In [1]:
```python
#Import required libraries
from keras.datasets import mnist
from keras.models import Sequential, load_model
from keras.utils import to_categorical
from keras import layers,  models,  optimizers
from keras.preprocessing.image import ImageDataGenerator

import numpy as np
import matplotlib.pyplot as plt
from pathlib import Path

import pandas as pd
import os
```

In [2]:
```python
# Instantiating a small convnet for dogs vs. cats classification
model = models.Sequential()
model.add(layers.Conv2D(32, (3, 3), activation='relu', input_shape=(28, 28, 1)))
model.add(layers.MaxPooling2D((2, 2)))
model.add(layers.Conv2D(64, (3, 3), activation='relu'))
model.add(layers.MaxPooling2D((2, 2)))
model.add(layers.Conv2D(64, (3, 3), activation='relu'))
#Display architecture of the convnet
model.summary()
```

```
Model: "sequential"
_________________________________________________________________
 Layer (type)                Output Shape              Param #   
=================================================================
 conv2d (Conv2D)             (None, 26, 26, 32)        320       
                                                                 
 max_pooling2d (MaxPooling2D  (None, 13, 13, 32)       0         
 )                                                               
                                                                 
 conv2d_1 (Conv2D)           (None, 11, 11, 64)        18496     
                                                                 
 max_pooling2d_1 (MaxPooling  (None, 5, 5, 64)         0         
 2D)                                                             
                                                                 
 conv2d_2 (Conv2D)           (None, 3, 3, 64)          36928     
                                                                 
=================================================================
Total params: 55,744
Trainable params: 55,744
Non-trainable params: 0
_________________________________________________________________
```

In [3]:
```python
#  Adding a classifier on top of the convnet
model.add(layers.Flatten())
model.add(layers.Dense(64, activation='relu'))
model.add(layers.Dense(10, activation='softmax'))
model.summary()
```

```
Model: "sequential"
_________________________________________________________________
 Layer (type)                Output Shape              Param #   
=================================================================
 conv2d (Conv2D)             (None, 26, 26, 32)        320       
                                                                 
 max_pooling2d (MaxPooling2D  (None, 13, 13, 32)       0         
 )                                                               
                                                                 
 conv2d_1 (Conv2D)           (None, 11, 11, 64)        18496     
                                                                 
 max_pooling2d_1 (MaxPooling  (None, 5, 5, 64)         0         
```

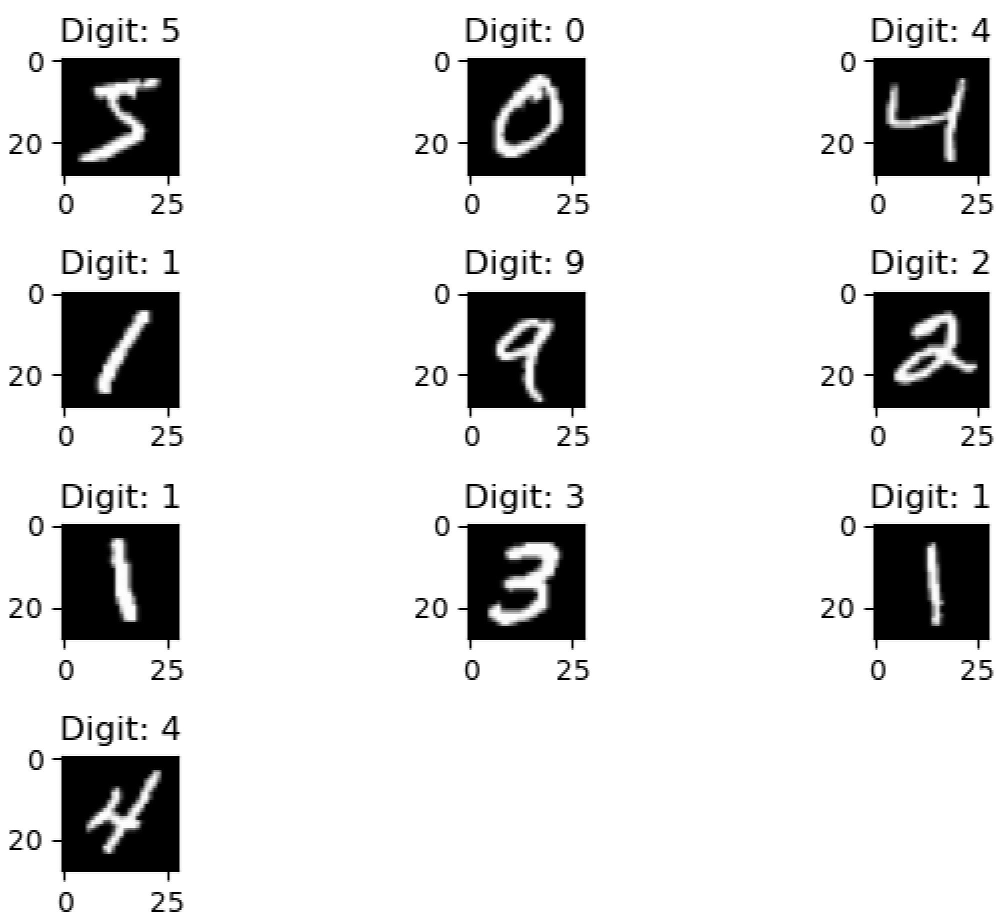
```
 2D)

 conv2d_2 (Conv2D)           (None, 3, 3, 64)          36928

 flatten (Flatten)           (None, 576)               0

 dense (Dense)               (None, 64)                36928

 dense_1 (Dense)             (None, 10)                650

=================================================================
Total params: 93,322
Trainable params: 93,322
Non-trainable params: 0
_________________________________________________________________
```

In [4]:
```
# Training the convnet on MNIST images
(train_images, train_labels), (test_images, test_labels) = mnist.load_data()
```

In [5]:
```
train_images.shape, train_labels.shape, test_images.shape, test_labels.shape
```

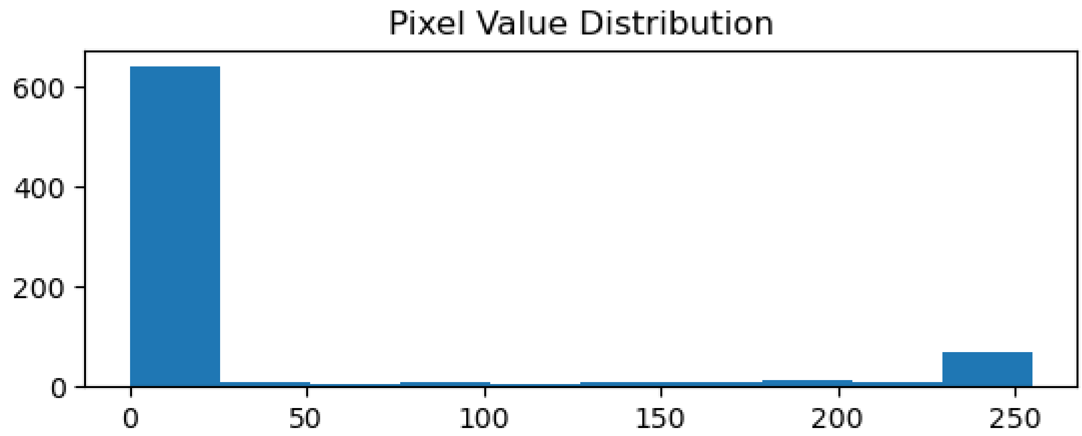
Out[5]:
```
((60000, 28, 28), (60000,), (10000, 28, 28), (10000,))
```

In [6]:
```
# First 10 training labels
for i in range(10):
    plt.subplot(4,3,i+1)
    plt.tight_layout()
    plt.imshow(train_images[i], cmap='gray')
    plt.title("Digit: {}".format(train_labels[i]))
plt.show()
```



In [7]:
```
plt.subplot(2,1,2)
plt.hist(train_images[0].reshape(784))
```

```
plt.title("Pixel Value Distribution")
plt.show()
```



In [8]:

```
train_images = train_images.reshape((60000, 28, 28, 1))
train_images = train_images.astype('float32') / 255

test_images = test_images.reshape((10000, 28, 28, 1))
test_images = test_images.astype('float32') / 255

train_labels = to_categorical(train_labels)
test_labels = to_categorical(test_labels)

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

# Training the model and saving metrics in history
history = model.fit(train_images, train_labels,batch_size=64,epochs=15,verbose=2,validat
```

```
Epoch 1/15
938/938 - 58s - loss: 0.1818 - accuracy: 0.9431 - val_loss: 0.1332 - val_accuracy: 0.952
9 - 58s/epoch - 62ms/step
Epoch 2/15
938/938 - 55s - loss: 0.0489 - accuracy: 0.9847 - val_loss: 0.0351 - val_accuracy: 0.989
0 - 55s/epoch - 59ms/step
Epoch 3/15
938/938 - 55s - loss: 0.0340 - accuracy: 0.9889 - val_loss: 0.0319 - val_accuracy: 0.989
7 - 55s/epoch - 58ms/step
Epoch 4/15
938/938 - 50s - loss: 0.0248 - accuracy: 0.9923 - val_loss: 0.0322 - val_accuracy: 0.991
3 - 50s/epoch - 53ms/step
Epoch 5/15
938/938 - 39s - loss: 0.0199 - accuracy: 0.9937 - val_loss: 0.0284 - val_accuracy: 0.990
9 - 39s/epoch - 41ms/step
Epoch 6/15
938/938 - 41s - loss: 0.0154 - accuracy: 0.9954 - val_loss: 0.0459 - val_accuracy: 0.988
1 - 41s/epoch - 44ms/step
Epoch 7/15
938/938 - 37s - loss: 0.0130 - accuracy: 0.9960 - val_loss: 0.0248 - val_accuracy: 0.993
4 - 37s/epoch - 40ms/step
Epoch 8/15
938/938 - 29s - loss: 0.0102 - accuracy: 0.9968 - val_loss: 0.0270 - val_accuracy: 0.992
7 - 29s/epoch - 31ms/step
Epoch 9/15
938/938 - 29s - loss: 0.0079 - accuracy: 0.9974 - val_loss: 0.0321 - val_accuracy: 0.992
0 - 29s/epoch - 31ms/step
Epoch 10/15
938/938 - 37s - loss: 0.0068 - accuracy: 0.9978 - val_loss: 0.0329 - val_accuracy: 0.992
2 - 37s/epoch - 39ms/step
Epoch 11/15
```

```
938/938 - 37s - loss: 0.0057 - accuracy: 0.9984 - val_loss: 0.0340 - val_accuracy: 0.992
9 - 37s/epoch - 39ms/step
Epoch 12/15
938/938 - 33s - loss: 0.0046 - accuracy: 0.9984 - val_loss: 0.0479 - val_accuracy: 0.990
2 - 33s/epoch - 35ms/step
Epoch 13/15
938/938 - 36s - loss: 0.0048 - accuracy: 0.9987 - val_loss: 0.0408 - val_accuracy: 0.992
1 - 36s/epoch - 39ms/step
Epoch 14/15
938/938 - 34s - loss: 0.0039 - accuracy: 0.9989 - val_loss: 0.0460 - val_accuracy: 0.991
6 - 34s/epoch - 36ms/step
Epoch 15/15
938/938 - 33s - loss: 0.0029 - accuracy: 0.9991 - val_loss: 0.0515 - val_accuracy: 0.991
7 - 33s/epoch - 35ms/step
```

In [9]:

```
# Evaluate the model on the test data
results = model.evaluate(test_images,test_labels)
print(results)

test_loss, test_acc = model.evaluate(test_images, test_labels)
test_acc, test_loss
```

```
313/313 [==============================] - 3s 10ms/step - loss: 0.0515 - accuracy: 0.991
7
[0.05152436345815658б, 0.9916999936103821]
313/313 [==============================] - 4s 11ms/step - loss: 0.0515 - accuracy: 0.991
7
```

Out[9]:

```
(0.9916999936103821, 0.051524363458156586)
```

In [10]:

```
predictions = np.argmax(model.predict(test_images), axis=1)

predictions = list(predictions)
actuals = list(test_labels)

pred_res = pd.DataFrame({'Actual': actuals, 'Predictions': predictions})
pred_res
```

```
313/313 [==============================] - 3s 10ms/step
```

Out[10]:

	Actual	Predictions
0	[0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 1.0, 0.0, ...	7
1	[0.0, 0.0, 1.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, ...	2
2	[0.0, 1.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, ...	1
3	[1.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, ...	0
4	[0.0, 0.0, 0.0, 0.0, 1.0, 0.0, 0.0, 0.0, 0.0, ...	4
...	...	...
9995	[0.0, 0.0, 1.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, ...	2
9996	[0.0, 0.0, 0.0, 1.0, 0.0, 0.0, 0.0, 0.0, 0.0, ...	3
9997	[0.0, 0.0, 0.0, 0.0, 1.0, 0.0, 0.0, 0.0, 0.0, ...	4
9998	[0.0, 0.0, 0.0, 0.0, 0.0, 1.0, 0.0, 0.0, 0.0, ...	5
9999	[0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 1.0, 0.0, 0.0, ...	6

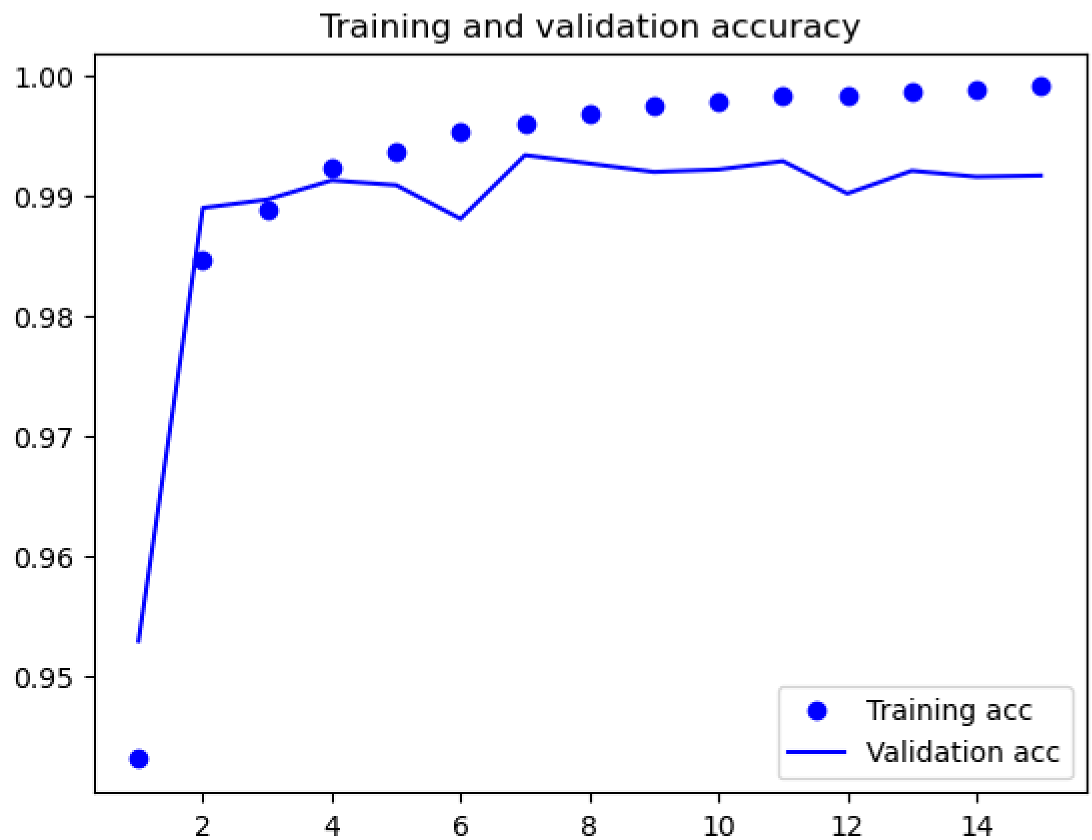
10000 rows × 2 columns

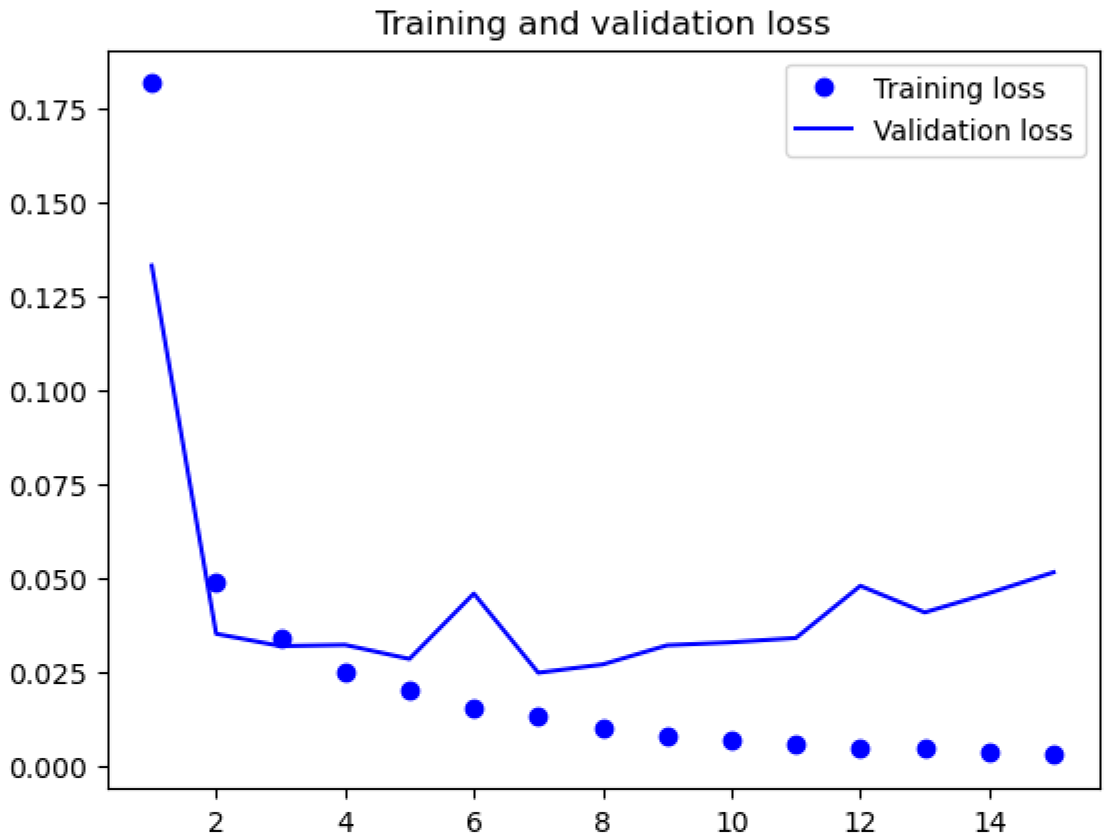
In [11]:

```
acc = history.history['accuracy']
val_acc = history.history['val_accuracy']
```

```python
loss = history.history['loss']
val_loss = history.history['val_loss']
epochs = range(1, len(acc) + 1)
```

In [17]:
```python
#  Plotting the results
plt.plot(epochs, acc, 'bo', label='Training acc')
plt.plot(epochs, val_acc, 'b', label='Validation acc')
plt.title('Training and validation accuracy')
plt.legend()
plt.figure()
plt.savefig('results/Assignment_6-1_Accuracy.png')
plt.plot(epochs, loss, 'bo', label='Training loss')
plt.plot(epochs, val_loss, 'b', label='Validation loss')
plt.title('Training and validation loss')
plt.legend()
plt.show()
plt.savefig('results/Assignment_6-1_Loss.png')
```






```
<Figure size 640x480 with 0 Axes>
```

In [14]:
```
# Get the current directory and add the results folder to the path.
current_dir = Path(os.getcwd()).absolute()
results_dir = current_dir.joinpath('results')
results_dir.mkdir(parents=True, exist_ok=True)
```

In [15]:
```
model.save('results/Assignment_6-1_model.h5')
```

In [22]:
```
#write metrics to file
with open('results/Assignment_6-1_metrics.txt', 'w') as f:
    f.write('Training Loss: {}'.format(str(history.history['loss'])))
    f.write('\nTraining Accuracy: {}'.format(str(history.history['accuracy'])))
    f.write('\nTest Loss: {}'.format(results[0]))
    f.write('\nTest Accuracy: {}'.format(results[1]))
predictions = pd.DataFrame(pred_res)
predictions.to_csv('results/Assignment_6-1_predictions.csv', index=False)
```