Group20_Assignment3_code

March 18, 2023

[1]:
```
from importlib import import_module
import tensorflow as tf
import keras
from keras.api._v2 import keras as KerasAPI
keras: KerasAPI = import_module("tensorflow.keras")
print(tf.__version__)

import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
from sklearn.metrics import confusion_matrix
import itertools
from keras.utils import plot_model

from keras.utils import load_img
from keras.utils import img_to_array

import os

from sklearn.preprocessing import LabelEncoder
```

```
2.9.0
```

[2]:
```
path = ''
# from google.colab import drive
# drive.mount('/content/drive')
# path = '/content/drive/MyDrive/deepLearningAs3/'

pathfinal = path + 'model_history/'
pathload = path + 'resultModel/'

epoch_val = 100
batch_size_val = 1
threshold_val = 1e-4

random_state_global = 42
learning_rate_val = 1e-3
momentum_val = 0.9
```

```
Hidden_layer_I_N = 20
Hidden_layer_II_N = 15
Hidden_layer_III_N = 10
Output_layer_N = 5

Hidden_layer_Activation = "tanh"
Output_layer_Activation = "softmax"

ema_momentum_val = 0.99 # beta
epsilon_val = 1e-8
beta_1_val = 0.9
beta_2_val = 0.999

i = 'a'
ii = 'a'
iii = 'a'
iv = 'a'
v = 'a'
vi = 'a'
vii = 'a'
al = 'a'

epoch_val_a = epoch_val
batch_size_val_a = batch_size_val

epoch_val_b = 30000
batch_size_val_b = 11385 # df_train.shape[0] # 11385

epoch_val_c = epoch_val
batch_size_val_c = batch_size_val

epoch_val_d = epoch_val
batch_size_val_d = batch_size_val

epoch_val_e = epoch_val
batch_size_val_ae = batch_size_val

epoch_val_f = epoch_val
batch_size_val_f = batch_size_val

epoch_val_g = epoch_val
batch_size_val_g = batch_size_val

class_l_r_to_d = {0:0, 1:1, 2:2, 4:3, 9:4}
class_l_d_to_r = {0:0, 1:1, 2:2, 3:4, 4:9}
```

read and saving data

[3]:
```
%%script echo skipping
# level 0 path
l0 = 'Group_20'

DATASET = {0:pd.DataFrame(), 1:pd.DataFrame(), 2:pd.DataFrame()}
temp_dict = {'train':0, 'val':1, 'test':2}

# iterate over files in
# that l0
for l1 in os.listdir(l0):
    f1 = os.path.join(l0, l1)
    for l2 in os.listdir(f1):
        f2 = os.path.join(f1, l2)
        for l3 in os.listdir(f2):
            f3 = os.path.join(f2, l3)
            # print(f3)
            img = load_img(f3, color_mode = "grayscale")
            data_point = tf.squeeze(tf.constant(img_to_array(img)))
            # print("shape:", data_point.shape) # shape: (28, 28)
            # data_point = data_point/255
            # print(tf.math.reduce_min(data_point), tf.math.
 ↪reduce_max(data_point))
            # plt.imshow(data_point)
            # plt.show()

            temp = tf.reshape(data_point, shape=[-1]).numpy().tolist()

            #appending label
            temp.append(int(l2))

            # print("shape:",temp.shape) #shape: (784,)
            row = pd.Series(temp)
            # print('1')
            DATASET[temp_dict[l1]] = pd.concat([DATASET[temp_dict[l1]], row],␣
 ↪axis=1)
            # plt.imshow(tf.reshape(temp, shape=(28,28)))
            # plt.show()


df_train = DATASET[0].transpose()
df_valid = DATASET[1].transpose()
df_test = DATASET[2].transpose()

## saving data
df_train.to_csv('df_train.csv', index=False)
df_valid.to_csv('df_valid.csv', index=False)
df_test.to_csv('df_test.csv', index=False)
```

skipping

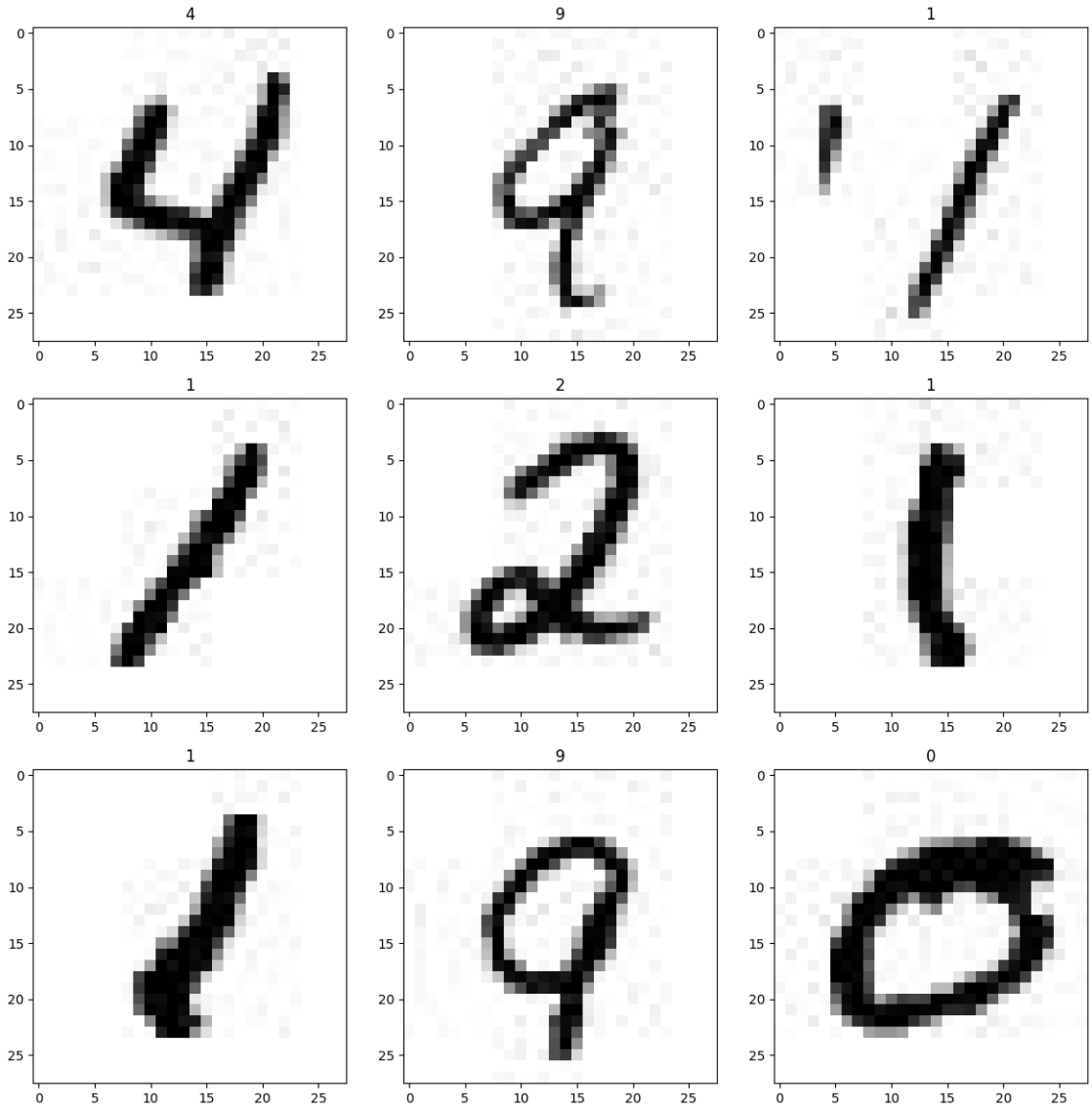
[4]:
```
def label_encoding(df):
    df[df.columns[-1]] = LabelEncoder().fit_transform(df.iloc[:,-1])
    return df

def normalizing_data(df):
    temp = df[df.columns[-1]]
    df = df/255
    df[df.columns[-1]] = temp
    return df

# plt.figure(figsize=(7, 10))
def data_visualize(df):
  np.random.seed(random_state_global)
  plt.figure(figsize=(12, 12))
  for i in range(9):
    plt.subplot(3, 3, i + 1)
    rand_index = np.random.choice(range(len(df)))
    plt.imshow(tf.reshape(df.iloc[rand_index,:-1], shape=(28,28)), cmap=plt.cm.
 ↪binary)
    plt.title(f'{class_l_d_to_r[df.iloc[rand_index,-1]]}')
    # plt.axis(False)
  plt.tight_layout()
```

[5]:
```
df_train = pd.read_csv(path+'df_train.csv', dtype='float32')
df_valid = pd.read_csv(path+'df_valid.csv', dtype='float32')
df_test = pd.read_csv(path+'df_test.csv', dtype='float32')

print('df_train:', df_train.groupby(['784']).count().iloc[:,-1].to_dict())
print('df_valid:', df_valid.groupby(['784']).count().iloc[:,-1].to_dict())
print('df_test:', df_test.groupby(['784']).count().iloc[:,-1].to_dict())
print()

print(f'Initial Data Range: {min(df_train.iloc[:,:-1].min())} to {max(df_train.
 ↪iloc[:,:-1].max())}')

df_train = label_encoding(normalizing_data(df_train))
df_valid = label_encoding(normalizing_data(df_valid))
df_test = label_encoding(normalizing_data(df_test))
print(f'Final Data Range: {min(df_train.iloc[:,:-1].min())} to {max(df_train.
 ↪iloc[:,:-1].max())}')
print('Label Encoded')

print('Train Data',df_train.shape)
print('Valid Data',df_valid.shape)
print('Test Data' ,df_test.shape)
```

```
df_train: {0.0: 2277, 1.0: 2277, 2.0: 2277, 4.0: 2277, 9.0: 2277}
df_valid: {0.0: 759, 1.0: 759, 2.0: 759, 4.0: 759, 9.0: 759}
df_test: {0.0: 759, 1.0: 759, 2.0: 759, 4.0: 759, 9.0: 759}

Initial Data Range: 0.0 to 255.0
Final Data Range: 0.0 to 1.0
Label Encoded
Train Data (11385, 785)
Valid Data (3795, 785)
Test Data (3795, 785)
```

[6]:
```
data_visualize(df_train)
```

```
Metal device set to: Apple M1

systemMemory: 8.00 GB
maxCacheSize: 2.67 GB


2023-03-18 18:55:24.996899: I
tensorflow/core/common_runtime/pluggable_device/pluggable_device_factory.cc:305]
Could not identify NUMA node of platform GPU ID 0, defaulting to 0. Your kernel
may not have been built with NUMA support.
2023-03-18 18:55:24.997047: I
tensorflow/core/common_runtime/pluggable_device/pluggable_device_factory.cc:271]
Created TensorFlow device (/job:localhost/replica:0/task:0/device:GPU:0 with 0
MB memory) -> physical PluggableDevice (device: 0, name: METAL, pci bus id:
<undefined>)
```



[7]:
```
# Import label encoder
ll = [9,9,4,0,0,1,2]
print(LabelEncoder().fit_transform(ll))

print(ll)
```

```
[4 4 3 0 0 1 2]
[9, 9, 4, 0, 0, 1, 2]
```

[8]:
```
# Check out a random image as well as its prediction
# Create a function for plotting a random image along with its prediction
def plot_random_image(model, images, true_labels, classes):
```

```
 """Picks a random image, plots it and labels it with a predicted and truth␣
↪label.

 Args:
   model: a trained model (trained on data similar to what's in images).
   images: a set of random images (in tensor form).
   true_labels: array of ground truth labels for images.
   classes: array of class names for images.

 Returns:
   A plot of a random image from `images` with a predicted class label from␣
↪`model`
   as well as the truth class label from `true_labels`.
 """
 np.random.seed(random_state_global+1)
 plt.figure(figsize=(12, 12))
 for iter in range(9):
   ax = plt.subplot(3, 3, iter + 1)

   # global seed
   # Setup random integer
   i = np.random.randint(0, len(images))

   # Create predictions and targets
   target_image = images.iloc[i,:]
   pred_probs = model.predict(tf.reshape(target_image, shape=(1,784)),␣
↪verbose=0) # have to reshape to get into right size for model
   pred_label = classes[pred_probs.argmax()]
   true_label = classes[true_labels[i]]

   # Plot the target image
   plt.imshow(tf.reshape(target_image, shape=(28,28)), cmap=plt.cm.binary)

   # Change the color of the titles depending on if the prediction is right or␣
↪wrong
   if pred_label == true_label:
     color = "green"
   else:
     color = "red"

   # Add xlabel information (prediction/true label)
   plt.xlabel(f'Pred: {pred_label} with {100*tf.reduce_max(pred_probs):.0f}%␣
↪accuracy (True: {true_label})', color=color)

   # plt.axis(False)
 plt.tight_layout()
```

```
def testingImages(model):
    for i in range(1):
        plot_random_image(model=model,
                    images=df_test.iloc[:,:-1],
                    true_labels=df_test.iloc[:,-1],
                    classes=[0,1,2,4,9])
```

[9]:
```
i = np.random.randint(0, 5)
i
```

[9]:
```
2
```

[10]:
```
# Note: The following confusion matrix code is a remix of Scikit-Learn's
# plot_confusion_matrix function - https://scikit-learn.org/stable/modules/
 ↪generated/sklearn.metrics.plot_confusion_matrix.html
# and Made with ML's introductory notebook - https://github.com/GokuMohandas/
 ↪MadeWithML/blob/main/notebooks/08_Neural_Networks.ipynb

# Our function needs a different name to sklearn's plot_confusion_matrix
def make_confusion_matrix(y_true, y_pred, classes=None, figsize=(10, 10),␣
 ↪text_size=10):
  """Makes a labelled confusion matrix comparing predictions and ground truth␣
 ↪labels.

  If classes is passed, confusion matrix will be labelled, if not, integer class␣
 ↪values
  will be used.

  Args:
    y_true: Array of truth labels (must be same shape as y_pred).
    y_pred: Array of predicted labels (must be same shape as y_true).
    classes: Array of class labels (e.g. string form). If `None`, integer labels␣
 ↪are used.
    figsize: Size of output figure (default=(10, 10)).
    text_size: Size of output figure text (default=15).

  Returns:
    A labelled confusion matrix plot comparing y_true and y_pred.

  Example usage:
    make_confusion_matrix(y_true=test_labels, # ground truth test labels
                          y_pred=y_preds, # predicted labels
                          classes=class_names, # array of class label names
                          figsize=(15, 15),
                          text_size=10)
  """
  # Create the confustion matrix
```

```
  cm = confusion_matrix(y_true, y_pred)
  cm_norm = cm.astype("float") / cm.sum(axis=1)[:, np.newaxis] # normalize it
  n_classes = cm.shape[0] # find the number of classes we're dealing with

  # Plot the figure and make it pretty
  fig, ax = plt.subplots(figsize=figsize)
  cax = ax.matshow(cm, cmap=plt.cm.Blues) # colors will represent how 'correct'␣
↪a class is, darker == better
  fig.colorbar(cax)

  # Are there a list of classes?
  if classes:
    labels = classes
  else:
    labels = np.arange(cm.shape[0])

  # Label the axes
  ax.set(title="Confusion Matrix",
         xlabel="Predicted label",
         ylabel="True label",
         xticks=np.arange(n_classes), # create enough axis slots for each class
         yticks=np.arange(n_classes),
         xticklabels=labels, # axes will labeled with class names (if they␣
↪exist) or ints
         yticklabels=labels)

  # Make x-axis labels appear on bottom
  ax.xaxis.set_label_position("bottom")
  ax.xaxis.tick_bottom()

  # Set the threshold for different colors
  threshold = (cm.max() + cm.min()) / 2.

  # Plot the text on each cell
  for i, j in itertools.product(range(cm.shape[0]), range(cm.shape[1])):
    plt.text(j, i, f"{cm[i, j]} ({cm_norm[i, j]*100:.1f}%)",
             horizontalalignment="center",
             color="white" if cm[i, j] > threshold else "black",
             size=text_size)


def inferences(df_model_history, model):
    print(f'Training Accuracy for model: {df_model_history["accuracy"].
↪to_list()[-1]*100:.2f}%')
    print(f'Validation Accuracy for model: {df_model_history["val_accuracy"].
↪to_list()[-1]*100:.2f}%')
```

```
    print(f'Test Accuracy for model: {model.evaluate(df_test.iloc[:,:-1],␣
↪df_test.iloc[:,-1], verbose=0)[1]*100:.2f}%')

    df_model_history.plot(title="Accuracy / Loss vs Epoch", xlabel='Epoch',␣
↪ylabel='Accuracy / Loss')
    plt.show()

    df_model_history['loss'].plot(title="Average training error vs epochs",␣
↪xlabel='Epoch', ylabel='Loss')
    plt.show()

def makingPredictionWithCM(model):
    #Predicting one sample
    print('y_prob_a for one sample',model.predict(tf.reshape(df_test.iloc[0,:
↪-1], shape=(1,784)), verbose=0))

    y_true = df_test.iloc[:,-1]
    y_prob_a = model.predict(df_test.iloc[:,:-1], verbose=0)
    y_pred_a = y_prob_a.argmax(axis=1)
    make_confusion_matrix(y_true, y_pred_a, classes=list(map(lambda el:␣
↪class_l_d_to_r[el], [0,1,2,3,4])))

def showResults(model, history):
    inferences(history, model)
    makingPredictionWithCM(model)
    testingImages(model)
```

[11]:
```
# class StopOnThreshold(keras.callbacks.Callback):
#     def __init__(self, threshold):
#         super(StopOnThreshold, self).__init__()
#         self.threshold = threshold
#         self.previous_error = float('inf')

#     def on_epoch_end(self, epoch, logs=None):
#         current_error = logs.get('loss')
#         # print(f'\nEpoch {epoch+1} curent Err:{current_error}, Previous Err:
↪{self.previous_error}')
#         if abs(current_error - self.previous_error) < self.threshold:
#             self.model.stop_training = True
#             print('\n\n********\nThreshold Reached\n********\n')
#         self.previous_error = current_error

class ModelSaving(keras.callbacks.Callback):
    def on_epoch_end(self, epoch, logs=None):
        # saving the model
        if(self.model.name=='model_b'):
            if((epoch+1)%500==0):
```

```
                self.model.save(f'{pathfinal}{self.model.name}_{epoch+1}.h5')
        else:
            self.model.save(f'{pathfinal}{self.model.name}_{epoch+1}.h5')

class HistorySaver(keras.callbacks.Callback):
    def __init__(self):
        super(HistorySaver, self).__init__()
        self.history = {}
# dict_items([('loss', 1.3612865209579468), ('accuracy', 0.46034255623817444),␣
 ↪('val_loss', 1.1157031059265137), ('val_accuracy', 0.6484848856925964)])
    def on_epoch_end(self, epoch, logs=None):
        for key, value in logs.items():
            self.history.setdefault(key, []).append(value)

        if(self.model.name=='model_b'):
            if((epoch+1)%500==0):
                pd.DataFrame(self.history).to_csv(f'{pathfinal}{self.model.
 ↪name}_{epoch+1}.csv', index=False)
        else:
            pd.DataFrame(self.history).to_csv(f'{pathfinal}{self.model.
 ↪name}_{epoch+1}.csv', index=False)


# create the callbacks

model_saver = ModelSaving()

# not initialize HistorySaver() here initialize inside function
# stop_on_threshold = StopOnThreshold(threshold=threshold_val)

# This means if for 5 epochs the accuracy has no progress on
# the validation set then it would stop and store the previous best value.
early_stopping_cb = keras.callbacks.EarlyStopping(monitor='loss',
                                                  patience=1,
                                                  min_delta=threshold_val,
                                                  mode='min',
                                                  restore_best_weights=True,
                                                  verbose=1)
```

1 (i) stochastic gradient descent (SGD) algorithm - (batch_size=1)

[12]:
```
%%script echo skipping
if(i!=''):
  # Set random seed
  tf.random.set_seed(random_state_global)
```

```
 # Create the model
 model_a = keras.Sequential([
   keras.Input(shape=(784,), name="Input_layer"),
   keras.layers.Dense(Hidden_layer_I_N, activation=Hidden_layer_Activation,␣
↪name="Hidden_layer_I"),
   keras.layers.Dense(Hidden_layer_II_N, activation=Hidden_layer_Activation,␣
↪name="Hidden_layer_II"),
   keras.layers.Dense(Hidden_layer_III_N, activation=Hidden_layer_Activation,␣
↪name="Hidden_layer_III"),
   keras.layers.Dense(Output_layer_N, activation=Output_layer_Activation,␣
↪name="Output_layer")
 ], name='model_a')

 # Compile the model
 model_a.compile(loss=keras.losses.SparseCategoricalCrossentropy(),
                 optimizer=keras.optimizers.
↪SGD(learning_rate=learning_rate_val),
                 metrics=["accuracy"])

 # Fit the model
 history_a = model_a.fit(df_train.iloc[:,:-1],
                       df_train.iloc[:,-1],
                       epochs=epoch_val_a,
                       batch_size=batch_size_val_a,
                       validation_data=(df_valid.iloc[:,:-1], df_valid.iloc[:
↪,-1]),
                       callbacks=[model_saver, HistorySaver(),␣
↪early_stopping_cb], verbose=0)
 df_model_a_history = pd.DataFrame(history_a.history)
 print('\n\n\n')

 # model_a.summary()
 print(df_model_a_history)

 # saving model and data history
 # model_a.save('model_a.h5')
 # df_model_a_history.to_csv('model_a.csv', index=False)

 # lodaing model and data history
 # model_a = keras.models.load_model('model_a.h5')
 # df_model_a_history = pd.read_csv('model_a.csv')
```

skipping

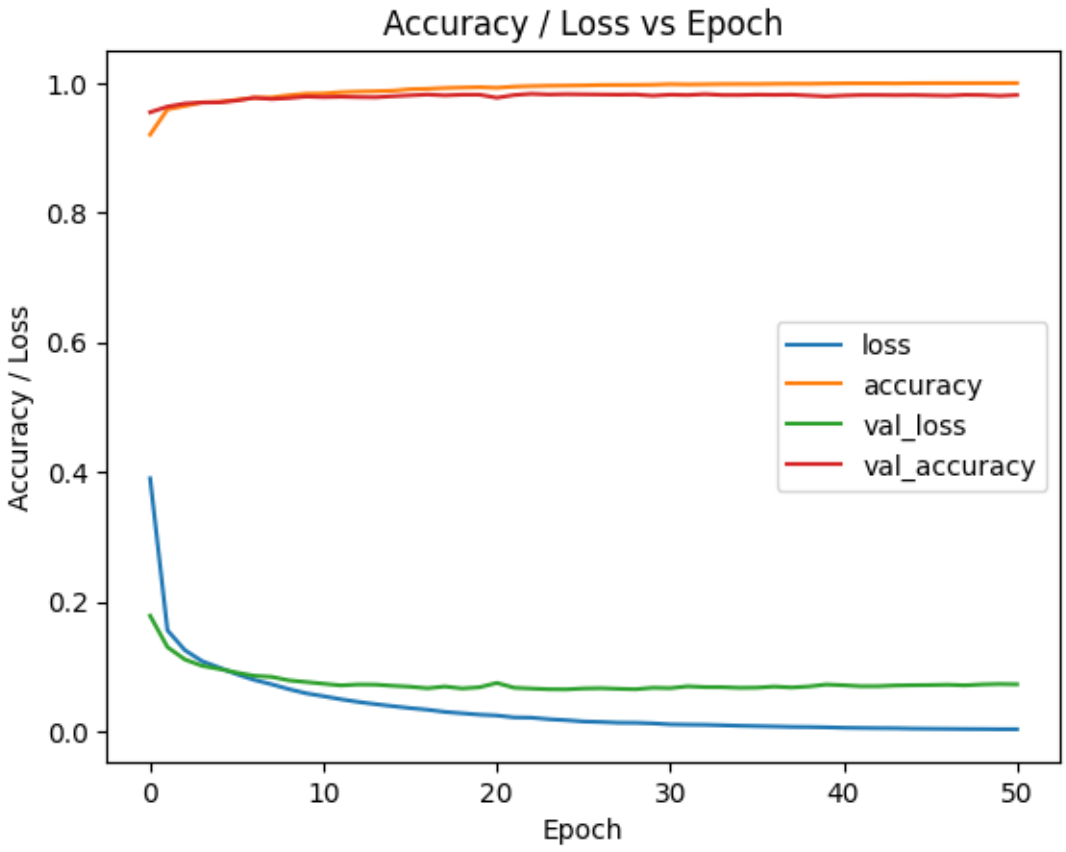
[13]:
```
model_a = keras.models.load_model(f'{pathload}model_a_51.h5', compile=False)
model_a.compile(loss=keras.losses.SparseCategoricalCrossentropy(),
```

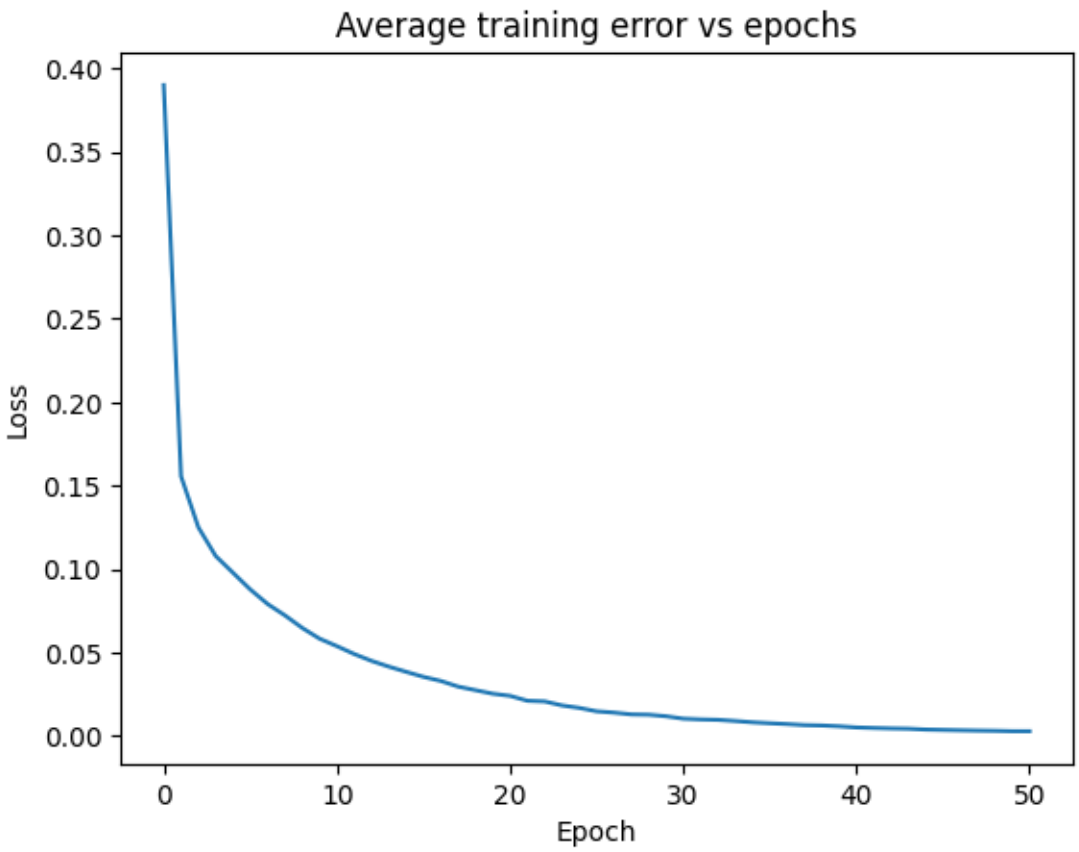
```
                  optimizer=keras.optimizers.
 ↪SGD(learning_rate=learning_rate_val),
                  metrics=["accuracy"])
df_model_a_history = pd.read_csv(f'{pathload}model_a_51.csv')
if(i!=''):
  showResults(model_a, df_model_a_history)
```

```
Training Accuracy for model: 100.00%
Validation Accuracy for model: 98.16%
```

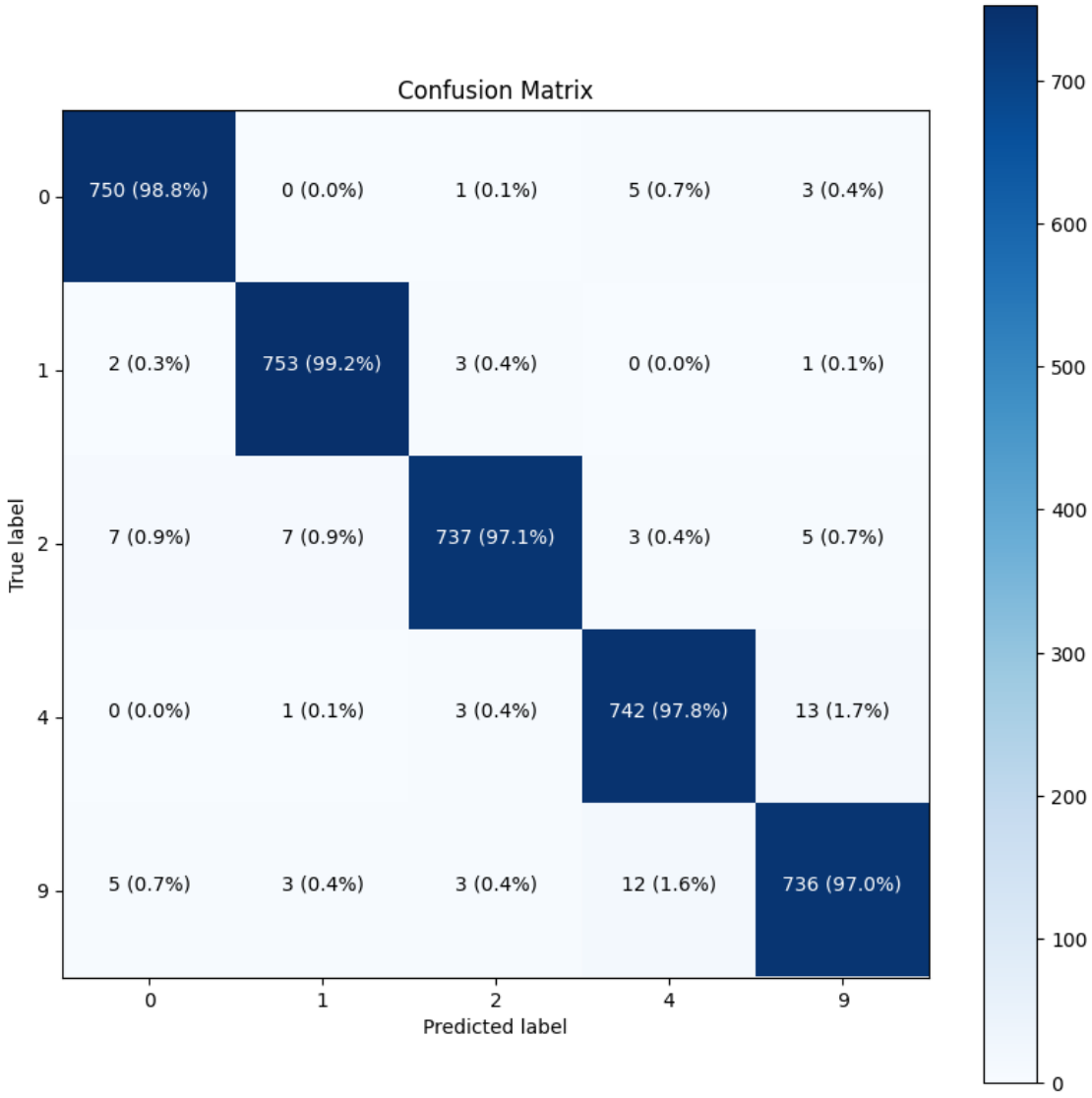
```
2023-03-18 18:55:26.085001: W
tensorflow/core/platform/profile_utils/cpu_utils.cc:128] Failed to get CPU
frequency: 0 Hz
2023-03-18 18:55:26.170575: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
Plugin optimizer for device_type GPU is enabled.
```

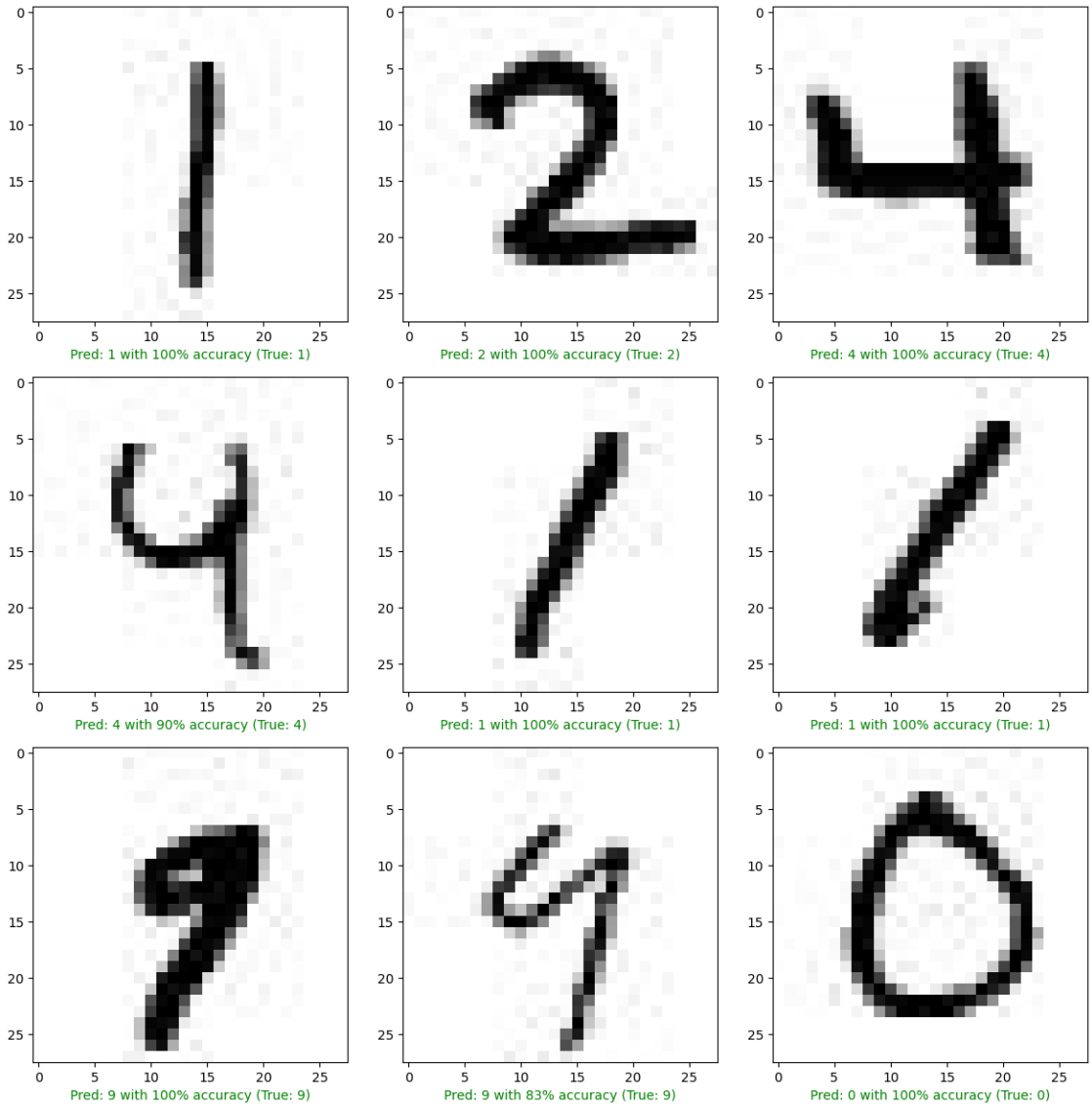
```
Test Accuracy for model: 97.97%
```






```
2023-03-18 18:55:26.996895: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
Plugin optimizer for device_type GPU is enabled.
2023-03-18 18:55:27.076470: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
Plugin optimizer for device_type GPU is enabled.

y_prob_a for one sample [[2.9198154e-05 5.5427015e-05 1.7310332e-06
6.1972401e-05 9.9985158e-01]]
```


Confusion Matrix
750 (98.8%)
0 (0.0%)
1 (0.1%)
5 (0.7%)
3 (0.4%)
2 (0.3%)
753 (99.2%)
3 (0.4%)
0 (0.0%)
1 (0.1%)
7 (0.9%)
7 (0.9%)
737 (97.1%)
3 (0.4%)
5 (0.7%)
0 (0.0%)
1 (0.1%)
3 (0.4%)
742 (97.8%)
13 (1.7%)
5 (0.7%)
3 (0.4%)
3 (0.4%)
12 (1.6%)
736 (97.0%)
True label
Predicted label
0
1
2
4
9
700
600
500
400
300
200
100
0



2 (ii) Batch gradient descent algorithm (vanilla gradient descent) – (batch_size=total number of training examples),

[14]:
```
%%script echo skipping

if(ii!=''):
  # Set random seed
  tf.random.set_seed(random_state_global)

  # Create the model
  model_b = keras.Sequential([
```

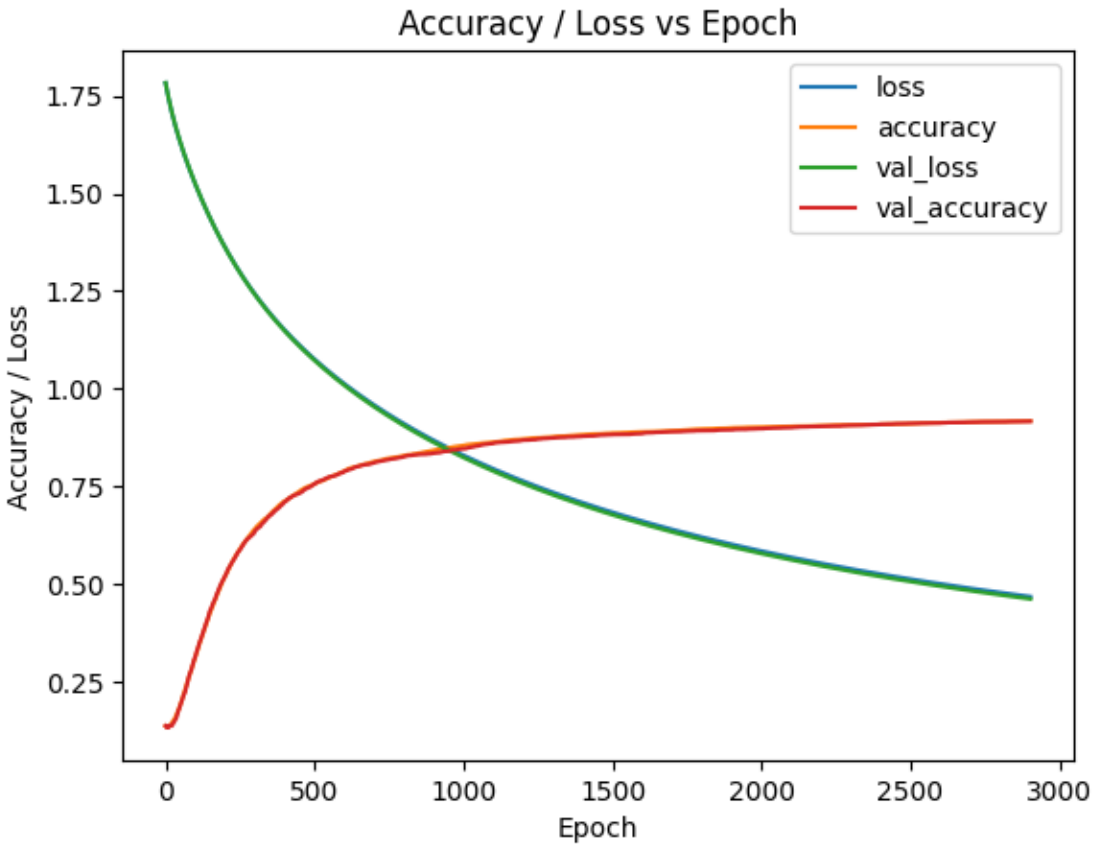
```
   keras.Input(shape=(784,), name="Input_layer"),
   keras.layers.Dense(Hidden_layer_I_N, activation=Hidden_layer_Activation,␣
↪name="Hidden_layer_I"),
   keras.layers.Dense(Hidden_layer_II_N, activation=Hidden_layer_Activation,␣
↪name="Hidden_layer_II"),
   keras.layers.Dense(Hidden_layer_III_N, activation=Hidden_layer_Activation,␣
↪name="Hidden_layer_III"),
   keras.layers.Dense(Output_layer_N, activation=Output_layer_Activation,␣
↪name="Output_layer")
 ], name='model_b')

 # Compile the model
 model_b.compile(loss=keras.losses.SparseCategoricalCrossentropy(),
                 optimizer=keras.optimizers.
↪SGD(learning_rate=learning_rate_val),
                 metrics=["accuracy"])



 # Fit the model
 history_b = model_b.fit(df_train.iloc[:,:-1],
                         df_train.iloc[:,-1],
                         epochs=epoch_val_b,
                         batch_size=batch_size_val_b,
                         validation_data=(df_valid.iloc[:,:-1], df_valid.iloc[:
↪,-1]),
                         callbacks=[model_saver, HistorySaver(),␣
↪early_stopping_cb], verbose=0)

 df_model_b_history = pd.DataFrame(history_b.history)

 df_model_b_history.to_csv(f'{pathfinal}model_b_{history_b.epoch[-1]}.csv',␣
↪index=False)
 model_b.save(f'{pathfinal}model_b_{history_b.epoch[-1]}.h5')

 print('\n\n\n')
 # model_b.summary()
 print(df_model_b_history)
```

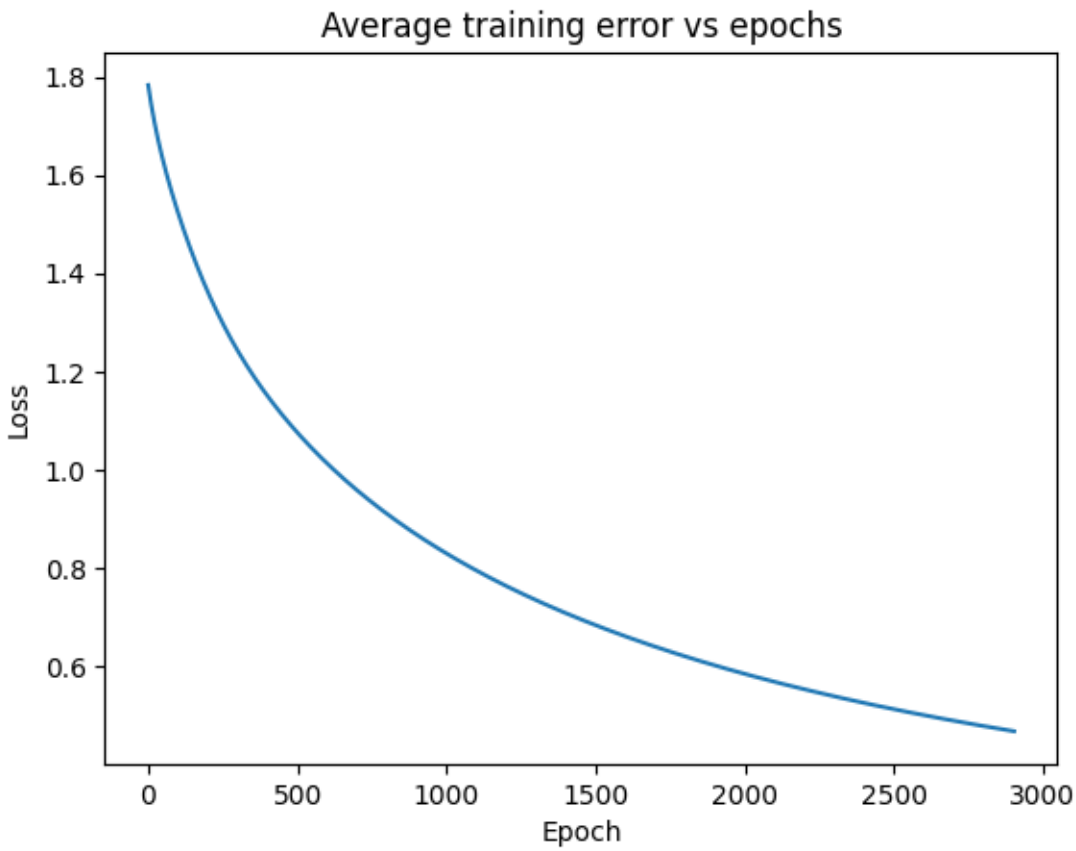
skipping

[15]:
```
df_model_b_history = pd.read_csv(f'{pathload}model_b_2903.csv')
model_b = keras.models.load_model(f'{pathload}model_b_2903.h5', compile=False)
model_b.compile(loss=keras.losses.SparseCategoricalCrossentropy(),
                optimizer=keras.optimizers.SGD(learning_rate=learning_rate_val),
                metrics=["accuracy"])
if(ii!=''):
```

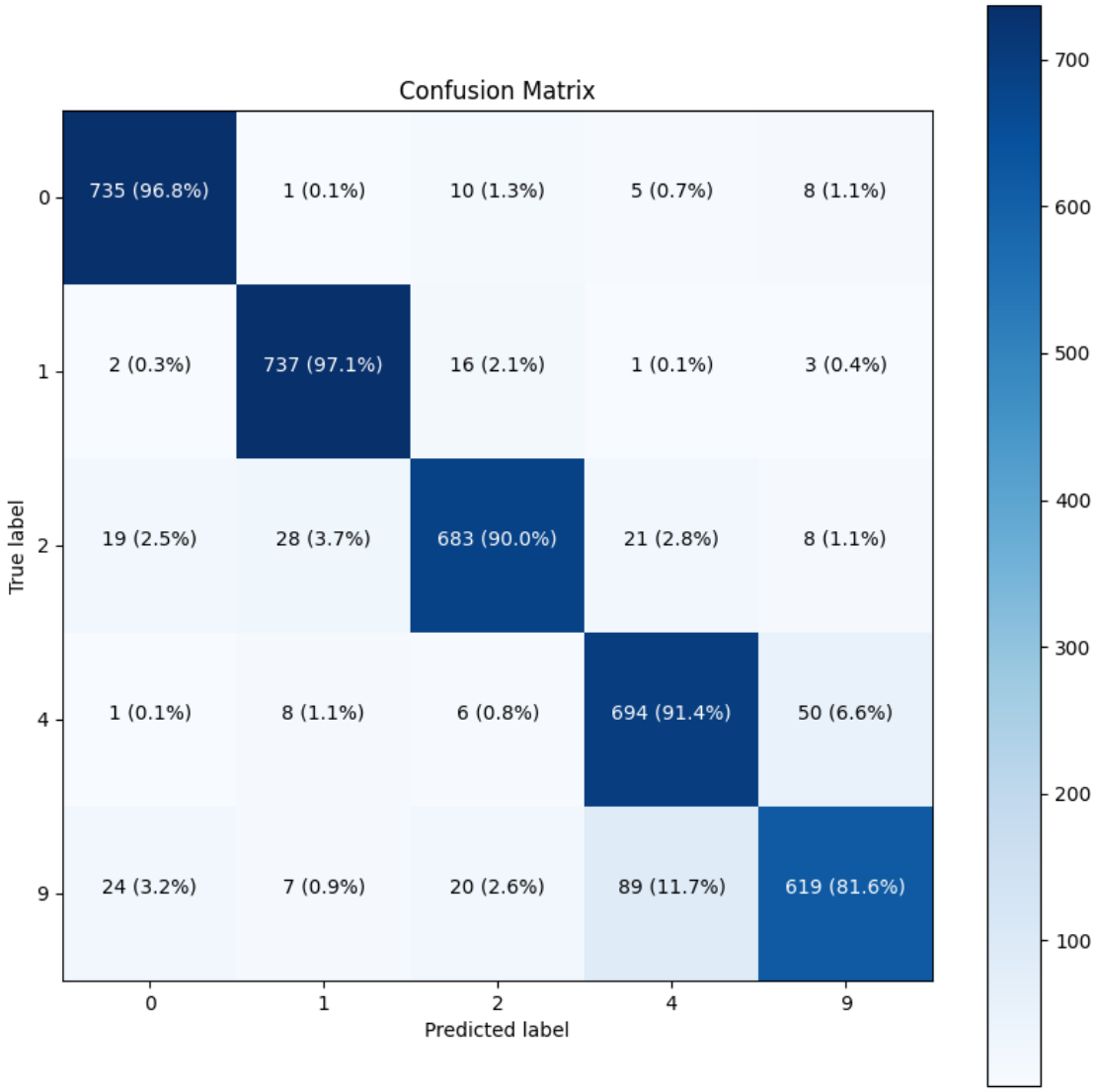
```
showResults(model_b, df_model_b_history)
```

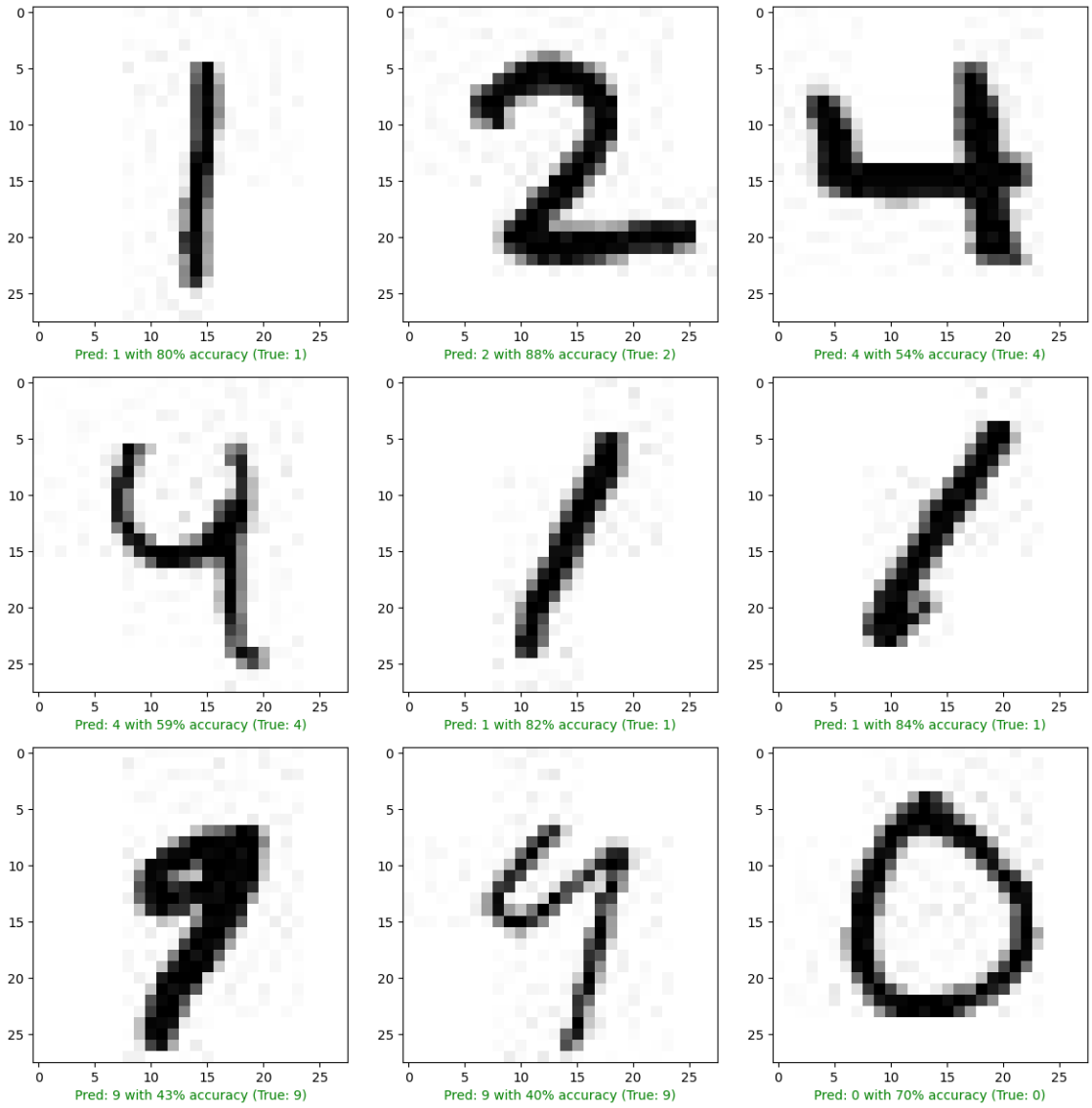
```
Training Accuracy for model: 91.74%
Validation Accuracy for model: 91.65%

2023-03-18 18:55:28.689414: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
Plugin optimizer for device_type GPU is enabled.

Test Accuracy for model: 91.38%
```






```
2023-03-18 18:55:29.569553: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
Plugin optimizer for device_type GPU is enabled.
2023-03-18 18:55:29.653752: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
Plugin optimizer for device_type GPU is enabled.

y_prob_a for one sample [[0.08553698 0.01303929 0.22374323 0.06115661
0.61652386]]
```


Confusion Matrix
735 (96.8%)
1 (0.1%)
10 (1.3%)
5 (0.7%)
8 (1.1%)
2 (0.3%)
737 (97.1%)
16 (2.1%)
1 (0.1%)
3 (0.4%)
19 (2.5%)
28 (3.7%)
683 (90.0%)
21 (2.8%)
8 (1.1%)
1 (0.1%)
8 (1.1%)
6 (0.8%)
694 (91.4%)
50 (6.6%)
24 (3.2%)
7 (0.9%)
20 (2.6%)
89 (11.7%)
619 (81.6%)
True label
Predicted label
0
1
2
4
9
700
600
500
400
300
200
100



3 (iii) SGD with momentum (generalized delta rule) – (batch_size=1) ,

[16]:
```
%%script echo skipping

if(iii!=''):
  # Set random seed
  tf.random.set_seed(random_state_global)

  # Create the model
  model_c = keras.Sequential([
```

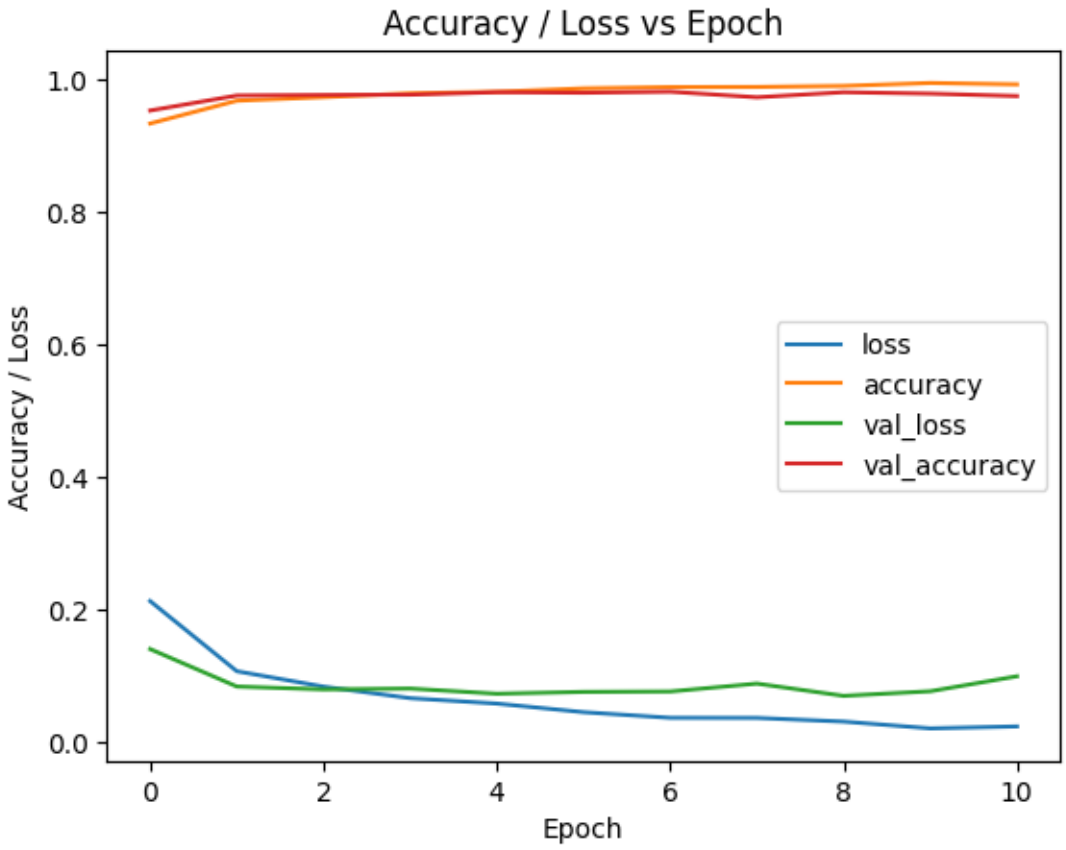
```
    keras.Input(shape=(784,), name="Input_layer"),
    keras.layers.Dense(Hidden_layer_I_N, activation=Hidden_layer_Activation,␣
↪name="Hidden_layer_I"),
    keras.layers.Dense(Hidden_layer_II_N, activation=Hidden_layer_Activation,␣
↪name="Hidden_layer_II"),
    keras.layers.Dense(Hidden_layer_III_N, activation=Hidden_layer_Activation,␣
↪name="Hidden_layer_III"),
    keras.layers.Dense(Output_layer_N, activation=Output_layer_Activation,␣
↪name="Output_layer")
  ], name='model_c')

  # Compile the model
  model_c.compile(loss=keras.losses.SparseCategoricalCrossentropy(),
                  optimizer=keras.optimizers.
↪SGD(learning_rate=learning_rate_val, momentum=momentum_val),
                  metrics=["accuracy"])


  # Fit the model
  history_c = model_c.fit(df_train.iloc[:,:-1],
                          df_train.iloc[:,-1],
                          epochs=epoch_val_c,
                          batch_size=batch_size_val_c,
                          validation_data=(df_valid.iloc[:,:-1], df_valid.iloc[:
↪,-1]),
                          callbacks=[model_saver, HistorySaver(),␣
↪early_stopping_cb], verbose=0)

  df_model_c_history = pd.DataFrame(history_c.history)

  print('\n\n\n')
  # model_c.summary()
  print(df_model_c_history)
```

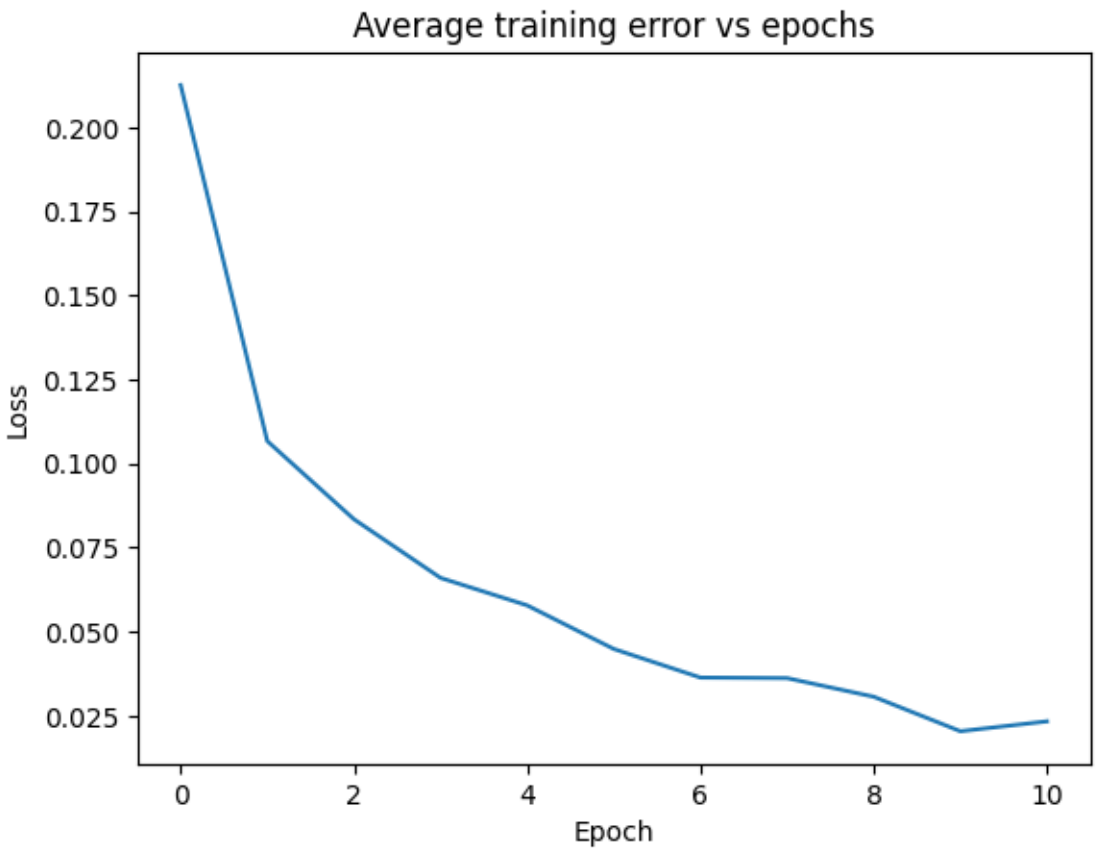
```
skipping
```

[17]:
```
df_model_c_history = pd.read_csv(f'{pathload}model_c_11.csv')
model_c = keras.models.load_model(f'{pathload}model_c_11.h5', compile=False)
model_c.compile(loss=keras.losses.SparseCategoricalCrossentropy(),
                optimizer=keras.optimizers.SGD(learning_rate=learning_rate_val,␣
↪momentum=momentum_val),
                metrics=["accuracy"])
if(iii!=''):
  showResults(model_c, df_model_c_history)
```

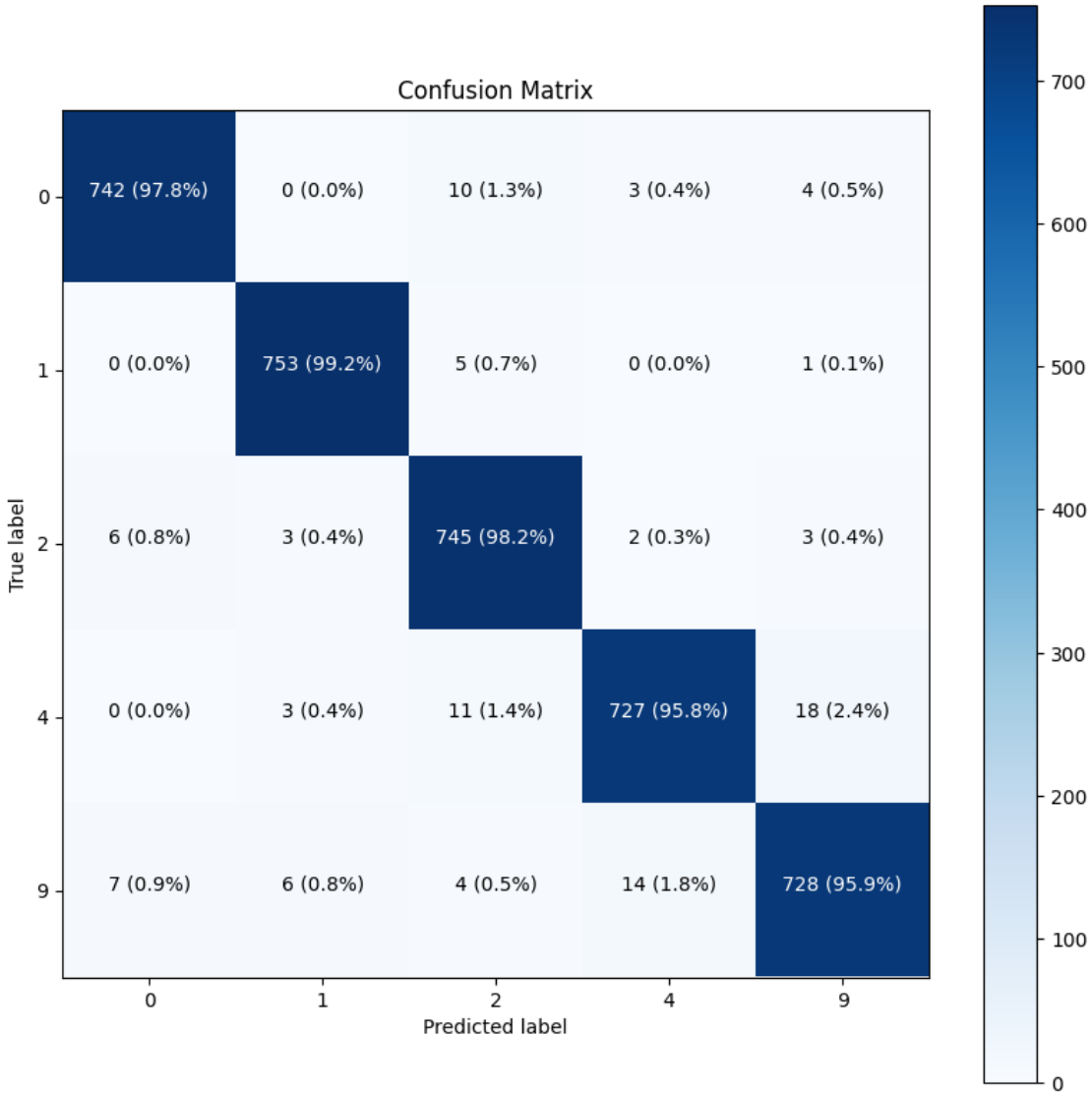
```
Training Accuracy for model: 99.26%
Validation Accuracy for model: 97.50%
```

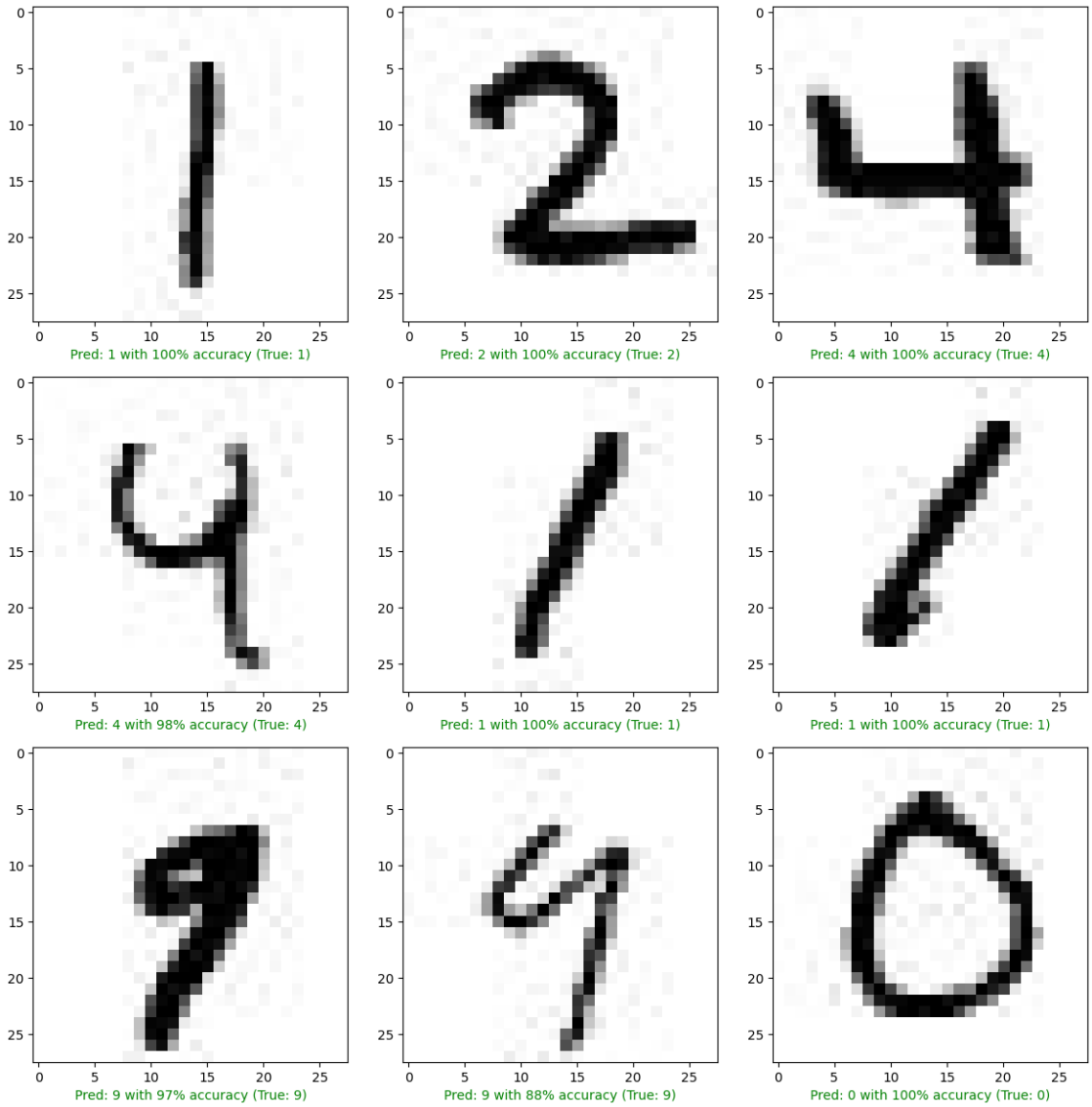
```
2023-03-18 18:55:31.257316: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
Plugin optimizer for device_type GPU is enabled.

Test Accuracy for model: 97.36%
```






```
2023-03-18 18:55:32.078878: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
Plugin optimizer for device_type GPU is enabled.
2023-03-18 18:55:32.155226: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
Plugin optimizer for device_type GPU is enabled.

y_prob_a for one sample [[2.8069773e-05 1.1282416e-04 3.1757661e-06
2.0497866e-04 9.9965084e-01]]
```


Confusion Matrix
742 (97.8%)
0 (0.0%)
10 (1.3%)
3 (0.4%)
4 (0.5%)
0 (0.0%)
753 (99.2%)
5 (0.7%)
0 (0.0%)
1 (0.1%)
6 (0.8%)
3 (0.4%)
745 (98.2%)
2 (0.3%)
3 (0.4%)
0 (0.0%)
3 (0.4%)
11 (1.4%)
727 (95.8%)
18 (2.4%)
7 (0.9%)
6 (0.8%)
4 (0.5%)
14 (1.8%)
728 (95.9%)
True label
Predicted label
0
1
2
4
9
700
600
500
400
300
200
100
0



4 (iv) SGD with momentum (NAG) – (batch_size=1)

[18]:
```
%%script echo skipping

if(iv!=''):
  # Set random seed
  tf.random.set_seed(random_state_global)

  # Create the model
  model_d = keras.Sequential([
    keras.Input(shape=(784,), name="Input_layer"),
```

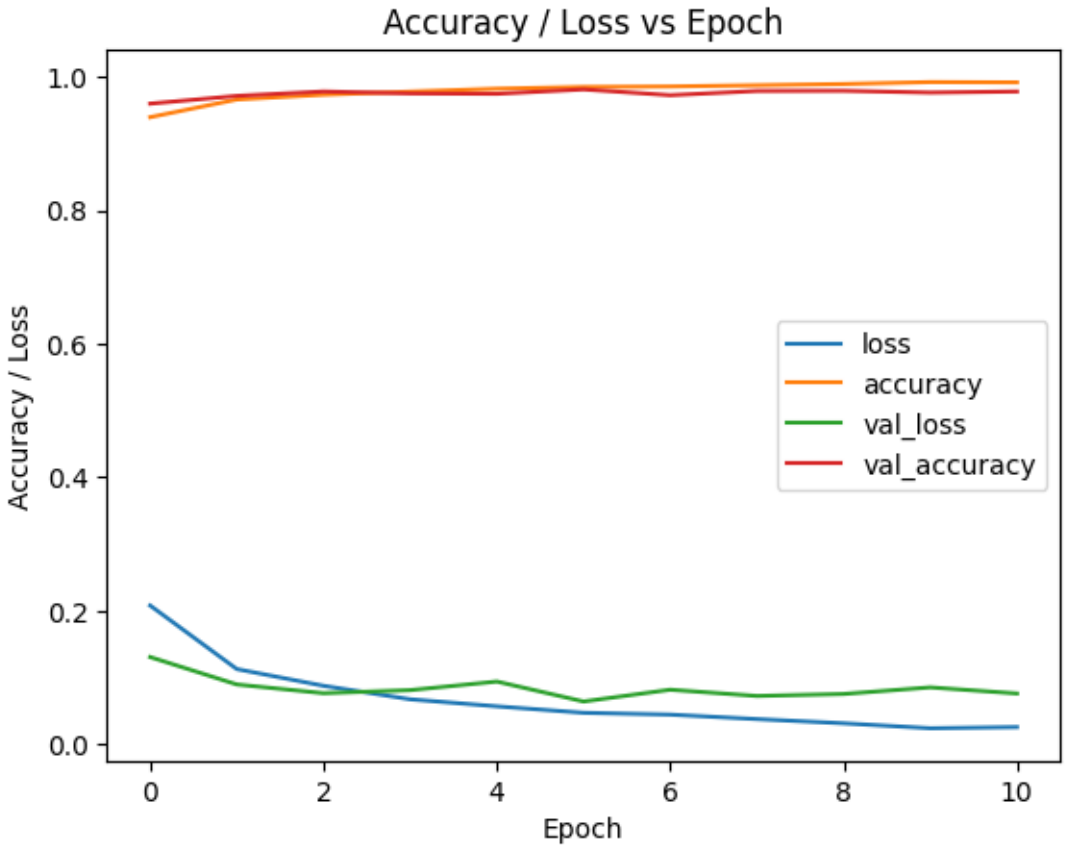
```
   keras.layers.Dense(Hidden_layer_I_N, activation=Hidden_layer_Activation,␣
↪name="Hidden_layer_I"),
   keras.layers.Dense(Hidden_layer_II_N, activation=Hidden_layer_Activation,␣
↪name="Hidden_layer_II"),
   keras.layers.Dense(Hidden_layer_III_N, activation=Hidden_layer_Activation,␣
↪name="Hidden_layer_III"),
   keras.layers.Dense(Output_layer_N, activation=Output_layer_Activation,␣
↪name="Output_layer")
 ], name='model_d')

 # Compile the model
 model_d.compile(loss=keras.losses.SparseCategoricalCrossentropy(),
                 optimizer=keras.optimizers.
↪SGD(learning_rate=learning_rate_val, momentum=momentum_val, nesterov=True),
                 metrics=["accuracy"])

 # Fit the model
 history_d = model_d.fit(df_train.iloc[:,:-1],
                       df_train.iloc[:,-1],
                       epochs=epoch_val_d,
                       batch_size=batch_size_val_d,
                       validation_data=(df_valid.iloc[:,:-1], df_valid.iloc[:
↪,-1]),
                       callbacks=[model_saver, HistorySaver(),␣
↪early_stopping_cb], verbose=0)

 df_model_d_history = pd.DataFrame(history_d.history)

 print('\n\n\n')
 # model_d.summary()
 print(df_model_d_history)
```

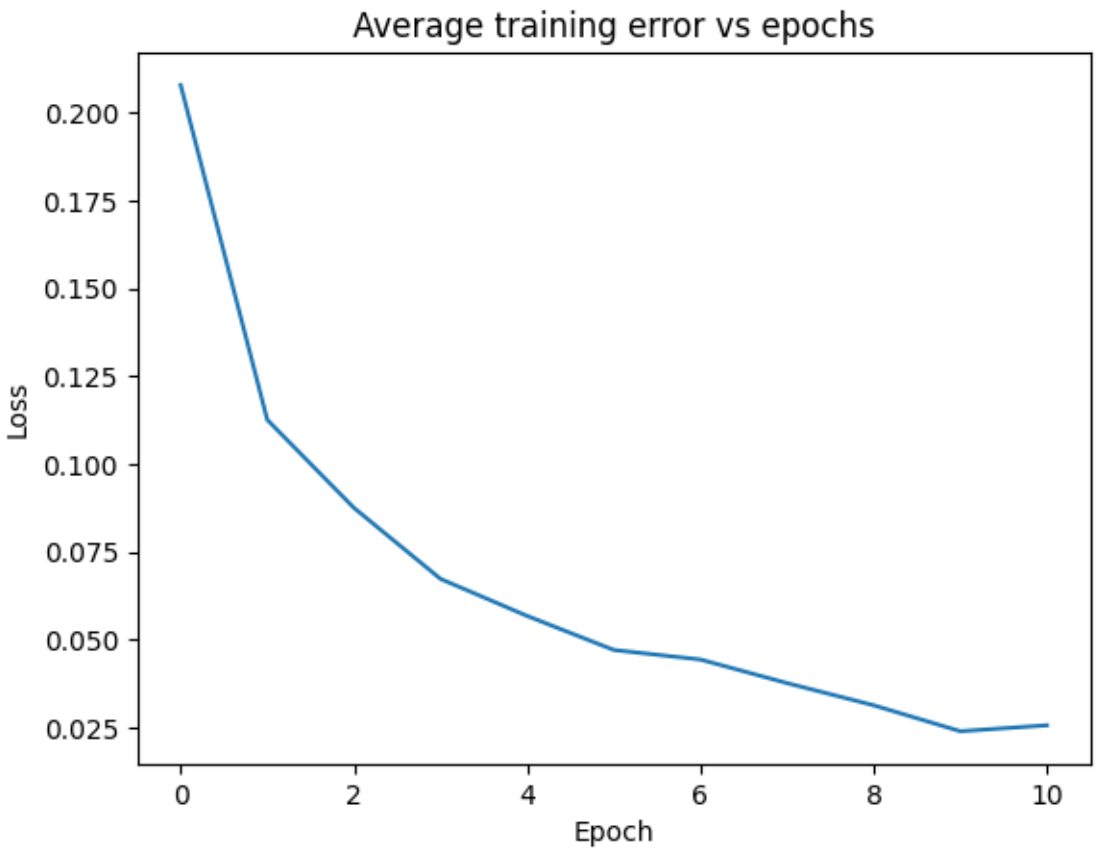
skipping

[19]:
```
df_model_d_history = pd.read_csv(f'{pathload}model_d_11.csv')
model_d = keras.models.load_model(f'{pathload}model_d_11.h5', compile=False)
model_d.compile(loss=keras.losses.SparseCategoricalCrossentropy(),
                optimizer=keras.optimizers.SGD(learning_rate=learning_rate_val,␣
↪momentum=momentum_val, nesterov=True),
                metrics=["accuracy"])
if(iv!=''):
  showResults(model_d, df_model_d_history)
```

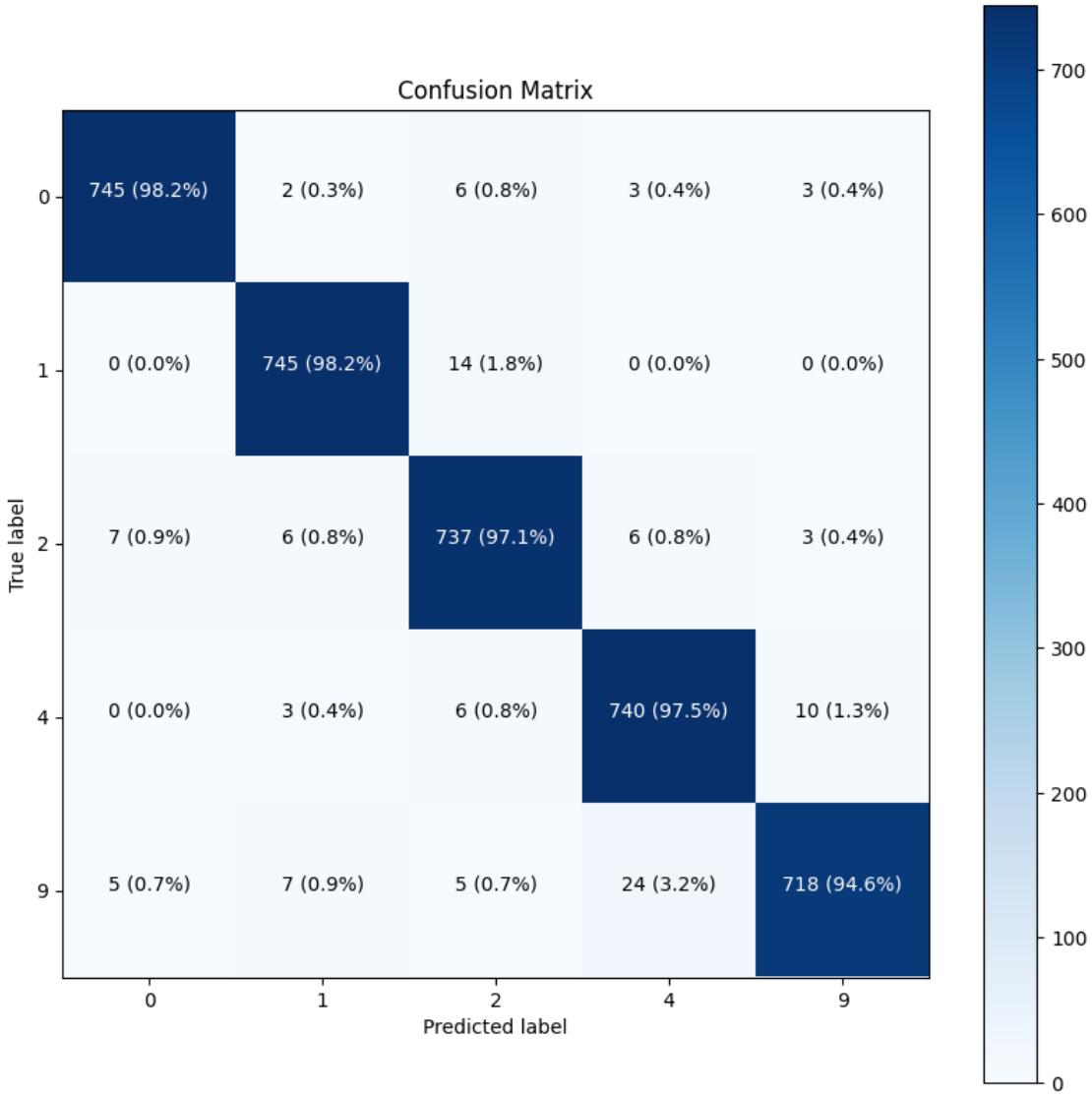
```
Training Accuracy for model: 99.16%
Validation Accuracy for model: 97.79%

2023-03-18 18:55:33.712283: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
```

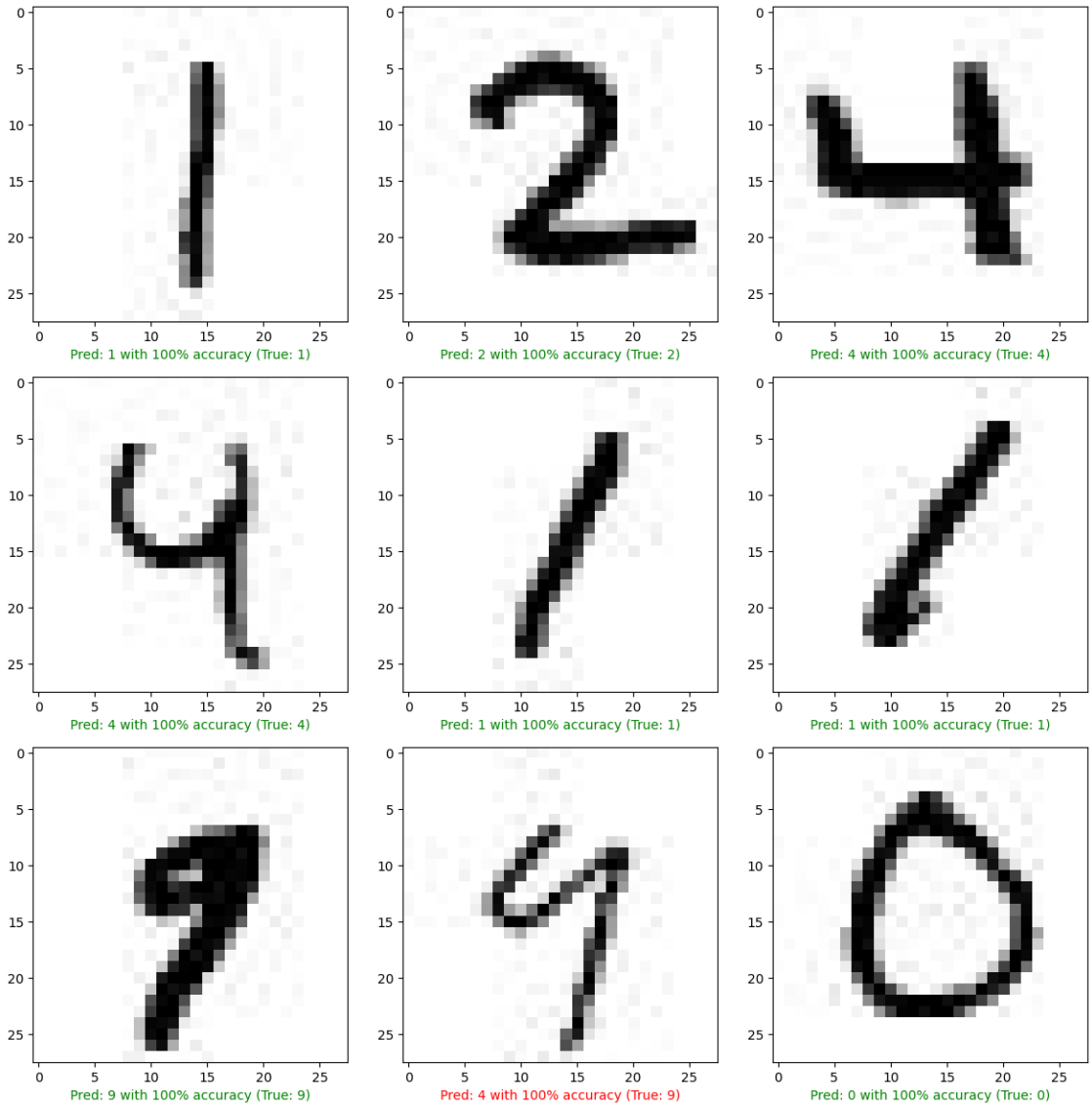
```
Plugin optimizer for device_type GPU is enabled.

Test Accuracy for model: 97.10%
```






```
2023-03-18 18:55:34.490402: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
Plugin optimizer for device_type GPU is enabled.
2023-03-18 18:55:34.560553: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
Plugin optimizer for device_type GPU is enabled.

y_prob_a for one sample [[2.8684158e-06 6.8683403e-05 2.7424753e-06
1.7308227e-04 9.9975258e-01]]
```


Confusion Matrix
745 (98.2%)
2 (0.3%)
6 (0.8%)
3 (0.4%)
3 (0.4%)
0 (0.0%)
745 (98.2%)
14 (1.8%)
0 (0.0%)
0 (0.0%)
7 (0.9%)
6 (0.8%)
737 (97.1%)
6 (0.8%)
3 (0.4%)
0 (0.0%)
3 (0.4%)
6 (0.8%)
740 (97.5%)
10 (1.3%)
5 (0.7%)
7 (0.9%)
5 (0.7%)
24 (3.2%)
718 (94.6%)
True label
Predicted label
0
1
2
4
9
700
600
500
400
300
200
100
0



5 (v) AdaGrad – (batch_size=1)

[20]:
```
%%script echo skipping

if(v!=''):
  # Set random seed
  tf.random.set_seed(random_state_global)

  # Create the model
  model_e = keras.Sequential([
    keras.Input(shape=(784,), name="Input_layer"),
```

```
   keras.layers.Dense(Hidden_layer_I_N, activation=Hidden_layer_Activation,␣
↪name="Hidden_layer_I"),
   keras.layers.Dense(Hidden_layer_II_N, activation=Hidden_layer_Activation,␣
↪name="Hidden_layer_II"),
   keras.layers.Dense(Hidden_layer_III_N, activation=Hidden_layer_Activation,␣
↪name="Hidden_layer_III"),
   keras.layers.Dense(Output_layer_N, activation=Output_layer_Activation,␣
↪name="Output_layer")
 ], name='model_e')

 # Compile the model
 model_e.compile(loss=keras.losses.SparseCategoricalCrossentropy(),
                 optimizer=keras.optimizers.
↪Adagrad(learning_rate=learning_rate_val),
                 metrics=["accuracy"])


 # Fit the model
 history_e = model_e.fit(df_train.iloc[:,:-1],
                      df_train.iloc[:,-1],
                      epochs=epoch_val_e,
                      batch_size=batch_size_val_e,
                      validation_data=(df_valid.iloc[:,:-1], df_valid.iloc[:
↪,-1]),
                      callbacks=[model_saver, HistorySaver(),␣
↪early_stopping_cb], verbose=0)

 df_model_e_history = pd.DataFrame(history_e.history)

 print('\n\n\n')
 # model_e.summary()
 print(df_model_e_history)
```

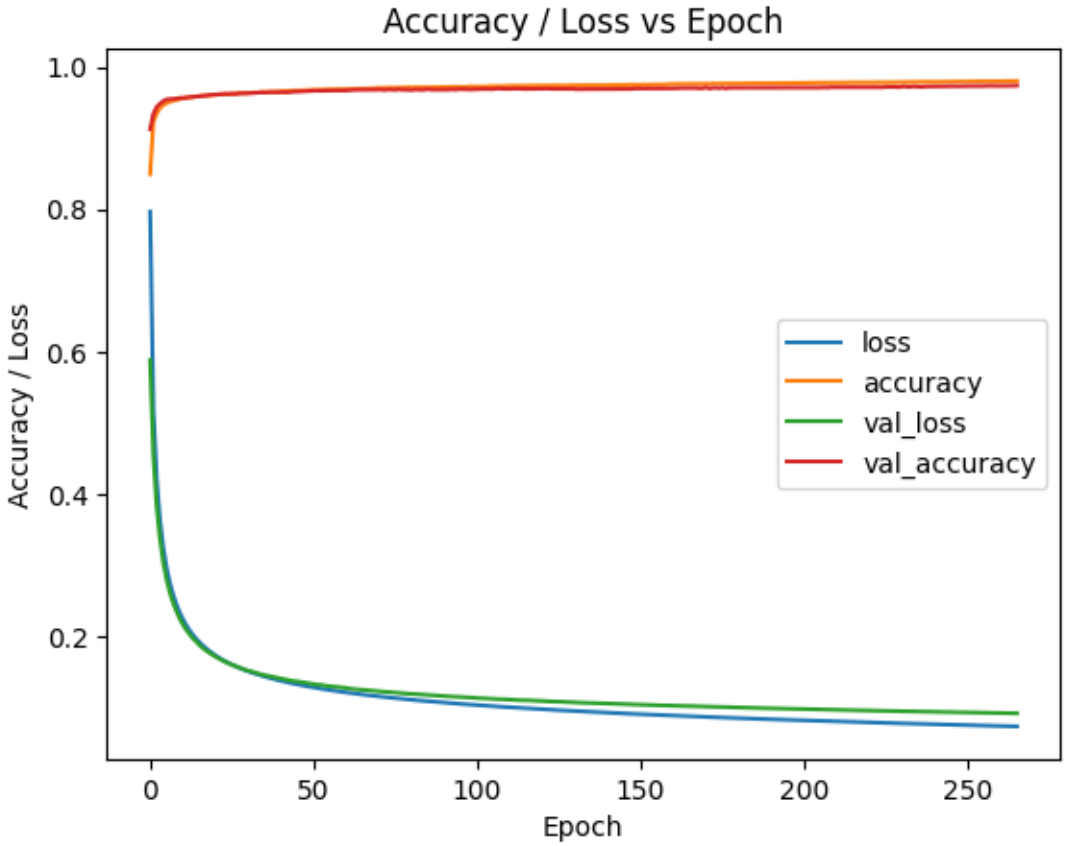
skipping

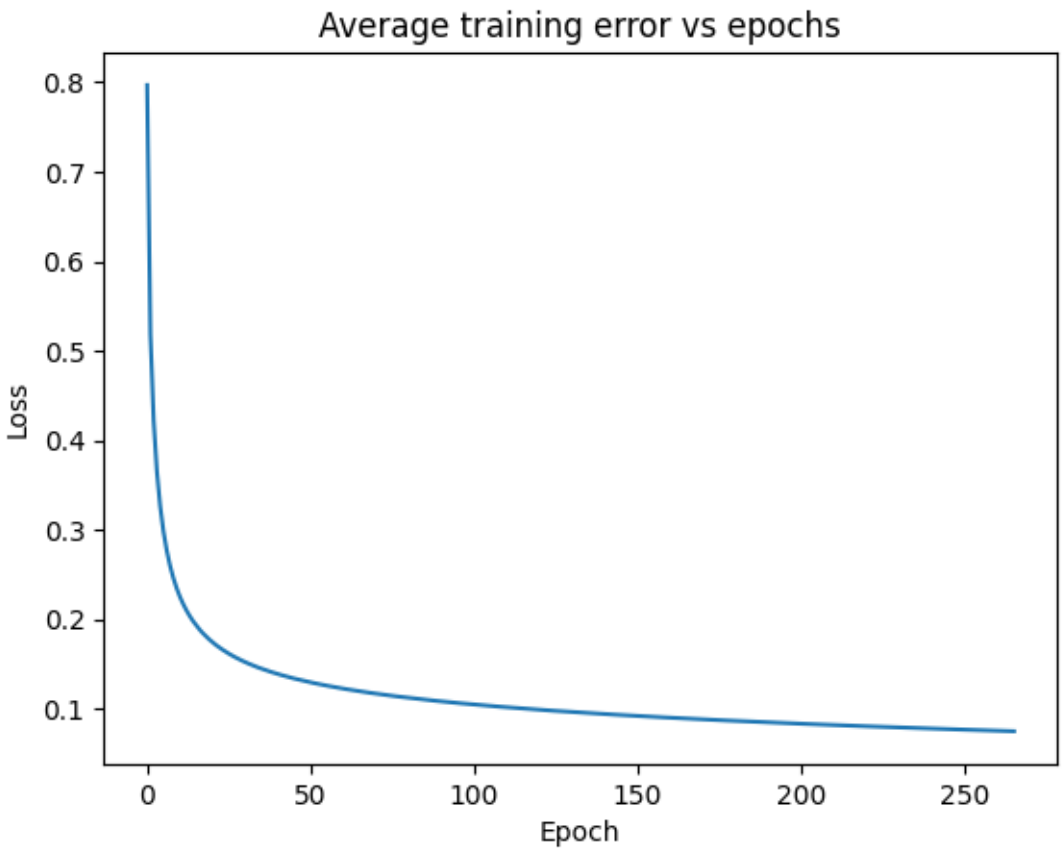
[21]:
```
df_model_e_history = pd.read_csv(f'{pathload}model_e_266.csv')
model_e = keras.models.load_model(f'{pathload}model_e_266.h5', compile=False)
model_e.compile(loss=keras.losses.SparseCategoricalCrossentropy(),
                optimizer=keras.optimizers.
↪Adagrad(learning_rate=learning_rate_val),
                metrics=["accuracy"])
if(v!=''):
  showResults(model_e, df_model_e_history)
```

```
Training Accuracy for model: 98.01%
Validation Accuracy for model: 97.36%
```

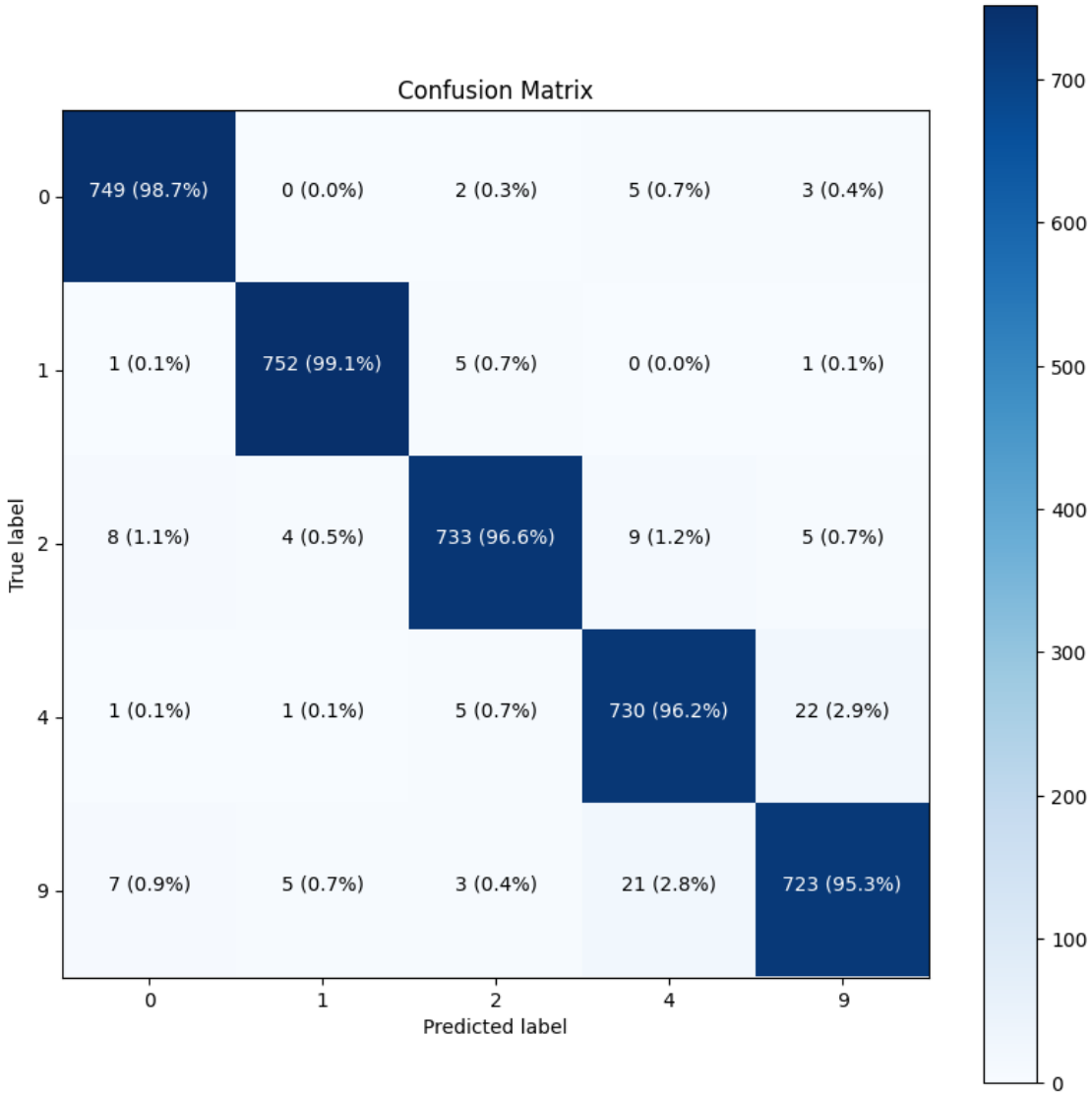
```
2023-03-18 18:55:35.920836: I
```

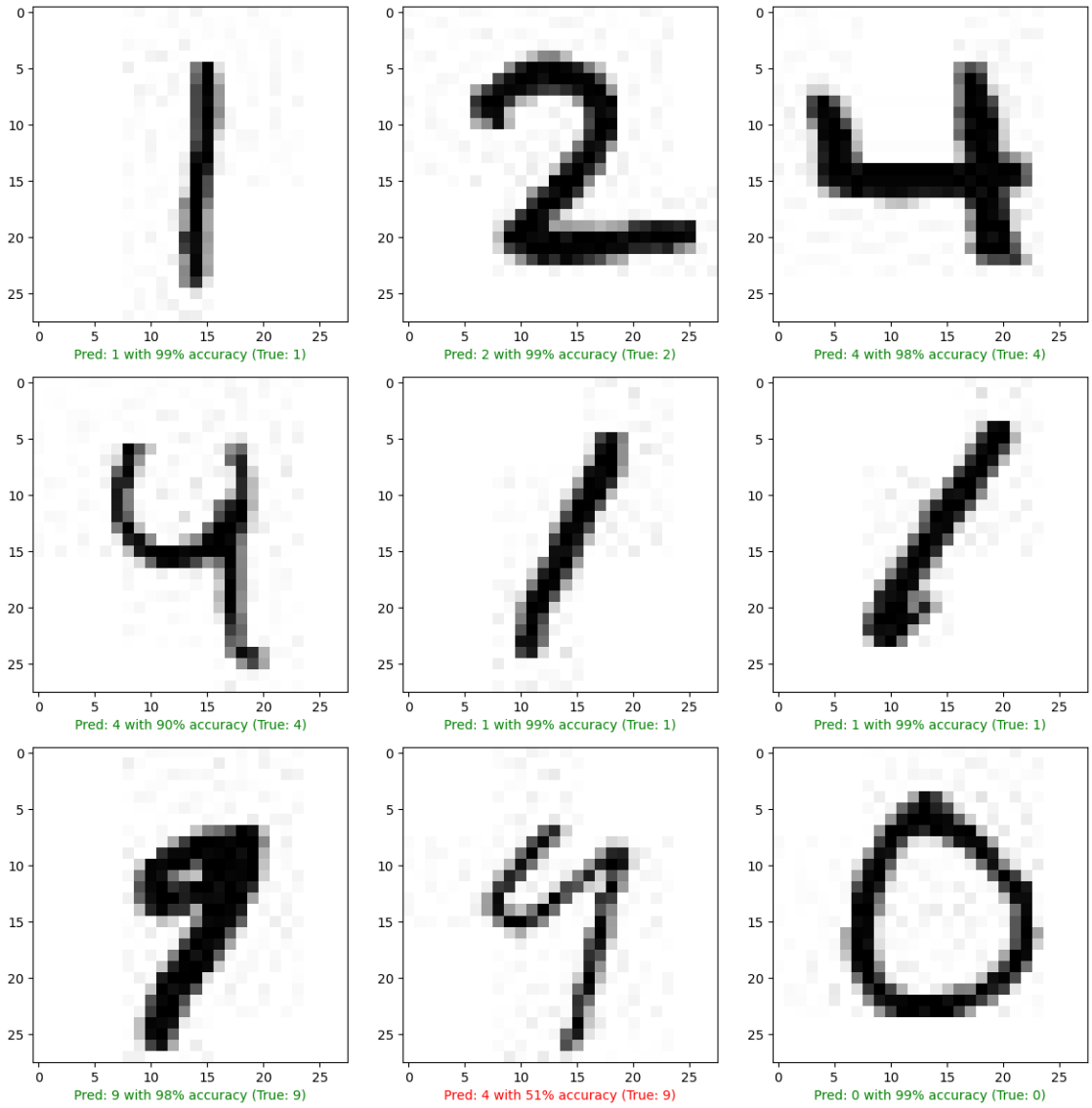
```
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
Plugin optimizer for device_type GPU is enabled.

Test Accuracy for model: 97.15%
```






```
2023-03-18 18:55:36.726429: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
Plugin optimizer for device_type GPU is enabled.
2023-03-18 18:55:36.792240: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
Plugin optimizer for device_type GPU is enabled.

y_prob_a for one sample [[5.0617667e-04 1.1615877e-03 6.7343600e-03
4.6806815e-03 9.8691726e-01]]
```


Confusion Matrix
749 (98.7%)
0 (0.0%)
2 (0.3%)
5 (0.7%)
3 (0.4%)
1 (0.1%)
752 (99.1%)
5 (0.7%)
0 (0.0%)
1 (0.1%)
8 (1.1%)
4 (0.5%)
733 (96.6%)
9 (1.2%)
5 (0.7%)
1 (0.1%)
1 (0.1%)
5 (0.7%)
730 (96.2%)
22 (2.9%)
7 (0.9%)
5 (0.7%)
3 (0.4%)
21 (2.8%)
723 (95.3%)
True label
Predicted label
0
1
2
4
9
700
600
500
400
300
200
100
0



6 (vi) RMSProp – (batch_size=1)

[22]:
```
%%script echo skipping

if(vi!=''):
  # Set random seed
  tf.random.set_seed(random_state_global)

  # Create the model
  model_f = keras.Sequential([
    keras.Input(shape=(784,), name="Input_layer"),
```

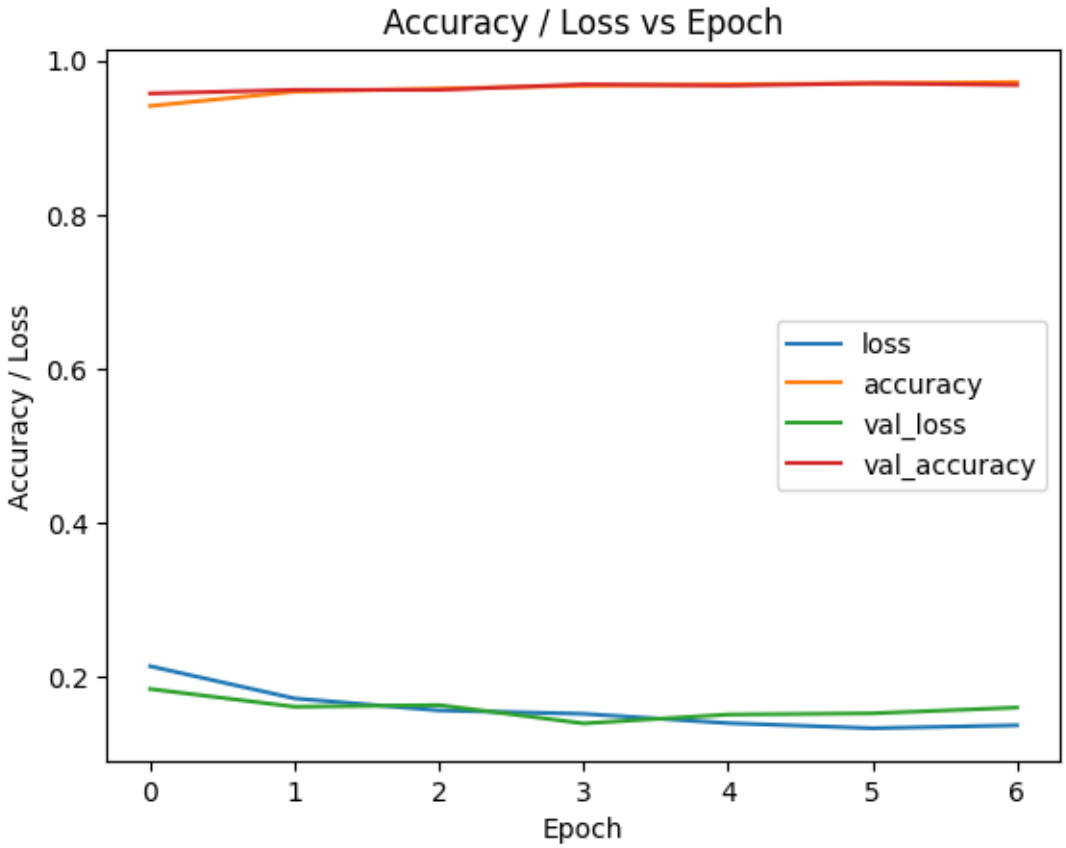
```
   keras.layers.Dense(Hidden_layer_I_N, activation=Hidden_layer_Activation,␣
↪name="Hidden_layer_I"),
   keras.layers.Dense(Hidden_layer_II_N, activation=Hidden_layer_Activation,␣
↪name="Hidden_layer_II"),
   keras.layers.Dense(Hidden_layer_III_N, activation=Hidden_layer_Activation,␣
↪name="Hidden_layer_III"),
   keras.layers.Dense(Output_layer_N, activation=Output_layer_Activation,␣
↪name="Output_layer")
 ], name='model_f')

 # Compile the model
 model_f.compile(loss=keras.losses.SparseCategoricalCrossentropy(),
                 optimizer=keras.optimizers.
↪RMSprop(learning_rate=learning_rate_val, epsilon=epsilon_val),
                 metrics=["accuracy"])

 # Fit the model
 history_f = model_f.fit(df_train.iloc[:,:-1],
                       df_train.iloc[:,-1],
                       epochs=epoch_val_f,
                       batch_size=batch_size_val_f,
                       validation_data=(df_valid.iloc[:,:-1], df_valid.iloc[:
↪,-1]),
                       callbacks=[model_saver, HistorySaver(),␣
↪early_stopping_cb], verbose=0)

 df_model_f_history = pd.DataFrame(history_f.history)

 print('\n\n\n')
 # model_f.summary()
 print(df_model_f_history)
```

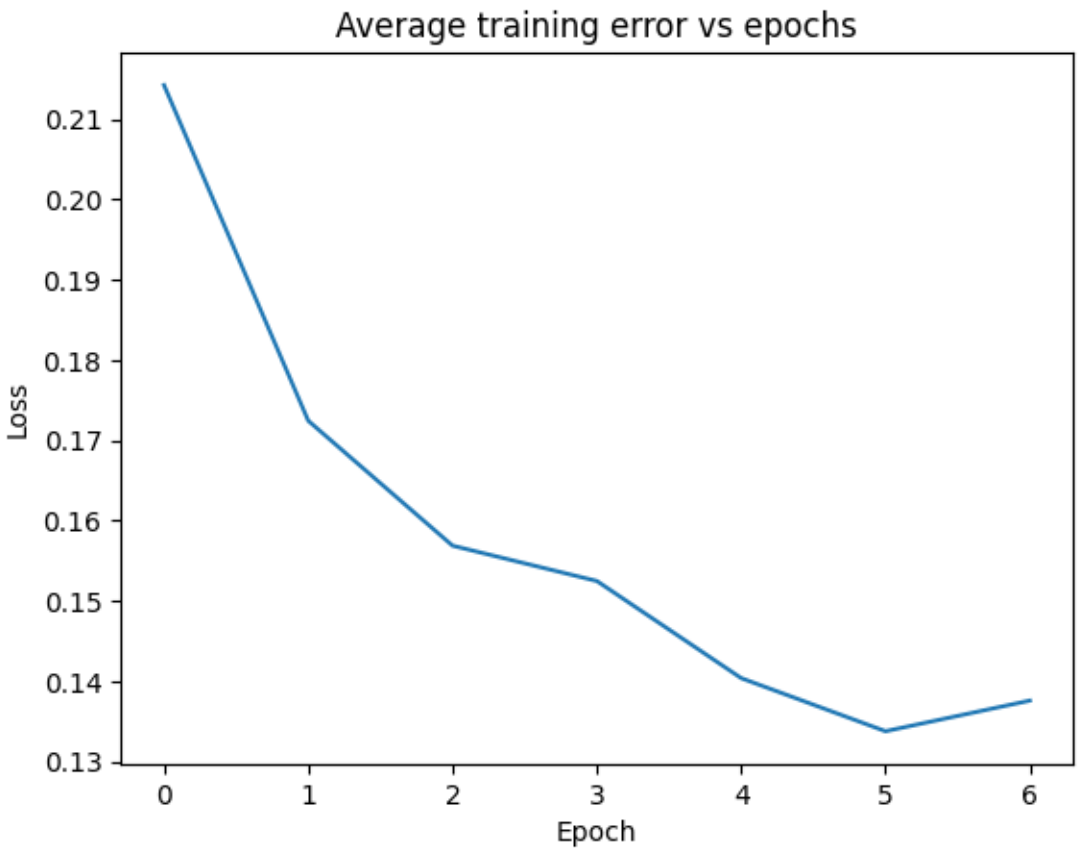
skipping

[23]:
```
df_model_f_history = pd.read_csv(f'{pathload}model_f_7.csv')
model_f = keras.models.load_model(f'{pathload}model_f_7.h5', compile=False)
model_f.compile(loss=keras.losses.SparseCategoricalCrossentropy(),
                optimizer=keras.optimizers.
↪RMSprop(learning_rate=learning_rate_val, epsilon=epsilon_val),
                metrics=["accuracy"])
if(vi!=''):
  showResults(model_f, df_model_f_history)
```

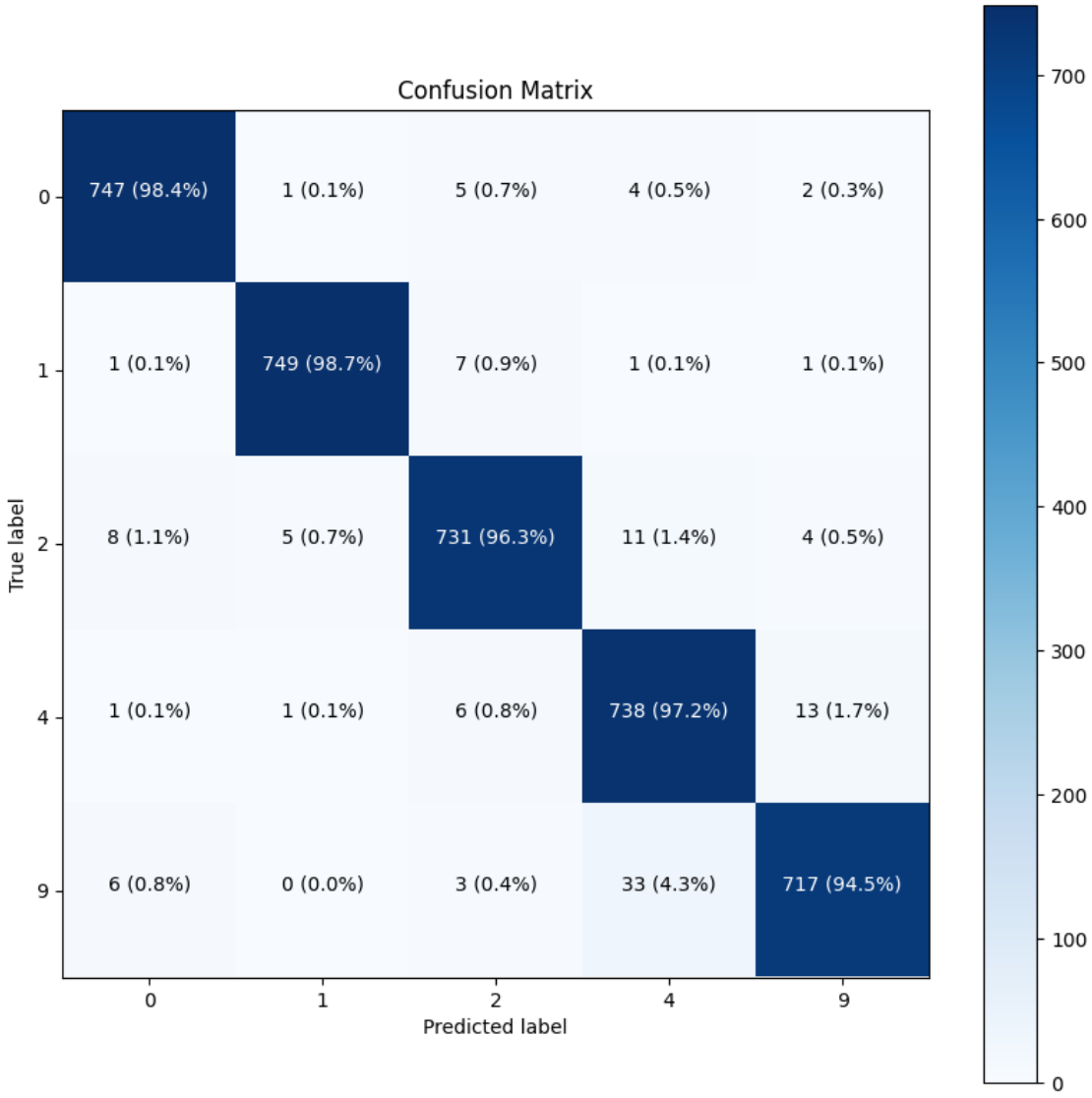
```
Training Accuracy for model: 97.22%
Validation Accuracy for model: 96.84%

2023-03-18 18:55:38.291216: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
```

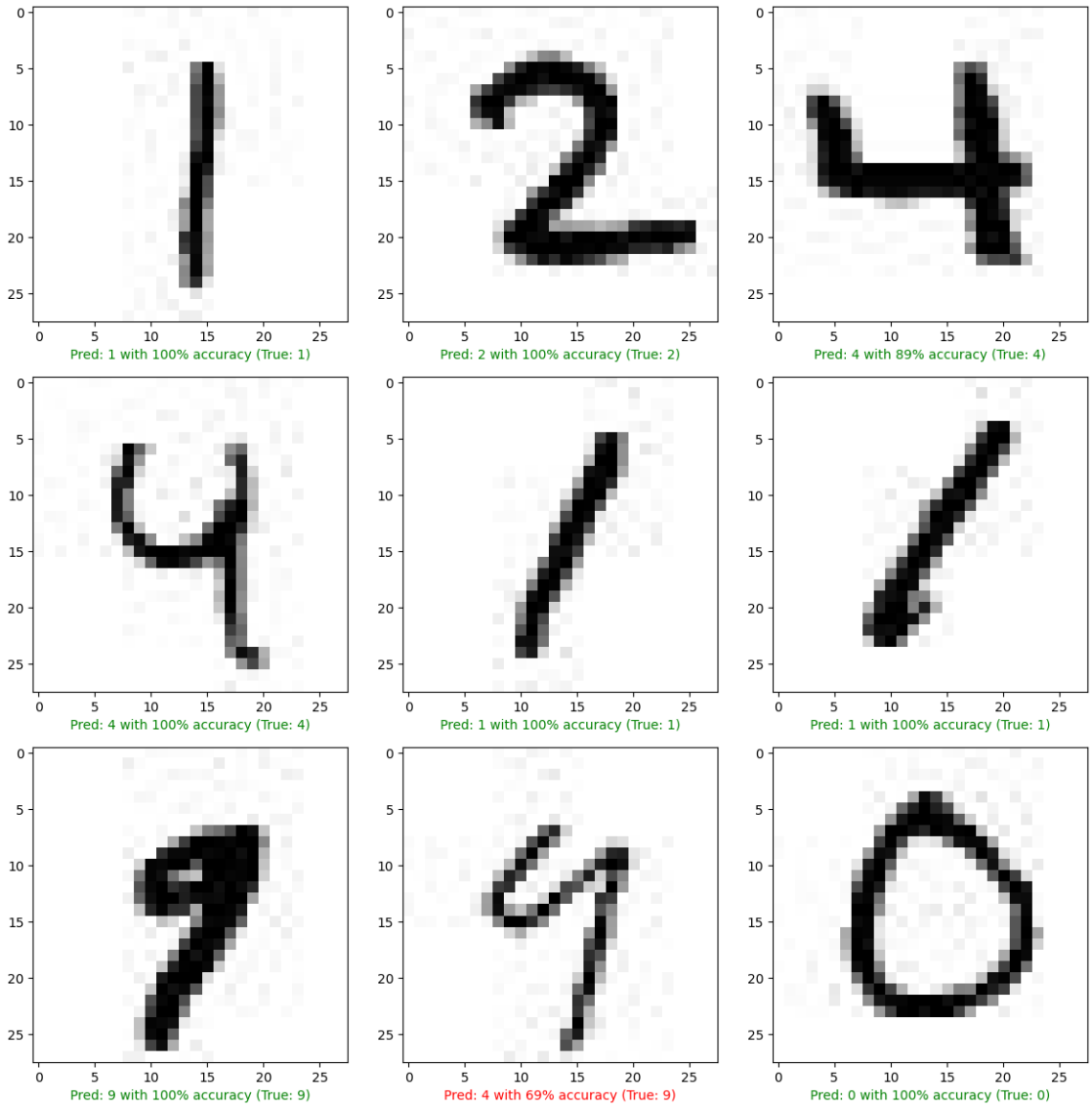
```
Plugin optimizer for device_type GPU is enabled.

Test Accuracy for model: 97.02%
```






```
2023-03-18 18:55:39.067683: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
Plugin optimizer for device_type GPU is enabled.
2023-03-18 18:55:39.135496: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
Plugin optimizer for device_type GPU is enabled.

y_prob_a for one sample [[4.0104670e-08 7.7932555e-06 1.0511450e-05
2.9708666e-04 9.9968469e-01]]
```


Confusion Matrix
747 (98.4%)
1 (0.1%)
5 (0.7%)
4 (0.5%)
2 (0.3%)
1 (0.1%)
749 (98.7%)
7 (0.9%)
1 (0.1%)
1 (0.1%)
8 (1.1%)
5 (0.7%)
731 (96.3%)
11 (1.4%)
4 (0.5%)
1 (0.1%)
1 (0.1%)
6 (0.8%)
738 (97.2%)
13 (1.7%)
6 (0.8%)
0 (0.0%)
3 (0.4%)
33 (4.3%)
717 (94.5%)
0
1
2
4
9
True label
Predicted label
700
600
500
400
300
200
100
0



7 (vii) Adam optimizer – (batch_size=1)

[24]:
```
%%script echo skipping

if(vii!=''):
  # Set random seed
  tf.random.set_seed(random_state_global)

  # Create the model
  model_g = keras.Sequential([
    keras.Input(shape=(784,), name="Input_layer"),
```

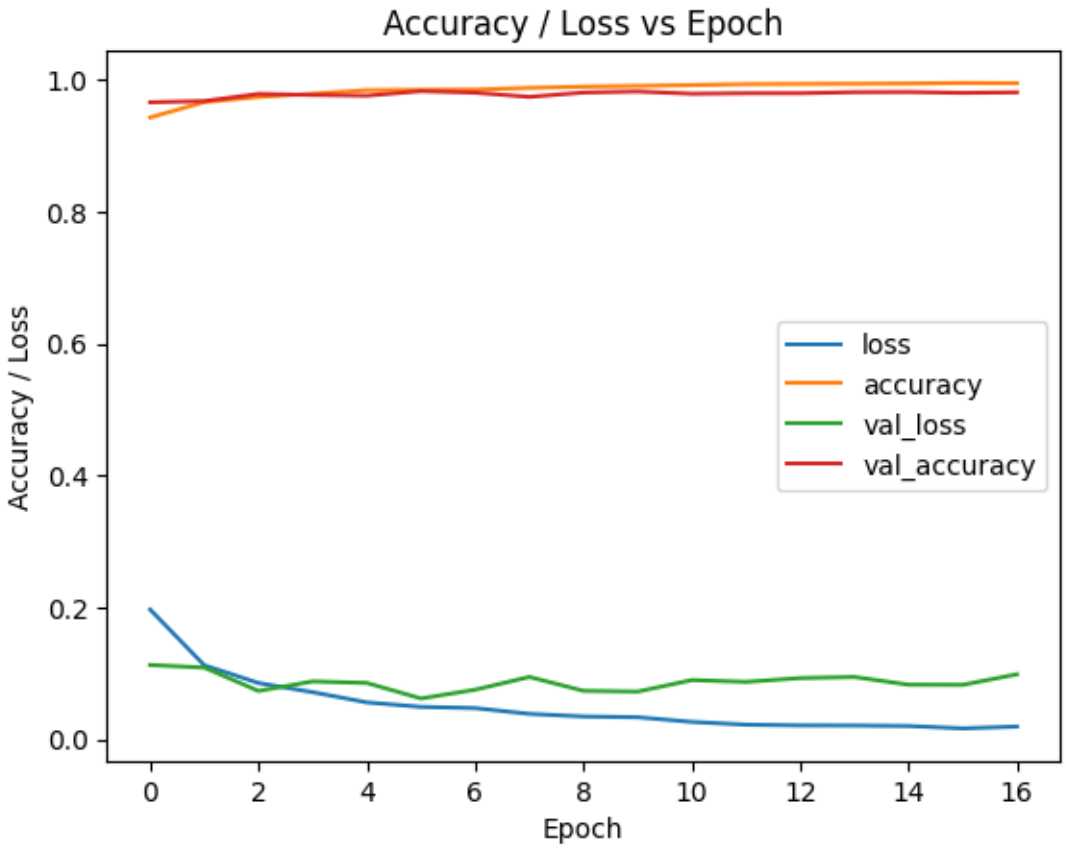
```
   keras.layers.Dense(Hidden_layer_I_N, activation=Hidden_layer_Activation,␣
↪name="Hidden_layer_I"),
   keras.layers.Dense(Hidden_layer_II_N, activation=Hidden_layer_Activation,␣
↪name="Hidden_layer_II"),
   keras.layers.Dense(Hidden_layer_III_N, activation=Hidden_layer_Activation,␣
↪name="Hidden_layer_III"),
   keras.layers.Dense(Output_layer_N, activation=Output_layer_Activation,␣
↪name="Output_layer")
 ], name='model_g')

 # Compile the model
 model_g.compile(loss=keras.losses.SparseCategoricalCrossentropy(),
                 optimizer=keras.optimizers.
↪Adam(learning_rate=learning_rate_val,
                                                 epsilon=epsilon_val,
                                                 beta_1=beta_1_val,
                                                 beta_2=beta_2_val),
                 metrics=["accuracy"])

 # Fit the model
 history_g = model_g.fit(df_train.iloc[:,:-1],
                         df_train.iloc[:,-1],
                         epochs=epoch_val_g,
                         batch_size=batch_size_val_g,
                         validation_data=(df_valid.iloc[:,:-1], df_valid.iloc[:
↪,-1]),
                         callbacks=[model_saver, HistorySaver(),␣
↪early_stopping_cb], verbose=0)

 df_model_g_history = pd.DataFrame(history_g.history)

 print('\n\n\n')
 # model_g.summary()
 print(df_model_g_history)
```

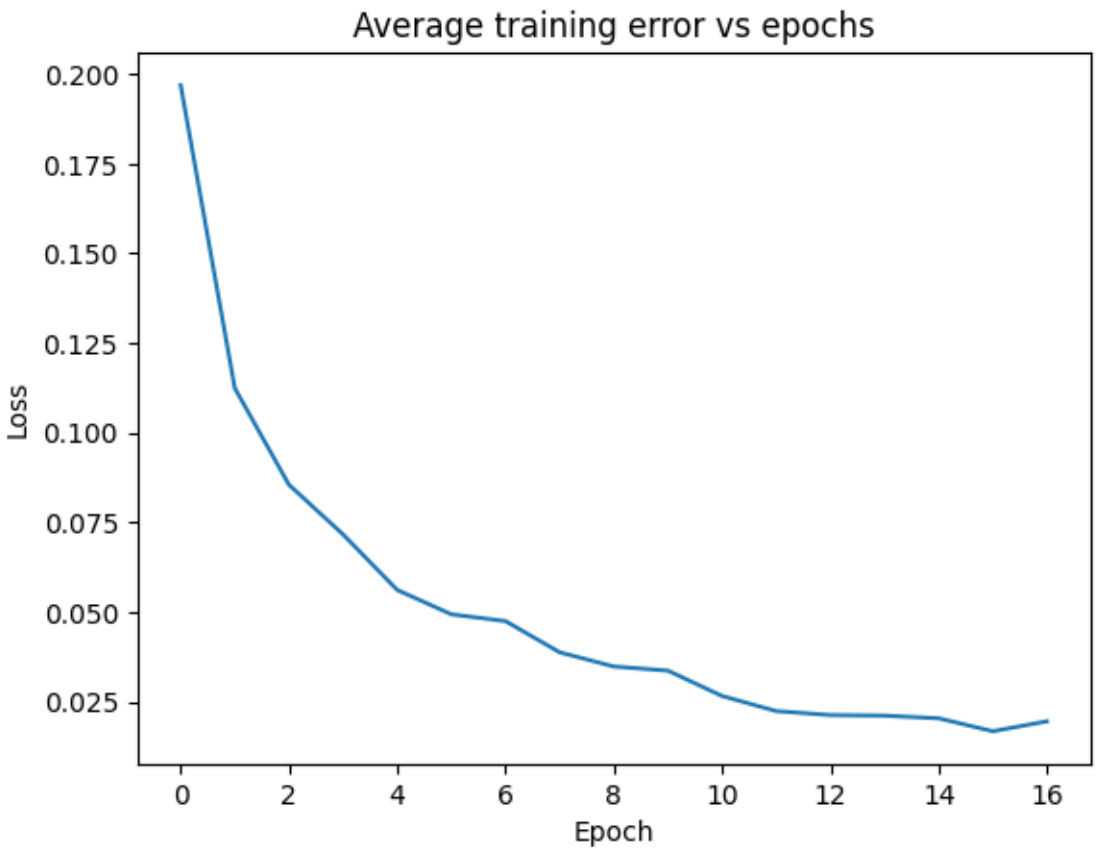
skipping

[25]:
```
df_model_g_history = pd.read_csv(f'{pathload}model_g_17.csv')
model_g = keras.models.load_model(f'{pathload}model_g_17.h5', compile=False)
model_g.compile(loss=keras.losses.SparseCategoricalCrossentropy(),
                 optimizer=keras.optimizers.
↪Adam(learning_rate=learning_rate_val,
                                                 epsilon=epsilon_val,
                                                 beta_1=beta_1_val,
                                                 beta_2=beta_2_val),
                 metrics=["accuracy"])
if(vii!=''):
```

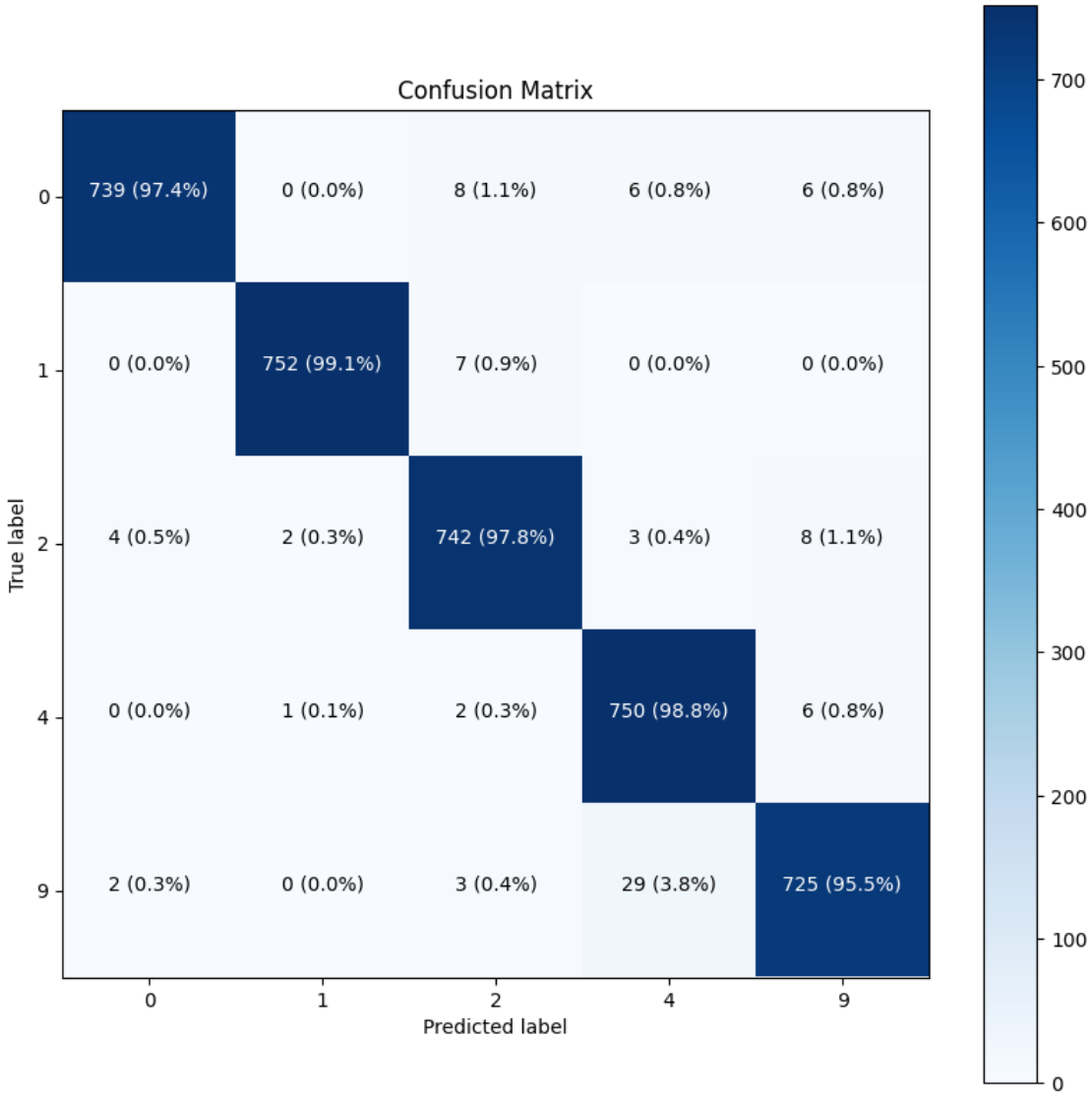
```
showResults(model_g, df_model_g_history)
```

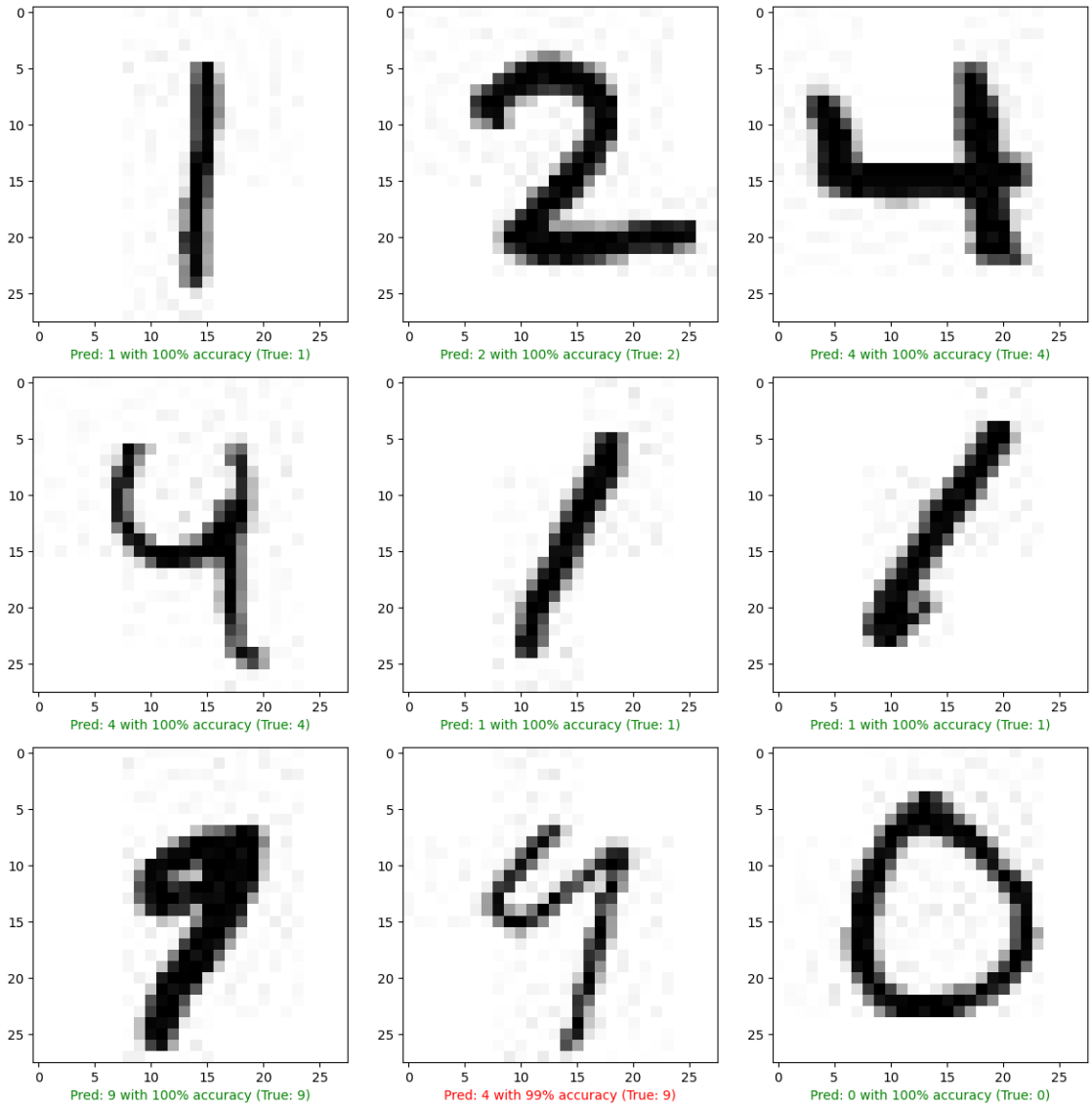
```
Training Accuracy for model: 99.46%
Validation Accuracy for model: 98.08%

2023-03-18 18:55:40.500559: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
Plugin optimizer for device_type GPU is enabled.

Test Accuracy for model: 97.71%
```





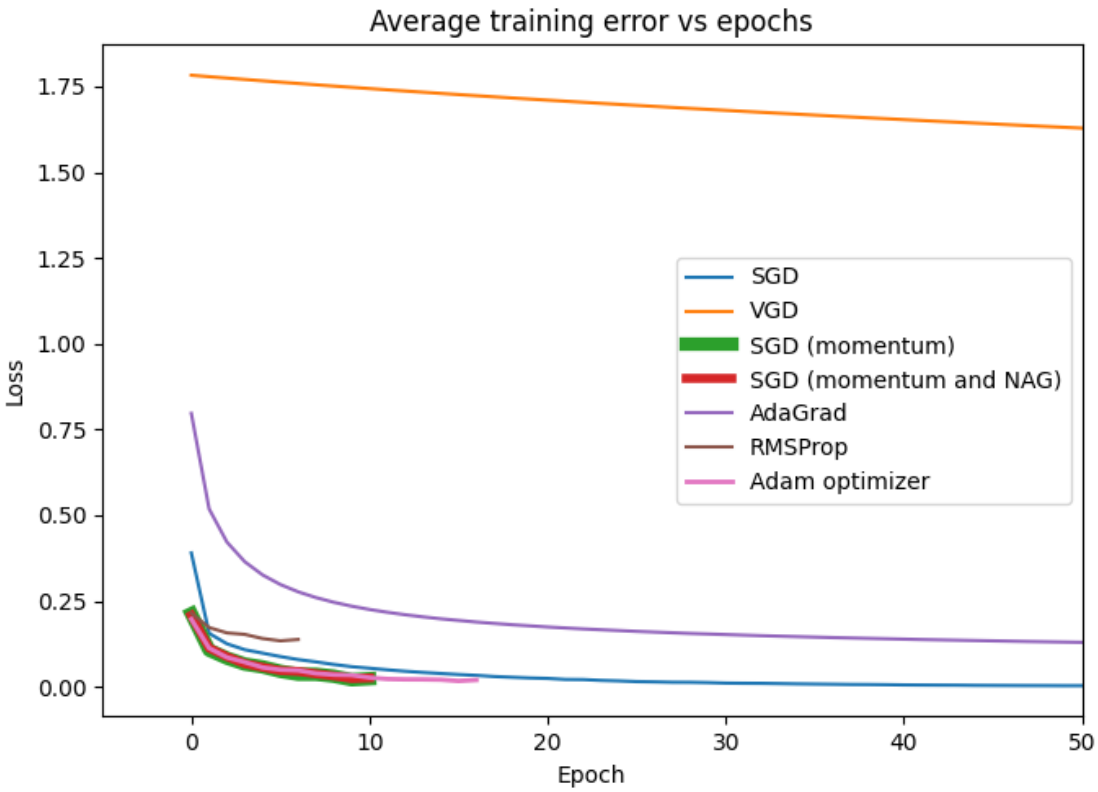

```
2023-03-18 18:55:41.266950: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
Plugin optimizer for device_type GPU is enabled.
2023-03-18 18:55:41.336116: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
Plugin optimizer for device_type GPU is enabled.

y_prob_a for one sample [[2.9145134e-05 5.9976114e-06 2.4517940e-05
7.8138011e-04 9.9915886e-01]]
```


Confusion Matrix
739 (97.4%)
0 (0.0%)
8 (1.1%)
6 (0.8%)
6 (0.8%)
0 (0.0%)
752 (99.1%)
7 (0.9%)
0 (0.0%)
0 (0.0%)
4 (0.5%)
2 (0.3%)
742 (97.8%)
3 (0.4%)
8 (1.1%)
0 (0.0%)
1 (0.1%)
2 (0.3%)
750 (98.8%)
6 (0.8%)
2 (0.3%)
0 (0.0%)
3 (0.4%)
29 (3.8%)
725 (95.5%)
True label
Predicted label
0
1
2
4
9
700
600
500
400
300
200
100
0



[26]:
```
if(al!=''):
  plt.figure(figsize=(7, 10))

  plt.subplot(2,1,1)
  plt.plot(df_model_a_history['loss'], label='SGD')
  plt.plot(df_model_b_history['loss'], label='VGD')
  plt.plot(df_model_c_history['loss'], label='SGD (momentum)', linewidth=6)
  plt.plot(df_model_d_history['loss'], label='SGD (momentum and NAG)',␣
↪linewidth=4)
  plt.plot(df_model_e_history['loss'], label='AdaGrad')
  plt.plot(df_model_f_history['loss'], label='RMSProp')
  plt.plot(df_model_g_history['loss'], label='Adam optimizer', linewidth=2)
```

```
plt.title("Average training error vs epochs")
plt.xlabel('Epoch')
plt.ylabel('Loss')
plt.xlim([-5, 50])
plt.legend()

plt.subplot(2,1,2)
plt.plot(df_model_a_history['loss'], label='SGD')
plt.plot(df_model_b_history['loss'], label='VGD')
plt.plot(df_model_c_history['loss'], label='SGD (momentum)')
plt.plot(df_model_d_history['loss'], label='SGD (momentum and NAG)')
plt.plot(df_model_e_history['loss'], label='AdaGrad')
plt.plot(df_model_f_history['loss'], label='RMSProp')
plt.plot(df_model_g_history['loss'], label='Adam optimizer')
plt.title("Average training error vs epochs")
plt.xlabel('Epoch')
plt.ylabel('Loss')
plt.legend()

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


Average training error vs epochs
Loss
Epoch
SGD
VGD
SGD (momentum)
SGD (momentum and NAG)
AdaGrad
RMSProp
Adam optimizer
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0
10
20
30
40
50


Average training error vs epochs
Loss
Epoch
SGD
VGD
SGD (momentum)
SGD (momentum and NAG)
AdaGrad
RMSProp
Adam optimizer
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0
500
1000
1500
2000
2500
3000

[27]:
```
plot_model(model_g, show_shapes=True, show_layer_activations=True)
```

[27]: