import libs

In [7]:

```
import os
import sys
import torch
import importlib
from tqdm.auto import tqdm

current_dir = os.getcwd()
project_root = os.path.dirname(current_dir)
sys.path.append(project_root)

# Import our custom modules
import src.utils as utils
import src.plots as plots
import src.neural_network_scratch as nn_scratch

importlib.reload(utils)
importlib.reload(plots)
importlib.reload(nn_scratch)

from src.utils import load_transform_split_mnist, per_class_accuracy
from src.plots import plot_train_val_curves, plot_confusion_matrix, plot_per_class_acc,plot_learning_curves_with_error_bars
from src.neural_network_scratch import NeuralNetworkScratch
```

Load Data loaders

In [2]:

```
# Using the same utility from Part A, but loading all classes
train_loader, val_loader, test_loader, _, _, _, _, _, _= load_transform_split_mnist(
    val_size=0.2,
    classes=None, # None means all 10 classes
    batch_size=64
)

print("Data loaders created successfully.")
```

```
Data loaders created successfully.
```

Initialize and Train Model

In [3]:

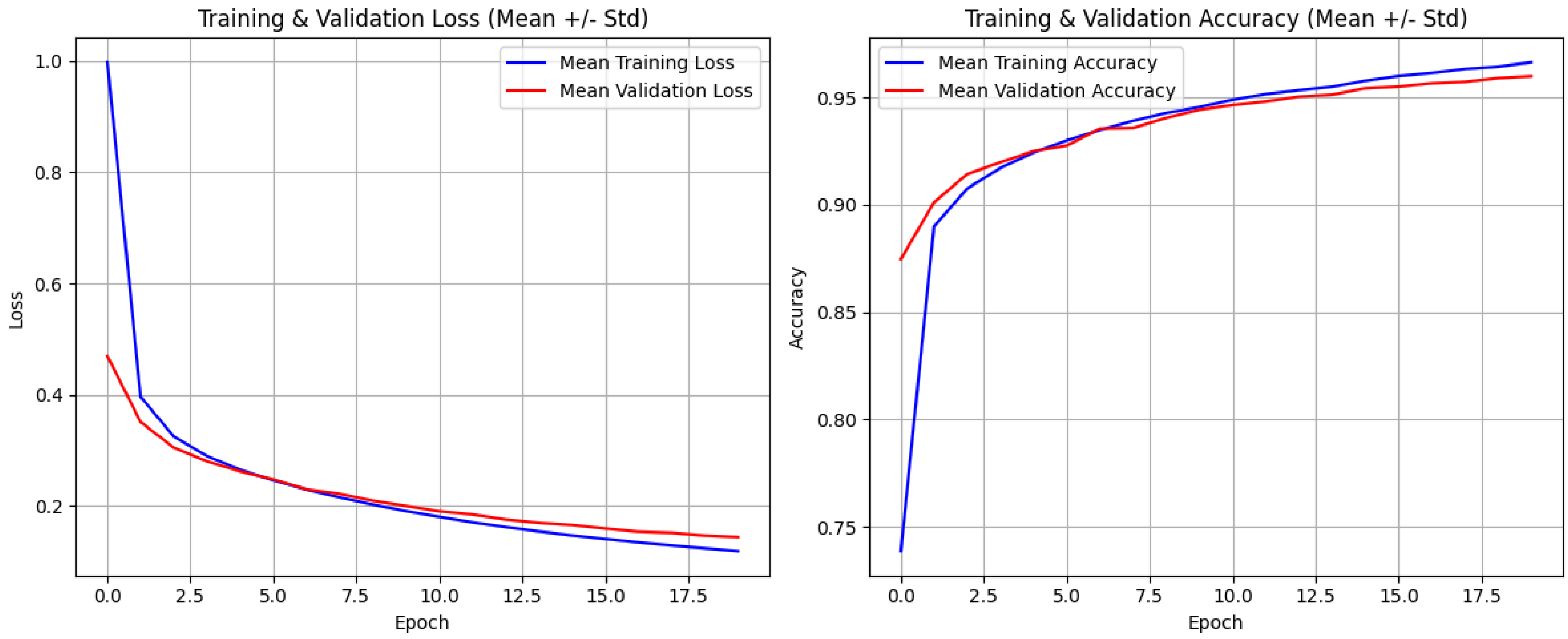
```
INPUT_DIM = 28 * 28   # for flattened 28x28 image
HIDDEN1 = 128
HIDDEN2 = 64
OUTPUT_DIM = 10

LEARNING_RATE = 0.01
EPOCHS = 20
N_RUNS = 5

all_histories = []
final_models = []

print(f"Starting {N_RUNS} training runs for error bar analysis...")
print("#" * 60)
i=0
for i in range(N_RUNS):
    print(f"--- Starting Run {i+1}/{N_RUNS} (Seed={i}) ---")
    model = NeuralNetworkScratch(INPUT_DIM, HIDDEN1, HIDDEN2, OUTPUT_DIM)
    history = model.fit(train_loader, val_loader, epochs=EPOCHS, lr=LEARNING_RATE)

    all_histories.append(history)
    final_models.append(model) # Save the model from this run
    print(f"Run {i+1} complete.")

print("#" * 60)
print("All training runs complete!")
```

```
Starting 5 training runs for error bar analysis...
############################################################
--- Starting Run 1/5 (Seed=0) ---
Epoch  1/20 | Train Loss: 0.9976, Train Acc: 73.87% | Val Loss: 0.4694,   Val Acc: 87.47%
Epoch  2/20 | Train Loss: 0.3965, Train Acc: 89.00% | Val Loss: 0.3512,   Val Acc: 90.12%
Epoch  3/20 | Train Loss: 0.3250, Train Acc: 90.76% | Val Loss: 0.3050,   Val Acc: 91.43%
Epoch  4/20 | Train Loss: 0.2899, Train Acc: 91.72% | Val Loss: 0.2806,   Val Acc: 91.98%
Epoch  5/20 | Train Loss: 0.2654, Train Acc: 92.44% | Val Loss: 0.2624,   Val Acc: 92.50%
Epoch  6/20 | Train Loss: 0.2463, Train Acc: 93.00% | Val Loss: 0.2479,   Val Acc: 92.76%
Epoch  7/20 | Train Loss: 0.2297, Train Acc: 93.49% | Val Loss: 0.2300,   Val Acc: 93.55%
Epoch  8/20 | Train Loss: 0.2155, Train Acc: 93.91% | Val Loss: 0.2220,   Val Acc: 93.58%
Epoch  9/20 | Train Loss: 0.2027, Train Acc: 94.28% | Val Loss: 0.2096,   Val Acc: 94.05%
Epoch 10/20 | Train Loss: 0.1909, Train Acc: 94.56% | Val Loss: 0.2002,   Val Acc: 94.43%
Epoch 11/20 | Train Loss: 0.1806, Train Acc: 94.90% | Val Loss: 0.1906,   Val Acc: 94.65%
Epoch 12/20 | Train Loss: 0.1708, Train Acc: 95.16% | Val Loss: 0.1848,   Val Acc: 94.82%
Epoch 13/20 | Train Loss: 0.1623, Train Acc: 95.34% | Val Loss: 0.1759,   Val Acc: 95.04%
Epoch 14/20 | Train Loss: 0.1545, Train Acc: 95.50% | Val Loss: 0.1700,   Val Acc: 95.13%
Epoch 15/20 | Train Loss: 0.1472, Train Acc: 95.79% | Val Loss: 0.1659,   Val Acc: 95.43%
Epoch 16/20 | Train Loss: 0.1409, Train Acc: 96.00% | Val Loss: 0.1597,   Val Acc: 95.51%
Epoch 17/20 | Train Loss: 0.1347, Train Acc: 96.14% | Val Loss: 0.1540,   Val Acc: 95.67%
Epoch 18/20 | Train Loss: 0.1292, Train Acc: 96.33% | Val Loss: 0.1519,   Val Acc: 95.73%
Epoch 19/20 | Train Loss: 0.1241, Train Acc: 96.44% | Val Loss: 0.1470,   Val Acc: 95.91%
Epoch 20/20 | Train Loss: 0.1191, Train Acc: 96.64% | Val Loss: 0.1443,   Val Acc: 95.99%
Run 1 complete.
--- Starting Run 2/5 (Seed=1) ---
Epoch  1/20 | Train Loss: 0.9976, Train Acc: 73.87% | Val Loss: 0.4694,   Val Acc: 87.47%
Epoch  2/20 | Train Loss: 0.3965, Train Acc: 89.00% | Val Loss: 0.3512,   Val Acc: 90.12%
Epoch  3/20 | Train Loss: 0.3250, Train Acc: 90.76% | Val Loss: 0.3050,   Val Acc: 91.43%
Epoch  4/20 | Train Loss: 0.2899, Train Acc: 91.72% | Val Loss: 0.2806,   Val Acc: 91.98%
Epoch  5/20 | Train Loss: 0.2654, Train Acc: 92.44% | Val Loss: 0.2624,   Val Acc: 92.50%
Epoch  6/20 | Train Loss: 0.2463, Train Acc: 93.00% | Val Loss: 0.2479,   Val Acc: 92.76%
Epoch  7/20 | Train Loss: 0.2297, Train Acc: 93.49% | Val Loss: 0.2300,   Val Acc: 93.55%
Epoch  8/20 | Train Loss: 0.2155, Train Acc: 93.91% | Val Loss: 0.2220,   Val Acc: 93.58%
Epoch  9/20 | Train Loss: 0.2027, Train Acc: 94.28% | Val Loss: 0.2096,   Val Acc: 94.05%
Epoch 10/20 | Train Loss: 0.1909, Train Acc: 94.56% | Val Loss: 0.2002,   Val Acc: 94.43%
Epoch 11/20 | Train Loss: 0.1806, Train Acc: 94.90% | Val Loss: 0.1906,   Val Acc: 94.65%
Epoch 12/20 | Train Loss: 0.1708, Train Acc: 95.16% | Val Loss: 0.1848,   Val Acc: 94.82%
Epoch 13/20 | Train Loss: 0.1623, Train Acc: 95.34% | Val Loss: 0.1759,   Val Acc: 95.04%
Epoch 14/20 | Train Loss: 0.1545, Train Acc: 95.50% | Val Loss: 0.1700,   Val Acc: 95.13%
Epoch 15/20 | Train Loss: 0.1472, Train Acc: 95.79% | Val Loss: 0.1659,   Val Acc: 95.43%
Epoch 16/20 | Train Loss: 0.1409, Train Acc: 96.00% | Val Loss: 0.1597,   Val Acc: 95.51%
Epoch 17/20 | Train Loss: 0.1347, Train Acc: 96.14% | Val Loss: 0.1540,   Val Acc: 95.67%
Epoch 18/20 | Train Loss: 0.1292, Train Acc: 96.33% | Val Loss: 0.1519,   Val Acc: 95.73%
Epoch 19/20 | Train Loss: 0.1241, Train Acc: 96.44% | Val Loss: 0.1470,   Val Acc: 95.91%
Epoch 20/20 | Train Loss: 0.1191, Train Acc: 96.64% | Val Loss: 0.1443,   Val Acc: 95.99%
Run 2 complete.
--- Starting Run 3/5 (Seed=2) ---
Epoch  1/20 | Train Loss: 0.9976, Train Acc: 73.87% | Val Loss: 0.4694,   Val Acc: 87.47%
Epoch  2/20 | Train Loss: 0.3965, Train Acc: 89.00% | Val Loss: 0.3512,   Val Acc: 90.12%
Epoch  3/20 | Train Loss: 0.3250, Train Acc: 90.76% | Val Loss: 0.3050,   Val Acc: 91.43%
Epoch  4/20 | Train Loss: 0.2899, Train Acc: 91.72% | Val Loss: 0.2806,   Val Acc: 91.98%
Epoch  5/20 | Train Loss: 0.2654, Train Acc: 92.44% | Val Loss: 0.2624,   Val Acc: 92.50%
Epoch  6/20 | Train Loss: 0.2463, Train Acc: 93.00% | Val Loss: 0.2479,   Val Acc: 92.76%
Epoch  7/20 | Train Loss: 0.2297, Train Acc: 93.49% | Val Loss: 0.2300,   Val Acc: 93.55%
Epoch  8/20 | Train Loss: 0.2155, Train Acc: 93.91% | Val Loss: 0.2220,   Val Acc: 93.58%
Epoch  9/20 | Train Loss: 0.2027, Train Acc: 94.28% | Val Loss: 0.2096,   Val Acc: 94.05%
Epoch 10/20 | Train Loss: 0.1909, Train Acc: 94.56% | Val Loss: 0.2002,   Val Acc: 94.43%
Epoch 11/20 | Train Loss: 0.1806, Train Acc: 94.90% | Val Loss: 0.1906,   Val Acc: 94.65%
Epoch 12/20 | Train Loss: 0.1708, Train Acc: 95.16% | Val Loss: 0.1848,   Val Acc: 94.82%
Epoch 13/20 | Train Loss: 0.1623, Train Acc: 95.34% | Val Loss: 0.1759,   Val Acc: 95.04%
Epoch 14/20 | Train Loss: 0.1545, Train Acc: 95.50% | Val Loss: 0.1700,   Val Acc: 95.13%
Epoch 15/20 | Train Loss: 0.1472, Train Acc: 95.79% | Val Loss: 0.1659,   Val Acc: 95.43%
Epoch 16/20 | Train Loss: 0.1409, Train Acc: 96.00% | Val Loss: 0.1597,   Val Acc: 95.51%
Epoch 17/20 | Train Loss: 0.1347, Train Acc: 96.14% | Val Loss: 0.1540,   Val Acc: 95.67%
Epoch 18/20 | Train Loss: 0.1292, Train Acc: 96.33% | Val Loss: 0.1519,   Val Acc: 95.73%
Epoch 19/20 | Train Loss: 0.1241, Train Acc: 96.44% | Val Loss: 0.1470,   Val Acc: 95.91%
Epoch 20/20 | Train Loss: 0.1191, Train Acc: 96.64% | Val Loss: 0.1443,   Val Acc: 95.99%
Run 3 complete.
--- Starting Run 4/5 (Seed=3) ---
Epoch  1/20 | Train Loss: 0.9976, Train Acc: 73.87% | Val Loss: 0.4694,   Val Acc: 87.47%
Epoch  2/20 | Train Loss: 0.3965, Train Acc: 89.00% | Val Loss: 0.3512,   Val Acc: 90.12%
Epoch  3/20 | Train Loss: 0.3250, Train Acc: 90.76% | Val Loss: 0.3050,   Val Acc: 91.43%
Epoch  4/20 | Train Loss: 0.2899, Train Acc: 91.72% | Val Loss: 0.2806,   Val Acc: 91.98%
Epoch  5/20 | Train Loss: 0.2654, Train Acc: 92.44% | Val Loss: 0.2624,   Val Acc: 92.50%
Epoch  6/20 | Train Loss: 0.2463, Train Acc: 93.00% | Val Loss: 0.2479,   Val Acc: 92.76%
Epoch  7/20 | Train Loss: 0.2297, Train Acc: 93.49% | Val Loss: 0.2300,   Val Acc: 93.55%
Epoch  8/20 | Train Loss: 0.2155, Train Acc: 93.91% | Val Loss: 0.2220,   Val Acc: 93.58%
Epoch  9/20 | Train Loss: 0.2027, Train Acc: 94.28% | Val Loss: 0.2096,   Val Acc: 94.05%
Epoch 10/20 | Train Loss: 0.1909, Train Acc: 94.56% | Val Loss: 0.2002,   Val Acc: 94.43%
Epoch 11/20 | Train Loss: 0.1806, Train Acc: 94.90% | Val Loss: 0.1906,   Val Acc: 94.65%
Epoch 12/20 | Train Loss: 0.1708, Train Acc: 95.16% | Val Loss: 0.1848,   Val Acc: 94.82%
Epoch 13/20 | Train Loss: 0.1623, Train Acc: 95.34% | Val Loss: 0.1759,   Val Acc: 95.04%
Epoch 14/20 | Train Loss: 0.1545, Train Acc: 95.50% | Val Loss: 0.1700,   Val Acc: 95.13%
Epoch 15/20 | Train Loss: 0.1472, Train Acc: 95.79% | Val Loss: 0.1659,   Val Acc: 95.43%
Epoch 16/20 | Train Loss: 0.1409, Train Acc: 96.00% | Val Loss: 0.1597,   Val Acc: 95.51%
Epoch 17/20 | Train Loss: 0.1347, Train Acc: 96.14% | Val Loss: 0.1540,   Val Acc: 95.67%
Epoch 18/20 | Train Loss: 0.1292, Train Acc: 96.33% | Val Loss: 0.1519,   Val Acc: 95.73%
Epoch 19/20 | Train Loss: 0.1241, Train Acc: 96.44% | Val Loss: 0.1470,   Val Acc: 95.91%
Epoch 20/20 | Train Loss: 0.1191, Train Acc: 96.64% | Val Loss: 0.1443,   Val Acc: 95.99%
Run 4 complete.
--- Starting Run 5/5 (Seed=4) ---
Epoch  1/20 | Train Loss: 0.9976, Train Acc: 73.87% | Val Loss: 0.4694,   Val Acc: 87.47%
Epoch  2/20 | Train Loss: 0.3965, Train Acc: 89.00% | Val Loss: 0.3512,   Val Acc: 90.12%
Epoch  3/20 | Train Loss: 0.3250, Train Acc: 90.76% | Val Loss: 0.3050,   Val Acc: 91.43%
Epoch  4/20 | Train Loss: 0.2899, Train Acc: 91.72% | Val Loss: 0.2806,   Val Acc: 91.98%
Epoch  5/20 | Train Loss: 0.2654, Train Acc: 92.44% | Val Loss: 0.2624,   Val Acc: 92.50%
Epoch  6/20 | Train Loss: 0.2463, Train Acc: 93.00% | Val Loss: 0.2479,   Val Acc: 92.76%
Epoch  7/20 | Train Loss: 0.2297, Train Acc: 93.49% | Val Loss: 0.2300,   Val Acc: 93.55%
Epoch  8/20 | Train Loss: 0.2155, Train Acc: 93.91% | Val Loss: 0.2220,   Val Acc: 93.58%
Epoch  9/20 | Train Loss: 0.2027, Train Acc: 94.28% | Val Loss: 0.2096,   Val Acc: 94.05%
Epoch 10/20 | Train Loss: 0.1909, Train Acc: 94.56% | Val Loss: 0.2002,   Val Acc: 94.43%
Epoch 11/20 | Train Loss: 0.1806, Train Acc: 94.90% | Val Loss: 0.1906,   Val Acc: 94.65%
Epoch 12/20 | Train Loss: 0.1708, Train Acc: 95.16% | Val Loss: 0.1848,   Val Acc: 94.82%
Epoch 13/20 | Train Loss: 0.1623, Train Acc: 95.34% | Val Loss: 0.1759,   Val Acc: 95.04%
Epoch 14/20 | Train Loss: 0.1545, Train Acc: 95.50% | Val Loss: 0.1700,   Val Acc: 95.13%
Epoch 15/20 | Train Loss: 0.1472, Train Acc: 95.79% | Val Loss: 0.1659,   Val Acc: 95.43%
Epoch 16/20 | Train Loss: 0.1409, Train Acc: 96.00% | Val Loss: 0.1597,   Val Acc: 95.51%
Epoch 17/20 | Train Loss: 0.1347, Train Acc: 96.14% | Val Loss: 0.1540,   Val Acc: 95.67%
Epoch 18/20 | Train Loss: 0.1292, Train Acc: 96.33% | Val Loss: 0.1519,   Val Acc: 95.73%
Epoch 19/20 | Train Loss: 0.1241, Train Acc: 96.44% | Val Loss: 0.1470,   Val Acc: 95.91%
Epoch 20/20 | Train Loss: 0.1191, Train Acc: 96.64% | Val Loss: 0.1443,   Val Acc: 95.99%
Run 5 complete.
############################################################
All training runs complete!
```

Performance Visualization

In [4]:

```python
# Plot Training and validation loss/accuracy over epochs
plot_learning_curves_with_error_bars(all_histories)
```

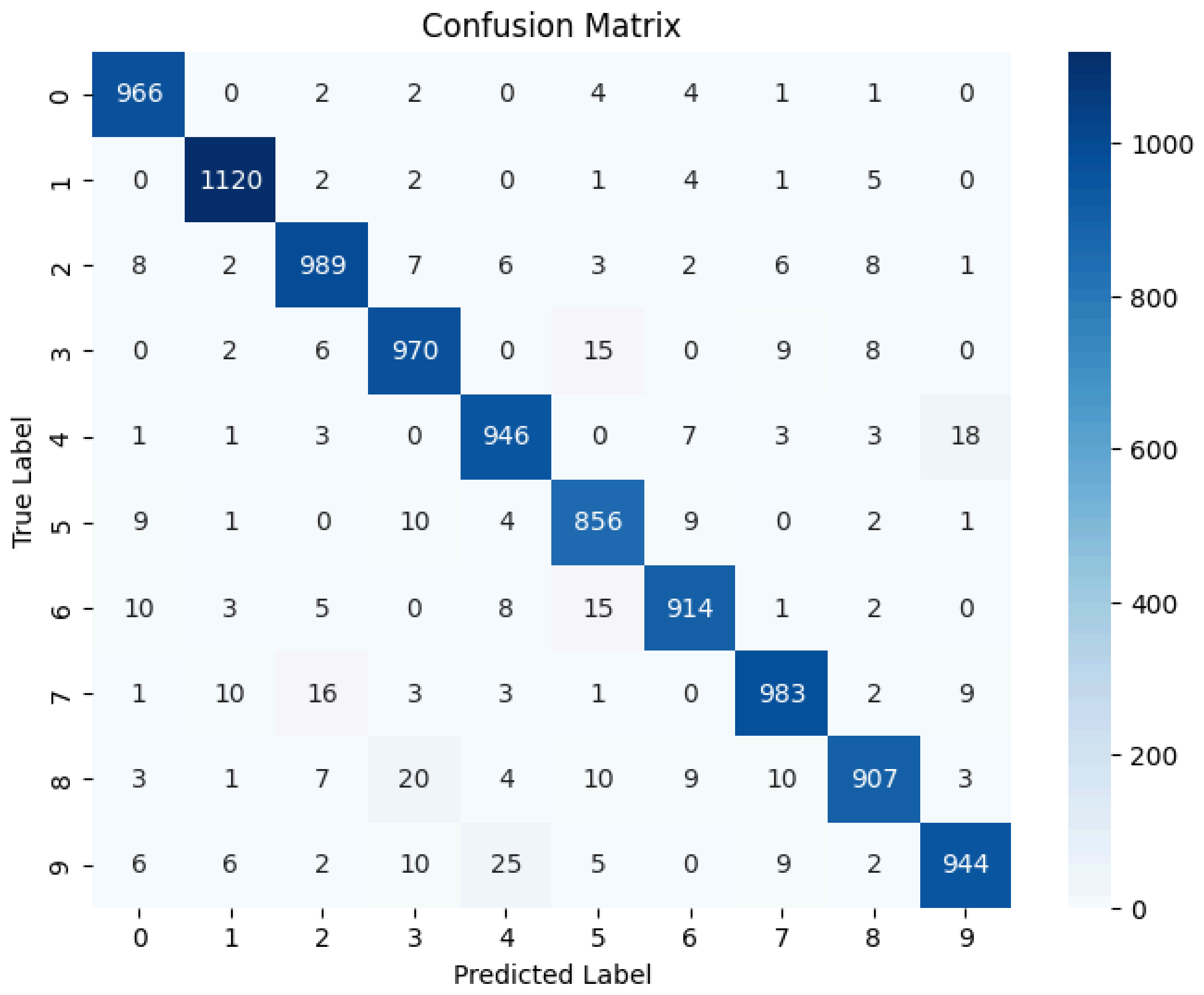


Final Test Set Evaluation

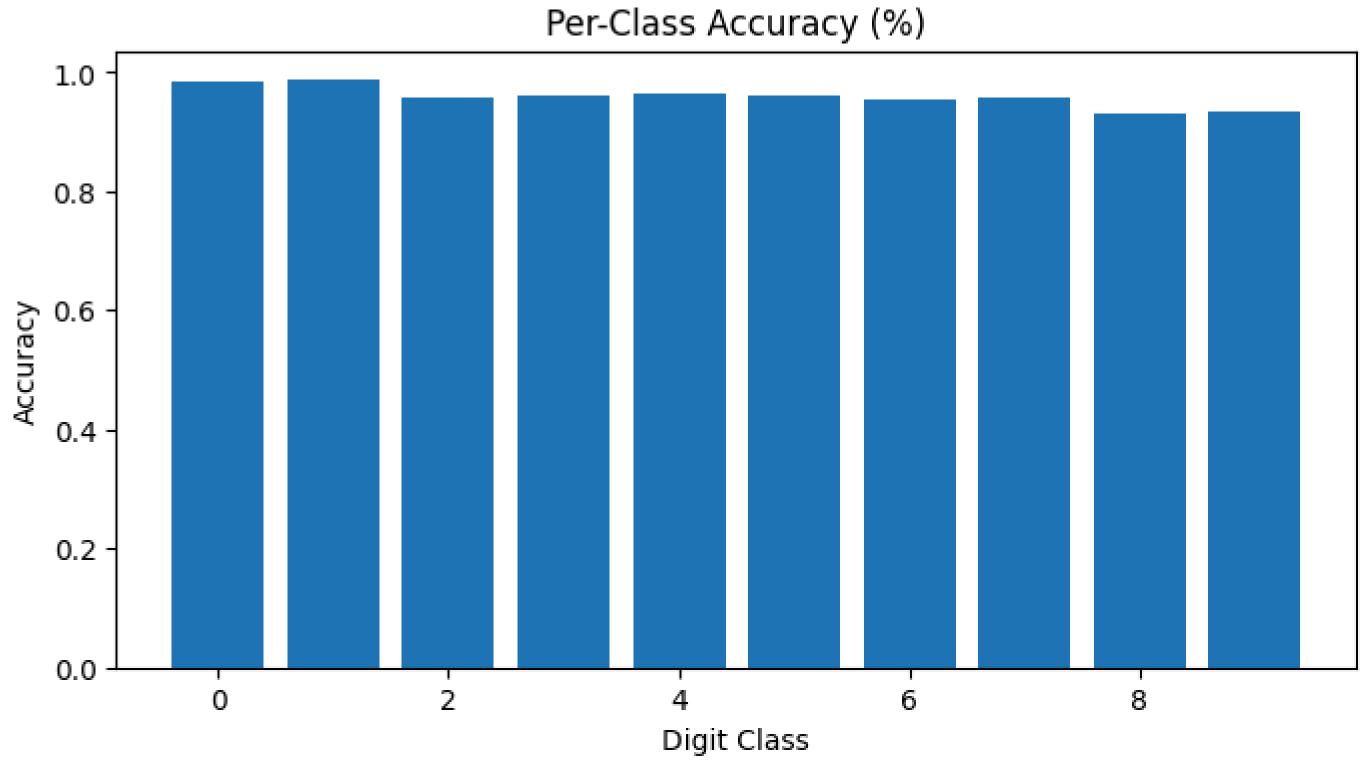
In [6]:

```python
import numpy as np
# Get predictions for the entire test set
y_test = []
y_pred_test = []

model.eval() # Set model to evaluation mode
with torch.no_grad():
    for X, y in test_loader:
        preds = model.predict(X)
        y_test.extend(y.numpy())
        y_pred_test.extend(preds.numpy())

# Plot Confusion Matrix
print("Generating Confusion Matrix for Test Set...")
cm = plot_confusion_matrix(y_test, y_pred_test)

# Per-class accuracy analysis
print("\nGenerating Per-Class Accuracy for Test Set...")
df_acc = per_class_accuracy(cm)
plot_per_class_acc(df_acc)
```

```
Generating Confusion Matrix for Test Set...
```



```
Generating Per-Class Accuracy for Test Set...
   Class  Accuracy
0      0  0.985714
1      1  0.986784
2      2  0.958333
3      3  0.960396
4      4  0.963340
5      5  0.959641
6      6  0.954071
7      7  0.956226
8      8  0.931211
9      9  0.935580
```


Per-Class Accuracy (%)
Accuracy
Digit Class