

CMPE 537 - 2020 Fall

Image Classification with Bag-of-Features

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1 Methodology

1.1 Keypoint Extraction

We use *Bag-of-Features* approach to classify images. In order to extract *features*, we use SIFT (Scale-Invariant Feature Transform). SIFT algorithm outputs keypoints which has a 128 dimensional descriptor.

1.2 Keypoints to Features

In order to convert keypoints to features, we use clustering. Then, we use found K cluster centers to convert keypoints to features (*Quantization*). In this experiment, we choose K-Means. Nevertheless, other cluster algorithms can also be replaced instead.

1.3 Bag-of-Features

Now, we use extracted features to create a histogram of an image. (*Bag-of-Features*) For that purpose, we count the occurrences of each feature in an image. As the result, we get K dimensional vector where each value represents how many times that feature occurred in that image.

1.4 Classification

As we can represent each image with a K dimensional vector, we use these data points to classify the data set. We can choose any classification algorithm, but for this experiment, we used Support Vector Classification with Chi-Squared kernel.

2 Experiment Setup

2.1 Dataset

For this experiment, we use Caltech20 datasets, which contains 20 class with additional reject class. (background_class) Classes do not contain equal amount of samples.

2.2 Parameters

There are several parameters that we will try to optimize.

First one is C value. C value determines the weakness of the regularization, which is squared L2.

Then, we will check if the model performs better or worse when we implement Chi-Squared kernel.

Lastly, we will observe the effect of K . We will test the model with 50,100 and 500 clusters.

2.3 Procedure & Evaluation

For each combination, we will use K-Fold cross verification with 5 partitions on training set. Then, using found y_{pred} and y_{true} , we calculate metrics.

The metrics include, F1 score for each class, F1 score mean, and confusion matrix. As we find the best combination of parameters, we will use that model to test set to get the final evaluation.

3 Results

We ran total of 24 tests. Parameters for each test is indicated in table below with resulting F1 macro score from 5-Fold cross validation. Chi² kernel is applied with γ value 0.5.

#	K	Kernel	C	F1
1	50	Linear	1	0.02
2	50	Linear	10	0.03
3	50	Linear	20	0.04
4	50	Linear	30	0.04
5	50	Chi ²	1	0.11
6	50	Chi ²	10	0.33
7	50	Chi ²	20	0.43
8	50	Chi ²	30	0.47
9	100	Linear	1	0.02
10	100	Linear	10	0.03
11	100	Linear	20	0.04
12	100	Linear	30	0.04
13	100	Chi ²	1	0.12
14	100	Chi ²	10	0.46
15	100	Chi ²	20	0.53
16	100	Chi ²	30	0.56
17	500	Linear	1	0.02
18	500	Linear	10	0.03
19	500	Linear	20	0.03
20	500	Linear	30	0.04
21	500	Chi ²	1	0.15
22	500	Chi ²	10	0.61
23	500	Chi ²	20	0.63
24	500	Chi ²	30	0.63

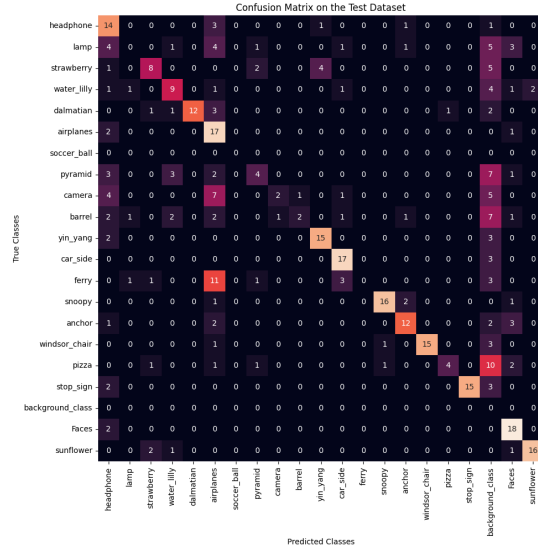
As it can be observed, when C and K values increase, results are improving. Also, Chi² kernel has significant advantage over linear kernel. Full results are shared in Appendix, with per-class F1 scores, and confusion matrices.

3.1 Best Model on the Test Set

Best parameters are set to be: K=500, Chi², C=30. After a model with this parameters is trained again, we get 0.64 F1 macro score on cross validation. However, at the test set, model results **0.49** F1 macro score with other scores below.

Class	F1 Score
headphone	0.48
lamp	0.00
strawberry	0.48
water_lilly	0.49
dalmatian	0.75
airplanes	0.45
soccer_ball	0.00
pyramid	0.28
camera	0.17

barrel	0.17
yin_yang	0.75
car_side	0.77
ferry	0.00
snoopy	0.84
anchor	0.65
windsor_chair	0.86
pizza	0.32
stop_sign	0.86
background_class	0.00
Faces	0.69
sunflower	0.84



3.2 Mislabeled Samples

As F1 scores are very low, this method can not be applied for critical applications such as self-driving cars. In this sections, we also observe stop signs that are mislabeled.



True: Ferry **Predicted:** Airplane



True: Ferry **Predicted:** Background Class



True: Water Lilly **Predicted:** Background Class



True: Strawberry **Predicted:** Yin Yang



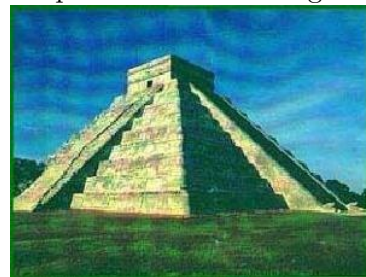
True: Camera **Predicted:** Headphone



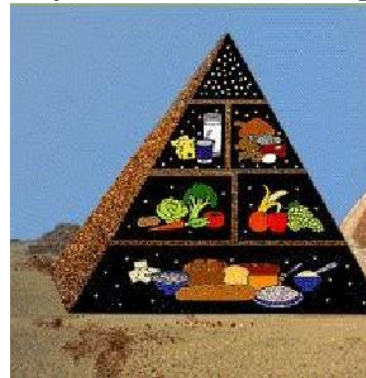
True: Camera **Predicted:** Headphone



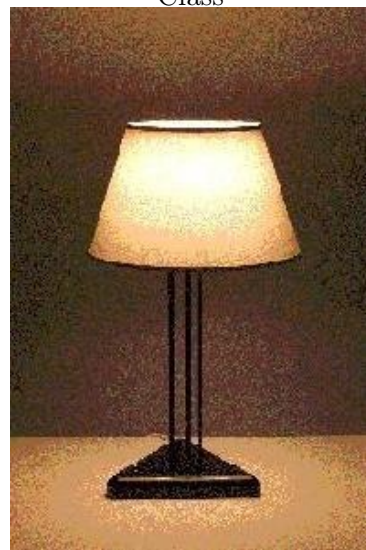
True: Lamp **Predicted:** Background Class



True: Pyramid **Predicted:** Airplanes



True: Pyramid **Predicted:** Background Class



True: Lamp **Predicted:** Headphone



True: Car Side **Predicted:** Background Class



True: Water Lilly **Predicted:** Background Class



True: Stop Sign **Predicted:** Background Class



True: Camera **Predicted:** Airplane



True: Ferry **Predicted:** Background Class



True: Barrel **Predicted:** Camera



True: Barrel **Predicted:** Airplane



True: Ferry **Predicted:** Car Side



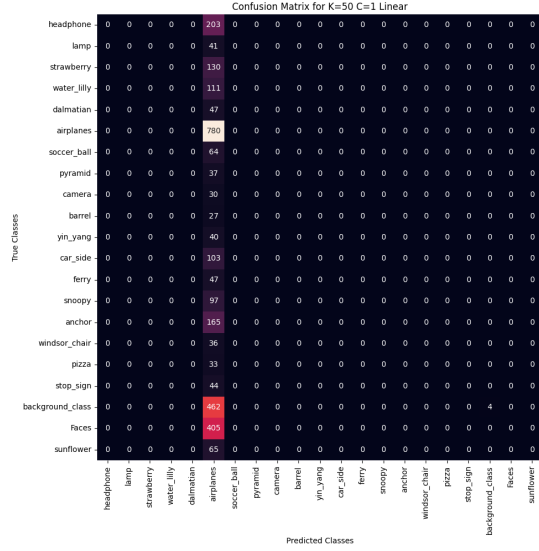
True: Ferry **Predicted:** Airplane



True: Stop Sign **Predicted:** Background Class

4 Appendix

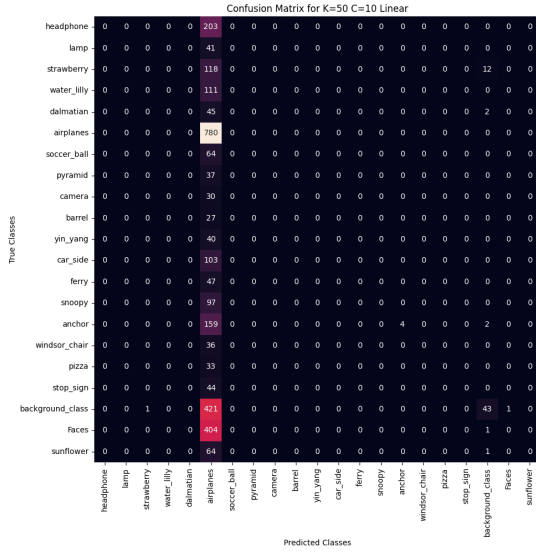
4.1 K=50 C=1 Linear



F1 Macro Score : 0.021

Class	F1 Score
headphone	0.00
lamp	0.00
strawberry	0.00
water_lilly	0.00
dalmatian	0.00
airplanes	0.42
soccer_ball	0.00
pyramid	0.00
camera	0.00
barrel	0.00
yin_yang	0.00
car_side	0.00
ferry	0.00
snoopy	0.00
anchor	0.00
windsor_chair	0.00
pizza	0.00
stop_sign	0.00
background_class	0.02
Faces	0.00
sunflower	0.00

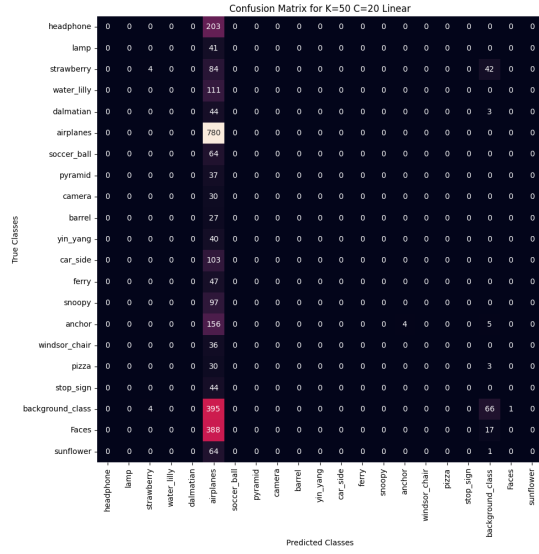
4.2 K=50 C=10 Linear



F1 Macro Score : 0.030

Class	F1 Score
headphone	0.00
lamp	0.00
strawberry	0.00
water_lilly	0.00
dalmatian	0.00
airplanes	0.42
soccer_ball	0.00
pyramid	0.00
camera	0.00
barrel	0.00
yin_yang	0.00
car_side	0.00
ferry	0.00
snoopy	0.00
anchor	0.05
windsor_chair	0.00
pizza	0.00
stop_sign	0.00
background_class	0.16
Faces	0.00
sunflower	0.00

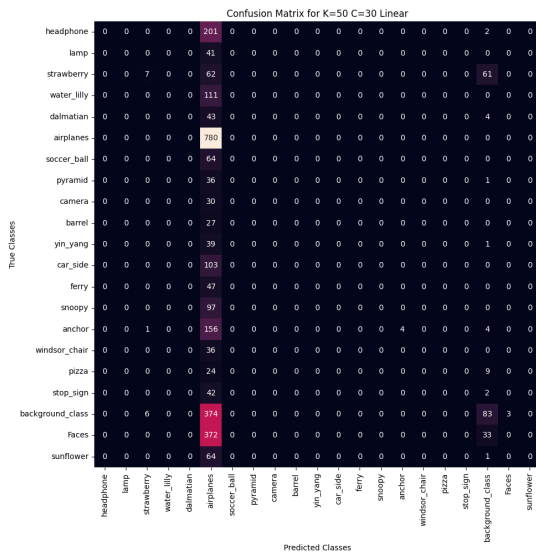
4.3 K=50 C=20 Linear



F1 Macro Score : 0.036

Class	F1 Score
headphone	0.00
lamp	0.00
strawberry	0.06
water_lilly	0.00
dalmatian	0.00
airplanes	0.43
soccer_ball	0.00
pyramid	0.00
camera	0.00
barrel	0.00
yin_yang	0.00
car_side	0.00
ferry	0.00
snoopy	0.00
anchor	0.05
windsor_chair	0.00
pizza	0.00
stop_sign	0.00
background_class	0.22
Faces	0.00
sunflower	0.00

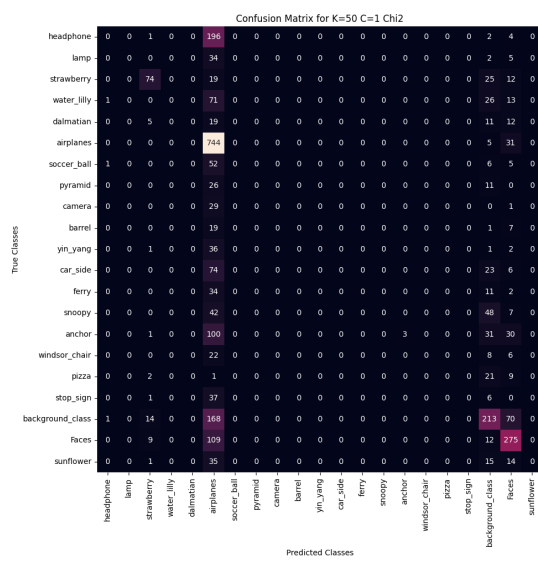
4.4 K=50 C=30 Linear



F1 Macro Score : 0.040

Class	F1 Score
headphone	0.00
lamp	0.00
strawberry	0.10
water_lilly	0.00
dalmatian	0.00
airplanes	0.44
soccer_ball	0.00
pyramid	0.00
camera	0.00
barrel	0.00
yin_yang	0.00
car_side	0.00
ferry	0.00
snoopy	0.00
anchor	0.05
windsor_chair	0.00
pizza	0.00
stop_sign	0.00
background_class	0.25
Faces	0.00
sunflower	0.00

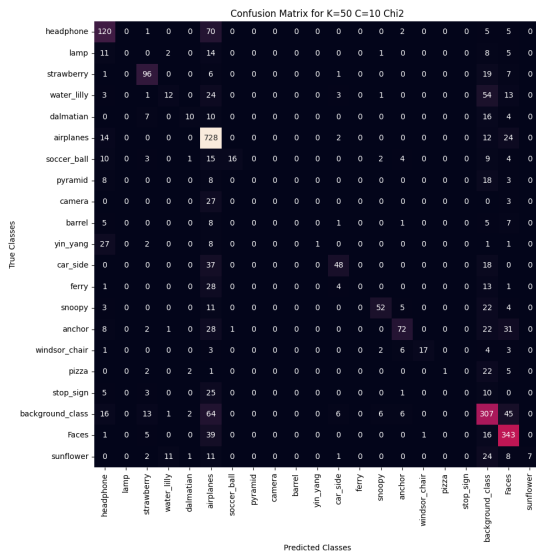
4.5 K=50 C=1 Chi-Squared



F1 Macro Score : 0.208

Class	F1 Score
headphone	0.00
lamp	0.00
strawberry	0.62
water_lilly	0.00
dalmatian	0.00
airplanes	0.56
soccer_ball	0.00
pyramid	0.00
camera	0.00
barrel	0.00
yin_yang	0.00
car_side	0.00
ferry	0.00
snoopy	0.00
anchor	0.04
windsor_chair	0.00
pizza	0.00
stop_sign	0.00
background_class	0.45
Faces	0.60
sunflower	0.00

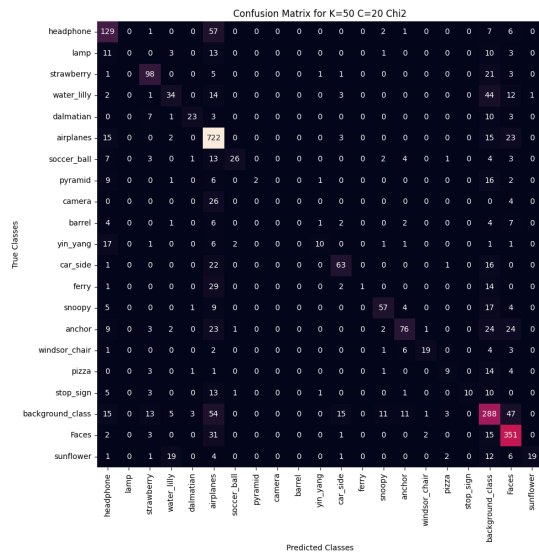
4.6 K=50 C=10 Chi-Squared



F1 Macro Score : 0.329

Class	F1 Score
headphone	0.55
lamp	0.00
strawberry	0.72
water_lilly	0.17
dalmatian	0.32
airplanes	0.75
soccer_ball	0.40
pyramid	0.00
camera	0.00
barrel	0.00
yin_yang	0.05
car_side	0.57
ferry	0.00
snoopy	0.65
anchor	0.55
windsor_chair	0.63
pizza	0.06
stop_sign	0.00
background_class	0.57
Faces	0.74
sunflower	0.19

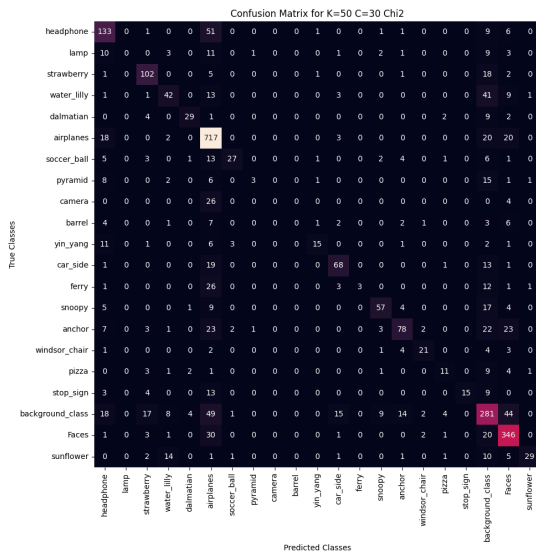
4.7 K=50 C=20 Chi-Squared



F1 Macro Score : 0.438

Class	F1 Score
headphone	0.59
lamp	0.00
strawberry	0.73
water_lilly	0.38
dalmatian	0.61
airplanes	0.79
soccer_ball	0.55
pyramid	0.10
camera	0.00
barrel	0.00
yin_yang	0.37
car_side	0.65
ferry	0.04
snoopy	0.65
anchor	0.56
windsor_chair	0.64
pizza	0.37
stop_sign	0.37
background_class	0.57
Faces	0.77
sunflower	0.45

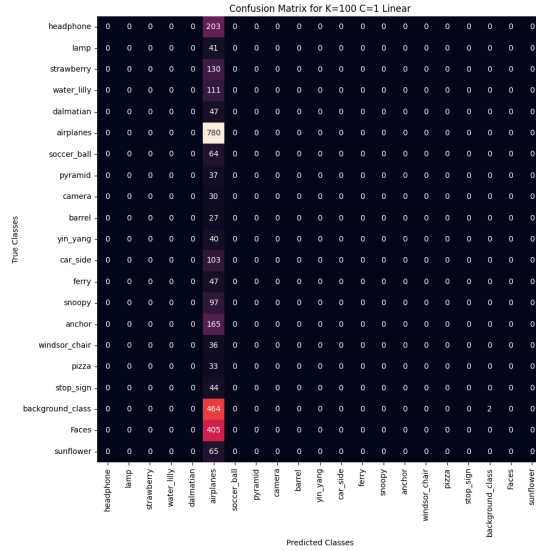
4.8 K=50 C=30 Chi-Squared



F1 Macro Score : 0.477

Class	F1 Score
headphone	0.62
lamp	0.00
strawberry	0.74
water_lilly	0.45
dalmatian	0.69
airplanes	0.79
soccer_ball	0.55
pyramid	0.14
camera	0.00
barrel	0.00
yin_yang	0.50
car_side	0.68
ferry	0.12
snoopy	0.66
anchor	0.57
windsor_chair	0.66
pizza	0.41
stop_sign	0.51
background_class	0.56
Faces	0.78
sunflower	0.59

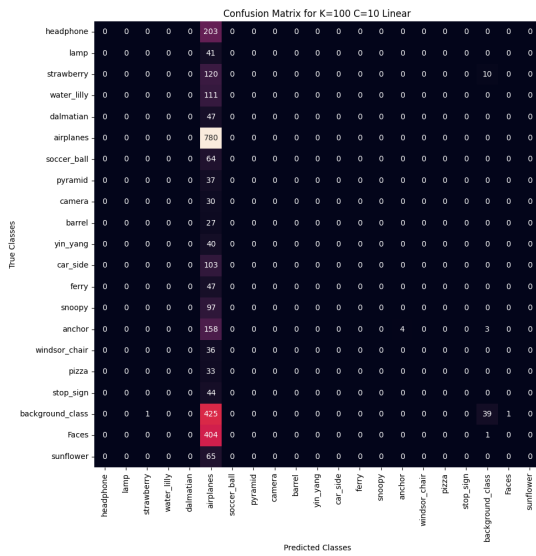
4.9 K=100 C=1 Linear



F1 Macro Score : 0.0202

Class	F1 Score
headphone	0.00
lamp	0.00
strawberry	0.00
water_lilly	0.00
dalmatian	0.00
airplanes	0.42
soccer_ball	0.00
pyramid	0.00
camera	0.00
barrel	0.00
yin_yang	0.00
car_side	0.00
ferry	0.00
snoopy	0.00
anchor	0.00
windsor_chair	0.00
pizza	0.00
stop_sign	0.00
background_class	0.01
Faces	0.00
sunflower	0.00

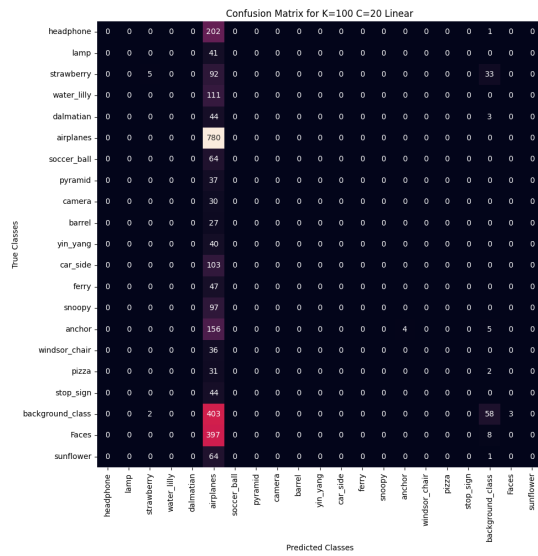
4.10 K=100 C=10 Linear



F1 Macro Score : 0.0295

Class	F1 Score
headphone	0.00
lamp	0.00
strawberry	0.00
water_lilly	0.00
dalmatian	0.00
airplanes	0.42
soccer_ball	0.00
pyramid	0.00
camera	0.00
barrel	0.00
yin_yang	0.00
car_side	0.00
ferry	0.00
snoopy	0.00
anchor	0.00
windsor_chair	0.00
pizza	0.00
stop_sign	0.00
background_class	0.15
Faces	0.00
sunflower	0.00

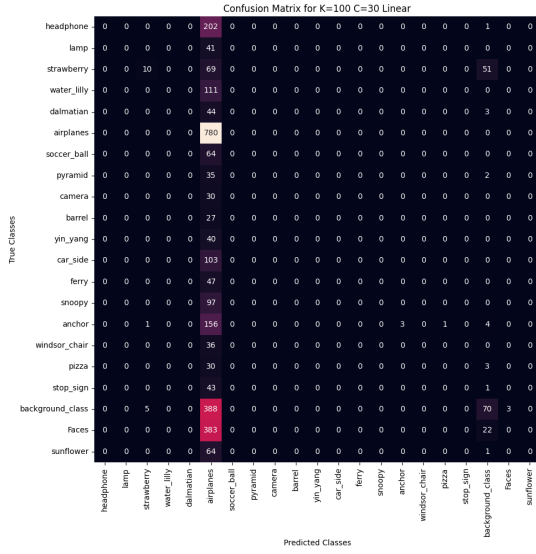
4.11 K=100 C=20 Linear



F1 Macro Score : 0.0358

Class	F1 Score
headphone	0.00
lamp	0.00
strawberry	0.07
water_lilly	0.00
dalmatian	0.00
airplanes	0.43
soccer_ball	0.00
pyramid	0.00
camera	0.00
barrel	0.00
yin_yang	0.00
car_side	0.00
ferry	0.00
snoopy	0.00
anchor	0.05
windsor_chair	0.00
pizza	0.00
stop_sign	0.00
background_class	0.20
Faces	0.00
sunflower	0.00

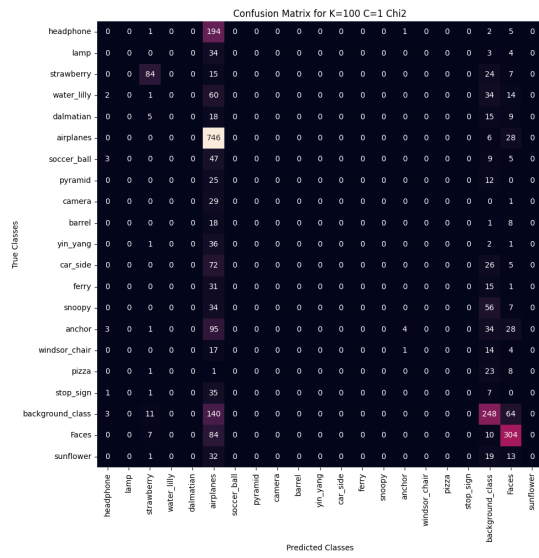
4.12 K=100 C=30 Linear



F1 Macro Score : 0.0397

Class	F1 Score
headphone	0.00
lamp	0.00
strawberry	0.14
water_lilly	0.00
dalmatian	0.00
airplanes	0.44
soccer_ball	0.00
pyramid	0.00
camera	0.00
barrel	0.00
yin_yang	0.00
car_side	0.00
ferry	0.00
snoopy	0.00
anchor	0.04
windsor_chair	0.00
pizza	0.00
stop_sign	0.00
background_class	0.22
Faces	0.00
sunflower	0.00

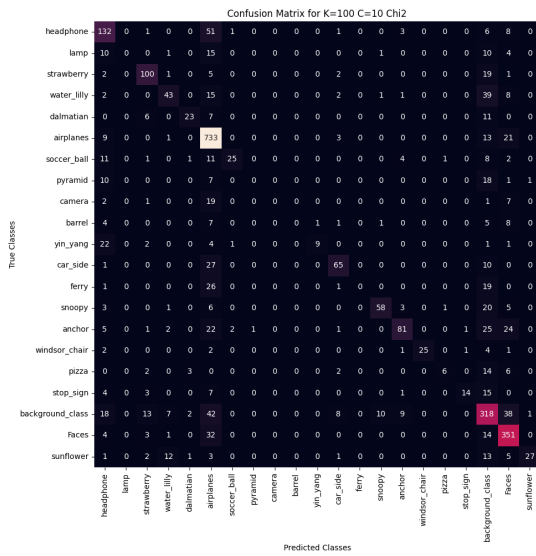
4.13 K=100 C=1 Chi-Squared



F1 Macro Score : 0.117

Class	F1 Score
headphone	0.00
lamp	0.00
strawberry	0.69
water_lilly	0.00
dalmatian	0.00
airplanes	0.59
soccer_ball	0.00
pyramid	0.00
camera	0.00
barrel	0.00
yin_yang	0.00
car_side	0.00
ferry	0.00
snoopy	0.00
anchor	0.05
windsor_chair	0.00
pizza	0.00
stop_sign	0.00
background_class	0.48
Faces	0.66
sunflower	0.00

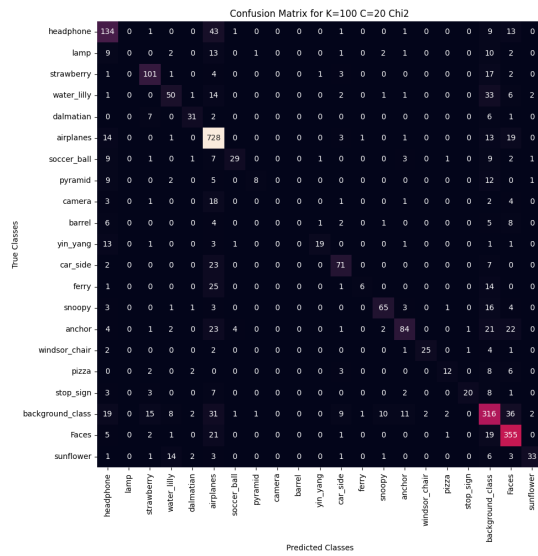
4.14 K=100 C=10 Chi-Squared



F1 Macro Score : 0.459

Class	F1 Score
headphone	0.59
lamp	0.00
strawberry	0.75
water_lilly	0.48
dalmatian	0.60
airplanes	0.81
soccer_ball	0.54
pyramid	0.00
camera	0.00
barrel	0.00
yin_yang	0.36
car_side	0.68
ferry	0.00
snoopy	0.69
anchor	0.60
windsor_chair	0.82
pizza	0.29
stop_sign	0.47
background_class	0.61
Faces	0.78
sunflower	0.57

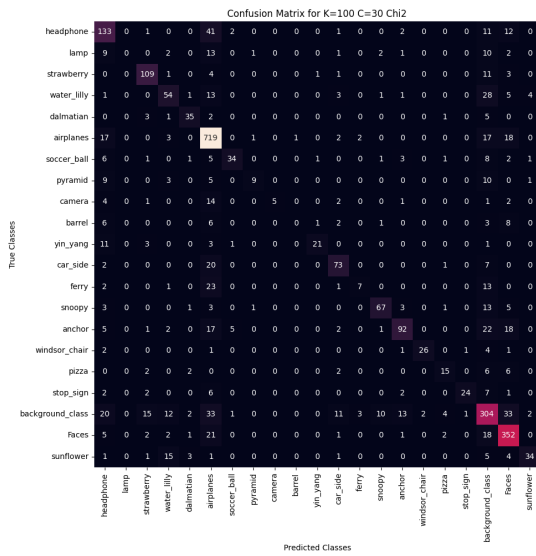
4.15 K=100 C=20 Chi-Squared



F1 Macro Score : 0.531

Class	F1 Score
headphone	0.61
lamp	0.00
strawberry	0.76
water_lilly	0.52
dalmatian	0.71
airplanes	0.83
soccer_ball	0.58
pyramid	0.34
camera	0.00
barrel	0.00
yin_yang	0.61
car_side	0.70
ferry	0.22
snoopy	0.73
anchor	0.61
windsor_chair	0.79
pizza	0.48
stop_sign	0.61
background_class	0.63
Faces	0.80
sunflower	0.63

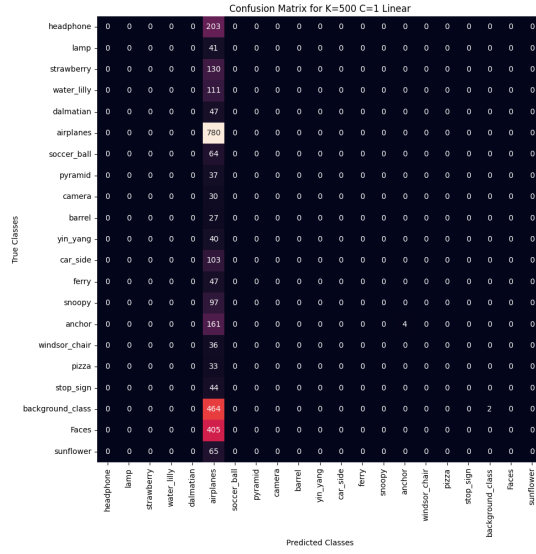
4.16 K=100 C=30 Chi-Squared



F1 Macro Score : 0.565

Class	F1 Score
headphone	0.60
lamp	0.00
strawberry	0.80
water_lilly	0.52
dalmatian	0.75
airplanes	0.83
soccer_ball	0.64
pyramid	0.37
camera	0.29
barrel	0.00
yin_yang	0.66
car_side	0.71
ferry	0.24
snoopy	0.74
anchor	0.65
windsor_chair	0.81
pizza	0.52
stop_sign	0.69
background_class	0.63
Faces	0.80
sunflower	0.64

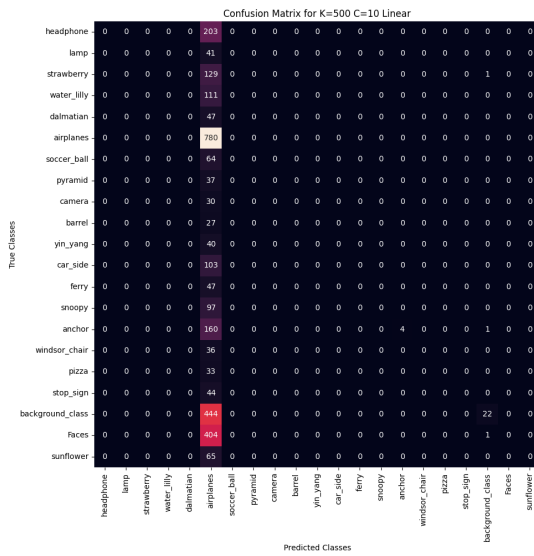
4.17 K=500 C=1 Linear



F1 Macro Score : 0.0225

Class	F1 Score
headphone	0.00
lamp	0.00
strawberry	0.00
water_lilly	0.00
dalmatian	0.00
airplanes	0.42
soccer_ball	0.00
pyramid	0.00
camera	0.00
barrel	0.00
yin_yang	0.00
car_side	0.00
ferry	0.00
snoopy	0.00
anchor	0.05
windsor_chair	0.00
pizza	0.00
stop_sign	0.00
background_class	0.01
Faces	0.00
sunflower	0.00

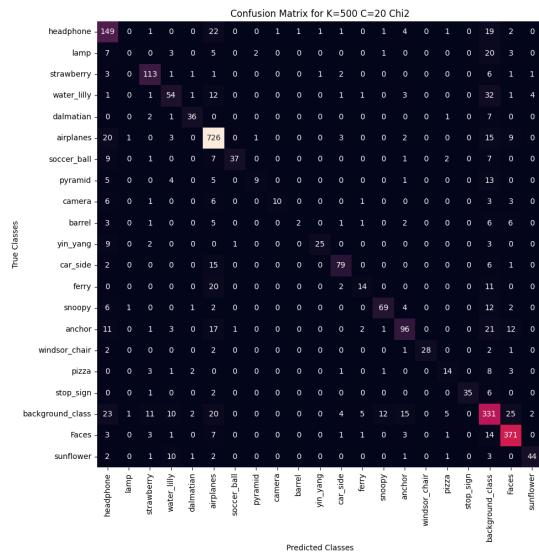
4.18 K=500 C=10 Linear



F1 Macro Score : 0.0265

Class	F1 Score
headphone	0.00
lamp	0.00
strawberry	0.00
water_lilly	0.00
dalmatian	0.00
airplanes	0.42
soccer_ball	0.00
pyramid	0.00
camera	0.00
barrel	0.00
yin_yang	0.00
car_side	0.00
ferry	0.00
snoopy	0.00
anchor	0.05
windsor_chair	0.00
pizza	0.00
stop_sign	0.00
background_class	0.09
Faces	0.00
sunflower	0.00

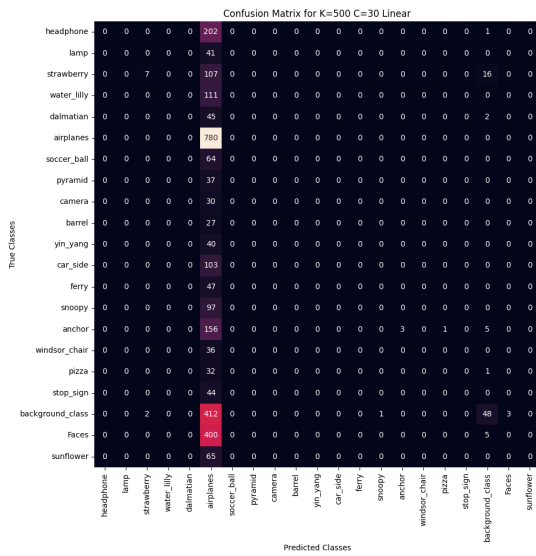
4.19 K=500 C=20 Linear



F1 Macro Score : 0.0304

Class	F1 Score
headphone	0.00
lamp	0.00
strawberry	0.00
water_lilly	0.00
dalmatian	0.00
airplanes	0.42
soccer_ball	0.00
pyramid	0.00
camera	0.00
barrel	0.00
yin_yang	0.00
car_side	0.00
ferry	0.00
snoopy	0.00
anchor	0.05
windsor_chair	0.00
pizza	0.00
stop_sign	0.00
background_class	0.17
Faces	0.00
sunflower	0.00

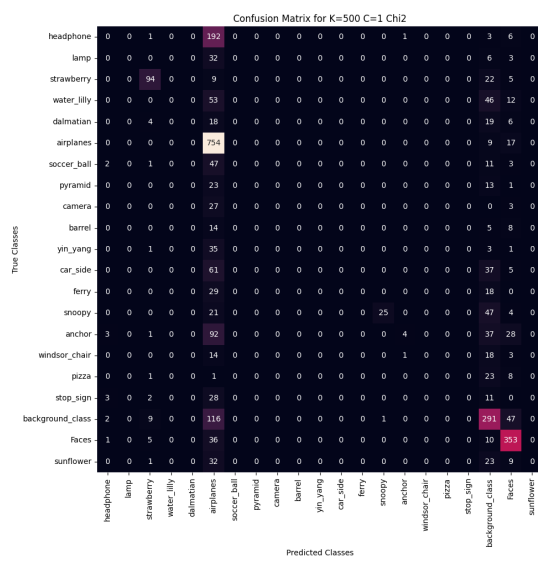
4.20 K=500 C=30 Linear



F1 Macro Score : 0.0352

Class	F1 Score
headphone	0.00
lamp	0.00
strawberry	0.10
water_lilly	0.00
dalmatian	0.00
airplanes	0.43
soccer_ball	0.00
pyramid	0.00
camera	0.00
barrel	0.00
yin_yang	0.00
car_side	0.00
ferry	0.00
snoopy	0.00
anchor	0.04
windsor_chair	0.00
pizza	0.00
stop_sign	0.00
background_class	0.18
Faces	0.00
sunflower	0.00

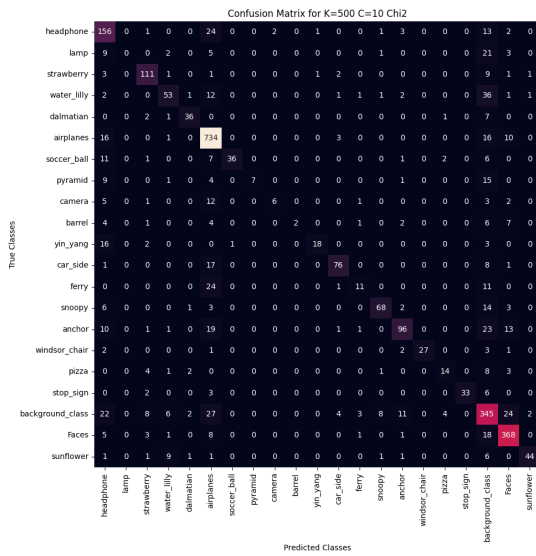
4.21 K=500 C=1 Chi-Squared



F1 Macro Score : 0.148

Class	F1 Score
headphone	0.00
lamp	0.00
strawberry	0.75
water_lilly	0.00
dalmatian	0.00
airplanes	0.62
soccer_ball	0.00
pyramid	0.00
camera	0.00
barrel	0.00
yin_yang	0.00
car_side	0.00
ferry	0.00
snoopy	0.41
anchor	0.05
windsor_chair	0.00
pizza	0.00
stop_sign	0.00
background_class	0.52
Faces	0.76
sunflower	0.00

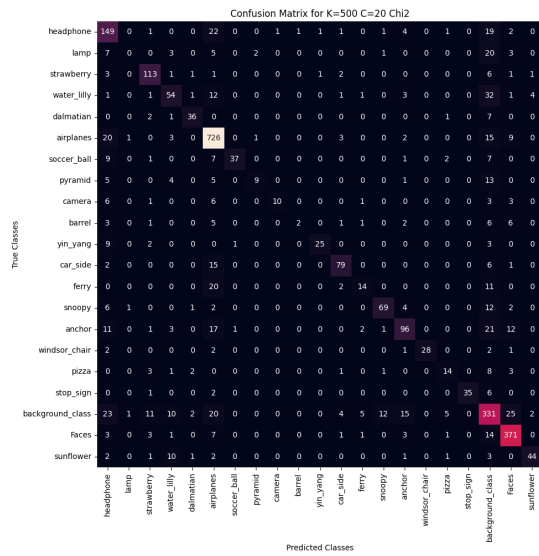
4.22 K=500 C=10 Chi-Squared



F1 Macro Score : 0.614

Class	F1 Score
headphone	0.65
lamp	0.00
strawberry	0.83
water_lilly	0.56
dalmatian	0.80
airplanes	0.87
soccer_ball	0.71
pyramid	0.32
camera	0.32
barrel	0.14
yin_yang	0.60
car_side	0.80
ferry	0.33
snoopy	0.76
anchor	0.67
windsor_chair	0.86
pizza	0.52
stop_sign	0.86
background_class	0.66
Faces	0.87
sunflower	0.78

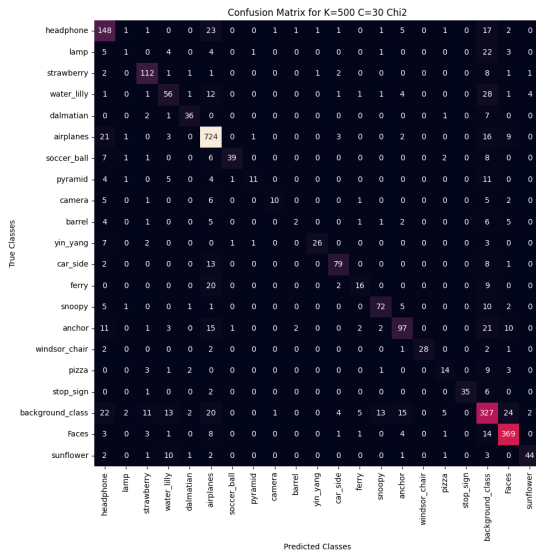
4.23 K=500 C=20 Chi-Squared



F1 Macro Score : 0.631

Class	F1 Score
headphone	0.64
lamp	0.00
strawberry	0.83
water_lilly	0.53
dalmatian	0.79
airplanes	0.88
soccer_ball	0.72
pyramid	0.37
camera	0.49
barrel	0.13
yin_yang	0.75
car_side	0.80
ferry	0.39
snoopy	0.76
anchor	0.64
windsor_chair	0.88
pizza	0.48
stop_sign	0.89
background_class	0.65
Faces	0.88
sunflower	0.76

4.24 K=500 C=30 Chi-Squared



F1 Macro Score : 0.640

Class	F1 Score
headphone	0.65
lamp	0.04
strawberry	0.83
water_lilly	0.54
dalmatian	0.79
airplanes	0.88
soccer_ball	0.74
pyramid	0.43
camera	0.48
barrel	0.12
yin_yang	0.76
car_side	0.81
ferry	0.43
snoopy	0.76
anchor	0.64
windsor_chair	0.88
pizza	0.48
stop_sign	0.89
background_class	0.65
Faces	0.88
sunflower	0.76