CIAFR-10 image-classfication project

Implemented by Yiyang Zhang 1800013111

Using **ResNet-50** model

About CIAFR-10 Datasets:
Datasets
References

Import modules

```
#import required packages#
import pickle
import numpy as np
import keras
from keras.layers import Dense, Conv2D, BatchNormalization, Activation, Add, Input, Flatten, ZeroPadding2D, MaxPooling2D, AveragePooling2D
from keras.models import Model
from keras.utils import to_categorical
from keras.preprocessing.image import ImageDataGenerator

```

```
Using TensorFlow backend.
```

Load Datasets

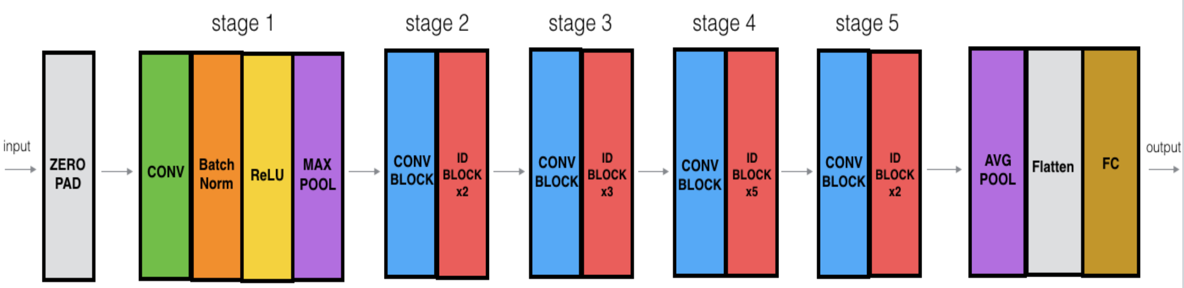
```
# If you have already downloaded the dataset and unpackaged it, make file_local true

file_local = True

#load dataset#
def unpickle(file):
    with open(file, 'rb') as fo:
        dict = pickle.load(fo, encoding='bytes')
    return dict

def load_data():

    #load train data
    X_train = []
    Y_train = []
    for i in range(1,6):
        train_batch = unpickle("data_batch_"+ str(i))
        X_orig = train_batch[b"data"]
        Y_orig = train_batch[b"labels"]
        X_processed = X_orig.reshape((10000,3,32,32)).transpose(0,2,3,1).astype('float32')
        Y_processed = to_categorical(np.array(Y_orig),10)
        X_train.append(X_processed)
        Y_train.append(Y_processed)
```

```
    X_train = np.concatenate(X_train)
    Y_train = np.concatenate(Y_train)

    #load test data
    test_batch = unpickle("test_batch")
    X_orig = test_batch[b"data"]
    Y_orig = test_batch[b"labels"]
    X_test = X_orig.reshape((10000,3,32,32)).transpose(0,2,3,1).astype('float32')
    Y_test = to_categorical(np.array(Y_orig),10)

    return X_train, Y_train, X_test, Y_test

if file_local :
    X_train, Y_train, X_test, Y_test = load_data()

else :
    (X_train, Y_train), (X_test, Y_test) = keras.datasets.cifar10.load_data()
    Y_train = to_categorical(np.array(Y_train),10)
    Y_test = to_categorical(np.array(Y_test),10)


(M, n_H, n_W, n_C) = X_train.shape
input_shape = (n_H,n_W,n_C)


print ("data loading completed")
print ("number of training examples = " + str(X_train.shape[0]))
print ("number of test examples = " + str(X_test.shape[0]))
print ("X_train shape: " + str(X_train.shape))
print ("Y_train shape: " + str(Y_train.shape))
print ("X_test shape: " + str(X_test.shape))
print ("Y_test shape: " + str(Y_test.shape))
```

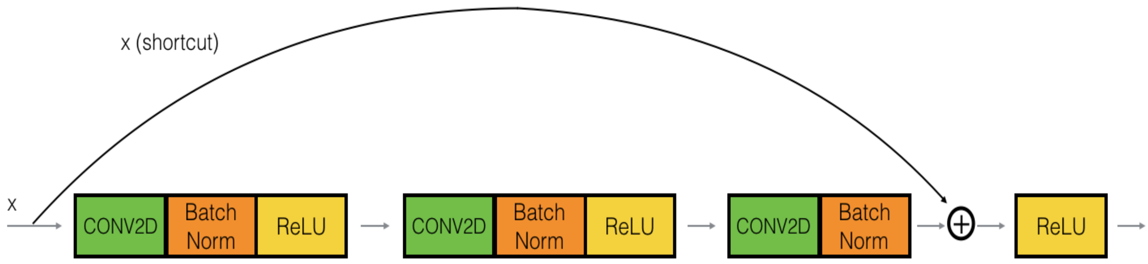
```
data loading completed
number of training examples = 50000
number of test examples = 10000
X_train shape: (50000, 32, 32, 3)
Y_train shape: (50000, 10)
X_test shape: (10000, 32, 32, 3)
Y_test shape: (10000, 10)
```

Build ResNet-50 Model

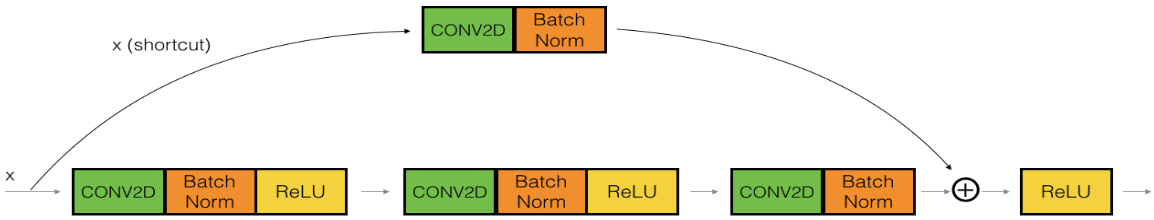
The following figure describes in detail the architecture of this network



And firstly We will impletemt convolutional residual block and identity residual block



Identity block



convolutional block

```
def id_block(X, f, kernel_channels ,activation = 'relu'):

    X_shortcut = X

    F1,F2,F3 = kernel_channels

    X = Conv2D(filters = F1, kernel_size = (1, 1), strides = (1,1), padding = 'valid')(X)
    X = BatchNormalization(axis = 3)(X)
    X = Activation(activation)(X)

    X = Conv2D(filters = F2, kernel_size = (f, f), strides = (1,1), padding = 'same')(X)
    X = BatchNormalization(axis = 3)(X)
    X = Activation(activation)(X)

    X = Conv2D(filters = F3, kernel_size = (1, 1), strides = (1,1), padding = 'valid')(X)
    X = BatchNormalization(axis = 3)(X)

    X = Add()([X,X_shortcut])
    X = Activation(activation)(X)

    return X


def conv_block(X, f, kernel_channels, strides, activation = 'relu'):

    X_shortcut = X

    F1,F2,F3 = kernel_channels

```

```
    X = Conv2D(filters = F1, kernel_size = (1, 1), strides = (strides,strides), padding = 'valid')(X)
    X = BatchNormalization(axis = 3)(X)
    X = Activation(activation)(X)

    X = Conv2D(filters = F2, kernel_size = (f, f), strides = (1,1), padding = 'same')(X)
    X = BatchNormalization(axis = 3)(X)
    X = Activation(activation)(X)

    X = Conv2D(filters = F3, kernel_size = (1, 1), strides = (1,1), padding = 'valid')(X)
    X = BatchNormalization(axis = 3)(X)

    X_shortcut = Conv2D(filters = F3, kernel_size = (1, 1), strides = (strides,strides), padding = 'valid')(X_shortcut)
    X_shortcut = BatchNormalization(axis = 3)(X_shortcut )

    X = Add()([X,X_shortcut])
    X = Activation(activation)(X)

    return X



def ResNet50(Input_shape = (32, 32, 3), classes = 10):

    X_input = Input(Input_shape)
    X = ZeroPadding2D((1, 1))(X_input)

    #stage 1
    X = Conv2D(64, (3, 3), strides = (2, 2), padding = 'valid')(X)
    X = BatchNormalization(axis = 3)(X)
    X = Activation('relu')(X)
    X = MaxPooling2D((3, 3), strides=(2, 2))(X)

    #stage 2

    X = conv_block(X , 3 , kernel_channels = [64, 64, 256], strides = 1)
    X = id_block(X, 3, kernel_channels = [64, 64, 256])
    X = id_block(X, 3, kernel_channels = [64, 64, 256])

    #stage 3

    X = conv_block(X, 3, kernel_channels = [128, 128, 512], strides = 2)
    X = id_block(X, 3, kernel_channels = [128, 128, 512])
    X = id_block(X, 3, kernel_channels = [128, 128, 512])
    X = id_block(X, 3, kernel_channels = [128, 128, 512])

    #stage 4

    X = conv_block(X, 3, kernel_channels = [256, 256, 1024], strides = 2)
    X = id_block(X, 3, kernel_channels = [256, 256, 1024])
    X = id_block(X, 3, kernel_channels = [256, 256, 1024])
    #X = id_block(X, 3, kernel_channels = [256, 256, 1024])
    #X = id_block(X, 3, kernel_channels = [256, 256, 1024])
    #X = id_block(X, 3, kernel_channels = [256, 256, 1024])

```

```
    #stage 5

    #X = conv_block(X, 3, kernel_channels = [512, 512, 2048], strides = 2)
    #X = id_block(X, 3, kernel_channels = [512, 512, 2048])
    #X = id_block(X, 3, kernel_channels = [512, 512, 2048])

    X = AveragePooling2D(pool_size = (2, 2))(X)

    X = Flatten()(X)
    X = Dense(1024, activation='relu')(X)
    X = Dense(classes, activation='softmax')(X)


    model = Model(inputs = X_input, outputs = X, name='ResNet50')

    return model

```

Train the model

```
model = ResNet50(input_shape, classes= 10)
model.compile(optimizer='adam', loss='categorical_crossentropy', metrics=['accuracy'])

model.fit(X_train, Y_train, epochs = 200, batch_size = 256)

preds = model.evaluate(X_test, Y_test)
print ("Loss = " + str(preds[0]))
print ("Test Accuracy = " + str(preds[1]))
```

```
Epoch 1/200
50000/50000 [==============================] - 25s 495us/step - loss: 1.6875 - accuracy: 0.4302s - l
Epoch 2/200
50000/50000 [==============================] - 18s 370us/step - loss: 1.0912 - accuracy: 0.6119
Epoch 3/200
50000/50000 [==============================] - 19s 372us/step - loss: 0.8783 - accuracy: 0.6904s - loss: 0.8779 - accu
Epoch 4/200
50000/50000 [==============================] - 19s 375us/step - loss: 0.7256 - accuracy: 0.7444
Epoch 5/200
50000/50000 [==============================] - 19s 374us/step - loss: 0.6015 - accuracy: 0.7894
Epoch 6/200
50000/50000 [==============================] - 19s 375us/step - loss: 0.5069 - accuracy: 0.8236
Epoch 7/200
50000/50000 [==============================] - 19s 376us/step - loss: 0.4209 - accuracy: 0.8531
Epoch 8/200
50000/50000 [==============================] - 19s 378us/step - loss: 0.3496 - accuracy: 0.8776
Epoch 9/200
```

```
50000/50000 [==============================] - 19s 377us/step - loss: 0.2966 - accuracy: 0.8969
Epoch 10/200
50000/50000 [==============================] - 19s 377us/step - loss: 0.2379 - accuracy: 0.9174
Epoch 11/200
50000/50000 [==============================] - 19s 378us/step - loss: 0.2019 - accuracy: 0.9297
Epoch 12/200
50000/50000 [==============================] - 19s 378us/step - loss: 0.1793 - accuracy: 0.9367s
Epoch 13/200
50000/50000 [==============================] - 19s 382us/step - loss: 0.1479 - accuracy: 0.9485
Epoch 14/200
50000/50000 [==============================] - 19s 381us/step - loss: 0.1376 - accuracy: 0.9523
Epoch 15/200
50000/50000 [==============================] - 19s 382us/step - loss: 0.1274 - accuracy: 0.9557
Epoch 16/200
50000/50000 [==============================] - 19s 379us/step - loss: 0.1254 - accuracy: 0.9549
Epoch 17/200
50000/50000 [==============================] - 19s 380us/step - loss: 0.1010 - accuracy: 0.9651
Epoch 18/200
50000/50000 [==============================] - 19s 381us/step - loss: 0.0926 - accuracy: 0.9676
Epoch 19/200
50000/50000 [==============================] - 19s 380us/step - loss: 0.0942 - accuracy: 0.9669
Epoch 20/200
50000/50000 [==============================] - 19s 380us/step - loss: 0.0794 - accuracy: 0.9731
Epoch 21/200
50000/50000 [==============================] - 19s 381us/step - loss: 0.0776 - accuracy: 0.9731
Epoch 22/200
50000/50000 [==============================] - 19s 382us/step - loss: 0.0768 - accuracy: 0.9735
Epoch 23/200
50000/50000 [==============================] - 19s 381us/step - loss: 0.0686 - accuracy: 0.9762
Epoch 24/200
50000/50000 [==============================] - 19s 381us/step - loss: 0.0819 - accuracy: 0.9723
Epoch 25/200
50000/50000 [==============================] - 19s 380us/step - loss: 0.0667 - accuracy: 0.9771
Epoch 26/200
50000/50000 [==============================] - 19s 381us/step - loss: 0.0549 - accuracy: 0.9808
Epoch 27/200
50000/50000 [==============================] - 19s 383us/step - loss: 0.0639 - accuracy: 0.9782
Epoch 28/200
```

```
50000/50000 [==============================] - 19s 381us/step - loss: 0.0679 - accuracy: 0.9771
Epoch 29/200
50000/50000 [==============================] - 19s 384us/step - loss: 0.0547 - accuracy: 0.9818
Epoch 30/200
50000/50000 [==============================] - 19s 381us/step - loss: 0.0655 - accuracy: 0.9770
Epoch 31/200
50000/50000 [==============================] - 19s 382us/step - loss: 0.0610 - accuracy: 0.9792
Epoch 32/200
50000/50000 [==============================] - 19s 387us/step - loss: 0.0516 - accuracy: 0.9830
Epoch 33/200
50000/50000 [==============================] - 19s 378us/step - loss: 0.0570 - accuracy: 0.9802
Epoch 34/200
50000/50000 [==============================] - 19s 379us/step - loss: 0.0501 - accuracy: 0.9830s - l
Epoch 35/200
50000/50000 [==============================] - 19s 379us/step - loss: 0.0523 - accuracy: 0.9824
Epoch 36/200
50000/50000 [==============================] - 19s 379us/step - loss: 0.0494 - accuracy: 0.9828
Epoch 37/200
50000/50000 [==============================] - 19s 379us/step - loss: 0.0500 - accuracy: 0.9837
Epoch 38/200
50000/50000 [==============================] - 19s 379us/step - loss: 0.0468 - accuracy: 0.9839s - loss: 0.0465
Epoch 39/200
50000/50000 [==============================] - 19s 378us/step - loss: 0.0471 - accuracy: 0.9841
Epoch 40/200
50000/50000 [==============================] - 19s 378us/step - loss: 0.0447 - accuracy: 0.9845
Epoch 41/200
50000/50000 [==============================] - 19s 379us/step - loss: 0.0446 - accuracy: 0.9848
Epoch 42/200
50000/50000 [==============================] - 19s 378us/step - loss: 0.0490 - accuracy: 0.9836
Epoch 43/200
50000/50000 [==============================] - 19s 380us/step - loss: 0.0416 - accuracy: 0.9863
Epoch 44/200
50000/50000 [==============================] - 19s 378us/step - loss: 0.0371 - accuracy: 0.9876
Epoch 45/200
50000/50000 [==============================] - 19s 378us/step - loss: 0.0389 - accuracy: 0.9865
Epoch 46/200
50000/50000 [==============================] - 19s 381us/step - loss: 0.0375 - accuracy: 0.9870
Epoch 47/200
```

```
50000/50000 [==============================] - 19s 379us/step - loss: 0.0513 - accuracy: 0.9826
Epoch 48/200
50000/50000 [==============================] - 19s 378us/step - loss: 0.0331 - accuracy: 0.9883
Epoch 49/200
50000/50000 [==============================] - 19s 380us/step - loss: 0.0362 - accuracy: 0.9875
Epoch 50/200
50000/50000 [==============================] - 19s 378us/step - loss: 0.0420 - accuracy: 0.9859
Epoch 51/200
50000/50000 [==============================] - 20s 398us/step - loss: 0.0332 - accuracy: 0.9890s - loss: 0.0330 - accu
Epoch 52/200
50000/50000 [==============================] - 19s 387us/step - loss: 0.0265 - accuracy: 0.9916
Epoch 53/200
50000/50000 [==============================] - 19s 385us/step - loss: 0.0311 - accuracy: 0.9894
Epoch 54/200
50000/50000 [==============================] - 19s 383us/step - loss: 0.0374 - accuracy: 0.9876
Epoch 55/200
50000/50000 [==============================] - 19s 383us/step - loss: 0.0364 - accuracy: 0.9878
Epoch 56/200
50000/50000 [==============================] - 19s 383us/step - loss: 0.0361 - accuracy: 0.9880
Epoch 57/200
50000/50000 [==============================] - 19s 383us/step - loss: 0.0349 - accuracy: 0.9884
Epoch 58/200
50000/50000 [==============================] - 19s 384us/step - loss: 0.0307 - accuracy: 0.9896
Epoch 59/200
50000/50000 [==============================] - 20s 394us/step - loss: 0.0347 - accuracy: 0.9882
Epoch 60/200
50000/50000 [==============================] - 19s 384us/step - loss: 0.0260 - accuracy: 0.9911
Epoch 61/200
50000/50000 [==============================] - 19s 383us/step - loss: 0.0303 - accuracy: 0.9893
Epoch 62/200
50000/50000 [==============================] - 20s 391us/step - loss: 0.0334 - accuracy: 0.9891
Epoch 63/200
50000/50000 [==============================] - 19s 382us/step - loss: 0.0309 - accuracy: 0.9900
Epoch 64/200
50000/50000 [==============================] - 19s 385us/step - loss: 0.0252 - accuracy: 0.9916
Epoch 65/200
50000/50000 [==============================] - 19s 384us/step - loss: 0.0302 - accuracy: 0.9899
Epoch 66/200
```

```
50000/50000 [==============================] - 20s 393us/step - loss: 0.0306 - accuracy: 0.9895
Epoch 67/200
50000/50000 [==============================] - 19s 383us/step - loss: 0.0426 - accuracy: 0.9859
Epoch 68/200
50000/50000 [==============================] - 19s 384us/step - loss: 0.0229 - accuracy: 0.9921
Epoch 69/200
50000/50000 [==============================] - 19s 383us/step - loss: 0.0277 - accuracy: 0.9905
Epoch 70/200
50000/50000 [==============================] - 19s 385us/step - loss: 0.0207 - accuracy: 0.9927
Epoch 71/200
50000/50000 [==============================] - 19s 386us/step - loss: 0.0246 - accuracy: 0.9916
Epoch 72/200
50000/50000 [==============================] - 20s 393us/step - loss: 0.0282 - accuracy: 0.9905
Epoch 73/200
50000/50000 [==============================] - 19s 385us/step - loss: 0.0241 - accuracy: 0.9918s - loss: 0
Epoch 74/200
50000/50000 [==============================] - 19s 385us/step - loss: 0.0237 - accuracy: 0.9921
Epoch 75/200
50000/50000 [==============================] - 19s 381us/step - loss: 0.0288 - accuracy: 0.9900
Epoch 76/200
50000/50000 [==============================] - 19s 382us/step - loss: 0.0199 - accuracy: 0.9931
Epoch 77/200
50000/50000 [==============================] - 19s 386us/step - loss: 0.0246 - accuracy: 0.9919
Epoch 78/200
50000/50000 [==============================] - 19s 380us/step - loss: 0.0276 - accuracy: 0.9906
Epoch 79/200
50000/50000 [==============================] - 20s 409us/step - loss: 0.0176 - accuracy: 0.9944
Epoch 80/200
50000/50000 [==============================] - 23s 456us/step - loss: 0.0246 - accuracy: 0.9914
Epoch 81/200
50000/50000 [==============================] - 21s 427us/step - loss: 0.0213 - accuracy: 0.9925
Epoch 82/200
50000/50000 [==============================] - 21s 420us/step - loss: 0.0184 - accuracy: 0.9937
Epoch 83/200
50000/50000 [==============================] - 21s 412us/step - loss: 0.0209 - accuracy: 0.9936
Epoch 84/200
50000/50000 [==============================] - 21s 412us/step - loss: 0.0244 - accuracy: 0.9917
Epoch 85/200
```

```
50000/50000 [==============================] - 20s 407us/step - loss: 0.0230 - accuracy: 0.9919
Epoch 86/200
50000/50000 [==============================] - 20s 405us/step - loss: 0.0222 - accuracy: 0.9925
Epoch 87/200
50000/50000 [==============================] - 21s 410us/step - loss: 0.0166 - accuracy: 0.9945
Epoch 88/200
50000/50000 [==============================] - 20s 408us/step - loss: 0.0168 - accuracy: 0.9941
Epoch 89/200
50000/50000 [==============================] - 21s 416us/step - loss: 0.0285 - accuracy: 0.9906
Epoch 90/200
50000/50000 [==============================] - 20s 398us/step - loss: 0.0230 - accuracy: 0.9922s - loss: 0.0227 - accura
Epoch 91/200
50000/50000 [==============================] - 19s 383us/step - loss: 0.0137 - accuracy: 0.9955
Epoch 92/200
50000/50000 [==============================] - 20s 410us/step - loss: 0.0200 - accuracy: 0.9935
Epoch 93/200
50000/50000 [==============================] - 21s 416us/step - loss: 0.0197 - accuracy: 0.9933
Epoch 94/200
50000/50000 [==============================] - 21s 417us/step - loss: 0.0189 - accuracy: 0.9935
Epoch 95/200
50000/50000 [==============================] - 22s 441us/step - loss: 0.0222 - accuracy: 0.9929
Epoch 96/200
50000/50000 [==============================] - 21s 419us/step - loss: 0.0196 - accuracy: 0.9934s - loss: 0.0195 - accuracy:
Epoch 97/200
50000/50000 [==============================] - 21s 428us/step - loss: 0.0167 - accuracy: 0.9946
Epoch 98/200
50000/50000 [==============================] - 21s 424us/step - loss: 0.0205 - accuracy: 0.9933
Epoch 99/200
50000/50000 [==============================] - 21s 422us/step - loss: 0.0167 - accuracy: 0.9945
Epoch 100/200
50000/50000 [==============================] - 21s 426us/step - loss: 0.0247 - accuracy: 0.9918
Epoch 101/200
50000/50000 [==============================] - 20s 409us/step - loss: 0.0184 - accuracy: 0.9941
Epoch 102/200
50000/50000 [==============================] - 21s 418us/step - loss: 0.0146 - accuracy: 0.9954
Epoch 103/200
50000/50000 [==============================] - 21s 422us/step - loss: 0.0150 - accuracy: 0.9951
Epoch 104/200
```

```
50000/50000 [==============================] - 20s 397us/step - loss: 0.0158 - accuracy: 0.9948
Epoch 105/200
50000/50000 [==============================] - 20s 398us/step - loss: 0.0217 - accuracy: 0.9925
Epoch 106/200
50000/50000 [==============================] - 20s 395us/step - loss: 0.0140 - accuracy: 0.9952s - loss: 0.014
Epoch 107/200
50000/50000 [==============================] - 19s 388us/step - loss: 0.0132 - accuracy: 0.9955
Epoch 108/200
50000/50000 [==============================] - 20s 394us/step - loss: 0.0231 - accuracy: 0.9922
Epoch 109/200
50000/50000 [==============================] - 20s 398us/step - loss: 0.0130 - accuracy: 0.9958
Epoch 110/200
50000/50000 [==============================] - 20s 399us/step - loss: 0.0183 - accuracy: 0.9941
Epoch 111/200
50000/50000 [==============================] - 20s 391us/step - loss: 0.0172 - accuracy: 0.9940
Epoch 112/200
50000/50000 [==============================] - 20s 396us/step - loss: 0.0169 - accuracy: 0.9945
Epoch 113/200
50000/50000 [==============================] - 20s 402us/step - loss: 0.0124 - accuracy: 0.9961
Epoch 114/200
50000/50000 [==============================] - 19s 385us/step - loss: 0.0112 - accuracy: 0.9962
Epoch 115/200
50000/50000 [==============================] - 19s 385us/step - loss: 0.0205 - accuracy: 0.9933
Epoch 116/200
50000/50000 [==============================] - 20s 399us/step - loss: 0.0144 - accuracy: 0.9954
Epoch 117/200
50000/50000 [==============================] - 20s 402us/step - loss: 0.0143 - accuracy: 0.9952
Epoch 118/200
50000/50000 [==============================] - 19s 390us/step - loss: 0.0128 - accuracy: 0.9954
Epoch 119/200
50000/50000 [==============================] - 20s 402us/step - loss: 0.0228 - accuracy: 0.9925
Epoch 120/200
50000/50000 [==============================] - 20s 405us/step - loss: 0.0107 - accuracy: 0.9962
Epoch 121/200
50000/50000 [==============================] - 20s 394us/step - loss: 0.0145 - accuracy: 0.9955
Epoch 122/200
50000/50000 [==============================] - 20s 394us/step - loss: 0.0178 - accuracy: 0.9940
Epoch 123/200
```

```
50000/50000 [==============================] - 19s 384us/step - loss: 0.0161 - accuracy: 0.9948
Epoch 124/200
50000/50000 [==============================] - 19s 386us/step - loss: 0.0123 - accuracy: 0.9960
Epoch 125/200
50000/50000 [==============================] - 20s 392us/step - loss: 0.0145 - accuracy: 0.9949
Epoch 126/200
50000/50000 [==============================] - 20s 400us/step - loss: 0.0104 - accuracy: 0.9963
Epoch 127/200
50000/50000 [==============================] - 20s 396us/step - loss: 0.0170 - accuracy: 0.9943
Epoch 128/200
50000/50000 [==============================] - 20s 394us/step - loss: 0.0160 - accuracy: 0.9950
Epoch 129/200
50000/50000 [==============================] - 19s 386us/step - loss: 0.0192 - accuracy: 0.9937
Epoch 130/200
50000/50000 [==============================] - 20s 395us/step - loss: 0.0077 - accuracy: 0.9974
Epoch 131/200
50000/50000 [==============================] - 20s 394us/step - loss: 0.0041 - accuracy: 0.9985
Epoch 132/200
50000/50000 [==============================] - 19s 387us/step - loss: 0.0206 - accuracy: 0.9934
Epoch 133/200
50000/50000 [==============================] - 19s 384us/step - loss: 0.0125 - accuracy: 0.9958
Epoch 134/200
50000/50000 [==============================] - 19s 385us/step - loss: 0.0093 - accuracy: 0.9970
Epoch 135/200
50000/50000 [==============================] - 19s 385us/step - loss: 0.0142 - accuracy: 0.9951
Epoch 136/200
50000/50000 [==============================] - 19s 385us/step - loss: 0.0157 - accuracy: 0.9948
Epoch 137/200
50000/50000 [==============================] - 19s 383us/step - loss: 0.0148 - accuracy: 0.9948
Epoch 138/200
50000/50000 [==============================] - 19s 387us/step - loss: 0.0131 - accuracy: 0.9957
Epoch 139/200
50000/50000 [==============================] - 20s 393us/step - loss: 0.0097 - accuracy: 0.9967
Epoch 140/200
50000/50000 [==============================] - 20s 394us/step - loss: 0.0150 - accuracy: 0.9949
Epoch 141/200
50000/50000 [==============================] - 19s 383us/step - loss: 0.0172 - accuracy: 0.9941
Epoch 142/200
```

```
50000/50000 [==============================] - 19s 388us/step - loss: 0.0133 - accuracy: 0.9955
Epoch 143/200
50000/50000 [==============================] - 19s 383us/step - loss: 0.0102 - accuracy: 0.9968
Epoch 144/200
50000/50000 [==============================] - 19s 380us/step - loss: 0.0106 - accuracy: 0.9965s - l
Epoch 145/200
50000/50000 [==============================] - 19s 383us/step - loss: 0.0110 - accuracy: 0.9964
Epoch 146/200
50000/50000 [==============================] - 19s 383us/step - loss: 0.0123 - accuracy: 0.9958
Epoch 147/200
50000/50000 [==============================] - 19s 382us/step - loss: 0.0100 - accuracy: 0.9968
Epoch 148/200
50000/50000 [==============================] - 19s 384us/step - loss: 0.0082 - accuracy: 0.9972
Epoch 149/200
50000/50000 [==============================] - 19s 380us/step - loss: 0.0130 - accuracy: 0.9956
Epoch 150/200
50000/50000 [==============================] - 19s 379us/step - loss: 0.0148 - accuracy: 0.9953
Epoch 151/200
50000/50000 [==============================] - 20s 392us/step - loss: 0.0093 - accuracy: 0.9969
Epoch 152/200
50000/50000 [==============================] - 20s 409us/step - loss: 0.0110 - accuracy: 0.9965
Epoch 153/200
50000/50000 [==============================] - 21s 418us/step - loss: 0.0123 - accuracy: 0.9959
Epoch 154/200
50000/50000 [==============================] - 19s 387us/step - loss: 0.0097 - accuracy: 0.9965
Epoch 155/200
50000/50000 [==============================] - 19s 390us/step - loss: 0.0137 - accuracy: 0.9960
Epoch 156/200
50000/50000 [==============================] - 20s 392us/step - loss: 0.0092 - accuracy: 0.9971
Epoch 157/200
50000/50000 [==============================] - 20s 391us/step - loss: 0.0111 - accuracy: 0.9963
Epoch 158/200
50000/50000 [==============================] - 19s 384us/step - loss: 0.0149 - accuracy: 0.9954
Epoch 159/200
50000/50000 [==============================] - 20s 393us/step - loss: 0.0102 - accuracy: 0.9967
Epoch 160/200
50000/50000 [==============================] - 20s 401us/step - loss: 0.0067 - accuracy: 0.9978
Epoch 161/200
```

```
50000/50000 [==============================] - 19s 383us/step - loss: 0.0108 - accuracy: 0.9967
Epoch 162/200
50000/50000 [==============================] - 19s 390us/step - loss: 0.0078 - accuracy: 0.9975
Epoch 163/200
50000/50000 [==============================] - 20s 400us/step - loss: 0.0122 - accuracy: 0.9960
Epoch 164/200
50000/50000 [==============================] - 20s 393us/step - loss: 0.0145 - accuracy: 0.9954s - l
Epoch 165/200
50000/50000 [==============================] - 20s 390us/step - loss: 0.0114 - accuracy: 0.9963
Epoch 166/200
50000/50000 [==============================] - 19s 384us/step - loss: 0.0120 - accuracy: 0.9959
Epoch 167/200
50000/50000 [==============================] - 19s 388us/step - loss: 0.0081 - accuracy: 0.9973s - loss: 0.0080 -
Epoch 168/200
50000/50000 [==============================] - 19s 388us/step - loss: 0.0117 - accuracy: 0.9961
Epoch 169/200
50000/50000 [==============================] - 19s 384us/step - loss: 0.0091 - accuracy: 0.9971
Epoch 170/200
50000/50000 [==============================] - 20s 397us/step - loss: 0.0078 - accuracy: 0.9976s - loss: 0.0075
Epoch 171/200
50000/50000 [==============================] - 19s 389us/step - loss: 0.0123 - accuracy: 0.9961
Epoch 172/200
50000/50000 [==============================] - 20s 399us/step - loss: 0.0093 - accuracy: 0.9967
Epoch 173/200
50000/50000 [==============================] - 20s 392us/step - loss: 0.0323 - accuracy: 0.9904
Epoch 174/200
50000/50000 [==============================] - 22s 449us/step - loss: 0.0083 - accuracy: 0.9971
Epoch 175/200
50000/50000 [==============================] - 20s 407us/step - loss: 0.0059 - accuracy: 0.9983
Epoch 176/200
50000/50000 [==============================] - 20s 408us/step - loss: 0.0100 - accuracy: 0.9968
Epoch 177/200
50000/50000 [==============================] - 20s 401us/step - loss: 0.0165 - accuracy: 0.9949s - los
Epoch 178/200
50000/50000 [==============================] - 19s 387us/step - loss: 0.0123 - accuracy: 0.9959
Epoch 179/200
50000/50000 [==============================] - 21s 416us/step - loss: 0.0056 - accuracy: 0.9982
Epoch 180/200
```

```
50000/50000 [==============================] - 21s 410us/step - loss: 0.0093 - accuracy: 0.9970
Epoch 181/200
50000/50000 [==============================] - 20s 406us/step - loss: 0.0050 - accuracy: 0.9980
Epoch 182/200
50000/50000 [==============================] - 21s 421us/step - loss: 0.0053 - accuracy: 0.9982
Epoch 183/200
50000/50000 [==============================] - 20s 403us/step - loss: 0.0148 - accuracy: 0.9955
Epoch 184/200
50000/50000 [==============================] - 21s 412us/step - loss: 0.0134 - accuracy: 0.9959
Epoch 185/200
50000/50000 [==============================] - 21s 416us/step - loss: 0.0081 - accuracy: 0.9974s - loss: 0.0081 - accura
Epoch 186/200
50000/50000 [==============================] - ETA: 0s - loss: 0.0050 - accuracy: 0.9984 ETA: 0s - loss: 0.0051 - accu - 21s 414us/step - loss: 0.0050 - accuracy: 0.9984
Epoch 187/200
50000/50000 [==============================] - 22s 444us/step - loss: 0.0084 - accuracy: 0.9974
Epoch 188/200
50000/50000 [==============================] - 23s 457us/step - loss: 0.0102 - accuracy: 0.9968
Epoch 189/200
50000/50000 [==============================] - 22s 437us/step - loss: 0.0077 - accuracy: 0.9976
Epoch 190/200
50000/50000 [==============================] - 21s 420us/step - loss: 0.0083 - accuracy: 0.9972
Epoch 191/200
50000/50000 [==============================] - 21s 410us/step - loss: 0.0118 - accuracy: 0.9959s -
Epoch 192/200
50000/50000 [==============================] - 20s 409us/step - loss: 0.0071 - accuracy: 0.9977
Epoch 193/200
50000/50000 [==============================] - 20s 394us/step - loss: 0.0061 - accuracy: 0.9981
Epoch 194/200
50000/50000 [==============================] - 20s 410us/step - loss: 0.0063 - accuracy: 0.9980
Epoch 195/200
50000/50000 [==============================] - 20s 396us/step - loss: 0.0090 - accuracy: 0.9969
Epoch 196/200
50000/50000 [==============================] - 20s 399us/step - loss: 0.0080 - accuracy: 0.9973
Epoch 197/200
50000/50000 [==============================] - 20s 405us/step - loss: 0.0115 - accuracy: 0.9963s - l
Epoch 198/200
50000/50000 [==============================] - 21s 421us/step - loss: 0.0095 - accuracy: 0.9969
Epoch 199/200
```

```
50000/50000 [==============================] - 20s 400us/step - loss:
0.0063 - accuracy: 0.9977
Epoch 200/200
50000/50000 [==============================] - 20s 400us/step - loss:
0.0100 - accuracy: 0.9968
10000/10000 [==============================] - 5s 523us/step
Loss = 1.8030616061210631
Test Accuracy = 0.7542999982833862
```

```

```