sign_language_cnn

May 5, 2020

In [245]:
```
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, D
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[245]:

	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 [246]:
```
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 [247]:
```
# 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 wi
    height_shift_range=0.1,  # randomly shift images vertically (fraction of total hei
    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 [248]:
```
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 [249]:
```
X_test.shape
```

Out[249]: (7171, 28, 28, 1)

In [250]:
```
# LeNet
model = create_model()
```

In [251]:
```
#keras.utils.plot_model(model, "my_mnist_model.png", show_shapes=True)
```

In [252]:
```
model.compile(loss="sparse_categorical_crossentropy",
              optimizer="adam",
              metrics=["accuracy"])
```

3 Model Training

In [253]:
```
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=800,
                    callbacks=[early_stopping, mcp_save])
```

```
Epoch 1/500
172/172 [==============================] - 21s 120ms/step - loss: 2.5789 - acc: 0.2031 - val_los
Epoch 2/500
172/172 [==============================] - 19s 108ms/step - loss: 1.4610 - acc: 0.5069 - val_los
Epoch 3/500
172/172 [==============================] - 18s 106ms/step - loss: 0.8856 - acc: 0.6932 - val_los
Epoch 4/500
172/172 [==============================] - 18s 106ms/step - loss: 0.5742 - acc: 0.8031 - val_los
Epoch 5/500
172/172 [==============================] - 18s 107ms/step - loss: 0.3976 - acc: 0.8627 - val_los
Epoch 6/500
172/172 [==============================] - 18s 106ms/step - loss: 0.2837 - acc: 0.9034 - val_los
Epoch 7/500
172/172 [==============================] - 18s 106ms/step - loss: 0.2215 - acc: 0.9239 - val_los
Epoch 8/500
172/172 [==============================] - 18s 106ms/step - loss: 0.1750 - acc: 0.9414 - val_los
Epoch 9/500
172/172 [==============================] - 18s 106ms/step - loss: 0.1369 - acc: 0.9546 - val_los
```

```
Epoch 10/500
172/172 [==============================] - 18s 105ms/step - loss: 0.1353 - acc: 0.9543 - val_los
Epoch 11/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0984 - acc: 0.9663 - val_los
Epoch 12/500
172/172 [==============================] - 18s 105ms/step - loss: 0.1006 - acc: 0.9661 - val_los
Epoch 13/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0857 - acc: 0.9715 - val_los
Epoch 14/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0763 - acc: 0.9746 - val_los
Epoch 15/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0614 - acc: 0.9794 - val_los
Epoch 16/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0619 - acc: 0.9797 - val_los
Epoch 17/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0507 - acc: 0.9831 - val_los
Epoch 18/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0566 - acc: 0.9816 - val_los
Epoch 19/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0496 - acc: 0.9823 - val_los
Epoch 20/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0417 - acc: 0.9866 - val_los
Epoch 21/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0434 - acc: 0.9851 - val_los
Epoch 22/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0508 - acc: 0.9827 - val_los
Epoch 23/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0383 - acc: 0.9873 - val_los
Epoch 24/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0340 - acc: 0.9884 - val_los
Epoch 25/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0274 - acc: 0.9916 - val_los
Epoch 26/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0393 - acc: 0.9876 - val_los
Epoch 27/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0283 - acc: 0.9917 - val_los
Epoch 28/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0306 - acc: 0.9901 - val_los
Epoch 29/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0295 - acc: 0.9906 - val_los
Epoch 30/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0323 - acc: 0.9893 - val_los
Epoch 31/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0297 - acc: 0.9900 - val_los
Epoch 32/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0283 - acc: 0.9907 - val_los
Epoch 33/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0312 - acc: 0.9896 - val_los
```

```
Epoch 34/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0239 - acc: 0.9926 - val_los
Epoch 35/500
172/172 [==============================] - 18s 107ms/step - loss: 0.0257 - acc: 0.9915 - val_los
Epoch 36/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0258 - acc: 0.9920 - val_los
Epoch 37/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0241 - acc: 0.9923 - val_los
Epoch 38/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0214 - acc: 0.9936 - val_los
Epoch 39/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0286 - acc: 0.9906 - val_los
Epoch 40/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0292 - acc: 0.9903 - val_los
Epoch 41/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0192 - acc: 0.9938 - val_los
Epoch 42/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0168 - acc: 0.9949 - val_los
Epoch 43/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0189 - acc: 0.9937 - val_los
Epoch 44/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0156 - acc: 0.9948 - val_los
Epoch 45/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0262 - acc: 0.9918 - val_los
Epoch 46/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0269 - acc: 0.9911 - val_los
Epoch 47/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0222 - acc: 0.9929 - val_los
Epoch 48/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0149 - acc: 0.9950 - val_los
Epoch 49/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0221 - acc: 0.9926 - val_los
Epoch 50/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0187 - acc: 0.9937 - val_los
Epoch 51/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0106 - acc: 0.9969 - val_los
Epoch 52/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0163 - acc: 0.9950 - val_los
Epoch 53/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0176 - acc: 0.9946 - val_los
Epoch 54/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0237 - acc: 0.9924 - val_los
Epoch 55/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0241 - acc: 0.9920 - val_los
Epoch 56/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0102 - acc: 0.9968 - val_los
Epoch 57/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0124 - acc: 0.9960 - val_los
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Epoch 58/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0147 - acc: 0.9955 - val_los
Epoch 59/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0166 - acc: 0.9948 - val_los
Epoch 60/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0130 - acc: 0.9957 - val_los
Epoch 61/500
172/172 [==============================] - 18s 104ms/step - loss: 0.0220 - acc: 0.9929 - val_los
Epoch 62/500
172/172 [==============================] - 18s 107ms/step - loss: 0.0109 - acc: 0.9964 - val_los
Epoch 63/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0154 - acc: 0.9950 - val_los
Epoch 64/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0139 - acc: 0.9956 - val_los
Epoch 65/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0130 - acc: 0.9964 - val_los
Epoch 66/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0098 - acc: 0.9969 - val_los
Epoch 67/500
172/172 [==============================] - 18s 104ms/step - loss: 0.0151 - acc: 0.9952 - val_los
Epoch 68/500
172/172 [==============================] - 18s 107ms/step - loss: 0.0155 - acc: 0.9950 - val_los
Epoch 69/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0137 - acc: 0.9954 - val_los
Epoch 70/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0088 - acc: 0.9970 - val_los
Epoch 71/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0228 - acc: 0.9936 - val_los
Epoch 72/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0143 - acc: 0.9961 - val_los
Epoch 73/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0113 - acc: 0.9964 - val_los
Epoch 74/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0092 - acc: 0.9970 - val_los
Epoch 75/500
172/172 [==============================] - 18s 104ms/step - loss: 0.0107 - acc: 0.9968 - val_los
Epoch 76/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0154 - acc: 0.9949 - val_los
Epoch 77/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0152 - acc: 0.9960 - val_los
Epoch 78/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0096 - acc: 0.9971 - val_los
Epoch 79/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0054 - acc: 0.9981 - val_los
Epoch 80/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0052 - acc: 0.9986 - val_los
Epoch 81/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0126 - acc: 0.9961 - val_los
```

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Epoch 82/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0164 - acc: 0.9945 - val_los
Epoch 83/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0116 - acc: 0.9967 - val_los
Epoch 84/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0079 - acc: 0.9974 - val_los
Epoch 85/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0167 - acc: 0.9947 - val_los
Epoch 86/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0071 - acc: 0.9979 - val_los
Epoch 87/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0139 - acc: 0.9950 - val_los
Epoch 88/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0069 - acc: 0.9979 - val_los
Epoch 89/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0162 - acc: 0.9947 - val_los
Epoch 90/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0070 - acc: 0.9977 - val_los
Epoch 91/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0109 - acc: 0.9962 - val_los
Epoch 92/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0111 - acc: 0.9965 - val_los
Epoch 93/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0094 - acc: 0.9972 - val_los
Epoch 94/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0076 - acc: 0.9975 - val_los
Epoch 95/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0158 - acc: 0.9952 - val_los
Epoch 96/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0090 - acc: 0.9973 - val_los
Epoch 97/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0098 - acc: 0.9970 - val_los
Epoch 98/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0059 - acc: 0.9978 - val_los
Epoch 99/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0041 - acc: 0.9987 - val_los
Epoch 100/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0089 - acc: 0.9970 - val_los
Epoch 101/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0075 - acc: 0.9980 - val_los
Epoch 102/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0085 - acc: 0.9976 - val_los
Epoch 103/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0159 - acc: 0.9954 - val_los
Epoch 104/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0094 - acc: 0.9975 - val_los
Epoch 105/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0097 - acc: 0.9973 - val_los
```

```
Epoch 106/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0107 - acc: 0.9967 - val_los
Epoch 107/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0100 - acc: 0.9974 - val_los
Epoch 108/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0094 - acc: 0.9969 - val_los
Epoch 109/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0105 - acc: 0.9969 - val_los
Epoch 110/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0071 - acc: 0.9979 - val_los
Epoch 111/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0067 - acc: 0.9979 - val_los
Epoch 112/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0054 - acc: 0.9982 - val_los
Epoch 113/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0128 - acc: 0.9968 - val_los
Epoch 114/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0123 - acc: 0.9963 - val_los
Epoch 115/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0102 - acc: 0.9970 - val_los
Epoch 116/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0063 - acc: 0.9980 - val_los
Epoch 117/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0060 - acc: 0.9980 - val_los
Epoch 118/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0046 - acc: 0.9987 - val_los
Epoch 119/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0105 - acc: 0.9967 - val_los
Epoch 120/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0051 - acc: 0.9986 - val_los
Epoch 121/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0044 - acc: 0.9988 - val_los
Epoch 122/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0091 - acc: 0.9969 - val_los
Epoch 123/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0089 - acc: 0.9972 - val_los
Epoch 124/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0165 - acc: 0.9954 - val_los
Epoch 125/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0089 - acc: 0.9977 - val_los
Epoch 126/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0087 - acc: 0.9975 - val_los
Epoch 127/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0050 - acc: 0.9980 - val_los
Epoch 128/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0036 - acc: 0.9989 - val_los
Epoch 129/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0078 - acc: 0.9975 - val_los
```

```
Epoch 130/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0051 - acc: 0.9983 - val_los
Epoch 131/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0093 - acc: 0.9971 - val_los
Epoch 132/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0052 - acc: 0.9984 - val_los
Epoch 133/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0066 - acc: 0.9978 - val_los
Epoch 134/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0126 - acc: 0.9960 - val_los
Epoch 135/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0042 - acc: 0.9990 - val_los
Epoch 136/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0044 - acc: 0.9987 - val_los
Epoch 137/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0054 - acc: 0.9982 - val_los
Epoch 138/500
172/172 [==============================] - 18s 104ms/step - loss: 0.0081 - acc: 0.9974 - val_los
Epoch 139/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0103 - acc: 0.9971 - val_los
Epoch 140/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0071 - acc: 0.9983 - val_los
Epoch 141/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0047 - acc: 0.9987 - val_los
Epoch 142/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0069 - acc: 0.9978 - val_los
Epoch 143/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0125 - acc: 0.9965 - val_los
Epoch 144/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0077 - acc: 0.9979 - val_los
Epoch 145/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0082 - acc: 0.9974 - val_los
Epoch 146/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0041 - acc: 0.9989 - val_los
Epoch 147/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0058 - acc: 0.9978 - val_los
Epoch 148/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0119 - acc: 0.9967 - val_los
Epoch 149/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0043 - acc: 0.9990 - val_los
Epoch 150/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0042 - acc: 0.9988 - val_los
Epoch 151/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0092 - acc: 0.9978 - val_los
Epoch 152/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0089 - acc: 0.9972 - val_los
Epoch 153/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0075 - acc: 0.9979 - val_los
```

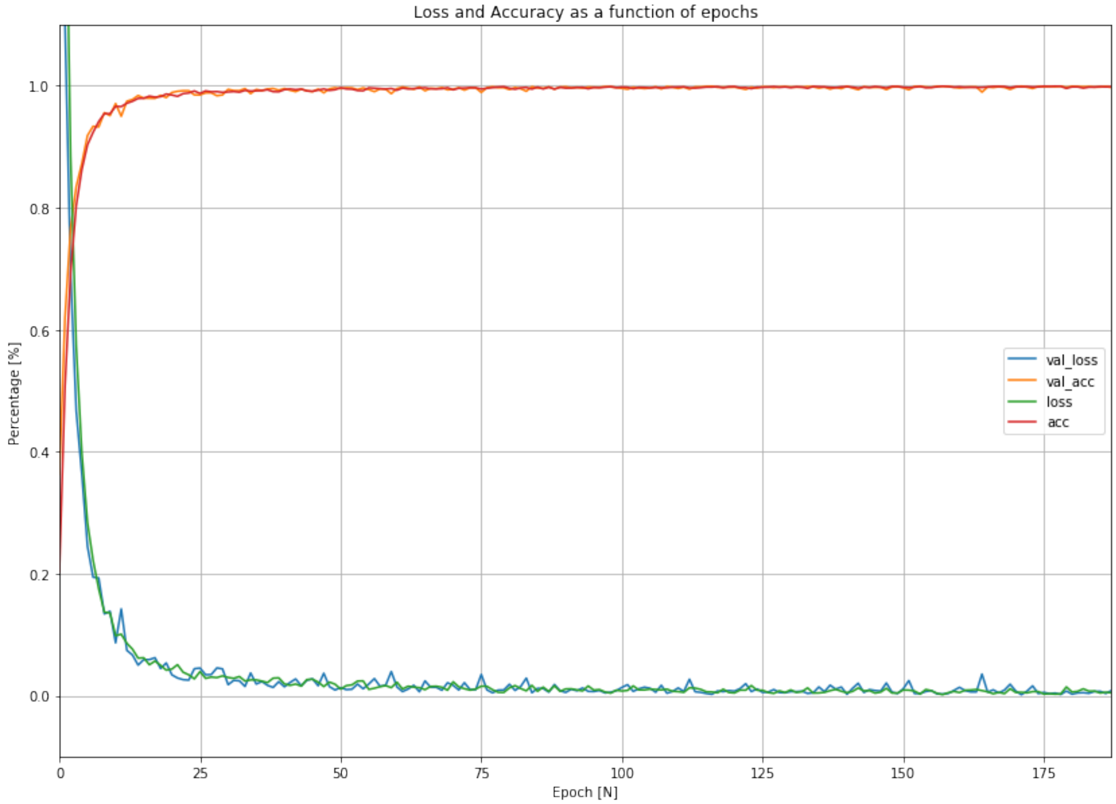
```
Epoch 154/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0025 - acc: 0.9990 - val_los
Epoch 155/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0100 - acc: 0.9969 - val_los
Epoch 156/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0080 - acc: 0.9975 - val_los
Epoch 157/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0037 - acc: 0.9985 - val_los
Epoch 158/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0016 - acc: 0.9995 - val_los
Epoch 159/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0047 - acc: 0.9988 - val_los
Epoch 160/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0071 - acc: 0.9978 - val_los
Epoch 161/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0051 - acc: 0.9984 - val_los
Epoch 162/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0088 - acc: 0.9975 - val_los
Epoch 163/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0092 - acc: 0.9977 - val_los
Epoch 164/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0100 - acc: 0.9975 - val_los
Epoch 165/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0080 - acc: 0.9975 - val_los
Epoch 166/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0062 - acc: 0.9981 - val_los
Epoch 167/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0030 - acc: 0.9990 - val_los
Epoch 168/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0053 - acc: 0.9990 - val_los
Epoch 169/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0032 - acc: 0.9989 - val_los
Epoch 170/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0112 - acc: 0.9970 - val_los
Epoch 171/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0052 - acc: 0.9987 - val_los
Epoch 172/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0055 - acc: 0.9985 - val_los
Epoch 173/500
172/172 [==============================] - 18s 106ms/step - loss: 0.0045 - acc: 0.9988 - val_los
Epoch 174/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0066 - acc: 0.9981 - val_los
Epoch 175/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0066 - acc: 0.9983 - val_los
Epoch 176/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0026 - acc: 0.9993 - val_los
Epoch 177/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0031 - acc: 0.9990 - val_los
```

```
Epoch 178/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0025 - acc: 0.9995 - val_los
Epoch 179/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0028 - acc: 0.9992 - val_los
Epoch 180/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0142 - acc: 0.9959 - val_los
Epoch 181/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0059 - acc: 0.9984 - val_los
Epoch 182/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0069 - acc: 0.9984 - val_los
Epoch 183/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0111 - acc: 0.9963 - val_los
Epoch 184/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0074 - acc: 0.9979 - val_los
Epoch 185/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0074 - acc: 0.9980 - val_los
Epoch 186/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0042 - acc: 0.9987 - val_los
Epoch 187/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0056 - acc: 0.9983 - val_los
Epoch 188/500
172/172 [==============================] - 18s 105ms/step - loss: 0.0044 - acc: 0.9988 - val_los
```

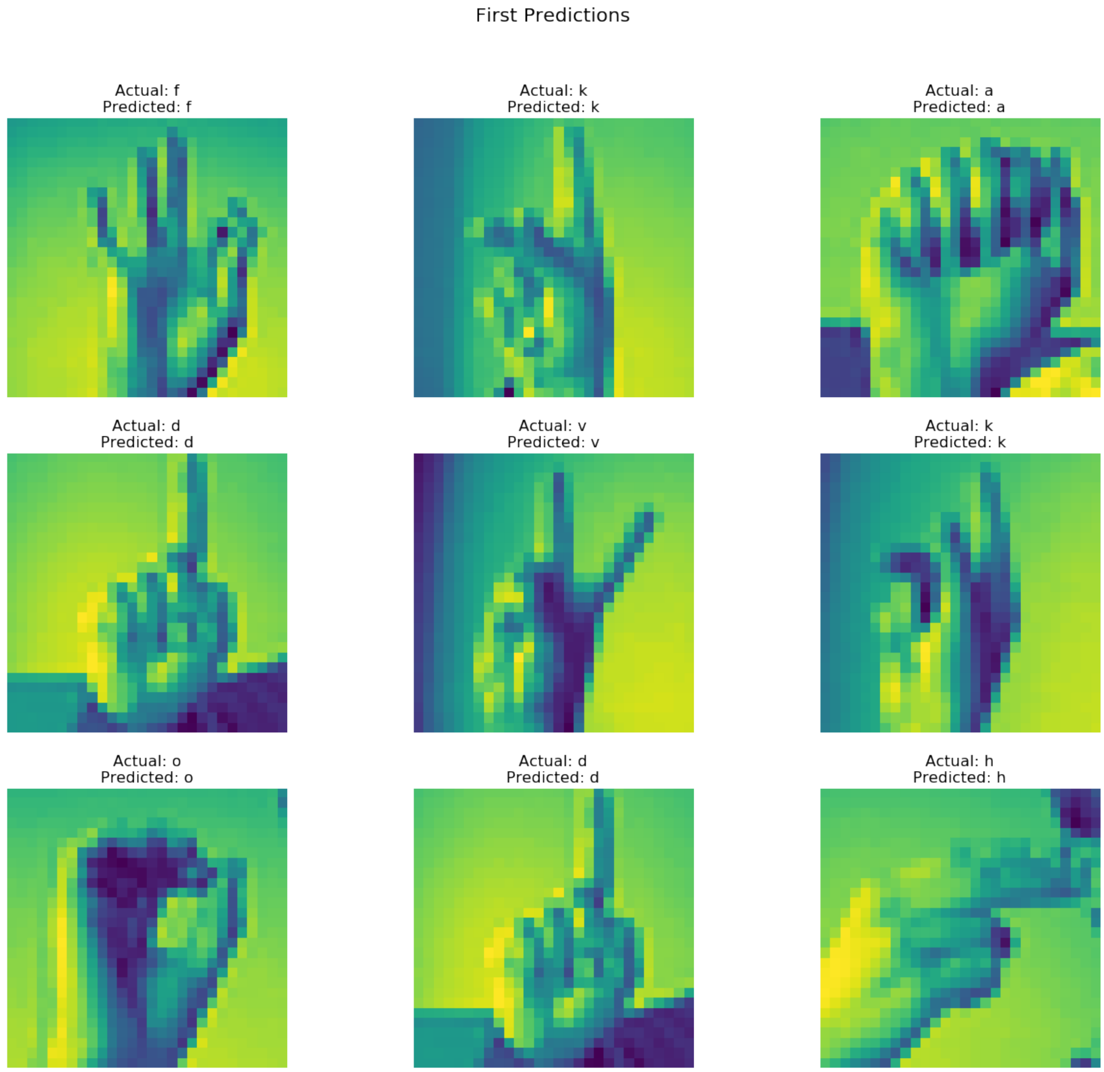
4 Model Evaluation

In [254]:
```python
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: [0.010196360219288898, 0.9960953841863059]
```

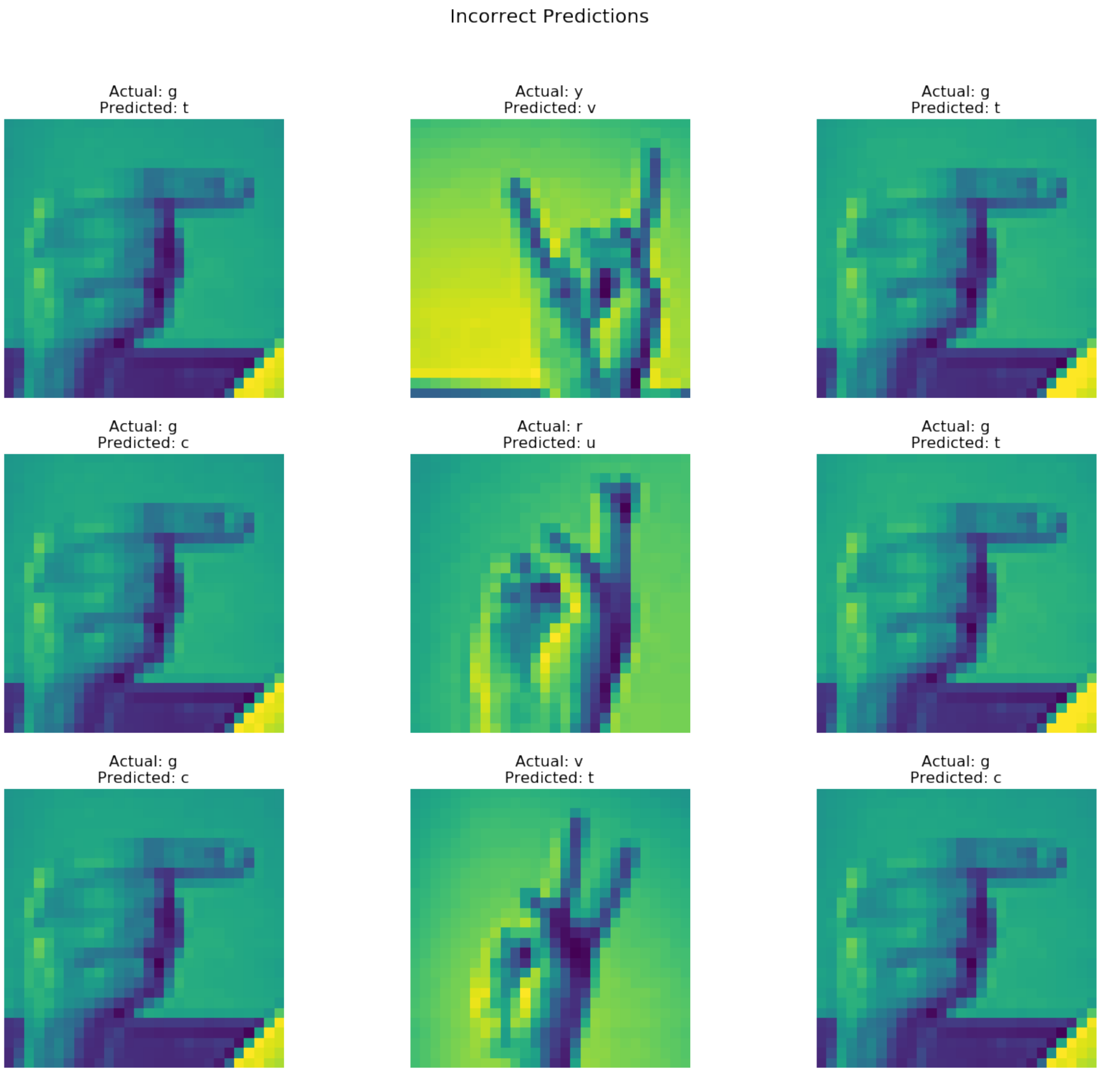


In [255]:
```
import math

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()
```



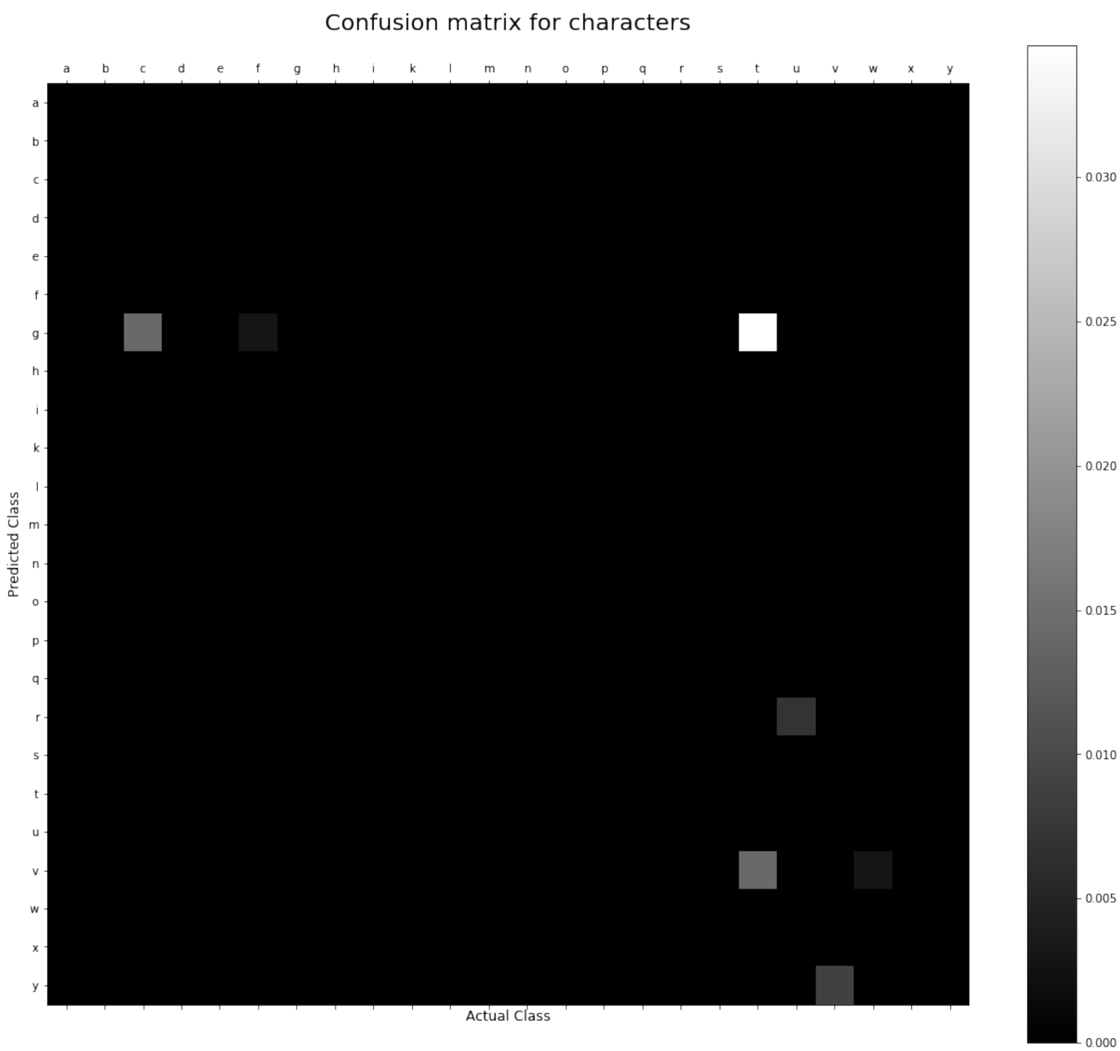
In [256]:
```
y_pred = model.predict_classes(X_test)

confusion_indices = np.where(y_pred != y_test)
X_confusion = X_test[confusion_indices]
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)), inte
    ax[math.floor(index/num_rows), index%num_rows].set_title(
        f"Actual: {class_names[y_test_confusion[index]]}\nPredicted: {class_names[y_pr
        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 [257]:
```
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 [258]: y_pred = model.predict_classes(X_test)
          print(metrics.f1_score(y_test, y_pred, average="micro"))
```

```
0.9960953841863059
```

5 Comparison with no Image Generation

```
In [83]: # Fit model without data augmentation
         no_data_aug_model = create_model()

         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 [==============================] - 7s 301us/step - loss: 1.6296 - acc: 0.4702 - val_
Epoch 2/500
21963/21963 [==============================] - 5s 220us/step - loss: 0.2515 - acc: 0.9162 - val_
Epoch 3/500
21963/21963 [==============================] - 5s 216us/step - loss: 0.0630 - acc: 0.9806 - val_
Epoch 4/500
21963/21963 [==============================] - 5s 221us/step - loss: 0.0263 - acc: 0.9930 - val_
Epoch 5/500
21963/21963 [==============================] - 5s 215us/step - loss: 4.2216e-04 - acc: 1.0000 -
Epoch 6/500
21963/21963 [==============================] - 5s 207us/step - loss: 1.6515e-04 - acc: 1.0000 -
Epoch 7/500
21963/21963 [==============================] - 4s 203us/step - loss: 9.0743e-05 - acc: 1.0000 -
Epoch 8/500
21963/21963 [==============================] - 4s 191us/step - loss: 6.1676e-05 - acc: 1.0000 -
Epoch 9/500
21963/21963 [==============================] - 4s 198us/step - loss: 3.7784e-05 - acc: 1.0000 -
Epoch 10/500
21963/21963 [==============================] - 4s 184us/step - loss: 2.5901e-05 - acc: 1.0000 -
Epoch 11/500
21963/21963 [==============================] - 4s 182us/step - loss: 1.8066e-05 - acc: 1.0000 -
Epoch 12/500
```

```
21963/21963 [==============================] - 4s 178us/step - loss: 1.3546e-05 - acc: 1.0000 -
Epoch 13/500
21963/21963 [==============================] - 4s 175us/step - loss: 0.1365 - acc: 0.9628 - val_
Epoch 14/500
21963/21963 [==============================] - 4s 168us/step - loss: 0.0519 - acc: 0.9841 - val_
Epoch 15/500
21963/21963 [==============================] - 4s 185us/step - loss: 3.8458e-04 - acc: 1.0000 -
Epoch 16/500
21963/21963 [==============================] - 4s 173us/step - loss: 1.1811e-04 - acc: 1.0000 -
Epoch 17/500
21963/21963 [==============================] - 4s 161us/step - loss: 5.6356e-05 - acc: 1.0000 -
Epoch 18/500
21963/21963 [==============================] - 4s 166us/step - loss: 3.6821e-05 - acc: 1.0000 -
Epoch 19/500
21963/21963 [==============================] - 4s 163us/step - loss: 0.0741 - acc: 0.9791 - val_
Epoch 20/500
21963/21963 [==============================] - 4s 172us/step - loss: 0.0158 - acc: 0.9952 - val_
Epoch 21/500
21963/21963 [==============================] - 4s 166us/step - loss: 0.0153 - acc: 0.9961 - val_
Epoch 22/500
21963/21963 [==============================] - 4s 172us/step - loss: 1.0545e-04 - acc: 1.0000 -
Epoch 23/500
21963/21963 [==============================] - 4s 169us/step - loss: 2.5898e-05 - acc: 1.0000 -
Epoch 24/500
21963/21963 [==============================] - 4s 170us/step - loss: 1.3527e-05 - acc: 1.0000 -
Epoch 25/500
21963/21963 [==============================] - 4s 163us/step - loss: 8.7413e-06 - acc: 1.0000 -
Epoch 26/500
21963/21963 [==============================] - 4s 165us/step - loss: 6.0230e-06 - acc: 1.0000 -
Epoch 27/500
21963/21963 [==============================] - 4s 174us/step - loss: 4.7647e-06 - acc: 1.0000 -
Epoch 28/500
21963/21963 [==============================] - 4s 168us/step - loss: 3.9214e-06 - acc: 1.0000 -
Epoch 29/500
21963/21963 [==============================] - 4s 167us/step - loss: 3.4976e-06 - acc: 1.0000 -
Epoch 30/500
21963/21963 [==============================] - 4s 162us/step - loss: 3.1914e-06 - acc: 1.0000 -
Epoch 31/500
21963/21963 [==============================] - 4s 165us/step - loss: 2.9981e-06 - acc: 1.0000 -
Epoch 32/500
21963/21963 [==============================] - 3s 159us/step - loss: 2.8608e-06 - acc: 1.0000 -
Epoch 33/500
21963/21963 [==============================] - 3s 158us/step - loss: 2.7835e-06 - acc: 1.0000 -
Epoch 34/500
21963/21963 [==============================] - 4s 167us/step - loss: 2.7236e-06 - acc: 1.0000 -
Epoch 35/500
21963/21963 [==============================] - 4s 165us/step - loss: 2.6872e-06 - acc: 1.0000 -
Epoch 36/500
```

```
21963/21963 [==============================] - 4s 165us/step - loss: 2.6498e-06 - acc: 1.0000 -
Epoch 37/500
21963/21963 [==============================] - 3s 156us/step - loss: 2.6307e-06 - acc: 1.0000 -
Epoch 38/500
21963/21963 [==============================] - 4s 169us/step - loss: 2.6154e-06 - acc: 1.0000 -
Epoch 39/500
21963/21963 [==============================] - 4s 164us/step - loss: 2.6047e-06 - acc: 1.0000 -
Epoch 40/500
21963/21963 [==============================] - 4s 166us/step - loss: 2.5952e-06 - acc: 1.0000 -
Epoch 41/500
21963/21963 [==============================] - 4s 162us/step - loss: 2.5890e-06 - acc: 1.0000 -
Epoch 42/500
21963/21963 [==============================] - 4s 162us/step - loss: 2.5855e-06 - acc: 1.0000 -
Epoch 43/500
21963/21963 [==============================] - 4s 162us/step - loss: 2.5825e-06 - acc: 1.0000 -
Epoch 44/500
21963/21963 [==============================] - 4s 175us/step - loss: 2.5806e-06 - acc: 1.0000 -
Epoch 45/500
21963/21963 [==============================] - 3s 159us/step - loss: 2.5791e-06 - acc: 1.0000 -
Epoch 46/500
21963/21963 [==============================] - 4s 167us/step - loss: 2.5781e-06 - acc: 1.0000 -
Epoch 47/500
21963/21963 [==============================] - 4s 164us/step - loss: 2.5773e-06 - acc: 1.0000 -
Epoch 48/500
21963/21963 [==============================] - 4s 160us/step - loss: 2.5769e-06 - acc: 1.0000 -
Epoch 49/500
21963/21963 [==============================] - 4s 174us/step - loss: 2.5766e-06 - acc: 1.0000 -
Epoch 50/500
21963/21963 [==============================] - 4s 168us/step - loss: 2.5764e-06 - acc: 1.0000 -
Epoch 51/500
21963/21963 [==============================] - 4s 167us/step - loss: 2.5763e-06 - acc: 1.0000 -
Epoch 52/500
21963/21963 [==============================] - 4s 165us/step - loss: 2.5762e-06 - acc: 1.0000 -
Epoch 53/500
21963/21963 [==============================] - 3s 159us/step - loss: 2.5762e-06 - acc: 1.0000 -
Epoch 54/500
21963/21963 [==============================] - 3s 158us/step - loss: 2.5762e-06 - acc: 1.0000 -
Epoch 55/500
21963/21963 [==============================] - 4s 166us/step - loss: 2.5762e-06 - acc: 1.0000 -
Epoch 56/500
21963/21963 [==============================] - 3s 158us/step - loss: 2.5761e-06 - acc: 1.0000 -
Epoch 57/500
21963/21963 [==============================] - 4s 160us/step - loss: 2.5761e-06 - acc: 1.0000 -
Epoch 58/500
21963/21963 [==============================] - 4s 167us/step - loss: 2.5761e-06 - acc: 1.0000 -
Epoch 59/500
21963/21963 [==============================] - 4s 165us/step - loss: 2.5761e-06 - acc: 1.0000 -
Epoch 60/500
```

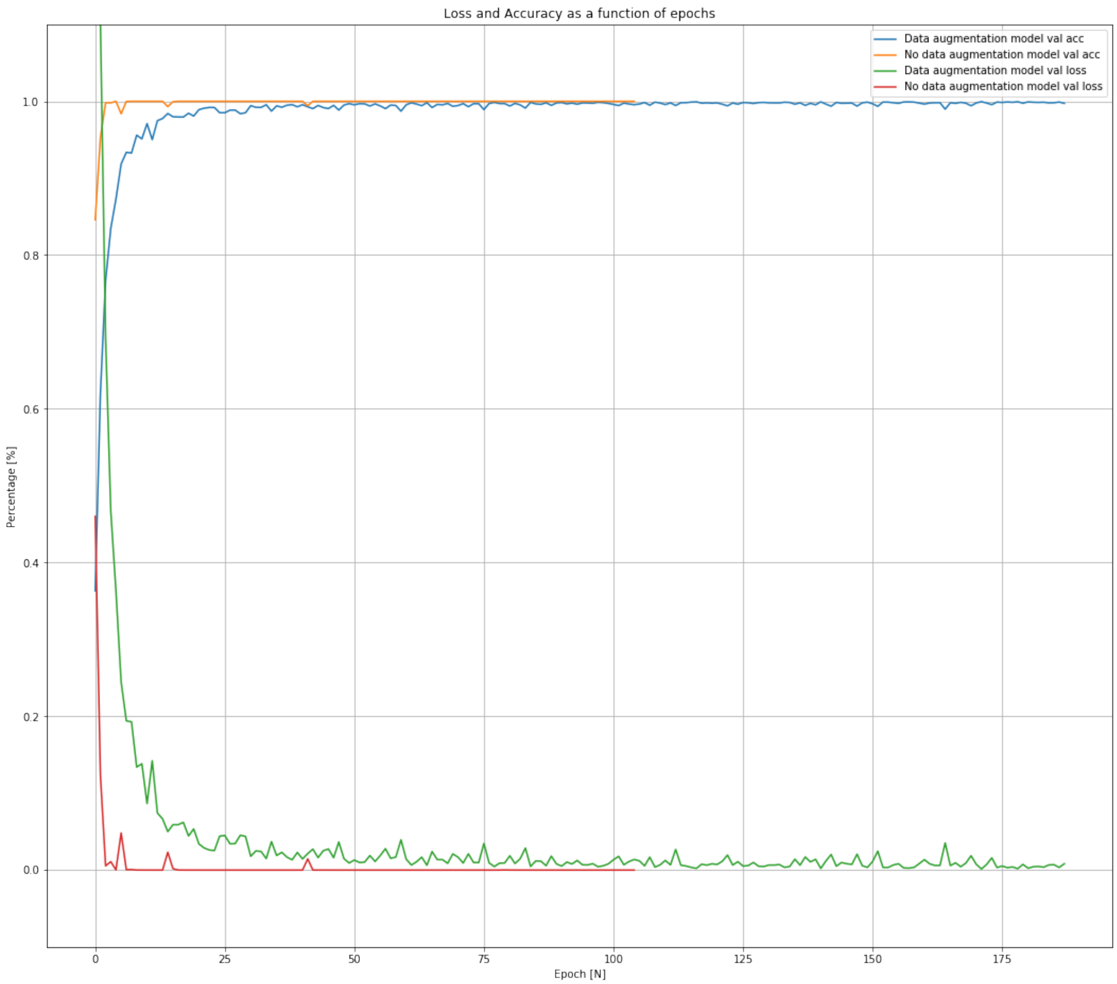
```
21963/21963 [==============================] - 4s 165us/step - loss: 4.7275e-04 - acc: 1.0000 -
Epoch 61/500
21963/21963 [==============================] - 4s 168us/step - loss: 0.0524 - acc: 0.9880 - val_
Epoch 62/500
21963/21963 [==============================] - 4s 165us/step - loss: 1.2115e-04 - acc: 1.0000 -
Epoch 63/500
21963/21963 [==============================] - 4s 160us/step - loss: 3.3200e-05 - acc: 1.0000 -
Epoch 64/500
21963/21963 [==============================] - 4s 160us/step - loss: 1.0719e-05 - acc: 1.0000 -
Epoch 65/500
21963/21963 [==============================] - 4s 168us/step - loss: 5.7423e-06 - acc: 1.0000 -
Epoch 66/500
21963/21963 [==============================] - 4s 165us/step - loss: 4.8632e-06 - acc: 1.0000 -
Epoch 67/500
21963/21963 [==============================] - 4s 166us/step - loss: 3.5535e-06 - acc: 1.0000 -
Epoch 68/500
21963/21963 [==============================] - 4s 173us/step - loss: 3.2152e-06 - acc: 1.0000 -
Epoch 69/500
21963/21963 [==============================] - 4s 167us/step - loss: 3.0465e-06 - acc: 1.0000 -
Epoch 70/500
21963/21963 [==============================] - 4s 161us/step - loss: 2.8758e-06 - acc: 1.0000 -
Epoch 71/500
21963/21963 [==============================] - 3s 158us/step - loss: 2.8338e-06 - acc: 1.0000 -
Epoch 72/500
21963/21963 [==============================] - 3s 158us/step - loss: 2.7403e-06 - acc: 1.0000 -
Epoch 73/500
21963/21963 [==============================] - 4s 163us/step - loss: 2.7050e-06 - acc: 1.0000 -
Epoch 74/500
21963/21963 [==============================] - 4s 164us/step - loss: 2.6985e-06 - acc: 1.0000 -
Epoch 75/500
21963/21963 [==============================] - 4s 172us/step - loss: 2.6557e-06 - acc: 1.0000 -
Epoch 76/500
21963/21963 [==============================] - 4s 163us/step - loss: 2.6205e-06 - acc: 1.0000 -
Epoch 77/500
21963/21963 [==============================] - 4s 167us/step - loss: 2.6093e-06 - acc: 1.0000 -
Epoch 78/500
21963/21963 [==============================] - 4s 166us/step - loss: 2.6196e-06 - acc: 1.0000 -
Epoch 79/500
21963/21963 [==============================] - 3s 158us/step - loss: 0.0797 - acc: 0.9831 - val_
Epoch 80/500
21963/21963 [==============================] - 4s 171us/step - loss: 9.3604e-04 - acc: 0.9997 -
Epoch 81/500
21963/21963 [==============================] - 4s 163us/step - loss: 5.1829e-05 - acc: 1.0000 -
Epoch 82/500
21963/21963 [==============================] - 4s 161us/step - loss: 1.3697e-05 - acc: 1.0000 -
Epoch 83/500
21963/21963 [==============================] - 4s 162us/step - loss: 8.1356e-06 - acc: 1.0000 -
Epoch 84/500
```

```
21963/21963 [==============================] - 3s 158us/step - loss: 4.6207e-06 - acc: 1.0000 -
Epoch 85/500
21963/21963 [==============================] - 4s 166us/step - loss: 3.8103e-06 - acc: 1.0000 -
Epoch 86/500
21963/21963 [==============================] - 4s 163us/step - loss: 3.5086e-06 - acc: 1.0000 -
Epoch 87/500
21963/21963 [==============================] - 3s 145us/step - loss: 3.2023e-06 - acc: 1.0000 -
Epoch 88/500
21963/21963 [==============================] - 3s 154us/step - loss: 3.0308e-06 - acc: 1.0000 -
```

In [291]:
```
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
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 30us/step
Model evaluation: [1.0886914953212061, 0.8923441639938642]
```

Out[291]:
```
Text(0.5, 1.0, 'Loss and Accuracy as a function of epochs')
```




```
In [85]: import sklearn.metrics as metrics

         y_pred = no_data_aug_model.predict_classes(X_test)

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

0.9213498814670199

```
In [263]: model.save('cnn_our_model.h5')
```

```
In [80]: 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()
```