Assignment 6.1

July 9, 2021

1 Assignment 6.1

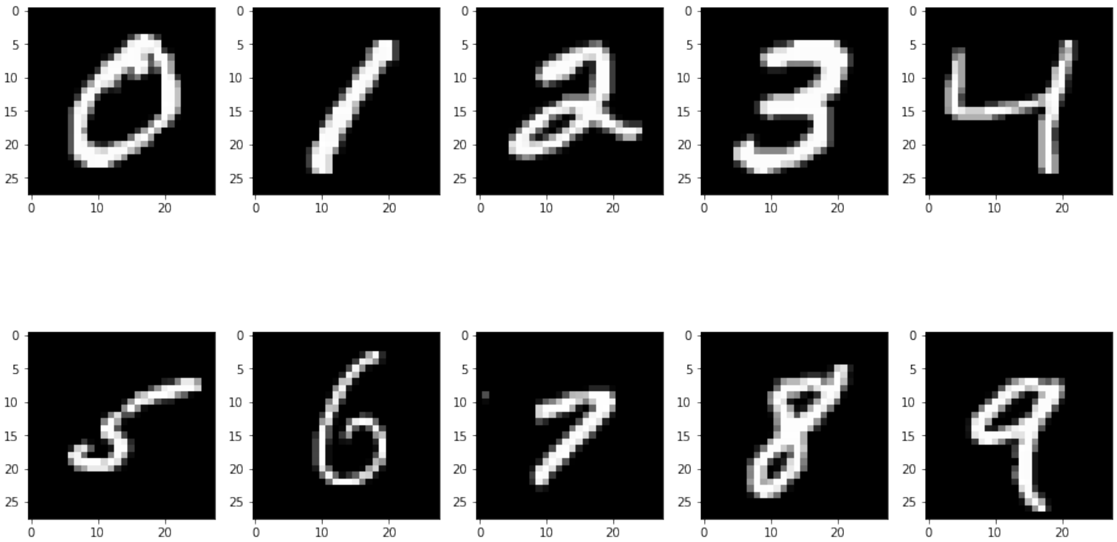
Using section 5.1 in Deep Learning with Python as a guide (listing 5.3 in particular), create a ConvNet model that classifies images in the MNIST digit dataset. Save the model, predictions, metrics, and validation plots in the dsc650/assignments/assignment06/results directory. If you are using JupyterHub, you can include those plots in your Jupyter notebook.

[1]:
```
from tensorflow.keras.datasets import mnist
import matplotlib.pyplot as plt
```

1.1 Data Exploration

[2]:
```
# Loading the data into memory
(train_images, train_labels), (test_images, test_labels) = mnist.load_data()

fig, [[ax0, ax1, ax2, ax3, ax4],
      [ax5, ax6, ax7, ax8, ax9]] = plt.subplots(2,5, figsize=(16,9))

ax0.imshow(train_images[1], cmap='gray')
ax1.imshow(train_images[3], cmap='gray')
ax2.imshow(train_images[5], cmap='gray')
ax3.imshow(train_images[7], cmap='gray')
ax4.imshow(train_images[2], cmap='gray')
ax5.imshow(train_images[11], cmap='gray')
ax6.imshow(train_images[18], cmap='gray')
ax7.imshow(train_images[29], cmap='gray')
ax8.imshow(train_images[17], cmap='gray')
ax9.imshow(train_images[4], cmap='gray')
```

[2]:
```
<matplotlib.image.AxesImage at 0x1fc95985460>
```



The training data contains 60,000 observations of 28x28 pixel images with targets ranging from 0 to 9

```
[3]: train_images.shape
```

```
[3]: (60000, 28, 28)
```

```
[4]: set(train_labels)
```

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

The testing set contains 10,000 images

```
[5]: test_images.shape
```

```
[5]: (10000, 28, 28)
```

The images contain gray level values ranging from 0 (black) to 255 (white)

```
[6]: train_images[0].max()
```

```
[6]: 255
```

1.2 Preparing the data

The data will need to be reshaped and normalized before we feed it into a neural network

```
[7]: train_images = train_images.reshape((60000, 28, 28, 1))
     train_images = train_images / train_images.max()

     test_images = test_images.reshape((10000, 28, 28, 1))
test_images = test_images / train_images.max()

train_images_val = train_images[:10000]
train_images = train_images[10000:]

train_labels_val = train_labels[:10000]
train_labels = train_labels[10000:]
```

1.3 Building the neural net

[8]:

```
from keras import models
from keras.layers import Conv2D, MaxPooling2D, Flatten, Dense
```

[9]:

```
model = models.Sequential()
model.add(Conv2D(32,(3,3),activation='relu',input_shape=(28,28,1)))
model.add(MaxPooling2D((2,2)))
model.add(Conv2D(64,(3,3),activation='relu',input_shape=(28,28,1)))
model.add(MaxPooling2D((2,2)))
model.add(Conv2D(64,(3,3),activation='relu',input_shape=(28,28,1)))
model.add(Flatten())
model.add(Dense(64,activation='relu'))
model.add(Dense(10,activation='softmax'))
```

[10]:

```
model.compile(optimizer='rmsprop',
             loss='sparse_categorical_crossentropy',
             metrics=['acc'])

history = model.fit(train_images,
                    train_labels,
                    epochs=20,
                    batch_size=64,
                    validation_data = (train_images_val, train_labels_val),
                    verbose=True)
```

```
Epoch 1/20
782/782 [==============================] - 34s 42ms/step - loss: 0.4694 - acc:
0.8456 - val_loss: 0.1131 - val_acc: 0.9671
Epoch 2/20
782/782 [==============================] - 33s 42ms/step - loss: 0.0537 - acc:
0.9832 - val_loss: 0.0443 - val_acc: 0.9881
Epoch 3/20
782/782 [==============================] - 30s 39ms/step - loss: 0.0351 - acc:
0.9890 - val_loss: 0.0438 - val_acc: 0.9886
Epoch 4/20
782/782 [==============================] - 31s 40ms/step - loss: 0.0254 - acc:
0.9921 - val_loss: 0.0376 - val_acc: 0.9890
Epoch 5/20
782/782 [==============================] - 32s 41ms/step - loss: 0.0207 - acc:
```

```
0.9936 - val_loss: 0.0533 - val_acc: 0.9882
Epoch 6/20
782/782 [==============================] - 32s 41ms/step - loss: 0.0154 - acc:
0.9955 - val_loss: 0.0458 - val_acc: 0.9900
Epoch 7/20
782/782 [==============================] - 36s 46ms/step - loss: 0.0110 - acc:
0.9966 - val_loss: 0.0407 - val_acc: 0.9898
Epoch 8/20
782/782 [==============================] - 34s 43ms/step - loss: 0.0097 - acc:
0.9969 - val_loss: 0.0459 - val_acc: 0.9910
Epoch 9/20
782/782 [==============================] - 32s 40ms/step - loss: 0.0083 - acc:
0.9974 - val_loss: 0.0521 - val_acc: 0.9910
Epoch 10/20
782/782 [==============================] - 33s 42ms/step - loss: 0.0065 - acc:
0.9979 - val_loss: 0.0558 - val_acc: 0.9889
Epoch 11/20
782/782 [==============================] - 33s 42ms/step - loss: 0.0043 - acc:
0.9986 - val_loss: 0.0644 - val_acc: 0.9886
Epoch 12/20
782/782 [==============================] - 33s 42ms/step - loss: 0.0052 - acc:
0.9981 - val_loss: 0.0589 - val_acc: 0.9906
Epoch 13/20
782/782 [==============================] - 33s 42ms/step - loss: 0.0046 - acc:
0.9987 - val_loss: 0.0729 - val_acc: 0.9905
Epoch 14/20
782/782 [==============================] - 32s 41ms/step - loss: 0.0054 - acc:
0.9984 - val_loss: 0.0612 - val_acc: 0.9909
Epoch 15/20
782/782 [==============================] - 32s 40ms/step - loss: 0.0040 - acc:
0.9988 - val_loss: 0.0742 - val_acc: 0.9903
Epoch 16/20
782/782 [==============================] - 33s 42ms/step - loss: 0.0035 - acc:
0.9990 - val_loss: 0.0823 - val_acc: 0.9902
Epoch 17/20
782/782 [==============================] - 32s 41ms/step - loss: 0.0034 - acc:
0.9990 - val_loss: 0.0637 - val_acc: 0.9917
Epoch 18/20
782/782 [==============================] - 33s 43ms/step - loss: 0.0042 - acc:
0.9989 - val_loss: 0.0852 - val_acc: 0.9909
Epoch 19/20
782/782 [==============================] - 33s 42ms/step - loss: 0.0026 - acc:
0.9994 - val_loss: 0.0752 - val_acc: 0.9905
Epoch 20/20
782/782 [==============================] - 33s 43ms/step - loss: 0.0022 - acc:
0.9993 - val_loss: 0.0815 - val_acc: 0.9914
```

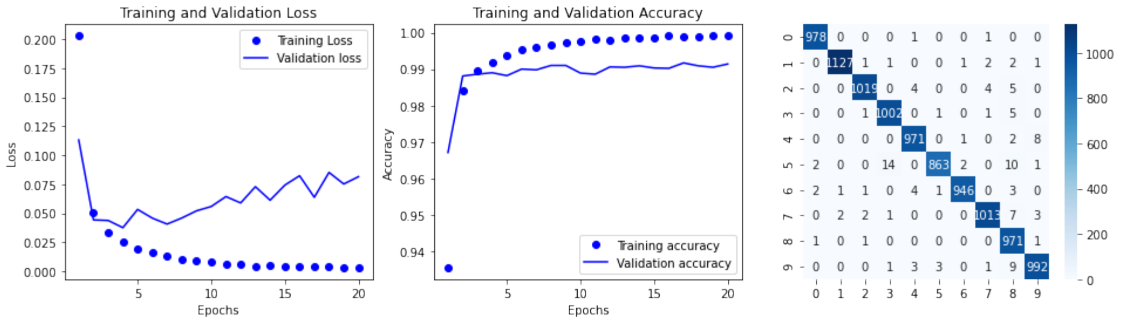
[11]:

```python
import sklearn.metrics as metrics
from seaborn import heatmap
import numpy as np
```

[12]:

```python
results = model.evaluate(test_images, test_labels)
print(results)

history_dict = history.history

acc = history_dict['acc']
val_acc = history_dict['val_acc']
loss_values = history_dict['loss']
val_loss_values = history_dict['val_loss']
epochs = range(1,len(acc) + 1)

# Plotting metrics
fig, [ax1, ax2, ax3] = plt.subplots(1,3, figsize=(16,4))

ax1.plot(epochs, loss_values,  'bo', label = 'Training Loss')
ax1.plot(epochs, val_loss_values, 'b', label = 'Validation loss')
ax1.set_title('Training and Validation Loss')
ax1.set_xlabel("Epochs")
ax1.set_ylabel("Loss")
ax1.legend()

ax2.plot(epochs, acc,  'bo', label = 'Training accuracy')
ax2.plot(epochs, val_acc, 'b', label = 'Validation accuracy')
ax2.set_title('Training and Validation Accuracy')
ax2.set_xlabel("Epochs")
ax2.set_ylabel("Accuracy")
ax2.legend()

confusion_matrix = metrics.confusion_matrix(y_true=test_labels,
                                            y_pred=model.predict(test_images).
 ↪argmax(axis = 1))
heatmap(confusion_matrix, annot = True, cmap='Blues', fmt='g', ax = ax3);
```

```
313/313 [==============================] - 2s 7ms/step - loss: 25.2807 - acc:
0.9882
[25.280717849731445, 0.9882000088691711]
```



	0	1	2	3	4	5	6	7	8	9
0	978	0	0	0	1	0	0	1	0	0
1	0	1127	1	1	0	0	1	2	2	1
2	0	0	1019	0	4	0	0	4	5	0
3	0	0	1	1002	0	1	0	1	5	0
4	0	0	0	0	971	0	1	0	2	8
5	2	0	0	14	0	863	2	0	10	1
6	2	1	1	0	4	1	946	0	3	0
7	0	2	2	1	0	0	0	1013	7	3
8	1	0	1	0	0	0	0	0	971	1
9	0	0	0	1	3	3	0	1	9	992

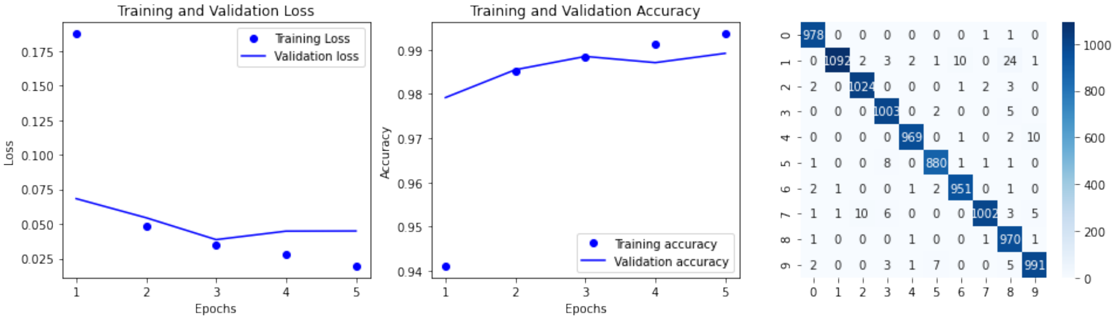
[13]:

```
model = models.Sequential()
model.add(Conv2D(32,(3,3),activation='relu',input_shape=(28,28,1)))
model.add(MaxPooling2D((2,2)))
model.add(Conv2D(64,(3,3),activation='relu',input_shape=(28,28,1)))
model.add(MaxPooling2D((2,2)))
model.add(Conv2D(64,(3,3),activation='relu',input_shape=(28,28,1)))
model.add(Flatten())
model.add(Dense(64,activation='relu'))
model.add(Dense(10,activation='softmax'))

model.compile(optimizer='rmsprop',
             loss='sparse_categorical_crossentropy',
             metrics=['accuracy'])

history = model.fit(train_images,
                    train_labels,
                    epochs=5,
                    batch_size=64,
                    validation_data = (train_images_val, train_labels_val))
```

```
Epoch 1/5
782/782 [==============================] - 33s 41ms/step - loss: 0.4356 -
accuracy: 0.8596 - val_loss: 0.0683 - val_accuracy: 0.9792
Epoch 2/5
782/782 [==============================] - 31s 40ms/step - loss: 0.0496 -
accuracy: 0.9852 - val_loss: 0.0545 - val_accuracy: 0.9855
Epoch 3/5
782/782 [==============================] - 32s 41ms/step - loss: 0.0337 -
accuracy: 0.9887 - val_loss: 0.0387 - val_accuracy: 0.9885
Epoch 4/5
782/782 [==============================] - 31s 39ms/step - loss: 0.0276 -
accuracy: 0.9916 - val_loss: 0.0448 - val_accuracy: 0.9871
Epoch 5/5
782/782 [==============================] - 31s 40ms/step - loss: 0.0192 -
accuracy: 0.9939 - val_loss: 0.0449 - val_accuracy: 0.9892
```

[14]:
```
results = model.evaluate(test_images, test_labels)
print(results)

history_dict = history.history

acc = history_dict['accuracy']
val_acc = history_dict['val_accuracy']
loss_values = history_dict['loss']
val_loss_values = history_dict['val_loss']
epochs = range(1,len(acc) + 1)

# Plotting metrics
fig, [ax1, ax2, ax3] = plt.subplots(1,3, figsize=(16,4))

ax1.plot(epochs, loss_values,  'bo', label = 'Training Loss')
ax1.plot(epochs, val_loss_values, 'b', label = 'Validation loss')
ax1.set_title('Training and Validation Loss')
ax1.set_xlabel("Epochs")
ax1.set_ylabel("Loss")
ax1.legend()

ax2.plot(epochs, acc,  'bo', label = 'Training accuracy')
ax2.plot(epochs, val_acc, 'b', label = 'Validation accuracy')
ax2.set_title('Training and Validation Accuracy')
ax2.set_xlabel("Epochs")
ax2.set_ylabel("Accuracy")
ax2.legend()

confusion_matrix = metrics.confusion_matrix(y_true=test_labels,
                                            y_pred=model.predict(test_images).
 ↪argmax(axis = 1))
heatmap(confusion_matrix, annot = True, cmap='Blues', fmt='g', ax = ax3);
```

```
313/313 [==============================] - 2s 6ms/step - loss: 11.5415 -
accuracy: 0.9860
[11.541476249694824, 0.9860000014305115]
```



1.4 Save Results

[15]:

```
model.save('results/model_6_1.h5')
```