Various_architectures_on_MNIST

April 1, 2019

In [2]:
```
%matplotlib inline

import warnings
warnings.filterwarnings('ignore')

from keras.utils import np_utils
from keras.datasets import mnist
from keras.initializers import RandomNormal

# Model
from keras.models import Sequential

# Layers
from keras.layers import Dense
from keras.layers.normalization import BatchNormalization
from keras.layers import Dropout

import seaborn as sns
import matplotlib.pyplot as plt
```

```
Using TensorFlow backend.
```

In [3]:
```
# MNIST Data Fetching and Preprocessing

(X_train, y_train), (X_test, y_test) = mnist.load_data()

# Convert 28*28 image into 784 size 1D tensor
X_train = X_train.reshape(X_train.shape[0], X_train.shape[1] * X_train.shape[2])
X_test = X_test.reshape(X_test.shape[0], X_test.shape[1] * X_test.shape[2])

# Convert labels into one-hot encoded vectors

y_train = np_utils.to_categorical(y_train, 10)
y_test = np_utils.to_categorical(y_test, 10)

# Normalize the input data using simple min max normalization
```

```
X_train = X_train / 255
X_test = X_test / 255
```

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

In [0]:
```
def plot_dynamic(x, vy, ty, ax, fig, colors=['b']):
    ax.plot(x, vy, 'r', label='Validation Loss')
    ax.plot(x, ty, 'b', label='Train Loss')
    plt.legend()
    plt.grid()
    fig.canvas.draw()
```

In [0]:
```
# Plotting Training/Validation Loss

def plot_loss(history):
    fig, ax = plt.subplots(1, 1)
    ax.set_xlabel("Epochs")
    ax.set_ylabel("Softmax Cross Entropy Loss")

    x = list(range(1, n_epochs+1))
    vy = history.history['val_loss']
    ty = history.history['loss']

    plot_dynamic(x, vy, ty, ax, fig)
```

In [0]:
```
'''
def plot_weight_distribution(weights):
    h1 = weights[0].flatten().reshape(-1, 1)
    h2 = weights[2].flatten().reshape(-1, 1)
    out = weights[4].flatten().reshape(-1, 1)
    fig = plt.figure()
    plt.title("Training Weights Distribution")

    plt.subplot(1, 3, 1)
    plt.title("Trained Weights")
    ax = sns.violinplot(y=h1, color='b')
    plt.xlabel("Layer 1")

    plt.subplot(1, 3, 2)
    plt.title("Trained Weights")
    ax = sns.violinplot(y=h2, color='r')
    plt.xlabel("Layer 2")

    plt.subplot(1, 3, 3)
    plt.title("Trained Weights")
    ax = sns.violinplot(y=out, color='g')
    plt.xlabel('Out Layer')
```

```
    plt.show()
'''
# Plot function for weight distribution

def plot_weight_distribution(weights, hidden_layers=None):
    colors = ['b', 'r', 'g', 'y', 'm']
    fig = plt.figure()
    plt.title("Training Weights Distribution")

    for i in range(0, hidden_layers+1):
        layer_weights = weights[i*2].flatten().reshape(-1, 1)
        plt.subplot(1, hidden_layers+1, i+1)
        plt.title("Trained Weights")
        ax = sns.violinplot(y=layer_weights, color=colors[i%5])
        if i == hidden_layers:
            plt.xlabel("Out Layer")
        else:
            plt.xlabel("Layer {}".format(i+1))
    plt.show()
```

```
In [0]: # Model Parameters

        input_dim = 784
        output_dim = 10
        batch_size = 100
        n_epochs = 20
```

MLP (2-hidden layers) + Adam Optimizer + ReLU activations

```
In [12]: # Model Architecture

         # Hidden layer 1 --> 256


         # Hidden layer 2 --> 64

         # Since we are using ReLU activation,
         # we will use He-initialization.

         model = Sequential()

         # Hidden Layer 1
         model.add(Dense(256, input_shape=(input_dim,), activation='relu',
                         kernel_initializer=RandomNormal(mean=0.0, stddev=0.055,
                                                         seed=None)))

         # Hidden Layer 2
```

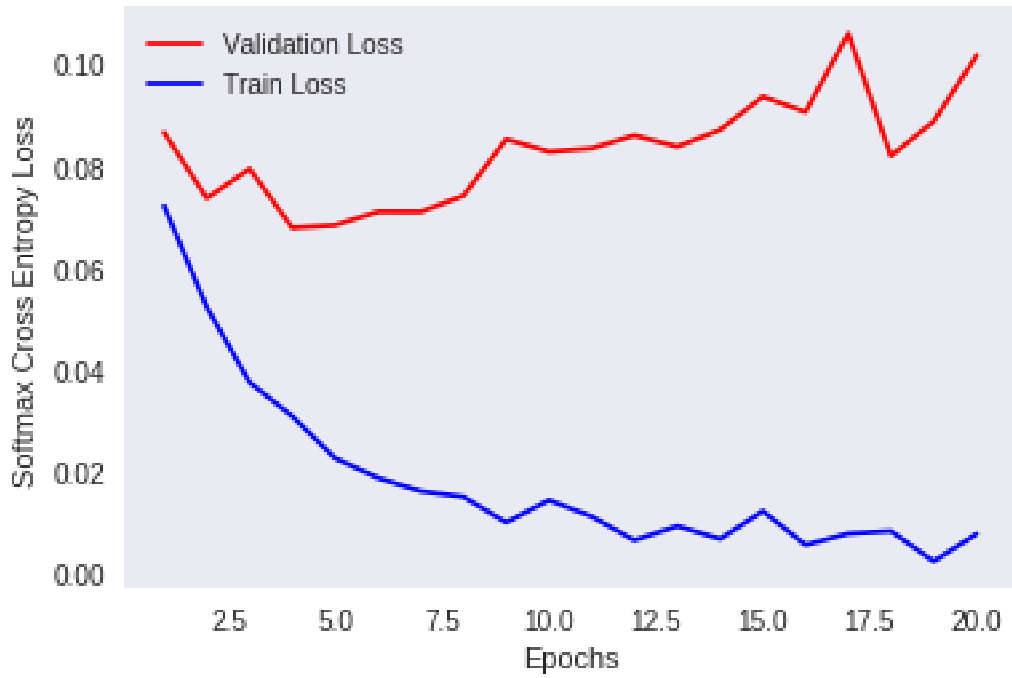
```
model.add(Dense(64, activation='relu',
                kernel_initializer=RandomNormal(mean=0.0, stddev=0.088,
                                                seed=None)))

# Output SoftMax Layer
model.add(Dense(output_dim, activation='softmax'))


# Defining optimizer, loss function and evaluation metric
model.compile(optimizer='adam', loss='categorical_crossentropy',
              metrics=['accuracy'])

model.summary()
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_13 (Dense)             (None, 256)               200960
_________________________________________________________________
dense_14 (Dense)             (None, 64)                16448
_________________________________________________________________
dense_15 (Dense)             (None, 10)                650
=================================================================
Total params: 218,058
Trainable params: 218,058
Non-trainable params: 0
_________________________________________________________________
```

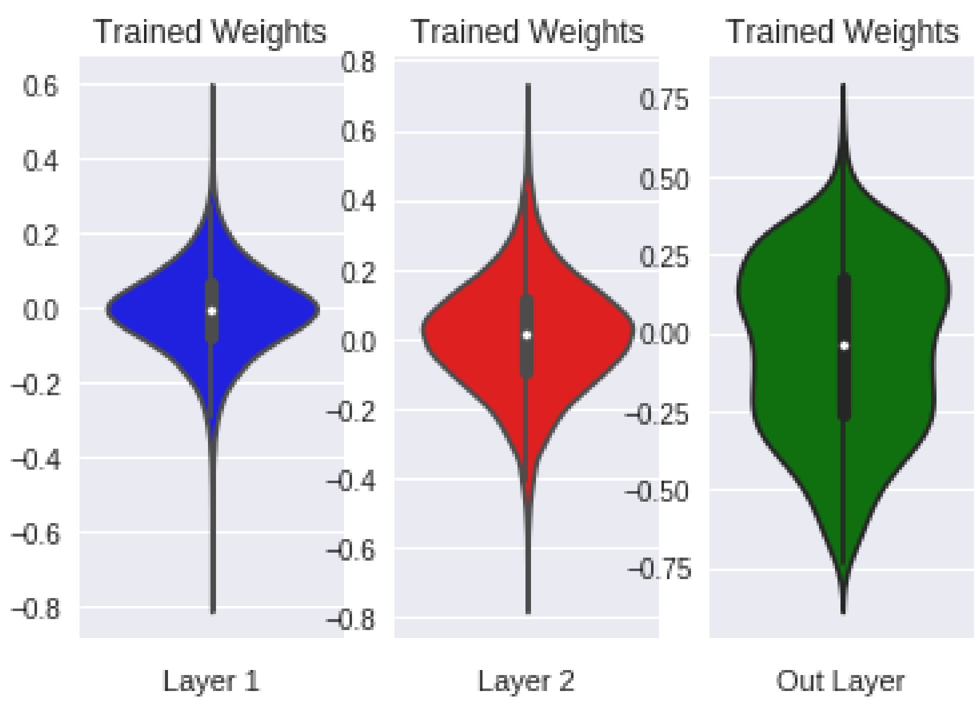
```
In [0]: history = model.fit(X_train, y_train, batch_size=batch_size, epochs=n_epochs,
                            verbose=0, validation_data=(X_test, y_test))

        # Test Loss and Accuracy
        score = model.evaluate(X_test, y_test, verbose=0)
        print("Test Loss : ", score[0])
        print("Test Accuracy : ", score[1])
```

```
Test Loss :  0.10167545924528686
Test Accuracy :  0.9802
```

```
In [0]: plot_loss(history)
```




```
In [0]: weights = model.get_weights()
        plot_weight_distribution(weights)
```



MLP (2-hidden layers) + Adam Optimizer + ReLU activations + BatchNorm + Dropout

In [13]:
```
# Model Architecture

# Hidden layer 1 --> 256

# Batch Normalization Layer
# Dropout layer with dropout_rate = 0.3

# Hidden layer 2 --> 64

# Batch Normalization Layer
# Dropout layer with dropout_rate = 0.3


# Since we are using ReLU activation,
# we will use He-initialization.

model = Sequential()

# Hidden Layer 1
model.add(Dense(256, input_shape=(input_dim,), activation='relu',
                kernel_initializer=RandomNormal(mean=0.0, stddev=0.055,
                                                seed=None)))
model.add(BatchNormalization())
model.add(Dropout(0.3))


# Hidden Layer 2
model.add(Dense(64, activation='relu',
                kernel_initializer=RandomNormal(mean=0.0, stddev=0.088,
                                                seed=None)))
model.add(BatchNormalization())
model.add(Dropout(0.3))


# Output SoftMax Layer
model.add(Dense(output_dim, activation='softmax'))


# Defining optimizer, loss function and evaluation metric
model.compile(optimizer='adam', loss='categorical_crossentropy',
              metrics=['accuracy'])

model.summary()
```

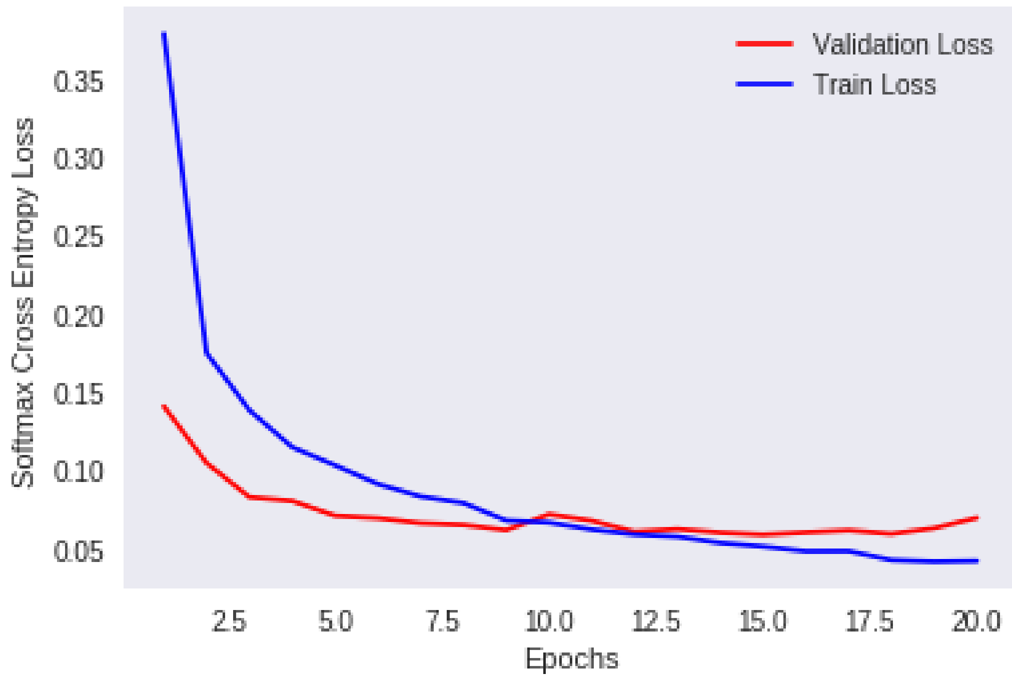
```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
```

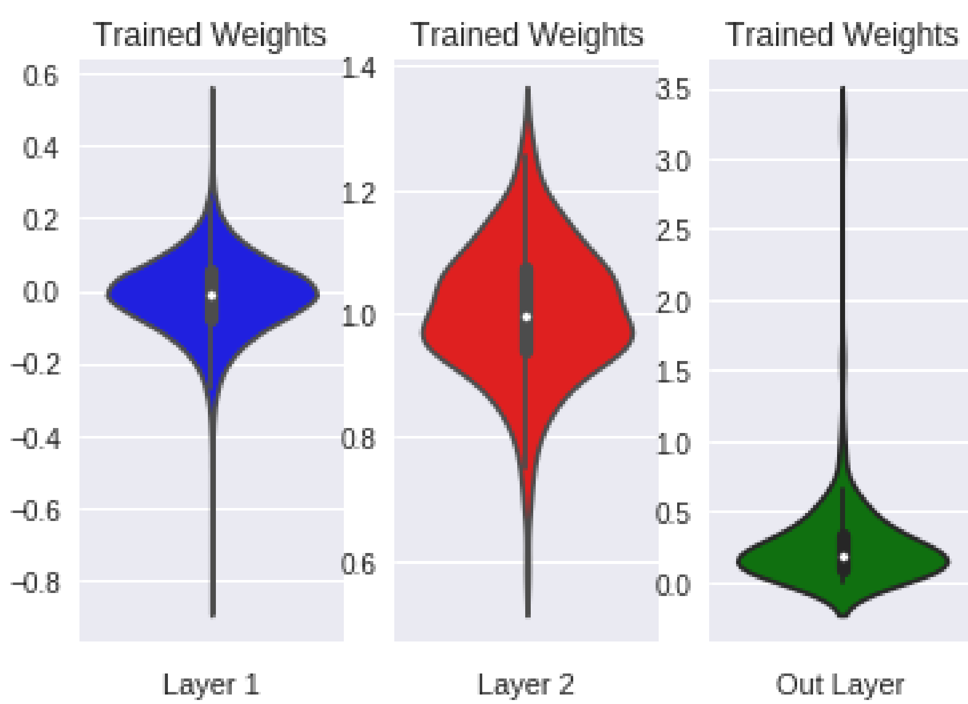
```
=================================================================
dense_16 (Dense)             (None, 256)               200960
_________________________________________________________________
batch_normalization_11 (Batc (None, 256)               1024
_________________________________________________________________
dropout_11 (Dropout)         (None, 256)               0
_________________________________________________________________
dense_17 (Dense)             (None, 64)                16448
_________________________________________________________________
batch_normalization_12 (Batc (None, 64)                256
_________________________________________________________________
dropout_12 (Dropout)         (None, 64)                0
_________________________________________________________________
dense_18 (Dense)             (None, 10)                650
=================================================================
Total params: 219,338
Trainable params: 218,698
Non-trainable params: 640
_________________________________________________________________
```

In [0]:
```
history = model.fit(X_train, y_train, batch_size=batch_size, epochs=n_epochs,
                            verbose=0, validation_data=(X_test, y_test))

# Test Loss and Accuracy
score = model.evaluate(X_test, y_test, verbose=0)
print("Test Loss : ", score[0])
print("Test Accuracy : ", score[1])
```

```
Test Loss :  0.06912141052252264
Test Accuracy :  0.9816
```

In [0]:
```
plot_loss(history)
weights = model.get_weights()
plot_weight_distribution(weights)
```





MLP (3-hidden layers) + Adam Optimizer + ReLU activations

In [14]:
```
# Model Architecture

# Hidden layer 1 --> 1024


# Hidden layer 2 --> 512


# Hidden layer 3 --> 256


# Since we are using ReLU activation,
# we will use He-initialization.

model = Sequential()

# Hidden Layer 1
model.add(Dense(1024, input_shape=(input_dim,), activation='relu',
                kernel_initializer=RandomNormal(mean=0.0, stddev=0.050,
                                                seed=None)))

# Hidden Layer 2
model.add(Dense(512, activation='relu',
                kernel_initializer=RandomNormal(mean=0.0, stddev=0.044,
                                                seed=None)))

# Hidden Layer 3
model.add(Dense(256, activation='relu',
                kernel_initializer=RandomNormal(mean=0.0, stddev=0.062,
                                                seed=None)))

# Output SoftMax Layer
model.add(Dense(output_dim, activation='softmax'))


# Defining optimizer, loss function and evaluation metric
model.compile(optimizer='adam', loss='categorical_crossentropy',
              metrics=['accuracy'])

model.summary()
```

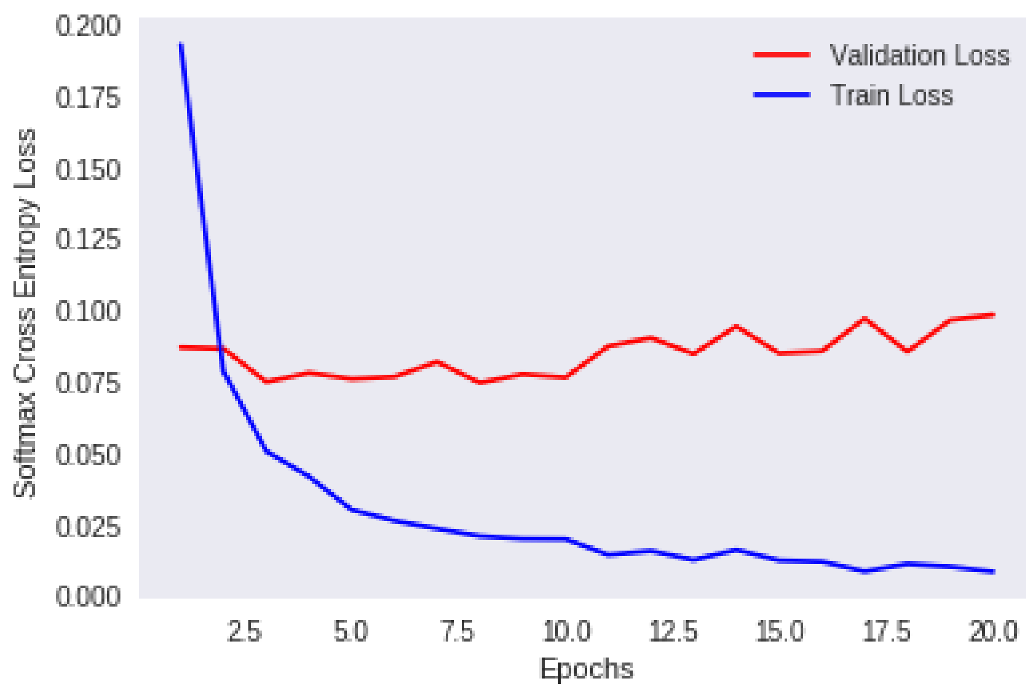
```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_19 (Dense)             (None, 1024)              803840
_________________________________________________________________
dense_20 (Dense)             (None, 512)               524800
_________________________________________________________________
```

```
dense_21 (Dense)             (None, 256)               131328
_________________________________________________________________
dense_22 (Dense)             (None, 10)                2570
=================================================================
Total params: 1,462,538
Trainable params: 1,462,538
Non-trainable params: 0
_________________________________________________________________
```

In [0]:
```python
history = model.fit(X_train, y_train, batch_size=batch_size, epochs=n_epochs,
                    verbose=0, validation_data=(X_test, y_test))

# Test Loss and Accuracy
score = model.evaluate(X_test, y_test, verbose=0)
print("Test Loss : ", score[0])
print("Test Accuracy : ", score[1])
```

```
Test Loss :  0.09790483784366265
Test Accuracy :  0.9812
```

In [0]:
```python
plot_loss(history)
```



In [0]:
```python
weights = model.get_weights()
plot_weight_distribution(weights, hidden_layers=5)
```

MLP (3-hidden layers) + Adam Optimizer + ReLU activations + BatchNorm + Dropout

In [15]:
```
# Model Architecture

# Hidden layer 1 --> 1024

# Batch Normalization Layer
# Dropout layer with dropout_rate = 0.5

# Hidden layer 2 --> 512

# Batch Normalization Layer
# Dropout layer with dropout_rate = 0.5

# Hidden layer 3 --> 256

# Batch Normalization Layer
# Dropout layer with dropout_rate = 0.5


model = Sequential()

# Hidden Layer 1
model.add(Dense(1024, input_shape=(input_dim,), activation='relu',
                kernel_initializer=RandomNormal(mean=0.0, stddev=0.050,
                                                seed=None)))
model.add(BatchNormalization())
model.add(Dropout(0.5))


# Hidden Layer 2
model.add(Dense(512, activation='relu',
                kernel_initializer=RandomNormal(mean=0.0, stddev=0.044,
                                                seed=None)))
model.add(BatchNormalization())
model.add(Dropout(0.5))


# Hidden Layer 3
model.add(Dense(256, activation='relu',
                kernel_initializer=RandomNormal(mean=0.0, stddev=0.062,
                                                seed=None)))
model.add(BatchNormalization())
model.add(Dropout(0.5))


# Output SoftMax Layer
model.add(Dense(output_dim, activation='softmax'))
```

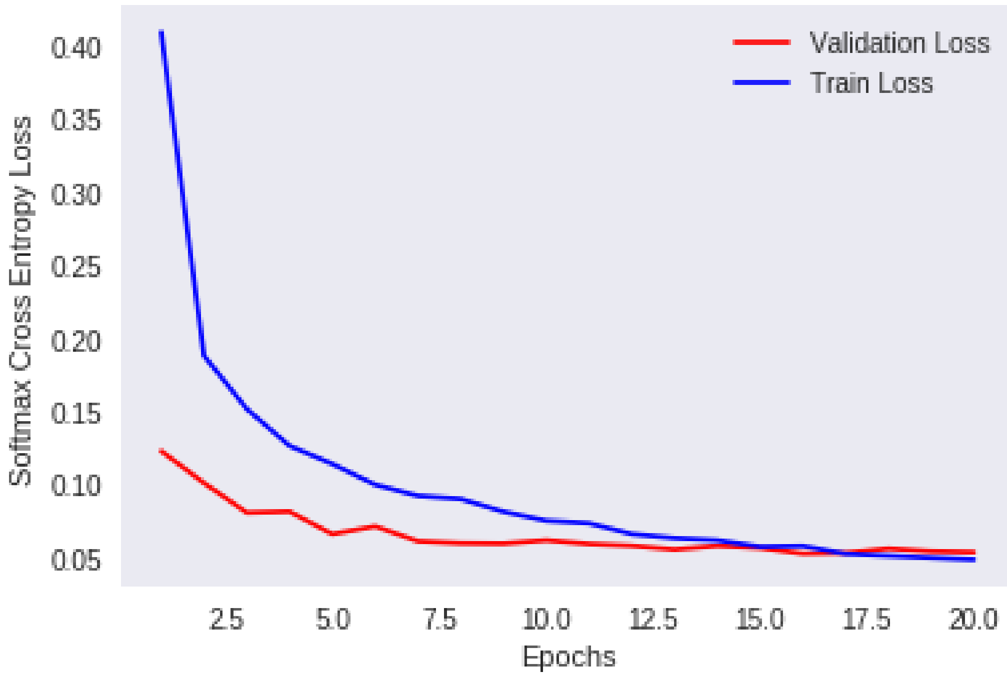
```python
# Defining optimizer, loss function and evaluation metric
model.compile(optimizer='adam', loss='categorical_crossentropy',
              metrics=['accuracy'])

model.summary()
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_23 (Dense)             (None, 1024)              803840
_________________________________________________________________
batch_normalization_13 (Batc (None, 1024)              4096
_________________________________________________________________
dropout_13 (Dropout)         (None, 1024)              0
_________________________________________________________________
dense_24 (Dense)             (None, 512)               524800
_________________________________________________________________
batch_normalization_14 (Batc (None, 512)               2048
_________________________________________________________________
dropout_14 (Dropout)         (None, 512)               0
_________________________________________________________________
dense_25 (Dense)             (None, 256)               131328
_________________________________________________________________
batch_normalization_15 (Batc (None, 256)               1024
_________________________________________________________________
dropout_15 (Dropout)         (None, 256)               0
_________________________________________________________________
dense_26 (Dense)             (None, 10)                2570
=================================================================
Total params: 1,469,706
Trainable params: 1,466,122
Non-trainable params: 3,584
_________________________________________________________________
```

```python
In [0]: history = model.fit(X_train, y_train, batch_size=batch_size, epochs=n_epochs,
                            verbose=0, validation_data=(X_test, y_test))

        # Test Loss and Accuracy
        score = model.evaluate(X_test, y_test, verbose=0)
        print("Test Loss : ", score[0])
        print("Test Accuracy : ", score[1])
```

```
Test Loss :  0.05362152259176073
Test Accuracy :  0.985
```

In [0]:
```
plot_loss(history)
weights = model.get_weights()
plot_weight_distribution(weights, hidden_layers=3)
```



MLP (5-hidden layers) + Adam Optimizer + ReLU activations

In [16]:
```
# Model Architecture

# Hidden layer 1 --> 2048


# Hidden layer 2 --> 1024


# Hidden layer 3 --> 256


# Hidden layer 4 --> 128


# Hidden layer 5 --> 64

# Since we are using ReLU activation,
# we will use He-initialization.

model = Sequential()

# Hidden Layer 1
model.add(Dense(2048, input_shape=(input_dim,), activation='relu',
                kernel_initializer=RandomNormal(mean=0.0, stddev=0.050,
                                                seed=None)))

# Hidden Layer 2
model.add(Dense(1024, activation='relu',
                kernel_initializer=RandomNormal(mean=0.0, stddev=0.031,
                                                seed=None)))

# Hidden Layer 3
model.add(Dense(256, activation='relu',
                kernel_initializer=RandomNormal(mean=0.0, stddev=0.044,
                                                seed=None)))

# Hidden Layer 4
model.add(Dense(128, activation='relu',
                kernel_initializer=RandomNormal(mean=0.0, stddev=0.088,
                                                seed=None)))

# Hidden Layer 5
model.add(Dense(64, activation='relu',
                kernel_initializer=RandomNormal(mean=0.0, stddev=0.125,
```

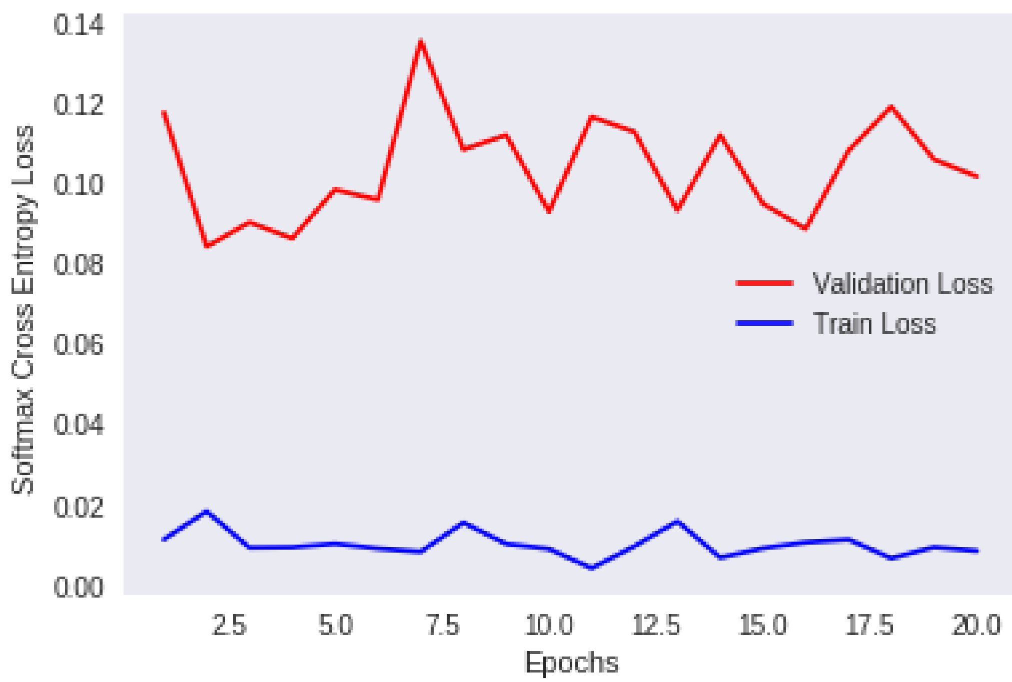
```
                                                                 seed=None)))

        # Output SoftMax Layer
        model.add(Dense(output_dim, activation='softmax'))


        # Defining optimizer, loss function and evaluation metric
        model.compile(optimizer='adam', loss='categorical_crossentropy',
                      metrics=['accuracy'])

        model.summary()
```

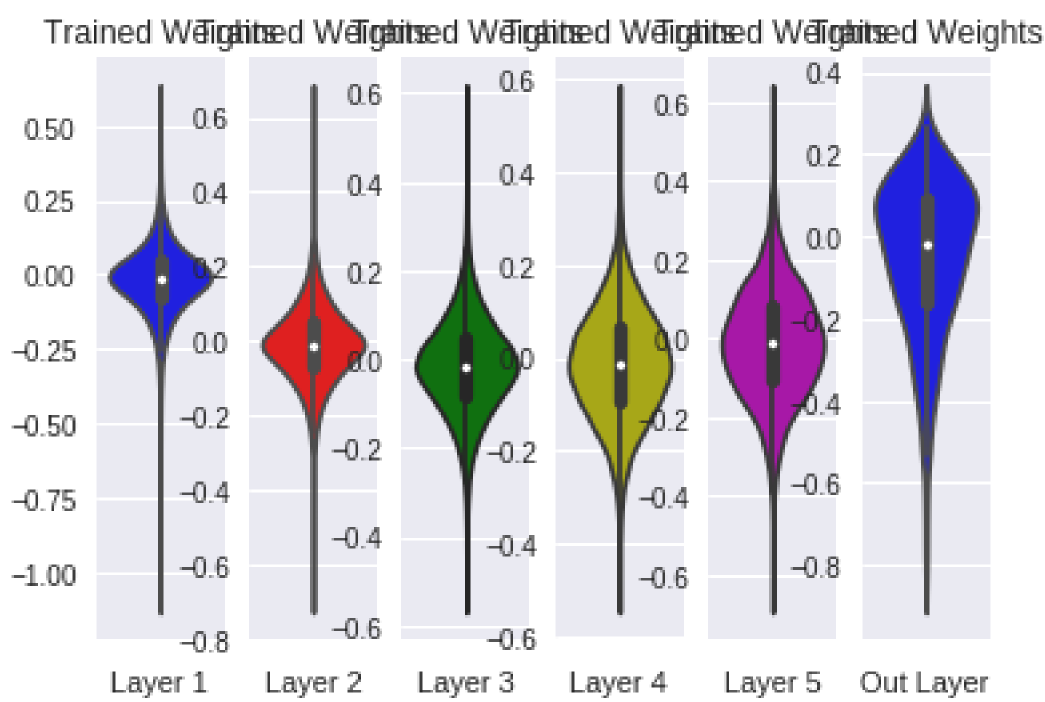
```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_27 (Dense)             (None, 2048)              1607680
_________________________________________________________________
dense_28 (Dense)             (None, 1024)              2098176
_________________________________________________________________
dense_29 (Dense)             (None, 256)               262400
_________________________________________________________________
dense_30 (Dense)             (None, 128)               32896
_________________________________________________________________
dense_31 (Dense)             (None, 64)                8256
_________________________________________________________________
dense_32 (Dense)             (None, 10)                650
=================================================================
Total params: 4,010,058
Trainable params: 4,010,058
Non-trainable params: 0
_________________________________________________________________
```

```
In [0]: history = model.fit(X_train, y_train, batch_size=batch_size, epochs=n_epochs,
                            verbose=0, validation_data=(X_test, y_test))

        # Test Loss and Accuracy
        score = model.evaluate(X_test, y_test, verbose=0)
        print("Test Loss : ", score[0])
        print("Test Accuracy : ", score[1])
```

```
Test Loss :  0.10174559558869126
Test Accuracy :  0.9858
```

```
In [0]: plot_loss(history)
        weights = model.get_weights()
        plot_weight_distribution(weights, hidden_layers=5)
```





MLP (5-hidden layers) + Adam Optimizer + ReLU activations + BatchNorm + Dropout

```
In [17]: # Model Architecture

         # Hidden layer 1 --> 2048

         # Batch Normalization Layer
         # Dropout layer with dropout_rate = 0.5

         # Hidden layer 2 --> 1024

         # Batch Normalization Layer
         # Dropout layer with dropout_rate = 0.5

         # Hidden layer 3 --> 256

         # Batch Normalization Layer
         # Dropout layer with dropout_rate = 0.5

         # Hidden layer 4 --> 128

         # Batch Normalization Layer
         # Dropout layer with dropout_rate = 0.5

         # Hidden layer 5 --> 64

         # Batch Normalization Layer
         # Dropout layer with dropout_rate = 0.5

         # Since we are using ReLU activation,
         # we will use He-initialization.

         model = Sequential()

         # Hidden Layer 1
         model.add(Dense(2048, input_shape=(input_dim,), activation='relu',
                         kernel_initializer=RandomNormal(mean=0.0, stddev=0.050,
                                                         seed=None)))
         model.add(BatchNormalization())
         model.add(Dropout(0.5))


         # Hidden Layer 2
         model.add(Dense(1024, activation='relu',
                         kernel_initializer=RandomNormal(mean=0.0, stddev=0.031,
                                                         seed=None)))
         model.add(BatchNormalization())
         model.add(Dropout(0.5))
```

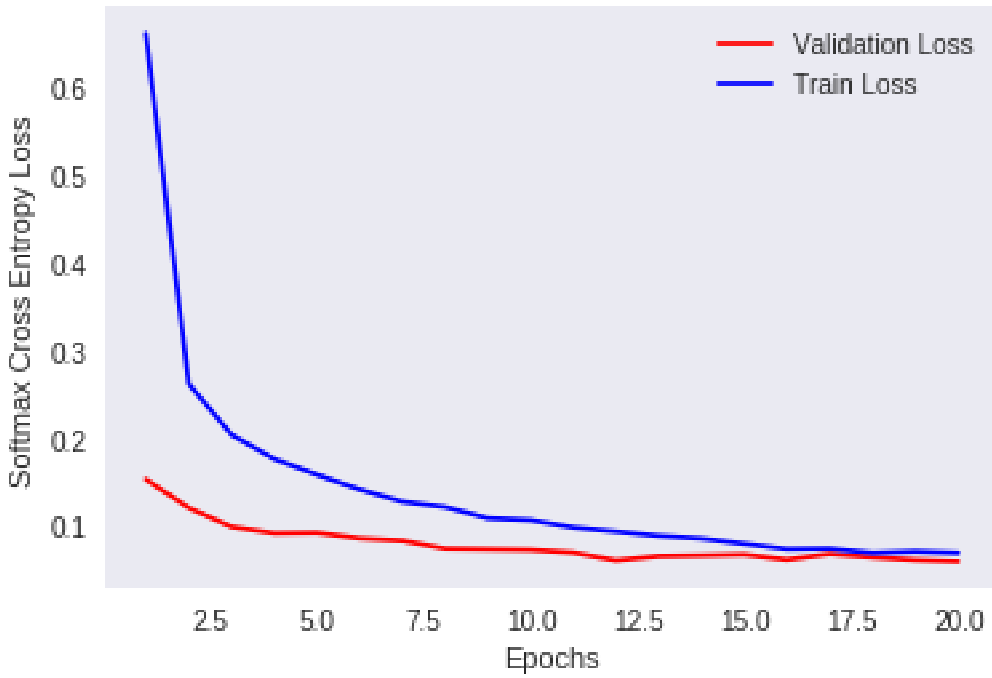
```python
# Hidden Layer 3
model.add(Dense(256, activation='relu',
                kernel_initializer=RandomNormal(mean=0.0, stddev=0.044,
                                                seed=None)))
model.add(BatchNormalization())
model.add(Dropout(0.5))


# Hidden Layer 4
model.add(Dense(128, activation='relu',
                kernel_initializer=RandomNormal(mean=0.0, stddev=0.088,
                                                seed=None)))
model.add(BatchNormalization())
model.add(Dropout(0.5))


# Hidden Layer 5
model.add(Dense(64, activation='relu',
                kernel_initializer=RandomNormal(mean=0.0, stddev=0.125,
                                                seed=None)))
model.add(BatchNormalization())
model.add(Dropout(0.5))


# Output SoftMax Layer
model.add(Dense(output_dim, activation='softmax'))


# Defining optimizer, loss function and evaluation metric
model.compile(optimizer='adam', loss='categorical_crossentropy',
              metrics=['accuracy'])

model.summary()
```

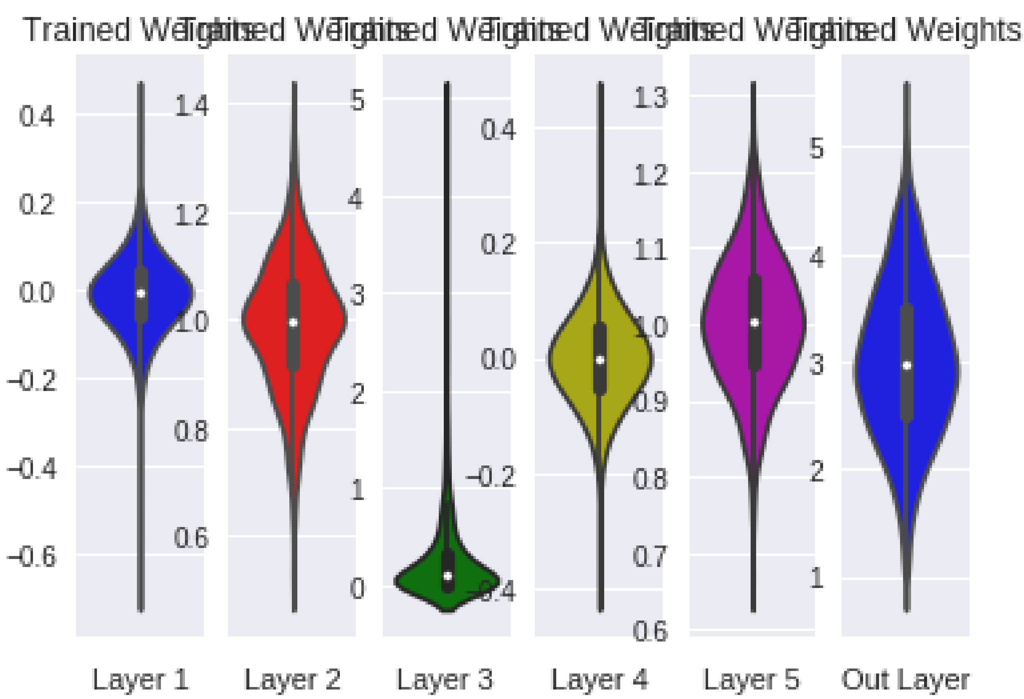
```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_33 (Dense)             (None, 2048)              1607680
_________________________________________________________________
batch_normalization_16 (Batc (None, 2048)              8192
_________________________________________________________________
dropout_16 (Dropout)         (None, 2048)              0
_________________________________________________________________
dense_34 (Dense)             (None, 1024)              2098176
_________________________________________________________________
batch_normalization_17 (Batc (None, 1024)              4096
_________________________________________________________________
dropout_17 (Dropout)         (None, 1024)              0
```

```
_________________________________________________________________
dense_35 (Dense)             (None, 256)               262400
_________________________________________________________________
batch_normalization_18 (Batc (None, 256)               1024
_________________________________________________________________
dropout_18 (Dropout)         (None, 256)               0
_________________________________________________________________
dense_36 (Dense)             (None, 128)               32896
_________________________________________________________________
batch_normalization_19 (Batc (None, 128)               512
_________________________________________________________________
dropout_19 (Dropout)         (None, 128)               0
_________________________________________________________________
dense_37 (Dense)             (None, 64)                8256
_________________________________________________________________
batch_normalization_20 (Batc (None, 64)                256
_________________________________________________________________
dropout_20 (Dropout)         (None, 64)                0
_________________________________________________________________
dense_38 (Dense)             (None, 10)                650
=================================================================
Total params: 4,024,138
Trainable params: 4,017,098
Non-trainable params: 7,040
_________________________________________________________________
```

In [11]:
```
history = model.fit(X_train, y_train, batch_size=batch_size, epochs=n_epochs,
                             verbose=0, validation_data=(X_test, y_test))

# Test Loss and Accuracy
score = model.evaluate(X_test, y_test, verbose=0)
print("Test Loss : ", score[0])
print("Test Accuracy : ", score[1])

plot_loss(history)
weights = model.get_weights()
plot_weight_distribution(weights, hidden_layers=5)
```

```
Test Loss :  0.05905918826502748
Test Accuracy :  0.9854
```


Validation Loss
Train Loss
Softmax Cross Entropy Loss
0.1
0.2
0.3
0.4
0.5
0.6
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
Epochs


Trained Weights
Trained Weights
Trained Weights
Trained Weights
Trained Weights
Trained Weights
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Out Layer

1 Observations

1. 2 hidden layer(256-64) --> Loss = 0.10, Accuracy = 98.02%
2. 2 hidden layer(256-64) --> Loss = 0.069, Accuracy = 98.16%
3. 3 hidden layer(1024-512-256) --> Loss = 0.097, Accuracy = 98.12%
4. 3 hidden layer(1024-512-256) --> Loss = 0.053, Accuracy = 98.50%
5. 5 hidden layer(2048-1024-256-128-64) --> Loss = 0.10, Accuracy = 98.58%
6. 5 hidden layer(2048-1024-256-128-64) --> Loss = 0.059, Accuracy = 98.54%

Getting best accuracy with 5 hidden layers and 3 hidden layers with batch normalization and dropout rate of 0.5.

Also the Train and Test Loss follow each other very closely when we use dropout and batch normalization layers.