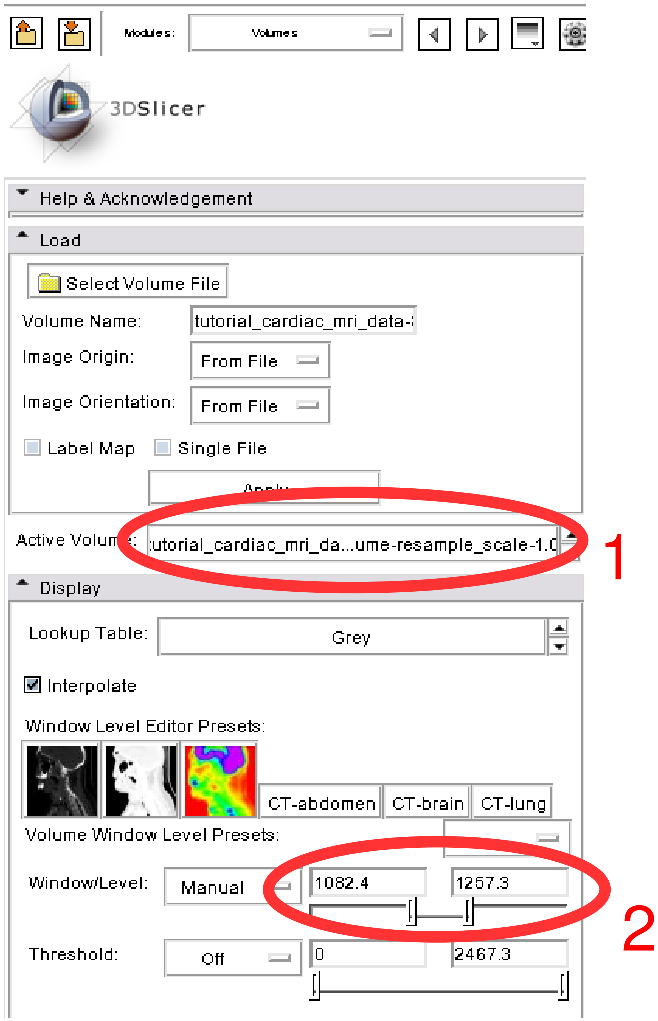
Extracting the ROI





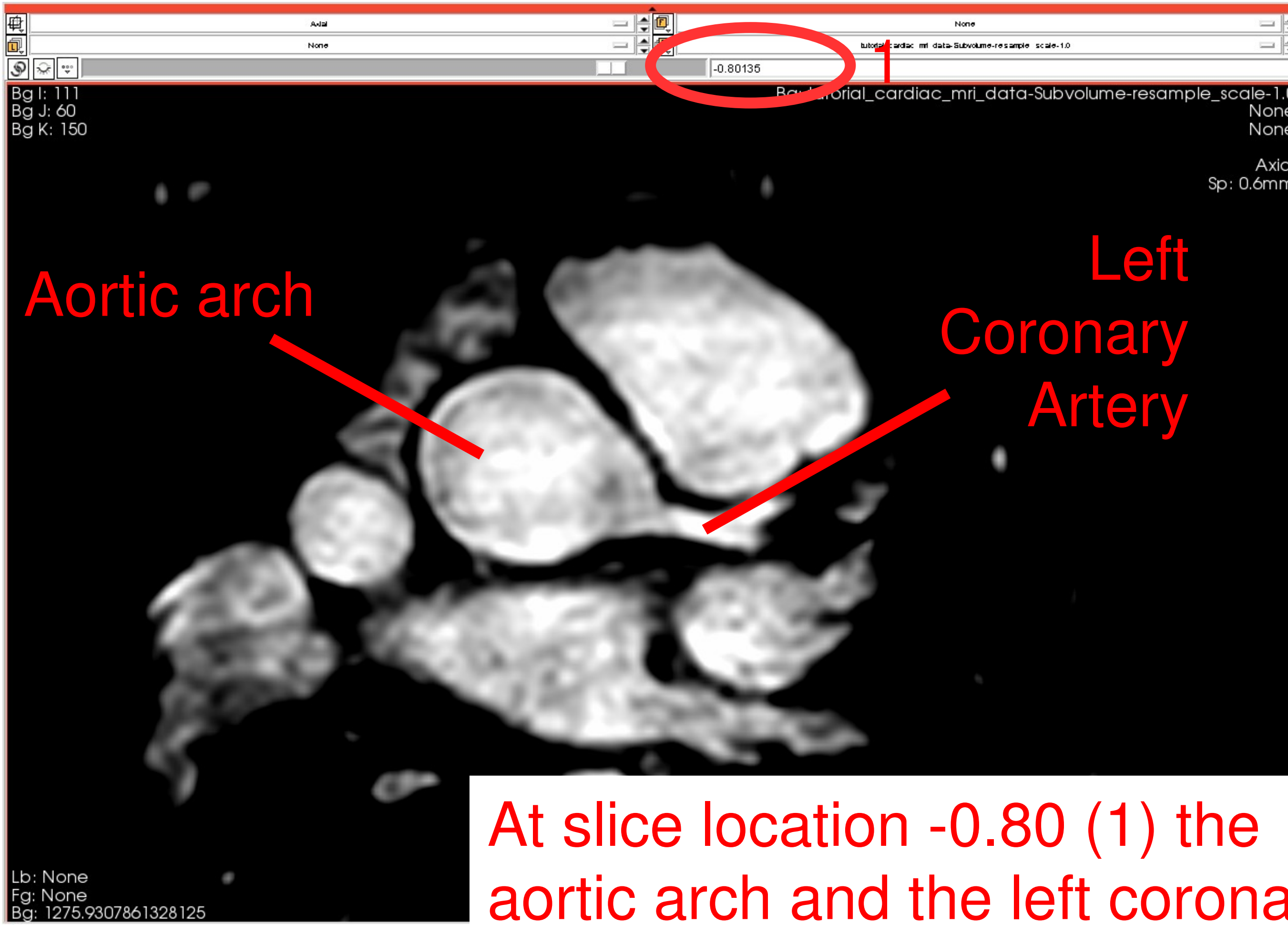
Use the modules selector (1) to navigate to the "Volumes" module (2)

Extracting the ROI



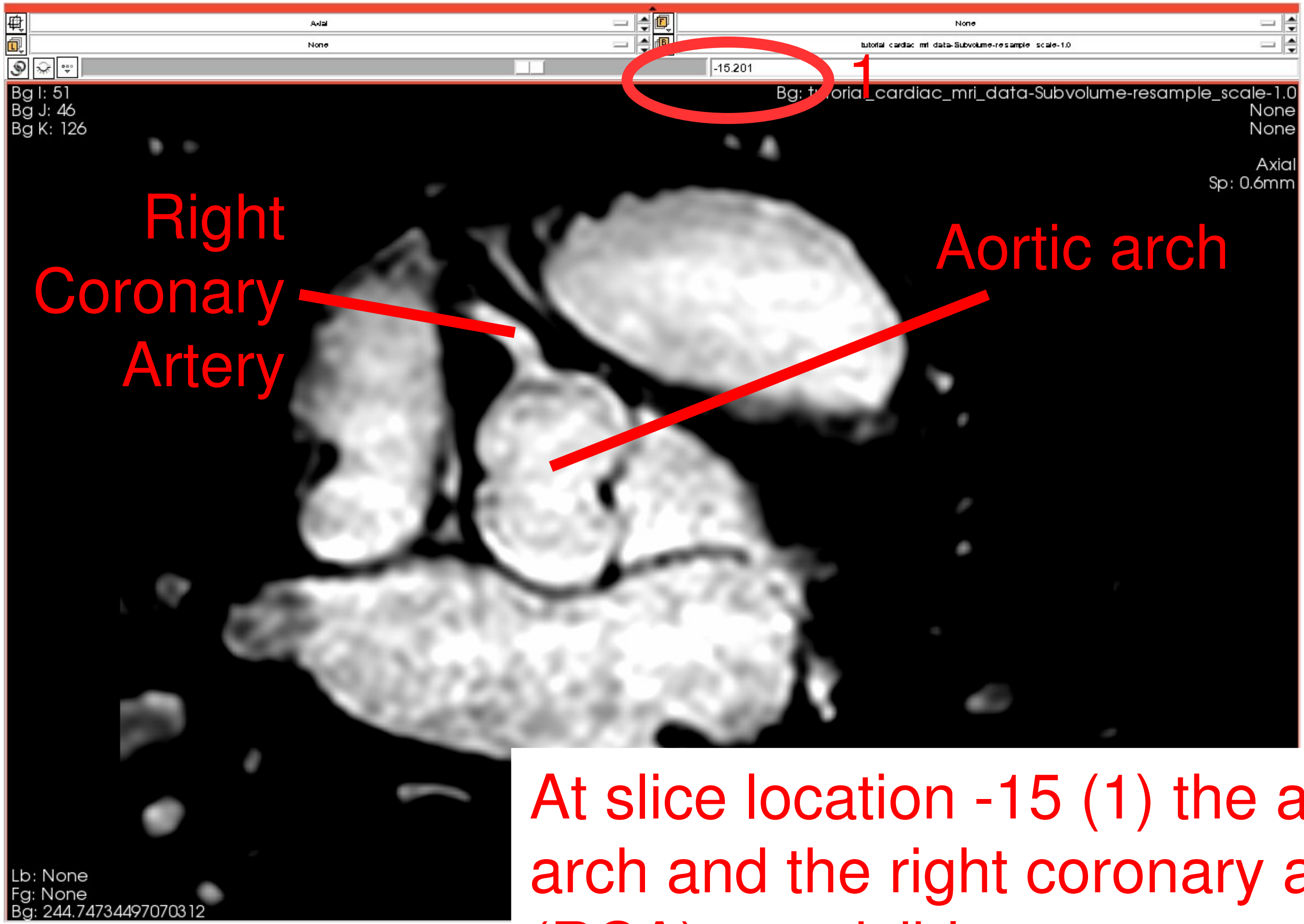
Be sure the extracted subvolume "tutorial_cardiac_mri_data-Subvolume-resample_scale-1.0" is the active Volume (1) and adjust the Window/Level setting to 1082 and 1257 (2) for better visualization

Extracting the ROI



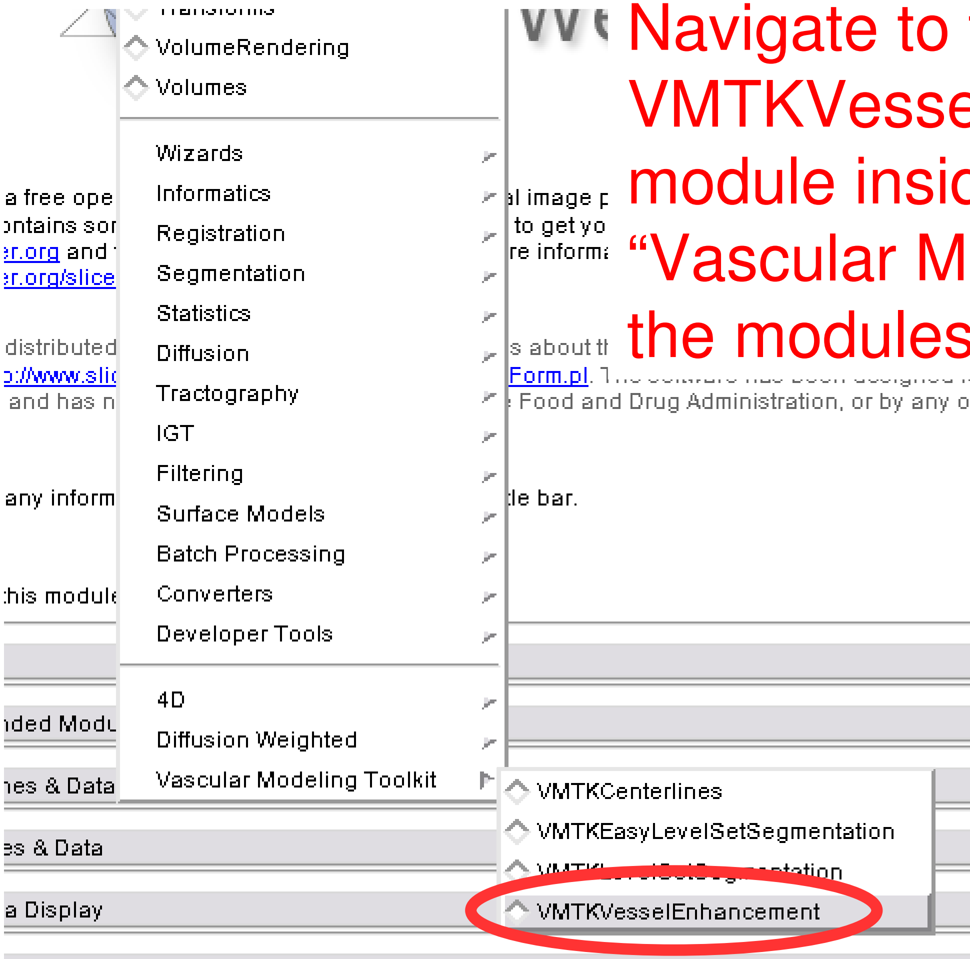
At slice location -0.80 (1) the aortic arch and the left coronary artery (LCA) are visible

Extracting the ROI



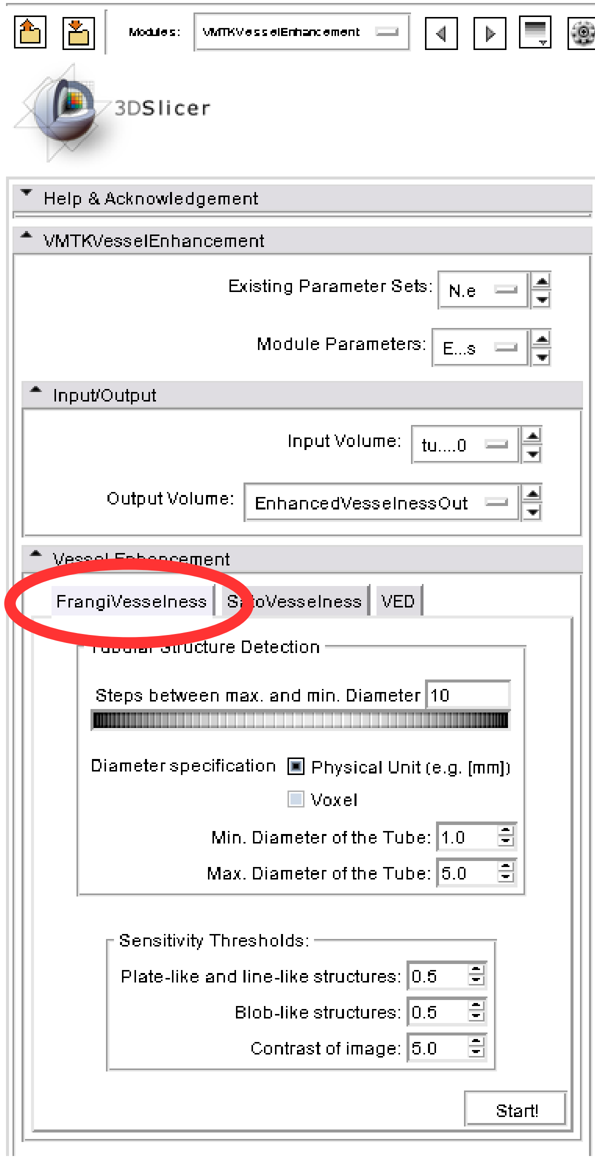
At slice location -15 (1) the aortic arch and the right coronary artery (RCA) are visible

Vesselness Filtering



Navigate to the VMTKVesselEnhancement module inside the category “Vascular Modeling Toolkit” using the modules selector

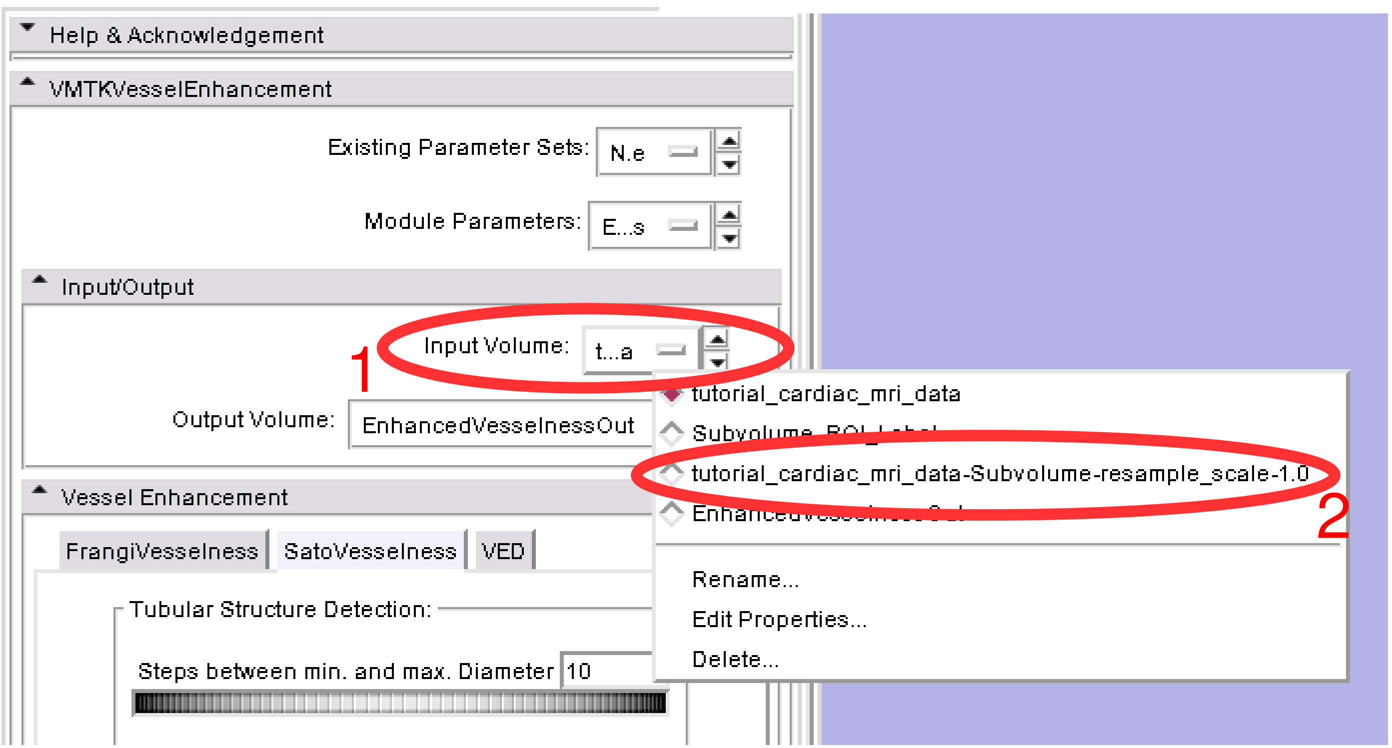
Vesselness Filtering



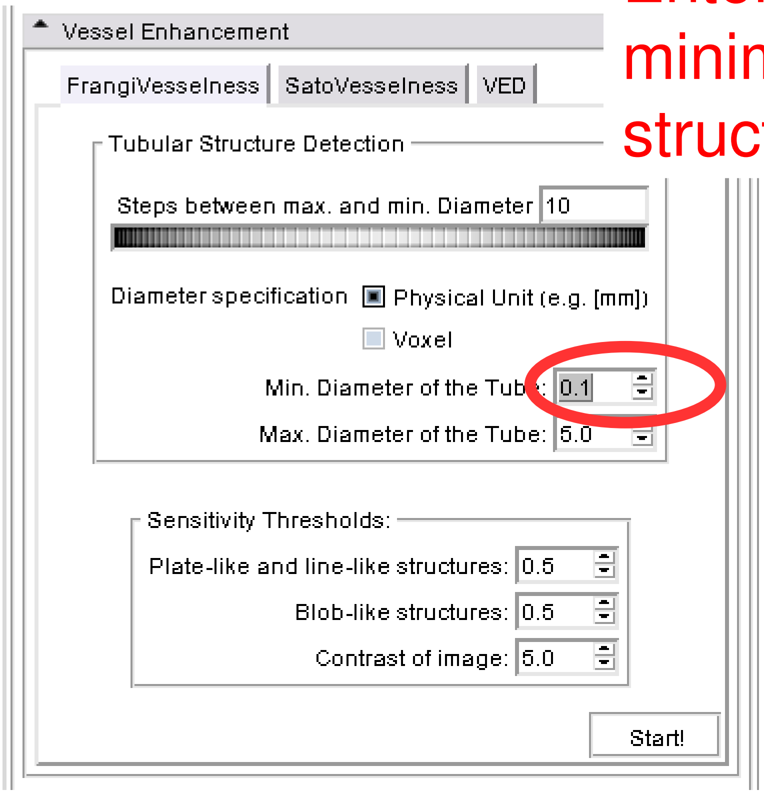
This panel appears. Switch to "FrangiVesselness".

Vesselness Filtering

Select the extracted subvolume (2) as the “Input Volume” (1)

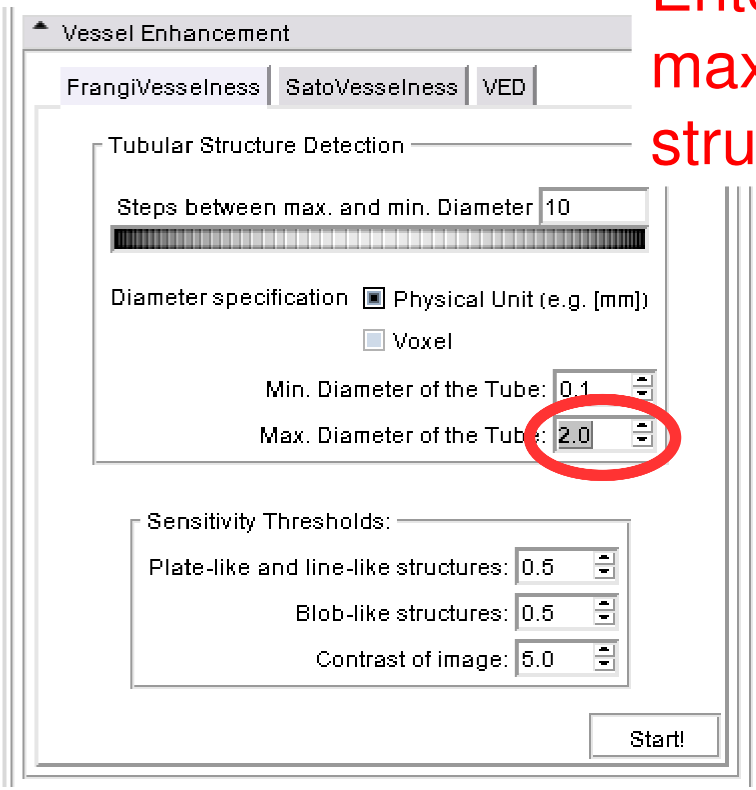


Vesselness Filtering



Enter “0.1” (unit: mm) as the minimal diameter of tubular structures to detect

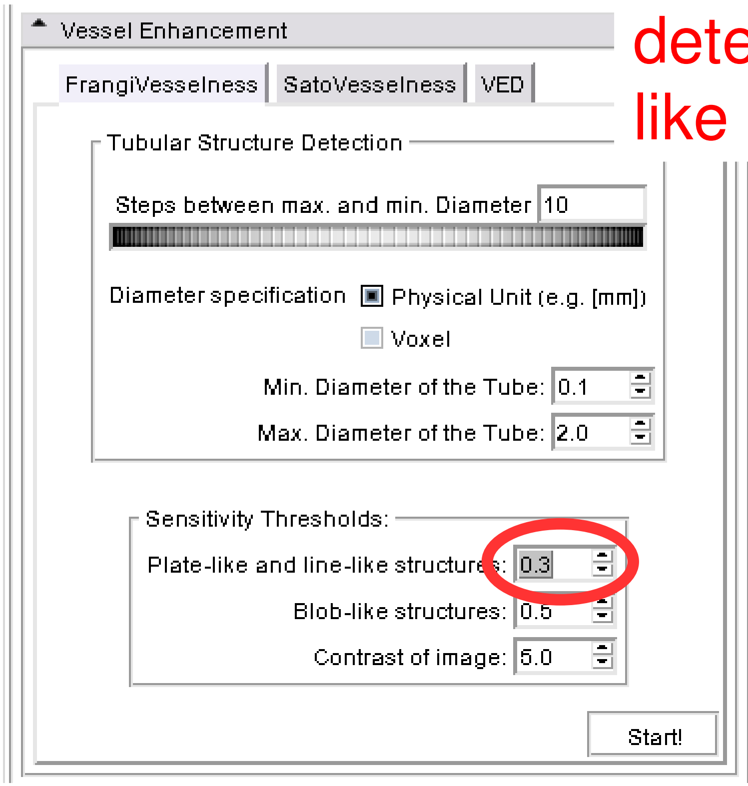
Vesselness Filtering



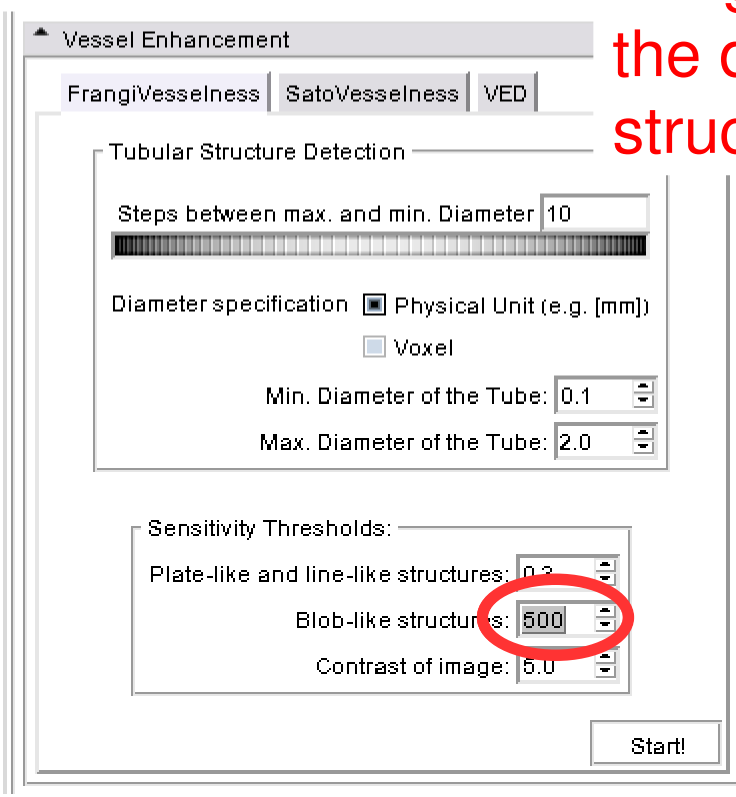
Enter “2.0” (unit: mm) as the maximum diameter of tubular structures to detect

Vesselness Filtering

Choose a low threshold of “0.3” to detect line-like rather than plate-like structures

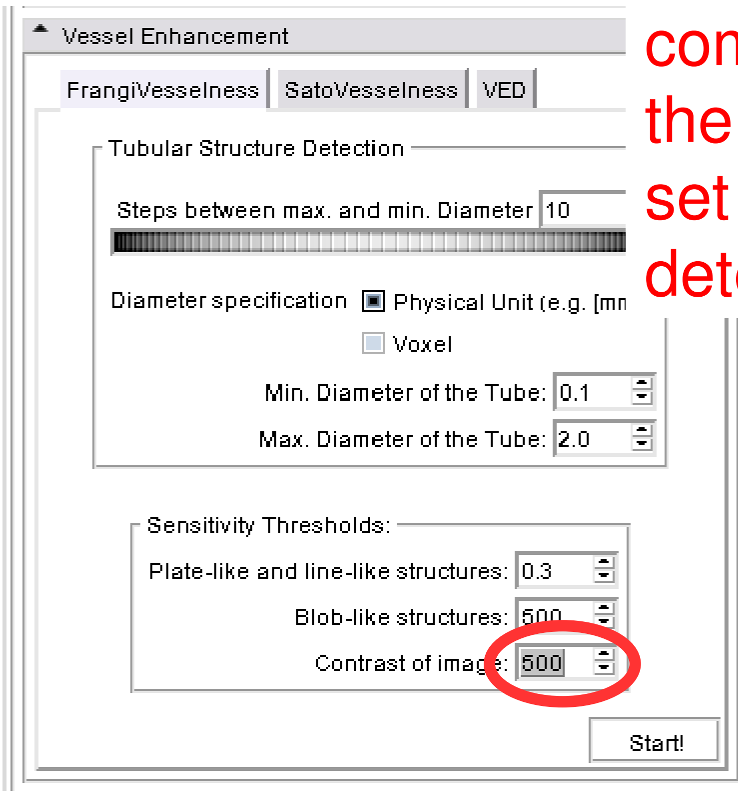


Vesselness Filtering



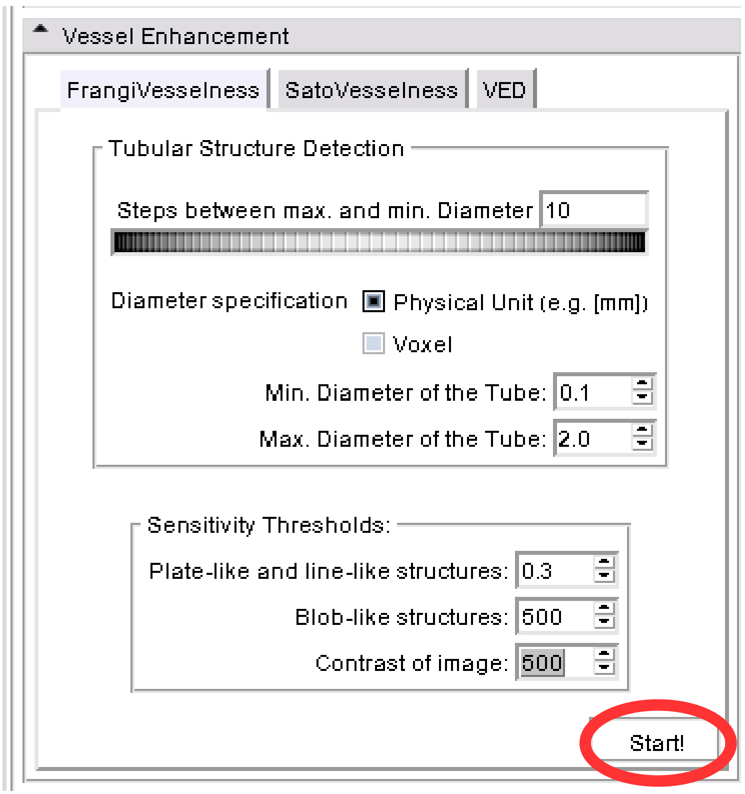
A higher threshold of “500” limits the detection of blob-like structures

Vesselness Filtering



The contrast of the vessels in comparision to the background in the tutorial data is very high, so set a higher threshold of "500" to detect only well visible structures

Vesselness Filtering



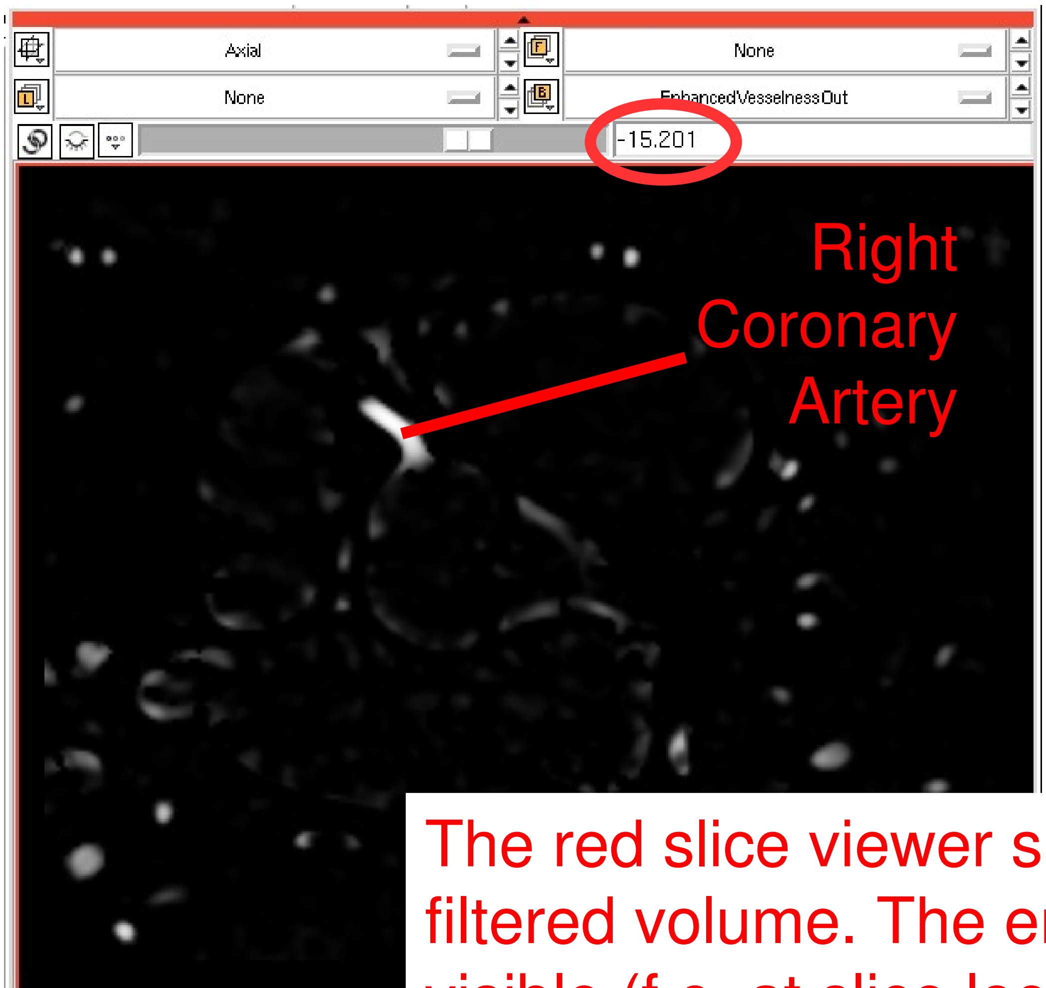
Click “Start!”

Vesselness Filtering

The filtering procedure takes approx. 6-10 minutes.

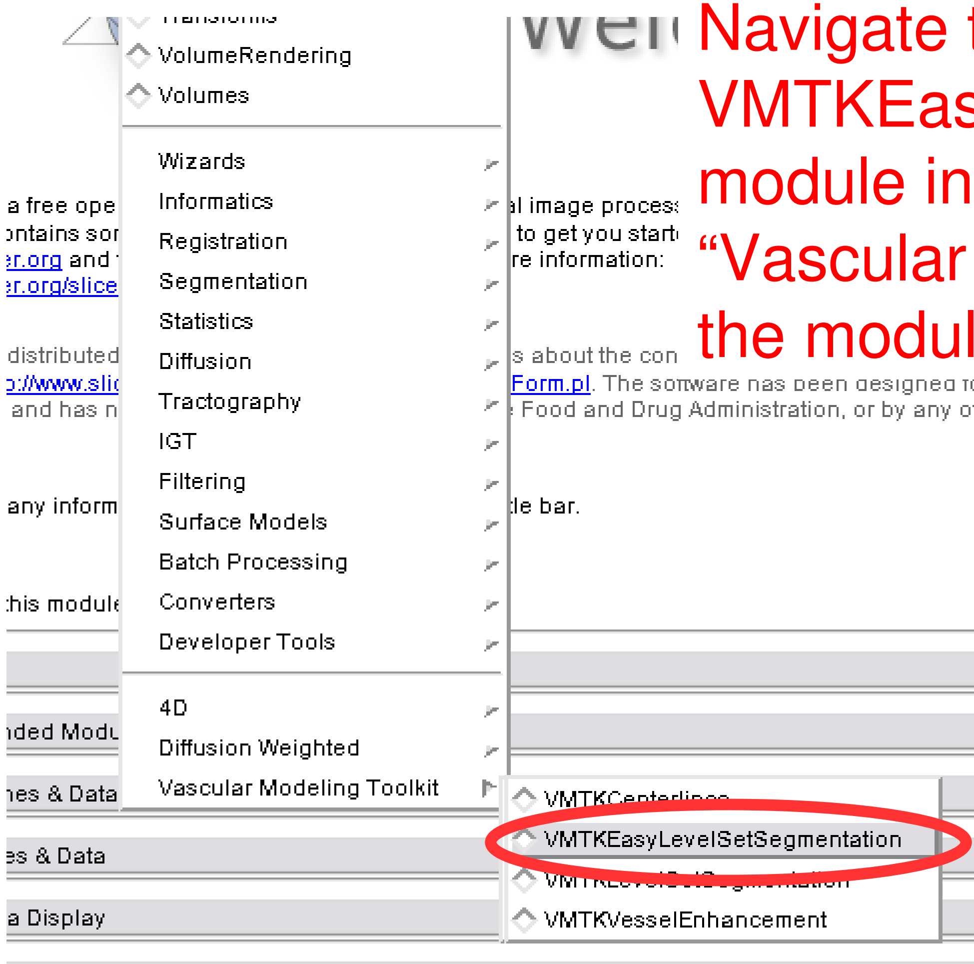
You can also directly load the prepared "EnhancedVesselnessOut.nrrd" file of the unzipped tutorial data to get the vesselness filtered volume (see the "Loading Data" section).

Vesselness Filtering



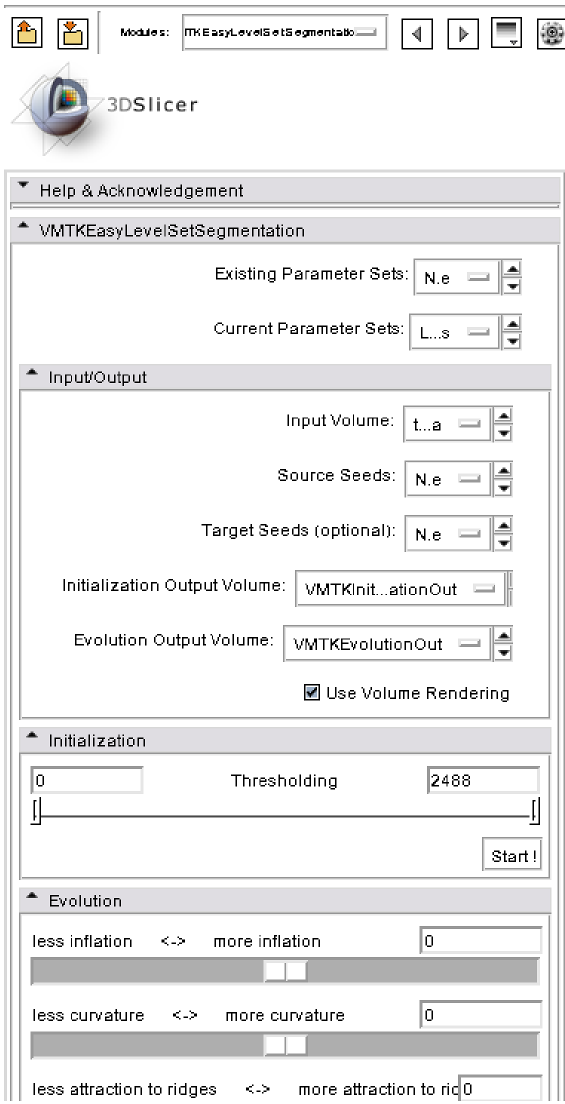
The red slice viewer shows the vesselness filtered volume. The enhanced tubes are visible (f.e. at slice location -15).

Level Set Segmentation



Navigate to the VMTKEasyLevelSetSegmentation module inside the category “Vascular Modeling Toolkit” using the modules selector

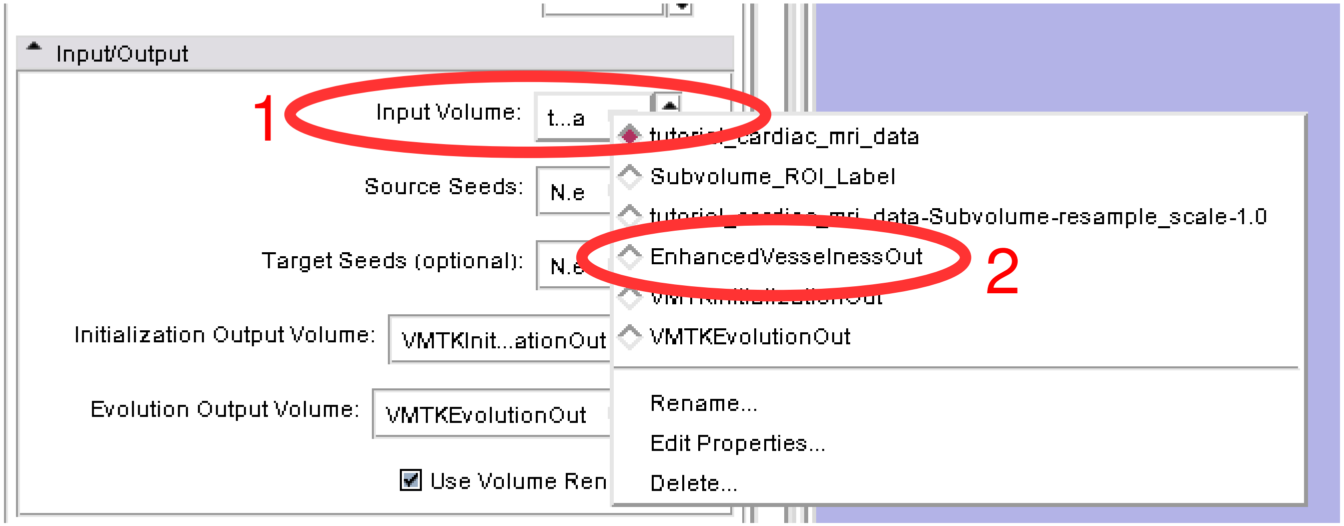
Level Set Segmentation



This panel now appears.

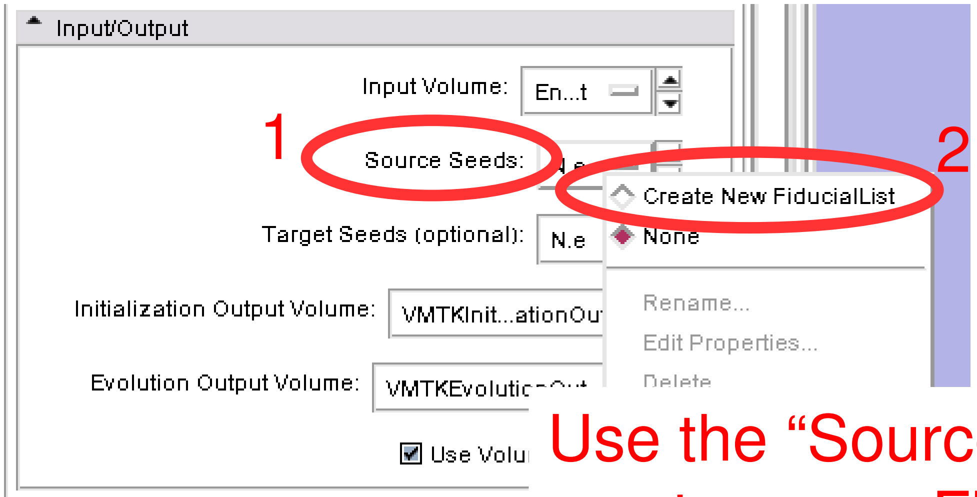
The Level Set Segmentation process consists of two steps: Initialization and Evolution

Level Set Segmentation

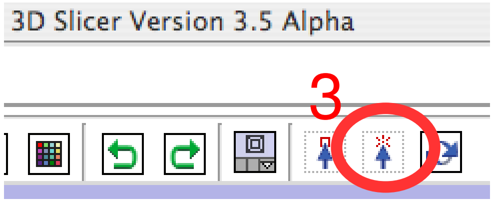


Select the "EnhancedVesselnessOut" volume (2) as the "Input Volume" (1)

Level Set Segmentation

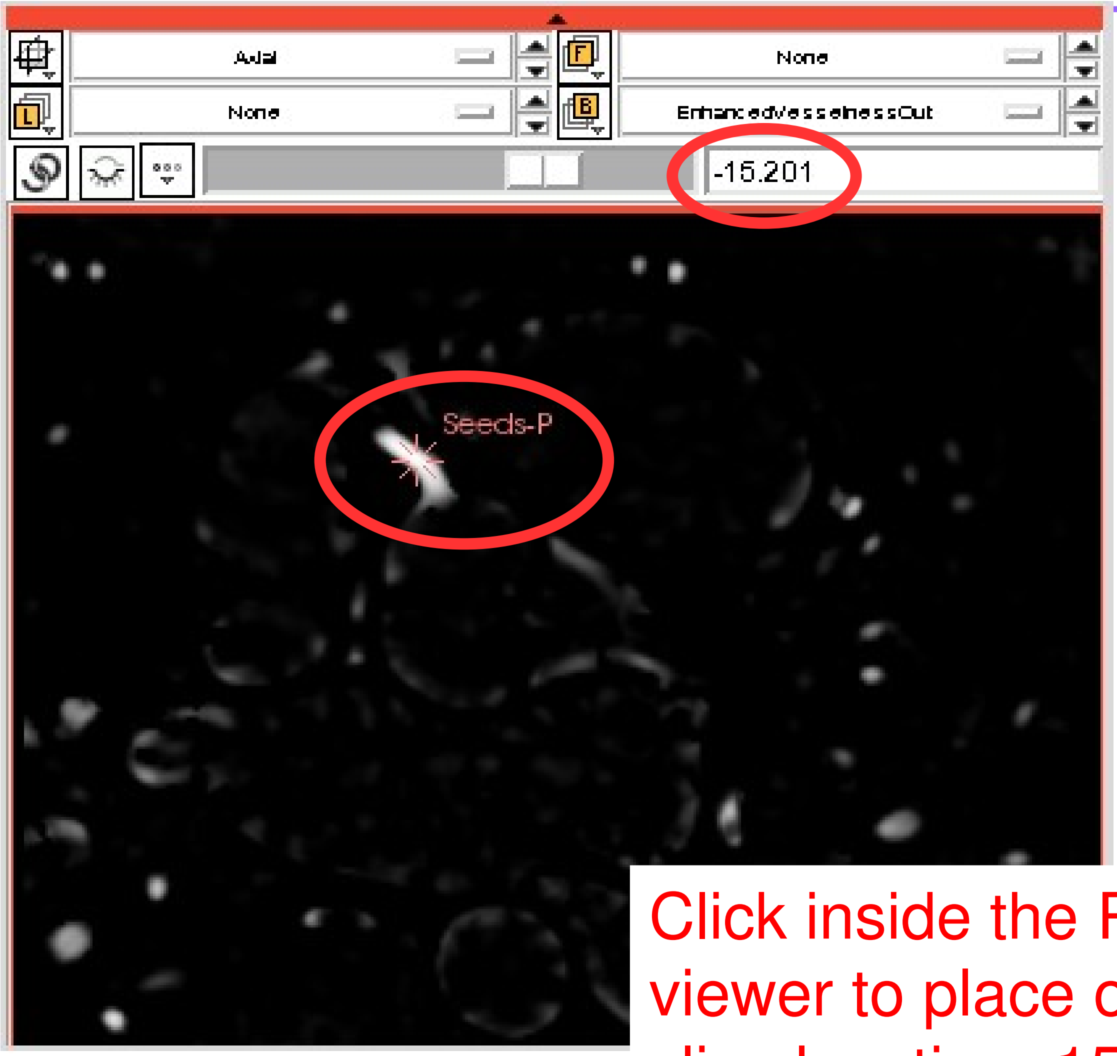


Use the "Source Seeds" selector (1) to create a new Fiducial List (2) which automatically becomes active



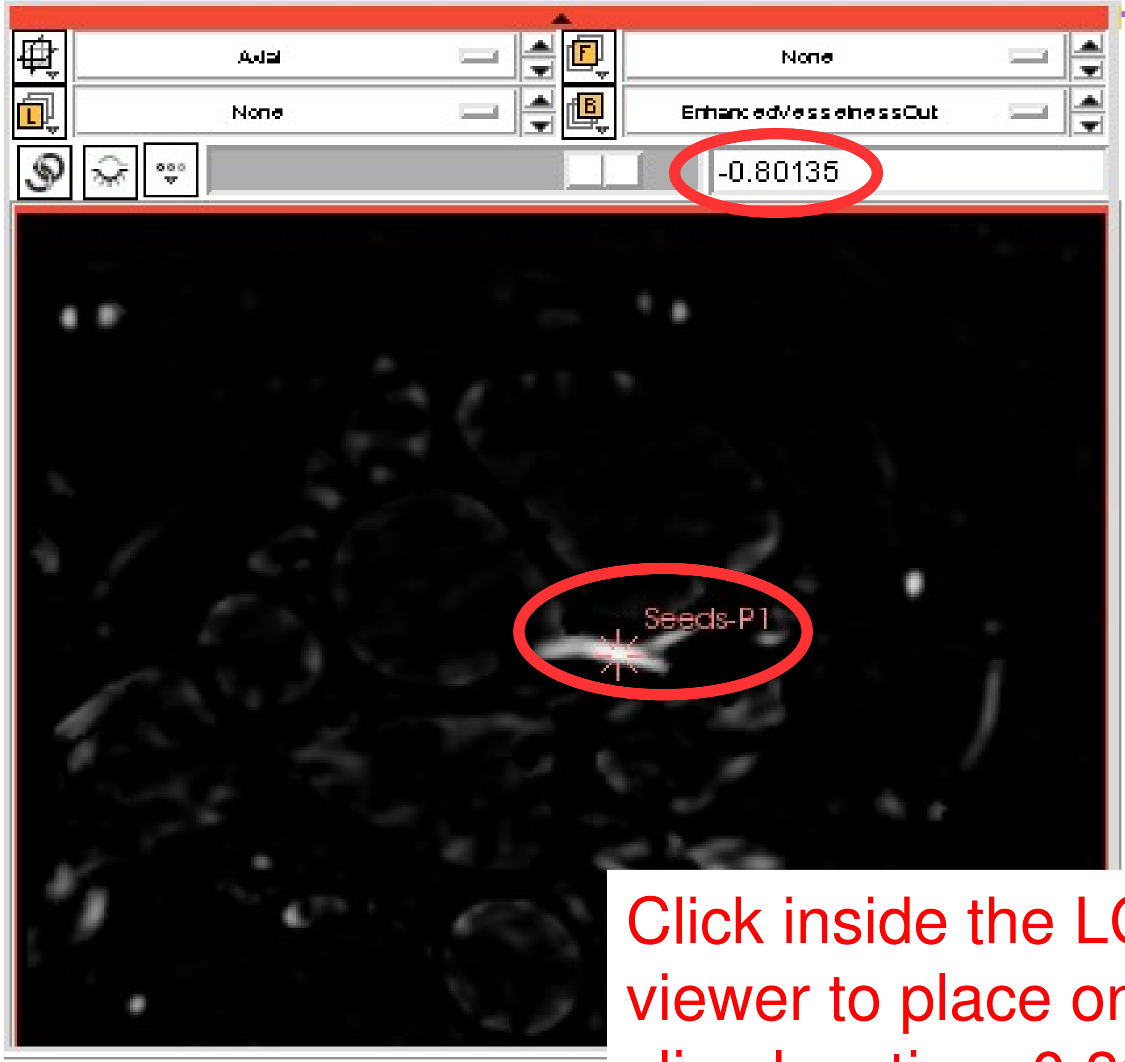
Switch to "Place" mode by using the icon (3) on the toolbar

Level Set Segmentation



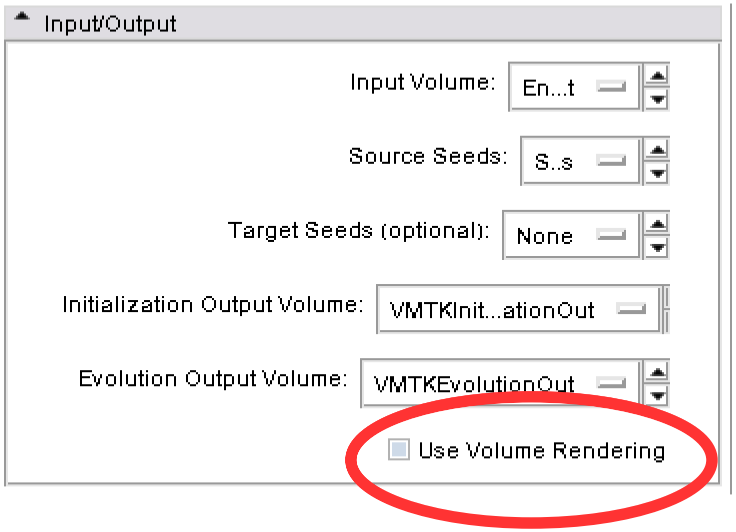
Click inside the RCA on the red slice viewer to place one seed point (f.e. at slice location -15)

Level Set Segmentation



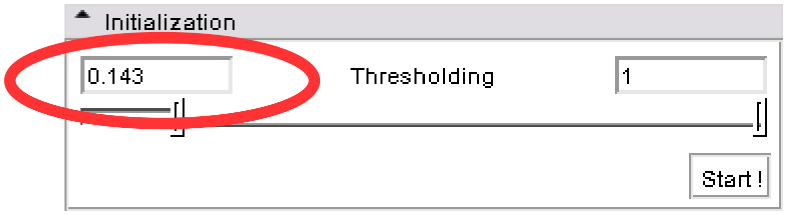
Click inside the LCA on the red slice viewer to place one seed point (f.e. at slice location -0.80)

Level Set Segmentation

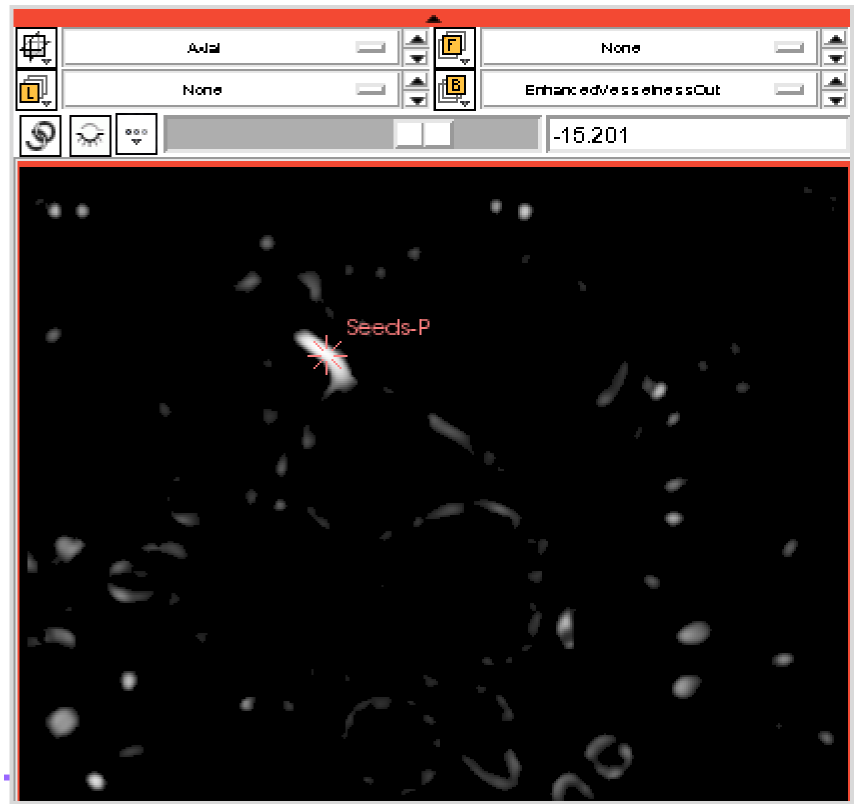


Deactivate "Use Volume Rendering" because Polydata is needed later

Level Set Segmentation

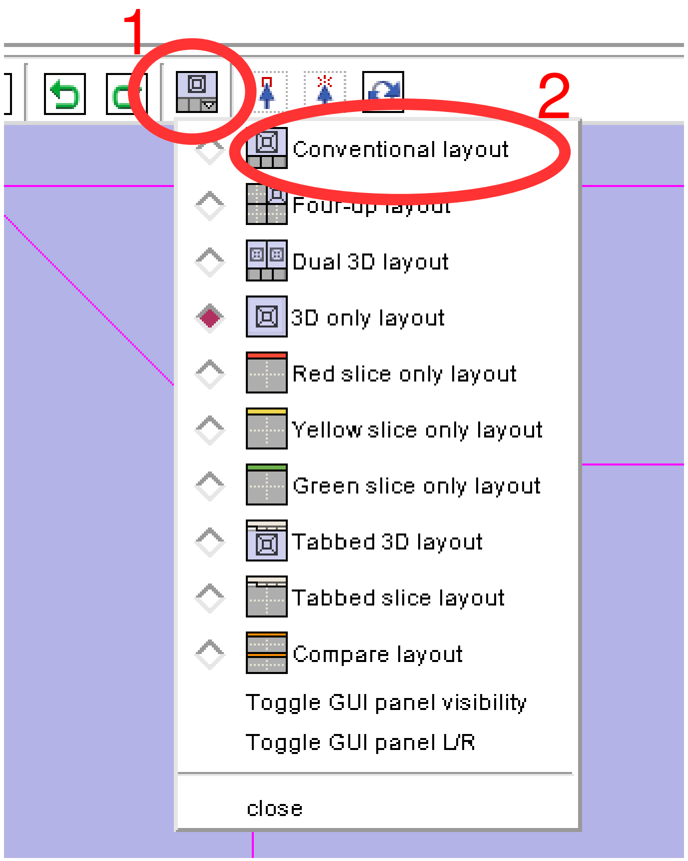


Set a lower threshold of "0.143"



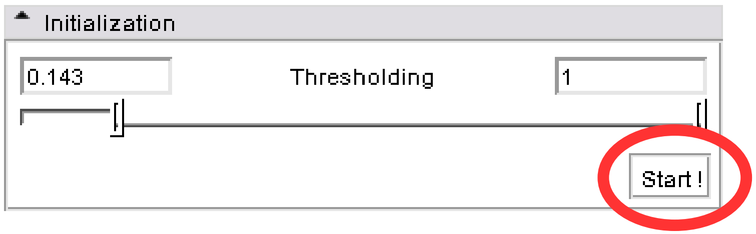
This results in immediate visualization feedback at the slice viewers

Level Set Segmentation



Use the layout selector (1) to switch to the “Conventional layout” (2)

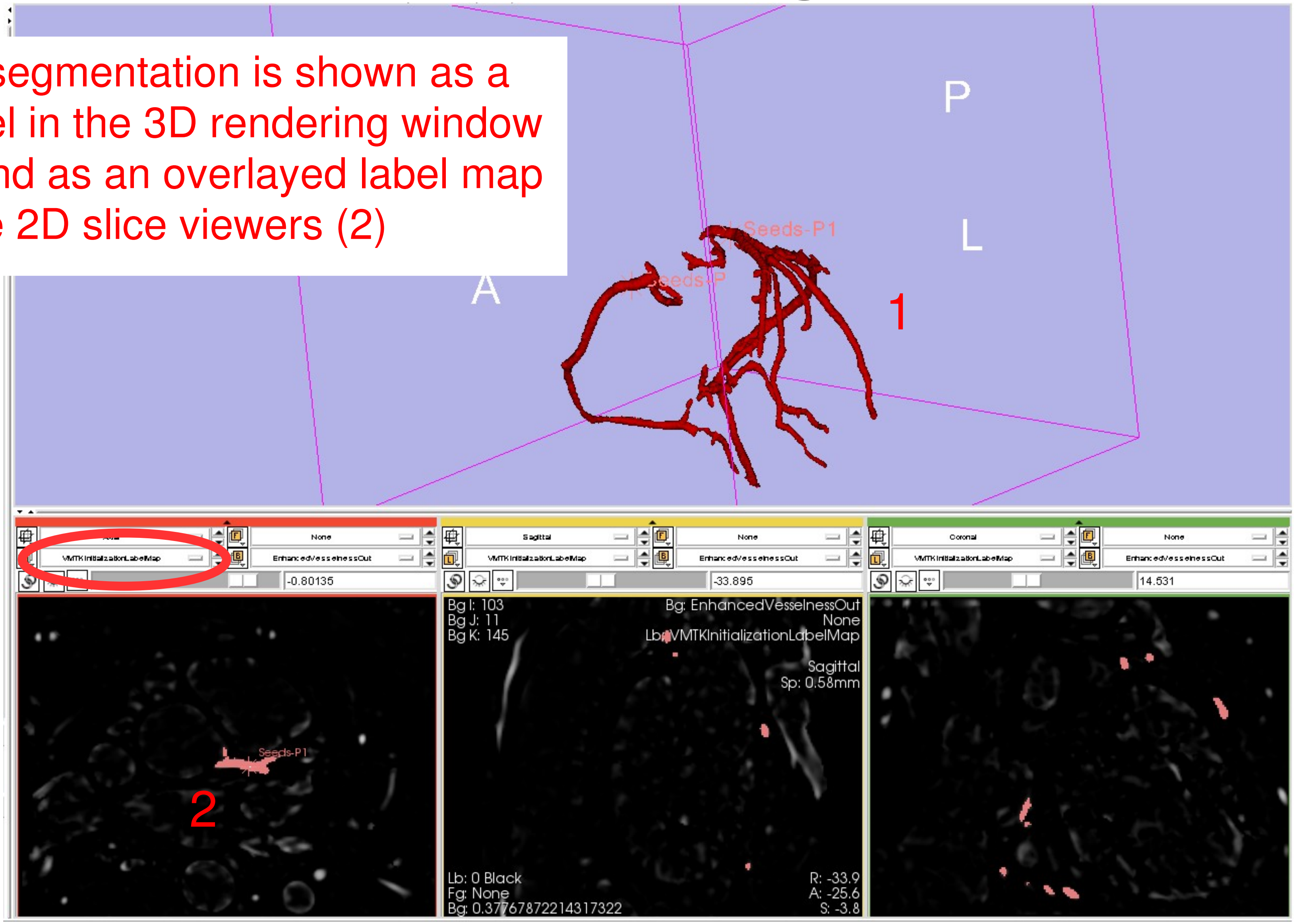
Level Set Segmentation



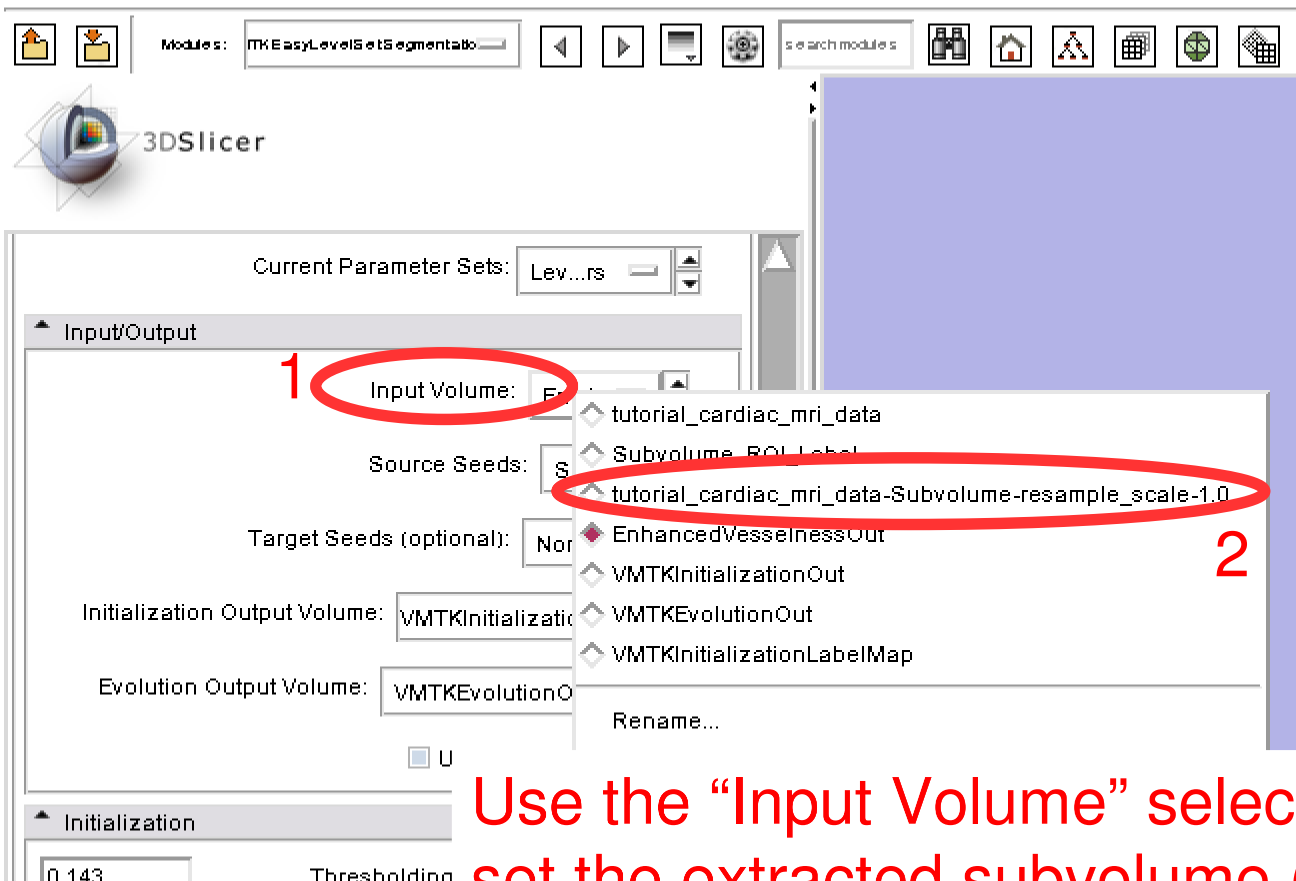
Click “Start!”

Level Set Segmentation

The segmentation is shown as a model in the 3D rendering window (1) and as an overlayed label map in the 2D slice viewers (2)

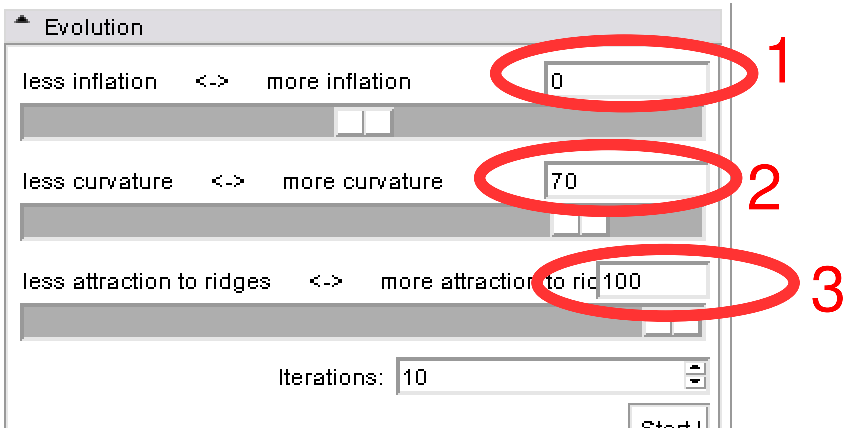


Level Set Segmentation



Use the “Input Volume” selector (1) to set the extracted subvolume (2) as the input for the evolution stage

Level Set Segmentation



Specify the behavior of the evolution by using the sliders.

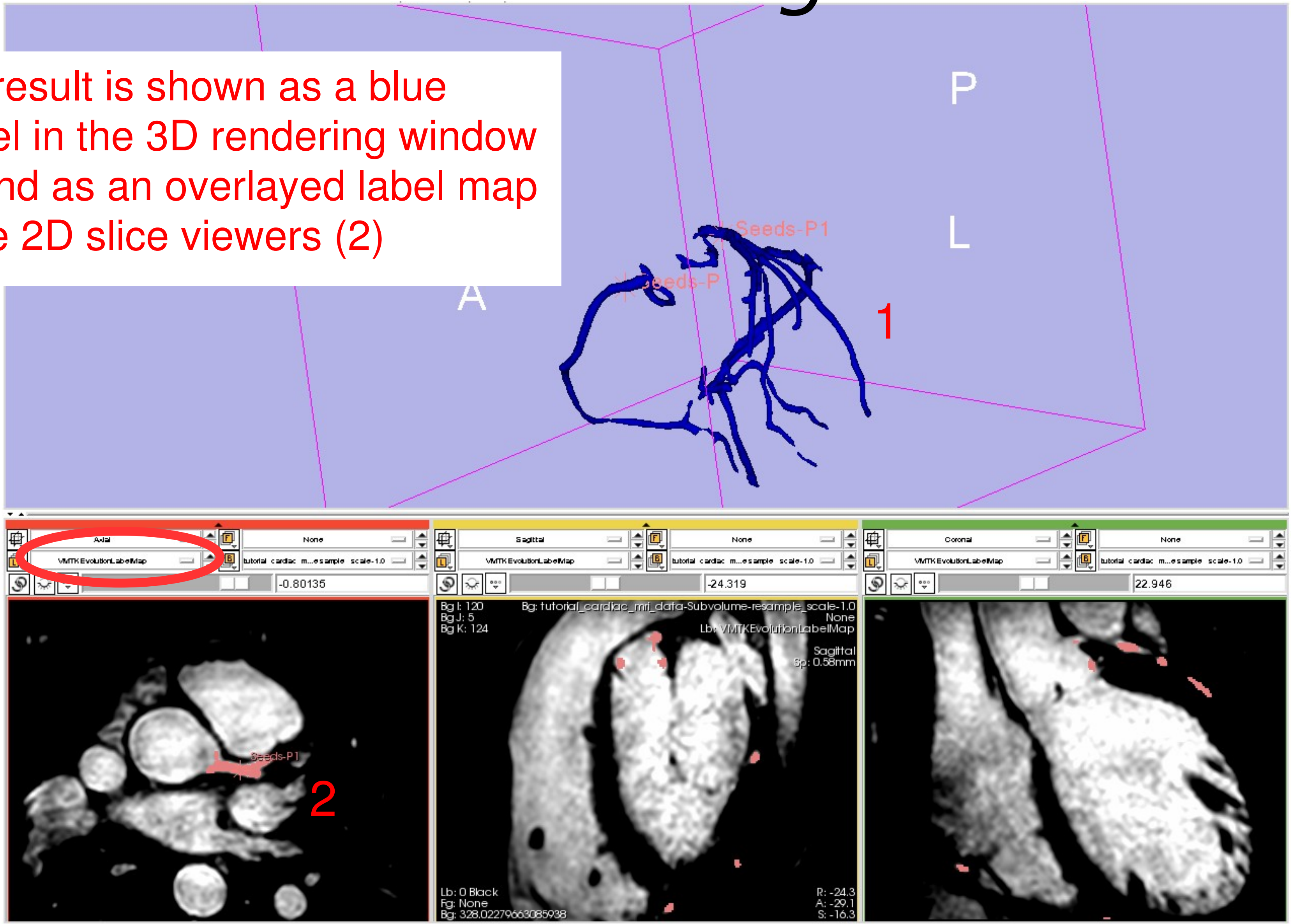
The initialization is already close to the edges of the vessels so no inflation is needed (1).

To get a smooth surface a higher curvature weight of “70” is important (2).

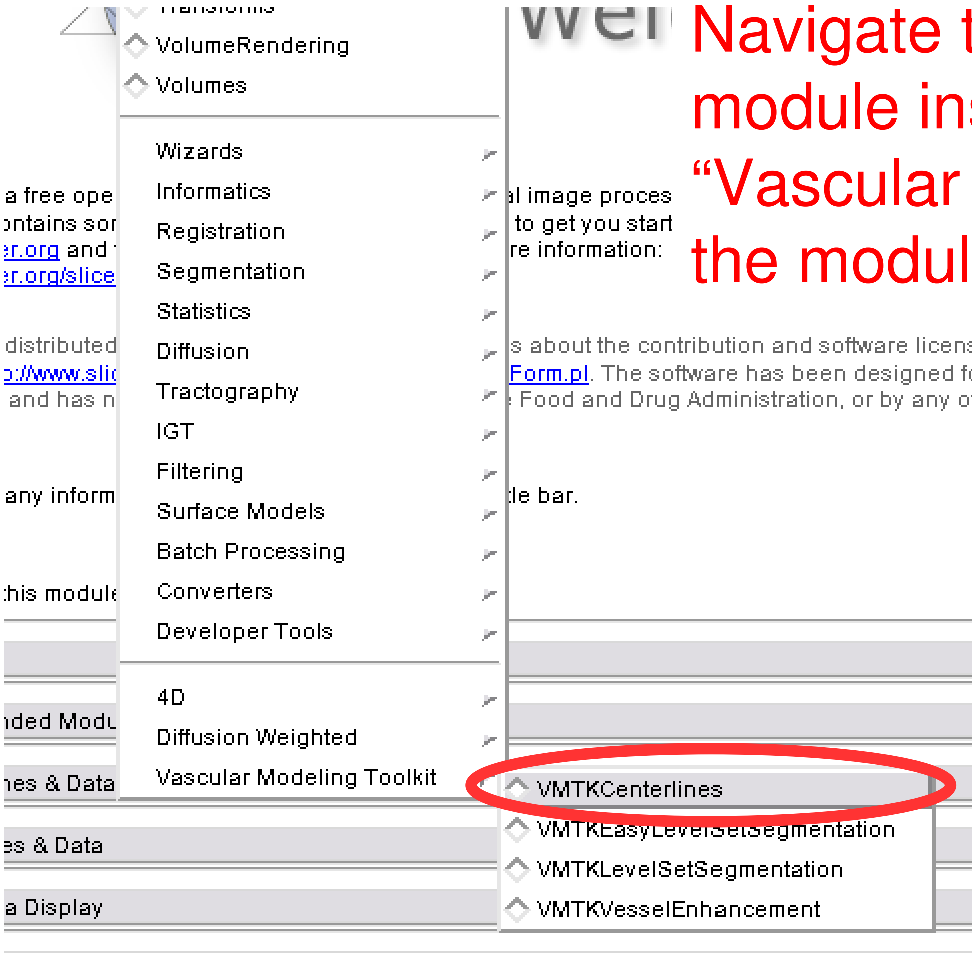
To attract the segmentation to the gradient ridges a high attraction weight of “100” is necessary (3).

Level Set Segmentation

The result is shown as a blue model in the 3D rendering window (1) and as an overlayed label map in the 2D slice viewers (2)

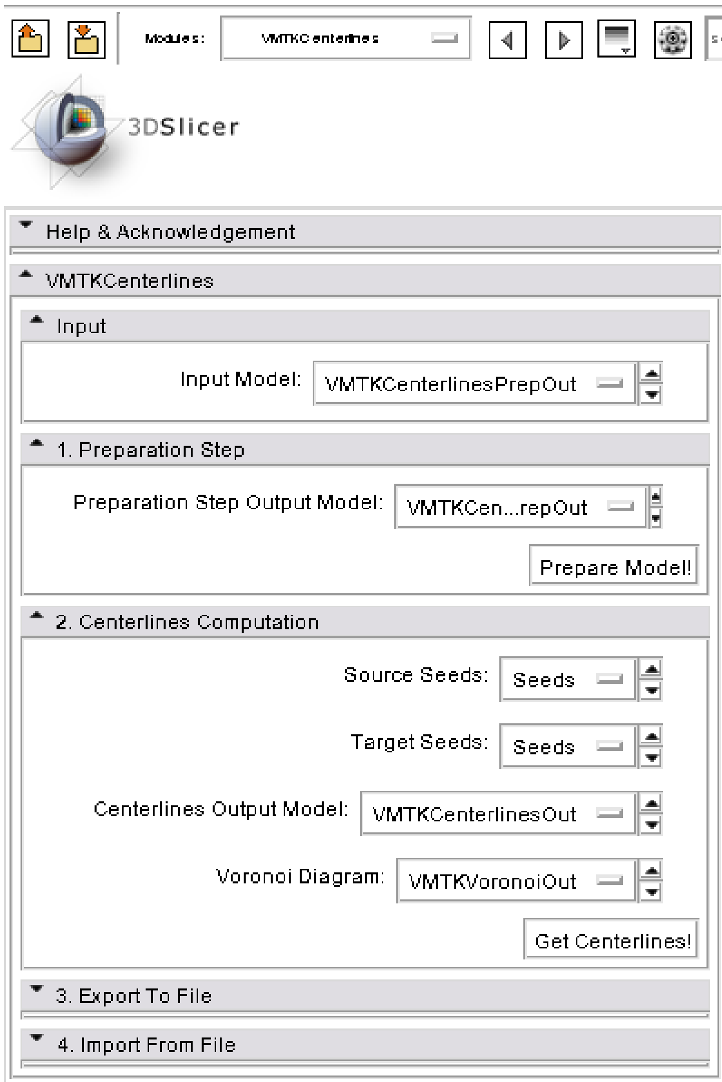


Centerline Computation



Navigate to the VMTKCenterlines module inside the category “Vascular Modeling Toolkit” using the modules selector

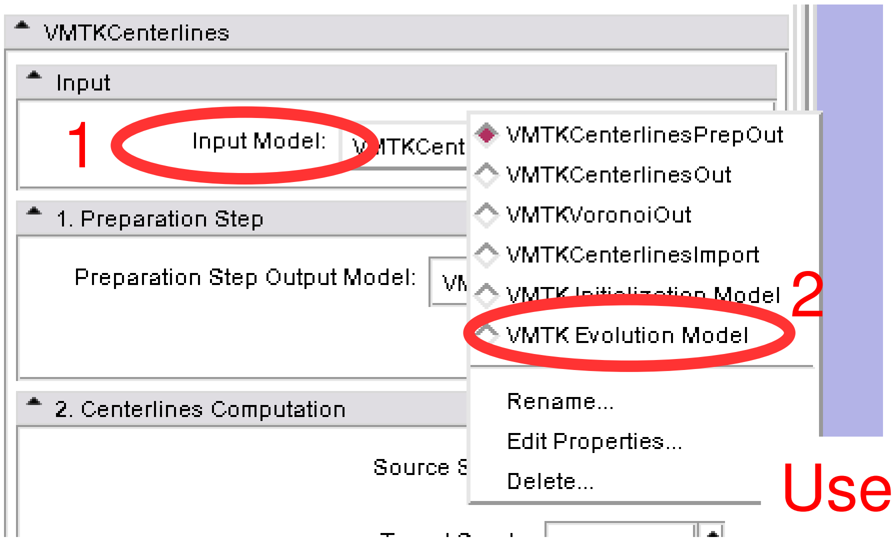
Centerline Computation



This panel now appears.

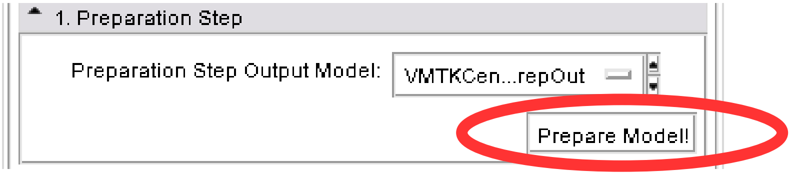
The Centerlines extraction consists of two steps: Model preparation and Centerline Computation

Centerline Computation



Use the "Input Model" selector (1) to set the "VMTKEvolution Model" (2) as the input

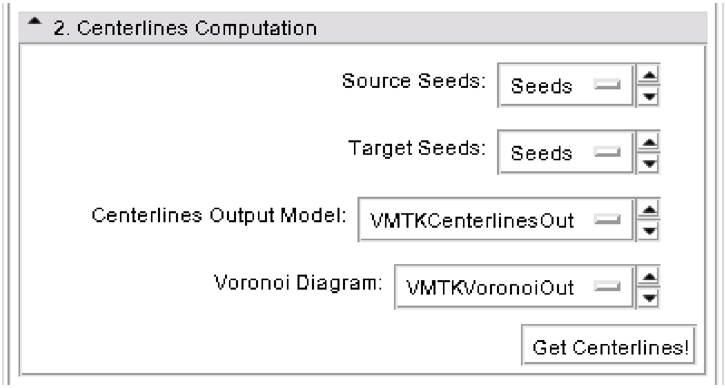
Centerline Computation



Click “Prepare Model!”

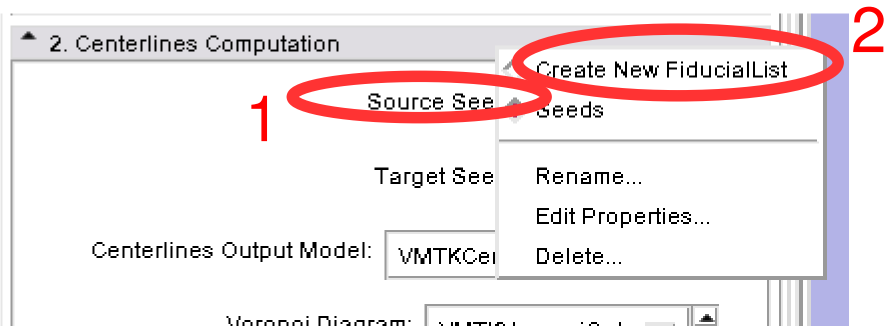
The blue model in the 3D Rendering Window turns green

Centerline Computation



Now use the “Centerlines Computation” panel for step 2

Centerline Computation

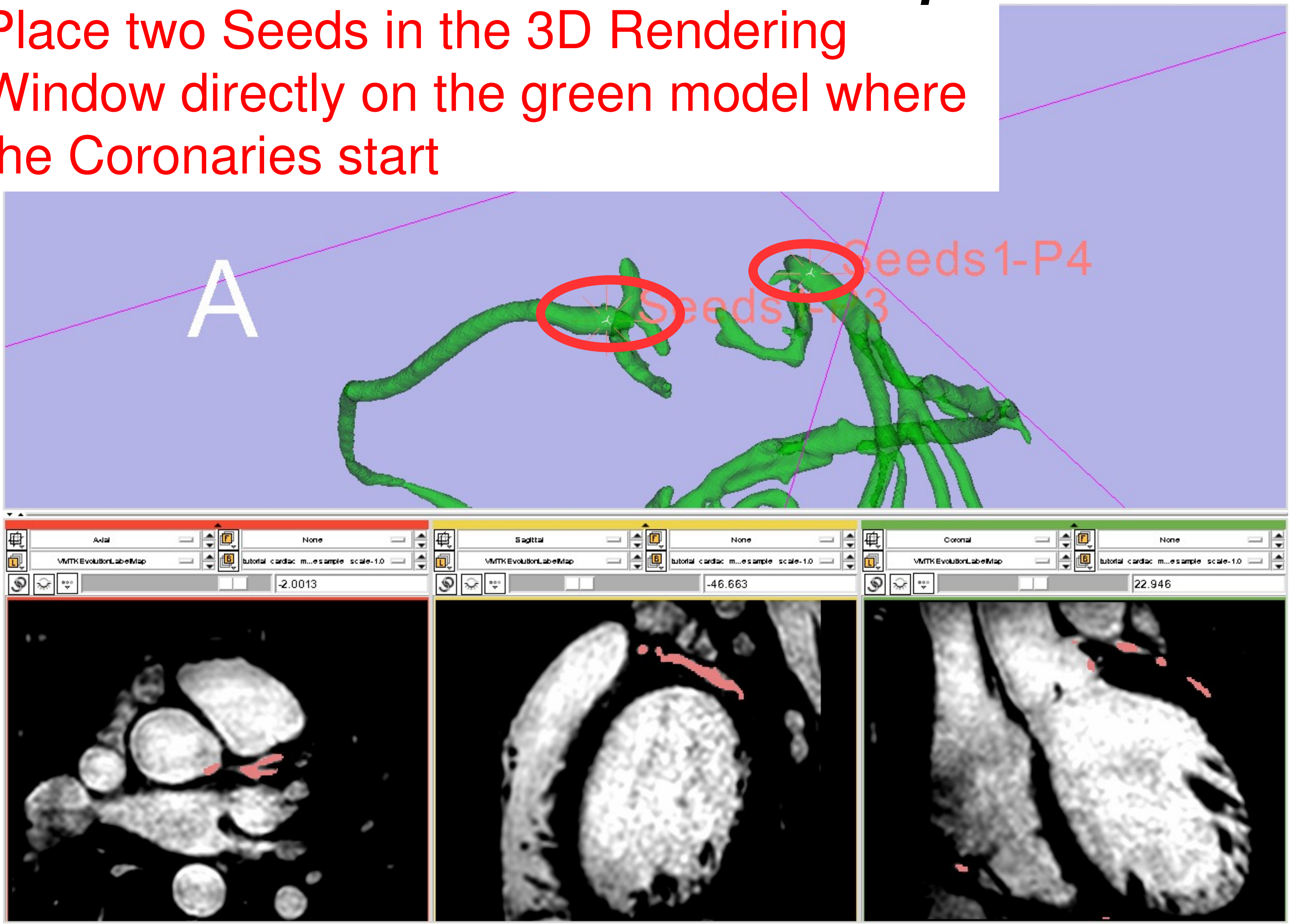


Use the "Source Seeds" selector (1) to create a new Fiducial list (2)

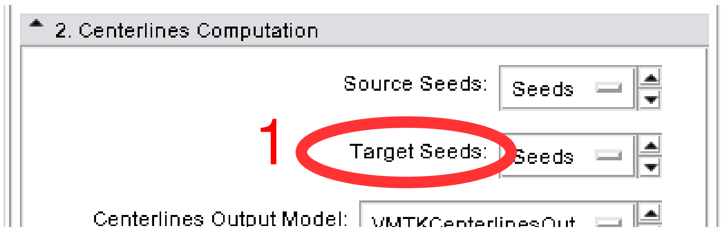
Note: It is recommended to use the Fiducials module to hide the Fiducial lists of the Level Set Segmentation process

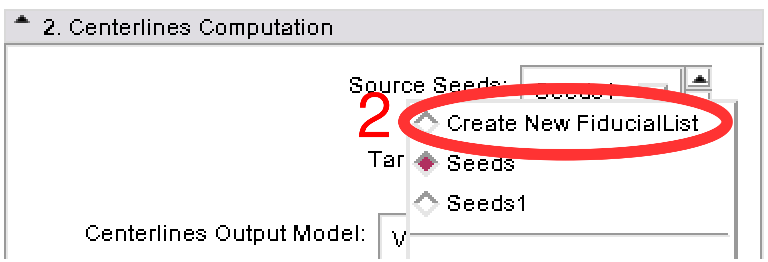
Centerline Computation

Place two Seeds in the 3D Rendering Window directly on the green model where the Coronaries start



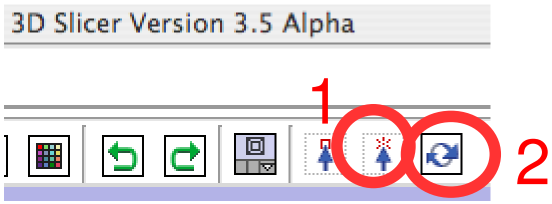
Centerline Computation





Use the “Target Seeds” selector (1) to create a new Fiducial list (2)

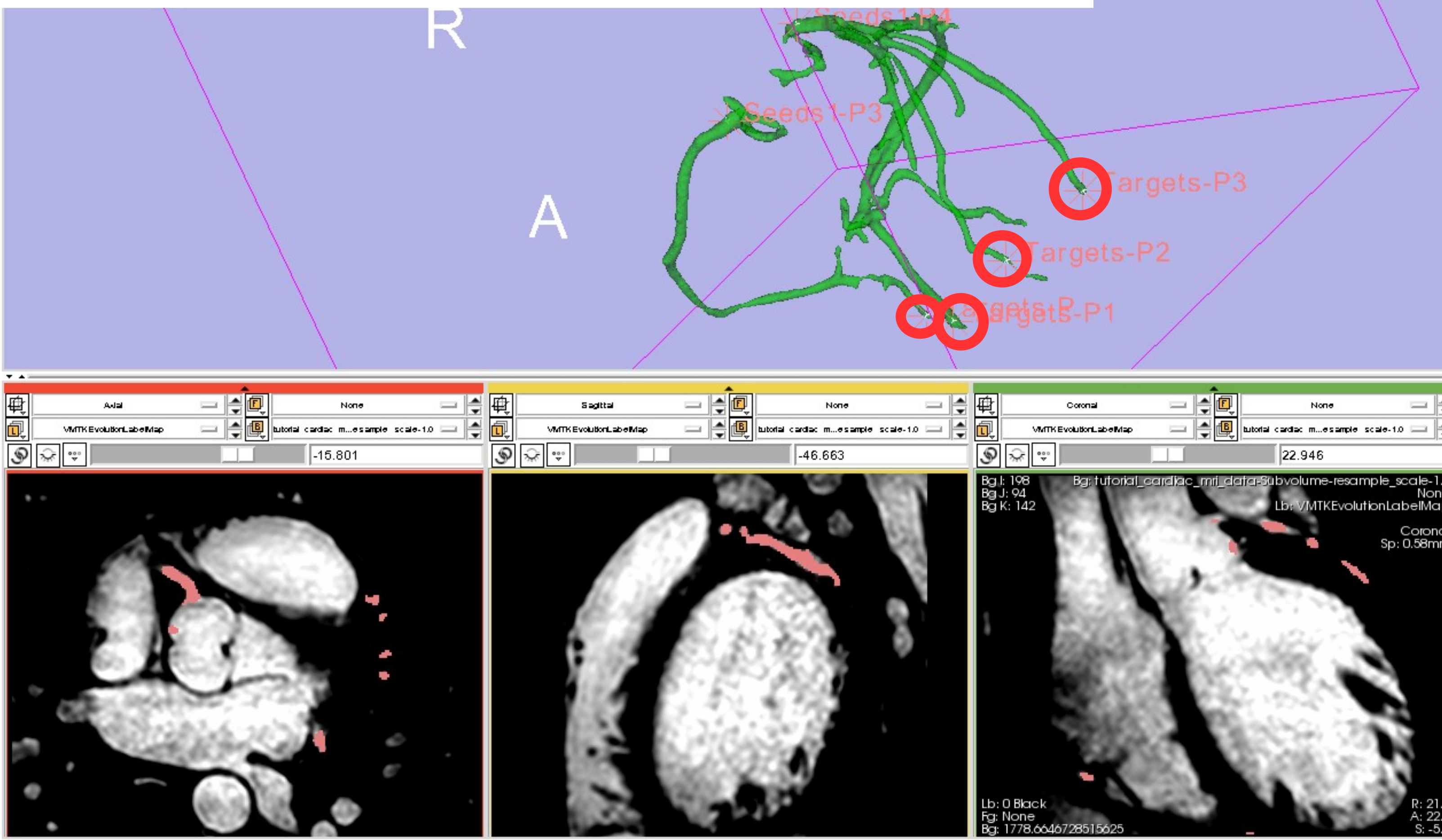
Centerline Computation



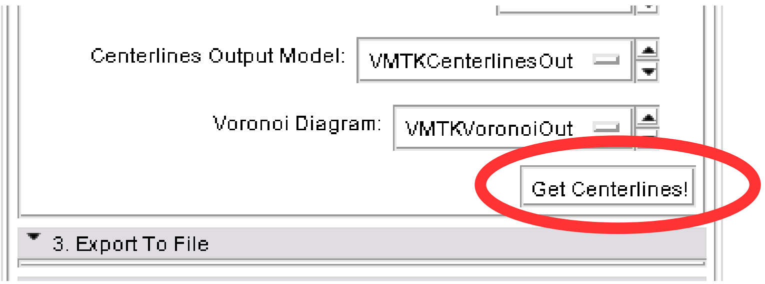
To place the Target Seeds correctly, it is recommended to first use the Transform mode (1) to rotate the model and then the Place mode (2) to set the fiducials

Centerline Computation

Place four Seeds in the 3D Rendering Window directly on the green model where the Coronaries end

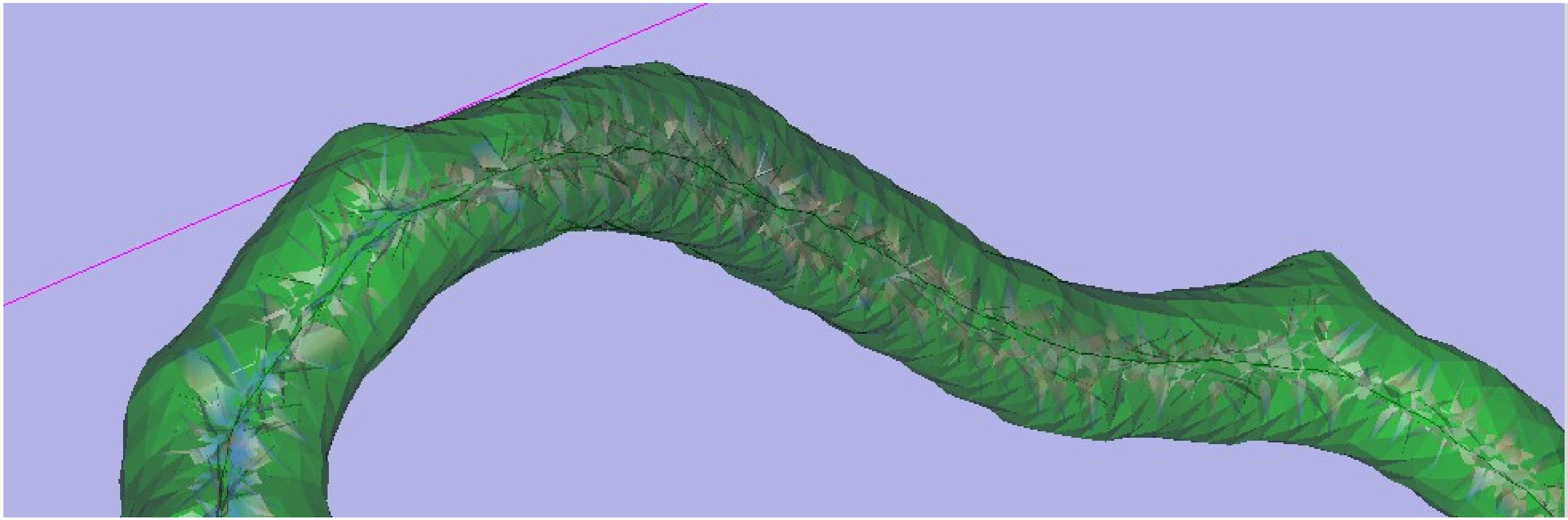


Centerline Computation



Click “Get Centerlines!”

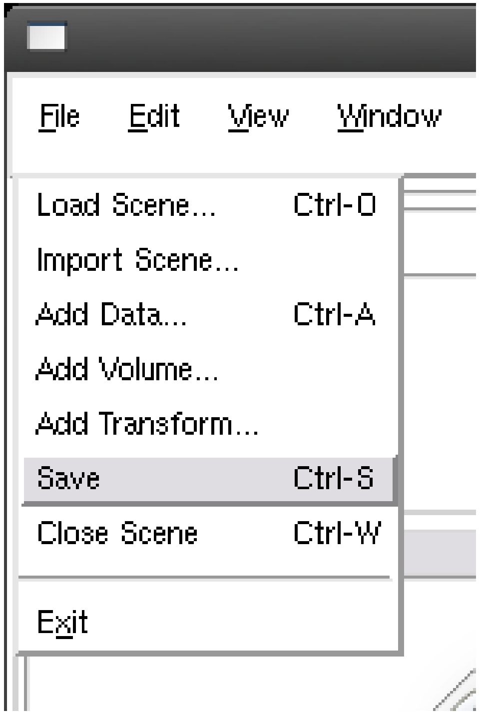
Centerline Computation



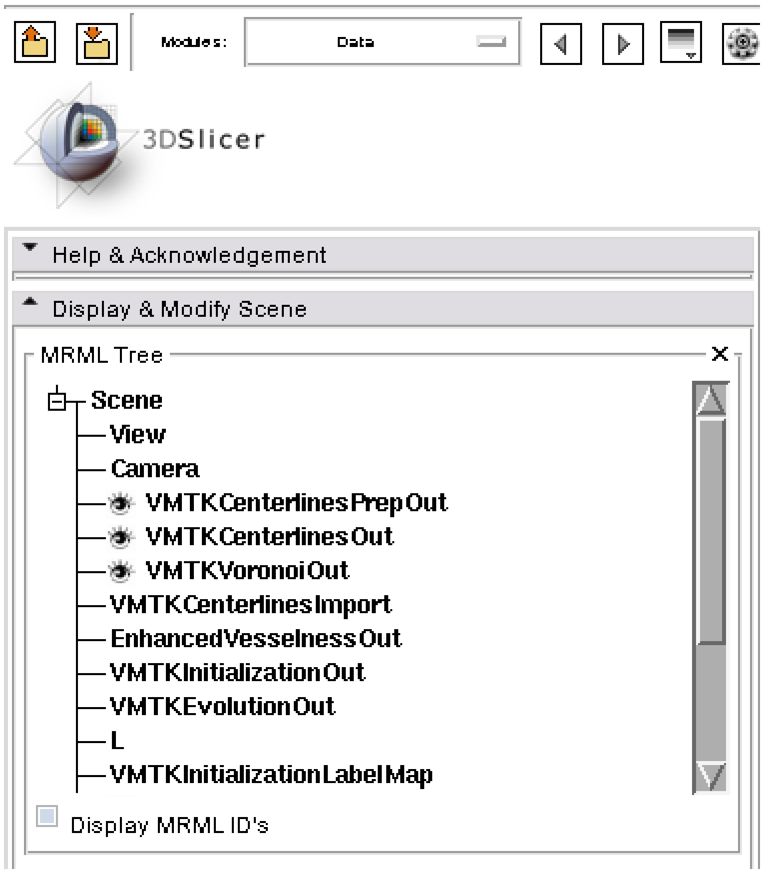
The Voronoi diagram and the corresponding Centerlines appear in the 3D Rendering Window. Use the right mouse button to Zoom into the 3D view

Centerline Computation

This is a good time to save the lumen segmentation, the generated Voronoi diagram, the Centerlines as Polydata and all other MRML data by using the “File” menu and “Save”.



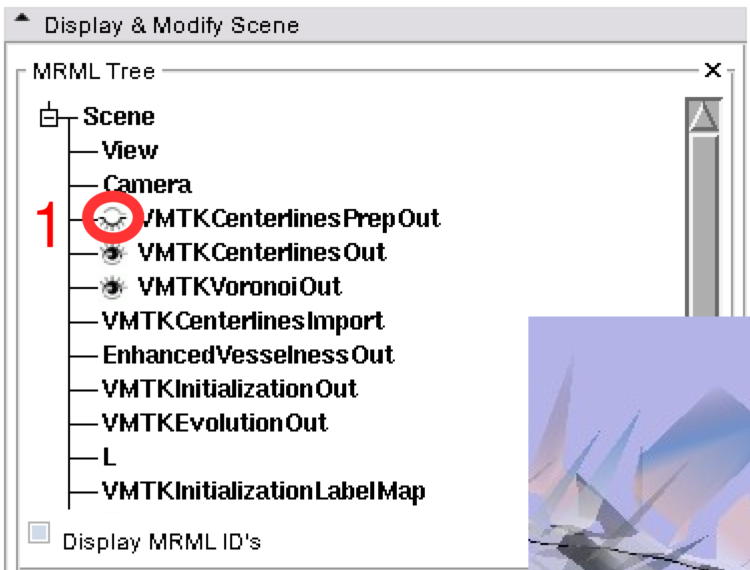
Results



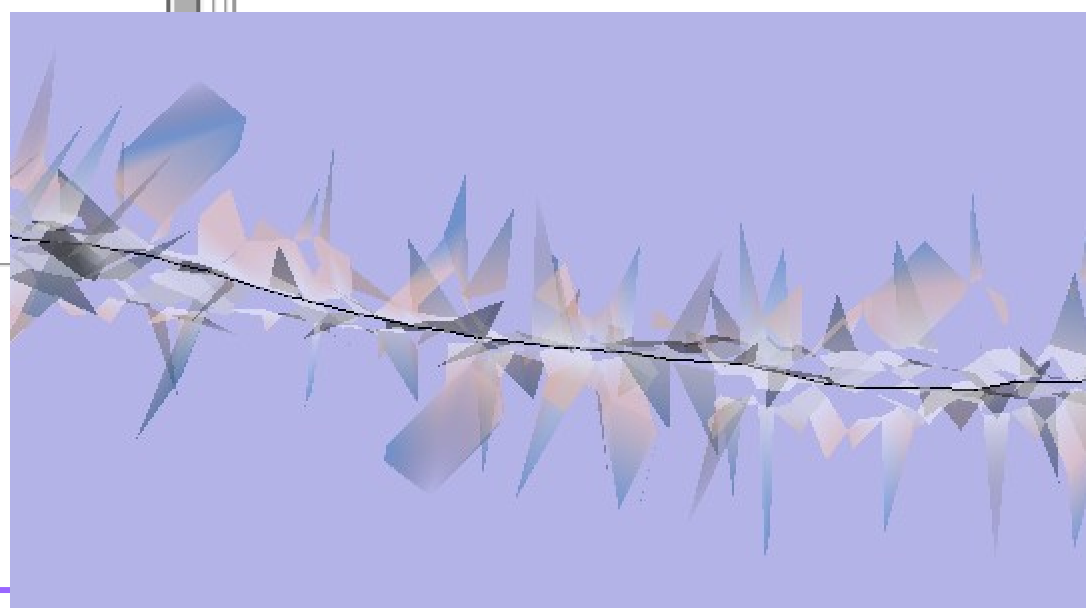
All segmentation parts are available as MRML nodes in the current scene. The “Data” module shows the MRML tree.

Results

Deactivate the “VMTKCenterlinesPrepOut” model to hide the segmented lumen (1).

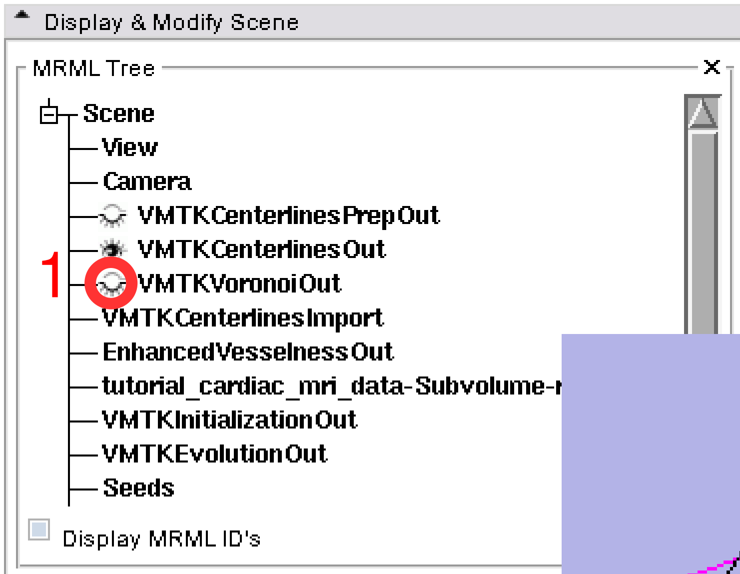


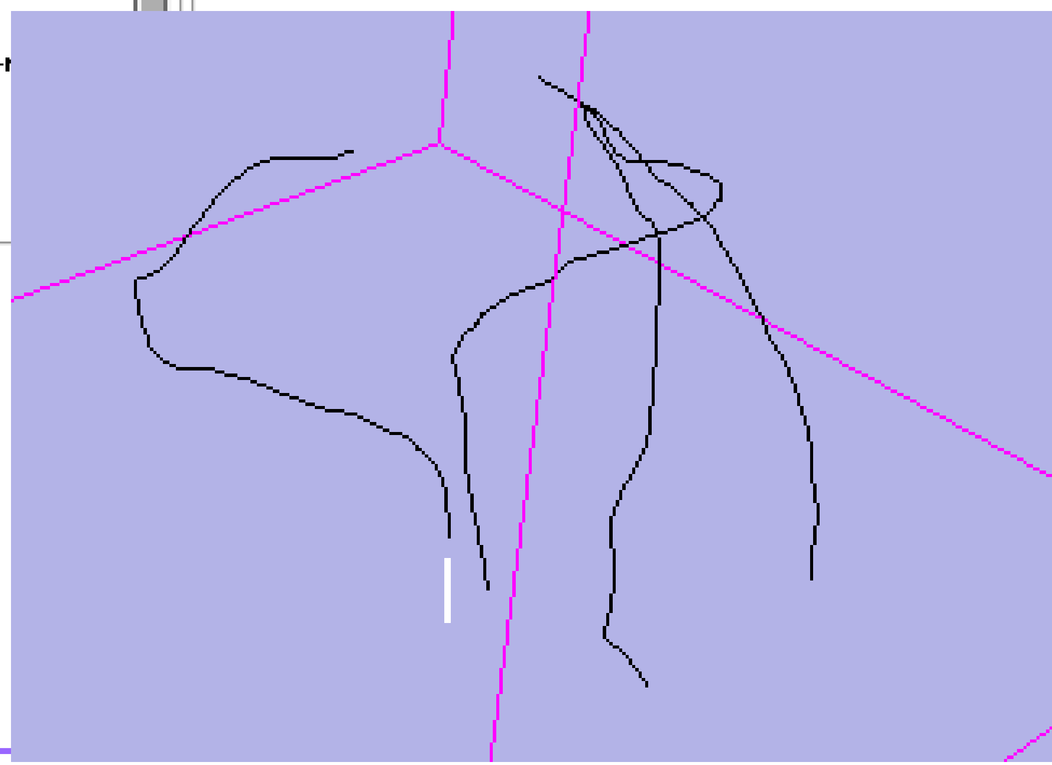
The 3D Rendering Window then shows the Voronoi diagram and the corresponding Centerlines only.



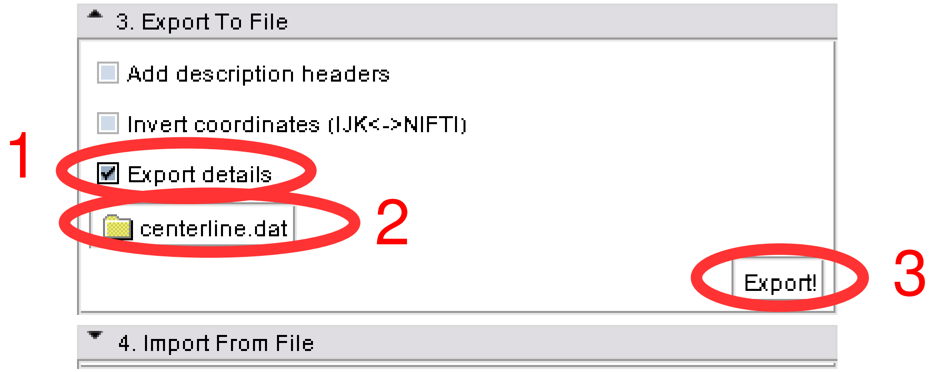
Results

Hide the “VMTKVoronoiOut” model (1) to show the Centerlines in the 3D Rendering Window only.





Results



The VMTKCenterlines module supports the export of extracted Centerlines as clouds of points to the filesystem.

To export details like the maximum inscribed sphere radius activate the checkbox (1), choose a destination (2) and click “Export!” (3).

Results

centerline.dat

```
-43.3799209595 23.5764255524 -2.75626325607 1.36027798035 83603.0 83156.0 0.768
-43.5243453979 23.6248474121 -2.82282710075 1.3566731071 83156.0 74764.0 0.076
-43.5672912598 23.6453304291 -2.84163999557 1.34768368553 83607.0 74764.0 0.048
-4[illegible]5085 23.6756229401 -2.90[illegible]1 1.34341124572 83609.0 83607.0 0.264
-44.3442382812 23.8746795654 -3.11588931084 1.31434156682 83606.0 83606.0 0.0
-44.[illegible]264 23.8921318054 -3.17[illegible]991 1.3036475189 82713.0 82713.0 0.0
-44.6662406921 23.9847869873 -3.34564328194 1.31296327481 81841.0 81841.0 0.0
-44.7160263062 24.0004348755 -3.36203813553 1.[illegible] 81391.0 84189.0 0.86
-45.0118713379 24.0653190613 -3.4202637672[illegible] 1.36677139288 8[illegible]204.0 84204.0 0.0
-45.1805000305 24.090801239 -3.53823828697 1.4[illegible] 82318.0 82318.0 0.0
-45.3257102966 24.1287307739 -3.57551217079 1.44477739523 67865.0 67865.0 0.0
-45.3494758606 24.1336631775 -3.5815103054 1.45031551176 82920.0 82930.0 0.72
-45.4803161621 24.1486034393 -3.61397314072 1.45145492922 59494.0 82920.0 0.872
-45.5894927979 24.1538124084 -3.6366481781 1.45405727223 82684.0 82699.0 0.104
-45.8841552734 24.2133865356 -3.7017223835 1.45863325172 82693.0 82693.0 0.0
-45.9728851318 24.2313556671 -3.73139214516 1.46847106443 54075.0 54075.0 0.0
-45.9736022949 24.2315006256 -3.73163151741 1.475319103 54075.0 81328.0 0.992
-46.1253738403 24.3120250702 -3.77564024925 1.47537432912 81328.0 81328.0 0.0
-46.2832069397 24.3910942078 -3.82611846924 1.46098955773 81335.0 83671.0 0.576
-46.5725059509 24.5075893402 -3.93619441986 1.45986542314 83675.0 83671.0 0.736
-46.5947151184 24.5178642273 -3.94453048706 1.47386688327 83672.0 83675.0 0.052
-46.6676940918 24.5478801727 -3.9686293602 1.47718453004 83732.0 83732.0 0.0
-46.7952346802 24.5904388428 -4.00715827942 1.48037306238 83731.0 83728.0 0.312
-46.8497428894 2
-47.119468689 24
-47.4573402405 2
-47.7022323608 2
-47.7347488403 2
-48.2051200867 2
-48.295879364 25
-48.3784751892 2
-48.4057388306 2
-48.4948959351 2
-48.6587486267 2
-48.765625 25.28
-48.8083724976 2
```

1

2

The exported file includes the world coordinates (1) of the Centerlines and also the Maximum Inscribed Sphere Radius (2) for each point.

Conclusion

- VMTK extensions installable using the extension wizard
- Vesselness Filtering using VMTKVesselEnhancement
- Lumen Segmentation using VMTKEasyLevelSetSegmentation
- Centerline Computation using VMTKCenterlines
- 3D Slicer Integration for further processing of the data (MRML nodes)
- Open Source Environment

References

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Thank you for using this tutorial!