

COMP5434 - Big Data Computing

10-Classes Image Classification

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Abstract

We study the impact of how changing different hyperparameters and the structure on Convolutional Neural Network (CNN) affect performance in image classification, and propose simple but improved CNN structure, referencing to the famous models for our image classification, LeNet (1998) and AlexNet (2012). We use CIFAR-10 dataset as input data to test our model. We demonstrate the possibility to get reasonable results with careful adjustment on hyper parameter without very deep network structure, which gives insights to other kinds of image recognition tasks based on simple CNN structure.

Index Terms

CNN, CIFAR-10, image classification

I. INTRODUCTION

IMAGE classification is the central problem in Machine Learning. The task of image classification is to identify which class an image belongs to a given number of options. There are many algorithms which use different approaches for recognition and classification task. A good image recognizer has the ability to detect the smallest details including all salient features. Convolutional Neural Networks has currently outperform most of the previous machine learning approaches in scope of image classification and become the state of art performance on various image datasets.

Image processing using CNN requires labeled images, and the labeling is done by human to ensure accuracy, so acquiring data is difficult. Besides, CNN requires a lot of data in order for the networks to be trained to a satisfied level.

CIFAR is one of the several labeled image datasets that are publicly available to provide machine learning practitioners and researchers benchmarking resources. This benchmarking sets allows comparison between image classification methods.

In this paper, we explore new CNN model with CIFAR-10 dataset. Methodology part will further elaborate the proposed network and implementation details, along with experiments to investigate impacts of parameters, finding the best combination. In last part we test performance using ROC curve, confusion matrix and simple test accuracy.

II. PROBLEM DEFINITION

The objective of the project is to approximate the accuracy and the value of loss function in CNN image classification by trying different architectures of CNN and reach high classification performance. The following are some of the problems that we have to face throughout the project.

Overfitting and underfitting problems often happen in both data mining and machine learnings. In overfitting, the classifier may be too biased to the training set and data and it will cause the wrong result of the testing data since it will fit too much data of the training samples. Regarding to the underfitting problem, the model is not trained enough and it ignores some of the important information of the model. It may make a wrong decision.

In addition, there is performance problem. It is one of the biggest problems which we need to handle. Since born of Alexnet in 2012, deep learning, specifically CNN experience massive advancement in

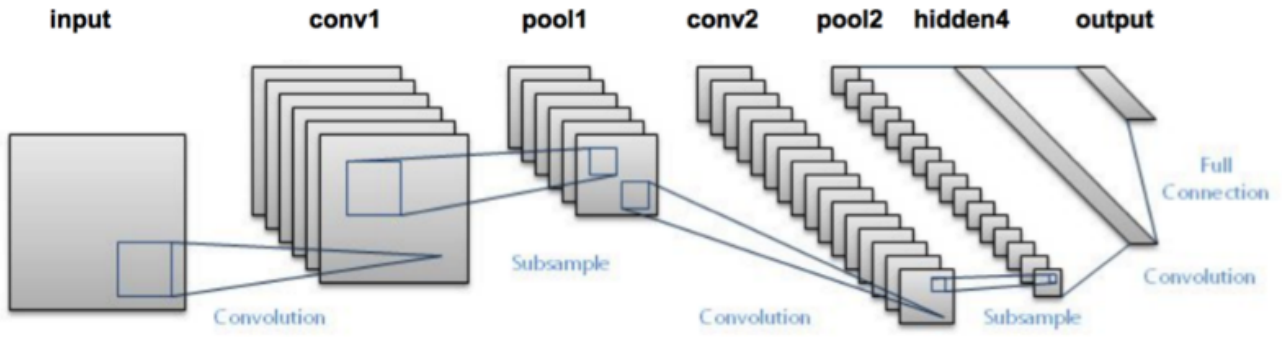


Fig. 1. LeNet

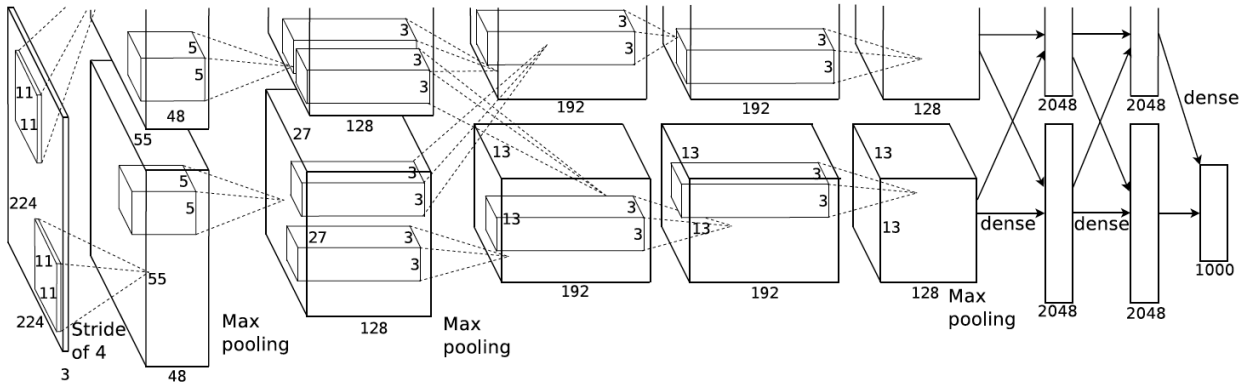


Fig. 2. AlexNet

complexity of neural network, leading models like VGGNet (2014), GoogleNet (2014), ResNet (2015) use much more layers, as high as 152 layers. These models are computationally expensive to calculate as it requires extensive memory and longer time to converge. Single GPU is incapable to handle these networks in reasonable amount of time. Therefore, it is worth exploring potential of simple CNN networks like Alexnet, targeting simple image classification tasks.

Based on performance, overfitting and underfitting problems, modification goes both with changing its architecture (e.g. the number of layers, adding or removing auxiliary layers like dropout or batch normalization) and tuning its parameters. This report aims to investigate the following:

Can the performance of the image classification performance be improved by tuning its parameters on limited layers? How is the CNN performance affected by changing its architecture (e.g. the number of layers)?

III. METHODOLOGY

We consider and reference TWO famous Models, LeNet and AlexNet in our project. LeNet is one of the very first convolutional neural networks, and what propelled the field of Deep Learning. Alexnet is a Deep Convolutional Neural Network for image classification that won the ILSVRC-2012 competition and achieved a winning top-5 test error rate of 15.3%.

A. Previous works



Fig. 3. CIFAR-10 sample image

1) *LeNet Architecture (1998)*: LeNet-5 contains a pioneering 7-level convolutional network by LeCun et al in 1998, that classifies digits, was applied by several banks to recognise handwritten numbers on checks (cheques) digitized in 32x32 pixel images.

2) *AlexNet Architecture (2012)*: AlexNet contains 5 convolutional layers and 3 fully connected layers, total 8 levels. Relu is applied after very convolutional and fully connected layer. Dropout is applied before the first and the second fully connected layer.

We first created the network based on AlexNet architecture when defining the various layers of the network. Several experiments are performed to find possible optimization direction. In every experiment, a hyperparameter is tested for different numbers of convolution layers. Only one parameters will be changed in a experiment, other variables such as number of training iterations, batch sizes, learning curve, etc. remain unchanged. Alexnet is used as baseline model for comparison.

B. Preprocessing

The CIFAR-10 dataset consists of 60,000 32x32 colour images in 10 classes, with 6,000 images per class. There are 50,000 training images and 10000 test images, that is the dataset is divided into five training batches and one test batch. We use all data for training and testing.

Before training the model with the dataset, images are preprocessed in three operations consecutively - randomly flip the image horizontally, randomly adjust the brightness and contrast. Image inputs are also standardized by formula $(x - \text{mean}) / \text{adjusted stddev}$, where stddev is standard deviation of 3 channels. Data standardization ensures that each input parameter has a similar data distribution and makes convergence faster while training the network. Rescaling is another way to normalize the images but standardization works better for images as they assume features to have a gaussian form. After all, the training data is randomly shuffled before feeding into model.

C. Network Architecture

The common form of the layers stacks a CONV—BATCH NORMALIZATION—RELU layer, follow by pooling layer. There are 3 groups of layer stacks in the network. The chosen size of kernel filters for convolution and pooling filter size are all 3x3, where all conv filters have stride 1 and pooling filters have stride 1 or 2. Repeat this pattern until has been merged spatially to a small size. At this point, it transits to an fully connected layer of size 1024. The last fully connected layer of size 10, corresponding to 10 possible image classes, holds the output with softmax layer to compute probability for each class.

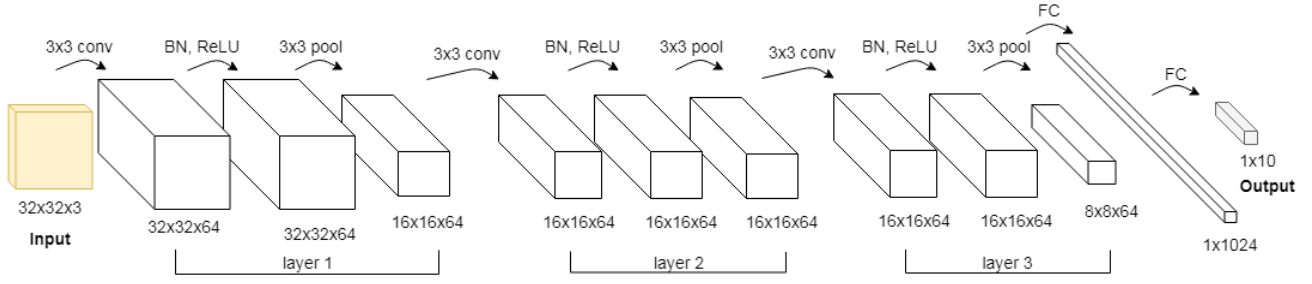


Fig. 4. Proposed network. The numbers below blocks show data size, text above arrows show type of operation.

IV. EXPERIMENTS

To explore the full potential of simple CNN structure, we tested the network by assignment one hyper parameter as variable in each experiment set, other parameters are kept constant. We use all training data in Cifar10 for training model. The loss function is defined as sparse softmax cross entropy between softmax outputs and labels. The numbers in tables below are computed from accuracy of cross validation training data. We stop running model after accuracy stop increasing and loss stop decreasing.

The experiments are split to 2 large groups, one is without batch normalization(BN), another with BN. Since BN is the major regularization operation in our model, it is meaningful to see if existence of BN affects parameter adjustment. All tests carried out using single GeForce GTX 1080 Ti GPU, under Windows/Linux platform.

A. Changing Convolutional Kernel (without BN)

Iteration	2 convolution layers			3 convolution layers			4 convolution layers	5 convolution layers
	2x2	3x3	5x5	5,5,3	5,3,3	3,3,3	5,5,3,3	5,5,3,3,3
5k	0.2	0.38	0.52	0.38	0.35	0.48	0.38	0.38
10k	0.31	0.37	0.54	0.42	0.53	0.6	0.45	0.5
15k	0.33	0.36	0.54	0.55	0.55	0.63	0.45	0.5
20k					0.65	0.68	0.47	0.55

B. Changing Pooling Window (without BN)

Iteration	3 convolution layers			4 convolution layers
	3,3,2	2,2,2	3,3,3	3x3x0x3
5k	0.37	0.39	0.53	0.35
10k	0.56	0.48	0.63	0.5
15k	0.62	0.51	0.66	0.5
20k			0.67	0.5

C. Changing batch size (without BN)

Iteration	32	64	128
5k	0.46	0.57	0.53
10k	0.55	0.61	0.63
15k	0.6	0.64	0.66
20k	0.62	0.61	0.67

D. Pooling In Different Layers(without BN)

Iteration	3 convolution layer				
	Pooling every layer	no pool after 1st layer	no pool after 2nd layer	no pool after 3rd layer	
5k	0.60	0.51	0.58	0.58	
10k	0.60	0.54	0.61	0.60	
15k	0.66	0.58	0.63	0.63	
test accuracy	0.61	0.54	0.61	0.56	

E. Changing batch norm position (with BN)

Iteration	3 convolution layer					4 convolution layer
	no BN after 1st layer	no BN after 1st, 2nd layer	no BN after 3rd layer	all layers with BN	all layers without BN	all layers with BN
5k	0.70	0.60	0.73	0.74	0.38	0.73
10k	0.75	0.62	0.77	0.82	0.48	0.8
15k	0.8	0.65	0.81	0.84	0.56	0.83
20k	0.81	0.68	0.86	0.86	0.62	0.85
test accuracy	0.69	0.55	0.78	0.80	0.48	0.77

F. Changing batch size (with BN)

Iteration	32	100	256	512
5k	0.5	0.73	0.83	0.90
10k	0.57	0.8	0.9	0.92
15k	0.65	0.83	0.93	0.93
20k	0.69	0.85	0.93	
test accuracy	0.59	0.77	0.80	0.81

G. Changing convolution (with BN)

Iteration	2 convolution layers		3 convolution layers			4 convolution layers		
	2x2	3x3	2x2	3x3	5x5	2x2x2x2	3x3x3x3	5x5x5x5
5k	0.78	0.76	0.76	0.79	0.75	0.68	0.73	0.7
10k	0.86	0.84	0.82	0.84	0.83	0.75	0.8	0.75
15k	0.86	0.86	0.86	0.87	0.85	0.78	0.83	0.8
20k		0.90		0.9		0.8	0.85	0.83
test accuracy	0.74	0.76	0.76	0.81	0.79	0.74	0.77	0.77

H. Changing learning rate (with BN)

Iteration	0.01	0.002	0.005	0.0005
5k	0.5	0.78	0.73	0.84
10k	0.68	0.88	0.83	0.88
15k	0.71	0.91	0.85	0.92
20k	0.73	0.93	0.91	0.91
test accuracy	0.71	0.81	0.79	0.79

V. ANALYSIS

A. Convolution

From experiment result, if the network has no batch normalization layer, generally 3 convolution layers is better than other number of layers. For 3 convolution layers, three 3x3 filters has better performance compared to other combination containing 5x5 filters. When batch normalization is applied, the variation in number of convolution layers do not make large difference, but generally 2 and 3 layers is better than 4 layers, where 3 layers with three 3x3 kernel size filters converge fastest. The result is same as without BN.

From results, we observe that model favours smaller filter size 3x3, this may be related to the input image size. Since all image sizes are 32x32, and later reduced to 16x16 / 8x8, 3x3 can effectively extract more features than 5x5, so the cross-validation accuracy is higher. Result also shows 3 layers should be complex enough for finding patterns in small size images, higher number of layers do not benefit.

B. Pooling

We tested pooling with different filter size and pooling position. In theory, pooling can reduce redundancy in image by throwing away local positional information. With translation invariance effect, pooling can keep the major features of images even there are minor distortions locally. It effectively reduce computation complexity.

Result shows model with more pooling layers perform better than less pooling, within same amount of iteration, more pooling enhance convergence and raise accuracy. Besides, 3x3 filter size performs little better than other sizes, but difference is not great. Therefore our model choose all 3x3 pooling size.

C. Batch Normalization & Dropout

When we feed data to model, feature scaling is an important preprocessing step, for i) reduce dependencies among features, ii) equalize average and variance for each feature. Since deep learning network has many layers stack together, distribution of each layers inputs changes when parameter of previous layer changes. This violates the assumption that source domain has the same distribution as target domain in statistical machine learning. We can refer this effect as Internal Covariate Shift (ICS). [4]

Batch normalization normalizes the activation of the previous layer at each batch. It uses mini-batch statistics. For all values of x over mini-batch $\{x_1, \dots, x_m\}$, it calculates mini-batch mean and variance, learns rescale and re-shift parameters. Batch normalization first normalize data to distribution of average 0, variance 1 for each feature, then rescale and reshift the output data. [4] BN solves the gradient explosion and vanishing problem in back propagation, by eliminating the effect of weight scale. It significantly speeds up training, and the number of training steps is near constant. Without batch normalization the number of training steps increases with each subsequent layer.

In our case, batch normalization acts as a regularizer and eliminates the need of using dropout. Dropout is typically used to reduce overfitting but batch normalization fulfills some of the goals as dropout. Dropout did not show any impact on performance after using batch normalization. The training network no longer producing deterministic values for the training dataset. Our experiment results match with the findings from [1]. Without using batch normalization, the accuracy are significantly lower than that of those used batch normalization, no matter it is used in which layer. Batch normalization in all layers give the highest accuracy around 80%, while missing batch normalization in any layer reduce accuracy significantly.

D. Batch Size

We tested different batch size with and without batch normalization to see effect of batch size. 4 batch size values are selected 32,64,128,256. In case without BN, higher batch size has slightly higher accuracy and faster converge, but difference is not significant. With BN, the raise in cross-validation accuracy

is more significant from batch size 32 to 256/512. The reason is that our model rely on mini-batch normalization, and BN do not work well when batch size is too small because it do not have accurate enough batch statistics to normalize data in each layer.

Although large batch size seems to provide better result, it is not always appropriate to use largest possible batch size. When batch size larger, though it increases data processing speed, it takes more time for each iteration, therefore to achieve same accuracy larger batch size may consume more time. However, when batch size too small, convergence is not stable. So we need to strike balance in batch size to get optimal time consumption. Our choice is batch size equals to 256.

E. Learning rate

When learning rate too high, convergence curve tends to be unstable, loss value easily explode. When learning rate too slow, model easily overfit training data, and converge very slowly. Inappropriate learning rate will let model converge to local minima with zero gradient. To avoid the issue, we start from higher learning rate to gain convergence speed, and then gradually decrease learning rate to stabilize curve. Result shows under 3 convolution layers with BN, initial learning rate 0.002 is best learning rate for convergence. To enhance convergence, we add decay factor and decay epoch to gradually decrease learning rate with increasing epoch.

VI. PERFORMANCE

After list of experiments on tuning parameter, we finalized the model as stated in methodology part and evaluate performance in depth. The model is evaluated with top1 accuracy, RMSE and confusion matrix. The best model is evaluated 3 times to take average values. The model is evaluated under learning rate 0.002, learning rate decay epoch 8000, learning rate decay factor 0.96, batch size 256. The result is obtained after 25k iterations, around 35 mins.

The top-1 test accuracy of model is 82%, root mean square error is 3.0491.

Since the overall accuracy cannot reveal the models individual performances on each class, to further analyse this, confusion matrix and f score are calculated as below.

$$\text{Confusion matrix} = \begin{bmatrix} 874 & 11 & 32 & 22 & 8 & 7 & 8 & 4 & 27 & 7 \\ 9 & 923 & 5 & 7 & 1 & 3 & 3 & 1 & 14 & 34 \\ 55 & 3 & 730 & 64 & 48 & 44 & 37 & 12 & 7 & 0 \\ 24 & 4 & 64 & 647 & 52 & 113 & 60 & 18 & 6 & 11 \\ 13 & 2 & 52 & 55 & 759 & 33 & 31 & 48 & 7 & 0 \\ 7 & 1 & 41 & 160 & 23 & 719 & 17 & 22 & 3 & 7 \\ 4 & 4 & 32 & 59 & 17 & 25 & 850 & 2 & 4 & 3 \\ 7 & 3 & 27 & 37 & 26 & 59 & 6 & 828 & 2 & 5 \\ 66 & 29 & 15 & 15 & 6 & 10 & 5 & 1 & 835 & 19 \\ 20 & 64 & 6 & 12 & 4 & 4 & 6 & 3 & 19 & 862 \end{bmatrix}$$

	airplane	automobile	bird	cat	deer	dog	frog	horse	ship	truck
accuracy	0.9669	0.9802	0.9456	0.9217	0.9574	0.9423	0.9678	0.9717	0.9746	0.9776
recall	0.874	0.923	0.73	0.648	0.759	0.72	0.85	0.828	0.835	0.862
precision	0.81	0.88	0.727	0.605	0.804	0.708	0.832	0.882	0.904	0.909
f score	0.841	0.903	0.729	0.62	0.781	0.71	0.841	0.854	0.868	0.885
MCC	0.085	0.091	0.07	0.060	0.074	0.0687	0.083	0.0816	0.083	0.085

We observe that the overall precision of classes are among 60-90%, on average around 80%. The most difficult class to classify is cat, second difficult one is dog. F-score is weighted average of precision and recall rate. Using F-score, the best classified class is automobile. ROC curve and Matthew Correlation Coefficient (MCC) also show the same results. From confusion matrix, we can see that diagonal matrix

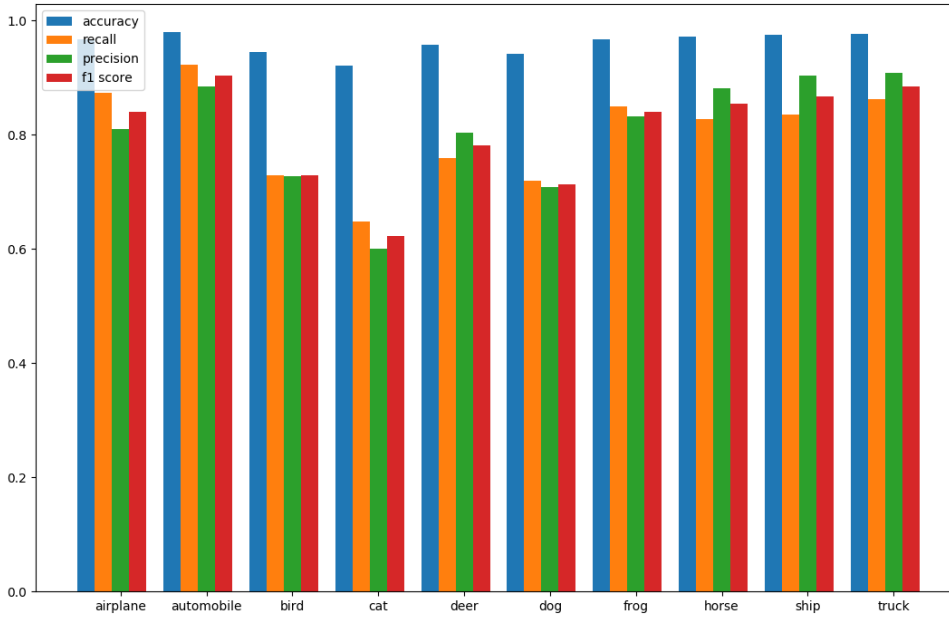


Fig. 5. Performance statistics

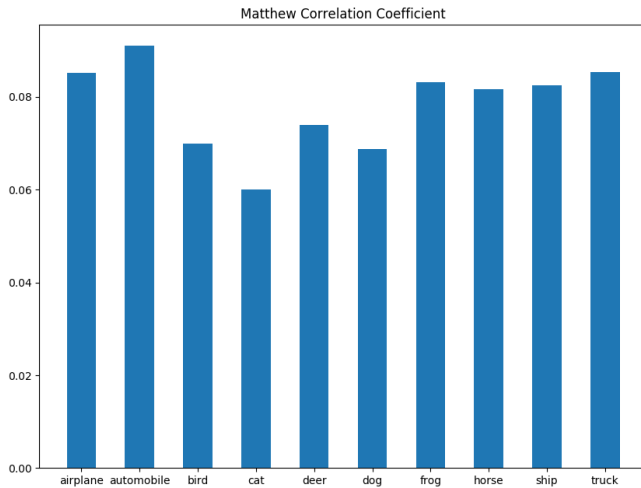


Fig. 6. Matthew Correlation Coefficient

values are much larger than others, implying that model is quite robust not only finding correct classification, but also exclude wrong classification to avoid false positive and false negative. Overall the performance among classes do not differ a lot, more than half of classes has higher than 80% of precision of F-score, the model proven to give reasonable result.

Comparing to our baseline model Alexnet, from various implements of Alexnet over dataset Cifar10, the test accuracies are ranging from 76-82%. [5], [6] Our models accuracy is comparable to Alexnet with less layers. We also made two modifications, using batch normalization to replace dropout layer in Alexnet, use decaying learning rate to replace static learning rate, and smaller number of neurons involved.

VII. CONCLUSION

The results in this paper suggest that simple CNN network structure is a promising approach for many image classification tasks, specifically with small image sizes. Our proposed network can train with fewer

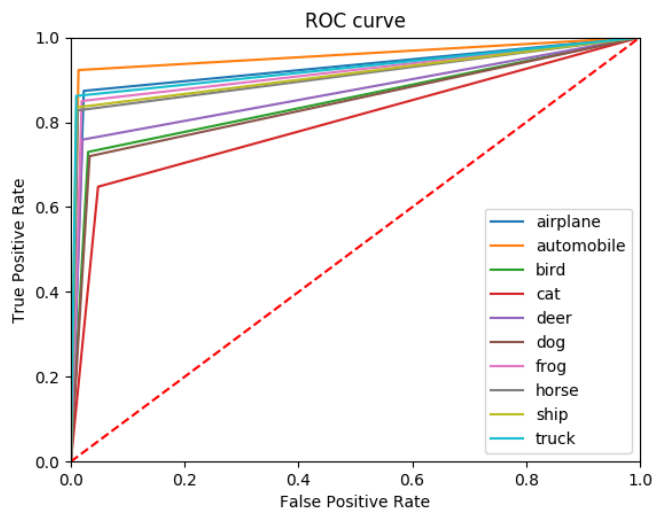


Fig. 7. ROC curve

resources but still achieve satisfactory result, which makes simple image classification tasks easier to handle.

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LEE Tak Chun	Report - Introduction, Problem Definition Code - Provide the information for the different combinations of the model
AU Tsz Man	Report - Abstract, Introduction, Problem Definition, Methodology, Analysis Code - participate in creating the basis of the model
LAI Chun Leung	Report - Experiment Code - Try different combinations of the model, train and test the model
LEE Chun Kit Edwin	Report - Methodology, Experiment, Analysis, Conclusion Code - Creating the basis of the model, Try different combinations of the model, train and test the model
CHEUNG Yuen Ting	Report - Abstract, Introduction, Problem Definition, Methodology Code - Test different kinds of Image Preprocessing

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