ETH zürich

Mixed Reality
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Real-time 3D Reconstruction Visualizer

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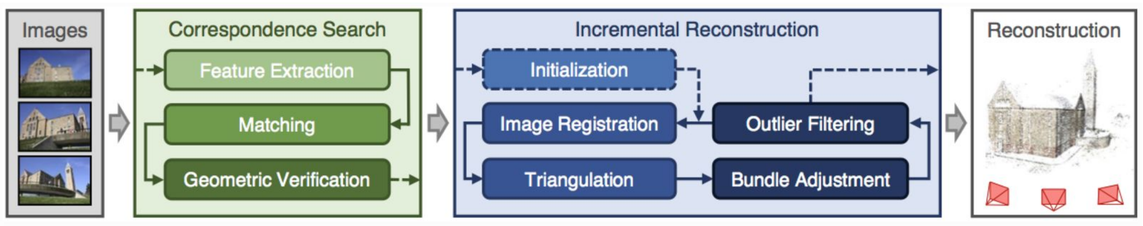
1. Introduction

The goal of this project is to enable interactive visualisation of 3D reconstructions so as to improve understanding of the complex pipeline involved in Structure-from-Motion (SfM) processes.

2. Background

COLMAP

- Popular incremental SfM pipeline used to produce a 3D reconstruction (point cloud and camera poses) from images
- Widely used by the computer vision research community as a preliminary step to generate ground truth
- Unclear how each stage of the pipeline and the order of image registration affects the resultant reconstruction



COLMAP's incremental Structure-from-Motion pipeline.

- ❖ **Image Registration**: Estimate camera position and orientation for each image using image features and correspondences
- ❖ **Triangulation**: Add new 3D points to the reconstruction through triangulation using feature matches from newly added images
- ❖ **Bundle Adjustment**: Perform nonlinear optimization on both point clouds and camera poses to minimize the sum of reprojection errors
- ❖ **Outlier Filtering**: Remove outliers identified during Bundle Adjustment and iterates Bundle Adjustment multiple times

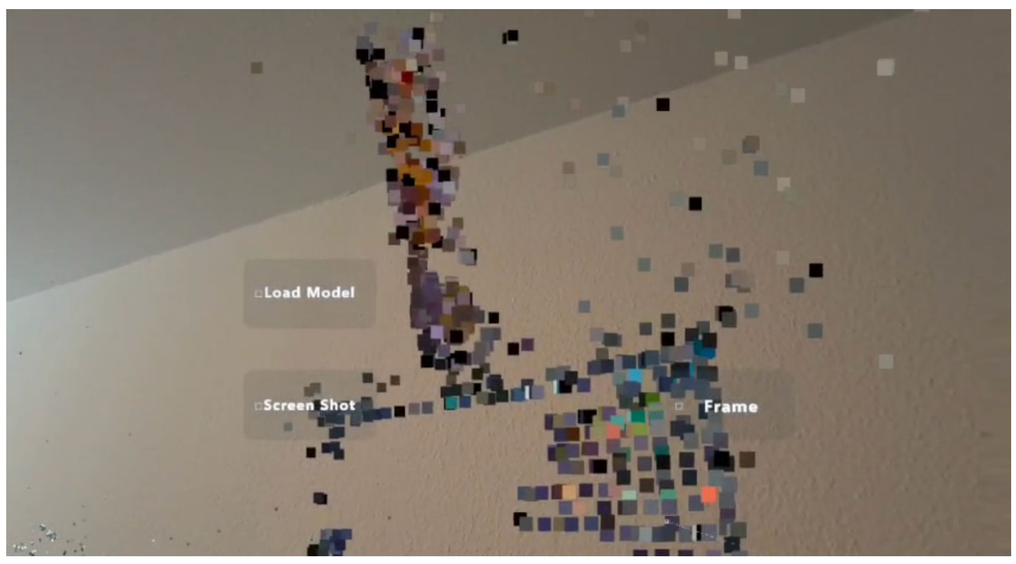
3. Method Overview

1. Add ability to add/remove images from reconstruction in user-specified order
   - Challenge: COLMAP designed for a fixed set of images, algorithmically decides order of image registration
   - Solution: Modify pipeline using pycolmap library to allow for custom incremental mapping
2. Add breakpoints to skip stages within COLMAP pipeline
   - Challenge: Need to support dynamic operations based on user input, such as desired pipeline stages and order of image registration
   - Solution: Multi-threaded server/COLMAP that pauses COLMAP while awaiting user input from client request

4. Results and Discussion

User-friendly Unity app on a Meta Quest 3 that acts as a "visual debugger" for COLMAP's incremental SfM pipeline.

- Collects images of the user's surroundings using Quest's onboard camera
- Offers real-time interactive visualization of the reconstruction after each stage of the pipeline for each image
- From the quality of the reconstructed point cloud, users can intuitively understand:
  - What types of images are suitable for SfM (e.g., avoiding translational image pairs).
  - The roles and importance of individual components, such as Bundle Adjustment, in achieving high-quality reconstructions.



5. Conclusion and Proposed Improvements

The visualizer serves as a valuable tool for researchers to form a deeper, more intuitive understanding into the complex COLMAP reconstruction process, crucial for thorough research.

Future Iterations

- Support user-defined conditions (e.g. min triangulation angle)
- Visualize dense reconstructions and additional information
- Support user-specified feature extractors and matchers

References

1. Schonberger, J. L., & Frahm, J. M. (2016). Structure-from-motion revisited. In Proceedings of the IEEE conference on computer vision and pattern recognition (pp. 4104-4113).
2. Sarlin, P. E., Cadena, C., Siegwart, R., & Dymczyk, M. (2019). From coarse to fine: Robust hierarchical localization at large scale. In Proceedings of the IEEE/CVF conference on computer vision and pattern recognition (pp. 12716-12725).

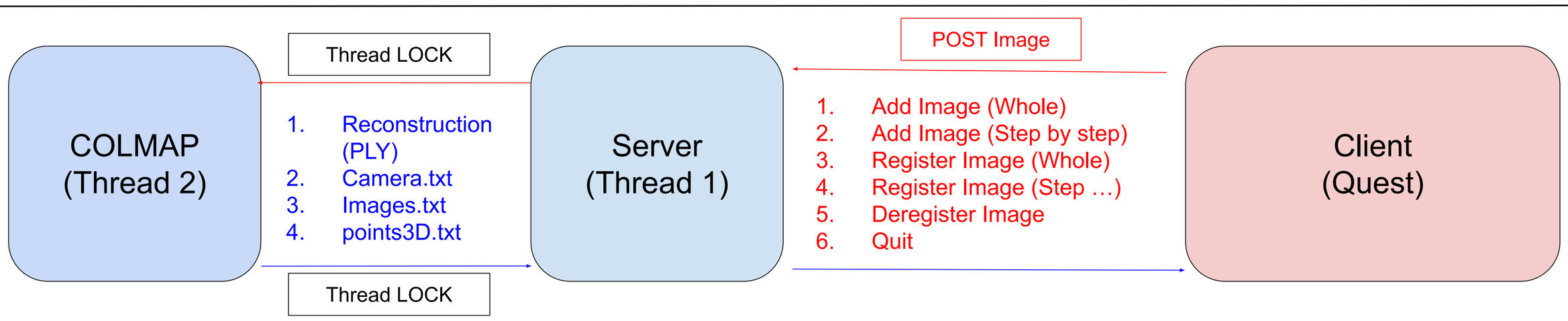


Figure of Method Pipeline. Data communication flow between COLMAP and the Unity application. The server employs thread-based synchronous processing to implement breakpoints within the pipeline. Reconstruction results up to the user-specified step are returned to the client and visualized interactively.