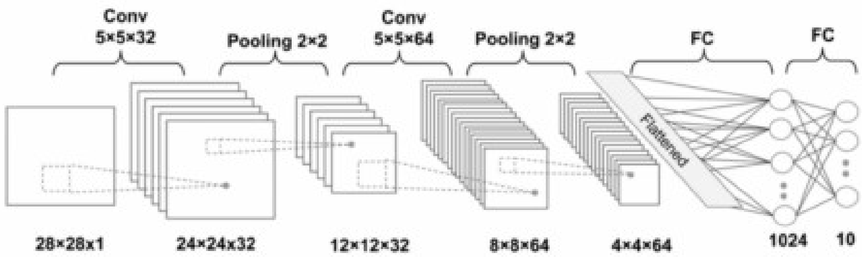
Classwork 3

```
import matplotlib.pyplot as plt
import matplotlib.image as mpimg
import os

# The exact path you provided
image_path =
"/var/folders/_7/f441syp12hxc66fp7hpbg3j40000gn/T/TemporaryItems/NSIRD
_screencaptureui_tN2XxM/Screenshot 2025-04-09 at 10.16.00 AM.png"

try:
    # Check if the file actually exists at the path
    if not os.path.exists(image_path):
        print(f"Error: File not found at the specified path:")
        print(image_path)
    else:
        # Read the image file into an array
        print(f"Loading '{os.path.basename(image_path)}'...")
        img_data = mpimg.imread(image_path)

        # Create a figure and axes to display the image
        fig, ax = plt.subplots()
        ax.imshow(img_data)

        # Optional: Hide axes and labels for a cleaner look
        ax.axis('off')
        ax.set_title(os.path.basename(image_path)) # Show filename as
title

        # Show the plot window
        print("Displaying image in a Matplotlib window...")
        plt.show()

except FileNotFoundError:
    print(f"Error: File not found (double check): {image_path}")
except Exception as e:
    print(f"An error occurred while trying to load or display the
image with Matplotlib:")
    print(e)
    print("\nEnsure the file is a valid image format supported by
Matplotlib (like PNG, JPG).")
    print("Make sure you have Matplotlib installed (`pip install
matplotlib`).")
```

```
Loading 'Screenshot 2025-04-09 at 10.16.00 AM.png'...
Displaying image in a Matplotlib window...
```

Screenshot 2025-04-09 at 10.16.00 AM.png

1. Given a LeNet model for handwritten digit classification as the following figure.



A formula to compute the size after convolution: input vector ***x*** has size ***n*** and the filter ***w*** is of size ***m***. The size of the output resulting from ***x***, ***w*** with padding ***p*** and stride ***s*** is determined as follows:

$$o=\left\lfloor \frac{n+2p-m}{s} \right\rfloor+1$$

(a) Describe the type of padding in each convolutional layer and verify the result.

(b) Write a code to implement a LeNet model on the basis of the digit MNIST dataset. The dataset is separated into 75% train set and 25% test set. Train the model using the Adam optimization (define epoch number by yourself). Compute the accuracy of classification on the train set and test set, respectively.

Verification of Padding in Convolutional Layers

It appears the LeNet model shown uses **no padding** in its convolutional layers. This corresponds to **"valid" padding** ($p=0$) in many frameworks. The calculations below verify this.

(Note: While the text initially mentioned `padding="same"`, the calculations consistently use $p=0$, which means "valid" or no padding was actually applied, leading to a reduction in feature map size after convolution).

Formula for Output Size

To verify the dimensions, we use the standard formula for convolutional layer output size:

$$o=\lfloor \frac{n+2p-m}{s} \rfloor+1$$

Where:

- n = Input feature map size (height or width)
- p = Padding applied to each side
- m = Filter (kernel) size (height or width)
- s = Stride

We assume a stride (s) of 1 for the convolutional layers.

Layer-by-Layer Verification

Conv2D_1 (First Convolutional Layer)

- Parameters: Input $n=28$, Padding $p=0$, Filter $m=5$, Stride $s=1$
- Calculation: $o=\lfloor \frac{28+2(0)-5}{1} \rfloor+1=\lfloor 23 \rfloor+1=24$
- Result: Output size is 24x24, matching the diagram.

MaxPooling_1 (First Pooling Layer)

- Parameters: Input $n=24$, Pool Size $m=2$, Stride $s=2$ (typical for 2x2 pooling)
- Calculation: Output size is typically halved with 2x2, stride 2 pooling.
  $o=\lfloor \frac{24-2}{2} \rfloor+1=\lfloor 10 \rfloor+1=12$ (using common pooling formula) *or simply* $o=24/2=12$
- Result: Output size is 12x12, matching the diagram.

Conv2D_2 (Second Convolutional Layer)

- Parameters: Input $n=12$, Padding $p=0$, Filter $m=5$, Stride $s=1$
- Calculation: $o=\lfloor \frac{12+2(0)-5}{1} \rfloor+1=\lfloor 7 \rfloor+1=8$
- Result: Output size is 8x8, matching the diagram.

MaxPooling_2 (Second Pooling Layer)

- Parameters: Input $n=8$, Pool Size $m=2$, Stride $s=2$
- Calculation: Output size is halved. $o=\lfloor \frac{8-2}{2} \rfloor+1=\lfloor 3 \rfloor+1=4$ (using common pooling formula) *or simply* $o=8/2=4$
- Result: Output size is 4x4, matching the diagram.

Final Output

The final output dimension after **MaxPooling_2** is indeed 4x4x64. This 3D feature map is then typically changed into a 1D array using a **Flatten** layer before being connected to the final **Dense** (Fully Connected) layers for classification.

Code to Implement a LeNet model on the basis of the digit MNIST dataset.

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

```
from tensorflow import keras
(x_train, y_train), (x_test, y_test) =
keras.datasets.mnist.load_data()

print(x_train.shape)
print(x_test.shape)
print(y_train.shape)
print(y_test.shape)

#normalizing the dataset
x_train = x_train.astype('float32') / 255
x_test = x_test.astype('float32') / 255

#In the Question it's asked to take training data as 75% and testing
as 25%
#Combine both the training and test data
x = np.concatenate((x_train, x_test), axis=0)
y = np.concatenate((y_train, y_test), axis=0)
print("-----------------------------------------------------------")
print(x.shape)
print(y.shape)
print("-----------------------------------------------------------")
#Now we will split the data into 75% training and 25% testing
import sklearn
from sklearn.model_selection import train_test_split
x_train_new, x_test_new, y_train_new, y_test_new = train_test_split(x,
y, test_size = 0.25, random_state = 42)
print(x_train_new.shape)
print(x_test_new.shape)
print(y_train_new.shape)
```

```
(60000, 28, 28)
(10000, 28, 28)
(60000,)
(10000,)
-----------------------------------------------------------
(70000, 28, 28)
(70000,)
-----------------------------------------------------------
(52500, 28, 28)
(17500, 28, 28)
(52500,)
```

```
#reshaping the dataset
#x_train = np.reshape(x_train, (len(x_train), 28, 28, 1))
#x_test = np.reshape(x_test, (len(x_test), 28, 28, 1))
#x_train = np.expand_dims(x_train, axis=-1)
#x_test = np.expand_dims(x_test, axis=-1)
```

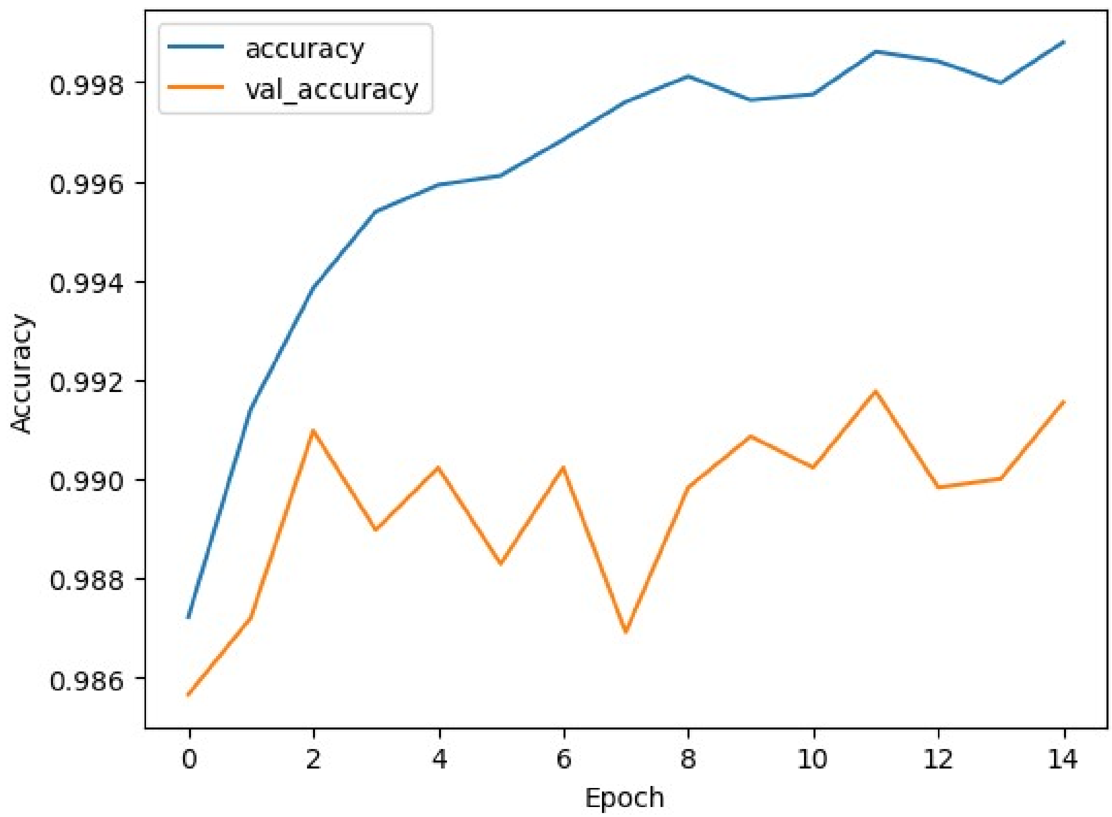
```python
#Building the LeNet model
from keras import layers
model = keras.Sequential([
    layers.Conv2D(filters=32, kernel_size=(5,5), activation='relu',
padding="valid", data_format="channels_last", input_shape=(28, 28,
1)),
    layers.MaxPooling2D(pool_size=(2,2), padding="valid", strides=(2),
data_format="channels_last"),
    layers.Conv2D(filters=64, kernel_size=(5,5), activation='relu',
padding="valid", data_format="channels_last"),
    layers.MaxPooling2D(pool_size=(2,2), padding="valid",strides=(2),
data_format="channels_last"),
    layers.Flatten(),
    layers.Dense(1024, activation='relu'),
    layers.Dense(10, activation='softmax')
])
model.summary()
```

```
Model: "sequential_6"
_________________________________________________________________
 Layer (type)                Output Shape              Param #   
=================================================================
 conv2d_12 (Conv2D)          (None, 24, 24, 32)        832       
                                                                 
 max_pooling2d_12 (MaxPooli  (None, 12, 12, 32)        0         
 ng2D)                                                           
                                                                 
 conv2d_13 (Conv2D)          (None, 8, 8, 64)          51264     
                                                                 
 max_pooling2d_13 (MaxPooli  (None, 4, 4, 64)          0         
 ng2D)                                                           
                                                                 
 flatten_6 (Flatten)         (None, 1024)              0         
                                                                 
 dense_12 (Dense)            (None, 1024)              1049600   
                                                                 
 dense_13 (Dense)            (None, 10)                10250     
                                                                 
=================================================================
Total params: 1111946 (4.24 MB)
Trainable params: 1111946 (4.24 MB)
Non-trainable params: 0 (0.00 Byte)
_________________________________________________________________
```

```python
#define the loss function and optimizer
model.compile(loss="sparse_categorical_crossentropy",
optimizer="adam", metrics=["accuracy"])
#train the model
history = model.fit(x_train_new, y_train_new, epochs=15,
batch_size=32,validation_data=(x_test_new,y_test_new), verbose=1)
```

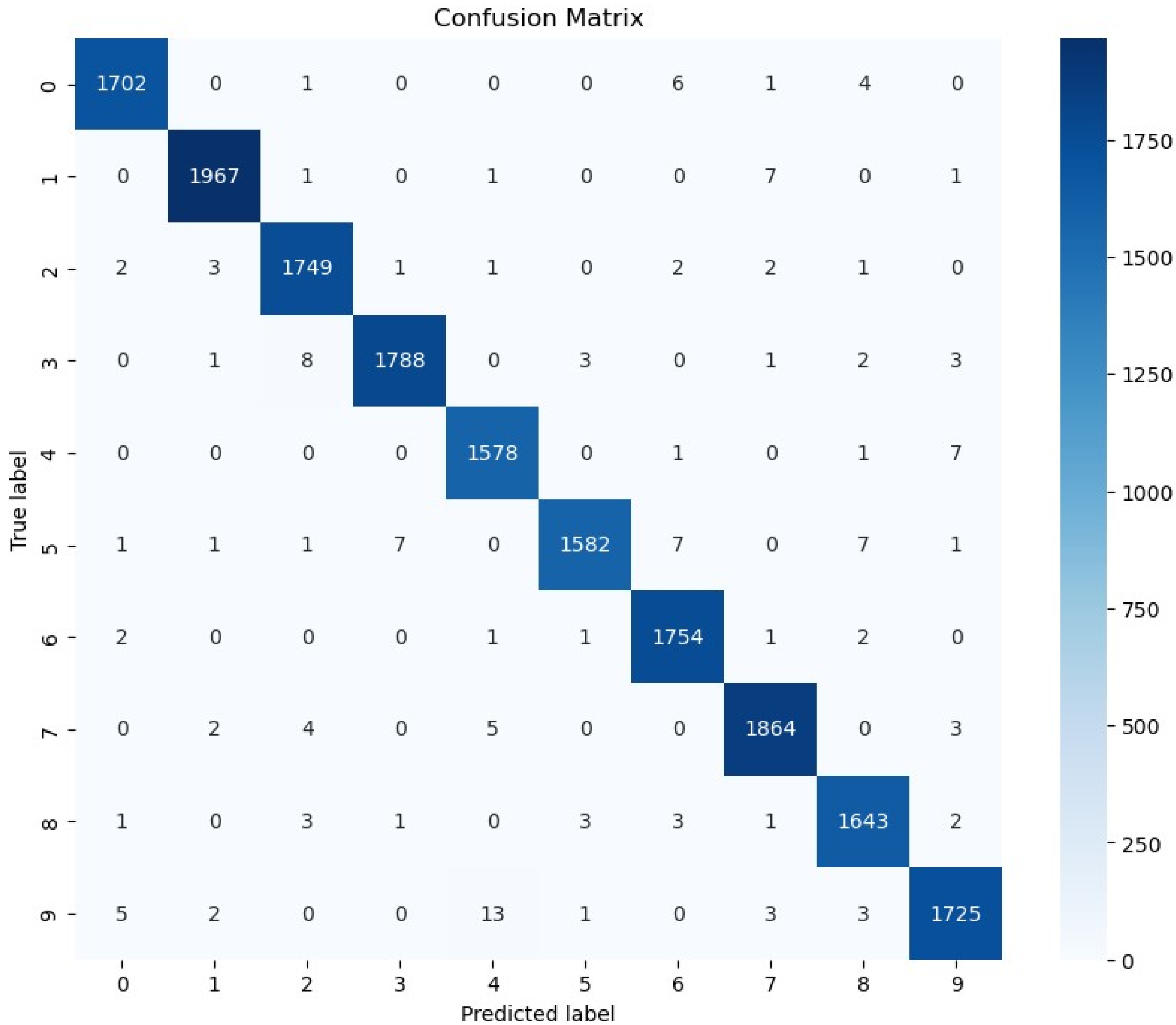
```
Epoch 1/15
1641/1641 [==============================] - 32s 19ms/step - loss:
0.0421 - accuracy: 0.9872 - val_loss: 0.0458 - val_accuracy: 0.9857
Epoch 2/15
1641/1641 [==============================] - 33s 20ms/step - loss:
0.0266 - accuracy: 0.9914 - val_loss: 0.0416 - val_accuracy: 0.9872
Epoch 3/15
1641/1641 [==============================] - 33s 20ms/step - loss:
0.0197 - accuracy: 0.9938 - val_loss: 0.0330 - val_accuracy: 0.9910
Epoch 4/15
1641/1641 [==============================] - 30s 19ms/step - loss:
0.0146 - accuracy: 0.9954 - val_loss: 0.0443 - val_accuracy: 0.9890
Epoch 5/15
1641/1641 [==============================] - 28s 17ms/step - loss:
0.0136 - accuracy: 0.9959 - val_loss: 0.0425 - val_accuracy: 0.9902
Epoch 6/15
1641/1641 [==============================] - 27s 17ms/step - loss:
0.0110 - accuracy: 0.9961 - val_loss: 0.0486 - val_accuracy: 0.9883
Epoch 7/15
1641/1641 [==============================] - 28s 17ms/step - loss:
0.0108 - accuracy: 0.9968 - val_loss: 0.0438 - val_accuracy: 0.9902
Epoch 8/15
1641/1641 [==============================] - 28s 17ms/step - loss:
0.0084 - accuracy: 0.9976 - val_loss: 0.0590 - val_accuracy: 0.9869
Epoch 9/15
1641/1641 [==============================] - 29s 18ms/step - loss:
0.0072 - accuracy: 0.9981 - val_loss: 0.0464 - val_accuracy: 0.9898
Epoch 10/15
1641/1641 [==============================] - 29s 18ms/step - loss:
0.0081 - accuracy: 0.9976 - val_loss: 0.0506 - val_accuracy: 0.9909
Epoch 11/15
1641/1641 [==============================] - 29s 18ms/step - loss:
0.0079 - accuracy: 0.9978 - val_loss: 0.0500 - val_accuracy: 0.9902
Epoch 12/15
1641/1641 [==============================] - 30s 18ms/step - loss:
0.0047 - accuracy: 0.9986 - val_loss: 0.0522 - val_accuracy: 0.9918
Epoch 13/15
1641/1641 [==============================] - 36s 22ms/step - loss:
0.0069 - accuracy: 0.9984 - val_loss: 0.0675 - val_accuracy: 0.9898
Epoch 14/15
1641/1641 [==============================] - 30s 18ms/step - loss:
0.0073 - accuracy: 0.9980 - val_loss: 0.0619 - val_accuracy: 0.9900
Epoch 15/15
1641/1641 [==============================] - 31s 19ms/step - loss:
0.0054 - accuracy: 0.9988 - val_loss: 0.0526 - val_accuracy: 0.9915

#evaluate the model
test_loss, test_accuracy = model.evaluate(x_test_new, y_test_new,
verbose=0)
print(f"Test accuracy: {test_accuracy:.4f}")
```

```
#plot the training and validation accuracy
plt.plot(history.history['accuracy'], label='accuracy')
plt.plot(history.history['val_accuracy'], label='val_accuracy')
plt.xlabel('Epoch')
plt.ylabel('Accuracy')
plt.legend()
plt.show()

Test accuracy: 0.9915
```




```
#plot the confusion matrix
from sklearn.metrics import confusion_matrix
import seaborn as sns
import matplotlib.pyplot as plt
import numpy as np
conf = confusion_matrix(y_test_new,
model.predict(x_test_new).argmax(axis=1))
plt.figure(figsize=(10, 8))
sns.heatmap(conf, annot=True, fmt='d', cmap='Blues')
plt.xlabel('Predicted label')
plt.ylabel('True label')
plt.title('Confusion Matrix')
plt.show()
```

```
547/547 [==============================] - 3s 5ms/step
```



Accuracy Metrics

The accuracy after training the model on 75% of training and testing it on 25% of the data we got the below accuracies:

Train accuracy: 0.9988 Test accuracy: 0.9915