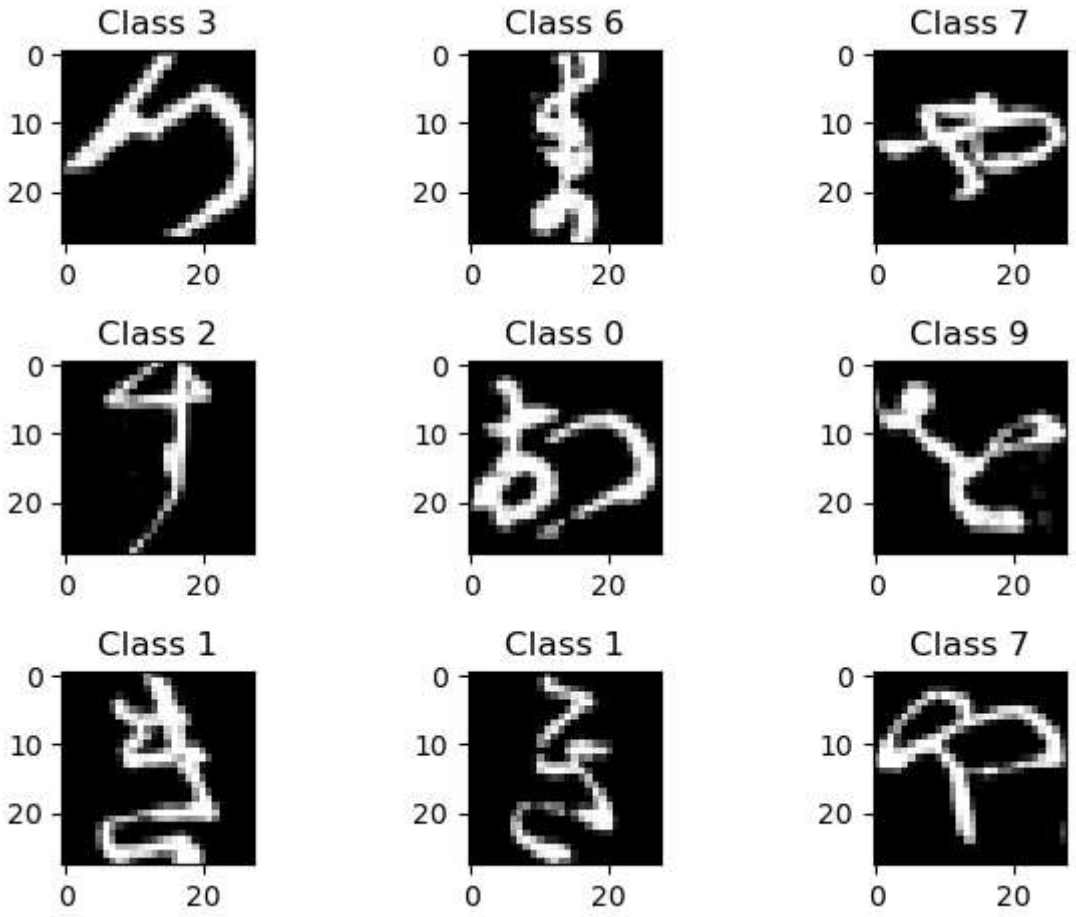
In [15]:
```
import numpy as np
import random

import matplotlib.pyplot as plt

from keras.models import Sequential
from keras.callbacks import EarlyStopping

from keras.layers import Dense, Dropout, Activation, Conv2D, MaxPooling2D, Flatten
from tensorflow.keras import utils
from tensorflow.keras.optimizers import SGD

from sklearn.metrics import confusion_matrix, ConfusionMatrixDisplay, accuracy_score,
```

In [16]:
```
data_train = np.load('kmnist-train-imgs.npz')
labels_train = np.load('kmnist-train-labels.npz')
data_test = np.load('kmnist-test-imgs.npz')
labels_test = np.load('kmnist-test-labels.npz')
```

In [17]:
```
k_train_samples = data_train['arr_0']
k_train_labels = labels_train['arr_0']
k_test_samples = data_test['arr_0']
k_test_labels = labels_test['arr_0']
```

In [18]:
```
for i in range(9):
    plt.subplot(3,3,i+1)
    num = random.randint(0, len(k_train_samples))
    plt.imshow(k_train_samples[num], cmap='gray', interpolation='none')
    plt.title("Class {}".format(k_train_labels[num]))

plt.tight_layout()
```



In [19]:
```
X_train = k_train_samples.reshape(60000, 784)
X_test = k_test_samples.reshape(10000, 784)

X_train = X_train.astype('float32')
X_test = X_test.astype('float32')

X_train /= 255
X_test /= 255

X_train = X_train.reshape((X_train.shape[0], 28, 28, 1))
X_test = X_test.reshape((X_test.shape[0], 28, 28, 1))

print("Training matrix shape", X_train.shape)
print("Testing matrix shape", X_test.shape)
```

```
Training matrix shape (60000, 28, 28, 1)
Testing matrix shape (10000, 28, 28, 1)
```

In [20]:
```
no_classes = 10

Y_train = utils.to_categorical(k_train_labels, no_classes)
Y_test = utils.to_categorical(k_test_labels, no_classes)
```

In [21]:
```
models = []
for i in range(1,5):
    model = Sequential()
    model.add(Conv2D(32,(3,3), activation='relu', kernel_initializer='he_uniform', inp
    model.add(MaxPooling2D((2,2)))
    model.add(Flatten())
    model.add(Dense(i*10, activation='relu', kernel_initializer='he_uniform'))
```

```
    model.add(Dense(10, activation='softmax'))
    model.summary()
    models.append(model)
```

```
Model: "sequential_24"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d_24 (Conv2D)          (None, 26, 26, 32)        320

 max_pooling2d_24 (MaxPooli  (None, 13, 13, 32)        0
 ng2D)

 flatten_24 (Flatten)        (None, 5408)              0

 dense_48 (Dense)            (None, 10)                54090

 dense_49 (Dense)            (None, 10)                110

=================================================================
Total params: 54520 (212.97 KB)
Trainable params: 54520 (212.97 KB)
Non-trainable params: 0 (0.00 Byte)
_________________________________________________________________
Model: "sequential_25"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d_25 (Conv2D)          (None, 26, 26, 32)        320

 max_pooling2d_25 (MaxPooli  (None, 13, 13, 32)        0
 ng2D)

 flatten_25 (Flatten)        (None, 5408)              0

 dense_50 (Dense)            (None, 20)                108180

 dense_51 (Dense)            (None, 10)                210

=================================================================
Total params: 108710 (424.65 KB)
Trainable params: 108710 (424.65 KB)
Non-trainable params: 0 (0.00 Byte)
_________________________________________________________________
Model: "sequential_26"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d_26 (Conv2D)          (None, 26, 26, 32)        320

 max_pooling2d_26 (MaxPooli  (None, 13, 13, 32)        0
 ng2D)

 flatten_26 (Flatten)        (None, 5408)              0

 dense_52 (Dense)            (None, 30)                162270

 dense_53 (Dense)            (None, 10)                310

=================================================================
Total params: 162900 (636.33 KB)
Trainable params: 162900 (636.33 KB)
Non-trainable params: 0 (0.00 Byte)
_________________________________________________________________
```

```
Model: "sequential_27"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d_27 (Conv2D)          (None, 26, 26, 32)        320

 max_pooling2d_27 (MaxPooli  (None, 13, 13, 32)        0
 ng2D)

 flatten_27 (Flatten)        (None, 5408)              0

 dense_54 (Dense)            (None, 40)                216360

 dense_55 (Dense)            (None, 10)                410

=================================================================
Total params: 217090 (848.01 KB)
Trainable params: 217090 (848.01 KB)
Non-trainable params: 0 (0.00 Byte)
_________________________________________________________________
```

In [22]:
```
#from keras.utils import plot_model
#plot_model(model, to_file='model_chart.png', show_shapes=True, show_layer_names=True)
#from IPython.display import Image
#Image("model_chart.png")
```

In [32]:
```
lr = [0.0001, 0.001, 0.01, 0.1, 1]
m = [0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9]
chosen_lr = []
chosen_m = []
for model in models:
    temp_lr = random.choice(lr)
    temp_m = random.choice(m)
    chosen_lr.append(temp_lr)
    chosen_m.append(temp_m)
    opt = SGD(learning_rate=temp_lr, momentum=temp_m)
    model.compile(optimizer=opt, loss='categorical_crossentropy', metrics=['accuracy']
```

In [33]:
```
callback = EarlyStopping(monitor='loss', patience=1, min_delta=0.1)
histories = []
for model in models:
    histories.append( model.fit(X_train, Y_train,
              batch_size=128, epochs=10,
              verbose=1, callbacks=[callback]))
```

```
Epoch 1/10
469/469 [==============================] - 6s 11ms/step - loss: 0.1094 - accuracy: 0.
9693
Epoch 2/10
469/469 [==============================] - 5s 11ms/step - loss: 0.0979 - accuracy: 0.
9729
Epoch 1/10
469/469 [==============================] - 6s 12ms/step - loss: 0.0822 - accuracy: 0.
9753
Epoch 2/10
469/469 [==============================] - 5s 11ms/step - loss: 0.0761 - accuracy: 0.
9775
Epoch 1/10
469/469 [==============================] - 6s 11ms/step - loss: 0.0593 - accuracy: 0.
9819
Epoch 2/10
469/469 [==============================] - 6s 13ms/step - loss: 0.0582 - accuracy: 0.
9822
Epoch 1/10
469/469 [==============================] - 6s 12ms/step - loss: 0.0576 - accuracy: 0.
9827
Epoch 2/10
469/469 [==============================] - 6s 12ms/step - loss: 0.0568 - accuracy: 0.
9829
```

In [25]:
```
len(histories)
```

Out[25]:
```
4
```

In [34]:
```
find_best_model = []
for history in histories:
    find_best_model.append(history.history['loss'][-1])

index = np.argmin(find_best_model)
best_model = models[index]

print("Chosen Model: " + str(index))
print("Final Loss: " + str(find_best_model[index]))
print("Final Accuracy: " + str(histories[index].history['accuracy'][-1]))
print("Final Learning Rate: " + str(chosen_lr[index]))
print("Final Momentum: " + str(chosen_m[index]))
```

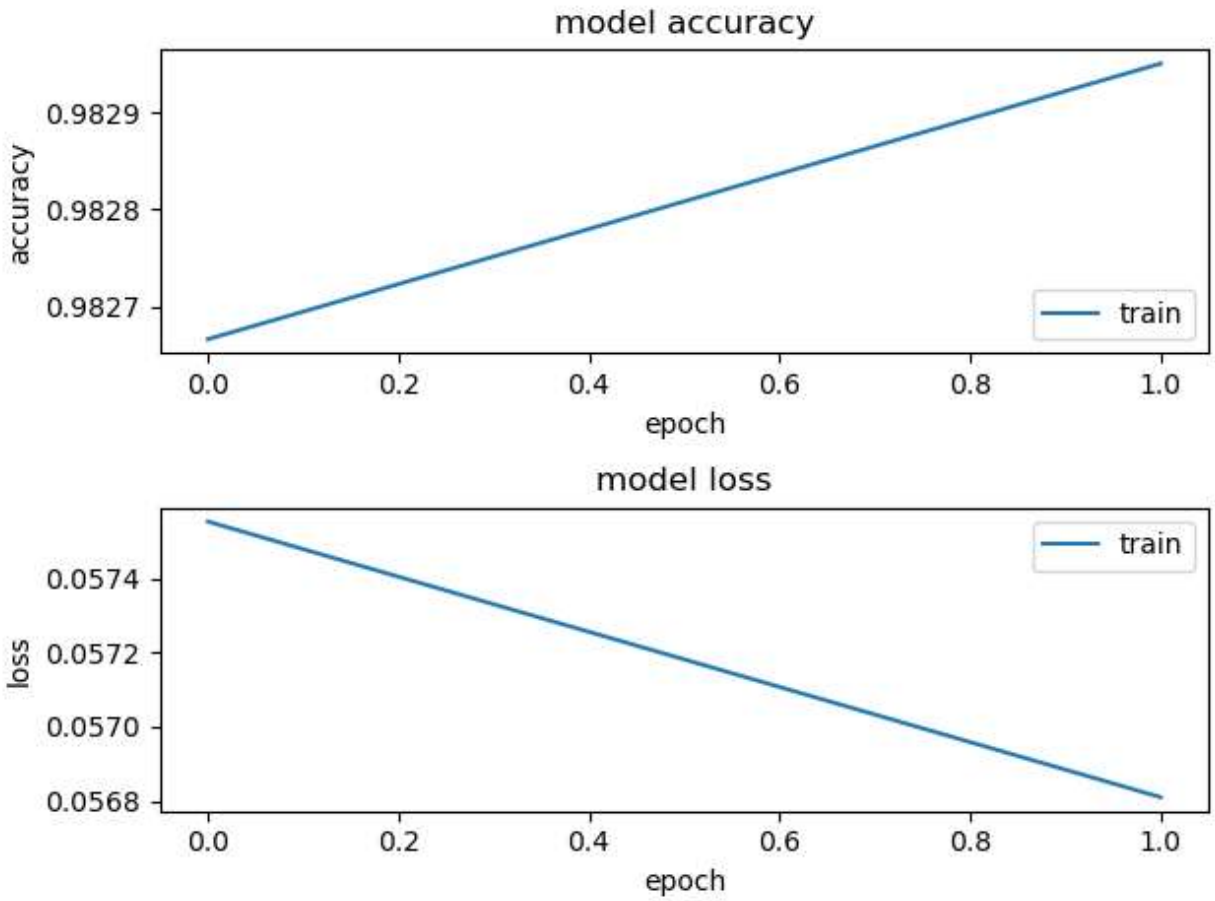
```
Chosen Model: 3
Final Loss: 0.05681043863296509
Final Accuracy: 0.98294997215271
Final Learning Rate: 0.0001
Final Momentum: 0.1
```

In [35]:
```
score = model.evaluate(X_test, Y_test)
print('Test accuracy:', score[1])
```

```
313/313 [==============================] - 1s 2ms/step - loss: 0.3802 - accuracy: 0.9
068
Test accuracy: 0.9067999720573425
```

In [36]:
```
fig = plt.figure()
plt.subplot(2,1,1)
plt.plot(histories[index].history['accuracy'])
plt.title('model accuracy')
plt.ylabel('accuracy')
```

```
plt.xlabel('epoch')
plt.legend(['train', 'test'], loc='lower right')

plt.subplot(2,1,2)
plt.plot(histories[index].history['loss'])
plt.title('model loss')
plt.ylabel('loss')
plt.xlabel('epoch')
plt.legend(['train', 'test'], loc='upper right')

plt.tight_layout()
```

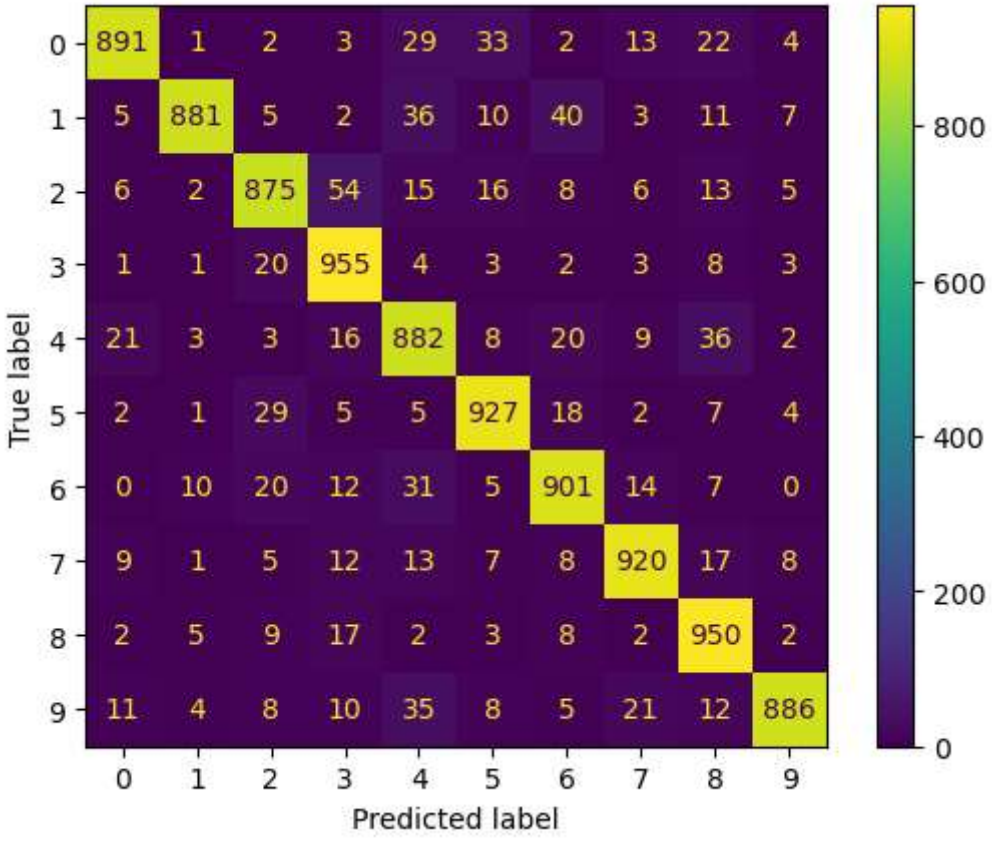


In [37]:
```
results = best_model.predict(X_test)
```

```
313/313 [==============================] - 1s 2ms/step
```

In [38]:
```
predicted_classes = best_model.predict(X_test)

true_labels = np.argmax(Y_test,axis=1)

predicted_labels = np.argmax(predicted_classes,axis=1)

cm = confusion_matrix(true_labels, predicted_labels)
disp = ConfusionMatrixDisplay(confusion_matrix=cm)
disp.plot()

print("Accuracy: " + str(accuracy_score(true_labels, predicted_labels)))
print("Weighted Precision: " + str(precision_score(true_labels, predicted_labels, aver
print("Weighted Recall: " + str(recall_score(true_labels, predicted_labels, average='w
print("Weighted F1 Score: " + str(f1_score(true_labels, predicted_labels, average='wei
```

```
313/313 [==============================] - 0s 2ms/step
Accuracy: 0.9068
Weighted Precision: 0.9088179565301647
Weighted Recall: 0.9068
Weighted F1 Score: 0.9069946885532583
```



Extensions to the project

1. Alter parameters of layers (Number of perceptrons, more Convolution and pooling layers)
2. Preprocessing on the data (filter?)
3. Ensemble learning
4. Utilize Graphcore IPU

In [ ]: