Automatic Brain Segmentation for 3D Printing

Phase 1 Report

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Abstract

The objective of this project is to develop a fast and reliable method to create accurate personalized 3D models of the human brain, both geometrically and in terms of its physical properties. The pipeline for creating a the 3D printed version of a brain is as follows: obtain the MRI image file of the brain scan, upload that file to a 3D segmentation tool to create a 3D model of the brain, upload the new model into a meshing program to be adjusted and smoothed out as necessary, and finally, send the finalized model to a 3D printer to be printed. During Phase 1, the main area of focus was solidifying the business model as well as experimenting with different programs that can be utilized for the segmentation and meshing steps in the process. This report will outline in detail the current progress of the project and what steps will be made in the future to reach a final product.

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Project Statement

Motivation

Doctors go through years of medical school, residency, and professional training in order to acquire as much knowledge about the human body and its possible conditions as they can. This allows them to effectively trace and diagnose many different types of issues that a patient may come to them with. Their patients, however, likely have not gone through this training and thus cannot fully comprehend things such as highly intricate brain scans and technical language. This project is meant to bridge the gap between the technical knowledge of doctors and their patients by providing a personalized 3D model of the patient's brain. With this model, doctors will have an accurate reference to use for educating their patients on any tumors, decay, surgical plans, etc. to hopefully alleviate the stresses caused by uncertainty. And, the fact that the model is of the patient's brain and not just an arbitrary model allows for doctors to be more precise with their explanations and, in turn, be more informative.

Goals and Objectives

The overarching goal of this project is to develop a method that can take the scans of a patient's brain produced by a magnetic resonance imaging (MRI) machine and use them to 3D print an accurate model of said brain. While this may sound simple, it is a multistep process that will require a lot of research, trial, and error to optimize and make it precise yet efficient. The process, itself, currently requires the consumer to manually put the MRI images into a 3D segmentation tool to create a 3D image of the brain, use a meshing program to smooth out the image and make it more realistic, and finally, convert that image into a file that can be 3D printed. Each of these steps require the utilization of a separate computer program, and the images must be manually edited to form an accurate representation of the brain. This team will explore as many of the current programs, or combinations of programs, as possible in order to find the most optimal one for the scope of this project. As it progresses, the goal will then be to convert the manual process into a fully automated process that can produce the same level of accuracy.

Providing an accurate model of the brain does not only rely on getting the correct shape, however. It also requires the use of a material that resembles the brain and its physical properties. Another goal of this project will be to find a material to use for the model that is cheap, able to be 3D printed, and mimics the physical properties of human brain matter.

Potential Issues

One of the biggest issues facing this project is defining the scope of it and making certain the goals are substantial yet achievable. The initial business model was to create 3D printed models of the brain that can be utilized in an educational setting to teach higher education students about the anatomy of the brain and possibly be used to demonstrate medical procedures. While this would be an incredibly useful tool and very helpful in this setting, it is simply not feasible to create a model which is that reliably accurate with the time and resources that are currently available. The plan was then oversimplified and pitched as a souvenir for patients receiving some sort of brain-related procedure or treatment. This was quickly deemed undesirable and below the means that will be able to be produced in this time frame. Finally, the business model that has been settled on is that the brain should be accurate enough for a doctor to be able to use it for demonstrations to their patients, but it does not have to be so realistic as it would have to be for medical education purposes.

The project also presents a few technical challenges. Since these 3D printed brain models have to be accurate, it is essential to have a very good understanding of the anatomy of the brain. This group is composed of mechanical engineers, so exposure to this subject is limited and will require a lot of research to become adept enough to spot potential errors along every step of the 3D printing process. Speaking of which, there are quite a few steps in the process of 3D printing a brain and issues can potentially occur anywhere along the way. It is going to be a significant challenge to keep every step of the process in check and make sure that the model is always where it needs to be before moving onto the next step. This will be especially difficult when eventually automating the process, since it will ideally be completely automated with no manual input needed. Since the models are personalized to the individual patient's brain, there is not a set standard that can just be applied to every model. Every brain is different, whether it's the folding or there is a tumor or decay, so the automated process must be able to adapt to these changes and still produce an accurate model. Finally, challenges will be faced when trying to make the entire process intuitive. Currently, there are many different programs that must be used and all require specific training to be able to be used effectively. In optimizing this process, the usability of the programs must be considered so the consumer will easily be able to pick it up and implement it. When researching possible programs to build off of, it will be useful to find one that is already fairly intuitive so there are less steps to optimize it.

In order to effectively evaluate the process developed by the team, a prototype needs to be created that validates the process. However, some challenges may appear when trying to create a prototype. Firstly, there will be difficulty in automating the segmentation process to make it quick and efficient enough to be able to print a 3D model quickly. Some software is quite costly, which for now limits the software options to free ones. Additionally, the printing process will have no me optimized to reduce as much printing time as possible. While printing may be left overnight, the iteration process would be somewhat slow and problems could arise in the middle of the night when no one is there to oversee.

Literature Review

State-of-the-Art Review

The team began its research by looking into any other person or company that attempted to accomplish a similar process in terms of steps from scan to print. In doing this the idea was to try and gain more information on the different softwares that can be utilized and gauge which one would be more beneficial for the type of model we are looking to create. The team started by utilizing google searches targeted at “3-D Printed Brain Models”, and “3-D Print your Own Brain”. The results of these led to finding youtube videos along with certain companies that 3-D print brains. This allowed for easy access to the processes in which these similar ideas were conducted along with the prices they were sold and some responses or feedback they received.

The first video that was analyzed demonstrated a specialist who shared a similar outcome that is desired of the team, taking an MRI scan and turning it into a lifesize model of the brain. The process explained was non automated and utilized the program Osirix primarily along with other programs such as blender and netfabb in order to clean up the model. Osirix was described as an easy program to learn with many different features that can be useful in creating the most accurate model. Also this program deals with DICOM series images. After looking at the comments on this video from other people there was much interest in the idea along with some comments about the process taking too long for people who tried to replicate it. This was an issue that has been identified by the team as a major feature that needs to be fixed.

The discovery of the specialist revealed that this concept of 3D printing a brain from an MRI scan has been thought of before and that there is interest in this idea. Further market research conducted allowed the group to find the company *Brains3D* which is a company that primarily sells on Etsy. The person behind this company is a neuroscientist who prints the brains scans of people that are sent to him. The process in creating this print is described as manual and takes a significant amount of time of at least two weeks to create, however the prints are accurate to the 1mm scale. Each print is sold for 250 dollars and a choice of 11 different colors to print in is given.

Figure 1: 3D Print from Brains3D

Another company that was found who also primarily sells on Etsy was *TheBrainCenter*. The main idea for their company was to use a standard brain MRI that would be sold to customers, however if desired they also offered the option for personalization if the customer uploaded their personal MRI to the seller. There is no information on the program or software that was utilized in order to convert the MRI scans into a 3D model that can be printed, however the material that is used for the brain is Polylactic Acid (PLA). This was chosen by the company due to the fact that it is biodegradable and is made from renewable biomass. The size of the brain is 25% that of an actual human brain sizing out at about three centimeters long.

Figure 2: 3D Printed Brains from TheBrainCenter

With continued research it was seen that the general trend was the majority of companies that were looking to sell these 3D printed models of brains whether they be personalized or not used Etsy as the selling platform. The last company that was looked at took a different approach to marketing their products. Instead of selling them as a gift or desk item for people that wanted something unique, *MedicalModddels* is a company that sold these 3D printed brains for educational purposes. The company sells all different 3D printed parts of the human body, including the brian. The brain model is made from a plastic material and is constructed at half the size of a human brain. The model is also printed in two pieces, two hemispheres, and can be attached together or taken apart to observe or learn more about the inside. While the main purpose is for educational purposes, the company offers the option of personalization.

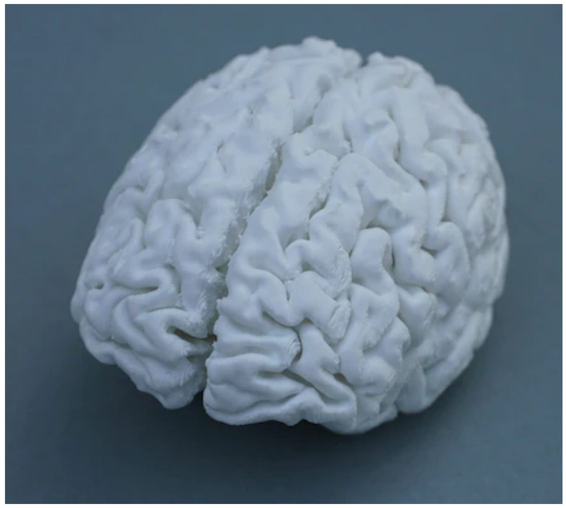


Figure 2: 3D Printed Brain with two hemispheres from MedicalModddels

In reading the reviews *MedicalModddels* received the feedback stating how there is an option of color coding different areas if that is desired. Also part of the educational options for this product, which is something the team is looking to target, was using the brain model for doctors or other medical professionals to demonstrate to their patients what the issues they are faced are along with how they are going to treat it. For this product the reviews stated that this concept is very useful in achieving these goals.

Overall in looking at all of these different products and company ideas the team was able to see different examples of which plans, materials and target consumers were effective.

Commercial Applications

Although there are other companies that were found to make and sell 3D printed brains that are both generic or personalized, they all lack one major feature. That feature is the fact that the process from brain scans to 3D print is manual. It is manual in a sense that someone has to use software to manually go in to correct flaws and smooth out the models to make them presentable. Having a manual process is what holds these companies back from producing high volumes of personalized 3D printed brains. This is the flaw that the team is looking to attack. Developing an automated process would allow the team to print large amounts of unique brains that are personalized for each individual that would receive them. The aspect of keeping it personalized would make the brain more meaningful to the recipient and more desirable to have. In order for competitor companies to print high volumes of brains, previously developed models would have to be relied on, making those brains generic to the buyer. The only way to make them personalized is through that longer manual process which is unable to compete with a faster, automated one.

<u>**Needs and Specifications**</u>

Societal

The purpose of this project is to provide doctors with a physical model of the brain so they can then use it to educate their patients on what exactly is going on in their heads. This can have an immense impact on the medical and civilian communities. One of the most important attributes that defines a great doctor, aside from their technical knowledge, is their ability to convey highly technical information to their patients in an easy to understand manner. As previously stated, most patients have not gone through the extensive schooling and training that doctors go through in order to understand complex medical phenomena. It is for this reason that doctors often make comparisons from their findings to things that are generally known by the public, for instance comparing the size of tumors to fruit. With a 3D printed model of the patient's actual brain, doctors will be able to reference what they are talking about on an accurate representation of the exact brain in question. This will make both the doctor's job of explaining complex information to the patient and the patient's understanding of that information a much easier and more comprehensive process.

Stakeholders and Needs

Primary stakeholders are those who hold influence over both the project and its success, while secondary stakeholders have a non direct influence on the product and no stake on the project's success. For this project, the primary stakeholders are:

- Stevens Institute of Technology
  - Project Team: Achira Fernandopulle, Bailey Gano, Leo Musacchia, Nicolas Re Nathan Carpenter
  - Advisor: Johannes Weickenmeier
  - Senior Design Review Board
  - Mechanical Engineering Department
- Secondary Stakeholders
  - Target Customers: Doctors, nurses, patients, relatives of patients
  - Supplier of Materials
  - 3D Printer Company

As these brain models will be specific models of a patient's brain, there are some specifications that have to be made in order to establish a strong base for the project. Firstly, the dimensioning of the brain model should be relatively 1:1, as having a realistic sized visual will better aid doctors use the model for explanations. Additionally, having a 1:1 model will be more impactful as a gift rather than a much smaller model. The model should also be durable and sturdy, light, and aesthetically pleasing. Meeting customer needs and demands are crucial in creating a successful project and product, as customers won't buy a product that doesn't fit their needs, no matter how "good" the product may be.

Index	**Category**	**Need**	**Priority (1-5)**
C1	Cost	Model is relatively inexpensive to make	5
D1	Design	Model is realistically sized	5
D2	Design	Model is durable	4
D3	Design	Model is aesthetically pleasing	1
D4	Design	Model is resistant to long term exposure to air	3
P1	Performance	Model is accurate enough to serve as general visual	5
S1	Safety	Model painted with non-toxic material	2

Table 1: Customer Needs Chart

Concept Selection/Generation

In order to get from an MRI image to a 3D printed brain, there are a few steps that must be taken. First, the file containing the information gathered from the machine must be acquired. There are 2 main forms that this file can be packaged in, DICOM and Nifti, both of which have their own pros and cons in terms of their usability moving forward in the process. When an MRI scan is saved as a DICOM series, the images of the brain are 2-dimensional slices which can be stacked to form a 3-dimensional model (shown in the figure below). DICOM is an industry standard and one of the most widely used types of file in the medical field, so most of the 3D segmentation tools (which will be discussed later in this section) are compatible with it. While it is a hassle to prepare every slice to be combined into a single rendering, using a DICOM file will have the ability to produce very accurate models because the segmentation process will be so detailed.

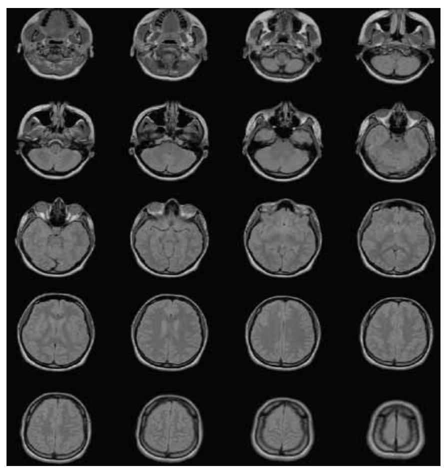


Figure 3: Slices of a Brain Images as would be seen in a DICOM File

Nifti files, on the other hand, are saved as 3D images instead of stacks of 2D images. It was developed specifically for neuroimaging purposes and is well suited for sharing and analysis. The downsides to using Nifti files are that they require extra conversion steps and will likely cause difficulty when refining the image because, instead of having a series of nicely portioned out images, all of the anatomical fixes will have to be dealt with simultaneously. In order to choose the best file type, however, the 3D segmentation tool must first be chosen and each of the file types experimented with inside of that program.

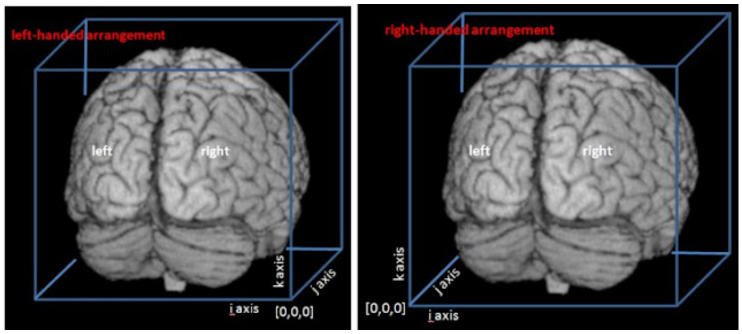


Figure 4: 3D Rendering of the Brain as would be seen in a Nifti File

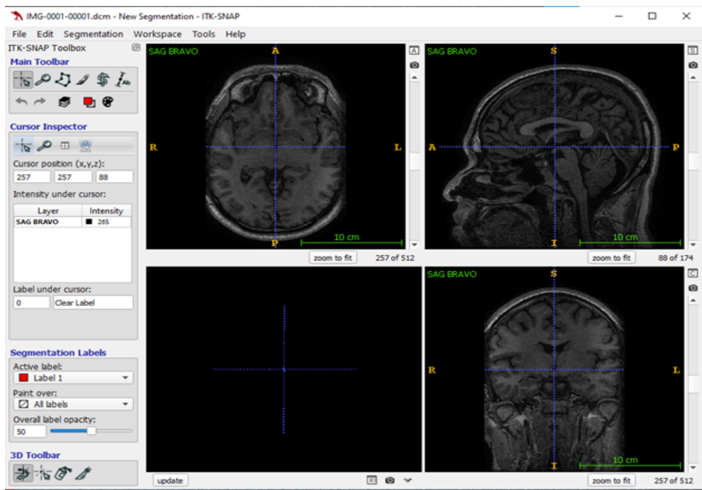
One of the most important steps in our project has been determining which software program we would be using. Initially, The team has limited our search to free programs in order to determine whether this idea is worth exploring further. So far we have experimented with ITK Snap's auto segmentation tool. This tool was incapable of handling the DICOM series. It would crash during the auto segmentation process. Next we will be looking into 3D Slicer and Free Surfer. Our team has had some trouble using Freesurfer because it is not compatible with Windows Operating Systems, but we have been exploring ways to work through this.

In order to determine which program will best suit our needs, the team will be grading their performance in a few different categories. Automatization, 3D visualization and Segmentation time will all be important parameters. Automatization determines how repeatable our model creation will be. We want to ensure that the software we select is capable of converting MRI Images into 3D models efficiently. 3D Visualization is another aspect that we will use to select our software program. This determines how clear the models can be seen once they have been created. While we do have tools such as Meshmixer that can help to improve the quality of the model, it is important that we do not rely heavily on this as it could possibly distort the results. Segmentation time will play a major role when we choose our software program. We want the printing process to be quick so that we can print more brains. Quality is more important than speed, however. The team will not sacrifice quality for speed.

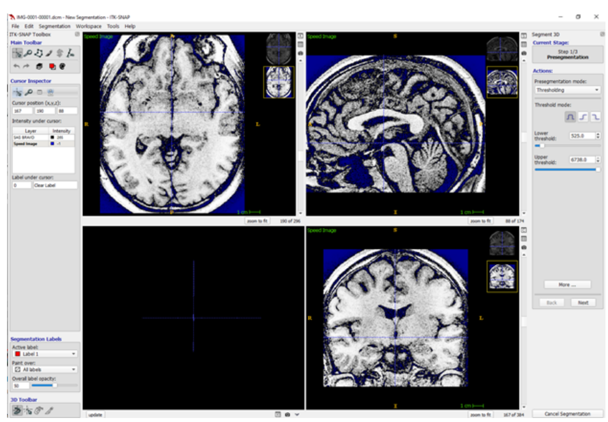
Pipeline for Model Creation

1. Obtain MRI Image File (DICOM series Image or NIFTI File)

2. Upload the file to the Segmentation Software Program

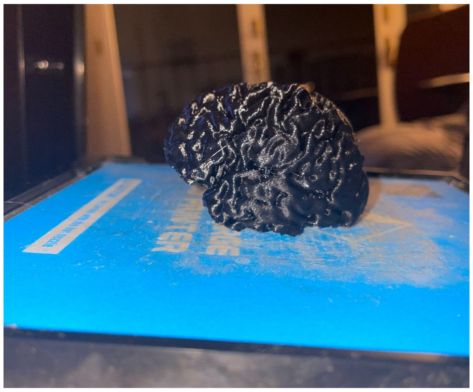


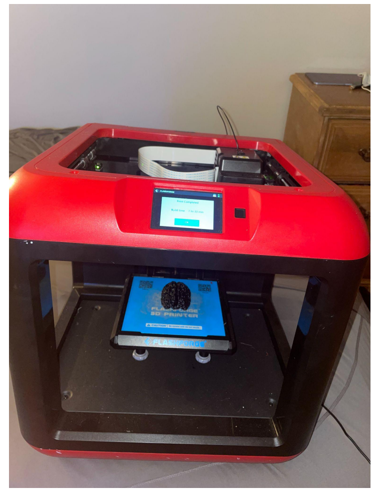
3. Create an accurate model of the brain using the contrast of colors between white and grey matter



4. Once the model is created, upload to Meshmixer to be finalized. This includes determining if support material will need to be generated and if a raft will be needed underneath the model.

5. Save the model in Meshmixer and connect to our Flashforge Finder 3D printer





Technical Analysis

Areas for Phase 2

Once the needs and specifications have been identified, the next crucial step is to identify areas of interest to further explore.With the completion of Phase 1, a general pipeline process for taking an MRI image and creating a 3D model from it was created. To complete the technical analysis, the team will need to tackle areas related to the segmentation process and automation, as well as potential printing and painting materials.

Exploring the segmentation software and determining the most suited one is a crucial step in the project's timeline. The team aims to explore and implement a segmentation process that is more automated and efficient than what is being currently used at Stevens (ITK Snap and manual segmentation). It is an imperative to explore this area because it allows the pipeline process to be more quick and streamlined. Manual segmentation can be tedious and time consuming, so to create a more reliable and appealing product, the segmentation needs to be as automated as possible.With the saved time from automated segmentation, more personalized brain models can be made and sold.

The material that the brain model will be printed out of is another crucial aspect of the product and an important customer need to address. The brain model will generally be printed from 1 material, and it is crucial that the material the team selects creates a model that meets the customer demands. The team will need to explore the possible materials that create a rigid, sturdy, and durable model that is still relatively lightweight and aesthetically pleasing. Many material properties will need to be analyzed and compared following Phase 1. The team will also need to explore different paints or materials to color the brain model. It is crucial that the model is colored with non-toxic materials that are safe for customers to come into contact with. For example, some acrylic paints and oil mediums release dangerous chemicals where ventilation is required to maintain a safe atmosphere.

Previous Modeling

A summer research group from Stevens has previously attempted to 3D print a brain model. The group tested two different materials: ABS plastic and synthetic gelatin. The synthetic gelatin model was painted with a silicone rubber mold to give realistic coloring. The synthetic gelatin model was found to be much softer than the model printed with ABS plastic, which allowed the gelatin model to more closely relate to a real brain. However, the goal of this project is to create display brain models, so the team will aim towards finding materials like ABS plastic, which is sturdier and more durable than synthetic gelatin.

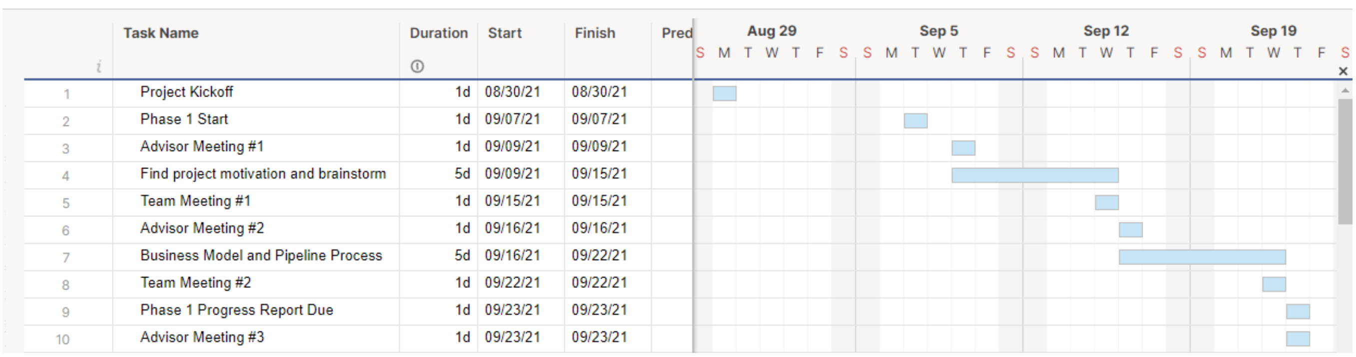
Project Plan

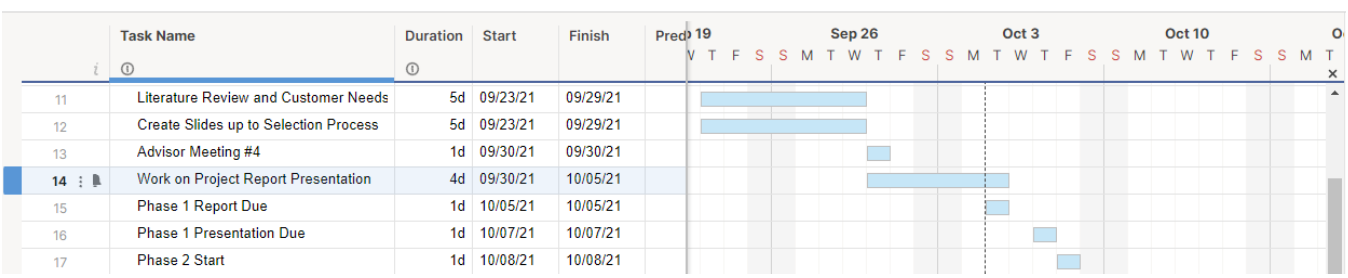
Deliverables

This project will run from the Fall 2021-Spring 2022 academic year. By the end of the first semester, the team will have completed Phases 1-3 with a project website being created in the second phase and an alpha prototype demo being presented at the end of the third phase. The last three phases will be completed in the second semester, with the fourth phase involving alpha prototype testing, the fifth phase involving beta prototype fabrication, and the last phase involving the final presentation and Innovation Expo.

Gantt Chart

In order to accomplish the phase and project goals in a timely and organized manner, the team has created a Gantt chart (in the figure below). The Gantt chart organizes and logs the team meetings, advisor meetings, and important deliverables and deadlines, such as the concept generation, report deadlines, and presentation deadlines.





	Task Name	Duration	Start	Finish	Pred
1	Project Kickoff	1d	08/30/21	08/30/21	
2	Phase 1 Start	1d	09/07/21	09/07/21	
3	Advisor Meeting #1	1d	09/09/21	09/09/21	
4	Find project motivation and brainstorm	5d	09/09/21	09/15/21	
5	Team Meeting #1	1d	09/15/21	09/15/21	
6	Advisor Meeting #2	1d	09/16/21	09/16/21	
7	Business Model and Pipeline Process	5d	09/16/21	09/22/21	
8	Team Meeting #2	1d	09/22/21	09/22/21	
9	Phase 1 Progress Report Due	1d	09/23/21	09/23/21	
10	Advisor Meeting #3	1d	09/23/21	09/23/21	
11	Literature Review and Customer Needs	5d	09/23/21	09/29/21	
12	Create Slides up to Selection Process	5d	09/23/21	09/29/21	
13	Advisor Meeting #4	1d	09/30/21	09/30/21	
14	Work on Project Report Presentation	4d	09/30/21	10/05/21	
15	Phase 1 Report Due	1d	10/05/21	10/05/21	
16	Phase 1 Presentation Due	1d	10/07/21	10/07/21	
17	Phase 2 Start	1d	10/08/21	10/08/21	

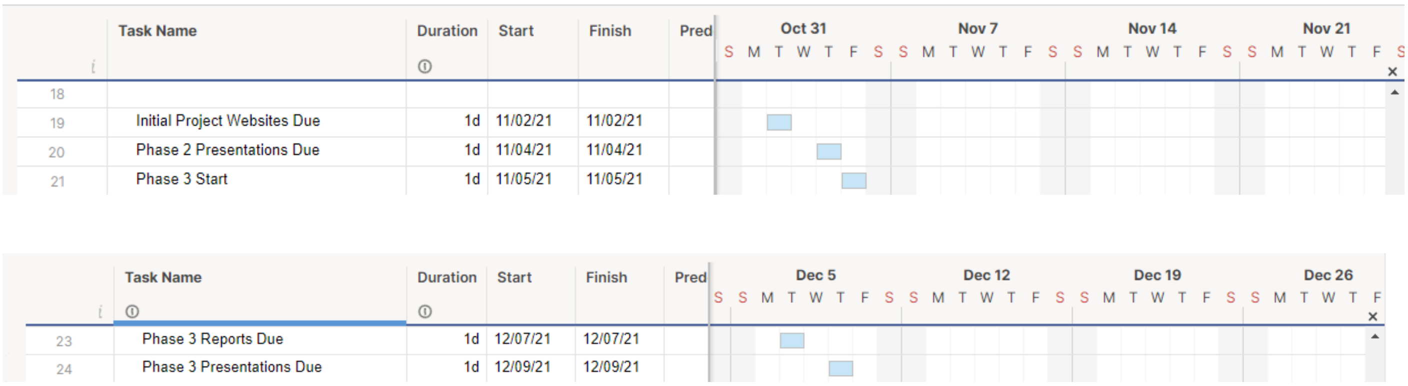


Figure 5: Gantt Chart

Budget

The budget for this project is the standard Stevens project budget that is given for senior design projects. There are no sponsors for this project. Additionally, at this stage, there is difficulty defining a budget, as the team still needs to identify the material that will be used and which segmentation software will be used. The main costs for this project will be from the printing material and the software license (if one is needed). As the project develops and the team gains a better insight, an accurate budget can be determined.

Conclusion

The team aims to create a method that will efficiently create 3D printed brain models from MRI scans. The team needs to find a way to automatically segment the MRI scans and find a quick way to print the 3D model. Additionally, there are experiments in material selection and software selection that need to be done in order to fully optimize the process. The goal is to create a viable prototype (in this case a 3D brain model created from MRI scans) that is viable and that can eventually be purchased and used by customers. In Phase 1, the team has looked into competitors in the market, identified the customer needs, brainstormed possible concepts, selected a general pipeline for the process, identified areas of exploration for the next phase, and created a timeline for the future of the project. There are software and material choices that are still left to be made, but the team will be focusing on aspects like those in the second phase.

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Appendix

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Table 2 Software comparison

Software	Automatization	Usability	3D visualization	Segmentation time	Registration	Tractography	OS		
							Windows	Linux	Macintosh
3D Slicer	3	3	4	15th	x	x	x	x	x
Anatomist	1	1	1	> 25 h			x	x	x
AW Server	3	3	3	> 20 h	x	x	x		x
Freesurfer	2	2	1	> 20 h	x	x		x	x
FSL	1	1	2	> 25 h	x	x		x	x
ImageJ	2	2	1	> 25 h	x		x	x	x
ITK-SNAP	3	4	4	10 h			x	x	x
Mango	1	3	2	> 20 h	x		x	x	x
MedInria	3	3	3	> 20 h	x	x	x	x	x
MIPAV	3	2	2	> 20 h	x	x	x	x	x
Myrian Studio	3	3	4	9 h	x		x		
Olea Sphere	3	33	4	> 20 h	x	x	x	x	x
OsiriX	3	3	4	> 20 h	x				x
Seg3D	2	4	3	20 h			x	x	x

A1: Comparison Table of Segmentation Software