In [169]:
```
# Libraries used
import pandas as pd
import matplotlib.pyplot as plt
from sklearn.model_selection import train_test_split
import numpy as np
import tensorflow as tf
from tensorflow.keras.preprocessing.image import ImageDataGenerator
from tensorflow import keras
import pickle
import seaborn as sb
from keras.models import Sequential
from keras.layers import Dense, Dropout, Flatten, Conv2D, MaxPool2D
from keras.optimizers import RMSprop
from keras.callbacks import ReduceLROnPlateau
from keras.callbacks import ModelCheckpoint, EarlyStopping
```

- note: Based off serveral notebooks available on kaggle, this version will be an improved version from the previous

read data

In [170]:
```
# check current Directory
import os
os.getcwd()
```

Out[170]:
```
'C:\\Users\\tanch\\OneDrive\\Documents\\Kaggle\\digit-recognizer\\predictions'
```

In [171]:
```
# set directory to the folder containing the dataset
os.chdir('C:\\Users\\tanch\\OneDrive\\Documents\\Kaggle\\digit-recognizer\\dataset')
# read the csv as data frame
total_training_set = pd.read_csv('train.csv')
total_test_set = pd.read_csv('test.csv')
```

Basic data exploration

In [172]:
```
# first column is the labels
total_training_set.head()
```

Out[172]:

	label	pixel0	pixel1	pixel2	pixel3	pixel4	pixel5	pixel6	pixel7	pixel8	...	pixel774	pixel775	pixel77
0	1	0	0	0	0	0	0	0	0	0	...	0	0	
1	0	0	0	0	0	0	0	0	0	0	...	0	0	
2	1	0	0	0	0	0	0	0	0	0	...	0	0	
3	4	0	0	0	0	0	0	0	0	0	...	0	0	
4	0	0	0	0	0	0	0	0	0	0	...	0	0	

5 rows × 785 columns

In [173]:
```
total_test_set.head()
```

Out[173]:

	pixel0	pixel1	pixel2	pixel3	pixel4	pixel5	pixel6	pixel7	pixel8	pixel9	...	pixel774	pixel775	pixel7
0	0	0	0	0	0	0	0	0	0	0	...	0	0	
1	0	0	0	0	0	0	0	0	0	0	...	0	0	
2	0	0	0	0	0	0	0	0	0	0	...	0	0	
3	0	0	0	0	0	0	0	0	0	0	...	0	0	
4	0	0	0	0	0	0	0	0	0	0	...	0	0	

5 rows × 784 columns

In [174]:
```
# split predictors from labels
y_train_full = total_training_set['label']
X_train_full = total_training_set.drop(['label'],axis=1)
```

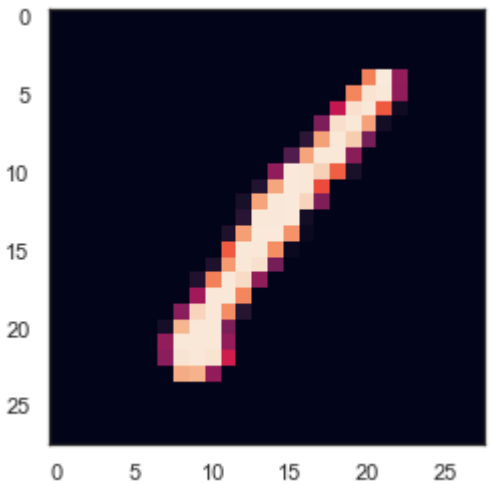
In [175]:
```
print('Training set has {} images with {} pixels.'.format(X_train_full.shape[0],X_train
print('Test set has {} images with {} pixels.'.format(total_test_set.shape[0],total_tes
```

```
Training set has 42000 images with 784 pixels.
Test set has 28000 images with 784 pixels.
```

In [176]:
```
# visualise a row to check validity
row = 0
print('Row {} is number {}.'.format(row,y_train_full[row]))
                                    # reshaped each row to 28 x 28 matrix
plt.imshow(X_train_full.values.reshape((42000,28,28))[row])
```

```
Row 0 is number 1.
```

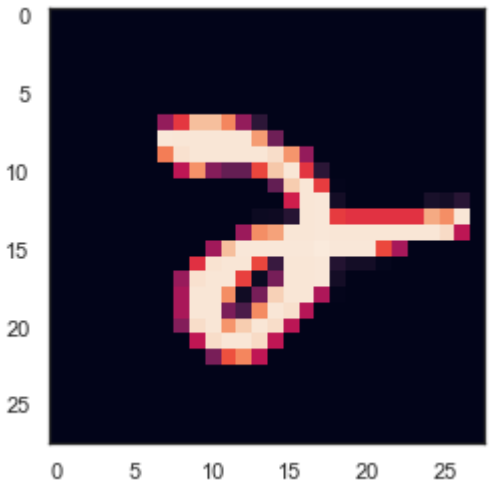
Out[176]:
```
<matplotlib.image.AxesImage at 0x1ad974e27c8>
```



In [177]:
```
# visualise a row to check validity
row = 34
print('Row {} is number {}.'.format(row,y_train_full[row]))
                                # reshaped each row to 28 x 28 matrix
plt.imshow(X_train_full.values.reshape((42000,28,28))[row])
```

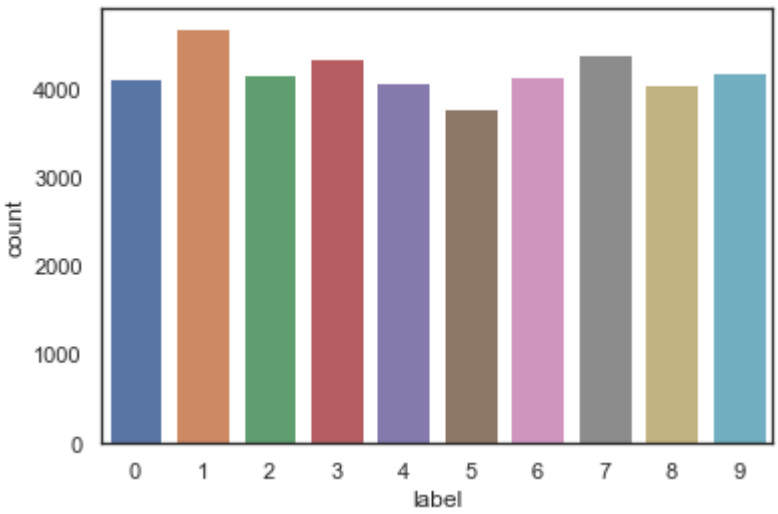
```
Row 34 is number 2.
```

Out[177]:
```
<matplotlib.image.AxesImage at 0x1ad96cc4088>
```



In [178]:
```
# counts of each number is quite even
sb.set(style='white', context='notebook', palette='deep')
sb.countplot(y_train_full)
```

Out[178]:
```
<matplotlib.axes._subplots.AxesSubplot at 0x1ad96fd6608>
```



Data Preprocessing

In [179]:
```
# reshape data to 28 x 28 x 1 dimension, required by the CNN model
                          # .values turns data frame to a matrix
X_train_full= X_train_full.values.reshape((42000,28,28,1))
X_test= total_test_set.values.reshape((28000,28,28,1))
```

In [180]:
```
# convert pixels to float values within [0,1]
X_train_full=X_train_full/255.
X_test=X_test/255.
```

In [181]:
```
# split to training and validation sets using train_test_split function
X_train, X_valid, y_train, y_valid = train_test_split(X_train_full, y_train_full, test_
```

In [182]:
```
X_train.shape, X_valid.shape, y_train.shape, y_valid.shape
```

Out[182]:
```
((31500, 28, 28, 1), (10500, 28, 28, 1), (31500,), (10500,))
```

In [183]:
```
# check dimensions
print('Training set Dimensions: \n\tX: {}\n\ty: {}'.format(X_train.shape,y_train.shape)
print('Validation set Dimensions: \n\tX: {}\n\ty: {}'.format(X_valid.shape,y_valid.shap
print('Test set Dimensions: \n\tX: {}'.format(X_test.shape))
```

```
Training set Dimensions:
        X: (31500, 28, 28, 1)
        y: (31500,)
Validation set Dimensions:
        X: (10500, 28, 28, 1)
        y: (10500,)
Test set Dimensions:
        X: (28000, 28, 28, 1)
```

Build Convolutional Neural Network

In [184]:
```
# setting seed to make results reproduceable
np.random.seed(1)
tf.random.set_seed(1)
```

In [185]:
```
# create ImageDataGenerator that augments image
train_datagen = ImageDataGenerator( # the generator can choose any value within these r
                                   rotation_range=40,
                                   width_shift_range=0.2,
                                   height_shift_range=0.2,
                                   shear_range=0.2,
                                   zoom_range=0.2,
                                     # trun off flipping to avoid misclassification of s
                                   horizontal_flip=False,
                                   vertical_flip=False  )


# data augmentation NOT required in validation set
test_datagen = ImageDataGenerator()
```

In [186]:
```
# generators to feed data into the model
train_generator = train_datagen.flow(X_train, y_train,
                                     # image will be fed in this batch sizes
                                     batch_size=32)
validation_generator = test_datagen.flow(X_valid, y_valid,
                                     # image will be fed in this batch sizes
                                     batch_size=32)
```

In [187]:
```
# for v2 architecture, there are dropouts at every layer, smaller ANN layer but more co
# also padding will be 'same' instead of valid
model = Sequential()

model.add(Conv2D(filters = 32, kernel_size = (5,5),padding = 'Same',
                 activation ='relu', input_shape = (28,28,1)))
model.add(Conv2D(filters = 32, kernel_size = (5,5),padding = 'Same',
                 activation ='relu'))
model.add(MaxPool2D(pool_size=(2,2)))
model.add(Dropout(0.25))


model.add(Conv2D(filters = 64, kernel_size = (3,3),padding = 'Same',
                 activation ='relu'))
model.add(Conv2D(filters = 64, kernel_size = (3,3),padding = 'Same',
                 activation ='relu'))
model.add(MaxPool2D(pool_size=(2,2), strides=(2,2)))
model.add(Dropout(0.25))


model.add(Flatten())
model.add(Dense(256, activation = "relu"))
model.add(Dropout(0.5))
model.add(Dense(10, activation = "softmax"))
```

In [188]:
```
model.summary()
```

```
Model: "sequential_2"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_5 (Conv2D)            (None, 28, 28, 32)        832
_________________________________________________________________
conv2d_6 (Conv2D)            (None, 28, 28, 32)        25632
_________________________________________________________________
max_pooling2d_3 (MaxPooling2 (None, 14, 14, 32)        0
_________________________________________________________________
dropout_4 (Dropout)          (None, 14, 14, 32)        0
_________________________________________________________________
conv2d_7 (Conv2D)            (None, 14, 14, 64)        18496
_________________________________________________________________
conv2d_8 (Conv2D)            (None, 14, 14, 64)        36928
_________________________________________________________________
max_pooling2d_4 (MaxPooling2 (None, 7, 7, 64)          0
_________________________________________________________________
dropout_5 (Dropout)          (None, 7, 7, 64)          0
_________________________________________________________________
flatten_2 (Flatten)          (None, 3136)              0
_________________________________________________________________
dense_3 (Dense)              (None, 256)               803072
_________________________________________________________________
dropout_6 (Dropout)          (None, 256)               0
_________________________________________________________________
dense_4 (Dense)              (None, 10)                2570
=================================================================
Total params: 887,530
Trainable params: 887,530
Non-trainable params: 0
_________________________________________________________________
```

In [189]:
```
# RMSprop used instead of SGD
optimizer = RMSprop(lr=0.001, rho=0.9, epsilon=1e-08, decay=0.0)
```

In [190]:
```
# compile model
model.compile(loss='sparse_categorical_crossentropy',
              # sgd refers to stochastic gradient descent
             optimizer=optimizer,
             metrics=['accuracy'])
```

In [191]:
```
# This decreases the LR dynamically every X steps (epochs) depending if it is necessary
learning_rate_reduction = ReduceLROnPlateau(monitor='val_acc',
                                            patience=3,
                                            verbose=1,
                                            factor=0.5,
                                            min_lr=0.00001)
```

In [192]:
```
# model is saved when validation accuracy does not improve after the patience value
checkpoint_cb = ModelCheckpoint('CNN_early_stopping_model_v2.h5',save_best_only = True)
                    # if there are no improvements after 10 epochs training stops
early_stopping_cb = EarlyStopping(patience = 10,
                    restore_best_weights = True)
```

In [46]:
```
# training the model
number_of_epochs = 1000
model_history = model.fit(X_train,y_train,
                          validation_data=(X_valid,y_valid),
                          epochs=number_of_epochs,
                          callbacks= [checkpoint_cb, early_stopping_cb,learning_rate_re
```

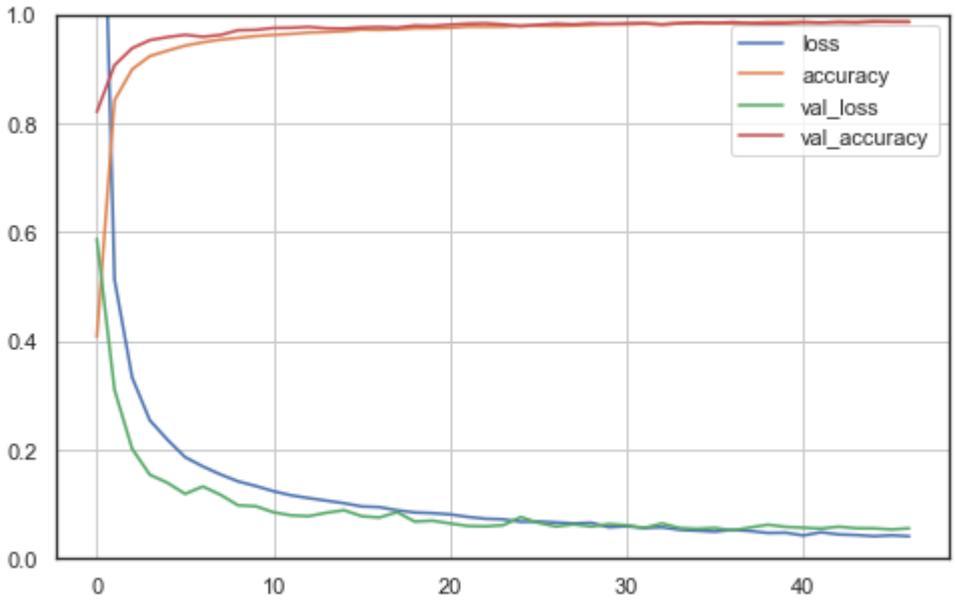
```
Train on 31500 samples, validate on 10500 samples
Epoch 1/1000
31500/31500 [==============================] - 184s 6ms/step - loss: 0.2207 - accur
acy: 0.9295 - val_loss: 0.0719 - val_accuracy: 0.9780
Epoch 2/1000
   32/31500 [..............................] - ETA: 2:16 - loss: 0.0148 - accuracy:
1.0000

C:\Users\tanch\Anaconda3\lib\site-packages\keras\callbacks\callbacks.py:1042: Runti
meWarning: Reduce LR on plateau conditioned on metric `val_acc` which is not availa
ble. Available metrics are: val_loss,val_accuracy,loss,accuracy,lr
  (self.monitor, ','.join(list(logs.keys()))), RuntimeWarning
```

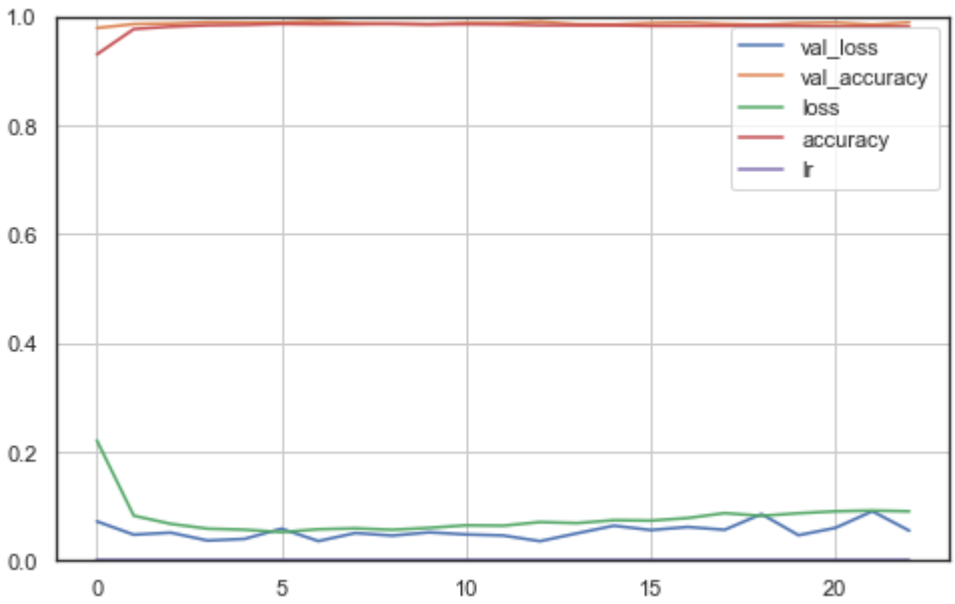
In [49]:
```
# saving new model history
os.chdir('C:\\Users\\tanch\\OneDrive\\Documents\\Kaggle\\digit-recognizer')
history_name='v2_trainHistoryDict.pickle'
with open(history_name, 'wb') as file_pi:
    pickle.dump(model_history.history, file_pi)
```

In [50]:
```
# load model history of previous model
with open('trainHistoryDict.pickle', 'rb') as file_pi:
    previous_model_history=pickle.load(file_pi, encoding='bytes')
```

In [51]:
```
# previous model
pd.DataFrame(previous_model_history).plot(figsize=(8,5))
plt.grid(True)
plt.gca().set_ylim(0,1)
plt.show()
```



In [47]:
```
# new model
pd.DataFrame(model_history.history).plot(figsize=(8,5))
plt.grid(True)
plt.gca().set_ylim(0,1)
plt.show()
```



- the new model converges reaches best accuracy much faster
- however, the loss seems to worsen over time

Make Predictions

In [53]:
```
# the test set
total_test_set.head()
```

Out[53]:

	pixel0	pixel1	pixel2	pixel3	pixel4	pixel5	pixel6	pixel7	pixel8	pixel9	...	pixel774	pixel775	pixel7
0	0	0	0	0	0	0	0	0	0	0	...	0	0	
1	0	0	0	0	0	0	0	0	0	0	...	0	0	
2	0	0	0	0	0	0	0	0	0	0	...	0	0	
3	0	0	0	0	0	0	0	0	0	0	...	0	0	
4	0	0	0	0	0	0	0	0	0	0	...	0	0	

5 rows × 784 columns

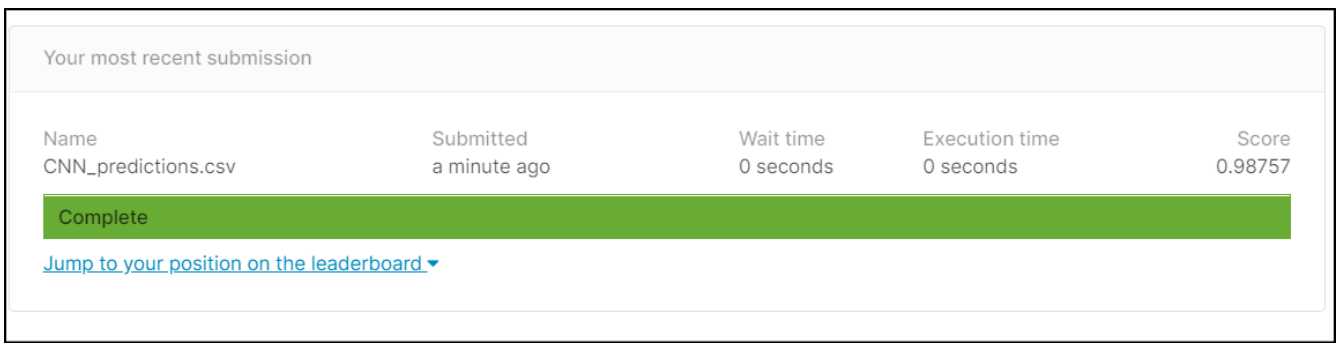
In [54]:
```
# make class predictions
y_pred = model.predict_classes(X_test)
y_pred
```

Out[54]:
```
array([2, 0, 9, ..., 3, 9, 2], dtype=int64)
```

In [55]:
```
# create the output in required format
predictions_dict={'ImageId':range(1,28001),'Label':y_pred}
output_df = pd.DataFrame(predictions_dict).set_index('ImageId')
```

In [56]:
```
# set directory and output the predictions
os.chdir('C:\\Users\\tanch\\OneDrive\\Documents\\Kaggle\\digit-recognizer\\predictions')
output_df.to_csv('CNN_predictions.csv')
```

results



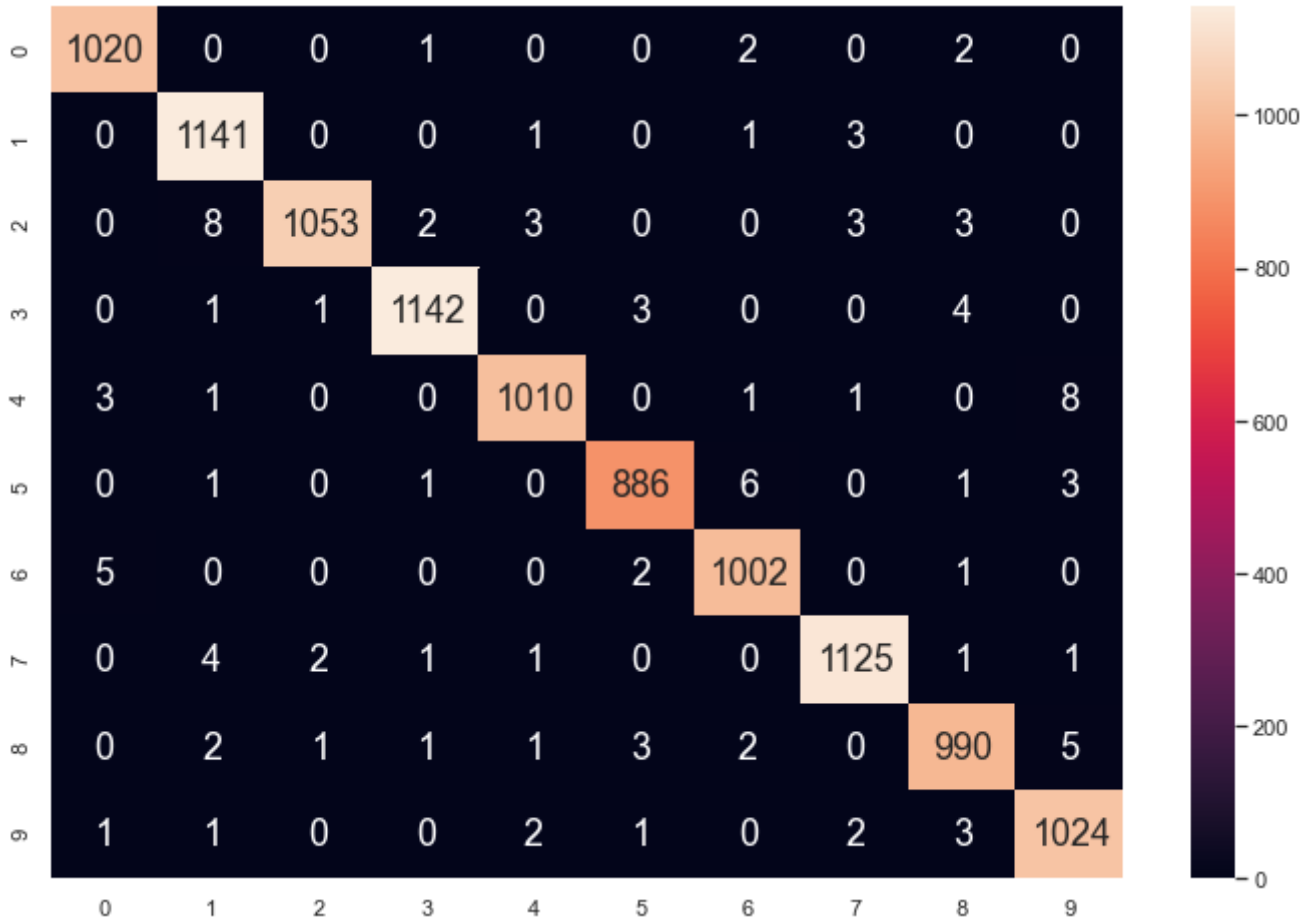
- a 0.005% improvement compared to previous preformance of 0.982%

Analysing the drawbacks of model

In [57]:
```
# make predictions on validation set
y_valid_pred = model.predict_classes(X_valid)
```

In [61]:
```
from sklearn.metrics import confusion_matrix
# Plot the Confusion Matrix for validation set
f, axes = plt.subplots(1, 1, figsize=(12, 8))
sb.heatmap(confusion_matrix(y_valid, y_valid_pred),
           annot = True, fmt=".0f", annot_kws={"size": 18}).set_xlab
```

Out[61]: <matplotlib.axes._subplots.AxesSubplot at 0x1ad95ec1648>



- significant number of misclassifications occur at predicting 4 and 9

visualising some misclassifications

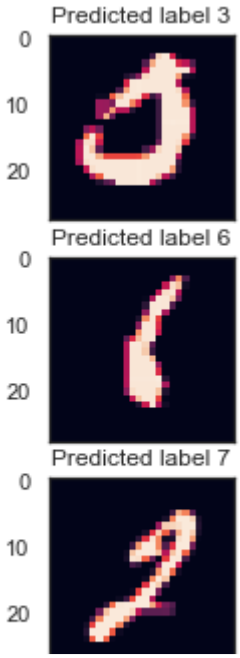
In [64]:
```
# Errors are difference between predicted labels and true labels
errors_boolean = (y_valid_pred - y_valid != 0)
```

In [66]:
```
true_values = y_valid[errors_boolean]
false_predictions = y_valid_pred[errors_boolean]
```

In [110]:
```
error_df=pd.DataFrame({'true':true_values.values,
                       'false':false_predictions},
                      index=true_values.index)
```

In [160]:
```
# extract one example of error for each number
ten_error_indices=[]
for n in range(10):
    for i in error_df.index:
        if error_df.loc[i,'true']==n:
            ten_error_indices.append(i)
            break
```

In [167]:
```
fig, ax = plt.subplots(10,1, figsize=(50, 20),sharex=True,sharey=True)
for i,row in enumerate(ten_error_indices):
    ax[i].imshow((X_train_full[row]).reshape((28,28)))
    ax[i].set_title("Predicted label {}".format(error_df.loc[row,'false']))
```



reload model and training history in future

In [ ]:
```
# # delete model
# del model
# keras.backend.clear_session()
```

In [ ]:
```
# to load the model and history again
# model = keras.models.load_model('CNN_early_stopping_model.h5')
# with open('trainHistoryDict.pickle', 'rb') as file_pi:
#     new_hist=pickle.load(file_pi, encoding='bytes')
```