Assignment 2

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Image Segmentation

Image segmentation is a process of grouping together pixels that have similar attributes, Pixels in a region are similar according to some homogeneity criteria such as color, intensity or texture so as to locate and identify objects and boundaries.

In this report we intend to perform image segmentation according to the color criteria where each pixel in the image has an RGB value where we want to group pixels of similar RGB colors. The grouping problem is a clustering problem. We want to apply K-means on the Berkeley Segmentation Benchmark.

1. Discovering the Dataset:

The dataset has 500 images. 200 train images, 200 test images and 100 validation images. We will report our results on only 50 images from the test set.

Each image has some number of ground truth segmentations and boundaries corresponding to it, (figure 1 and 1.a -> 1.d) represents an image with some of its ground truths and boundaries.

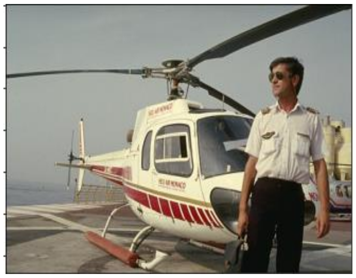


Figure 1 original image

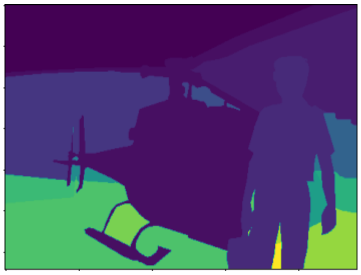


Figure 1.a segmentation of image

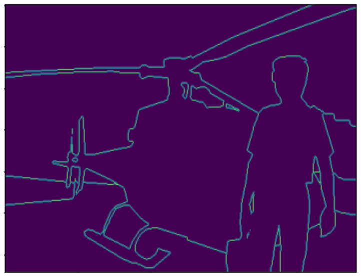


Figure 1.b boundaries of image

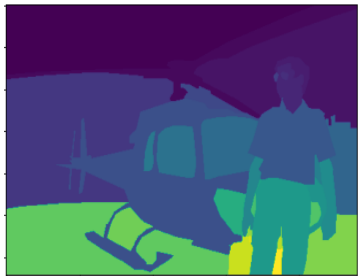


Figure 1.c segmentation of image

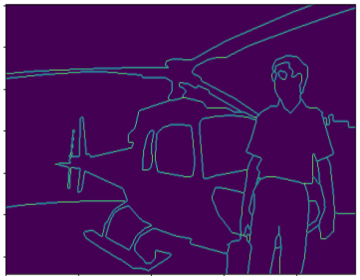
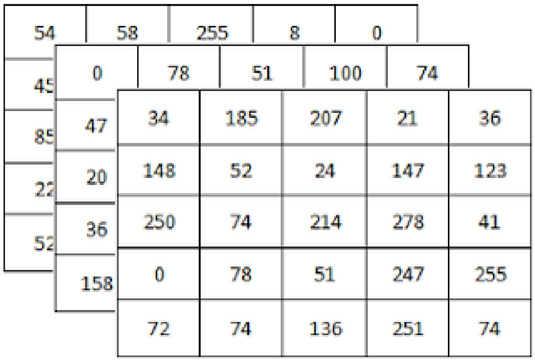


Figure 1.d boundaries of image

2. Applying K-means on images:

2.1: Changing the image format:



34	185	207	21	36
148	52	24	147	123
250	74	214	278	41
0	78	51	247	255
72	74	136	251	74

Figure 2.1 3D array for the original image

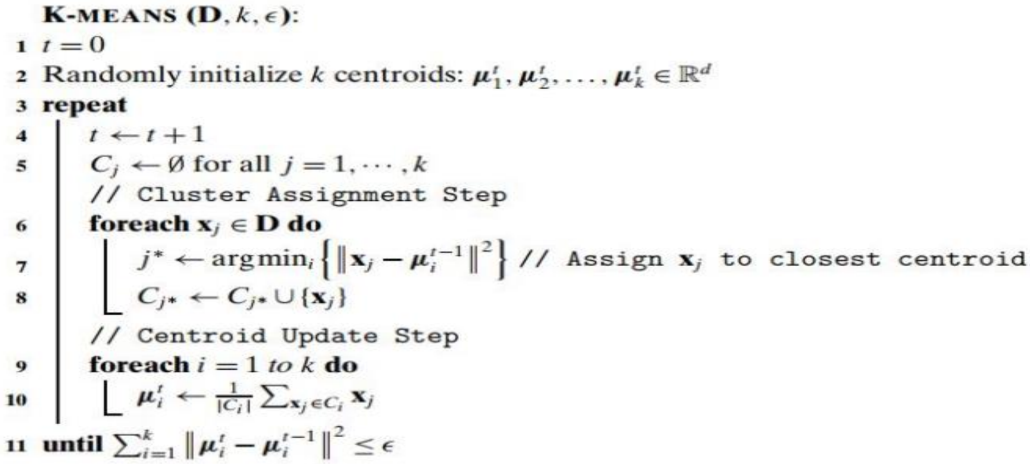
Originally each image is 3 dimensional numpy array, where each inner array represents Red, Green and Blue channel each value within that array along the three channels represents one pixel in the image (figure 2.1)

Before passing the images through our Kmeans function we first make every image pixel into a feature vector of 3-dimensions {R, G, B} and this is done for all pixels, which results into a datamatrix [which will be refered to as vectorized image through out the rest of the report] of (n x m) rows and 3 columns, where (n & m) are the number of rows and columns respectively from one array of the original 3D array in (figure 2.1).

2.2: Implementing K-means function:

First, In the function we choose the centeroids to each be one of the datamatrix rows at random. Then, we normalize the vectorized image by dividing all the numbers in it by 255 to have all the numbers in it be between 0 and 1[1].

Finally, we proceeded to follow the algorithm in (figure 2.2)



```
K-MEANS ($\mathbf{D}, k, \epsilon$):
$t = 0$
Randomly initialize $k$ centroids: $\boldsymbol{\mu}_1^t, \boldsymbol{\mu}_2^t, \ldots, \boldsymbol{\mu}_k^t \in \mathbb{R}^d$
repeat
    $t \leftarrow t + 1$
    $C_j \leftarrow \emptyset$ for all $j = 1, \cdots, k$
    // Cluster Assignment Step
    foreach $\mathbf{x}_j \in \mathbf{D}$ do
        $j^* \leftarrow \arg\min_i \left\{ \|\mathbf{x}_j - \boldsymbol{\mu}_i^{t-1}\|^2 \right\}$ // Assign $\mathbf{x}_j$ to closest centroid
        $C_{j^*} \leftarrow C_{j^*} \cup \{\mathbf{x}_j\}$
    // Centroid Update Step
    foreach $i = 1$ to $k$ do
        $\boldsymbol{\mu}_i^t \leftarrow \frac{1}{|C_i|} \sum_{\mathbf{x}_j \in C_i} \mathbf{x}_j$
until $\sum_{i=1}^k \|\boldsymbol{\mu}_i^t - \boldsymbol{\mu}_i^{t-1}\|^2 \leq \epsilon$
```

Figure 2.2 K-means Algorithm

[1] This normalization did not differ in the results of K-means with only RGB encoding but produced better clusters with RGB with spatial encoding, which we discuss later in the report.

3. Resulting clustering and its evaluation:

A vectorized image is run through our K-means algorithm with K = {3, 5, 7, 9, 11} which would produce different segmentations, Then these segmentation would be colored where each cluster has the same color.

We would run K-means on an image and then use external evaluation measures like F-measure and Conditional Entropy to asses the goodness of the resulting clusters. (figure 3.a-c) shows the resulted clustering against the image's ground truths with the Conditional Entropy and Fmeasure for each ground truth.

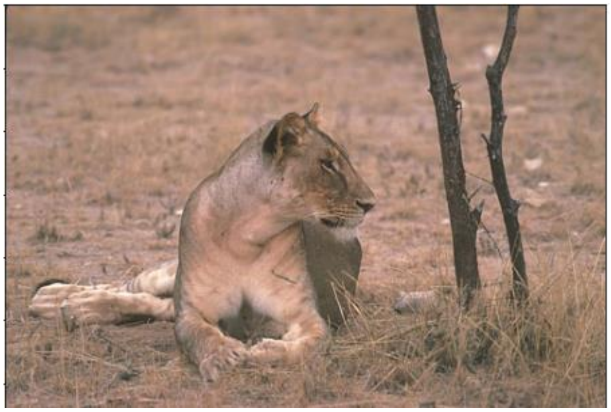


Figure 3.a image 12

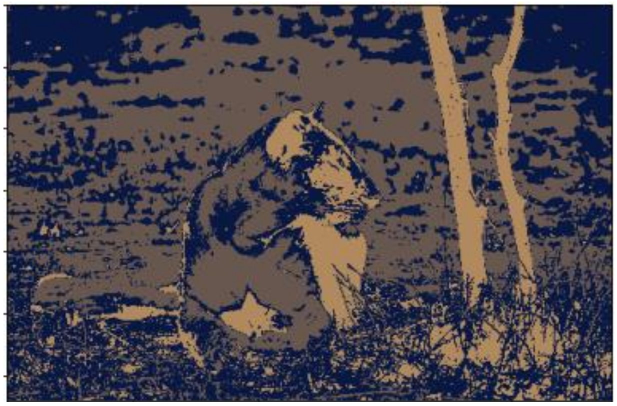
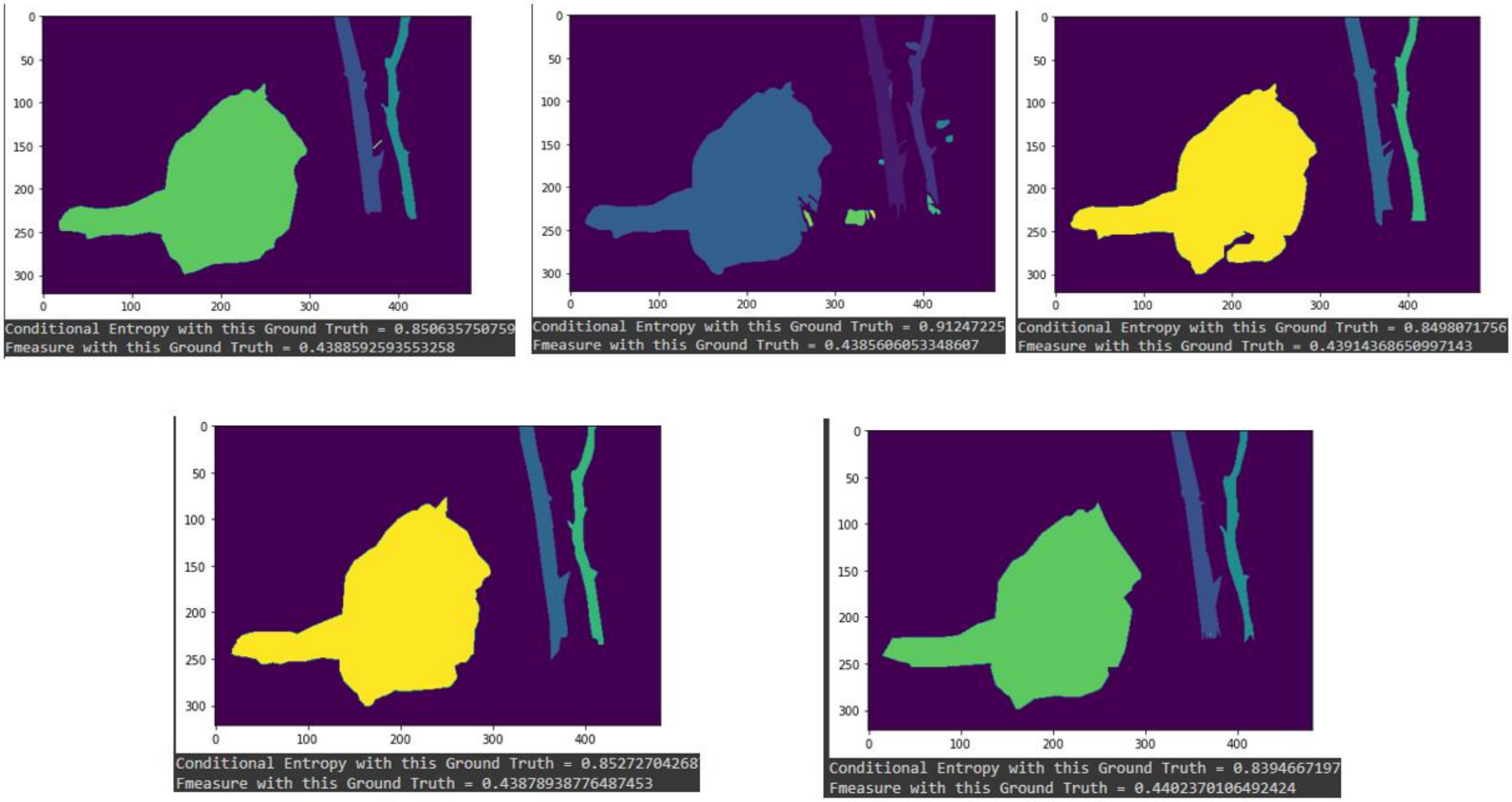


Figure 3.b our clustering with K-means at K = 3



```
Conditional Entropy with this Ground Truth = 0.850635750759
Fmeasure with this Ground Truth = 0.4388592593553258
```

```
Conditional Entropy with this Ground Truth = 0.91247225
Fmeasure with this Ground Truth = 0.4385606053348607
```

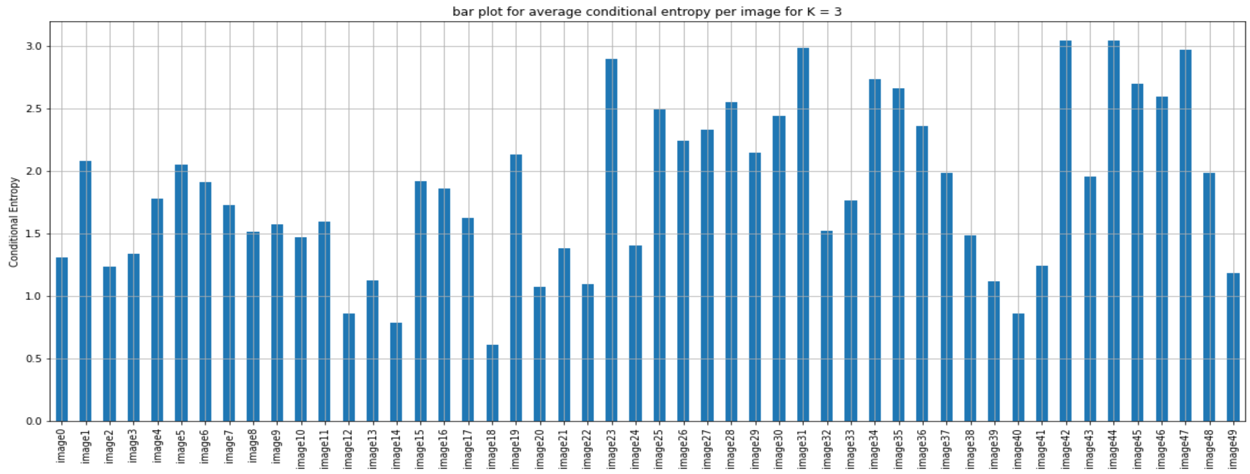
```
Conditional Entropy with this Ground Truth = 0.8498071756
Fmeasure with this Ground Truth = 0.43914368650997143
```

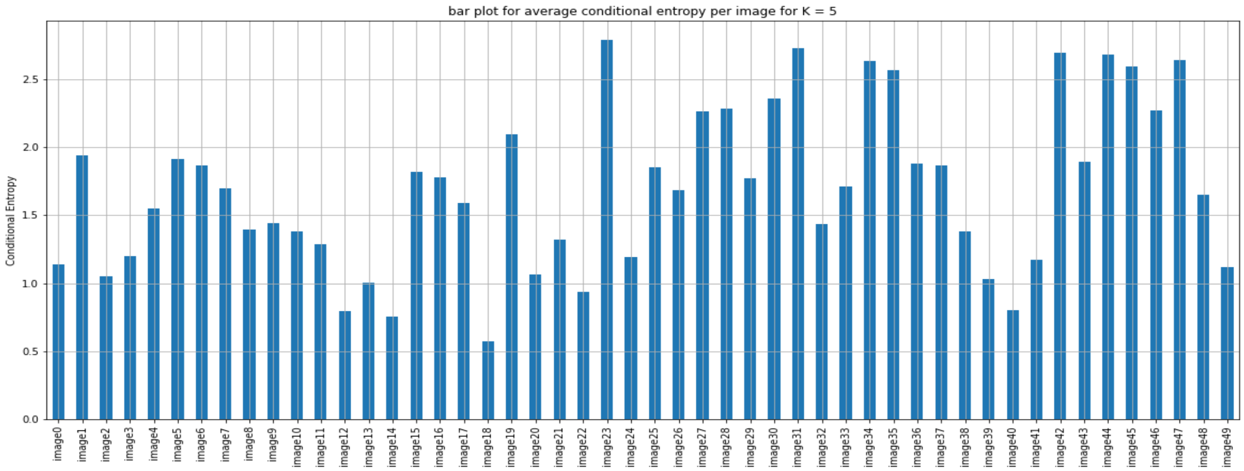
```
Conditional Entropy with this Ground Truth = 0.85272704268
Fmeasure with this Ground Truth = 0.43878938776487453
```

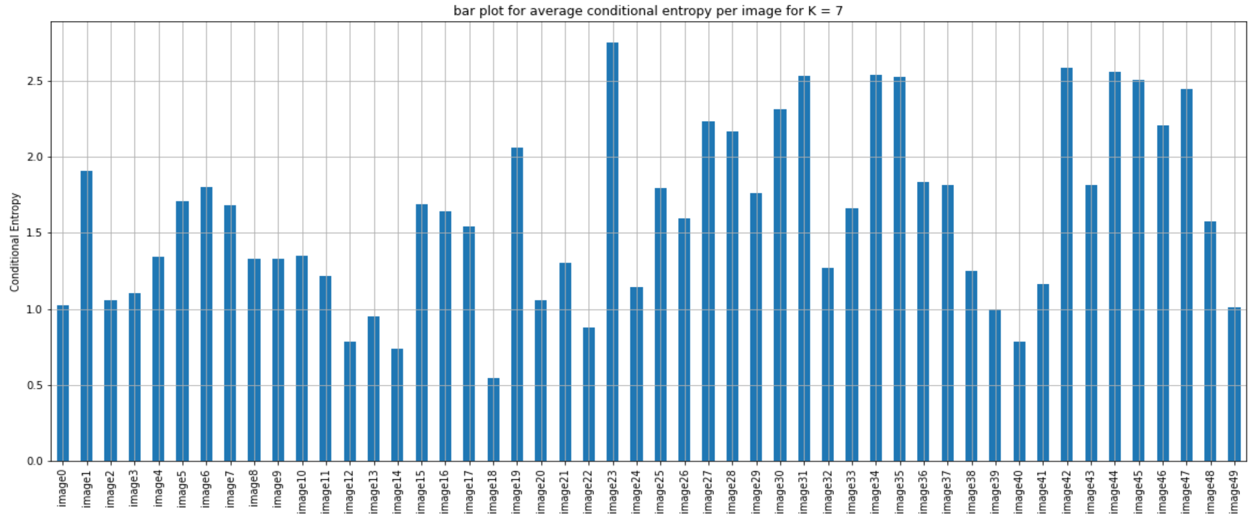
```
Conditional Entropy with this Ground Truth = 0.8394667197
Fmeasure with this Ground Truth = 0.4402370106492424
```

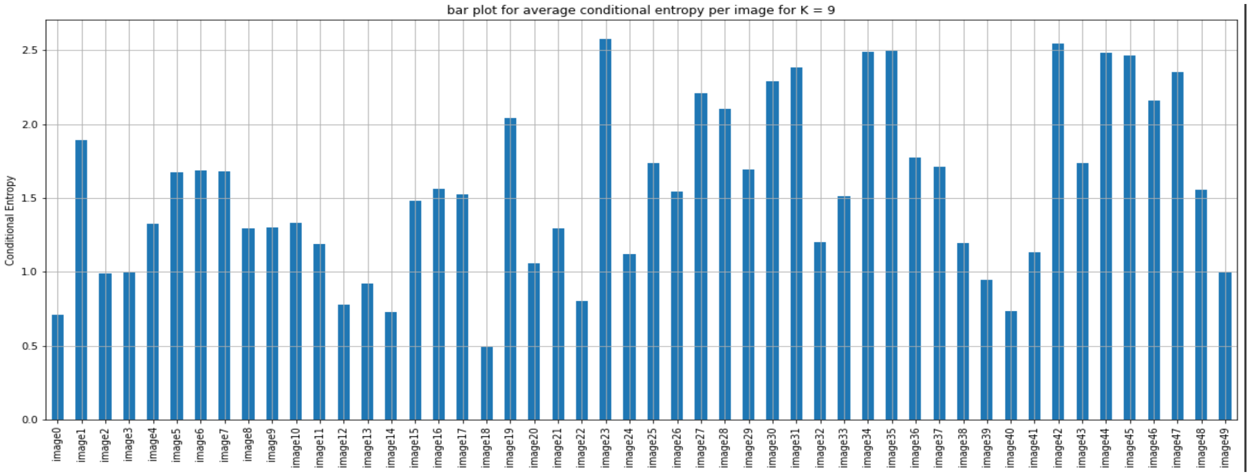
Figure 3.c Every ground Truth for image 12 with its clustering evaluation

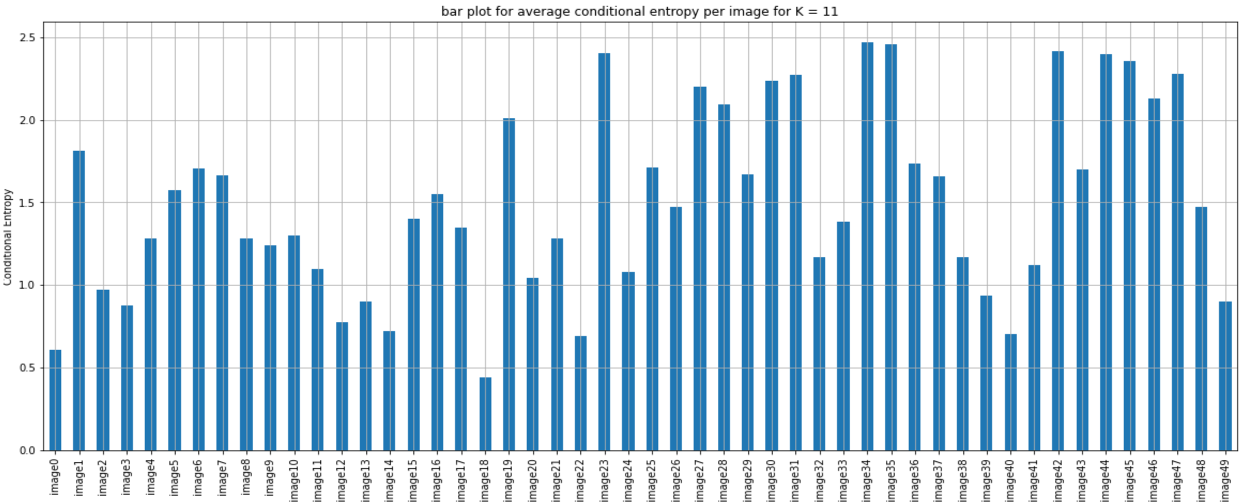
We then ran the entire dataset on the K-means algorithm, the following plots are the average evaluation measures for each produced image cluster and all its ground truths.

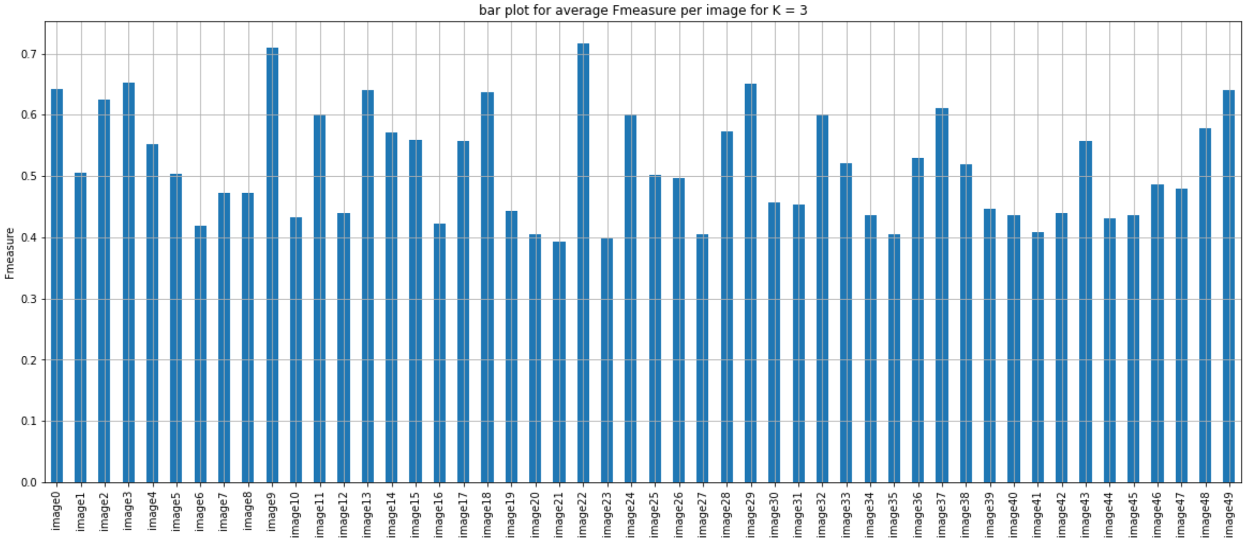


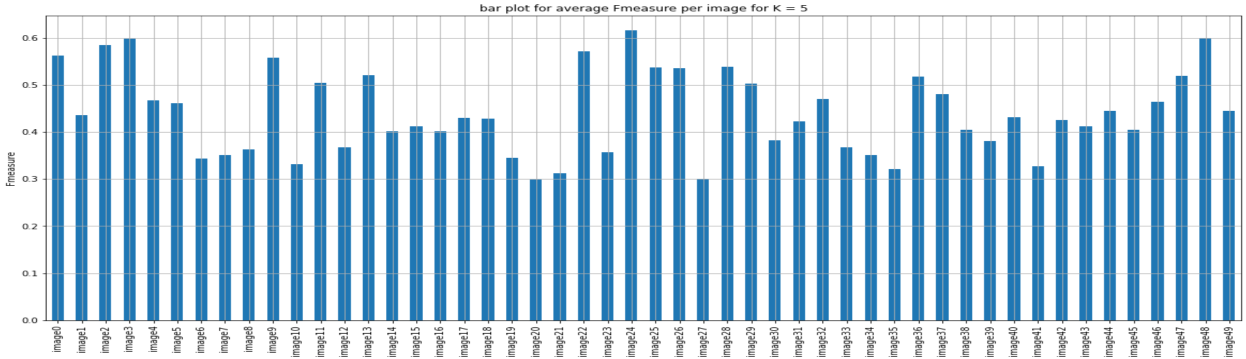


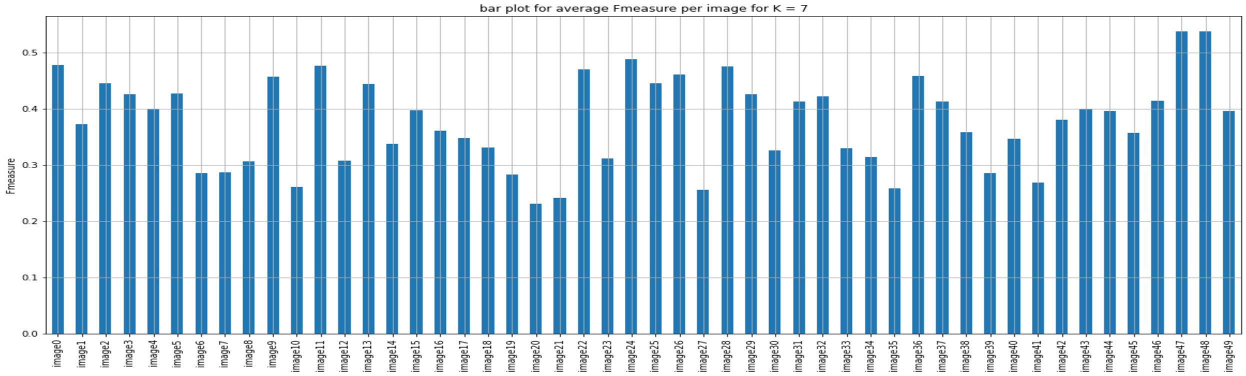


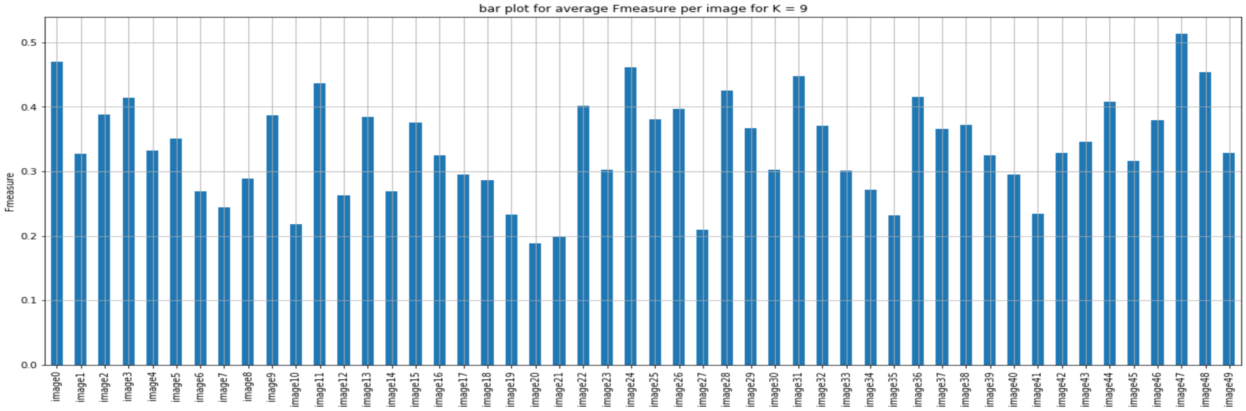

bar plot for average conditional entropy per image for K = 9
Conditional Entropy
0.0
0.5
1.0
1.5
2.0
2.5
image0
image1
image2
image3
image4
image5
image6
image7
image8
image9
image10
image11
image12
image13
image14
image15
image16
image17
image18
image19
image20
image21
image22
image23
image24
image25
image26
image27
image28
image29
image30
image31
image32
image33
image34
image35
image36
image37
image38
image39
image40
image41
image42
image43
image44
image45
image46
image47
image48
image49

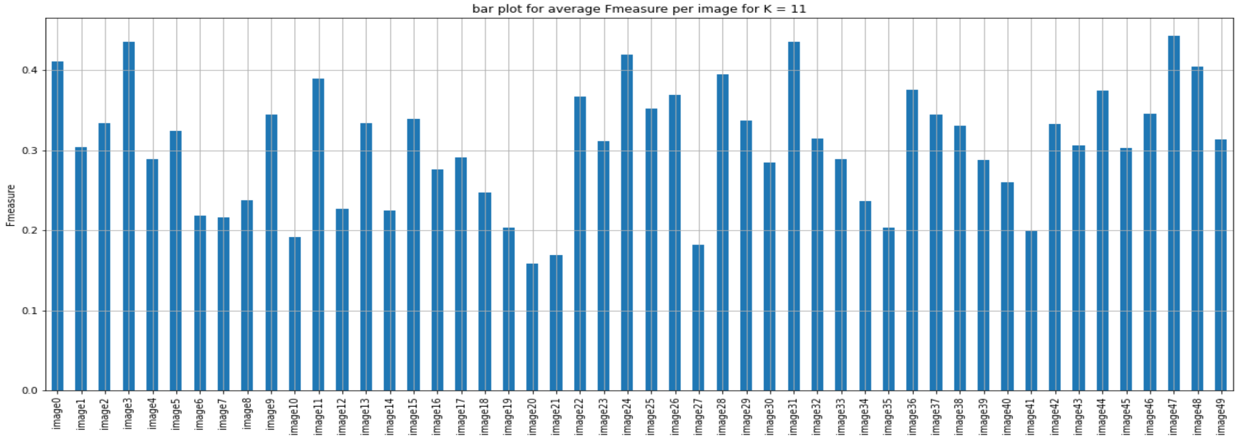

bar plot for average conditional entropy per image for K = 11
Conditional Entropy
0.0
0.5
1.0
1.5
2.0
2.5
image0
image1
image2
image3
image4
image5
image6
image7
image8
image9
image10
image11
image12
image13
image14
image15
image16
image17
image18
image19
image20
image21
image22
image23
image24
image25
image26
image27
image28
image29
image30
image31
image32
image33
image34
image35
image36
image37
image38
image39
image40
image41
image42
image43
image44
image45
image46
image47
image48
image49

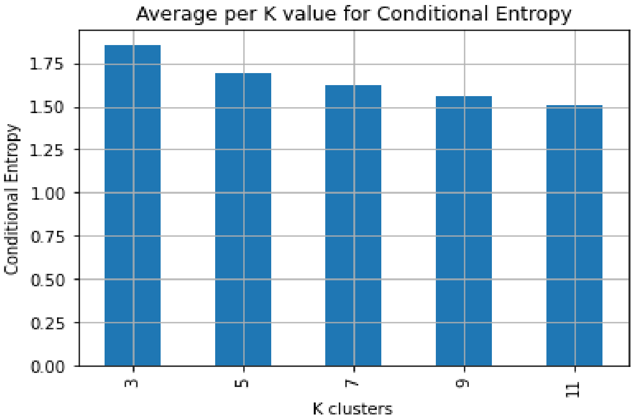

bar plot for average Fmeasure per image for K = 3
Fmeasure
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
image0
image1
image2
image3
image4
image5
image6
image7
image8
image9
image10
image11
image12
image13
image14
image15
image16
image17
image18
image19
image20
image21
image22
image23
image24
image25
image26
image27
image28
image29
image30
image31
image32
image33
image34
image35
image36
image37
image38
image39
image40
image41
image42
image43
image44
image45
image46
image47
image48
image49

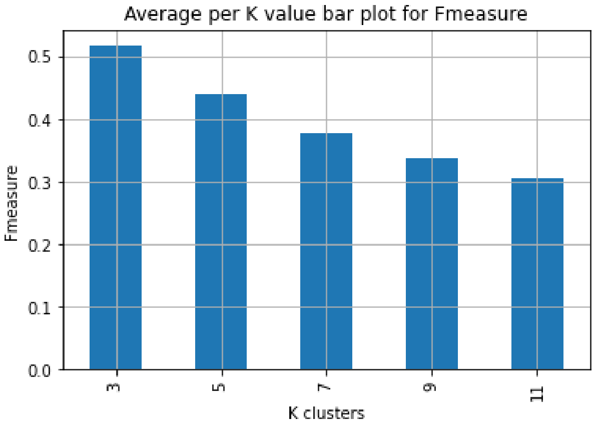

bar plot for average Fmeasure per image for K = 5
Fmeasure
0.0
0.1
0.2
0.3
0.4
0.5
0.6
image0 image1 image2 image3 image4 image5 image6 image7 image8 image9 image10 image11 image12 image13 image14 image15 image16 image17 image18 image19 image20 image21 image22 image23 image24 image25 image26 image27 image28 image29 image30 image31 image32 image33 image34 image35 image36 image37 image38 image39 image40 image41 image42 image43 image44 image45 image46 image47 image48 image49


bar plot for average Fmeasure per image for K = 7
Fmeasure
0.0
0.1
0.2
0.3
0.4
0.5
image0 image1 image2 image3 image4 image5 image6 image7 image8 image9 image10 image11 image12 image13 image14 image15 image16 image17 image18 image19 image20 image21 image22 image23 image24 image25 image26 image27 image28 image29 image30 image31 image32 image33 image34 image35 image36 image37 image38 image39 image40 image41 image42 image43 image44 image45 image46 image47 image48 image49


bar plot for average Fmeasure per image for K = 9
Fmeasure
0.0
0.1
0.2
0.3
0.4
0.5
image0 image1 image2 image3 image4 image5 image6 image7 image8 image9 image10 image11 image12 image13 image14 image15 image16 image17 image18 image19 image20 image21 image22 image23 image24 image25 image26 image27 image28 image29 image30 image31 image32 image33 image34 image35 image36 image37 image38 image39 image40 image41 image42 image43 image44 image45 image46 image47 image48 image49


bar plot for average Fmeasure per image for K = 11
Fmeasure
0.0
0.1
0.2
0.3
0.4
image0 image1 image2 image3 image4 image5 image6 image7 image8 image9 image10 image11 image12 image13 image14 image15 image16 image17 image18 image19 image20 image21 image22 image23 image24 image25 image26 image27 image28 image29 image30 image31 image32 image33 image34 image35 image36 image37 image38 image39 image40 image41 image42 image43 image44 image45 image46 image47 image48 image49





From all these plots we were able to determine the good and bad results of the clustering. (figure 3.d) shows an example of good results and (figure 3.e) shows an example of bad results.

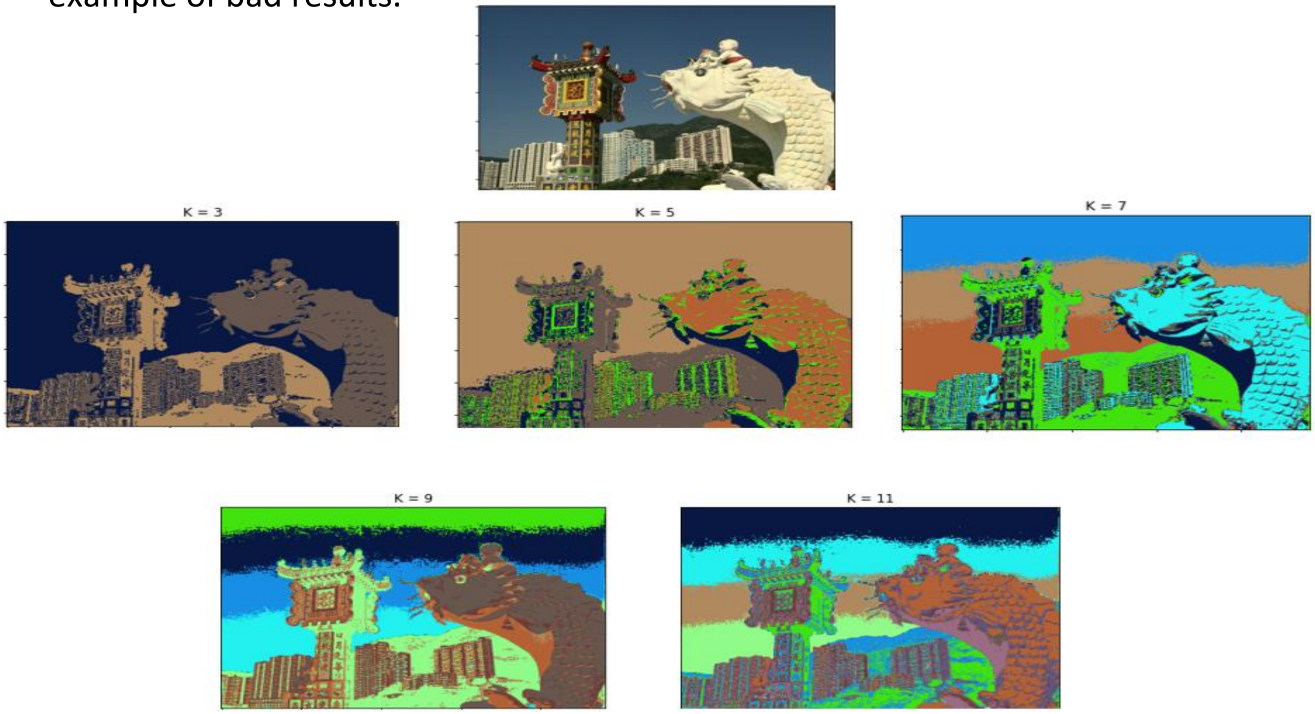


Figure 3.d Good results of clustering

Table 1 Avg Conditional entropy and F-measure for all ground truths with image 29 clustering

K clusters	Avg. Conditional Entropy for all GTs	Avg. Fmeasure for all GTs
3	2.14466	0.65
5	1.77119	0.502
7	1.7589	0.4256
9	1.6933	0.36717
11	1.6697	0.3368

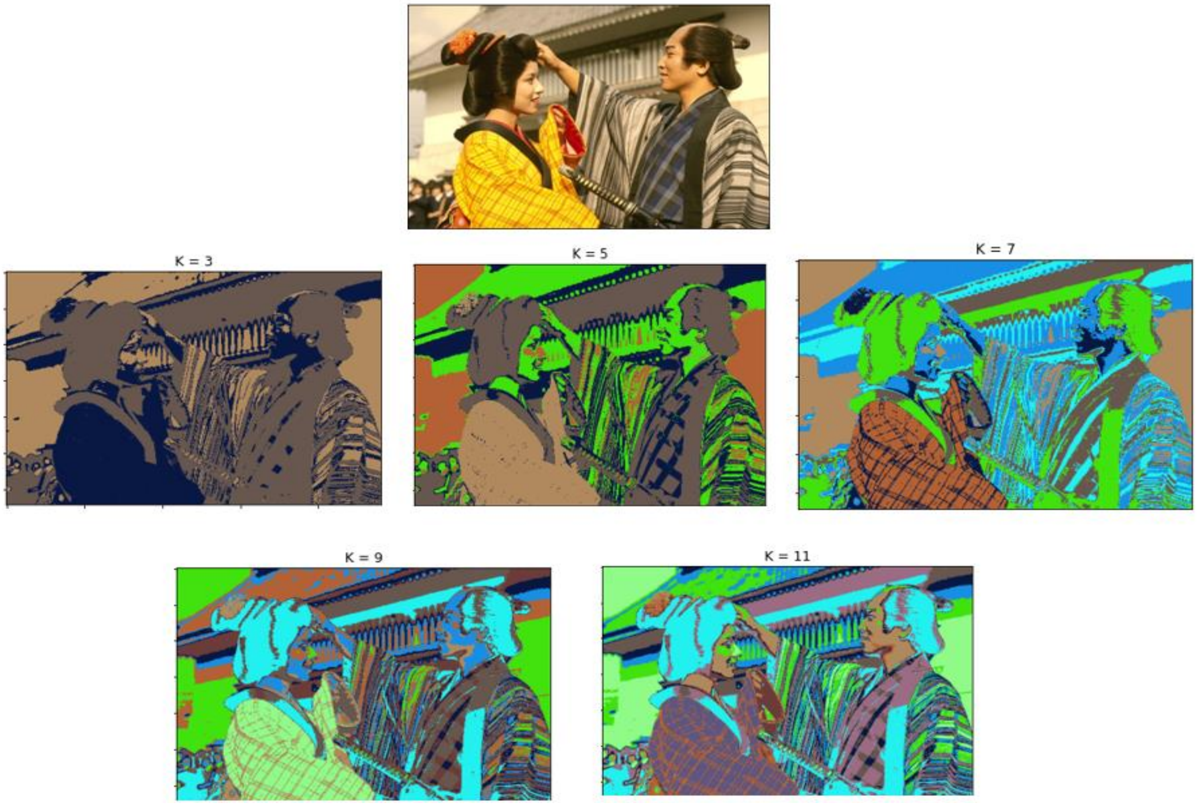


Figure 3.e Bad results of clustering

Table 2 Avg Conditional entropy and F-measure for all ground truths with image 42 clustering

K clusters	Avg. Conditional Entropy for all GTs	Avg. Fmeasure for all GTs
3	3.04	0.439
5	2.69312	0.42518
7	2.58522	0.37977
9	2.547523	0.328868
11	2.418	0.33244

Conditional Entropy of a clustering depends on the number of clusters in the ground truth images, because the more a cluster's members are split into different partitions the higher the conditional entropy. So, when we increased number of clusters K the Conditional entropy decreased because it depended on the number of clusters in the ground truth.

F-measure requires 2 things, precision and recall. The precision is the same as the purity which quantifies the extent to which a cluster contains entities from only one partition. While recall measures the fraction of points in a cluster from the majority partition.

Thus, F-measure tires to balance the precision and recall values across all the clusters, but when the number of ground truth partitions is different from the number of clusters K, F-measure did decrease. Because according to F-measure, perfect clustering is when number of ground truth partitions = number of clusters.

4. Big Picture:

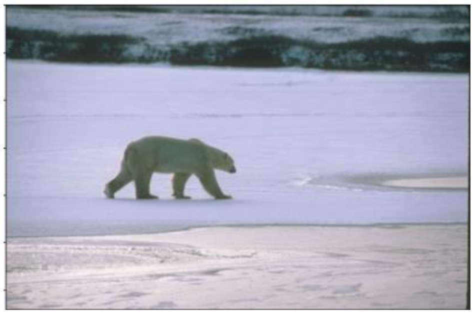


Figure 4.1.1 image0

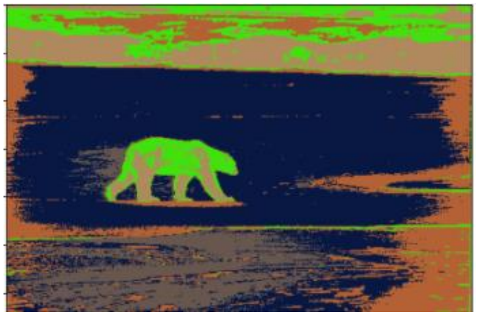


Figure 4.1.2 image0 with kmeans K = 5

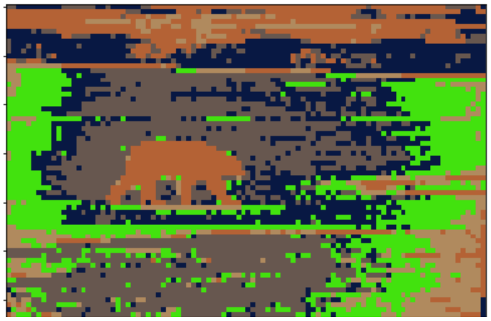


Figure 4.1.3 image0 Ncut 5NN

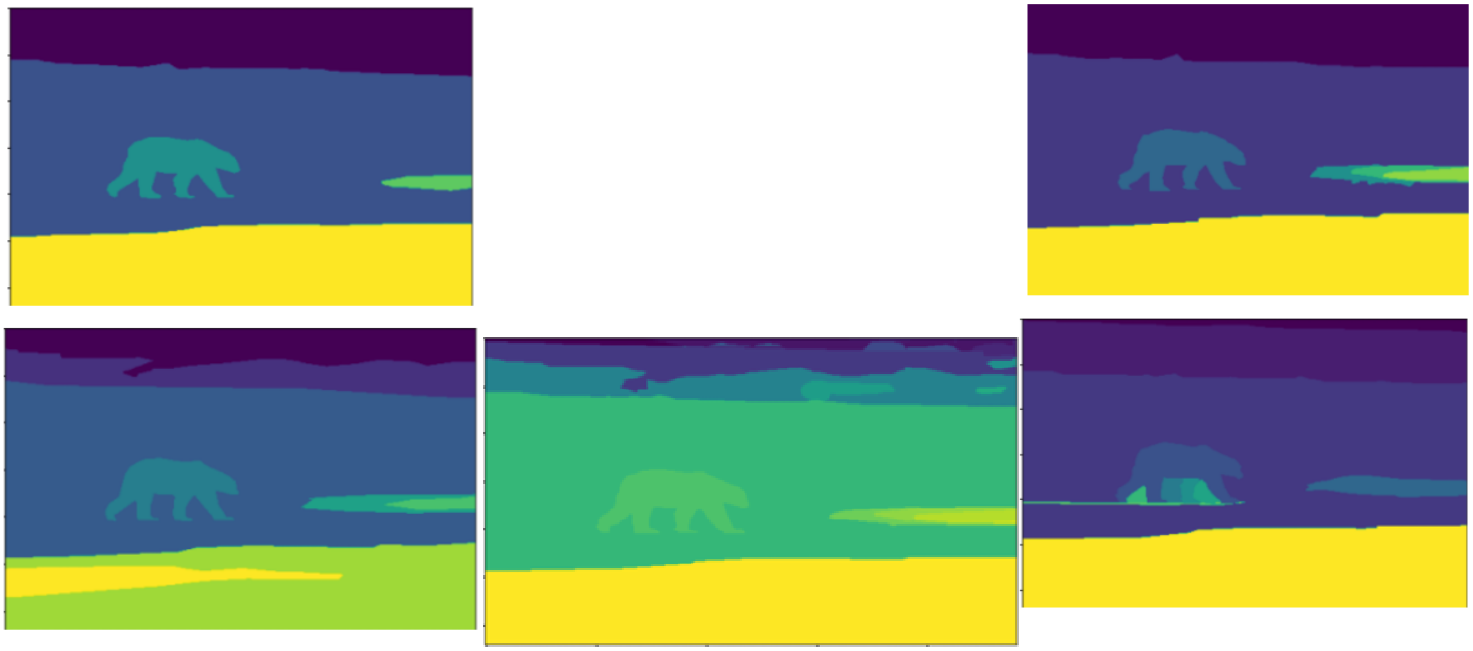
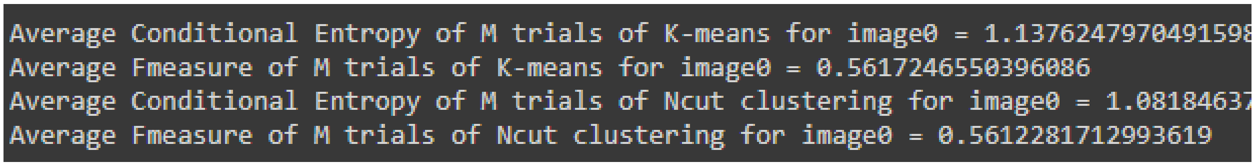


Figure 4.1.4 ground truth segmentations for image0



```
Average Conditional Entropy of M trials of K-means for image0 = 1.1376247970491598
Average Fmeasure of M trials of K-means for image0 = 0.5617246550396086
Average Conditional Entropy of M trials of Ncut clustering for image0 = 1.081846377
Average Fmeasure of M trials of Ncut clustering for image0 = 0.5612281712993619
```

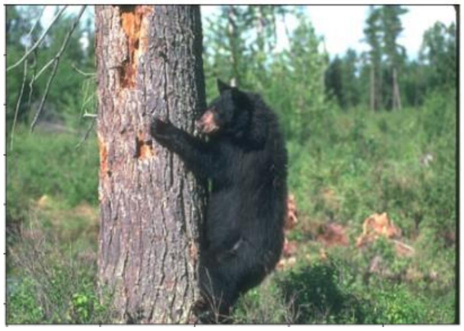


Figure 4.2.1 image1

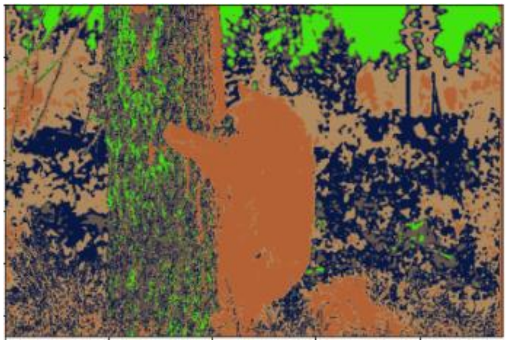


Figure 4.2.2 image1 with kmeans K = 5

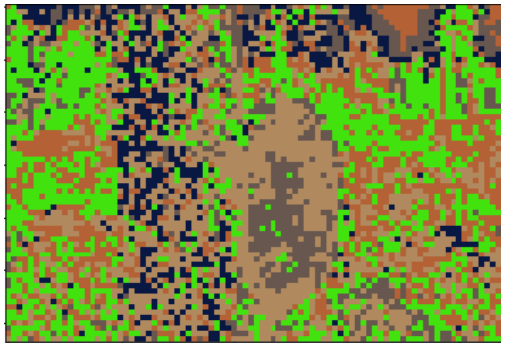


Figure 4.2.3 image1 Ncut 5NN

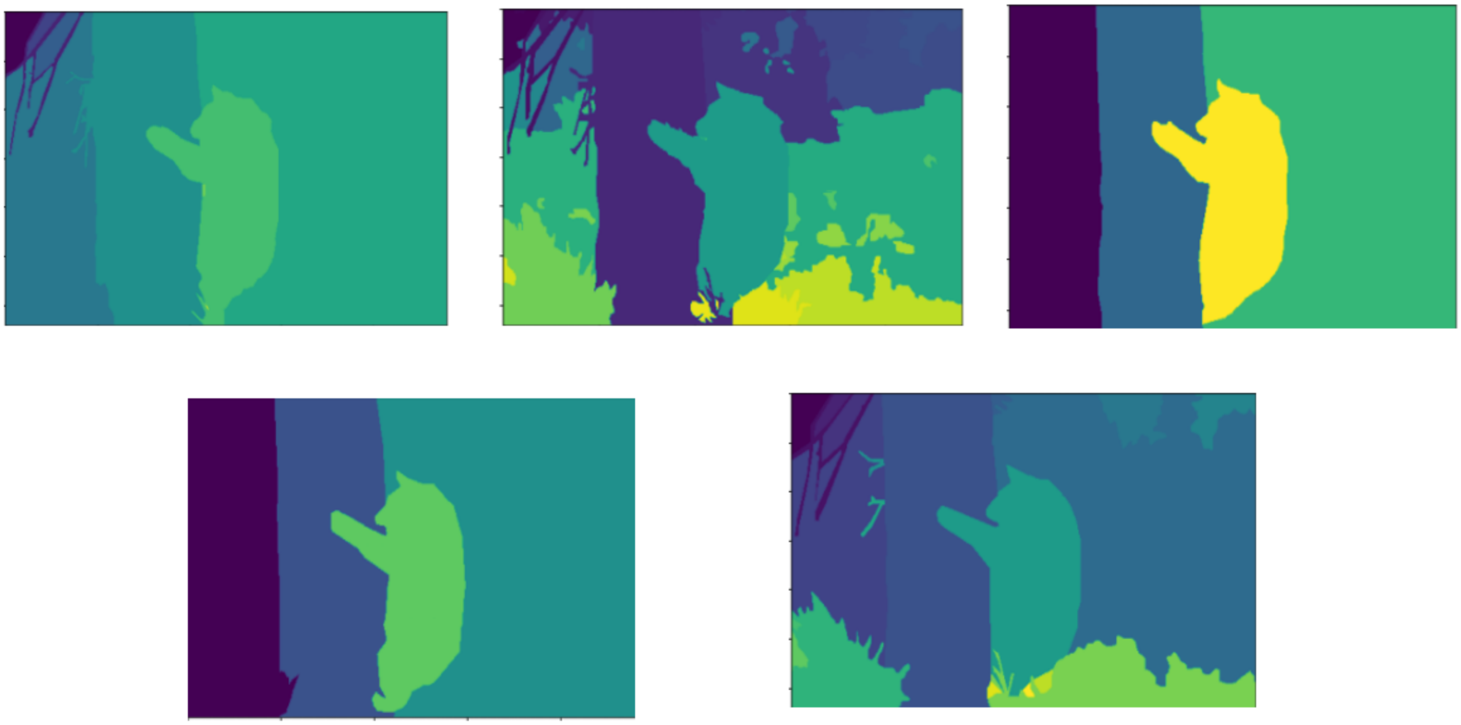
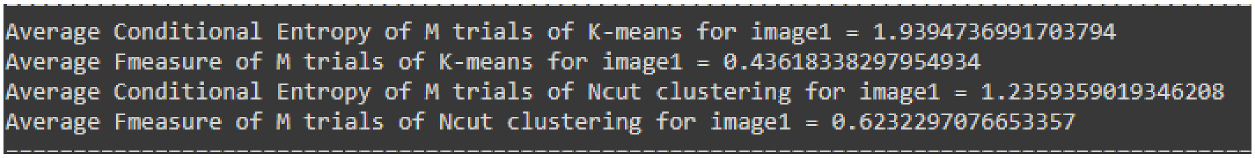


Figure 4.2.4 ground truth segmentations for image1



```
Average Conditional Entropy of M trials of K-means for image1 = 1.93947369917O3794
Average Fmeasure of M trials of K-means for image1 = 0.43618338297954934
Average Conditional Entropy of M trials of Ncut clustering for image1 = 1.2359359019346208
Average Fmeasure of M trials of Ncut clustering for image1 = 0.6232297076653357
```

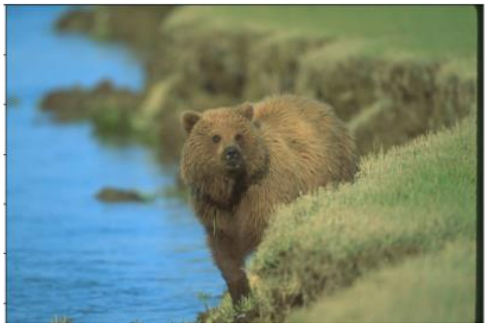


Figure 4.3.1 image2

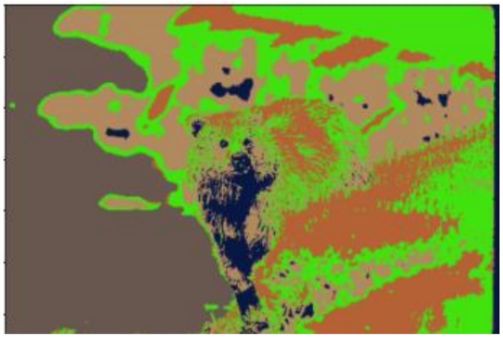


Figure 4.3.2 image2 with kmeans K = 5

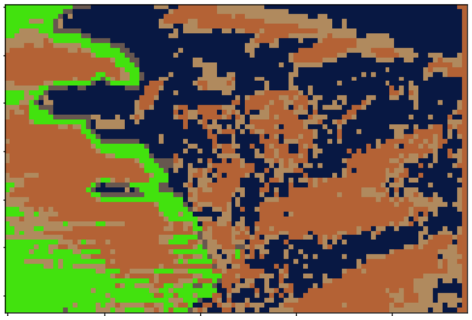


Figure 4.3.3 image1 Ncut 5NN

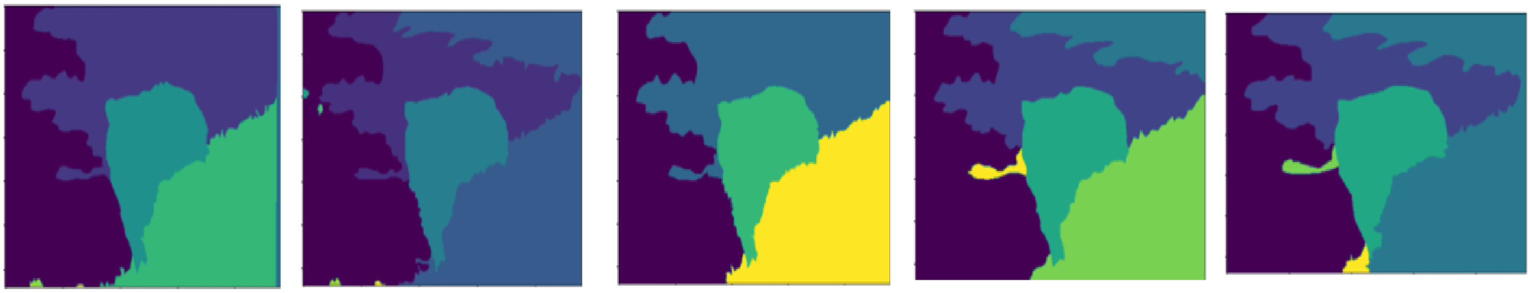
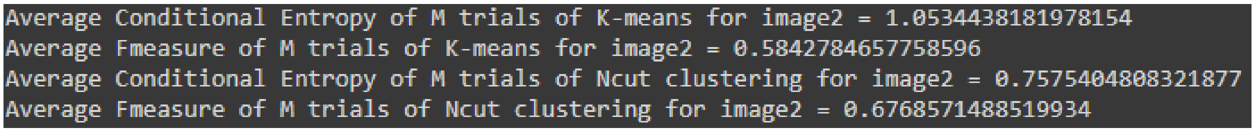


Figure 4.3.4 ground truth segmentations for image2



```
Average Conditional Entropy of M trials of K-means for image2 = 1.0534438181978154
Average Fmeasure of M trials of K-means for image2 = 0.5842784657758596
Average Conditional Entropy of M trials of Ncut clustering for image2 = 0.7575404808321877
Average Fmeasure of M trials of Ncut clustering for image2 = 0.6768571488519934
```

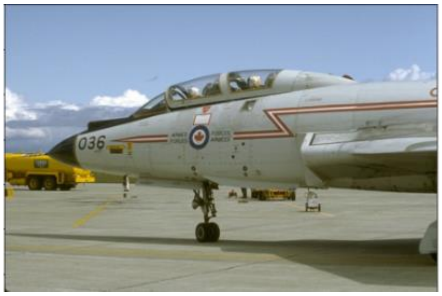


Figure 4.4.1 image3

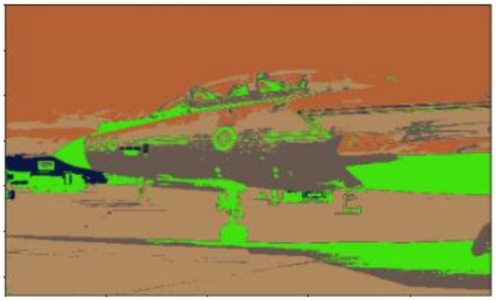


Figure 4.4.2 image3 with kmeans K = 5

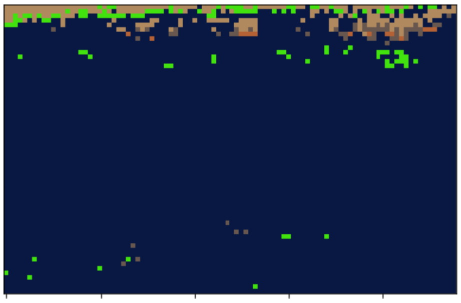


Figure 4.4.3 image3 Ncut 5NN

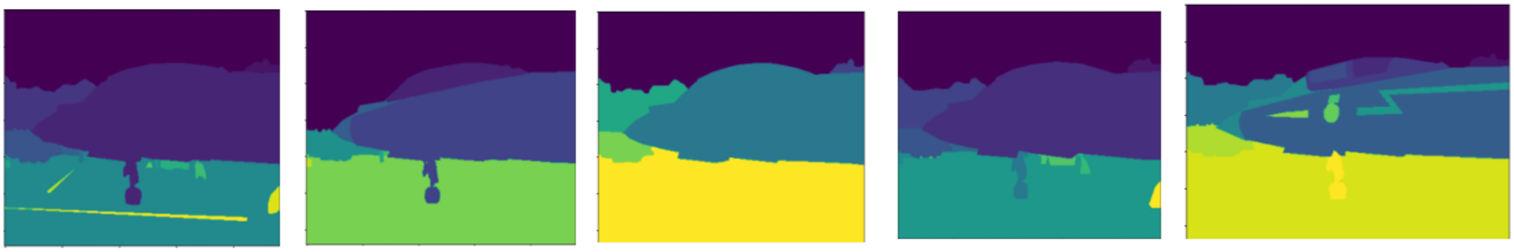
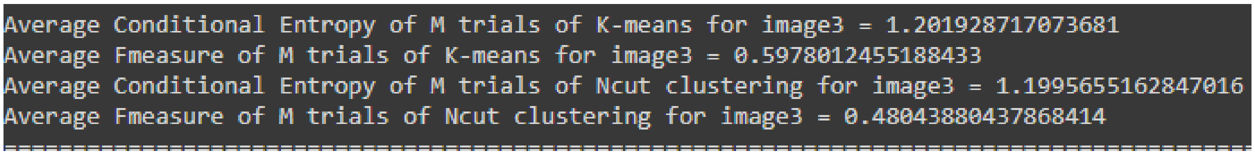


Figure 4.4.4 ground truth segmentations of image3



```
Average Conditional Entropy of M trials of K-means for image3 = 1.201928717073681
Average Fmeasure of M trials of K-means for image3 = 0.5978012455188433
Average Conditional Entropy of M trials of Ncut clustering for image3 = 1.1995655162847016
Average Fmeasure of M trials of Ncut clustering for image3 = 0.48043880437868414
```

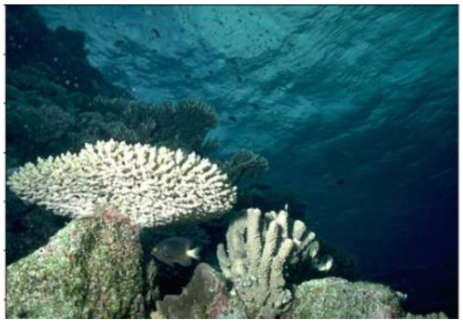


Figure 4.5.1 image4

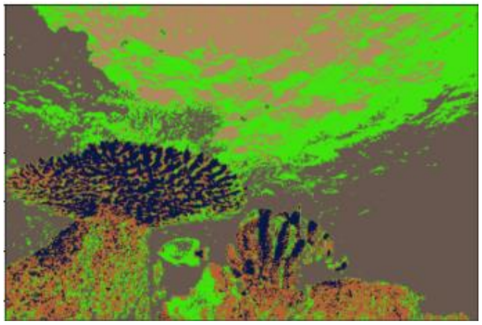


Figure 4.5.2 image4 with kmeans K = 5

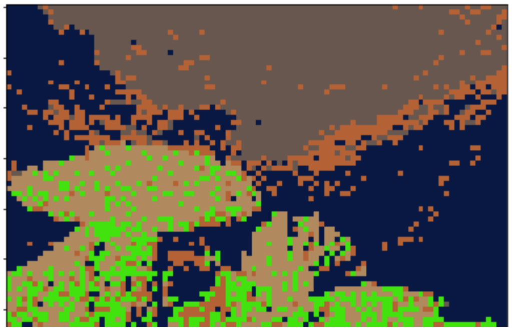


Figure 4.5.3 image2 Ncut 5NN

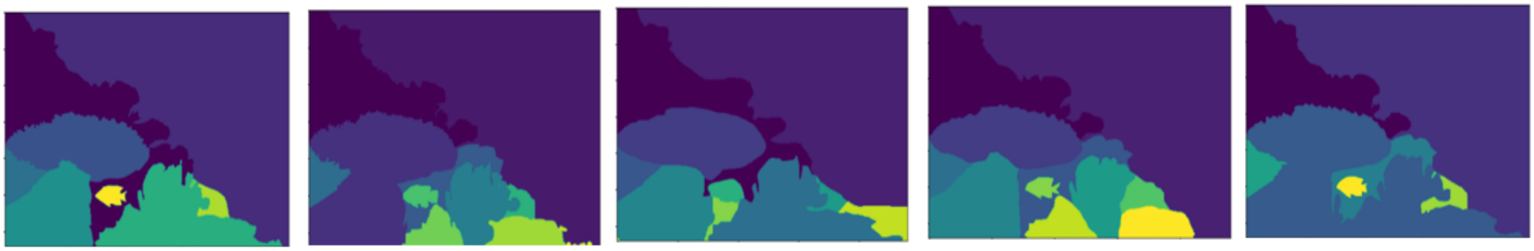
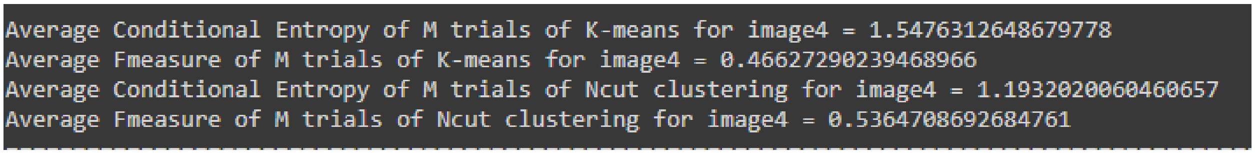


Figure 4.5.4 ground truth segmentations of image4



```
Average Conditional Entropy of M trials of K-means for image4 = 1.5476312648679778
Average Fmeasure of M trials of K-means for image4 = 0.46627290239468966
Average Conditional Entropy of M trials of Ncut clustering for image4 = 1.1932020060460657
Average Fmeasure of M trials of Ncut clustering for image4 = 0.5364708692684761
```

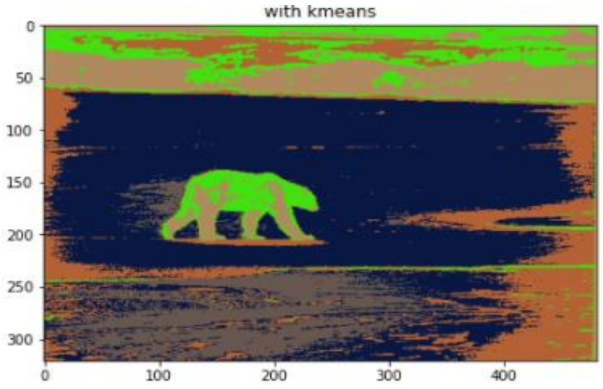
For the clustered images after K-means with K = 5, the results are not perfect, and that is majorly because how we encoded the pixels into the vectorized image, which was only by RGB. So, the resulted clusters are mostly pixels with the same color not necessarily close to each other in the image.

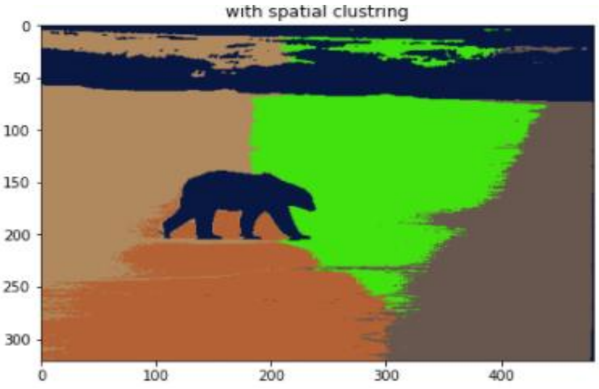
For Normalized-Cut, it has the same problem of only matching pixels according to the RGB color, and since before putting the image through the normalized clustering algorithm we resized it to 20% of it's original size because it we didn't it would have needed more memory than that was available. So sometimes the clustering was acceptable and other images just lost most the pixels to one cluster like (figure 4.4.3).

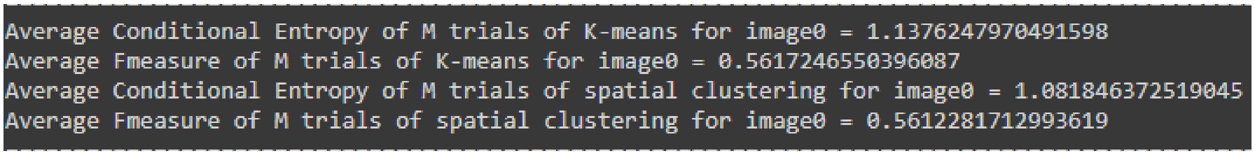
5. Spatial layout:

Previously we encoded that pixels according to RGB color only, but we didn't encode the layout of the pixels. So, we modified the vectorized image to 5 attributes which are {R, G, B, xi, yi} where xi is the x co-ordinate of pixel (i) and yi is the y co-ordinate of pixel (i).

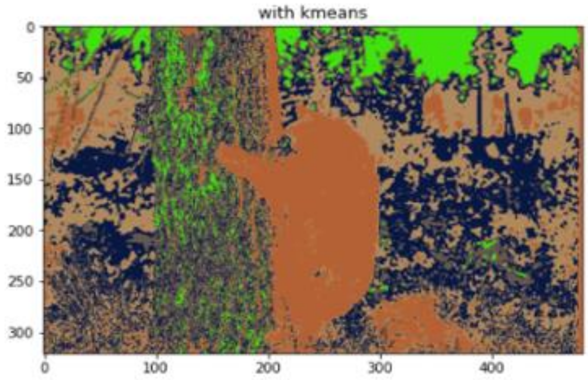
5.a.ii Contrasting the results with original K-means with K = 5:

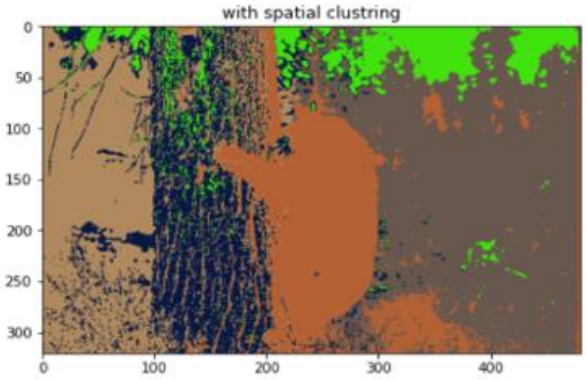


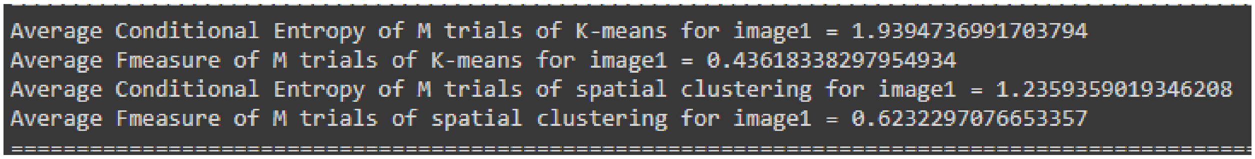




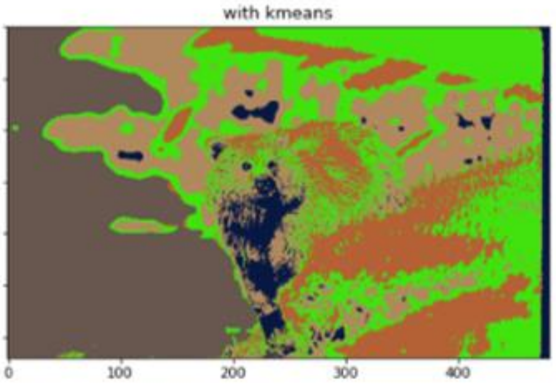
```
---------------------------------------------------------------------------------------------
Average Conditional Entropy of M trials of K-means for image0 = 1.1376247970491598
Average Fmeasure of M trials of K-means for image0 = 0.5617246550396087
Average Conditional Entropy of M trials of spatial clustering for image0 = 1.081846372519045
Average Fmeasure of M trials of spatial clustering for image0 = 0.5612281712993619
---------------------------------------------------------------------------------------------
```

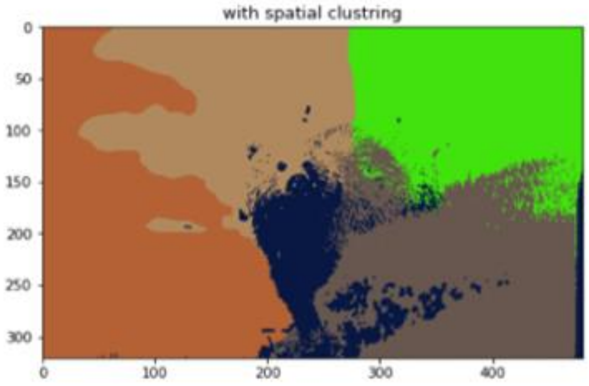


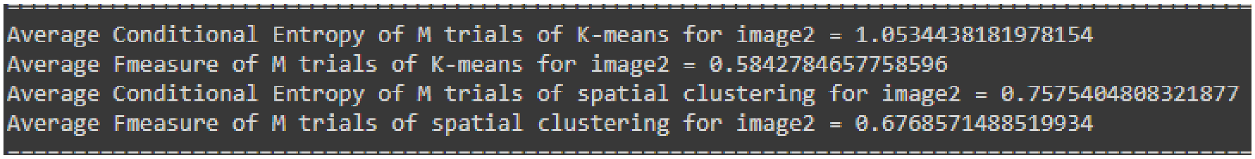




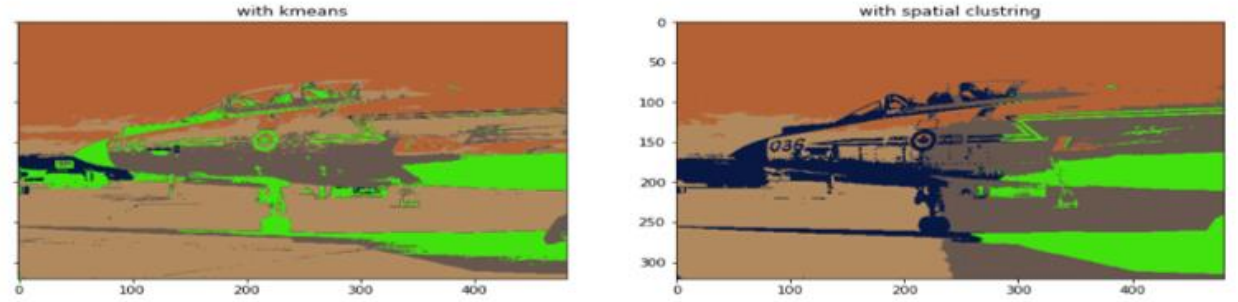
```
---------------------------------------------------------------------------------------------
Average Conditional Entropy of M trials of K-means for image1 = 1.9394736991703794
Average Fmeasure of M trials of K-means for image1 = 0.43618338297954934
Average Conditional Entropy of M trials of spatial clustering for image1 = 1.2359359019346208
Average Fmeasure of M trials of spatial clustering for image1 = 0.6232297076653357
=============================================================================================
```

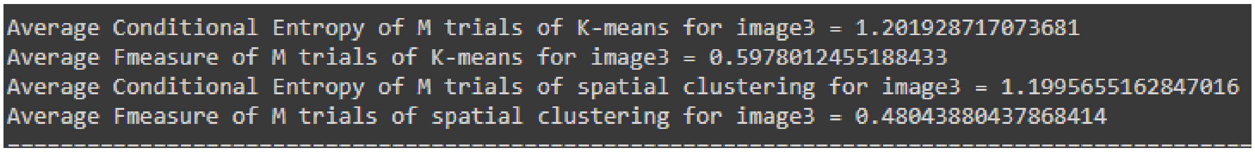




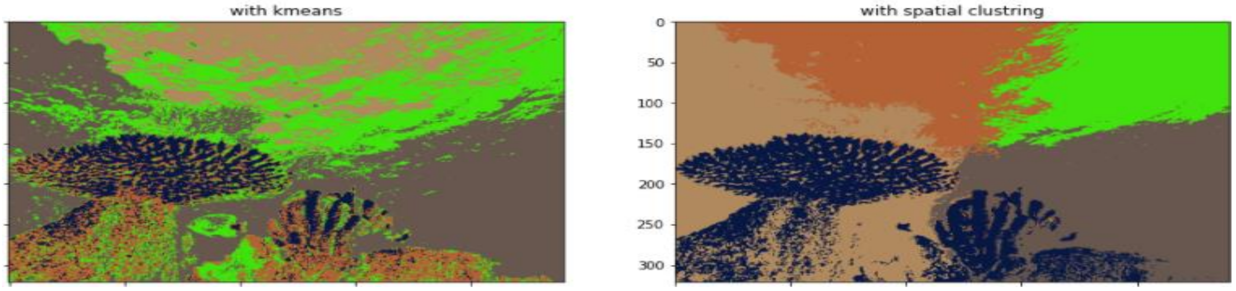


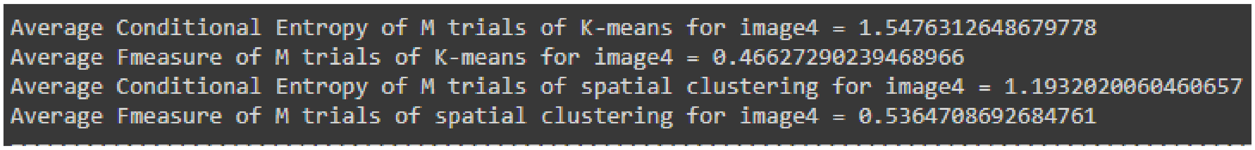
```
---------------------------------------------------------------------------------------------
Average Conditional Entropy of M trials of K-means for image2 = 1.0534438181978154
Average Fmeasure of M trials of K-means for image2 = 0.5842784657758596
Average Conditional Entropy of M trials of spatial clustering for image2 = 0.7575404808321877
Average Fmeasure of M trials of spatial clustering for image2 = 0.6768571488519934
---------------------------------------------------------------------------------------------
```





```
Average Conditional Entropy of M trials of K-means for image3 = 1.201928717073681
Average Fmeasure of M trials of K-means for image3 = 0.5978012455188433
Average Conditional Entropy of M trials of spatial clustering for image3 = 1.1995655162847016
Average Fmeasure of M trials of spatial clustering for image3 = 0.48043880437868414
-----------------------------------------------------------------------------------------
```





```
Average Conditional Entropy of M trials of K-means for image4 = 1.5476312648679778
Average Fmeasure of M trials of K-means for image4 = 0.46627290239468966
Average Conditional Entropy of M trials of spatial clustering for image4 = 1.1932020060460657
Average Fmeasure of M trials of spatial clustering for image4 = 0.5364708692684761
-----------------------------------------------------------------------------------------
```

As we see in the figure above the new clustering with spatial layout encoding, was able to specify bodies and pixels that are closer to each other. So, that is why parts in the image that is not only close to each other but of the same color also was assigned to the same cluster.