WEB-BASED MODEL SLICING
FOR 3D PRINTERS

BY

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Abstract

3D printing currently contains a large gap between software and hardware. A hobbyist machine can now be purchased for less than $500 but having good software to drive it is difficult to find. Currently the only competent and free slicing software available is Cura and Repetier Host. Currently, Cura has varied support on all platforms, and Repetier Host is intended only for Windows. The purpose of this research is to construct an open source, web based slicing software and make it simple for users without any prior knowledge of 3D printing to take full advantage of their printer and as a result will make 3D printing much more approachable for users who are not computer savvy. Additionally, this opens up opportunities for educators in STEM programs to teach students about 3D printing in a simple and practical way.

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Chapter 1

Introduction

(Jones et al., 2011) Over the past few years, 3D printing, has become immensely popular due in part to its reduction in cost and its easy availability. An enthusiast can now purchase a do it yourself (DIY) 3D printer kit for less than \$500 however, one major pitfall that remains is the software support which leaves much to be desired. Most of the big name companies that used to hold all of the patents for 3D printers have retained the software patents but not the hardware patents. This creates a gap in knowledge between building the printer and running it. This research has served as an exploration of what software existed in the open source for 3D slicing and using that software to build a web based 3D print slicer. This will, effectively "democratize" the world of 3D printing, much in the same way that Google has democratized the way we search the web. In an article written by Harvard Business review, they theorize that this rise in the popularity of 3D printing will spur an industrial revolution as manufacturing becomes more personalized and decentralized (D'Aveni, 2015).

To print something on a 3D printer, there is a multi-step process that can be daunting to many first time users. The first step in the process is to either create or download a model. Creating a model can be achieved with any standard 3D CAD software, such as AutoCAD or SolidWorks. Downloading pre-existing models from an online repository can be done from websites such as Thingiverse or YouMagine. Once a model file is obtained, it is time to "slice" the model. Slicing is the act of

taking this model file and splitting it up into many thin layers that the 3D printer can understand. This process can only be executed by a dedicated slicing software which can often be complicated to use and difficult to install. Once the file has been sliced, the resulting file is a G-code file, which is simply a set of movement instructions that the printer head must follow. This file is then loaded to an SD card or sent via a print server similar to the way that a normal 2D printer is networked. Once the G-code file has been loaded all, that is left is to hit print either manually using the printers interface for the SD card or by hitting print on the network interface for the file that was uploaded.

Figure 1-1: (a) High level view of the normal 3D printing process. (b) High level view of proposed new process using WebSlicer.

1.1   The RepRap Idea

The Replication Rapid-Prototyper Project (RepRap) is a movement with the goal of providing Open-source, diy 3D printers at low cost (Jones et al., 2011). RepRap printers are 3D printers with the additional ability to produce most of the parts necessary to assemble another identical printer. This idea also extends outside of hardware but to the software as well. Much of the software available for RepRap style printers are open source projects put together by the community. Unfortunately, community based software development is slow and leads to hardware that outpaces its software.

1.2   Sudden Growth of 3D Printing

In an article written by Forbes, the market trend for 3D printing was analyzed. They determined that 3D printing is becoming one of the fastest growing emerging markets, stating that "The worldwide 3D printing industry is now expected to grow from $3.07 billion in revenue in 2013 to $12.8 billion by 2018, and exceed $21 billion

in worldwide revenue by 2020" (Columbus, 2015). 3D printing may be reaching more people as a result of the availability of the RepRap designs. Additionally, building a 3D printer from a kit only requires basic hand tools and a moderate knowledge of electronics, which means that it has been opened up to a much broader audience.

1.3   Purpose of Research

The purpose of this research is to construct a web based slicer and simplify it for users who not well versed in 3D printing, so they are able to slice models and run their 3D printers. This will make 3D printing much more approachable for occasional users who are not prepared to spend thousands of dollars on a professional machine and expensive software. Additionally, this opens up opportunities for educators in STEM programs to teach students about 3D printing in a simple and practical way. Under normal circumstances, this would not be a feasible project for a year-long Masters thesis; however, many of the technologies required to complete this project exist in varying states of completeness. Combining them into a cohesive application will be the subject of this study.

1.4   Research Objectives

This research encountered several milestones which had to be met for it to be considered complete. These milestones are listed in no particular order; however, several of them must be completed before allowing other milestones to be completed as detailed below. However, several of them must be completed before allowing other milestones to be completed as detailed below.

CuraEngine is an open-source slicing engine designed to take model files in .stl file format and convert them into G-code for 3D printing. For this project, wrapping this code and making it callable from the web is the heart of this application.

1.4.1   Design Intuitive Web Interface

This project requires both an intuitive and easy to way to slice a model file for 3D printing. This would be completed using Bootstrap and AngularJS because they are both scalable and flexible for almost any web design. These technologies also allow for small scale or even mobile use.

1.4.2   Run Beta Testing with Actual Users

No research would be complete without testing the software in question. Running a closed beta test of this software is a milestone that must be met as one of the major aspects of this application is its usability. The goals of this test were to see if WebSlicer is both easy to use and useful to those who decide to use it with their 3D printer.

1.5   Related Work

AstroPrint is an all-inclusive cloud operating system for 3D printers. It attempts to encompass the entire package of 3D printing to a dedicated Raspberry Pi, or similar computer system. It is also one of the only software platforms that currently exists that attempts to do web based slicing. Unfortunately, the AstroPrint software tries to accomplish too many tasks at once and has become somewhat like a Swiss army knife, being capable of many functions but only complete a few tasks well. Additionally, their cloud-based slicing software, while being reasonably fast, lacks any support for reviewing the sliced model. This review stage is critical for anyone who is printing something that will take more than a few hours to complete.

1.6   Thesis Map

- Chapter 2: Background and design choices.

This chapter discusses many of the external resources used and why they are relevant to this research.

- Chapter 3: Software architecture review.

Compiled here is a complete overview of the architecture of WebSlicer. It follows the user through the entire process of slicing while explaining briefly some of the details of what is really happening.

- Chapter 4: Client side in detail.

Here is where all of the possible client interactions and application specific details are explained.

- Chapter 5: Server side in detail.

Details of exactly how a C++ executable is tied into a Java process are explained here as well as the exposed web API created for this research.

- Chapter 6: Discussion about usability testing and further improvements.

Included in this chapter are the formal results from closed beta testing and a discussion of the printer which inspired this research.

Chapter 2

Libraries & Existing Code

This chapter discusses many of the external resources used and why they are relevant to this research. All of the resources discussed in this chapter are open source projects and libraries.

2.1   CuraEngine

CuraEngine is the server side of a larger application called Cura. Cura is an open source 3D print slicer designed by Ultimaker that is part of the software suite for their Ultimaker line of 3D printers (Kuipers, 2016). As it is the main portion of the server side of WebSlicer, Cura will be discussed extensively in latter portions of this paper.

The reason for choosing to use CuraEngine as the slicing engine is that it has the most clear separation between application and interface. Another option was to use Slicer, which is much older and has better documentation, but is unfortunately written on Windows and would require a large amount of extra effort to get working properly for my needs. CuraEngine is also platform agnostic, as it is written in C++ and uses one library called protobuf, which is its main interface library for the Cura application.

2.2   Client Side Libraries

When structuring a website for optimal layout and scalability, there are few better options than using the combination of Bootstrap and AngularJS. Bootstrap is a client side CSS library which includes most commonly used CSS options such as buttons and input fields and styles them all accordingly. AngularJS creates a client side environment to support higher level language constructs and features that are normally reserved for complex server side applications.

2.2.1   Bootstrap

Bootstrap is one of the most popular CSS and JS frameworks for developing responsive and mobile projects on the web (Mark Otto, 2016). Being responsive means that Bootstrap is capable of being dynamically displayed on screens of varying sizes. When the screen size changes, Bootstrap is capable of moving and resizing elements on the page without losing any content or overlapping items (Mango, 2013). In addition, it speeds up the process of developing web based applications, as it removes the need to write heavy amounts of CSS to make an application look and preform nicely. Bootstrap also includes many standard features which most web developers use every day, further simplifying the process of building a website.

2.2.2   AngularJS

AngularJS is a framework that allows for easy development of dynamic web pages (Brat Tech LLC, 2016). It contains many ways to logically separate code similar to popular object oriented programming languages like Java or C++. Freeman (2014) states, "the goal of AngularJS is to bring the tools and capabilities that have been available only for server-side development to the web client and, in doing so, make it easier to develop, test, and maintain rich and complex web applications" (p. 48). Therefore, the use of Bootstrap for the unified look, responsiveness, and mobile support combined with the power of AngularJS as a framework, make it the easy choice for a web based application such as WebSlicer.

2.3   JavaEE

JavaEE is a layer built on top of JavaSE the standard Java development environment (Gosling, 2016). This additional layer provides many important architectural interfaces, such as the ability to encapsulate code in EJB containers or web containers for deployment of large applications which may have many of such containers (Pilgrim, 2013). JavaEE also provides frameworks for working with RESTful web services which streamlines the creation of a useful application API.

There are many server side frameworks which have support for RESTful web services, but most lack real scalability like that provided in JavaEE. Furthermore, JavaEE provides the ability to easily distribute computing as more resources are needed. As this research may eventually scale to supporting many users, it was logical to choose a framework which allowed for this kind of growth. The use of JavaEE as a framework also provides the full platform cross compatibility which is standard in Java. Allowing for cross platform compatability would facilitate the process of linking many computers that are running on different operating systems together, further simplifying the prospect of scaling.

To run a JavaEE based application, it must run in a web capable application container. This container must be placed on an application server which exposes it to the web under some context. For WebSlicer, the application server WildFly was chosen for this task as it is well known for its reliability (Fleury, 2016).

2.4   OctoPrint

OctoPrint is a small server that connects a Raspberry Pi to a 3D printer and serves printer info and files to the printer remotely (Häußge, 2016). The Raspberry Pi serves a small webpage which allows the user to easily keep track of the temperature of the printer and the current print progress. This interface allows for a web based connection between your remote g-code files and the local printer (Horvath, 2014).

OctoPrint also contains its own API which makes for easy integration into other web applications.

The fact that OctoPrint is so easily integrated into other web based applications made it a logical choice for integration with WebSlicer. Integrating with OctoPrint would allow for one touch printing by allowing me to send g-code files directly to a connected OctoPrint server. The only interaction that is required of the user is to connect their OctoPrint server which is done by simply indicating the address at which the server can be reached at. Additionally, users are required to include an API key to allow for other applications to directly access the servers API.

2.5 G-Code Visualizer

When building the G-code visualizer, it seemed logical to find one which already existed and worked well. gCodeViewer is an open source project originally written by Nils Hitze (Hitze, 2015). This project was written in pure JavaScript and would be seemingly easy to integrate with WebSlicer.

Unfortunately, many of the libraries that were needed to make this code needed to be updated. Additionally, integrated into the existing AngularJS framework which was more challenging than anticipated. Thus, what ultimately remained from the existing open source project was very small.

Chapter 3

Methodology

This chapter discusses the architecture of WebSlicer. It also serves to justify the design choices that were made.

3.1 Research Design

This thesis is a mixture of both research and design implementation. The research portion of this project focused on linking an existing C++ application (CuraEngine) into a larger JavaEE based project. This research also included running a closed beta test of the software and logging the results.

Figure 3-1: High level view of how WebSlicer functions and how users will interact with it

3.2 Working Procedure

As shown in Figure 3-1, the application will have 3 major components that all need to work together in a cycle until the user decides that the output is what they desire.

3.2.1 Web Interface

The web interface includes a set of forms for collecting the user's settings for their printer and the settings as they relate to printing the model itself. This interface also includes a method so the user may retain the files they have uploaded for future use. This does not include the actual slicing engine, which must be driven and accessed independently.

3.2.2 Slicing Engine

To comprehend the slicing engine it is vital to understand what G-code is. G-code consists of sequential machine instructions that command a 3D printer to move in a sequence of patters to build a three dimentional part (Thornton, 2012). Listing 3.1 shows a sample of G-code that results from slicing using CuraEngine. Comments in G-code are preceded by a semicolon and the first line denotes the type of G-code, we are only focusing on RepRap G-code in this case. Commands in G-code follow a standard pattern of a letter, either M or G, and a number which denotes the type of command. All subsequent items that are separated by spaces are arguments to the command.

Listing 3.1: A sample of G-code that results from slicing using CuraEngine.

```
{
FLAVOR: RepRap
M190 S110.000000
M104 S245.000000
M109 S245.000000
G21 ; metric values
G90 ; absolute positioning
M82 ; set extruder to absolute mode
M107 ; start with the fan off
G28 X0 Y0 ; move X/Y to min endstops
G28 Z0 ; move Z to min endstops
```

```
G1 Z15.0 F9000 ;move the platform down 15mm
G92 E0 ;zero the extruded length
G1 F200 E3 ;extrude 3mm of feed stock
G92 E0 ;zero the extruded length again
G1 F9000
;Put printing message on LCD screen
M117 Printing...
;Generated with Cura_SteamEngine master
;LAYER_COUNT:158
;LAYER:0
M107
G0 F7200.000000 X99.430 Y80.760 Z0.300
G0 X102.806 Y78.243
;TYPE:SKIRT
G1 F1800.000 X103.337 Y78.033 E0.01074
G1 X103.441 Y77.996 E0.01282
G1 X103.842 Y77.875 E0.02070
G1 X104.142 Y77.800 E0.02651
}
```

The slicing engine rests at the core of this project as most of the computation time is spent preforming geometry calculations and converting them to G-code. This process of converting from model to G-code is known as slicing. An application which is encapsulated and preforms slicing is known as as a slicing engine. The engine which carries out the raw geometry calculations for WebSlicer is CuraEngine which is written in C++. Thus, this portion of the project required deploying the CuraEngine application on a remote server and creating a RESTful API to interface with it.

3.2.3 Web Tool Path Viewer

After configuring and generating the G-code representation for a 3D model, there must be a way to visually review how the slicing engine will divide the model. This is executed by loading the resulting G-code from the slicing engine into a web based visualizer. The user is then able to view each of the layers and the steps involved in creating each one in detail. As displayed in Figure 3-1, this process of changing settings, slicing, and reviewing can occur an arbitrary number of times before the user decides they are satisfied with the result.

3.3 Review and Usability Testing

After preforming all steps of the working procedure, it was then necessary to test WebSlicer by running a small beta test. This beta test consisted of a small group of users with varying familiarity with 3D printing to test how simple WebSlicer is to use through a series of simple tasks. These simple tasks ranged from uploading a file to finding and adjusting the correct setting for a printer.

Chapter 4

Client Side

This chapter discusses the client side of WebSlicer in detail. It also includes some necessary background about AngularJS as it will be crucial to understanding latter sections of this chapter.

4.1 AngularJS

In order to understand the structure of WebSlicer a few things must be known about how AngularJS applications are structured and how AngularJS itself works.

4.1.1 Controllers & Data Binding

The controller structure in AngularJS that sits between the view and the JavaScript world acts like the glue between the two. From a controller the user is allowed access to "scope" variables, which are similar to normal JavaScript variables, but they have a special two-way data binding property. Two-way data binding is one of the most interesting features of AngularJS, as it gives the user real time updates as the user interacts with a view. In traditional JavaScript, a developer must identify key events that occur in the browser as the trigger for a sequence of events. AngularJS also has a sequence of events but no trigger is required as the sequence of events is triggered automatically. This action is known as a digest cycle. AngularJS has a watch function

for each variable attached to its scope. When any changes to this variable occur, they propagate that change to the functions that are associated with that variable (Freeman, 2014).

4.1.2 Factories & Services

JavaScript has many pitfalls, including the lack of any kind of larger design pattern support, such as Object Oriented Programming (OOP). The current trend with web based applications is to create single page applications with the same functionality as prior designs that have many pages. AngularJS is the answer to this with Factories and Services which mimic the design of a POJO (Plain Old Java Object) and Singleton objects in Java.

4.1.3 Directives

A directive is one of the most powerful structures in AngularJS. It allows the programmer the power to write their own HTML5 tag with its own parameters and rules. Directives also contain support for templates which are HTML snippets that replace the main tag when the code is loaded. Combining this with the use of the aforementioned design patterns creates a very powerful tool to create and organize dynamic content.

4.2 WebSlicer AngularJS Structure

This section discusses the entire client side structure of WebSlicer when it is broken down into its respective Controllers, Factories, and Directives.

Figure 4-1: Full AngularJS structure breakdown

4.2.1 app.js

The full graphical AngularJS structure of WebSlicer is shown in Figure 4-1. Flow through this diagram starts with the app.js node which represents the main controller of the application. This can be thought of as a main function in C++. The main control variables are also inside of app.js which are similar to global variables. Variables in this controller are used to store the current settings, file pointer, and output G-code.

4.2.2 index.html

Figure 4-1 also shows that index.html is large hub and, as WebSlicer is a single page web application, this is the only static HTML file. Index.html has several other functions, such as bringing in all libraries and custom directives.

4.2.3 Settings

Figure 4-2: The flow of data through the application from beginning to end of client side user interaction

As shown in Figure 4-2, settings have a long path that they must travel before they are submitted to be used while slicing. This data flow starts with loading a static JavaScript Object Notation (JSON) file, which describes the settings in a pattern as shown in Listing 4.1.

Listing 4.1: A sample from a static settings file in JSON format.

```json
{
    "setting": "layer_height",
    "default": 0.1,
    "type": "float",
    "category": "Quality",
    "label": "Layer Height (mm)",
    "description": "Layer height in millimeters. This is the most
        important setting to determine the quality of your print.
```

```
        Normal quality prints are 0.1mm, high quality is 0.06mm.
        You can go up to 0.25mm."
}
```

Listing 4.2: An example of a ng-repeat looping construct in HTML5.

```html
<table class="table">
  <tr><td>Action</td><td>Done</td></tr>
  <tr ng-repeat="item in todos">
    <td>{{item.action}}</td>
    <td>{{item.done}}</td>
  </tr>
</table>
```

A directive called curasettings takes this static JSON file and divides it so an input field exists in the template for each setting object. AngularJS provides this functionality through the use of an ng-repeat, which is written in a similar fashion to that of a for-loop in Python which is shown in Listing 4.2. Using a template for a directive in this case also means that the user can have control over many different fields, such as drop-downs and number-specific inputs. The curasettings directive also gave the logical separation of one static JSON file per tab of settings in the UI, which made it simple to find and modify the settings as needed.

Settings in WebSlicer have a complex method of being tracked after loading to the client. In most applications such as this, there would be an individual watch on each field or a submit button which would trigger grabbing all the fields. WebSlicer, however, uses a single object to track all of the settings for the application and uses a dynamic method of AngularJS to map from the input field to a field of a single object. Thus, when the settings are submitted, there is no more interpolation needed, as the settings object already has the current state as shown in the Figure 4-2 as "Pull Current Settings."

4.2.4   G-code Visualizer

The G-code visualizer for WebSlicer is written using a combination of D3 and a JavaScript web worker. From Figure 4-1, it can be seen that the controller for the visualizer is sent in a G-code file, which it splits up to two separate services. The controller completes an initial parse of the file, which places each one of the lines into its own entry in an array before exchanging it with gCodeFactory and Worker. Both of these files parse through this entire array, but do so at roughly the same time to expedite the process of visualizing. The worker takes the array of lines and ignores the header to just focus on converting the raw movement commands into D3 lines so that they may be rendered. The gCodeFactory takes the headers from the array and uses them to do analytics of the G-code file, such as total print time.

The final steps in the process of visualizing the G-code require splitting the G-code file into layers for rendering. This task which is made simple by following the given tags in the G-code which signal a layer change. Once all of the cumbersome tasks of parsing and splitting up the G-code file are finished, it is simply a matter of returning layer requests with canvas frames. Each time a layer is requested, a progress for that layer is also sent. The controller then indexes to the layer height in the array and renders a frame with the number of lines that are described by the current progress. As array indexing is nearly instantaneous, the visualizer once parsed and loaded runs very quickly to display layers.

4.3   Key Challenges

Discussed in this section were the most notable challenges that had to be overcome when developing the client side of WebSlicer.

4.3.1   Visualizer Integration

The visualizer starter code for this was originally written by Nils Hitze as an open source project which had many other features (Hitze, 2015). This code, however,

required a lot of work to integrate properly with the rest of the application. AngularJS, despite its many features does not mix well with other projects. Ultimately, the only code that remained from the original was the JavaScript web worker and some of the parser code.

4.3.2 Interpolating Settings

A method was required to be designed for the application to handle a lot of input fields. A simpler method would have been to create a series of fields, each with their own variable, and submit methods and triggers; however, if settings ever change format it would require refactoring many files. Thus, spending the extra time to design an intelligent method of handing large amounts of input data seemed logical. This, however, took much more time and effort than anticipated. At one point, this even required contacting the original developers of CuraEngine discuss the meaning of some of their settings. Documentation for many of the settings was dissatisfactory and in many instances was non existent which further slowed down development.

4.4 Other Planned Integrations

During the development process often many items do not make it into the final product for various reasons. Included in this section are some items which were cut from WebSlicer before beta testing.

4.4.1 OctoPrint

A feature that was removed at a late state in the process of building this application was an integration with OctoPrint. OctoPrint has a exceptional API that allows for external applications to integrate easily, making it an ideal choice for this application. This integration was to allow a user who was running an OctoPrint server to be able to send files directly to their server. This would eliminate the need to download the G-code from WebSlicer only to be uploaded to the print server seconds later. It was

decided at the last moment that this feature need not be in the minimum viable product and that time was best allocated to finishing more crucial features of the application.

4.4.2   Thingiverse & YouMagine

Another planned integration was the ability to import from a web based repository such as Thingiverse or YouMagine. These repositories are public sites where users can upload their 3D designs so others can 3D print them. Thingiverse in particular has a effective API for accessing models from their site, which would make it an easy integration for a web based slicing software; however, this feature was terminated early on, as it would have required too much unnecessary development time to finish.

4.5   Issues & Known Bugs

As mentioned in prior sections, WebSlicer was designed with a minimum viable product in mind. Developing a working 3D print slicer for the web was the primary task and all other features needed to support this or extend this functionality. For this reason, there is no login or user database, which would normally be the first item to be developed for an application such as this. There is also no way to view any of the models in 3D which, for most users, makes the software significantly harder to use.

Chapter 5

Server Side

This chapter discusses the server side of WebSlicer in detail. Included with this is some necessary background about JavaEE and some of its functions.

Figure 5-1: The structure of the server side of WebSlicer

5.1 JavaEE Structure

The server side of WebSlicer was written in JavaEE, the structure for which is shown in Figure 5-1. JavaEE was the optimal choice for this application, as it allowed for the easiest deployment and was also the easiest to scale (Pilgrim, 2013). Additionally, JavaEE has a excellent code packaging mechanism for web and non web based applications alike. The web container which is in use for this application exposes a RESTful API on a privately hosted server.

To further simplify the development process, Maven was also used. Maven is a build tool for Java and has support for deploying complex applications such as those in JavaEE (Vincent Massol, 2005). Thus, when a build was completed, it was automatically deployed and ready for testing.

5.2   ProcessBuilder

At the core of the server side application is an executable called CuraEngine. It is
the main executable which is compiled from the open source slicing platform Cura
which is written in C++. This presented a problem, as all of the server side code in this
application is written in Java. ProcessBuilder was the solution to this problem as it is
capable of redirecting the input and output streams of a local executable process into
the Java server application. CuraEngine from Figure 5-1 uses a ProcessBuilder and the
PlatformExecutable to create a runnable Java method that is capable of executing like
a C++ executable. CuraOptions feeds the CuraEngine class with all of the parameters
that it needs from the API. It gathers the path to the appropriate settings file and
includes all of the parameters needed to run the CuraEngine executable.

Listing 5.1: An example of running CuraEngine C++ executable directly from the
command line.

```
CuraEngine slice -v -j {settings.json} -g -e -o {output.
    gcode} -l {model-file.stl}
```

An example of running the CuraEngine C++ executable from the command line
is shown in Listing 5.1. When the ProcessBuilder class of WebSlicer receives a slice
command from the API it gathers the arguments listed in brackets and sends them
to PlatformExecutable. PlatformExecutable then spawns a native process and pipes
its input and output streams into the respective Java streams. In the meantime,
StreamDrainer spawns a new thread and waits for the output stream that was created
by PlatformExecutable. StreamDrainer's task is to take the unneeded output from
stdout and pipe it into a log file for debugging.

After CuraEngine has finished slicing the current file and PlatformExecutable has
returned the REST API, which has been waiting, it unblocks and starts reading the
output gcode file. This file is then packaged and sent back to the client as the response
of the "/slice/{clientId}/{modelId}" command as shown in Table 5.1.

5.3 REST API

Type	Address	Description
GET	/ping	A simple ping endpoint used for testing.
POST	/setupClient	Sets aside all needed files for a new client and return its unique ID.
POST	/importStl/{clientId}	Takes a MIME type file stream and imports the file to the clientId specified in the URL. It also returns a unique identifier for the file.
POST	/importSettings/{clientId}	Similar to importStl this endpoint takes a settings JSON file and imports it to the specified clientId
POST	/slice/{clientId}/{modelId}	This is the main slice function of the API. It combines all of the parameters specified by the calls before and returns a gcode file to the user.
POST	/testSlice	A test endpoint that requires no parameters and simply returns some arbitrary gcode to the user.
GET	/getFiles/{clientId}	Returns all the model file names and their tracking ID's that are associated with a clientId.

Table 5.1: Documentation of all exposed endpoints of my RESTful API

The goal of the client is to satisfy all the requirements needed to run the "/slice" command from Table 5.1. A typical call pattern to the API in begins with creating a user if one does not already exist. Creating a new user requires calling "/setupClient" and recording the returned unique user identifier. Using the recorded unique identifier the client must then upload a model file and settings file to the corresponding "/importStl" and "/importSettings" functions. This returns unique identifier strings for all settings and model files that the client uploads to the server. Finally, to run a slice, the client takes all acquired unique identifiers and places them into the call to "/slice" as shown in Table 5.1. Upon successful completion of all aforementioned calls the user will be returned a G-code file in raw textual form.

5.4   Key Challenges

5.4.1   ProcessBuilder Deadlock

Figure 5-2: Diagram of a deadlock issue that took weeks to resolve

One considerable bug encountered while developing this project was a thread deadlock issue. The server side code uses Java's ProcessBuilder, which builds a system native call to an executable and then pipes the input and output into the corresponding pipes of Java's stdio as shown in Figure 5-2. This is suitable for small platform executables with limited I/O, but can become problematic when complex native calls such as CuraEngine are used.

ProcessBuilder executes its normal writes to stdout and the drainer pipes them into a file; however, the drainer must wait for a file pointer using the fp.available() function. This is a non-blocking function that only estimates the buffer size that it has for the file. The check for file pointer availability was determining whether this function returned something greater than 0 as an estimate before notifying the ProcessBuilder that it was ready; however, the buffer size would often start as zero before allocation and, as this check was not part of a loop, it would stay stuck forever as the notify was missed.

This problem was solved by using the correct blocking file pointer available check. Occasionally, the buffer size was larger than 0 and the application ran suitably but, with some models, it would consistently fail, as the buffer had not been allocated yet. This solution is seemingly obvious yet it took many days to find and correct because the application did not fail consistently.

5.4.2 FileTracker Revamp

The first iteration of FileTracker was crude and not well planned out. It tracked two hash maps: one for model files and the other for settings files with no mind for the client who required access to those files. This worked for testing, but experienced many pitfalls including the inability to reuse files that already existed. As soon as the client closed their session, those files were lost, which is a major inefficiency.

The fdmprinter.json file within the unique client folder is symbolically linked to the fdmprinter.json file within the common folder. The CuraEngine executable requires that all of the settings files rest within the same directory when performing a slice as shown in Listing 5.2. Unfortunately, this leaves the potential result of having this file copied for many clients. Thus, symbolically linking the file to the rescue.

The output.gcode and settings.json files are dynamically overwritten for every iteration so their existence here is only for the sake of running CuraEngine through file arguments. The user has no access to these files and is only able to obtain their content through the web interface, which parses in and out of files.

Listing 5.2: WebSlicer's underlying file structure supported by FileTracker.

```
webslicer/
- b1a2a69e-5893-4d7c-aa1f-d639fa3b4ed1/
  - fdmprinter.json -> /tmp/webslicer/common/fdmprinter.
    json
  - models/
    - balanced_die_version_2.stl
    - raldrich_planetary.stl
  - output.gcode
  - settings.json
- common/
  - fdmprinter.json
  - presets/
    - prusa_i3.json
    - ultimaker2.json
```

5.5   Future Improvements

Currently, FileTracker does not take advantage of the presets within the common/presets/ folder as described by Listing 5.2. These files contain the default settings for the corresponding printer, which are the ultimaker2 and a basic configuration of a prusa i3 variant. Optimally, the user would select from one of these starting presets and then modify and save their own. This would allow users an optimal starting point while lowering the amount of starting knowledge and increasing the usability of WebSlicer.

This new file structure also allowed for an easy client index. In the future, the unique folder ID will become the client's identification number, which will be attached to their login. Additionally, simplifying the login process with Google's OAuth 2.0 system was also planned.

5.6   Issues & Known Bugs

Currently there is no way for the server to import existing user files into its structure. Thus, when the server is restarted for any reason, the supporting file structure with all user files is lost. Resolving this is just a matter of writing an initial import function that indexes all of the existing files. It was removed from the initial version due to time constraints.

Chapter 6

Discussion

This chapter summarizes the experience of running usability testing of WebSlicer and the construction of a RepRap 3D printer that was used during software trials.

6.1 Usability Testing

Good design goes through many design iterations before it is considered production ready. Between iterations feedback is given through usability testing. Unfortunately, this research had a short time line thus, only one cycle of usability testing was possible.

6.1.1 Task Description

WebSlicer was evaluated by giving research participants a series of tasks to preform in a controlled environment. This environment consisted of a lab computer with a small collection of model files and a web browser. The tasks that were given to participants are formalized in Table 6.1. Participants were also asked to fill out a questionnaire when they had completed the study. This questionnaire asked participants to rate the level of difficulty of each task from 1 to 5 and to include comments of what they thought of each task. Results of the average difficulty reported by users is shown in Table 6.1. As an incentive to participate, participants were given a small 3D printed figure of their choosing.

Task #	Task Name	Average Difficulty	Description
1	Create a new user	4.66 out of 5	Participants were simply asked to click a button which generated a unique ID for them.
2	Upload your file	5 out of 5	Uploading a model file of the participants choosing from a given USB drive.
3	Adjust slicer settings	4.33 out of 5	Participants were presented with a table of settings and their value. They were instructed to find these settings and change them while ignoring all other settings.
4	Analyze and download G-code	4.66 out of 5	This task simply required the user to toggle the visualizer to see the output of their actions in prior tasks.

Table 6.1: The tasks given to participants of the usability study. The participants were asked to complete the tasks in numerical order.

6.1.2 Results

The expected result of usability testing was to expose some minor flaws of the user interface (UI) design; however, the results showed that more than minor changes would be required before the next iteration of WebSlicer. G-code output in textual form exposed to the user was found to be a bug in certain cases during usability testing. The output when slicing certain models was so large that the browser crashed when trying to load the text to the screen. This bug could be resolved by filtering the amount of text displayed at one time to the user.

Another flaw that was exposed during testing was the functionality of the G-code visualizer. Most participants found that both the controls, and explanation of what it was meant to accomplish was lacking. Concluded from this is that more textual explanations and user guidance was required in further iterations of WebSlicer.

6.2 Printer Build

6.3 Future of WebSlicer

The goal of future versions of WebSlicer are to lay the groundwork for a larger manufacturing software tool. This manufacturing software will link together many 3D printers and allow for unified control from a web based hub. Unified control such as this would allow for users to preform small scale manufacturing which would fill a void that currently exists in the manufacture of plastic parts.

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Appendix A

IRB Compliance Documents

Included in this appendix are all the IRB compliance documents that were requited for preforming usability testing.

A.1   IRB Exempt Form

The following pages are the IRB Exempt Form which contains the offical summery of the research to be undertaken.

IRB <u>EXEMPT</u> STATUS APPLICATION

IRB No.: 16-061-MAR-EXM   Rev. No./Date: 2/4-11-16

Submit all documents to <u>IRB@uml.edu</u>   Date Submitted to IRB: 3/29/16

(This form is ONLY for minimal risk research where no identifiers are collected.)

A. GENERAL INFORMATION

Project Title: WebSlicer Usability Testing	
PI: Fred Martin	Email:fredm@cs.uml.edu
Department: Computer Science	Work Address (Bldg and No.): Olsen Hall 306
Phone: 978-934-1964	Emergency Phone: 978-934-2705
Co-PI(s):	Co-PI(s) Contact Info:
Student Researcher: Michael Meding	Student Researcher Contact info: 214-334-1905

1. **Sponsor Information- Check One** (Double left click on each check box to access tool.)

(x) Not funded.

( ) Internal funding. Type:

( ) Government/Federal funding. List agency name:

( ) Subcontract. List organization name and include contact name, telephone no., and address:

( ) Other. List organization/company name and include contact name, telephone no., and address:

The proposal to the funding source noted has also been submitted to the IRB: ( )Yes   ( )No

2. Project Personnel: Include the PI and all personnel who may interact with subjects or access identifiable human subject data. Training certification should be submitted with the application.

Name and Title(Check one)	Email Address	Training Completed
Fred Martin (x)Faculty ( )Staff ( )Student	fredm@cs.uml.edu	(x) CITI Basic, Date: 06/27/2014 ( ) NIH, Date:
Michael Meding ( )Faculty ( )Staff (x)Student	mike@mikemeding.com	(x) CITI Basic, Date: 03/01/2016 ( ) NIH, Date:
  ( )Faculty ( )Staff ( )Student		( ) CITI Basic, Date: ( ) NIH, Date:
  ( )Faculty ( )Staff ( )Student		( ) CITI Basic, Date: ( ) NIH, Date:
  ( )Faculty ( )Staff ( )Student		( ) CITI Basic, Date: ( ) NIH, Date:
  ( )Faculty ( )Staff ( )Student		( ) CITI Basic, Date: ( ) NIH, Date:

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		( ) CITI Basic, Date:
( )Faculty ( )Staff ( )Student		( ) NIH, Date:

Additional personnel or other information:

a. Is this a student research project?   (x)Yes ( ) No
   If yes, (x) Graduate or ( ) Undergraduate, please specify below:
   ( ) Dissertation (x) Thesis ( ) Directed Study ( ) Class Project ( ) Other:

B. SCREENING QUESTIONS

1. Conflict of Interest Disclosure:
   a.   Do you or any family members have a financial interest in this research activity (such as an equity position or outside consulting arrangement with the company whose drug, procedure, device or product is used or tested in this study)?   ( )Yes (x) No
   If **yes**, explain the nature of the relationship and the conflict(s):

   b.   Do other faculty or staff involved with this research have a financial interest in this research activity?
   ( )Yes (x) No
   If **yes**, indicate the nature of the relationship and the conflict(s):

   c.To your knowledge, does the University have a financial interest in the company whose drug, procedure, device or product is used or tested in this study (such as patent rights, equity)?   ( )Yes (x)No
   If **yes**, indicate the nature of the relationship and the conflict(s):

2. Will the research expose participants to discomfort or distress beyond that normally encountered in daily life?
   ( )Yes (x)No

3. Could disclosure of participants' responses outside the research reasonably place them at risk of criminal or civil liability or be damaging to their financial standing, employability, or reputation?   ( ) Yes (x)No

4. Does any part of the research require deception or incomplete disclosure of information to participants?
           ( )Yes (x)No

5. Will prisoners (or their data and/or specimens) be participants in the research?   ( )Yes (x)No

6. For research proposed under categories 1-5, is the research subject to FDA regulations?   ( )Yes (x5)No

   Note: a **YES** for **questions 2-6** above indicates your research does NOT meet exempt criteria. Submit an Application for Expedited or Full Review.

C. EXEMPT CATEGORY CLAIMED (check all that apply):
( ) 1. Research conducted in established or commonly accepted educational settings, involving normal educational practices, such as research on regular and special education instructional strategies, or research

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on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

    If you checked this category, to do the research under this exempt category, it must be conducted in commonly accepted educational settings and not deviate from normal educational practices.

    Is this true?　( )Yes　( )No　　If no, please submit an application for expedited or full review.

(X) 2. Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior, **unless**: Information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

    If you checked this category, the activity may **not** involve any interactions of the researcher with children, if they are participants.　Does it involve interactions with children?　( )Yes　(X)No

    If yes, submit an application for expedited or full review.

( ) 3. Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (2) of this section, if: the human subjects are elected or appointed public officials, or candidates for public office; or federal statute(s) require(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.

( ) 4. Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

    For research under this category, will any of the data, documents, records, or biological specimens be collected or created **after** the date of this application?　( )Yes　( )No

    If yes, submit an application for expedited or full review.

    For research under this category, will any of the information obtained from private sources of data, documents, records, or biological specimens be recorded by the investigator in such a manner that subjects could be identified directly or through identifiers linked to the subjects?　( )Yes　( )No

    If yes, submit an application for expedited or full review.

( ) 5. Research and demonstration projects conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: public benefit or service programs; procedures for obtaining benefits or services under those programs; possible changes in or alternatives to those programs or procedures; or possible changes in methods or levels of payment for benefits or services under those programs.

( ) 6. Taste and food quality evaluation and consumer acceptance studies, if wholesome foods without additives are consumed or if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the Food and Drug Administration or approved by the Environmental Protection Agency or the Food Safety and Inspection Service of the U.S. Department of Agriculture.

  D.　**RESEARCH ACTIVITIES-Check all that apply:**

( ) Internet or email data collection	(x) Observation of participants
( ) Existing data, publicly available	( ) Record review
( ) Existing data, NOT publicly available	( ) Research using existing specimens
( ) Focus groups	(x) Surveys or questionnaires
( ) Audio recordings	( ) Interviews
( ) Other:	

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E. **RESEARCH SUMMARY**

    1.   Describe the research purpose and objectives: In this research study, we are evaluating a web-based 3D print slicer. Participants will choose a small model or figure from a set of pre selected models and follow the steps provided in the "Task Instructions" document to take that model from design to printable file. The objective of this study is to gain insight into the usability of this software so that it may be evaluated and improved as part of the thesis study.

    2.   Describe the research methods: Participants will be recruited via email. Upon response from recruitment email participants will choose a time to join us in our lab Olsen 306, From there, participants will be asked to review the consent form (which will be provided as a web link) and then indicate that they have read the form and consent to the study in an online survey form. If they indicate they have not read the consent form, or decline consent, the session will end there. Sessons will last between 20 to 30 minutes depending on the amount of prior knowledge that the participant has of 3D printing and its surrounding technologies. Prior knowledge is not required to participate in this study. Upon consent, participants will be asked to complete a pre-activity survey on a computer in our lab Olsen 306. Then participants will be provided a printed version of the Task Instructions, and asked to use the web-based software to perform the set of tasks described therein. While each participant is completing the tasks, the researcher will record brief observations on a observations form (attached). After the tasks are complete, participants will be asked to take at post-study survey (which is provided as a continuation of the pre-survey). During this time, they can watch the 3D printer output a model. At the conclusion of the study, participants will receive a previously-printed model as a token of appreciation for their participation. The researcher will match surveys and observation notes by numbering the first participant "1", the second "2", and so on, on the observation form. No personally identifiable data will be collected during this study.

3. Describe the participant population: Students and faculty at UMass Lowell whom have little to no knowledge of 3D printing or its surrounding technologies.

4. Recruitment Information
    a. Describe how the participants will be recruited:
Students will be recruited via email from the Computer Science email message board. The recruitment email will be sent from the PI's email and responses will be sent to the student researcher's email as included in the instructions in the email.
    b. Indicate the anticipated number of participants: 6 to 8
    c. Will any participants be under 18 years of age?   ( )Yes (x)No

        If yes, justify and describe how you will meet the exemption requirements:

5. Estimate the duration of the study: 1 Month

6. Will all of the research activities be conducted at UMass Lowell?   (x)Yes ( )No

    a. If no, list the site/collaborator(s):
    b. A letter(s) has been submitted to the IRB from the collaborator to document how they intend to   support the research.   ( ) Yes ( )No

7. Describe how participants will provide consent: Participants will be asked to read a consent form and then asked to click yes or no on the survey page.

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8. Does research involve the use of publicly available or currently existing data?   ( )Yes (x)No

      a. If yes, list source of the data or specimens:

      b. Indicate whether the data is currently de-identified or how it will be de-identified:

9. Describe any potential risk to participants from participating in the research: There is no more than minimal risk to participants since no identifying information will be collected. Participants who experience discomfort from using a computer will be advised in the consent form to refrain from particpating.

10. Indicate how you intend to minimize any risks to participants: Participants will be informed that they may leave the study at any time should they feel uncomfortable and no identifying information will be collected.

11. Describe procedures to protect participants' privacy and confidentiality: Personally identifiable data will not be collected.

12. Describe the potential benefits from the research: Design improvements of the software being researched.

13. Check all of the supporting materials submitted with this application:

    (x) Questionnaires, surveys

    ( ) Standard Research Tools (published testing materials, etc.)

    (x) Recruitment Materials

    (x) Consent Documents

    (x) Other, list: Observation rubric to be used by researcher while participant completes tasks; Task Instructions document.

F. PRINCIPAL INVESTIGATOR ASSURANCE AND SIGNATURE

(X) I understand that, as the PI, I am ultimately responsibility for the protection of the rights and welfare of human participants and the ethical conduct of research under this protocol. I agree to conduct the study in accordance with the approved protocol and ensure that all personnel involved in the research will do the same.

(X) I agree to follow the [UMass Lowell IRB Policies and Procedures](#).

(X) I certify that the information provided in this application is complete and correct, and believe that my project qualifies as Exempt from the Federal Regulations.

(X) I agree to personally conduct or supervise the described investigation(s).

(X) I agree to maintain copies of all questionnaires, survey instruments, interview questions, data collection instruments, and information sheets for human participants for three years following termination of the project,

(X) I understand all investigators associated with this research must renew their human participant research training every 3 years.

(X) I understand it is my responsibility to resubmit an application to the IRB if I need to make any changes that alter the exempt status determination and approval.

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(X) I understand this project will be closed by the IRB one year from the date of approval and records will be retained in the IRB office for 3 years after that date.

Project Title: WebSlicer Usability Testing

The signature page only may be submitted as a scanned document, faxed to x6012, or sent by intercampus mail to the IRB Administrator at Wannalancit, 2nd Floor. The entire application should be emailed as a word document to IRB@uml.edu

SIGNATURE: **Note: Students are not eligible to sign this page.**

PI Signature: /s/ Fred G. Martin	Date:3/29/16
Printed Name of PI: Fred G. Martin	

OR (X) Check here if submitted electronically from the PI's email account.

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A.2 IRB Consent Form

The document that follows is the consent form which was distributed to participants before beginning the usability study.

WEBSLICER USABILITY TESTING
INFORMED CONSENT

INTRODUCTION

You are invited to join a research study under the direction of Fred Martin and conducted by Michael Meding, "Webslicer Usability Testing." This study will involve the process of bringing a 3D model from digital design to physical world using our new slicing software. Please take whatever time you need to discuss the study with your family and friends, or anyone else you wish to. The decision to join, or not to join, is up to you.

In testing WebSlicer, we will be evaluating a web 3D print slicer. A print slicer is a piece of software which takes 3D models and divides them into virtual layers in preparation for being 3D printed. As a participant your role will be to choose a small model or figure from a set of pre-selected models. From there the participant will take this model through all of the steps necessary to prep it for being printed on a supplied 3D printer.

From this focused study I hope to gain insight into some of the strengths and weaknesses of my software design so that I may improve its final design.

WHAT IS INVOLVED IN THE STUDY?

If you decide to participate you will be asked to sit at a computer in one of our labs and answer questions from a pre-study survey. The questions will be about your general knowledge of 3D printing and should take no more than 5 minutes.

Participants will then be asked to perform a set of tasks to the best of their ability using our software. The tasks are short and simple, such as inputting given information into text fields or uploading a file.

Finally, participants will be asked to take a short post-study survey which asks them to rank the difficulty of given tasks from the prior exercise. Participants will also be able to add their own notes about their experience using our new software.

This research will take you about 30 min from start to finish.

You can stop participating at any time.

RISKS

There are no anticipated risks to participating in this study. However, if you experience any discomfort with using a computer then it is not recommended that you participate in this study.

BENEFITS TO TAKING PART IN THE STUDY?

There are no direct benefits to you however, participating in this research you may develop a better understanding of 3D printing and its surrounding technologies.

CONFIDENTIALITY

We will not be collecting any personally identifiable data during this study.

The results from this study will be published as a part of the student researcher's master's thesis and will only be shown in the form of what has been gained by the insight that you as a participant tell me is wrong with my software.

INCENTIVES

The only incentive in this study is the ability to take home a 3D printed model of your choice at the end of the study.

YOUR RIGHTS AS A RESEARCH PARTICIPANT

Participation in this study is voluntary. You have the right not to participate at all or to leave the study at any time. Deciding not to participate or choosing to leave the study will not result in any penalty or loss of benefits to which you are entitled, and it will not harm your relationship with WebSlicer and any University of Massachusetts Lowell staff.

CONTACTS FOR QUESTIONS OR PROBLEMS?

Call Fred Martin at 978-934-1964 or email at fredm@cs.uml.edu if you have questions about the study, any problems, unexpected physical or psychological discomforts, any injuries, or think that something unusual or unexpected is happening.

A.3   WebSlicer Recruitment Email

A recruitment email was needed to find a sufficient number of participants to preform usability testing.

Subject Line: 3D print slicer software prototype study

Professor Fred Martin and I, Michael Meding are looking for a small group of students to participate in our study, "Webslicer Usability Testing."

You will use our new software called WebSlicer. WebSlicer is a 3D print slicer designed to run entirely on the web. Its purpose is to take a model from a 3D modeling software such as AutoCAD and "slice" it into layers such that a 3D printer can understand how to build it.

Your participation in this study will take about 30 minutes upon arrival you will be asked to give your consent for the study. The study will take place in our lab (Olsen 306) and will be in the form of an online survey given on one of our lab computers. As a participant you are free to stop the study at any time with no consequence. As a token of our appreciation you will be able to go home with a 3D printed model of your choice.

If you choose to participate please send an email to Michael_Meding@student.uml.edu with the subject "WebSlicer Study". Please include your time availabilities and we will try our best to schedule you a time to meet with us.

Requirements:
- The ability to comfortably use a lab computer
- Some knowledge of the process of 3D printing is helpful but not required to participate

Please reply to Mike Meding, mikeymeding@gmail.com, if interested.

Thanks for your help!

A.4   WebSlicer Survey

The document that follows is the survey that was given to participants of the study. It consists of a few short questions and open ended comments.

WebSlicer Pre-Study Survey

Consent and questions while testing WebSlicer

* Required

1. **Have you read and signed the Consent Form and hereby give consent to participate in this study? ***
   Mark only one oval.

   ( ) Yes

   ( ) No   *Stop filling out this form.*

Pre-Study Question 1

2. **Have you ever used a 3D printer before?**
   Mark only one oval.

   ( ) Yes

   ( ) No   *Skip to question 5.*

Pre-Study Question 2

3. **Do you know what a slicer is or what slicing software does?**
   Mark only one oval.

   ( ) Yes

   ( ) No   *Skip to question 5.*

Pre-Study Question 3

4. **What slicing software have you used or know about?**
   Check all that apply.

   [ ] Cura

   [ ] Repetier Host

   [ ] KISSlicer

   [ ] Other: ....

Post-Study Survey

5. **How would you rate the difficulty of Task 1 (Create a new user)? ***
   Mark only one oval.

	1	2	3	4	5	
difficult	◯	◯	◯	◯	◯	easy

6. **Comments about Task 1**

   ....

7. **How would you rate the difficulty of Task 2 (Upload a file)? ***
   Mark only one oval.

	1	2	3	4	5	
difficult	◯	◯	◯	◯	◯	easy

8. **Comments about Task 2**

   ....

9. **How would you rate the difficulty of Task 3 (Adjust slicer settings)? ***
   Mark only one oval.

	1	2	3	4	5	
difficult	◯	◯	◯	◯	◯	easy

10. **Comments about Task 3**

    ....

11. **How would you rate the difficulty of Task 4 (Analyze and download Gcode)? ***
    Mark only one oval.

	1	2	3	4	5	
difficult	◯	◯	◯	◯	◯	easy

12. **Comments about Task 4**

    ....

13. **What is one thing that you would change about this software?**

    ....

14. **Did you run into any problems while preforming the tasks given?**

   ....

15. **Was anything difficult to use or hard to find when you needed it?**

   ....

16. **Additional comments**

   ....

   ....

   ....

   ....

   ....

Powered by

A.5 WebSlicer Tasks

Participants in the usability study were given a series of tasks as described by the document that follows.

WebSlicer

181 Bacon St
Natick, MA 01760
(214) 334-1905

Task Instructions

March 03, 2016

Overview

As a participant your goal today is to follow all the steps involved in taking a model from the virtual world into the physical world with the power of 3D printing. Starting by choosing from a small subset of models which I have pre-selected, you will download this and load it into the slicing software which I have developed. The models which you will be using for this study have been pre printed and you will be able to take one home at the end of the study.

Choose Your Model

3
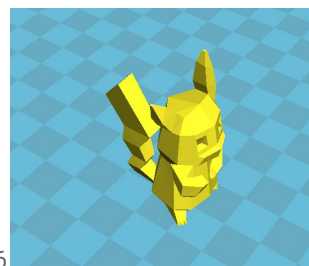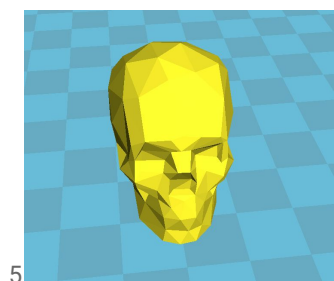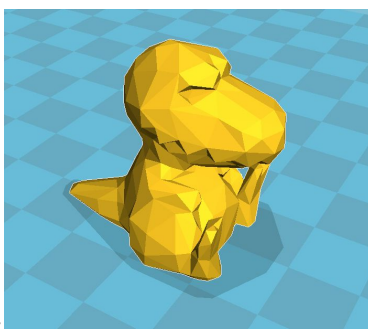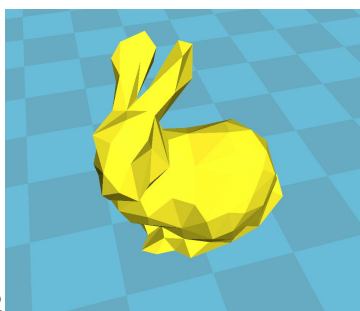
Task 1: Create a new user

User Goal: Get a new login ID.

This task is pretty simple. All you need to do is click the orange button labeled "generate new id." If you wish to return to your work later please copy this number as it is your reference number to your file.

Login

Client ID

8336d14c-b556-44db-b48f-73a4dc69e5cc

[generate new id]

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Task 2: Upload your file

User Goal: Take your chosen model file and upload it to WebSlicer.

In this task you simply need to take the file which you have chosen and upload it using the upload button under slicer controls. The file will be provided to you on a USB stick. You upload to Webslicer in the same way that you would by selecting a file in Word.
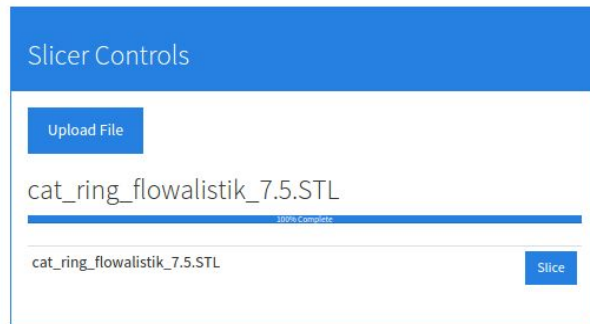
Your output should look something similar to the picture above.

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Task 3: Adjust slicer settings

User Goal: Adjust settings so that the model will print correctly.
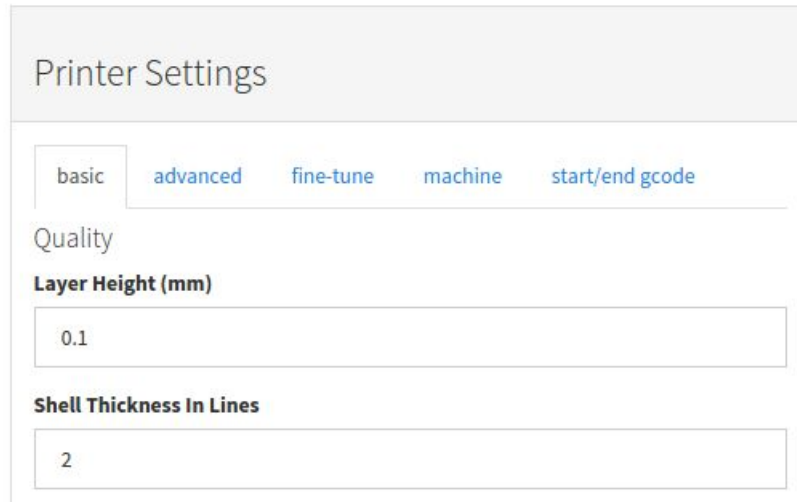
Basic Settings

The only settings that you will need to adjust will be under the basic tab. The settings that you need to find and change are as follows,

- Layer Height: 0.2
- Infill: 80%
- Filament Diameter: 1.75
- Shell Thickness in Lines: 2
- Printing Temperature: 245
- Bed Temperature: 110
- Print Speed: 40

The default values for the rest of the settings should do fine for your model.

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Printer Settings

| basic | advanced | fine-tune | machine | start/end gcode |

Quality

Layer Height (mm)
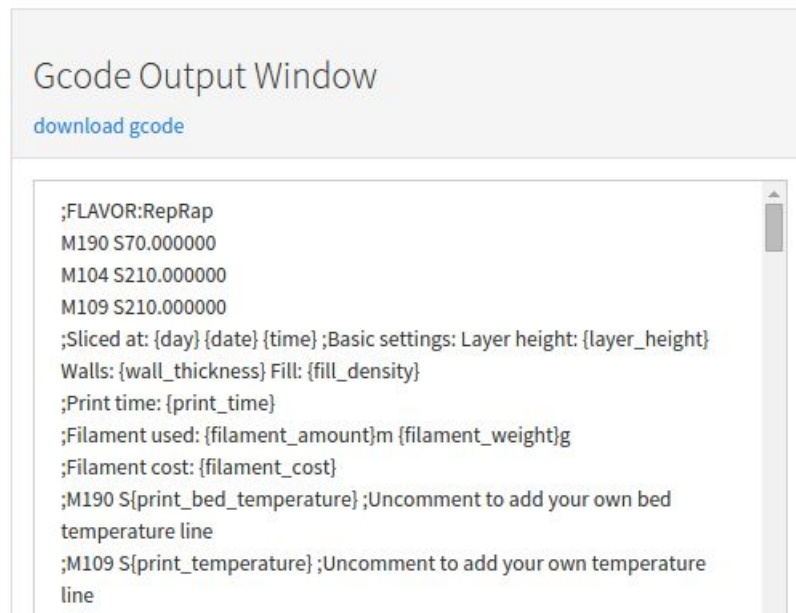
0.1

Shell Thickness In Lines

2

Your window will look different from the one above. The picture is simply as a reference.

Task 4: Analyze and download Gcode

User Goal: Use visualizer to see the resultant Gcode and download it for printing.

When you have completed task 4 you have to press the slice button next to the model you wish to slice. The slice button should change into a spinning cog to indicate that it is working on slicing your model in the cloud. When it completes you should see some output that looks something like the following image,

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Gcode Output Window

download gcode

```
;FLAVOR:RepRap
M190 S70.000000
M104 S210.000000
M109 S210.000000
;Sliced at: {day} {date} {time} ;Basic settings: Layer height: {layer_height}
Walls: {wall_thickness} Fill: {fill_density}
;Print time: {print_time}
;Filament used: {filament_amount}m {filament_weight}g
;Filament cost: {filament_cost}
;M190 S{print_bed_temperature} ;Uncomment to add your own bed
temperature line
;M109 S{print_temperature} ;Uncomment to add your own temperature
line
```

You should also see a visualizer window like the one in the next picture. This is where you can step through all of the layers of your model and see exactly what it will do while it is printing.

When you are satisfied with this output you can press the "download gcode" text as it appears in the photo above. You will then get your Gcode file ready to be printed.

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Gcode Visualizer

layerNumber 2 **progress** 50
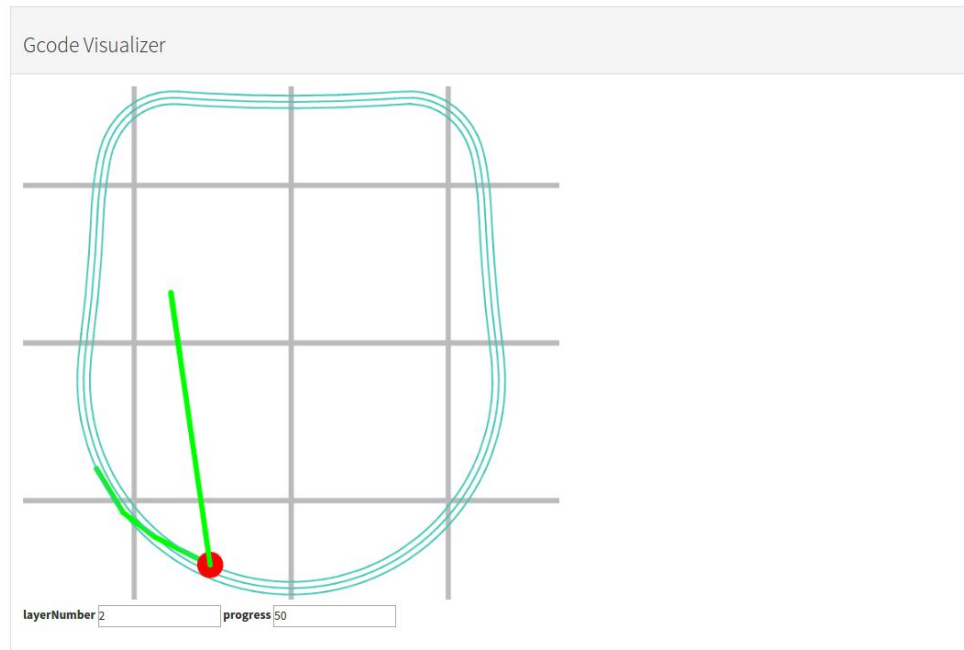
And that's it! You have successfully sliced your first model using WebSlicer. All that is left to do is grab the person conducting the research and tell them that you are done and you can watch as your model will get printed for you.

Thank you for your participation.