SKULL SEGMENTATION,
VECTOR DESIGN AND SURFACE GENERATION

Using Analyze

AnalyzeDirect

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Introduction

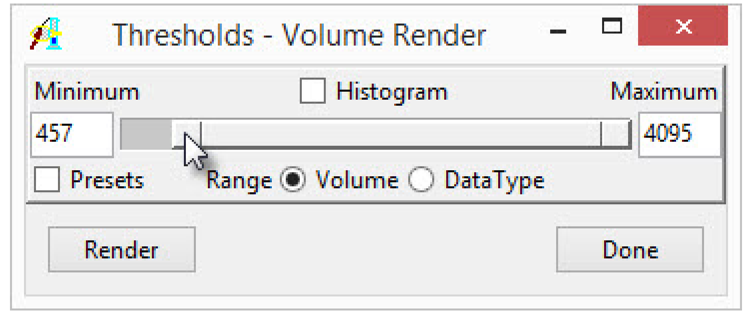
Cranial implants of different types are used by neuroscientists to record, stimulate, or block neural signals in animal studies. In addition, cranial implants may eventually be used in a clinical context as neural prosthetics or brain-machine interfaces to treat neurological disorders.

Previous cranial implant designs have experienced several issues due to the materials used in implants and the methods used to attach implants to the skull. Mulliken et al. have designed custom-fit cranial implants that solve many of these problems[1]. This new implant design features a custom fit based on skull structure as determined from segmentation of MR scans of each individual animal. Segmentation of the skull from MR obviates the need to acquire CT data and register it to the MR data.

The goal of this guide is to provide instructions to segment the cranium from the surrounding soft tissue (brain and skin) using a T1-weighted MRI data set, create a target vector object at a given stereotaxic coordinate to specify the position and orientation of the implant in relation to the skull, and to generate surface files for both the cranium object and vector object using Analyze.

Segmentation of Skull Surface and Vector Creation

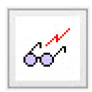
Skull Segmentation



Cortical bone has no signal in T1-weighted MRI, therefore voxels representing the skull have similar signal values to those representing the airspace or background in the image data. We are able to leverage this characteristic to isolate the skull from the head using Analyze. Once the skull is segmented the target vector can be easily created using the object fabrication tools provided by the Volume Render module.

Load the image data into Analyze using **File > Load.**

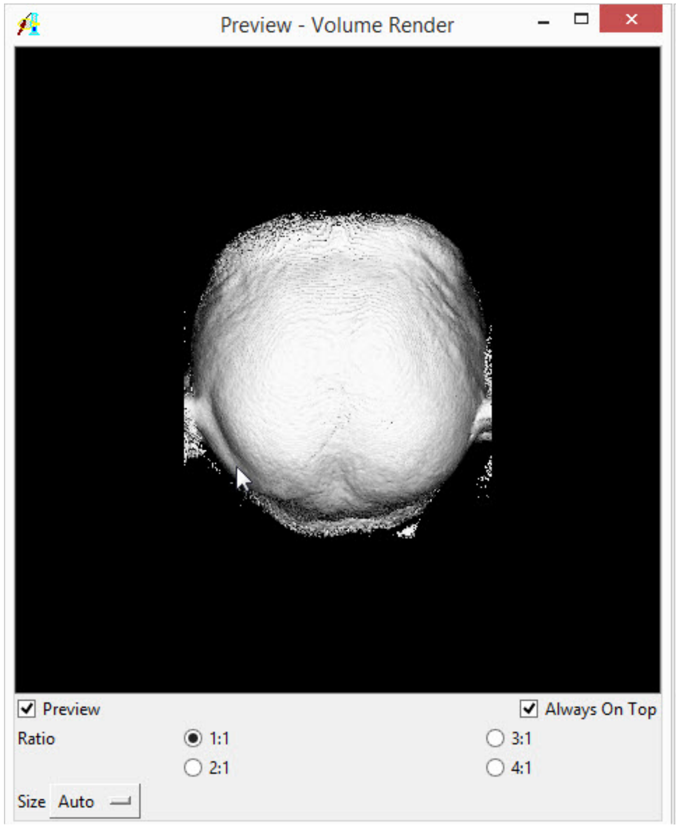
Select the loaded data and then open **Display > Volume Render.**

In the Volume Render module open the Preview  window and the Thresholds 

window.

In the Thresholds window increase the minimum threshold value using the double-ended slider. Note that the image displayed in the Preview window will automatically update. Adjust the value until the airspace is removed from the image in the Preview window and the soft tissue is displayed.

If required, adjust the position of the data by clicking and dragging the image in the Preview window to a new orientation.



Next select **Tools > Manipulate > Threshold Tool**. In the window set **Change to Object Map**. Note the Objects window will automatically open.

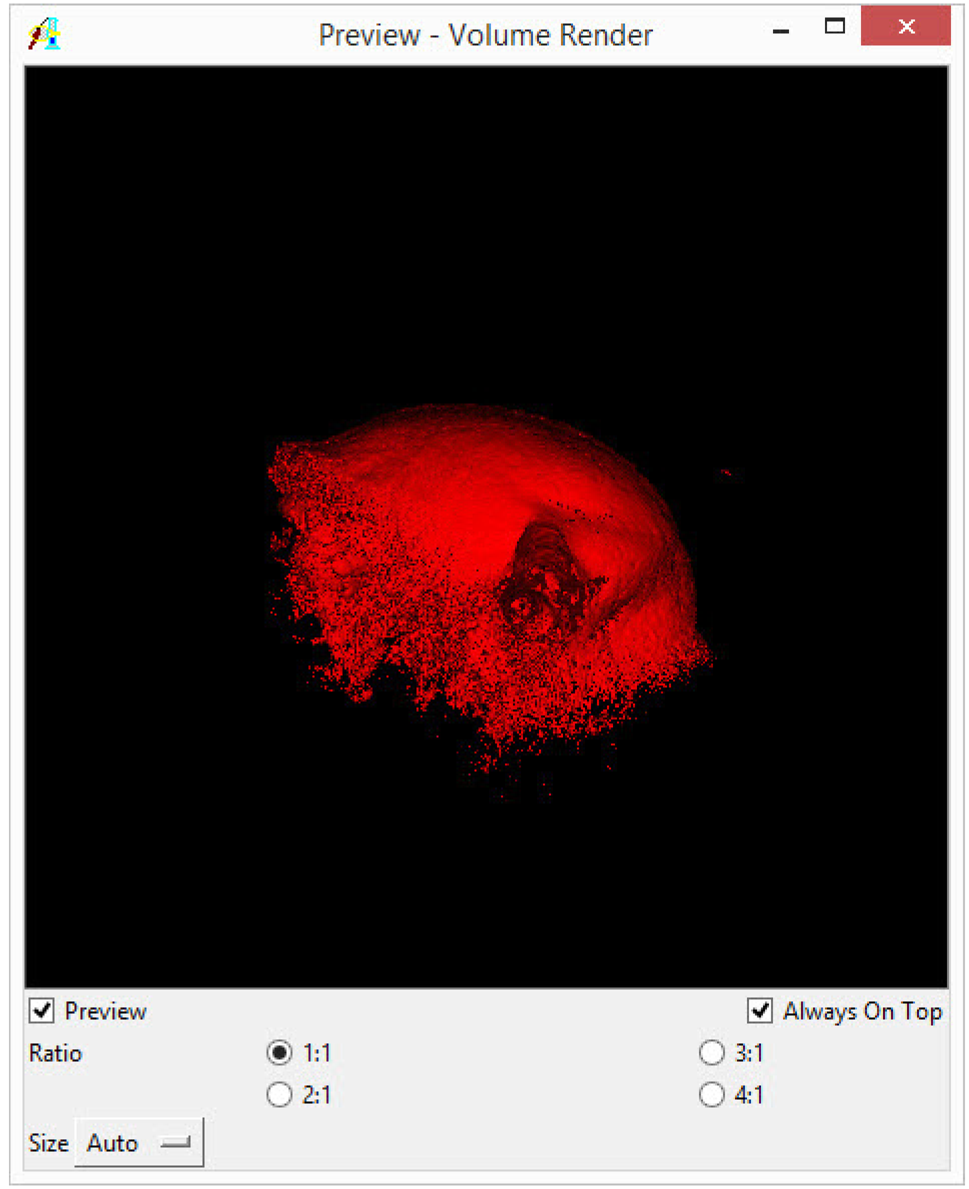
Next use the drop-down menu to change the Defined Object to ***New*** and then click the Threshold Volume button.

All rendered voxels (those representing the soft tissue, brain parenchyma, etc.) will be assigned to a new object, Object_2.

All voxels outside the specified threshold range, those with a low grayscale signal value (background and cortical bone), will remain as part of the Original object.

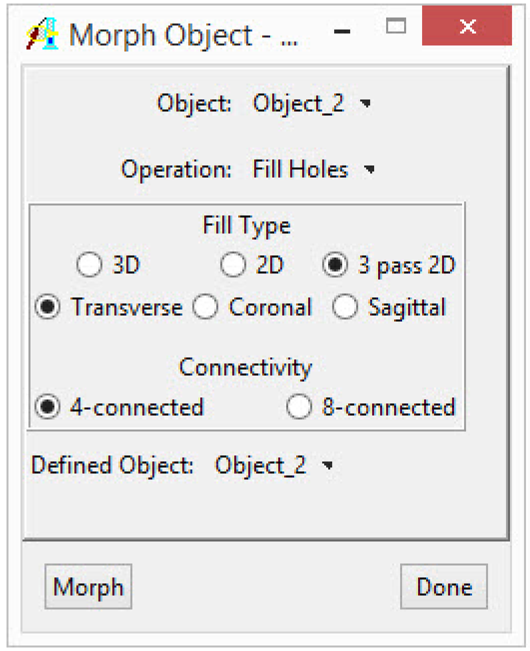
Note the appearance of the image displayed in the Preview window will change from white to red once the process is complete.

Close the Threshold Tool.

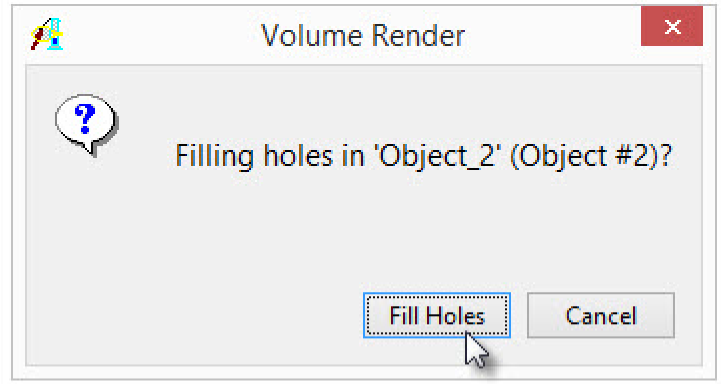


From the Objects window select the Morph Object button.

In the **Morph Object** window returned, set the **Object** to **Object_2**, set the Operation to Fill Holes, set the Defined Object to the input object, Object_2, and then click Morph.

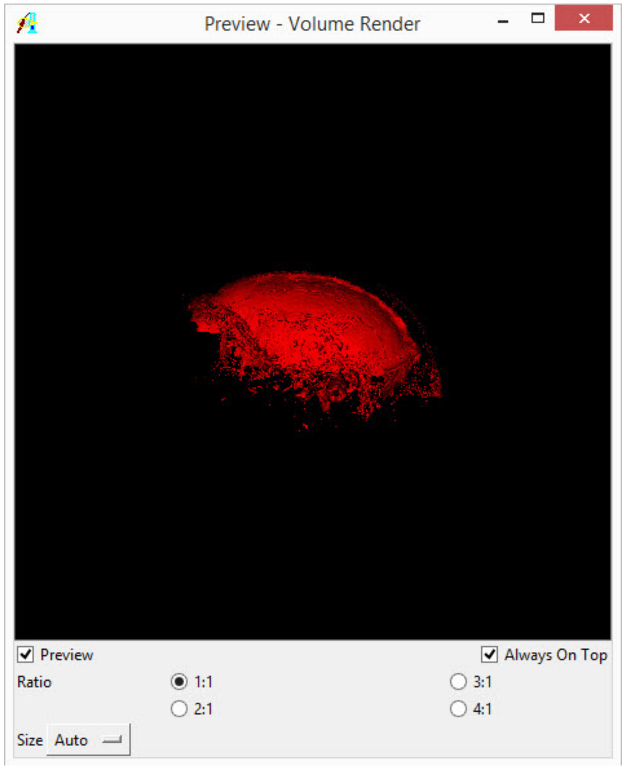


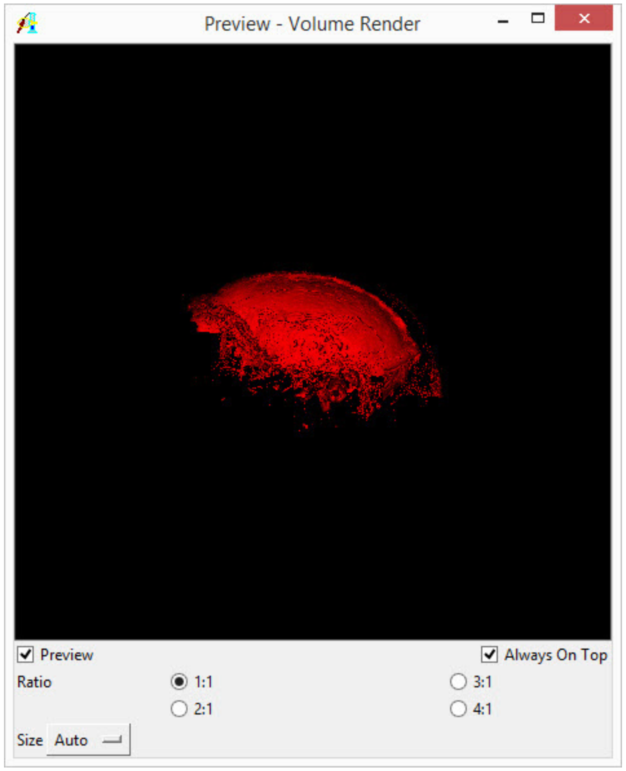
Confirm that you would like to conduct the specified fill operation by clicking Fill Holes in the verification window that appears. The algorithm will now fill any spaces (those left by the voxels representing cortical bone) in the segmented head object (Object_2), creating a solid object.



Once the process is complete close the Morph Object window.

In the Object window set the Object to Original and then set the Display of the object to Off.

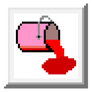




Use the Threshold window to invert the selected voxels. Set the minimum threshold level to the lowest possible value and then reduce the maximum threshold value until only the voxels with a low signal value, those representing the skull, are visible.

Note that the voxels representing the airspace surrounding the head are not visible as they are assigned to the Original object, the display of which is disabled. Click the Render button; the rendered skull will be displayed in the main Volume Render window and the current object status updated for all tools in the module.

For this procedure we are only concerned with the upper skull, therefore we can remove the lower skull and noise from the current object. **Select Tools > Manipulate > Trace**. In the Trace tool choose any of the region definition tools from the tool palette on the right-hand side and then draw a closed trace around the region to be removed.

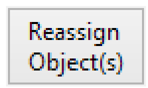


Select the Flood Fill Tool and then click in the region to be removed. If the region is defined by a closed trace then this region only will appear as a solid red region. If the entire image becomes red click the Undo button and repeat the region definition step, ensuring the trace is closed. With the Defined Object set to Original click the Change Memory button. All voxels in the 3D image positioned under the defined 2D region will be reassigned to the Original object. Because the display of the Original object is switched off, these voxels will be removed from view. Close the Trace tool.

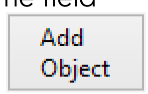
In later steps 3D surface files of the skull will be generated for rapid typing, therefore it is necessary to remove any spatially disconnected voxels from the skull. This can be achieved quickly by performing a 3D region grow to isolate the skull.

Select **Tools > Manipulate > Connect Tool**. In the Connect Tool click on the skull to establish a seed point, set the Defined Object to ***New***, and click Connect. The tool will perform a 3D region grow assigning connected voxels into a new object. These voxels will be assigned to Object_3, and the image in the preview window will update from Red to Green, while spatially disconnected voxels will remain red. Close the Connect tool.

At this point we can remove (delete) Object_2 from our object map by reassigning it to the Original object.



In the Objects window click on the Reassign Object(s) button. In the Reassign Object(s) window returned select Object_2 and reassign it to the Original object. Click Apply to perform the reassignment and then click OK to close the window.

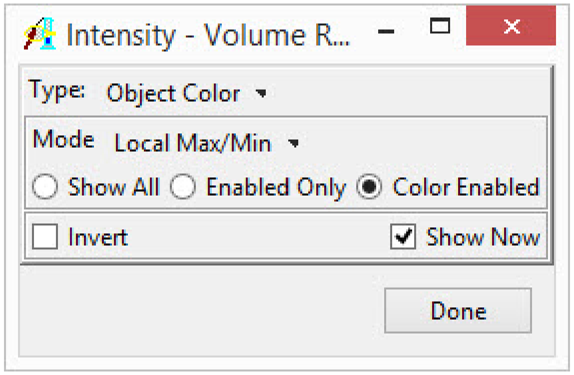


Change the name of Object_3 to Skull by updating the Name field for the object in the Objects window. Click the Add Object button to create a new object for the target vector and change the name of the new object to Line. Change the color of this object to red. Click Done to close the Objects window.

At this point you can also close the Preview window and the Thresholds window.

Target Vector Creation

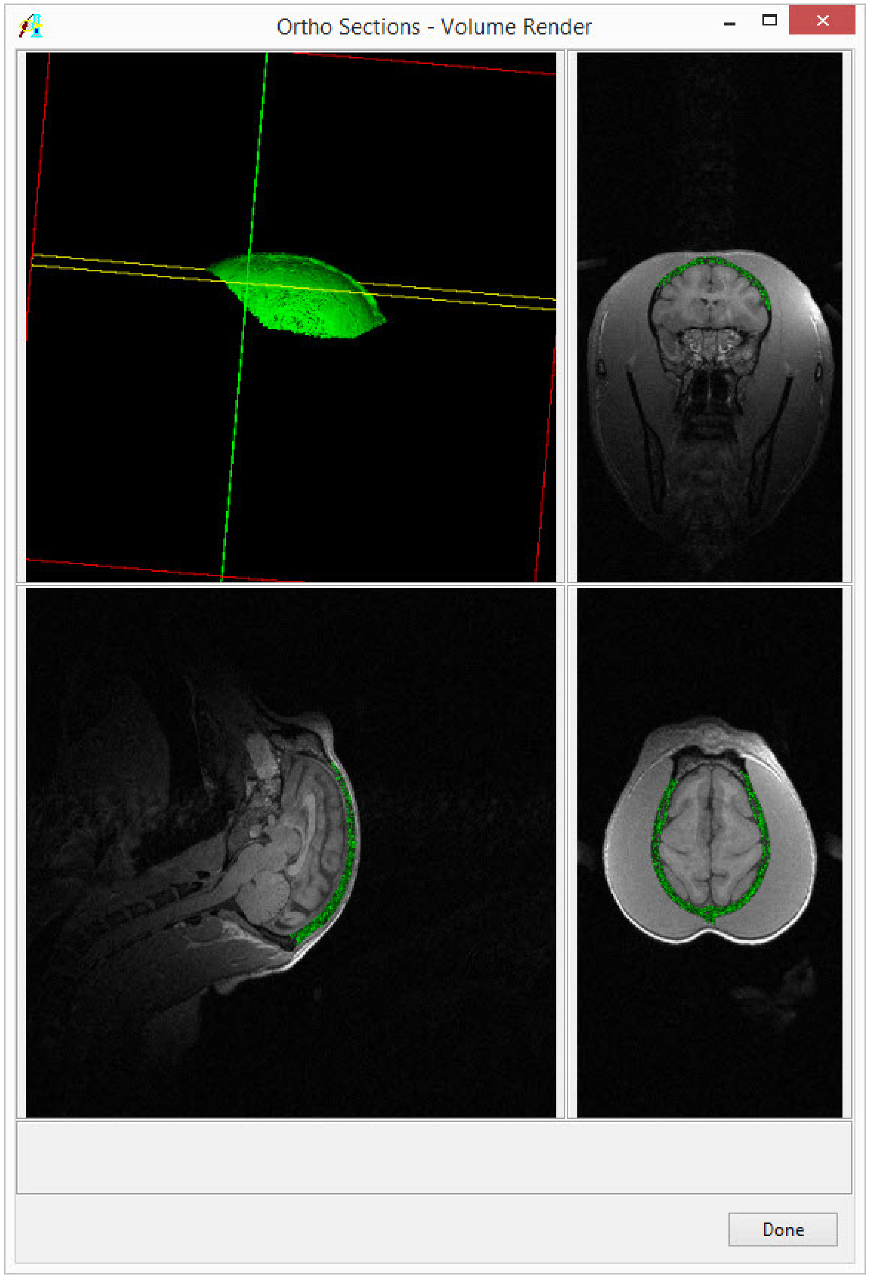
Select **View > Intensities > Loaded Volume**. In the Intensity window set Type to Object Color and then set Mode to Local Max/Min.



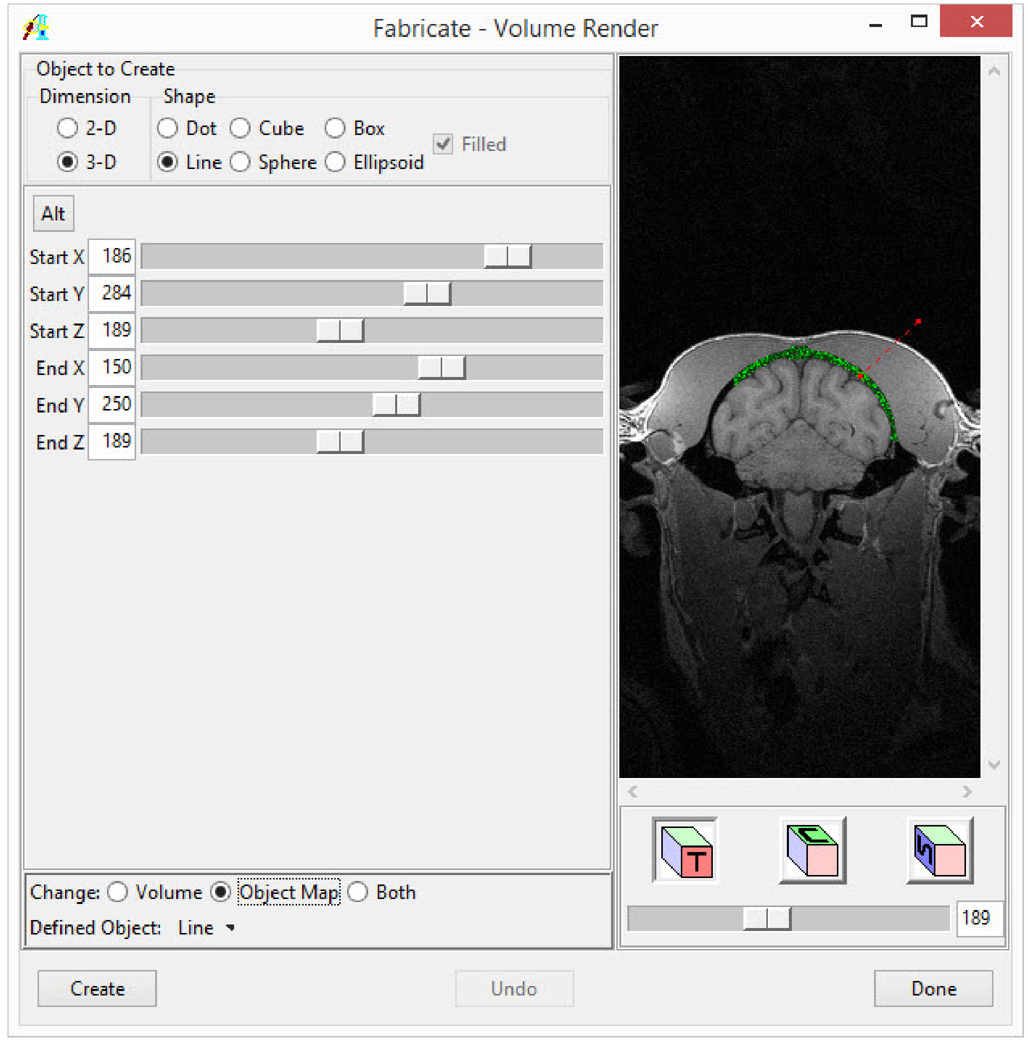
This Object Color display mode will display the segmented skull over the 2D grayscale slice data, which is necessary for optimal target vector placement.

Select **Tools > Display > Ortho Sections**. It may be necessary to increase the display size of the data. To do this, right-click on the rendering, then select Size and then the desired display size.

Note: the segmented skull can be seen as the green region of the 2D slices.



Select **Tools > Manipulate > Fabricate**. The Fabricate tool will facilitate the creation of the target vector object. In the Fabricate tool set the Shape to Line.



The Ortho Sections tool is linked to the Fabricate tool when both tools are open and can be used to accurately place the first point of the 3D Line object which will become the target vector object. Use the Ortho Sections tool to navigate through the image data or use the rendering to adjust the XYZ starting position of the 3D Line. Note that the position will interactively update in the Fabricate tool.

Once the first point of the 3D Line is positioned on the skull, the second point of the 3D Line can be positioned using the Fabricate tool. Set Change to Object Map, then set the Defined Object to Line, and then click Create. Note that the target vector will appear as a thin red line best seen on the 2D orthogonal slice data.

Close the Fabricate tool and the Ortho Sections tool and save the object map by clicking **File > Save Object Map**. The object map will be saved and used to generate surface files as described in the next protocol.

Surface Extraction

The goal of this procedure is to convert the skull and target vector objects generated in the first procedure from voxel-based volume image data to explicit surface description files. For this purpose Analyze will efficiently and accurately extract and represent a surface from the segmented objects, exporting these surfaces as STL files.

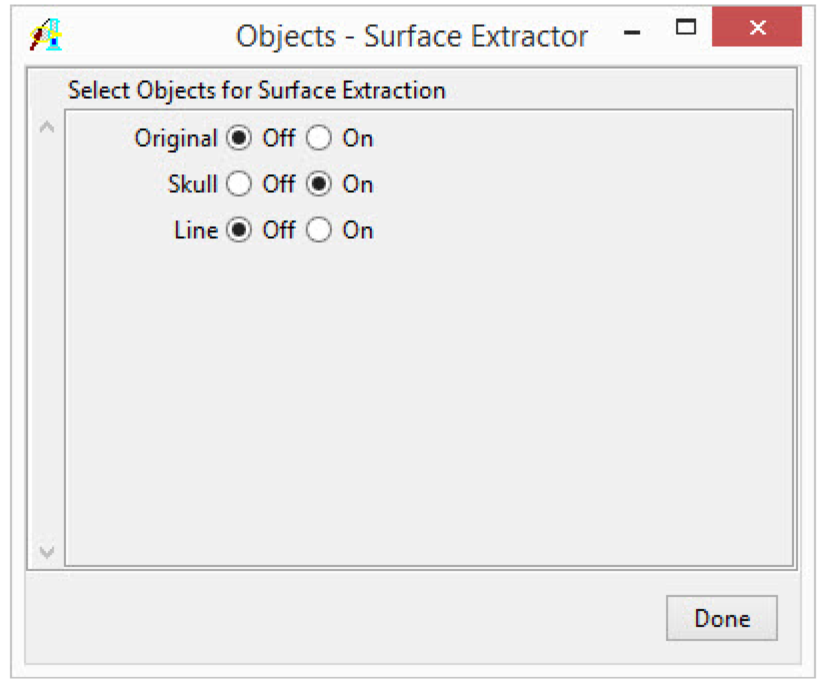
Select the data and then open **Segment > Surface Extractor**.

In the Surface Extractor module load the object map (**File > Load Object Map**) saved in the first procedure.

Select **Generate > Extraction** to open the Extraction Parameters window.

In the Extraction Parameters window select the Objects button to open the Objects window.

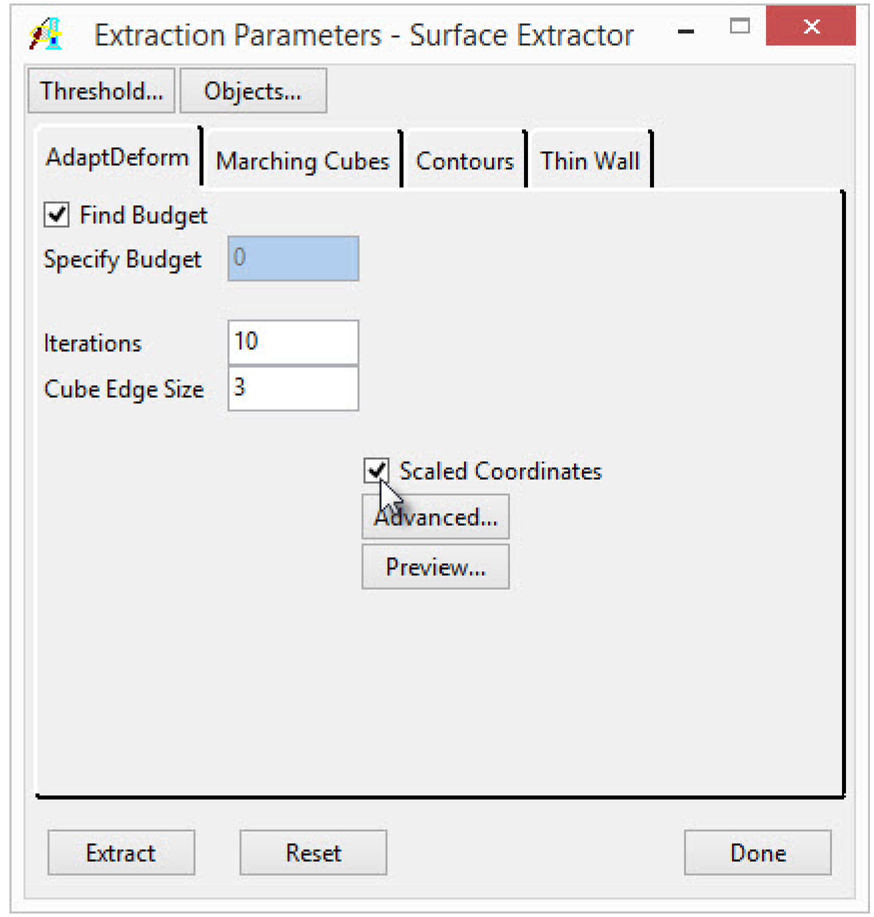
Set the Line (target vector) object to Off. The only object that should be set to On is the Skull.



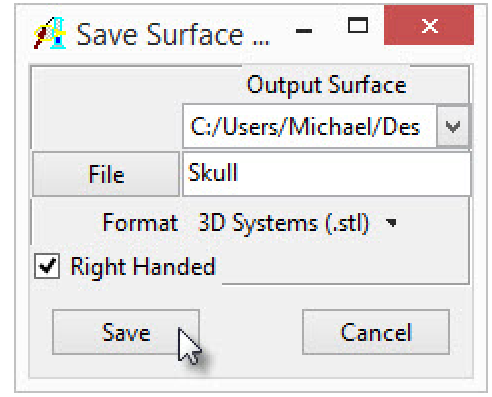
In the Extraction Parameters window make sure that the Scaled Coordinates option is checked. This will ensure that the surface file is generated in real world coordinates and not in voxel units.

Next click the Extract button. When the process is complete a window will be returned informing you of the number of polygons generated for this surface. This will initiate the surface extraction process.

Now click Done to dismiss the window.



Next click the Save Surfaces  button. In the Save Surfaces window select the File button.



In the window returned, navigate to a destination to save the surface file, then name the file Skull and click Save. The window will close. In the Save Surfaces window set the Format to 3D Systems (.stl) by selecting this option from the drop-down menu and then click Save. The skull surface file will be saved out of Analyze in the STL surface description file format.

In the Objects window, set the Skull object to Off and the Line object to On.

Repeat the previous steps to extract and save the surface out of Analyze in the STL surface description file format. Remember to name this surface file Target Vector or Line.

References

1. G. H. Mulliken, N. P. Bichot, A. Ghadooshahy, J. Sharma, S. Kornblith, M. Philcock, and R. Desimone, "Custom-fit radiolucent cranial implants for neurophysiological recording and stimulation," *J. Neurosci. Methods*, Dec. 2014.

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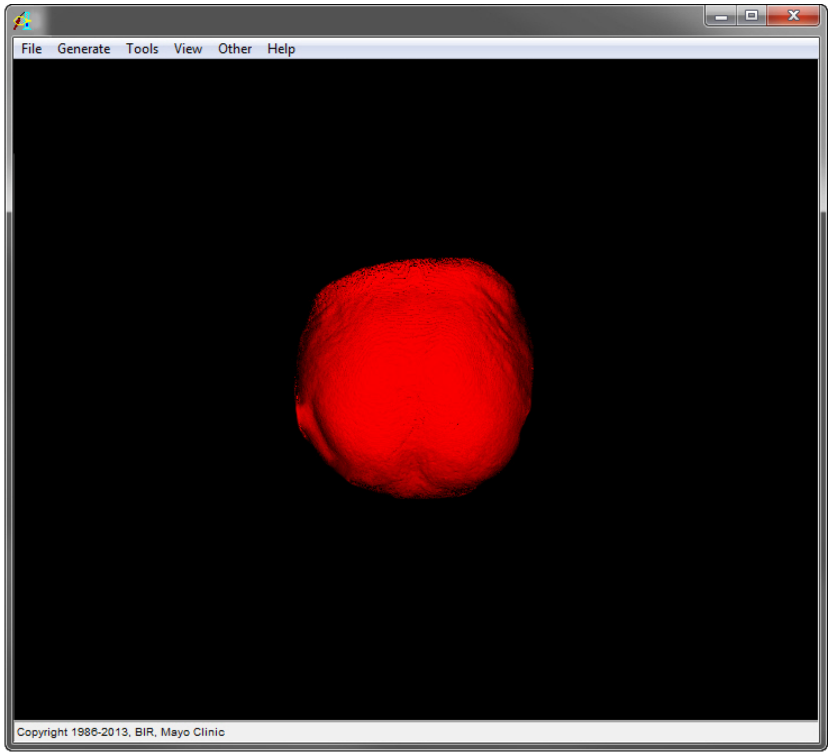

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