Homework 3 Final Models (CIFAR-10)

Adam Kiehl
4/30/23

```python
# import analysis packages
import keras
from keras.applications import ResNet50, VGG16
from keras.callbacks import EarlyStopping
from keras.datasets import cifar10
from keras.layers import AveragePooling2D, BatchNormalization, Conv2D, Dense, Dropout, Fla
from keras.regularizers import l2
from keras import models
from keras.utils import to_categorical
import matplotlib.pyplot as plt
import numpy as np
import pandas as pd
import tensorflow as tf
```

```python
# import dataset
(imgTrain, lblTrain), (imgTest, lblTest) = cifar10.load_data()

# scale image data
imgTrain = imgTrain.astype('float32') / 255
imgTest = imgTest.astype('float32') / 255

# factor categorical response
lblTrain = to_categorical(lblTrain)
```

```python
# set random seed
np.random.seed(4252023)
tf.random.set_seed(4252023)

# define model architecture
model1 = models.Sequential([
    Conv2D(128, (3, 3), padding = 'same', activation = 'relu', input_shape = (32, 32, 3)),
    MaxPooling2D((2, 2)),
    Conv2D(128, (3, 3), padding = 'same', activation = 'relu'),
    MaxPooling2D((2, 2)),
    Conv2D(32, (3, 3), padding = 'same', activation = 'relu'),
    Flatten(),
```

```python
    Dense(64, activation = 'relu'),
    Dense(10, activation = 'softmax')
])

# compile model
model1.compile(optimizer = 'rmsprop',
               loss = 'categorical_crossentropy',
               metrics = ['accuracy'])

# model summary
model1.summary()

# number of epochs
EPOCHS = 50

# early stopping criteria
earlyStop = EarlyStopping(monitor = 'loss', mode = 'min', verbose = 1, patience = 3)

# train model
trained = model1.fit(imgTrain,
                     lblTrain,
                     epochs = EPOCHS,
                     batch_size = 32,
                     callbacks = earlyStop,
                     verbose = 2)

# predict on test set
pred1 = model1.predict(imgTest)

# prediction accuracy
display(f"Validation accuracy: {round(np.mean(np.argmax(pred1, axis = 1).reshape(10000, 1)
```

Metal device set to: Apple M1

systemMemory: 8.00 GB
maxCacheSize: 2.67 GB

Model: "sequential"

```
-----------------------------------------------------------------
 Layer (type)                 Output Shape              Param #
=================================================================
 conv2d (Conv2D)              (None, 32, 32, 128)       3584
```

```
 max_pooling2d (MaxPooling2D  (None, 16, 16, 128)       0
 )

 conv2d_1 (Conv2D)           (None, 16, 16, 128)       147584

 max_pooling2d_1 (MaxPooling  (None, 8, 8, 128)         0
 2D)

 conv2d_2 (Conv2D)           (None, 8, 8, 32)          36896

 flatten (Flatten)           (None, 2048)              0

 dense (Dense)               (None, 64)                131136

 dense_1 (Dense)             (None, 10)                650

=================================================================
Total params: 319,850
Trainable params: 319,850
Non-trainable params: 0
_____
Epoch 1/50

2023-04-30 11:13:26.178850: W tensorflow/core/platform/profile_utils/cpu_utils.cc:128] Failed

1563/1563 - 29s - loss: 1.4566 - accuracy: 0.4780 - 29s/epoch - 18ms/step
Epoch 2/50
1563/1563 - 27s - loss: 1.0122 - accuracy: 0.6515 - 27s/epoch - 17ms/step
Epoch 3/50
1563/1563 - 27s - loss: 0.8582 - accuracy: 0.7020 - 27s/epoch - 17ms/step
Epoch 4/50
1563/1563 - 27s - loss: 0.7636 - accuracy: 0.7384 - 27s/epoch - 17ms/step
Epoch 5/50
1563/1563 - 27s - loss: 0.6919 - accuracy: 0.7635 - 27s/epoch - 17ms/step
Epoch 6/50
1563/1563 - 27s - loss: 0.6347 - accuracy: 0.7836 - 27s/epoch - 17ms/step
Epoch 7/50
1563/1563 - 27s - loss: 0.5880 - accuracy: 0.7997 - 27s/epoch - 17ms/step
Epoch 8/50
1563/1563 - 27s - loss: 0.5483 - accuracy: 0.8125 - 27s/epoch - 17ms/step
Epoch 9/50
```

```
1563/1563 - 27s - loss: 0.5187 - accuracy: 0.8246 - 27s/epoch - 17ms/step
Epoch 10/50
1563/1563 - 27s - loss: 0.4923 - accuracy: 0.8350 - 27s/epoch - 17ms/step
Epoch 11/50
1563/1563 - 27s - loss: 0.4736 - accuracy: 0.8431 - 27s/epoch - 17ms/step
Epoch 12/50
1563/1563 - 27s - loss: 0.4542 - accuracy: 0.8515 - 27s/epoch - 17ms/step
Epoch 13/50
1563/1563 - 27s - loss: 0.4388 - accuracy: 0.8567 - 27s/epoch - 17ms/step
Epoch 14/50
1563/1563 - 27s - loss: 0.4266 - accuracy: 0.8616 - 27s/epoch - 17ms/step
Epoch 15/50
1563/1563 - 27s - loss: 0.4306 - accuracy: 0.8611 - 27s/epoch - 18ms/step
Epoch 16/50
1563/1563 - 27s - loss: 0.4185 - accuracy: 0.8678 - 27s/epoch - 18ms/step
Epoch 17/50
1563/1563 - 27s - loss: 0.4126 - accuracy: 0.8681 - 27s/epoch - 18ms/step
Epoch 18/50
1563/1563 - 27s - loss: 0.4097 - accuracy: 0.8727 - 27s/epoch - 17ms/step
Epoch 19/50
1563/1563 - 27s - loss: 0.4177 - accuracy: 0.8723 - 27s/epoch - 17ms/step
Epoch 20/50
1563/1563 - 27s - loss: 0.4301 - accuracy: 0.8706 - 27s/epoch - 17ms/step
Epoch 21/50
1563/1563 - 28s - loss: 0.4182 - accuracy: 0.8702 - 28s/epoch - 18ms/step
Epoch 21: early stopping
313/313 [==============================] - 2s 6ms/step
```

'Validation accuracuy: 71.78%'

```python
# create submission data frame
submission = pd.DataFrame({'id': range(1, len(pred1) + 1), 'class': np.argmax(pred1, axis

# export submission
submission.to_csv('./submission1.csv', index = False)

# set trainable layers
VGGBase = VGG16(weights = 'imagenet', include_top = False, input_shape = (32, 32, 3))
VGGBase.trainable = True
for layer in VGGBase.layers:
    if layer.name in ['block2_conv1', 'block3_conv1']:
```

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```python
            layer.trainable = True
        else:
            layer.trainable = False

    # define model architecture
    model2 = models.Sequential([
        VGGBase,
        Flatten(),
        Dense(64, activation = 'relu'),
        Dense(10, activation = 'softmax')
    ])

    # compile model
    model2.compile(optimizer = 'rmsprop',
                   loss = 'categorical_crossentropy',
                   metrics = ['accuracy'])

    # model summary
    model2.summary()

    # number of epochs
    EPOCHS = 50

    # early stopping criteria
    earlyStop = EarlyStopping(monitor = 'loss', mode = 'min', verbose = 1, patience = 3)

    # train model
    trained = model2.fit(imgTrain,
                         lblTrain,
                         epochs = EPOCHS,
                         batch_size = 32,
                         callbacks = earlyStop,
                         verbose = 2)

    # predict on test set
    pred2 = model2.predict(imgTest)

    # prediction accuracy
    display(f"Validation accuracy: {round(np.mean(np.argmax(pred2, axis = 1).reshape(10000, 1)
```

```
Model: "sequential_1"
_____
```

```
 Layer (type)                 Output Shape              Param #
=================================================================
 vgg16 (Functional)           (None, 1, 1, 512)         14714688

 flatten_1 (Flatten)          (None, 512)               0

 dense_2 (Dense)              (None, 64)                32832

 dense_3 (Dense)              (None, 10)                650


=================================================================
Total params: 14,748,170
Trainable params: 402,506
Non-trainable params: 14,345,664

-----------------------------------------------------------------
Epoch 1/50
1563/1563 - 44s - loss: 1.3419 - accuracy: 0.5138 - 44s/epoch - 28ms/step
Epoch 2/50
1563/1563 - 43s - loss: 0.9630 - accuracy: 0.6597 - 43s/epoch - 28ms/step
Epoch 3/50
1563/1563 - 43s - loss: 0.8454 - accuracy: 0.7059 - 43s/epoch - 28ms/step
Epoch 4/50
1563/1563 - 43s - loss: 0.7714 - accuracy: 0.7315 - 43s/epoch - 27ms/step
Epoch 5/50
1563/1563 - 43s - loss: 0.7227 - accuracy: 0.7485 - 43s/epoch - 27ms/step
Epoch 6/50
1563/1563 - 43s - loss: 0.6816 - accuracy: 0.7639 - 43s/epoch - 27ms/step
Epoch 7/50
1563/1563 - 43s - loss: 0.6473 - accuracy: 0.7763 - 43s/epoch - 27ms/step
Epoch 8/50
1563/1563 - 43s - loss: 0.6182 - accuracy: 0.7854 - 43s/epoch - 27ms/step
Epoch 9/50
1563/1563 - 43s - loss: 0.5875 - accuracy: 0.7965 - 43s/epoch - 27ms/step
Epoch 10/50
1563/1563 - 43s - loss: 0.5628 - accuracy: 0.8051 - 43s/epoch - 27ms/step
Epoch 11/50
1563/1563 - 43s - loss: 0.5405 - accuracy: 0.8127 - 43s/epoch - 27ms/step
Epoch 12/50
1563/1563 - 43s - loss: 0.5207 - accuracy: 0.8200 - 43s/epoch - 27ms/step
Epoch 13/50
1563/1563 - 43s - loss: 0.5011 - accuracy: 0.8268 - 43s/epoch - 27ms/step
Epoch 14/50
1563/1563 - 43s - loss: 0.4837 - accuracy: 0.8307 - 43s/epoch - 27ms/step
```

```
Epoch 15/50
1563/1563 - 43s - loss: 0.4677 - accuracy: 0.8368 - 43s/epoch - 27ms/step
Epoch 16/50
1563/1563 - 43s - loss: 0.4498 - accuracy: 0.8429 - 43s/epoch - 27ms/step
Epoch 17/50
1563/1563 - 43s - loss: 0.4344 - accuracy: 0.8488 - 43s/epoch - 27ms/step
Epoch 18/50
1563/1563 - 43s - loss: 0.4185 - accuracy: 0.8541 - 43s/epoch - 27ms/step
Epoch 19/50
1563/1563 - 43s - loss: 0.4071 - accuracy: 0.8599 - 43s/epoch - 27ms/step
Epoch 20/50
1563/1563 - 43s - loss: 0.3938 - accuracy: 0.8635 - 43s/epoch - 27ms/step
Epoch 21/50
1563/1563 - 43s - loss: 0.3819 - accuracy: 0.8677 - 43s/epoch - 27ms/step
Epoch 22/50
1563/1563 - 43s - loss: 0.3703 - accuracy: 0.8717 - 43s/epoch - 27ms/step
Epoch 23/50
1563/1563 - 43s - loss: 0.3566 - accuracy: 0.8772 - 43s/epoch - 27ms/step
Epoch 24/50
1563/1563 - 43s - loss: 0.3454 - accuracy: 0.8808 - 43s/epoch - 27ms/step
Epoch 25/50
1563/1563 - 43s - loss: 0.3341 - accuracy: 0.8846 - 43s/epoch - 27ms/step
Epoch 26/50
1563/1563 - 43s - loss: 0.3195 - accuracy: 0.8880 - 43s/epoch - 27ms/step
Epoch 27/50
1563/1563 - 43s - loss: 0.3190 - accuracy: 0.8903 - 43s/epoch - 27ms/step
Epoch 28/50
1563/1563 - 43s - loss: 0.3075 - accuracy: 0.8945 - 43s/epoch - 27ms/step
Epoch 29/50
1563/1563 - 43s - loss: 0.2945 - accuracy: 0.8987 - 43s/epoch - 27ms/step
Epoch 30/50
1563/1563 - 43s - loss: 0.2904 - accuracy: 0.9016 - 43s/epoch - 28ms/step
Epoch 31/50
1563/1563 - 44s - loss: 0.2754 - accuracy: 0.9049 - 44s/epoch - 28ms/step
Epoch 32/50
1563/1563 - 45s - loss: 0.2747 - accuracy: 0.9061 - 45s/epoch - 29ms/step
Epoch 33/50
1563/1563 - 43s - loss: 0.2685 - accuracy: 0.9079 - 43s/epoch - 28ms/step
Epoch 34/50
1563/1563 - 43s - loss: 0.2571 - accuracy: 0.9129 - 43s/epoch - 28ms/step
Epoch 35/50
1563/1563 - 45s - loss: 0.2479 - accuracy: 0.9165 - 45s/epoch - 29ms/step
Epoch 36/50
```

```
1563/1563 - 44s - loss: 0.2441 - accuracy: 0.9171 - 44s/epoch - 28ms/step
Epoch 37/50
1563/1563 - 44s - loss: 0.2388 - accuracy: 0.9176 - 44s/epoch - 28ms/step
Epoch 38/50
1563/1563 - 43s - loss: 0.2302 - accuracy: 0.9224 - 43s/epoch - 27ms/step
Epoch 39/50
1563/1563 - 42s - loss: 0.2274 - accuracy: 0.9238 - 42s/epoch - 27ms/step
Epoch 40/50
1563/1563 - 43s - loss: 0.2242 - accuracy: 0.9240 - 43s/epoch - 27ms/step
Epoch 41/50
1563/1563 - 43s - loss: 0.2152 - accuracy: 0.9282 - 43s/epoch - 27ms/step
Epoch 42/50
1563/1563 - 46s - loss: 0.2109 - accuracy: 0.9309 - 46s/epoch - 29ms/step
Epoch 43/50
1563/1563 - 44s - loss: 0.2086 - accuracy: 0.9305 - 44s/epoch - 28ms/step
Epoch 44/50
1563/1563 - 45s - loss: 0.2000 - accuracy: 0.9335 - 45s/epoch - 29ms/step
Epoch 45/50
1563/1563 - 44s - loss: 0.1980 - accuracy: 0.9336 - 44s/epoch - 28ms/step
Epoch 46/50
1563/1563 - 44s - loss: 0.1970 - accuracy: 0.9364 - 44s/epoch - 28ms/step
Epoch 47/50
1563/1563 - 43s - loss: 0.1863 - accuracy: 0.9381 - 43s/epoch - 27ms/step
Epoch 48/50
1563/1563 - 42s - loss: 0.1850 - accuracy: 0.9388 - 42s/epoch - 27ms/step
Epoch 49/50
1563/1563 - 43s - loss: 0.1804 - accuracy: 0.9414 - 43s/epoch - 27ms/step
Epoch 50/50
1563/1563 - 43s - loss: 0.1737 - accuracy: 0.9431 - 43s/epoch - 28ms/step
313/313 [==============================] - 4s 13ms/step
```

'Validation accuracuy: 75.87%'

```python
# create submission data frame
submission = pd.DataFrame({'id': range(1, len(pred2) + 1), 'class': np.argmax(pred2, axis

# export submission
submission.to_csv('./submission2.csv', index = False)


# set trainable layers
VGGBase = VGG16(weights = 'imagenet', include_top = False, input_shape = (32, 32, 3))
```

```python
VGGBase.trainable = True
for layer in VGGBase.layers:
    if layer.name in ['block2_conv1', 'block3_conv1']:
        layer.trainable = True
    else:
        layer.trainable = False

# define model hyperparameters
PENALTY = 0.005
RATE = 0.1

# define model architecture
model3 = models.Sequential([
    VGGBase,
    Flatten(),
    Dense(128, activation = 'relu', kernel_regularizer = l2(PENALTY)),
    Dropout(RATE),
    Dense(64, activation = 'relu', kernel_regularizer = l2(PENALTY)),
    Dense(10, activation = 'softmax')
])

# compile model
model3.compile(optimizer = 'rmsprop',
               loss = 'categorical_crossentropy',
               metrics = ['accuracy'])

# model summary
model3.summary()

# number of epochs
EPOCHS = 100

# early stopping criteria
earlyStop = EarlyStopping(monitor = 'loss', mode = 'min', verbose = 1, patience = 3)

# train model
trained = model3.fit(imgTrain,
                     lblTrain,
                     epochs = EPOCHS,
                     batch_size = 32,
                     callbacks = earlyStop,
```

```
                verbose = 2)

  # predict on test set
  pred3 = model3.predict(imgTest)

  # prediction accuracy
  display(f"Validation accuracy: {round(np.mean(np.argmax(pred3, axis = 1).reshape(10000, 1)
```

Metal device set to: Apple M1

systemMemory: 8.00 GB
maxCacheSize: 2.67 GB

Model: "sequential"

```
_____
 Layer (type)              Output Shape            Param #
=================================================================
 vgg16 (Functional)        (None, 1, 1, 512)       14714688

 flatten (Flatten)         (None, 512)             0

 dense (Dense)             (None, 128)             65664

 dropout (Dropout)         (None, 128)             0

 dense_1 (Dense)           (None, 64)              8256

 dense_2 (Dense)           (None, 10)              650

=================================================================
Total params: 14,789,258
Trainable params: 443,594
Non-trainable params: 14,345,664
_____
```

Epoch 1/100

2023-04-30 13:10:29.208332: W tensorflow/core/platform/profile_utils/cpu_utils.cc:128] Failed

1563/1563 - 47s - loss: 1.6251 - accuracy: 0.4576 - 47s/epoch - 30ms/step
Epoch 2/100
1563/1563 - 45s - loss: 1.1629 - accuracy: 0.6153 - 45s/epoch - 29ms/step

```
Epoch 3/100
1563/1563 - 45s - loss: 1.0232 - accuracy: 0.6639 - 45s/epoch - 29ms/step
Epoch 4/100
1563/1563 - 45s - loss: 0.9442 - accuracy: 0.6920 - 45s/epoch - 29ms/step
Epoch 5/100
1563/1563 - 45s - loss: 0.8816 - accuracy: 0.7134 - 45s/epoch - 29ms/step
Epoch 6/100
1563/1563 - 45s - loss: 0.8318 - accuracy: 0.7305 - 45s/epoch - 29ms/step
Epoch 7/100
1563/1563 - 45s - loss: 0.7947 - accuracy: 0.7454 - 45s/epoch - 29ms/step
Epoch 8/100
1563/1563 - 46s - loss: 0.7608 - accuracy: 0.7549 - 46s/epoch - 30ms/step
Epoch 9/100
1563/1563 - 45s - loss: 0.7224 - accuracy: 0.7697 - 45s/epoch - 29ms/step
Epoch 10/100
1563/1563 - 45s - loss: 0.6925 - accuracy: 0.7787 - 45s/epoch - 29ms/step
Epoch 11/100
1563/1563 - 45s - loss: 0.6689 - accuracy: 0.7879 - 45s/epoch - 29ms/step
Epoch 12/100
1563/1563 - 45s - loss: 0.6459 - accuracy: 0.7962 - 45s/epoch - 29ms/step
Epoch 13/100
1563/1563 - 45s - loss: 0.6200 - accuracy: 0.8049 - 45s/epoch - 29ms/step
Epoch 14/100
1563/1563 - 45s - loss: 0.6028 - accuracy: 0.8105 - 45s/epoch - 29ms/step
Epoch 15/100
1563/1563 - 45s - loss: 0.5792 - accuracy: 0.8182 - 45s/epoch - 29ms/step
Epoch 16/100
1563/1563 - 45s - loss: 0.5664 - accuracy: 0.8233 - 45s/epoch - 29ms/step
Epoch 17/100
1563/1563 - 45s - loss: 0.5456 - accuracy: 0.8307 - 45s/epoch - 29ms/step
Epoch 18/100
1563/1563 - 45s - loss: 0.5275 - accuracy: 0.8368 - 45s/epoch - 29ms/step
Epoch 19/100
1563/1563 - 45s - loss: 0.5134 - accuracy: 0.8421 - 45s/epoch - 29ms/step
Epoch 20/100
1563/1563 - 45s - loss: 0.4985 - accuracy: 0.8462 - 45s/epoch - 29ms/step
Epoch 21/100
1563/1563 - 45s - loss: 0.4828 - accuracy: 0.8517 - 45s/epoch - 29ms/step
Epoch 22/100
1563/1563 - 45s - loss: 0.4684 - accuracy: 0.8571 - 45s/epoch - 29ms/step
Epoch 23/100
1563/1563 - 45s - loss: 0.4568 - accuracy: 0.8612 - 45s/epoch - 29ms/step
Epoch 24/100
```

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1563/1563 - 45s - loss: 0.4407 - accuracy: 0.8665 - 45s/epoch - 29ms/step
Epoch 25/100
1563/1563 - 45s - loss: 0.4302 - accuracy: 0.8696 - 45s/epoch - 29ms/step
Epoch 26/100
1563/1563 - 45s - loss: 0.4170 - accuracy: 0.8745 - 45s/epoch - 29ms/step
Epoch 27/100
1563/1563 - 45s - loss: 0.4050 - accuracy: 0.8797 - 45s/epoch - 29ms/step
Epoch 28/100
1563/1563 - 45s - loss: 0.3968 - accuracy: 0.8819 - 45s/epoch - 29ms/step
Epoch 29/100
1563/1563 - 45s - loss: 0.3859 - accuracy: 0.8854 - 45s/epoch - 29ms/step
Epoch 30/100
1563/1563 - 45s - loss: 0.3742 - accuracy: 0.8880 - 45s/epoch - 29ms/step
Epoch 31/100
1563/1563 - 45s - loss: 0.3662 - accuracy: 0.8917 - 45s/epoch - 29ms/step
Epoch 32/100
1563/1563 - 45s - loss: 0.3555 - accuracy: 0.8953 - 45s/epoch - 29ms/step
Epoch 33/100
1563/1563 - 45s - loss: 0.3488 - accuracy: 0.8973 - 45s/epoch - 29ms/step
Epoch 34/100
1563/1563 - 49s - loss: 0.3362 - accuracy: 0.9010 - 49s/epoch - 31ms/step
Epoch 35/100
1563/1563 - 47s - loss: 0.3291 - accuracy: 0.9036 - 47s/epoch - 30ms/step
Epoch 36/100
1563/1563 - 46s - loss: 0.3206 - accuracy: 0.9068 - 46s/epoch - 29ms/step
Epoch 37/100
1563/1563 - 45s - loss: 0.3113 - accuracy: 0.9106 - 45s/epoch - 29ms/step
Epoch 38/100
1563/1563 - 45s - loss: 0.3026 - accuracy: 0.9127 - 45s/epoch - 29ms/step
Epoch 39/100
1563/1563 - 45s - loss: 0.2942 - accuracy: 0.9160 - 45s/epoch - 29ms/step
Epoch 40/100
1563/1563 - 46s - loss: 0.2848 - accuracy: 0.9173 - 46s/epoch - 29ms/step
Epoch 41/100
1563/1563 - 46s - loss: 0.2793 - accuracy: 0.9208 - 46s/epoch - 29ms/step
Epoch 42/100
1563/1563 - 45s - loss: 0.2744 - accuracy: 0.9219 - 45s/epoch - 29ms/step
Epoch 43/100
1563/1563 - 45s - loss: 0.2643 - accuracy: 0.9259 - 45s/epoch - 29ms/step
Epoch 44/100
1563/1563 - 45s - loss: 0.2640 - accuracy: 0.9256 - 45s/epoch - 29ms/step
Epoch 45/100
1563/1563 - 45s - loss: 0.2574 - accuracy: 0.9279 - 45s/epoch - 29ms/step
```

```
Epoch 46/100
1563/1563 - 45s - loss: 0.2514 - accuracy: 0.9291 - 45s/epoch - 29ms/step
Epoch 47/100
1563/1563 - 45s - loss: 0.2457 - accuracy: 0.9316 - 45s/epoch - 29ms/step
Epoch 48/100
1563/1563 - 45s - loss: 0.2401 - accuracy: 0.9345 - 45s/epoch - 29ms/step
Epoch 49/100
1563/1563 - 45s - loss: 0.2343 - accuracy: 0.9352 - 45s/epoch - 29ms/step
Epoch 50/100
1563/1563 - 45s - loss: 0.2267 - accuracy: 0.9362 - 45s/epoch - 29ms/step
Epoch 51/100
1563/1563 - 45s - loss: 0.2230 - accuracy: 0.9380 - 45s/epoch - 29ms/step
Epoch 52/100
1563/1563 - 45s - loss: 0.2201 - accuracy: 0.9398 - 45s/epoch - 29ms/step
Epoch 53/100
1563/1563 - 45s - loss: 0.2150 - accuracy: 0.9404 - 45s/epoch - 29ms/step
Epoch 54/100
1563/1563 - 45s - loss: 0.2109 - accuracy: 0.9412 - 45s/epoch - 29ms/step
Epoch 55/100
1563/1563 - 45s - loss: 0.2040 - accuracy: 0.9439 - 45s/epoch - 29ms/step
Epoch 56/100
1563/1563 - 45s - loss: 0.2009 - accuracy: 0.9453 - 45s/epoch - 29ms/step
Epoch 57/100
1563/1563 - 45s - loss: 0.1979 - accuracy: 0.9465 - 45s/epoch - 29ms/step
Epoch 58/100
1563/1563 - 45s - loss: 0.1936 - accuracy: 0.9475 - 45s/epoch - 29ms/step
Epoch 59/100
1563/1563 - 45s - loss: 0.1926 - accuracy: 0.9488 - 45s/epoch - 29ms/step
Epoch 60/100
1563/1563 - 45s - loss: 0.1865 - accuracy: 0.9495 - 45s/epoch - 29ms/step
Epoch 61/100
1563/1563 - 45s - loss: 0.1826 - accuracy: 0.9510 - 45s/epoch - 29ms/step
Epoch 62/100
1563/1563 - 45s - loss: 0.1793 - accuracy: 0.9516 - 45s/epoch - 29ms/step
Epoch 63/100
1563/1563 - 45s - loss: 0.1778 - accuracy: 0.9533 - 45s/epoch - 29ms/step
Epoch 64/100
1563/1563 - 45s - loss: 0.1750 - accuracy: 0.9534 - 45s/epoch - 29ms/step
Epoch 65/100
1563/1563 - 45s - loss: 0.1708 - accuracy: 0.9539 - 45s/epoch - 29ms/step
Epoch 66/100
1563/1563 - 45s - loss: 0.1700 - accuracy: 0.9557 - 45s/epoch - 29ms/step
Epoch 67/100
```

```
1563/1563 - 45s - loss: 0.1619 - accuracy: 0.9575 - 45s/epoch - 29ms/step
Epoch 68/100
1563/1563 - 45s - loss: 0.1602 - accuracy: 0.9582 - 45s/epoch - 29ms/step
Epoch 69/100
1563/1563 - 45s - loss: 0.1580 - accuracy: 0.9581 - 45s/epoch - 29ms/step
Epoch 70/100
1563/1563 - 45s - loss: 0.1548 - accuracy: 0.9593 - 45s/epoch - 29ms/step
Epoch 71/100
1563/1563 - 45s - loss: 0.1548 - accuracy: 0.9604 - 45s/epoch - 29ms/step
Epoch 72/100
1563/1563 - 45s - loss: 0.1477 - accuracy: 0.9618 - 45s/epoch - 29ms/step
Epoch 73/100
1563/1563 - 45s - loss: 0.1484 - accuracy: 0.9610 - 45s/epoch - 29ms/step
Epoch 74/100
1563/1563 - 45s - loss: 0.1455 - accuracy: 0.9621 - 45s/epoch - 29ms/step
Epoch 75/100
1563/1563 - 45s - loss: 0.1453 - accuracy: 0.9625 - 45s/epoch - 29ms/step
Epoch 76/100
1563/1563 - 45s - loss: 0.1384 - accuracy: 0.9651 - 45s/epoch - 29ms/step
Epoch 77/100
1563/1563 - 45s - loss: 0.1409 - accuracy: 0.9648 - 45s/epoch - 29ms/step
Epoch 78/100
1563/1563 - 45s - loss: 0.1399 - accuracy: 0.9640 - 45s/epoch - 29ms/step
Epoch 79/100
1563/1563 - 45s - loss: 0.1363 - accuracy: 0.9640 - 45s/epoch - 29ms/step
Epoch 80/100
1563/1563 - 45s - loss: 0.1334 - accuracy: 0.9667 - 45s/epoch - 29ms/step
Epoch 81/100
1563/1563 - 45s - loss: 0.1348 - accuracy: 0.9655 - 45s/epoch - 29ms/step
Epoch 82/100
1563/1563 - 45s - loss: 0.1313 - accuracy: 0.9657 - 45s/epoch - 29ms/step
Epoch 83/100
1563/1563 - 45s - loss: 0.1249 - accuracy: 0.9684 - 45s/epoch - 29ms/step
Epoch 84/100
1563/1563 - 45s - loss: 0.1283 - accuracy: 0.9677 - 45s/epoch - 29ms/step
Epoch 85/100
1563/1563 - 45s - loss: 0.1230 - accuracy: 0.9691 - 45s/epoch - 29ms/step
Epoch 86/100
1563/1563 - 45s - loss: 0.1252 - accuracy: 0.9693 - 45s/epoch - 29ms/step
Epoch 87/100
1563/1563 - 45s - loss: 0.1236 - accuracy: 0.9692 - 45s/epoch - 29ms/step
Epoch 88/100
1563/1563 - 45s - loss: 0.1174 - accuracy: 0.9704 - 45s/epoch - 29ms/step
```

```
Epoch 89/100
1563/1563 - 45s - loss: 0.1208 - accuracy: 0.9694 - 45s/epoch - 29ms/step
Epoch 90/100
1563/1563 - 45s - loss: 0.1174 - accuracy: 0.9716 - 45s/epoch - 29ms/step
Epoch 91/100
1563/1563 - 45s - loss: 0.1168 - accuracy: 0.9714 - 45s/epoch - 29ms/step
Epoch 92/100
1563/1563 - 45s - loss: 0.1163 - accuracy: 0.9714 - 45s/epoch - 29ms/step
Epoch 93/100
1563/1563 - 45s - loss: 0.1169 - accuracy: 0.9717 - 45s/epoch - 29ms/step
Epoch 94/100
1563/1563 - 45s - loss: 0.1130 - accuracy: 0.9724 - 45s/epoch - 29ms/step
Epoch 95/100
1563/1563 - 45s - loss: 0.1136 - accuracy: 0.9727 - 45s/epoch - 29ms/step
Epoch 96/100
1563/1563 - 45s - loss: 0.1119 - accuracy: 0.9719 - 45s/epoch - 29ms/step
Epoch 97/100
1563/1563 - 45s - loss: 0.1088 - accuracy: 0.9727 - 45s/epoch - 29ms/step
Epoch 98/100
1563/1563 - 45s - loss: 0.1079 - accuracy: 0.9735 - 45s/epoch - 29ms/step
Epoch 99/100
1563/1563 - 45s - loss: 0.1051 - accuracy: 0.9741 - 45s/epoch - 29ms/step
Epoch 100/100
1563/1563 - 45s - loss: 0.1065 - accuracy: 0.9742 - 45s/epoch - 29ms/step
313/313 [==============================] - 4s 13ms/step
```

'Validation accuracy: 78.09%'

```python
# create submission data frame
submission = pd.DataFrame({'id': range(1, len(pred3) + 1), 'class': np.argmax(pred3, axis

# export submission
submission.to_csv('./submission3.csv', index = False)
```