Week 2 Method Summary: PCA + Plane Fitting Classification

This document summarizes the **geometric classification approach** used to distinguish between **FLAT** and **FREE-FORM** 3D models.

1. Method Overview

The method uses **three complementary geometric approaches**, combined with **OR logic**, to classify a model:

- **Principal Component Analysis (PCA – Eigenvalue Ratio)**

    - PCA identifies the main directions of variation in the 3D point cloud.

    - If one direction (the smallest eigenvalue) contributes negligibly compared to the others, the shape is essentially 2D.

    - Interpretation: A flat surface has most of its variation in two directions, with very little in the third.

    - **Threshold used**: eigen_ratio < 0.01 → FLAT.

- **Z-Ratio (Bounding Box Proportions)**

    - Compares the model's thickness in the Z direction to its spread in X or Y.

    - Very thin objects (low Z compared to X/Y) are likely flat.

    - Interpretation: Works like checking if an object is "disc-shaped."

    - **Threshold used**: z_ratio < 0.03 → FLAT.

- **Plane Fitting with RMS Error**

    - Fits a best-fit plane using Singular Value Decomposition (SVD).

    - Measures how far vertices deviate from this plane.

    - If deviations are small (low RMS error), the model lies close to a plane.

    - Interpretation: Captures "waviness" or bending that PCA or Z-ratio might miss.

    - **Threshold used**: normalized_rms < 0.02 → FLAT.

The model is classified as **FLAT** if **any** of these three conditions are satisfied; otherwise, it is considered **FREE-FORM**.

2. Implementation

- **Environment**: Implemented in Python using trimesh, numpy, and pandas.

- **Steps**:

    1. **Load STL mesh** and validate with trimesh.

    2. **Extract features**: eigenvalues, bounding box sizes, best-fit plane RMS error.

    3. **Apply classification logic** using thresholds.

    4. **Compare predictions** against **manually checked results** (AllModels.csv).

    5. **Evaluate accuracy** using standard classification metrics.

3. Results (compared to the manually checked results set)

Performance Metrics

- **Accuracy**: 70.0%

- **F1-Score (FREE)**: 0.799

- Only **26/87 FLAT models** detected correctly.

- **147/160 FREE models** detected correctly.

Classification Distribution

- **Manually checked results**: 87 FLAT, 160 FREE

- **Predicted**: 39 FLAT, 208 FREE

    Clear bias toward FREE-FORM classification.

Misclassifications

- **Total misclassifications**: 74

- Majority are **FLAT → FREE misclassifications**.

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