Assignment11_ErenAkgunduz

April 20, 2024

1 Assignment 11

1.1 Eren Akgunduz

1.1.1 Deep Learning — 20 April 2024

1.1.2 Link to notebook

[1]:
```
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd
import tensorflow as tf
from keras.callbacks import ModelCheckpoint
from keras.datasets import cifar10
from keras.models import Sequential, load_model
from keras.regularizers import l2
from keras.layers import Dense, Conv2D, Flatten, Dropout, Activation,␣
↪MaxPooling2D
from keras.utils import to_categorical
from sklearn.metrics import accuracy_score, confusion_matrix, recall_score
```

1.1.3 Helper functions

[2]:
```
def img_plt(images, labels):
    plt.figure()
    for i in range(1, 11):
        plt.subplot(2, 5, i)
        plt.imshow(images[i-1,:,:])
        plt.title(f"Label: {str(labels[i-1])}")
    plt.show()
```

[3]:
```
def feat_plot(features, labels, classes):
    for class_i in classes:
        plt.plot(features[labels[:]==classes[class_i],0], features[labels[:
↪]==classes[class_i],1], 'o', markersize=15)

    plt.xlabel('x: feature 1')
    plt.ylabel('y: feature 2')
    plt.legend(['Class' + str(classes[class_i]) for class_i in classes])
```

```
    plt.show()
```

[4]:
```
def acc_fun(labels_actual, labels_pred):
    acc = np.sum(labels_actual==labels_pred)/len(labels_actual) * 100
    return acc
```

[5]:
```
def plot_curve(accuracy_train, loss_train, accuracy_val, loss_val):
    epochs = np.arange(loss_train.shape[0])
    plt.subplot(1,2,1)
    plt.plot(epochs, accuracy_train, epochs, accuracy_val)
    plt.xlabel('Epoch #')
    plt.ylabel('Accuracy')
    plt.title('Accuracy')
    plt.legend(['Training', 'Validation'])

    plt.subplot (1,2,2)
    plt.plot(epochs, loss_train, epochs, loss_val)
    plt.xlabel('Epoch #')
    plt.ylabel('Binary crossentropy loss')
    plt.title('Loss')
    plt.legend(['Training', 'Validation'])
    plt.show()
```

1.1.4 Dataset

[6]:
```
(x_train, y_train), (x_test, y_test) = cifar10.load_data()
```

[7]:
```
classes = np.arange(10)
print(x_train.shape)
```

```
(50000, 32, 32, 3)
```

[8]:
```
# Selecting 20% of training data as the validation set
num_train_img=x_train.shape[0]
train_ind=np.arange(0,num_train_img)
train_ind_s=np.random.permutation(train_ind)
x_train=x_train[train_ind_s,:,:,:]
y_train=y_train[train_ind_s]
# Selecting 20% of training images for validation
x_val=x_train[0:int(0.2*num_train_img),:,:,:]
y_val=y_train[0:int(0.2*num_train_img)]
# The rest of the training set
x_train=x_train[int(0.2*num_train_img):,:,:,:]
y_train=y_train[int(0.2*num_train_img):]
```

1.1.5 Preprocessing

[9]:
```
# Scaling the images
x_train=x_train.astype('float32')
x_val=x_val.astype('float32')
x_test=x_test.astype('float32')
x_train /= 255
x_val /= 255
x_test /= 255

# convert class vectors to binary class matrices
y_train_c = to_categorical(y_train, len(classes))
y_val_c = to_categorical(y_val, len(classes))
y_test_c = to_categorical(y_test, len(classes))
```

1.1.6 Model

[10]:
```
model_a = Sequential()
model_a.add(Conv2D(32, (3, 3), padding='same', input_shape=x_train.shape[1:]))
model_a.add(Activation('relu'))
model_a.add(Conv2D(32, (3, 3), padding='same'))
model_a.add(Activation('relu'))
model_a.add(MaxPooling2D(pool_size=(2, 2)))

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

model_a.add(Flatten())
model_a.add(Dense(units=512, activation='relu'))
model_a.add(Dropout(0.5))
model_a.add(Dense(units=len(classes), activation='softmax'))
model_a.summary()
```

```
Model: "sequential"

_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d (Conv2D)             (None, 32, 32, 32)        896

 activation (Activation)     (None, 32, 32, 32)        0

 conv2d_1 (Conv2D)           (None, 32, 32, 32)        9248

 activation_1 (Activation)   (None, 32, 32, 32)        0
```

```
 max_pooling2d (MaxPooling2  (None, 16, 16, 32)        0
 D)

 conv2d_2 (Conv2D)           (None, 16, 16, 64)        18496

 activation_2 (Activation)   (None, 16, 16, 64)        0

 conv2d_3 (Conv2D)           (None, 16, 16, 64)        36928

 activation_3 (Activation)   (None, 16, 16, 64)        0

 max_pooling2d_1 (MaxPoolin  (None, 8, 8, 64)          0
 g2D)

 flatten (Flatten)           (None, 4096)              0

 dense (Dense)               (None, 512)               2097664

 dropout (Dropout)           (None, 512)               0

 dense_1 (Dense)             (None, 10)                5130

=================================================================
Total params: 2168362 (8.27 MB)
Trainable params: 2168362 (8.27 MB)
Non-trainable params: 0 (0.00 Byte)
_________________________________________________________________
```

[11]:
```
opt = tf.keras.optimizers.Adam(learning_rate=0.001)
model_a.compile(optimizer=opt,
              loss="categorical_crossentropy",
              metrics=["accuracy"])
```

[12]:
```
# Creating a checkpoint to save the best model based on the lowest validation␣
 ↪loss.
save_path='/content/drive/My Drive/model_a_cifar10.h5'
callbacks_save=ModelCheckpoint(save_path, monitor='val_loss', verbose=0,␣
 ↪save_best_only=True, period=1)

history=model_a.fit(x_train, y_train_c,
                    batch_size=32,
                    epochs=50,
                    verbose=1,
                    validation_data=(x_val, y_val_c),
                    callbacks=[callbacks_save])
```

```
WARNING:tensorflow:`period` argument is deprecated. Please use `save_freq` to
specify the frequency in number of batches seen.
```

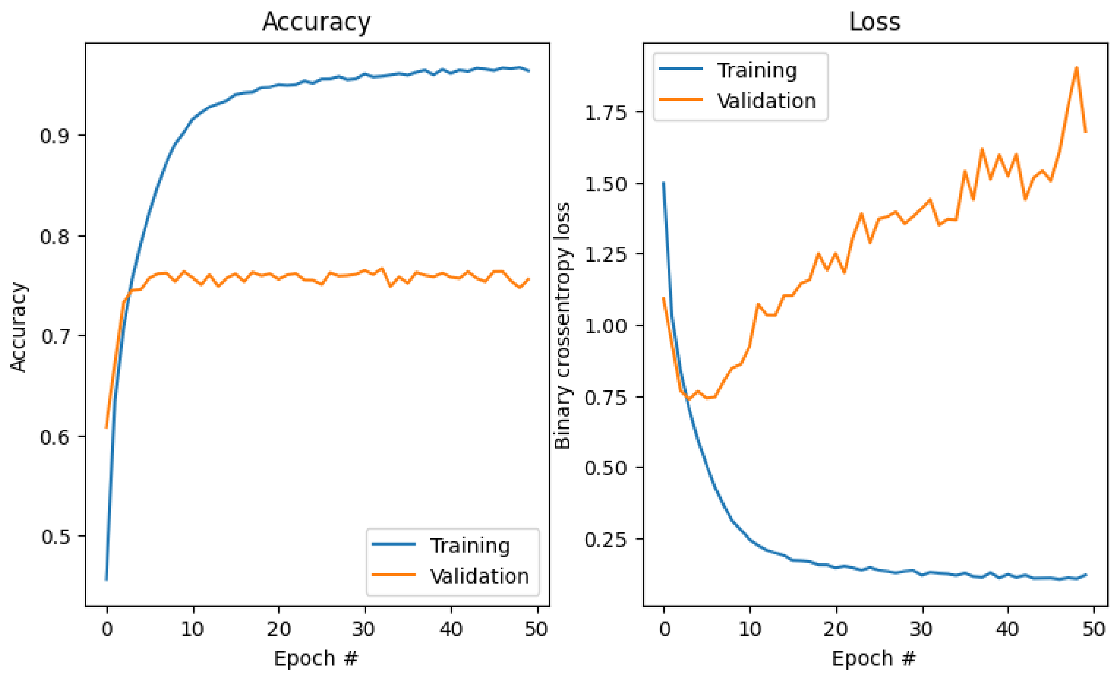
```
Epoch 1/50
1250/1250 [==============================] - 23s 10ms/step - loss: 1.4961 -
accuracy: 0.4559 - val_loss: 1.0912 - val_accuracy: 0.6080
Epoch 2/50
  12/1250 […] - ETA: 6s - loss: 1.1437 - accuracy:
0.6016

/usr/local/lib/python3.10/dist-packages/keras/src/engine/training.py:3103:
UserWarning: You are saving your model as an HDF5 file via `model.save()`. This
file format is considered legacy. We recommend using instead the native Keras
format, e.g. `model.save('my_model.keras')`.
  saving_api.save_model(

1250/1250 [==============================] - 8s 6ms/step - loss: 1.0301 -
accuracy: 0.6339 - val_loss: 0.9334 - val_accuracy: 0.6714
Epoch 3/50
1250/1250 [==============================] - 8s 7ms/step - loss: 0.8358 -
accuracy: 0.7078 - val_loss: 0.7672 - val_accuracy: 0.7328
Epoch 4/50
1250/1250 [==============================] - 8s 7ms/step - loss: 0.7037 -
accuracy: 0.7551 - val_loss: 0.7373 - val_accuracy: 0.7445
Epoch 5/50
1250/1250 [==============================] - 7s 6ms/step - loss: 0.5956 -
accuracy: 0.7916 - val_loss: 0.7653 - val_accuracy: 0.7455
Epoch 6/50
1250/1250 [==============================] - 8s 6ms/step - loss: 0.5087 -
accuracy: 0.8220 - val_loss: 0.7413 - val_accuracy: 0.7567
Epoch 7/50
1250/1250 [==============================] - 8s 6ms/step - loss: 0.4283 -
accuracy: 0.8495 - val_loss: 0.7453 - val_accuracy: 0.7612
Epoch 8/50
1250/1250 [==============================] - 7s 6ms/step - loss: 0.3655 -
accuracy: 0.8727 - val_loss: 0.8016 - val_accuracy: 0.7618
Epoch 9/50
1250/1250 [==============================] - 8s 7ms/step - loss: 0.3109 -
accuracy: 0.8909 - val_loss: 0.8478 - val_accuracy: 0.7535
Epoch 10/50
1250/1250 [==============================] - 7s 6ms/step - loss: 0.2788 -
accuracy: 0.9024 - val_loss: 0.8613 - val_accuracy: 0.7633
Epoch 11/50
1250/1250 [==============================] - 7s 6ms/step - loss: 0.2454 -
accuracy: 0.9153 - val_loss: 0.9225 - val_accuracy: 0.7575
Epoch 12/50
1250/1250 [==============================] - 8s 6ms/step - loss: 0.2245 -
accuracy: 0.9222 - val_loss: 1.0720 - val_accuracy: 0.7503
Epoch 13/50
1250/1250 [==============================] - 9s 7ms/step - loss: 0.2078 -
accuracy: 0.9277 - val_loss: 1.0330 - val_accuracy: 0.7602
Epoch 14/50
```

```
1250/1250 [==============================] - 8s 7ms/step - loss: 0.1983 -
accuracy: 0.9310 - val_loss: 1.0323 - val_accuracy: 0.7487
Epoch 15/50
1250/1250 [==============================] - 8s 6ms/step - loss: 0.1888 -
accuracy: 0.9342 - val_loss: 1.1015 - val_accuracy: 0.7569
Epoch 16/50
1250/1250 [==============================] - 8s 6ms/step - loss: 0.1720 -
accuracy: 0.9400 - val_loss: 1.1018 - val_accuracy: 0.7610
Epoch 17/50
1250/1250 [==============================] - 8s 7ms/step - loss: 0.1706 -
accuracy: 0.9418 - val_loss: 1.1453 - val_accuracy: 0.7534
Epoch 18/50
1250/1250 [==============================] - 8s 6ms/step - loss: 0.1677 -
accuracy: 0.9424 - val_loss: 1.1574 - val_accuracy: 0.7626
Epoch 19/50
1250/1250 [==============================] - 7s 6ms/step - loss: 0.1567 -
accuracy: 0.9471 - val_loss: 1.2490 - val_accuracy: 0.7592
Epoch 20/50
1250/1250 [==============================] - 8s 7ms/step - loss: 0.1563 -
accuracy: 0.9475 - val_loss: 1.1909 - val_accuracy: 0.7612
Epoch 21/50
1250/1250 [==============================] - 8s 6ms/step - loss: 0.1461 -
accuracy: 0.9502 - val_loss: 1.2493 - val_accuracy: 0.7557
Epoch 22/50
1250/1250 [==============================] - 7s 6ms/step - loss: 0.1521 -
accuracy: 0.9495 - val_loss: 1.1816 - val_accuracy: 0.7600
Epoch 23/50
1250/1250 [==============================] - 8s 7ms/step - loss: 0.1465 -
accuracy: 0.9502 - val_loss: 1.3041 - val_accuracy: 0.7613
Epoch 24/50
1250/1250 [==============================] - 7s 6ms/step - loss: 0.1374 -
accuracy: 0.9538 - val_loss: 1.3896 - val_accuracy: 0.7550
Epoch 25/50
1250/1250 [==============================] - 8s 6ms/step - loss: 0.1478 -
accuracy: 0.9516 - val_loss: 1.2869 - val_accuracy: 0.7548
Epoch 26/50
1250/1250 [==============================] - 8s 7ms/step - loss: 0.1373 -
accuracy: 0.9557 - val_loss: 1.3708 - val_accuracy: 0.7506
Epoch 27/50
1250/1250 [==============================] - 7s 6ms/step - loss: 0.1336 -
accuracy: 0.9558 - val_loss: 1.3789 - val_accuracy: 0.7621
Epoch 28/50
1250/1250 [==============================] - 8s 7ms/step - loss: 0.1275 -
accuracy: 0.9582 - val_loss: 1.3954 - val_accuracy: 0.7589
Epoch 29/50
1250/1250 [==============================] - 11s 9ms/step - loss: 0.1340 -
accuracy: 0.9550 - val_loss: 1.3548 - val_accuracy: 0.7594
Epoch 30/50
```

```
1250/1250 [==============================] - 11s 9ms/step - loss: 0.1369 -
accuracy: 0.9560 - val_loss: 1.3786 - val_accuracy: 0.7606
Epoch 31/50
1250/1250 [==============================] - 7s 6ms/step - loss: 0.1193 -
accuracy: 0.9608 - val_loss: 1.4086 - val_accuracy: 0.7645
Epoch 32/50
1250/1250 [==============================] - 10s 8ms/step - loss: 0.1301 -
accuracy: 0.9578 - val_loss: 1.4394 - val_accuracy: 0.7604
Epoch 33/50
1250/1250 [==============================] - 8s 7ms/step - loss: 0.1264 -
accuracy: 0.9585 - val_loss: 1.3499 - val_accuracy: 0.7666
Epoch 34/50
1250/1250 [==============================] - 8s 6ms/step - loss: 0.1244 -
accuracy: 0.9596 - val_loss: 1.3703 - val_accuracy: 0.7485
Epoch 35/50
1250/1250 [==============================] - 8s 6ms/step - loss: 0.1189 -
accuracy: 0.9610 - val_loss: 1.3678 - val_accuracy: 0.7580
Epoch 36/50
1250/1250 [==============================] - 8s 6ms/step - loss: 0.1270 -
accuracy: 0.9595 - val_loss: 1.5382 - val_accuracy: 0.7517
Epoch 37/50
1250/1250 [==============================] - 7s 6ms/step - loss: 0.1149 -
accuracy: 0.9624 - val_loss: 1.4389 - val_accuracy: 0.7625
Epoch 38/50
1250/1250 [==============================] - 9s 7ms/step - loss: 0.1123 -
accuracy: 0.9645 - val_loss: 1.6158 - val_accuracy: 0.7596
Epoch 39/50
1250/1250 [==============================] - 8s 6ms/step - loss: 0.1284 -
accuracy: 0.9598 - val_loss: 1.5106 - val_accuracy: 0.7581
Epoch 40/50
1250/1250 [==============================] - 8s 6ms/step - loss: 0.1100 -
accuracy: 0.9652 - val_loss: 1.5956 - val_accuracy: 0.7618
Epoch 41/50
1250/1250 [==============================] - 8s 6ms/step - loss: 0.1228 -
accuracy: 0.9613 - val_loss: 1.5210 - val_accuracy: 0.7578
Epoch 42/50
1250/1250 [==============================] - 7s 6ms/step - loss: 0.1119 -
accuracy: 0.9646 - val_loss: 1.5974 - val_accuracy: 0.7566
Epoch 43/50
1250/1250 [==============================] - 9s 7ms/step - loss: 0.1197 -
accuracy: 0.9632 - val_loss: 1.4392 - val_accuracy: 0.7633
Epoch 44/50
1250/1250 [==============================] - 8s 6ms/step - loss: 0.1086 -
accuracy: 0.9665 - val_loss: 1.5151 - val_accuracy: 0.7567
Epoch 45/50
1250/1250 [==============================] - 7s 6ms/step - loss: 0.1093 -
accuracy: 0.9656 - val_loss: 1.5396 - val_accuracy: 0.7533
Epoch 46/50
```

```
1250/1250 [==============================] - 8s 6ms/step - loss: 0.1097 -
accuracy: 0.9641 - val_loss: 1.5046 - val_accuracy: 0.7632
Epoch 47/50
1250/1250 [==============================] - 8s 7ms/step - loss: 0.1050 -
accuracy: 0.9667 - val_loss: 1.6076 - val_accuracy: 0.7633
Epoch 48/50
1250/1250 [==============================] - 7s 6ms/step - loss: 0.1109 -
accuracy: 0.9660 - val_loss: 1.7698 - val_accuracy: 0.7542
Epoch 49/50
1250/1250 [==============================] - 8s 7ms/step - loss: 0.1072 -
accuracy: 0.9672 - val_loss: 1.9027 - val_accuracy: 0.7472
Epoch 50/50
1250/1250 [==============================] - 8s 6ms/step - loss: 0.1202 -
accuracy: 0.9639 - val_loss: 1.6780 - val_accuracy: 0.7557
```

[13]:
```python
plt.figure(figsize=[9, 5])
acc_curve_train = np.array(history.history['accuracy'])
loss_curve_train = np.array(history.history['loss'])
acc_curve_val = np.array(history.history['val_accuracy'])
loss_curve_val = np.array(history.history['val_loss'])
plot_curve(acc_curve_train, loss_curve_train, acc_curve_val, loss_curve_val)
```



1.1.7 Scores

[14]:
```
# Loading the best model - saved based on the lowest validation loss
model_a = load_model(save_path)
```

[15]:
```
# Evaluating the model on the training samples
score = model_a.evaluate(x_train, y_train_c)
print(f"Total loss on training set: {score[0]}")
print(f"Accuracy of training set: {score[1]}")
```

```
1250/1250 [==============================] - 4s 3ms/step - loss: 0.5000 -
accuracy: 0.8353
Total loss on training set: 0.5000460147857666
Accuracy of training set: 0.8352749943733215
```

[16]:
```
# Evaluating the model on the validation samples
score = model_a.evaluate(x_val, y_val_c)
print(f"Total loss on validation set: {score[0]}")
print(f"Accuracy of validation set: {score[1]}")
```

```
313/313 [==============================] - 1s 3ms/step - loss: 0.7373 -
accuracy: 0.7445
Total loss on validation set: 0.737325131893158
Accuracy of validation set: 0.7444999814033508
```

[17]:
```
# Evaluating the model on the held out samples
score = model_a.evaluate(x_test, y_test_c)
print(f"Total loss on testing set: {score[0]}")
print(f"Accuracy of testing set: {score[1]}")
```

```
313/313 [==============================] - 1s 4ms/step - loss: 0.7370 -
accuracy: 0.7456
Total loss on testing set: 0.7370343208312988
Accuracy of testing set: 0.7455999851226807
```