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MNIST Dataset

The MNIST database of handwritten digits (http://yann.lecun.com)

Data Card Code (225) Discussion (0) Suggestions (0)

About Dataset

Context

MNIST is a subset of a larger set available from NIST (it's copied from http://yann.lecun.com/exdb/mnist/)

Content

The MNIST database of handwritten digits has a training set of 60,000 examples, and a test set of 10,000 examples. .

Four files are available:

- train-images-idx3-ubyte.gz: training set images (9912422 bytes)
- train-labels-idx1-ubyte.gz: training set labels (28881 bytes)
- t10k-images-idx3-ubyte.gz: test set images (1648877 bytes)
- t10k-labels-idx1-ubyte.gz: test set labels (4542 bytes)

How to read

See sample MNIST reader

Usability ⓘ

7.50

License

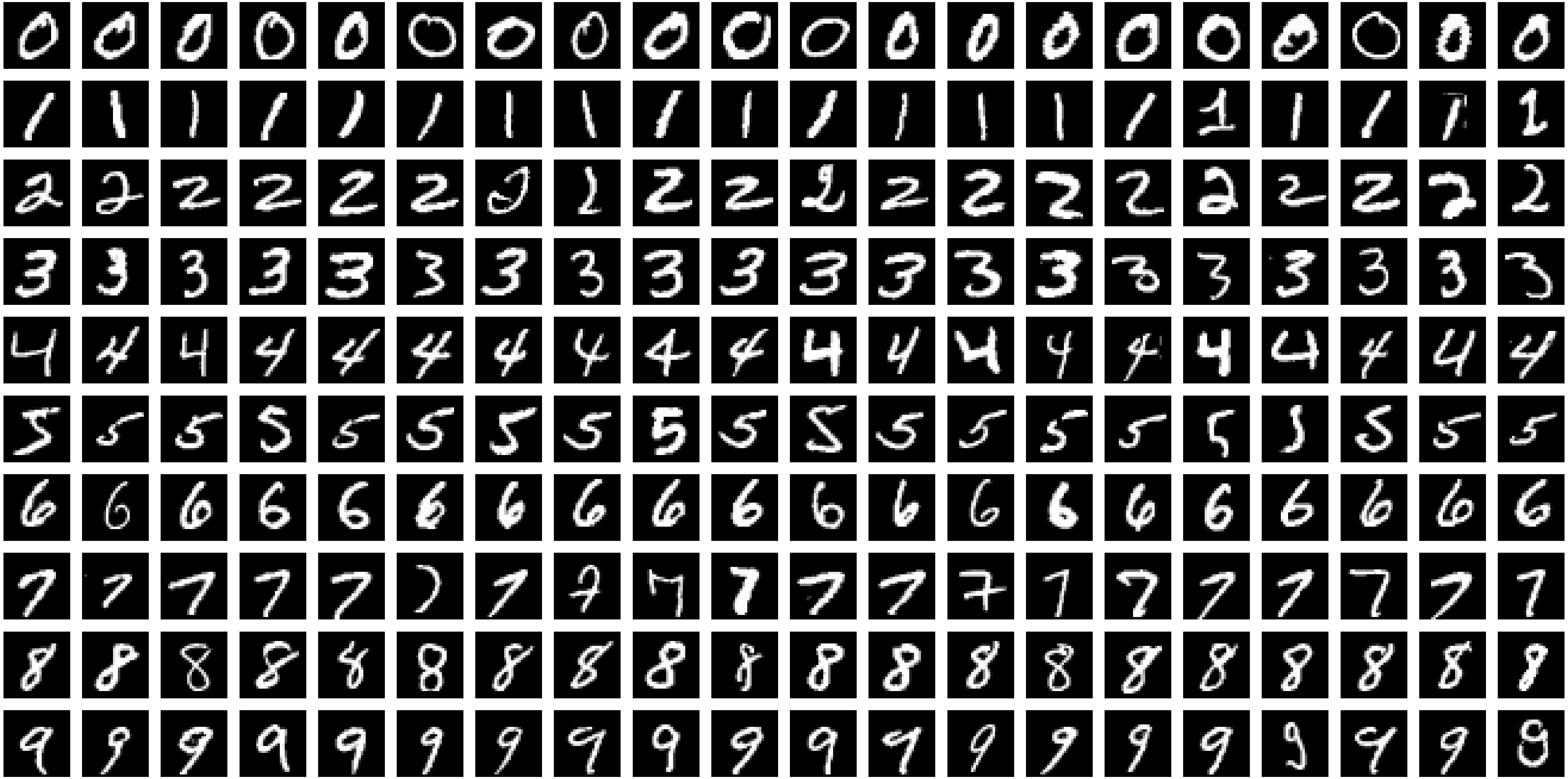
Data files © Original Authors

Expected update frequency

Not specified

Tags

Computer Science Image Multiclass Classification



Trianing Data

- 60,000 images of handwritten digits from 250 individuals. Among these, 50% are high school students and the other 50% are employees from the Census Bureau.
- All images are composed of 224×224 pixels. Each image also has a corresponding label indicating the digit represented in the image.

Testing Data

- The test data contains 10,000 images of handwritten digits, also sourced from U.S. high school students and Census Bureau employees.
- These images come from a different set of 250 individuals than those whose handwriting was included in the training data.

Why MNIST Dataset?

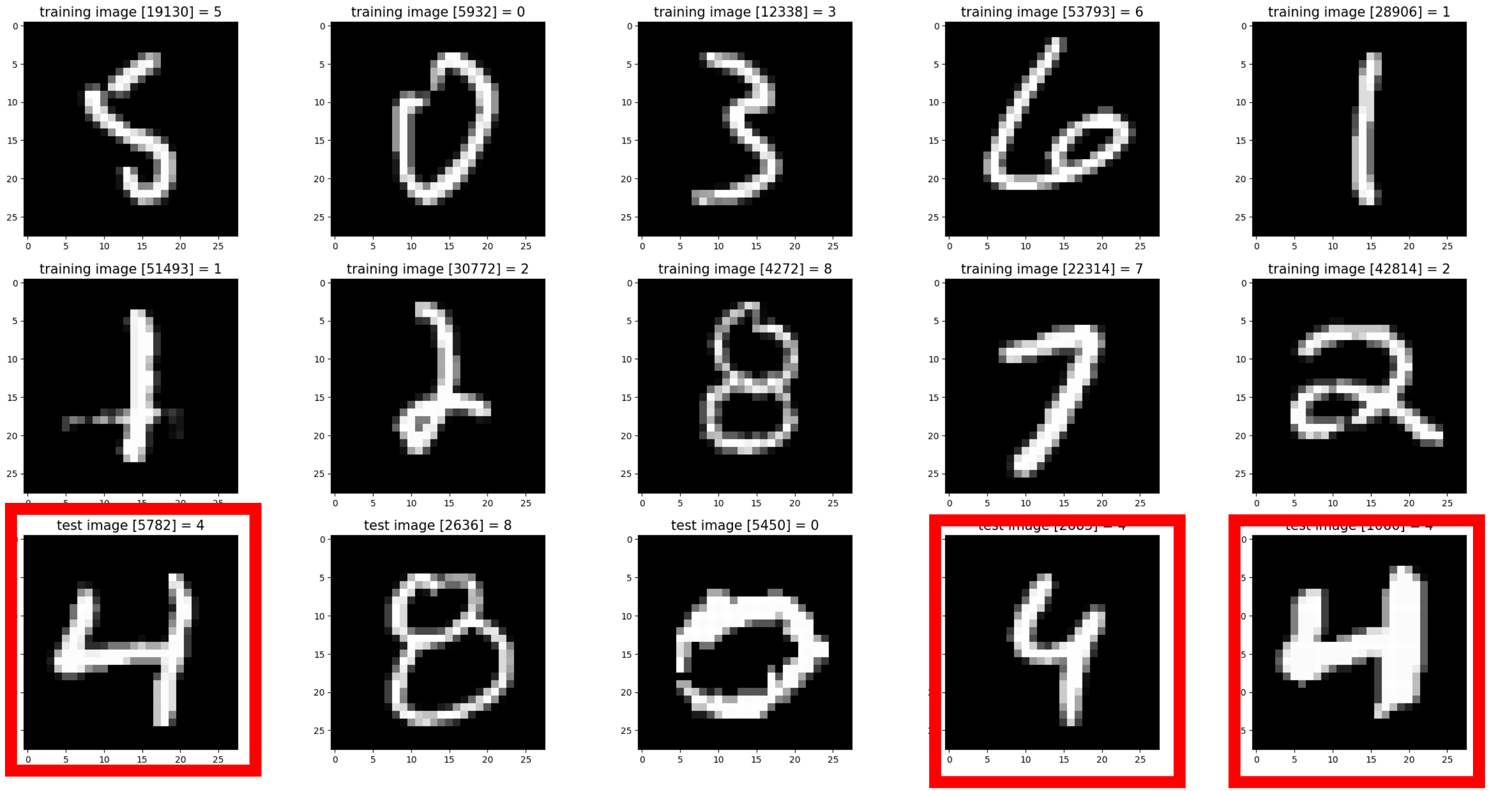
- **Data Availability**: The MNIST dataset, which stands for the Modified National Institute of Standards and Technology dataset, is widely used for training and testing in the field of machine learning. It is a large database of handwritten digits that is publicly available and thus easy to access.
- **Well-defined Problem**: Since the dataset and problem (digit recognition) are well-defined, you can focus more on the modeling aspects rather than spending a lot of time in the data gathering and cleaning stages.

Identify an Unsupervised Learning Problem

- The MNIST dataset is a well-known problem. It is labeled. Most of the top-performing model are supervised methods.
- Why unsupervised learning?
  - Room for improvement: top supervised methods like CNN achieved over 99% accuracy. There is little room for improvement.
  - Less data required: Unsupervised methods is less sensitive to lack of training data.
  - Faster run time: Compared to CNN, unsupervised method has shorter run time.

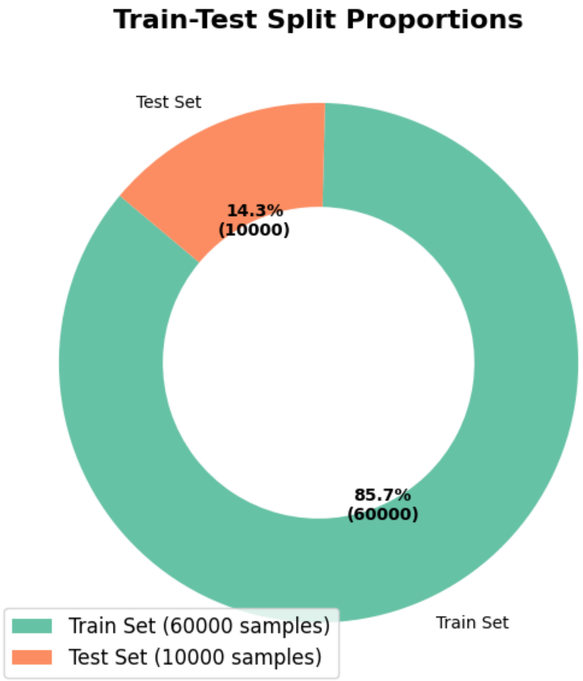
EDA

- We take a look into the input data
- Most of the handwritings are easy to identify by human eyes
- But I do see a variety of writing styles


training image [19130] = 5
training image [5932] = 0
training image [12338] = 3
training image [53793] = 6
training image [28906] = 1
training image [51493] = 1
training image [30772] = 2
training image [4272] = 8
training image [22314] = 7
training image [42814] = 2
test image [5782] = 4
test image [2636] = 8
test image [5450] = 0
test image [2063] = 4
test image [1060] = 4
0
5
10
15
20
25

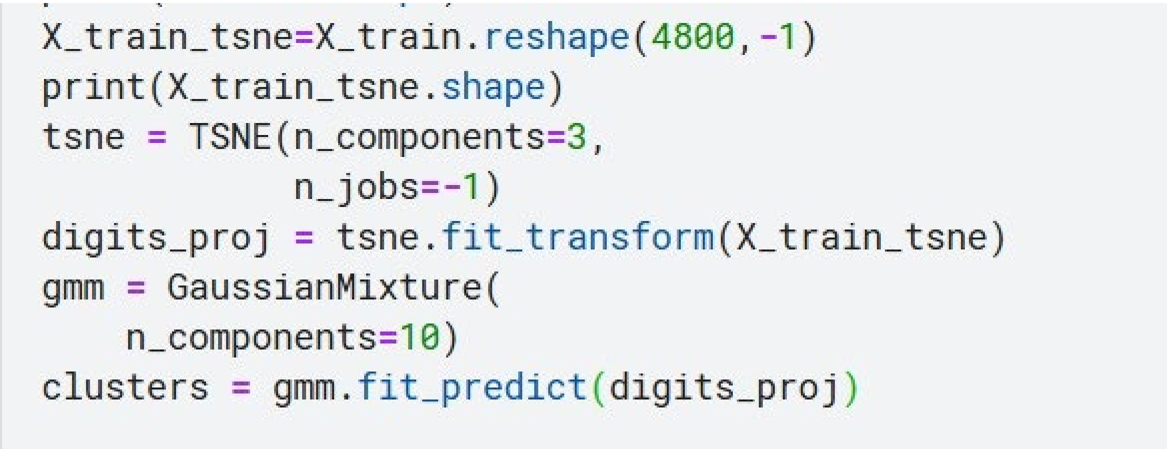
EDA

- Each input picture is 224x224x3
- Dataset is well balanced among all 10 digits
- Pre-defined test/train split
- I believe no transform is required, as 2D pictures are ideal target of CNN



Analysis: Unsupervised model

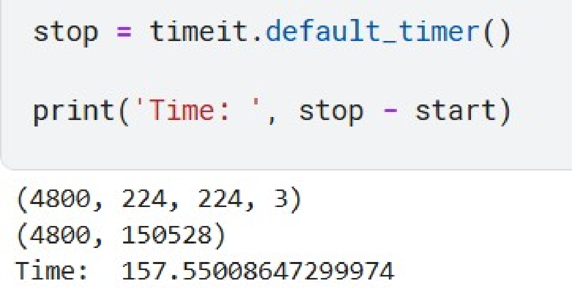
- We use first TSNE to perform dimension reduction
- Followed by GMM clustering
- Ended with label permutation to match with ground truth



```
X_train_tsne=X_train.reshape(4800,-1)
print(X_train_tsne.shape)
tsne = TSNE(n_components=3,
            n_jobs=-1)
digits_proj = tsne.fit_transform(X_train_tsne)
gmm = GaussianMixture(
    n_components=10)
clusters = gmm.fit_predict(digits_proj)
```

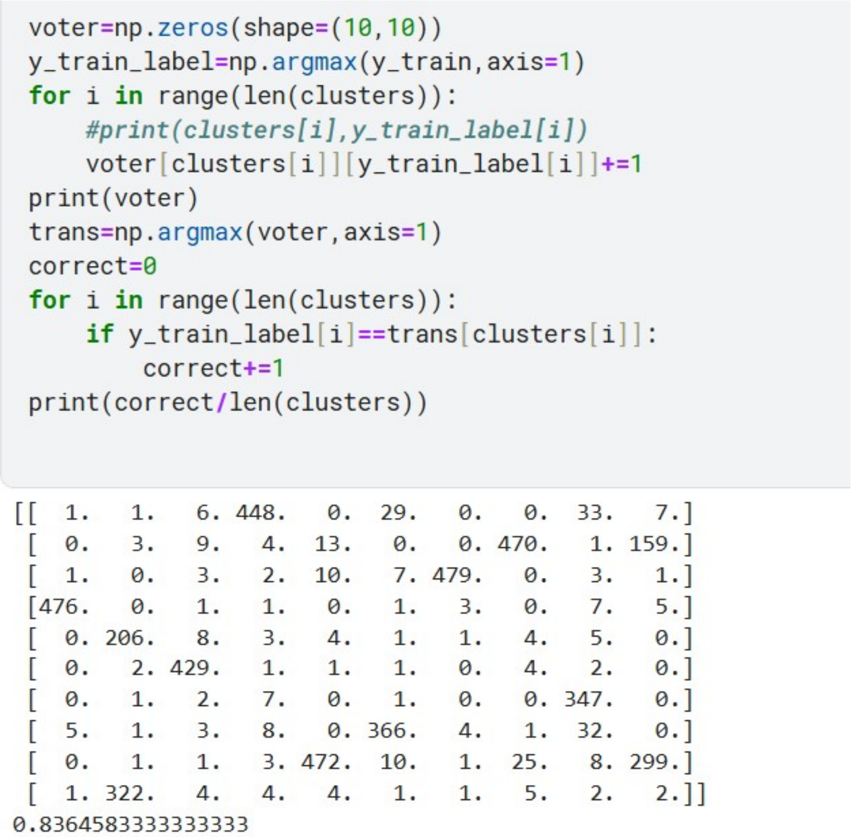
Analysis: Unsupervised model Performance

- The accuracy is 83.6%
  - Not bad
- Run time ~ 2 min
- Increasing TSNE component does not improve accuracy



```
stop = timeit.default_timer()

print('Time: ', stop - start)
```

```
(4800, 224, 224, 3)
(4800, 150528)
Time:  157.55008647299974
```

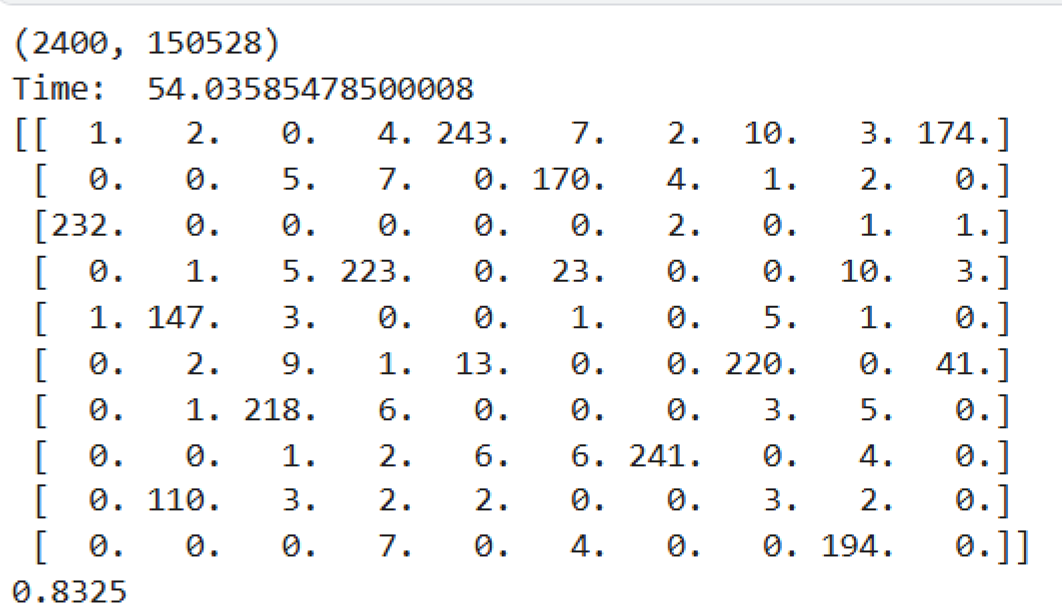


```
voter=np.zeros(shape=(10,10))
y_train_label=np.argmax(y_train,axis=1)
for i in range(len(clusters)):
    #print(clusters[i],y_train_label[i])
    voter[clusters[i]][y_train_label[i]]+=1
print(voter)
trans=np.argmax(voter,axis=1)
correct=0
for i in range(len(clusters)):
    if y_train_label[i]==trans[clusters[i]]:
        correct+=1
print(correct/len(clusters))
```

```
[[  1.   1.   6. 448.   0.  29.   0.   0.  33.   7.]
 [  0.   3.   9.   4.  13.   0.   0. 470.   1. 159.]
 [  1.   0.   3.   2.  10.   7. 479.   0.   3.   1.]
 [476.   0.   1.   1.   0.   1.   3.   0.   7.   5.]
 [  0. 206.   8.   3.   4.   1.   1.   4.   5.   0.]
 [  0.   2. 429.   1.   1.   1.   0.   4.   2.   0.]
 [  0.   1.   2.   7.   0.   1.   0.   0. 347.   0.]
 [  5.   1.   3.   8.   0. 366.   4.   1.  32.   0.]
 [  0.   1.   1.   3. 472.  10.   1.  25.   8. 299.]
 [  1. 322.   4.   4.   4.   1.   1.   5.   2.   2.]]
0.8364583333333333
```

Analysis: Unsupervised model Performance on less data point

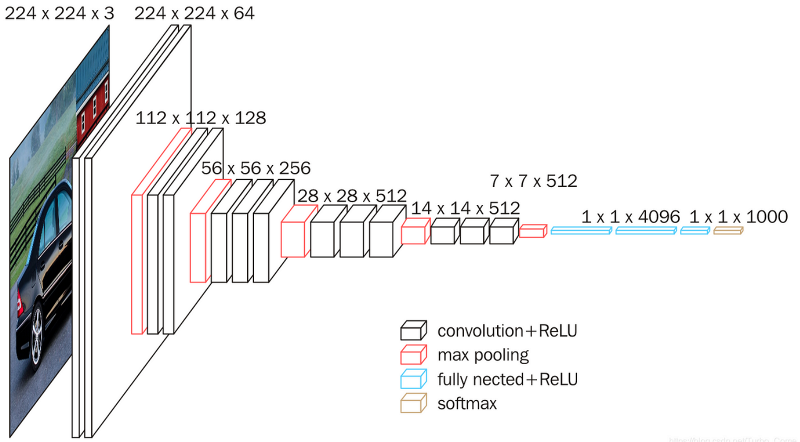
- Unsupervised methods is less sensitive to insufficient training data
- We experiment using only half of the training set for training
- Accuracy drops from 83.6% to 83.2%
- While run time drops from 2 min to less than 1 min



```
(2400, 150528)
Time:  54.03585478500008
[[  1.   2.   0.   4. 243.   7.   2.  10.   3. 174.]
 [  0.   0.   5.   7.   0. 170.   4.   1.   2.   0.]
 [232.   0.   0.   0.   0.   0.   2.   0.   1.   1.]
 [  0.   1.   5. 223.   0.  23.   0.   0.  10.   3.]
 [  1. 147.   3.   0.   0.   1.   0.   5.   1.   0.]
 [  0.   2.   9.   1.  13.   0.   0. 220.   0.  41.]
 [  0.   1. 218.   6.   0.   0.   0.   3.   5.   0.]
 [  0.   0.   1.   2.   6.   6. 241.   0.   4.   0.]
 [  0. 110.   3.   2.   2.   0.   0.   3.   2.   0.]
 [  0.   0.   0.   7.   0.   4.   0.   0. 194.   0.]]
0.8325
```

Analysis: Deep-Learning model

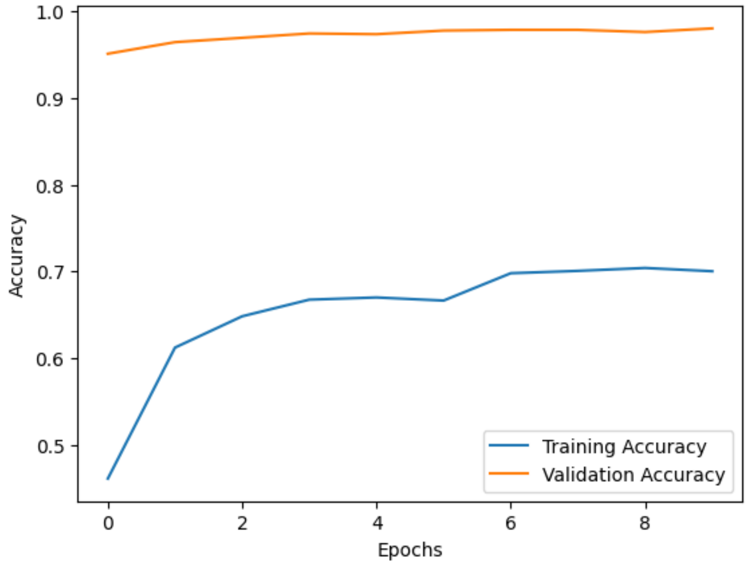
- Since CNN is the king for 2D images, I decided to compare it with our unsupervised method
- Since 224x224 is the input size of the famous VGG16, we use the pre-trained model provided in keras to solve the problem.
- Below is the architecture of VGG16. The schematic consists of CNN feature extractor and the following fully-connected classifier.



https://blog.csdn.net/Turbo_Come

Analysis: Deep-Learning model Performance

- Achieved 99.5% accuracy
- Accuracy is almost 90% at the beginning of training, thanks to the pretrained weight.
- Run time is ~15min



Conclusion

- Unsupervised methods can produce good results even with insufficient training data
- CNN is more powerful than TSNE + GMM regarding 2D image classification.
- CNN is more time-consuming than TSNE + GMM

```
import numpy as np
import pandas as pd

import os
for dirname, _, filenames in os.walk('/kaggle/input'):
    for filename in filenames:
        print(os.path.join(dirname, filename))
```

```
/kaggle/input/mnist-dataset/train-images.idx3-ubyte
/kaggle/input/mnist-dataset/t10k-labels.idx1-ubyte
/kaggle/input/mnist-dataset/t10k-images.idx3-ubyte
/kaggle/input/mnist-dataset/train-labels.idx1-ubyte
/kaggle/input/mnist-dataset/t10k-labels-idx1-ubyte/t10k-labels-idx1-
ubyte
/kaggle/input/mnist-dataset/t10k-images-idx3-ubyte/t10k-images-idx3-
ubyte
/kaggle/input/mnist-dataset/train-labels-idx1-ubyte/train-labels-idx1-
ubyte
/kaggle/input/mnist-dataset/train-images-idx3-ubyte/train-images-idx3-
ubyte
```

Libraries to be used

```
import tensorflow as tf
from keras.datasets import mnist
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Conv2D, MaxPooling2D, Flatten,
Dense, Dropout
from tensorflow.keras.utils import to_categorical
import matplotlib.pyplot as plt

from sklearn.model_selection import train_test_split
```

Load Data

```
(train_images, train_labels), (test_images, test_labels) =
mnist.load_data()
train_images, test_images = train_images / 255.0, test_images / 255.0
# normalising the dimensions of images to increase the performance of
cnn

# Load the MNIST dataset
(train_images, train_labels), (test_images, test_labels) =
mnist.load_data()

# Normalize the images
train_images, test_images = train_images / 255.0, test_images / 255.0
```

```
# Use only 60% of the dataset
train_images, train_labels = train_images[:int(0.1 *
len(train_images))], train_labels[:int(0.1 * len(train_labels))]

# Convert images to 3-channel (RGB) and resize to 224x224 for VGG16
def preprocess_images(images):
    images = tf.expand_dims(images, axis=-1)  # Add channel dimension
    images = tf.image.grayscale_to_rgb(images)  # Convert to RGB
    images = tf.image.resize(images, [224, 224])  # Resize to 224x224
    return images.numpy()

train_images = preprocess_images(train_images)
test_images = preprocess_images(test_images)

# Convert labels to one-hot encoding
train_labels = to_categorical(train_labels, num_classes=10)
test_labels = to_categorical(test_labels, num_classes=10)

# Split train data into train and validation sets (80-20 split of 60%
dataset)
X_train, X_val, y_train, y_val = train_test_split(train_images,
train_labels, test_size=0.2, random_state=42)

random_index = np.random.randint(0,len(train_images))
random_image = train_images[random_index]
random_label = train_labels[random_index]
```

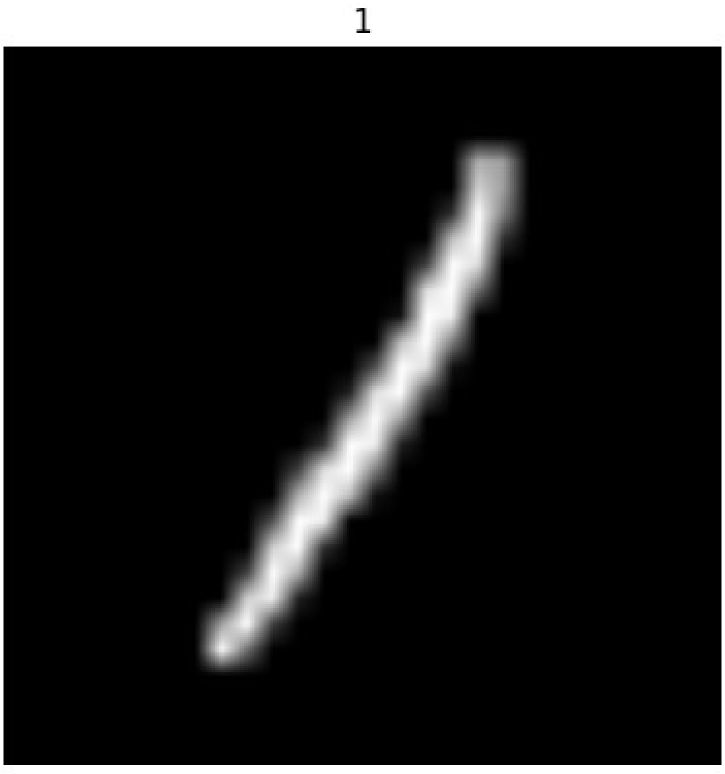
EDA

```
temp=np.argmax(train_labels, axis=1)
d={}
for i in range(10):
    d[i]=0
for q in temp:
    d[q]+=1
print(d)
#balanced dataset
```

```
{0: 592, 1: 671, 2: 581, 3: 608, 4: 623, 5: 514, 6: 608, 7: 651, 8:
551, 9: 601}
```

```
for i in range(20):
    random_index = np.random.randint(0, len(train_images))
    random_image = train_images[random_index]
    random_label = train_labels[random_index]

    plt.imshow(random_image, cmap='gray')  # Use 'gray' for MNIST
images
```

```
    plt.axis('off')
    plt.title(np.argmax(random_label))  # Convert one-hot label back to a class index
    plt.show()
```



0

6

9

4

1

3

1

8

7

0

4

4

8

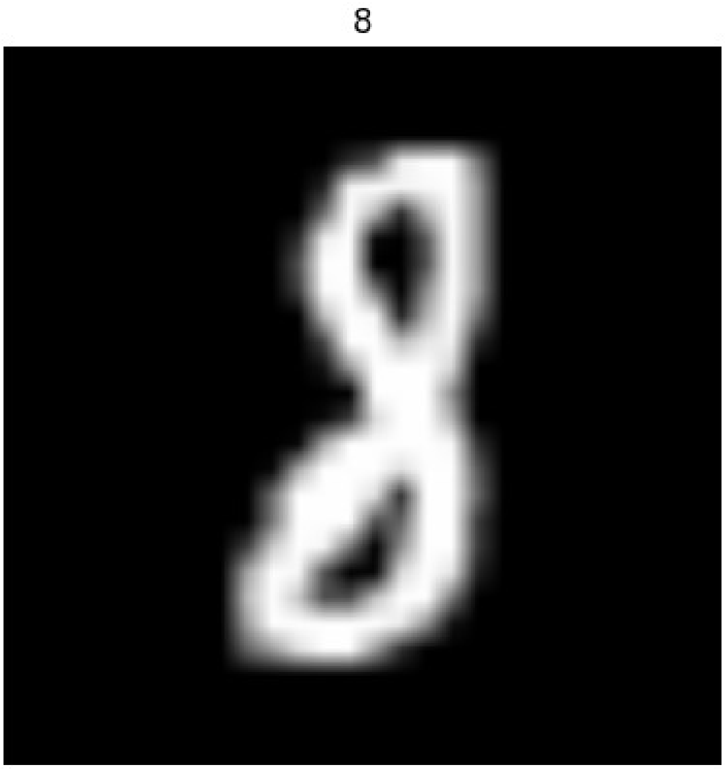
9

9

6

0

7



```
random_image.shape

(224, 224, 3)

labels = str(list(range(0,10)))
labels

'[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]'

num_samples = 12
random_indices = np.random.choice(train_images.shape[0], num_samples,
replace=False)
sample_images = train_images[random_indices]
sample_labels = train_labels[random_indices]

train_labels = to_categorical(train_labels)
test_labels = to_categorical(test_labels)

from tensorflow.keras.applications import VGG16
from tensorflow.keras.models import Model
from tensorflow.keras.layers import Flatten, Dense, Dropout
vgg_base = VGG16(weights='imagenet', include_top=False,
input_shape=(224, 224, 3))

# Freeze the VGG16 base layers
for layer in vgg_base.layers:
    layer.trainable = False
```

```python
# Add custom layers on top of VGG16
x = Flatten()(vgg_base.output)
x = Dense(128, activation='relu')(x)
x = Dropout(0.5)(x)
output = Dense(10, activation='softmax')(x)  # 10 classes for MNIST

# Create final model
model = Model(inputs=vgg_base.input, outputs=output)
# Compile the model
model.compile(optimizer='adam', loss='categorical_crossentropy',
metrics=['accuracy'])
```

```
Downloading data from https://storage.googleapis.com/tensorflow/keras-
applications/vgg16/vgg16_weights_tf_dim_ordering_tf_kernels_notop.h5
58889256/58889256 ━━━━━━━━━━━━━━━━━━━━ 0s 0us/step
```

```python
# Train the model without using ImageDataGenerator
history = model.fit(
    X_train, y_train,  # Directly use the training data
    validation_data=(X_val, y_val),  # Directly use the validation
data
    epochs=10,
    batch_size=32  # Set batch size here
)
```

```
Epoch 1/10

WARNING: All log messages before absl::InitializeLog() is called are
written to STDERR
I0000 00:00:1733860691.609322     104 service.cc:145] XLA service
0x7bb580105750 initialized for platform CUDA (this does not guarantee
that XLA will be used). Devices:
I0000 00:00:1733860691.609369     104 service.cc:153]   StreamExecutor
device (0): Tesla T4, Compute Capability 7.5
I0000 00:00:1733860691.609373     104 service.cc:153]   StreamExecutor
device (1): Tesla T4, Compute Capability 7.5

  1/150 ━━━━━━━━━━━━━━━━━━━━ 43:32 18s/step - accuracy: 0.0938 - loss:
2.5070

I0000 00:00:1733860707.849357     104 device_compiler.h:188] Compiled
cluster using XLA!  This line is logged at most once for the lifetime
of the process.

150/150 ━━━━━━━━━━━━━━━━━━━━ 57s 262ms/step - accuracy: 0.3393 - loss:
1.9881 - val_accuracy: 0.9492 - val_loss: 0.4647
Epoch 2/10
150/150 ━━━━━━━━━━━━━━━━━━━━ 26s 176ms/step - accuracy: 0.6187 - loss:
0.9654 - val_accuracy: 0.9700 - val_loss: 0.2271
Epoch 3/10
```

```
150/150 ━━━━━━━━━━━━━━━━━━━━ 25s 166ms/step - accuracy: 0.6688 - loss:
0.8045 - val_accuracy: 0.9700 - val_loss: 0.1801
Epoch 4/10
150/150 ━━━━━━━━━━━━━━━━━━━━ 26s 171ms/step - accuracy: 0.7079 - loss:
0.7316 - val_accuracy: 0.9725 - val_loss: 0.1468
Epoch 5/10
150/150 ━━━━━━━━━━━━━━━━━━━━ 26s 173ms/step - accuracy: 0.7163 - loss:
0.6900 - val_accuracy: 0.9700 - val_loss: 0.1375
Epoch 6/10
150/150 ━━━━━━━━━━━━━━━━━━━━ 25s 170ms/step - accuracy: 0.7196 - loss:
0.6797 - val_accuracy: 0.9750 - val_loss: 0.1097
Epoch 7/10
150/150 ━━━━━━━━━━━━━━━━━━━━ 26s 170ms/step - accuracy: 0.7473 - loss:
0.6259 - val_accuracy: 0.9775 - val_loss: 0.0926
Epoch 8/10
150/150 ━━━━━━━━━━━━━━━━━━━━ 26s 172ms/step - accuracy: 0.7272 - loss:
0.6564 - val_accuracy: 0.9742 - val_loss: 0.1076
Epoch 9/10
150/150 ━━━━━━━━━━━━━━━━━━━━ 26s 172ms/step - accuracy: 0.7298 - loss:
0.6290 - val_accuracy: 0.9833 - val_loss: 0.0817
Epoch 10/10
150/150 ━━━━━━━━━━━━━━━━━━━━ 26s 171ms/step - accuracy: 0.7240 - loss:
0.6339 - val_accuracy: 0.9683 - val_loss: 0.1314
```

Unsupervised method: TSNE+GMM

```python
from sklearn.manifold import Isomap, TSNE
from sklearn.decomposition import PCA
# Clustering
from sklearn.mixture import GaussianMixture
import timeit

start = timeit.default_timer()

print(X_train.shape)
X_train_tsne=X_train.reshape(4800,-1)
print(X_train_tsne.shape)
tsne = TSNE(n_components=3,
            n_jobs=-1)
digits_proj = tsne.fit_transform(X_train_tsne)
gmm = GaussianMixture(
    n_components=10)
clusters = gmm.fit_predict(digits_proj)
#Your statements here

stop = timeit.default_timer()

print('Time: ', stop - start)
```

```
(4800, 224, 224, 3)
(4800, 150528)
Time:  157.55008647299974
```

```
voter=np.zeros(shape=(10,10))
y_train_label=np.argmax(y_train,axis=1)
for i in range(len(clusters)):
    #print(clusters[i],y_train_label[i])
    voter[clusters[i]][y_train_label[i]]+=1
print(voter)
trans=np.argmax(voter,axis=1)
correct=0
for i in range(len(clusters)):
    if y_train_label[i]==trans[clusters[i]]:
        correct+=1
print(correct/len(clusters))
```

```
[[  1.   1.   6. 448.   0.  29.   0.   0.  33.   7.]
 [  0.   3.   9.   4.  13.   0.   0. 470.   1. 159.]
 [  1.   0.   3.   2.  10.   7. 479.   0.   3.   1.]
 [476.   0.   1.   1.   0.   1.   3.   0.   7.   5.]
 [  0. 206.   8.   3.   4.   1.   1.   4.   5.   0.]
 [  0.   2. 429.   1.   1.   1.   0.   4.   2.   0.]
 [  0.   1.   2.   7.   0.   1.   0.   0. 347.   0.]
 [  5.   1.   3.   8.   0. 366.   4.   1.  32.   0.]
 [  0.   1.   1.   3. 472.  10.   1.  25.   8. 299.]
 [  1. 322.   4.   4.   4.   1.   1.   5.   2.   2.]]
0.8364583333333333
```

Unsupervised method: reduce training data

```
start = timeit.default_timer()

X_train_tsne2=X_train_tsne[:2400][:]
y_train_label2=np.argmax(y_train,axis=1)[:2400]
print(X_train_tsne2.shape)
tsne2 = TSNE(n_components=3,
            n_jobs=-1)
digits_proj2 = tsne2.fit_transform(X_train_tsne2)
gmm2 = GaussianMixture(
    n_components=10)
clusters2 = gmm2.fit_predict(digits_proj2)
#Your statements here

stop = timeit.default_timer()

print('Time: ', stop - start)
```

```
voter2=np.zeros(shape=(10,10))

for i in range(len(clusters2)):
    #print(clusters[i],y_train_label[i])
    voter2[clusters2[i]][y_train_label2[i]]+=1
print(voter2)
trans2=np.argmax(voter2,axis=1)
correct2=0
for i in range(len(clusters2)):
    if y_train_label2[i]==trans2[clusters2[i]]:
        correct2+=1
print(correct2/len(clusters2))
```

```
(2400, 150528)
Time:  54.03585478500008
[[  1.   2.   0.   4. 243.   7.   2.  10.   3. 174.]
 [  0.   0.   5.   7.   0. 170.   4.   1.   2.   0.]
 [232.   0.   0.   0.   0.   0.   2.   0.   1.   1.]
 [  0.   1.   5. 223.   0.  23.   0.   0.  10.   3.]
 [  1. 147.   3.   0.   0.   1.   0.   5.   1.   0.]
 [  0.   2.   9.   1.  13.   0.   0. 220.   0.  41.]
 [  0.   1. 218.   6.   0.   0.   0.   3.   5.   0.]
 [  0.   0.   1.   2.   6.   6. 241.   0.   4.   0.]
 [  0. 110.   3.   2.   2.   0.   0.   3.   2.   0.]
 [  0.   0.   0.   7.   0.   4.   0.   0. 194.   0.]]
0.8325
```

```
from tensorflow.keras.optimizers import Adagrad

# Modeling
model.compile(optimizer='Adagrad', loss='categorical_crossentropy',
metrics=['accuracy'])

model.summary()
```

```
Model: "functional_1"

┏━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━┳━━━━━━━━━━━━━━━━━━━━━━━━┳━━━━━━━━━━
━━━━━┓
┃ Layer (type)                    ┃ Output Shape           ┃
Param # ┃
┡━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━╇━━━━━━━━━━━━━━━━━━━━━━━━╇━━━━━━━━━━
━━━━━┩
│ input_layer (InputLayer)        │ (None, 224, 224, 3)    │
0 │
├─────────────────────────────────┼────────────────────────┼──────────
─────┤
│ block1_conv1 (Conv2D)           │ (None, 224, 224, 64)   │
1,792 │
```

```
├─────────────────────────────────┼────────────────────────┼──────────
─────┤
│ block1_conv2 (Conv2D)           │ (None, 224, 224, 64)   │
36,928 │
├─────────────────────────────────┼────────────────────────┼──────────
─────┤
│ block1_pool (MaxPooling2D)      │ (None, 112, 112, 64)   │
0 │
├─────────────────────────────────┼────────────────────────┼──────────
─────┤
│ block2_conv1 (Conv2D)           │ (None, 112, 112, 128)  │
73,856 │
├─────────────────────────────────┼────────────────────────┼──────────
─────┤
│ block2_conv2 (Conv2D)           │ (None, 112, 112, 128)  │
147,584 │
├─────────────────────────────────┼────────────────────────┼──────────
─────┤
│ block2_pool (MaxPooling2D)      │ (None, 56, 56, 128)    │
0 │
├─────────────────────────────────┼────────────────────────┼──────────
─────┤
│ block3_conv1 (Conv2D)           │ (None, 56, 56, 256)    │
295,168 │
├─────────────────────────────────┼────────────────────────┼──────────
─────┤
│ block3_conv2 (Conv2D)           │ (None, 56, 56, 256)    │
590,080 │
├─────────────────────────────────┼────────────────────────┼──────────
─────┤
│ block3_conv3 (Conv2D)           │ (None, 56, 56, 256)    │
590,080 │
├─────────────────────────────────┼────────────────────────┼──────────
─────┤
│ block3_pool (MaxPooling2D)      │ (None, 28, 28, 256)    │
0 │
├─────────────────────────────────┼────────────────────────┼──────────
─────┤
│ block4_conv1 (Conv2D)           │ (None, 28, 28, 512)    │
1,180,160 │
├─────────────────────────────────┼────────────────────────┼──────────
─────┤
│ block4_conv2 (Conv2D)           │ (None, 28, 28, 512)    │
2,359,808 │
├─────────────────────────────────┼────────────────────────┼──────────
─────┤
│ block4_conv3 (Conv2D)           │ (None, 28, 28, 512)    │
2,359,808 │
├─────────────────────────────────┼────────────────────────┼──────────
```

```
─────┤
│ block4_pool (MaxPooling2D)      │ (None, 14, 14, 512)    │
0 │
├─────────────────────────────────┼────────────────────────┼──────────
─────┤
│ block5_conv1 (Conv2D)           │ (None, 14, 14, 512)    │
2,359,808 │
├─────────────────────────────────┼────────────────────────┼──────────
─────┤
│ block5_conv2 (Conv2D)           │ (None, 14, 14, 512)    │
2,359,808 │
├─────────────────────────────────┼────────────────────────┼──────────
─────┤
│ block5_conv3 (Conv2D)           │ (None, 14, 14, 512)    │
2,359,808 │
├─────────────────────────────────┼────────────────────────┼──────────
─────┤
│ block5_pool (MaxPooling2D)      │ (None, 7, 7, 512)      │
0 │
├─────────────────────────────────┼────────────────────────┼──────────
─────┤
│ flatten (Flatten)               │ (None, 25088)          │
0 │
├─────────────────────────────────┼────────────────────────┼──────────
─────┤
│ dense (Dense)                   │ (None, 128)            │
3,211,392 │
├─────────────────────────────────┼────────────────────────┼──────────
─────┤
│ dropout (Dropout)               │ (None, 128)            │
0 │
├─────────────────────────────────┼────────────────────────┼──────────
─────┤
│ dense_1 (Dense)                 │ (None, 10)             │
1,290 │
└─────────────────────────────────┴────────────────────────┴──────────
─────┘
```

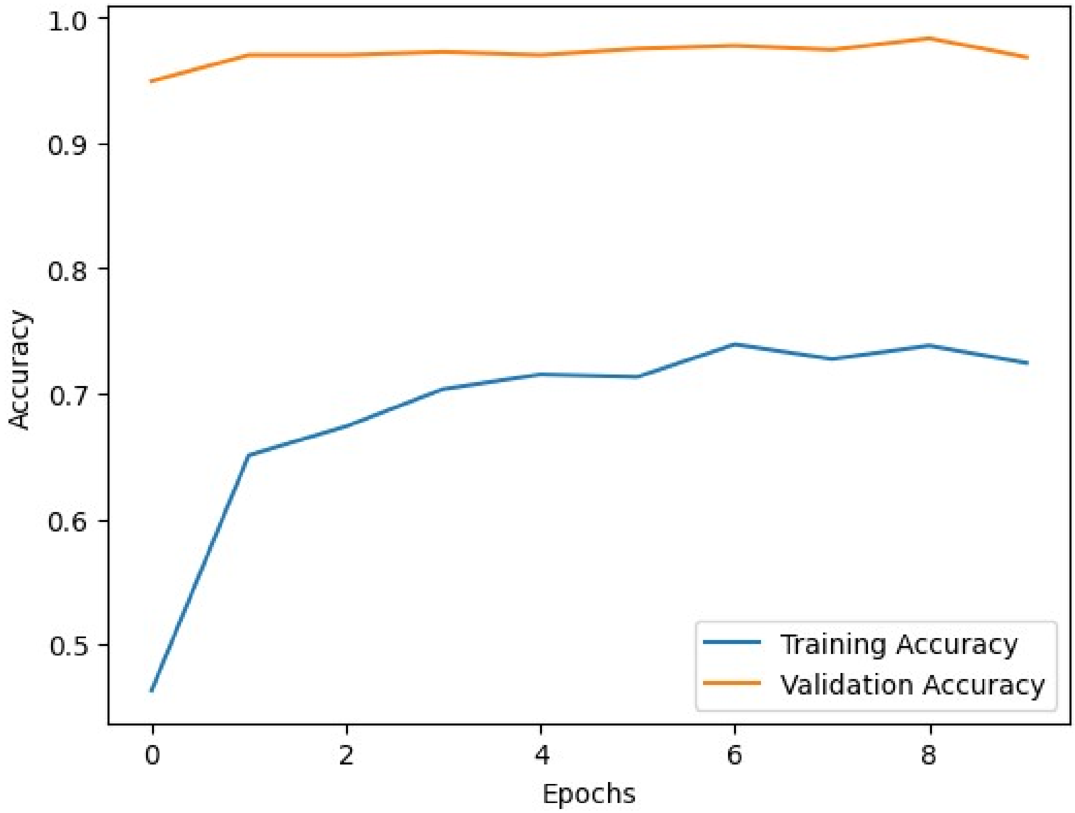
```
 Total params: 17,927,370 (68.39 MB)

 Trainable params: 3,212,682 (12.26 MB)

 Non-trainable params: 14,714,688 (56.13 MB)
```

```
loss,accuracy = model.evaluate(X_train,y_train)
print(f"The model accuracy is : {accuracy} \n the model loss :
{loss}")
```

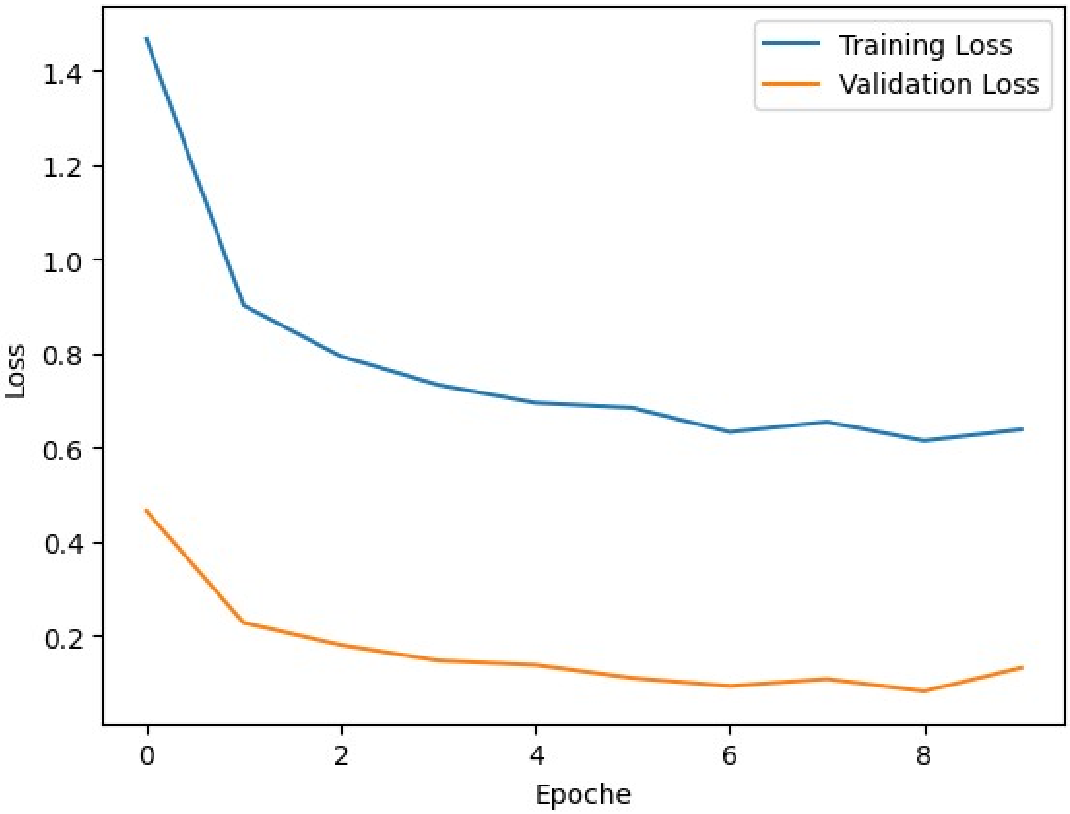
```
150/150 ━━━━━━━━━━━━━━━━━━━━ 21s 138ms/step - accuracy: 0.9898 - loss:
0.0684
```

```
The model accuracy is : 0.9879166483879089
 the model loss : 0.07202592492103577
```

```
plt.plot(history.history['accuracy'],label='Training Accuracy')
plt.plot(history.history['val_accuracy'], label = 'Validation
Accuracy')
plt.xlabel("Epochs")
plt.ylabel('Accuracy')
plt.legend()
plt.show()
```



```
plt.plot(history.history['loss'],label='Training Loss')
plt.plot(history.history['val_loss'],label='Validation Loss')
plt.xlabel("Epoche")
plt.ylabel("Loss")
plt.legend()
plt.show()
```



```
import numpy as np

# Predict the class probabilities for the test dataset
predictions = model.predict(X_val)

# Convert probabilities to class labels
predicted_labels = np.argmax(predictions, axis=1)
true_labels = np.argmax(y_val, axis=1)  # Convert one-hot to class
indices
```

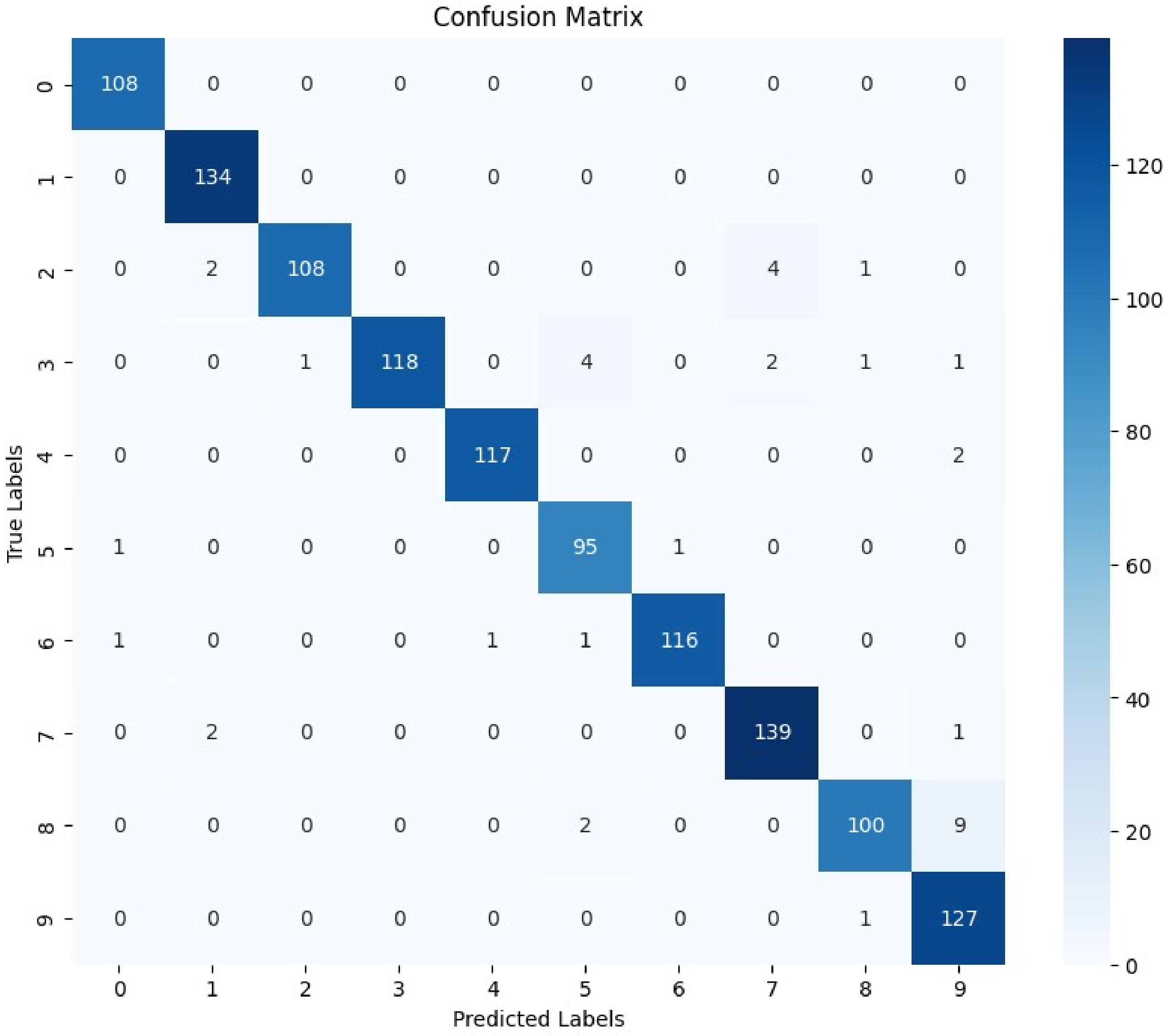
```
38/38 ━━━━━━━━━━━━━━━━━━━━ 6s 150ms/step
```

```
from sklearn.metrics import confusion_matrix
import matplotlib.pyplot as plt
import seaborn as sns

# Generate the confusion matrix
true_labels = np.argmax(y_val, axis=1)  # Convert one-hot encoded to
class indices
predicted_labels = np.argmax(predictions, axis=1)  # Already
converting probabilities to class indices
correct=0
for i in range(len(true_labels)):
    if true_labels[i]==predicted_labels[i]:
        correct+=1
```

```
print(correct/len(true_labels))
from sklearn.metrics import confusion_matrix

# Generate confusion matrix
conf_matrix = confusion_matrix(true_labels, predicted_labels)
```

```
0.9683333333333334
```

```
# Plot the confusion matrix
plt.figure(figsize=(10, 8))
sns.heatmap(conf_matrix, annot=True, fmt='d', cmap='Blues',
xticklabels=range(10), yticklabels=range(10))
plt.xlabel('Predicted Labels')
plt.ylabel('True Labels')
plt.title('Confusion Matrix')
plt.show()
```



	0	1	2	3	4	5	6	7	8	9
0	108	0	0	0	0	0	0	0	0	0
1	0	134	0	0	0	0	0	0	0	0
2	0	2	108	0	0	0	0	4	1	0
3	0	0	1	118	0	4	0	2	1	1
4	0	0	0	0	117	0	0	0	0	2
5	1	0	0	0	0	95	1	0	0	0
6	1	0	0	0	1	1	116	0	0	0
7	0	2	0	0	0	0	0	139	0	1
8	0	0	0	0	0	2	0	0	100	9
9	0	0	0	0	0	0	0	0	1	127