sign_language_cnn_le_net

May 5, 2020

In [10]:
```
import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
import pandas as pd
from tensorflow import keras
from tensorflow.keras.layers import Conv2D, Flatten, MaxPooling2D, AveragePooling2D, De
from keras.preprocessing.image import ImageDataGenerator
import string

from libitmal import kernelfuns as itmalkernelfuns
itmalkernelfuns.EnableGPU()

%matplotlib inline

def get_mnist_dataset():

    test_pd = pd.read_csv("./SignLanguageData/sign_mnist_test.csv",
        skiprows=1)
    train_pd = pd.read_csv("./SignLanguageData/sign_mnist_train.csv",
        skiprows=1)

    return train_pd, test_pd

train_pd, test_pd = get_mnist_dataset()
X_train, X_test = train_pd.values[:,1:], test_pd.values[:,1:]
y_train, y_test = train_pd.values[:,0], test_pd.values[:,0]

class_names = list(string.ascii_lowercase)

train_pd.head()
```

Out[10]:

	3	107	118	127	134	139	143	146	150	153	...	207.4	207.5	207.6	\
0	6	155	157	156	156	156	157	156	158	158	...	69	149	128	
1	2	187	188	188	187	187	186	187	188	187	...	202	201	200	
2	2	211	211	212	212	211	210	211	210	210	...	235	234	233	
3	13	164	167	170	172	176	179	180	184	185	...	92	105	105	
4	16	161	168	172	173	178	184	189	193	196	...	76	74	68	

```
   207.7  206.4  206.5  206.6  204.6  203.8  202.13
0     87     94    163    175    103    135     149
1    199    198    199    198    195    194     195
2    231    230    226    225    222    229     163
3    108    133    163    157    163    164     179
4     62     53     55     48    238    255     255

[5 rows x 785 columns]
```

1 Data Processing

In [11]:
```
X_train = X_train / 255
X_test =  X_test / 255

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

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

batch_size, height, width, channel = X_train.shape

print(X_train.shape)
```

```
(27454, 28, 28, 1)
```

In [12]:
```
# Datageneration form https://www.kaggle.com/madz2000/cnn-using-keras-99-7-accuracy
datagen = ImageDataGenerator(
    featurewise_center=False,  # set input mean to 0 over the dataset
    samplewise_center=False,  # set each sample mean to 0
    featurewise_std_normalization=False,  # divide inputs by std of the dataset
    samplewise_std_normalization=False,  # divide each input by its std
    zca_whitening=False,  # apply ZCA whitening
    rotation_range=10,  # randomly rotate images in the range (degrees, 0 to 180)
    zoom_range = 0.1, # Randomly zoom image
    width_shift_range=0.1,  # randomly shift images horizontally (fraction of total wid
    height_shift_range=0.1,  # randomly shift images vertically (fraction of total heig
    horizontal_flip=False,  # randomly flip images
    vertical_flip=False, # randomly flip images,
    validation_split=0.2 #20 % validation split
)


datagen.fit(X_train)
```

2 Model Creation

In [13]:
```
def create_le_net():
    model = keras.models.Sequential([
        ZeroPadding2D(input_shape=X_train.shape[1:], padding=(3, 3)),
        Conv2D(filters=6, kernel_size=(5, 5), strides=1, activation="tanh"),
        AveragePooling2D(pool_size=6, strides=2, padding="same"),
        Conv2D(filters=16, kernel_size=(5, 5), strides=1, activation="tanh"),
        AveragePooling2D(pool_size=6, strides=2, padding="same"),
        Conv2D(filters=120, kernel_size=(5, 5), strides=1, activation="tanh"),
        Flatten(),
        Dense(84, activation="tanh"),
        Dense(len(class_names), activation="softmax")
    ])

    return model

def create_model():
    model = keras.models.Sequential([
        ZeroPadding2D(input_shape=X_train.shape[1:], padding=(3, 3)),
        Conv2D(filters=16, kernel_size=(3, 3), activation="relu"),
        AveragePooling2D(),
        Conv2D(filters=32, kernel_size=(3, 3), activation="relu"),
        AveragePooling2D(),
        Flatten(),
        Dense(256, activation="relu"),
        Dense(512, activation="relu"),
        Dense(128, activation="relu"),
        Dense(64, activation="relu"),
        Dense(len(class_names), activation="softmax")
    ])

    return model
```

In [14]:
```
X_test.shape
```

Out[14]:
```
(7171, 28, 28, 1)
```

In [15]:
```
# LeNet
model = create_le_net()
```

In [16]:
```
#keras.utils.plot_model(model, "my_mnist_model.png", show_shapes=True)
```

In [17]:
```
model.compile(loss="sparse_categorical_crossentropy",
              optimizer="adam",
              metrics=["accuracy"])
```

3 Model Training

```
In [18]: from keras.callbacks import EarlyStopping, ModelCheckpoint

         early_stopping = EarlyStopping(monitor='loss',
                                        patience=30,
                                        verbose=0,
                                        mode='min')

         mcp_save = ModelCheckpoint('cnn_model_checkpoint.h5',
                                    save_best_only=True,
                                    monitor='val_loss',
                                    mode='min')

         train_generator = datagen.flow(X_train,
                                        y_train,
                                        batch_size = 128,
                                        subset="training")

         validation_generator = datagen.flow(X_train,
                                             y_train,
                                             batch_size = 128,
                                             subset="validation")

         history = model.fit(train_generator,
                             epochs=500,
                             validation_data=validation_generator,
                             validation_steps=400,
                             callbacks=[early_stopping, mcp_save])
```

```
Epoch 1/500
172/172 [==============================] - 11s 62ms/step - loss: 2.6082 - acc: 0.2169 - val_loss
Epoch 2/500
172/172 [==============================] - 10s 60ms/step - loss: 1.9183 - acc: 0.4091 - val_loss
Epoch 3/500
172/172 [==============================] - 10s 61ms/step - loss: 1.6526 - acc: 0.4866 - val_loss
Epoch 4/500
172/172 [==============================] - 10s 61ms/step - loss: 1.4581 - acc: 0.5473 - val_loss
Epoch 5/500
172/172 [==============================] - 10s 61ms/step - loss: 1.3017 - acc: 0.5954 - val_loss
Epoch 6/500
172/172 [==============================] - 10s 61ms/step - loss: 1.1771 - acc: 0.6332 - val_loss
Epoch 7/500
172/172 [==============================] - 10s 61ms/step - loss: 1.0622 - acc: 0.6679 - val_loss
Epoch 8/500
172/172 [==============================] - 10s 61ms/step - loss: 0.9530 - acc: 0.7056 - val_loss
Epoch 9/500
172/172 [==============================] - 10s 61ms/step - loss: 0.8623 - acc: 0.7338 - val_loss
```

```
Epoch 10/500
172/172 [==============================] - 10s 61ms/step - loss: 0.7932 - acc: 0.7586 - val_loss
Epoch 11/500
172/172 [==============================] - 10s 61ms/step - loss: 0.7078 - acc: 0.7823 - val_loss
Epoch 12/500
172/172 [==============================] - 10s 60ms/step - loss: 0.6679 - acc: 0.7932 - val_loss
Epoch 13/500
172/172 [==============================] - 10s 61ms/step - loss: 0.6086 - acc: 0.8129 - val_loss
Epoch 14/500
172/172 [==============================] - 10s 61ms/step - loss: 0.5607 - acc: 0.8304 - val_loss
Epoch 15/500
172/172 [==============================] - 10s 61ms/step - loss: 0.5168 - acc: 0.8444 - val_loss
Epoch 16/500
172/172 [==============================] - 10s 61ms/step - loss: 0.4623 - acc: 0.8620 - val_loss
Epoch 17/500
172/172 [==============================] - 10s 61ms/step - loss: 0.4315 - acc: 0.8718 - val_loss
Epoch 18/500
172/172 [==============================] - 10s 61ms/step - loss: 0.4006 - acc: 0.8783 - val_loss
Epoch 19/500
172/172 [==============================] - 11s 61ms/step - loss: 0.3769 - acc: 0.8867 - val_loss
Epoch 20/500
172/172 [==============================] - 11s 61ms/step - loss: 0.3378 - acc: 0.9012 - val_loss
Epoch 21/500
172/172 [==============================] - 10s 61ms/step - loss: 0.3237 - acc: 0.9032 - val_loss
Epoch 22/500
172/172 [==============================] - 10s 61ms/step - loss: 0.3056 - acc: 0.9112 - val_loss
Epoch 23/500
172/172 [==============================] - 11s 61ms/step - loss: 0.2790 - acc: 0.9225 - val_loss
Epoch 24/500
172/172 [==============================] - 10s 61ms/step - loss: 0.2673 - acc: 0.9245 - val_loss
Epoch 25/500
172/172 [==============================] - 10s 60ms/step - loss: 0.2459 - acc: 0.9297 - val_loss
Epoch 26/500
172/172 [==============================] - 10s 60ms/step - loss: 0.2411 - acc: 0.9277 - val_loss
Epoch 27/500
172/172 [==============================] - 10s 60ms/step - loss: 0.2340 - acc: 0.9304 - val_loss
Epoch 28/500
172/172 [==============================] - 10s 60ms/step - loss: 0.2114 - acc: 0.9384 - val_loss
Epoch 29/500
172/172 [==============================] - 10s 60ms/step - loss: 0.2026 - acc: 0.9419 - val_loss
Epoch 30/500
172/172 [==============================] - 10s 60ms/step - loss: 0.1914 - acc: 0.9443 - val_loss
Epoch 31/500
172/172 [==============================] - 10s 61ms/step - loss: 0.1883 - acc: 0.9444 - val_loss
Epoch 32/500
172/172 [==============================] - 10s 61ms/step - loss: 0.1760 - acc: 0.9499 - val_loss
Epoch 33/500
172/172 [==============================] - 10s 61ms/step - loss: 0.1677 - acc: 0.9513 - val_loss
```

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Epoch 34/500
172/172 [==============================] - 10s 60ms/step - loss: 0.1591 - acc: 0.9554 - val_loss
Epoch 35/500
172/172 [==============================] - 10s 61ms/step - loss: 0.1526 - acc: 0.9554 - val_loss
Epoch 36/500
172/172 [==============================] - 10s 61ms/step - loss: 0.1518 - acc: 0.9563 - val_loss
Epoch 37/500
172/172 [==============================] - 10s 60ms/step - loss: 0.1357 - acc: 0.9613 - val_loss
Epoch 38/500
172/172 [==============================] - 10s 60ms/step - loss: 0.1378 - acc: 0.9601 - val_loss
Epoch 39/500
172/172 [==============================] - 10s 60ms/step - loss: 0.1253 - acc: 0.9642 - val_loss
Epoch 40/500
172/172 [==============================] - 10s 60ms/step - loss: 0.1288 - acc: 0.9633 - val_loss
Epoch 41/500
172/172 [==============================] - 10s 61ms/step - loss: 0.1187 - acc: 0.9660 - val_loss
Epoch 42/500
172/172 [==============================] - 10s 60ms/step - loss: 0.1248 - acc: 0.9636 - val_loss
Epoch 43/500
172/172 [==============================] - 10s 60ms/step - loss: 0.1132 - acc: 0.9669 - val_loss
Epoch 44/500
172/172 [==============================] - 10s 60ms/step - loss: 0.1063 - acc: 0.9699 - val_loss
Epoch 45/500
172/172 [==============================] - 10s 61ms/step - loss: 0.1065 - acc: 0.9696 - val_loss
Epoch 46/500
172/172 [==============================] - 10s 60ms/step - loss: 0.1009 - acc: 0.9712 - val_loss
Epoch 47/500
172/172 [==============================] - 10s 60ms/step - loss: 0.1042 - acc: 0.9702 - val_loss
Epoch 48/500
172/172 [==============================] - 10s 61ms/step - loss: 0.1008 - acc: 0.9716 - val_loss
Epoch 49/500
172/172 [==============================] - 11s 61ms/step - loss: 0.0934 - acc: 0.9733 - val_loss
Epoch 50/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0909 - acc: 0.9739 - val_loss
Epoch 51/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0850 - acc: 0.9764 - val_loss
Epoch 52/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0856 - acc: 0.9750 - val_loss
Epoch 53/500
172/172 [==============================] - 10s 61ms/step - loss: 0.0905 - acc: 0.9736 - val_loss
Epoch 54/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0907 - acc: 0.9726 - val_loss
Epoch 55/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0881 - acc: 0.9732 - val_loss
Epoch 56/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0780 - acc: 0.9778 - val_loss
Epoch 57/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0751 - acc: 0.9788 - val_loss
```

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Epoch 58/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0707 - acc: 0.9801 - val_loss
Epoch 59/500
172/172 [==============================] - 10s 61ms/step - loss: 0.0719 - acc: 0.9796 - val_loss
Epoch 60/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0670 - acc: 0.9808 - val_loss
Epoch 61/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0642 - acc: 0.9819 - val_loss
Epoch 62/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0742 - acc: 0.9790 - val_loss
Epoch 63/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0685 - acc: 0.9802 - val_loss
Epoch 64/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0662 - acc: 0.9816 - val_loss
Epoch 65/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0630 - acc: 0.9825 - val_loss
Epoch 66/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0634 - acc: 0.9820 - val_loss
Epoch 67/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0566 - acc: 0.9847 - val_loss
Epoch 68/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0629 - acc: 0.9808 - val_loss
Epoch 69/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0631 - acc: 0.9808 - val_loss
Epoch 70/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0610 - acc: 0.9818 - val_loss
Epoch 71/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0522 - acc: 0.9849 - val_loss
Epoch 72/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0553 - acc: 0.9837 - val_loss
Epoch 73/500
172/172 [==============================] - 10s 61ms/step - loss: 0.0592 - acc: 0.9829 - val_loss
Epoch 74/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0660 - acc: 0.9807 - val_loss
Epoch 75/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0579 - acc: 0.9827 - val_loss
Epoch 76/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0563 - acc: 0.9831 - val_loss
Epoch 77/500
172/172 [==============================] - 10s 61ms/step - loss: 0.0543 - acc: 0.9841 - val_loss
Epoch 78/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0498 - acc: 0.9855 - val_loss
Epoch 79/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0534 - acc: 0.9831 - val_loss
Epoch 80/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0493 - acc: 0.9856 - val_loss
Epoch 81/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0525 - acc: 0.9842 - val_loss
```

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Epoch 82/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0486 - acc: 0.9860 - val_loss
Epoch 83/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0461 - acc: 0.9863 - val_loss
Epoch 84/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0490 - acc: 0.9861 - val_loss
Epoch 85/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0444 - acc: 0.9870 - val_loss
Epoch 86/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0466 - acc: 0.9865 - val_loss
Epoch 87/500
172/172 [==============================] - 10s 61ms/step - loss: 0.0454 - acc: 0.9862 - val_loss
Epoch 88/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0480 - acc: 0.9849 - val_loss
Epoch 89/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0471 - acc: 0.9851 - val_loss
Epoch 90/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0459 - acc: 0.9863 - val_loss
Epoch 91/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0428 - acc: 0.9870 - val_loss
Epoch 92/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0406 - acc: 0.9883 - val_loss
Epoch 93/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0453 - acc: 0.9860 - val_loss
Epoch 94/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0500 - acc: 0.9844 - val_loss
Epoch 95/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0456 - acc: 0.9866 - val_loss
Epoch 96/500
172/172 [==============================] - 10s 61ms/step - loss: 0.0403 - acc: 0.9874 - val_loss
Epoch 97/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0365 - acc: 0.9890 - val_loss
Epoch 98/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0439 - acc: 0.9872 - val_loss
Epoch 99/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0447 - acc: 0.9858 - val_loss
Epoch 100/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0397 - acc: 0.9878 - val_loss
Epoch 101/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0393 - acc: 0.9881 - val_loss
Epoch 102/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0371 - acc: 0.9892 - val_loss
Epoch 103/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0374 - acc: 0.9887 - val_loss
Epoch 104/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0412 - acc: 0.9871 - val_loss
Epoch 105/500
172/172 [==============================] - 10s 61ms/step - loss: 0.0409 - acc: 0.9880 - val_loss
```

```
Epoch 106/500
172/172 [==============================] - 10s 61ms/step - loss: 0.0384 - acc: 0.9890 - val_loss
Epoch 107/500
172/172 [==============================] - 10s 61ms/step - loss: 0.0397 - acc: 0.9877 - val_loss
Epoch 108/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0383 - acc: 0.9883 - val_loss
Epoch 109/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0403 - acc: 0.9878 - val_loss
Epoch 110/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0377 - acc: 0.9887 - val_loss
Epoch 111/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0334 - acc: 0.9909 - val_loss
Epoch 112/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0363 - acc: 0.9889 - val_loss
Epoch 113/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0379 - acc: 0.9880 - val_loss
Epoch 114/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0346 - acc: 0.9889 - val_loss
Epoch 115/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0339 - acc: 0.9900 - val_loss
Epoch 116/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0279 - acc: 0.9914 - val_loss
Epoch 117/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0357 - acc: 0.9893 - val_loss
Epoch 118/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0341 - acc: 0.9901 - val_loss
Epoch 119/500
172/172 [==============================] - 10s 61ms/step - loss: 0.0328 - acc: 0.9898 - val_loss
Epoch 120/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0376 - acc: 0.9880 - val_loss
Epoch 121/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0332 - acc: 0.9904 - val_loss
Epoch 122/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0311 - acc: 0.9907 - val_loss
Epoch 123/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0327 - acc: 0.9896 - val_loss
Epoch 124/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0381 - acc: 0.9879 - val_loss
Epoch 125/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0316 - acc: 0.9891 - val_loss
Epoch 126/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0260 - acc: 0.9926 - val_loss
Epoch 127/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0288 - acc: 0.9911 - val_loss
Epoch 128/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0339 - acc: 0.9896 - val_loss
Epoch 129/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0346 - acc: 0.9893 - val_loss
```

```
Epoch 130/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0329 - acc: 0.9891 - val_loss
Epoch 131/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0357 - acc: 0.9883 - val_loss
Epoch 132/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0302 - acc: 0.9907 - val_loss
Epoch 133/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0354 - acc: 0.9891 - val_loss
Epoch 134/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0289 - acc: 0.9906 - val_loss
Epoch 135/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0263 - acc: 0.9917 - val_loss
Epoch 136/500
172/172 [==============================] - 11s 61ms/step - loss: 0.0312 - acc: 0.9907 - val_loss
Epoch 137/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0274 - acc: 0.9920 - val_loss
Epoch 138/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0288 - acc: 0.9912 - val_loss
Epoch 139/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0319 - acc: 0.9905 - val_loss
Epoch 140/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0232 - acc: 0.9933 - val_loss
Epoch 141/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0276 - acc: 0.9919 - val_loss
Epoch 142/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0325 - acc: 0.9889 - val_loss
Epoch 143/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0349 - acc: 0.9891 - val_loss
Epoch 144/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0274 - acc: 0.9914 - val_loss
Epoch 145/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0321 - acc: 0.9897 - val_loss
Epoch 146/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0235 - acc: 0.9927 - val_loss
Epoch 147/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0298 - acc: 0.9904 - val_loss
Epoch 148/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0305 - acc: 0.9904 - val_loss
Epoch 149/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0295 - acc: 0.9905 - val_loss
Epoch 150/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0264 - acc: 0.9917 - val_loss
Epoch 151/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0255 - acc: 0.9922 - val_loss
Epoch 152/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0284 - acc: 0.9912 - val_loss
Epoch 153/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0303 - acc: 0.9904 - val_loss
```

```
Epoch 154/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0294 - acc: 0.9907 - val_loss
Epoch 155/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0274 - acc: 0.9923 - val_loss
Epoch 156/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0270 - acc: 0.9921 - val_loss
Epoch 157/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0332 - acc: 0.9891 - val_loss
Epoch 158/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0272 - acc: 0.9917 - val_loss
Epoch 159/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0234 - acc: 0.9931 - val_loss
Epoch 160/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0221 - acc: 0.9933 - val_loss
Epoch 161/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0239 - acc: 0.9923 - val_loss
Epoch 162/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0261 - acc: 0.9919 - val_loss
Epoch 163/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0251 - acc: 0.9920 - val_loss
Epoch 164/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0242 - acc: 0.9921 - val_loss
Epoch 165/500
172/172 [==============================] - 11s 61ms/step - loss: 0.0346 - acc: 0.9894 - val_loss
Epoch 166/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0269 - acc: 0.9920 - val_loss
Epoch 167/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0282 - acc: 0.9914 - val_loss
Epoch 168/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0260 - acc: 0.9916 - val_loss
Epoch 169/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0236 - acc: 0.9923 - val_loss
Epoch 170/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0261 - acc: 0.9924 - val_loss
Epoch 171/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0192 - acc: 0.9942 - val_loss
Epoch 172/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0236 - acc: 0.9928 - val_loss
Epoch 173/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0235 - acc: 0.9923 - val_loss
Epoch 174/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0273 - acc: 0.9921 - val_loss
Epoch 175/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0262 - acc: 0.9922 - val_loss
Epoch 176/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0229 - acc: 0.9927 - val_loss
Epoch 177/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0245 - acc: 0.9926 - val_loss
```

```
Epoch 178/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0264 - acc: 0.9915 - val_loss
Epoch 179/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0284 - acc: 0.9911 - val_loss
Epoch 180/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0262 - acc: 0.9920 - val_loss
Epoch 181/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0290 - acc: 0.9904 - val_loss
Epoch 182/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0205 - acc: 0.9933 - val_loss
Epoch 183/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0238 - acc: 0.9929 - val_loss
Epoch 184/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0205 - acc: 0.9936 - val_loss
Epoch 185/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0206 - acc: 0.9928 - val_loss
Epoch 186/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0307 - acc: 0.9900 - val_loss
Epoch 187/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0244 - acc: 0.9925 - val_loss
Epoch 188/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0222 - acc: 0.9927 - val_loss
Epoch 189/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0186 - acc: 0.9939 - val_loss
Epoch 190/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0223 - acc: 0.9934 - val_loss
Epoch 191/500
172/172 [==============================] - 10s 60ms/step - loss: 0.0232 - acc: 0.9928 - val_loss
Epoch 192/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0241 - acc: 0.9924 - val_los
Epoch 193/500
172/172 [==============================] - 23s 133ms/step - loss: 0.0232 - acc: 0.9929 - val_los
Epoch 194/500
172/172 [==============================] - 21s 122ms/step - loss: 0.0290 - acc: 0.9911 - val_los
Epoch 195/500
172/172 [==============================] - 23s 134ms/step - loss: 0.0212 - acc: 0.9936 - val_los
Epoch 196/500
172/172 [==============================] - 22s 127ms/step - loss: 0.0207 - acc: 0.9932 - val_los
Epoch 197/500
172/172 [==============================] - 23s 132ms/step - loss: 0.0217 - acc: 0.9940 - val_los
Epoch 198/500
172/172 [==============================] - 23s 136ms/step - loss: 0.0229 - acc: 0.9928 - val_los
Epoch 199/500
172/172 [==============================] - 18s 104ms/step - loss: 0.0205 - acc: 0.9940 - val_los
Epoch 200/500
172/172 [==============================] - 17s 101ms/step - loss: 0.0200 - acc: 0.9939 - val_los
Epoch 201/500
172/172 [==============================] - 18s 102ms/step - loss: 0.0240 - acc: 0.9921 - val_los
```

```
Epoch 202/500
172/172 [==============================] - 17s 101ms/step - loss: 0.0262 - acc: 0.9919 - val_los
Epoch 203/500
172/172 [==============================] - 15s 86ms/step - loss: 0.0235 - acc: 0.9926 - val_loss
Epoch 204/500
172/172 [==============================] - 15s 88ms/step - loss: 0.0242 - acc: 0.9923 - val_loss
Epoch 205/500
172/172 [==============================] - 15s 86ms/step - loss: 0.0250 - acc: 0.9924 - val_loss
Epoch 206/500
172/172 [==============================] - 23s 133ms/step - loss: 0.0170 - acc: 0.9950 - val_los
Epoch 207/500
172/172 [==============================] - 26s 152ms/step - loss: 0.0236 - acc: 0.9926 - val_los
Epoch 208/500
172/172 [==============================] - 25s 147ms/step - loss: 0.0227 - acc: 0.9927 - val_los
Epoch 209/500
172/172 [==============================] - 26s 151ms/step - loss: 0.0209 - acc: 0.9927 - val_los
Epoch 210/500
172/172 [==============================] - 26s 151ms/step - loss: 0.0310 - acc: 0.9901 - val_los
Epoch 211/500
172/172 [==============================] - 27s 155ms/step - loss: 0.0277 - acc: 0.9911 - val_los
Epoch 212/500
172/172 [==============================] - 25s 147ms/step - loss: 0.0204 - acc: 0.9940 - val_los
Epoch 213/500
172/172 [==============================] - 26s 151ms/step - loss: 0.0168 - acc: 0.9944 - val_los
Epoch 214/500
172/172 [==============================] - 23s 134ms/step - loss: 0.0185 - acc: 0.9937 - val_los
Epoch 215/500
172/172 [==============================] - 24s 140ms/step - loss: 0.0225 - acc: 0.9925 - val_los
Epoch 216/500
172/172 [==============================] - 25s 146ms/step - loss: 0.0191 - acc: 0.9938 - val_los
Epoch 217/500
172/172 [==============================] - 24s 141ms/step - loss: 0.0215 - acc: 0.9931 - val_los
Epoch 218/500
172/172 [==============================] - 27s 155ms/step - loss: 0.0251 - acc: 0.9927 - val_los
Epoch 219/500
172/172 [==============================] - 23s 136ms/step - loss: 0.0194 - acc: 0.9940 - val_los
Epoch 220/500
172/172 [==============================] - 22s 130ms/step - loss: 0.0198 - acc: 0.9937 - val_los
Epoch 221/500
172/172 [==============================] - 21s 124ms/step - loss: 0.0184 - acc: 0.9941 - val_los
Epoch 222/500
172/172 [==============================] - 21s 122ms/step - loss: 0.0240 - acc: 0.9929 - val_los
Epoch 223/500
172/172 [==============================] - 22s 128ms/step - loss: 0.0179 - acc: 0.9947 - val_los
Epoch 224/500
172/172 [==============================] - 21s 121ms/step - loss: 0.0242 - acc: 0.9921 - val_los
Epoch 225/500
172/172 [==============================] - 22s 130ms/step - loss: 0.0208 - acc: 0.9937 - val_los
```

```
Epoch 226/500
172/172 [==============================] - 16s 90ms/step - loss: 0.0218 - acc: 0.9926 - val_loss
Epoch 227/500
172/172 [==============================] - 13s 78ms/step - loss: 0.0182 - acc: 0.9937 - val_loss
Epoch 228/500
172/172 [==============================] - 13s 75ms/step - loss: 0.0222 - acc: 0.9926 - val_loss
Epoch 229/500
172/172 [==============================] - 11s 62ms/step - loss: 0.0267 - acc: 0.9910 - val_loss
Epoch 230/500
172/172 [==============================] - 11s 61ms/step - loss: 0.0194 - acc: 0.9936 - val_loss
Epoch 231/500
172/172 [==============================] - 11s 62ms/step - loss: 0.0200 - acc: 0.9932 - val_loss
Epoch 232/500
172/172 [==============================] - 11s 62ms/step - loss: 0.0204 - acc: 0.9933 - val_loss
Epoch 233/500
172/172 [==============================] - 11s 62ms/step - loss: 0.0174 - acc: 0.9949 - val_loss
Epoch 234/500
172/172 [==============================] - 11s 62ms/step - loss: 0.0204 - acc: 0.9938 - val_loss
Epoch 235/500
172/172 [==============================] - 11s 62ms/step - loss: 0.0196 - acc: 0.9935 - val_loss
Epoch 236/500
172/172 [==============================] - 11s 62ms/step - loss: 0.0244 - acc: 0.9923 - val_loss
Epoch 237/500
172/172 [==============================] - 11s 61ms/step - loss: 0.0172 - acc: 0.9949 - val_loss
Epoch 238/500
172/172 [==============================] - 11s 62ms/step - loss: 0.0222 - acc: 0.9928 - val_loss
Epoch 239/500
172/172 [==============================] - 11s 62ms/step - loss: 0.0248 - acc: 0.9915 - val_loss
Epoch 240/500
172/172 [==============================] - 11s 62ms/step - loss: 0.0192 - acc: 0.9937 - val_loss
Epoch 241/500
172/172 [==============================] - 11s 63ms/step - loss: 0.0216 - acc: 0.9923 - val_loss
Epoch 242/500
172/172 [==============================] - 11s 62ms/step - loss: 0.0254 - acc: 0.9917 - val_loss
Epoch 243/500
172/172 [==============================] - 11s 62ms/step - loss: 0.0208 - acc: 0.9936 - val_loss
```

4 Model Evaluation

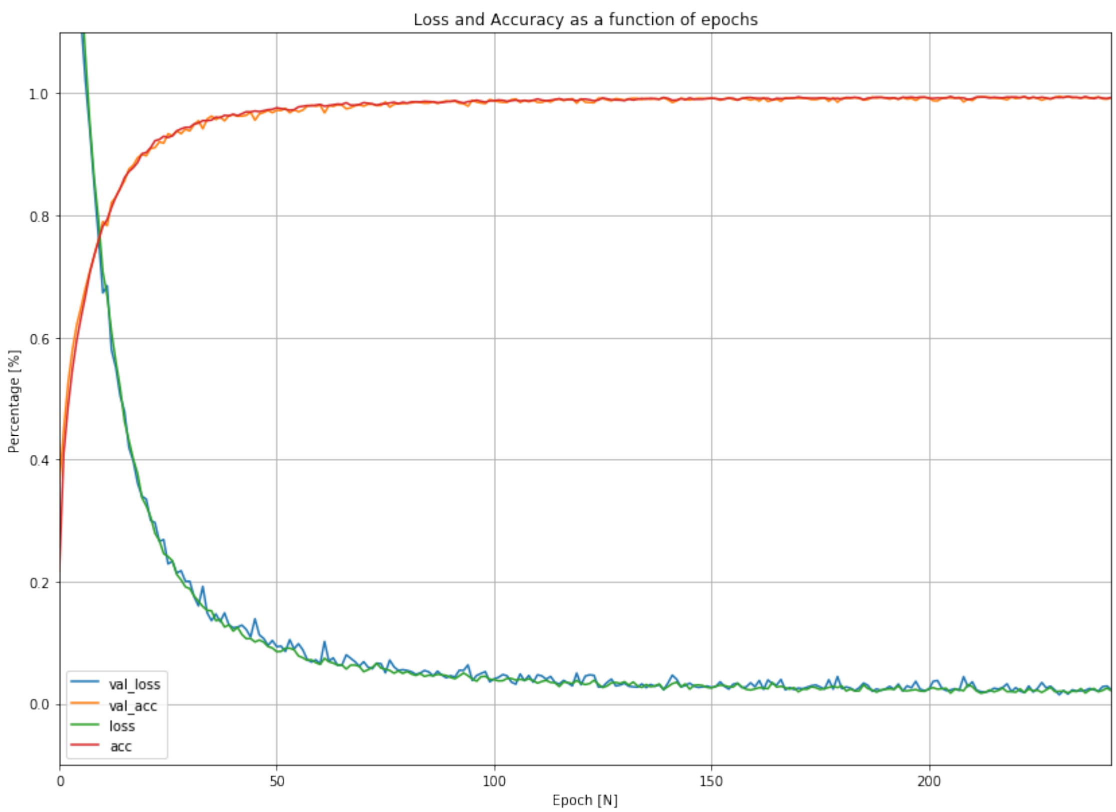
```
In [19]: import pandas as pd

         evaluation = model.evaluate(X_test, y_test)
         print(f'Model evaluation: {evaluation}')

         pd.DataFrame(history.history).plot(figsize=(14, 10))
         plt.grid(True)
```

```
        plt.gca().set_ylim(-0.1, 1.1)
        plt.xlabel("Epoch [N]")
        plt.ylabel("Percentage [%]")
        plt.title("Loss and Accuracy as a function of epochs")
        plt.show()
```

```
7171/7171 [==============================] - 0s 31us/step
Model evaluation: [0.06010350688544694, 0.983544833356575]
```




```
In [20]: import math

         num_rows = 3
         num_cols = 3

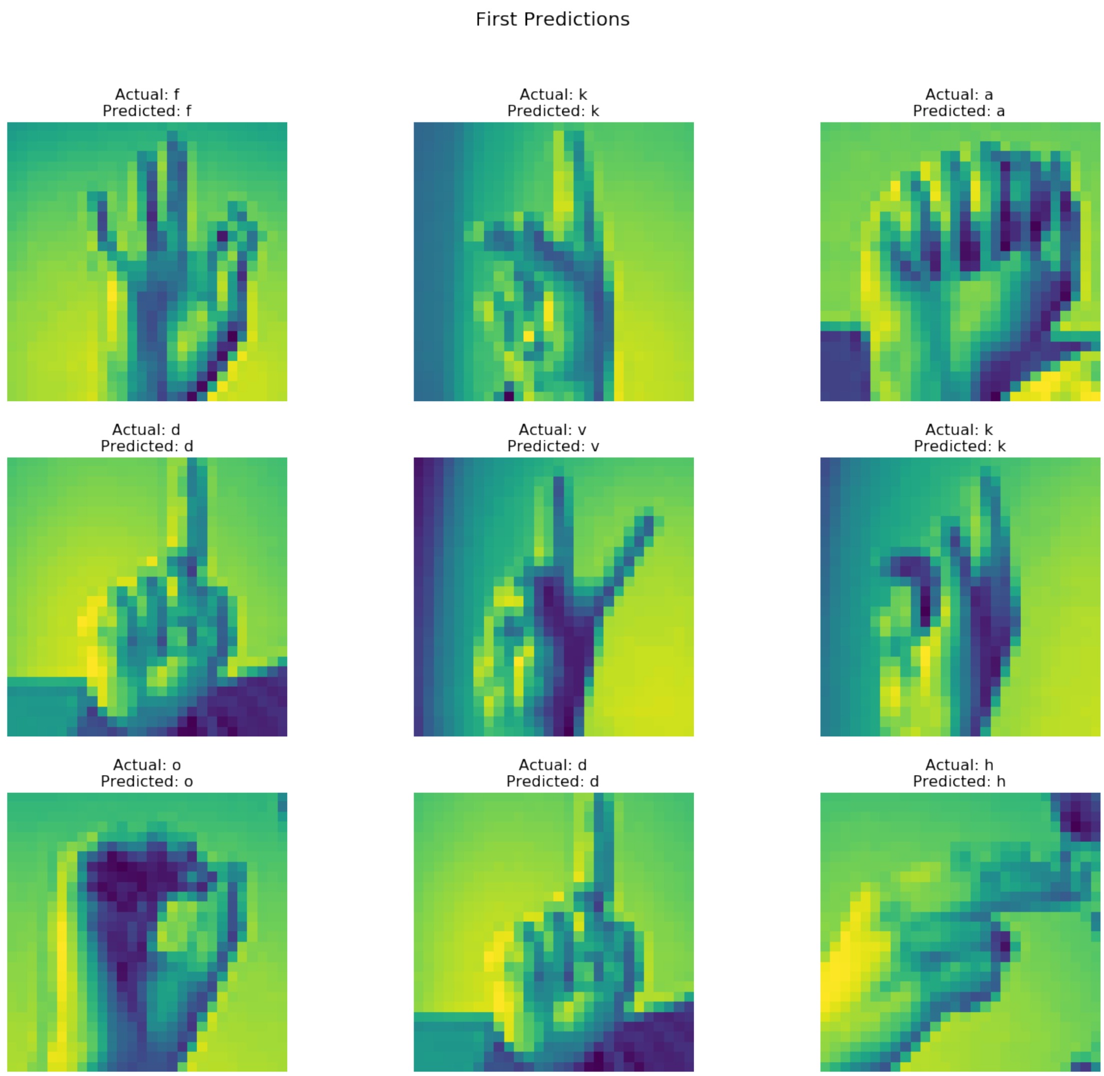
         X_new = X_test[:num_rows*num_cols]

         y_pred = model.predict_classes(X_new)

         fig, ax = plt.subplots(num_rows, num_cols, figsize=(18, 16))
         for index, image in enumerate(X_new):
             ax[math.floor(index/num_rows), index%num_rows].imshow(image.reshape((28,28)))
```

```
        ax[math.floor(index/num_rows), index%num_rows].set_title(
            f"Actual: {class_names[y_test[index]]}\nPredicted: {class_names[y_pred[index]]}
            fontsize=16)
        ax[int(index/num_rows), index%num_rows].axis('off')

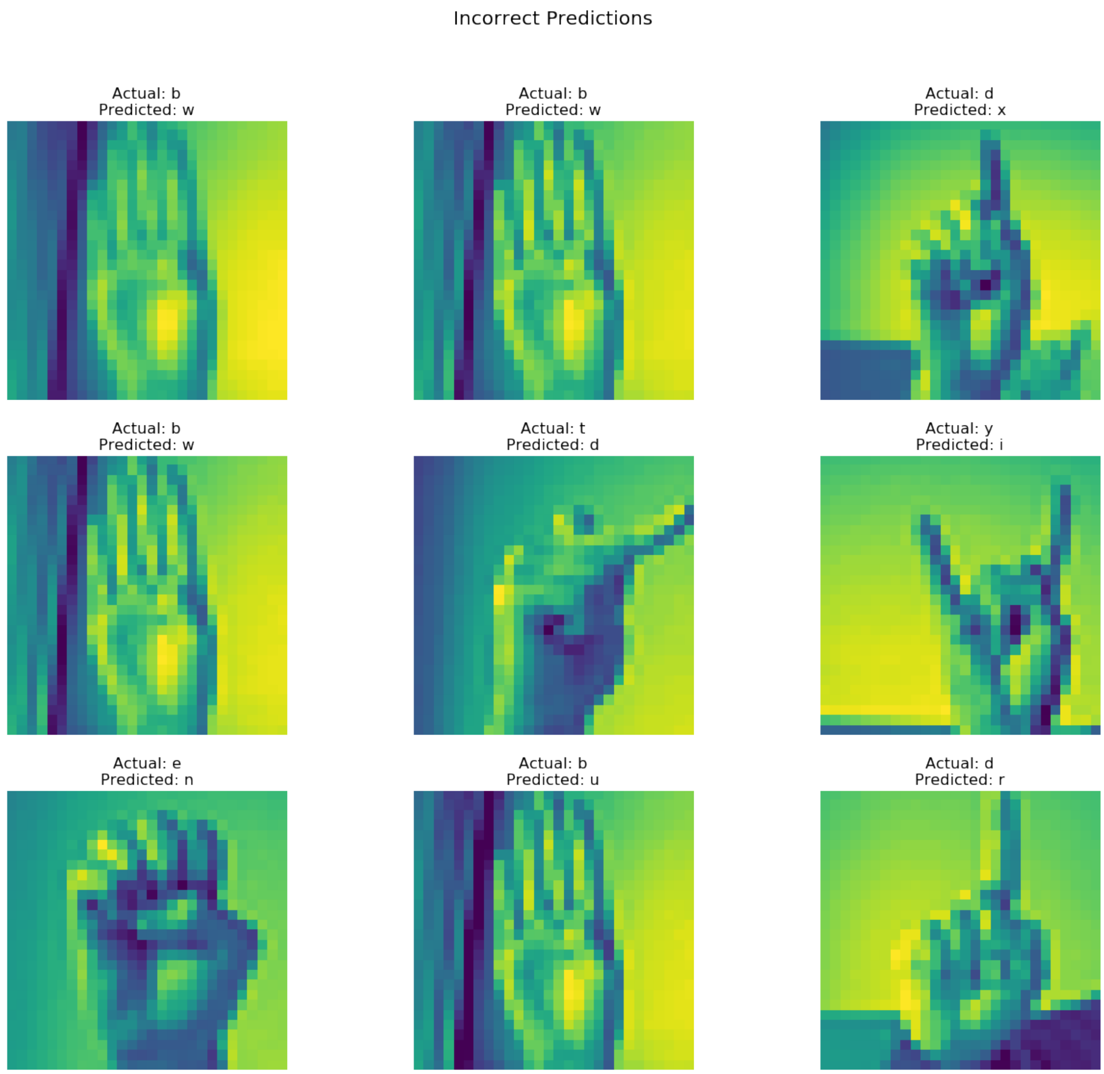
    fig.tight_layout()
    fig.suptitle(f'First Predictions', fontsize=20)
    fig.subplots_adjust(top=0.88)
    fig.show()
```



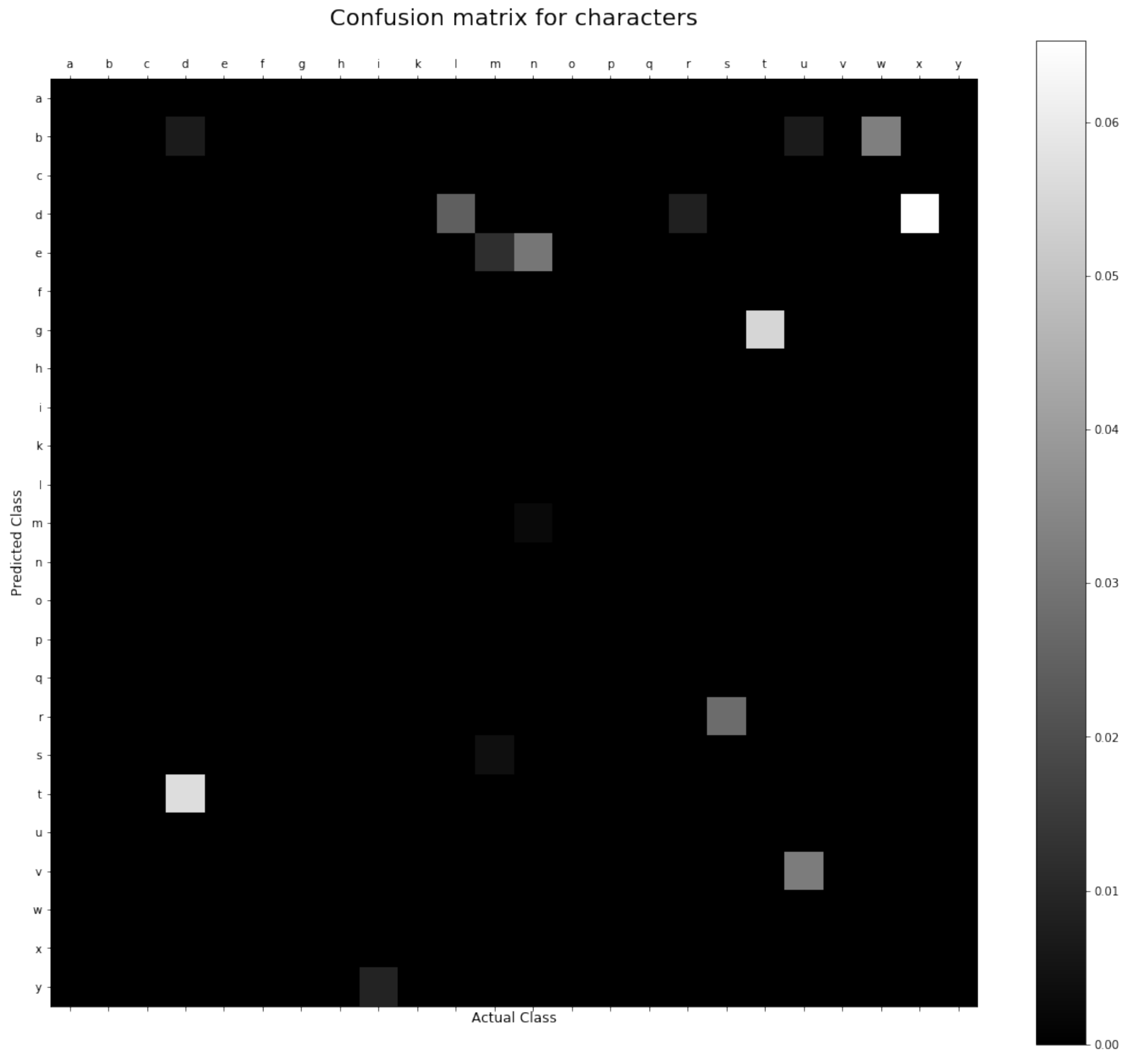

```
In [21]: y_pred = model.predict_classes(X_test)

         confusion_indices = np.where(y_pred != y_test)
         X_confusion = X_test[confusion_indices]
```

```python
y_pred_confusion = y_pred[confusion_indices]
y_test_confusion = y_test[confusion_indices]

fig, ax = plt.subplots(num_rows, num_cols, figsize=(18, 16))
for index, image in enumerate(X_confusion[:num_rows*num_cols]):
    ax[math.floor(index/num_rows), index%num_rows].imshow(image.reshape((28,28)), inter
    ax[math.floor(index/num_rows), index%num_rows].set_title(
        f"Actual: {class_names[y_test_confusion[index]]}\nPredicted: {class_names[y_pre
        fontsize=16)
    ax[int(index/num_rows), index%num_rows].axis('off')


fig.tight_layout()
fig.suptitle('Incorrect Predictions', fontsize=20)
fig.subplots_adjust(top=0.88)
fig.show()
```



In [22]:
```
import sklearn.metrics as metrics

confusion_matrix = metrics.confusion_matrix(y_test, y_pred)
row_sum = confusion_matrix.sum(axis=1, keepdims=True)
norm_confusion_matrix = confusion_matrix / row_sum

# Becausse j and z aren't possible we cant include them in confusion matrix
class_names_clean = class_names.copy()
class_names_clean.remove('j')
class_names_clean.remove('z')

np.fill_diagonal(norm_confusion_matrix, 0)

fig, ax = plt.subplots(figsize=(18, 16))

mat_ax = ax.matshow(norm_confusion_matrix, interpolation='nearest', cmap=plt.cm.gray)
fig.colorbar(mat_ax)
ax.set_title('Confusion matrix for characters', fontsize=20)
ax.set_xlabel('Actual Class', fontsize=12)
ax.set_ylabel('Predicted Class', fontsize=12)
ax.set_xticks(ticks=np.arange(0, len(class_names_clean)))
ax.set_xticklabels(class_names_clean)
ax.set_yticks(ticks=np.arange(0, len(class_names_clean)))
ax.set_yticklabels(class_names_clean)
fig.show()
```




```
In [23]: y_pred = model.predict_classes(X_test)
         print(metrics.f1_score(y_test, y_pred, average="micro"))
```

```
0.983544833356575
```

5 Comparison with no Image Generation

```
In [24]: # Fit model without data augmentation
         no_data_aug_model = create_le_net()

         no_data_aug_model.compile(loss="sparse_categorical_crossentropy",
                       optimizer="adam",
                       metrics=["accuracy"])
```

```
history_no_data_aug = no_data_aug_model.fit(X_train,
                    y_train,
                    epochs=500,
                    validation_split=0.2,
                    callbacks=[early_stopping])
```

```
Train on 21963 samples, validate on 5491 samples
Epoch 1/500
21963/21963 [==============================] - 3s 119us/step - loss: 1.7651 - acc: 0.4575 - val_
Epoch 2/500
21963/21963 [==============================] - 2s 102us/step - loss: 0.6691 - acc: 0.8125 - val_
Epoch 3/500
21963/21963 [==============================] - 2s 103us/step - loss: 0.3225 - acc: 0.9292 - val_
Epoch 4/500
21963/21963 [==============================] - 2s 102us/step - loss: 0.1495 - acc: 0.9787 - val_
Epoch 5/500
21963/21963 [==============================] - 2s 103us/step - loss: 0.0675 - acc: 0.9959 - val_
Epoch 6/500
21963/21963 [==============================] - 2s 102us/step - loss: 0.0365 - acc: 0.9985 - val_
Epoch 7/500
21963/21963 [==============================] - 2s 103us/step - loss: 0.0201 - acc: 0.9993 - val_
Epoch 8/500
21963/21963 [==============================] - 2s 102us/step - loss: 0.0369 - acc: 0.9922 - val_
Epoch 9/500
21963/21963 [==============================] - 2s 102us/step - loss: 0.0071 - acc: 0.9999 - val_
Epoch 10/500
21963/21963 [==============================] - 2s 101us/step - loss: 0.0232 - acc: 0.9951 - val_
Epoch 11/500
21963/21963 [==============================] - 2s 103us/step - loss: 0.0162 - acc: 0.9969 - val_
Epoch 12/500
21963/21963 [==============================] - 2s 102us/step - loss: 0.0024 - acc: 1.0000 - val_
Epoch 13/500
21963/21963 [==============================] - 2s 103us/step - loss: 0.0017 - acc: 1.0000 - val_
Epoch 14/500
21963/21963 [==============================] - 2s 102us/step - loss: 0.0013 - acc: 1.0000 - val_
Epoch 15/500
21963/21963 [==============================] - 2s 102us/step - loss: 9.5004e-04 - acc: 1.0000 -
Epoch 16/500
21963/21963 [==============================] - 2s 103us/step - loss: 0.0490 - acc: 0.9852 - val_
Epoch 17/500
21963/21963 [==============================] - 2s 103us/step - loss: 0.0025 - acc: 1.0000 - val_
Epoch 18/500
21963/21963 [==============================] - 2s 101us/step - loss: 0.0014 - acc: 1.0000 - val_
Epoch 19/500
21963/21963 [==============================] - 2s 103us/step - loss: 9.3622e-04 - acc: 1.0000 -
Epoch 20/500
21963/21963 [==============================] - 2s 103us/step - loss: 6.7558e-04 - acc: 1.0000 -
```

```
Epoch 21/500
21963/21963 [==============================] - 2s 103us/step - loss: 5.0628e-04 - acc: 1.0000 -
Epoch 22/500
21963/21963 [==============================] - 2s 102us/step - loss: 3.8776e-04 - acc: 1.0000 -
Epoch 23/500
21963/21963 [==============================] - 2s 102us/step - loss: 3.0281e-04 - acc: 1.0000 -
Epoch 24/500
21963/21963 [==============================] - 2s 102us/step - loss: 0.0315 - acc: 0.9904 - val_
Epoch 25/500
21963/21963 [==============================] - 2s 102us/step - loss: 0.0226 - acc: 0.9938 - val_
Epoch 26/500
21963/21963 [==============================] - 2s 102us/step - loss: 0.0013 - acc: 1.0000 - val_
Epoch 27/500
21963/21963 [==============================] - 2s 102us/step - loss: 8.1913e-04 - acc: 1.0000 -
Epoch 28/500
21963/21963 [==============================] - 2s 102us/step - loss: 5.6420e-04 - acc: 1.0000 -
Epoch 29/500
21963/21963 [==============================] - 2s 102us/step - loss: 4.1122e-04 - acc: 1.0000 -
Epoch 30/500
21963/21963 [==============================] - 2s 101us/step - loss: 3.0973e-04 - acc: 1.0000 -
Epoch 31/500
21963/21963 [==============================] - 2s 103us/step - loss: 2.3852e-04 - acc: 1.0000 -
Epoch 32/500
21963/21963 [==============================] - 2s 102us/step - loss: 1.8368e-04 - acc: 1.0000 -
Epoch 33/500
21963/21963 [==============================] - 2s 102us/step - loss: 1.4499e-04 - acc: 1.0000 -
Epoch 34/500
21963/21963 [==============================] - 2s 114us/step - loss: 1.1282e-04 - acc: 1.0000 -
Epoch 35/500
21963/21963 [==============================] - 3s 122us/step - loss: 8.8819e-05 - acc: 1.0000 -
Epoch 36/500
21963/21963 [==============================] - 3s 121us/step - loss: 6.8102e-05 - acc: 1.0000 -
Epoch 37/500
21963/21963 [==============================] - 3s 121us/step - loss: 5.3130e-05 - acc: 1.0000 -
Epoch 38/500
21963/21963 [==============================] - 3s 121us/step - loss: 4.3177e-05 - acc: 1.0000 -
Epoch 39/500
21963/21963 [==============================] - 3s 121us/step - loss: 3.0663e-05 - acc: 1.0000 -
Epoch 40/500
21963/21963 [==============================] - 3s 121us/step - loss: 2.3437e-05 - acc: 1.0000 -
Epoch 41/500
21963/21963 [==============================] - 3s 122us/step - loss: 1.7879e-05 - acc: 1.0000 -
Epoch 42/500
21963/21963 [==============================] - 3s 123us/step - loss: 1.3630e-05 - acc: 1.0000 -
Epoch 43/500
21963/21963 [==============================] - 3s 123us/step - loss: 1.0571e-05 - acc: 1.0000 -
Epoch 44/500
21963/21963 [==============================] - 3s 122us/step - loss: 8.2532e-06 - acc: 1.0000 -
```

```
Epoch 45/500
21963/21963 [==============================] - 3s 123us/step - loss: 6.6078e-06 - acc: 1.0000 -
Epoch 46/500
21963/21963 [==============================] - 3s 122us/step - loss: 5.3826e-06 - acc: 1.0000 -
Epoch 47/500
21963/21963 [==============================] - 3s 122us/step - loss: 0.0615 - acc: 0.9822 - val_
Epoch 48/500
21963/21963 [==============================] - 3s 121us/step - loss: 7.8687e-04 - acc: 1.0000 -
Epoch 49/500
21963/21963 [==============================] - 3s 121us/step - loss: 3.9734e-04 - acc: 1.0000 -
Epoch 50/500
21963/21963 [==============================] - 3s 122us/step - loss: 2.7092e-04 - acc: 1.0000 -
Epoch 51/500
21963/21963 [==============================] - 3s 122us/step - loss: 1.9712e-04 - acc: 1.0000 -
Epoch 52/500
21963/21963 [==============================] - 3s 122us/step - loss: 1.4705e-04 - acc: 1.0000 -
Epoch 53/500
21963/21963 [==============================] - 3s 122us/step - loss: 1.1151e-04 - acc: 1.0000 -
Epoch 54/500
21963/21963 [==============================] - 3s 122us/step - loss: 8.5432e-05 - acc: 1.0000 -
Epoch 55/500
21963/21963 [==============================] - 3s 122us/step - loss: 6.5648e-05 - acc: 1.0000 -
Epoch 56/500
21963/21963 [==============================] - 3s 123us/step - loss: 5.0312e-05 - acc: 1.0000 -
Epoch 57/500
21963/21963 [==============================] - 3s 122us/step - loss: 3.7846e-05 - acc: 1.0000 -
Epoch 58/500
21963/21963 [==============================] - 3s 122us/step - loss: 2.8749e-05 - acc: 1.0000 -
Epoch 59/500
21963/21963 [==============================] - 3s 123us/step - loss: 2.2172e-05 - acc: 1.0000 -
Epoch 60/500
21963/21963 [==============================] - 3s 122us/step - loss: 1.7469e-05 - acc: 1.0000 -
Epoch 61/500
21963/21963 [==============================] - 3s 123us/step - loss: 1.3764e-05 - acc: 1.0000 -
Epoch 62/500
21963/21963 [==============================] - 3s 122us/step - loss: 1.1051e-05 - acc: 1.0000 -
Epoch 63/500
21963/21963 [==============================] - 3s 122us/step - loss: 8.9612e-06 - acc: 1.0000 -
Epoch 64/500
21963/21963 [==============================] - 2s 108us/step - loss: 7.3854e-06 - acc: 1.0000 -
Epoch 65/500
21963/21963 [==============================] - 2s 109us/step - loss: 6.1750e-06 - acc: 1.0000 -
Epoch 66/500
21963/21963 [==============================] - 2s 98us/step - loss: 5.2373e-06 - acc: 1.0000 - v
Epoch 67/500
21963/21963 [==============================] - 2s 78us/step - loss: 4.5520e-06 - acc: 1.0000 - v
Epoch 68/500
21963/21963 [==============================] - 2s 77us/step - loss: 4.0290e-06 - acc: 1.0000 - v
```

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Epoch 69/500
21963/21963 [==============================] - 2s 77us/step - loss: 3.6541e-06 - acc: 1.0000 - v
Epoch 70/500
21963/21963 [==============================] - 2s 77us/step - loss: 3.3678e-06 - acc: 1.0000 - v
Epoch 71/500
21963/21963 [==============================] - 2s 77us/step - loss: 3.1585e-06 - acc: 1.0000 - v
Epoch 72/500
21963/21963 [==============================] - 2s 77us/step - loss: 2.9984e-06 - acc: 1.0000 - v
Epoch 73/500
21963/21963 [==============================] - 2s 77us/step - loss: 2.8813e-06 - acc: 1.0000 - v
Epoch 74/500
21963/21963 [==============================] - 2s 77us/step - loss: 2.7949e-06 - acc: 1.0000 - v
Epoch 75/500
21963/21963 [==============================] - 2s 77us/step - loss: 2.7309e-06 - acc: 1.0000 - v
Epoch 76/500
21963/21963 [==============================] - 2s 78us/step - loss: 2.6862e-06 - acc: 1.0000 - v
Epoch 77/500
21963/21963 [==============================] - 2s 78us/step - loss: 2.6537e-06 - acc: 1.0000 - v
Epoch 78/500
21963/21963 [==============================] - 2s 77us/step - loss: 2.6318e-06 - acc: 1.0000 - v
Epoch 79/500
21963/21963 [==============================] - 2s 78us/step - loss: 2.6159e-06 - acc: 1.0000 - v
Epoch 80/500
21963/21963 [==============================] - 2s 78us/step - loss: 2.6040e-06 - acc: 1.0000 - v
Epoch 81/500
21963/21963 [==============================] - 2s 77us/step - loss: 2.5965e-06 - acc: 1.0000 - v
Epoch 82/500
21963/21963 [==============================] - 2s 78us/step - loss: 2.5912e-06 - acc: 1.0000 - v
Epoch 83/500
21963/21963 [==============================] - 2s 78us/step - loss: 2.5875e-06 - acc: 1.0000 - v
Epoch 84/500
21963/21963 [==============================] - 2s 77us/step - loss: 2.5852e-06 - acc: 1.0000 - v
Epoch 85/500
21963/21963 [==============================] - 2s 77us/step - loss: 2.5831e-06 - acc: 1.0000 - v
Epoch 86/500
21963/21963 [==============================] - 2s 78us/step - loss: 2.5815e-06 - acc: 1.0000 - v
Epoch 87/500
21963/21963 [==============================] - 2s 78us/step - loss: 2.5811e-06 - acc: 1.0000 - v
Epoch 88/500
21963/21963 [==============================] - 2s 77us/step - loss: 0.0265 - acc: 0.9933 - val_l
Epoch 89/500
21963/21963 [==============================] - 2s 78us/step - loss: 0.0410 - acc: 0.9898 - val_l
Epoch 90/500
21963/21963 [==============================] - 2s 78us/step - loss: 4.5622e-04 - acc: 1.0000 - v
Epoch 91/500
21963/21963 [==============================] - 2s 77us/step - loss: 2.5176e-04 - acc: 1.0000 - v
Epoch 92/500
21963/21963 [==============================] - 2s 77us/step - loss: 1.7036e-04 - acc: 1.0000 - v
```

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Epoch 93/500
21963/21963 [==============================] - 2s 77us/step - loss: 1.2104e-04 - acc: 1.0000 - v
Epoch 94/500
21963/21963 [==============================] - 2s 77us/step - loss: 8.8157e-05 - acc: 1.0000 - v
Epoch 95/500
21963/21963 [==============================] - 2s 77us/step - loss: 6.5286e-05 - acc: 1.0000 - v
Epoch 96/500
21963/21963 [==============================] - 2s 78us/step - loss: 4.8872e-05 - acc: 1.0000 - v
Epoch 97/500
21963/21963 [==============================] - 2s 77us/step - loss: 3.6672e-05 - acc: 1.0000 - v
Epoch 98/500
21963/21963 [==============================] - 2s 77us/step - loss: 2.7755e-05 - acc: 1.0000 - v
Epoch 99/500
21963/21963 [==============================] - 2s 77us/step - loss: 2.1139e-05 - acc: 1.0000 - v
Epoch 100/500
21963/21963 [==============================] - 2s 78us/step - loss: 1.6314e-05 - acc: 1.0000 - v
Epoch 101/500
21963/21963 [==============================] - 2s 77us/step - loss: 1.2822e-05 - acc: 1.0000 - v
Epoch 102/500
21963/21963 [==============================] - 2s 77us/step - loss: 1.0224e-05 - acc: 1.0000 - v
Epoch 103/500
21963/21963 [==============================] - 2s 77us/step - loss: 8.2825e-06 - acc: 1.0000 - v
Epoch 104/500
21963/21963 [==============================] - 2s 77us/step - loss: 6.8615e-06 - acc: 1.0000 - v
Epoch 105/500
21963/21963 [==============================] - 2s 77us/step - loss: 5.7824e-06 - acc: 1.0000 - v
Epoch 106/500
21963/21963 [==============================] - 2s 77us/step - loss: 4.9695e-06 - acc: 1.0000 - v
Epoch 107/500
21963/21963 [==============================] - 2s 77us/step - loss: 4.3530e-06 - acc: 1.0000 - v
Epoch 108/500
21963/21963 [==============================] - 2s 77us/step - loss: 3.8882e-06 - acc: 1.0000 - v
Epoch 109/500
21963/21963 [==============================] - 2s 77us/step - loss: 3.5349e-06 - acc: 1.0000 - v
Epoch 110/500
21963/21963 [==============================] - 2s 77us/step - loss: 3.2667e-06 - acc: 1.0000 - v
Epoch 111/500
21963/21963 [==============================] - 2s 77us/step - loss: 3.0712e-06 - acc: 1.0000 - v
Epoch 112/500
21963/21963 [==============================] - 2s 77us/step - loss: 2.9311e-06 - acc: 1.0000 - v
Epoch 113/500
21963/21963 [==============================] - 2s 77us/step - loss: 2.8293e-06 - acc: 1.0000 - v
Epoch 114/500
21963/21963 [==============================] - 2s 77us/step - loss: 2.7551e-06 - acc: 1.0000 - v
Epoch 115/500
21963/21963 [==============================] - 2s 77us/step - loss: 2.7023e-06 - acc: 1.0000 - v
Epoch 116/500
21963/21963 [==============================] - 2s 78us/step - loss: 2.6650e-06 - acc: 1.0000 - v
```

```
Epoch 117/500
21963/21963 [==============================] - 2s 77us/step - loss: 2.6390e-06 - acc: 1.0000 - v
```

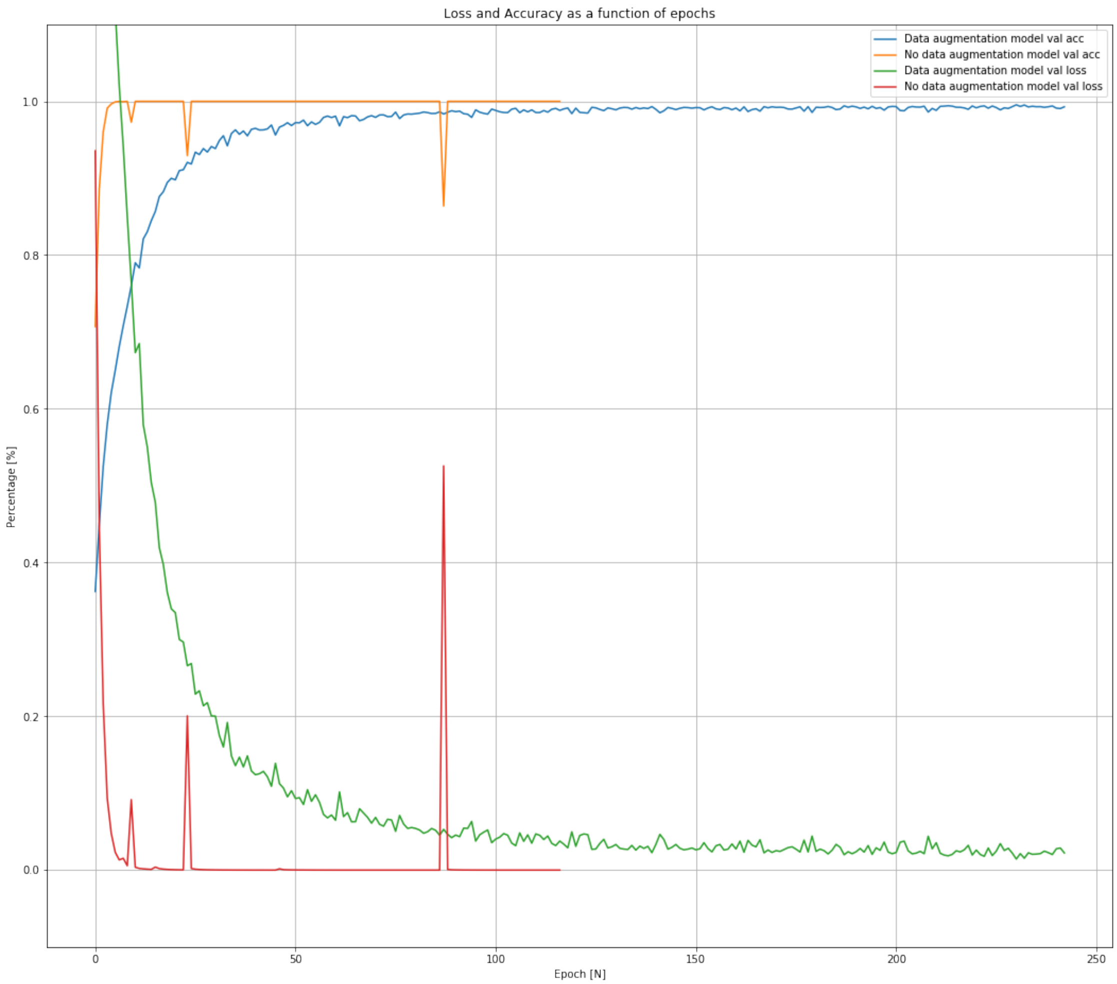
In [25]:
```python
fig, ax = plt.subplots(figsize=(18, 16))

evaluation = no_data_aug_model.evaluate(X_test, y_test)
print(f'Model evaluation: {evaluation}')

ax.plot(history.history['val_acc'], label='Data augmentation model val acc')
ax.plot(history_no_data_aug.history['val_acc'], label='No data augmentation model val a
ax.plot(history.history['val_loss'], label='Data augmentation model val loss')
ax.plot(history_no_data_aug.history['val_loss'], label='No data augmentation model val
ax.legend(loc="upper right")
ax.grid(True)
fig.gca().set_ylim(-0.1, 1.1)
ax.set_xlabel("Epoch [N]")
ax.set_ylabel("Percentage [%]")
ax.set_title("Loss and Accuracy as a function of epochs")
```

```
7171/7171 [==============================] - 0s 22us/step
Model evaluation: [0.7251484119123586, 0.8899735043926927]
```

Out[25]:
```
Text(0.5, 1.0, 'Loss and Accuracy as a function of epochs')
```




```
In [27]: y_pred = no_data_aug_model.predict_classes(X_test)

         print(metrics.f1_score(y_test, y_pred, average="micro"))
```

0.8899735043926927

```
In [ ]: model.save('cnn_model_le_net.h5')
```

```
In [28]: import math
         import numpy as np

         word_to_predict = "helloworld"
         num_cols_pr_row = 5
         num_rows = int(len(word_to_predict)/num_cols_pr_row)

         X_new_indeces = []
```

```
y_labels  = np.array([class_names[y] for y in y_test])

for c in word_to_predict:
    index = np.where(y_labels==c)[0][2]
    X_new_indeces.append(index)

X_new_indeces = np.array(X_new_indeces)
y_pred = model.predict_classes(X_test[X_new_indeces])


fig, ax = plt.subplots(num_rows, int(len(word_to_predict)/num_rows), figsize=(18, 10))
for index, val in enumerate(X_new_indeces):
    ax[math.floor(index/num_cols_pr_row), index%num_cols_pr_row].imshow(X_test[val].res
    ax[math.floor(index/num_cols_pr_row), index%num_cols_pr_row].set_title(
        f"Actual: {class_names[y_test[val]]}\nPredicted: {class_names[y_pred[index]]}",
        fontsize=16)
    ax[math.floor(index/num_cols_pr_row), index%num_cols_pr_row].axis('off')

fig.tight_layout()
fig.suptitle(f'Prediction of {word_to_predict}', fontsize=20)
fig.subplots_adjust(top=0.88)
fig.show()
```