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Deep Learning Lab

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Date : *5/4/2023*

AIM - To implement autoencoders, AlexNet, LeNet-5 and VGG16 on MNIST hand digit recognition dataset

```
import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
import pandas as pd
```

```
(x_train, y_train), (x_test, y_test) = tf.keras.datasets.mnist.load_data()

x_train.shape, y_train.shape
```

```
Downloading data from https://storage.googleapis.com/tensorflow/tf-keras-datasets/mnist.npz
11490434/11490434 [==============================] - 1s 0us/step

((60000, 28, 28), (60000,))
```

```
x_train = x_train.reshape(x_train.shape[0], 28, 28, 1)
x_train = x_train.astype('float32')
x_train /= 255

x_train_flat = x_train.reshape(x_train.shape[0], 784, 1)

print(f"x_train shape : {x_train.shape}, sample : {x_train[0].T}")
print(f"x_train shape : {x_train_flat.shape}, sample : {x_train_flat[0].T}")

x_test = x_test.reshape(x_test.shape[0], 28, 28, 1)
x_test = x_test.astype('float32')
x_test /= 255

x_test_flat = x_test.reshape(x_test.shape[0], 784, 1)
```

```
x_train shape : (60000, 28, 28, 1), sample : [[[0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.        ]
  [0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.        ]
  [0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.        ]
  [0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.         0.         0.
   0.         0.         0.         0.        ]
```

Autoencoder with 1 Hidden Layer

```
# Input layer
input_img = tf.keras.layers.Input(shape=(784,))

# Hidden layer
encoded = tf.keras.layers.Dense(32, activation='relu')(input_img)

# Output layer
decoded = tf.keras.layers.Dense(784, activation='sigmoid')(encoded)

# Autoencoder model
autoencoder = tf.keras.models.Model(input_img, decoded)

autoencoder.compile(optimizer='adam', loss='binary_crossentropy')
```

```
%%time

autoencoder.fit(x_train_flat, x_train_flat, epochs=50, batch_size=256, shuffle=True, validation_split=0.2)
```

```
Epoch 1/50
188/188 [==============================] - 1s 5ms/step - loss: 0.2967 - val_loss: 0.1985
Epoch 2/50
188/188 [==============================] - 1s 4ms/step - loss: 0.1802 - val_loss: 0.1652
Epoch 3/50
188/188 [==============================] - 1s 4ms/step - loss: 0.1552 - val_loss: 0.1455
Epoch 4/50
188/188 [==============================] - 1s 4ms/step - loss: 0.1390 - val_loss: 0.1325
Epoch 5/50
188/188 [==============================] - 1s 5ms/step - loss: 0.1278 - val_loss: 0.1231
Epoch 6/50
188/188 [==============================] - 1s 5ms/step - loss: 0.1196 - val_loss: 0.1162
Epoch 7/50
188/188 [==============================] - 1s 5ms/step - loss: 0.1134 - val_loss: 0.1109
Epoch 8/50
188/188 [==============================] - 1s 5ms/step - loss: 0.1085 - val_loss: 0.1067
Epoch 9/50
188/188 [==============================] - 1s 5ms/step - loss: 0.1047 - val_loss: 0.1036
Epoch 10/50
188/188 [==============================] - 1s 5ms/step - loss: 0.1017 - val_loss: 0.1011

<keras.callbacks.History at 0x1bfe3937c40>
```

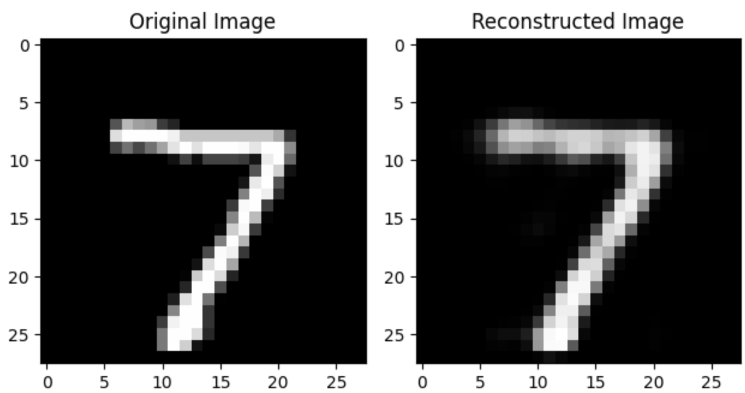
```
%%time

score = autoencoder.evaluate(x_test_flat, x_test_flat, verbose=0)
print('Test loss:', score)
```

```
Test loss: 0.09173693507909775
CPU times: total: 78.1 ms
Wall time: 387 ms
```

```
img = x_test_flat[0]

# Reconstruct the image using the autoencoder model
reconstructed_img = autoencoder.predict(np.array([img]))

# Reshape the reconstructed image into a 28x28 pixel format
reconstructed_img = reconstructed_img.reshape((28, 28))

fig, axes = plt.subplots(nrows=1, ncols=2)
ax1, ax2 = axes.flatten()

ax1.imshow(img.reshape(28, 28), cmap='gray')
ax1.set_title('Original Image')

ax2.imshow(reconstructed_img, cmap='gray')
ax2.set_title('Reconstructed Image')

plt.tight_layout()
plt.show()
```

```
1/1 [==============================] - 0s 88ms/step


<Figure size 640x480 with 2 Axes>
```

Download



AlexNet

```
alexNet = tf.keras.Sequential([
    tf.keras.layers.Conv2D(filters=32, kernel_size=(3, 3), activation='relu',
                           input_shape=(28, 28, 1)),
    tf.keras.layers.MaxPool2D(strides=(2, 2)),
    tf.keras.layers.Conv2D(filters=64, kernel_size=(5, 5), strides=(1, 1), activation='relu', padding="same"),
    tf.keras.layers.MaxPool2D(strides=(2, 2)),
    tf.keras.layers.Conv2D(filters=128, kernel_size=(3, 3), strides=(1, 1), activation='relu', padding="same"),
    tf.keras.layers.Conv2D(filters=128, kernel_size=(3, 3), strides=(1, 1), activation='relu', padding="same"),
    tf.keras.layers.Conv2D(filters=64, kernel_size=(3, 3), strides=(1, 1), activation='relu', padding="same"),
    tf.keras.layers.MaxPool2D(strides=(2, 2)),
    tf.keras.layers.Flatten(),
```

```
alexNet.summary()
```

```
Model: "sequential_3"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d_15 (Conv2D)          (None, 18, 18, 32)        3904

 max_pooling2d_9 (MaxPooling  (None, 9, 9, 32)         0
 2D)

 conv2d_16 (Conv2D)          (None, 9, 9, 64)          51264

 max_pooling2d_10 (MaxPoolin  (None, 4, 4, 64)         0
 g2D)

 conv2d_17 (Conv2D)          (None, 4, 4, 128)         73856

 conv2d_18 (Conv2D)          (None, 4, 4, 128)         147584

 conv2d_19 (Conv2D)          (None, 4, 4, 64)          73792
```

```
%%time

alexNet.fit(x_train, y_train, epochs=10, batch_size=256, shuffle=True, validation_split=0.2)
```

```
Epoch 1/10
188/188 [==============================] - 24s 123ms/step - loss: 1.7721 - accuracy: 0.3328 - val_loss: 0.8729 - val_accuracy: 0.
Epoch 2/10
188/188 [==============================] - 23s 120ms/step - loss: 0.5409 - accuracy: 0.8210 - val_loss: 0.3104 - val_accuracy: 0.
Epoch 3/10
188/188 [==============================] - 25s 131ms/step - loss: 0.2761 - accuracy: 0.9119 - val_loss: 0.2305 - val_accuracy: 0.
Epoch 4/10
188/188 [==============================] - 25s 134ms/step - loss: 0.1972 - accuracy: 0.9371 - val_loss: 0.1805 - val_accuracy: 0.
Epoch 5/10
188/188 [==============================] - 26s 137ms/step - loss: 0.1608 - accuracy: 0.9495 - val_loss: 0.1609 - val_accuracy: 0.
Epoch 6/10
188/188 [==============================] - 27s 145ms/step - loss: 0.1412 - accuracy: 0.9553 - val_loss: 0.1326 - val_accuracy: 0.
Epoch 7/10
188/188 [==============================] - 28s 147ms/step - loss: 0.1165 - accuracy: 0.9638 - val_loss: 0.1106 - val_accuracy: 0.
Epoch 8/10
188/188 [==============================] - 27s 145ms/step - loss: 0.1073 - accuracy: 0.9664 - val_loss: 0.1162 - val_accuracy: 0.
Epoch 9/10
188/188 [==============================] - 28s 151ms/step - loss: 0.0975 - accuracy: 0.9686 - val_loss: 0.1069 - val_accuracy: 0.
Epoch 10/10
188/188 [==============================] - 30s 162ms/step - loss: 0.0878 - accuracy: 0.9722 - val_loss: 0.0893 - val_accuracy: 0.

<keras.callbacks.History at 0x1bfe505e790>
```

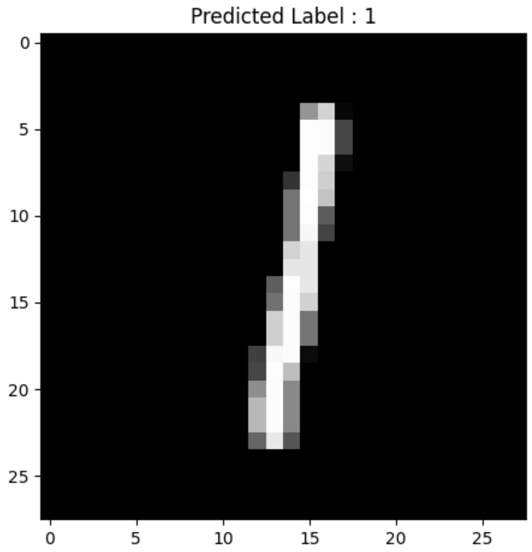
```
alexNet.evaluate(x_test, y_test)
```

```
313/313 [==============================] - 3s 8ms/step - loss: 776.6279 - accuracy: 0.3601

[776.6279296875, 0.36010000109672546]
```

```python
img = x_test[1280]

# classify image using the alexNet model
predicted_label = alexNet.predict(np.array([img]))
predicted_label = np.argmax(predicted_label)

fig, ax = plt.subplots()
ax.imshow(img.reshape(28, 28), cmap='gray')
ax.set_title(f'Predicted Label : {predicted_label}')

plt.tight_layout()
plt.show()
```

```
1/1 [==============================] - 0s 14ms/step


<Figure size 640x480 with 1 Axes>
```

Download



LeNet-5

```python
%%time

leNet = tf.keras.Sequential(
    [
        tf.keras.layers.Conv2D(filters=6, kernel_size=(5, 5), activation='relu', input_shape=(28, 28, 1)),
        tf.keras.layers.MaxPool2D(strides=(2, 2)),
        tf.keras.layers.Conv2D(filters=16, kernel_size=(5, 5), activation='relu'),
        tf.keras.layers.MaxPool2D(strides=(2, 2)),
        tf.keras.layers.Flatten(),
        tf.keras.layers.Dense(120, activation='relu'),
        tf.keras.layers.Dense(84, activation='relu'),
        tf.keras.layers.Dense(10, activation='softmax')
    ]
)

leNet.compile(optimizer='adam', loss='sparse_categorical_crossentropy', metrics=['accuracy'])
```

```
CPU times: total: 0 ns
Wall time: 45 ms
```

```python
leNet.summary()
```

```
Model: "sequential_4"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d_20 (Conv2D)          (None, 24, 24, 6)         156

 max_pooling2d_12 (MaxPoolin  (None, 12, 12, 6)        0
 g2D)

 conv2d_21 (Conv2D)          (None, 8, 8, 16)          2416

 max_pooling2d_13 (MaxPoolin  (None, 4, 4, 16)         0
 g2D)

 flatten_4 (Flatten)         (None, 256)               0

 dense_26 (Dense)            (None, 120)               30840

 dense_27 (Dense)            (None, 84)                10164
```

```
%%time

leNet.fit(x_train, y_train, epochs=10, batch_size=256, shuffle=True, validation_split=0.2)
```

```
Epoch 1/10
188/188 [==============================] - 6s 29ms/step - loss: 1.8275 - accuracy: 0.3497 - val_loss: 1.1407 - val_accuracy: 0.62
Epoch 2/10
188/188 [==============================] - 5s 28ms/step - loss: 0.7774 - accuracy: 0.7564 - val_loss: 0.5421 - val_accuracy: 0.83
Epoch 3/10
188/188 [==============================] - 5s 28ms/step - loss: 0.5158 - accuracy: 0.8415 - val_loss: 0.4391 - val_accuracy: 0.86
Epoch 4/10
188/188 [==============================] - 5s 29ms/step - loss: 0.4259 - accuracy: 0.8709 - val_loss: 0.3551 - val_accuracy: 0.89
Epoch 5/10
188/188 [==============================] - 5s 28ms/step - loss: 0.3570 - accuracy: 0.8918 - val_loss: 0.3076 - val_accuracy: 0.90
Epoch 6/10
188/188 [==============================] - 5s 28ms/step - loss: 0.3056 - accuracy: 0.9074 - val_loss: 0.2600 - val_accuracy: 0.92
Epoch 7/10
188/188 [==============================] - 5s 28ms/step - loss: 0.2645 - accuracy: 0.9199 - val_loss: 0.2362 - val_accuracy: 0.92
Epoch 8/10
188/188 [==============================] - 5s 28ms/step - loss: 0.2337 - accuracy: 0.9281 - val_loss: 0.2210 - val_accuracy: 0.93
Epoch 9/10
188/188 [==============================] - 5s 29ms/step - loss: 0.2101 - accuracy: 0.9351 - val_loss: 0.1885 - val_accuracy: 0.94
Epoch 10/10
188/188 [==============================] - 5s 28ms/step - loss: 0.1889 - accuracy: 0.9423 - val_loss: 0.1815 - val_accuracy: 0.94

<keras.callbacks.History at 0x1bfe57a29d0>
```

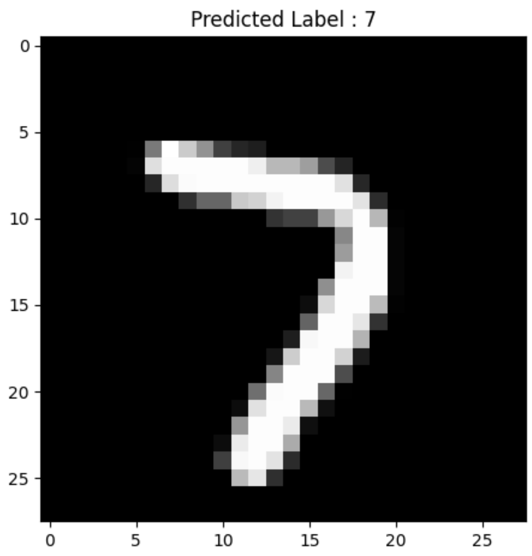
```
leNet.evaluate(x_test, y_test)
```

```
313/313 [==============================] - 1s 3ms/step - loss: 40.9487 - accuracy: 0.9008

[40.94874954223633, 0.9007999897003174]
```

```
img = x_test[2874]

# classify image using the leNet model
predicted_label = leNet.predict(np.array([img]))
predicted_label = np.argmax(predicted_label)

fig, ax = plt.subplots()
ax.imshow(img.reshape(28, 28), cmap='gray')
ax.set_title(f'Predicted Label : {predicted_label}')

plt.tight_layout()
plt.show()
```

```
1/1 [==============================] - 0s 15ms/step

<Figure size 640x480 with 1 Axes>
```

Download



VGG-16

```
vgg16 = tf.keras.Sequential(
    [
        tf.keras.layers.Conv2D(filters=64, kernel_size=(3, 3), activation='relu', padding='same',
                               input_shape=(28, 28, 1)),
        tf.keras.layers.Conv2D(filters=64, kernel_size=(3, 3), activation='relu', padding='same'),
        tf.keras.layers.MaxPool2D(strides=(2, 2), padding='same'),
        tf.keras.layers.Conv2D(filters=128, kernel_size=(3, 3), activation='relu', padding='same'),
        tf.keras.layers.Conv2D(filters=128, kernel_size=(3, 3), activation='relu', padding='same'),
        tf.keras.layers.MaxPool2D(strides=(2, 2), padding='same'),
        tf.keras.layers.Conv2D(filters=256, kernel_size=(3, 3), activation='relu', padding='same'),
        tf.keras.layers.Conv2D(filters=256, kernel_size=(3, 3), activation='relu', padding='same'),
        tf.keras.layers.Conv2D(filters=256, kernel_size=(3, 3), activation='relu', padding='same'),
        tf.keras.layers.MaxPool2D(strides=(2, 2), padding='same'),
        tf.keras.layers.Conv2D(filters=512, kernel_size=(3, 3), activation='relu', padding='same'),
        tf.keras.layers.Conv2D(filters=512, kernel_size=(3, 3), activation='relu', padding='same'),
        tf.keras.layers.Conv2D(filters=512, kernel_size=(3, 3), activation='relu', padding='same'),
        tf.keras.layers.MaxPool2D(strides=(2, 2), padding='same'),
        tf.keras.layers.Conv2D(filters=512, kernel_size=(3, 3), activation='relu', padding='same'),
        tf.keras.layers.Conv2D(filters=512, kernel_size=(3, 3), activation='relu', padding='same'),
        tf.keras.layers.Conv2D(filters=512, kernel_size=(3, 3), activation='relu', padding='same'),
        tf.keras.layers.MaxPool2D(strides=(2, 2), padding='same'),
        tf.keras.layers.Flatten()
```

```
%%time

vgg16.fit(x_train, y_train, epochs=10, batch_size=256, shuffle=True, validation_split=0.2)
```

```
Epoch 1/10
  6/188 [.............................] - ETA: 1:25:12 - loss: 2.3024 - accuracy: 0.0983
```

```
vgg16.evaluate(x_test, y_test)
```