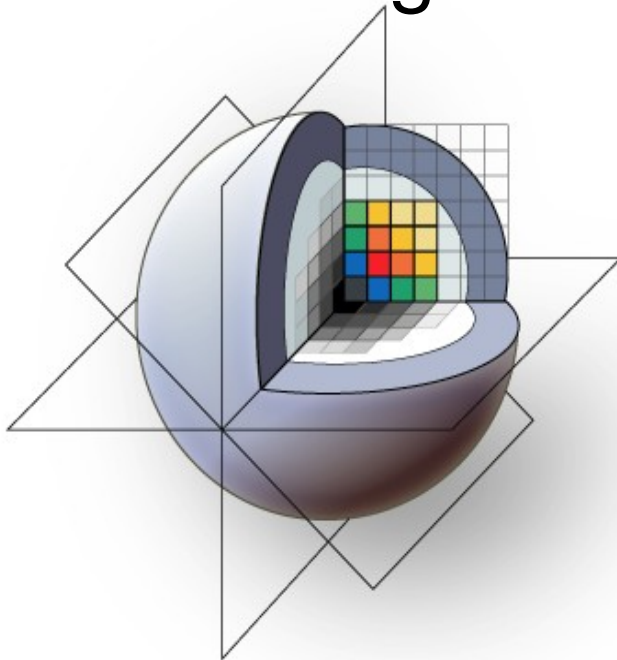


## Slicer3 Training Tutorial

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



Daniel Hähn

Student of Medical Informatics  
University of Heidelberg, Germany

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# *Learning Objective*

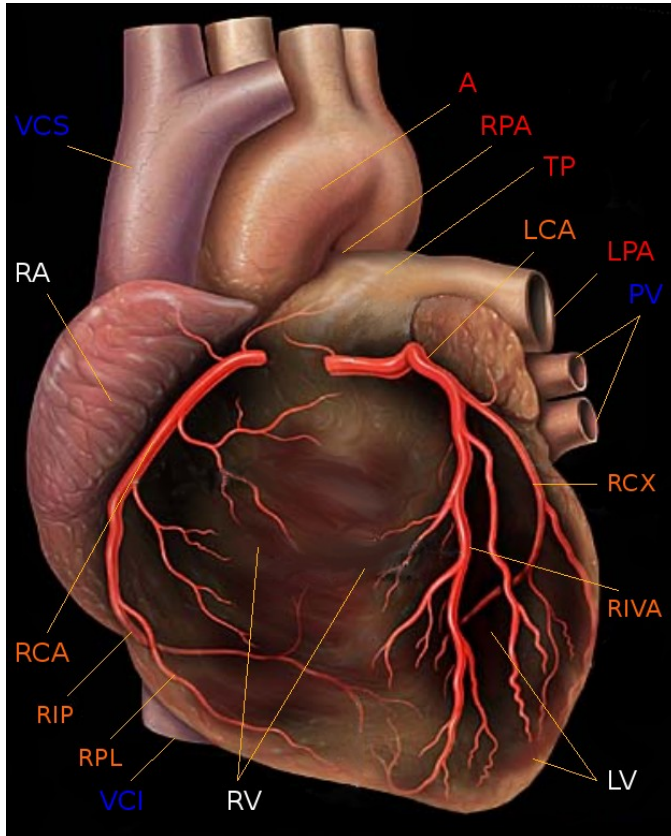
---



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](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

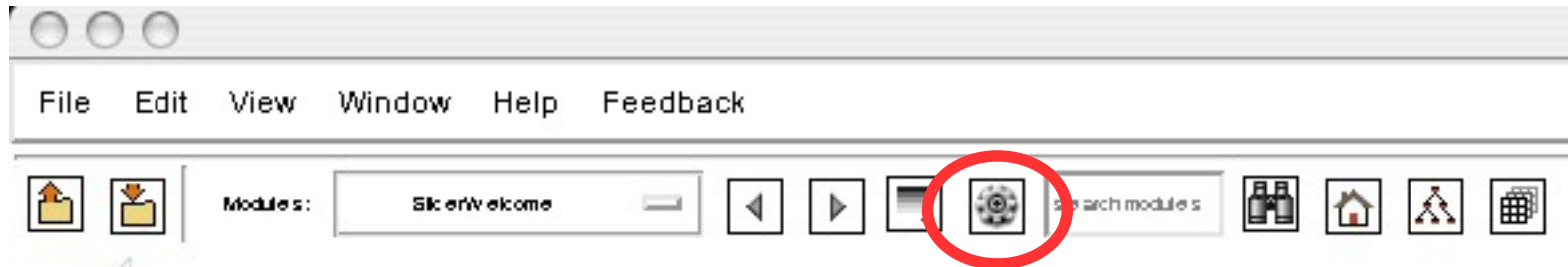
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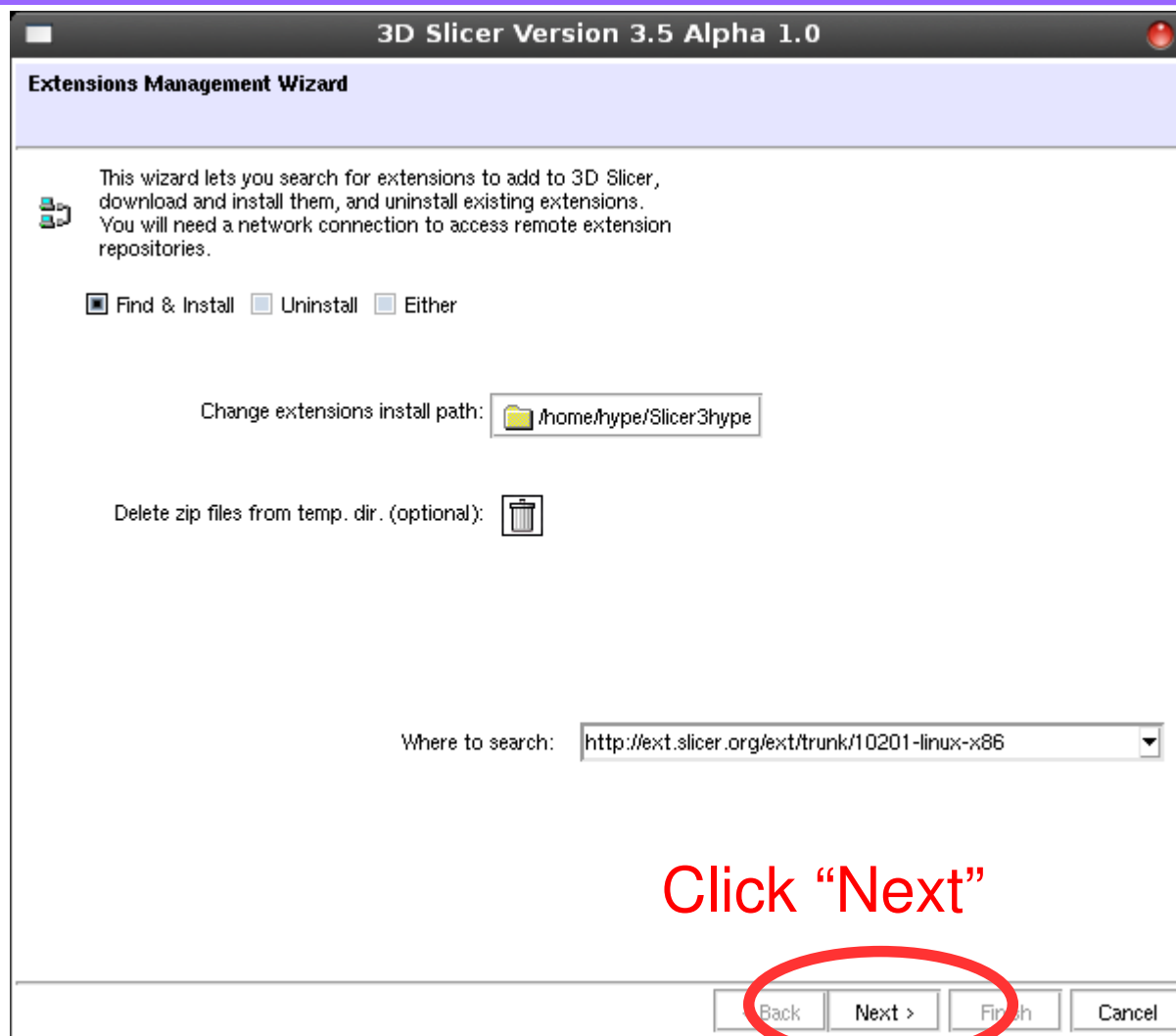
# Installing VMTK in 3D Slicer

---



Start the Extension Wizard





Click "Next"

3D Slicer Version 3.5 Alpha 1.0

Extension Management Wizard

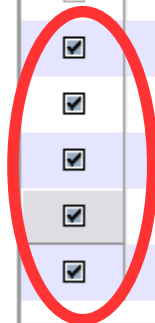
Select extensions, then click uninstall to remove them from your version of 3D Slicer, or click download to retrieve them.

Select	Status	Name	Category	Description	Home
<input type="checkbox"/>		PythonSampleScriptedModule	Developer Tools	This is an exam	
<input type="checkbox"/>		RobustStatisticsSegModule	Segmentation	Skull sttipping 1	
<input type="checkbox"/>		RobustStatisticsSegModule	Segmentation	Skull sttipping 1	
<input type="checkbox"/>		PythonSampleScriptedModule	Developer Tools	This is an exam	
<input checked="" type="checkbox"/>		VMTKCenterlines	Segmentation	Centerline com	
<input checked="" type="checkbox"/>		VMTKEasyLevelSetSegmentation	Segmentation	Easier interface	
<input checked="" type="checkbox"/>		VMTKLevelSetSegmentation	Segmentation	Interactive Leve	
<input checked="" type="checkbox"/>		VmtkSlicerModule	Library	The Vascular Iv	
<input checked="" type="checkbox"/>		VMTKVesselEnhancement	Filtering	Vessel Enhanc	

Download & Install Uninstall

< Back Next > Finish Cancel

Select all VMTK Extensions





3D Slicer Version 3.5 Alpha 1.0

Extension Management Wizard

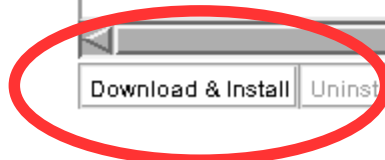
Select extensions, then click uninstall to remove them from your version of 3D Slicer, or click download to retrieve them.

Select	Status	Name	Category	Description	Home
<input type="checkbox"/>		PythonSampleScriptedModule	Developer Tools	This is an exam	
<input type="checkbox"/>		RobustStatisticsSegModule	Segmentation	Skull sttipping 1	
<input type="checkbox"/>		SkullStripperModule	Segmentation	Skull sttipping 1	
<input type="checkbox"/>		TclSampleScriptedModule	Developer Tools	This is an exam	
<input checked="" type="checkbox"/>		VMTKCenterlines	Segmentation	Centerline com	
<input checked="" type="checkbox"/>		VMTKEasyLevelSetSegmentation	Segmentation	Easier interface	
<input checked="" type="checkbox"/>		VMTKLevelSetSegmentation	Segmentation	Interactive Leve	
			Library	The Vascular Iv	
			Filtering	Vessel Enhanc	

Download & Install   Uninstall

< Back   Next >   Finish   Cancel

Click "Download & Install"



3D Slicer Version 3.5 Alpha 1.0

Extension Management Wizard

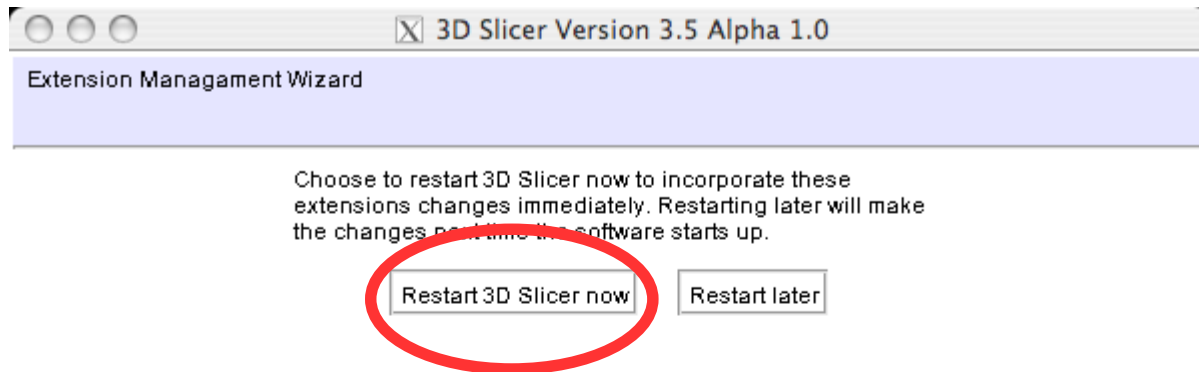
Select extensions, then click uninstall to remove them from your version of 3D Slicer, or click download to retrieve them.

Select	Status	Name	Category	Description	Home
<input type="checkbox"/>		PythonSampleScriptedModule	Developer Tools	This is an exam	
<input type="checkbox"/>		RobustStatisticsSegModule	Segmentation	Skull sttipping 1	
<input type="checkbox"/>		SkullStripperModule	Segmentation	Skull sttipping 1	
<input type="checkbox"/>		TclSampleScriptedModule	Developer Tools	This is an exam	
<input checked="" type="checkbox"/>		VMTKCenterlines	Segmentation	Centerline com	
<input checked="" type="checkbox"/>		VMTKEasyLevelSetSegmentation	Segmentation	Easier interface	
<input checked="" type="checkbox"/>		VMTKLevelSetSegmentation	Segmentation	Interactive Leve	
<input checked="" type="checkbox"/>		VmtkSlicerModule	Library	The Vascular Iv	
<input checked="" type="checkbox"/>		VMTKVesselEnhancement	Filtering	Vessel Enhanc	

Download & Install Uninstall

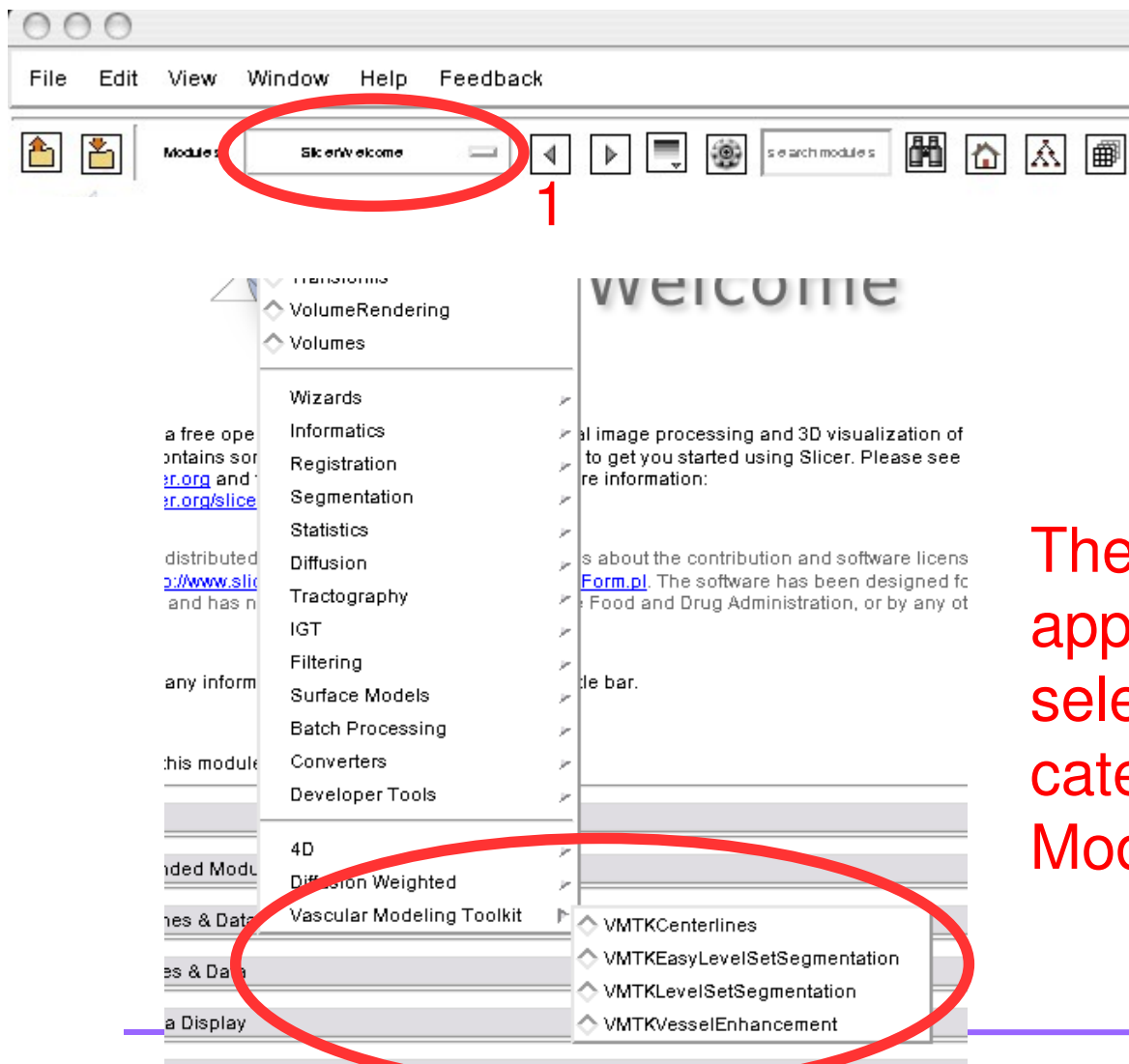
Click "Next"

< Back Next > Finish Cancel



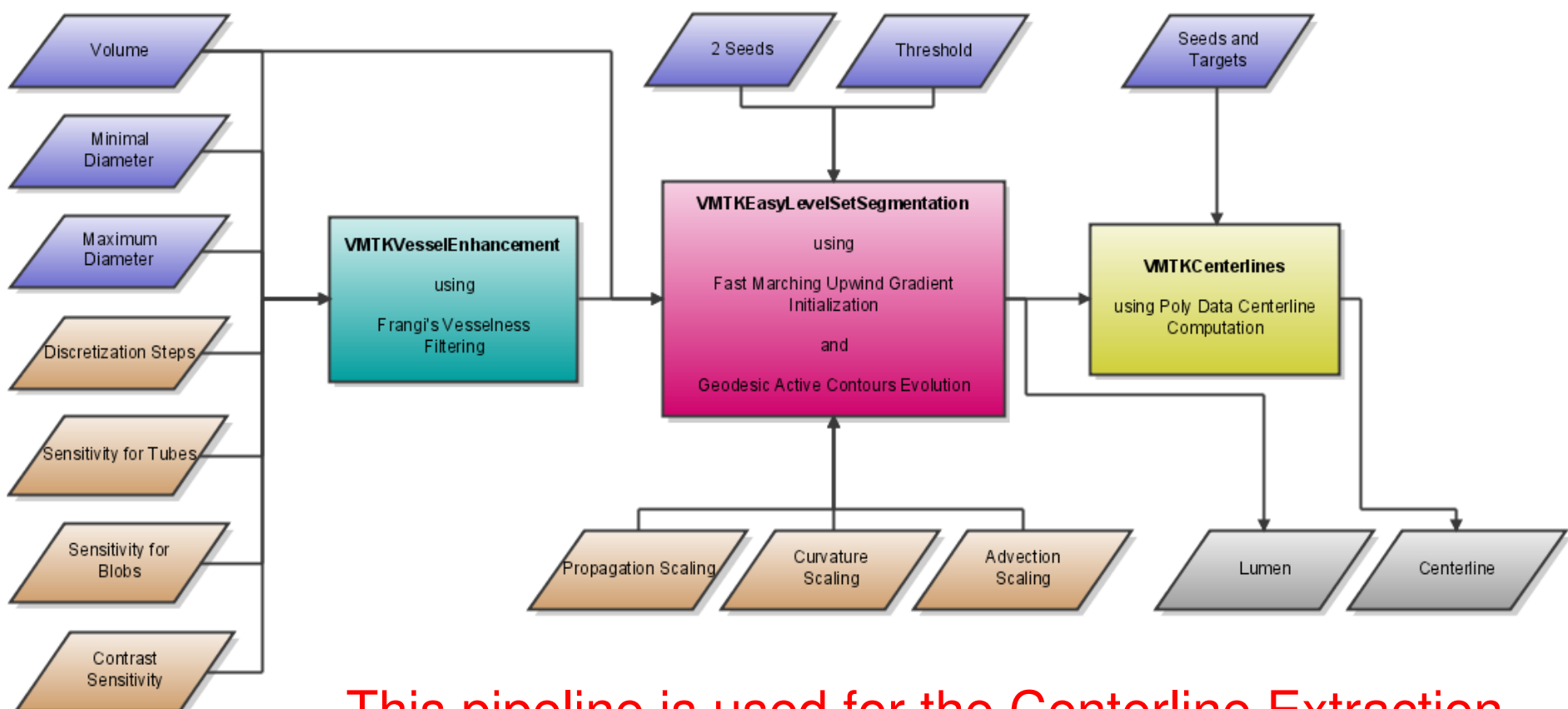
**Restart 3D Slicer**



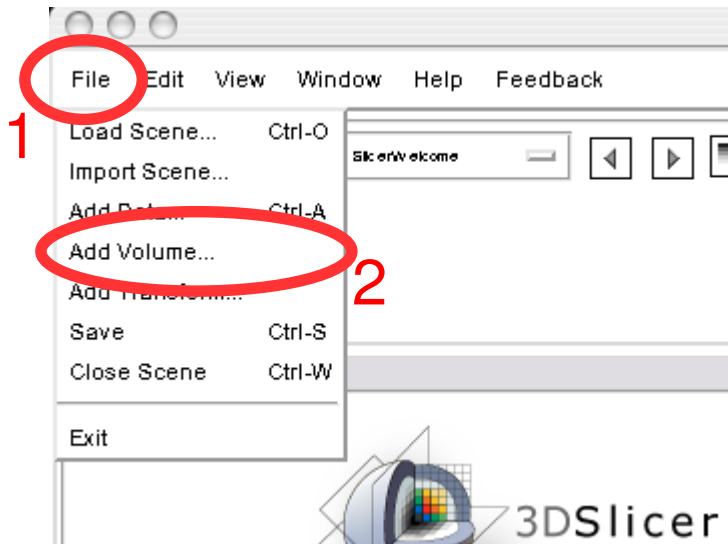


The VMTK Extensions appear in the modules selector (1) inside the category “Vascular Modeling Toolkit”

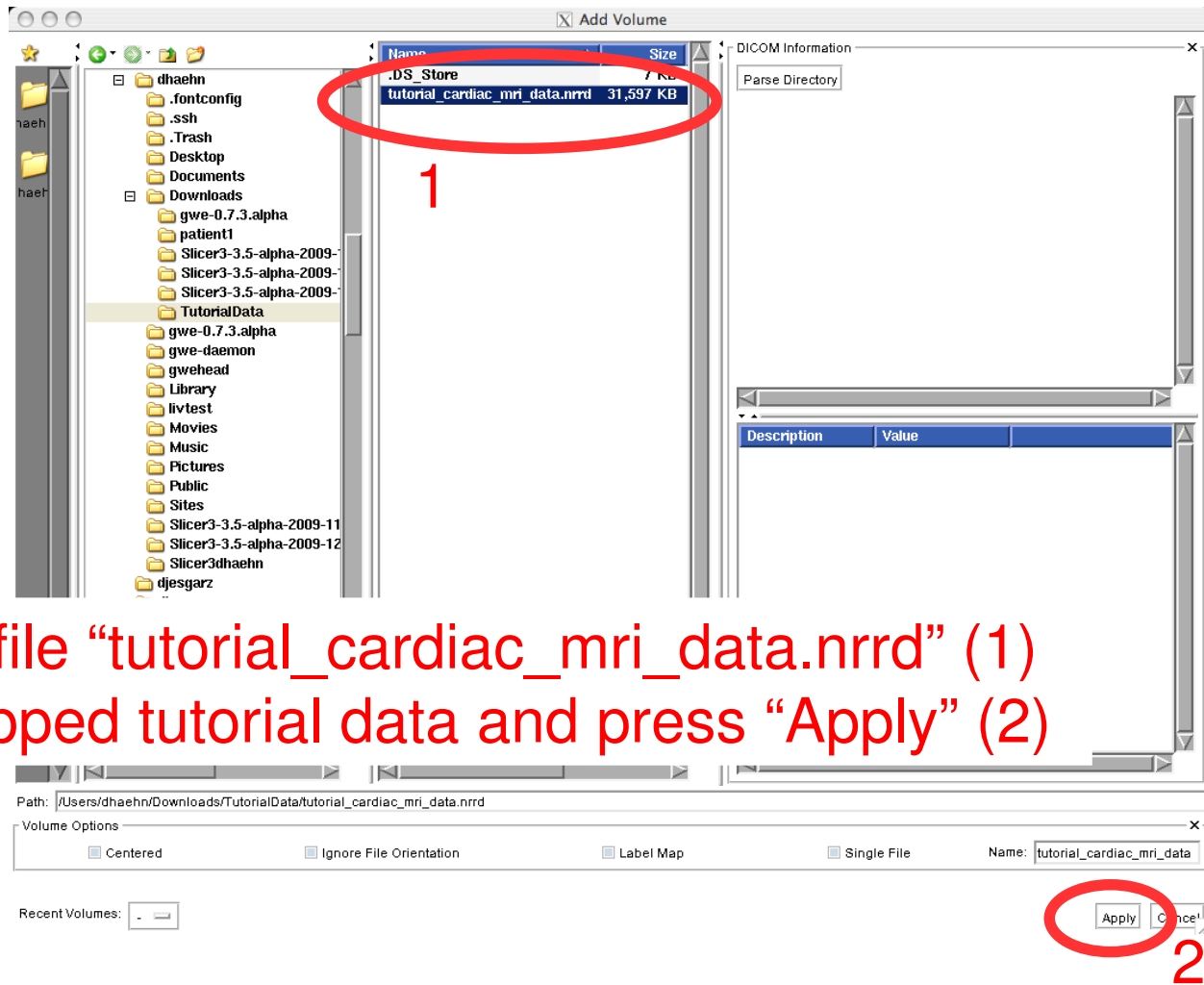
# The Pipeline



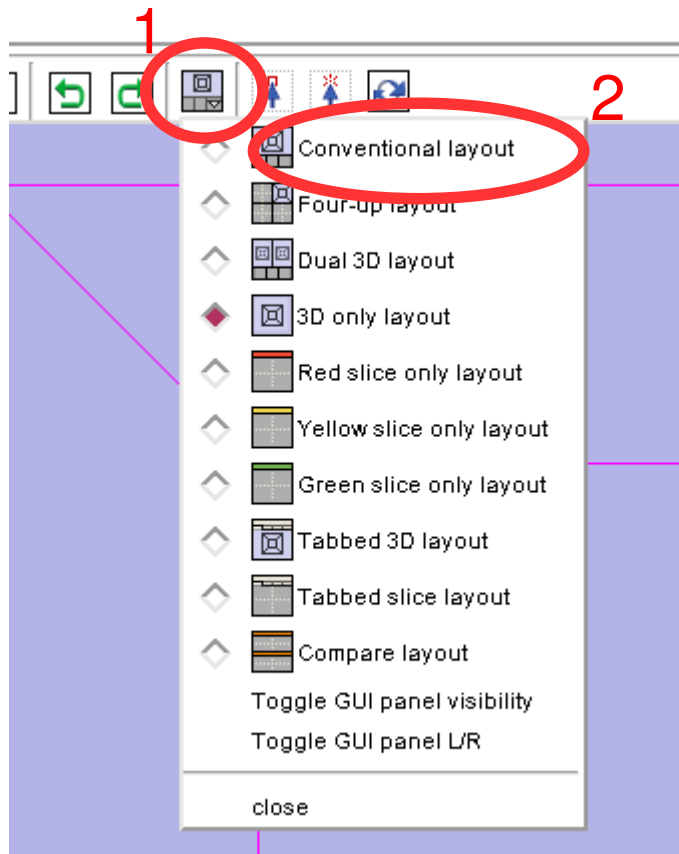
This pipeline is used for the Centerline Extraction.



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



Select the file “tutorial\_cardiac\_mri\_data.nrrd” (1)  
of the unzipped tutorial data and press “Apply” (2)

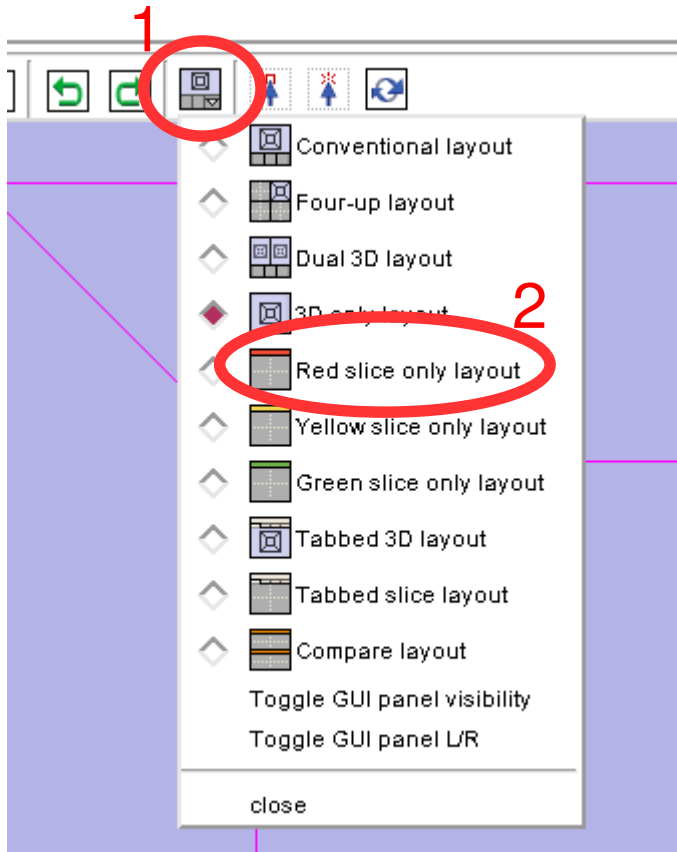


Use the layout selector (1) to switch to the “Conventional layout” (2)

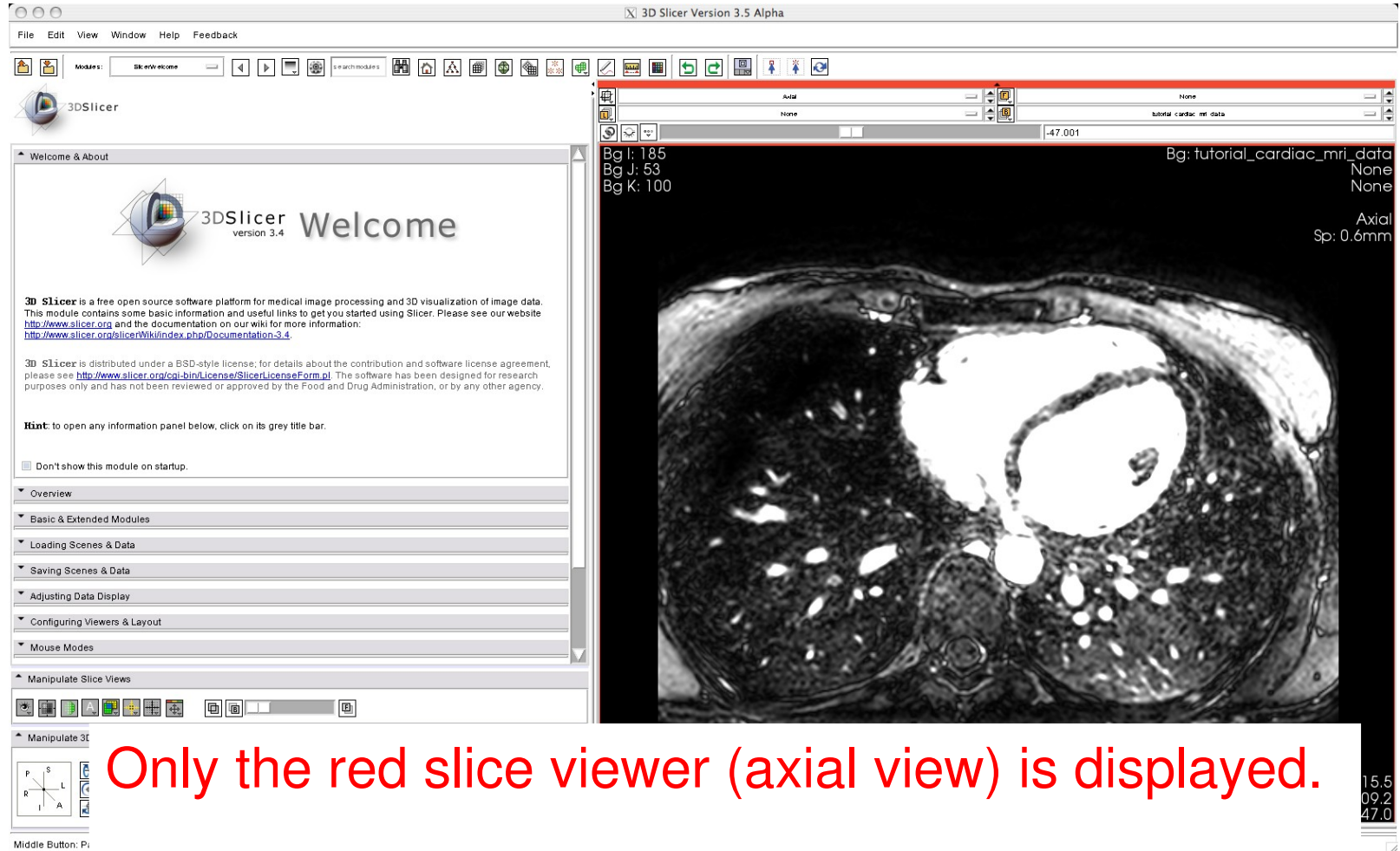


The 2D slice viewers show the loaded volume.

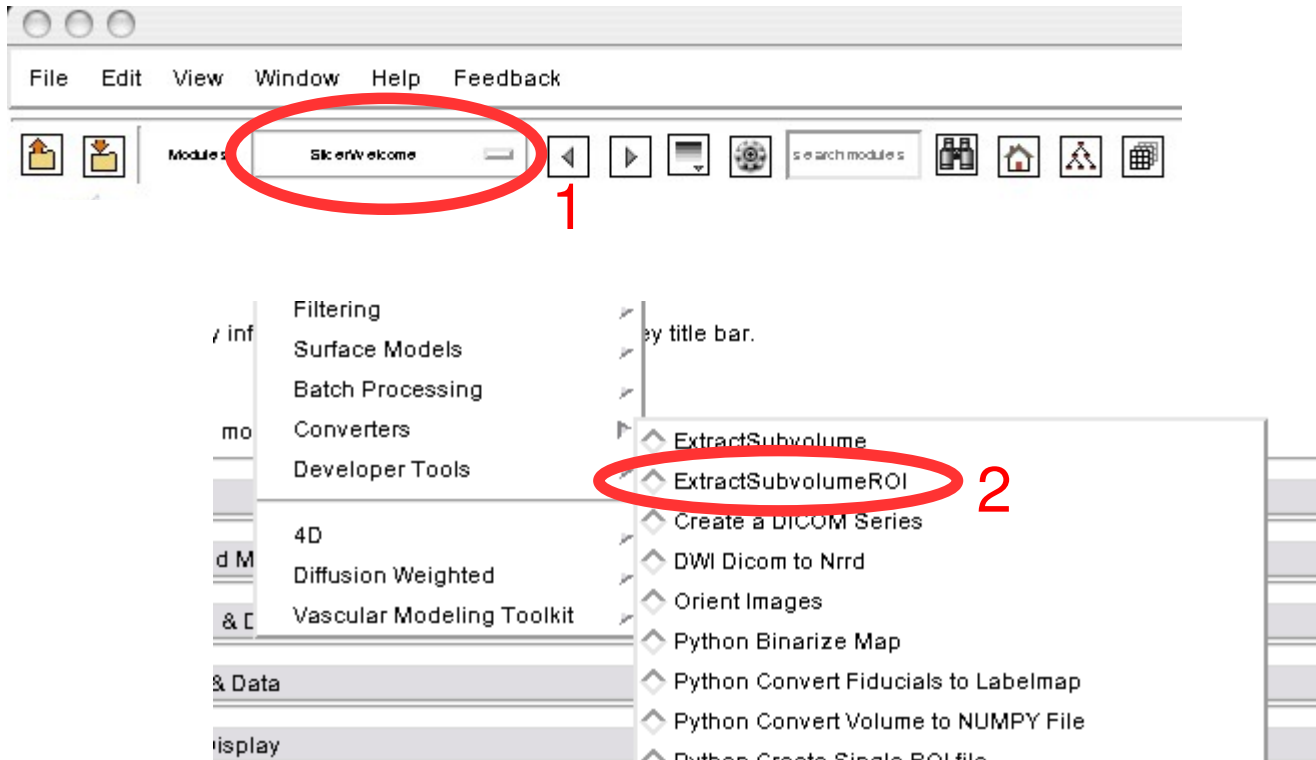




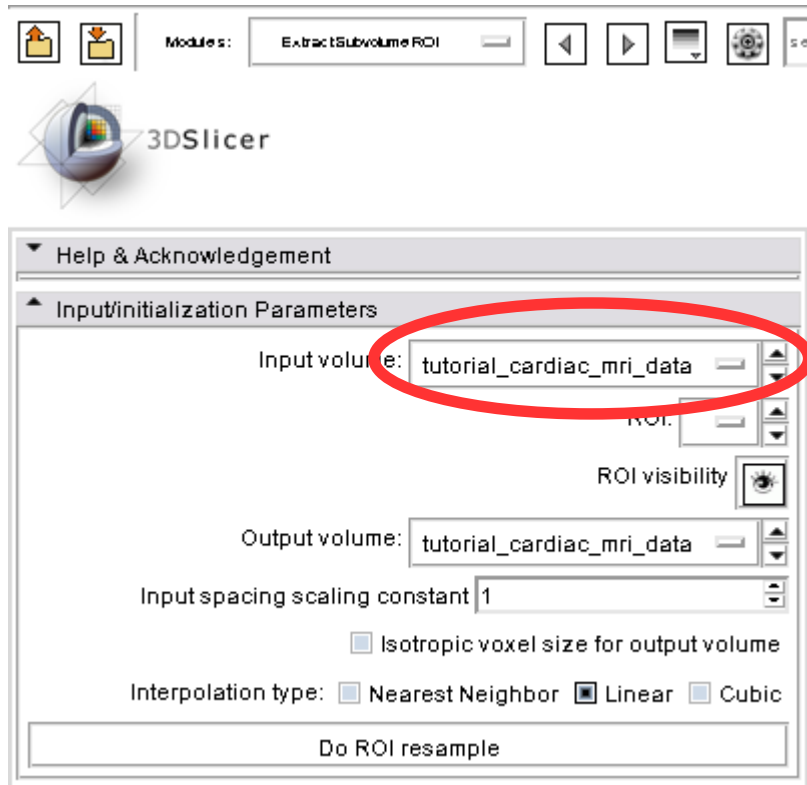
Use the layout selector (1) to switch to the “Red slice only layout” (2)



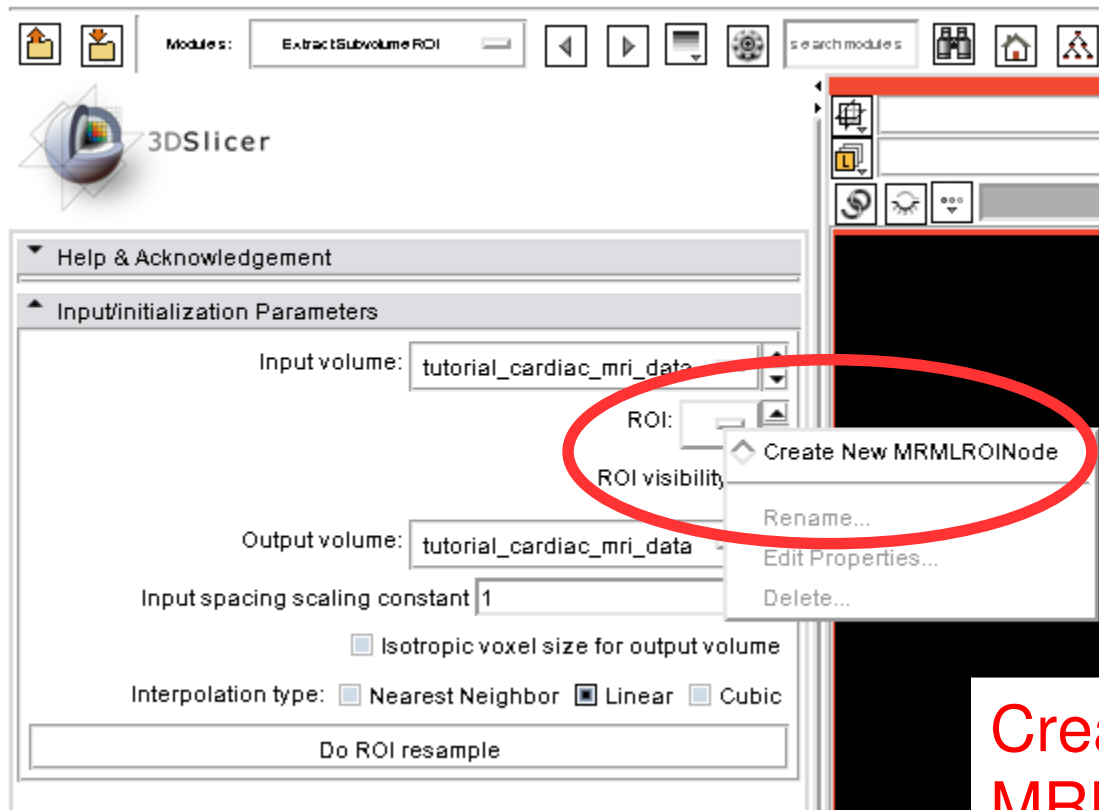
# Extracting the ROI



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

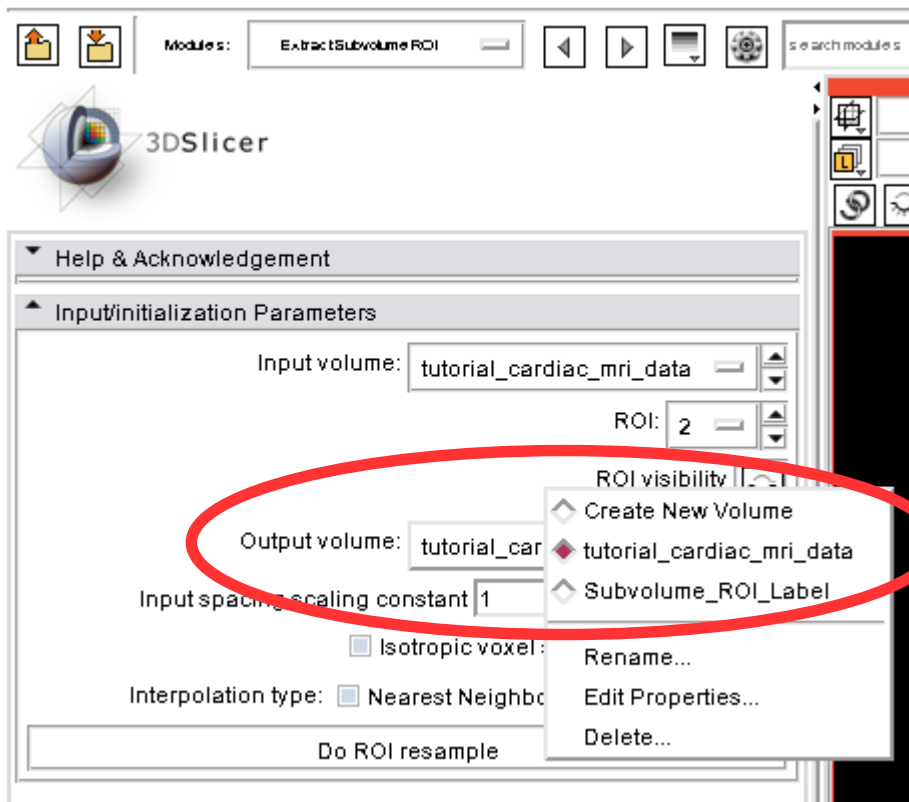


This panel now appears.  
Be sure that the “Input  
volume” is the loaded  
tutorial data.

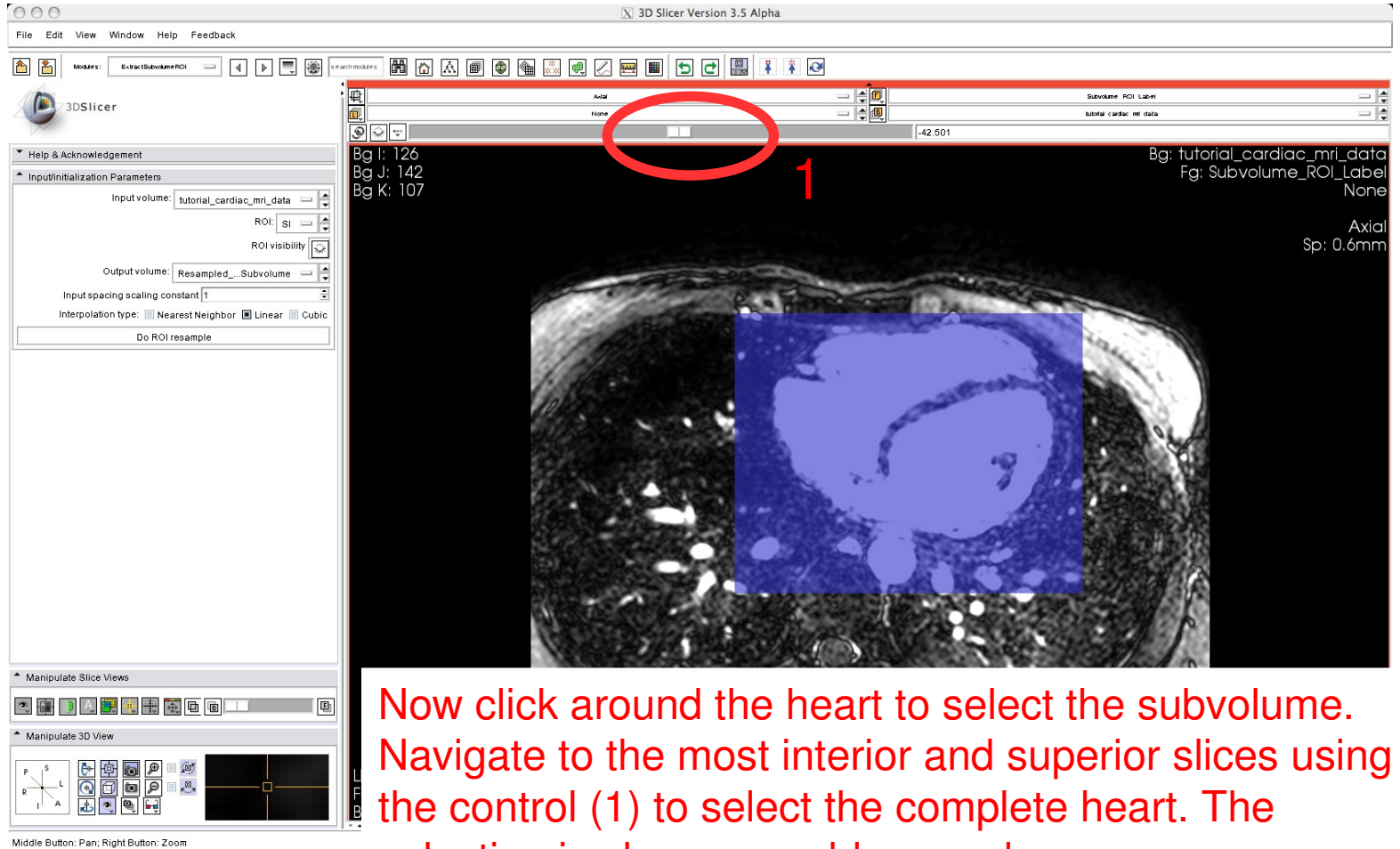


The screenshot shows the 3DSlicer interface with the 'ExtractSubvolume ROI' module selected. The 'Input/Initialization Parameters' section is visible, containing fields for 'Input volume', 'ROI', 'ROI visibility', 'Output volume', 'Input spacing scaling constant', and 'Interpolation type'. A red circle highlights the 'ROI' dropdown menu, which is open and showing the option 'Create New MRMLROINode'. Other options in the menu include 'Rename...', 'Edit Properties...', and 'Delete...'.

Create a new  
MRMLROINode

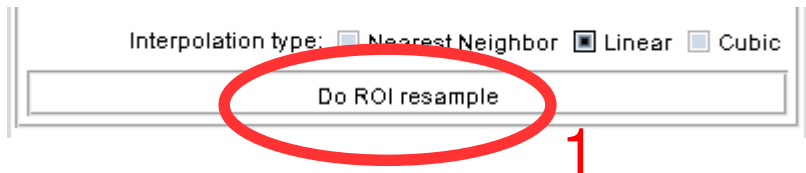


Create a new Volume  
as “Output volume”



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.

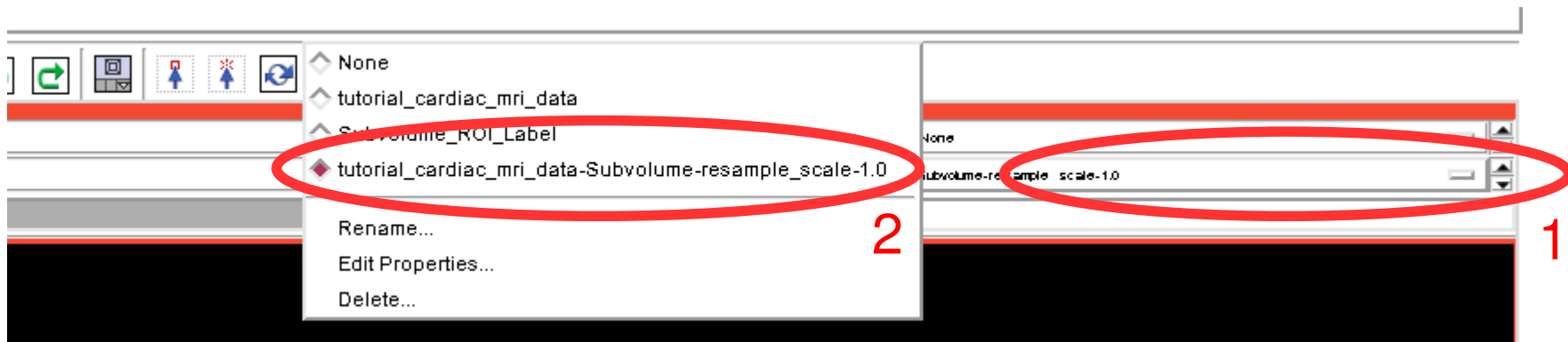




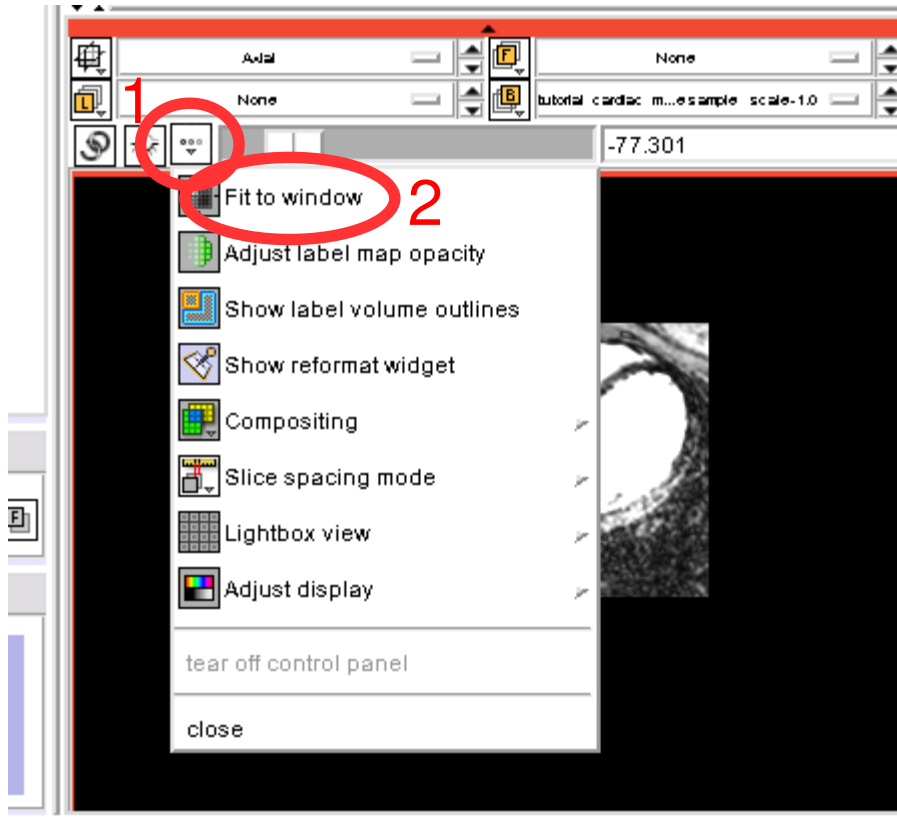
Click “Do ROI resample” (1) to extract the subvolume and click toggle the “ROI visibility” (2) to hide the blue overlay



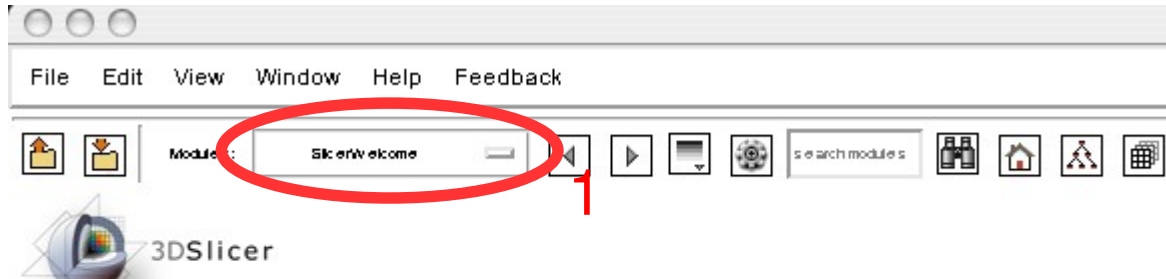
You can also directly load the “tutorial\_cardiac\_mri\_data-Subvolume-resample\_scale-1.0.nrrd” file of the unzipped tutorial data to get the extracted subvolume (see the “Loading Data” section).



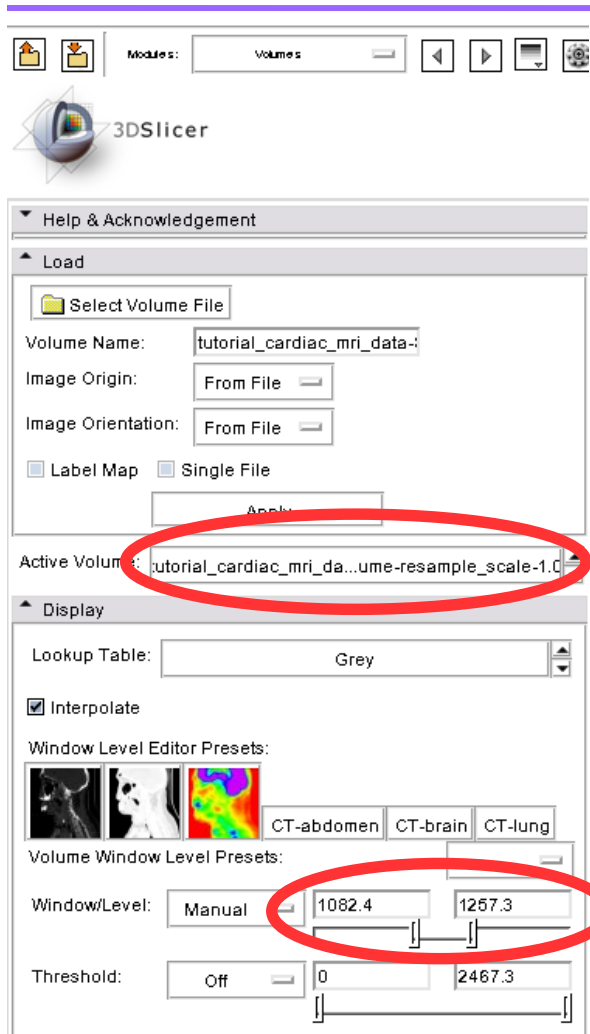
Select the extracted subvolume (2) in the red slice viewer by using the volume selector (1)



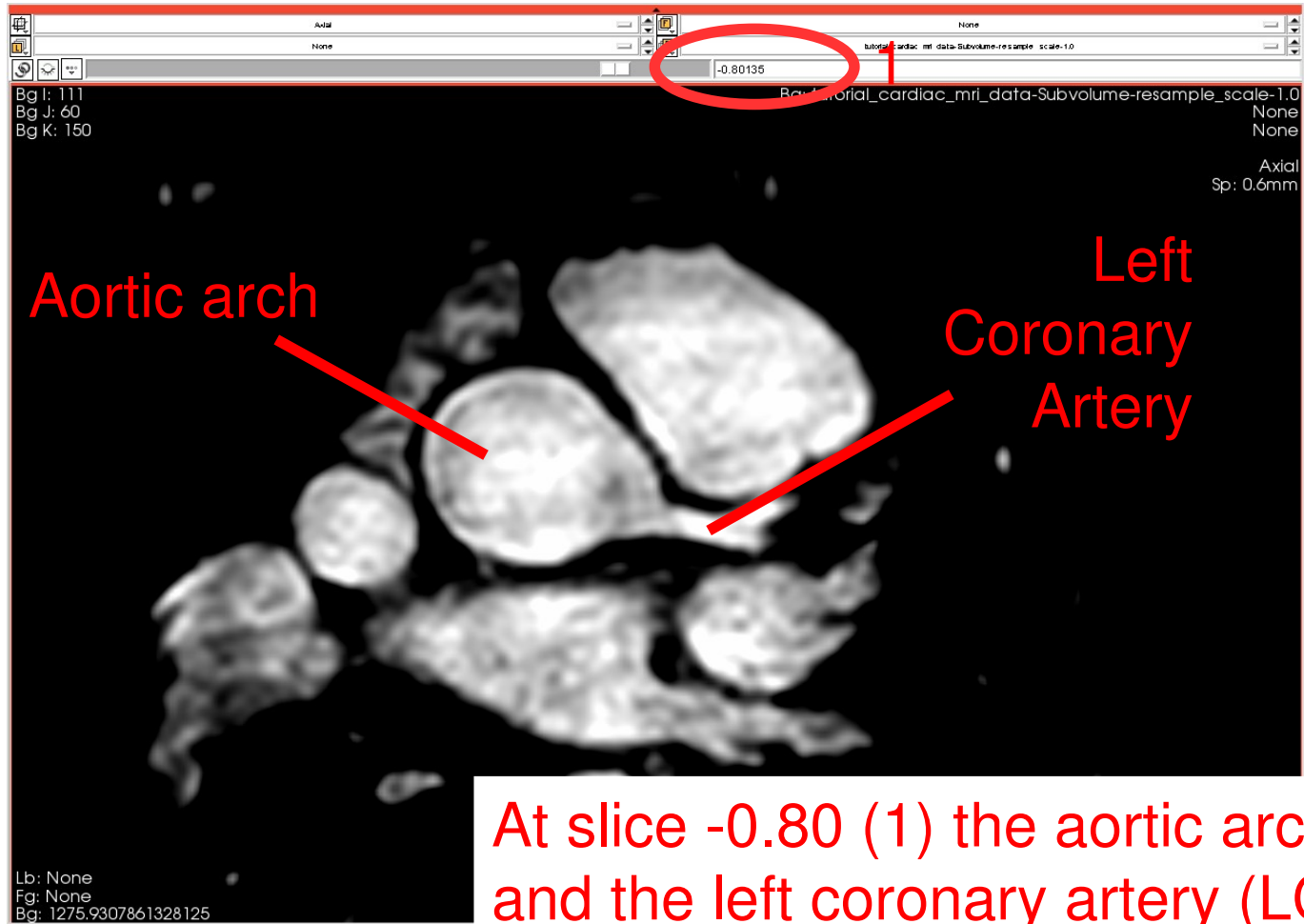
Fit the volume to the window by using the options icon (1) and selecting “Fit to window” (2)

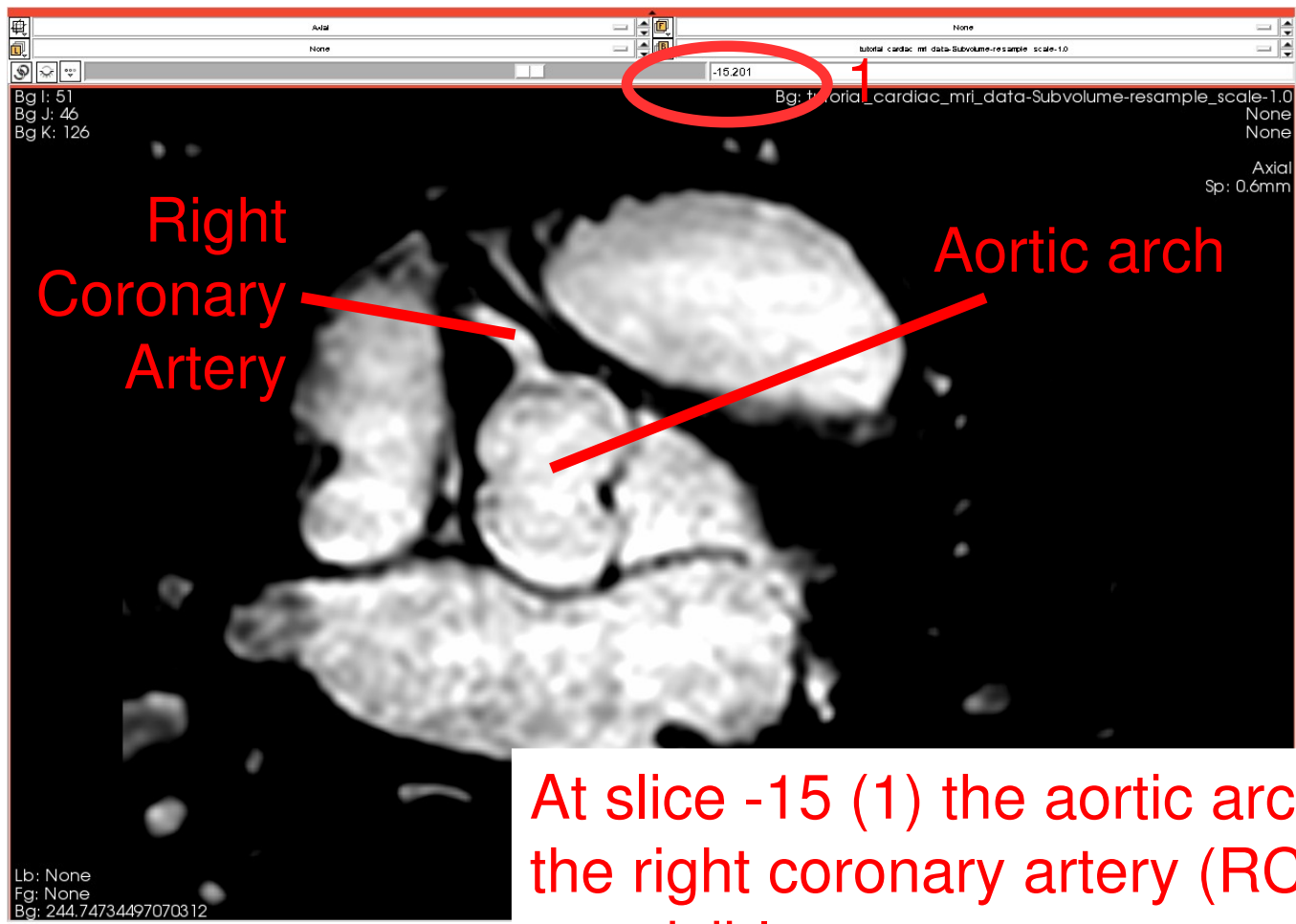


Use the modules selector (1)  
to navigate to the “Volumes”  
module (2)



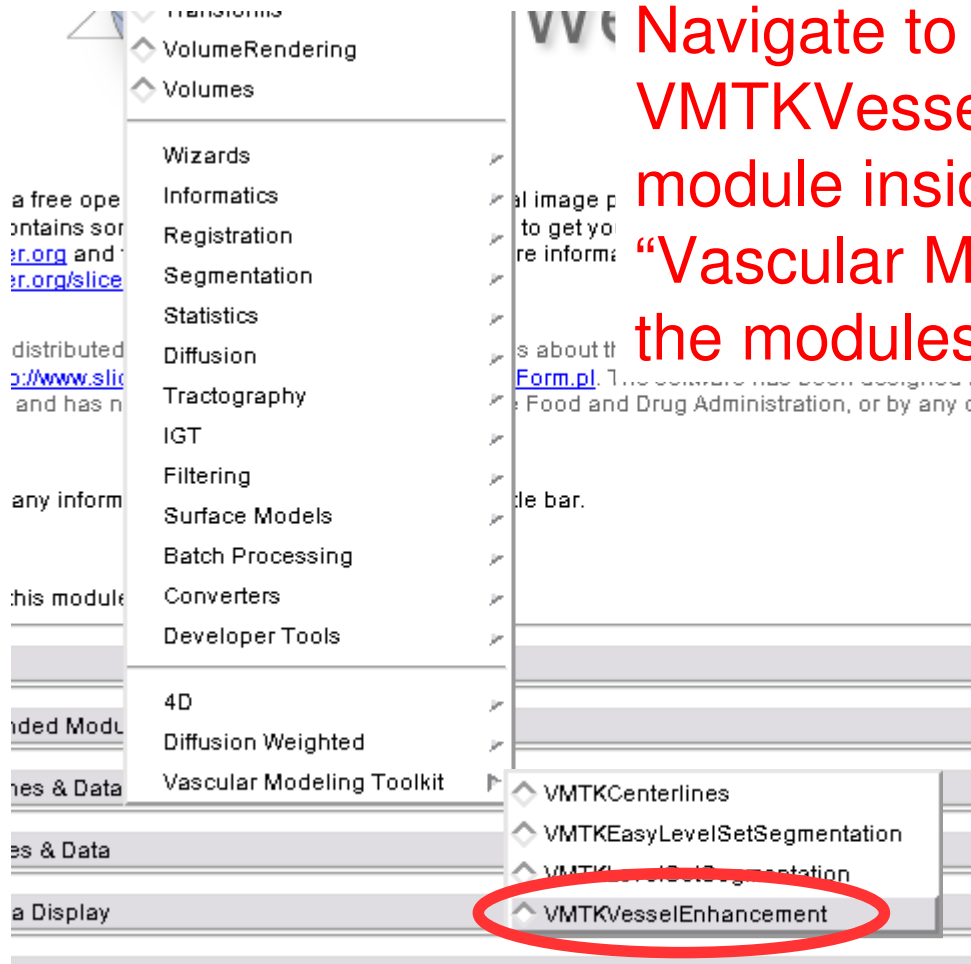
Be sure the extracted subvolume “tutorial\_cardiac\_mri\_data-Subvolume-resample\_scale-1.0” is the active Volume (1) and adjust the Window/Level setting to 1082 and 1257 (2) for better visualization



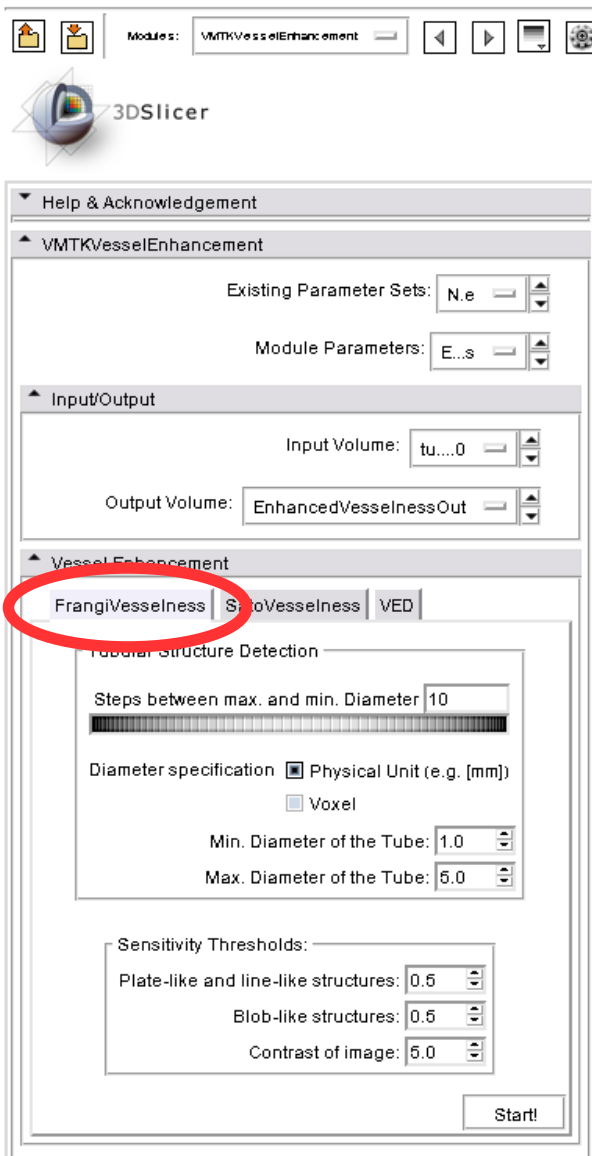




# Vesselness Filtering

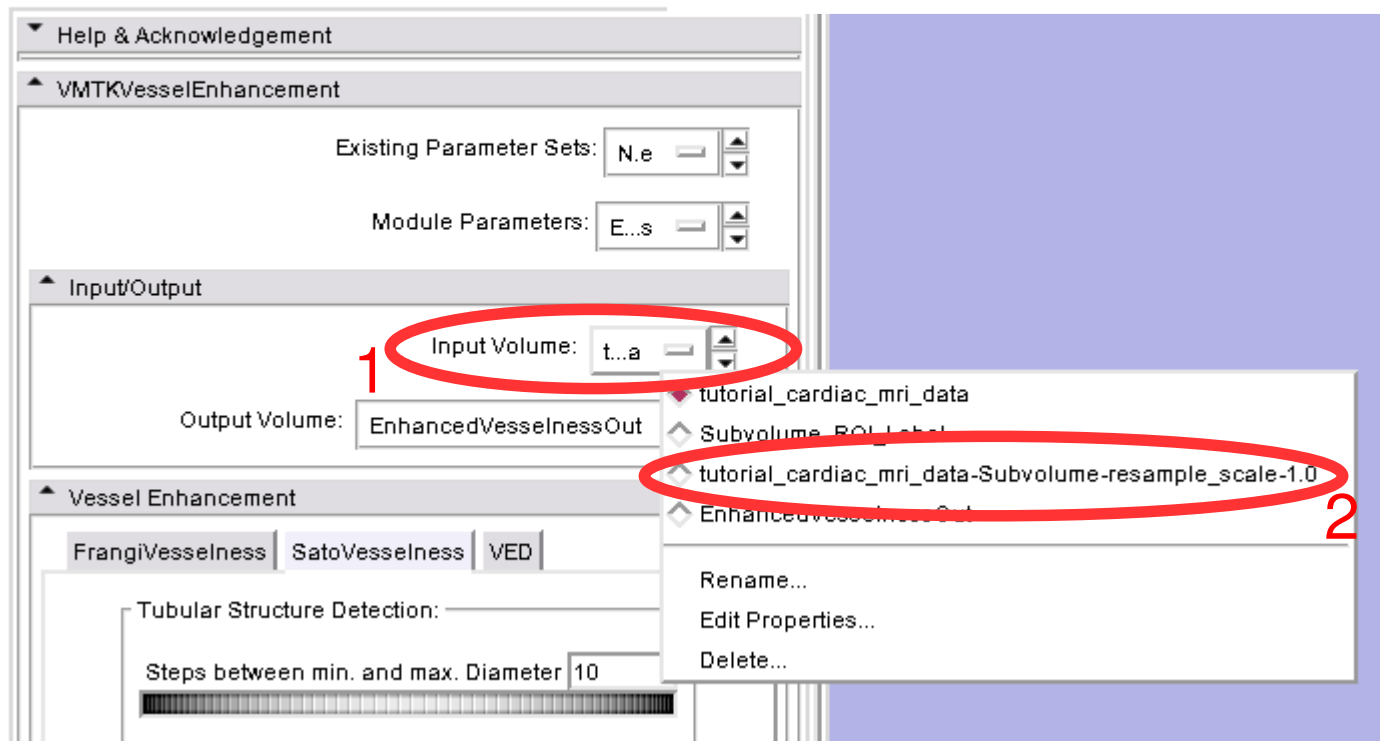


Navigate to the VMTKVesselEnhancement module inside the category “Vascular Modeling Toolkit” using the modules selector

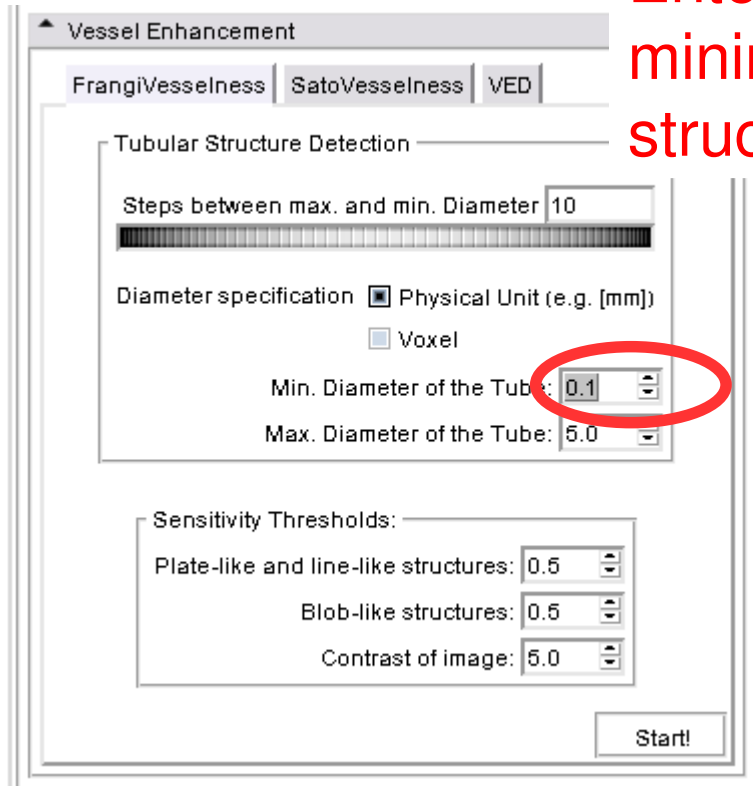


This panel appears. Switch to “FrangiVesselness”.

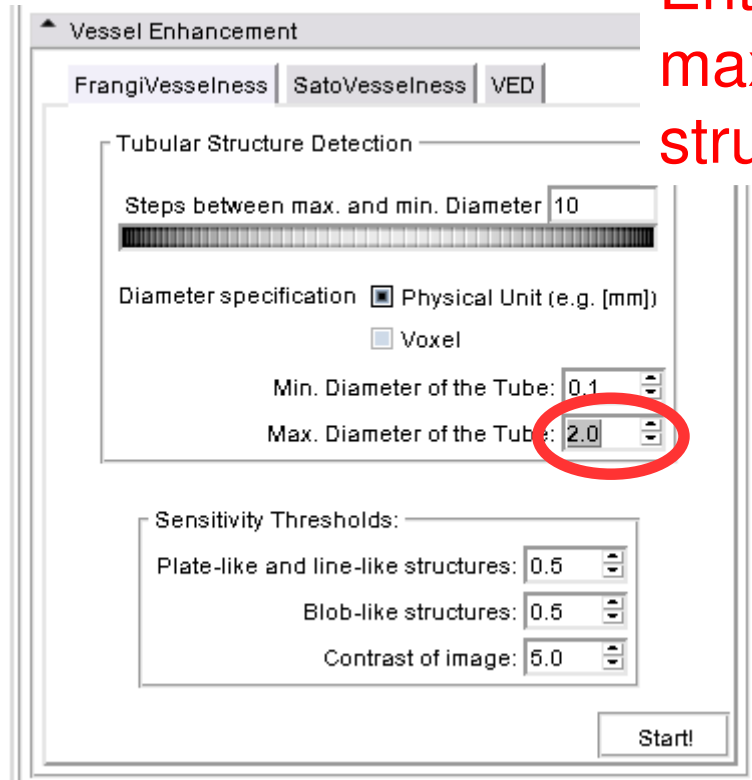
Select the extracted subvolume (2) as the “Input Volume” (1)



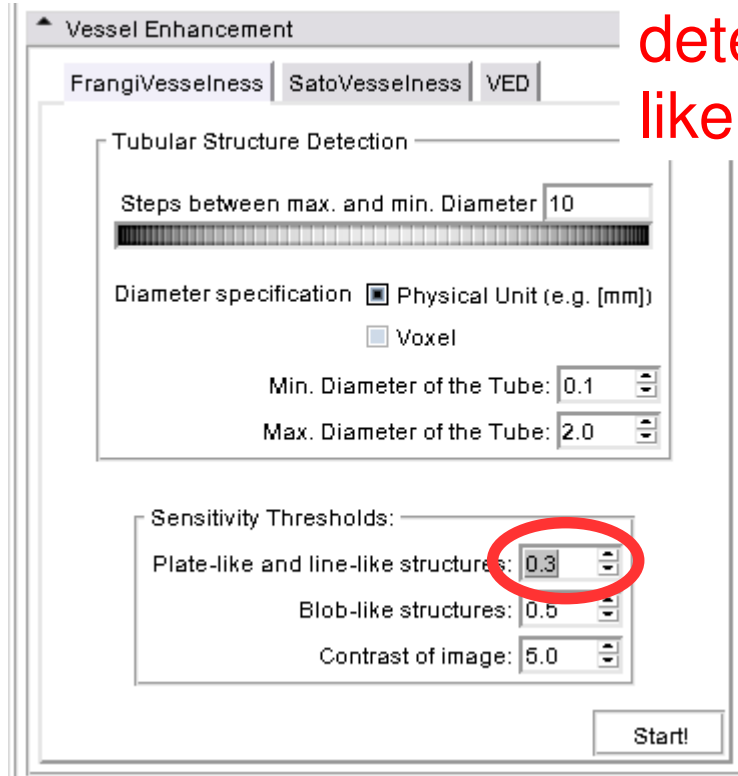
Enter “0.1” (unit: mm) as the minimal diameter of tubular structures to detect



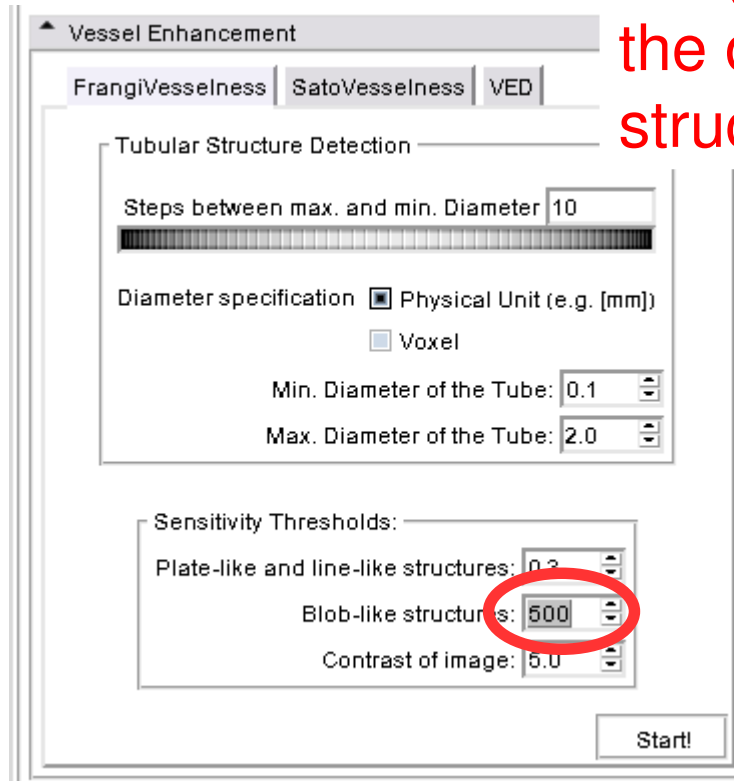
Enter “2.0” (unit: mm) as the maximum diameter of tubular structures to detect

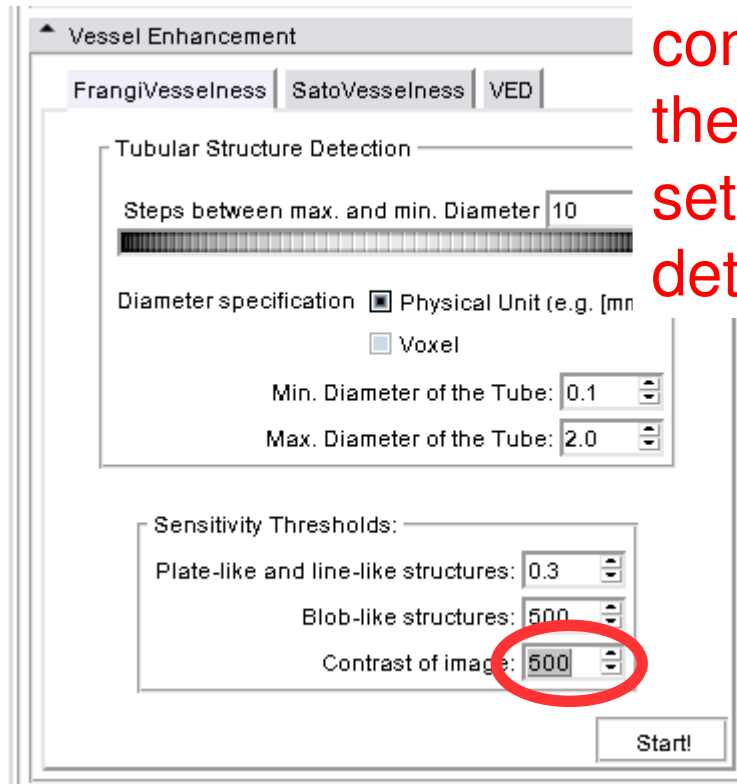


Choose a low threshold of “0.3” to detect line-like rather than plate-like structures



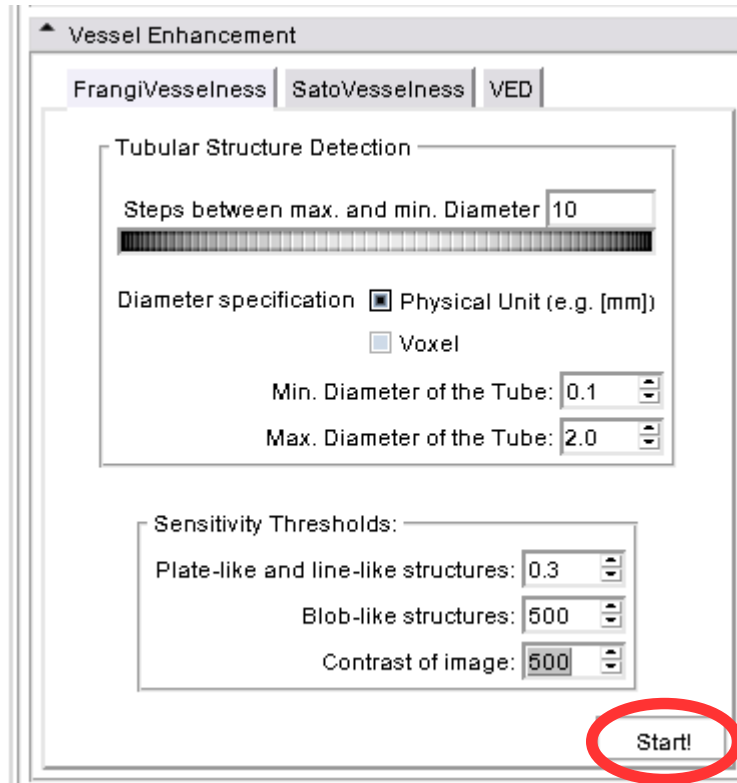
A higher threshold of “500” limits the detection of blob-like structures





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





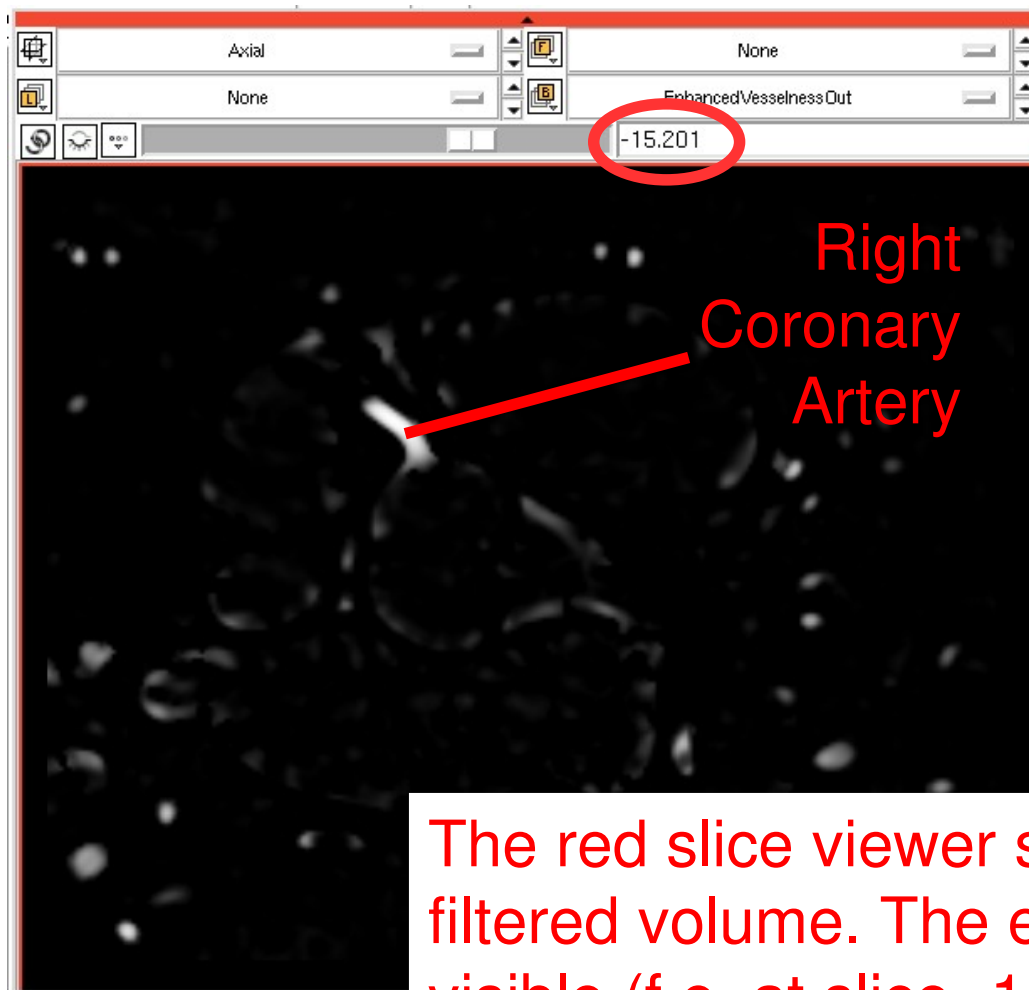
Click “Start!”



The filtering procedure takes approx. 6-10 minutes.

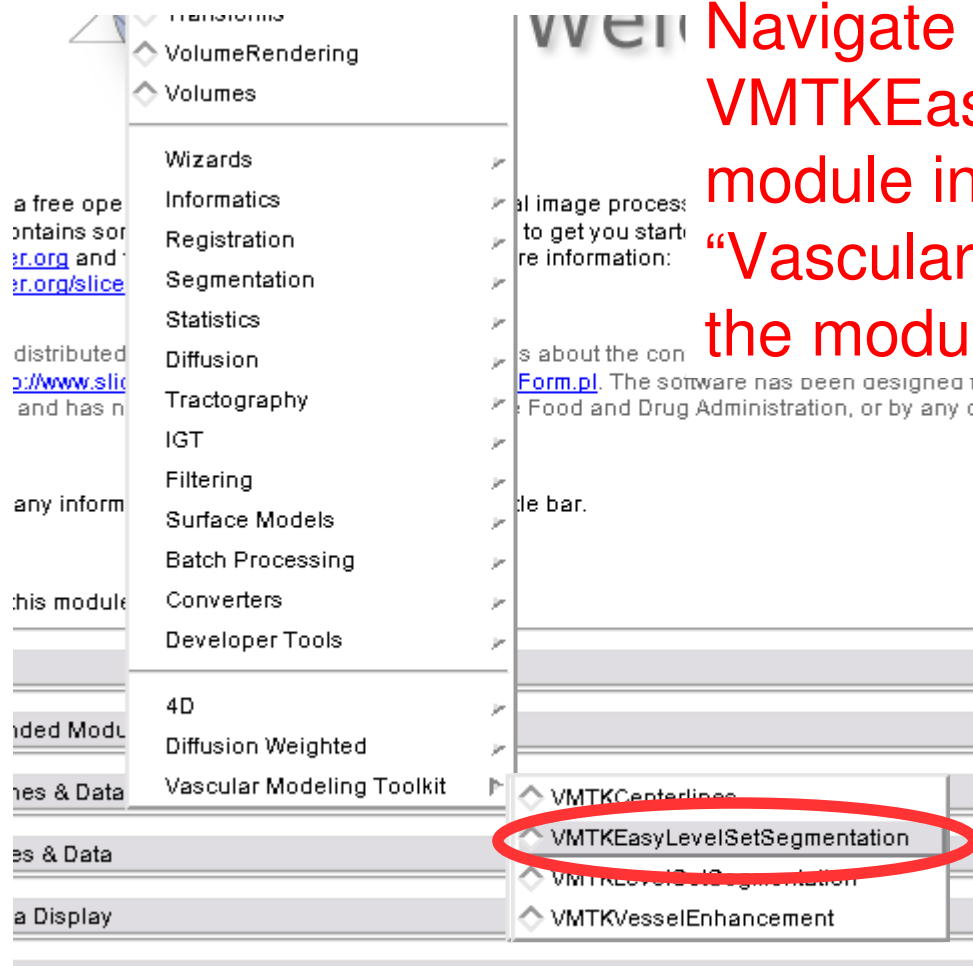


You can also directly load the “EnhancedVesselnessOut.nrrd” file of the unzipped tutorial data to get the vesselness filtered volume (see the “Loading Data” section).



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

# Level Set Segmentation



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



Help & Acknowledgement

VMTKEasyLevelSetSegmentation

Existing Parameter Sets: N.e

Current Parameter Sets: L...s

Input/Output

Input Volume: t...a

Source Seeds: N.e

Target Seeds (optional): N.e

Initialization Output Volume: VMTKInit...ationOut

Evolution Output Volume: VMTKEvolutionOut

Use Volume Rendering

Initialization

0 Thresholding 2488

Start!

Evolution

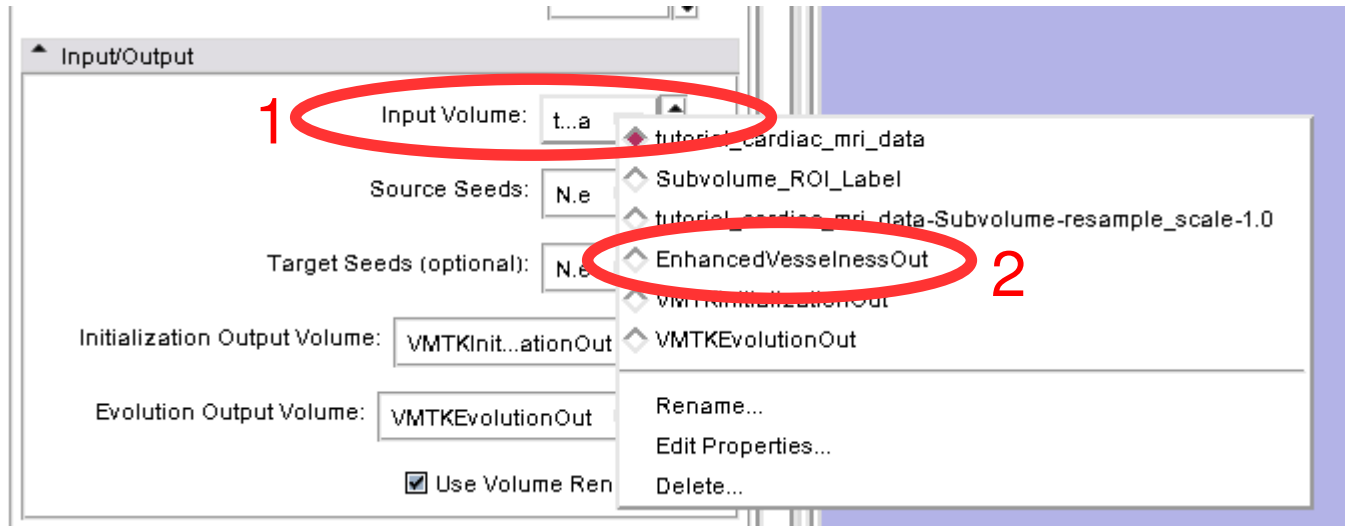
less inflation <-> more inflation 0

less curvature <-> more curvature 0

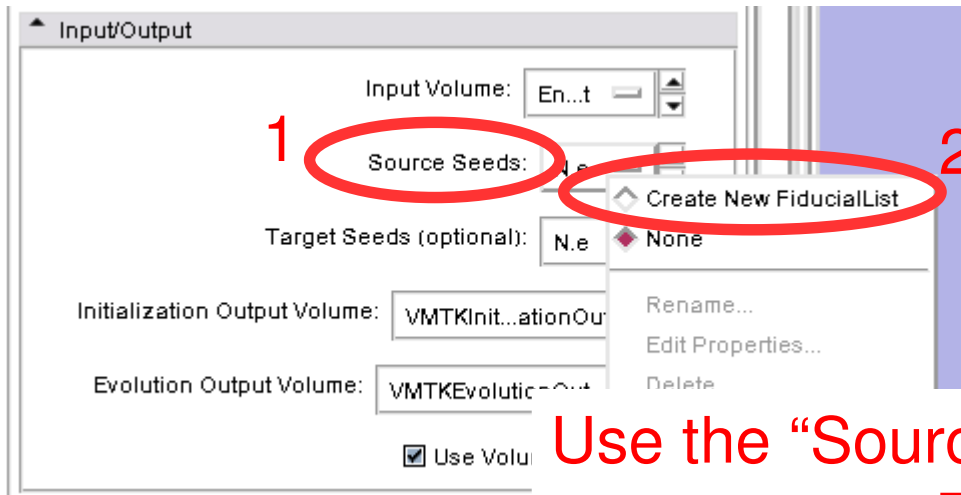
less attraction to ridges <-> more attraction to ridges 0

This panel now appears.

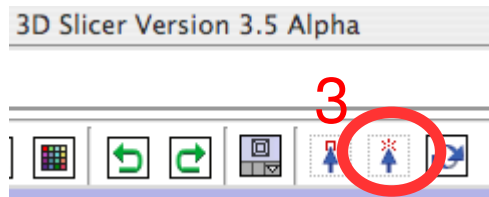
The Level Set Segmentation process consists of two steps: Initialization and Evolution



Select the “EnhancedVesselnessOut” volume (2) as the “Input Volume” (1)



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

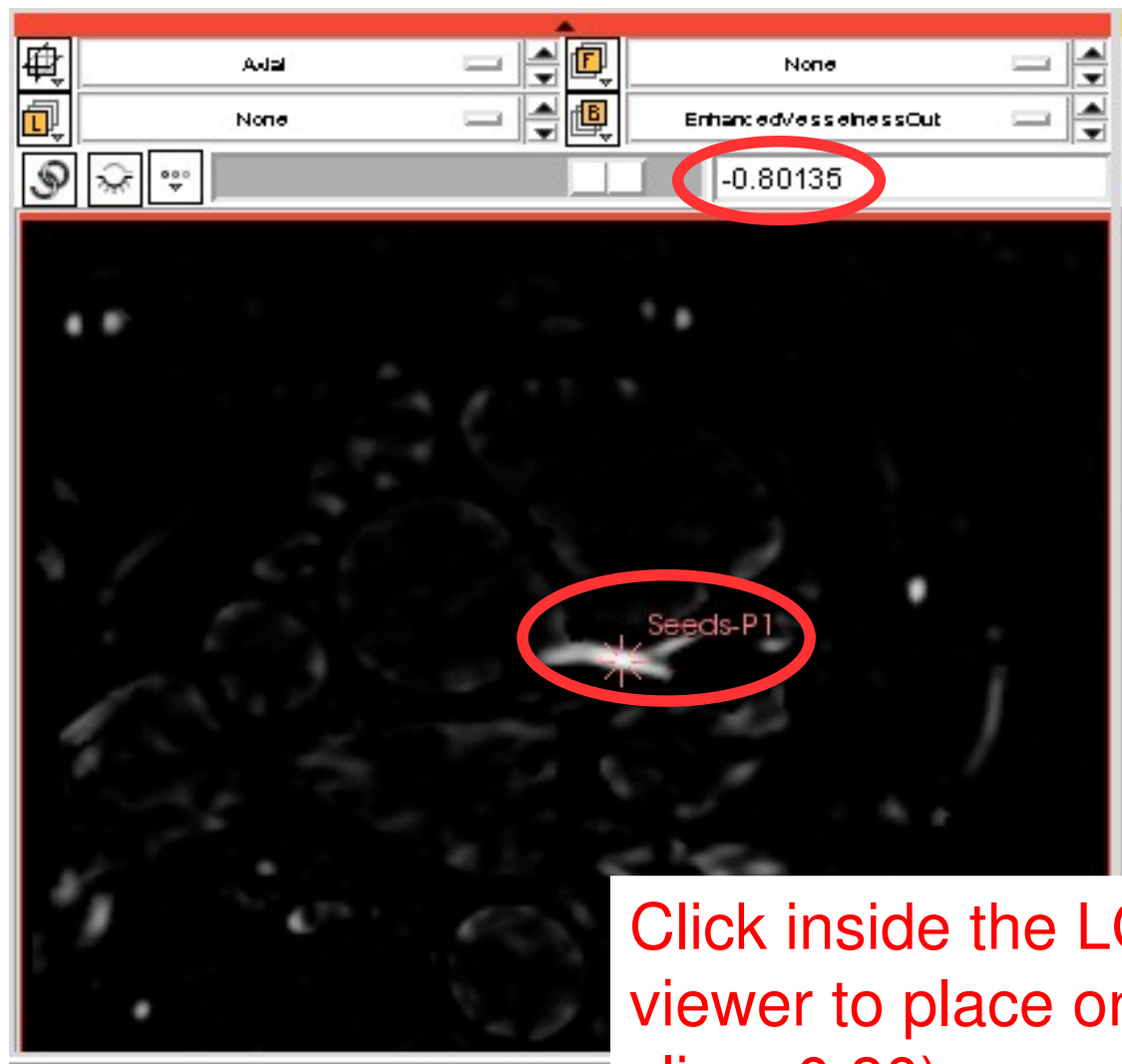


Switch to “Place” mode by using the icon (3) on the toolbar

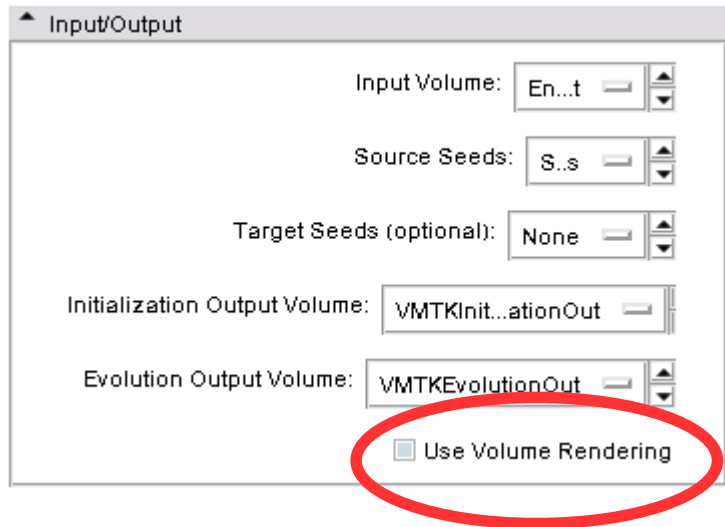


Click inside the RCA on the red slice viewer to place one seed point (f.e. at slice -15)

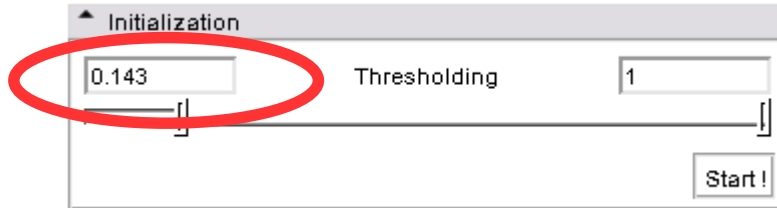




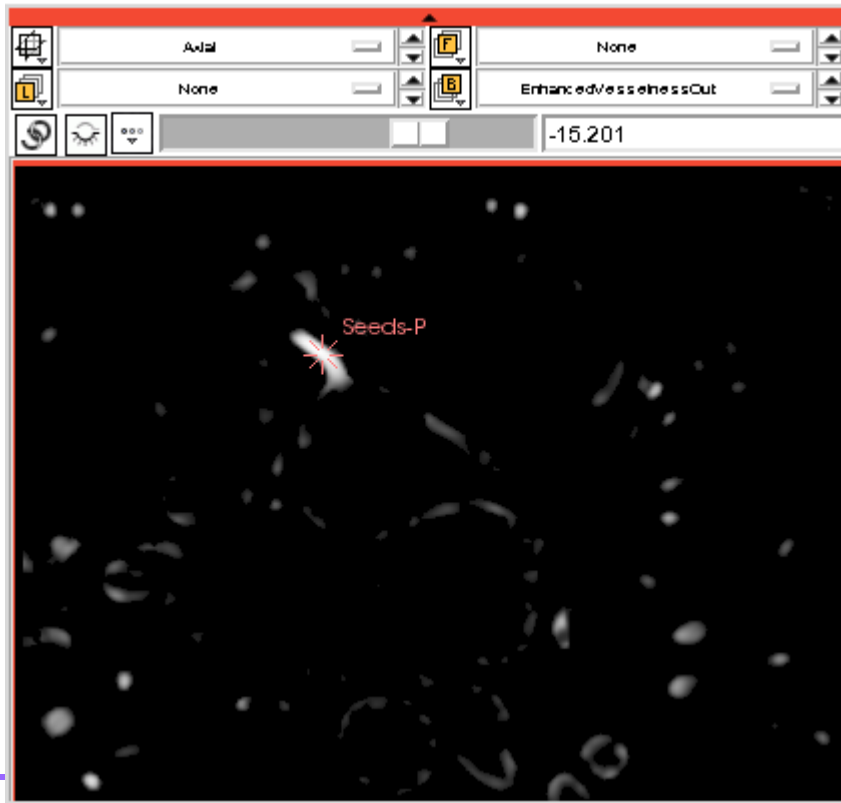
Click inside the LCA on the red slice viewer to place one seed point (f.e. at slice -0.80)



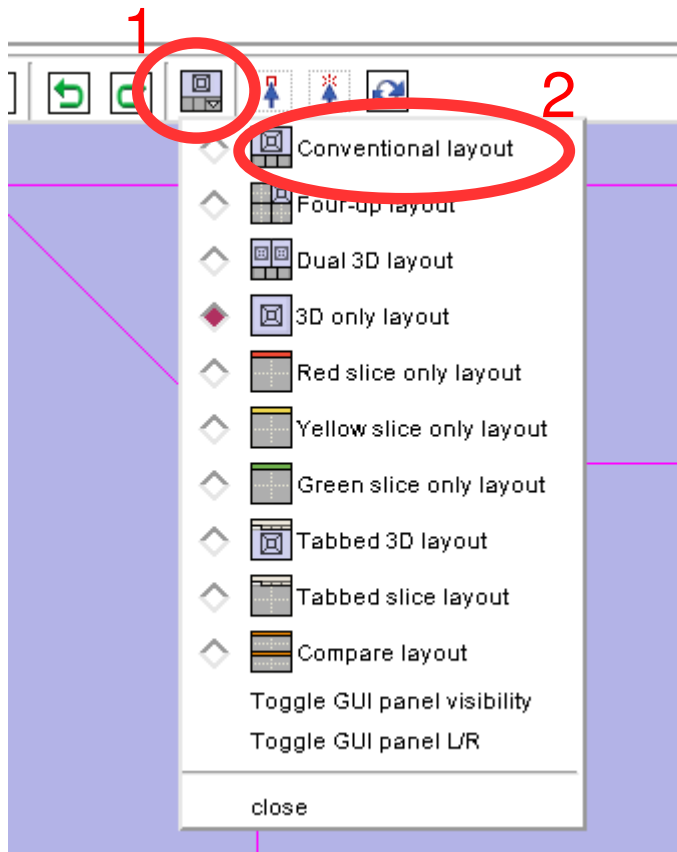
Deactivate “Use Volume Rendering”  
because Polydata is needed later



Set a lower threshold of  
“0.143”



This results in immediate  
visualization feedback at  
the slice viewers

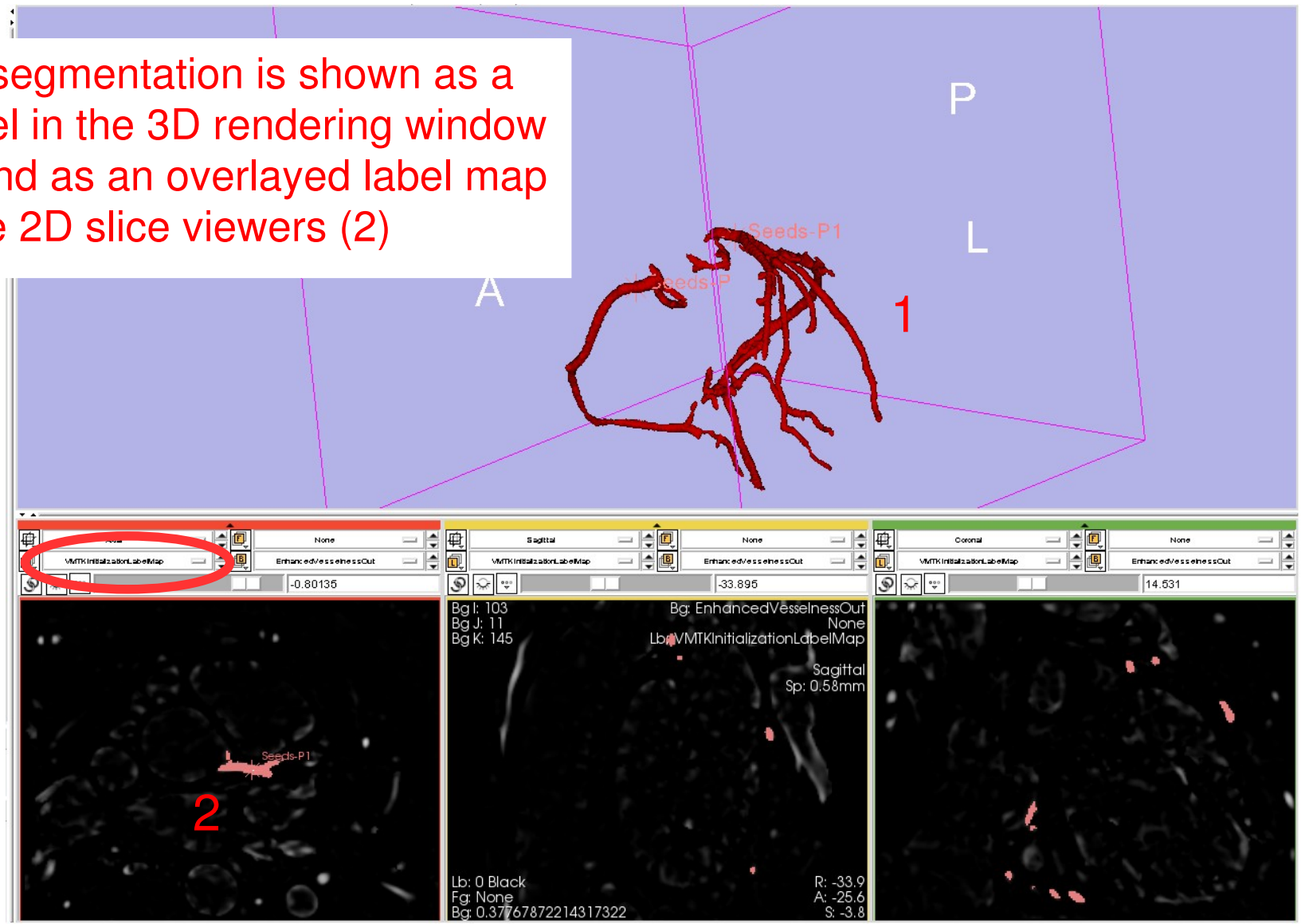


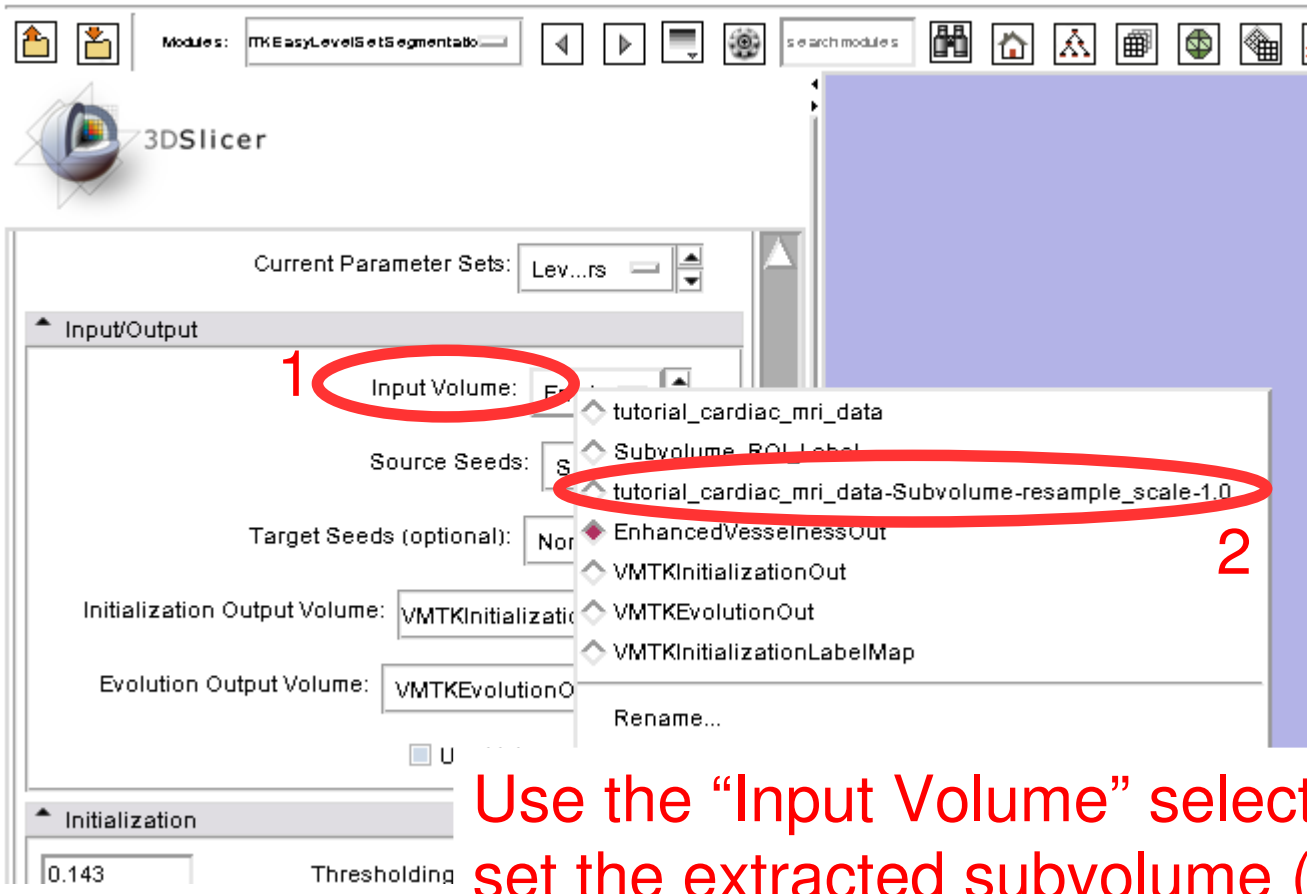
Use the layout selector (1) to switch to the “Conventional layout” (2)



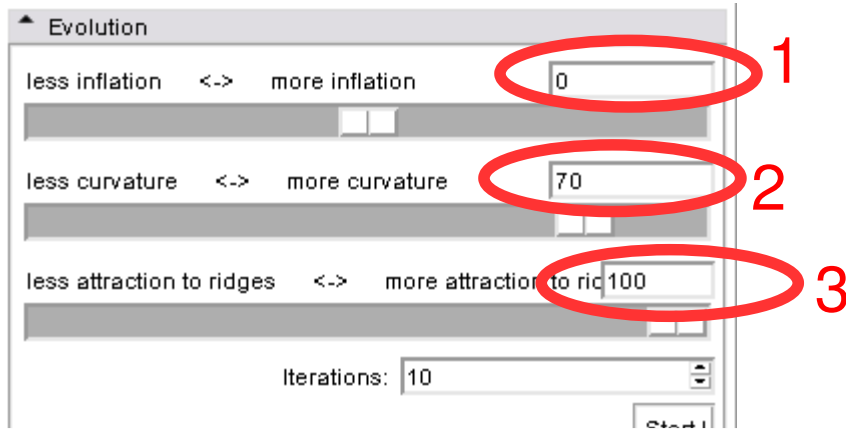
Click "Start!"

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





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



Specify the behavior of the evolution by using the sliders.

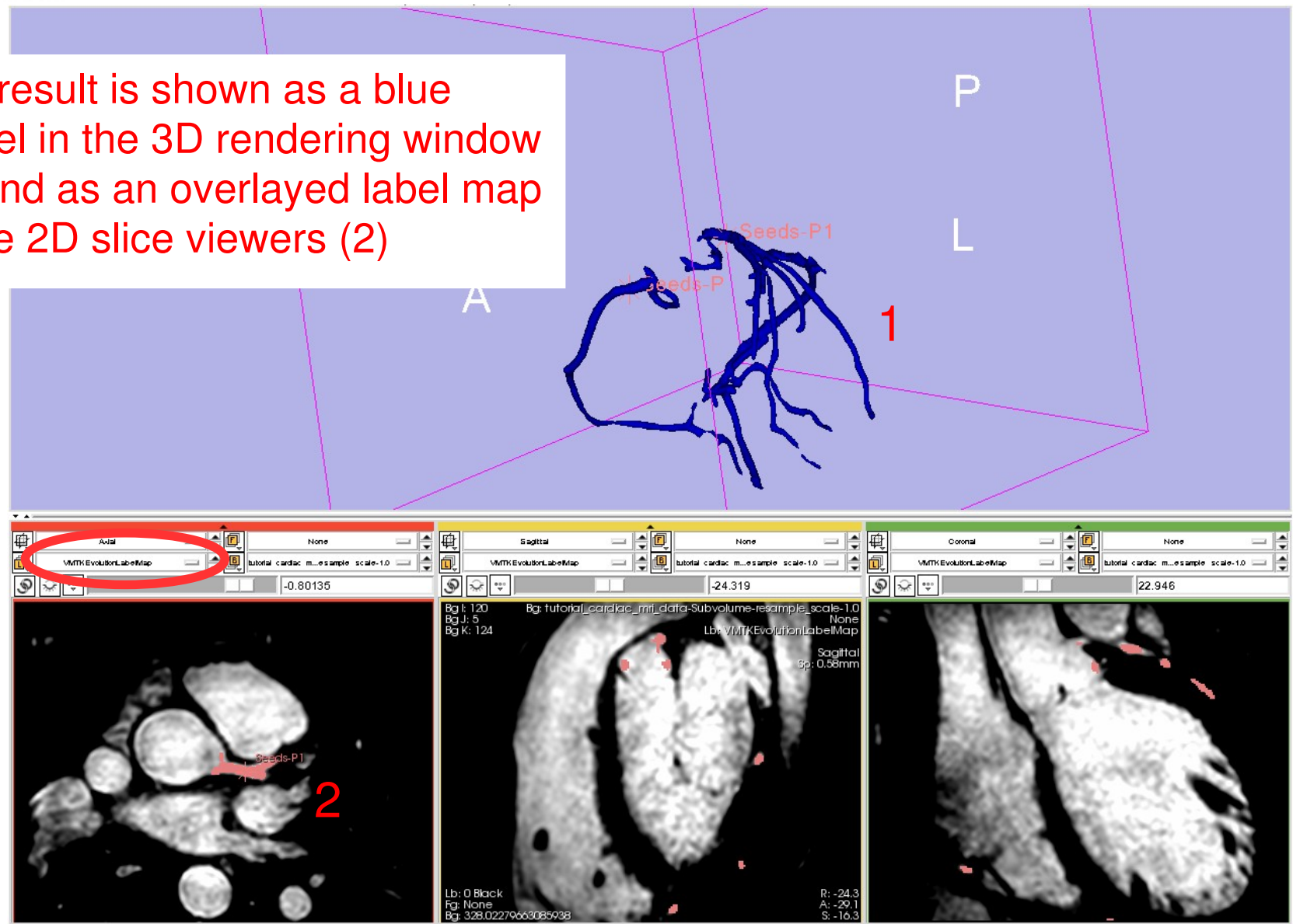
The initialization is already close to the edges of the vessels so no inflation is needed (1).

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).

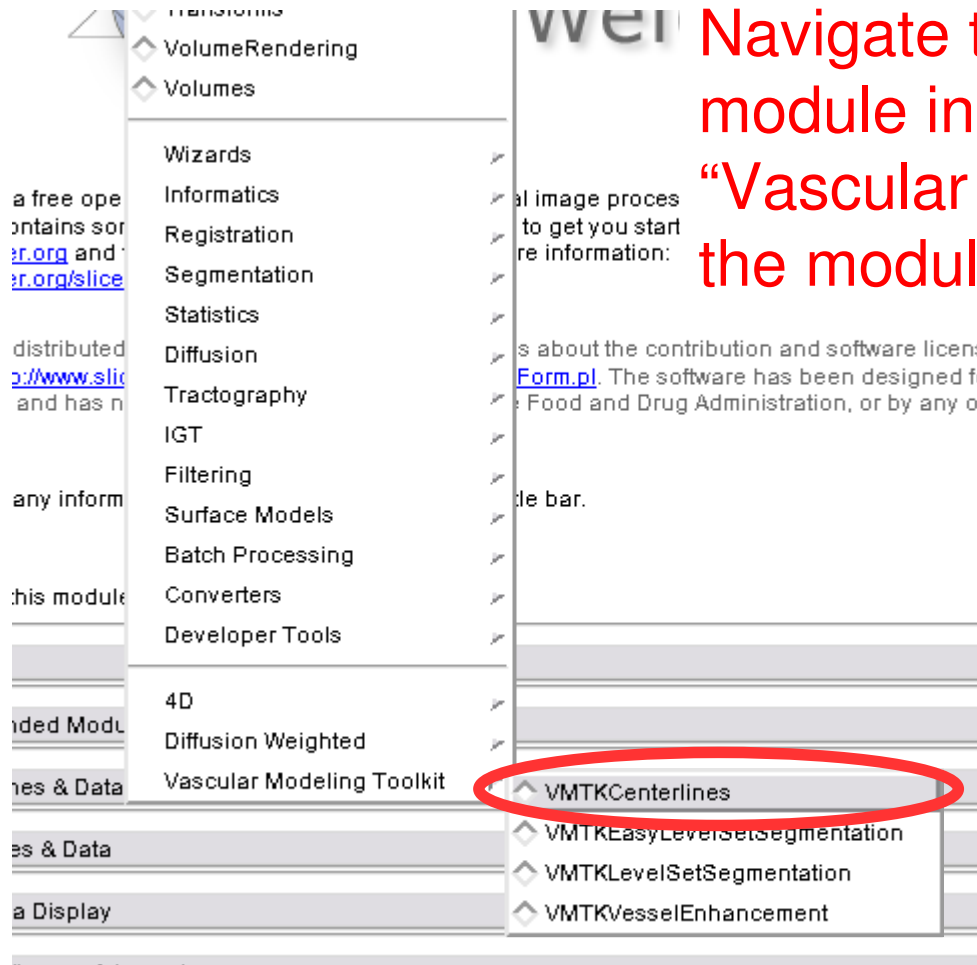


The result is shown as a blue model in the 3D rendering window (1) and as an overlaid label map in the 2D slice viewers (2)

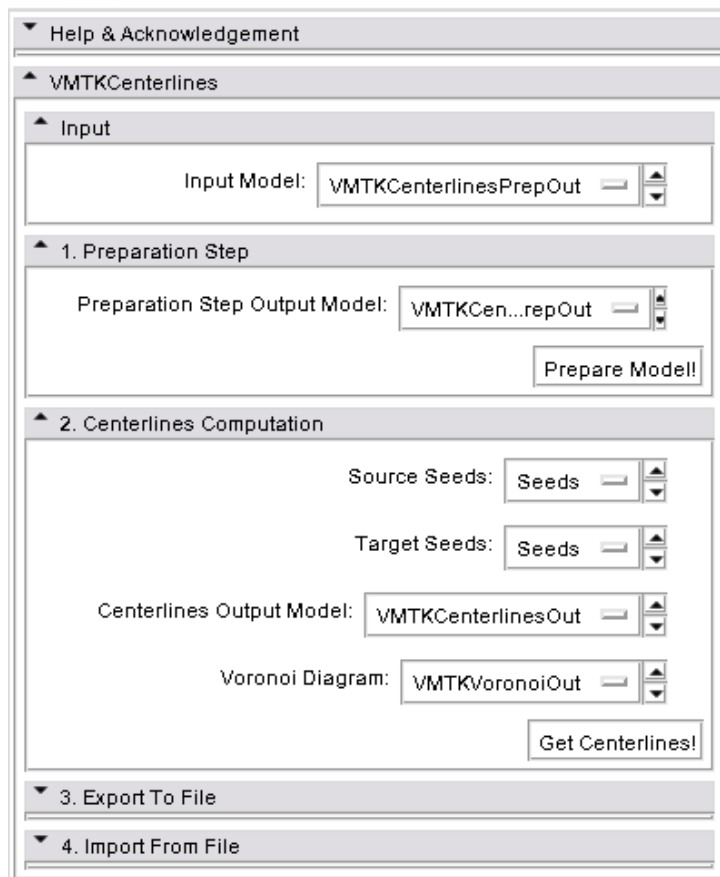




# Centerline Computation

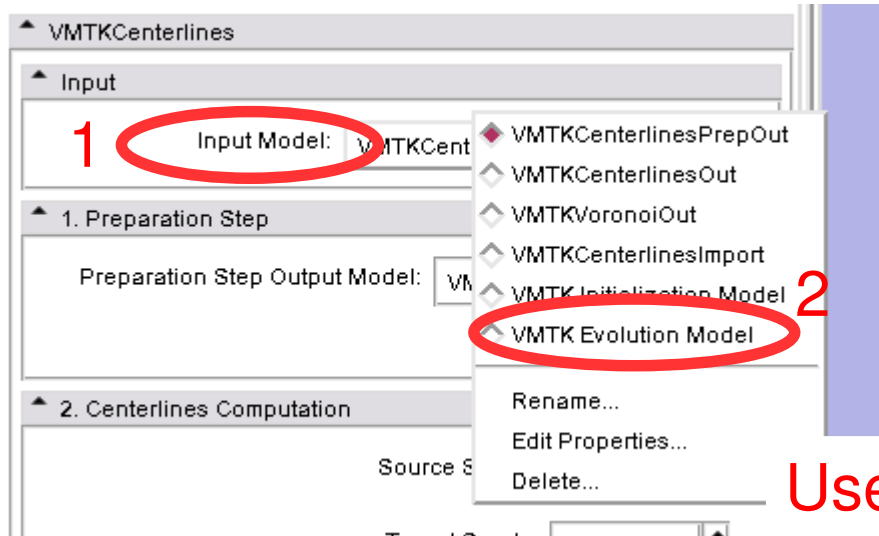


Navigate to the VMTKCenterlines module inside the category "Vascular Modeling Toolkit" using the modules selector



This panel now appears.

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

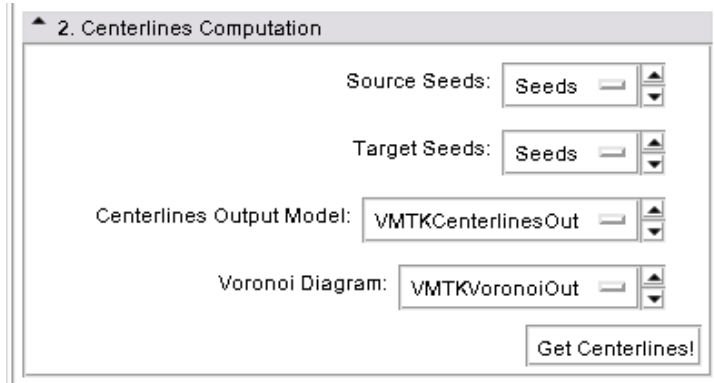


Use the “Input Model” selector (1) to set the “VMTKEvolution Model” (2) as the input

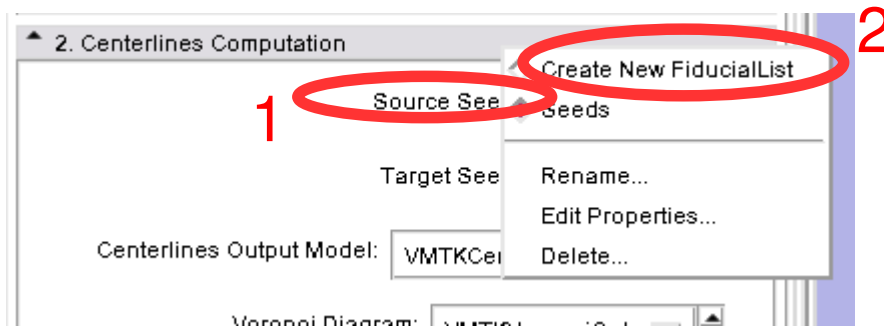


Click “Prepare Model!”

The blue model in the 3D  
Rendering Window turns  
green



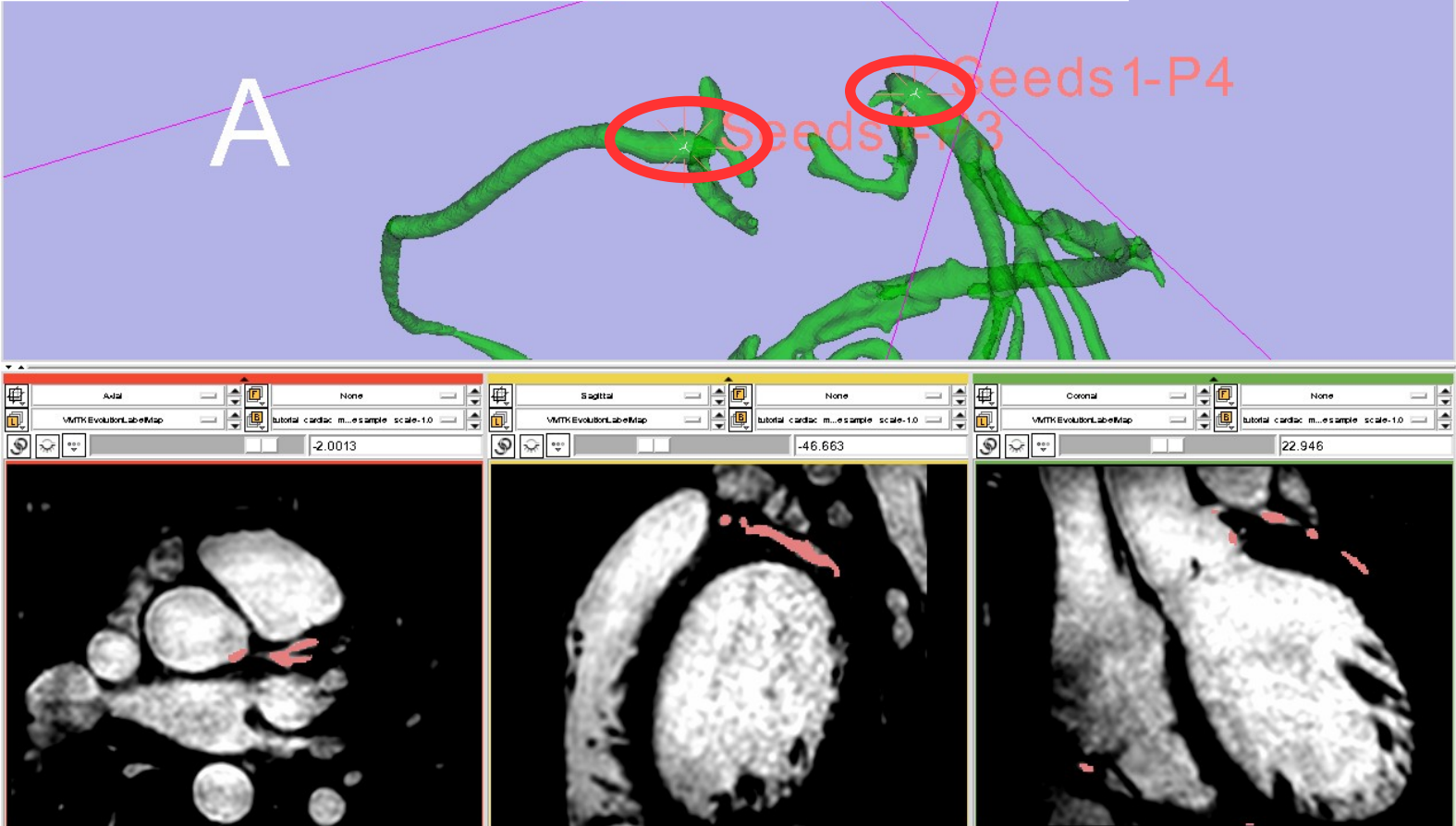
Now step 2: “Centerlines Computation” starts



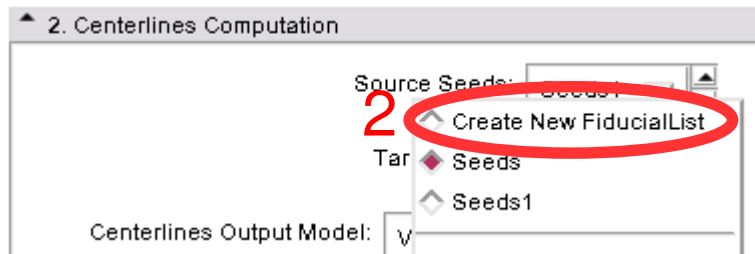
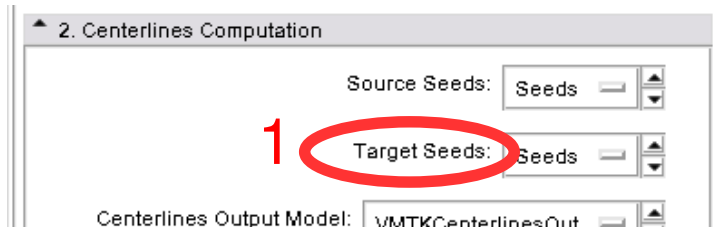
Use the “Source Seeds” selector (1) to create a new Fiducial list (2)

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

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



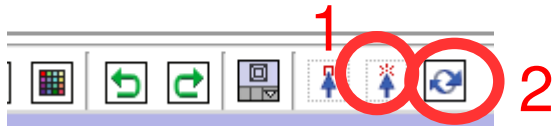




Use the “Target Seeds” selector (1) to create a new Fiducial list (2)

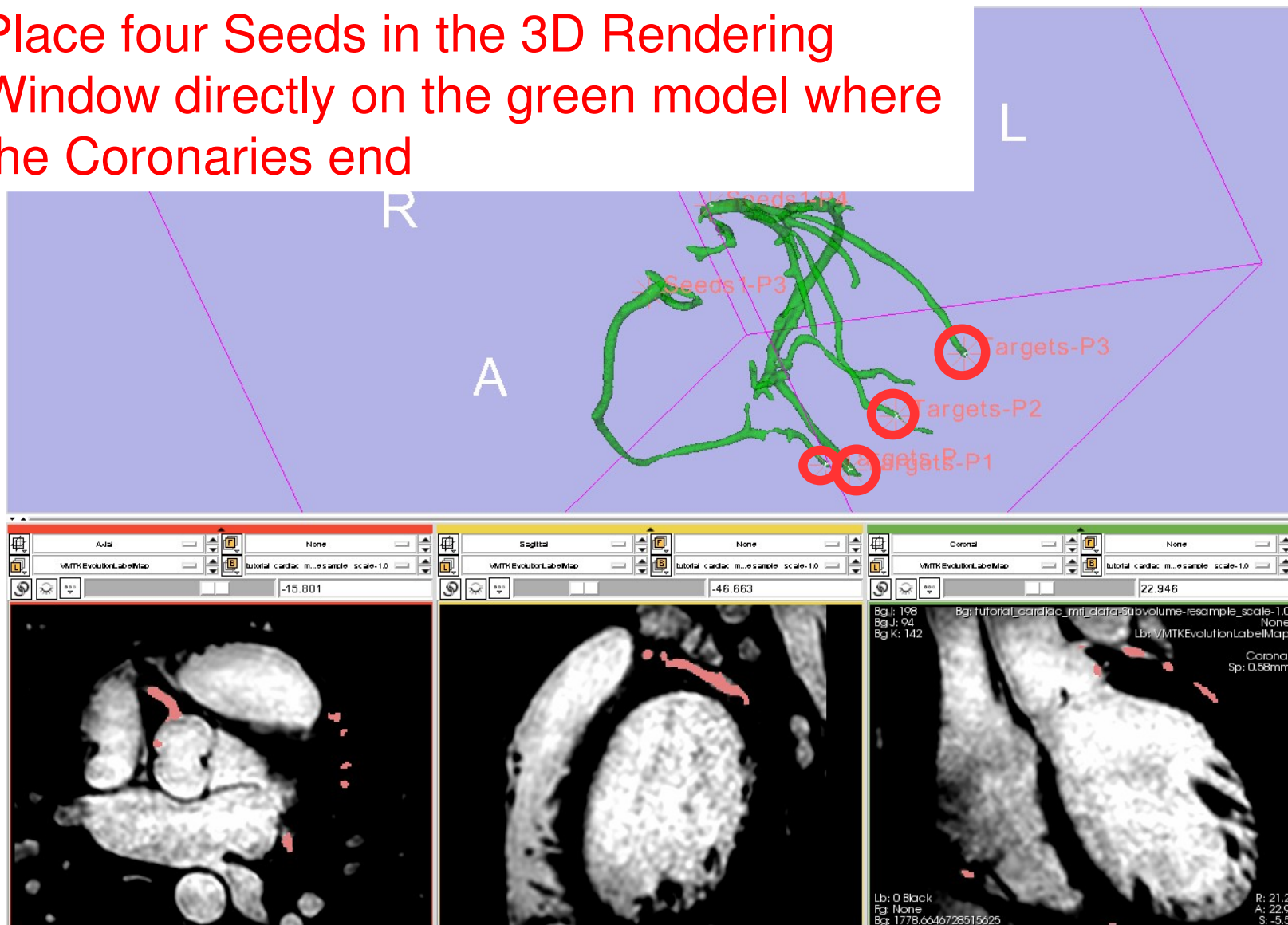
---

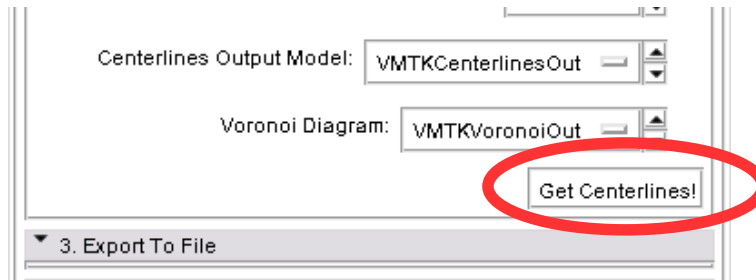
3D Slicer Version 3.5 Alpha



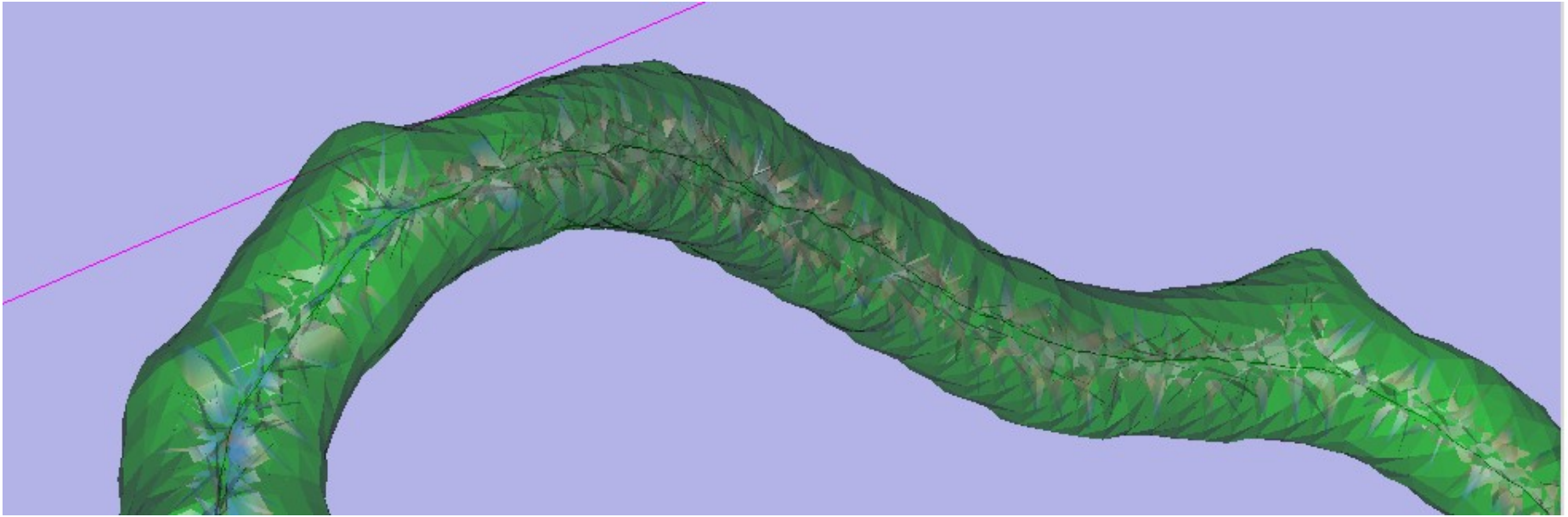
To place the Target Seeds correctly, it is recommended to first use the Transform mode (1) to rotate the model and then the Place mode (2) to set the fiducials

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

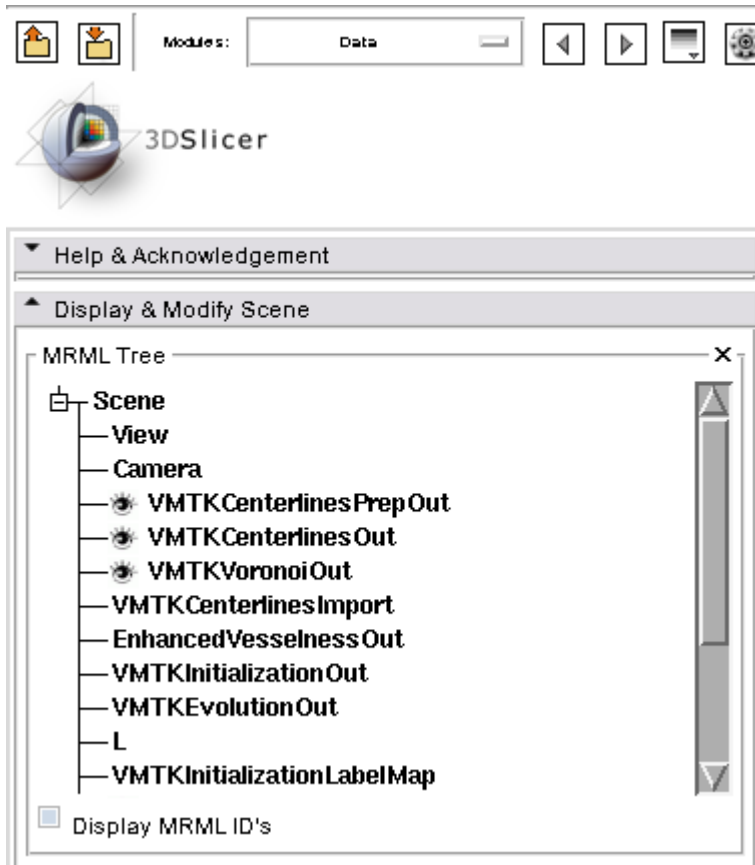




Click “Get Centerlines!”

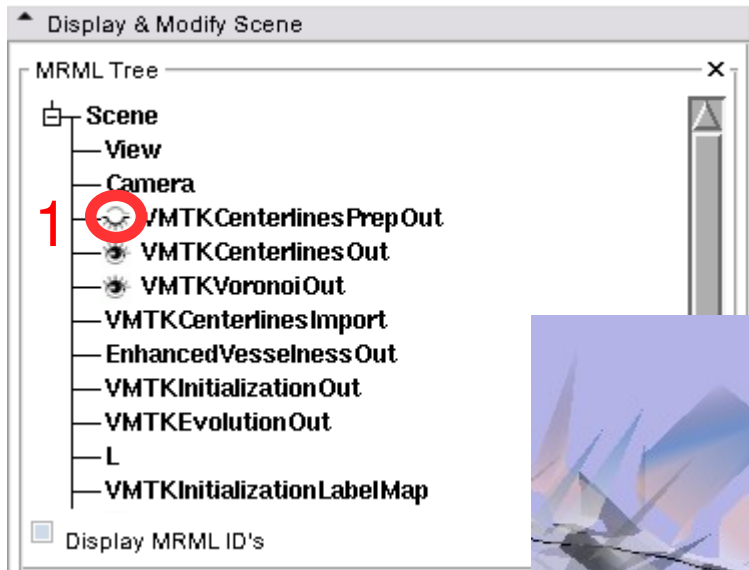


The Voronoi diagram and the corresponding Centerlines appear in the 3D Rendering Window

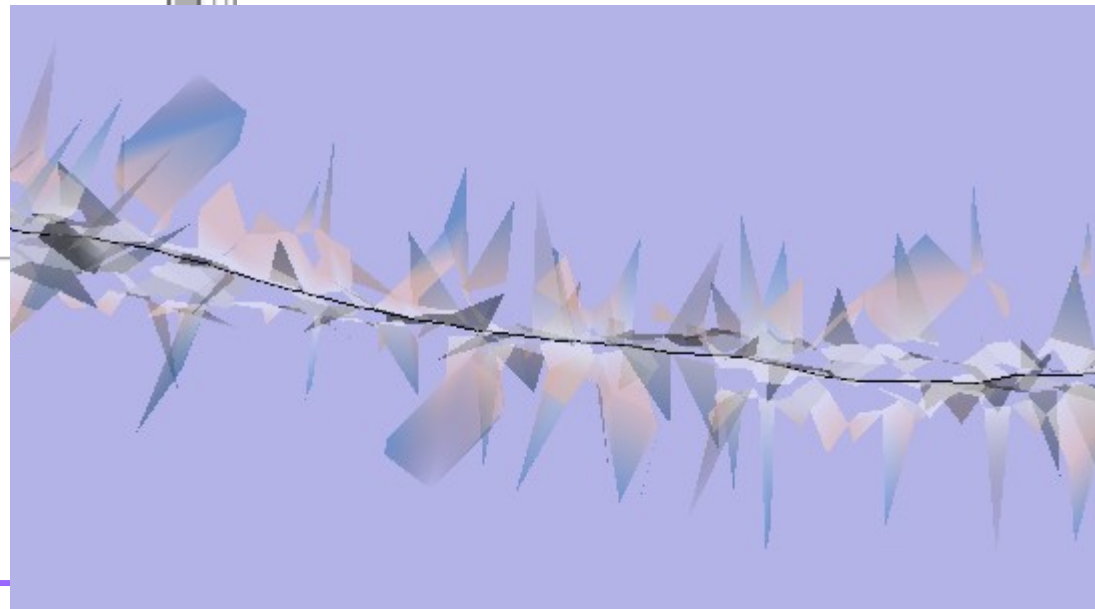


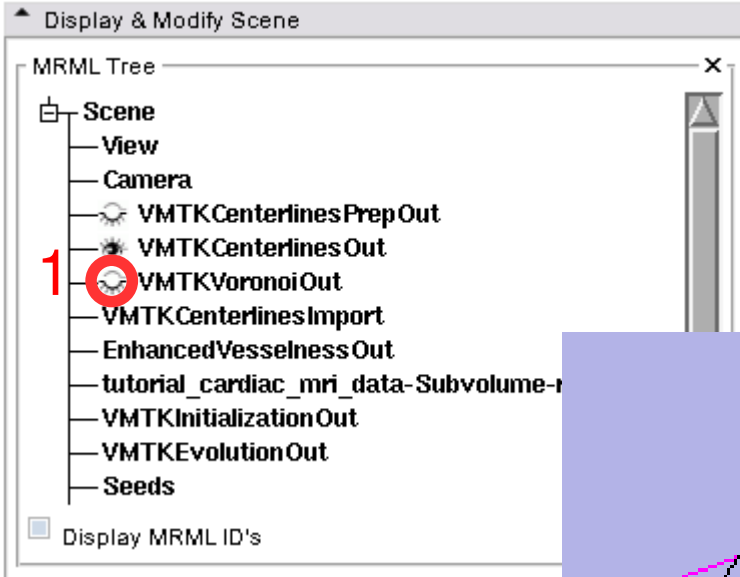
All segmentation parts are available as MRML nodes in the current scene. The “Data” module shows the MRML tree.

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

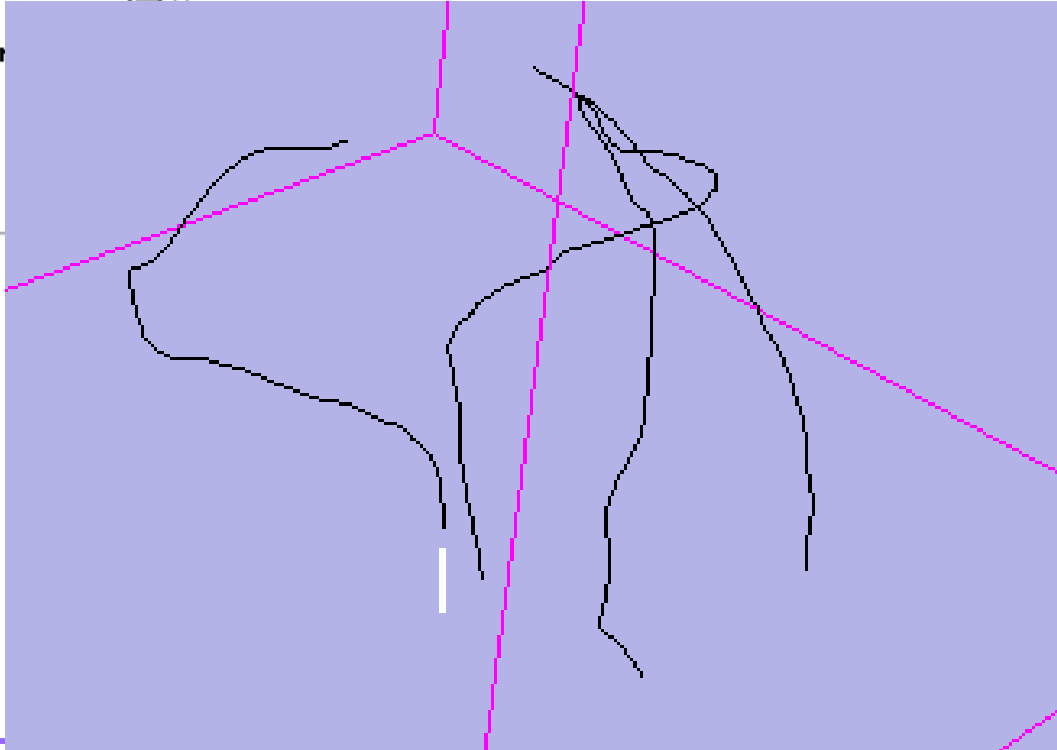


The 3D Rendering Window then shows the Voronoi diagram and the corresponding Centerlines only.

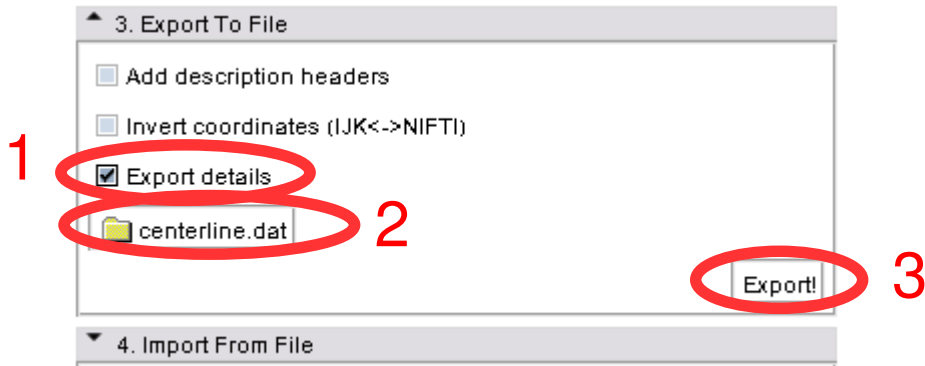




Hide the “VMTKVoronoiOut” model (1) to show the Centerlines in the 3D Rendering Window only.







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

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

```
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
-43.5702279005 23.6756229401 -2.9027071044 1.34341124572 83609.0 83607.0 0.264
-44.3442382812 23.8746795654 -3.11588931084 1.31434156682 83606.0 83606.0 0.0
-44.4300005264 23.8921318054 -3.12345123991 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 1.30802900025 81391.0 84189.0 0.86
-45.0118713379 24.0653190613 -3.4202637674 1.36677139288 84204.0 84204.0 0.0
-45.1805000305 24.090801239 -3.53823828697 1.4202217277 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
.....
```

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



# Conclusion

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- 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

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Thank you for using this  
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