E0-270 (O): Assignment 2 Report

K-Means Clustering for Image Compression

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1 Introduction

This report presents the implementation of the K-Means clustering algorithm for compressing a 512×512×3 RGB image by replacing each pixel with the nearest cluster centroid.

The experiment evaluates how the number of clusters ($k = 2, 5, 10, 20, 50$) affects the visual reconstruction and Mean Squared Error (MSE).

2 Methodology

2.1 Algorithm Overview

The K-Means clustering algorithm was implemented from scratch using `numpy`.
The steps are as follows:

- **Initialization:**

  Randomly select k pixels as initial cluster centroids.

- **Assignment Step:**

  Compute Euclidean distances between each pixel and the centroids, assigning each pixel to the nearest cluster.

- **Update Step:**

  Update each centroid as the mean of all pixels assigned to it.

- **Convergence:**

  The algorithm terminates when centroid shifts are less than 10^{-6} or after 100 iterations.

MSE Calculation:

$$\text{MSE} = \frac{1}{N}\sum_{i=1}^{N} \|x_i - c_i\|^2$$

where x_i is the original pixel and c_i is its corresponding cluster centroid.

3 Results

3.1 Clustered Images

(a) $k = 2$

(b) $k = 5$

(c) $k = 10$

(d) $k = 20$

(e) $k = 50$

Figure 1: Clustered reconstructions for various k. Higher k values retain more color details and structure.

3.2 MSE vs. Number of Clusters

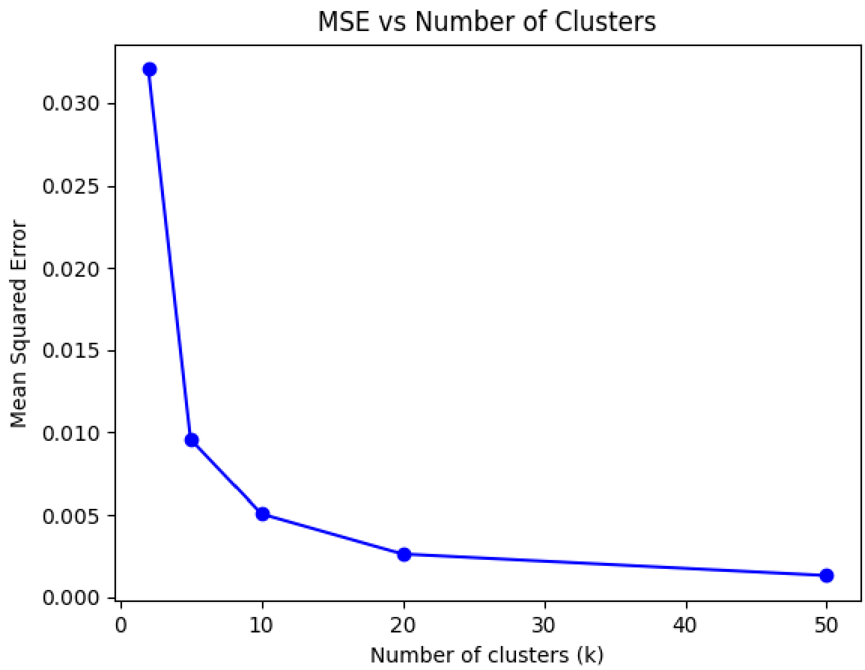

Figure 2: Mean Squared Error decreases with increasing k, indicating improved reconstruction quality. However, the rate of improvement diminishes as k increases.

4 Discussion

- **Visual Quality:** Lower values of k result in significant color quantization and visible artifacts. As k increases, image quality improves due to better color representation.
- **Computational Cost:** Higher k values lead to increased computation time and memory usage.
- **Limitations:** K-Means assumes spherical and equally sized clusters, which may not accurately represent real-world color distributions in images.

5 Conclusion

K-Means clustering can effectively compress RGB images by reducing color space redundancy. The trade-off between compression and quality is evident: MSE consistently decreases with increasing k, though the improvements diminish after $k = 20$. This suggests a sweet spot for balancing quality and efficiency.

Appendix

- **Source Code:** `main.py`, `model.py`, `utils.py`
- **Clustered Images:** `image_clustered_{k}.jpg`
- **Plot:** `mse_vs_k.png`