Image Segmentation: Using Edge Detection Based, Region-Based and Clustering-Based Techniques

IT-524 Computer Vision

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Introduction

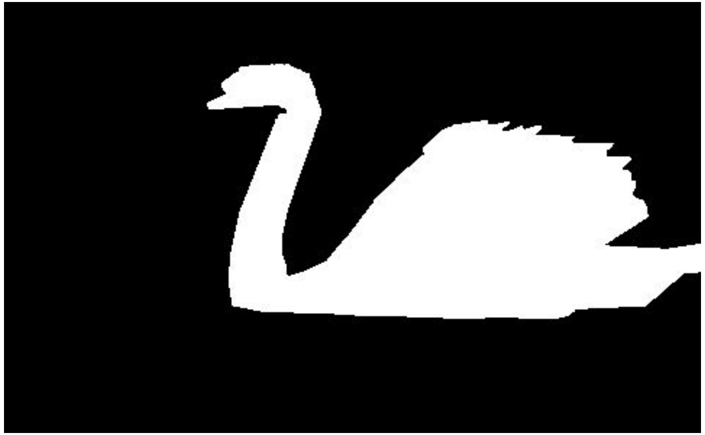
- In computer vision, Image segmentation is the process of partitioning a digital image into multiple segments (sets of pixels, also known as image objects).
- Image segmentation is typically used to locate objects and boundaries (lines, curves, etc.) in images. More precisely, Image segmentation is the process of assigning a label to every pixel in an image such that pixels with the same label share certain characteristics such as color, intensity, or texture. Adjacent regions are significantly different with respect to the same characteristic(s).
- **Techniques**: Region-Based Segmentation, Edge Detection Based Segmentation, Clustering Methods, etc.
- **Applications**: Medical Imaging, Object Detection, Object Recognition Tasks, Traffic Control Systems, etc.

Problem Description

- To solve the Image segmentation task on the given dataset[1] using Edge Detection Based, Region-Based and Clustering Based Techniques and compare the results using metrics such as F1 score and IoU(Intersection Over Union) score.

Dataset Description

- The Dataset[1] used contains 100 images with their ground truth.
- 50 images were used from the dataset for the experiment.
- Sample Image with its ground truth:



Source: https://www.ntu.edu.sg/home/asjfcai/Benchmark_Website/benchmark_index.html

Edge Detection Based Segmentation

- For edge detection canny edge detector is used.
- Canny edge detector is composed of below steps:
  - Smooth the image with a Gaussian filter to reduce noise and unwanted details and textures.

$$g(m,n) = G_\sigma(m,n) * f(m,n) \qquad G_\sigma = \frac{1}{\sqrt{2\pi\sigma^2}} exp\left(-\frac{m^2+n^2}{2\sigma^2}\right)$$

  - Compute gradient using sobel operator .

$$M(n,n) = \sqrt{g_m^2(m,n) + g_n^2(m,n)} \qquad \theta(m,n) = tan^{-1}[g_n(m,n)/g_m(m,n)]$$

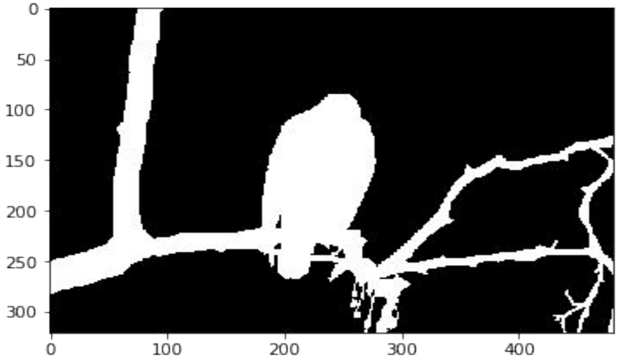
  - Non-Maximum Suppression:
    - After getting gradient magnitude and direction, a full scan of image is done to remove any unwanted pixels which may not constitute the edge.
    - For this, at every pixel, pixel is checked if it is a local maximum in its neighborhood in the direction of gradient.
    - The result you get is a binary image with "thin edges".

Edge Detection Based Segmentation

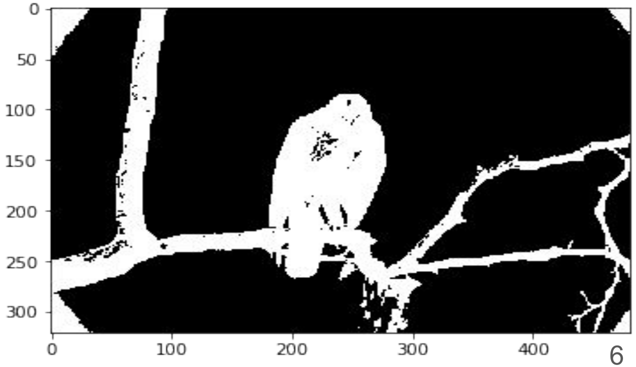
- Hysteresis Thresholding:
  - This stage decides which are all edges are really edges and which are not using two threshold values, minVal and maxVal.
  - Any edges with intensity gradient more than maxVal are sure to be edges and those below minVal are sure to be non-edges, so they are discarded.
- Canny() function of OpenCV library is used for Canny Edge Detection.
- Threshold() function of OpenCV library is used to convert edge detected image to binary image.

Original Image

Ground Truth



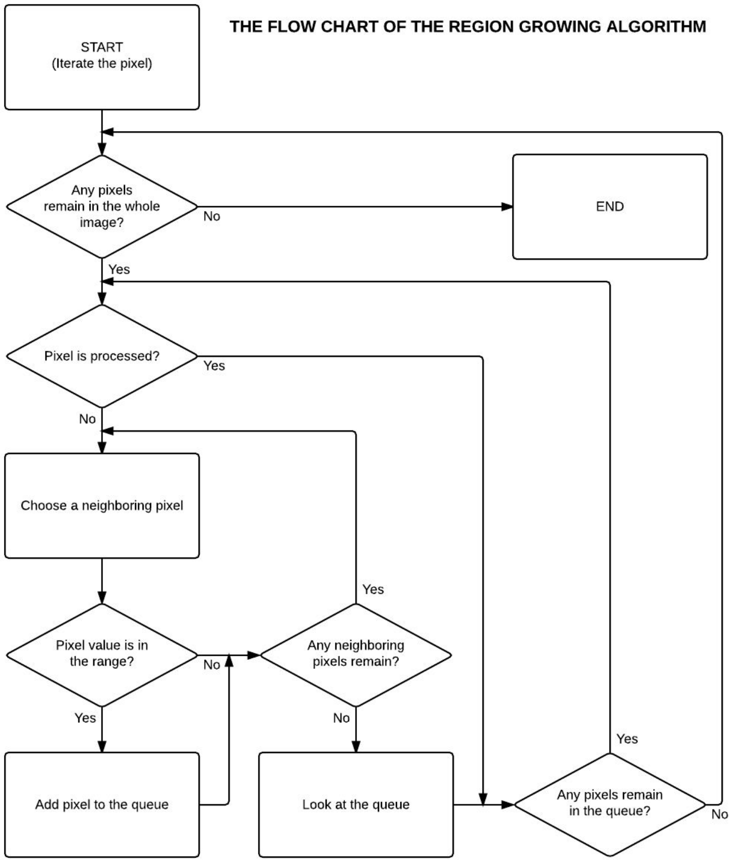
Result



Region-Based Segmentation

- Two Techniques used for Region-Based Segmentation:
  - Region Growing
  - Region Split and Merge
- Region Growing:
  - Region growing is a pixel-based image segmentation process.
  - Goal is to map individual pixel to a set of pixels called regions based on the characteristics of the image.
  - Algorithm starts with selecting the initial seed. Then it examines neighboring pixels of initial seed point and determines whether the pixel neighbors should be added to the region. The process is iterated on, in the same manner as general data clustering algorithms.

Region-Based Segmentation



Source: http://tanergungor.blogspot.com/2015/10/image-segmentation-region-growing.html

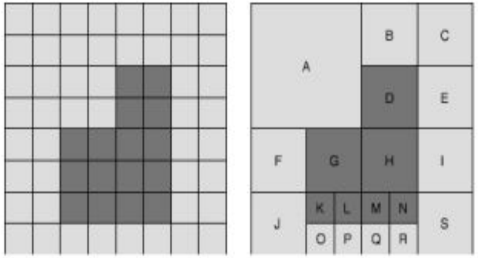
Region-Based Segmentation

- Region Split and Merge:
  - In this technique, image is successively split into quadrants based on a homogeneity criterion and similar regions are merged to create the segmented result.
  - The technique incorporates a quadtree data structure, meaning that there is a parent-child node relationship. The total region is a parent, and each of the four splits is a child.
  - **Algorithm**:

    START: consider entire image as one region

    1. If region satisfies homogeneity criteria, leave it unmodified

    2. If not, split it into four quadrants and recursively apply 1 and 2

    to each newly generated region and STOP when all regions in th homogeneity criterion.

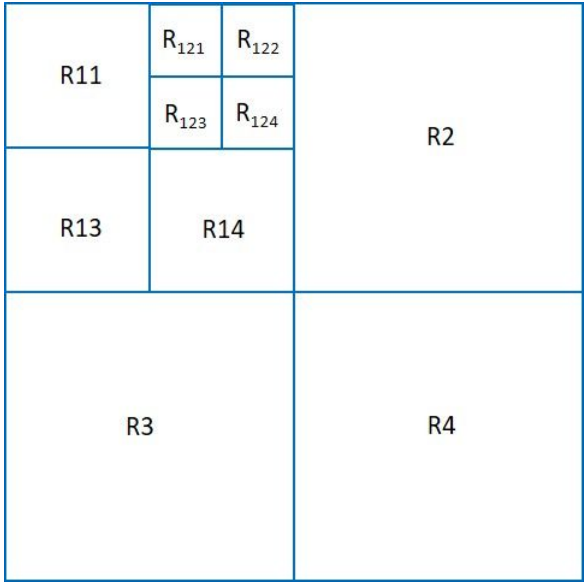
    3. If any two adjacent regions Ri , Rj can be merged into a homogeneous region, merge them.

    STOP: when no merging is possible any more.

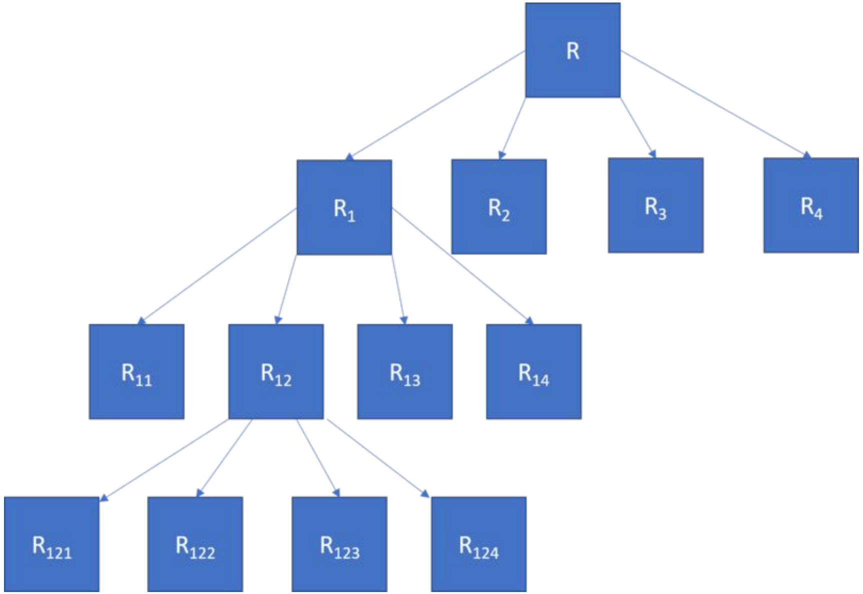
Source: https://www.ece.uvic.ca/~aalbu/computer%20vision%202010/L16.%20Segmentation-region-based.pdf

Region-Based Segmentation

- Partitioned Image after splitting:



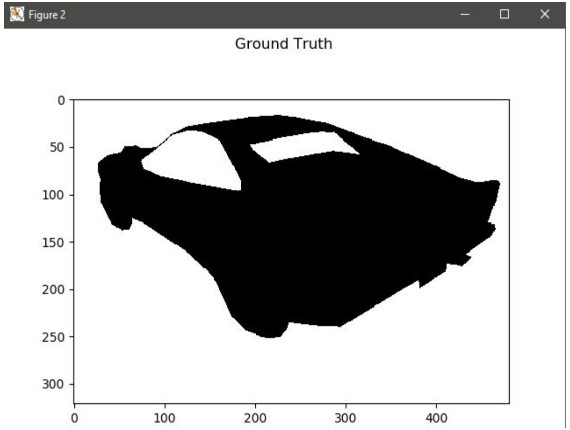
- Quadtree Data Structure:



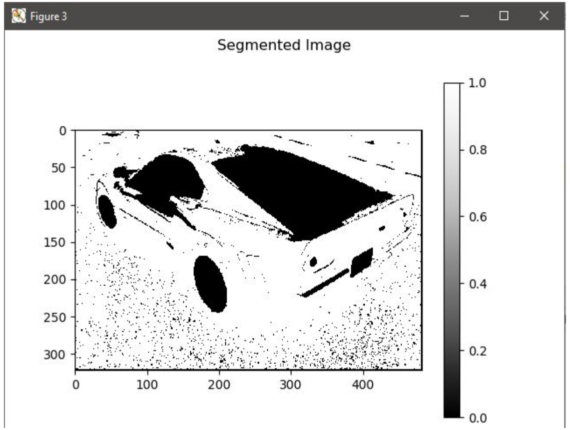
Source: https://en.wikipedia.org/wiki/Split_and_merge_segmentation

Region-Based Segmentation

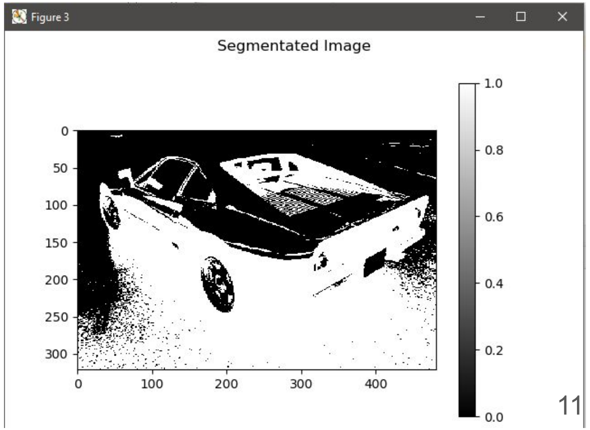
- Ground Truth:



- Region Growing:



- Region Split and Merge:



Clustering Based Segmentation

Three techniques are used for segmentation:

A. K-Means Clustering Algorithm

1. Specify number of clusters K. (K = 2 here)
2. Initialize centroids by first shuffling the dataset and then randomly selecting K data points for the centroids without replacement.
3. Keep iterating until there is no change to the centroids. i.e assignment of data points to clusters isn't ever-changing.
    - ❖ Compute the sum of the squared distance between data points and all centroids.
    - ❖ Assign each data point to the nearest cluster (centroid).
    - ❖ Compute the centroids for the clusters by taking the average of the all data points that belong to each cluster [2].

Clustering Based Segmentation

B. K-Medoids Clustering Algorithm

1. A medoid can be defined as the object of a cluster whose average dissimilarity to all the objects in the cluster is minimal, that is, it is the most centrally located point in the cluster.

2. In contrast to the k-means algorithm, k-medoids chooses data points as centers (medoids or exemplars) and can be used with arbitrary distances, while in k-means the centre of a cluster is not necessarily one of the input data points (it is the average between the points in the cluster).

3. The PAM method (Partitioning around medoids) was proposed in 1987 [3] for the work with L1 norm and other distances. It is more robust to noise and outliers as compared to k-means because it minimizes a sum of pairwise dissimilarities instead of a sum of squared Euclidean distances.

Clustering Based Segmentation

C. Fuzzy C-Means Clustering Algorithm [4]

1. Fuzzy clustering (also referred to as soft clustering or soft k-means) is a form of clustering in which each data point can belong to more than one cluster.
2. The fuzzy c-means algorithm is very similar to the k-means algorithm:

a. Choose a number of clusters.

b. Assign coefficients randomly to each data point for being in the clusters.

c. Repeat until the algorithm has converged (that is, the coefficients' change between two iterations is no more than eps, the given sensitivity threshold) :

d. Compute the centroid for each cluster (shown below).

e. For each data point, compute its coefficients of being

in the clusters.

$$c_k = \frac{\sum_x w_k(x)^m x}{\sum_x w_k(x)^m},$$

The FCM aims to minimize an objective function:

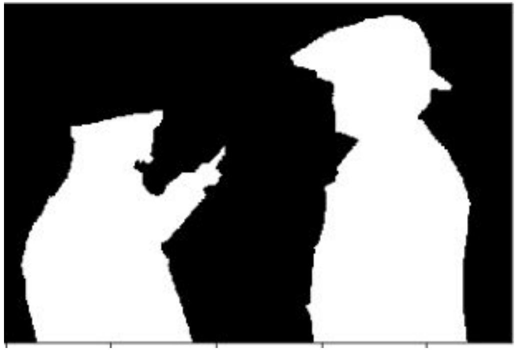
$$\underset{C}{\arg\min} \sum_{i=1}^{n} \sum_{j=1}^{c} w_{ij}^m \|\mathbf{x}_i - \mathbf{c}_j\|^2,$$

where:

$$w_{ij} = \frac{1}{\sum_{k=1}^{c} \left(\frac{\|\mathbf{x}_i - \mathbf{c}_j\|}{\|\mathbf{x}_i - \mathbf{c}_k\|} \right)^{\frac{2}{m-1}}}.$$

Clustering-Based Segmentation (K =2, iters =10)

- Ground Truth:



- K Means:

- K Medoids

- Fuzzy C Means

Clustering-Based Segmentation (K =2, iters =10)

- Ground Truth:

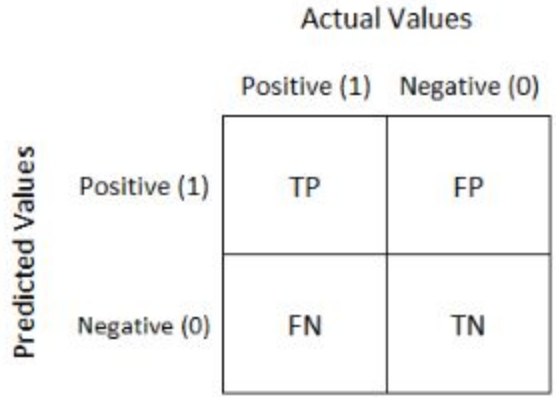
- K Means:

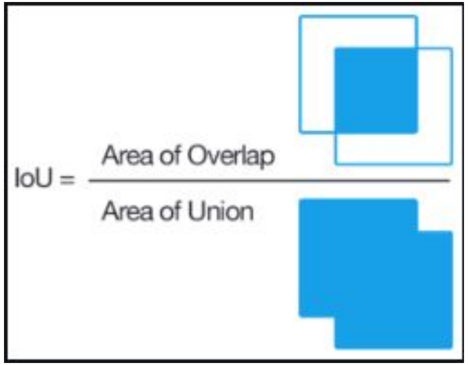
- K Medoids

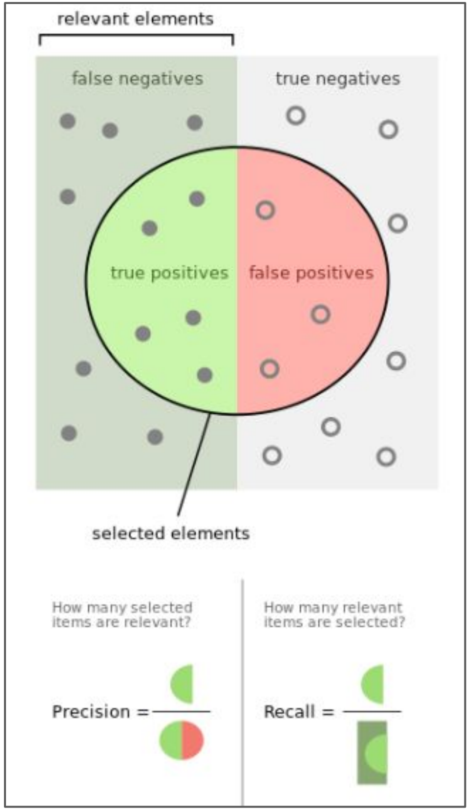
- Fuzzy C Means

Evaluation Metrics

1. Precision
2. Recall
3. F1 Score = Harmonic Mean of Precision and Recall
4. IoU Score = Intersection over Union =TP /(TP + FN + FP)
5. 00 = TN, 01 = FP, 10 = FN, 11 = TP (ground_truth, result)





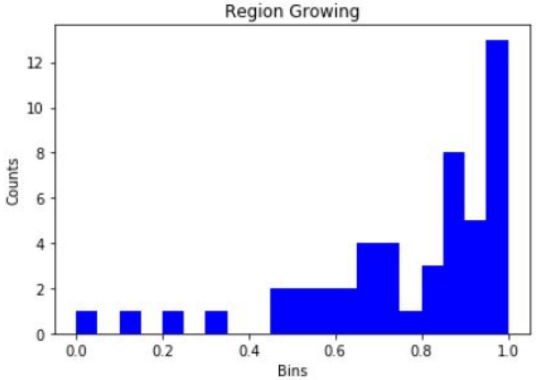


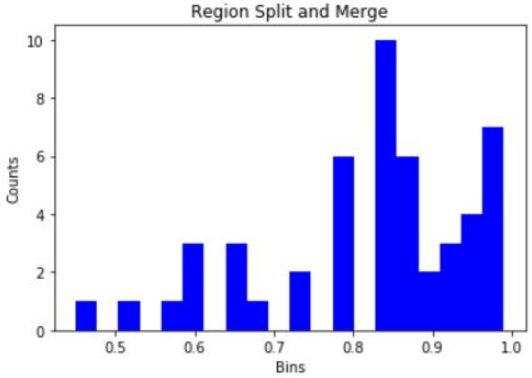
Reference : https://creativecommons.org/licenses/by-sa/4.0/
https://www.pyimagesearch.com/2016/11/07/intersection-over-union-iou-for-object-detection/

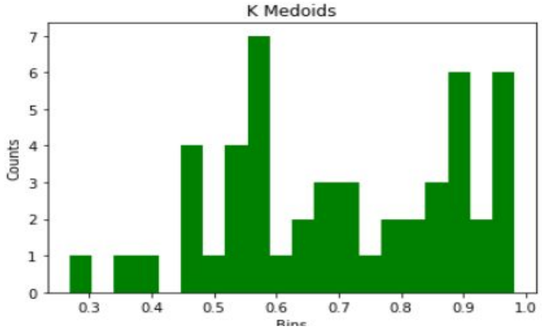
Results (Average over 50 images)

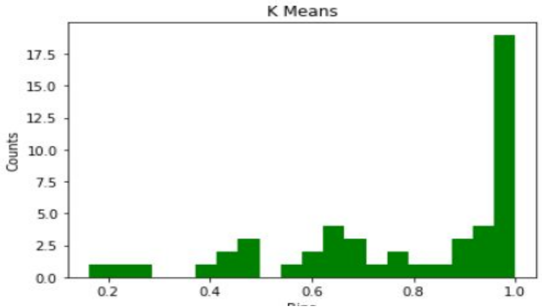
Algorithms	Region S & M	Region Growing	Edge Based	K-Means	K-Medoids	Fuzzy C-Means
Precision	**0.82**	0.77	0.67	0.78	0.70	0.67
Recall	0.64	0.69	**0.80**	0.49	0.24	0.51
F1 Score	**0.70**	0.65	**0.70**	0.52	0.33	0.52
IoU Score	0.56	0.55	**0.57**	0.39	0.22	0.38

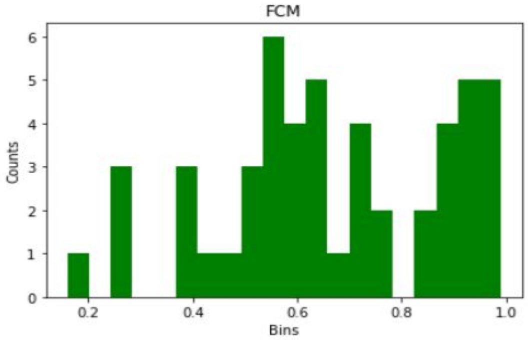
Precision histograms of respective techniques

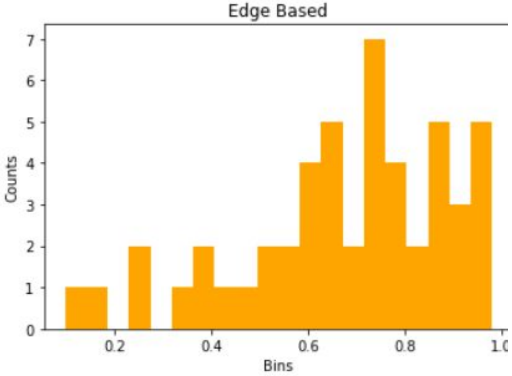




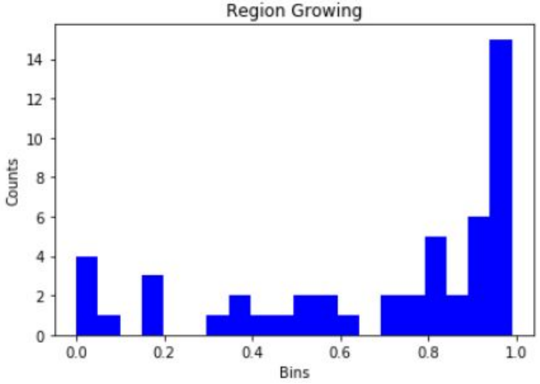


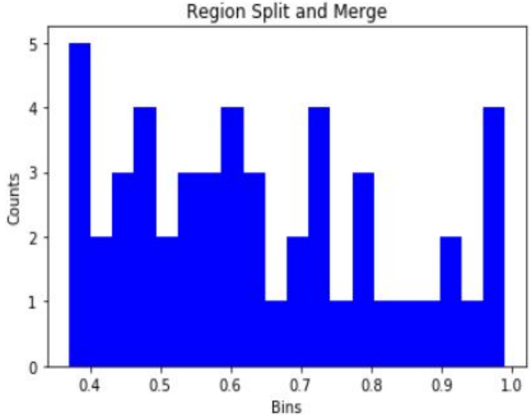


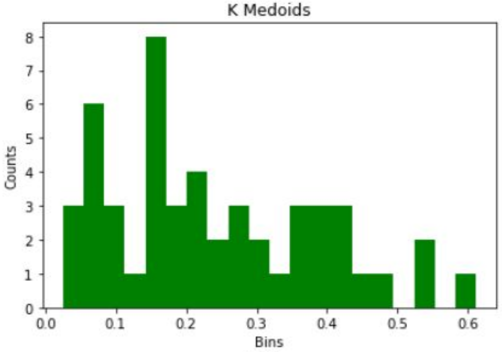


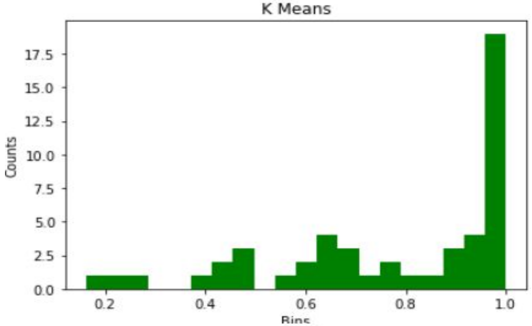


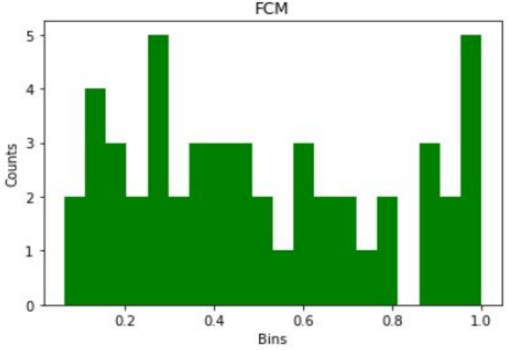
Recall histograms of respective techniques

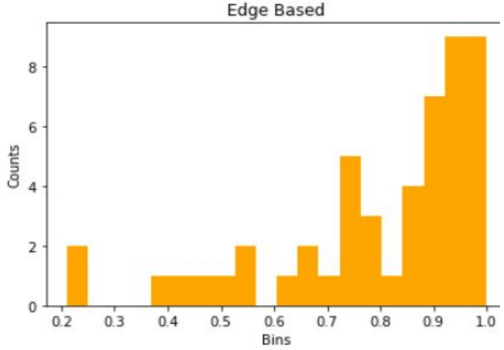










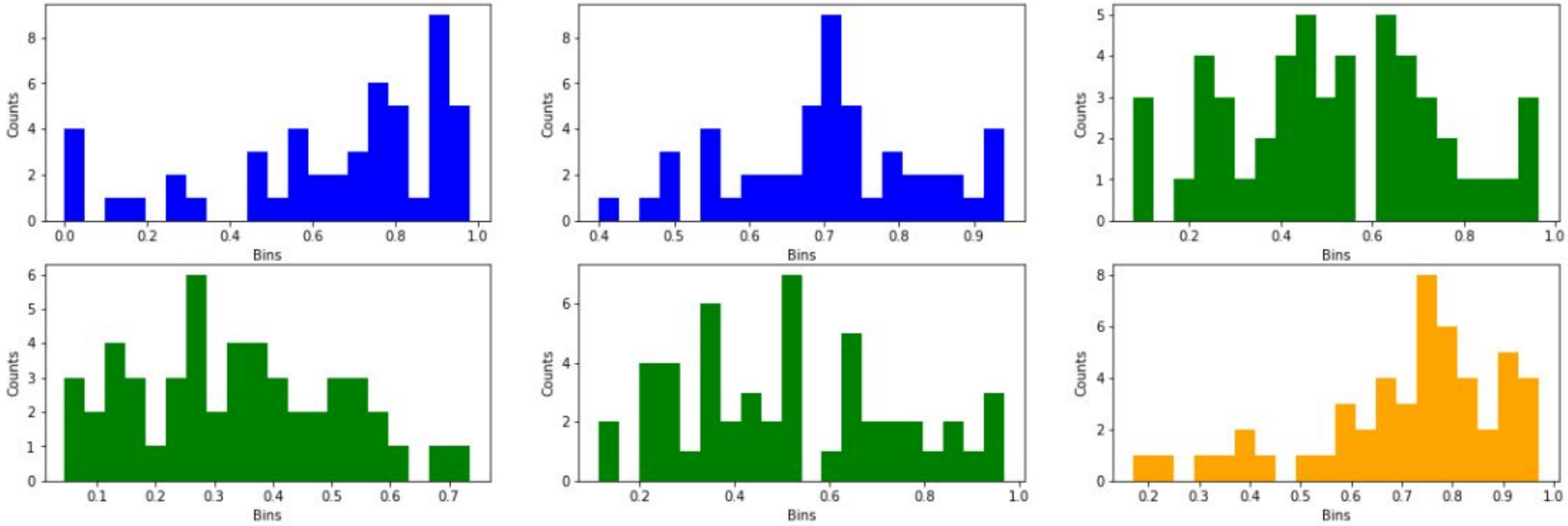


F1 Scores

Region Growing

Region S&M

K-means



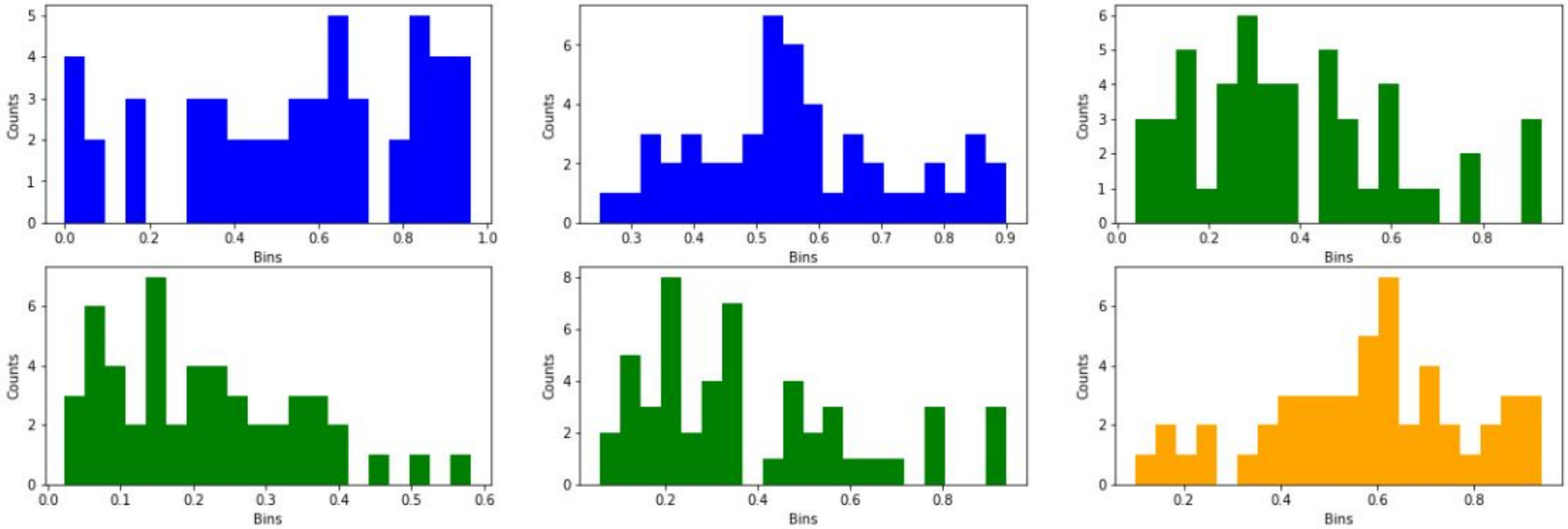
K-Medoids

FCM

Edge Based

IoU Scores

Region Growing　　Region S&M　　K-means



K-Medoids　　FCM　　Edge Based

Conclusion

- Region Split and Merge and Canny Edge Detection Based Segmentation techniques gives better results among all other techniques.
- Region growing algorithm depends on initial seed position and threshold value.
- In Clustering techniques, Fuzzy C-Means gives average accuracy of 64% which is better than that of K-Means (58%) and K-Medoids (21.45%)
- Metrics like Precision and Recall use pixel by pixel comparison of ground truth and segmented image. Other metrics can be used which compare regions having different weights may prove better.
- For binary image segmentation, Edge based and Region based are better as having F1 scores as 70% and also IoU scores as 0.57.

References

[1] Hui Li, Jianfei Cai, Thi Nhat Anh Nguyen, Jianmin Zheng. A BENCHMARK FOR SEMANTIC IMAGE SEGMENTATION. IEEE ICME 2013.

[2] https://towardsdatascience.com/understanding-k-means-clustering-in-machine-learning-6a6e67336aa1

[3] Kaufman, L. and Rousseeuw, P.J. (1987), Clustering by means of Medoids, in Statistical Data Analysis Based on the L1–Norm and Related Methods, edited by Y. Dodge, North-Holland, 405–416.

[4] M. C. J. Christ and R. M. S. Parvathi, "Fuzzy c-means algorithm for medical image segmentation," 2011 3rd International Conference on Electronics Computer Technology, Kanyakumari, 2011, pp. 33-36.