

Exercise 3.2 Deep learning

e12045110 Maria de Ronde
e12040873 Quentin Andre
e11921655 Fabian Holzberger

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Datasets

iiiiii HEAD For exercise 3.2 Deep Learning we decided to apply deep learning on image classification. The data sets that we will use are CIFAR-10 ¹ and Tiny-Imagenet ². With these two datasets we have variation in the number of classes represented in the data. This enables us to explore the difference in performance when the number of classes increase. In sections and both datasets are described in more detail. The pictures also differ in input size.

We used Python as our programming language and implemented the deep learning using Tensor Flow.
===== For exercise 3.2 Deep Learning we decided to apply deep learning on image classification. The data sets that we will use are CIFAR-10 [INCLUDE REFERENCE] and Tiny-Imagenet[Include REFERENCE]. With these two datasets we have variation in the classes represented in the data. This enables us to explore the difference in performance when the number of classes increase. In the following sections both datasets are described in more detail.
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CIFAR-10

CIFAR-10 is a dataset which consists of 60.000 images, of which 50.000 training images and 10.000 test images. Each image has 32×32 colored pixels. There are 10 different classes (airplane, automobile, bird, cat, deer, dog, frog, horse, ship and truck) each class has exactly 5.000 images in the training data and 1.000 images in the test data. Each image only belongs to one class. There are no multi-label images.

Tiny ImageNet

iiiiii HEAD Tiny ImageNet is a dataset containing of 100000 training images, divided in 200 different classes. There are 500 images per class in the training data. Next to the training data there are 10000 testing and 10000 validation images as well. Each picture has 64×64 pixels. The test set of this data is not labeled. To load the data some code from Github ³ was used. ===== Tiny ImageNet is a dataset containing of 100.000 training images, divided in 200 different classes. There are 500 images per class in the training data. Next for the training data there are 10.000 testing and 10.000 validation images as well. Each picture has 64×64 pixels. The images in the test-set are not labelled and therefore we will not make use of them.
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¹<https://www.cs.toronto.edu/~kriz/cifar.html>

²<http://cs231n.stanford.edu/tiny-imagenet-200.zip>

³<https://github.com/rmccorm4/Tiny-Imagenet-200>

Traditional classifiers

In order to have a baseline for our deep classifier some traditional classifiers have been executed. The following traditional classifiers have been trained:

1. **Multinomial Naive Bayes:** `alpha = 1.0, fit_prior= True, class_prior= None`
2. **Random forest:** `n_estimators = 100, criterion='gini', max_depth=None, min_samples_split=2, min_samples_leaf=1, min_weight_fraction_leaf=0.0, max_features='auto', max_leaf_nodes = None, min_impurity_decrease=0.0, min_impurity_split=None, bootstrap=True, oob_score=False, n_jobs=None, random_state=None, verbose=0, warm_start=False, class_weight=None, cc_alpha=0.0, max_samples=None`
3. **Single layer perceptron:** `penalty=None, alpha=0.0001, l1_ratio=0.15, fit_intercept=True, max_iter=1000, tol=0.001, shuffle=True, verbose=0, eta0=1.0, n_jobs=None, random_state=0, early_stopping=False, validation_fraction=0.1, n_iter_no_change=5, class_weight=None, warm_start=False`
4. **Multi layer perceptron:** 2 Relu activation layers 256, 1 softmax activation 10 epochs=15, batch_size=32, verbose=0

Before we could train the traditional classifiers, we extracted features from our images. We performed two type of feature extraction.

1. Color histogram
2. SIFT

Color histograms

Color histograms is one of the simplest feature extraction method for images. It counts the frequency of pixels with a certain color. The bins are based on the RGB coding, each pixel has a value for red, green and blue between 0 and 255. Color histograms do not take spatial information into account. All spatial information gets lost during this feature extraction. In Figure 1 an example picture with the corresponding color histogram for both datasets is given.

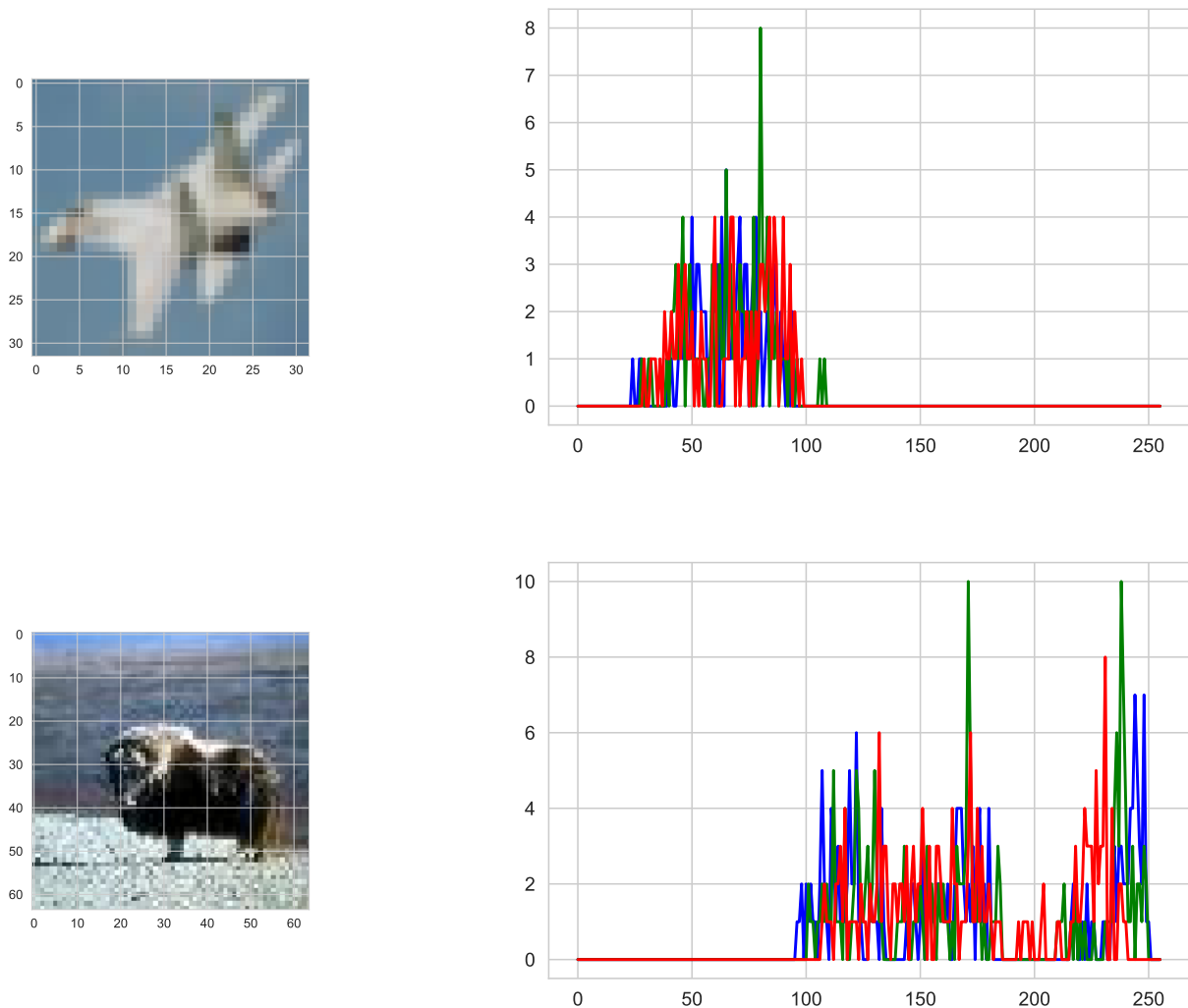


Figure 1: Top: Example picture and color histogram of Cifar dataset. Down: Example picture and color histogram of Tiny Imagenet dataset

We created 4 different datasets using color hisograms, two based on one dimensional histograms (one with 256 bins per channel and one with 64 bins per channel), one on two dimensional histograms (16 bins per channel) and one of 3 dimensional histograms (8 bins per channel). This is based on the example shown in simple-image-feature-extraction ⁴. In order to create the color histograms we used the package OpenCV.

Sift back of visual words

iiiiiii HEAD First the images are converted into grey scale images. With use of SIFT the key-points and descriptors are detected. K-means-clustering is applied to find 20 clusters in the detected descriptors. Finally vectors with the visual words are created and vectorized in a histogram (frequency of visual words). The histogram is scaled to a standard normal distribution before running the classifiers.

⁴<https://tuwel.tuwien.ac.at/course/view.php?id=35929>

Results

In Figure 2 and ?? the accuracy for the different base classifiers can be found for the Cifar-10 and Tiny image dataset respectively. It can be seen that the random forest out performs all classifiers with the color histogram features, the best performance was obtained using the 2-d color histograms.

Accuracy of BOW The confusion matrices shown in Figure 3 are based on the 2-d feature color histograms as this gave the best results. The confusion matrix of the single-layer-perceptron shows pretty much a random classifier. Furthermore it can be seen that trucks are often classified as cars and birds are often classified as ship

. The confusion matrix of the Naive Bayes, Random Forest and multi-layer-perceptron show similar results. They show that airplanes, ships and trucks are predicted best even though airplanes and ships are also often confused. It can also be seen that the different animals get confused.

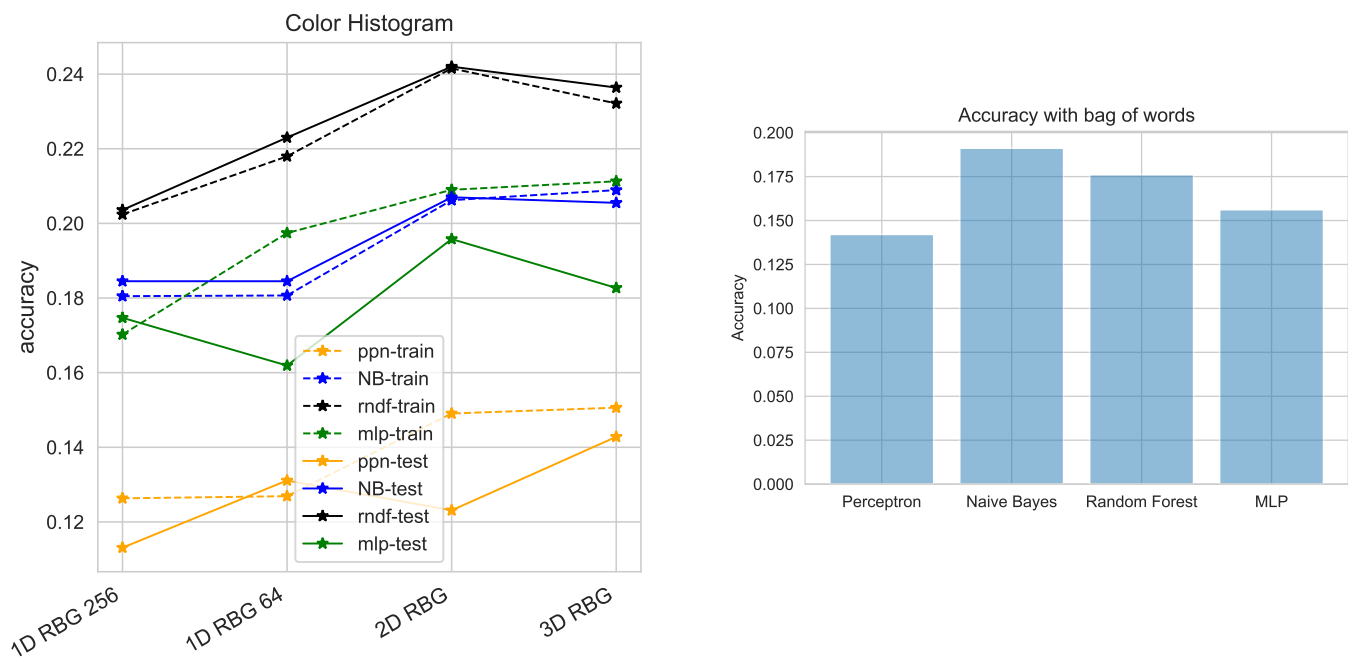


Figure 2: Accuracy Cifar-10

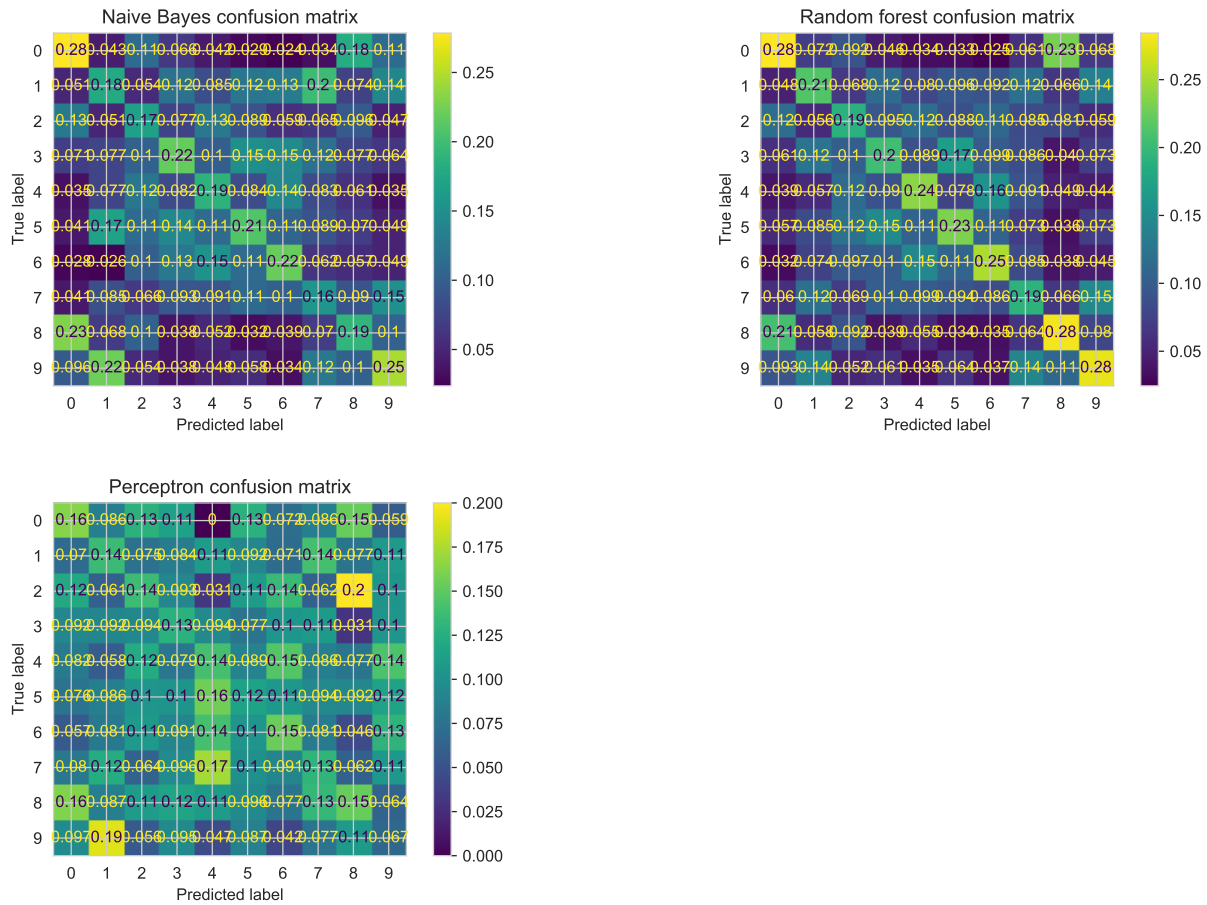


Figure 3: Confusion matrices color histogram Cifar-10: 1. Naive Bayes 2. Random forest 3. Single-layer-perceptron 4. Multi-layer-perceptron

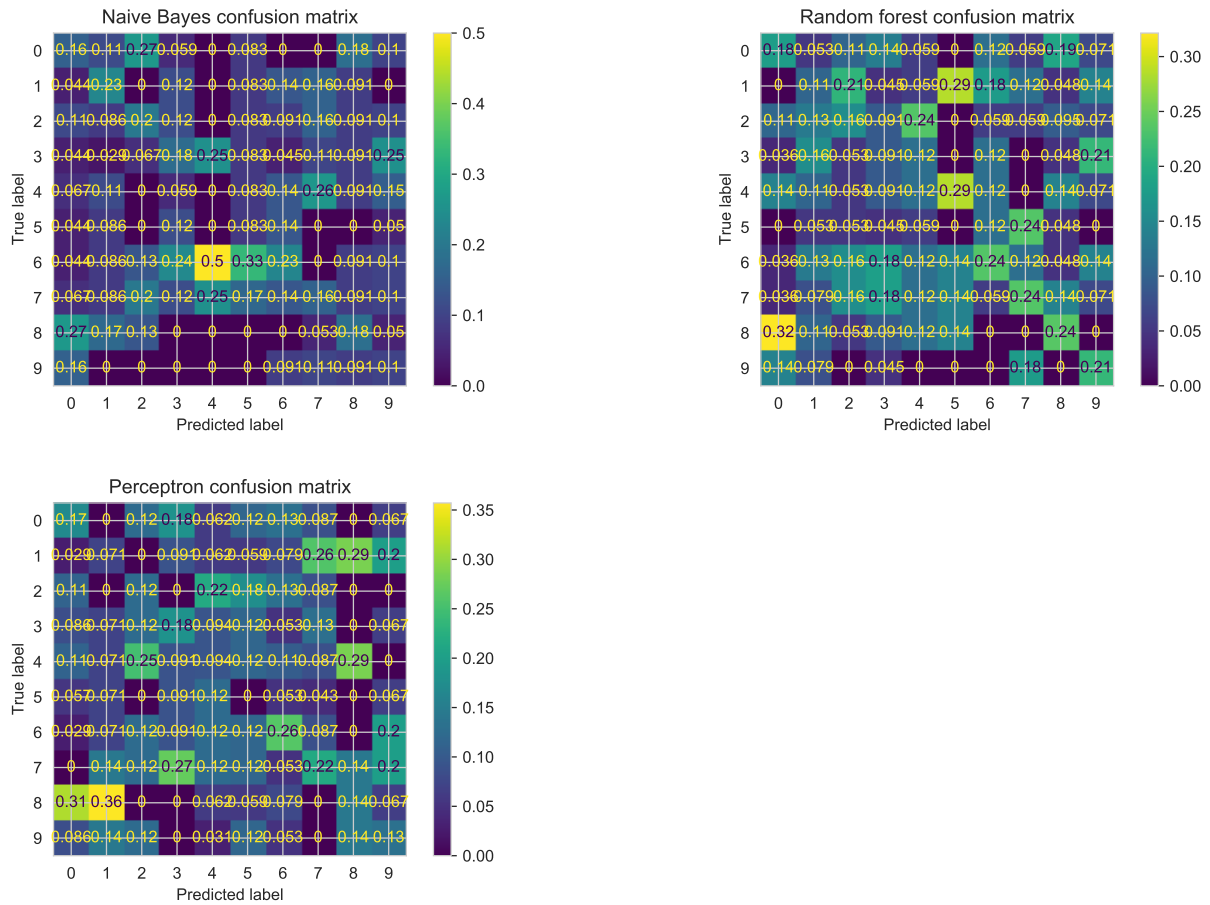


Figure 4: Confusion matrices bag of words Cifar-10: 1. Naive Bayes 2. Random forest 3. Single-layer-perceptron 4. Multi-layer-perceptron



Figure 5: Comparison of time required for different feature extractions and training of models

Convolutional Neural Networks (CNN's)

In this section we introduce the CNN architectures used for this work.

SqueezeNet

For the first architecture we decided on using SqueezeNet [2]. SqueezeNet was developed with the goal to make it as compact as possible, but still achieving state of art results. In the original paper it is shown that SqueezeNet can achieve the same performance as an AlexNet for the ImageNet competition but with $50\times$ less parameters. This makes SqueezeNet particularly well suited for our small project where we need to rely on limited resources.

Wrapped Res50Net for Transfer learning

For the second architecture we have chosen intentionally a large one with many parameters, that gives the opportunity for transfer learning. Here we aim to use Res50Net [1], which has over 23 Million trainable parameters. We wrap this architecture by a custom network. For the training we freeze all layers till layer 168 and train the remaining layers of Res50Net and the additional custom layers. More details are given in the Results section.

Training Details for CNN's

For the training we are performing image augmentation and compare the obtained results to the case when no augmentation is applied. We apply for all CNN's the same random augmentations:

- width/height shift up to 10%
- shearing up to 10%
- zoom up to 10%
- rotation up to 30°
- horizontal flip

For the training it was observed that the ADAM optimizer with learning rate 0.0001 works well for all our cases. While performing the parameter search we decrease the learning rate by a factor 0.1 if the loss function did not decrease for the 5 previous iterations, where the loss function is the categorical-crossentropy. Additionally if the loss function does not improve for 15 iterations we stop the parameter search early. The parameter search is accelerated by a NVidia K80 GPU, but test-set evaluation times are measured when employing our CNN's on a Intel i5 CPU. Another important aspect is that we don't normalize the RGB scales of the pixels since this caused non-convergence for the most parameter searches. All CNN-related analysis is performed as holdout, meaning we create a test, train validation set split.

Results Cifar10 Dataset

SqueezeNet

For the Cifar10 Dataset the resulting SqueezeNet architecture has 740.554 trainable parameters. A holdout analysis is performed where we take 10% of the train-data as validation data to evaluate the performance of the CNN at training time.

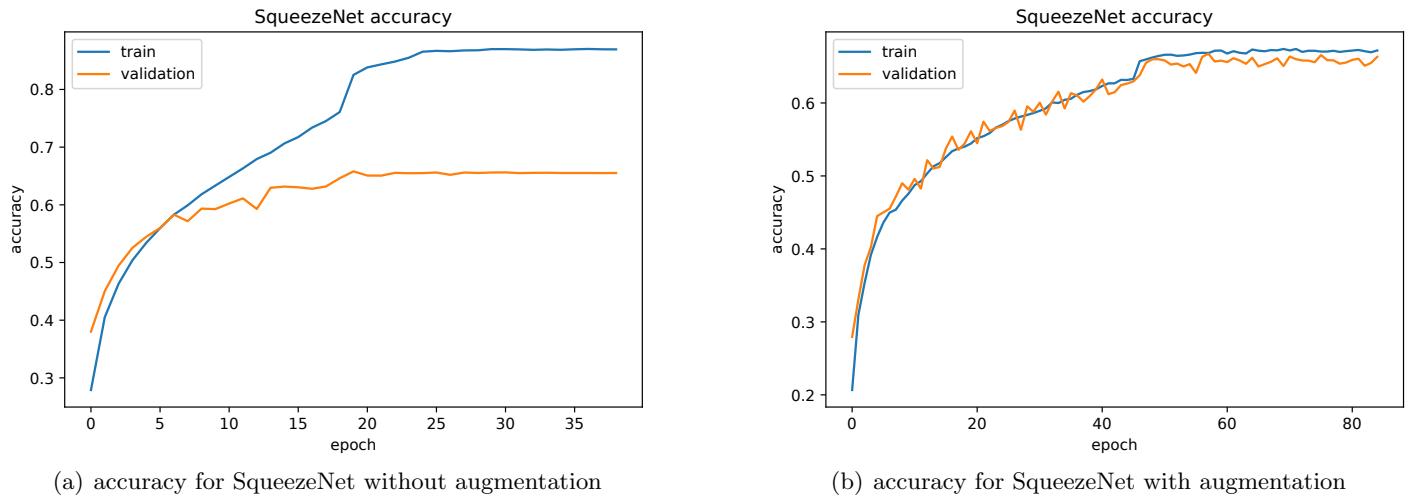


Figure 6: Training-accuracy for SqueezeNet on the Cifar10 Dataset

In figure 6 we can see the effect of the augmentation on the accuracy of the predictions while training. We have a clear overfitting of the CNN when not applying augmentation. This overfitting is largely decreased by applying the image-augmentation as can be seen in the figure. When applying the augmentation the accuracy of SqueezeNet on the Test-set increased from 65.21% to 67.33%. Augmentation of the images has an influence on the efficiency of the parameter search for the Network. Without augmentation the optimal parameters are found after 6 min and less than 40 epochs, whereas augmentation causes the time for parameter search to increase to 46 min and 84 epochs. For the prediction of the 313 samples in the test-set SqueezeNet needs about 9s

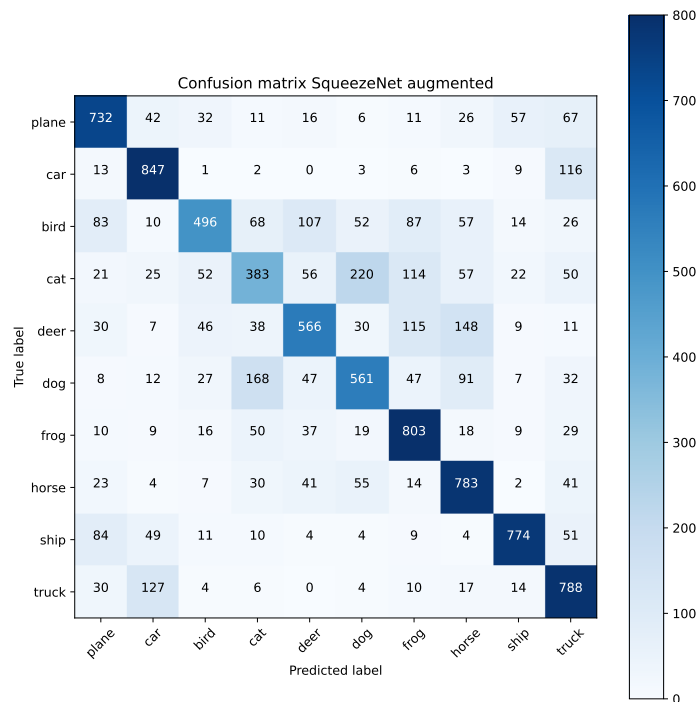


Figure 7: Confusion matrix for the SqueezeNet trained on the augmented Cifar10 Dataset.

In figure 7 we show the corresponding confusion matrix for the SqueezeNet trained on the augmented Cifar10 images. The most true positive labels are predicted for the car class with 847 where we note that 127 times a truck sample gets confused to be a car. The least true positive labels are predicted for cats with 383 where this class often gets confused with the dog class. The most false negative predictions are made for the truck class with 423 samples closely followed by the horse class with 421 falsely predicted samples. This is due to the fact that Trucks are often confused with cars and horses are often confused with deers or dogs.

Res50Net

To create our wrapped Res50Net we strip off the top layers and replace that layer by a custom layer of $32 \times 32 \times 3$ for reading our images. The output of the Res50Net gets fed into 3 dense layers with 256, 128, 64 neurons till it reaches the softmax layers for prediction. Note that our dense layers consist each at the top of a batch normalisation layer and the dense layers with a dropout of 50% for regularisation purposes. For the Res50Net layers in our CNN we enable the training of the 168 bottom layers and freeze the rest of them. By that we end up with a CNN that has in total 24.163.786 parameters from which are 3.986.762 trainable. For the transfer learning we apply the same image augmentation as for SqueezeNet.

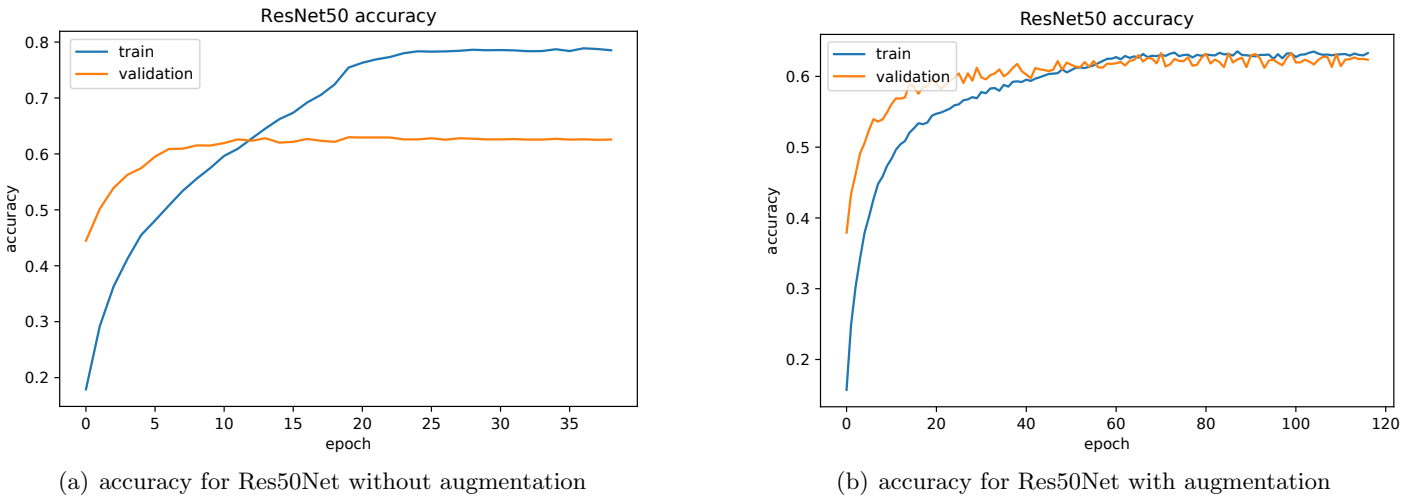


Figure 8: Training-accuracy for Res50Net on the Cifar10 Dataset

In figure 8 we show the accuracy while executing the transfer learning of Res50Net. Again without augmentation the CNN overfits till about 80% accuracy on the trainset while the accuracy on the validation-set is 20% lower. With augmentation we have diminished this effect and additionally improve the accuracy on the test-set from 62.16% for no augmentation to 64.69% with augmentation. The parameter-fitting for the augmented process took 117 epochs with a total time of 64 min compared to that the parameter-fitting with no augmentation took 39 epochs and about 10 min in total. The evaluation on the testset took 38s which is more 4 than longer than for the SqueezeNet.

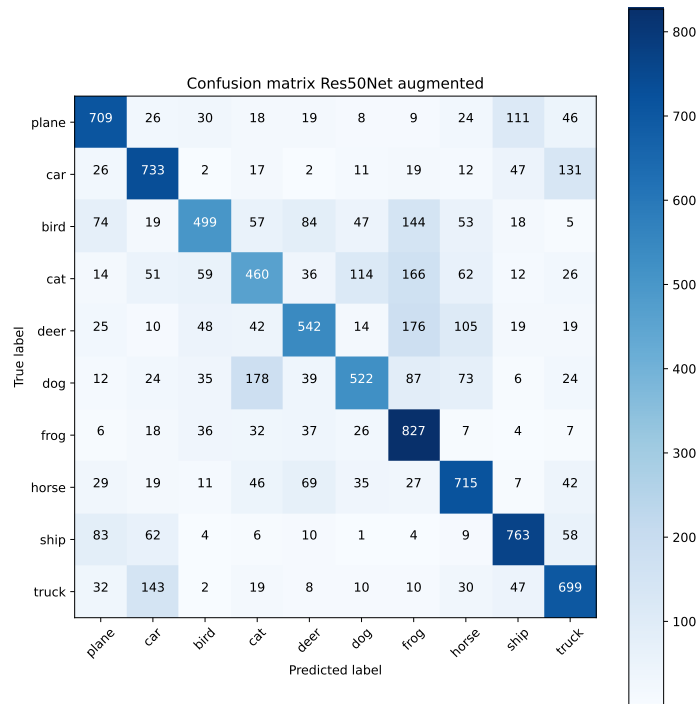


Figure 9: Confusion matrix for the SqueezeNet trained on the augmented Cifar10 Datas.

In figure 9 the corresponding confusion matrix for the Res50Net trained on the augmented Cifar10 images is plotted. The most true positive predictions are made for the frog class with 827. We also see that the frog class has aswell the most true negative predictions where it seems particularly hard for the CNN to differentiate it from other animals. The cat class with the one with lowest true positives at 460, where we note that 148 dogs get wrongly classified as cats. Also notable is that cars get often cofused as trucks and ships are often confused as planes.

Results Tiny ImageNet Dataset

SqueezeNet

On the Tiny ImageNet SqueezeNet has 838.024 trainable parameters. First we plot in figure 10 the auccuracy over the number of training epochs.

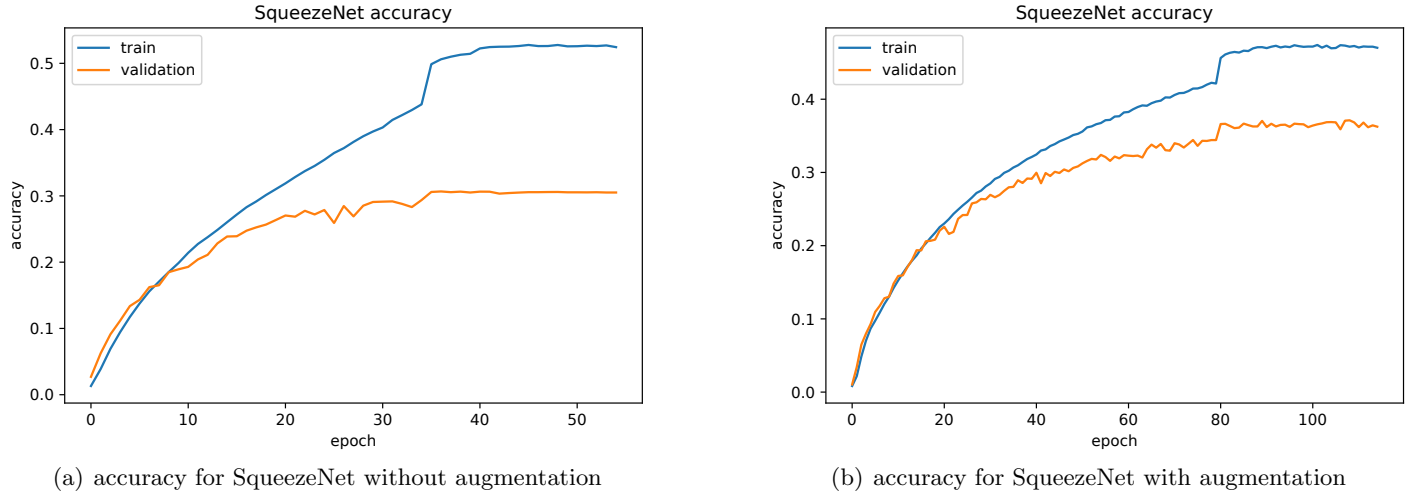


Figure 10: Training-accuracy for SqueezeNet on the Tiny ImageNet Dataset

As before we can examine less overfitting for the augmented case, but this time even with augmentation the SqueezeNet is overfitting as can be seen in the much higher accuracy of on the train-set compared to the accuracy on the validation-set. In both graphs we can identify the first decrease in learning rate by the jump in the training accuracy. Note that this jump occurs at a much later epoch for the augmented case showing more potential for improvement of the accuracy in the augmented case before reaching a local optima. For the evaluation on the test-set the SqueezeNet without augmented training-data has an accuracy of 31.26% and augmentation caused the accuracy on the test-set to increase up to 34%. The tradeoff we pay is that for the training with no augmentation the parameter-search takes 55 epochs and 41 min, but with augmentation 115 epochs and 297 min. Since the Tiny ImageNet is larger than Cifar10 our evaluation time for SqueezeNet on the 10.000 samples test-set is here about 60s.

If we analyze the confusion matrix in figure 11 we can measure the quality of our classifier by the size of the diagonal entries and the small offdiagonal entries.

Many classes have a large number of true positiv predicted labels but to understand the classifier better analyze some special labels more closely. In table 1 is a summary of some important properties of the confusion matrix given.

label	correct amount	label	correct amount	actual label	predicted label	times confused
water jug	0	monarch	43	bee	monarch	13
plunger	1	school bus	40	sports car	convertible	12
pop bottle	2	fire salamander	37	CD player	scoreboard	11
barrel	3	black widow	36	altar	organ	11
umbrella	3	lifeboat	36	convertible	beach wagon	11
Labrador	3	brass	34	coral reef	brain coral	10
Chihuahua	3	espresso	34	dam	steel arch bridge	10
bucket	3	rugby ball	34	beach wagon	convertible	10
chain	3	maypole	34	scorpion	centipede	9
dumbbell	4	triumphal arch	33	slug	centipede	9

Table 1: Some detailed information about the Confusion matrix of the SqueezeNet with augmented Tiny ImageNet

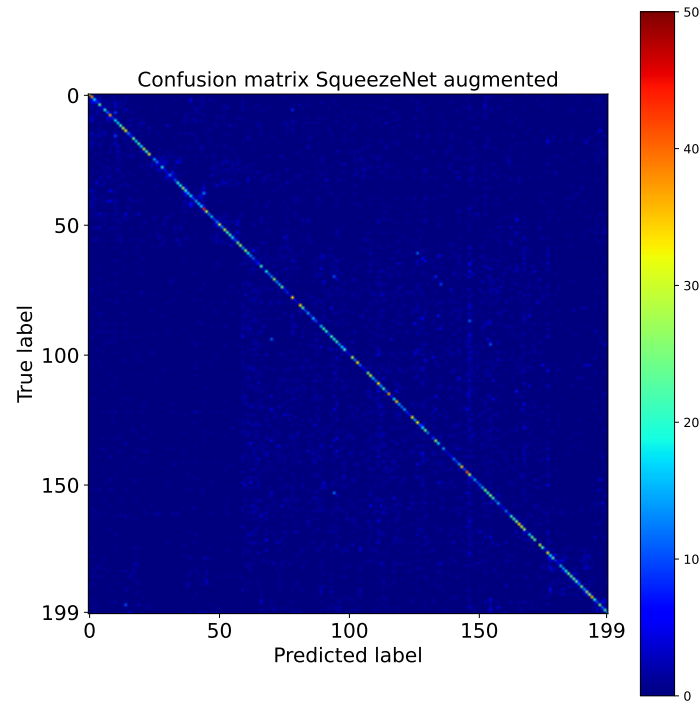


Figure 11: Confusion matrix for the SqueezeNet trained on the augmented Tiny ImageNet Dataset.

The first two columns state the classes that have the least ammount of true positive predicted labels. Here we see that for the water jug we have no correct prediction whereas all other classes have at least one true positive predicted sample. For the classes with the highest amount of correct predetions we see in the next two columns that the monach butterfly and secondly school busses were mostly correct identified. Further we can state that often strong colored subjects are easily identified like school busses ir life boats. In the last three columns the most confused labels are stated. Here we can extract that our SqueezeNet often confuses bees for monachs or secondly sports cars as convertables. This behaviour is as expected since auch subjects are very closely related in shape and color.

Res50Net

For the Res50Net we again create a custom wrapper CNN where the Input layer is defined for $64 \times 64 \times 3$ images as required for Tiny ImageNet. The Res50Net first 168 layers are not trained and we append additional three 256 dense layers at the end where each has a batch normalisation layer at top and a dropout of 50%. The total parameters of the wrapped Res50Net are 25.902.920 where 5.713.352 are trainable.

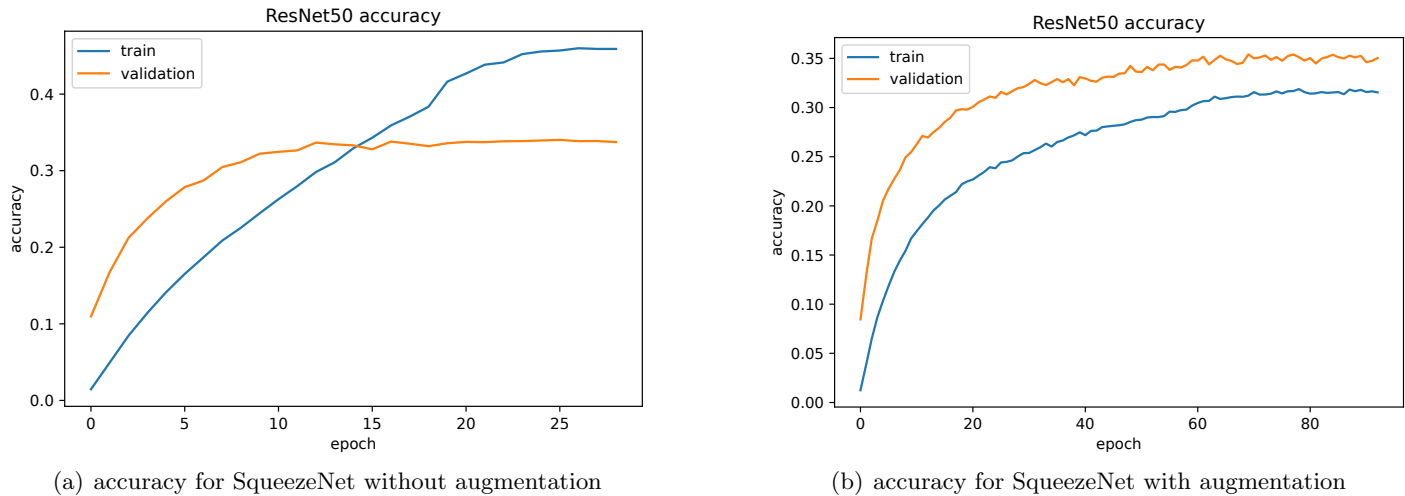


Figure 12: Training-accuracy for wrapped Res50Net on the Tiny ImageNet Dataset

The training accuracies for the wrapped Res50Net are given in the two plots in figure 12. For this case when using augmented images the accuracy on the validation-set always higher than on the test-set in contrast to the studies before in this work.

Results

squeezeNet

For the second architecture we decided on using SqueezeNet [2]. Squeezenet claims to have an accuracy equal to AlexNet but has a lot less parameters to learn. For SqueezeNet no weights are available, therefore we recreated the model and re-trained it.

Results

References

- [1] Kaiming He, Xiangyu Zhang, Shaoqing Ren, and Jian Sun. Deep residual learning for image recognition. In *Proceedings of the IEEE conference on computer vision and pattern recognition*, pages 770–778, 2016.
- [2] Forrest N Iandola, Song Han, Matthew W Moskewicz, Khalid Ashraf, William J Dally, and Kurt Keutzer. Squeezenet: Alexnet-level accuracy with 50x fewer parameters andj 0.5 mb model size. *arXiv preprint arXiv:1602.07360*, 2016.