Segmenting Medical Imaging Data

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This document outlines the procedures to segment raw medical imaging data using the software *Seg3D* (http://www.sci.utah.edu/cibc-software/seg3d.html) The input is a three-dimensional grayscale image, and the output is an *image mask*, or a matrix that assigns each voxel in the image a value corresponding to the tissue to which it belongs. This image mask is used as input for the surface mesh generation tool *Shabaka.*, whose output in turn can be piped into a mesh generation tool for the purpose of performing image-based modeling and simulation.

Getting Started

To install *Seg3D*, refer to the installation instructions in `$shabaka_dir/README`.

Image data can come in a variety of formats, including DICOM (.dcm.), PNG (.png), NIfTI (.nii), and NRRD (.nrrd). These file types can be loaded directly into *Seg3D*.

In the event that the file type is Analyze (.img + .hdr), the files must first be opened in the program *3D Slicer* (http://www.slicer.org/) and saved in an appropriate format. The process in *3D Slicer* is simply:

- File --> Add Data
- Select the appropriate .img and .hdr files
- File --> Save
- Identify the .img file and in the scroll down menu for "File Format," select NRRD and click Save

it is recommended (but not required) to have isotropic voxel spacing, i.e., the same voxel spacing in each of the three dimensions of the image. It is also typically desirable to pad the image with void space if your object reaches the extents of the image. Assuming your image is named *image.nrrd*, run the following from the command line to resample and pad your image:

```
python $shabaka_dir/src/ptcloudgen/resample.py image.nrrd
```

Segmentation

Segmentation from Raw Data

The following are steps to produce an image mask from raw data using *Seg3D*. The screenshots shown are taken *after* each of the steps is already performed. In the language below, a "data layer" refers to image data. A "mask layer" refers to a segmentation layer, which is displayed in bright colors in *Seg3D*.

- Open *Seg3D*
- Select "Start New Project"
    - Choose Save Location, press Continue, press Done
- Go to File --> Import Layer from Single File
    - Select the file (or series of files)
    - Import file as Data Volume and select Import
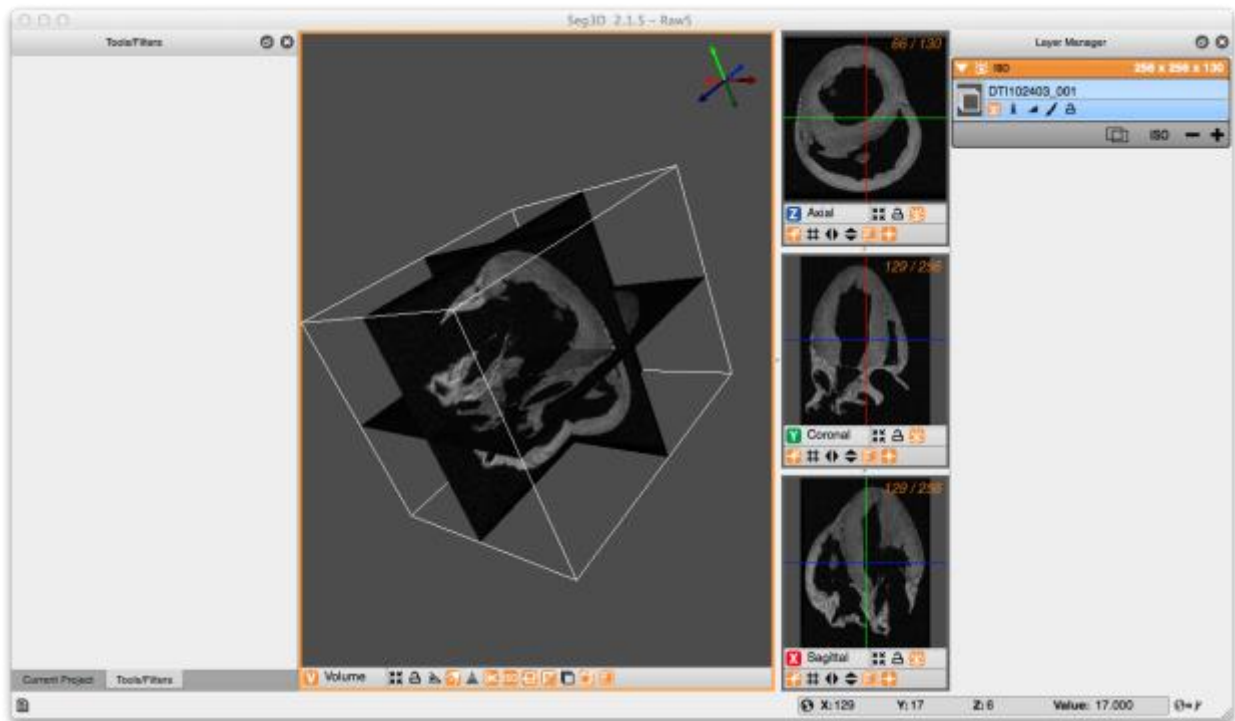
Image Processing

It is recommended to filter the image before performing segmentation. Image smoothing can especially improve the success of automatic segmentation techniques. Play with Data Filters and Advanced Filters to determine which filters are best for your data. Data Filters --> Median Filter is an especially effective filter, and can potentially allow you to skip the steps below that involve additional resampling of data.

- Go to Tools --> Threshold
  - Note if there are significant outliers in the histogram, you may wish to adjust the upper and lower intensity values of the threshold. In this example, the values were not adjusted.
 - Click Create Threshold Layer
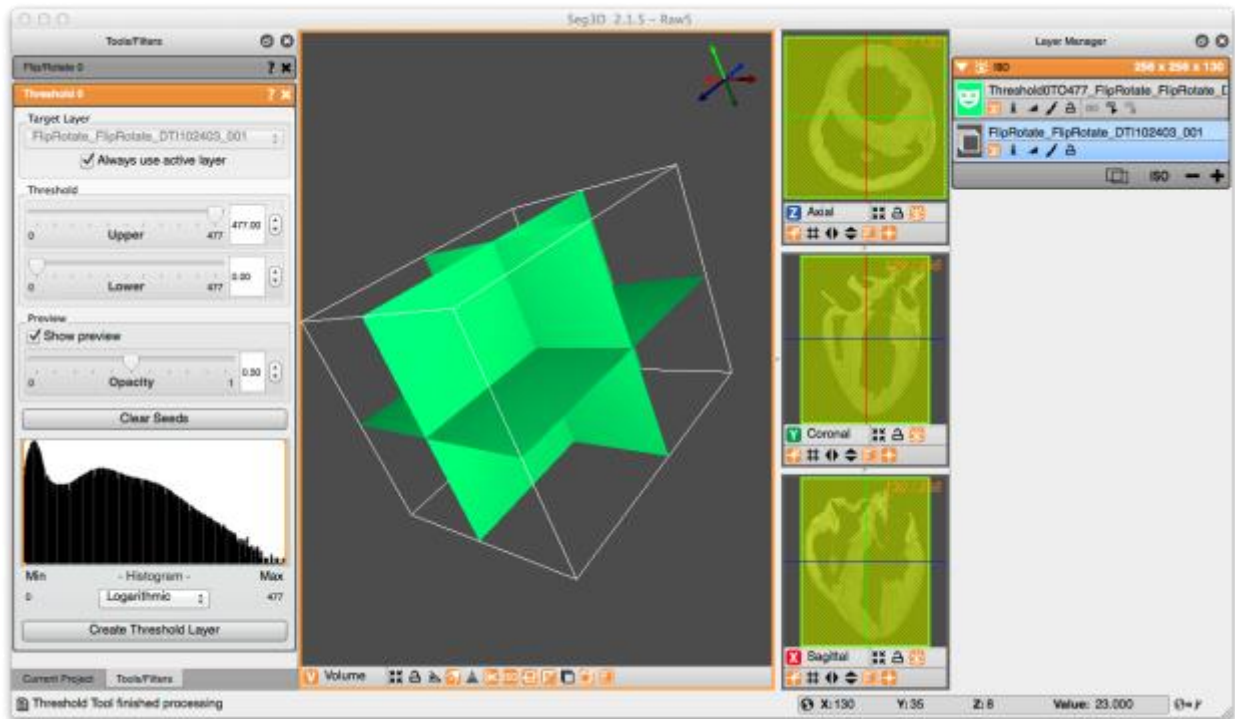
**THE STEP ON THIS PAGE IS SPECIFICALLY FOR CARDIAC MODELING PURPOSES ONLY**

- Go to Tools --> Crop
  - Make sure the new threshold layer on the right pane is the active layer (click it to make it your active layer, the one that is highlighted light blue is the active layer)
  - Go to the Size tab
  - Adjust Depth to a location that is acceptable to crop the atria from the ventricles of the heart.
  - Make sure to choose an even slide number to crop to. The reason for this is that a resampling will be done later one in which the resolution will be cut in half for the purposes of level set segmentation.
  - Click the Replace check box
  - Click Crop
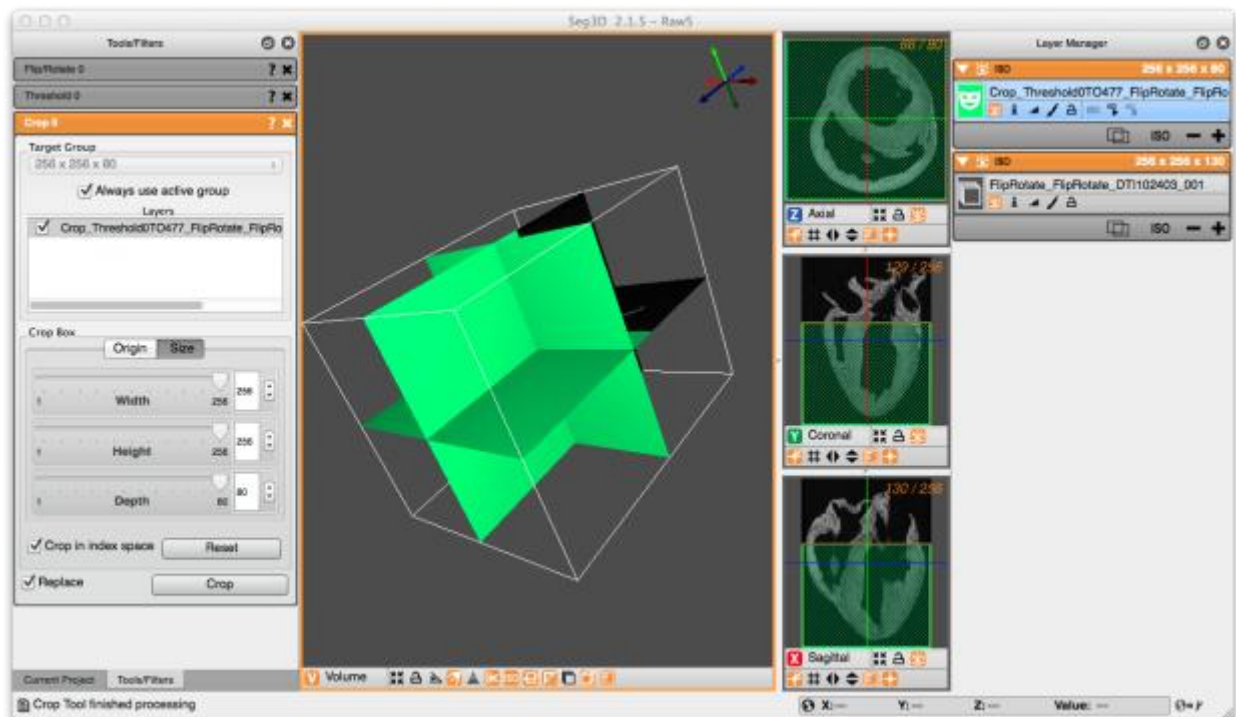
- Go to Tools --> Resample
  - Make sure the correct layer is chosen on the left pane
  - Click Resample to Match Another Group
  - Under Destination Group, select the original image size, in this case 256 x 256 x 130
 - Click the Replace check box
  - Click Resample
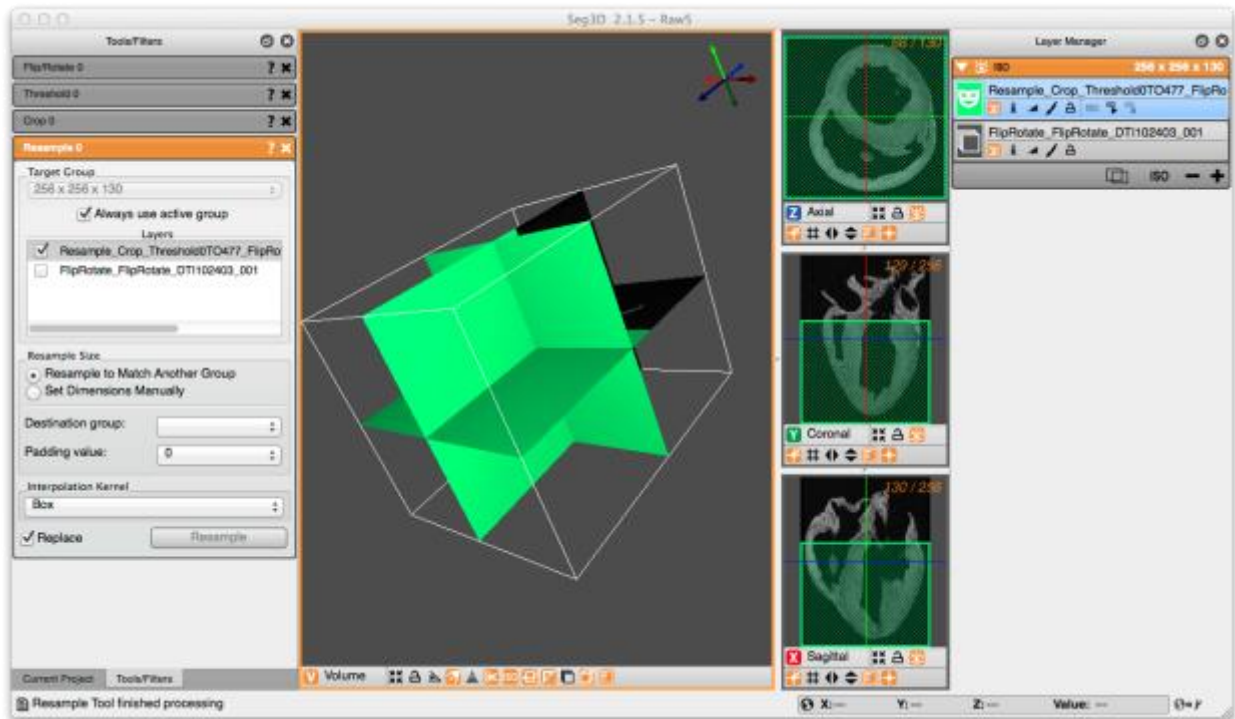
- Go to Data Filters --> Mask Data
  - Select on the right pane the original data layer: FlipRotate_FlipRotate_DTI102403_001
  - Under Mask Layer back on the left pane, select from the scroll down menu the threshold layer with the name beginning with Resample_Crop_Threshold
  - Do not check the Replace check box in this case
  - Click Run Filter
  - After the filter has been run, click the orange eye symbol for the original data layer FlipRotate_FlipRotate_DTI102403_001 to turn off its visibility.
  - The reason for cropping the data in this manner and not simply using the Crop tool directly on the raw data is several pieces of software (including *Shabaka*) require a buffer of voxels between the object of interest and the extents of the image
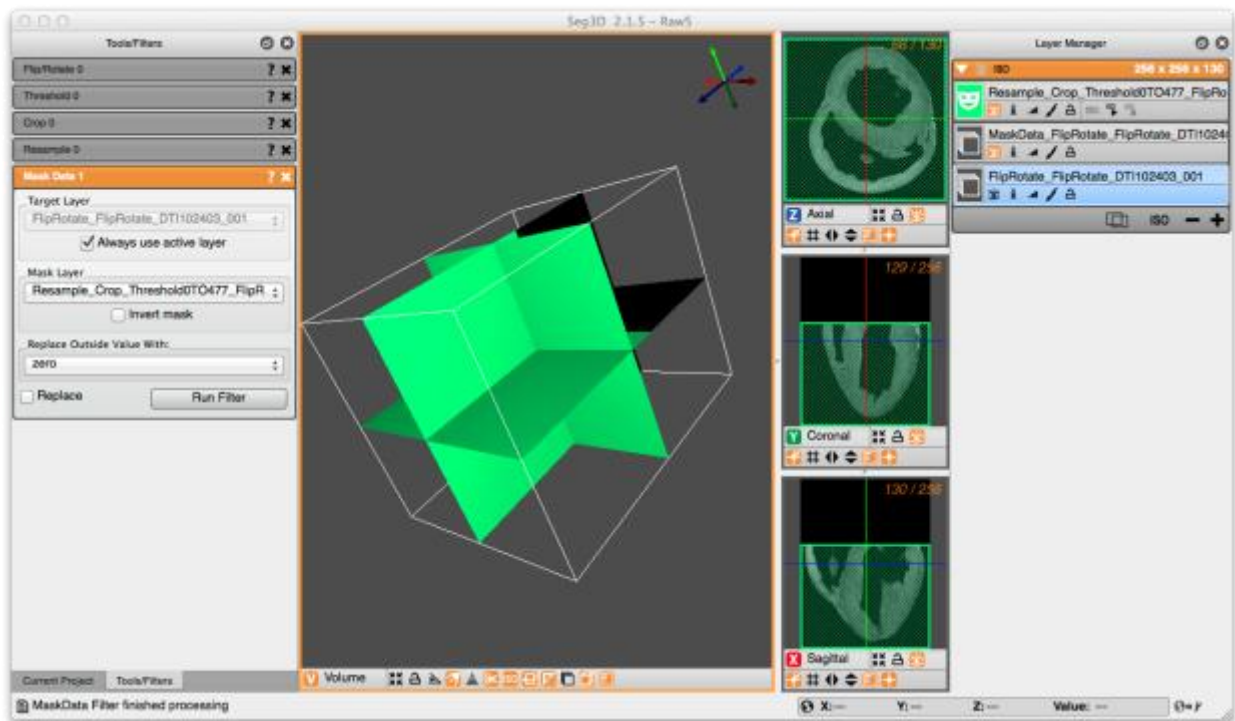
- In the main window on the bottom left, click "V Volume" and change to "Z Axial"
- Go to Tools --> Resample
    - The Level Set Method in *Seg3D* struggles with performing the segmentation directly on the data, so we will segment a resampled data set first, as a starting point for the final segmentation
    - Make sure the visible cropped data layer beginning with MaskData is the active layer
    - On the left pane, ensure the MaskData data layer is the only layer that is selected
    - Under Resample size, ensure Constrain aspect is checked, and change Scale to 0.5
    - Do not click the Replace check box
    - Click Resample
    - After the resample is complete, turn off visibility of the Threshold and MaskData layers by clicking the orange eye symbols underneath their names.
    - Remember, the following screenshot is *after* the resampling occurred. The left pane will not look as it does below while you are following the steps just laid out until after you perform the resample.
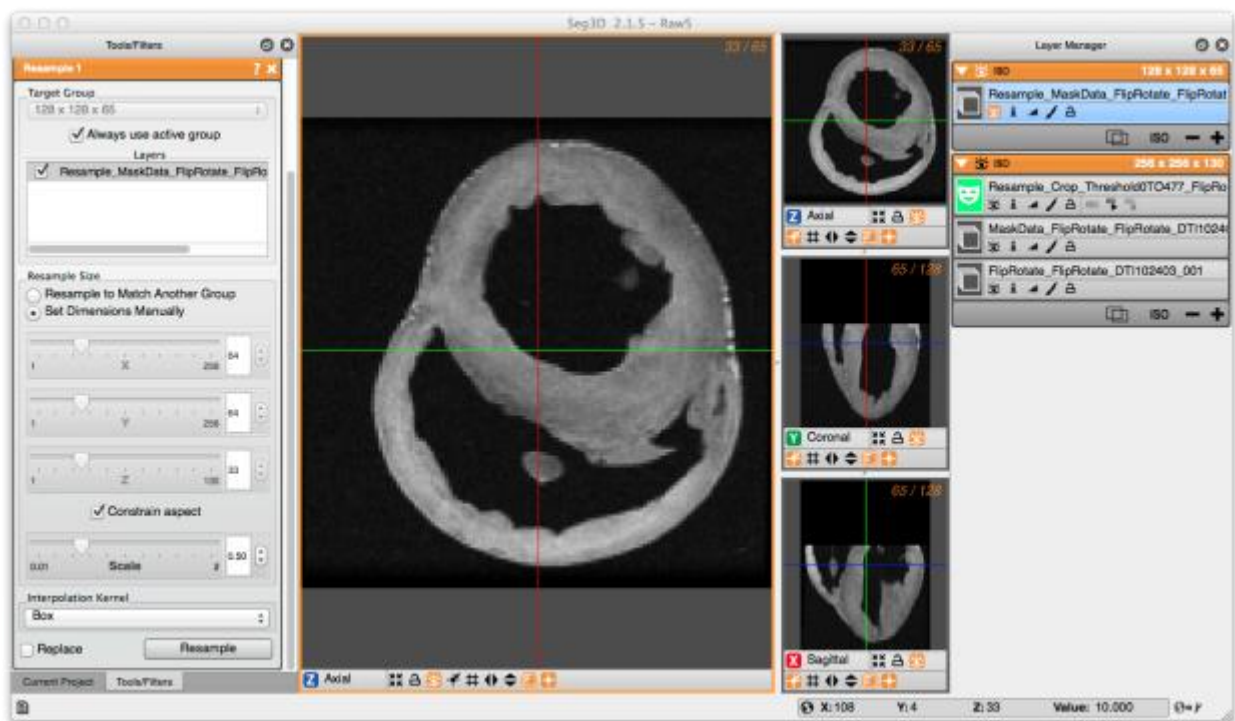
- Click the + sign below and to the right of the newly Resampled layer. This adds a new layer titled MaskLayer
- Go to Tools --> Paint Brush
  - Make sure MaskLayer is your active layer
  - The mouse wheel can be used to change the size of the paint brush
  - On the main Axial view, draw in a basic starting point for the level set segmentation
  - Holding on the Command key on a Mac and Ctrl otherwise, while scrolling the mouse wheel allows you to scroll through different slices. Basic stencils for the forthcoming level set segmentation were drawn for roughly 1 in 4 slices
  - Repeat this process for the other two views. Again, to change the view go to the bottom left of the main window, click "Z Axial" and change to Coronal or Sagittal views.
  - The more effort that is put in this step reduces the work for the following level set segmentation, and makes it less likely that it struggles to identify regions
  - If you want to undo some work, click the Erase check box. *Seg3D* also has Undo and Redo capability with Command-z and Command-Shift-z on a Mac or Ctrl-z and Ctrl-Shift-z otherwise.
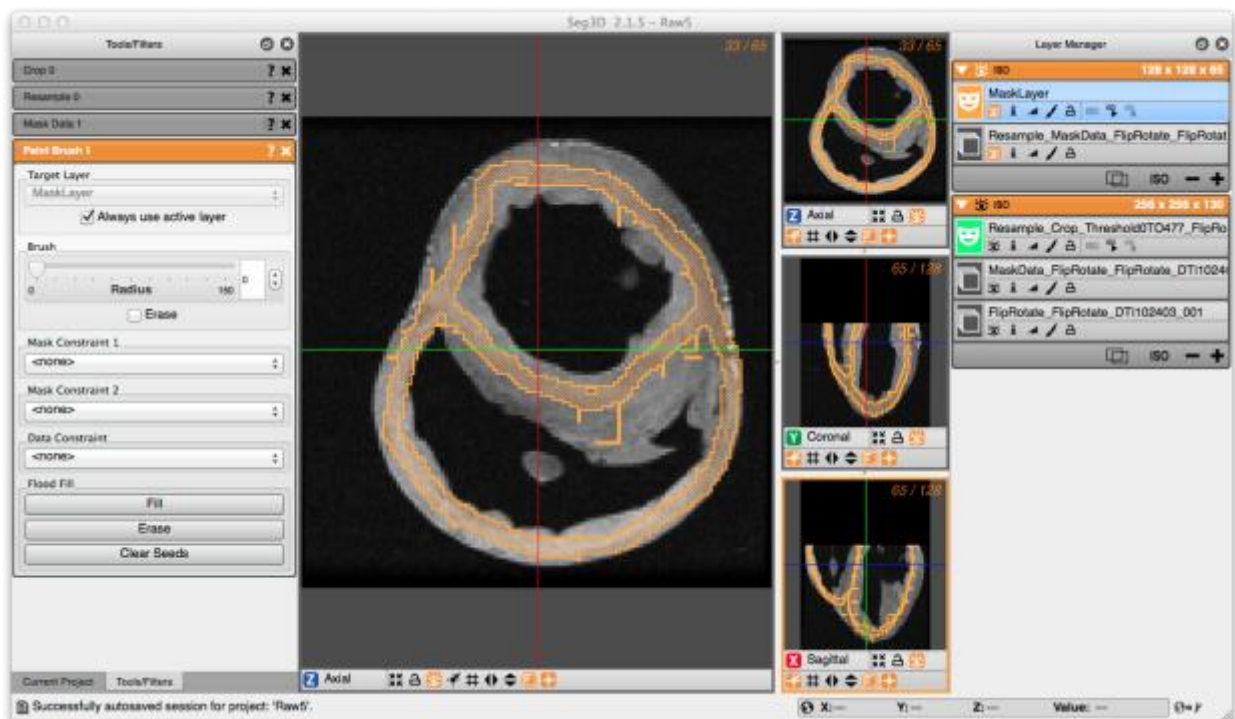
- When you are finally done, you may switch back to the Volume view in the main window
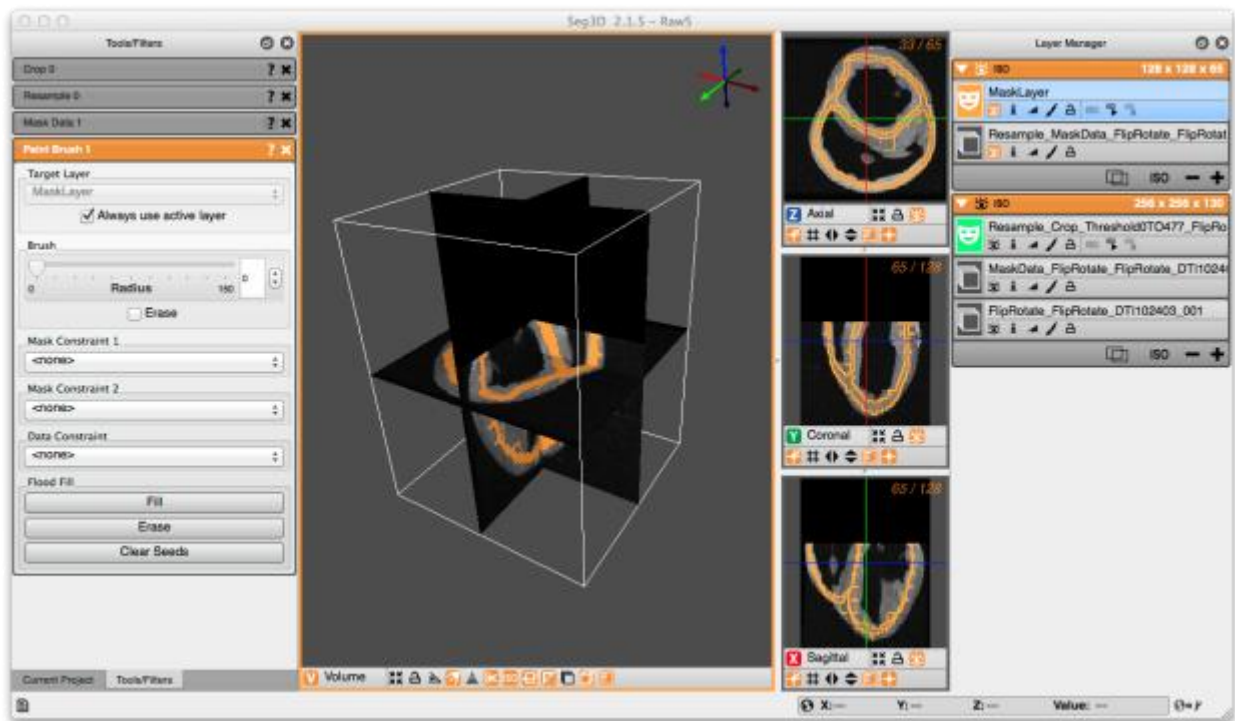
- Go to Advanced Filters --> Segmentation Level Set
  - Select the data layer with name beginning with "Resample…" as the active layer
  - For Seed Mask Layer, select MaskLayer, the layer in which the paint brush strokes were performed
  - For Iterations, make it the max allowable number. You can always manually Finish the segmentation prematurely.
  - Threshold Range, Curvature Weight, Propagation Weight, and Edge Weight are parameters of the level set algorithm. Threshold Range and Propagation Weight affect the ease with with the level surface grows, and were minimally adjusted. Curvature Weight and Edge Weight were never altered from the defaults.
  - Click Run Filter
  - After a short period of time (<2 minutes), the level surface should have significantly slowed down in its growth. Click Finish in the right pane.
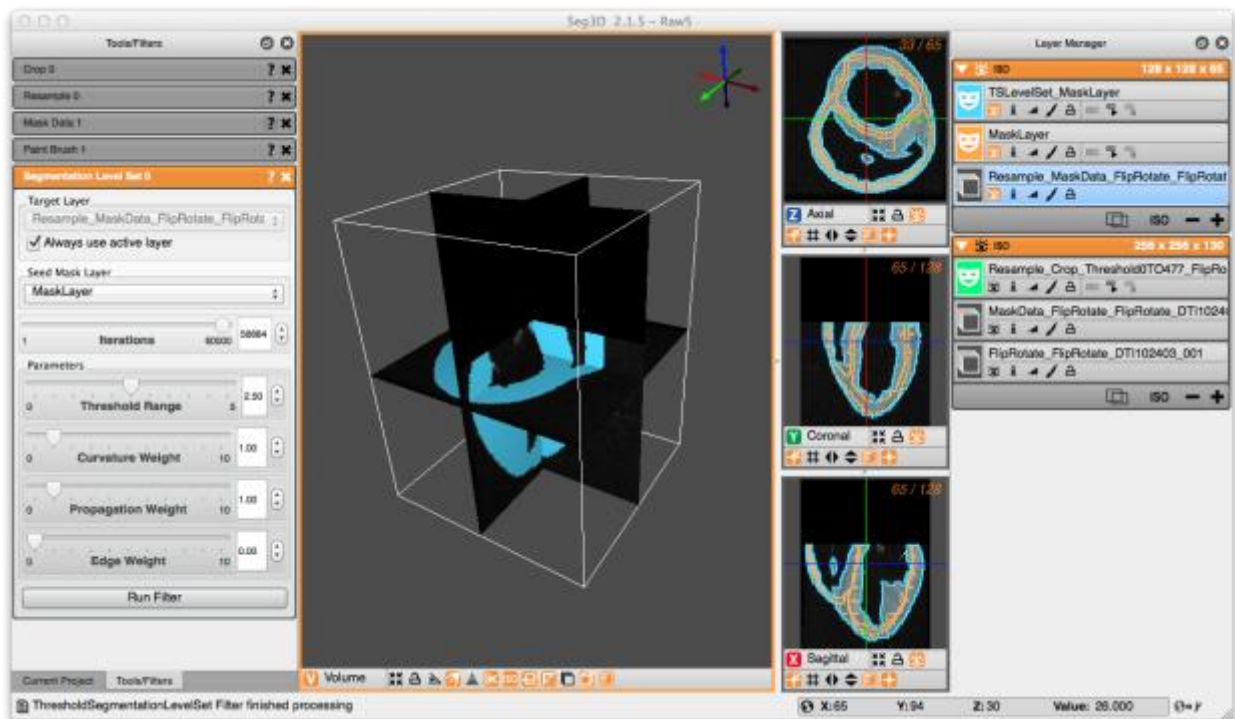
- You may now use this as a starting point for future iterations of improvement on the segmentation
- Toggle through Axial, Coronal, and Sagittal views as necessary during this improvement process
- There are likely holes left behind that the level set algorithm was not able to fill in
- Go to Mask Filters --> Fill Holes
  - Ensure that TSLevelSet_MaskLayer is the active layer
  - Click the Replace check box
  - There is a way to add seeds to guide this tool as to where to fill the holes, but that has not been tested
  - Click Run Filter
  - There is a chance that the entire left and right ventricles are filled when using this tool. Obviously undo if that is the case and this tool may not be useful until later on in this iterative process
- You will still likely have to go back and manually fill some holes using the Paint Brush tool as well
  - Remember, when Paint Brush is the active tool, you must hold on Command or Ctrl while scrolling the mouse wheel in order to scroll through layers. If any other tool is active in the left pane, you may just scroll the mouse wheel
- You can also run another Level Set Segmentation with the Seed Mask Layer being the most current segmentation. Remember, the active layer must be the data layer (the MRI) when using the Level Set Segmentation tool.
- If a new layer is not visibly appealing or it is difficult to see how well it is segmenting the raw data, click the icon that looks like a paint brush below the name of the layer of interest, and select a different color. This actually can make a big difference.
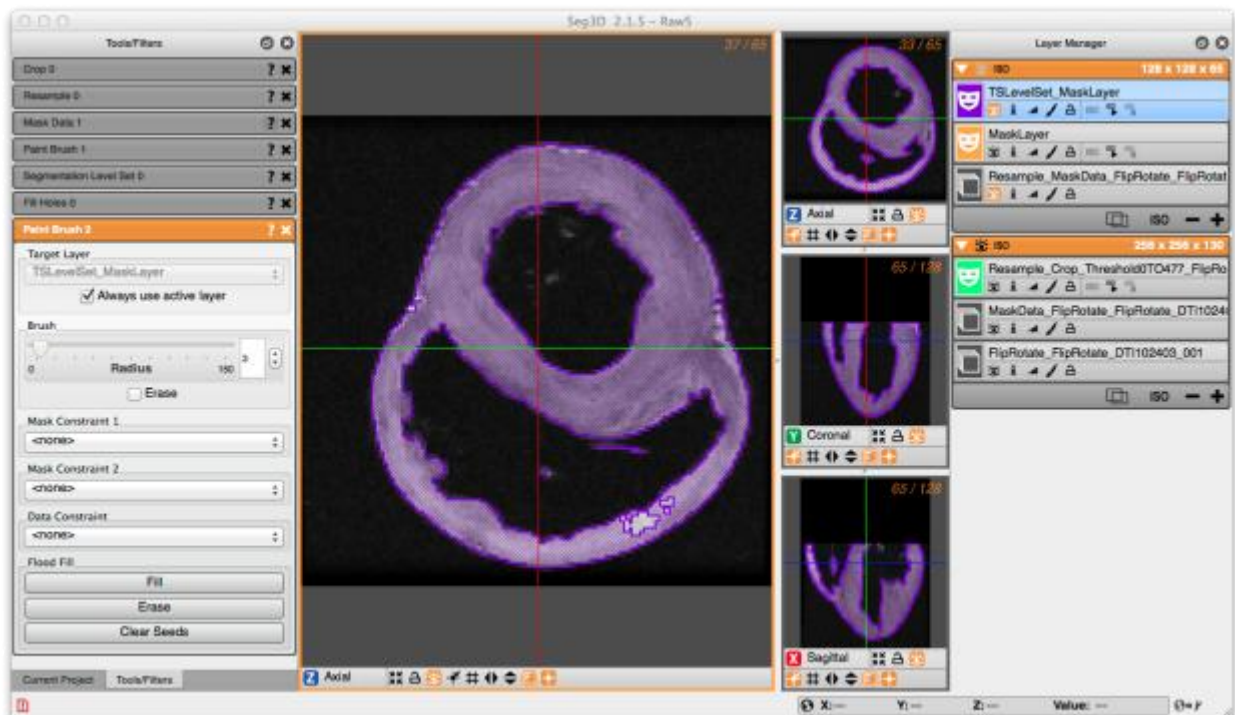
- Once you are satisfied with your segmentation using a combination of Segmentation Level Set, Fill Holes, Paint Brush, and any other tools, switch back to the Volume view in the main window
- Go to Tools --> Resample
  - Ensure the segmentation layer you want is the active layer and the only layer selected in the left pane
  - Click Resample to Match Another Group
  - Under Destination Group, select the original scan size, for this case 256 x 256 x 130
  - Do not click the Replace check box
  - Click Resample
  - This resamples the segmentation back to the original scan size
- For the new resampled layer that was just produced, click the button below the name of the layer that has a play symbol and the word ISO to compute the isosurface for the given segmentation:

- In the main window along the bottom, there are several different view options. Hover over the items to see what they do. Turn off Show Slice Planes for a better view of the isosurface.
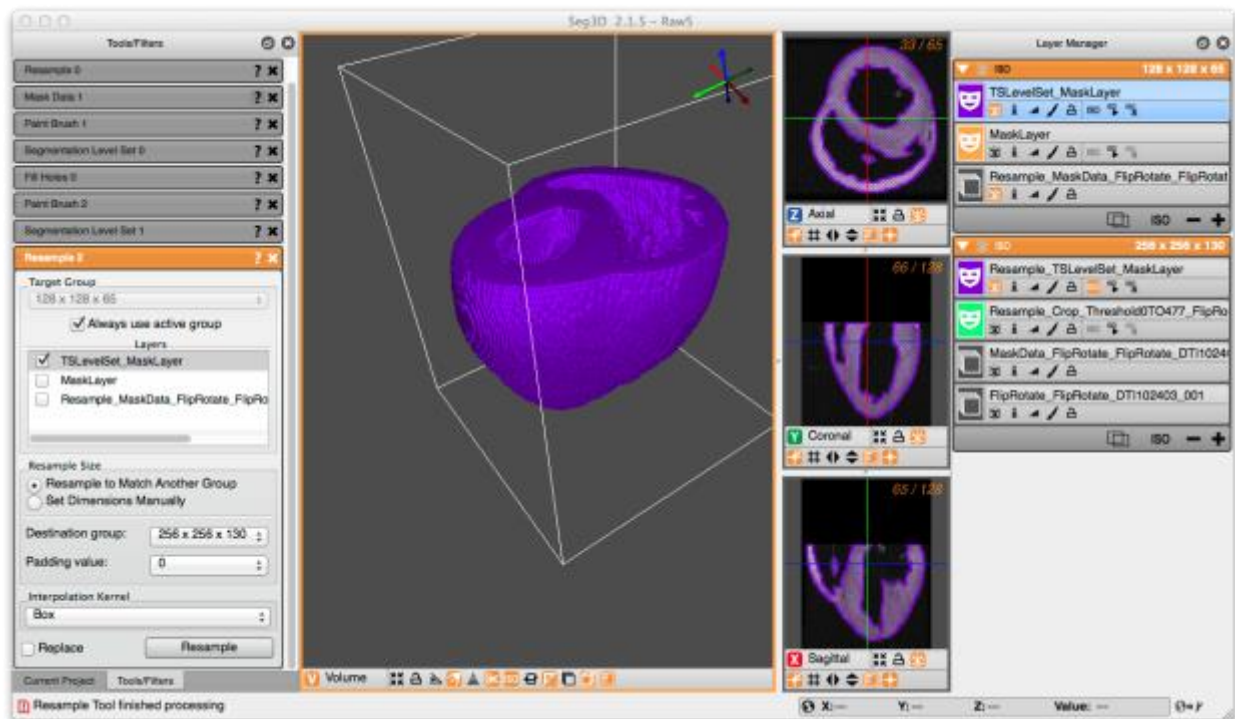
- Turn off visibility of all layers in the reduced size and turn on the original masked data layer beginning with the name MaskData
    - At this point you now have a starting point for segmenting the original data rather than the resampled data
- Run the Level Set Segmentation again with this new resampled layer as the seed mask layer
    - You may need to play with some of the parameters, particularly Threshold Range and Propagation Weight for the filter to work correctly
    - Also beware of running the level set algorithm for too long, as there were cases in which the segmentation began to degrade and produce new holes over time
- Again, toggle through different views and using a combination of the tools available, to produce a final segmentation and isosurface that you are pleased with
- Make sure to compute and visualize the isosurface of the final segmentation to be used
- Note you may change the name of any layer simply by clicking on its name in the right pane and typing in the new name.
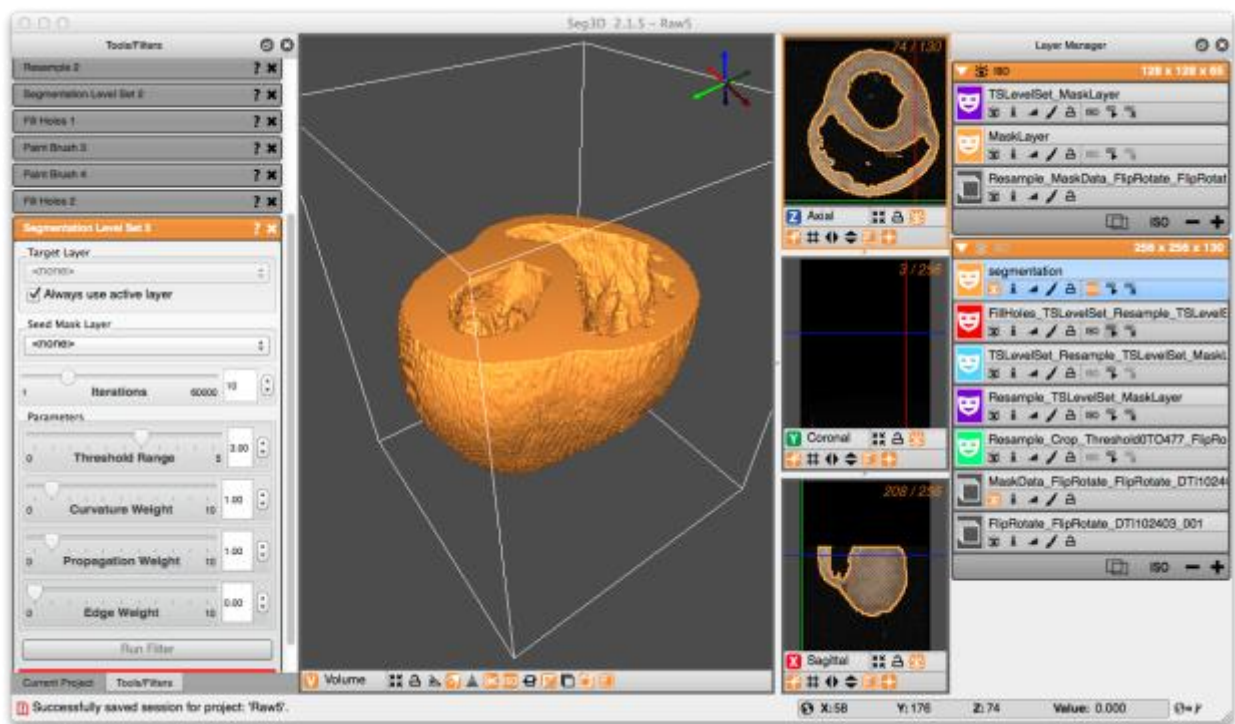
- Go to File --> Export Segmentation…
  - Select only the final segmentation layer
  - Ensure that Save masks as a single file is selected and the file type is NRRD.
  - Click Continue and Save the file in the desired location
- When exporting the segmentation, make absolutely certain the file has saved in the desired location. There are occasional errors that pop up in the bottom left corner of the *Seg3D* window in red font that says to choose a different directory to save to. These are likely issues with saving to Desktop and/or replacing an already existing file. Worst case scenario is to save to an arbitrary location and moving the file to your desired location after the fact

This concludes the steps to produce a segmentation and isosurface from Seg3D beginning from raw data. Note these are very basic steps. *Seg3D* has several more tools available that may come in handy in the future. Some comments on those tools:
- The **Median and/or Gaussian Blur** data filters could potentially replace the steps involving resampling the data
- Instead of drawing in a seed mask with paint brush, the Threshold tool could potentially be used instead or in conjunction
- The **Fill Holes** mask filter may come in handy as well
- The **Smooth Binary Dilate -> Erode** mask filter is recommended to be used as a final step prior to exporting the image mask, particularly for objects that are intrinsically smooth

Processing Pre-Segmented Data

Alternatively, the data provided may already be segmented, whether in the format of Analyze (.img + .hdr) or Matlab matrix (.mat). Again, if Analyze format is provided, the files must first be opened in *3D Slicer* and converted to NRRD. Seg3D can open .mat files directly. If a segmented file is loaded into *Seg3D*, the steps are:

- File --> import layer from single file
- Select file and click open
- Select Import file as data volume and click import

In the event that .mat pre-segmented files are to be used, there is no header information regarding the spacing of the data points. Thus, after loading the file, the following steps must be performed:

- Tools --> Transform
- On the left pane, uncheck "Keep aspect ratio"
- Enter the correct spacing. For example, X: 0.3125, Y: 0.3125, Z: 0.8
- Check the "Replace" box
- Click Transform. The old layer will be replaced by a new layer on the right hand side with the prefix "Transform_".
- You will need to do some scrolling in the views on the right in order to have the scan in view again.
- Use the Threshold tool to create a threshold layer that excludes voxels of intensity 0 (this process is explained in the previous section).
    - Because the image is really already segmented, this is a trivial task. Simply change the lower threshold limit to a value larger than 0, and create the threshold layer
- Compute and visualize the isosurface (this process is explained in the previous section).

At this point you may export the segmentation in the same manner as explained in the previous section.