Content-based Image Retrieval

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Project Overview

The project implements a system for content-based image retrieval (CBIR) using various methods, including baseline matching, histogram matching, multi-histogram matching, texture and color analysis, and deep network embeddings. The system allows for the extraction of features from images, comparison of these features using different metrics, and identification of images in a database that are similar to a target image.

Functionality Demonstrations

The project is structured into four critical components:

1. **Feature Extraction**: This phase is dedicated to extracting features from a collection of images using a variety of algorithms. The extracted features are subsequently stored in specified .csv files for additional processing.
2. **Image Matching and Similarity Ranking**: At this stage, the target image is located within the .csv files. This is followed by a process that ranks the images according to their similarity to the target image, facilitating an efficient comparison.
3. **Deep Neural Network (DNN) Embedding matching**: This component utilizes DNN embedding techniques to analyze and interpret the pre-processed data from earlier phases. It enhances the accuracy and depth of the feature analysis, contributing to more precise image matching.
4. **Face Detection**: Incorporated into the main feature extraction program, the face detection function identifies images containing faces and generates a .csv file listing these images. This function adds a specialized layer of analysis, particularly useful in contexts where facial features are of interest.

Data Analysis

1. Baseline Matching

The program extracts a 7x7 pixel feature vector from the center of an image and computes the sum of squared differences (SSD) between two vectors. It can be used for image matching by comparing the central visual features of images, enabling identification of similar images based on their central pixel values. The extraction process focuses on a small, central area, reducing complexity and computational cost, while the SSD function provides a measure of similarity, with lower values indicating closer matches.

Target image: pic.1016.jpg.

The top 3 images: pic.0986.jpg, pic.0641.jpg, pic.0547.jpg.

```
jeff@Yuans-MacBook-Pro bin % ./matching b /Users/jeff/Desktop/Project2_YZ/olympus/pic.1016.jpg
N is set to 3
Method is set to baseline
CSV file is set to /Users/jeff/Desktop/Project2_YZ/bin/image_features_baseline.csv
Reading /Users/jeff/Desktop/Project2_YZ/bin/image_features_baseline.csv
Finished reading CSV file
Top 3 Matches:
pic.0986.jpg with similarity: 14049
pic.0641.jpg with similarity: 21756
pic.0547.jpg with similarity: 49703
jeff@Yuans-MacBook-Pro bin %
```


pic.1016.jpg


pic.0986.jpg


pic.0641.jpg


pic.0547.jpg

The outcomes align with the program's concept designed to extract the center of the images, focusing on a very small area of 7x7 feature vectors. The center of the target image is predominantly red, and correspondingly, the centers of all resulting images are also red.

2. Histogram Matching

This code defines methods to extract color histograms from images for matching purposes. The *calculateRG_2DChromaHistogram* function computes a 2D histogram based on the red and green components, normalizing pixel values to sum up to 1, enabling comparison of color distributions regardless of image brightness. Similarly, *calculateRGB_3DChromaHistogram* extends this to a 3D histogram, including the blue component for a more detailed color profile. The *computeHistogramIntersection* function compares two histograms, calculating the intersection distance to measure similarity.

a. 2D - whole image RG chromaticity

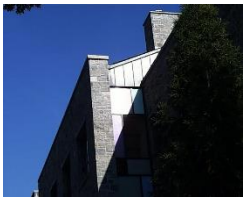
Target image: pic.0164.jpg.

Top3 images: pic.0080.jpg, pic.1032.jpg, pic.0461.jpg

```
jeff@Yuans-MacBook-Pro bin % ./matching h2 /Users/jeff/Desktop/Project2_YZ/olympus/pic.0164.jpg
N is set to 3
Method is set to 2D_histogram
CSV file is set to /Users/jeff/Desktop/Project2_YZ/bin/image_features_2D_histogram.csv
Reading /Users/jeff/Desktop/Project2_YZ/bin/image_features_2D_histogram.csv
Finished reading CSV file
Top 3 Matches:
pic.0080.jpg with similarity: 0.690754
pic.1032.jpg with similarity: 0.627326
pic.0461.jpg with similarity: 0.560584
```


pic.0164.jpg


pic.0080.jpg


pic.1032.jpg


pic.0461.jpg

In predominantly blue images, the function's 2D chroma histogram will show lower red and green values, as it calculates these as proportions of total color intensity. Consequently, bins with lower red and green values will have higher counts, indicating blue's dominance in the color distribution.

b. 3D- whole image RGB chromaticity

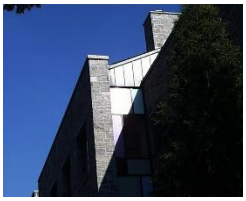
Target image: pic.0164.jpg.

Top3 images: pic.0110.jpg, pic.1032.jpg, pic.0092.jpg

```
jeff@Yuans-MacBook-Pro bin % ./matching h3 /Users/jeff/Desktop/Project2_YZ/olympus/pic.0164.jpg
N is set to 3
Method is set to 3D_histogram
CSV file is set to /Users/jeff/Desktop/Project2_YZ/bin/image_features_3D_histogram.csv
Reading /Users/jeff/Desktop/Project2_YZ/bin/image_features_3D_histogram.csv
Finished reading CSV file
Top 3 Matches:
pic.0110.jpg with similarity: 0.42442
pic.1032.jpg with similarity: 0.423683
pic.0092.jpg with similarity: 0.389066
```


pic.0164.jpg


pic.0110.jpg


pic.1032.jpg


pic.0092.jpg

Comparing results using the same target image reveals that the 3D approach is more precise than the 2D method. The 2D histogram focuses on chroma, specifically the red (R) and green (G) channels, and normalizes these against the sum of all color channels (R, G, B), ignoring brightness. This is effective for color distribution analysis under consistent lighting.

In contrast, the 3D histogram considers all three-color channels, providing a detailed view of color distribution and indirectly capturing brightness by reflecting the intensity values of R, G, and B. This method offers a more comprehensive analysis, incorporating both color and brightness information.

3. Multi-histogram Matching

This code defines a method for extracting color histograms from the top and bottom halves of an image, creating a feature vector that represents the color distribution across these parts. By calculating and comparing these multi-part histograms for different images, it enables image matching based on the similarity of color distributions. This technique can be utilized in image retrieval systems, where images are matched or searched based on color content, enhancing accuracy by considering the spatial distribution of colors within the images.

Target image: pic.0274.jpg.

Top3 images: pic.0273.jpg, pic.1031.jpg, pic.0409.jpg

```
jeff@Yuans-MacBook-Pro bin % ./matching m /Users/jeff/Desktop/Project2_YZ/olympus/pic.0274.jpg
N is set to 3
Method is set to multi_histogram
CSV file is set to /Users/jeff/Desktop/Project2_YZ/bin/image_features_multi_histogram.csv
Reading /Users/jeff/Desktop/Project2_YZ/bin/image_features_multi_histogram.csv
Finished reading CSV file
Top 3 Matches:
pic.0273.jpg with similarity: 0.652567
pic.1031.jpg with similarity: 0.624657
pic.0409.jpg with similarity: 0.620328
```


pic.0274.jpg


pic.0273.jpg


pic.1031.jpg


pic.0409.jpg

The resulting images align with the concept of feature extraction and matching design. For the images, the upper section predominantly features the blue sky, while the lower section is characterized by darker elements such as trees, grass, or shadows. It conforms to the top-bottom distribution concept inherent in the images.

4. Texture and Color

a. Extracting and matching texture and color features from whole image

This “texture and color” method for matching images based on their textures and colors. It involves applying Sobel filters to an image to detect edges in both the X and Y directions, generating a gradient magnitude image that highlights the texture. Additionally, it calculates histograms for both color and texture, normalizing them to create a unified feature vector for each image. This combined color and texture feature vector can then be used to compare and match images, offering a robust way to identify similarities between images based on both their color distributions and textural patterns.

Target image: pic.0535.jpg.

Top3 images: pic.0285.jpg, pic.0628.jpg, pic.0952.jpg

```
jeff@Yuans-MacBook-Pro bin % ./matching tc /Users/jeff/Desktop/Project2_YZ/olympus/pic.0535.jpg
N is set to 3
Method is set to texturecolor
CSV file is set to /Users/jeff/Desktop/Project2_YZ/bin/image_features_texturecolor.csv
Reading /Users/jeff/Desktop/Project2_YZ/bin/image_features_texturecolor.csv
Finished reading CSV file
Top 3 Matches:
/Users/jeff/Desktop/Project2_YZ/olympus/pic.0285.jpg with similarity: 0.389491
/Users/jeff/Desktop/Project2_YZ/olympus/pic.0628.jpg with similarity: 0.386955
/Users/jeff/Desktop/Project2_YZ/olympus/pic.0952.jpg with similarity: 0.36862
```


pic.0535.jpg


pic.0285.jpg


pic.0628.jpg


pic.0952.jpg

The target image predominantly features white, wood-orange, and brown hues. The top three results closely match these color specifications. Additionally, in terms of texture, the target image—including elements such as the fireplace, table, floor, and bricks—exhibits distinct horizontal and vertical features. The texture feature vector captures the distribution of edge strengths within the image, independent of color.

Image pic.0285.jpg and pic.0628.jpg display the closest match in terms of texture and color distribution, with pic.0285.jpg particularly showcasing pronounced vertical and horizontal edges that align closely with the target image's texture. Pic.0628.jpg also presents a highly compatible texture feature, along with a color distribution that includes white and wood-orange hues, closely mirroring the target image.

Pic.0925.jpg contributes to the similarity with its depiction of trees and stairs, whose edges and colors correspond to the features of the target image, further demonstrating the effectiveness of the feature extraction and matching process in identifying images with similar attributes.

b. Compare with 2D/3D-Color Histogram and Multi-histogram.

For the target image, pic.0535.jpg, the results using a 2D-RG-Color Histogram are as follows:

Top3 images: pic.0733.jpg, pic.0628.jpg, pic.0658.jpg

```
jeff@Yuans-MacBook-Pro bin % ./matching h2 /Users/jeff/Desktop/Project2_YZ/olympus/pic.0535.jpg
N is set to 3
Method is set to 2D_histogram
CSV file is set to /Users/jeff/Desktop/Project2_YZ/bin/image_features_2D_histogram.csv
Reading /Users/jeff/Desktop/Project2_YZ/bin/image_features_2D_histogram.csv
Finished reading CSV file
Top 3 Matches:
pic.0733.jpg with similarity: 0.867557
pic.0628.jpg with similarity: 0.857268
pic.0658.jpg with similarity: 0.851928
```


pic.0535.jpg


pic.0733.jpg


pic.0628.jpg


pic.0658.jpg

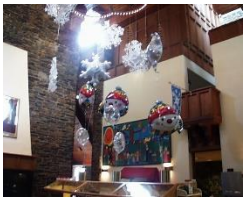
For the target image, pic.0535.jpg, the results using a 3D-RGB-Color Histogram are as follows:

Top3 images: pic.0285.jpg, pic.0628.jpg, pic.0952.jpg

```
jeff@Yuans-MacBook-Pro bin % ./matching h3 /Users/jeff/Desktop/Project2_YZ/olympus/pic.0535.jpg
N is set to 3
Method is set to 3D_histogram
CSV file is set to /Users/jeff/Desktop/Project2_YZ/bin/image_features_3D_histogram.csv
Reading /Users/jeff/Desktop/Project2_YZ/bin/image_features_3D_histogram.csv
Finished reading CSV file
Top 3 Matches:
pic.0285.jpg with similarity: 0.778982
pic.0628.jpg with similarity: 0.773909
pic.0952.jpg with similarity: 0.737239
```


pic.0535.jpg


pic.0285.jpg


pic.0628.jpg


pic.0952.jpg

In the texture and color analysis, the 3D-RGB-color method yields the most similar results, indicating that color plays a significant role in the Texture and Color method. Compared to the 2D approach, the 3D method's histogram captures absolute color intensities across the RGB spectrum, unlike the 2D method, which primarily focuses on color ratios rather than absolute color intensities.

5. Deep Network Embeddings

This segment of the project employs *calculateCosineSimilarity*, a metric utilized in machine learning to ascertain the similarity between vectors, with values ranging from -1 to 1. This measure is used to calculate the distance between the target feature vector and the images. By extracting the feature and applying the *calculateCosineSimilarity*, the top 3 most similar images are identified.

Target image: pic.0893.jpg.

Top3 images: pic.897.jpg, pic.0136.jpg, pic.0146.jpg.

```
jeff@Yuans-MacBook-Pro bin % ./dnn_embedding pic.0893.jpg
Reading /Users/jeff/Desktop/Project2_YZ/olympus/ResNet18_olym.csv
Finished reading CSV file
Top 3 similar images:
1: pic.0897.jpg (Similarity: 0.848232)
2: pic.0136.jpg (Similarity: 0.823843)
3: pic.0146.jpg (Similarity: 0.775143)
```


pic.0893.jpg


pic.897.jpg


pic.0136.jpg

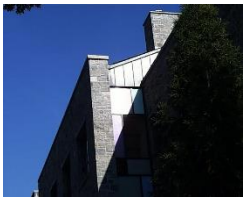

pic.0146.jpg

Target image: pic.0164.jpg.

Top3 images: pic.1032.jpg, pic.0213.jpg, pic.0690.jpg.

```
jeff@Yuans-MacBook-Pro bin % ./dnn_embedding pic.0164.jpg
Reading /Users/jeff/Desktop/Project2_YZ/olympus/ResNet18_olym.csv
Finished reading CSV file
Top 3 similar images:
1: pic.1032.jpg (Similarity: 0.78781)
2: pic.0213.jpg (Similarity: 0.787164)
3: pic.0690.jpg (Similarity: 0.764863)
```


pic.0164.jpg


pic.1032.jpg


pic.0213.jpg


pic.0690.jpg

For the target image pic.0893.jpg, the DNN-embedding features closely match the target and the top 3 images, capturing even the varying orientations of the fire hydrant. In the case of pic.0164.jpg, the top 3 results highlight buildings, showcasing parts of the structures against the blue sky, and effectively recognizing edges, shapes, and color patterns and distributions.

When compared to the previous 2D/3D histogram analyses, only pic.0213.jpg appears in both the DNN results and the histogram-based results. The 2D method identified pic.0080.jpg and pic.0461.jpg, which feature a computer blue screen and blue clothing, respectively; these share only the color blue and are unrelated to buildings. For the 3D analysis using the 3D-RGB-histogram function on pic.0893.jpg, the results included pic.0136.jpg, pic.0368.jpg, and pic.0897.jpg. The notable difference between the 3D-RGB-histogram and DNN-embedding methods is the inclusion of pic.0146.jpg in the DNN results and pic.0368.jpg in the 3D results, highlighting the distinct capabilities of each approach in analyzing and matching images.

```
jeff@Yuans-MacBook-Pro bin % ./matching h3 /Users/jeff/Desktop/Project2_YZ/olympus/pic.0893.jpg
N is set to 3
Method is set to 3D_histogram
CSV file is set to /Users/jeff/Desktop/Project2_YZ/bin/image_features_3D_histogram.csv
Reading /Users/jeff/Desktop/Project2_YZ/bin/image_features_3D_histogram.csv
Finished reading CSV file
Top 3 Matches:
pic.0136.jpg with similarity: 0.809408
pic.0368.jpg with similarity: 0.784457
pic.0897.jpg with similarity: 0.749889
```

pic.0368.jpg


pic.0146.jpg

Pic.0368.jpg likely possesses greater color similarity to the target image, pic.0893.jpg, yet the edges and shape of the object in the target are entirely irrelevant.

6. Compare DNN Embeddings and Classic Features

The project employs the Classic Features method, specifically the Texture and Color method, which utilizes combined feature results. These are then compared with DNN embeddings results for the target images: pic.1072.jpg, pic.0948.jpg, and pic.0734.jpg.

a. Target image: pic.1072.jpg.

Top3 images-DNN: pic.0143.jpg, pic.0863.jpg, pic.0329.jpg.

```
jeff@Yuans-MacBook-Pro bin % ./dnn_embedding pic.1072.jpg
Reading /Users/jeff/Desktop/Project2_YZ/olympus/ResNet18_olym.csv
Finished reading CSV file
Top 3 similar images:
1: pic.0143.jpg (Similarity: 0.838968)
2: pic.0863.jpg (Similarity: 0.799554)
3: pic.0329.jpg (Similarity: 0.792813)
```


pic.1072.jpg


pic.0143.jpg


pic.0863.jpg


pic.0329.jpg

Top3 images-Texture and Color: pic.0937.jpg, pic.0732.jpg, pic.0673.jpg.

```
jeff@Yuans-MacBook-Pro bin % ./matching tc /Users/jeff/Desktop/Project2_YZ/olympus/pic.1072.jpg
N is set to 3
Method is set to texturecolor
CSV file is set to /Users/jeff/Desktop/Project2_YZ/bin/image_features_texturecolor.csv
Reading /Users/jeff/Desktop/Project2_YZ/bin/image_features_texturecolor.csv
Finished reading CSV file
Top 3 Matches:
/Users/jeff/Desktop/Project2_YZ/olympus/pic.0937.jpg with similarity: 0.353457
/Users/jeff/Desktop/Project2_YZ/olympus/pic.0732.jpg with similarity: 0.342548
/Users/jeff/Desktop/Project2_YZ/olympus/pic.0673.jpg with similarity: 0.33005
```


pic.1072.jpg


pic.0937.jpg


pic.0732.jpg


pic.0673.jpg

From the comparison results, it's evident that through DNN analysis, the resulting images all feature flowers and various types of plants. This is despite pic.0329.jpg and pic.0863.jpg having a somewhat different color composition compared to the target image, pic.1072.jpg. Nevertheless, these results demonstrate DNN's capability to recognize plants and flowers.

In the Texture and Color analysis, pic.0937.jpg and pic.0673.jpg display similarities in color and texture to the target image, including elements like flowers, plants, and the clothing color of the individual in pic.0673.jpg, which somewhat resembles that of the target image. However, the object in pic.0732.jpg significantly differs, highlighting the variability in how different methods interpret and match images based on texture, color, and content.

b. Target image: pic.0948.jpg.

Top3 images-DNN: pic.0930.jpg, pic.0960.jpg, pic.0928.jpg.

```
jeff@Yuans-MacBook-Pro bin % ./dnn_embedding pic.0948.jpg
Reading /Users/jeff/Desktop/Project2_YZ/olympus/ResNet18_olym.csv
Finished reading CSV file
Top 3 similar images:
1: pic.0930.jpg (Similarity: 0.871691)
2: pic.0960.jpg (Similarity: 0.799633)
3: pic.0928.jpg (Similarity: 0.795906)
```


pic.0948.jpg


pic.0930.jpg


pic.0960.jpg


pic.0928.jpg

Top3 images-Texture and Color: pic.0217.jpg, pic.0675.jpg, pic.0735.jpg.

```
jeff@Yuans-MacBook-Pro bin % ./matching tc /Users/jeff/Desktop/Project2_YZ/olympus/pic.0948.jpg
N is set to 3
Method is set to texturecolor
CSV file is set to /Users/jeff/Desktop/Project2_YZ/bin/image_features_texturecolor.csv
Reading /Users/jeff/Desktop/Project2_YZ/bin/image_features_texturecolor.csv
Finished reading CSV file
Top 3 Matches:
/Users/jeff/Desktop/Project2_YZ/olympus/pic.0217.jpg with similarity: 0.375226
/Users/jeff/Desktop/Project2_YZ/olympus/pic.0675.jpg with similarity: 0.366945
/Users/jeff/Desktop/Project2_YZ/olympus/pic.0735.jpg with similarity: 0.36537
```




The comparison results illustrate that the DNN-embedding method is capable of identifying the chipmunk toy and distinguishing it from the background. The target image predominantly features gray with a hint of red in the center. Despite pic.0928.jpg having a mostly green grass background, it is still recognizable by the DNN method. Conversely, in the Texture and Color analysis, none of the resulting images feature the chipmunk toy; instead, they predominantly display gray and brownish hues. The images identified by the Texture and Color method exhibit pronounced horizontal and vertical edges, reflecting the target image's distinct horizontal stair structure.

c. Target image: pic.0734.jpg.

Top3 images-DNN: pic.0731.jpg, pic.0735.jpg, pic.0739.jpg.

```
jeff@Yuans-MacBook-Pro bin % ./dnn_embedding pic.0734.jpg
Reading /Users/jeff/Desktop/Project2_YZ/olympus/ResNet18_olym.csv
Finished reading CSV file
Top 3 similar images:
1: pic.0731.jpg (Similarity: 0.845069)
2: pic.0735.jpg (Similarity: 0.834601)
3: pic.0739.jpg (Similarity: 0.817069)
```


pic.0734.jpg


pic.0731.jpg


pic.0735.jpg


pic.0739.jpg

Top3 images-Texture and Color: pic.0217.jpg, pic.0675.jpg, pic.0735.jpg.

```
jeff@Yuans-MacBook-Pro bin % ./matching tc /Users/jeff/Desktop/Project2_YZ/olympus/pic.0734.jpg
N is set to 3
Method is set to texturecolor
CSV file is set to /Users/jeff/Desktop/Project2_YZ/bin/image_features_texturecolor.csv
Reading /Users/jeff/Desktop/Project2_YZ/bin/image_features_texturecolor.csv
Finished reading CSV file
Top 3 Matches:
/Users/jeff/Desktop/Project2_YZ/olympus/pic.0450.jpg with similarity: 0.368937
/Users/jeff/Desktop/Project2_YZ/olympus/pic.0577.jpg with similarity: 0.361537
/Users/jeff/Desktop/Project2_YZ/olympus/pic.0140.jpg with similarity: 0.357602
```


pic.0734.jpg


pic.0217.jpg


pic.0675.jpg


pic.0735

The comparison results demonstrate the DNN-embedding method's ability to identify tractors regardless of their shape, indicating a level of image understanding by the DNN. In contrast, the Texture and Color method successfully recognizes a tractor in only one of the top three results, with most results primarily reflecting similar texture features to the target image.

In conclusion, DNN-embedding methods exhibit robust image recognition capabilities, providing distinct advantages over traditional, simpler non-convolutional methods in representing data within a high-dimensional space.

7. Custom Design

In this section, the project introduces a custom method for extracting feature vectors, utilizing varying weight configurations to process the input image at multiple scales (whole, half, quarter, and eighth sizes). This strategy enables the capture of features at different levels of detail, ranging from broad, global characteristics to fine, local nuances. For matching small objects within the image, different weights are applied to the whole, half, quarter, and eighth sizes. The smaller the object in the center, the greater the weight added to the feature vector, whereas larger objects are given more weight for the whole or half image sizes.

This approach was tested on three object images to represent small, medium, and large objects for matching: pic.0928.jpg, pic.287.jpg, and pic.0746.jpg. Initially, the program was run on a small subset of the database for training purposes. Surprisingly, it also performed reasonably well on the entire database. Consequently, the whole database was used to obtain matches for these images. The results contain 10 images as follows.

a. For small size object, the weight for {whole, half, quarter, and eighth sizes} is {1, 2, 4, 8}.

Target image: pic.0928.jpg.

Top 10 images: pic.0950.jpg, pic.0937.jpg, pic.0933.jpg, pic.0930.jpg, pic.0948.jpg, pic.0935.jpg, pic.1016.jpg, pic.0924.jpg, pic.0336.jpg, pic.1048.jpg

```
jeff@Yuans-MacBook-Pro bin % ./matching custom_s /Users/jeff/Desktop/Project2_YZ/olympus/pic.0928.jpg 10
N is set to 10
Method is set to custom_s
CSV file is set to /Users/jeff/Desktop/Project2_YZ/bin/image_features_custom_s.csv
Reading /Users/jeff/Desktop/Project2_YZ/bin/image_features_custom_s.csv
Finished reading CSV file
Top 10 Matches:
pic.0950.jpg with similarity: 22.8608
pic.0937.jpg with similarity: 22.4636
pic.0933.jpg with similarity: 22.4487
pic.0930.jpg with similarity: 22.4117
pic.0948.jpg with similarity: 22.347
pic.0935.jpg with similarity: 22.3459
pic.1016.jpg with similarity: 22.3265
pic.0924.jpg with similarity: 22.2288
pic.0336.jpg with similarity: 22.1726
pic.1048.jpg with similarity: 22.1676
```


pic.0950.jpg


pic.0937.jpg


pic.0933.jpg


pic.0930.jpg


pic.0948.jpg


pic.0935.jpg


pic.1016.jpg


pic.0924.jpg


pic.0336.jpg


pic.1048.jpg

The results indicate that 6 out of the top 10 matching images accurately correspond to the chipmunk toy feature. The 4 images that do not depict the chipmunk toy still feature a small object in the center of the image, such as a red toy or a lamp, aligning with the small object feature criteria. Pic.0336.jpg is a particularly reasonable match, as it contains multiple small objects in the center with colors like red, grey, and white, similar to the target. Additionally, the

presence of a fire extinguisher in the image shares similar features with the target object. Additionally, the top 5 results demonstrate perfect performance.

b. For medium size object, the weight for {whole, half, quarter, and eighth sizes} is {1, 2, 8, 4}.

Target image: pic.0287.jpg.

Top 10 images: pic.0289.jpg, pic.0665.jpg, pic.0291.jpg, pic.0288.jpg, pic.0666.jpg, pic.0159.jpg, pic.0214.jpg, pic.0407.jpg, pic.0663.jpg, pic.0488.jpg.

```
jeff@Yuans-MacBook-Pro bin % ./matching custom_m /Users/jeff/Desktop/Project2_YZ/olympus/pic.0287.jpg 10
N is set to 10
Method is set to custom_m
CSV file is set to /Users/jeff/Desktop/Project2_YZ/bin/image_features_custom_m.csv
Reading /Users/jeff/Desktop/Project2_YZ/bin/image_features_custom_m.csv
Finished reading CSV file
Top 10 Matches:
pic.0289.jpg with similarity: 25.3065
pic.0665.jpg with similarity: 21.6252
pic.0291.jpg with similarity: 20.5474
pic.0288.jpg with similarity: 20.2934
pic.0666.jpg with similarity: 20.0382
pic.0159.jpg with similarity: 19.7975
pic.0214.jpg with similarity: 19.7556
pic.0407.jpg with similarity: 19.6896
pic.0663.jpg with similarity: 19.6031
pic.0488.jpg with similarity: 19.2152
jeff@Yuans-MacBook-Pro bin % ./extractFeature_custom_l /Users/jeff/Desktop/Project2_YZ/olympus
```


pic.0289.jpg


pic.0665.jpg


pic.0291.jpg


pic.0288.jpg


pic.0666.jpg


pic.0159.jpg


pic.0214.jpg


pic.0407.jpg


pic.0663.jpg


pic.0488.jpg

The results predominantly feature objects in the center, or a quarter of the whole image, that are blue. Among the top 10 images, 3 contain recycling bins, and 2 feature gift packages that closely resemble the recycling bins in terms of their square shape and blue color. The mailbox also shares a strong similarity. The remaining 3 images, although not directly relevant to the target image, still display blue features in the central area. Additionally, the top 5 results demonstrate good performance.

c. For large size object, the weight for {whole, half, quarter, and eighth sizes} is {1, 8, 4, 2}.

Target image: pic.0746.jpg.

Top 10 images: pic.0750.jpg, pic.0747.jpg, pic.0754.jpg, pic.0755.jpg, pic.0751.jpg, pic.0904.jpg, pic.0921.jpg, pic.0753.jpg, pic.0896.jpg, pic.0933.jpg.

```
jeff@Yuans-MacBook-Pro bin % ./matching custom_l /Users/jeff/Desktop/Project2_YZ/olympus/pic.0746.jpg 10
N is set to 10
Method is set to custom_l
CSV file is set to /Users/jeff/Desktop/Project2_YZ/bin/image_features_custom_l.csv
Reading /Users/jeff/Desktop/Project2_YZ/bin/image_features_custom_l.csv
Finished reading CSV file
Top 10 Matches:
pic.0750.jpg with similarity: 22.5837
pic.0747.jpg with similarity: 21.8598
pic.0754.jpg with similarity: 21.3988
pic.0755.jpg with similarity: 20.8553
pic.0751.jpg with similarity: 20.7257
pic.0904.jpg with similarity: 20.2592
pic.0921.jpg with similarity: 20.1873
pic.0753.jpg with similarity: 20.1507
pic.0896.jpg with similarity: 20.1049
pic.0933.jpg with similarity: 19.7935
```


pic.0750.jpg


pic.0747.jpg


pic.0754.jpg


pic.0755.jpg


pic.0751.jpg


pic.0904.jpg


pic.0921.jpg


pic.0753.jpg


pic.0896.jpg


pic.0933.jpg

The results primarily showcase objects in the center, occupying half or more of the entire image, that are green. Within the top 10 images, 6 feature waste containers, and 3 display green 2-liter plastic bottles that occupy most of the image space. The only outlier is an image of a chipmunk toy positioned against a green grass background, which likely matches due to the similar green hue of the grass and the green waste containers. These findings indicate that the majority of the images contain a large green object as a significant feature. Additionally, the top 5 results demonstrate perfect performance.

8. Extensions

In the extension phase of this project, a variety of implementations have been explored, including the use of GLCM, and Gabor feature extractors for analyzing and matching images. Addtionally, a face detection method has been implemented across all images in the database. This addition allows for the analysis of the outcome images to determine the percentage of faces that can be accurately recognized.

a. GLCM (Gray Level Co-occurrence Matrix) method

The GLCM function calculates several statistical measures from the normalized GLCM, including:
Energy: Sum of squared elements in the GLCM. It indicates texture uniformity; higher values mean more uniform texture.
Entropy: Measure of randomness in the texture. Higher entropy values indicate more complex textures.
Contrast: Measures the intensity contrast between a pixel and its neighbor over the whole image. Higher contrast values indicate a more variable texture.
Homogeneity: Measures the closeness of the distribution of elements in the GLCM to the GLCM diagonal. Higher values indicate a more homogeneous texture.
Max Probability: The maximum value in the GLCM, indicating the most prevalent pair of intensities in the texture.

This section has curated a collection of 30 images, dividing them into two distinct categories based on their texture complexity. The first category includes images with minimal texture, exemplified by scenes featuring a solitary pen against a backdrop. The second category comprises images that depict bicycles, alongside other visuals characterized by more intricate textures.

To analyze these images, the Gray Level Co-occurrence Matrix (GLCM) method is employed for feature calculation. This approach facilitates the extraction of two specific target images for detailed analysis: pic.0034.jpg, which showcases a simple texture, and pic.1088.jpg, which

displays a complex texture. This methodology allows for a nuanced examination of texture features across a spectrum of image complexities.

Target image: pic.0034.jpg

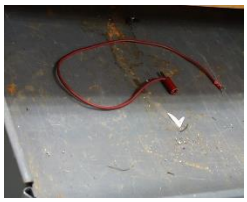
Top 5 images: pic.0032.jpg, pic.0030.jpg, pic.0049.jpg, pic.0511.jpg, pic.0507.jpg

```
jeff@Yuans-MacBook-Pro bin % ./matching glcm /Users/jeff/Desktop/Project2_YZ/olympus/glcm/pic.0034.jpg 5
N is set to 5
Method is set to glcm
CSV file is set to /Users/jeff/Desktop/Project2_YZ/bin/image_features_glcm.csv
Reading /Users/jeff/Desktop/Project2_YZ/bin/image_features_glcm.csv
Finished reading CSV file
Top 5 Matches:
pic.0032.jpg with similarity: 33.7245
pic.0030.jpg with similarity: 65.1882
pic.0049.jpg with similarity: 69.9227
pic.0511.jpg with similarity: 111.264
pic.0507.jpg with similarity: 149.08
```

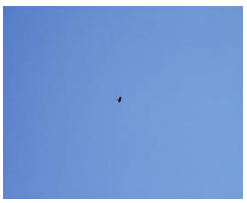
pic.0034.jpg

pic.0032.jpg

pic.0030.jpg



pic.0049.jpg



pic.0511.jpg

pic.0507.jpg

The results reveal that the texture feature of the target image is quite simple, characterized by a very low entropy. This simplicity is due to the background containing a uniform or similar texture throughout.

Target image: pic.1088.jpg

Top 5 images: pic.0150.jpg, pic.1083.jpg, pic.1082.jpg, pic.0233.jpg, pic.0427.jpg

```
jeff@Yuans-MacBook-Pro bin % ./matching glcm /Users/jeff/Desktop/Project2_YZ/olympus/glcm/pic.1088.jpg 5
N is set to 5
Method is set to glcm
CSV file is set to /Users/jeff/Desktop/Project2_YZ/bin/image_features_glcm.csv
Reading /Users/jeff/Desktop/Project2_YZ/bin/image_features_glcm.csv
Finished reading CSV file
Top 5 Matches:
pic.0150.jpg with similarity: 9.99799
pic.1083.jpg with similarity: 84.5899
pic.1082.jpg with similarity: 593.005
pic.0233.jpg with similarity: 18463
pic.0427.jpg with similarity: 18982.5
jeff@Yuans-MacBook-Pro bin %
```


pic.1088.jpg


pic.0150.jpg


pic.1083.jpg


pic.1082.jpg


pic.0233.jpg


pic.0427.jpg

The results indicate that the texture feature of the target image, pic.1088.jpg, is significantly more complex than that of pic.0034.jpg. This complexity is reflected in a much higher entropy, attributable to the intricate structure of the bicycle contained within the image. Additionally, it is observed that images of flowers and buildings share similar features with the target image, highlighting the method's ability to identify and compare complex texture patterns across different subjects.

b. Gabor filter implementation

Compared to the GLCM method, which is effective in capturing texture by analyzing the distribution of intensity levels, the Gabor filter places a greater emphasis on spatial frequencies and orientations within an image. In this section, 34 images from the Olympus database were selected for analysis. These images can be broadly divided into two categories: those featuring vertical objects and those containing parallel objects at various angles.

Target image: pic.0025.jpg
Top 5 images: pic.0024.jpg, pic.0013.jpg, pic.0018.jpg, pic.0023.jpg, pic.0996.jpg

```
jeff@Yuans-MacBook-Pro bin % ./matching gabor /Users/jeff/Desktop/Project2_YZ/olympus/gabor/pic.0025.jpg 5
N is set to 5
Method is set to gabor
CSV file is set to /Users/jeff/Desktop/Project2_YZ/bin/image_features_gabor.csv
Reading /Users/jeff/Desktop/Project2_YZ/bin/image_features_gabor.csv
Finished reading CSV file
Top 5 Matches:
pic.0024.jpg with similarity: 1536.73
pic.0013.jpg with similarity: 1777.97
pic.0018.jpg with similarity: 3078.3
pic.0023.jpg with similarity: 9823.34
pic.0996.jpg with similarity: 29453.4
```


pic.0025.jpg


pic.0024.jpg


pic.0013.jpg


pic.0018.jpg


pic.0023.jpg


pic.0996.jpg

The results indicate that the texture feature of the target image is relatively low, characterized by sparse pictures on the wall and infrequent vertical lines, leading to a generally low frequency. The top 5 images identified in the results share similar features with the target image, demonstrating the effectiveness of the analysis in matching images with comparable texture characteristics.

Target image: pic.0994.jpg
Top 5 images: pic.1025.jpg, pic.0979.jpg, pic.0706.jpg, pic.0216.jpg, pic.0648.jpg

```
jeff@Yuans-MacBook-Pro bin % ./matching gabor /Users/jeff/Desktop/Project2_YZ/olympus/gabor/pic.0994.jpg 5
N is set to 5
Method is set to gabor
CSV file is set to /Users/jeff/Desktop/Project2_YZ/bin/image_features_gabor.csv
Reading /Users/jeff/Desktop/Project2_YZ/bin/image_features_gabor.csv
Finished reading CSV file
Top 5 Matches:
pic.1025.jpg with similarity: 195629
pic.0979.jpg with similarity: 280537
pic.0706.jpg with similarity: 281977
pic.0216.jpg with similarity: 307210
pic.0648.jpg with similarity: 312751
```


pic.0994.jpg


pic.1025.jpg


pic.0979.jpg


pic.0706.jpg


pic.0216.jpg


pic.0427.jpg

The top 5 images identified in the results exhibit textures with higher frequency compared to pic.0025.jpg, and the textures display distinct angles, particularly evident in the top 3 images. Pic.0216.jpg features a texture of higher frequency, while pic.0427.jpg showcases horizontal parallel lines, aligning more closely with the target image than the vertical orientation observed in pic.0025.jpg.

c. Face Recognition

The Face Recognition method employed in this project is derived from Project 1, specifically the `faceDetect.cpp` program. Upon scanning the entire Olympus database, 66 images were detected as containing faces. Each image from the results was reviewed to confirm the presence of face features. The results of the face detection are stored at https://github.com/jeff8971/Project2_YZ/blob/main/data/faceDetect_result.rtf.

Upon reviewing all the images listed, it was determined that 27 of them do not actually feature faces, thus are considered false positives. Additionally, 2 images, pic.0326.jpg and pic.0324.jpg, include individuals wearing face masks, yet still contain discernible face features. Furthermore, pic.0930.jpg, which depicts a chipmunk toy, and pic.0299.jpg, featuring a poster with a male face, were also identified as containing face-like features, demonstrating the method's broad interpretation of what constitutes a face in an image.

Conclusion

Throughout the course of this project, I have explored a wide array of methods for image feature extraction and matching. Each method, from histograms to Euclidean distance, employs distinct distance metrics such as histogram intersection or sum-of-squared distance metric, tailored to the specific characteristics of the images being analyzed. For instance, when categorizing images based on color distribution and type, the 3D RGB histogram extraction method proves effective. Conversely, for categorizing images by their texture features, including variations in frequency, angle, and other specific texture characteristics, techniques such as Gabor filters, Laws' filters, and GLCM are more suitable.

Moreover, Deep Neural Network (DNN) embeddings have demonstrated a strong capability for matching, showcasing a form of learning ability that enables the recognition of objects within images even when there are variations in color or texture. This suggests that DNN embeddings can effectively identify and match images based on a deeper understanding of their content, beyond mere surface-level features.