# LAB:7 Exploration of DNN design choices using MNIST dataset

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### Import libraries

In [3]:
```
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt

import tensorflow as tf
import keras

from keras.datasets import mnist

from keras.utils import to_categorical

from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense, Flatten, Activation, Dropout

from keras import regularizers

from sklearn.model_selection import train_test_split
```

### Import dataset

In [4]:
```
data = mnist.load_data()
```

In [5]:
```
(X_train, y_train), (X_test, y_test) = data
```

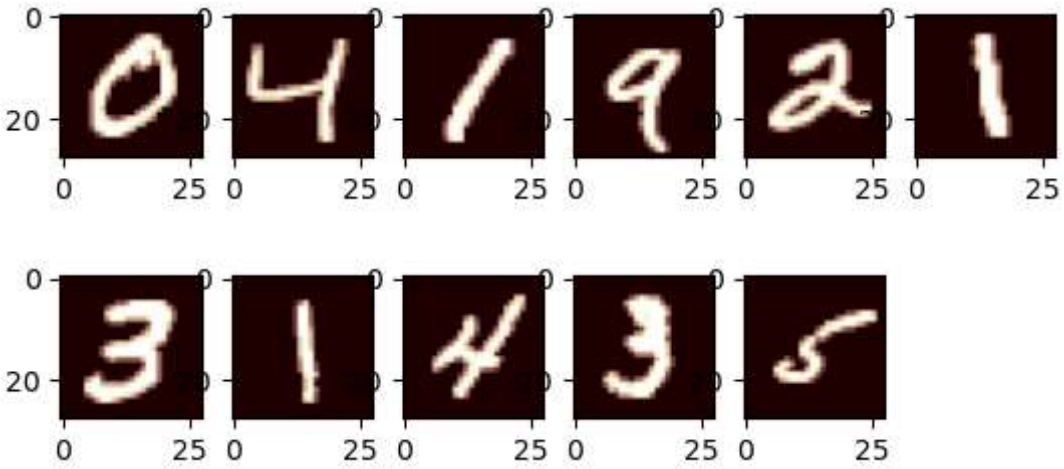
In [6]:
```
print('Train: X=%s, y=%s' % (X_train.shape, y_train.shape))
print('Test: X=%s, y=%s' % (X_test.shape, y_test.shape))
```

```
Train: X=(60000, 28, 28), y=(60000,)
Test: X=(10000, 28, 28), y=(10000,)
```

### Printing some training images

In [9]:
```
for i in range(1, 12):
    plt.subplot(3, 6, i)
    plt.imshow(X_train[i], cmap=plt.get_cmap('pink'))

plt.show()
```



**Flatten the data**

In [6]:
```
X_train = X_train.reshape((X_train.shape[0], 28*28)).astype('float32')
X_test = X_test.reshape((X_test.shape[0], 28*28)).astype('float32')
```

**Normalize the data**

In [7]:
```
X_train = X_train / 255
X_test = X_test / 255
```

# Exploration

In [8]:

```
def model(nodes, layers, activation_in, activation_out, loss, optimizer, r

    model = Sequential()

    model.add(Dense(nodes, input_dim=28*28, activation=activation_in))

    for x in range(layers):
        model.add(Dense(nodes, activation=activation_in))

    model.add(Dense(10, activation=activation_out))

    model.compile(loss=loss, optimizer=optimizer, metrics=metrics)

    model.fit(X_train, to_categorical(y_train), epochs=epochs)

    score = model.evaluate(X_test, to_categorical(y_test))

    print(model.summary(), "\n", "Accuracy =", score[1]*100)
```

## 1. Numbers of Nodes

In [9]:
```
model1 = model(4, 0, 'relu', 'softmax', 'categorical_crossentropy', 'Adam
```

```
Epoch 1/10
1875/1875 [==============================] - 8s 3ms/step - loss: 0.9293
- accuracy: 0.6960
Epoch 2/10
1875/1875 [==============================] - 5s 3ms/step - loss: 0.6472
- accuracy: 0.7994
Epoch 3/10
1875/1875 [==============================] - 5s 3ms/step - loss: 0.5800
- accuracy: 0.8267
Epoch 4/10
1875/1875 [==============================] - 5s 3ms/step - loss: 0.5445
- accuracy: 0.8395
Epoch 5/10
1875/1875 [==============================] - 5s 3ms/step - loss: 0.5211
- accuracy: 0.8476
Epoch 6/10
1875/1875 [==============================] - 5s 3ms/step - loss: 0.5028
- accuracy: 0.8540
Epoch 7/10
1875/1875 [==============================] - 6s 3ms/step - loss: 0.4868
- accuracy: 0.8593
Epoch 8/10
1875/1875 [==============================] - 5s 3ms/step - loss: 0.4752
- accuracy: 0.8619
Epoch 9/10
1875/1875 [==============================] - 6s 3ms/step - loss: 0.4662
- accuracy: 0.8647
Epoch 10/10
1875/1875 [==============================] - 6s 3ms/step - loss: 0.4594
- accuracy: 0.8681
313/313 [==============================] - 1s 3ms/step - loss: 0.4797 -
accuracy: 0.8639
Model: "sequential"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 dense (Dense)               (None, 4)                 3140

 dense_1 (Dense)             (None, 10)                50

=================================================================
Total params: 3,190
Trainable params: 3,190
Non-trainable params: 0
_________________________________________________________________
None
 Accuracy = 86.39000058174133
```

## 2. Numbers of Layers

In [11]:
```
model7 = model(32, 3, 'relu', 'softmax', 'categorical_crossentropy', 'Adar
```

```
Epoch 1/10
1875/1875 [==============================] - 8s 3ms/step - loss: 0.3455
- accuracy: 0.8964
Epoch 2/10
1875/1875 [==============================] - 6s 3ms/step - loss: 0.1637
- accuracy: 0.9511
Epoch 3/10
1875/1875 [==============================] - 7s 4ms/step - loss: 0.1291
- accuracy: 0.9607
Epoch 4/10
1875/1875 [==============================] - 7s 4ms/step - loss: 0.1086
- accuracy: 0.9664
Epoch 5/10
1875/1875 [==============================] - 7s 4ms/step - loss: 0.0937
- accuracy: 0.9713
Epoch 6/10
1875/1875 [==============================] - 8s 4ms/step - loss: 0.0850
- accuracy: 0.9738
Epoch 7/10
1875/1875 [==============================] - 9s 5ms/step - loss: 0.0736
- accuracy: 0.9772
Epoch 8/10
1875/1875 [==============================] - 9s 5ms/step - loss: 0.0696
- accuracy: 0.9776
Epoch 9/10
1875/1875 [==============================] - 8s 4ms/step - loss: 0.0629
- accuracy: 0.9805
Epoch 10/10
1875/1875 [==============================] - 9s 5ms/step - loss: 0.0591
- accuracy: 0.9809
313/313 [==============================] - 2s 4ms/step - loss: 0.1099 -
accuracy: 0.9704
Model: "sequential_2"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 dense_4 (Dense)             (None, 32)                25120

 dense_5 (Dense)             (None, 32)                1056

 dense_6 (Dense)             (None, 32)                1056

 dense_7 (Dense)             (None, 32)                1056

 dense_8 (Dense)             (None, 10)                330

=================================================================
Total params: 28,618
Trainable params: 28,618
Non-trainable params: 0
_________________________________________________________________
None
 Accuracy = 97.03999757766724
```

## 3. Activation Function

In [12]:
```
model11 = model(32, 2, 'sigmoid','softmax','categorical_crossentropy','Ada
```

```
Epoch 1/10
1875/1875 [==============================] - 9s 4ms/step - loss: 0.8990
- accuracy: 0.7691
Epoch 2/10
1875/1875 [==============================] - 7s 4ms/step - loss: 0.2582
- accuracy: 0.9288
Epoch 3/10
1875/1875 [==============================] - 10s 6ms/step - loss: 0.1896
- accuracy: 0.9453
Epoch 4/10
1875/1875 [==============================] - 8s 4ms/step - loss: 0.1573
- accuracy: 0.9548
Epoch 5/10
1875/1875 [==============================] - 8s 4ms/step - loss: 0.1379
- accuracy: 0.9610
Epoch 6/10
1875/1875 [==============================] - 8s 4ms/step - loss: 0.1231
- accuracy: 0.9646
Epoch 7/10
1875/1875 [==============================] - 8s 4ms/step - loss: 0.1116
- accuracy: 0.9672
Epoch 8/10
1875/1875 [==============================] - 8s 4ms/step - loss: 0.1033
- accuracy: 0.9699
Epoch 9/10
1875/1875 [==============================] - 8s 4ms/step - loss: 0.0939
- accuracy: 0.9727
Epoch 10/10
1875/1875 [==============================] - 6s 3ms/step - loss: 0.0883
- accuracy: 0.9743
313/313 [==============================] - 1s 3ms/step - loss: 0.1347 -
accuracy: 0.9609
Model: "sequential_3"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 dense_9 (Dense)             (None, 32)                25120

 dense_10 (Dense)            (None, 32)                1056

 dense_11 (Dense)            (None, 32)                1056

 dense_12 (Dense)            (None, 10)                330

=================================================================
Total params: 27,562
Trainable params: 27,562
Non-trainable params: 0
_________________________________________________________________
None
 Accuracy = 96.09000086784363
```

## 4. Activation Function combinations

In [13]:

```
def model_afc(activation1, activation2, activation3):

    model = Sequential()

    model.add(Dense(32, input_dim=28*28, activation=activation1))

    model.add(Dense(32, activation=activation2))

    model.add(Dense(32, activation=activation2))

    model.add(Dense(10, activation='softmax'))

    model.compile(loss='categorical_crossentropy', optimizer='Adam', metri

    model.fit(X_train, to_categorical(y_train), epochs=10)

    score = model.evaluate(X_test, to_categorical(y_test))

    print(model.summary(), "\n", "Accuracy =", score[1]*100)
```

In [14]:
```
model14 = model_afc('sigmoid','relu','tanh')
```

```
Epoch 1/10
1875/1875 [==============================] - 7s 3ms/step - loss: 0.4505
- accuracy: 0.8751
Epoch 2/10
1875/1875 [==============================] - 6s 3ms/step - loss: 0.2022
- accuracy: 0.9397
Epoch 3/10
1875/1875 [==============================] - 6s 3ms/step - loss: 0.1586
- accuracy: 0.9527
Epoch 4/10
1875/1875 [==============================] - 6s 3ms/step - loss: 0.1340
- accuracy: 0.9591
Epoch 5/10
1875/1875 [==============================] - 6s 3ms/step - loss: 0.1169
- accuracy: 0.9652
Epoch 6/10
1875/1875 [==============================] - 7s 4ms/step - loss: 0.1060
- accuracy: 0.9678
Epoch 7/10
1875/1875 [==============================] - 7s 4ms/step - loss: 0.0956
- accuracy: 0.9703
Epoch 8/10
1875/1875 [==============================] - 6s 3ms/step - loss: 0.0864
- accuracy: 0.9734
Epoch 9/10
1875/1875 [==============================] - 6s 3ms/step - loss: 0.0826
- accuracy: 0.9741
Epoch 10/10
1875/1875 [==============================] - 6s 3ms/step - loss: 0.0758
- accuracy: 0.9763
313/313 [==============================] - 1s 2ms/step - loss: 0.1175 -
accuracy: 0.9657
Model: "sequential_4"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 dense_13 (Dense)            (None, 32)                25120

 dense_14 (Dense)            (None, 32)                1056

 dense_15 (Dense)            (None, 32)                1056

 dense_16 (Dense)            (None, 10)                330

=================================================================
Total params: 27,562
Trainable params: 27,562
Non-trainable params: 0
_________________________________________________________________
None
 Accuracy = 96.56999707221985
```

## 5. Layer-node combinations

In [15]:
```
model17 = model(32, 1, 'relu', 'softmax', 'categorical_crossentropy', 'Ada
```

```
Epoch 1/10
1875/1875 [==============================] - 8s 3ms/step - loss: 0.3432
- accuracy: 0.9000
Epoch 2/10
1875/1875 [==============================] - 6s 3ms/step - loss: 0.1738
- accuracy: 0.9486
Epoch 3/10
1875/1875 [==============================] - 6s 3ms/step - loss: 0.1322
- accuracy: 0.9599
Epoch 4/10
1875/1875 [==============================] - 7s 4ms/step - loss: 0.1085
- accuracy: 0.9678
Epoch 5/10
1875/1875 [==============================] - 12s 6ms/step - loss: 0.0949
- accuracy: 0.9704
Epoch 6/10
1875/1875 [==============================] - 12s 6ms/step - loss: 0.0847
- accuracy: 0.9742
Epoch 7/10
1875/1875 [==============================] - 12s 6ms/step - loss: 0.0754
- accuracy: 0.9765
Epoch 8/10
1875/1875 [==============================] - 11s 6ms/step - loss: 0.0701
- accuracy: 0.9779
Epoch 9/10
1875/1875 [==============================] - 12s 6ms/step - loss: 0.0628
- accuracy: 0.9805
Epoch 10/10
1875/1875 [==============================] - 8s 4ms/step - loss: 0.0584
- accuracy: 0.9817
313/313 [==============================] - 2s 4ms/step - loss: 0.1180 -
accuracy: 0.9657
Model: "sequential_5"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 dense_17 (Dense)            (None, 32)                25120

 dense_18 (Dense)            (None, 32)                1056

 dense_19 (Dense)            (None, 10)                330

=================================================================
Total params: 26,506
Trainable params: 26,506
Non-trainable params: 0
_________________________________________________________________
None
 Accuracy = 96.56999707221985
```

## 6. Optimizer

In [16]:

```
def model_opt(optimizer):

    model = Sequential()

    model.add(Dense(32, input_dim=28*28, activation='relu'))

    model.add(Dense(32, activation='relu'))

    model.add(Dense(32, activation='relu'))

    model.add(Dense(10, activation='softmax'))

    model.compile(loss='categorical_crossentropy', optimizer=optimizer, me

    model.fit(X_train, to_categorical(y_train), epochs=10)

    score = model.evaluate(X_test, to_categorical(y_test))

    print(model.summary(), "\n", "Accuracy =", score[1]*100)
```

In [17]:
```
model20 = model_opt('SGD')
```

```
Epoch 1/10
1875/1875 [==============================] - 10s 4ms/step - loss: 0.8653
- accuracy: 0.7379
Epoch 2/10
1875/1875 [==============================] - 7s 4ms/step - loss: 0.3263
- accuracy: 0.9057
Epoch 3/10
1875/1875 [==============================] - 10s 5ms/step - loss: 0.2606
- accuracy: 0.9242
Epoch 4/10
1875/1875 [==============================] - 9s 5ms/step - loss: 0.2239
- accuracy: 0.9349
Epoch 5/10
1875/1875 [==============================] - 7s 3ms/step - loss: 0.1988
- accuracy: 0.9423
Epoch 6/10
1875/1875 [==============================] - 6s 3ms/step - loss: 0.1796
- accuracy: 0.9474
Epoch 7/10
1875/1875 [==============================] - 7s 4ms/step - loss: 0.1640
- accuracy: 0.9521
Epoch 8/10
1875/1875 [==============================] - 7s 4ms/step - loss: 0.1509
- accuracy: 0.9548
Epoch 9/10
1875/1875 [==============================] - 6s 3ms/step - loss: 0.1398
- accuracy: 0.9590
Epoch 10/10
1875/1875 [==============================] - 7s 4ms/step - loss: 0.1310
- accuracy: 0.9616
313/313 [==============================] - 2s 3ms/step - loss: 0.1341 -
accuracy: 0.9598
Model: "sequential_6"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 dense_20 (Dense)            (None, 32)                25120

 dense_21 (Dense)            (None, 32)                1056

 dense_22 (Dense)            (None, 32)                1056

 dense_23 (Dense)            (None, 10)                330

=================================================================
Total params: 27,562
Trainable params: 27,562
Non-trainable params: 0
_________________________________________________________________
None
 Accuracy = 95.98000049591064
```

## 7. L1, L2 Regularization

In [18]:

```
def model_reg(reg):

    model = Sequential()

    model.add(Dense(128, input_dim=28*28, activation='relu', kernel_regula

    model.add(Dense(128, activation='relu', kernel_regularizer=reg))

    model.add(Dense(128, activation='relu', kernel_regularizer=reg))

    model.add(Dense(10, activation='softmax'))

    model.compile(loss='categorical_crossentropy', optimizer='Adam', metri

    model.fit(X_train, to_categorical(y_train), epochs=10)

    score = model.evaluate(X_test, to_categorical(y_test))

    print(model.summary(), "\n", "Accuracy =", score[1]*100)
```

In [19]:
```
model23 = model_reg(regularizers.l1(0.01))
```

```
Epoch 1/10
1875/1875 [==============================] - 13s 5ms/step - loss: 3.8030
- accuracy: 0.1197
Epoch 2/10
1875/1875 [==============================] - 10s 6ms/step - loss: 2.4614
- accuracy: 0.1121
Epoch 3/10
1875/1875 [==============================] - 10s 5ms/step - loss: 2.4612
- accuracy: 0.1124
Epoch 4/10
1875/1875 [==============================] - 11s 6ms/step - loss: 2.4611
- accuracy: 0.1124
Epoch 5/10
1875/1875 [==============================] - 9s 5ms/step - loss: 2.4610
- accuracy: 0.1124
Epoch 6/10
1875/1875 [==============================] - 8s 4ms/step - loss: 2.4610
- accuracy: 0.1124
Epoch 7/10
1875/1875 [==============================] - 8s 4ms/step - loss: 2.4610
- accuracy: 0.1124
Epoch 8/10
1875/1875 [==============================] - 7s 4ms/step - loss: 2.4610
- accuracy: 0.1124
Epoch 9/10
1875/1875 [==============================] - 8s 4ms/step - loss: 2.4610
- accuracy: 0.1124
Epoch 10/10
1875/1875 [==============================] - 8s 4ms/step - loss: 2.4610
- accuracy: 0.1124
313/313 [==============================] - 1s 3ms/step - loss: 2.4609 -
accuracy: 0.1135
Model: "sequential_7"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 dense_24 (Dense)            (None, 128)               100480

 dense_25 (Dense)            (None, 128)               16512

 dense_26 (Dense)            (None, 128)               16512

 dense_27 (Dense)            (None, 10)                1290

=================================================================
Total params: 134,794
Trainable params: 134,794
Non-trainable params: 0
_________________________________________________________________
None
 Accuracy = 11.349999904632568
```

In [20]:
```
model25 = model_reg(regularizers.l2(0.01))
```

```
Epoch 1/10
1875/1875 [==============================] - 9s 4ms/step - loss: 0.9803
- accuracy: 0.8890
Epoch 2/10
1875/1875 [==============================] - 8s 4ms/step - loss: 0.5753
- accuracy: 0.9227
Epoch 3/10
1875/1875 [==============================] - 8s 4ms/step - loss: 0.5012
- accuracy: 0.9323
Epoch 4/10
1875/1875 [==============================] - 8s 4ms/step - loss: 0.4571
- accuracy: 0.9373
Epoch 5/10
1875/1875 [==============================] - 8s 4ms/step - loss: 0.4295
- accuracy: 0.9410
Epoch 6/10
1875/1875 [==============================] - 7s 4ms/step - loss: 0.4065
- accuracy: 0.9437
Epoch 7/10
1875/1875 [==============================] - 7s 4ms/step - loss: 0.3930
- accuracy: 0.9446
Epoch 8/10
1875/1875 [==============================] - 7s 4ms/step - loss: 0.3832
- accuracy: 0.9469
Epoch 9/10
1875/1875 [==============================] - 7s 4ms/step - loss: 0.3757
- accuracy: 0.9467
Epoch 10/10
1875/1875 [==============================] - 7s 4ms/step - loss: 0.3683
- accuracy: 0.9474
313/313 [==============================] - 2s 3ms/step - loss: 0.3422 -
accuracy: 0.9553
Model: "sequential_8"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 dense_28 (Dense)            (None, 128)               100480

 dense_29 (Dense)            (None, 128)               16512

 dense_30 (Dense)            (None, 128)               16512

 dense_31 (Dense)            (None, 10)                1290

=================================================================
Total params: 134,794
Trainable params: 134,794
Non-trainable params: 0
_________________________________________________________________
None
 Accuracy = 95.5299973487854
```

## 8. Dropout Regularization

In [21]:

```
def model_dropout(rate):

    model = Sequential()

    model.add(Dense(128, input_dim=28*28, activation='relu'))
    model.add(Dropout(rate))

    model.add(Dense(128, activation='relu'))
    model.add(Dropout(rate))

    model.add(Dense(128, activation='relu'))
    model.add(Dropout(rate))

    model.add(Dense(10, activation='softmax'))

    model.compile(loss='categorical_crossentropy', optimizer='Adam', metri

    model.fit(X_train, to_categorical(y_train), epochs=10)

    score = model.evaluate(X_test, to_categorical(y_test))

    print(model.summary(), "\n", "Accuracy =", score[1]*100)
```

In [22]:
```
model29 = model_dropout(0.5)
```

```
Epoch 1/10
1875/1875 [==============================] - 9s 4ms/step - loss: 0.6405
- accuracy: 0.8000
Epoch 2/10
1875/1875 [==============================] - 9s 5ms/step - loss: 0.3360
- accuracy: 0.9090
Epoch 3/10
1875/1875 [==============================] - 11s 6ms/step - loss: 0.2814
- accuracy: 0.9226
Epoch 4/10
1875/1875 [==============================] - 9s 5ms/step - loss: 0.2533
- accuracy: 0.9307
Epoch 5/10
1875/1875 [==============================] - 11s 6ms/step - loss: 0.2416
- accuracy: 0.9343
Epoch 6/10
1875/1875 [==============================] - 10s 5ms/step - loss: 0.2295
- accuracy: 0.9391
Epoch 7/10
1875/1875 [==============================] - 10s 5ms/step - loss: 0.2116
- accuracy: 0.9416
Epoch 8/10
1875/1875 [==============================] - 10s 5ms/step - loss: 0.2120
- accuracy: 0.9421
Epoch 9/10
1875/1875 [==============================] - 11s 6ms/step - loss: 0.2007
- accuracy: 0.9447
Epoch 10/10
1875/1875 [==============================] - 13s 7ms/step - loss: 0.1997
- accuracy: 0.9460
313/313 [==============================] - 4s 7ms/step - loss: 0.1107 -
accuracy: 0.9683
Model: "sequential_9"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 dense_32 (Dense)            (None, 128)               100480

 dropout (Dropout)           (None, 128)               0

 dense_33 (Dense)            (None, 128)               16512

 dropout_1 (Dropout)         (None, 128)               0

 dense_34 (Dense)            (None, 128)               16512

 dropout_2 (Dropout)         (None, 128)               0

 dense_35 (Dense)            (None, 10)                1290

=================================================================
Total params: 134,794
Trainable params: 134,794
Non-trainable params: 0
_________________________________________________________________
```

```
None
 Accuracy = 96.82999849319458
```

## 9. Input Size

In [23]:

```
def model_input_dim(input_dim):

    model = Sequential()

    model.add(Dense(128, input_dim=input_dim, activation='relu'))

    model.add(Dense(128, activation='relu'))

    model.add(Dense(128, activation='relu'))

    model.add(Dense(10, activation='softmax'))

    model.compile(loss='categorical_crossentropy', optimizer='Adam', metri

    model.fit(X_train, to_categorical(y_train), epochs=10)

    score = model.evaluate(X_test, to_categorical(y_test))

    print(model.summary(), "\n", "Accuracy =", score[1]*100)
```

## 10. Dataset Split

In [25]:

```
(X_train, y_train), (X_test, y_test) = data
X1 = np.concatenate((X_train, X_test))
y1 = np.concatenate((y_train, y_test))

X_train1, X_test1, y_train1, y_test1 = train_test_split(X1, y1, train_size
```

In [ ]:

```
model33 = Sequential([Dense(32, input_dim=28*28, activation='relu'),
                      Dense(32, activation='relu'),
                      Dense(32, activation='relu'),
                      Dense(10, activation='softmax')])
model33.compile(loss='mean_squared_error', optimizer='Adam', metrics='accu
model33.fit(X_train1, y_train1, epochs=10)
score33 = model33.evaluate(X_test1, y_test1)
print(model33.summary(), "\n", "Accuracy =", score33[1]*100)
```