

2 Low-Rank Approximation

Low-rank approximation tries to find an approximation to a given matrix, where the approximation matrix has a lower rank compared to the original matrix. This is useful for mathematical modeling and data compression. Mathematically, given a matrix M , we try to find \hat{M} in the following optimization problem,

$$\underset{\hat{M}}{\operatorname{argmin}} \|M - \hat{M}\|_F \quad \text{subject to} \quad \operatorname{rank}(\hat{M}) \leq k \quad (1)$$

where $\|A\|_F = \sqrt{\sum_i \sum_j a_{ij}^2}$ is the Frobenius norm, i.e., the sum of squares of all entries in the matrix, followed by a square root.

This problem can be solved using Singular Value Decomposition (SVD). Specifically, let $M = U\Sigma V^T$, where $\Sigma = \operatorname{diag}(\sigma_1, \dots, \sigma_n)$. Then a rank- k approximation of M can be written as $\hat{M} = U\hat{\Sigma}V^T$, where $\hat{\Sigma} = \operatorname{diag}(\sigma_1, \dots, \sigma_k, 0, \dots, 0)$. In this problem, we aim to perform this approximation method on gray-scale images, which can be thought of as a 2D matrix.

- (a) Using the image `low-rank_data/face.jpg`, perform a rank-5, rank-20, and rank-100 approximation on the image. Show both the original image as well as the low-rank images you obtain in your report.
- (b) Now perform the same rank-5, rank-20, and rank-100 approximation on `low-rank_data/sky.jpg`. Show both the original image as well as the low-rank images you obtain in your report.
- (c) In one plot, plot the Mean Squared Error (MSE) between the rank- k approximation and the original image for both `low-rank_data/face.jpg` and `low-rank_data/sky.jpg`, for k ranging from 1 to 100. Be sure to label each curve in the plot. The MSE between two images $I, J \in \mathbb{R}^{m \times n}$ is

$$\operatorname{MSE}(I, J) = \sum_{i,j} (I_{i,j} - J_{i,j})^2. \quad (2)$$

Low Rank Approximation Low Rank Approximation

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