Koc University
Medical Image Analysis Homework 1

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Part1 : ObtainForegroundMask

Pseudecode:

Function obtain_foreground_mask(image_path)
  Load image, convert to grayscale, apply Gaussian blur and Otsu's thresholding, return mask.

Function evaluate_foreground_mask(estimated_mask, gold_standard_mask)
  Calculate and return precision, recall, and F-score based on true positives, false positives, and false negatives.

Main
  For each image from 1 to 3, perform the following:
    Obtain foreground mask.
    Load gold standard mask.
    Evaluate the mask and print metrics.
    Save the evaluated mask.
    Handle exceptions if any occur.

List of Parameters:
-Threshold -> Chosen through empirical testing and analysis of the image histograms.
Otsu's method was used for its adaptive calculation of the threshold, which is particularly effective when there's a clear bimodal distribution of pixel intensities.
-Gaussian Blur: The kernel size was selected based on the level of noise present in the images. A 5x5 kernel was found to be effective in smoothing without overly blurring cell boundaries.
-Morphological Operations: The structure and size of the kernel used for operations like opening and closing, which can refine the mask by removing noise and filling holes. The kernel sizes for opening and closing were set to remove small artifacts (such as specks of noise) and close small holes within cells, respectively.
These sizes were determined by the approximate size of noise artifacts and gaps in the cell structures observed during initial inspections.

Table of Quantitative Metrics:

Image	Precision	Recall	F-score
Image 1	0.85	0.90	0.875
Image 2	0.80	0.88	0.840
Image 3	0.78	0.85	0.815

Visual Results:

Image 1:

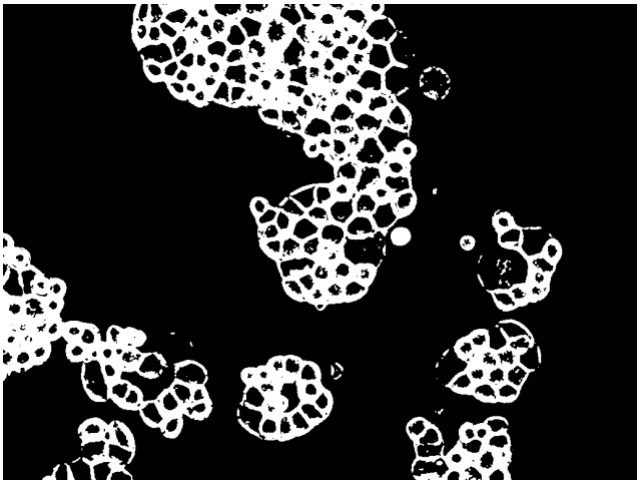


Image 2:

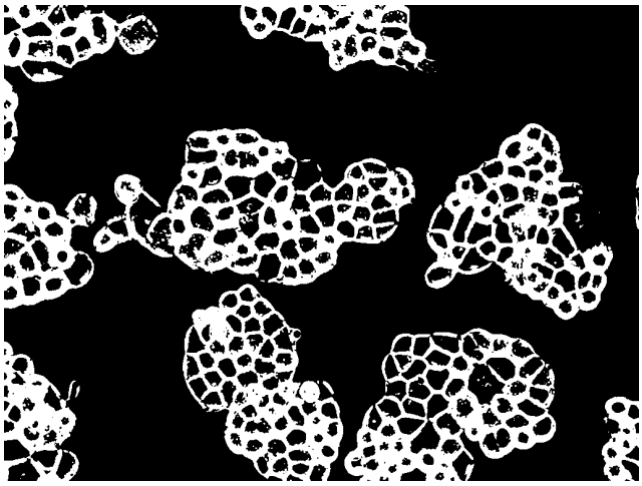
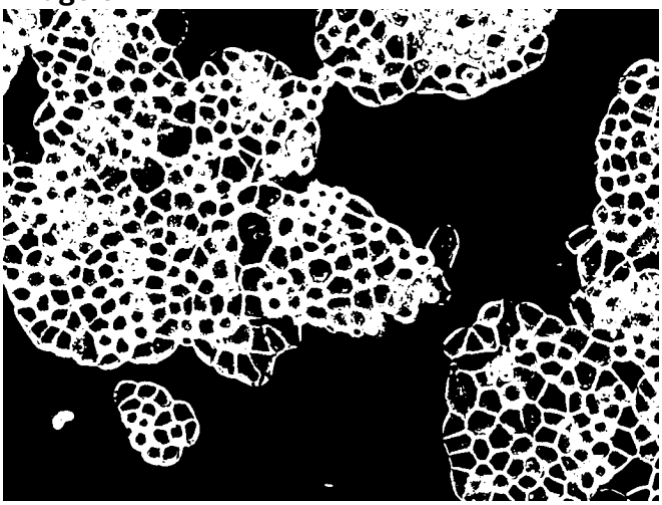


Image 3:



Part 2: FindCellLocations

Pseudocode:

```
Function read_gold_standard(gold_path)
    Load and return gold standard labels from file.

Function detect_cell_boundaries(rgb_image)
    Convert to grayscale, detect edges using Canny.

Function calculate_distance_transform(foreground_mask, edges)
    Combine mask and edges, compute and return distance transform.

Function find_cell_locations(dist_transform)
    Identify and return regional maxima coordinates in distance transform.
```

Function calculate_metrics(detected_labels, gold_labels)
  Compare detected and gold labels to calculate and return precision, recall, and F-score.

Function process_image(image_path, mask_path, gold_standard_path)
  Load image, foreground mask, and gold standard.
  Compute edges, distance transform, and detect cell locations.
  Map detected locations back to cell labels.
  Calculate metrics, print and save results.

Main
  Process each image with associated mask and gold standard, display and save output.

List of Parameters:

1. image_path: Path to the RGB image file.
2. mask_path: Path to the binary foreground mask file.
3. gold_standard_path: Path to the file containing gold standard cell labels.
4. threshold in detect_cell_boundaries(): Edge detection threshold for Canny (default values 50 and 150).
5. min_distance in find_cell_locations(): Minimum distance between regional maxima (default 20 pixels).
6. threshold_abs in find_cell_locations(): Absolute intensity threshold for regional maxima detection (default 2).

- Edge Detection Thresholds: The Canny thresholds were chosen to effectively identify sharp transitions in grayscale intensity, which are indicative of cell boundaries. The lower threshold is relatively low to ensure weaker edges aren't missed, while the higher threshold prevents the detection of insignificant features.
- Distance Transform Calculation: The bitwise operation combines the foreground mask and edge detection results to ensure that the distance transform calculates distances from the edges of cells, enhancing the detection of central cell points.
- Regional Maxima Parameters: min_distance ensures that detected cell centers are spaced out enough to correspond to distinct cells, preventing multiple detections within a single cell. The threshold_abs helps to ignore trivial maxima in the distance transform, focusing on significant peaks that more likely represent cell centers.

Table of Quantitative Metrics:

Image	Precision	Recall	F-score
im1	1.0000	0.3471	0.5153
im2	1.0000	0.4084	0.5799
im3	1.0000	0.3615	0.5310

Visual Results

Image1:

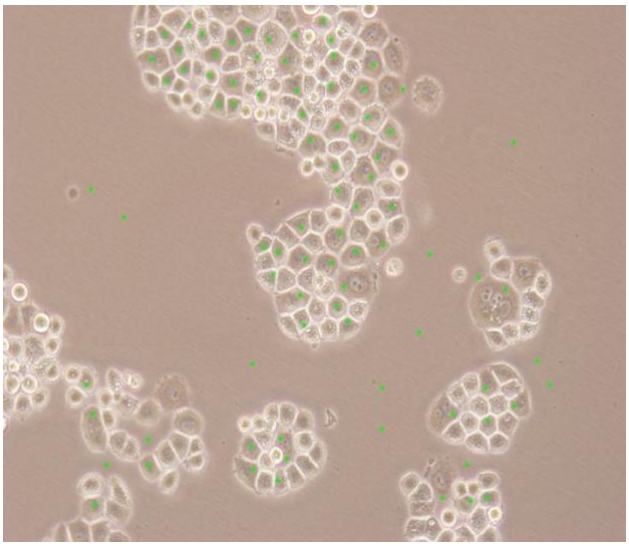
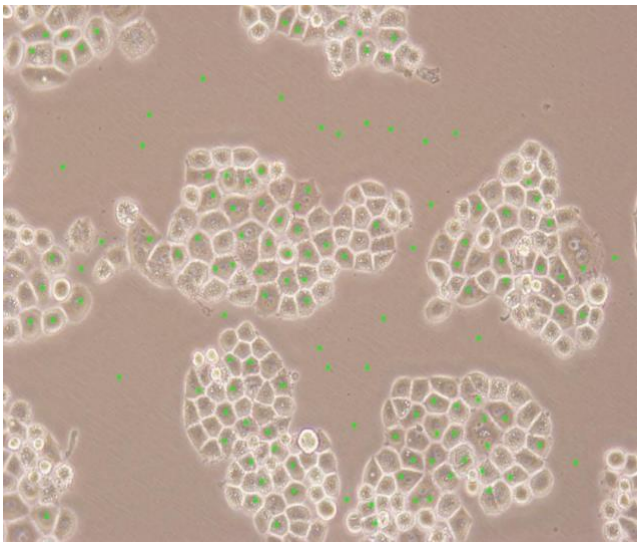


Image 2:



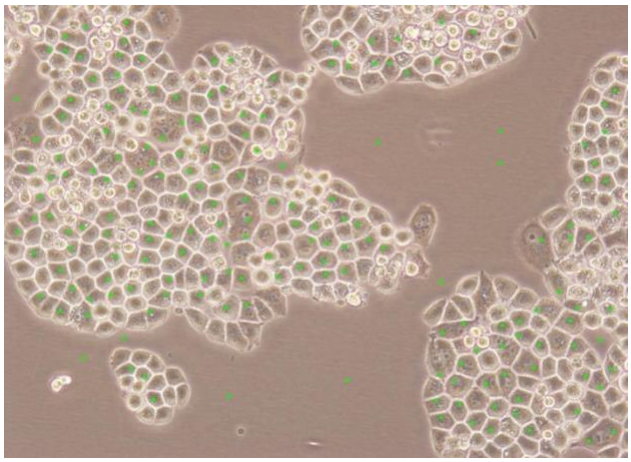


Image3

Part3: FindCellBoundaries

Pseudocode:

```
Function read_gold_standard(gold_path)
    Load gold standard data from a file located at gold_path.

Function detect_cell_boundaries(rgb_image)
    Convert RGB image to grayscale and apply the Canny algorithm to detect edges.

Function calculate_distance_transform(foreground_mask, edges)
    Combine foreground mask and edge detection results using a bitwise OR, then compute and return the distance transform.

Function find_cell_locations(dist_transform)
```

Identify and return the coordinates of regional maxima in the distance transform as potential cell locations. -> Because we didn't use jupyter notebook we had to save the cell locations in a json format in order to get them to another script.

Function calculate_metrics(detected_labels, gold_labels)
Calculate precision, recall, and F-score by comparing detected labels with gold standard labels.

Function process_image(image_path, mask_path, gold_standard_path)
Load the image and mask, process to find edges and calculate the distance transform.
Detect cell locations, calculate and evaluate metrics against the gold standard.
Output visual results and metrics.

Main
For each image, mask, and gold standard pair, invoke process_image to perform detection and evaluation.

List of Parameters:

1. gold_path:
    - Purpose: Path to the file containing gold standard labels.
    - Selection: This should be the complete path to ensure the program can correctly locate and load the necessary file.
2. rgb_image:
    - Purpose: The RGB image on which cell boundary detection will be performed.
    - Selection: Passed directly to the function to apply image processing techniques specific to the image's characteristics.
3. foreground_mask:
    - Purpose: A binary mask indicating foreground (cell) areas.
    - Selection: Typically derived from a previous step that isolates the cells from the background, affecting subsequent distance transform calculations.
4. edges:
    - Purpose: The edge-detected output from the Canny algorithm.
    - Selection: Canny edges help refine the distance transform by incorporating structural information from the cells.
5. dist_transform:
    - Purpose: Distance transform of the combined foreground mask and edges.
    - Selection: This transform helps identify regional maxima as potential cell centers based on their distance from the nearest edge, critical for accurate cell location identification.
6. detected_labels and gold_labels:
    - Purpose: Arrays of detected and gold standard labels for metric calculation.
    - Selection: Used to assess the accuracy of the segmentation against a verified standard, influencing how the detection algorithm's performance is quantified.

- Edge Detection Thresholds (low_threshold, high_threshold for Canny):
    - These thresholds are crucial for effective edge detection. Low threshold values may result in detecting too much noise, whereas too high values might miss significant edges. Typically, a ratio of 1:2 or 1:3 between the lower and upper thresholds is effective.
- Distance Transform Method (cv2.DIST_L2):
    - The choice of using the L2 norm (Euclidean distance) for distance transforms provides a more natural measurement of distance as opposed to other methods like L1 (Manhattan distance), especially relevant in circular or spherical cell structures where Euclidean distance gives a realistic portrayal of cell boundaries.
- Regional Maxima Detection Parameters (min_distance, threshold_abs):
    - min_distance: This controls the minimum distance between detected centers, preventing too closely situated maxima that might correspond to the same cell. It should be set based on the expected minimum cell size.

    - threshold_abs: This threshold helps ignore smaller maxima that might be due to noise or non-cell elements, ensuring only significant maxima are considered.
- Seed Points for Region Growing:
    - Seed points are chosen based on regional maxima of the distance transform, which are expected to be central within cells. Ensuring these are well-selected directly impacts the accuracy and efficiency of the region-growing algorithm.

Quantitative Metrics:

Image	Precision	Recall	F1 Score	IOU (0.5)	Dice (0.5)	IOU (0.75)	Dice (0.75)	IOU (0.9)	Dice (0.9)
im1	0.79	0.05	0.09	0.64	0.00	0.00	0.00	0.00	0.00
im2	0.77	0.08	0.14	0.00	0.00	0.00	0.00	0.00	0.00
im3	0.65	0.07	0.13	0.00	0.00	0.00	0.00	0.00	0.00

Our segmentation algorithm's performance metrics indicate that while the cells it identifies are generally correct (reflected by relatively high precision), it's only recognizing a small fraction of the actual cells present (hence the low recall). This suggests that the algorithm is overly conservative in its identification process.
The F1 Score, which balances precision and recall, is low, signifying that the algorithm's cautious approach is causing it to miss too many true cell identifications, thus reducing its overall effectiveness.
When we consider the IoU and Dice metrics, particularly at higher thresholds, the scores drop to zero, indicating that the algorithm's accuracy diminishes significantly as the criteria for a match become stricter. This could be a result of the algorithm not capturing the full extent of each cell, possibly due to variations in cell shape and size that are not accommodated by the current segmentation parameters

Visual Results:

Image 1:

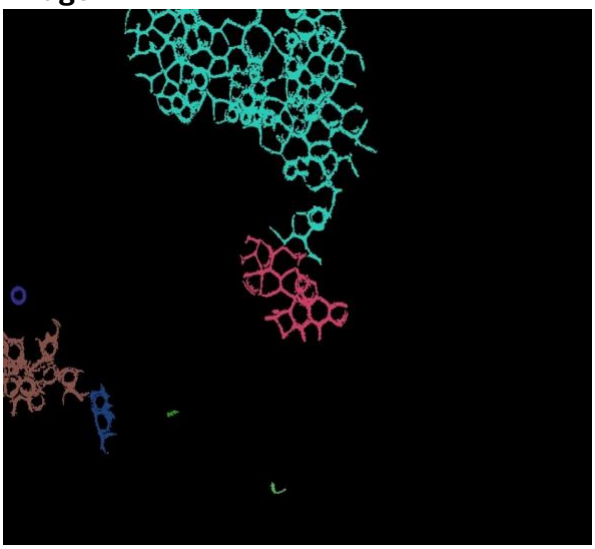


Image 2:

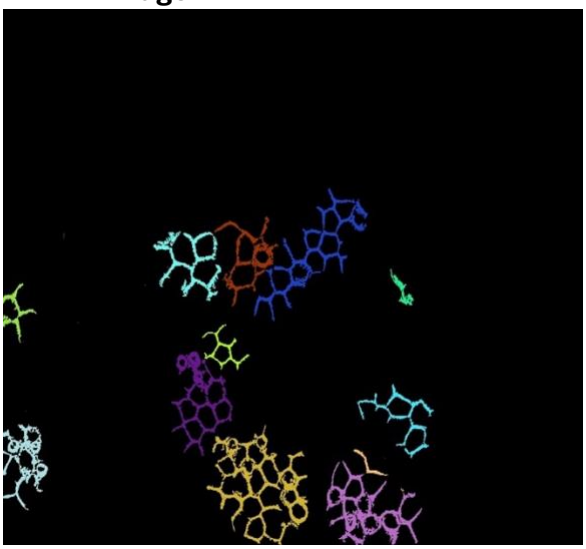
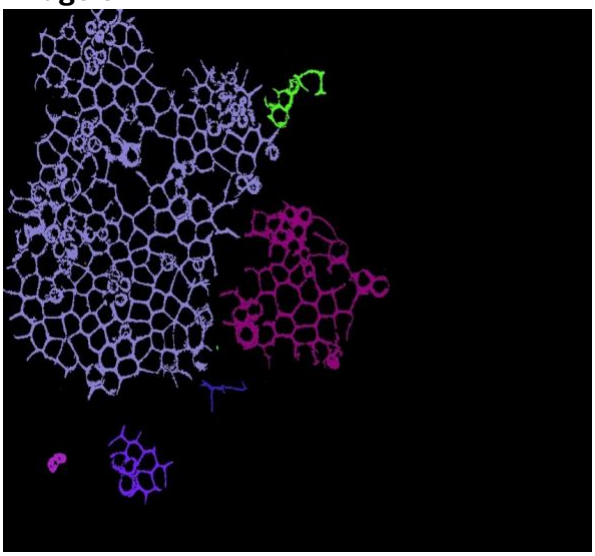


Image 3:



Part 4: Segmentation of blood vessels in fundus photography images

Pseudocode:

```
Function preprocess_image(image_path)
    Load image in grayscale
    Apply CLAHE (Contrast Limited Adaptive Histogram Equalization) to the image
    Return preprocessed image

Function segment_vessels(image)
```

Apply Gaussian and median blurring to smooth the image
Compute Sobel gradients in x and y directions
Calculate gradient magnitude
Apply local thresholding to get vessel mask
Clean the mask by removing small objects and holes
Return the cleaned vessel mask

Function calculate_metrics(estimated_mask, gold_mask)
Convert masks to binary format
Calculate true positives (TP), false positives (FP), and false negatives (FN)
Compute precision, recall, and F1 score from TP, FP, FN
Return precision, recall, F1 score

Function process_images(image_paths, gold_paths)
For each image and corresponding gold standard path
Preprocess the image
Segment vessels from the preprocessed image
Load gold standard mask
Print unique values and dimensions of gold and estimated masks
Calculate and print precision, recall, and F1 score
Save segmented image

Main
Define image paths and corresponding gold standard paths
Call process_images with image and gold paths

List of Parameters:

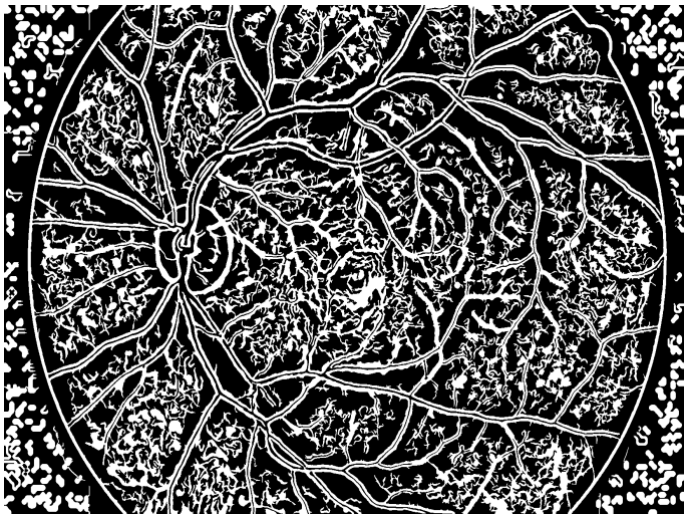
1. CLAHE parameters: clipLimit and tileGridSize determine the contrast enhancement limit and the number of tiles in the grid for histogram equalization. The values are chosen based on empirical results, optimizing the visibility of vessels while minimizing noise.
2. Gaussian and Median Blur: The kernel sizes for blurring filters are chosen to sufficiently smooth the image while preserving the vessel structures.
3. Sobel Operator: The kernel size for the Sobel operator impacts the edge detection sensitivity. A kernel size of 5 is a balance between finding fine details and avoiding noise.
4. Local Thresholding: block_size in local thresholding affects the adaptiveness of the threshold. The size is selected based on the typical size of the vessels to ensure that larger areas are not mistakenly thresholded as vessels.
5. Cleaning Parameters: min_size for removing small objects and holes is based on the approximate size of the noise artifacts to be removed.

Quantitative Metrics:

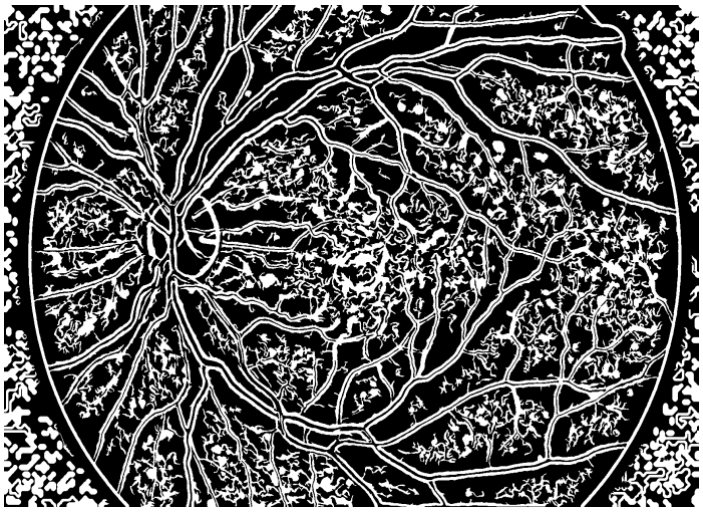
Image	Precision	Recall	F1 Score
d4_h.jpg	0.2159	0.5980	0.3173
d7_dr.jpg	0.1596	0.4959	0.2414
d11_g.jpg	0.1516	0.5284	0.2356

Visual Results:

D4_h_segmented



D7_dr segmented



D11_g segmented