A_12 (1)

June 1, 2019

In [0]:
```
import matplotlib.pyplot as plt
from keras.utils import np_utils
from keras.datasets import mnist
from keras.models import Sequential
from keras.layers import Dropout
from keras.layers.normalization import BatchNormalization
from keras.optimizers import Adam
from keras.layers import Dense, Activation
import seaborn as sns
import numpy as np
import keras


%matplotlib inline
```

In [2]:
```
(X_train, y_train), (X_test, y_test) = mnist.load_data()
```

```
Downloading data from https://s3.amazonaws.com/img-datasets/mnist.npz
11493376/11490434 [==============================] - 0s 0us/step
```

In [3]:
```
print("Training data shape: ", X_train.shape) # (60000, 28, 28) -- 60000 images, each
print("Test data shape", X_test.shape)

print("Training label shape: ", y_train.shape) # (60000,) -- 60000 numbers (all 0-9)
print("First 5 training labels: ", y_train[:5]) # [5, 0, 4, 1, 9]
```

```
Training data shape:  (60000, 28, 28)
Test data shape (10000, 28, 28)
Training label shape:  (60000,)
First 5 training labels:  [5 0 4 1 9]
```

In [0]:
```
# Flatten the images
image_vector_size = 28*28
X_train = X_train.reshape(X_train.shape[0], image_vector_size)
X_test = X_test.reshape(X_test.shape[0], image_vector_size)
```

```
In [5]: # Convert to "one-hot" vectors using the to_categorical function
        num_classes = 10
        y_train = keras.utils.to_categorical(y_train, num_classes)
        y_test = keras.utils.to_categorical(y_test, num_classes)
        print("First 5 training lables as one-hot encoded vectors:\n", y_train[:5])
```

```
First 5 training lables as one-hot encoded vectors:
 [[0. 0. 0. 0. 0. 1. 0. 0. 0. 0.]
 [1. 0. 0. 0. 0. 0. 0. 0. 0. 0.]
 [0. 0. 0. 0. 1. 0. 0. 0. 0. 0.]
 [0. 1. 0. 0. 0. 0. 0. 0. 0. 0.]
 [0. 0. 0. 0. 0. 0. 0. 0. 0. 1.]]
```

0.1 Model 1 without dropout and BN

```
In [0]: output_dim = 10
        input_dim = X_train.shape[1]

        nb_epoch = 10
        batch_size = 128
```

```
In [0]: model1 = Sequential()

        model1.add(Dense(364, activation='relu', input_shape=(input_dim,),kernel_initializer='
        model1.add(Dense(120, activation='relu', kernel_initializer='random_uniform'))

        model1.add(Dense(output_dim, activation='softmax'))

        print(model1.summary())
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_15 (Dense)             (None, 364)               285740
_________________________________________________________________
dense_16 (Dense)             (None, 120)               43800
_________________________________________________________________
dense_17 (Dense)             (None, 10)                1210
=================================================================
Total params: 330,750
Trainable params: 330,750
Non-trainable params: 0
_________________________________________________________________
None
```

```
In [0]: model1.compile(optimizer='adam',
                       loss='categorical_crossentropy',
                       metrics=['accuracy'])
```

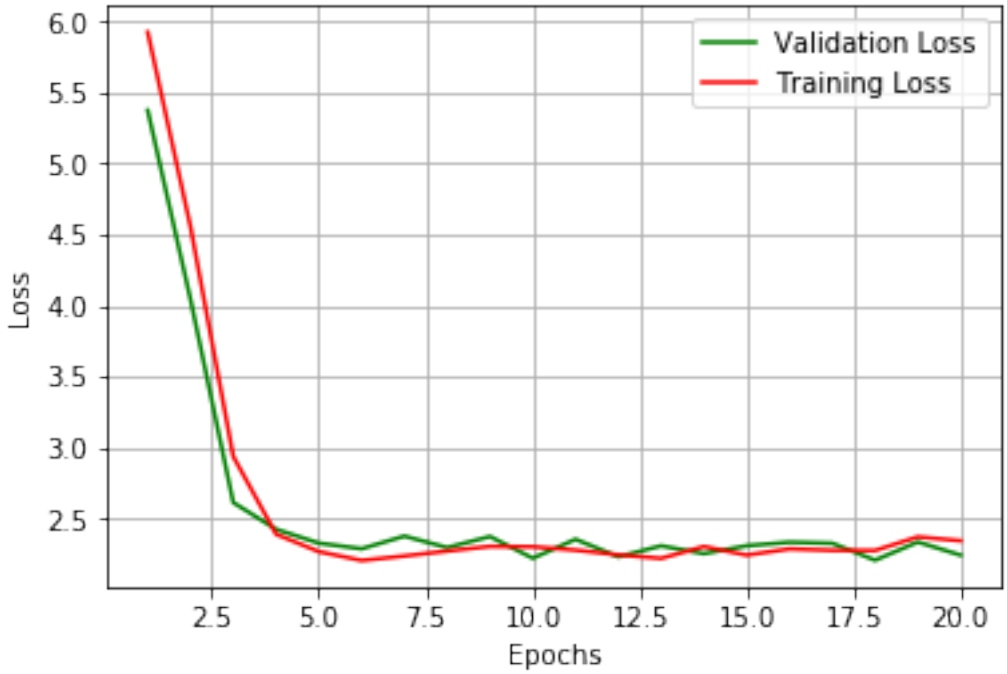
```
In [0]: # Training the model
        history = model1.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbos
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/20
Epoch 2/20
Epoch 3/20
Epoch 4/20
Epoch 5/20
Epoch 6/20
Epoch 7/20
Epoch 8/20
Epoch 9/20
Epoch 10/20
Epoch 11/20
Epoch 12/20
Epoch 13/20
Epoch 14/20
Epoch 15/20
Epoch 16/20
Epoch 17/20
Epoch 18/20
Epoch 19/20
Epoch 20/20
```

```
In [0]: score = model1.evaluate(X_test, y_test)
```

```
10000/10000 [==============================] - 0s 49us/step
```

```
In [0]: fig,ax = plt.subplots(1,1)
        ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

        # list of epoch numbers
        list_of_epoch = list(range(1,nb_epoch+1))

        train_loss = history.history['loss']
        val_loss = history.history['val_loss']

        ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
        ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
        plt.legend()
        plt.grid()
        plt.show();
```




```
In [0]: print('Test accuracy:', score[1])

Test accuracy: 0.8604
```

0.1.1 2 Layers with BN and Dropout

```
In [0]: model2 = Sequential()

        model2.add(Dense(364, activation='relu', input_shape=(input_dim,),kernel_initializer='
        model2.add(Dense(128, activation='relu',kernel_initializer='random_uniform'))

        model2.add(BatchNormalization())
        model2.add(Dropout(0.5))

        model2.add(Dense(output_dim, activation='softmax'))

        print(model2.summary())
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_21 (Dense)             (None, 364)               285740
_________________________________________________________________
dense_22 (Dense)             (None, 128)               46720
```

```
_________________________________________________________________
batch_normalization_3 (Batch (None, 128)               512
_________________________________________________________________
dropout_3 (Dropout)          (None, 128)               0
_________________________________________________________________
dense_23 (Dense)             (None, 10)                1290
=================================================================
Total params: 334,262
Trainable params: 334,006
Non-trainable params: 256
_________________________________________________________________
None
```

```
In [0]: model2.compile(optimizer='adam',
                       loss='categorical_crossentropy',
                       metrics=['accuracy'])
```

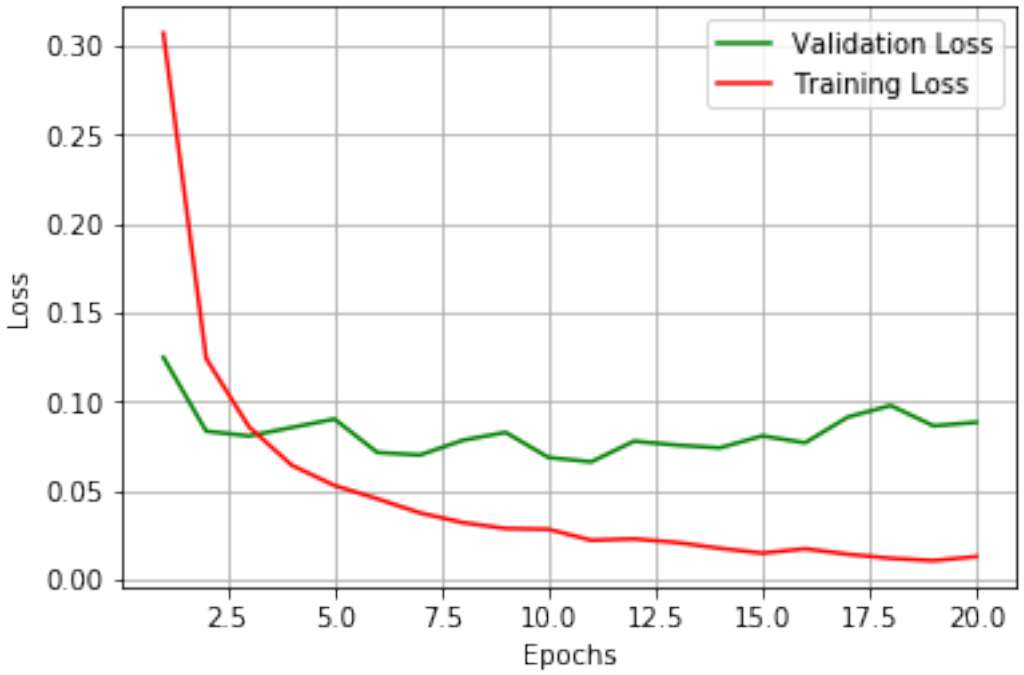
```
In [0]: # Training the model
        history = model2.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbos
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/20
Epoch 2/20
Epoch 3/20
Epoch 4/20
Epoch 5/20
Epoch 6/20
Epoch 7/20
Epoch 8/20
Epoch 9/20
Epoch 10/20
Epoch 11/20
Epoch 12/20
Epoch 13/20
Epoch 14/20
Epoch 15/20
Epoch 16/20
Epoch 17/20
Epoch 18/20
Epoch 19/20
Epoch 20/20
```

```
In [0]: score = model2.evaluate(X_test, y_test)
```

```
10000/10000 [==============================] - 1s 55us/step
```

```
In [0]: fig,ax = plt.subplots(1,1)
        ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

        # list of epoch numbers
        list_of_epoch = list(range(1,nb_epoch+1))

        train_loss = history.history['loss']
        val_loss = history.history['val_loss']

        ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
        ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
        plt.legend()
        plt.grid()
        plt.show();
```




```
In [0]: print('Test accuracy:', score[1])

Test accuracy: 0.9819
```

0.1.2 Changing dropout rate to 0.8

```
In [16]: model2 = Sequential()

         model2.add(Dense(364, activation='relu', input_shape=(input_dim,),kernel_initializer=
```

```
        model2.add(Dense(128, activation='relu',kernel_initializer='random_uniform'))

        model2.add(BatchNormalization())
        model2.add(Dropout(0.8))

        model2.add(Dense(output_dim, activation='softmax'))

        print(model2.summary())
```

```
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorflow_backend
Instructions for updating:
Please use `rate` instead of `keep_prob`. Rate should be set to `rate = 1 - keep_prob`.
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_1 (Dense)              (None, 364)               285740
_________________________________________________________________
dense_2 (Dense)              (None, 128)               46720
_________________________________________________________________
batch_normalization_1 (Batch (None, 128)               512
_________________________________________________________________
dropout_1 (Dropout)          (None, 128)               0
_________________________________________________________________
dense_3 (Dense)              (None, 10)                1290
=================================================================
Total params: 334,262
Trainable params: 334,006
Non-trainable params: 256
_________________________________________________________________
None
```

```
In [0]: model2.compile(optimizer='adam',
                       loss='categorical_crossentropy',
                       metrics=['accuracy'])
```

```
In [19]: # Training the model
         history = model2.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbo
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/20
60000/60000 [==============================] - 6s 93us/step - loss: 0.1610 - acc: 0.9561 - val
Epoch 2/20
60000/60000 [==============================] - 6s 92us/step - loss: 0.1238 - acc: 0.9661 - val
Epoch 3/20
60000/60000 [==============================] - 6s 94us/step - loss: 0.1043 - acc: 0.9710 - val
Epoch 4/20
60000/60000 [==============================] - 6s 92us/step - loss: 0.0880 - acc: 0.9758 - val
Epoch 5/20
```

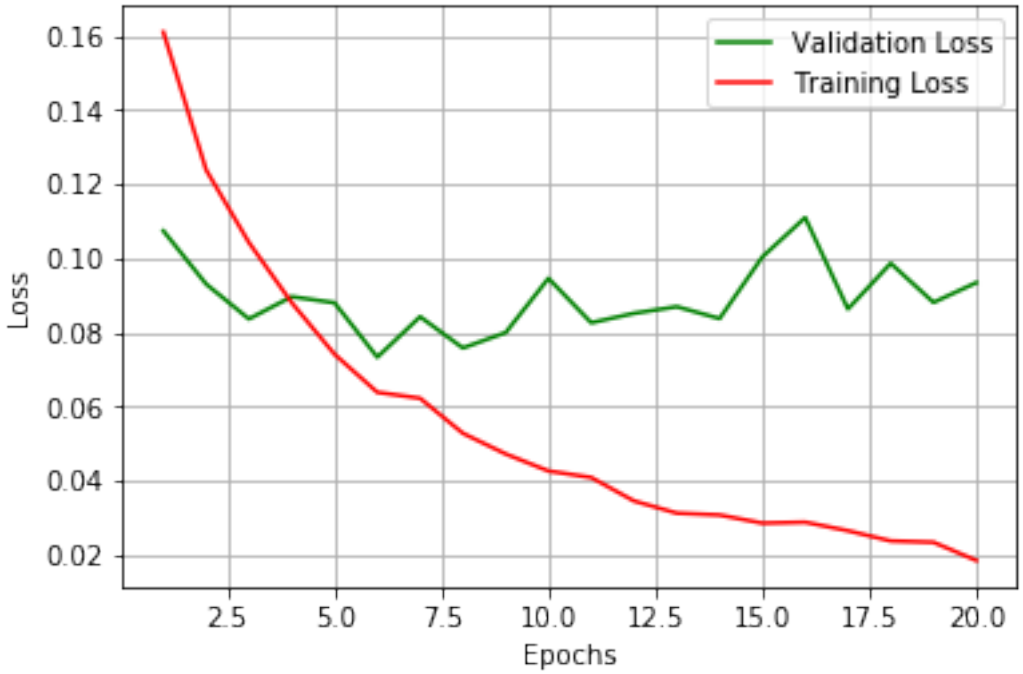
```
60000/60000 [==============================] - 6s 93us/step - loss: 0.0741 - acc: 0.9792 - val
Epoch 6/20
60000/60000 [==============================] - 5s 91us/step - loss: 0.0638 - acc: 0.9816 - val
Epoch 7/20
60000/60000 [==============================] - 6s 93us/step - loss: 0.0622 - acc: 0.9829 - val
Epoch 8/20
60000/60000 [==============================] - 6s 93us/step - loss: 0.0528 - acc: 0.9850 - val
Epoch 9/20
60000/60000 [==============================] - 6s 92us/step - loss: 0.0472 - acc: 0.9863 - val
Epoch 10/20
60000/60000 [==============================] - 6s 92us/step - loss: 0.0426 - acc: 0.9875 - val
Epoch 11/20
60000/60000 [==============================] - 5s 91us/step - loss: 0.0409 - acc: 0.9878 - val
Epoch 12/20
60000/60000 [==============================] - 6s 92us/step - loss: 0.0345 - acc: 0.9894 - val
Epoch 13/20
60000/60000 [==============================] - 5s 92us/step - loss: 0.0312 - acc: 0.9905 - val
Epoch 14/20
60000/60000 [==============================] - 5s 91us/step - loss: 0.0307 - acc: 0.9911 - val
Epoch 15/20
60000/60000 [==============================] - 5s 89us/step - loss: 0.0285 - acc: 0.9915 - val
Epoch 16/20
60000/60000 [==============================] - 5s 89us/step - loss: 0.0288 - acc: 0.9913 - val
Epoch 17/20
60000/60000 [==============================] - 5s 90us/step - loss: 0.0265 - acc: 0.9922 - val
Epoch 18/20
60000/60000 [==============================] - 6s 93us/step - loss: 0.0237 - acc: 0.9927 - val
Epoch 19/20
60000/60000 [==============================] - 6s 95us/step - loss: 0.0234 - acc: 0.9930 - val
Epoch 20/20
60000/60000 [==============================] - 6s 98us/step - loss: 0.0185 - acc: 0.9945 - val
```

```
In [20]: score = model2.evaluate(X_test, y_test)
```

```
10000/10000 [==============================] - 0s 50us/step
```

```
In [21]: fig,ax = plt.subplots(1,1)
         ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

         # list of epoch numbers
         list_of_epoch = list(range(1,nb_epoch+1))

         train_loss = history.history['loss']
         val_loss = history.history['val_loss']

         ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
```

```
ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
plt.legend()
plt.grid()
plt.show();
```




```
In [22]: print('Test accuracy:', score[1])
```

```
Test accuracy: 0.9803
```

0.1.3 Changing dropout rate to 0.2

```
In [30]: model2 = Sequential()

         model2.add(Dense(364, activation='relu', input_shape=(input_dim,),kernel_initializer=
         model2.add(Dense(128, activation='relu',kernel_initializer='random_uniform'))

         model2.add(BatchNormalization())
         model2.add(Dropout(0.2))

         model2.add(Dense(output_dim, activation='softmax'))

         print(model2.summary())
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
```

```
=================================================================
dense_7 (Dense)              (None, 364)               285740
_________________________________________________________________
dense_8 (Dense)              (None, 128)               46720
_________________________________________________________________
batch_normalization_3 (Batch (None, 128)               512
_________________________________________________________________
dropout_3 (Dropout)          (None, 128)               0
_________________________________________________________________
dense_9 (Dense)              (None, 10)                1290
=================================================================
Total params: 334,262
Trainable params: 334,006
Non-trainable params: 256
_________________________________________________________________
None
```

```
In [0]: model2.compile(optimizer='adam',
                       loss='categorical_crossentropy',
                       metrics=['accuracy'])
```

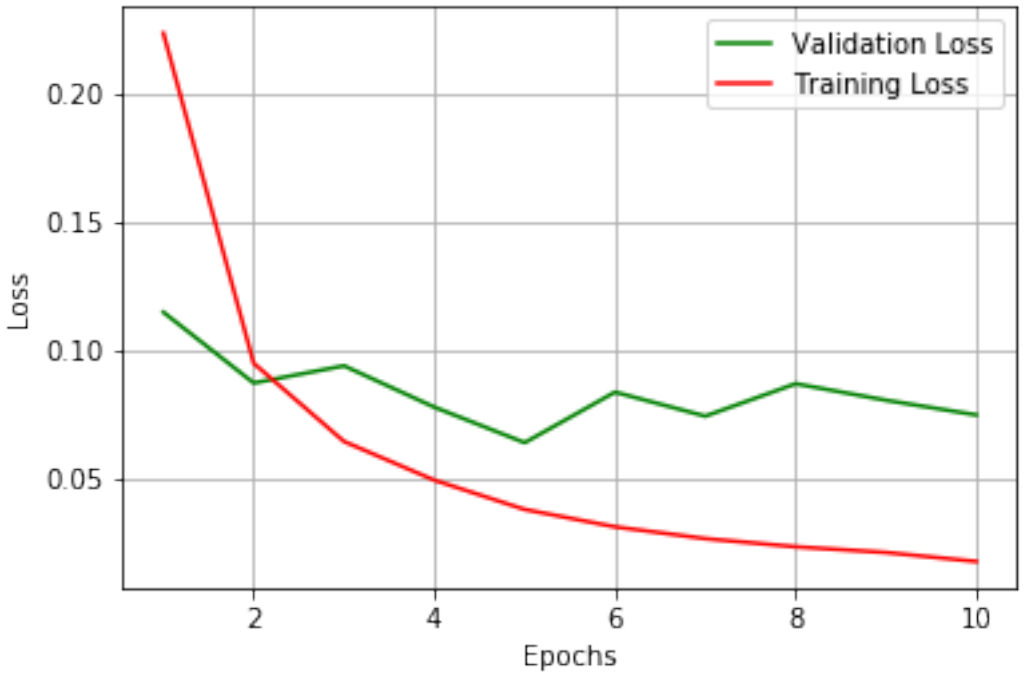
```
In [32]: # Training the model
         history = model2.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbo
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 6s 101us/step - loss: 0.2233 - acc: 0.9340 - val
Epoch 2/10
60000/60000 [==============================] - 5s 89us/step - loss: 0.0950 - acc: 0.9714 - val_
Epoch 3/10
60000/60000 [==============================] - 5s 89us/step - loss: 0.0646 - acc: 0.9803 - val_
Epoch 4/10
60000/60000 [==============================] - 5s 90us/step - loss: 0.0496 - acc: 0.9841 - val_
Epoch 5/10
60000/60000 [==============================] - 5s 89us/step - loss: 0.0382 - acc: 0.9874 - val_
Epoch 6/10
60000/60000 [==============================] - 5s 90us/step - loss: 0.0315 - acc: 0.9902 - val_
Epoch 7/10
60000/60000 [==============================] - 5s 90us/step - loss: 0.0269 - acc: 0.9912 - val_
Epoch 8/10
60000/60000 [==============================] - 6s 92us/step - loss: 0.0237 - acc: 0.9925 - val_
Epoch 9/10
60000/60000 [==============================] - 6s 92us/step - loss: 0.0215 - acc: 0.9926 - val_
Epoch 10/10
60000/60000 [==============================] - 5s 90us/step - loss: 0.0180 - acc: 0.9941 - val_
```

```
In [33]: score = model2.evaluate(X_test, y_test)
```

```
10000/10000 [==============================] - 0s 48us/step
```

```
In [34]: fig,ax = plt.subplots(1,1)
         ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

         # list of epoch numbers
         list_of_epoch = list(range(1,nb_epoch+1))

         train_loss = history.history['loss']
         val_loss = history.history['val_loss']

         ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
         ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
         plt.legend()
         plt.grid()
         plt.show();
```




```
In [35]: print('Test accuracy:', score[1])
```

```
Test accuracy: 0.9813
```

0.1.4 Model with 3 hidden layers

```
In [0]: model3 = Sequential()
```

```
        model3.add(Dense(364, activation='relu', input_shape=(input_dim,),kernel_initializer='
        model3.add(Dense(128, activation='relu',kernel_initializer='random_uniform'))
        model3.add(Dense(64, activation='relu', kernel_initializer='random_uniform'))

        #model2.add(BatchNormalization())
        #model2.add(Dropout(0.5))

        model3.add(Dense(output_dim, activation='softmax'))

        print(model3.summary())
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_28 (Dense)             (None, 364)               285740
_________________________________________________________________
dense_29 (Dense)             (None, 128)               46720
_________________________________________________________________
dense_30 (Dense)             (None, 64)                8256
_________________________________________________________________
dense_31 (Dense)             (None, 10)                650
=================================================================
Total params: 341,366
Trainable params: 341,366
Non-trainable params: 0
_________________________________________________________________
None
```

```
In [0]: model3.compile(optimizer='adam',
                       loss='categorical_crossentropy',
                       metrics=['accuracy'])
```

```
In [0]: # Training the model
        history = model3.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbos
```

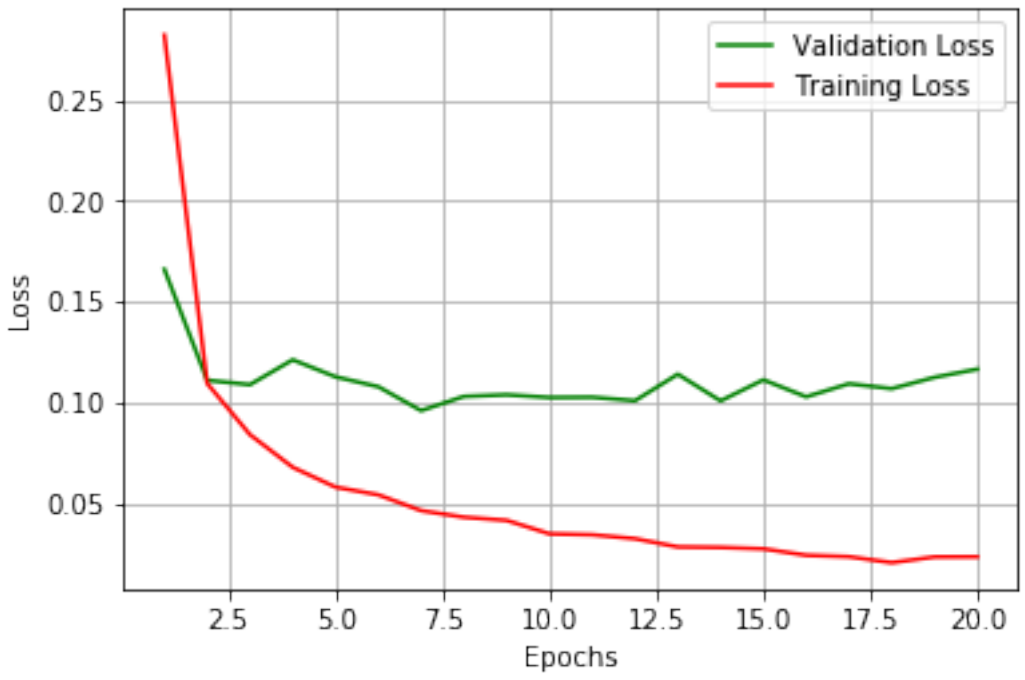
```
Train on 60000 samples, validate on 10000 samples
Epoch 1/20
Epoch 2/20
Epoch 3/20
Epoch 4/20
Epoch 5/20
Epoch 6/20
Epoch 7/20
Epoch 8/20
Epoch 9/20
Epoch 10/20
Epoch 11/20
Epoch 12/20
```

```
Epoch 13/20
Epoch 14/20
Epoch 15/20
Epoch 16/20
Epoch 17/20
Epoch 18/20
Epoch 19/20
Epoch 20/20
```

```
In [0]: score = model3.evaluate(X_test, y_test)
```

```
10000/10000 [==============================] - 1s 53us/step
```

```
In [0]: fig,ax = plt.subplots(1,1)
        ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

        # list of epoch numbers
        list_of_epoch = list(range(1,nb_epoch+1))

        train_loss = history.history['loss']
        val_loss = history.history['val_loss']

        ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
        ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
        plt.legend()
        plt.grid()
        plt.show();
```



```
In [0]: print('Test accuracy:', score[1])
```

```
Test accuracy: 0.9774
```

0.1.5 Model with 3 hidden layers along with BN and dropout

```
In [0]: model4 = Sequential()

        model4.add(Dense(364, activation='relu', input_shape=(input_dim,),kernel_initializer='
        model4.add(Dense(128, activation='relu',kernel_initializer='random_uniform'))
        model4.add(Dense(64, activation='relu', kernel_initializer='random_uniform'))

        model4.add(BatchNormalization())
        model4.add(Dropout(0.5))

        model4.add(Dense(output_dim, activation='softmax'))

        print(model4.summary())
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_32 (Dense)             (None, 364)               285740
_________________________________________________________________
dense_33 (Dense)             (None, 128)               46720
_________________________________________________________________
dense_34 (Dense)             (None, 64)                8256
_________________________________________________________________
batch_normalization_4 (Batch (None, 64)                256
_________________________________________________________________
dropout_4 (Dropout)          (None, 64)                0
_________________________________________________________________
dense_35 (Dense)             (None, 10)                650
=================================================================
Total params: 341,622
Trainable params: 341,494
Non-trainable params: 128
_________________________________________________________________
None
```

```
In [0]: model4.compile(optimizer='adam',
                       loss='categorical_crossentropy',
                       metrics=['accuracy'])
```

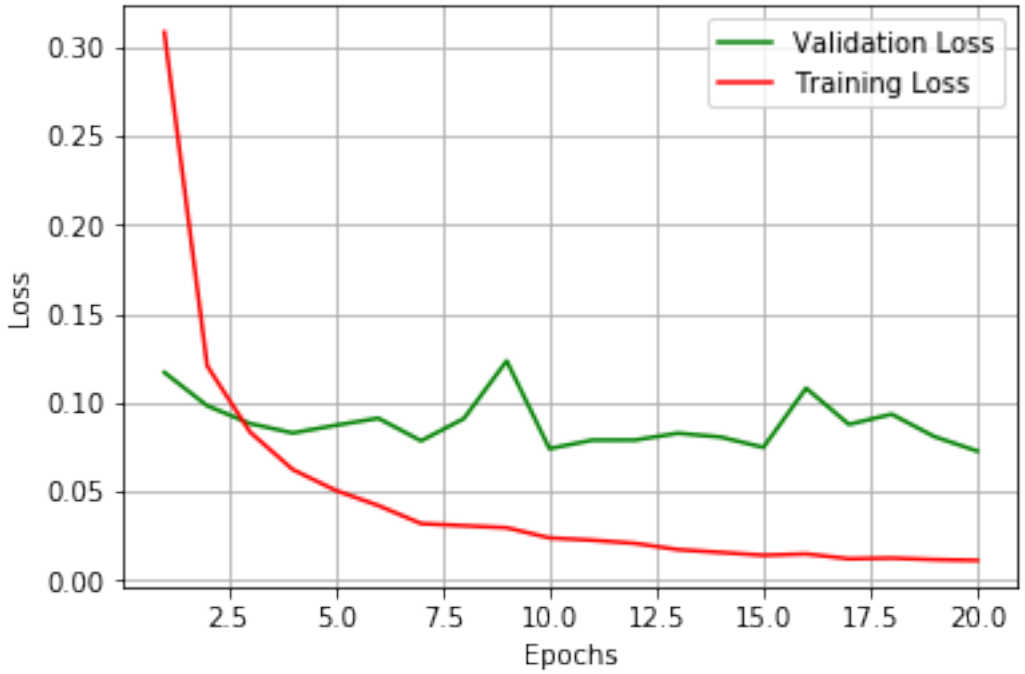
```
In [0]: # Training the model
        history = model4.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbos
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/20
Epoch 2/20
Epoch 3/20
Epoch 4/20
Epoch 5/20
Epoch 6/20
Epoch 7/20
Epoch 8/20
Epoch 9/20
Epoch 10/20
Epoch 11/20
Epoch 12/20
Epoch 13/20
Epoch 14/20
Epoch 15/20
Epoch 16/20
Epoch 17/20
Epoch 18/20
Epoch 19/20
Epoch 20/20
```

```
In [0]: score = model4.evaluate(X_test, y_test)
```

```
10000/10000 [==============================] - 1s 58us/step
```

```
In [0]: fig,ax = plt.subplots(1,1)
        ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

        # list of epoch numbers
        list_of_epoch = list(range(1,nb_epoch+1))

        train_loss = history.history['loss']
        val_loss = history.history['val_loss']

        ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
        ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
        plt.legend()
        plt.grid()
        plt.show();
```




```
In [0]: print('Test accuracy:', score[1])

Test accuracy: 0.9837
```

0.1.6 changing dropout rate to 0.8

```
In [36]: model4 = Sequential()

         model4.add(Dense(364, activation='relu', input_shape=(input_dim,),kernel_initializer=
         model4.add(Dense(128, activation='relu',kernel_initializer='random_uniform'))
         model4.add(Dense(64, activation='relu', kernel_initializer='random_uniform'))

         model4.add(BatchNormalization())
         model4.add(Dropout(0.8))

         model4.add(Dense(output_dim, activation='softmax'))

         print(model4.summary())
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_10 (Dense)             (None, 364)               285740
_________________________________________________________________
```

```
dense_11 (Dense)             (None, 128)               46720
_________________________________________________________________
dense_12 (Dense)             (None, 64)                8256
_________________________________________________________________
batch_normalization_4 (Batch (None, 64)                256
_________________________________________________________________
dropout_4 (Dropout)          (None, 64)                0
_________________________________________________________________
dense_13 (Dense)             (None, 10)                650
=================================================================
Total params: 341,622
Trainable params: 341,494
Non-trainable params: 128
_________________________________________________________________
None
```

```
In [0]: model4.compile(optimizer='adam',
                       loss='categorical_crossentropy',
                       metrics=['accuracy'])
```

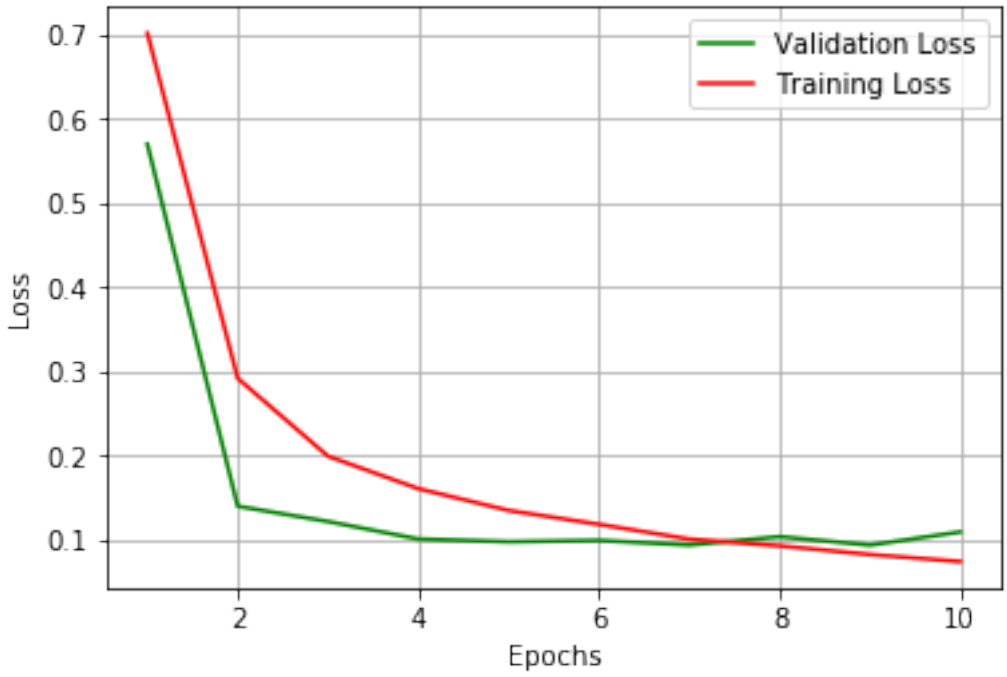
```
In [38]: # Training the model
         history = model4.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbo
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 6s 104us/step - loss: 0.7021 - acc: 0.7874 - val
Epoch 2/10
60000/60000 [==============================] - 5s 90us/step - loss: 0.2923 - acc: 0.9194 - val_
Epoch 3/10
60000/60000 [==============================] - 5s 91us/step - loss: 0.1997 - acc: 0.9452 - val_
Epoch 4/10
60000/60000 [==============================] - 5s 91us/step - loss: 0.1612 - acc: 0.9552 - val_
Epoch 5/10
60000/60000 [==============================] - 5s 92us/step - loss: 0.1353 - acc: 0.9605 - val_
Epoch 6/10
60000/60000 [==============================] - 5s 90us/step - loss: 0.1188 - acc: 0.9655 - val_
Epoch 7/10
60000/60000 [==============================] - 5s 91us/step - loss: 0.1013 - acc: 0.9692 - val_
Epoch 8/10
60000/60000 [==============================] - 5s 89us/step - loss: 0.0933 - acc: 0.9719 - val_
Epoch 9/10
60000/60000 [==============================] - 5s 90us/step - loss: 0.0830 - acc: 0.9746 - val_
Epoch 10/10
60000/60000 [==============================] - 5s 88us/step - loss: 0.0747 - acc: 0.9760 - val_
```

```
In [39]: score = model4.evaluate(X_test, y_test)
```

```
10000/10000 [==============================] - 1s 51us/step
```

```
In [40]: fig,ax = plt.subplots(1,1)
         ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

         # list of epoch numbers
         list_of_epoch = list(range(1,nb_epoch+1))

         train_loss = history.history['loss']
         val_loss = history.history['val_loss']

         ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
         ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
         plt.legend()
         plt.grid()
         plt.show();
```




```
In [41]: print('Test accuracy:', score[1])
```

```
Test accuracy: 0.9767
```

0.1.7 changing dropout rate to 0.2

```
In [42]: model4 = Sequential()
```

```
        model4.add(Dense(364, activation='relu', input_shape=(input_dim,),kernel_initializer=
        model4.add(Dense(128, activation='relu',kernel_initializer='random_uniform'))
        model4.add(Dense(64, activation='relu', kernel_initializer='random_uniform'))

        model4.add(BatchNormalization())
        model4.add(Dropout(0.2))

        model4.add(Dense(output_dim, activation='softmax'))

        print(model4.summary())
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_14 (Dense)             (None, 364)               285740
_________________________________________________________________
dense_15 (Dense)             (None, 128)               46720
_________________________________________________________________
dense_16 (Dense)             (None, 64)                8256
_________________________________________________________________
batch_normalization_5 (Batch (None, 64)                256
_________________________________________________________________
dropout_5 (Dropout)          (None, 64)                0
_________________________________________________________________
dense_17 (Dense)             (None, 10)                650
=================================================================
Total params: 341,622
Trainable params: 341,494
Non-trainable params: 128
_________________________________________________________________
None
```

```
In [0]: model4.compile(optimizer='adam',
                       loss='categorical_crossentropy',
                       metrics=['accuracy'])
```

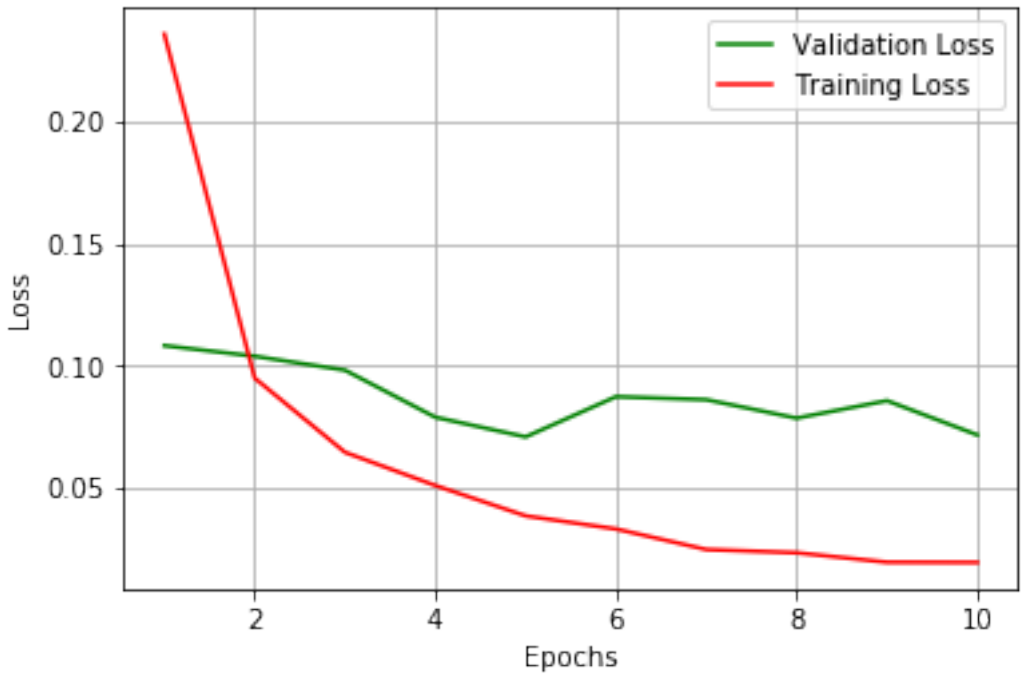
```
In [44]: # Training the model
         history = model4.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbo
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 6s 105us/step - loss: 0.2361 - acc: 0.9319 - val
Epoch 2/10
60000/60000 [==============================] - 5s 89us/step - loss: 0.0951 - acc: 0.9717 - val_
Epoch 3/10
60000/60000 [==============================] - 5s 90us/step - loss: 0.0647 - acc: 0.9810 - val_
Epoch 4/10
60000/60000 [==============================] - 5s 88us/step - loss: 0.0511 - acc: 0.9843 - val_
```

```
Epoch 5/10
60000/60000 [==============================] - 5s 88us/step - loss: 0.0386 - acc: 0.9879 - val
Epoch 6/10
60000/60000 [==============================] - 5s 90us/step - loss: 0.0332 - acc: 0.9896 - val
Epoch 7/10
60000/60000 [==============================] - 5s 87us/step - loss: 0.0248 - acc: 0.9918 - val
Epoch 8/10
60000/60000 [==============================] - 5s 88us/step - loss: 0.0235 - acc: 0.9921 - val
Epoch 9/10
60000/60000 [==============================] - 5s 87us/step - loss: 0.0196 - acc: 0.9939 - val
Epoch 10/10
60000/60000 [==============================] - 5s 88us/step - loss: 0.0195 - acc: 0.9937 - val
```

```
In [45]: score = model4.evaluate(X_test, y_test)

10000/10000 [==============================] - 1s 55us/step
```

```
In [46]: fig,ax = plt.subplots(1,1)
         ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

         # list of epoch numbers
         list_of_epoch = list(range(1,nb_epoch+1))

         train_loss = history.history['loss']
         val_loss = history.history['val_loss']

         ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
         ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
         plt.legend()
         plt.grid()
         plt.show();
```




```
In [47]: print('Test accuracy:', score[1])

Test accuracy: 0.9813
```

0.1.8 Model with 5 hidden layers

```
In [0]: model5 = Sequential()

        model5.add(Dense(364, activation='relu', input_shape=(input_dim,),kernel_initializer='
        model5.add(Dense(128, activation='relu',kernel_initializer='random_uniform'))
        model5.add(Dense(96, activation='relu', kernel_initializer='random_uniform'))
        model5.add(Dense(64, activation='relu', kernel_initializer='random_uniform'))
        model5.add(Dense(32, activation='relu', kernel_initializer='random_uniform'))

        #model2.add(BatchNormalization())
        #model2.add(Dropout(0.5))

        model5.add(Dense(output_dim, activation='softmax'))

        print(model5.summary())

_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
```

```
dense_36 (Dense)             (None, 364)               285740
_________________________________________________________________
dense_37 (Dense)             (None, 128)               46720
_________________________________________________________________
dense_38 (Dense)             (None, 96)                12384
_________________________________________________________________
dense_39 (Dense)             (None, 64)                6208
_________________________________________________________________
dense_40 (Dense)             (None, 32)                2080
_________________________________________________________________
dense_41 (Dense)             (None, 10)                330
=================================================================
Total params: 353,462
Trainable params: 353,462
Non-trainable params: 0
_________________________________________________________________
None
```

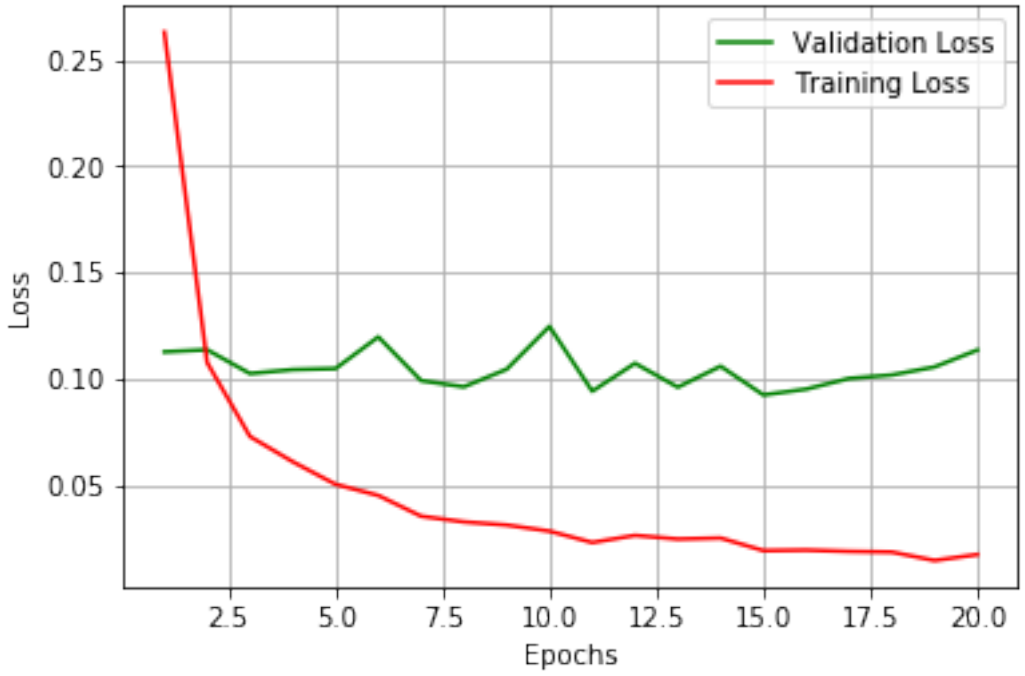
```
In [0]: model5.compile(optimizer='adam',
                       loss='categorical_crossentropy',
                       metrics=['accuracy'])
```

```
In [0]: # Training the model
        history = model5.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbos
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/20
Epoch 2/20
Epoch 3/20
Epoch 4/20
Epoch 5/20
Epoch 6/20
Epoch 7/20
Epoch 8/20
Epoch 9/20
Epoch 10/20
Epoch 11/20
Epoch 12/20
Epoch 13/20
Epoch 14/20
Epoch 15/20
Epoch 16/20
Epoch 17/20
Epoch 18/20
Epoch 19/20
Epoch 20/20
```

```
In [0]: score = model5.evaluate(X_test, y_test)

10000/10000 [==============================] - 1s 61us/step
```

```
In [0]: fig,ax = plt.subplots(1,1)
        ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

        # list of epoch numbers
        list_of_epoch = list(range(1,nb_epoch+1))

        train_loss = history.history['loss']
        val_loss = history.history['val_loss']

        ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
        ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
        plt.legend()
        plt.grid()
        plt.show();
```




```
In [0]: print('Test accuracy:', score[1])

Test accuracy: 0.9804
```

0.1.9 Model with 5 hidden layers along with BN and Dropout

```
In [0]: model6 = Sequential()

        model6.add(Dense(364, activation='relu', input_shape=(input_dim,),kernel_initializer='
        model6.add(Dense(128, activation='relu',kernel_initializer='random_uniform'))
        model6.add(Dense(96, activation='relu', kernel_initializer='random_uniform'))
        model6.add(Dense(64, activation='relu', kernel_initializer='random_uniform'))
        model6.add(Dense(32, activation='relu', kernel_initializer='random_uniform'))

        model6.add(BatchNormalization())
        model6.add(Dropout(0.5))

        model6.add(Dense(output_dim, activation='softmax'))

        print(model6.summary())
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_48 (Dense)             (None, 364)               285740
_________________________________________________________________
dense_49 (Dense)             (None, 128)               46720
_________________________________________________________________
dense_50 (Dense)             (None, 96)                12384
_________________________________________________________________
dense_51 (Dense)             (None, 64)                6208
_________________________________________________________________
dense_52 (Dense)             (None, 32)                2080
_________________________________________________________________
batch_normalization_6 (Batch (None, 32)                128
_________________________________________________________________
dropout_6 (Dropout)          (None, 32)                0
_________________________________________________________________
dense_53 (Dense)             (None, 10)                330
=================================================================
Total params: 353,590
Trainable params: 353,526
Non-trainable params: 64
_________________________________________________________________
None
```

```
In [0]: model6.compile(optimizer='adam',
                       loss='categorical_crossentropy',
                       metrics=['accuracy'])
```

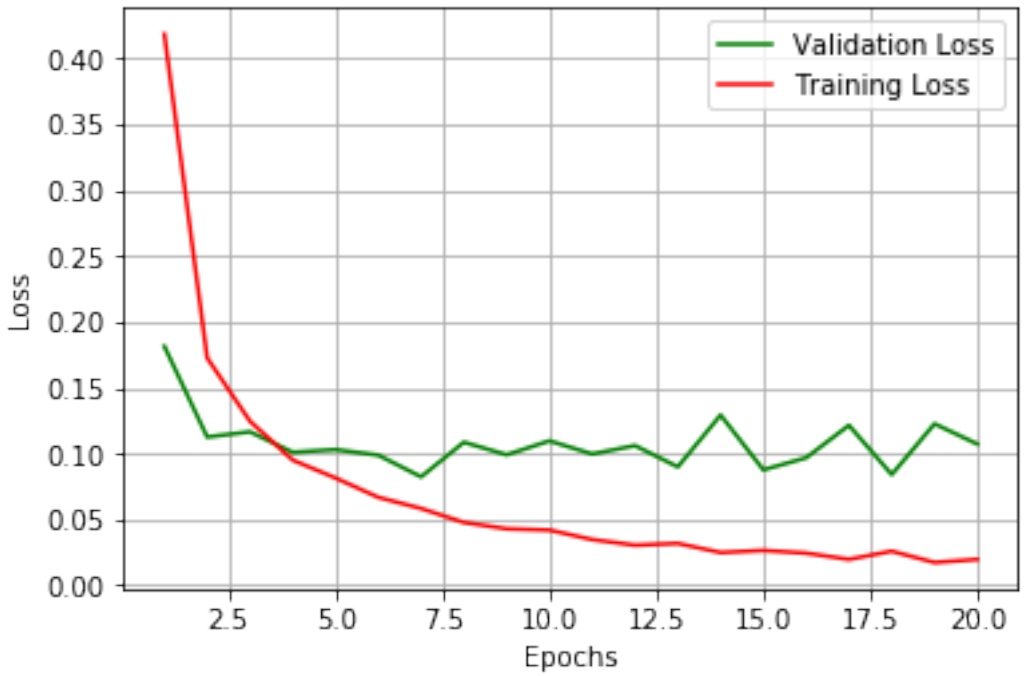
```
In [0]: # Training the model
        history = model6.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbos
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/20
Epoch 2/20
Epoch 3/20
Epoch 4/20
Epoch 5/20
Epoch 6/20
Epoch 7/20
Epoch 8/20
Epoch 9/20
Epoch 10/20
Epoch 11/20
Epoch 12/20
Epoch 13/20
Epoch 14/20
Epoch 15/20
Epoch 16/20
Epoch 17/20
Epoch 18/20
Epoch 19/20
Epoch 20/20
```

```
In [0]: score = model6.evaluate(X_test, y_test)
```

```
10000/10000 [==============================] - 1s 83us/step
```

```
In [0]: fig,ax = plt.subplots(1,1)
        ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

        # list of epoch numbers
        list_of_epoch = list(range(1,nb_epoch+1))

        train_loss = history.history['loss']
        val_loss = history.history['val_loss']

        ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
        ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
        plt.legend()
        plt.grid()
        plt.show();
```




```
In [0]: print('Test accuracy:', score[1])

Test accuracy: 0.9814
```

0.1.10 Changing Dropout to 0.8

```
In [48]: model6 = Sequential()

         model6.add(Dense(364, activation='relu', input_shape=(input_dim,),kernel_initializer=
         model6.add(Dense(128, activation='relu',kernel_initializer='random_uniform'))
         model6.add(Dense(96, activation='relu', kernel_initializer='random_uniform'))
         model6.add(Dense(64, activation='relu', kernel_initializer='random_uniform'))
         model6.add(Dense(32, activation='relu', kernel_initializer='random_uniform'))

         model6.add(BatchNormalization())
         model6.add(Dropout(0.8))

         model6.add(Dense(output_dim, activation='softmax'))

         print(model6.summary())

_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
```

```
dense_18 (Dense)             (None, 364)               285740
_________________________________________________________________
dense_19 (Dense)             (None, 128)               46720
_________________________________________________________________
dense_20 (Dense)             (None, 96)                12384
_________________________________________________________________
dense_21 (Dense)             (None, 64)                6208
_________________________________________________________________
dense_22 (Dense)             (None, 32)                2080
_________________________________________________________________
batch_normalization_6 (Batch (None, 32)                128
_________________________________________________________________
dropout_6 (Dropout)          (None, 32)                0
_________________________________________________________________
dense_23 (Dense)             (None, 10)                330
=================================================================
Total params: 353,590
Trainable params: 353,526
Non-trainable params: 64
_________________________________________________________________
None
```

```
In [0]: model6.compile(optimizer='adam',
                       loss='categorical_crossentropy',
                       metrics=['accuracy'])
```

```
In [50]: # Training the model
         history = model6.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbo
```

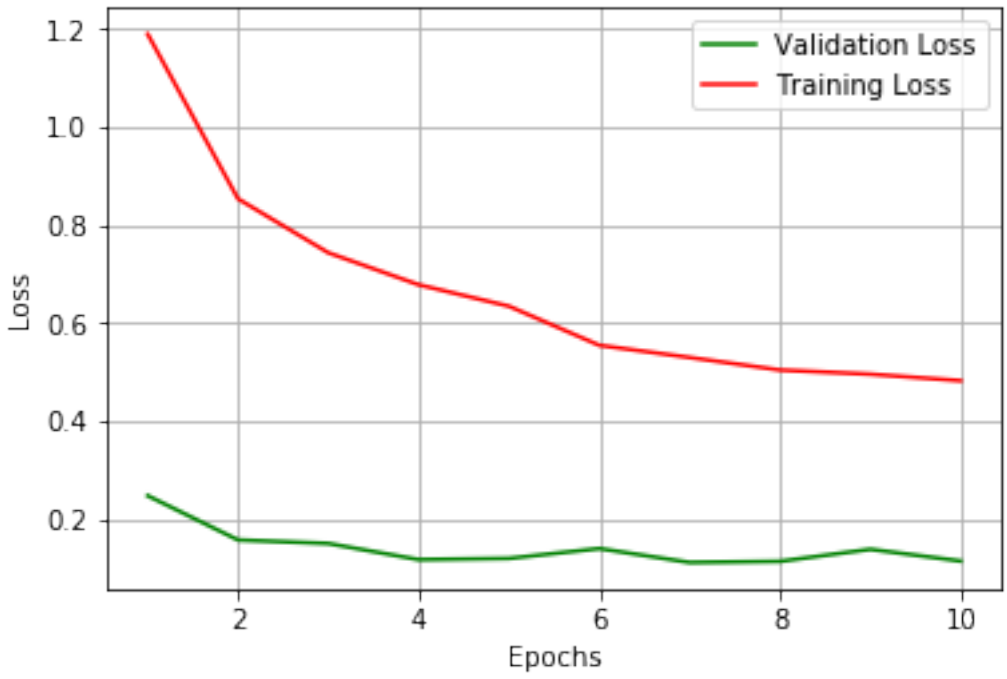
```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
Epoch 2/10
Epoch 3/10
Epoch 4/10
Epoch 5/10
Epoch 6/10
Epoch 7/10
Epoch 8/10
Epoch 9/10
Epoch 10/10
```

```
In [51]: score = model6.evaluate(X_test, y_test)
```

```
10000/10000 [==============================] - 1s 56us/step
```

```
In [52]: fig,ax = plt.subplots(1,1)
         ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')
```

```
# list of epoch numbers
list_of_epoch = list(range(1,nb_epoch+1))

train_loss = history.history['loss']
val_loss = history.history['val_loss']

ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
plt.legend()
plt.grid()
plt.show();
```




```
In [53]: print('Test accuracy:', score[1])

Test accuracy: 0.9774
```

0.1.11 Changing dropout to 0.2

```
In [54]: model6 = Sequential()

model6.add(Dense(364, activation='relu', input_shape=(input_dim,),kernel_initializer=
model6.add(Dense(128, activation='relu',kernel_initializer='random_uniform'))
model6.add(Dense(96, activation='relu', kernel_initializer='random_uniform'))
```

```
        model6.add(Dense(64, activation='relu', kernel_initializer='random_uniform'))
        model6.add(Dense(32, activation='relu', kernel_initializer='random_uniform'))

        model6.add(BatchNormalization())
        model6.add(Dropout(0.2))

        model6.add(Dense(output_dim, activation='softmax'))

        print(model6.summary())
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_24 (Dense)             (None, 364)               285740
_________________________________________________________________
dense_25 (Dense)             (None, 128)               46720
_________________________________________________________________
dense_26 (Dense)             (None, 96)                12384
_________________________________________________________________
dense_27 (Dense)             (None, 64)                6208
_________________________________________________________________
dense_28 (Dense)             (None, 32)                2080
_________________________________________________________________
batch_normalization_7 (Batch (None, 32)                128
_________________________________________________________________
dropout_7 (Dropout)          (None, 32)                0
_________________________________________________________________
dense_29 (Dense)             (None, 10)                330
=================================================================
Total params: 353,590
Trainable params: 353,526
Non-trainable params: 64
_________________________________________________________________
None
```

```
In [0]: model6.compile(optimizer='adam',
                       loss='categorical_crossentropy',
                       metrics=['accuracy'])
```

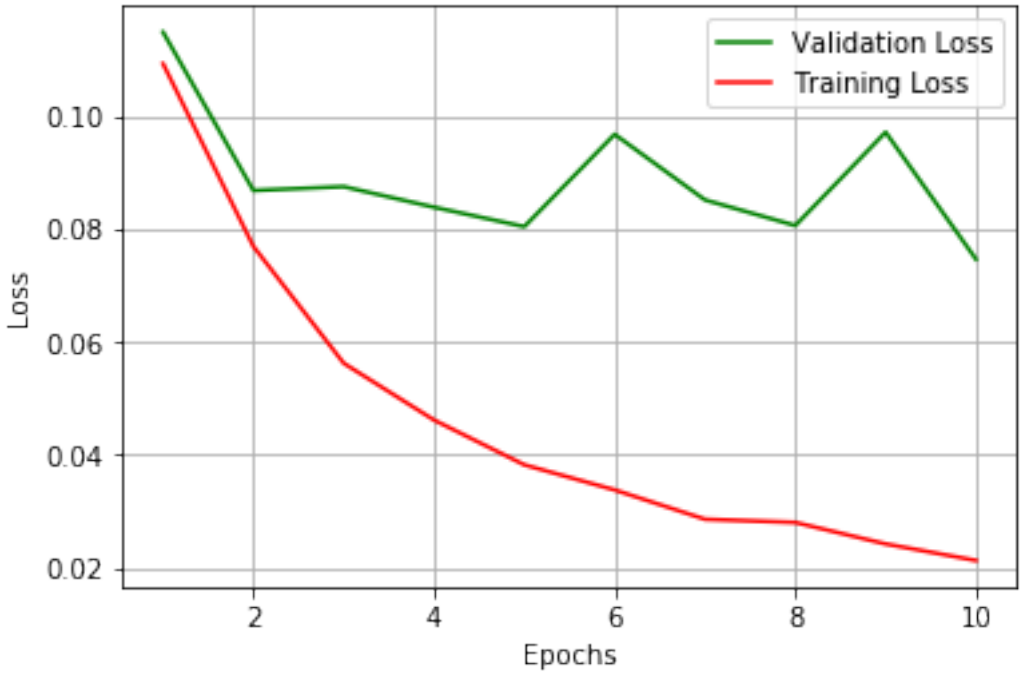
```
In [57]: # Training the model
         history = model6.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbo
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 6s 96us/step - loss: 0.1093 - acc: 0.9702 - val_
Epoch 2/10
60000/60000 [==============================] - 6s 94us/step - loss: 0.0770 - acc: 0.9781 - val_
Epoch 3/10
```

```
60000/60000 [==============================] - 6s 96us/step - loss: 0.0563 - acc: 0.9838 - val
Epoch 4/10
60000/60000 [==============================] - 6s 97us/step - loss: 0.0462 - acc: 0.9865 - val
Epoch 5/10
60000/60000 [==============================] - 6s 95us/step - loss: 0.0383 - acc: 0.9890 - val
Epoch 6/10
60000/60000 [==============================] - 6s 95us/step - loss: 0.0338 - acc: 0.9899 - val
Epoch 7/10
60000/60000 [==============================] - 6s 93us/step - loss: 0.0286 - acc: 0.9916 - val
Epoch 8/10
60000/60000 [==============================] - 6s 94us/step - loss: 0.0280 - acc: 0.9916 - val
Epoch 9/10
60000/60000 [==============================] - 6s 94us/step - loss: 0.0242 - acc: 0.9927 - val
Epoch 10/10
60000/60000 [==============================] - 6s 95us/step - loss: 0.0213 - acc: 0.9934 - val
```

```
In [59]: score = model6.evaluate(X_test, y_test)

10000/10000 [==============================] - 1s 65us/step
```

```
In [60]: fig,ax = plt.subplots(1,1)
         ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

         # list of epoch numbers
         list_of_epoch = list(range(1,nb_epoch+1))

         train_loss = history.history['loss']
         val_loss = history.history['val_loss']

         ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
         ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
         plt.legend()
         plt.grid()
         plt.show();
```




```
In [58]: print('Test accuracy:', score[1])

Test accuracy: 0.9774
```

---

1 Conclusions

```
In [64]: # Please compare all your models using Prettytable library
         from prettytable import PrettyTable

         x = PrettyTable()

         x.field_names = ["Numer of Layers", "BN","Dropout", "Accuracy"]

         x.add_row(["2", 'NO',"NO", 0.86])
         x.add_row(["2", 'YES',0.5, 0.98])
         x.add_row(["2", 'YES',0.8, 0.98])
         x.add_row(["2", 'YES',0.2, 0.98])

         x.add_row(["3", 'NO',"NO", 0.87])
         x.add_row(["3", 'YES',0.5, 0.98])
         x.add_row(["3", 'YES',0.8, 0.97])
```

```
x.add_row(["3", 'YES',0.2, 0.98])

x.add_row(["5", 'NO','NO', 0.98])
x.add_row(["5", 'YES',0.5, 0.98])
x.add_row(["5", 'YES',0.8, 0.97])
x.add_row(["5", 'YES',0.2, 0.97])


print(x)
```

```
+-----------------+-----+---------+----------+
| Numer of Layers |  BN | Dropout | Accuracy |
+-----------------+-----+---------+----------+
|        2        |  NO |    NO   |   0.86   |
|        2        | YES |   0.5   |   0.98   |
|        2        | YES |   0.8   |   0.98   |
|        2        | YES |   0.2   |   0.98   |
|        3        |  NO |    NO   |   0.87   |
|        3        | YES |   0.5   |   0.98   |
|        3        | YES |   0.8   |   0.97   |
|        3        | YES |   0.2   |   0.98   |
|        5        |  NO |    NO   |   0.98   |
|        5        | YES |   0.5   |   0.98   |
|        5        | YES |   0.8   |   0.97   |
|        5        | YES |   0.2   |   0.97   |
+-----------------+-----+---------+----------+
```