Vocabulary:

Topology Optimization:

- A program/model that takes a provided part and optimizes it for specific conditions such as strength, weight, aerodynamics, or other parameters.

Additive Manufacturing:

- Any method that takes a virtual part and constructs it by adding material repeatedly. One example would be 3D printing, and one example of what it isn't would be a CNC machine.

LANL:

- LANL is short for Los Alamos National Laboratory.

Brief Summary:

This project uses the Marching Cubes algorithm to connect topology optimization to additive manufacturing. It allows engineers to CAD parts and quickly create physical objects that they can interact with. The project focuses on converting the continuous scalar field from topology optimization to a discrete mesh representing the part's surface so it can be easily printed. The project will not focus on the implementation of topology optimization or the process of 3D printing.

Project Description:

This project's problem is that topology optimization constructs a continuous scalar field, while additive manufacturing, such as 3D printing, requires a discrete mesh of the part surface with defined boundaries. This project focuses on neither topology optimization nor additive manufacturing processes but rather a crucial step in the pipeline between the two. The goal is to provide a solution to fill the missing step and create a streamlined method for engineering and prototyping complex parts.

Marching cubes is a method that takes a continuous scalar field defined on a volume mesh and creates a discrete mesh of its surface (given by an isocontour of the scalar field). The algorithm looks through each cell of the volume mesh and analyses the eight corner points. Based on these points, an approximate polygonal shape is inserted and interpolated to the precise boundary points on the edges. The discrete surface representation of the part is constructed from the polygons. The precision of the final surface mesh can be set to a desired level by altering the resolution of the volume mesh. A derivative of Marching Cubes, Marching Tetrahedra, was also explored during this project, although its increased complexity outweighed its benefits.

After implementing the software in C++, it was verified using multiple known test cases online. A website provided multiple test scenarios along with the desired outputs. Upon entering the scenarios and calculating the discrete surface for them, the results were compared, and in all cases, they matched the expected results. Some of the test cases are provided below in Figure 1.

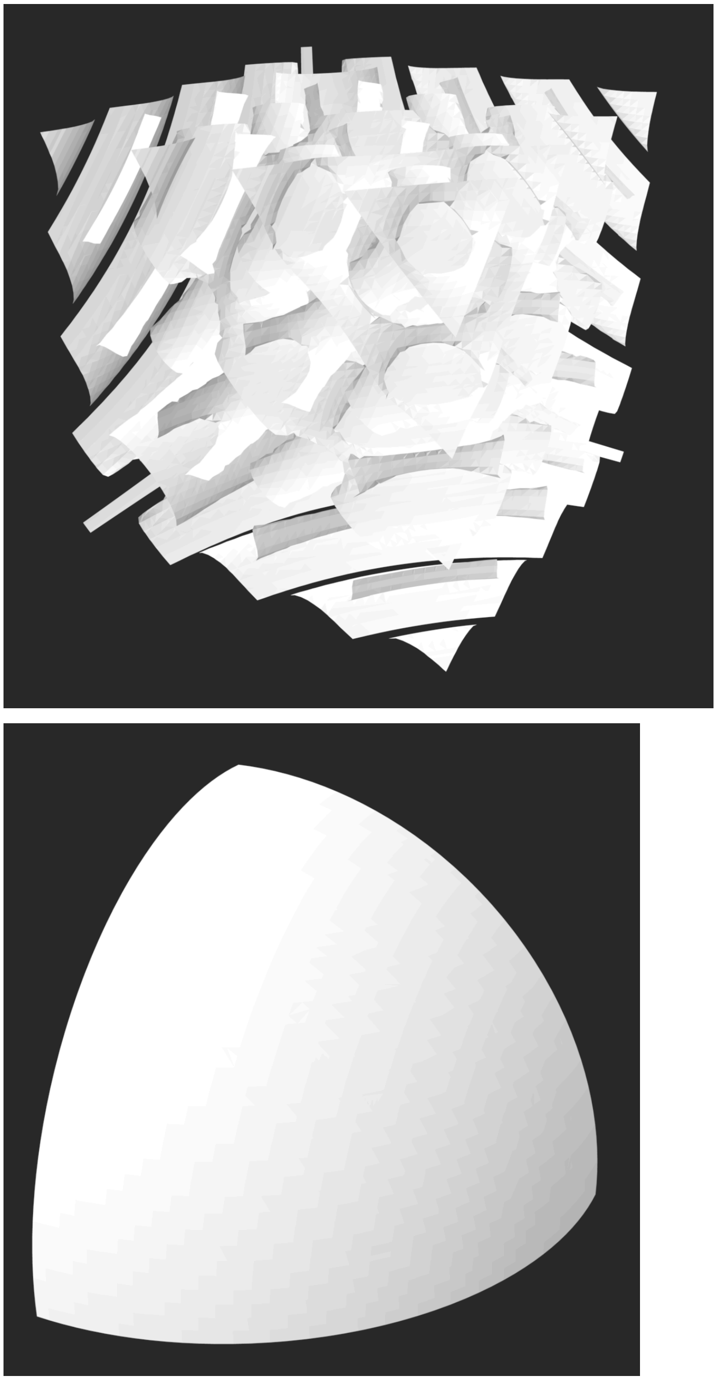

Figure 1: verification test results of the Marching Cubes implementation.

Multiple different optimized parts were created and then run through the software. The software was able to return a discrete mesh, in the form of an STL file, representing the surface of the part, which was, in turn, able to be printed using traditional commercial software for additive manufacturing. The results were rendered in 3D software and printed to be physically interacted with.

Demonstrating the software's functionality, it was used with a topology optimization code at LANL to export designs to 3D printers. A version of the software, along with renders of the parts (the part files are from LANL, and they optimized them using their topology optimization program), can be found on GitHub: https://github.com/AndrewDMorgan/Marching-Cubes. In addition, some screenshots of the provided renders are attached below in Figure 2.

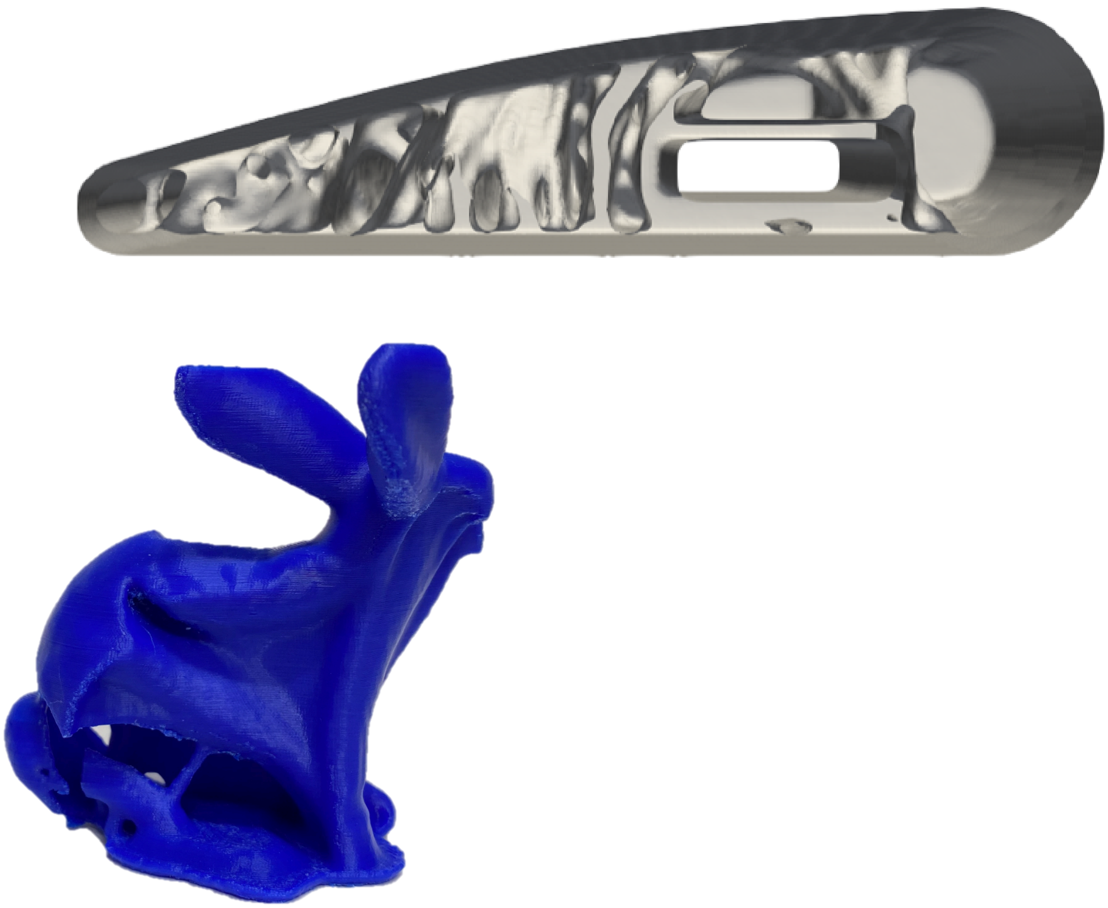

Figure 2: Topology-optimized parts by LANL, surface reconstructed using the software created for this project, and exported to 3D printers.

One of the most significant results of this project was the ability to create a streamlined design-to-manufacturing pipeline, enabling engineers to CAD prototypes and functional parts and quickly see their results in action. As mentioned in Figure 2, the design-to-manufacturing pipeline was tested by taking an airplane wing, optimizing it, and printing it all within quick succession, proving the versatility and effectiveness of this pipeline along with the functionality of the critical pipeline step this project developed.

The initial inspiration for this project came from a video on Marching Cubes created by Sebastian Lague. In addition, his recourses and algorithm breakdown were helpful in constructing the Marching Cubes software. The optimized parts were made by LANL using their topology optimization script. LANL also printed the parts. LANL made this project possible by offering help with additive manufacturing and topology optimization.

References:

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