

BUILDING AN ASSURANCE CASE FOR
AORTAGEOMRECON SOFTWARE

BUILDING AN ASSURANCE CASE FOR AORTA GEOMETRY
RECONSTRUCTION SOFTWARE

BY
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TITLE: Building an Assurance Case for Aorta Geometry Reconstruction Software

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Abstract

Assurance cases has been proven to be effective developing a real-time system software.

Another domain that requires the high standard correctness, completeness is medical software.

Throughout the development of the Aorta Geometry Reconstruction software, we implicitly listed the evidences that are essential to build our confidence in the software for assurance cases, build the artifact and the evidences simultaneously.

Finally, we present this software with the list of the evidences built for assurance cases, to show that the assurance cases can apply well on the medical software

Your Dedication
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Acknowledgements

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Notation, Definitions, and Abbreviations

Notation

$A \leq B$ A is less than or equal to B

Definitions

Challenge With respect to video games, a challenge is a set of goals presented to the player that they are tasks with completing; challenges can test a variety of player skills, including accuracy, logical reasoning, and creative problem solving

Abbreviations

AortaGeomRecon

3D Slicer’s extension module, Aorta Geometry Reconstruction

SRS

Software Requirements Specification

MG

Module Guide

Declaration of Academic Achievement

The student will declare his/her research contribution and, as appropriate, those of colleagues or other contributors to the contents of the thesis.

Chapter 1

Introduction

This chapter includes an introduction for AortaGeomRecon assurance cases study. In section [1.1](#), we are discussing the objective of this case study, and this documentation. In section [1.2](#), we are explaining some terms and definitions used throughout this document. Section [1.3](#) discussed about the problem statement, and finally section [1.4](#) gives the brief outline for this document.

1.1 Objective

In this study, we present the result of applying of assurance cases in a developing medical software to build the stakeholders' confidence in this software.

1.2 Background

Aorta is the largest artery that carries blood from the heart to the circulatory system. It has a cane-like shape with Ascending aorta, Aortic arch and Descending aorta.

Unlike the real cane stick, the descending aorta might not be straight for each patient.

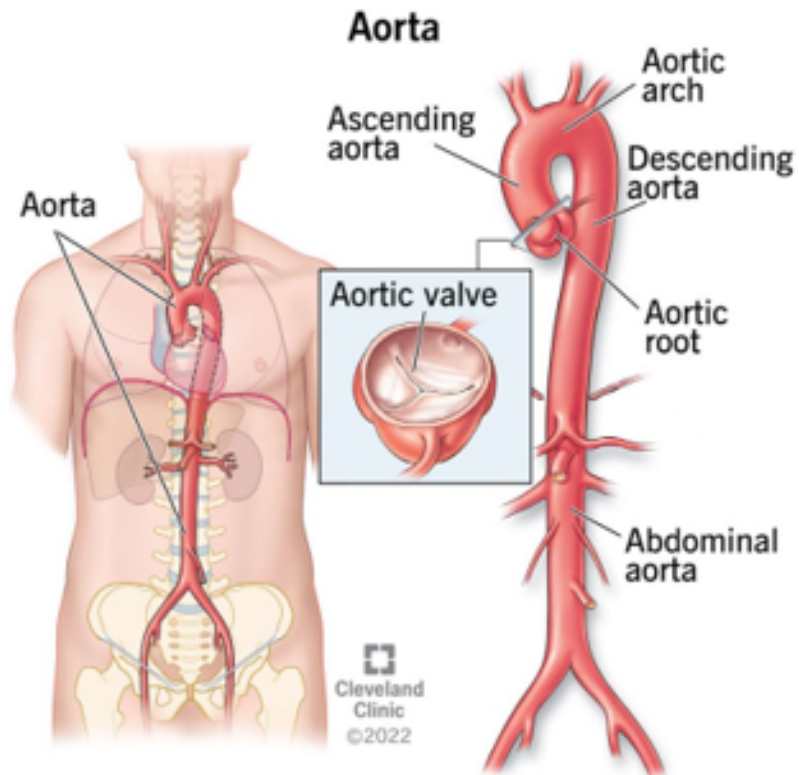


Figure 1.1: Aorta

Aorta segmentation in CT scans is important for:

- Coarctation of the aorta
- Aortic calcification quantification
- To guide the segmentation of other central vessels.

Assurance cases

3D Slicer

Image Processing

1.3 Problem Statement

The main goals of this project is building a software that can quickly build the 3D geometry of the Aorta from CT Chest scans, while applying the assurance cases for this academic medical software. This project shows the assurance cases can indeed help build up our confidence in the medial software in general, because medical software like real-time system software, needed completeness and correctness.

Build Software and Assurance cases for this software. Start with a list of Functional and Non-Functional requirements.

1.4 Thesis Outline

Chapter 2

AortaGeomRecon Research and Development

This chapter will discuss about the research and development of the AortaGeomRecon.

AortaGeomRecon stands for Aorta Geometry Reconstruction. The main objective of this software is to semi-automatically build 3D geometry of the Aorta from the patient's chest ct scans. The existing methods are often involved of extensive manual works by using a software with many steps. An experienced user, who might be a medical domain expert, needs to do a minimum of 10 minutes of manual works.

The implementation till the date of this report can let the users who have the user characteristics described in SRS ([Lin, 2023](#)) get the Aorta 3D geometry with only a few hyperparameters which can be set within half a minute, and the result requires maximum 2 minutes of execution time.

2.1 Existing Methods

There are many segmentation software available to the users, we will discuss the two main methods on two softwares.

2.1.1 ITK-Snap bubble method

ITK-Snap provides a segmentation method that first let user to select multiple voxels with a custom initial size and expanding size within any volume. We refer this method as “bubble method”.

Through many iterations, the voxels expand to fill the entire volume, finally user will need to cut the extra part of the volume. This [Figure 2.1](#) shows the ITK-Snap UI executing the segmentation.

The advantages of the bubble method is that it guarantees to produce a correct segmentation result. A medical domain expert can manually control the wanted area, and visually observing the segmentation result expanding, shrinking and the user can erase the unwanted part.

The disadvantages of this method is that the operations described above are complicated. Easier to say than do, an operator who has previous experience building the geometry with this method still needed 20 minutes of manual work building a new aorta geometry. Plus, ITK-Snap software can only read VTK file, therefore the chest CT scans are usually DICOM needed a manual conversion before using this software and its segmentation method.

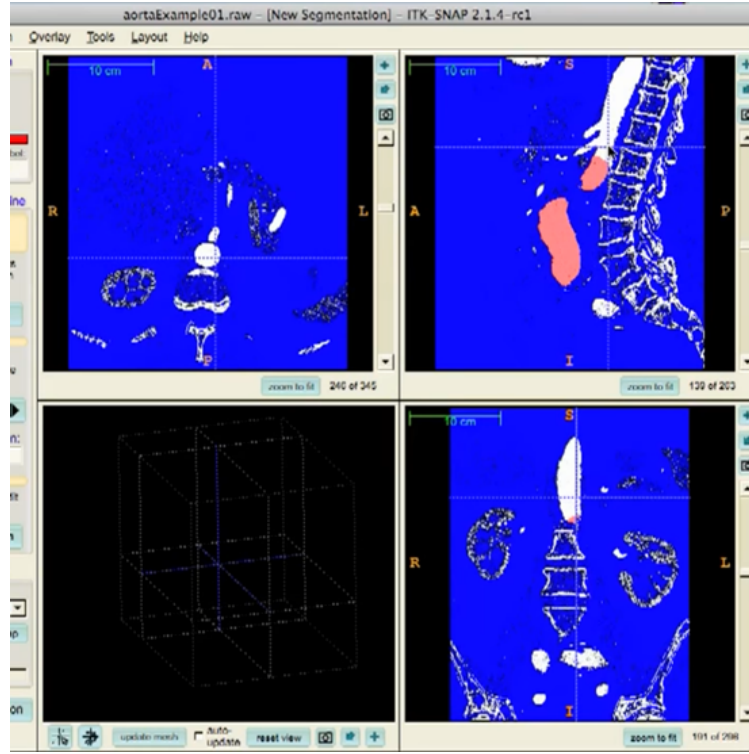


Figure 2.1: ITK-Snap's Bubble segmentation method

2.1.2 3D Slicer intensity interval segmentation

3D Slicer is another well-known medical image processing software for academic. 3D Slicer provides multiple segmentation methods, and one of the quickest and easiest to use is the intensity based segmentation.

This method first let user select a small area that belongs to the wanted area on a 2D plane (Axial, Sagittal, and Coronal). 3D Slicer read the pixels' intensity of the surrounding area, and segment based on the intensity. Any pixels's intensity that is within the range will be segmented as the segmentation result.

Like the bubble method, this method often reads extra volume, and requires user to cut the unwanted parts. A Youtube video shows an experience user who gets the

aorta 3D geometry with 10 minutes of manual works.

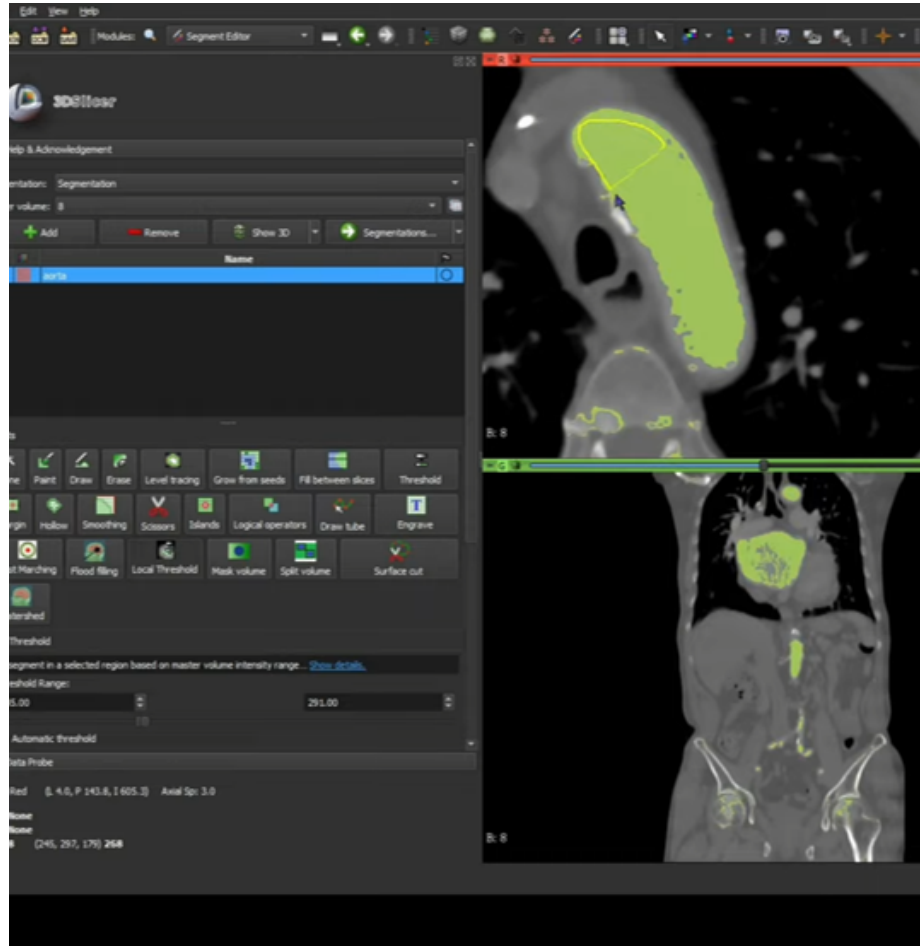


Figure 2.2: 3D Slicer BuiltIn Segmentation Method

2.2 Segmentation Algorithm

This section introduces the key concepts of the implementation on the segmentation algorithm. The algorithm is developed in Python, by using external libraries including SimpleITK and Numpy.

2.2.1 Background

SimpleITK is an open-source multi-dimensional image analysis library Developed by the Insight Toolkit community for the biomedical sciences and beyond. NumPy is the fundamental package for scientific computing with Python, especially for the performance on multi-dimensional array processing. The algorithm will use functions from these two libraries for image processing and multi-dimensional array processing.

The algorithm works best with the chest volume cropped to a rectangular prism that contains the aorta and parts of the other organs such as the backbone, blood vessels, and the heart. This can be done with 3D Slicer and its builtIn modules, Volume rendering and Crop Volume.

At the beginning of the algorithm, the user inputs two integer coordinates indicating the position of the descending aorta and ascending aorta centre on a single slice. This algorithm segments each slice with `SITK::ThresholdSegmentationLevelSetImageFilter`. The principles of this image filter can be explained with two terms: Level sets segmentation method, and a threshold range that defines the intensity of the acceptable pixel. The following steps elaborate on how the algorithm calculated the necessary values to perform segmentation.

For each slice starting from the user's selected slice, going in the inferior first, then superior direction:

2.2.2 Algorithm Overview

Label Map

The algorithm uses `SITK::BinaryDilateImageFilter` to perform binary dilation to generate a circle-like shape around the centre coordinates (user input's or calculated by

the algorithm). Each pixel within this shape will be labeled as a white pixel (value of 1), and the rest of the pixels are labeled as black pixels (value of 0). The generated result is the label map image, and we will use it in the next few steps. The size of the circle-like shape is determined by the kernel size.

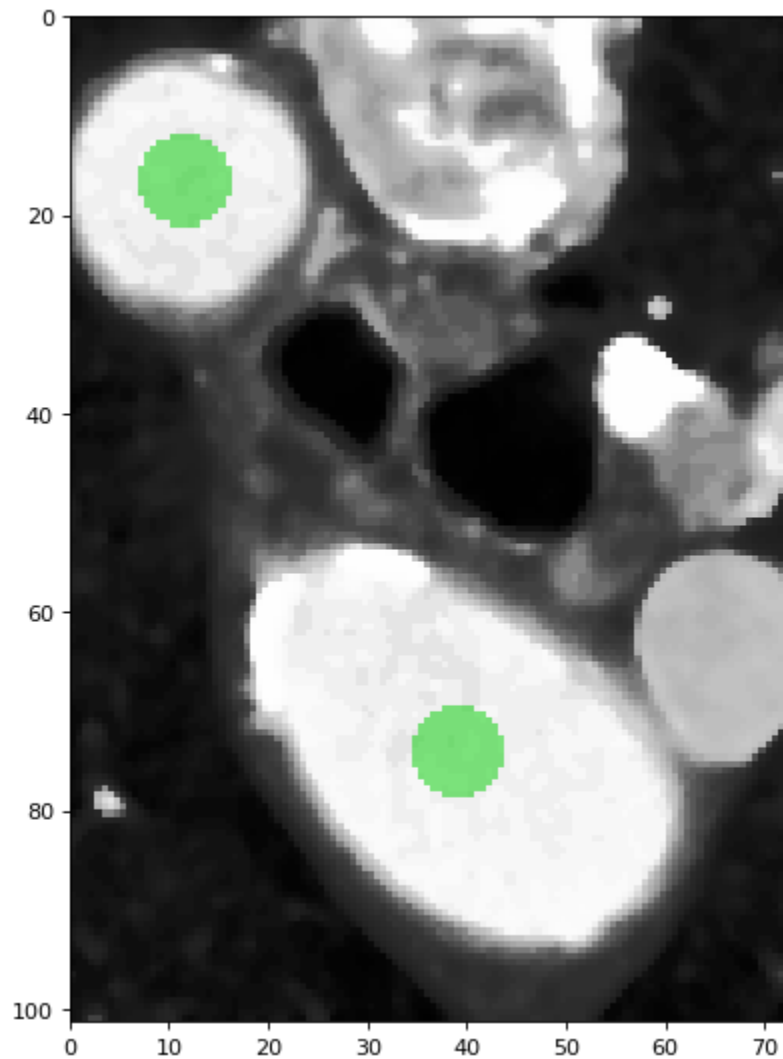


Figure 2.3: A label image

Distance Map

With `SITK::SignedMaurerDistanceMapImageFilter`, the algorithm creates another image, the Euclidean distance transform of the label image. This is used as a contour line that helps build the gradient mentioned in Level sets.

Calculate a threshold range

By using `SITK::LabelStatisticsImageFilter`, the algorithm gets the mean and the standard deviation of the intensity values of the pixels that were labeled as the white pixel in the previous step. The algorithm uses threshold coefficient to calculate the lower and upper threshold to be used in the next step.

Segment a single slice

With `SITK::ThresholdSegmentationLevelSetImageFilter`, the seed image calculated in step 2, and the lower and upper threshold value calculated in step 3, the algorithm performs segmentation and generated a segmented slice.

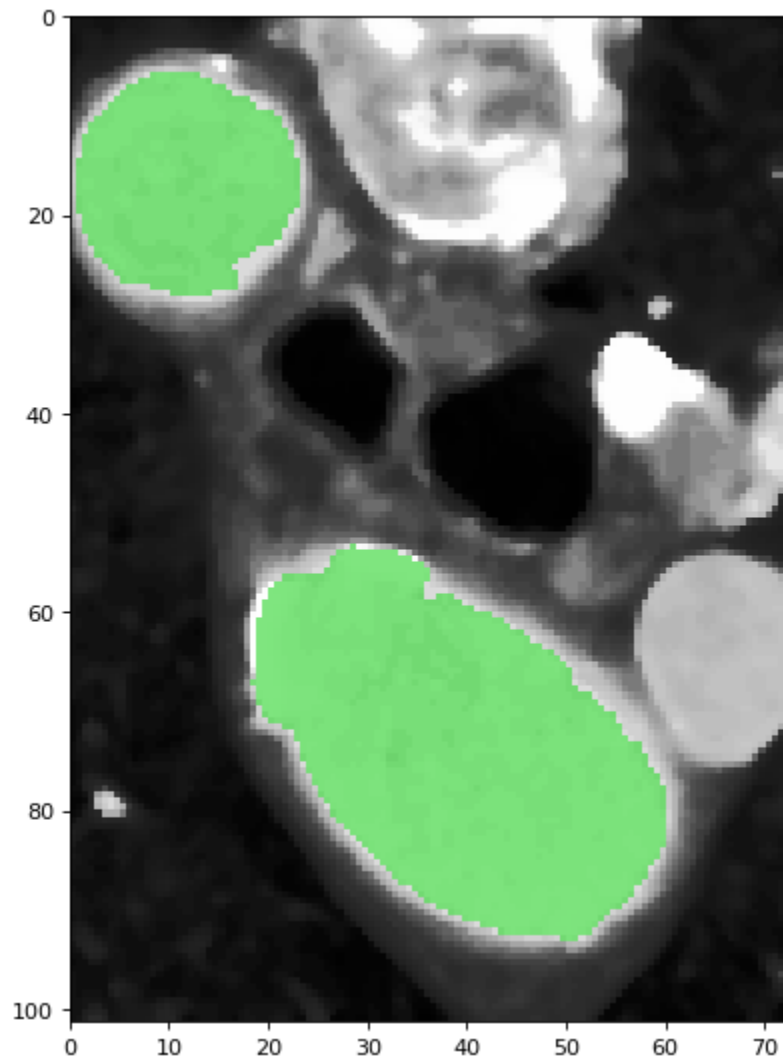


Figure 2.4: A segmented image

Calculate new centroids

By comparing each pixel segmented as aorta to the previous descending centroid and the previous ascending centroid, the algorithm use the positions of the points closer to the previous descending centroid to calculate new descending aorta centroid, and vice-versa for the ascending aorta centroid. However, at certain point during the

segmentation in inferior direction, the slice might reach the end of the ascending aorta, where the voxels belong to the part of the heart. The algorithm will stop using ascending aorta centroid and only compute descending aorta centroid for the slices afterward.

2.2.3 Parameters

The main parameters inputs from the users are:

- The centre coordinates of Descending Aorta and Ascending Aorta locate on the same axial plane
- The stop limit which controls the stop condition
- The threshold coefficient which controls the segmentation acceptable intensity range
- The kernel size which controls the init size
- The threshold Segmentation Level Sets Image Filter parameters, including:
 - The rms error
 - The maximum iteration
 - The curvature scaling
 - The propagation scaling

2.3 3D Slicer Extension Development

The project has started with the a simple segmentation algorithm build on the jupyter notebook. When getting a new patient’s data, the user will need to investigate the chest ct scans using another software (3D Slicer, ITK-Snap), to get the readings of the starting voxel and the size crop the volume, and get the index of the aorta seed. This Figure 2.5 shows an example of the aorta seeds.

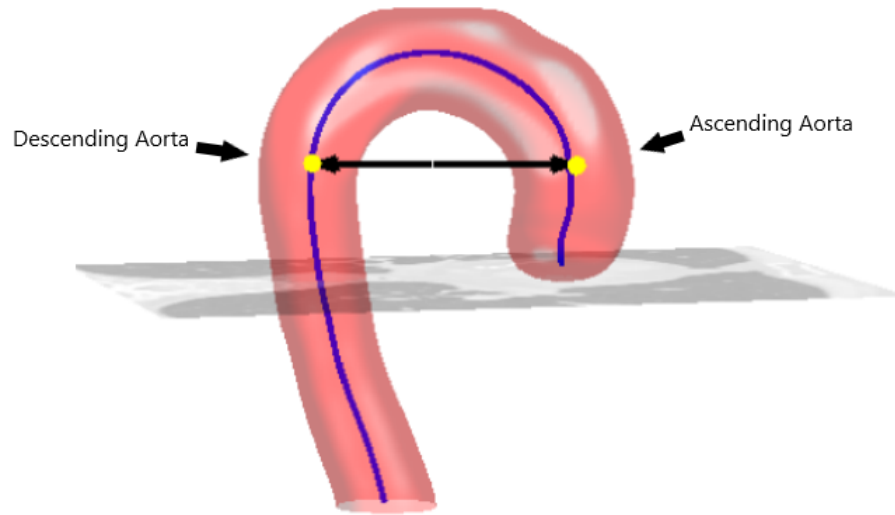


Figure 2.5: The aorta seeds ([Kurugol et al., 2012](#))

To improve the usability of the AortaGeomRecon (reduce the amount of time for user inputs and execution), we implemented an extension module on 3D Slicer.

3D Slicer is a open-sourced medical image processing software for research. 3D Slicer provides useful modules such as Crop Volume module and Volume Rendering module, and it’s highly modulizable with Python Scripting to control the extension module sequence, and QT designer to generate Graphical User Interface.

3D Slicer supports modulization with an extension. An extension is a software

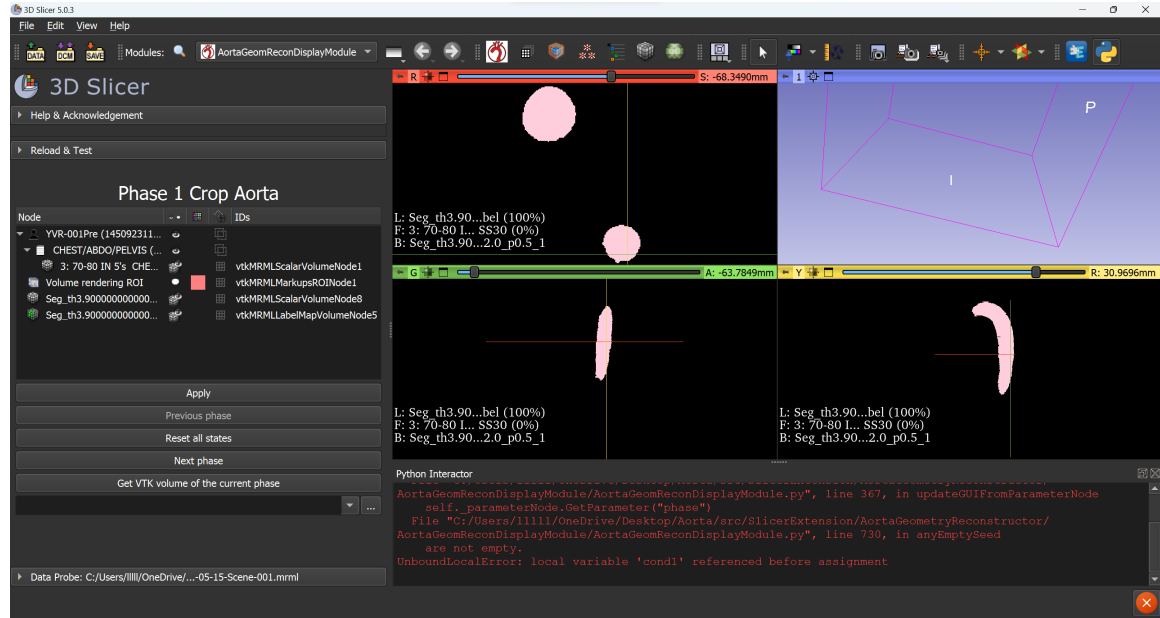


Figure 2.6: AortaGeomRecon UI phase 1

bundle that includes every modules to solve a specific medical image problem. An extension can compose multiple module, where each module is dedicated to solve a sub-problem.

2.3.1 3D Slicer's data structure

3D Slicer's Data Structure can be divided into two categories: Node for storing large data such as DICOM with a Volume Node, Volume rendering Region of Interest Node, Label Map Volume Node, and parameters are read from extension's module UI and are stored as string. Every data stored in 3D Slicer can be accessed by the 3D Slicer's Widget Class and Logic Class for further processing.

On a higher level, 3D Slicer stores all the above data in a scene object. 3D Slicer can load any MRMLscene file, this allowed user to retrieve all the data nodes and parameters. On the other hand, 3D Slicer has a special input module, the DICOM

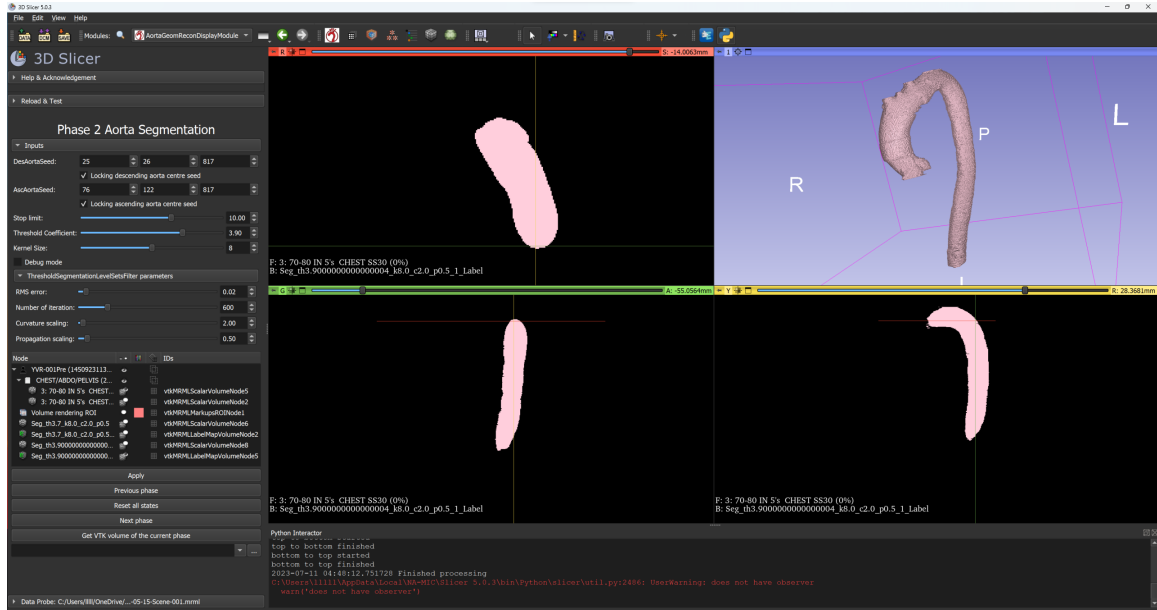


Figure 2.7: AortaGeomRecon UI phase 2

database allowed user to store DICOM metadata in 3D Slicer.

2.3.2 3D Slicer’s scripted module

Every ScriptLoadableModule in 3D Slicer have a Widget Class and a Logic Class. The Widget Class is used to initialize the extension module’s UI component, and the parameters tied to the UI component. The module’s Logic Class is used to perform the processing of the data. In the Logic Class, we initialize an AortaGeomRecon Segmenter object with the attributes set to the parameters reading from UI component, which are inputs by the user. After completing the segmentation with Segmenter object, we convert the SimpleITK image object to a volume node corresponding in 3D Slicer, which allow the user to visualize the segmentation result.

2.4 GitHub and Workflows

This project uses GitHub for version control.

GitHub issues tracker use to keep track the items to work on throughout the development of the project

GitHub Project is used for dividing a large issue into smaller tasks, expected date of the completion. This is useful for project management.

GitHub Workflow is a great tool for Continuous Integration tests.

We uses GitHub Workflow for Linter and Continuous Integration tests.

Chapter 3

Assurance Cases and Selected Evidence for AortaGeomRecon

3.1 Assurance Case Development

3.2 Assurance Case for Software Specification Requirements

- ([Lin, 2023](#))
- Goals
- Assumptions
- Data Definitions
- Instance Model

- Functional Requirements
- Non-Functional Requirements
- Traceability Matrix Between Different Sections
- Traceability Matrix Between Requirements and Other Sections

3.3 Assurance Case for Implementation

- Design Document
 - Sphinx - Python Documentation Generator
 - Comments in the source code
 - Algorithm Overview - Explanation and Program Workflow
 - Glossary
- Module Guide
 - Module Decomposition
 - Traceability Matrix between Modules and Requirements
 - Traceability Matrix between Modules and Source Code
- Test Case
 - GitHub Workflow
 - Continuous Integration tests
 - * build “Ground Truth Data”

- * Steps
- * Coverage

3.4 Algorithm Review

- Python Spyder IDE - Data Visualization and Debugging tool
- Algorithm Review with Kailin Chu
- Algorithm Review with Dr. Dean Inglis

Chapter 4

Conclusion and Future Works

4.1 Thesis Summary

4.2 Future Works

([Kurugol et al., 2012](#)) discussed about a segmentation workflow that required less hyperparameters.

Appendix A

Your Appendix

Your appendix goes here.

Appendix B

Long Tables

This appendix demonstrates the use of a long table that spans multiple pages.

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- Jingyi Lin. 2023. System Requirements Specification. <https://github.com/smiths/aorta/blob/main/docs/SRS/SRS.pdf>.