Comprehensive Report: Jigsaw Puzzle Image Assembly Pipeline

Submitted to:

Dr. Mahmoud Khalil

Eng. Ali Ahmed Al

Submitted by:

Loaiy Mahmoud 23p0419

Omar Ayman 23P0244

Ali Moataz 23P0280

Omar Osama 2300090

Mostafa Amr 23P0206

I. Introduction

This report details the design, methodology, and rationale behind the **Jigsaw Puzzle Image Processing & Assembly Pipeline**, which encompasses **Milestone 1 (Image Processing & Feature Preparation)** and **Milestone 2 (Puzzle Solving & Reconstruction)**. The entire, authoritative implementation for both stages is consolidated within the Milestone1notebook.ipynb. The project's core objective is to achieve **deterministic, training-free** reconstruction of grid-based jigsaw puzzles (2x2, 4x4, and 8x8) by transforming a raw image into a standardized set of pieces, and then utilizing a global optimization algorithm to restore the original image structure.

II. Overall Flow and What Happens

The complete system follows a clear, sequential pipeline:

Step	Milestone	Action/Logic	Purpose (Contribution to Goal)
1-3	Milestone 1	**Structural Standardization & Slicing**: Raw images are resized to a fixed **224×224 pixels** and uniformly sliced into N^2 discrete tiles (4, 16, or 64 pieces).	Provides a **clean, standardized input** and the essential **ground truth** (known correct arrangement) for the solver.
4	Milestone 2	**Tile Representation**: Pieces are represented by their raw image patches, relying on **patch-level color information**.	Preserves all visual information necessary for reliable comparison while avoiding information loss.
5	Milestone 2	**Global Matching**: Puzzle pieces are compared using mean absolute difference in **LAB color space**. The resulting cost matrix is solved by the **Hungarian Algorithm** (linear sum assignment).	Produces a **globally optimal one-to-one assignment**, preventing local placement errors.
6	Milestone 2	**Reconstruction**: Matched tiles are placed exactly once into their assigned grid positions to form the final reconstructed image.	Ensures deterministic and repeatable restoration of the original image structure.

III. Milestone 1: Slicer Logic and Method Rationale

The role of Milestone 1 was intentionally **restricted to deterministic image standardization and slicing only**. No perceptual filtering or feature extraction is performed at this stage, ensuring a clean, lossless representation.

Flow and Slicer Logic

The PuzzleSlicer component performs the following:

1. **Fixed Global Resize:** Input images are resized to **224×224 pixels** using area-based interpolation. This guarantees uniform spatial dimensions, eliminating scale-related ambiguity during reconstruction.
2. **Deterministic Grid Slicing:** Images are sliced into uniform $N \times N$ grids using fixed index arithmetic. This produces perfectly aligned, non-overlapping tiles and preserves the true spatial relationships.

Comparison with Alternative Milestone 1 Approaches

The final Milestone 1 approach (deterministic resizing and slicing) was selected over earlier, more complex preprocessing techniques due to its superior reliability.

Final Method Advantage	Alternative Approaches (Rejected)	Rationale for Rejection
Lossless Data Preservation	**Perceptual Preprocessing** (e.g., Mean Shift Filtering, CLAHE, Canny Edge Detection)	Filtering operations caused **irreversible information loss** and introduced sensitivity to noise/illumination, negatively affecting downstream matching.
Structural Consistency	Contour-Based Representations	Contour-based features increased implementation complexity without providing consistent accuracy gains for rectangular, grid-based pieces.

The slicer logic, by creating standardized and perfectly aligned tiles, provides the essential **structurally consistent puzzle representation** that the Milestone 2 solver relies on.

IV. Milestone 2: Algorithm and Method Rationale

Milestone 2 performs the final tile-to-slot assignment, using a combination of a perceptually accurate cost metric and a global optimization method.

Key Methods

1. **Patch-Based LAB Color Matching:** The cost metric uses the mean absolute difference in the **LAB color space**. This space correlates better with human perceptual similarity, making the matching metric **robust against illumination changes**.
2. **Hungarian Algorithm (Linear Sum Assignment):** This globally optimal assignment algorithm is used to solve the cost matrix.

Comparison with Alternative Milestone 2 Strategies

The combination of LAB matching and the Hungarian Algorithm was selected to optimize for **accuracy, robustness, interpretability, and computational efficiency**.

Final Method Advantage	Alternative Algorithms (Rejected)	Rationale for Selection
Global Optimality	Greedy and Local Matching Methods	Greedy approaches suffer from **cascading errors** and produce locally optimal but globally incorrect assemblies. The Hungarian Algorithm guarantees a globally optimal assignment, minimizing total error.
Color-Based Robustness	Edge-Based and Contour-Based Solvers	Edge-based methods are unreliable for grid-based puzzles due to limited geometric information and sensitivity to noise. **LAB color similarity** provides a stronger, more stable cue for rectangular pieces.
Deterministic & Simple	**Feature-Descriptor Methods** (SIFT, ORB) or **Learning-Based Methods**	Feature-descriptor methods are complex and require strong local features. Learning-based methods require large datasets and lack interpretability. The adopted solution is **training-free**, transparent, and reproducible.

V. Conclusion

The Jigsaw Puzzle Assembly Pipeline successfully integrates a minimalistic, structurally precise front-end (Milestone 1) with a globally optimal back-end (Milestone 2).

By restricting Milestone 1 to **lossless standardization and deterministic slicing**, the system ensures that Milestone 2 receives a perfectly prepared data set. The subsequent choice of **Patch-Based LAB Color Matching** combined with the **Hungarian Algorithm** addresses the inherent weaknesses of local heuristics, delivering a globally optimal reconstruction solution. This methodology achieves the project's goal of a **deterministic, interpretable, and highly accurate** puzzle solver across various grid complexities, reliably restoring the original image structure.

VI. Github link

loaymahmoud10/jigsaw-puzzle-processing: Milestone 1: High-Fidelity Image Processing Pipeline for Puzzle Tiles.