

*DGMD E-599, Fall 2019: Digital Media Design Capstone Studio*

# **3D-Printing the Brain for PubMed Interactivity**

*by Rachael Serur*

**December 8th, 2019**

**A Capstone Project for Harvard Extension School, Harvard University**

<b>1. Introduction</b>	<b>3</b>
<b>2. Technology Components</b>	<b>5</b>
2.1. Introduction & Diagram	5
2.2. 3D Modeling	6
2.2.2. 3D Printing	8
2.2.3. Virtual 3D Model Preparation	10
2.3 Physical Computing: Open-Source Single-Board Computer (SBC) & Touch Sensors	11
2.4: Backend Python Application	12
2.5: Javascript Framework & Visualization Libraries	13
<b>3. Life of the project beyond capstone</b>	<b>14</b>
<b>4. References</b>	<b>16</b>

## 1. Introduction

In my initial proposal for my capstone project, I planned to build a 3D-printed interactive model of the human brain that controls the navigation of a single-page web application. The end product was meant to be a proof-of-concept research tool for psychology and neuroscience as well as an artistic exploration.

The proposed web application would primarily:

1. react to user interactions with the 3D-printed brain model;
2. mirror interactions in easy-to-understand and eye-catching visualizations of the brain on-screen;
3. and trigger searches of PubMed databases.

All three of these main features were built out successfully in the final capstone project as described. A stretch goal of adding a backend for predictive modeling was not met due to high work demands after an unexpected job offer that was not accounted for in my initial proposal timeline.

The digital media learning goals of these projects were to:

- modify, enhance, and render 3D model files using a modern 3D modeling software;
- understand and use 3D printing technology;
- explore physical computing fundamentals and design a working system of electronic interactions;
- exercise advanced-level frontend visualization techniques;
- and exercise intermediate-level predictive modeling and applied machine learning (sadly, a missed stretch goal).

In the following section, I will describe the process of applying each technology to build the final prototype: "Neuro UI" (a working title).

## 2. Technology Components

### 2.1. User Workflow

The project ultimately combined two user interface (UI) modalities: a physical UI and a frontend web UI, as illustrated in Figure 1 below. The physical prototype requires a USB connection to the user's computer to provide internet connectivity and power to the BeagleBone Black. The web UI is served on the localhost of the computer. Once both the physical and web UIs are up and running, the user may interact with either to trigger searches to PubMed and browse displayed journal articles.

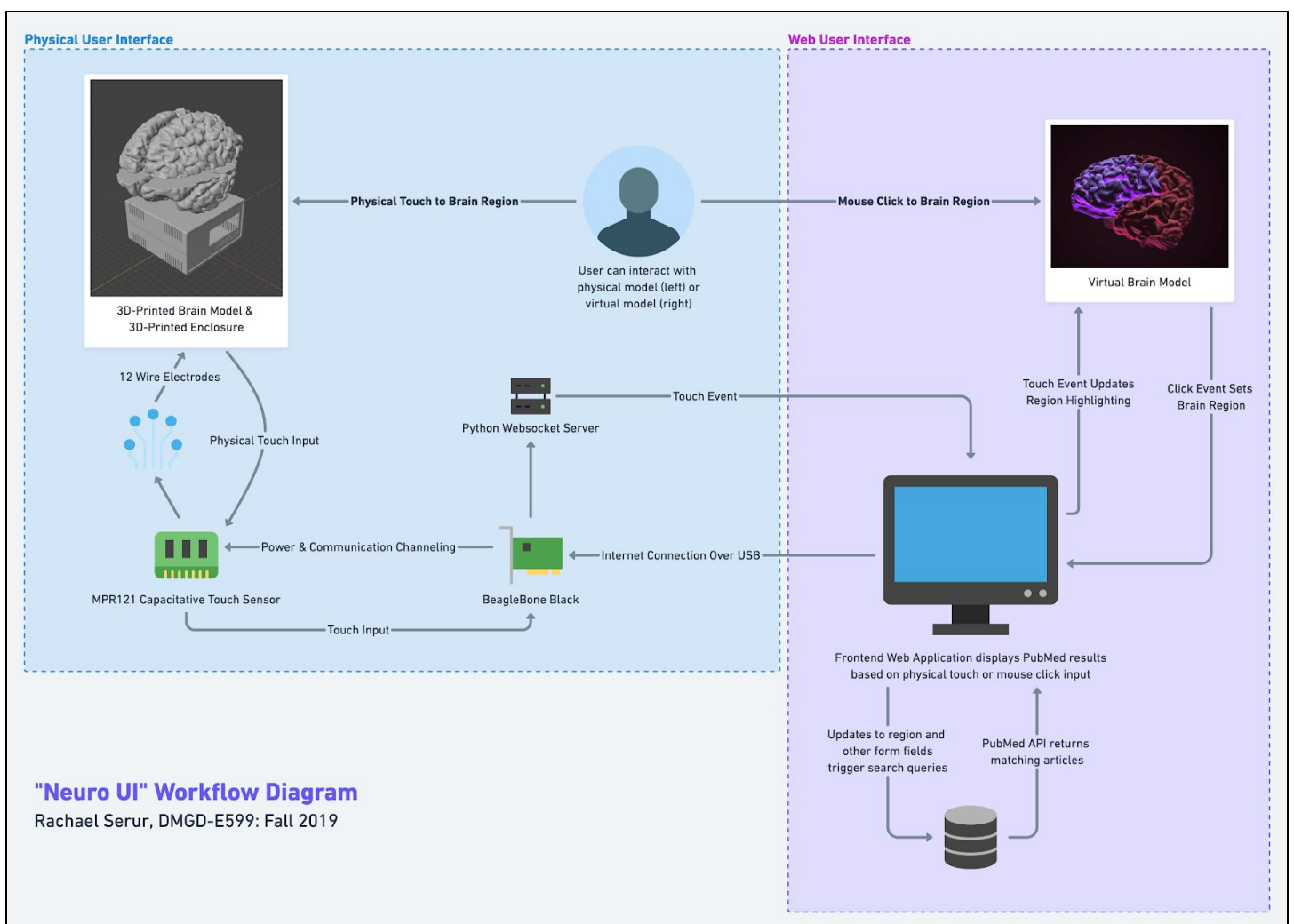


Figure 1: "Neuro UI" Workflow Diagram

Each component required the application of a different technology, as described in the below sections.

## 2.2. 3D Modeling

**Reason:** To design a physical model that is 1) divided into meaningful anatomical regions of the brain, 2) compatible with physical computing components, and 3) visually appealing and engaging.

### 2.2.1. Initial 3D STL (Stereolithography) Model

To create a physical model of the human brain using 3D printing, I first needed a virtual 3D model. To get as realistic representation as possible, I converted real MRI scans to a surface model after researching open MRI datasets available for immediate use and perusing several research initiatives with open data.

I selected the [Human Connectome Project](#) (HCP) Young Adult project dataset (2017), which provides open source structural and functional MRI data, as well as behavioral measure results, from 1200 subjects. I downloaded several individual subject datasets to explore, but selected a single data subject's brain whose behavioral measures were unique in an interesting way (perfect emotional recognition and high conscientiousness). Using the data for statistical analysis was not in scope for this project, but I could imagine extending the project in that direction.

Once equipped with MRI data, I learned and experimented with how to use [FreeSurfer](#), an open source software suite developed by the Martinos Center at Massachusetts General Hospital for the analysis of magnetic resonance imaging (MRI) scan data. I loaded up and explored HCP data, comparing different MRI scans before settling on a single participant's MRI data for the physical print prototype. In Figure 2 below, the volumetric data of the selected MRI can be seen in FreeSurfer.



Figure 2: The selected research subject's scan data in FreeSurfer.

Readily available open source code, [3Dprinting\\_brain.sh](#) (Notter, 2019), helped me through the process of creating a 3D model of cortical areas via the open source system for processing and editing 3D meshes for 3D printing preparation in [MeshLab](#) (Figure 3).

All of the process thus far went as planned in the initial capstone pre-proposal and proposal.

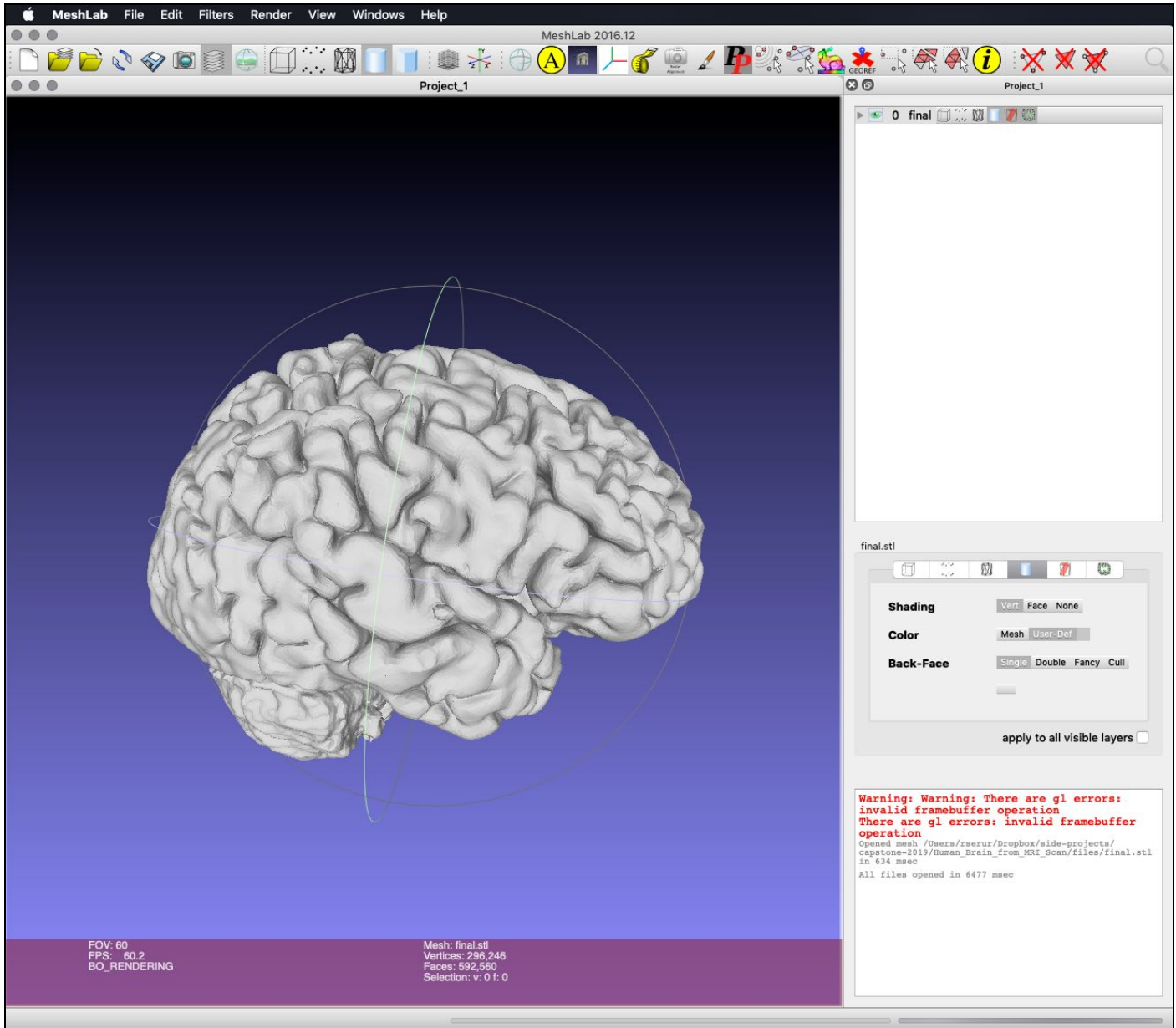


Figure 3: The smoothed surface model in MeshLab (still solid).

## 2.2.2. 3D Printing

The final model was prepared for 3D printing using a combination of MeshMixer, Blender, PrusaSlicer, and Cura. I divided the surface model into four even quadrants and hollowed it out to contain electronics. Figure 4 below shows the pre-sliced STLs in Blender.



Figure 4: The final STL models for hollowed brain quadrants (eventually printed at half-size for hobbyist-level 3D printer) and microboard enclosure.

While my capstone proposal did include 3D printing, it did not include the extensive modeling, slicing, and machine-tweaking I ended up performing. See Figure 5 below for a GIF video of the 3D printing process on an Ender 3 Pro printer. This technology was the one I had the least experience in (besides physical computing), so I was excited to take the time to learn and produce something beyond my initial expectations thanks to a great deal of online hobbyist resources on general 3D printing techniques (countless YouTube videos, ready-made models to practice and calibrate the printer with on [Thingiverse.com](https://www.thingiverse.com), reddit threads, etc).

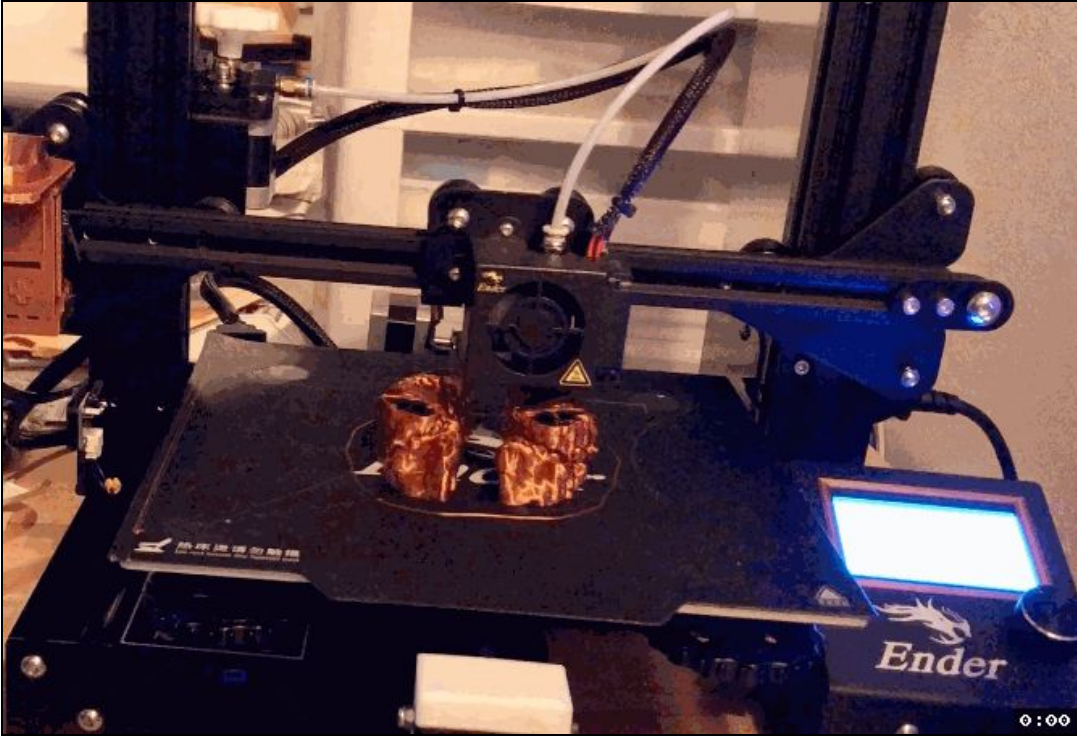


Figure 5: Video of partially printed bottom quadrants of hollowed brain model (on an Ender 3 Pro).

3D Printing was also used to build the chassis for the electronics. An [open-source model](#) was adapted parametrically with OpenSCAD and SketchUp 3D modeling software to house the BeagleBone, MPR121, and wiring. Figure 6 shows the box in OpenSCAD with the open-source code and editable parameters.

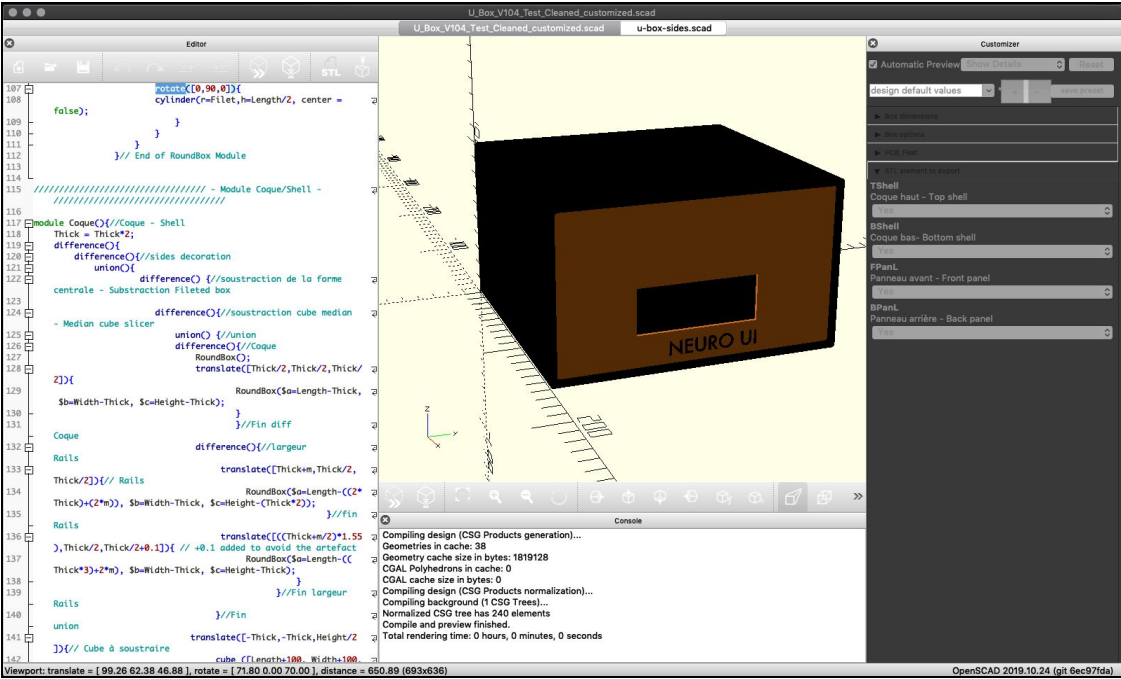


Figure 6: The “Ultimate Box” open-source model modified in OpenSCAD.



### 2.2.3. Virtual 3D Modelling

Since the virtual 3D model in the web interface would mirror interactions with the physical model and help the user keep track of what is being searched, I prepared the same base model used for 3D printing for use in the single-page web application. I used Blender (see Figure 7) to manually dissect the model into regions, rather than relying on the simple quadrants used for 3D printing (which do not represent any real anatomical divisions). I divided it into the 4 major lobes (frontal, parietal, temporal, and occipital) as well as the cerebellum.

While producing a virtual 3D model was a goal in the initial capstone proposal, I again did not anticipate going into as much detail into process as I did. I expected to do some minor tweaks in 3D modeling software, but ended up heavily modifying the model and learning a great deal about modeling in Blender.

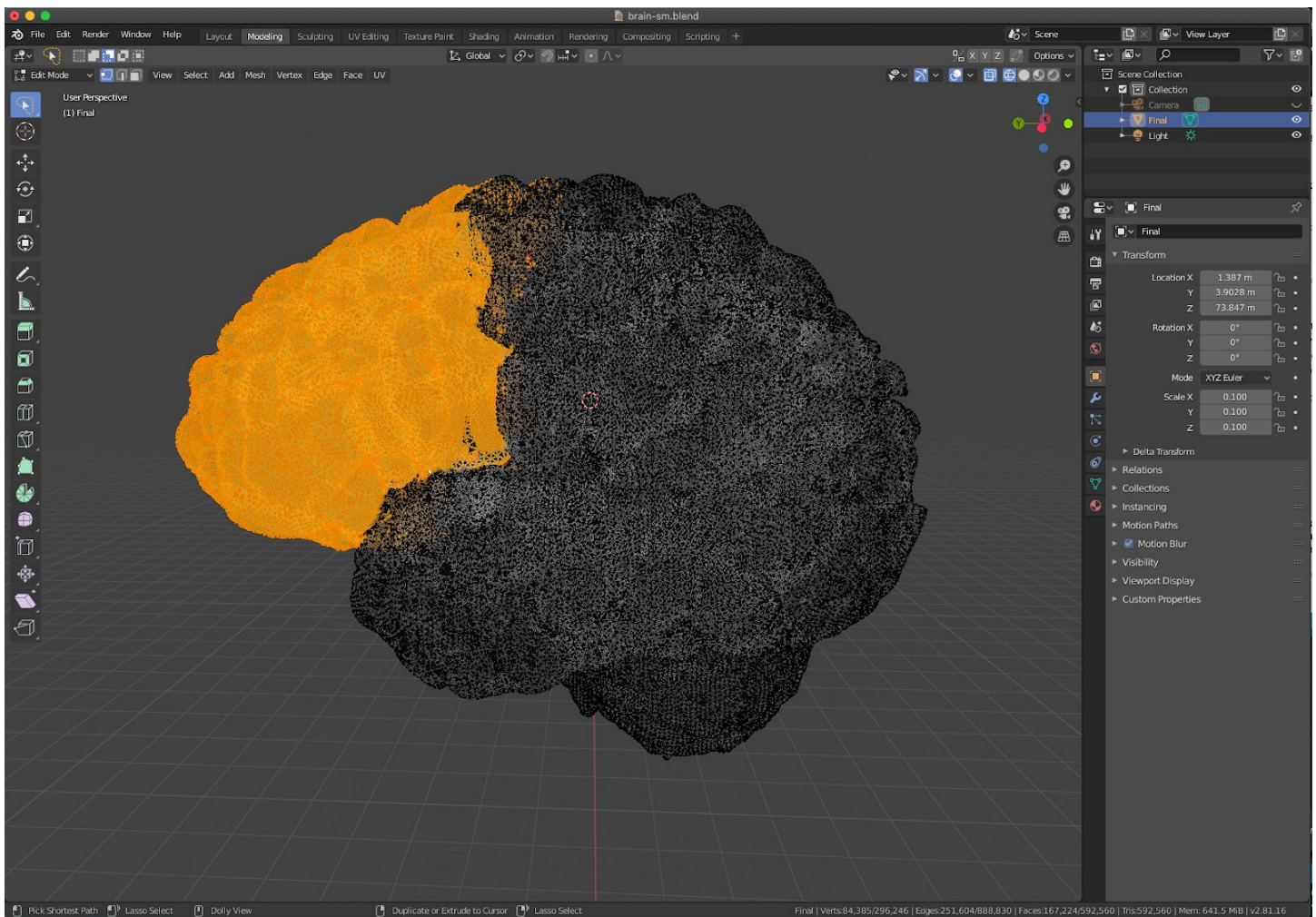


Figure 7: In Blender, manually moving the vertices for the frontal lobe to a separate object in the 3D scene.

### 2.3 Physical Computing: Open-Source Single-Board Computer (SBC) & Touch Sensors

**Reason:** To connect touch sensor input from the physical model to the web application such that specific regions or points of the brain are recognizable to the app.

The BeagleBone Black and MPR121 set up went roughly as planned in my capstone proposal, though using a BeagleBone Black from 2014 with little built-in disk space (2GB) required a lot of extra time updating the Debian OS. I realized I needed to boot from an SD card instead of the eMMC (embedded Multi-Media Controller) flash memory and configure a great deal via command line in SSH (secure shell) of an old, unsupported version of Debian to be compatible with the MPR121 Python library. In future versions of this project, it's likely I'll need to either switch to a brand new BeagleBone Black or to a Raspberry Pi so that these technologies are less outdated, but for this prototype it was preferable to use existing on-hand parts instead of purchasing a new SBC.

After printing the model following a tutorial by Tony DiCola on Adafruit (2014), I soldered the MPR121 Adafruit breakout onto a breadboard along with 12 touch sensor pins. I then connected it to the BeagleBone Black with jumper cables. Sensors were cabled to act as electrodes pulled into the brain model cavities and exposed through small drilled holes. The exposed electrodes were covered with conductive copper tape to expand surface area for touch responses and help delineate separate areas. Figure 8 below is a picture of all working physical components connected together.



*Figure 8: The complete physical UI wired together (the enclosure can be easily opened to access electronics, as seen here).*

## *2.4: Backend Python Application*

**Reason:** To access input data from the physical computing sensors within the embedded linux system of the single-board computer.

An Adafruit module library for the MPR121 was used on a Python-based websocket server (using the Tornado python library) to emit touch sensor events served off the BeagleBone.

In my capstone proposal, I expected to explore and leverage Node.js IOT libraries. Once using the MPR121 library, I realized it would be more practical to build a websocket server entirely in Python pulling in this library.

## 2.5: Javascript Framework & Visualization Libraries

**Reason:** To create a cohesive and visually engaging frontend for the web application that guides the user through the search and exploration of articles and insights.

The user interface loosely resembles that of the original 2D, digital “PubBrain” project, my spring 2014 final for DGMD-E15 (Serur, 2014), “Creative Explorations in Screen-Based and Physical Computing.” But for this final capstone project, I developed a completely new green-field app leveraging modern technologies: React, Three.js with a GLTF scene exported from the original STL model, Evergreen UI, websockets, CSS Grid, and CSS Flexbox.

The React frontend features a sidebar form with a dropdown mirroring touch sensory input (from the websocket server off the Beaglebone) for brain regions, a dropdown for DSM/ICD Disorders, and a keyword search. Those form fields combine with input from the physical 3D model to trigger PubMed searches for relevant articles. In Figure 9, the physical UI and virtual UI are pictured in concert.

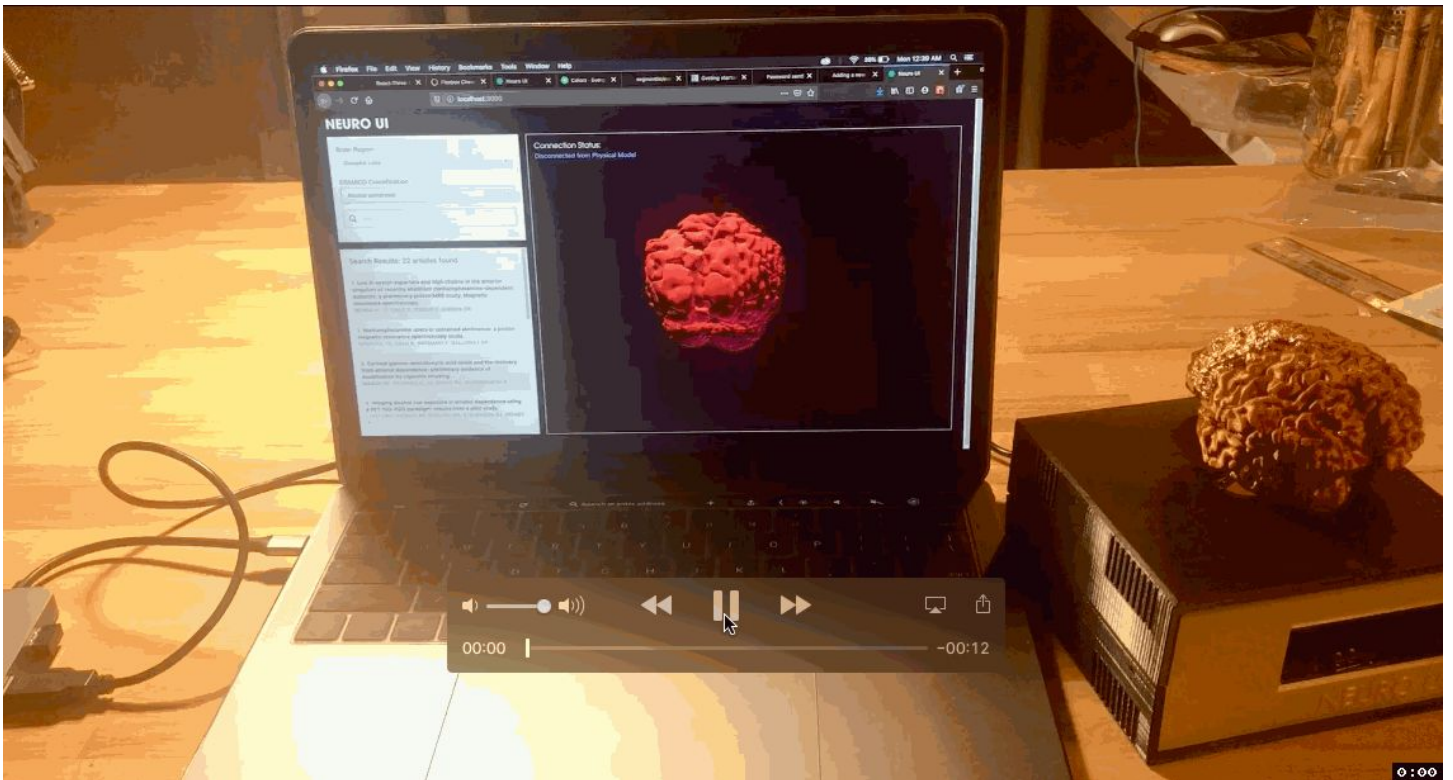


Figure 9: The final prototype system: the physical and virtual UIs.

I further developed the virtual 3D model by loading the major lobe (frontal, parietal, temporal, and occipital) and cerebellum 3D objects as separate GLTF (GL Transmission Format) files into three.js using

[React Three Fiber](#). Hover and click events are possible through raycasting behind the scenes thanks to this open-source library.

In my capstone proposal, I did not plan to add interactivity to the virtual 3D model beyond mirroring physical model interactions. I decided to add click-based interactivity once I figured out how it would be possible with Three.js. In Figure 10, the virtual, click-based user flow is displayed in a recording.

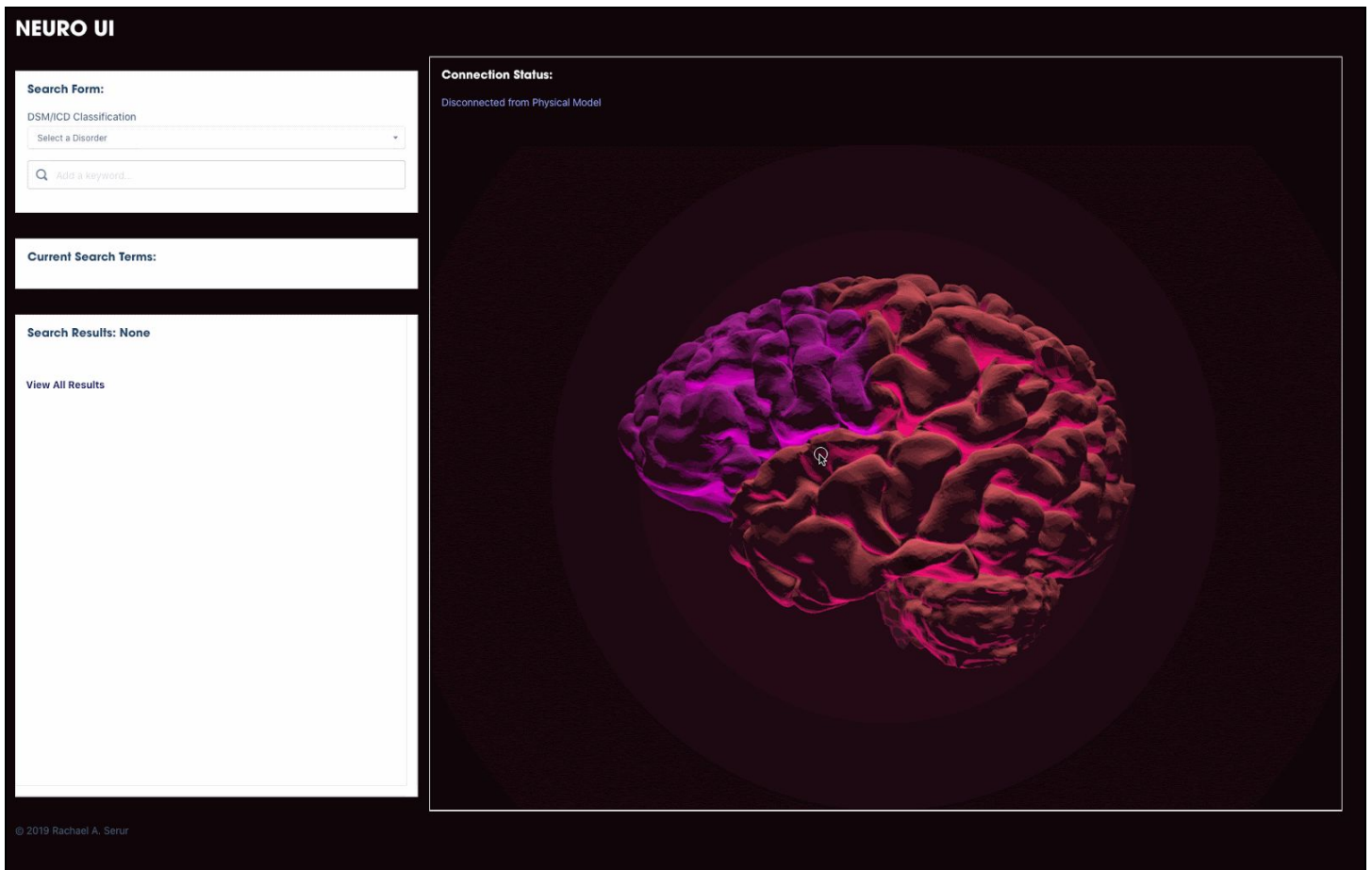


Figure 10: The full, click-driven virtual 3D model workflow in the React application.

### 3. Life of the project beyond capstone

There are several ways I will expand upon the current state of the prototype.

*Physical Model:* The STL model for printing will be enhanced with interlocking parts, so that its individual pieces can lock together. It will also be printed at 2x the size (life-size). The brainstem and cerebellum will be printed to hold the model in a stable position atop the chassis.

*BeagleBone Black and Chassis:* The wiring from the MPR121 capacitive touch sensor breakout to the physical brain model could be shortened and replaced with sturdier wiring so that a smaller, more convenient chassis can be 3D-printed. A character LCD screen will be added to display the basic connectivity status of the BeagleBone and touch sensors. Most importantly, wireless functionality could be added to the board so any computer with access to the web app can use it.

*Web Application:* Basic functionality can be expanded for “production” use: cloud hosting, a CI/CI pipeline, a test suite, state management, user accounts, bookmarking, and social media sharing. The web application will include relevant and API-driven notes on each brain region. In addition, noteworthy attributes and quantities of search results will be stored within a backend database and used to train a prediction model around queries. The model will be used to empower the user with insights as they navigate within the application.

*Augmented Reality:* In addition to accepting event data from a physical model, the frontend web application could easily be extended to accept event data from an augmented reality 3D model of the brain. In a free-floating form, UX could be explored for finer, granular-level medical data. An AR-driven server outfitted with websocket events would need to be developed for such functionality.

*EHR:* As a software engineer focused on healthcare applications, I already specialize in Electronic Health Record (EHR) integration for third-party applications wishing to use exhaustive medical patient-level or population-level data for non-recordkeeping purposes-- e.g., for AI-driven medical insights or enhanced/unique user experiences. I could take my own application and integrate it with major EHR platforms, such as Epic and Cerner, so that real medical data can be explored with my alternative physical model and AR-driven user experiences.

*Research:* The MRI data was already procured from an open data research project, The Human Connectome Project (HCP) (2017). A future branch of this project could entail bringing in additional open data from the open datasets available, building a feature-rich UX for the exploration of the HCP itself.

*Business:* I am extremely interested in finding a life for this project beyond my capstone. At minimum, I could reach out to my former mentors in psychology research at Beth Israel Deaconess Medical Center for advice in taking the project further in academic spheres.

I do not have much of a mind for business, but time permitting, I may do some research into VC funding or Kickstarter. It would be worthwhile to explore my connections in academia to gauge interests in co-founding a company, if only to rule it out. I would love to find a way to get the final product in real classrooms without having to start a whole company.

Given the physical interface of the product, I would need to investigate mass-manufacturing or perhaps, a DIY starter kit with pre-fab parts that could easily be put together by a layperson or hobbyist. Alternatively, there may be a way to present the project in a small but public conceptual art venue of some kind. Timing and money not permitting, I would consider publishing writings on Medium.com about the project and open sourcing the code.

#### 4. References

- Serur, R. A. (2014, July 19). PubBrain. Retrieved from <https://github.com/rserur/PubBrain>
- Notter, M. (2019, March 15). Miykael/3dprintyourbrain. Retrieved from <https://github.com/miykael/3dprintyourbrain>
- DiCola, T. (2014, December 23). MPR121 Capacitive Touch Sensor on Raspberry Pi & BeagleBone Black. Retrieved from <https://learn.adafruit.com/mpr121-capacitive-touch-sensor-on-raspberry-pi-and-beaglebone-black/overview>
- National Center for Biotechnology Information. (n.d.). Retrieved August 4, 2019, from <https://www.ncbi.nlm.nih.gov/>
- Human Connectome Project (2017, March 2017). Retrieved December 9, 2019, from <https://www.humanconnectome.org/study/hcp-young-adult>