In [1]:
```
import numpy as np
import numpy.random as npr
import matplotlib.pyplot as plt
%matplotlib inline
plt.style.use('bmh')
```

In [2]:
```
import os
import numpy as np
import cv2
from sklearn import svm, metrics, datasets
from sklearn.utils import Bunch
from sklearn.model_selection import GridSearchCV, train_test_split
from sklearn.discriminant_analysis import LinearDiscriminantAnalysis
from sklearn.linear_model import Perceptron
from sklearn.naive_bayes import GaussianNB
from sklearn.svm import SVC
from sklearn.pipeline import Pipeline

from sklearn.metrics import confusion_matrix, ConfusionMatrixDisplay
from sklearn.model_selection import train_test_split
from sklearn.metrics import plot_confusion_matrix
from sklearn.metrics import classification_report
from sklearn.preprocessing import MinMaxScaler
from sklearn.neighbors import KNeighborsClassifier
from sklearn.metrics import confusion_matrix, ConfusionMatrixDisplay
from sklearn.pipeline import Pipeline
from sklearn.decomposition import PCA
import tensorflow as tf
```

In [3]:
```
import numpy as np
from tensorflow import keras
from keras.models import Sequential
from keras.layers import Dense
from keras.utils import np_utils
from keras.layers import Dropout
from keras.layers import Flatten
from keras.layers import Input
from keras.layers.convolutional import Conv2D
from keras.layers.convolutional import MaxPooling2D
from sklearn.preprocessing import MinMaxScaler
from sklearn.model_selection import train_test_split
from sklearn.decomposition import PCA
import matplotlib.pyplot as plt
import cv2
```

In [4]:
```
    X = np.load('data_train.npy').T
    t = np.load('t_train_corrected.npy')
```

In [5]:
```
X = np.array([ cv2.resize(x.reshape(300,300),(300,100)).reshape(300*100) for x in X ])
```

In [6]:
```
X_train, X_test, t_train, t_test = train_test_split(X, t, test_size=0.33)
t_test_de=t_test
```

In [7]:
```
class_names= ['x','square root','plus sign','negative sign',
                'equal','percent','partial','product','pi','summation']

t_train= np_utils.to_categorical(t_train)
t_test= np_utils.to_categorical(t_test)
num_classes=t_train.shape[1]
```

In [8]:
```
X_train_re = X_train.reshape(6051, 300, 100)
t_train_re = t_train
X_test_re = X_test.reshape(2981, 300, 100)
t_test_re = t_test
```

In [9]:
```
(_, IMAGE_WIDTH, IMAGE_HEIGHT) = X_train_re.shape
IMAGE_CHANNELS = 3

print('IMAGE_WIDTH:', IMAGE_WIDTH);
print('IMAGE_HEIGHT:', IMAGE_HEIGHT);
print('IMAGE_CHANNELS:', IMAGE_CHANNELS)
```

```
IMAGE_WIDTH: 300
IMAGE_HEIGHT: 100
IMAGE_CHANNELS: 3
```

In [11]:
```
X_train_with_chanels = X_train_re.reshape(
    X_train_re.shape[0],
    100,
    IMAGE_HEIGHT,
    IMAGE_CHANNELS
)

X_test_with_chanels = X_test_re.reshape(
    X_test_re.shape[0],
    100,
    IMAGE_HEIGHT,
    IMAGE_CHANNELS
)
```

Normalizing Data

In [12]:
```
X_train_normalized = X_train_with_chanels / 255
X_test_normalized = X_test_with_chanels / 255
```

In [13]:
```
print(X_train_normalized.shape, t_train.shape, X_test_normalized.shape, t_test.shape)
```

```
(6051, 100, 100, 3) (6051, 10) (2981, 100, 100, 3) (2981, 10)
```

In [14]:
```
from tensorflow import keras
from tensorflow.keras import layers
```

Transfer Learning

In [15]:
```
def inceptV3_model(D,num_classes):
    base_model = tf.keras.applications.inception_v3.InceptionV3(
        weights="imagenet",
        input_shape=(D, D, 3),
        include_top=False,
    )
    # Freeze the base_model
    base_model.trainable = False

    inputs = tf.keras.Input(shape=(D, D, 3))
    data_augmentation = keras.Sequential(
    [layers.RandomFlip("horizontal"), layers.RandomRotation(0.1),]
)
    x = data_augmentation(inputs)

    # Pre-trained Xception weights requires that input be scaled
    # from (0, 255) to a range of (-1., +1.), the rescaling layer
    # outputs: `(inputs * scale) + offset`
    scale_layer = tf.keras.layers.Rescaling(scale=1 / 127.5, offset=-1)
    x = scale_layer(inputs)


    #here we can add our additional layers for training this model on our own dataset
    x = base_model(x, training=False)
    x = tf.keras.layers.GlobalAveragePooling2D()(x)
    x = keras.layers.Dropout(0.2)(x)  # Regularize with dropout
    outputs = keras.layers.Dense(num_classes)(x)

    model = tf.keras.Model(inputs, outputs)
    base_model.trainable=True
    model.compile(
        optimizer=tf.keras.optimizers.Adam(1e-5),  # Low learning rate
        loss=tf.keras.losses.BinaryCrossentropy(from_logits=True),
        metrics=[tf.keras.metrics.BinaryAccuracy()],
    )

    return model
```

In [16]:
```
D=100
```

Fitting Model

In [17]:
```
inceptv3 = inceptV3_model(D,num_classes)
training = inceptv3.fit(X_train_normalized, t_train, validation_data=(X_test_normalized,t_test),epochs=20, batch_size=64, ver
score= inceptv3.evaluate(X_test_normalized, t_test, verbose=0)
print('The error is: %.2f%%'%(100-score[1]*100))
```

```
WARNING:tensorflow:Using a while_loop for converting RngReadAndSkip cause there is no registered converter for this op.
WARNING:tensorflow:Using a while_loop for converting Bitcast cause there is no registered converter for this op.
WARNING:tensorflow:Using a while_loop for converting Bitcast cause there is no registered converter for this op.
WARNING:tensorflow:Using a while_loop for converting StatelessRandomUniformV2 cause there is no registered converter for thi
s op.
WARNING:tensorflow:Using a while_loop for converting ImageProjectiveTransformV3 cause there is no registered converter for t
his op.
WARNING:tensorflow:Using a while_loop for converting RngReadAndSkip cause there is no registered converter for this op.
WARNING:tensorflow:Using a while_loop for converting Bitcast cause there is no registered converter for this op.
WARNING:tensorflow:Using a while_loop for converting Bitcast cause there is no registered converter for this op.
WARNING:tensorflow:Using a while_loop for converting StatelessRandomUniformV2 cause there is no registered converter for thi
s op.
WARNING:tensorflow:Using a while_loop for converting ImageProjectiveTransformV3 cause there is no registered converter for t
his op.
Epoch 1/20
95/95 - 216s - loss: 0.2872 - binary_accuracy: 0.9046 - val_loss: 0.1908 - val_binary_accuracy: 0.9212 - 216s/epoch - 2s/ste
p
Epoch 2/20
95/95 - 209s - loss: 0.1595 - binary_accuracy: 0.9422 - val_loss: 0.1648 - val_binary_accuracy: 0.9427 - 209s/epoch - 2s/ste
p
Epoch 3/20
95/95 - 245s - loss: 0.1235 - binary_accuracy: 0.9571 - val_loss: 0.1041 - val_binary_accuracy: 0.9644 - 245s/epoch - 3s/ste
p
Epoch 4/20
95/95 - 266s - loss: 0.1045 - binary_accuracy: 0.9642 - val_loss: 0.0964 - val_binary_accuracy: 0.9663 - 266s/epoch - 3s/ste
p
Epoch 5/20
95/95 - 246s - loss: 0.0953 - binary_accuracy: 0.9683 - val_loss: 0.0940 - val_binary_accuracy: 0.9685 - 246s/epoch - 3s/ste
p
Epoch 6/20
95/95 - 256s - loss: 0.0882 - binary_accuracy: 0.9700 - val_loss: 0.0881 - val_binary_accuracy: 0.9705 - 256s/epoch - 3s/ste
p
Epoch 7/20
95/95 - 246s - loss: 0.0787 - binary_accuracy: 0.9730 - val_loss: 0.0789 - val_binary_accuracy: 0.9730 - 246s/epoch - 3s/ste
p
Epoch 8/20
95/95 - 244s - loss: 0.0747 - binary_accuracy: 0.9743 - val_loss: 0.0797 - val_binary_accuracy: 0.9727 - 244s/epoch - 3s/ste
p
Epoch 9/20
95/95 - 245s - loss: 0.0676 - binary_accuracy: 0.9770 - val_loss: 0.0761 - val_binary_accuracy: 0.9751 - 245s/epoch - 3s/ste
p
Epoch 10/20
95/95 - 246s - loss: 0.0638 - binary_accuracy: 0.9780 - val_loss: 0.0708 - val_binary_accuracy: 0.9770 - 246s/epoch - 3s/ste
p
Epoch 11/20
95/95 - 246s - loss: 0.0594 - binary_accuracy: 0.9798 - val_loss: 0.0751 - val_binary_accuracy: 0.9752 - 246s/epoch - 3s/ste
p
Epoch 12/20
95/95 - 287s - loss: 0.0564 - binary_accuracy: 0.9809 - val_loss: 0.0732 - val_binary_accuracy: 0.9763 - 287s/epoch - 3s/ste
p
Epoch 13/20
95/95 - 308s - loss: 0.0550 - binary_accuracy: 0.9808 - val_loss: 0.0719 - val_binary_accuracy: 0.9761 - 308s/epoch - 3s/ste
p
Epoch 14/20
95/95 - 286s - loss: 0.0501 - binary_accuracy: 0.9823 - val_loss: 0.0740 - val_binary_accuracy: 0.9763 - 286s/epoch - 3s/ste
p
Epoch 15/20
95/95 - 267s - loss: 0.0477 - binary_accuracy: 0.9832 - val_loss: 0.0724 - val_binary_accuracy: 0.9769 - 267s/epoch - 3s/ste
p
Epoch 16/20
95/95 - 291s - loss: 0.0422 - binary_accuracy: 0.9854 - val_loss: 0.0733 - val_binary_accuracy: 0.9778 - 291s/epoch - 3s/ste
p
Epoch 17/20
95/95 - 267s - loss: 0.0414 - binary_accuracy: 0.9858 - val_loss: 0.0851 - val_binary_accuracy: 0.9753 - 267s/epoch - 3s/ste
p
Epoch 18/20
95/95 - 251s - loss: 0.0403 - binary_accuracy: 0.9856 - val_loss: 0.0721 - val_binary_accuracy: 0.9781 - 251s/epoch - 3s/ste
p
Epoch 19/20
95/95 - 270s - loss: 0.0413 - binary_accuracy: 0.9854 - val_loss: 0.0817 - val_binary_accuracy: 0.9766 - 270s/epoch - 3s/ste
p
Epoch 20/20
95/95 - 280s - loss: 0.0372 - binary_accuracy: 0.9870 - val_loss: 0.0757 - val_binary_accuracy: 0.9782 - 280s/epoch - 3s/ste
p
The error is: 2.18%
```

Running Test set

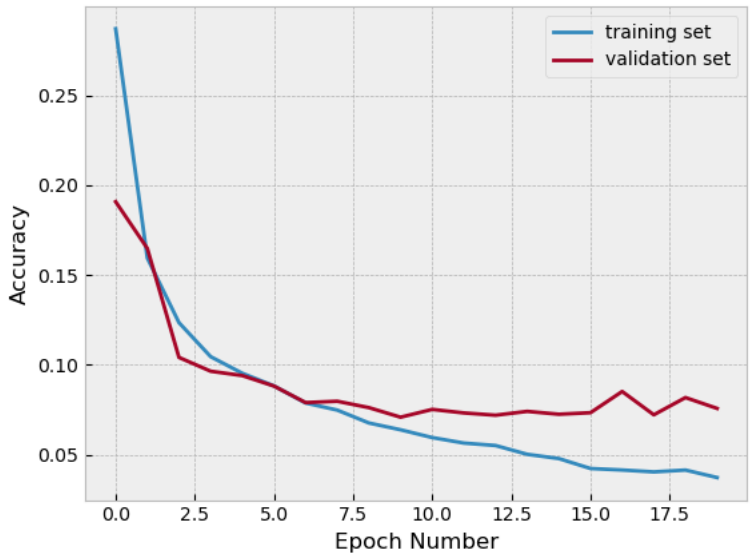
In [18]:
```
validation_loss, validation_accuracy = inceptv3.evaluate(X_test_normalized, t_test)
```

```
94/94 [==============================] - 14s 151ms/step - loss: 0.0757 - binary_accuracy: 0.9782
```

PLOTTING LOSS AND ACCURACY

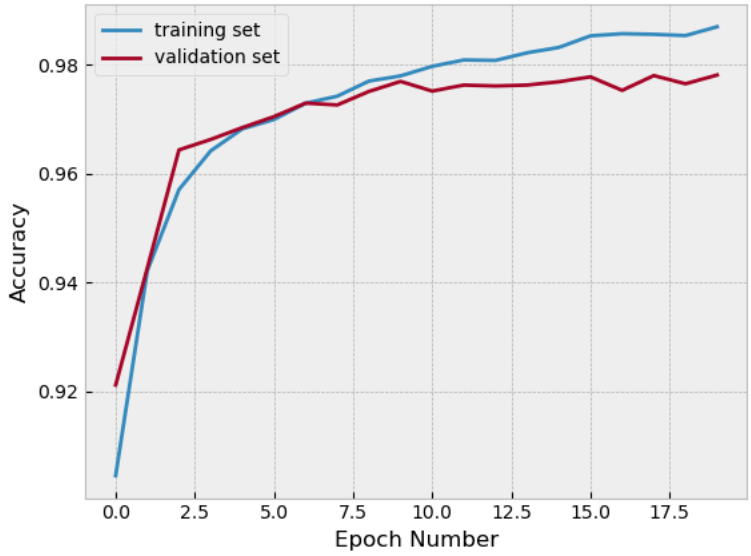
In [20]:
```
plt.xlabel('Epoch Number')
plt.ylabel('Accuracy')
plt.plot(training.history['loss'], label='training set')
plt.plot(training.history['val_loss'], label='validation set')
plt.legend()
```

Out[20]:
```
<matplotlib.legend.Legend at 0x1740746f788>
```



In [22]:
```
plt.xlabel('Epoch Number')
plt.ylabel('Accuracy')
plt.plot(training.history['binary_accuracy'], label='training set')
plt.plot(training.history['val_binary_accuracy'], label='validation set')
plt.legend()
```

Out[22]:
```
<matplotlib.legend.Legend at 0x17406546c08>
```



MODEL

In [25]:
```
inceptv3.summary()
```

```
Model: "model"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 input_2 (InputLayer)        [(None, 100, 100, 3)]     0

 rescaling (Rescaling)       (None, 100, 100, 3)       0

 inception_v3 (Functional)   (None, 1, 1, 2048)        21802784

 global_average_pooling2d (G  (None, 2048)             0
 lobalAveragePooling2D)

 dropout (Dropout)           (None, 2048)              0

 dense (Dense)               (None, 10)                20490

=================================================================
Total params: 21,823,274
Trainable params: 21,788,842
Non-trainable params: 34,432
_________________________________________________________________
```

In [26]:
```
print('Validation loss: ', validation_loss)
print('Validation accuracy: ', validation_accuracy)
```

```
Validation loss:  0.0756683349609375
Validation accuracy:  0.9781616926193237
```

SAVING MODEL

In [27]:
```
model_name = 'handwritten_math_recognition_cnn.h5'
inceptv3.save(model_name, save_format='h5')
```

In [28]:
```
loaded_model = tf.keras.models.load_model(model_name)
```

In [29]:
```
predictions_one_hot = loaded_model.predict([X_test_normalized])
```

```
94/94 [==============================] - 15s 133ms/step
```

In [30]:
```
print('predictions_one_hot:', predictions_one_hot.shape)
```

```
predictions_one_hot: (2981, 10)
```

In [31]:
```
import pandas as pd
```

In [32]:
```
predictions = np.argmax(predictions_one_hot, axis=1)
pd.DataFrame(predictions)
```

Out[32]:

	0
0	7
1	2
2	3
3	8
4	0
...	...
2976	8
2977	4
2978	9
2979	9
2980	4

2981 rows × 1 columns

In [33]:
```
tf.math.confusion_matrix(
    t_test_de,
    predictions,
    num_classes=None,
    weights=None,
    dtype=tf.dtypes.int32,
    name=None
)
```

Out[33]:
```
<tf.Tensor: shape=(10, 10), dtype=int32, numpy=
array([[296,   2,   1,   1,   1,   5,   2,   0,   6,   2],
       [  7, 277,   3,   6,   1,   1,   1,   0,   8,   0],
       [ 14,   0, 249,   4,   1,   1,   0,   1,   0,   0],
       [  5,   0,   2, 270,  14,   1,   0,   0,   1,   2],
       [ 14,   0,   2,   7, 273,   4,   2,   2,   2,   5],
       [  8,   0,   4,   4,   3, 269,   0,   0,   0,   0],
       [ 15,   1,   1,   1,   3,   1, 275,   1,   3,   3],
       [  9,   3,   0,   0,   3,   4,   0, 233,  53,   1],
       [ 36,   0,   2,   0,   1,   4,   1,  29, 213,   3],
       [ 11,   0,   0,   0,   3,   5,   1,   0,   1, 277]])>
```

Plotting Confusion Matrix

In [34]:
```
import seaborn as sn
```

In [35]:
```
confusion_matrix = tf.math.confusion_matrix(t_test_de, predictions)
f, ax = plt.subplots(figsize=(9, 7))
sn.heatmap(
    confusion_matrix,
    annot=True,
    linewidths=.5,
    fmt="d",
    square=True,
    ax=ax
)
plt.show()
```