MNIST

April 19, 2024

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Homework 3

[1]:
```
import warnings
warnings.filterwarnings("ignore")

import os
os.environ["KMP_DUPLICATE_LIB_OK"]="TRUE"
```

[2]:
```
import numpy as np
import pandas as pd
from datetime import datetime

import PIL
import PIL.Image
import pathlib

from matplotlib import pyplot as plt
import matplotlib as mpl
import tensorflow as tf

from sklearn.metrics import confusion_matrix
import seaborn as sns

print(tf.__version__)
```

```
2.10.0
```

[3]:
```
print(tf.config.list_physical_devices('GPU'))
print(tf.test.is_built_with_cuda)
print(tf.test.gpu_device_name())
print(tf.config.get_visible_devices())
```

```
[]
<function is_built_with_cuda at 0x000001D8545C4D30>

[PhysicalDevice(name='/physical_device:CPU:0', device_type='CPU')]
```

Parameters

[4]:
```
AUTOTUNE = tf.data.AUTOTUNE
```

[5]:
```
batch_size = 32
img_height = 28
img_width = 28
```

Data

[6]:
```
data_dirpathname = r'E:\Data Science\ECE565 - Machine Learning\datasets\mnist\trainingSet\trainingSet'
data_dir = pathlib.Path(data_dirpathname)

class_names = os.listdir(data_dir)
num_classes = len(class_names)
```

0.1 1. 2.a) Code that will count number of classes

0.2 1. 2.b) Number of images in each class

[7]:
```
images_per_class = {}
for class_name in class_names:
    images_per_class[class_name] = len(os.listdir(os.path.join(data_dir, class_name)))

print("Number of classes:", num_classes)
print("Number of images in each class:", images_per_class)
```

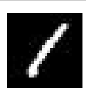
```
Number of classes: 10
Number of images in each class: {'0': 4132, '1': 4684, '2': 4177, '3': 4351,
'4': 4072, '5': 3795, '6': 4137, '7': 4401, '8': 4063, '9': 4188}
```

[8]:
```
image_count =  len(list(data_dir.glob('*/*.jpg')))
print('Image count:', image_count)
```

```
Image count: 42000
```

[9]:
```
one = list(data_dir.glob('1/*'))
PIL.Image.open(str(one[0]))
```

[9]:



[10]:
```
sample_image = PIL.Image.open(str(one[1]))
img = np.asarray(sample_image)
img.shape
```

[10]: (28, 28)

Setup Dataset Pipeline

[11]:
```
list_ds = tf.data.Dataset.list_files(str(data_dir/'*/*'), shuffle=False)
list_ds = list_ds.shuffle(image_count, reshuffle_each_iteration=False)
list_ds
```

[11]:
```
<ShuffleDataset element_spec=TensorSpec(shape=(), dtype=tf.string, name=None)>
```

[12]:
```
for f in list_ds.take(5):
    print(f.numpy())
```

```
b'E:\\Data Science\\ECE565 - Machine
Learning\\datasets\\mnist\\trainingSet\\trainingSet\\1\\img_21024.jpg'
b'E:\\Data Science\\ECE565 - Machine
Learning\\datasets\\mnist\\trainingSet\\trainingSet\\3\\img_25032.jpg'
b'E:\\Data Science\\ECE565 - Machine
Learning\\datasets\\mnist\\trainingSet\\trainingSet\\4\\img_32604.jpg'
b'E:\\Data Science\\ECE565 - Machine
Learning\\datasets\\mnist\\trainingSet\\trainingSet\\2\\img_7024.jpg'
b'E:\\Data Science\\ECE565 - Machine
Learning\\datasets\\mnist\\trainingSet\\trainingSet\\2\\img_22214.jpg'
```

0.3 1. 1. Data must be split in train/test and validation set

[13]:
```
test_size = int(image_count*0.2)
train_ds = list_ds.skip(test_size)
val_ds = list_ds.take(test_size)
```

[14]:
```
print(tf.data.experimental.cardinality(train_ds).numpy())
print(tf.data.experimental.cardinality(val_ds).numpy())
```

```
33600
8400
```

Helper Functions

[15]:
```
def get_label(file_path):
    parts = tf.strings.split(file_path, os.path.sep)
    one_hot = parts[-2] == class_names
    return tf.argmax(one_hot)
```

[16]:
```
def decode_img(img):
    img = tf.io.decode_jpeg(img, channels=3)
    return tf.image.resize(img, [img_height, img_width])
```

[17]:
```
def process_path(file_path):
    label = get_label(file_path)
    img = tf.io.read_file(file_path)
    img = decode_img(img)
    return img, label
```

[18]:
```python
# Set 'num_parallel_calls' so multiple images are loaded/processed in parallel.

train_ds = train_ds.map(process_path, num_parallel_calls=AUTOTUNE)
val_ds = val_ds.map(process_path, num_parallel_calls=AUTOTUNE)
```

0.4 1. 2.c) Image resized to 101x101xNo_Of_channels.

0.5 1. 2.d) Automatic data label extraction based on sub-directory name.

0.6 1. 2.e) Display one batch of image/label using the dataset api.

[19]:
```python
for image, label in train_ds.take(1):
    print("Image shape:", image.numpy().shape)
    print("Label:", class_names[label.numpy()])
```

```
Image shape: (28, 28, 3)
Label: 3
```

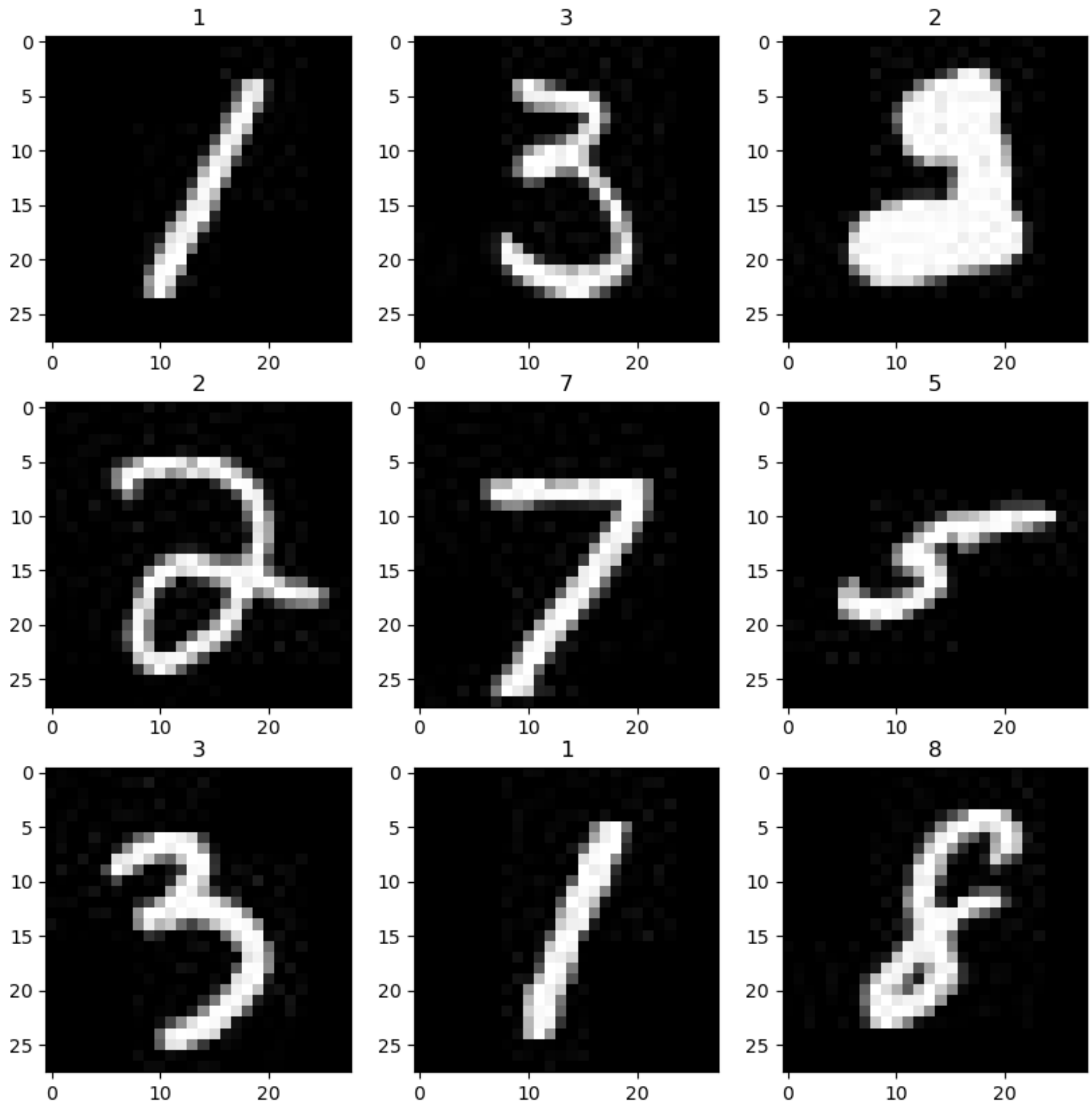
[20]:
```python
def configure_for_performance(ds):
    ds = ds.cache()
    ds = ds.shuffle(buffer_size=1000)
    ds = ds.batch(batch_size=64)
    return ds
```

[21]:
```python
train_ds = configure_for_performance(train_ds)
val_ds = configure_for_performance(val_ds)
```

Test Dataset Pipeline

[22]:
```python
image_batch, label_batch = next(iter(train_ds))
```

[23]:
```python
plt.figure(figsize=(10,10))
for i in range(9):
    ax = plt.subplot(3, 3, i+1)
    plt.imshow(image_batch[i].numpy().astype("uint8"))
    label = label_batch[i]
    plt.title(class_names[label])
```



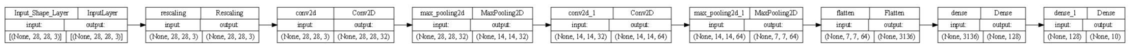
0.7 2. Model

[24]:
```
model = tf.keras.Sequential([
    tf.keras.layers.InputLayer(input_shape=(img_height, img_width, 3),␣
 ↪name='Input_Shape_Layer'),
    tf.keras.layers.Rescaling(1./255),  # Normalize pixel values
    tf.keras.layers.Conv2D(32, 3, activation='relu', padding='same'),
    tf.keras.layers.MaxPooling2D(),
    tf.keras.layers.Conv2D(64, 3, activation='relu', padding='same'),
    tf.keras.layers.MaxPooling2D(),
    tf.keras.layers.Flatten(),
    tf.keras.layers.Dense(128, activation='relu'),
```

```
    tf.keras.layers.Dense(num_classes, activation='softmax')
])
```

[25]:
```
tf.keras.utils.plot_model(model=model, rankdir="LR", dpi=72, show_shapes=True)
```

[25]:



[26]:
```
model.compile(
    optimizer='adam',
    loss=tf.keras.losses.SparseCategoricalCrossentropy(from_logits=True),
    metrics=['accuracy']
)
```

0.7.1 Training / Validation Cycle

[27]:
```
logdir = "logs/" + datetime.now().strftime("%Y%m%d-%H%M%S")
tensorboard_callback = tf.keras.callbacks.TensorBoard(log_dir=logdir)
```

0.8 3. Train/Validation

0.9 3. 1. Early stopping

[28]:
```
early_stopping_callback = tf.keras.callbacks.
 ↪EarlyStopping(monitor='val_accuracy', mode='max', patience=5)
```

[29]:
```
model.fit(
    train_ds,
    validation_data=val_ds,
    epochs=101,
    callbacks=[tensorboard_callback, early_stopping_callback],
    verbose=1
)
```

```
Epoch 1/101
525/525 [==============================] - 35s 65ms/step - loss: 0.1909 -
accuracy: 0.9410 - val_loss: 0.0627 - val_accuracy: 0.9804
Epoch 2/101
525/525 [==============================] - 7s 13ms/step - loss: 0.0528 -
accuracy: 0.9829 - val_loss: 0.0517 - val_accuracy: 0.9857
Epoch 3/101
525/525 [==============================] - 7s 13ms/step - loss: 0.0371 -
accuracy: 0.9881 - val_loss: 0.0441 - val_accuracy: 0.9874
Epoch 4/101
525/525 [==============================] - 7s 13ms/step - loss: 0.0259 -
accuracy: 0.9924 - val_loss: 0.0399 - val_accuracy: 0.9886
Epoch 5/101
```

```
525/525 [==============================] - 7s 13ms/step - loss: 0.0184 -
accuracy: 0.9942 - val_loss: 0.0412 - val_accuracy: 0.9892
Epoch 6/101
525/525 [==============================] - 7s 14ms/step - loss: 0.0163 -
accuracy: 0.9946 - val_loss: 0.0528 - val_accuracy: 0.9858
Epoch 7/101
525/525 [==============================] - 7s 13ms/step - loss: 0.0103 -
accuracy: 0.9965 - val_loss: 0.0561 - val_accuracy: 0.9857
Epoch 8/101
525/525 [==============================] - 8s 14ms/step - loss: 0.0099 -
accuracy: 0.9968 - val_loss: 0.0504 - val_accuracy: 0.9883
Epoch 9/101
525/525 [==============================] - 7s 13ms/step - loss: 0.0105 -
accuracy: 0.9962 - val_loss: 0.0682 - val_accuracy: 0.9838
Epoch 10/101
525/525 [==============================] - 7s 14ms/step - loss: 0.0091 -
accuracy: 0.9970 - val_loss: 0.0579 - val_accuracy: 0.9868
```

[29]:
```
<keras.callbacks.History at 0x1d859459c10>
```

Evaluate Trained Model

0.10 4. Model Evaluation

0.11 4. 2. Accuracy Metrics

[30]:
```python
test_loss, test_acc = model.evaluate(val_ds, verbose=2)
print('\nTest Accuracy:', test_acc)
```

```
132/132 - 1s - loss: 0.0579 - accuracy: 0.9868 - 669ms/epoch - 5ms/step

Test Accuracy: 0.9867857098579407
```

[31]:
```python
all_predictions = []
all_labels = []
```

0.12 4. 1. Confusion Matrix

[32]:
```python
for images, labels in val_ds:
    predictions = model.predict(images)
    predicted_classes = np.argmax(predictions, axis=1)
    true_classes = labels.numpy()

    all_predictions.extend(predicted_classes)
    all_labels.extend(true_classes)
```

```
2/2 [==============================] - 0s 11ms/step
2/2 [==============================] - 0s 7ms/step
2/2 [==============================] - 0s 11ms/step
```

```
2/2 [==============================] - 0s 7ms/step
2/2 [==============================] - 0s 9ms/step
2/2 [==============================] - 0s 20ms/step
2/2 [==============================] - 0s 7ms/step
2/2 [==============================] - 0s 13ms/step
2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 8ms/step
2/2 [==============================] - 0s 5ms/step
2/2 [==============================] - 0s 16ms/step
2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 6ms/step
2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 0s/step
2/2 [==============================] - 0s 18ms/step
2/2 [==============================] - 0s 4ms/step
2/2 [==============================] - 0s 18ms/step
2/2 [==============================] - 0s 6ms/step
2/2 [==============================] - 0s 21ms/step
2/2 [==============================] - 0s 5ms/step
2/2 [==============================] - 0s 14ms/step
2/2 [==============================] - 0s 5ms/step
2/2 [==============================] - 0s 8ms/step
2/2 [==============================] - 0s 6ms/step
2/2 [==============================] - 0s 4ms/step
2/2 [==============================] - 0s 6ms/step
2/2 [==============================] - 0s 7ms/step
2/2 [==============================] - 0s 6ms/step
2/2 [==============================] - 0s 18ms/step
2/2 [==============================] - 0s 5ms/step
2/2 [==============================] - 0s 17ms/step
2/2 [==============================] - 0s 5ms/step
2/2 [==============================] - 0s 6ms/step
2/2 [==============================] - 0s 4ms/step
2/2 [==============================] - 0s 5ms/step
2/2 [==============================] - 0s 9ms/step
2/2 [==============================] - 0s 16ms/step
2/2 [==============================] - 0s 7ms/step
2/2 [==============================] - 0s 7ms/step
2/2 [==============================] - 0s 19ms/step
2/2 [==============================] - 0s 4ms/step
2/2 [==============================] - 0s 4ms/step
2/2 [==============================] - 0s 7ms/step
2/2 [==============================] - 0s 4ms/step
2/2 [==============================] - 0s 4ms/step
2/2 [==============================] - 0s 5ms/step
2/2 [==============================] - 0s 6ms/step
2/2 [==============================] - 0s 20ms/step
2/2 [==============================] - 0s 19ms/step
```

```
2/2 [==============================] - 0s 2ms/step
2/2 [==============================] - 0s 8ms/step
2/2 [==============================] - 0s 4ms/step
2/2 [==============================] - 0s 5ms/step
2/2 [==============================] - 0s 19ms/step
2/2 [==============================] - 0s 8ms/step
2/2 [==============================] - 0s 5ms/step
2/2 [==============================] - 0s 11ms/step
2/2 [==============================] - 0s 12ms/step
2/2 [==============================] - 0s 7ms/step
2/2 [==============================] - 0s 4ms/step
2/2 [==============================] - 0s 19ms/step
2/2 [==============================] - 0s 5ms/step
2/2 [==============================] - 0s 25ms/step
2/2 [==============================] - 0s 4ms/step
2/2 [==============================] - 0s 4ms/step
2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 11ms/step
2/2 [==============================] - 0s 15ms/step
2/2 [==============================] - 0s 17ms/step
2/2 [==============================] - 0s 8ms/step
2/2 [==============================] - 0s 7ms/step
2/2 [==============================] - 0s 7ms/step
2/2 [==============================] - 0s 8ms/step
2/2 [==============================] - 0s 23ms/step
2/2 [==============================] - 0s 4ms/step
2/2 [==============================] - 0s 4ms/step
2/2 [==============================] - 0s 5ms/step
2/2 [==============================] - 0s 6ms/step
2/2 [==============================] - 0s 13ms/step
2/2 [==============================] - 0s 12ms/step
2/2 [==============================] - 0s 16ms/step
2/2 [==============================] - 0s 11ms/step
2/2 [==============================] - 0s 1ms/step
2/2 [==============================] - 0s 6ms/step
2/2 [==============================] - 0s 4ms/step
2/2 [==============================] - 0s 7ms/step
2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 5ms/step
2/2 [==============================] - 0s 9ms/step
2/2 [==============================] - 0s 19ms/step
2/2 [==============================] - 0s 16ms/step
2/2 [==============================] - 0s 18ms/step
2/2 [==============================] - 0s 7ms/step
2/2 [==============================] - 0s 16ms/step
2/2 [==============================] - 0s 6ms/step
2/2 [==============================] - 0s 5ms/step
2/2 [==============================] - 0s 19ms/step
```

```
2/2 [==============================] - 0s 11ms/step
2/2 [==============================] - 0s 7ms/step
2/2 [==============================] - 0s 3ms/step
2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 16ms/step
2/2 [==============================] - 0s 5ms/step
2/2 [==============================] - 0s 18ms/step
2/2 [==============================] - 0s 5ms/step
2/2 [==============================] - 0s 6ms/step
2/2 [==============================] - 0s 18ms/step
2/2 [==============================] - 0s 19ms/step
2/2 [==============================] - 0s 17ms/step
2/2 [==============================] - 0s 17ms/step
2/2 [==============================] - 0s 6ms/step
2/2 [==============================] - 0s 15ms/step
2/2 [==============================] - 0s 4ms/step
2/2 [==============================] - 0s 19ms/step
2/2 [==============================] - 0s 17ms/step
2/2 [==============================] - 0s 13ms/step
2/2 [==============================] - 0s 15ms/step
2/2 [==============================] - 0s 17ms/step
2/2 [==============================] - 0s 5ms/step
2/2 [==============================] - 0s 4ms/step
2/2 [==============================] - 0s 5ms/step
2/2 [==============================] - 0s 4ms/step
2/2 [==============================] - 0s 14ms/step
2/2 [==============================] - 0s 7ms/step
2/2 [==============================] - 0s 7ms/step
2/2 [==============================] - 0s 5ms/step
2/2 [==============================] - 0s 2ms/step
2/2 [==============================] - 0s 8ms/step
2/2 [==============================] - 0s 10ms/step
1/1 [==============================] - 0s 130ms/step
```

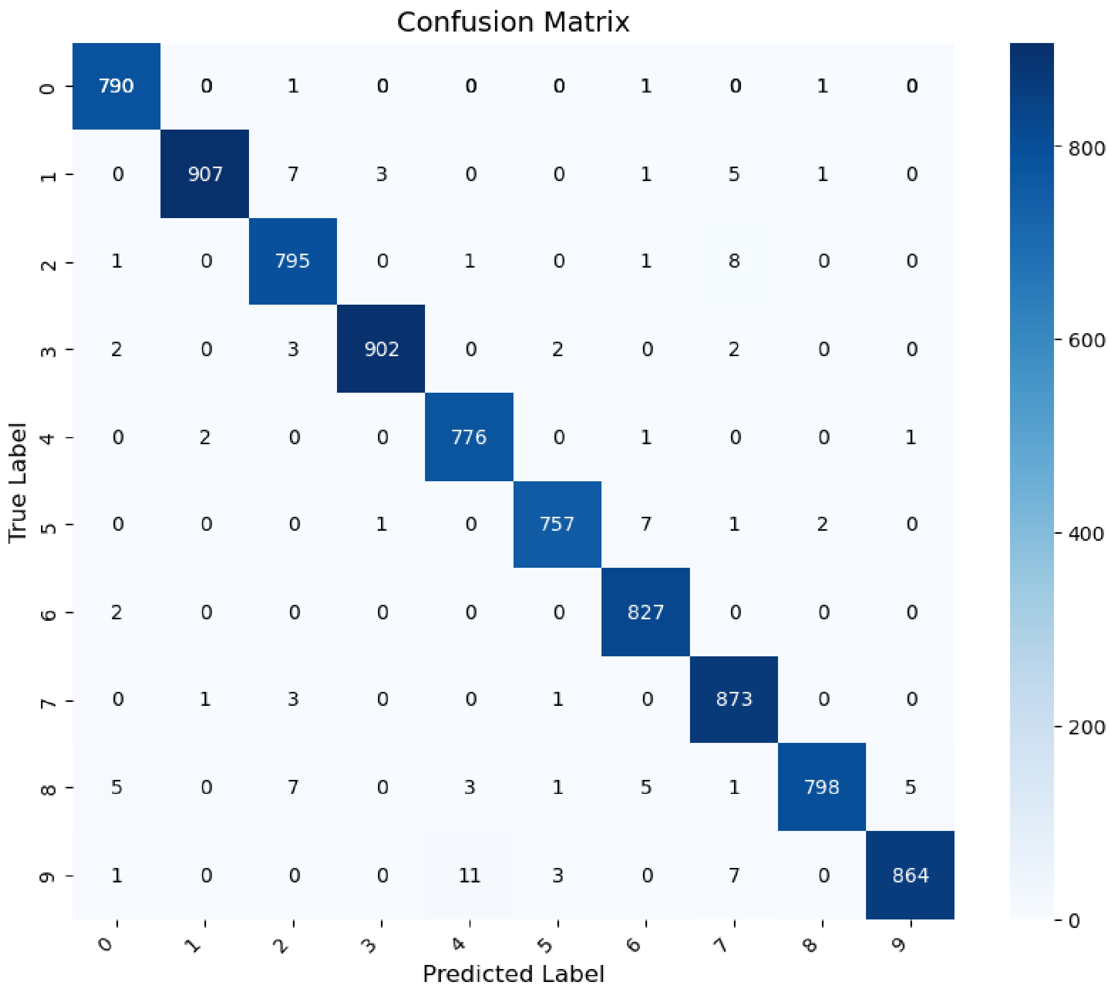
[33]:

```
cm = confusion_matrix(all_labels, all_predictions)
class_names_array = np.array(class_names)
```

[34]:

```
plt.figure(figsize=(10, 8))  # Increase figure size to make room for labels
ax = sns.heatmap(cm, annot=True, fmt='d', cmap='Blues',
                 xticklabels=class_names, yticklabels=class_names)

# Set tick labels appearance
plt.xticks(rotation=45, ha='right', fontsize=10)  # Adjust font size or␣
 ↪rotation as needed
plt.yticks(fontsize=10)

# Colorbar label and title
```

```
plt.title('Confusion Matrix', fontsize=14)  # Increase title font size
plt.ylabel('True Label', fontsize=12)
plt.xlabel('Predicted Label', fontsize=12)

# Loop over data dimensions and create text annotations with contrasting colors
thresh = cm.max() / 2.
for i in range(cm.shape[0]):
    for j in range(cm.shape[1]):
        ax.text(j+0.5, i+0.5, format(cm[i, j], 'd'),
                ha='center', va='center',
                color='white' if cm[i, j] > thresh else 'black')

plt.show()
```



Make Predictions

[35]:
```
probability_model = tf.keras.Sequential([model, tf.keras.layers.Softmax()])
```

[36]:
```
predictions = probability_model.predict(val_ds)
```

```
132/132 [==============================] - 1s 7ms/step
```

[37]:
```
predictions[0]
```

[37]:
```
array([0.08533755, 0.08533755, 0.08533755, 0.08534262, 0.08533755,
       0.2319567 , 0.08533785, 0.08533755, 0.08533763, 0.08533755],
      dtype=float32)
```

[38]:
```
class_names[np.argmax(predictions[0])]
```

[38]:
```
'5'
```

[39]:
```
image_batch, label_batch = next(iter(val_ds))
```

[40]:
```
label_batch
```

[40]:
```
<tf.Tensor: shape=(64,), dtype=int64, numpy=
array([9, 6, 9, 6, 3, 8, 0, 2, 4, 3, 9, 8, 0, 0, 4, 3, 1, 1, 2, 7, 2, 5,
       7, 9, 0, 3, 7, 7, 4, 5, 8, 5, 7, 6, 5, 6, 3, 3, 3, 9, 8, 5, 5, 9,
       3, 1, 1, 9, 7, 5, 9, 7, 5, 2, 4, 7, 4, 3, 2, 4, 7, 2, 8, 8],
      dtype=int64)>
```

[41]:
```
predictions = probability_model.predict(image_batch)
```

```
2/2 [==============================] - 0s 4ms/step
```

[42]:
```
np.argmax(predictions, axis=1)
```

[42]:
```
array([9, 6, 9, 6, 3, 8, 0, 2, 4, 3, 9, 8, 0, 0, 4, 3, 1, 1, 2, 7, 2, 5,
       7, 9, 0, 3, 7, 7, 4, 5, 8, 5, 7, 6, 5, 6, 3, 3, 3, 9, 8, 5, 5, 9,
       3, 1, 1, 9, 7, 5, 9, 7, 5, 2, 4, 7, 4, 3, 2, 4, 7, 2, 8, 4],
      dtype=int64)
```

[43]:
```
image_batch[0].shape
```

[43]:
```
TensorShape([28, 28, 3])
```

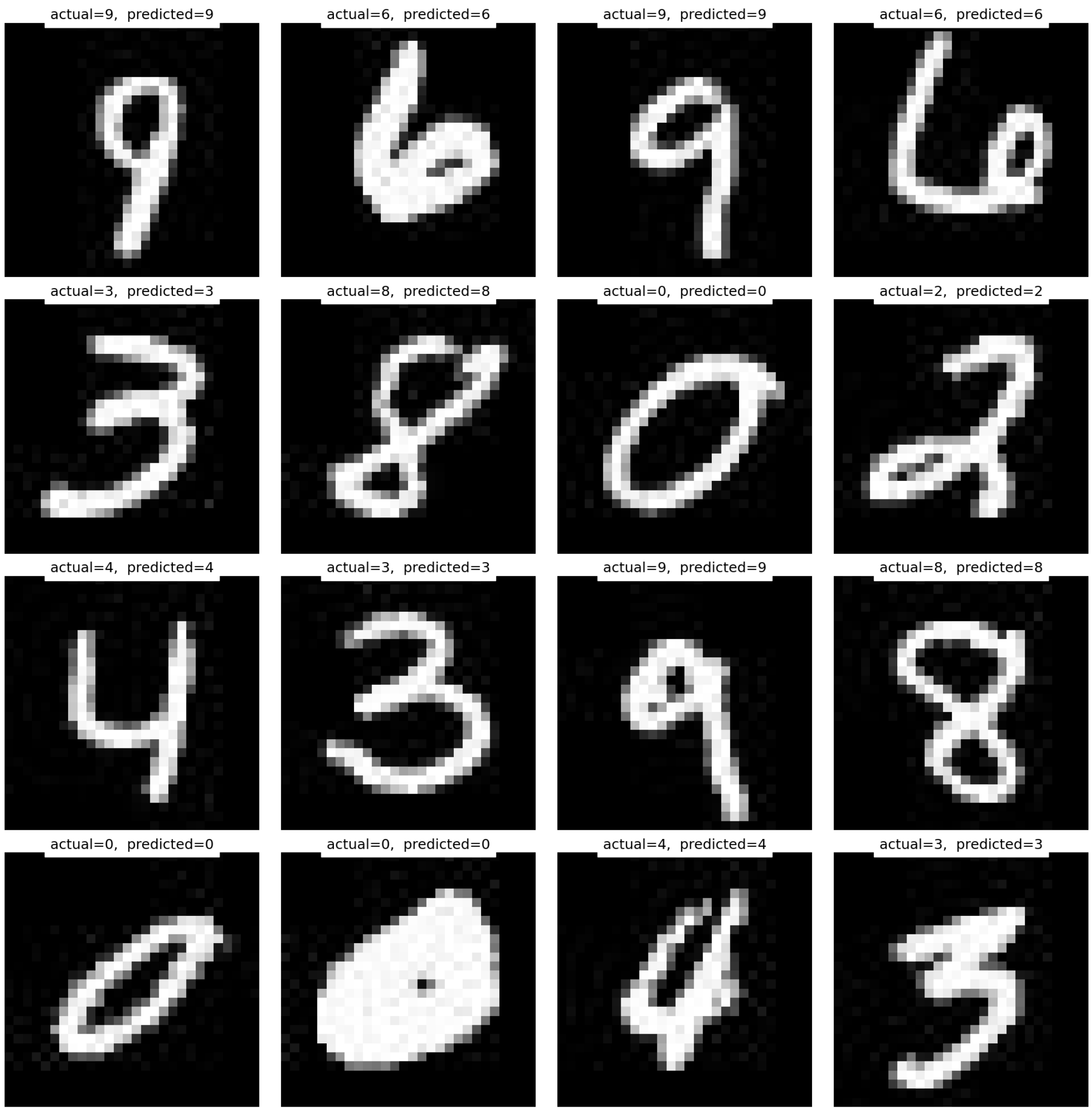
[44]:
```
predictions_prob = probability_model.predict(image_batch)
predictions = np.argmax(predictions_prob, axis=1)
```

```
2/2 [==============================] - 0s 15ms/step
```

0.13 5. Model Predictions

[45]:
```
plt.figure(figsize=(20, 20))
mpl.rcParams['axes.titlesize'] = 10
mpl.rcParams['axes.titlepad'] = 5
```

```python
for i in range(16):
    ax = plt.subplot(4, 4, i+1)
    plt.imshow(image_batch[i].numpy().astype("uint8"))
    true_label = class_names[label_batch[i]]
    predicted_label = class_names[predictions[i]]
    title_text = f'actual={true_label},  predicted={predicted_label}'
    plt.title(title_text, wrap=True, backgroundcolor='white', fontsize=18)
    plt.axis('off')

plt.tight_layout(pad=1.0)
plt.show()
```



0.14 3. 2. Tensorboard

[46]:
```
%load_ext tensorboard
%tensorboard --logdir {logdir}
```

```
<IPython.core.display.HTML object>
```

[ ]:
```
```