We performed image segmentation on the Berkeley Segmentation Benchmark and displayed different clustering and evaluation results.

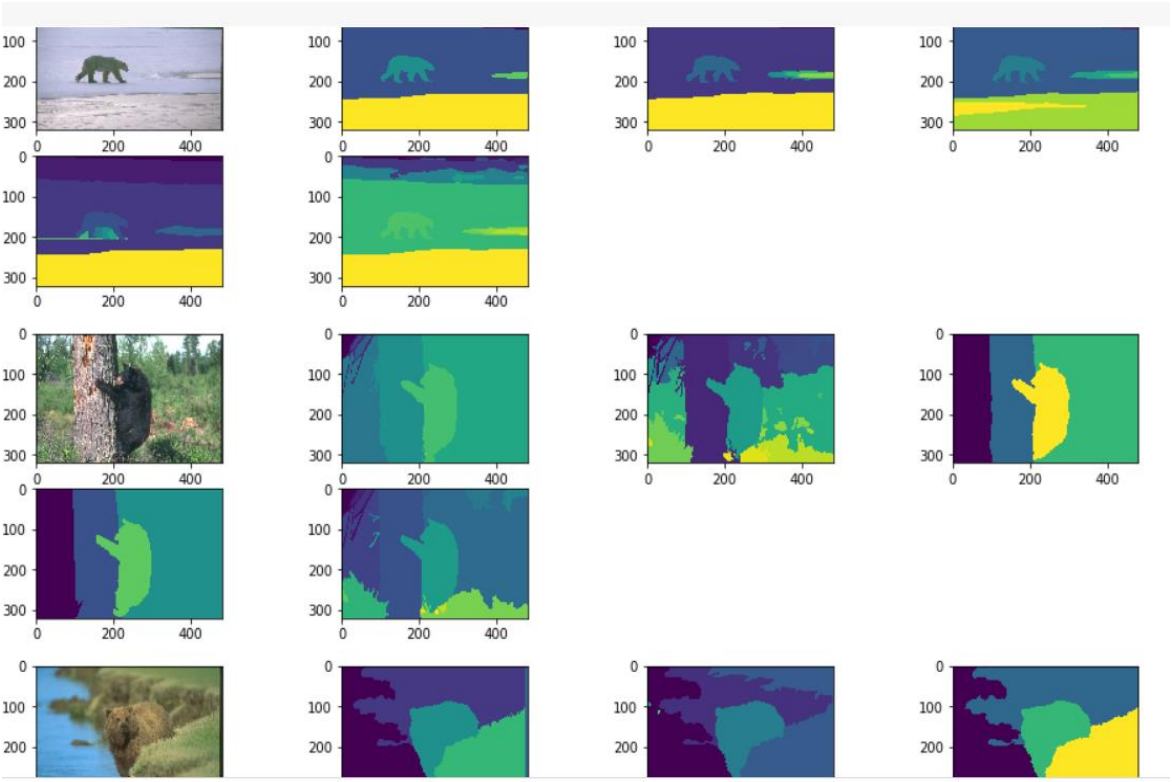
Part 1:

We downloaded the dataset, unzipped it, and added the first 50 images of the test set and their ground truth segmentations into lists to use them to report our results.

Part 2:

In this part, we displayed every image from our list and its corresponding M ground truth segmentations.

Here is a sample of the output:

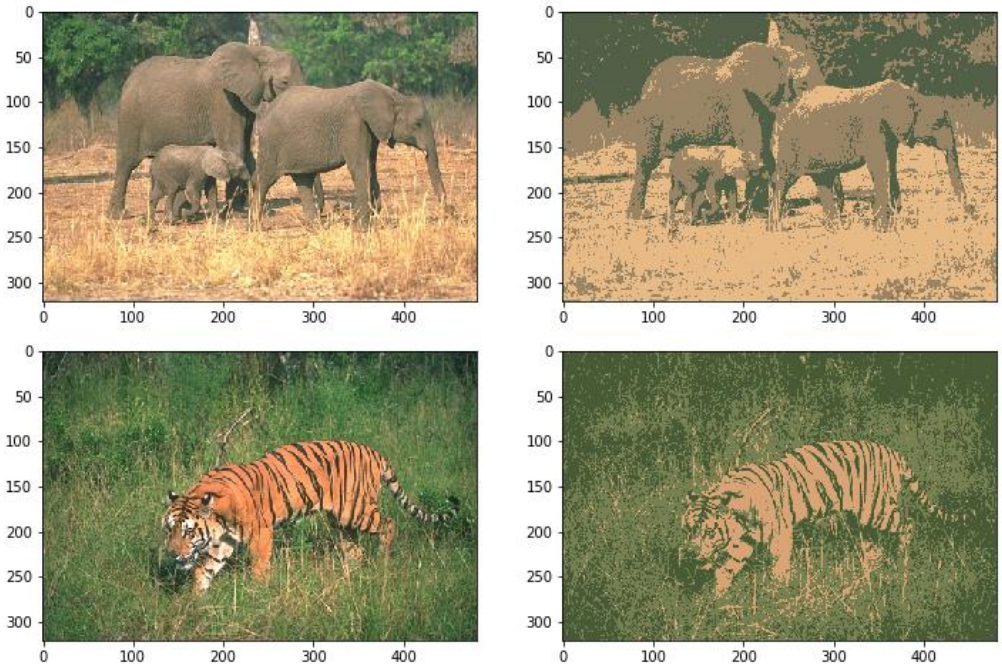


Part 3:

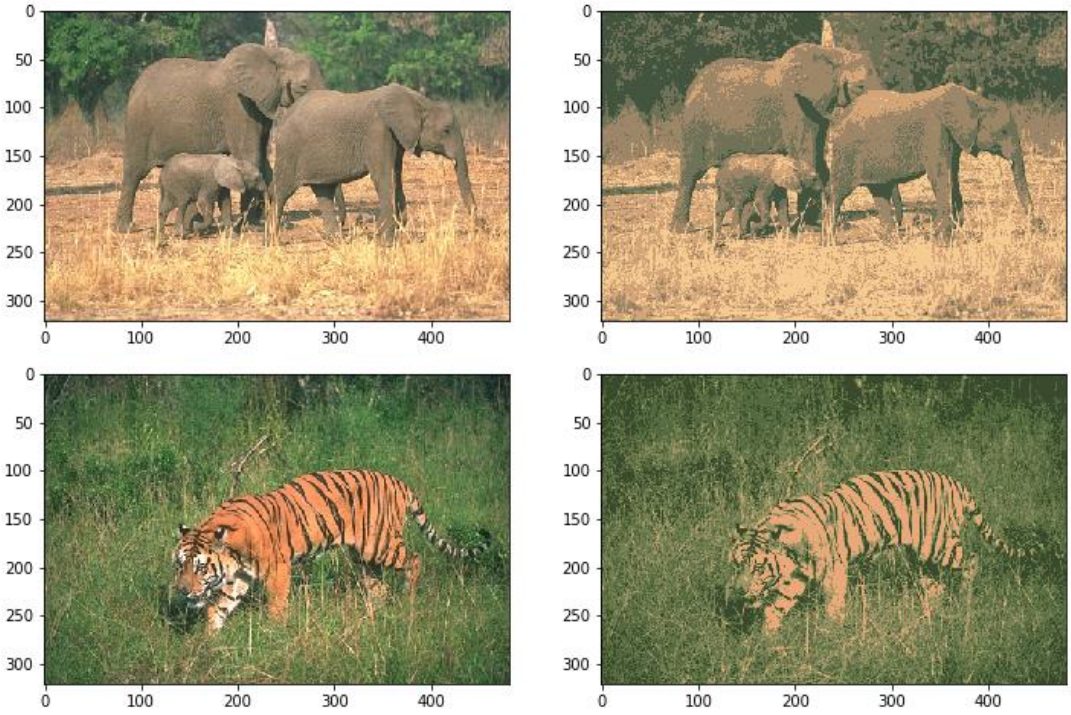
A. Segmentation Using K-Means

We created a function called Kmeans which takes parameter dataset, size of dataset and k number of clusters required. In this function, the built-in function cv2.kmeans is used to perform kmeans clustering on each image. Therefore, each image from our dataset is reshaped and changed to datatype float as cv2.kmeans only accepts float as an input. Then the centers and labels of the clusters created are returned and then changed to 1D arrays. The centers are changed back to integer and reshaped to display the images. Each original image and segmented image are then displayed side by side.

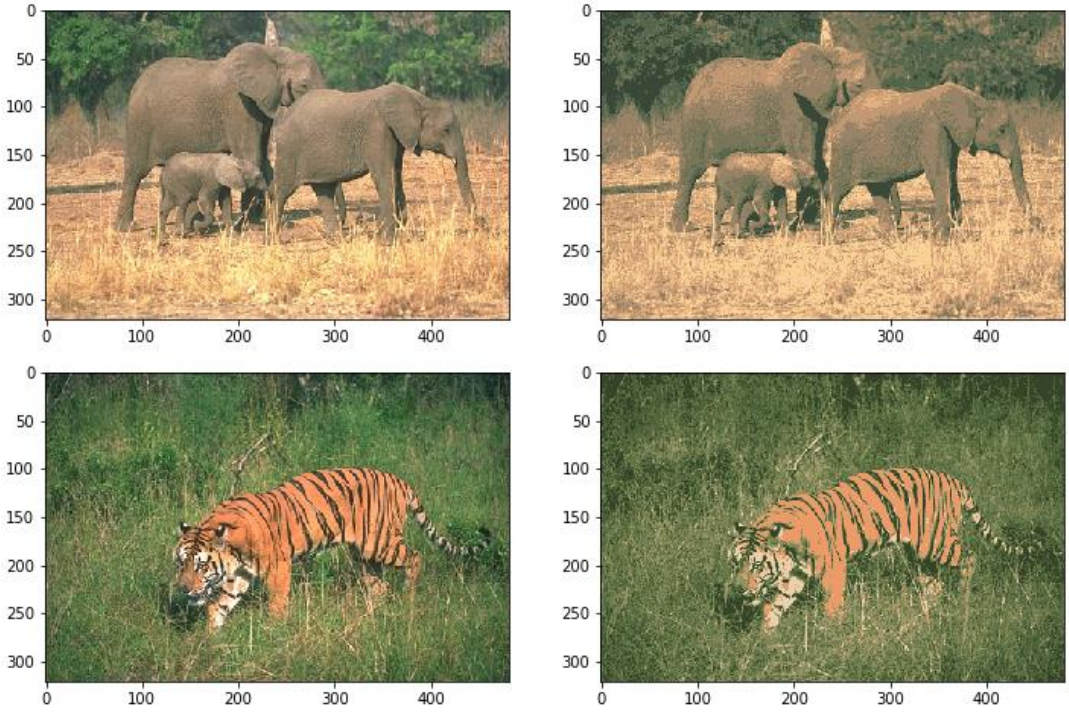
Here is a sample of the output for K = 3:



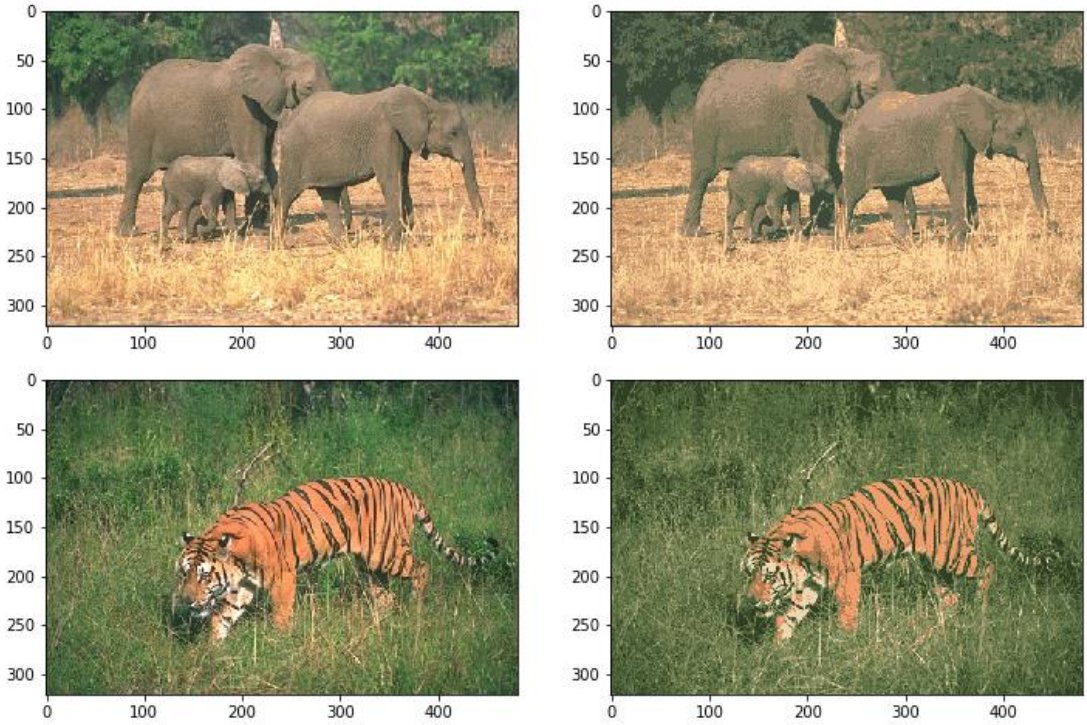
Here is a sample of the output for K = 5:



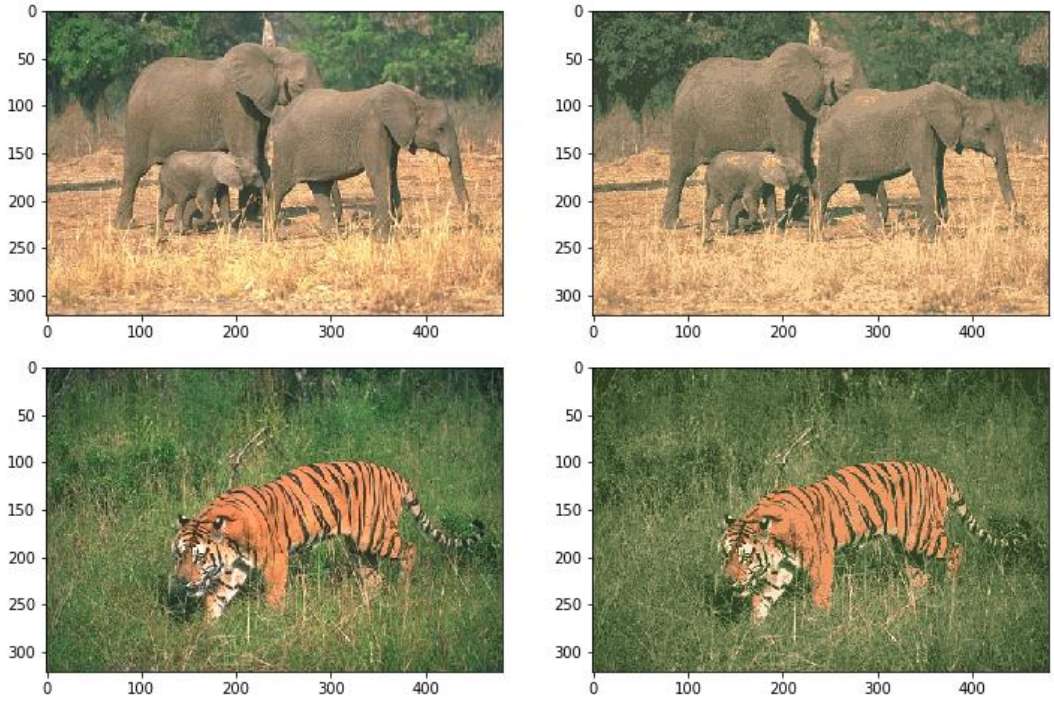
Here is a sample of the output for K = 7:



Here is a sample of the output for K = 9:



Here is a sample of the output for K = 11:



B. Evaluation of Clusters

In this part, we created two functions called F_Measure and Conditional_Entropy that take the predicted labels from clustering of each image and the ground truth labels and compute the F Measure and Conditional Entropy, respectively, of each image. We call these functions for each image I and its M ground truth segments. Then, for each image, the averages of these M F Measures and M Conditional Entropies are computed and displayed, and finally the average of the whole dataset is also displayed.

Here is a sample of the output for K =3:

F Measure:

```
Image # 47
----------------------
F Measure with Segment # 0  =  0.6421017796398291
F Measure with Segment # 1  =  0.6816411583734472
F Measure with Segment # 2  =  0.6344336223234949
F Measure with Segment # 3  =  0.6449409026460697
F Measure with Segment # 4  =  0.6964845724294797
Average F Measure =  0.659920407082464

Image # 48
----------------------
F Measure with Segment # 0  =  0.5864861436610268
F Measure with Segment # 1  =  0.572392831924235
F Measure with Segment # 2  =  0.5625213371970624
F Measure with Segment # 3  =  0.5999238274846028
F Measure with Segment # 4  =  0.5396707559700465
F Measure with Segment # 5  =  0.6043605805184539
Average F Measure =  0.5775592461259046

Image # 49
----------------------
F Measure with Segment # 0  =  0.7122705882687704
F Measure with Segment # 1  =  0.6159643348238618
F Measure with Segment # 2  =  0.7068283867582504
F Measure with Segment # 3  =  0.5859398846998342
F Measure with Segment # 4  =  0.5811135168762016
Average F Measure =  0.6404233422853837

Average F Measure of Dataset =  0.5220272644140294
-----------------------------------------------------------------------
```

Conditional Entropy:

```
Image # 47
----------------------
Conditional Entropy with Segment # 0  =  0.35850974025980636
Conditional Entropy with Segment # 1  =  0.4450809453865733
Conditional Entropy with Segment # 2  =  0.4439400607372608
Conditional Entropy with Segment # 3  =  0.3563009597606955
Conditional Entropy with Segment # 4  =  0.3658216214709786
Average Conditional Entropy =  0.3939306655230629

Image # 48
----------------------
Conditional Entropy with Segment # 0  =  0.5384084957329365
Conditional Entropy with Segment # 1  =  0.6525640521354868
Conditional Entropy with Segment # 2  =  0.48855865026684764
Conditional Entropy with Segment # 3  =  0.4316328952709227
Conditional Entropy with Segment # 4  =  0.5295326080576729
Conditional Entropy with Segment # 5  =  0.3885210453839108
Average Conditional Entropy =  0.5048696244746296

Image # 49
----------------------
Conditional Entropy with Segment # 0  =  0.5724142884943064
Conditional Entropy with Segment # 1  =  0.5117788297789391
Conditional Entropy with Segment # 2  =  0.5607563219180943
Conditional Entropy with Segment # 3  =  0.510813995066694
Conditional Entropy with Segment # 4  =  0.6815787581601923
Average Conditional Entropy =  0.5674684386836453

Average Conditional Entropy of Dataset =  0.6914597388430558
```

Here is a sample of the output for K =5:

F Measure:

```
Image # 48
---------------------
F Measure with Segment # 0  =  0.6166140655555324
F Measure with Segment # 1  =  0.6055286739814854
F Measure with Segment # 2  =  0.5576018233501482
F Measure with Segment # 3  =  0.6224182850958383
F Measure with Segment # 4  =  0.5523859914438665
F Measure with Segment # 5  =  0.6435688526710583
Average F Measure =  0.5996862820163215

Image # 49
---------------------
F Measure with Segment # 0  =  0.48208262399968616
F Measure with Segment # 1  =  0.4108273197402285
F Measure with Segment # 2  =  0.4788742305671646
F Measure with Segment # 3  =  0.41865861150866845
F Measure with Segment # 4  =  0.4323215299393276
Average F Measure =  0.44455286315101505

Average F Measure of Dataset =  0.438036474548865
```

Conditional Entropy:

```
Image # 48
---------------------
Conditional Entropy with Segment # 0  =  0.762605285541695
Conditional Entropy with Segment # 1  =  0.8817931996414687
Conditional Entropy with Segment # 2  =  0.7069409542384589
Conditional Entropy with Segment # 3  =  0.6553879250640232
Conditional Entropy with Segment # 4  =  0.7383870064547025
Conditional Entropy with Segment # 5  =  0.5796394730835294
Average Conditional Entropy =  0.7207923073373129

Image # 49
---------------------
Conditional Entropy with Segment # 0  =  0.9219117506892386
Conditional Entropy with Segment # 1  =  0.8504776295452893
Conditional Entropy with Segment # 2  =  0.9280863955572575
Conditional Entropy with Segment # 3  =  0.8147231659161077
Conditional Entropy with Segment # 4  =  1.0241577120769942
Average Conditional Entropy =  0.9078713307569775

Average Conditional Entropy of Dataset =  1.0612901198495557
```

Here is a sample of the output for K =7:

F Measure:

```
Image # 48
---------------------
F Measure with Segment # 0  =  0.5227774595119336
F Measure with Segment # 1  =  0.49542251424292105
F Measure with Segment # 2  =  0.5438029591204107
F Measure with Segment # 3  =  0.5826622599880376
F Measure with Segment # 4  =  0.487698958901516
F Measure with Segment # 5  =  0.6012446036261659
Average F Measure =  0.5389347925651641

Image # 49
---------------------
F Measure with Segment # 0  =  0.40146443024054107
F Measure with Segment # 1  =  0.41701844924469
F Measure with Segment # 2  =  0.39970217909142497
F Measure with Segment # 3  =  0.40662298171711264
F Measure with Segment # 4  =  0.4194788597988436
Average F Measure =  0.4088573800185224

Average F Measure of Dataset =  0.3829226671291426
```

Conditional Entropy:

```
Image # 48
---------------------
Conditional Entropy with Segment # 0  =  1.084097312425638
Conditional Entropy with Segment # 1  =  1.2077811159779168
Conditional Entropy with Segment # 2  =  1.0168606679901357
Conditional Entropy with Segment # 3  =  0.958385085757837
Conditional Entropy with Segment # 4  =  1.0596613982037637
Conditional Entropy with Segment # 5  =  0.8771644106878754
Average Conditional Entropy =  1.033991665173861

Image # 49
---------------------
Conditional Entropy with Segment # 0  =  1.3028688020193535
Conditional Entropy with Segment # 1  =  1.1638906414310175
Conditional Entropy with Segment # 2  =  1.3182755997750268
Conditional Entropy with Segment # 3  =  1.1261289565886263
Conditional Entropy with Segment # 4  =  1.335330353707466
Average Conditional Entropy =  1.249298870704298

Average Conditional Entropy of Dataset =  1.3273252340631103
```

Here is a sample of the output for K =9:

F Measure:

```
Image # 48
---------------------
F Measure with Segment # 0  =  0.4364791338343778
F Measure with Segment # 1  =  0.4120785078790032
F Measure with Segment # 2  =  0.4510912727514314
F Measure with Segment # 3  =  0.49240379053425204
F Measure with Segment # 4  =  0.40078165626680723
F Measure with Segment # 5  =  0.5087249412929622
Average F Measure =  0.4502598837598057

Image # 49
---------------------
F Measure with Segment # 0  =  0.33199392321310667
F Measure with Segment # 1  =  0.3719148560189886
F Measure with Segment # 2  =  0.3350842092710754
F Measure with Segment # 3  =  0.36699377338796835
F Measure with Segment # 4  =  0.3589409639851147
Average F Measure =  0.3529855451752507

Average F Measure of Dataset =  0.3388818223536865
```

Conditional Entropy:

```
Image # 48
---------------------
Conditional Entropy with Segment # 0  =  1.3435068241913724
Conditional Entropy with Segment # 1  =  1.4615967431894112
Conditional Entropy with Segment # 2  =  1.2733127139718867
Conditional Entropy with Segment # 3  =  1.2082166861533072
Conditional Entropy with Segment # 4  =  1.3177200551217985
Conditional Entropy with Segment # 5  =  1.1322027497417537
Average Conditional Entropy =  1.289425962061588

Image # 49
---------------------
Conditional Entropy with Segment # 0  =  1.4603375765495956
Conditional Entropy with Segment # 1  =  1.3107230232469842
Conditional Entropy with Segment # 2  =  1.4706583970052378
Conditional Entropy with Segment # 3  =  1.2752139842048202
Conditional Entropy with Segment # 4  =  1.481171163014561
Average Conditional Entropy =  1.3996208288042398

Average Conditional Entropy of Dataset =  1.5323951594614895
```

Here is a sample of the output for K =11:

F Measure:

```
Image # 47
---------------------
F Measure with Segment # 0  =  0.5218210830515456
F Measure with Segment # 1  =  0.500694275981767
F Measure with Segment # 2  =  0.4877970785808666
F Measure with Segment # 3  =  0.522935795131544
F Measure with Segment # 4  =  0.5288182646691086
Average F Measure =  0.5124132994829664

Image # 48
---------------------
F Measure with Segment # 0  =  0.4377067582800014
F Measure with Segment # 1  =  0.4129534763829992
F Measure with Segment # 2  =  0.4520063451454351
F Measure with Segment # 3  =  0.49375801387082874
F Measure with Segment # 4  =  0.4017664248709504
F Measure with Segment # 5  =  0.510305063918811
Average F Measure =  0.4514160137448376

Image # 49
---------------------
F Measure with Segment # 0  =  0.33110400158557546
F Measure with Segment # 1  =  0.3636845832202631
F Measure with Segment # 2  =  0.33437792917160436
F Measure with Segment # 3  =  0.3569360319388479
F Measure with Segment # 4  =  0.3391283226220514
Average F Measure =  0.34504617370766844

Average F Measure of Dataset =  0.33792938216739277
--------------------------------------------------------------------------
```

Conditional Entropy:

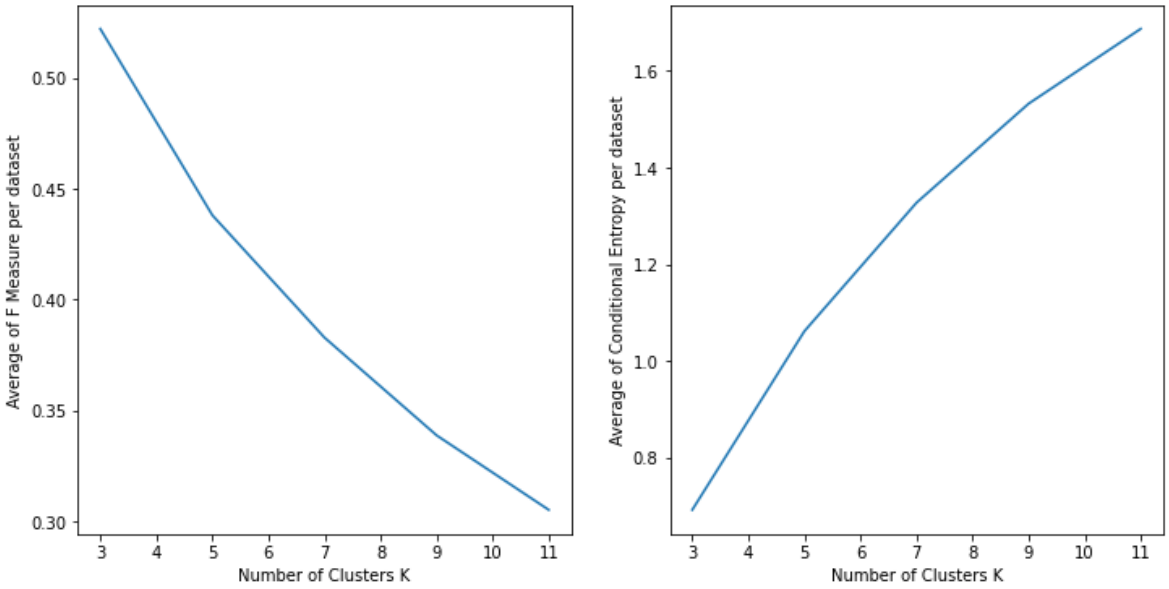
```
Image # 47
---------------------
Conditional Entropy with Segment # 0  =  1.193181161376491
Conditional Entropy with Segment # 1  =  1.3634420657726665
Conditional Entropy with Segment # 2  =  1.3587940154671105
Conditional Entropy with Segment # 3  =  1.188054803089386
Conditional Entropy with Segment # 4  =  1.228139426559443
Average Conditional Entropy =  1.2663222944530195

Image # 48
---------------------
Conditional Entropy with Segment # 0  =  1.3412684232766054
Conditional Entropy with Segment # 1  =  1.459636662604494
Conditional Entropy with Segment # 2  =  1.2709550137399086
Conditional Entropy with Segment # 3  =  1.205779528032379
Conditional Entropy with Segment # 4  =  1.3154079140823398
Conditional Entropy with Segment # 5  =  1.1300028100547006
Average Conditional Entropy =  1.287175058631738

Image # 49
---------------------
Conditional Entropy with Segment # 0  =  1.45883334959761
Conditional Entropy with Segment # 1  =  1.3222350902701365
Conditional Entropy with Segment # 2  =  1.4694763006791487
Conditional Entropy with Segment # 3  =  1.2866659448457942
Conditional Entropy with Segment # 4  =  1.4929012624928386
Average Conditional Entropy =  1.4060223895771058

Average Conditional Entropy of Dataset =  1.530519298040392
```

A plot of the average per dataset for F Measure and Conditional Entropy against the number of cluster K:

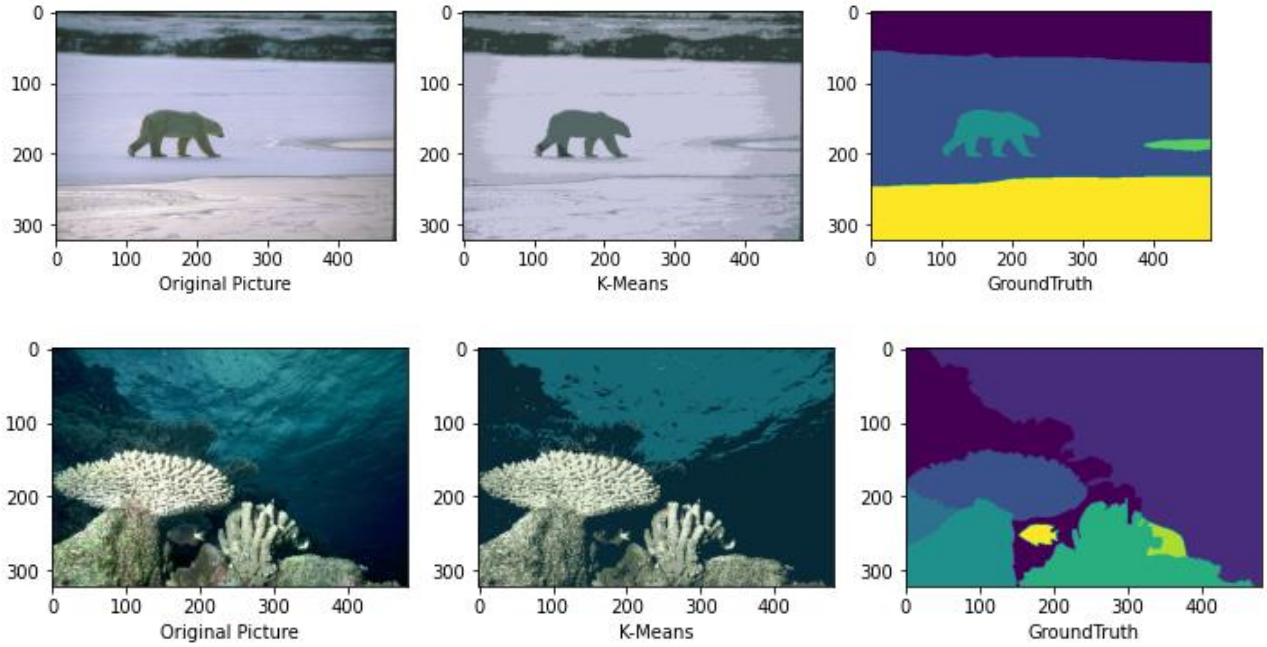


As seen from the samples above and the plot, the value for F Measure decreases as the number of clusters increase, and the value for Conditional Entropy increases as the numbers of clusters increase. This suggests that fewer clusters yield better results.

Part 4:

A. K-Means with K = 5

We selected the 5 five pictures from bench/Data/images and their ground truth in bench/Data/groundTruth. The previously mentioned, Kmeans function was used and the returned arrays was colored images and colored labels. Each colored image was displayed alongside the original image and its ground truth segmentations.



B. Normalized Cut

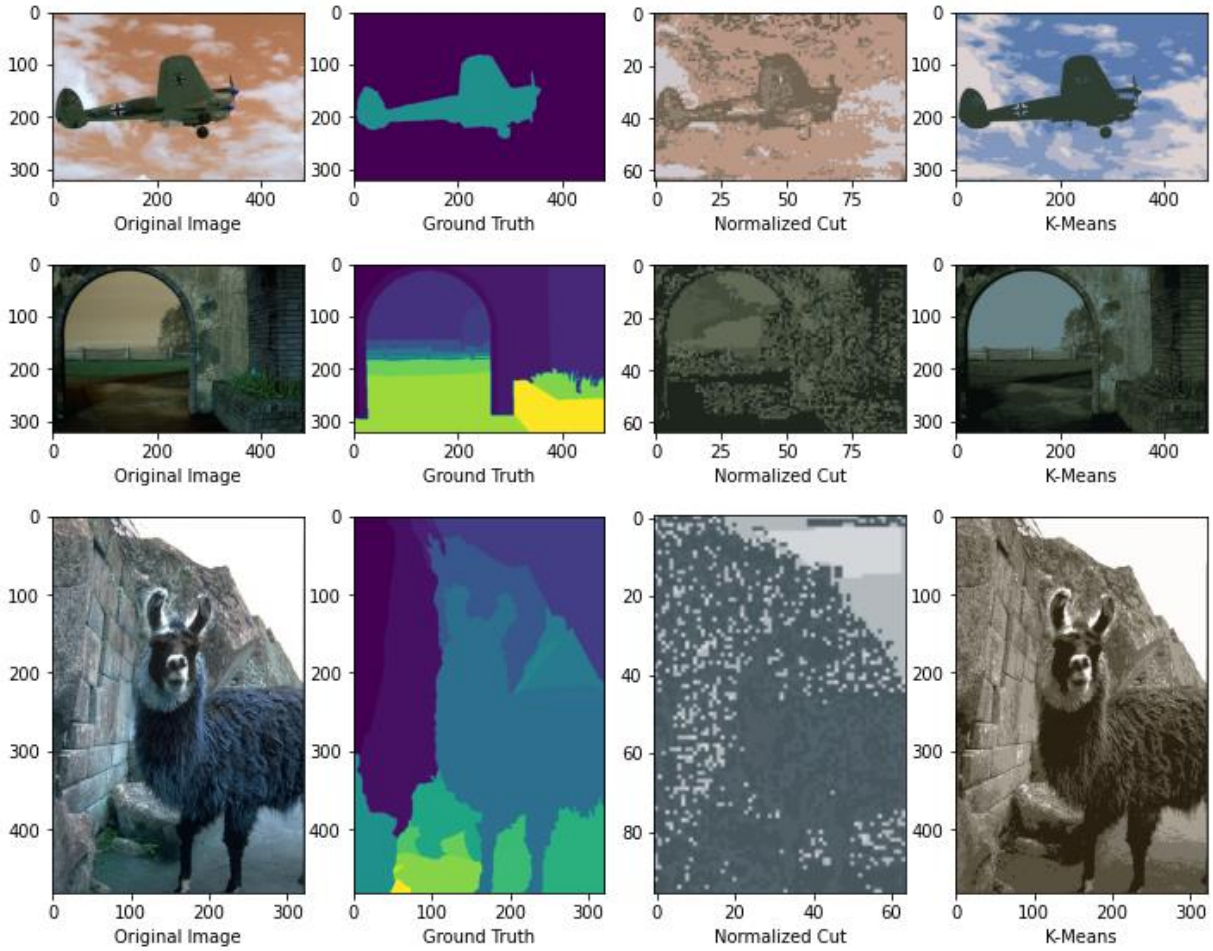
We selected the 5 five pictures from bench/Data/images and their ground truth in bench/Data/groundTruth. Firstly, we resized the images and displayed the original image and its ground truth then we called the normalized cut function and passed the data for the resized images, the neighbors and the number of clusters and the width and height of the image.

In the normalized cut function, we get the symmetry matrix, the delta matrix and the Laplacian matrix, then multiply the inverse of the delta matrix and Laplacian matrix to obtain the Eigenvectors and Eigenvalues. We perform k-means clustering on the Eigenvectors then get the labels for the image and make the centers by making a matrix (5,3) and summing all the labels with the same label then returning the clustered image.

C. Comparison between A and B:

K-Means yields better and clearer results than normalized cut.

Here is a sample of the output:



Part 5:

In this part, we used the same five images we used in part 4.a and reshaped each image into a 3-dimension (RGB) feature vector first, and then added 2 more columns that represent the (x, y) coordinates of each pixel in the image, and thus creating a 5-dimension feature vector. Then, we performed k-means on it and displayed the segmented output.

Here is a sample of the output: