In [1]:
```
import tensorflow as tf
from tensorflow.keras import layers
from tensorflow.keras import models
import numpy as np
import tensorflow.keras as keras
import matplotlib.pyplot as plt
from tensorflow.keras.utils import to_categorical
```

In [2]:
```
(train_mnist_img, train_mnist_label), (test_mnist_img, test_mnist_label) = ker
```

```
Downloading data from https://storage.googleapis.com/tensorflow/tf-keras-datas
ets/train-labels-idx1-ubyte.gz
32768/29515 [================================] - 0s 0us/step
Downloading data from https://storage.googleapis.com/tensorflow/tf-keras-datas
ets/train-images-idx3-ubyte.gz
26427392/26421880 [==============================] - 0s 0us/step
Downloading data from https://storage.googleapis.com/tensorflow/tf-keras-datas
ets/t10k-labels-idx1-ubyte.gz
8192/5148 [===============================================] - 0s 0us/step
Downloading data from https://storage.googleapis.com/tensorflow/tf-keras-datas
ets/t10k-images-idx3-ubyte.gz
4423680/4422102 [==============================] - 0s 0us/step
```

In [4]:
```
modeld = models.Sequential()
modeld.add(layers.Dense(512, activation='relu', input_shape=(28 * 28,)))
modeld.add(layers.Dense(10, activation='softmax'))
modeld.compile(optimizer='rmsprop',
loss='mean_squared_error',
metrics=['accuracy'])
```

In [5]:
```
train_mnist_img_norm = train_mnist_img.reshape((60000, 28 * 28))
train_mnist_img_flat = train_mnist_img_norm.astype('float32') / 255

test_mnist_img_norm = test_mnist_img.reshape((10000, 28 * 28))
test_mnist_img_flat = test_mnist_img_norm.astype('float32') / 255
```

In [6]:
```
modeld.compile(optimizer='rmsprop',
loss='categorical_crossentropy',
metrics=['accuracy'])
```

In [7]:
```
train_mnist_label = to_categorical(train_mnist_label)
test_mnist_label = to_categorical(test_mnist_label)
```

In [8]:
```
modeld.fit(train_mnist_img_flat, train_mnist_label, epochs=5, batch_size=128)
```

```
Epoch 1/5
469/469 [==============================] - 5s 10ms/step - loss: 0.7595 - accur
acy: 0.7404
Epoch 2/5
469/469 [==============================] - 5s 10ms/step - loss: 0.3980 - accur
acy: 0.8556
Epoch 3/5
```

```
469/469 [==============================] - 5s 10ms/step - loss: 0.3463 - accur
acy: 0.8728
Epoch 4/5
469/469 [==============================] - 5s 10ms/step - loss: 0.3116 - accur
acy: 0.8851
Epoch 5/5
469/469 [==============================] - 5s 10ms/step - loss: 0.2918 - accur
acy: 0.8937
```

Out[8]: `<tensorflow.python.keras.callbacks.History at 0x7fd7380414d0>`

In [9]:
```
train_loss, train_acc = modeld.evaluate(train_mnist_img_flat, train_mnist_labe
test_loss, test_acc = modeld.evaluate(test_mnist_img_flat, test_mnist_label)
```

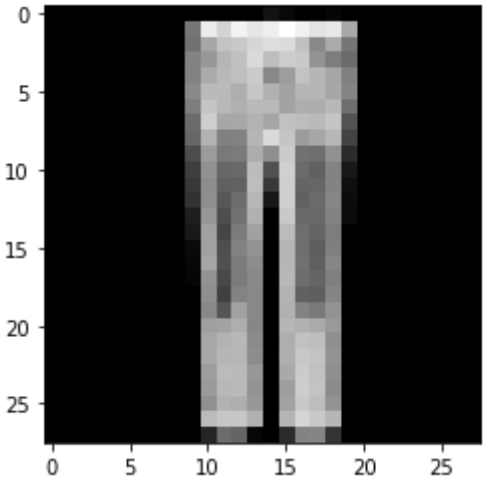
```
1875/1875 [==============================] - 4s 2ms/step - loss: 0.3002 - accu
racy: 0.8907
313/313 [==============================] - 1s 3ms/step - loss: 0.3845 - accura
cy: 0.8666
```

In [10]:
```
print('test_acc:', test_acc)
print('train_acc:', test_acc)
```

```
test_acc: 0.866599977016449
train_acc: 0.866599977016449
```

In [18]:
```
pred = modeld.predict(test_mnist_img_flat[:12])
img_num =15
print(test_mnist_label[img_num])
plt.imshow(test_mnist_img[img_num], cmap=plt.get_cmap('gray'))
plt.show()
```

```
[0. 1. 0. 0. 0. 0. 0. 0. 0. 0.]
```



In [20]:
```
model2 = models.Sequential()
model2.add(layers.Conv2D(32, (3, 3), activation='relu', input_shape=(28, 28, 1
model2.add(layers.MaxPooling2D((2, 2)))
model2.add(layers.Conv2D(64, (3, 3), activation='relu'))
model2.add(layers.MaxPooling2D((2, 2)))
model2.add(layers.Conv2D(64, (3, 3), activation='relu'))
model2.add(layers.Flatten())
model2.add(layers.Dense(64, activation='relu'))
model2.add(layers.Dense(10, activation='softmax'))
```

In [21]:
```
train2_mnist_img_norm = train_mnist_img.reshape((60000, 28 , 28, 1))
train2_mnist_img_flat = train2_mnist_img_norm.astype('float32') / 255

test2_mnist_img_norm = test_mnist_img.reshape((10000, 28 , 28, 1))
test2_mnist_img_flat = test2_mnist_img_norm.astype('float32') / 255
```

In [22]:
```
model2.compile(optimizer='rmsprop', loss='categorical_crossentropy', metrics=[
```

In [23]:
```
model2.fit(train2_mnist_img_flat, train_mnist_label, epochs=10, batch_size=64)
```

```
Epoch 1/10
938/938 [==============================] - 52s 55ms/step - loss: 0.7413 - accu
racy: 0.7248
Epoch 2/10
938/938 [==============================] - 52s 55ms/step - loss: 0.3457 - accu
racy: 0.8729
Epoch 3/10
938/938 [==============================] - 52s 56ms/step - loss: 0.2811 - accu
racy: 0.8961
Epoch 4/10
938/938 [==============================] - 52s 56ms/step - loss: 0.2473 - accu
racy: 0.9087
Epoch 5/10
938/938 [==============================] - 53s 56ms/step - loss: 0.2289 - accu
racy: 0.9155
Epoch 6/10
938/938 [==============================] - 52s 56ms/step - loss: 0.2025 - accu
racy: 0.9241
Epoch 7/10
938/938 [==============================] - 52s 55ms/step - loss: 0.1854 - accu
racy: 0.9316
Epoch 8/10
938/938 [==============================] - 52s 55ms/step - loss: 0.1728 - accu
racy: 0.9354
Epoch 9/10
938/938 [==============================] - 52s 55ms/step - loss: 0.1599 - accu
racy: 0.9403
Epoch 10/10
938/938 [==============================] - 52s 55ms/step - loss: 0.1478 - accu
racy: 0.9446
```

Out[23]:
```
<tensorflow.python.keras.callbacks.History at 0x7fd730a9d550>
```

In [26]:
```
train2_loss, train2_acc = model2.evaluate(train2_mnist_img_flat, train_mnist_l
test2_loss, test2_acc = model2.evaluate(test2_mnist_img_flat, test_mnist_label
```

```
1875/1875 [==============================] - 18s 10ms/step - loss: 0.1344 - ac
curacy: 0.9508
313/313 [==============================] - 3s 10ms/step - loss: 0.2968 - accur
acy: 0.9095
```

In [28]:
```
print('Train2_accuracy:', train2_acc)
print('Test2_accuracy:', test2_acc)
print('Train_accuracy:', train_acc)
print('Test_accuracy:',test_acc)
```

```
Train2_accuracy: 0.9507666826248169
Test2_accuracy: 0.909500002861023
```

```
Train_accuracy: 0.890666663646698
Test_accuracy: 0.866599977016449
```

In [32]:

```
from tensorflow.keras.callbacks import EarlyStopping
modelb = models.Sequential()
modelb.add(layers.Conv2D(32, (3, 3), activation='relu', input_shape=(28, 28, 1
modelb.add(layers.MaxPooling2D((2, 2)))
modelb.add(layers.Conv2D(64, (3, 3), activation='relu'))
modelb.add(layers.Flatten())
modelb.add(layers.Dense(64, activation='relu'))
modelb.add(layers.Dense(10, activation='softmax'))

modelb.summary(line_length=None, positions=None, print_fn=None)


modelb.compile(loss='categorical_crossentropy', optimizer='rmsprop', metrics=[
#deleting 3 layers and applying early stopping
trained_models = modelb.fit(train2_mnist_img_flat, train_mnist_label, epochs=3

callbacks = [EarlyStopping(monitor='val_accuracy', patience=3)])
```

```
Model: "sequential_6"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_10 (Conv2D)           (None, 26, 26, 32)        320
_________________________________________________________________
max_pooling2d_6 (MaxPooling2 (None, 13, 13, 32)        0
_________________________________________________________________
conv2d_11 (Conv2D)           (None, 11, 11, 64)        18496
_________________________________________________________________
flatten_4 (Flatten)          (None, 7744)              0
_________________________________________________________________
dense_12 (Dense)             (None, 64)                495680
_________________________________________________________________
dense_13 (Dense)             (None, 10)                650
=================================================================
Total params: 515,146
Trainable params: 515,146
Non-trainable params: 0
_________________________________________________________________
Epoch 1/30
469/469 [==============================] - 48s 102ms/step - loss: 0.6839 - acc
uracy: 0.7529 - val_loss: 0.3263 - val_accuracy: 0.8847
Epoch 2/30
469/469 [==============================] - 48s 102ms/step - loss: 0.3022 - acc
uracy: 0.8903 - val_loss: 0.2946 - val_accuracy: 0.8890
Epoch 3/30
469/469 [==============================] - 48s 101ms/step - loss: 0.2462 - acc
uracy: 0.9100 - val_loss: 0.2916 - val_accuracy: 0.8920
Epoch 4/30
469/469 [==============================] - 48s 102ms/step - loss: 0.2068 - acc
uracy: 0.9241 - val_loss: 0.2377 - val_accuracy: 0.9157
Epoch 5/30
469/469 [==============================] - 48s 102ms/step - loss: 0.1750 - acc
uracy: 0.9357 - val_loss: 0.2470 - val_accuracy: 0.9112
Epoch 6/30
469/469 [==============================] - 48s 102ms/step - loss: 0.1543 - acc
uracy: 0.9437 - val_loss: 0.2428 - val_accuracy: 0.9160
Epoch 7/30
469/469 [==============================] - 48s 102ms/step - loss: 0.1361 - acc
uracy: 0.9501 - val_loss: 0.2359 - val_accuracy: 0.9166
Epoch 8/30
```

```
469/469 [==============================] - 48s 103ms/step - loss: 0.1176 - acc
uracy: 0.9585 - val_loss: 0.2325 - val_accuracy: 0.9232
Epoch 9/30
469/469 [==============================] - 48s 102ms/step - loss: 0.1018 - acc
uracy: 0.9629 - val_loss: 0.2380 - val_accuracy: 0.9230
Epoch 10/30
469/469 [==============================] - 48s 102ms/step - loss: 0.0862 - acc
uracy: 0.9689 - val_loss: 0.2803 - val_accuracy: 0.9184
Epoch 11/30
469/469 [==============================] - 48s 102ms/step - loss: 0.0795 - acc
uracy: 0.9715 - val_loss: 0.2462 - val_accuracy: 0.9232
```

In [34]:

```
trainb_loss, trainb_acc = modelb.evaluate(train2_mnist_img_flat, train_mnist_l
testb_loss, testb_acc = modelb.evaluate(test2_mnist_img_flat, test_mnist_label
```

```
1875/1875 [==============================] - 19s 10ms/step - loss: 0.0579 - ac
curacy: 0.9818
313/313 [==============================] - 3s 9ms/step - loss: 0.2462 - accura
cy: 0.9232
```

In [37]:

```
print('Test_accuracy:', test_acc)
print('Train_accuracy:', test_acc)
print('')
print('Train2_accuracy:', train2_acc)
print('Test2_accuracy:', test2_acc)
print('')
print('Trainb_accuracy:', trainb_acc)
print('Testb_accuracy:', testb_acc)
print('')
print('Better:', trainb_acc - train2_acc)
```

```
Test_accuracy: 0.866599977016449
Train_accuracy: 0.866599977016449

Train2_accuracy: 0.9507666826248169
Test2_accuracy: 0.909500002861023

Trainb_accuracy: 0.9817500114440918
Testb_accuracy: 0.9232000112533569

Better: 0.030983328819274902
```