IBM Machine Learning

Course 5: Deep Learning

Topic: CIFAR-10 Data

1. Introduction

We will work ont he famouse CIFAR-10 dataset, which consists of 60000 32x32 color images. The dataset can be split into 50k training image and 10k validation images.
The objective is to classify the images to 10 different classes. The 10 classes are:

0. airplane
1. automobile
2. bird
3. cat
4. deer
5. dog
6. frog
7. horse
8. ship
9. truck

2. Explorative Data Analysis

2.1 CIFAR data

In [45]:
```
## load the data
from keras.datasets import cifar10
import numpy as np

import matplotlib.pyplot as plt
import keras
from tensorflow.keras.preprocessing.image import ImageDataGenerator
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense, Dropout, Activation, Flatten
from tensorflow.keras.layers import Conv2D, MaxPooling2D
from tensorflow.keras.optimizers import Adam, SGD, RMSprop
import warnings

warnings.filterwarnings('ignore')
```

In [46]:
```
# class list
class_list=['airplane', 'automobile', 'bird', 'cat', 'deer',
            'dog', 'frog', 'horse', 'ship', 'truck']
```

In [47]:
```
(x_train, y_train), (x_test, y_test)=cifar10.load_data()
```

In [48]:
```
## the size of training and test set
print('x_train shape:', x_train.shape)
print(x_train.shape[0], 'train samples')
print(x_test.shape[0], 'test samples')
```

```
x_train shape: (50000, 32, 32, 3)
50000 train samples
10000 test samples
```

In [49]:
```
## randomly select one image from training set
selected=np.random.randint(50000)

print("The image selected is: ", selected)
```

```
The image selected is:  8486
```

In [50]:
```
int(y_train[selected])
```

Out[50]:
```
1
```

In [51]:
```
## Let's look at one of the images

print(class_list[int(y_train[selected])])
plt.imshow(x_train[selected])
plt.axis('off')
```

```
automobile
```

Out[51]:
```
(-0.5, 31.5, 31.5, -0.5)
```

2.2 Data preprocess

In [52]:
```
# Let's make everything float and scale
x_train = x_train.astype('float32')
x_test = x_test.astype('float32')
x_train /= 255
x_test /= 255
```

In [53]:
```
# The distribution of class in test set
unique, counts = np.unique(y_test, return_counts=True)
dict(zip(unique, counts))
```

Out[53]:
```
{0: 1000,
 1: 1000,
 2: 1000,
 3: 1000,
 4: 1000,
 5: 1000,
 6: 1000,
 7: 1000,
 8: 1000,
 9: 1000}
```

3. Build Model

3.1 Get a baseline performance using Random Forest

In [54]:
```
## flatten our data
x_train_flat=x_train.reshape(len(x_train), -1)
x_test_flat=x_test.reshape(len(x_test), -1)
```

In [55]:
```
## the size of training
print('x_train_flat shape:', x_train_flat.shape)
```

```
x_train_flat shape: (50000, 3072)
```

In [56]:
```
## the size of testing
print('x_test_flat shape:', x_test_flat.shape)
```

```
x_test_flat shape: (10000, 3072)
```

In [57]:
```
import datetime
#used to help some of the timing functions
now = datetime.datetime.now
```

In [58]:
```
from sklearn.metrics import confusion_matrix, precision_recall_curve, roc_auc_score, roc_curve, accurac
y_score
from sklearn.ensemble import RandomForestClassifier

## Train the RF Model
t = now()
rf_model = RandomForestClassifier(n_estimators=200)
rf_model.fit(x_train_flat, y_train)
print('Training time: %s' % (now() - t))
```

```
Training time: 0:06:34.270555
```

In [59]:
```
# Make predictions on the test set - both "hard" predictions, and the scores (percent of trees voting y
es)
y_pred_class_rf = rf_model.predict(x_test_flat)
y_pred_prob_rf = rf_model.predict_proba(x_test_flat)


print('accuracy is {:.3f}'.format(accuracy_score(y_test,y_pred_class_rf)))
```

```
accuracy is 0.485
```

In [60]:
```
confusion_matrix(y_test,y_pred_class_rf)
```

Out[60]:
```
array([[570,  38,  52,  21,  36,  18,  26,  22, 160,  57],
       [ 29, 546,  16,  33,  15,  28,  43,  28,  62, 200],
       [ 90,  45, 349,  72, 142,  67, 124,  50,  33,  28],
       [ 50,  43,  68, 289,  71, 183, 144,  57,  22,  73],
       [ 58,  15, 143,  58, 400,  47, 155,  80,  21,  23],
       [ 26,  26,  83, 141,  83, 414,  86,  82,  28,  31],
       [ 11,  38,  70,  73,  92,  54, 597,  21,   5,  39],
       [ 43,  36,  43,  59, 102,  73,  46, 479,  23,  96],
       [ 87,  87,  17,  28,  19,  33,   9,  22, 628,  70],
       [ 39, 153,  20,  33,  18,  24,  24,  36,  78, 575]], dtype=int64)
```

As we can see above, the training time is long and the accuracy is quite low(less than 50%)

3.2 Build a full connected neural network

In [61]:
```
num_classes = 10

y_train = keras.utils.to_categorical(y_train, num_classes)
y_test = keras.utils.to_categorical(y_test, num_classes)
```

In [62]:
```
model_1=Sequential()
model_1.add(Dense(100,input_shape=(3072,), activation='sigmoid'))
model_1.add(Dense(10,activation='softmax'))
```

In [63]:
```
model_1.summary()
```

```
Model: "sequential_4"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_8 (Dense)              (None, 100)               307300
_________________________________________________________________
dense_9 (Dense)              (None, 10)                1010
=================================================================
Total params: 308,310
Trainable params: 308,310
Non-trainable params: 0
_________________________________________________________________
```

In [74]:
```
t = now()

# Compile the model with Optimizer, Loss Function and Metrics
opt_1 = keras.optimizers.RMSprop(lr=0.0005)

model_1.compile(optimizer=opt_1, loss="categorical_crossentropy", metrics=["accuracy"])
run_hist_1 = model_1.fit(x_train_flat, y_train, validation_data=(x_test_flat, y_test), epochs=200)

print('Training time: %s' % (now() - t))
```

```
Epoch 1/200
1563/1563 [==============================] - 7s 5ms/step - loss: 1.7753 - accuracy: 0.3732 - val_los
s: 1.8364 - val_accuracy: 0.3599
Epoch 2/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.7714 - accuracy: 0.3757 - val_los
s: 1.8379 - val_accuracy: 0.3595
Epoch 3/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.7708 - accuracy: 0.3762 - val_los
s: 1.8450 - val_accuracy: 0.3596
Epoch 4/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.7662 - accuracy: 0.3793 - val_los
s: 1.8249 - val_accuracy: 0.3642
Epoch 5/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.7632 - accuracy: 0.3775 - val_los
s: 1.8341 - val_accuracy: 0.3648
Epoch 6/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.7604 - accuracy: 0.3805 - val_los
s: 1.8345 - val_accuracy: 0.3594
Epoch 7/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.7570 - accuracy: 0.3825 - val_los
s: 1.8225 - val_accuracy: 0.3676
Epoch 8/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.7573 - accuracy: 0.3823 - val_los
s: 1.8215 - val_accuracy: 0.3632
Epoch 9/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.7509 - accuracy: 0.3845 - val_los
s: 1.8144 - val_accuracy: 0.3664
Epoch 10/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.7487 - accuracy: 0.3873 - val_los
s: 1.8236 - val_accuracy: 0.3596
Epoch 11/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.7448 - accuracy: 0.3875 - val_los
s: 1.8130 - val_accuracy: 0.3689
Epoch 12/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.7406 - accuracy: 0.3887 - val_los
s: 1.8159 - val_accuracy: 0.3625
Epoch 13/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.7396 - accuracy: 0.3897 - val_los
s: 1.8114 - val_accuracy: 0.3708
Epoch 14/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.7369 - accuracy: 0.3902 - val_los
s: 1.8179 - val_accuracy: 0.3690
Epoch 15/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.7315 - accuracy: 0.3928 - val_los
s: 1.8024 - val_accuracy: 0.3760
Epoch 16/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.7293 - accuracy: 0.3943 - val_los
s: 1.8054 - val_accuracy: 0.3730
Epoch 17/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.7259 - accuracy: 0.3965 - val_los
s: 1.8081 - val_accuracy: 0.3699
Epoch 18/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.7230 - accuracy: 0.3946 - val_los
s: 1.7994 - val_accuracy: 0.3782
Epoch 19/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.7208 - accuracy: 0.3990 - val_los
s: 1.8170 - val_accuracy: 0.3729
Epoch 20/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.7182 - accuracy: 0.3979 - val_los
s: 1.7920 - val_accuracy: 0.3760
Epoch 21/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.7152 - accuracy: 0.4010 - val_los
s: 1.8056 - val_accuracy: 0.3778
Epoch 22/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.7113 - accuracy: 0.4038 - val_los
s: 1.7907 - val_accuracy: 0.3775
Epoch 23/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.7079 - accuracy: 0.4007 - val_los
s: 1.7980 - val_accuracy: 0.3812
Epoch 24/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.7059 - accuracy: 0.4023 - val_los
s: 1.7958 - val_accuracy: 0.3803
Epoch 25/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.7042 - accuracy: 0.4051 - val_los
s: 1.7860 - val_accuracy: 0.3843
Epoch 26/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6995 - accuracy: 0.4069 - val_los
s: 1.7882 - val_accuracy: 0.3825
Epoch 27/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6978 - accuracy: 0.4072 - val_los
s: 1.7851 - val_accuracy: 0.3793
Epoch 28/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.6955 - accuracy: 0.4089 - val_los
s: 1.7939 - val_accuracy: 0.3811
Epoch 29/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.6946 - accuracy: 0.4090 - val_los
s: 1.7917 - val_accuracy: 0.3860
Epoch 30/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.6905 - accuracy: 0.4104 - val_los
s: 1.7914 - val_accuracy: 0.3749
Epoch 31/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.6873 - accuracy: 0.4111 - val_los
s: 1.7907 - val_accuracy: 0.3866
Epoch 32/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.6811 - accuracy: 0.4156 - val_los
s: 1.8059 - val_accuracy: 0.3841
Epoch 33/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.6765 - accuracy: 0.4174 - val_los
s: 1.7768 - val_accuracy: 0.3865
Epoch 34/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.6713 - accuracy: 0.4185 - val_los
s: 1.7791 - val_accuracy: 0.3921
Epoch 35/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.6693 - accuracy: 0.4215 - val_los
s: 1.7829 - val_accuracy: 0.3840
Epoch 36/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.6683 - accuracy: 0.4213 - val_los
s: 1.7931 - val_accuracy: 0.3933
Epoch 37/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.6627 - accuracy: 0.4234 - val_los
s: 1.7589 - val_accuracy: 0.4036
Epoch 38/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.6614 - accuracy: 0.4227 - val_los
s: 1.7588 - val_accuracy: 0.3979
Epoch 39/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.6592 - accuracy: 0.4263 - val_los
s: 1.7726 - val_accuracy: 0.3939
Epoch 40/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.6545 - accuracy: 0.4277 - val_los
s: 1.7608 - val_accuracy: 0.3974
Epoch 41/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.6552 - accuracy: 0.4263 - val_los
s: 1.7616 - val_accuracy: 0.3961
Epoch 42/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.6516 - accuracy: 0.4284 - val_los
s: 1.7589 - val_accuracy: 0.3976
Epoch 43/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6497 - accuracy: 0.4285 - val_los
s: 1.7775 - val_accuracy: 0.3979
Epoch 44/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6455 - accuracy: 0.4294 - val_los
s: 1.7616 - val_accuracy: 0.4044
Epoch 45/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6449 - accuracy: 0.4309 - val_los
s: 1.7745 - val_accuracy: 0.3997
Epoch 46/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6446 - accuracy: 0.4332 - val_los
s: 1.7648 - val_accuracy: 0.3958
Epoch 47/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6416 - accuracy: 0.4331 - val_los
s: 1.7610 - val_accuracy: 0.3998
Epoch 48/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6391 - accuracy: 0.4324 - val_los
s: 1.7561 - val_accuracy: 0.3945
Epoch 49/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6382 - accuracy: 0.4335 - val_los
s: 1.7722 - val_accuracy: 0.3981
Epoch 50/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6359 - accuracy: 0.4347 - val_los
s: 1.7564 - val_accuracy: 0.4027
Epoch 51/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6332 - accuracy: 0.4353 - val_los
s: 1.7558 - val_accuracy: 0.4016
Epoch 52/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6353 - accuracy: 0.4340 - val_los
s: 1.7559 - val_accuracy: 0.4004
Epoch 53/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6309 - accuracy: 0.4382 - val_los
s: 1.7531 - val_accuracy: 0.3997
Epoch 54/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6302 - accuracy: 0.4368 - val_los
s: 1.7627 - val_accuracy: 0.3930
Epoch 55/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6294 - accuracy: 0.4374 - val_los
s: 1.7664 - val_accuracy: 0.3967
Epoch 56/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6270 - accuracy: 0.4383 - val_los
s: 1.7551 - val_accuracy: 0.4027
Epoch 57/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6239 - accuracy: 0.4379 - val_los
s: 1.7495 - val_accuracy: 0.4101
Epoch 58/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6228 - accuracy: 0.4383 - val_los
s: 1.7484 - val_accuracy: 0.4051
Epoch 59/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6220 - accuracy: 0.4389 - val_los
s: 1.7505 - val_accuracy: 0.4049
Epoch 60/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6183 - accuracy: 0.4392 - val_los
s: 1.7420 - val_accuracy: 0.4093
Epoch 61/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6174 - accuracy: 0.4405 - val_los
s: 1.7462 - val_accuracy: 0.4098
Epoch 62/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6169 - accuracy: 0.4415 - val_los
s: 1.7469 - val_accuracy: 0.4059
Epoch 63/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6140 - accuracy: 0.4415 - val_los
s: 1.7463 - val_accuracy: 0.4061
Epoch 64/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6119 - accuracy: 0.4436 - val_los
s: 1.7801 - val_accuracy: 0.4023
Epoch 65/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6119 - accuracy: 0.4418 - val_los
s: 1.7809 - val_accuracy: 0.3961
Epoch 66/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6080 - accuracy: 0.4448 - val_los
s: 1.7486 - val_accuracy: 0.4150
Epoch 67/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6061 - accuracy: 0.4421 - val_los
s: 1.7626 - val_accuracy: 0.3997
Epoch 68/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6052 - accuracy: 0.4443 - val_los
s: 1.7455 - val_accuracy: 0.4101
Epoch 69/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6050 - accuracy: 0.4448 - val_los
s: 1.7549 - val_accuracy: 0.4049
Epoch 70/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6037 - accuracy: 0.4448 - val_los
s: 1.7660 - val_accuracy: 0.4008
Epoch 71/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6027 - accuracy: 0.4461 - val_los
s: 1.7568 - val_accuracy: 0.4108
Epoch 72/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6000 - accuracy: 0.4478 - val_los
s: 1.7776 - val_accuracy: 0.4033
Epoch 73/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.6013 - accuracy: 0.4456 - val_los
s: 1.7602 - val_accuracy: 0.4126
Epoch 74/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5971 - accuracy: 0.4488 - val_los
s: 1.7679 - val_accuracy: 0.3958
Epoch 75/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5967 - accuracy: 0.4472 - val_los
s: 1.7799 - val_accuracy: 0.4002
Epoch 76/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5952 - accuracy: 0.4466 - val_los
s: 1.7412 - val_accuracy: 0.4064
Epoch 77/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5952 - accuracy: 0.4495 - val_los
s: 1.7412 - val_accuracy: 0.4044
Epoch 78/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5934 - accuracy: 0.4489 - val_los
s: 1.7488 - val_accuracy: 0.4083
Epoch 79/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5916 - accuracy: 0.4484 - val_los
s: 1.7437 - val_accuracy: 0.4100
Epoch 80/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5911 - accuracy: 0.4486 - val_los
s: 1.7842 - val_accuracy: 0.4001
Epoch 81/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5905 - accuracy: 0.4489 - val_los
s: 1.7744 - val_accuracy: 0.4113
Epoch 82/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5890 - accuracy: 0.4511 - val_los
s: 1.7774 - val_accuracy: 0.3965
Epoch 83/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5866 - accuracy: 0.4519 - val_los
s: 1.7413 - val_accuracy: 0.4068
Epoch 84/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5872 - accuracy: 0.4492 - val_los
s: 1.7353 - val_accuracy: 0.4130
Epoch 85/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5852 - accuracy: 0.4497 - val_los
s: 1.7641 - val_accuracy: 0.4103
Epoch 86/200
1563/1563 [==============================] - 7s 4ms/step - loss: 1.5850 - accuracy: 0.4511 - val_los
s: 1.7369 - val_accuracy: 0.4110
Epoch 87/200
1563/1563 [==============================] - 7s 4ms/step - loss: 1.5831 - accuracy: 0.4514 - val_los
s: 1.7397 - val_accuracy: 0.4083
Epoch 88/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5820 - accuracy: 0.4519 - val_los
s: 1.7731 - val_accuracy: 0.4015
Epoch 89/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5810 - accuracy: 0.4492 - val_los
s: 1.7452 - val_accuracy: 0.4117
Epoch 90/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5798 - accuracy: 0.4502 - val_los
s: 1.7639 - val_accuracy: 0.4077
Epoch 91/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5785 - accuracy: 0.4535 - val_los
s: 1.7573 - val_accuracy: 0.4008
Epoch 92/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5783 - accuracy: 0.4513 - val_los
s: 1.7611 - val_accuracy: 0.4135
Epoch 93/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5753 - accuracy: 0.4526 - val_los
s: 1.7617 - val_accuracy: 0.4085
Epoch 94/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5748 - accuracy: 0.4533 - val_los
s: 1.7625 - val_accuracy: 0.3946
Epoch 95/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5737 - accuracy: 0.4533 - val_los
s: 1.7971 - val_accuracy: 0.4034
Epoch 96/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5734 - accuracy: 0.4524 - val_los
s: 1.7784 - val_accuracy: 0.4091
Epoch 97/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5719 - accuracy: 0.4537 - val_los
s: 1.7541 - val_accuracy: 0.3980
Epoch 98/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5726 - accuracy: 0.4526 - val_los
s: 1.7499 - val_accuracy: 0.4050
Epoch 99/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5698 - accuracy: 0.4552 - val_los
s: 1.7507 - val_accuracy: 0.4035
Epoch 100/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5707 - accuracy: 0.4545 - val_los
s: 1.7452 - val_accuracy: 0.4119
Epoch 101/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5691 - accuracy: 0.4550 - val_los
s: 1.7272 - val_accuracy: 0.4162
Epoch 102/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5679 - accuracy: 0.4536 - val_los
s: 1.7612 - val_accuracy: 0.3999
Epoch 103/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5663 - accuracy: 0.4566 - val_los
s: 1.7401 - val_accuracy: 0.4124
Epoch 104/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5667 - accuracy: 0.4555 - val_los
s: 1.7727 - val_accuracy: 0.4004
Epoch 105/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5661 - accuracy: 0.4543 - val_los
s: 1.7521 - val_accuracy: 0.4147
Epoch 106/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5644 - accuracy: 0.4574 - val_los
s: 1.7428 - val_accuracy: 0.4125
Epoch 107/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5639 - accuracy: 0.4553 - val_los
s: 1.7601 - val_accuracy: 0.4103
Epoch 108/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5634 - accuracy: 0.4542 - val_los
s: 1.7645 - val_accuracy: 0.4035
Epoch 109/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5618 - accuracy: 0.4565 - val_los
s: 1.7324 - val_accuracy: 0.4164
Epoch 110/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5605 - accuracy: 0.4583 - val_los
s: 1.7436 - val_accuracy: 0.4111
Epoch 111/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5608 - accuracy: 0.4570 - val_los
s: 1.7548 - val_accuracy: 0.4166
Epoch 112/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5599 - accuracy: 0.4561 - val_los
s: 1.7500 - val_accuracy: 0.4136
Epoch 113/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5590 - accuracy: 0.4569 - val_los
s: 1.7451 - val_accuracy: 0.4081
Epoch 114/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5584 - accuracy: 0.4579 - val_los
s: 1.7352 - val_accuracy: 0.4071
Epoch 115/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5570 - accuracy: 0.4587 - val_los
s: 1.7414 - val_accuracy: 0.4120
Epoch 116/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5571 - accuracy: 0.4567 - val_los
s: 1.7536 - val_accuracy: 0.4079
Epoch 117/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5564 - accuracy: 0.4566 - val_los
s: 1.7513 - val_accuracy: 0.4054
Epoch 118/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5529 - accuracy: 0.4589 - val_los
s: 1.7357 - val_accuracy: 0.4167
Epoch 119/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5546 - accuracy: 0.4567 - val_los
s: 1.7779 - val_accuracy: 0.4043
Epoch 120/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5543 - accuracy: 0.4572 - val_los
s: 1.7536 - val_accuracy: 0.4056
Epoch 121/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5528 - accuracy: 0.4589 - val_los
s: 1.7670 - val_accuracy: 0.4045
Epoch 122/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5525 - accuracy: 0.4600 - val_los
s: 1.7615 - val_accuracy: 0.4069
Epoch 123/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5513 - accuracy: 0.4602 - val_los
s: 1.7469 - val_accuracy: 0.4145
Epoch 124/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5505 - accuracy: 0.4582 - val_los
s: 1.7449 - val_accuracy: 0.4114
Epoch 125/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5501 - accuracy: 0.4601 - val_los
s: 1.7653 - val_accuracy: 0.4150
Epoch 126/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5485 - accuracy: 0.4602 - val_los
s: 1.7530 - val_accuracy: 0.4100
Epoch 127/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5482 - accuracy: 0.4598 - val_los
s: 1.8053 - val_accuracy: 0.3922
Epoch 128/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5485 - accuracy: 0.4617 - val_los
s: 1.7721 - val_accuracy: 0.4122
Epoch 129/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5491 - accuracy: 0.4601 - val_los
s: 1.7802 - val_accuracy: 0.4111
Epoch 130/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5492 - accuracy: 0.4606 - val_los
s: 1.7479 - val_accuracy: 0.4158
Epoch 131/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5464 - accuracy: 0.4613 - val_los
s: 1.7580 - val_accuracy: 0.4018
Epoch 132/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5484 - accuracy: 0.4618 - val_los
s: 1.7623 - val_accuracy: 0.4126
Epoch 133/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5449 - accuracy: 0.4629 - val_los
s: 1.8178 - val_accuracy: 0.4029
Epoch 134/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5447 - accuracy: 0.4630 - val_los
s: 1.7783 - val_accuracy: 0.4064
Epoch 135/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5463 - accuracy: 0.4606 - val_los
s: 1.7805 - val_accuracy: 0.4046
Epoch 136/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5435 - accuracy: 0.4616 - val_los
s: 1.7468 - val_accuracy: 0.4184
Epoch 137/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5439 - accuracy: 0.4626 - val_los
s: 1.7811 - val_accuracy: 0.4074
Epoch 138/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5426 - accuracy: 0.4617 - val_los
s: 1.7743 - val_accuracy: 0.4043
Epoch 139/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5402 - accuracy: 0.4638 - val_los
s: 1.7563 - val_accuracy: 0.4158
Epoch 140/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5393 - accuracy: 0.4627 - val_los
s: 1.7738 - val_accuracy: 0.4108
Epoch 141/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5391 - accuracy: 0.4637 - val_los
s: 1.7505 - val_accuracy: 0.4111
Epoch 142/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5369 - accuracy: 0.4641 - val_los
s: 1.7794 - val_accuracy: 0.4039
Epoch 143/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5365 - accuracy: 0.4635 - val_los
s: 1.7590 - val_accuracy: 0.4081
Epoch 144/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5363 - accuracy: 0.4625 - val_los
s: 1.7358 - val_accuracy: 0.4120
Epoch 145/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5349 - accuracy: 0.4639 - val_los
s: 1.7710 - val_accuracy: 0.4104
Epoch 146/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5335 - accuracy: 0.4635 - val_los
s: 1.7428 - val_accuracy: 0.4092
Epoch 147/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5334 - accuracy: 0.4640 - val_los
s: 1.7604 - val_accuracy: 0.4065
Epoch 148/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5322 - accuracy: 0.4658 - val_los
s: 1.7377 - val_accuracy: 0.4199
Epoch 149/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5317 - accuracy: 0.4652 - val_los
s: 1.7622 - val_accuracy: 0.4036
Epoch 150/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5300 - accuracy: 0.4665 - val_los
s: 1.7730 - val_accuracy: 0.4073
Epoch 151/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5309 - accuracy: 0.4648 - val_los
s: 1.7722 - val_accuracy: 0.4085
Epoch 152/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5291 - accuracy: 0.4659 - val_los
s: 1.7544 - val_accuracy: 0.4206
Epoch 153/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5297 - accuracy: 0.4647 - val_los
s: 1.7698 - val_accuracy: 0.4030
Epoch 154/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5288 - accuracy: 0.4666 - val_los
s: 1.7402 - val_accuracy: 0.4175
Epoch 155/200
1563/1563 [==============================] - 7s 4ms/step - loss: 1.5269 - accuracy: 0.4672 - val_los
s: 1.7677 - val_accuracy: 0.4088
Epoch 156/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5266 - accuracy: 0.4685 - val_los
s: 1.7678 - val_accuracy: 0.4080
Epoch 157/200
1563/1563 [==============================] - 7s 5ms/step - loss: 1.5242 - accuracy: 0.4665 - val_los
s: 1.7380 - val_accuracy: 0.4167
Epoch 158/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5248 - accuracy: 0.4676 - val_los
s: 1.7763 - val_accuracy: 0.4044
Epoch 159/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5261 - accuracy: 0.4672 - val_los
s: 1.7697 - val_accuracy: 0.4007
Epoch 160/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5246 - accuracy: 0.4678 - val_los
s: 1.7637 - val_accuracy: 0.4041
Epoch 161/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5238 - accuracy: 0.4672 - val_los
s: 1.8007 - val_accuracy: 0.3998
Epoch 162/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5223 - accuracy: 0.4684 - val_los
s: 1.7691 - val_accuracy: 0.4040
Epoch 163/200
1563/1563 [==============================] - 6s 4ms/step - loss: 1.5210 - accuracy: 0.4694 - val_los
s: 1.7559 - val_accuracy: 0.4189
Epoch 164/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5215 - accuracy: 0.4687 - val_los
s: 1.7640 - val_accuracy: 0.4120
Epoch 165/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5196 - accuracy: 0.4692 - val_los
s: 1.7571 - val_accuracy: 0.4075
Epoch 166/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5192 - accuracy: 0.4688 - val_los
s: 1.8014 - val_accuracy: 0.3929
Epoch 167/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5191 - accuracy: 0.4700 - val_los
s: 1.7407 - val_accuracy: 0.4191
Epoch 168/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5183 - accuracy: 0.4698 - val_los
s: 1.7611 - val_accuracy: 0.4081
Epoch 169/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5181 - accuracy: 0.4694 - val_los
s: 1.7514 - val_accuracy: 0.4132
Epoch 170/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5175 - accuracy: 0.4683 - val_los
s: 1.7457 - val_accuracy: 0.4151
Epoch 171/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5174 - accuracy: 0.4699 - val_los
s: 1.7496 - val_accuracy: 0.4116
Epoch 172/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5172 - accuracy: 0.4703 - val_los
s: 1.7909 - val_accuracy: 0.4140
Epoch 173/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5141 - accuracy: 0.4706 - val_los
s: 1.7446 - val_accuracy: 0.4165
Epoch 174/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5139 - accuracy: 0.4713 - val_los
s: 1.7878 - val_accuracy: 0.4068
Epoch 175/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5136 - accuracy: 0.4712 - val_los
s: 1.7577 - val_accuracy: 0.4127
Epoch 176/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5128 - accuracy: 0.4707 - val_los
s: 1.7484 - val_accuracy: 0.4103
Epoch 177/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5130 - accuracy: 0.4714 - val_los
s: 1.8095 - val_accuracy: 0.4026
Epoch 178/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5106 - accuracy: 0.4711 - val_los
s: 1.7601 - val_accuracy: 0.4184
Epoch 179/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5103 - accuracy: 0.4728 - val_los
s: 1.7458 - val_accuracy: 0.4156
Epoch 180/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5105 - accuracy: 0.4714 - val_los
s: 1.7469 - val_accuracy: 0.4165
Epoch 181/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5086 - accuracy: 0.4721 - val_los
s: 1.8107 - val_accuracy: 0.4093
Epoch 182/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5095 - accuracy: 0.4738 - val_los
s: 1.7556 - val_accuracy: 0.4114
Epoch 183/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5067 - accuracy: 0.4735 - val_los
s: 1.7903 - val_accuracy: 0.4042
Epoch 184/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5065 - accuracy: 0.4736 - val_los
s: 1.7793 - val_accuracy: 0.4065
Epoch 185/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5060 - accuracy: 0.4751 - val_los
s: 1.7729 - val_accuracy: 0.4118
Epoch 186/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5063 - accuracy: 0.4729 - val_los
s: 1.7790 - val_accuracy: 0.3999
Epoch 187/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5021 - accuracy: 0.4756 - val_los
s: 1.7628 - val_accuracy: 0.4096
Epoch 188/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5027 - accuracy: 0.4746 - val_los
s: 1.7712 - val_accuracy: 0.4132
Epoch 189/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5016 - accuracy: 0.4773 - val_los
s: 1.8199 - val_accuracy: 0.3956
Epoch 190/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5003 - accuracy: 0.4761 - val_los
s: 1.7568 - val_accuracy: 0.4180
Epoch 191/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.5012 - accuracy: 0.4735 - val_los
s: 1.8485 - val_accuracy: 0.3959
Epoch 192/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.4985 - accuracy: 0.4759 - val_los
s: 1.7831 - val_accuracy: 0.4067
Epoch 193/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.4995 - accuracy: 0.4756 - val_los
s: 1.7515 - val_accuracy: 0.4168
Epoch 194/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.4974 - accuracy: 0.4747 - val_los
s: 1.7682 - val_accuracy: 0.4162
Epoch 195/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.4986 - accuracy: 0.4759 - val_los
s: 1.7533 - val_accuracy: 0.4206
Epoch 196/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.4972 - accuracy: 0.4775 - val_los
s: 1.8539 - val_accuracy: 0.3975
Epoch 197/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.4954 - accuracy: 0.4782 - val_los
s: 1.8442 - val_accuracy: 0.3968
Epoch 198/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.4975 - accuracy: 0.4768 - val_los
s: 1.7631 - val_accuracy: 0.4150
Epoch 199/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.4941 - accuracy: 0.4764 - val_los
s: 1.7488 - val_accuracy: 0.4108
Epoch 200/200
1563/1563 [==============================] - 5s 3ms/step - loss: 1.4930 - accuracy: 0.4783 - val_los
s: 1.7833 - val_accuracy: 0.4139
Training time: 0:18:59.958390
```

In [77]:
```
score = model_1.evaluate(x_test_flat, y_test, verbose=0)
print('Test score:', score[0])
print('Test accuracy:', score[1])
```

```
Test score: 1.783251166343689
Test accuracy: 0.4138999879360199
```

The full connection neural network perform slightly better than random forest. The accuray is similar to random forest. We can increase the hidden layers and number of epochs, however the time will increase too.

3.3 Convolutional Neural Network

In [65]:
```
model_2 = Sequential()

model_2.add(Conv2D(32, (3, 3), padding='same',
                   input_shape=x_train.shape[1:]))
model_2.add(Activation('relu'))
model_2.add(Conv2D(32, (3, 3)))
model_2.add(Activation('relu'))
model_2.add(MaxPooling2D(pool_size=(2, 2)))
model_2.add(Dropout(0.25))

model_2.add(Conv2D(64, (3, 3), padding='same'))
model_2.add(Activation('relu'))
model_2.add(Conv2D(64, (3, 3)))
model_2.add(Activation('relu'))
model_2.add(MaxPooling2D(pool_size=(2, 2)))
model_2.add(Dropout(0.25))

model_2.add(Flatten())
model_2.add(Dense(512))
model_2.add(Activation('relu'))
model_2.add(Dropout(0.5))
model_2.add(Dense(num_classes))
model_2.add(Activation('softmax'))
```

In [66]:
```
model_2.summary()
```

```
Model: "sequential_5"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_4 (Conv2D)            (None, 32, 32, 32)        896
_________________________________________________________________
activation_6 (Activation)    (None, 32, 32, 32)        0
_________________________________________________________________
conv2d_5 (Conv2D)            (None, 30, 30, 32)        9248
_________________________________________________________________
activation_7 (Activation)    (None, 30, 30, 32)        0
_________________________________________________________________
max_pooling2d_2 (MaxPooling2 (None, 15, 15, 32)        0
_________________________________________________________________
dropout_3 (Dropout)          (None, 15, 15, 32)        0
_________________________________________________________________
conv2d_6 (Conv2D)            (None, 15, 15, 64)        18496
_________________________________________________________________
activation_8 (Activation)    (None, 15, 15, 64)        0
_________________________________________________________________
conv2d_7 (Conv2D)            (None, 13, 13, 64)        36928
_________________________________________________________________
activation_9 (Activation)    (None, 13, 13, 64)        0
_________________________________________________________________
max_pooling2d_3 (MaxPooling2 (None, 6, 6, 64)          0
_________________________________________________________________
dropout_4 (Dropout)          (None, 6, 6, 64)          0
_________________________________________________________________
flatten_1 (Flatten)          (None, 2304)              0
_________________________________________________________________
dense_10 (Dense)             (None, 512)               1180160
_________________________________________________________________
activation_10 (Activation)   (None, 512)               0
_________________________________________________________________
dropout_5 (Dropout)          (None, 512)               0
_________________________________________________________________
dense_11 (Dense)             (None, 10)                5130
_________________________________________________________________
activation_11 (Activation)   (None, 10)                0
=================================================================
Total params: 1,250,858
Trainable params: 1,250,858
Non-trainable params: 0
_________________________________________________________________
```

In [67]:
```
batch_size = 32

# initiate RMSprop optimizer
opt_2 = keras.optimizers.RMSprop(lr=0.0005)

# Let's train the model using RMSprop
model_2.compile(loss='categorical_crossentropy',
              optimizer=opt_2,
              metrics=['accuracy'])
```

In [68]:
```
t = now()
model_2.fit(x_train, y_train,
              batch_size=batch_size,
              epochs=10,
              validation_data=(x_test, y_test),
              shuffle=True)
print('Training time: %s' % (now() - t))
```

```
Epoch 1/10
1563/1563 [==============================] - 121s 77ms/step - loss: 1.5786 - accuracy: 0.4241 - val_l
oss: 1.2191 - val_accuracy: 0.5587
Epoch 2/10
1563/1563 [==============================] - 121s 77ms/step - loss: 1.1826 - accuracy: 0.5803 - val_l
oss: 1.1232 - val_accuracy: 0.6035
Epoch 3/10
1563/1563 [==============================] - 122s 78ms/step - loss: 1.0084 - accuracy: 0.6490 - val_l
oss: 0.8676 - val_accuracy: 0.6975
Epoch 4/10
1563/1563 [==============================] - 121s 78ms/step - loss: 0.9088 - accuracy: 0.6838 - val_l
oss: 0.8868 - val_accuracy: 0.7032
Epoch 5/10
1563/1563 [==============================] - 121s 78ms/step - loss: 0.8552 - accuracy: 0.7069 - val_l
oss: 0.8810 - val_accuracy: 0.6986
Epoch 6/10
1563/1563 [==============================] - 121s 78ms/step - loss: 0.8237 - accuracy: 0.7176 - val_l
oss: 0.8932 - val_accuracy: 0.7008
Epoch 7/10
1563/1563 [==============================] - 122s 78ms/step - loss: 0.8139 - accuracy: 0.7250 - val_l
oss: 0.8127 - val_accuracy: 0.7383
Epoch 8/10
1563/1563 [==============================] - 123s 79ms/step - loss: 0.8150 - accuracy: 0.7280 - val_l
oss: 0.8685 - val_accuracy: 0.7352
Epoch 9/10
1563/1563 [==============================] - 123s 79ms/step - loss: 0.8285 - accuracy: 0.7278 - val_l
oss: 0.8039 - val_accuracy: 0.7467
Epoch 10/10
1563/1563 [==============================] - 122s 78ms/step - loss: 0.8387 - accuracy: 0.7237 - val_l
oss: 0.9243 - val_accuracy: 0.7309
Training time: 0:20:19.926330
```

In [78]:
```
score = model_2.evaluate(x_test, y_test, verbose=0)
print('Test score:', score[0])
print('Test accuracy:', score[1])
```

```
Test score: 0.9243311285972595
Test accuracy: 0.73089998960495
```

4. Conclusion

In this course, we learn different deep learning architecture. They are suitable for different task. Convolutional Neural network is very good in image classfication tasks. Each pixel can be treated as one feature. The relative location and value of each pixel is very important for image.