Week 01: Summary

The first method focused on using curvature-based analysis to differentiate between flat and free-form surfaces. Curvature values, combined with methods such as gaussian curvature, were tested as classification accuracy.

Challenges Encountered

Real-world STL files often contain broken or messy geometry, like zero-area triangles (blank spaces between two objects of the same model), which caused curvature calculations to slow down and crash. To solve this, curvature-based methods were removed from the classifier and replaced with more reliable geometry-based metrics.

New methods:

We used a combination of methods and calculated a vote score such as:

- **Height ratio** – compares height to maximum width/depth.
- **Normalized Z variation** – measures how much surfaces undulate vertically.
- **Normal variation** – evaluates how many different directions the surfaces face.
- **Aspect ratio** – checks how tall/slender a model is.

Remaining Issues and Solutions:

Misclassification of Tall diamond shape (Prismatic) Models – Some objects were wrongly flagged as free- form because they were tall and had multiple face orientations. For this problem we introduced a planarity dominance metric, which checks whether most of the surface area lies in just a few flat planes. This adjustment allowed tall but prismatic parts to be correctly identified as flat (We assumed it was tall because we didn't know the scale in the slicer rendering).

Final Classifier

The final system used a combination of the above metrics with a decision rule:

- If planarity dominance is high and at least one surface variation metric is low, then we classify it as flat. Otherwise, use a majority vote across all metrics to find it is flat or free form.

Equations we used:

1. Height Ratio:

$$\text{height\_ratio} = \frac{\text{height (Z)}}{\text{max(width (X),depth (Y))}}$$

2. Normalized Z variation:

$$\text{z\_std\_normalized} = \frac{\text{std\_dev}(Z)}{Z_{\text{max}} - Z_{\text{min}}}$$

3. Normal variation:
   - Calculate the standard deviation of normal along each axis.

$$\sigma_x = \text{std}(x_1, x_2, ..., x_N)$$
$$\sigma_y = \text{std}(y_1, y_2, ..., y_N)$$
$$\sigma_z = \text{std}(z_1, z_2, ..., z_N)$$

   - Take the mean of those standard deviation values.

$$\text{normal\_variation} = \frac{\sigma_x + \sigma_y + \sigma_z}{3}$$

4. Aspect ratio:

$$\text{max\_aspect\_ratio} = \max\left(\frac{\text{height}}{\text{width}}, \frac{\text{height}}{\text{depth}}\right)$$

5. planarity dominance:
   - Normals are continuous 3D vectors. They can point anywhere on the unit sphere. To group “similar” orientations, we need to divide the space of directions. This is what binning does: Divide the sphere into chunks (like a grid on a globe) so each chunk is a bin. Any face normal falls into exactly one bin, based on its direction. Then we sum up the areas of all faces in the same bin.

$$\text{planarity\_dominance} = \frac{\text{area of largest bin}}{\text{total surface area of the model}}$$