SeamGPT Mesh Data Processing Report

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Project: SeamGPT Hiring Assignment - Data Processing & Quantization

This report summarizes the implementation and results of a 3D mesh data processing pipeline. The system performs normalization, quantization, dequantization, and reconstruction of 3D meshes. It also evaluates a bonus adaptive quantization prototype based on vertex density and rotational invariance testing.

1. Pipeline Overview

The pipeline automates 3D mesh preprocessing, including:

- Mesh loading via Trimesh and Open3D
- Normalization (Min-Max and Unit Sphere)
- Uniform quantization (1024 bins)
- Dequantization and reconstruction
- Error computation (MSE, MAE)
- Visualization and rendering (via PyRender and Pyglet)

Additionally, a prototype adaptive quantization was implemented, which allocates bin precision per vertex based on local vertex density estimated using KDTree.

2. Implementation Modules

The source code is modularized under src/ with the following key files:

- io.py - Handles mesh input/output and metadata management.
- loader.py - Safe mesh loading and vertex statistics computation.
- transforms.py - Normalization and quantization methods.
- metrics.py - Error computation and visualization utilities.
- viz.py - High-quality rendering (HQ PNGs).
- pipeline.py - Unified processing flow for both Uniform and Adaptive quantization.

3. Uniform Quantization Results

The uniform quantization (1024 bins) demonstrates highly accurate reconstruction across all test meshes.

Average metrics:
- Mean MSE ~ 7.8x10^-7
- Mean MAE ~ 7.3x10^-4

The uniform quantization pipeline preserves geometric fidelity with negligible vertex displacement.

4. Adaptive Quantization Prototype

An adaptive quantization scheme was tested using three levels of precision (256 / 1024 / 4096 bins) based on vertex density.

Summary of results (mean MSE per mesh):

branch.obj : uniform=7.92e-07 adaptive=4.48e-06
cylinder.obj : uniform=1.99e-06 adaptive=1.28e-05
explosive.obj: uniform=1.71e-07 adaptive=9.71e-07
fence.obj : uniform=2.65e-07 adaptive=1.52e-06
girl.obj : uniform=2.05e-07 adaptive=1.16e-06
person.obj : uniform=6.62e-07 adaptive=3.68e-06
table.obj : uniform=3.07e-07 adaptive=1.73e-06
talwar.obj : uniform=1.11e-07 adaptive=6.20e-07

Observation: Uniform quantization consistently outperforms the adaptive prototype.

5. Sample Visuals

Sample high-quality renders comparing original and reconstructed meshes below.

6. Analysis and Discussion

Uniform quantization demonstrates stable performance with minimal error, while the adaptive prototype, though conceptually promising, introduces instability due to per-vertex bin variations.

Adaptive improvement directions:

- Region-based adaptive quantization
- Per-axis adaptive bins
- Smooth interpolation between bin levels

7. Conclusion

This project fulfills all assignment requirements: data loading, normalization, quantization, reconstruction, visualization, and evaluation.

The adaptive quantization serves as an experimental feature. Uniform quantization remains the stable, high-fidelity solution.

End of Report.