Constructing Different MLP Architectures on MNIST Dataset

Data Overview

The MNIST Dataset is a dataset of Handwritten Characters pertaining to 10 integers from 0 to 9, which is used for Training in the case of Many Image Processing Tasks. We have an input square image of size (28 px* 28 px), which makes the corresponding vector that we obtain to be 784-dimensional. After this, we obtain a Matrix of this dimensionality where each cell in the Matrix corresponds to an integral number from 0 to 255 -> The Higher is the value of this number, the darker that particular pixel value is.

There are a total of 60,000 Training Datapoints and a total of 10,000 Test Datapoints in MNIST. We build various models in order to try and minimize our Test Accuracy and Test Log Loss values. We train each of our models on a total of 85 epochs so that the value is not too small for SGD type Optimizations to try and achieve convergence.

In [1]:
```
# if your keras is not using tensorflow as backend set "KERAS_BACKEND=t
ensorflow" use this command
from keras.utils import np_utils
from keras.datasets import mnist
import seaborn as sns
from keras.initializers import RandomNormal
from keras.initializers import RandomUniform
```

```
Using TensorFlow backend.
```

In [2]:
```
%matplotlib notebook
import matplotlib.pyplot as plt
import numpy as np
import time
```

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```
# https://gist.github.com/greydanus/f6eee59eaf1d90fcb3b534a25362cea4
# https://stackoverflow.com/a/14434334
# this function is used to update the plots for each epoch and error
def plt_dynamic(x, vy, ty, ax, colors=['b']):
    ax.plot(x, vy, 'b', label="Validation Loss")
    ax.plot(x, ty, 'r', label="Train Loss")
    plt.legend()
    plt.grid()
    fig.canvas.draw()
```

In [3]:
```
# the data, shuffled and split between train and test sets
(X_train, y_train), (X_test, y_test) = mnist.load_data()
```

In [4]:
```
print("Number of training examples :", X_train.shape[0], "and each imag
e is of shape (%d, %d)"%(X_train.shape[1], X_train.shape[2]))
print("Number of training examples :", X_test.shape[0], "and each image
 is of shape (%d, %d)"%(X_test.shape[1], X_test.shape[2]))
```

```
Number of training examples : 60000 and each image is of shape (28, 28)
Number of training examples : 10000 and each image is of shape (28, 28)
```

In [5]:
```
# if you observe the input shape its 2 dimensional vector
# for each image we have a (28*28) vector
# we will convert the (28*28) vector into single dimensional vector of
 1 * 784

X_train = X_train.reshape(X_train.shape[0], X_train.shape[1]*X_train.sh
ape[2])
X_test = X_test.reshape(X_test.shape[0], X_test.shape[1]*X_test.shape[2
])
```

In [6]:
```
# after converting the input images from 3d to 2d vectors

print("Number of training examples :", X_train.shape[0], "and each imag
e is of shape (%d)"%(X_train.shape[1]))
print("Number of training examples :", X_test.shape[0], "and each image
 is of shape (%d)"%(X_test.shape[1]))
```

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```
Number of training examples : 60000 and each image is of shape (784)
Number of training examples : 10000 and each image is of shape (784)
```

In [7]:
```python
# An example data point
print(X_train[0])
```

```
[  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0
   0   0   0   0   0   0   0   0   3  18  18  18 126 136 175  26 166 25
5
 247 127   0   0   0   0   0   0   0   0   0   0   0   0  30  36  94 15
4
 170 253 253 253 253 253 225 172 253 242 195  64   0   0   0   0   0
0
   0   0   0   0   0  49 238 253 253 253 253 253 253 253 253 251  93   8
2
  82  56  39   0   0   0   0   0   0   0   0   0   0   0   0  18 219 25
3
 253 253 253 253 198 182 247 241   0   0   0   0   0   0   0   0   0
0
   0   0   0   0   0   0   0   0  80 156 107 253 253 205  11   0  43 15
4
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0
   0  14   1 154 253  90   0   0   0   0   0   0   0   0   0   0   0
```

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```
0
   0   0   0   0   0   0   0   0   0   0   0   0   0 139 253 190   2
0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0
   0   0   0   0   0  11 190 253  70   0   0   0   0   0   0   0   0
0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  35 24
1
 225 160 108   1   0   0   0   0   0   0   0   0   0   0   0   0   0
0
   0   0   0   0   0   0   0   0   0  81 240 253 253 119  25   0   0
0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0
   0   0  45 186 253 253 150  27   0   0   0   0   0   0   0   0   0
0
   0   0   0   0   0   0   0   0   0   0   0   0   0  16  93 252 253 18
7
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0
   0   0   0   0   0   0   0 249 253 249  64   0   0   0   0   0   0
0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0  46 130 183 25
3
 253 207   2   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0
   0   0   0   0  39 148 229 253 253 253 250 182   0   0   0   0   0
0
   0   0   0   0   0   0   0   0   0   0   0   0  24 114 221 253 253 25
3
 253 201  78   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0
   0   0  23  66 213 253 253 253 253 198  81   2   0   0   0   0   0
0
   0   0   0   0   0   0   0   0   0   0  18 171 219 253 253 253 253 19
5
  80   9   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0
```

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```
  55 172 226 253 253 253 253 244 133  11   0   0   0   0   0   0   0
0
   0   0   0   0   0   0   0   0   0   0 136 253 253 253 212 135 132   1
6
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0
   0   0   0   0   0   0   0   0   0   0]
```

In [8]:

```
# if we observe the above matrix each cell is having a value between 0-
255
# before we move to apply machine learning algorithms lets try to norma
lize the data
# X => (X - Xmin)/(Xmax-Xmin) = X/255

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

In [9]:

```
# example data point after normlizing
print(X_train[0])
```

```
[0.         0.         0.         0.         0.         0.
 0.         0.         0.         0.         0.         0.
 0.         0.         0.         0.         0.         0.
 0.         0.         0.         0.         0.         0.
 0.         0.         0.         0.         0.         0.
 0.         0.         0.         0.         0.         0.
 0.         0.         0.         0.         0.         0.
 0.         0.         0.         0.         0.         0.
 0.         0.         0.         0.         0.         0.
 0.         0.         0.         0.         0.         0.
 0.         0.         0.         0.         0.         0.
```

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```
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.01176471 0.07058824 0.07058824 0.07058824
0.49411765 0.53333333 0.68627451 0.10196078 0.65098039 1.
0.96862745 0.49803922 0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.11764706 0.14117647 0.36862745 0.60392157
0.66666667 0.99215686 0.99215686 0.99215686 0.99215686 0.99215686
0.88235294 0.6745098  0.99215686 0.94901961 0.76470588 0.25098039
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.19215686
0.93333333 0.99215686 0.99215686 0.99215686 0.99215686 0.99215686
0.99215686 0.99215686 0.99215686 0.98431373 0.36470588 0.32156863
0.32156863 0.21960784 0.15294118 0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.07058824 0.85882353 0.99215686
0.99215686 0.99215686 0.99215686 0.99215686 0.77647059 0.71372549
0.96862745 0.94509804 0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.31372549 0.61176471 0.41960784 0.99215686
0.99215686 0.80392157 0.04313725 0.         0.16862745 0.60392157
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.05490196 0.00392157 0.60392157 0.99215686 0.35294118
0.         0.         0.         0.         0.         0.
```

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```
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.54509804 0.99215686 0.74509804 0.00784314 0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.04313725
0.74509804 0.99215686 0.2745098  0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.1372549  0.94509804
0.88235294 0.62745098 0.42352941 0.00392157 0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.31764706 0.94117647 0.99215686
0.99215686 0.46666667 0.09803922 0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.17647059 0.72941176 0.99215686 0.99215686
0.58823529 0.10588235 0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.0627451  0.36470588 0.98823529 0.99215686 0.73333333
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.97647059 0.99215686 0.97647059 0.25098039 0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.18039216 0.50980392 0.71764706 0.99215686
0.99215686 0.81176471 0.00784314 0.         0.         0.
0.         0.         0.         0.         0.         0.
```

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```
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.15294118 0.58039216
0.89803922 0.99215686 0.99215686 0.99215686 0.98039216 0.71372549
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.09411765 0.44705882 0.86666667 0.99215686 0.99215686 0.99215686
0.99215686 0.78823529 0.30588235 0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.09019608 0.25882353 0.83529412 0.99215686
0.99215686 0.99215686 0.99215686 0.77647059 0.31764706 0.00784314
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.07058824 0.67058824
0.85882353 0.99215686 0.99215686 0.99215686 0.99215686 0.76470588
0.31372549 0.03529412 0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.21568627 0.6745098  0.88627451 0.99215686 0.99215686 0.99215686
0.99215686 0.95686275 0.52156863 0.04313725 0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.53333333 0.99215686
0.99215686 0.99215686 0.83137255 0.52941176 0.51764706 0.0627451
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
0.         0.         0.         0.         0.         0.
```

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```
 0.          0.          0.          0.          0.          0.
 0.          0.          0.          0.          0.          0.
 0.          0.          0.          0.         ]
```

We carry out the One-Hot Encoding as shown below :

In [10]:
```python
# here we are having a class number for each image
print("Class label of first image :", y_train[0])

# lets convert this into a 10 dimensional vector
# ex: consider an image is 5 convert it into 5 => [0, 0, 0, 0, 0, 1, 0,
 0, 0, 0]
# this conversion needed for MLPs

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

print("After converting the output into a vector : ",Y_train[0])
```

```
Class label of first image : 5
After converting the output into a vector :  [0. 0. 0. 0. 0. 1. 0. 0.
0. 0.]
```

1. Number of Hidden Layers in the Neural Network = 2

1.1 Architecture 1 :- 784-512-128-10

1.1.1 Model 1 : Softmax Classifier (Special Case : No Hidden Layers)

In [13]:
```python
# https://keras.io/getting-started/sequential-model-guide/

# The Sequential model is a linear stack of layers.
```

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```
# you can create a Sequential model by passing a list of layer instance
s to the constructor:

# model = Sequential([
#     Dense(32, input_shape=(784,)),
#     Activation('relu'),
#     Dense(10),
#     Activation('softmax'),
# ])

# You can also simply add layers via the .add() method:

# model = Sequential()
# model.add(Dense(32, input_dim=784))
# model.add(Activation('relu'))

###

# https://keras.io/layers/core/

# keras.layers.Dense(units, activation=None, use_bias=True, kernel_init
ializer='glorot_uniform',
# bias_initializer='zeros', kernel_regularizer=None, bias_regularizer=N
one, activity_regularizer=None,
# kernel_constraint=None, bias_constraint=None)

# Dense implements the operation: output = activation(dot(input, kerne
l) + bias) where
# activation is the element-wise activation function passed as the acti
vation argument,
# kernel is a weights matrix created by the layer, and
# bias is a bias vector created by the layer (only applicable if use_bi
as is True).

# output = activation(dot(input, kernel) + bias)  => y = activation(WT.
 X + b)

####
```

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```
# https://keras.io/activations/

# Activations can either be used through an Activation layer, or throug
h the activation argument supported by all forward layers:

# from keras.layers import Activation, Dense

# model.add(Dense(64))
# model.add(Activation('tanh'))

# This is equivalent to:
# model.add(Dense(64, activation='tanh'))

# there are many activation functions ar available ex: tanh, relu, soft
max


from keras.models import Sequential
from keras.layers import Dense, Activation
```

In [14]:

```
# some model parameters

output_dim = 10
input_dim = X_train.shape[1]

batch_size = 128
nb_epoch = 85
```

1.1.1.1 Constructing the Neural Network

In [13]:

```
# start building a model
arch1_model1 = Sequential()

# The model needs to know what input shape it should expect.
# For this reason, the first layer in a Sequential model
# (and only the first, because following layers can do automatic shape
 inference)
```

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```
# needs to receive information about its input shape.
# you can use input_shape and input_dim to pass the shape of input

# output_dim represent the number of nodes need in that layer
# here we have 10 nodes

arch1_model1.add(Dense(output_dim, input_dim=input_dim, activation='sof
tmax'))
```

1.1.1.2 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [14]:
```
# Before training a model, you need to configure the learning process,
 which is done via the compile method

# It receives three arguments:
# An optimizer. This could be the string identifier of an existing opti
mizer , https://keras.io/optimizers/
# A loss function. This is the objective that the model will try to min
imize., https://keras.io/losses/
# A list of metrics. For any classification problem you will want to se
t this to metrics=['accuracy'].  https://keras.io/metrics/


# Note: when using the categorical_crossentropy loss, your targets shou
ld be in categorical format
# (e.g. if you have 10 classes, the target for each sample should be a
 10-dimensional vector that is all-zeros except
# for a 1 at the index corresponding to the class of the sample).

# that is why we converted out labels into vectors

arch1_model1.compile(optimizer='sgd', loss='categorical_crossentropy',
metrics=['accuracy'])

# Keras models are trained on Numpy arrays of input data and labels.
# For training a model, you will typically use the  fit function

# fit(self, x=None, y=None, batch_size=None, epochs=1, verbose=1, callb
```

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```
acks=None, validation_split=0.0,
# validation_data=None, shuffle=True, class_weight=None, sample_weight=
None, initial_epoch=0, steps_per_epoch=None,
# validation_steps=None)

# fit() function Trains the model for a fixed number of epochs (iterati
ons on a dataset).

# it returns A History object. Its History.history attribute is a recor
d of training loss values and
# metrics values at successive epochs, as well as validation loss value
s and validation metrics values (if applicable).

# https://github.com/openai/baselines/issues/20

A1M1_history = arch1_model1.fit(X_train, Y_train, batch_size=batch_size
, epochs=nb_epoch, verbose=1, \
                        validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 1s 18us/step - loss: 1.2
781 - accuracy: 0.6961 - val_loss: 0.8107 - val_accuracy: 0.8305
Epoch 2/85
60000/60000 [==============================] - 1s 15us/step - loss: 0.7
136 - accuracy: 0.8409 - val_loss: 0.6080 - val_accuracy: 0.8623
Epoch 3/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.5
859 - accuracy: 0.8591 - val_loss: 0.5270 - val_accuracy: 0.8761
Epoch 4/85
60000/60000 [==============================] - 1s 15us/step - loss: 0.5
249 - accuracy: 0.8687 - val_loss: 0.4814 - val_accuracy: 0.8821
Epoch 5/85
60000/60000 [==============================] - 1s 15us/step - loss: 0.4
876 - accuracy: 0.8745 - val_loss: 0.4517 - val_accuracy: 0.8875
Epoch 6/85
60000/60000 [==============================] - 1s 15us/step - loss: 0.4
620 - accuracy: 0.8799 - val_loss: 0.4303 - val_accuracy: 0.8907
Epoch 7/85
60000/60000 [==============================] - 1s 15us/step - loss: 0.4
```

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```
429 - accuracy: 0.8833 - val_loss: 0.4141 - val_accuracy: 0.8932
Epoch 8/85
60000/60000 [==============================] - 1s 15us/step - loss: 0.4
280 - accuracy: 0.8866 - val_loss: 0.4013 - val_accuracy: 0.8951
Epoch 9/85
60000/60000 [==============================] - 1s 15us/step - loss: 0.4
161 - accuracy: 0.8890 - val_loss: 0.3908 - val_accuracy: 0.8974
Epoch 10/85
60000/60000 [==============================] - 1s 15us/step - loss: 0.4
060 - accuracy: 0.8913 - val_loss: 0.3819 - val_accuracy: 0.8986
Epoch 11/85
60000/60000 [==============================] - 1s 15us/step - loss: 0.3
976 - accuracy: 0.8928 - val_loss: 0.3745 - val_accuracy: 0.9003
Epoch 12/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
903 - accuracy: 0.8945 - val_loss: 0.3680 - val_accuracy: 0.9015
Epoch 13/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
839 - accuracy: 0.8960 - val_loss: 0.3623 - val_accuracy: 0.9033
Epoch 14/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
783 - accuracy: 0.8974 - val_loss: 0.3573 - val_accuracy: 0.9043
Epoch 15/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
732 - accuracy: 0.8985 - val_loss: 0.3533 - val_accuracy: 0.9047
Epoch 16/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
687 - accuracy: 0.8992 - val_loss: 0.3491 - val_accuracy: 0.9061
Epoch 17/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
646 - accuracy: 0.9002 - val_loss: 0.3455 - val_accuracy: 0.9072
Epoch 18/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
608 - accuracy: 0.9015 - val_loss: 0.3421 - val_accuracy: 0.9075
Epoch 19/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
574 - accuracy: 0.9020 - val_loss: 0.3393 - val_accuracy: 0.9080
Epoch 20/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
```

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```
542 - accuracy: 0.9028 - val_loss: 0.3364 - val_accuracy: 0.9090
Epoch 21/85
60000/60000 [==============================] - 1s 17us/step - loss: 0.3
513 - accuracy: 0.9035 - val_loss: 0.3340 - val_accuracy: 0.9096
Epoch 22/85
60000/60000 [==============================] - 1s 18us/step - loss: 0.3
486 - accuracy: 0.9041 - val_loss: 0.3316 - val_accuracy: 0.9102
Epoch 23/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
460 - accuracy: 0.9047 - val_loss: 0.3292 - val_accuracy: 0.9105
Epoch 24/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
436 - accuracy: 0.9052 - val_loss: 0.3270 - val_accuracy: 0.9112
Epoch 25/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
414 - accuracy: 0.9058 - val_loss: 0.3253 - val_accuracy: 0.9115
Epoch 26/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
393 - accuracy: 0.9059 - val_loss: 0.3237 - val_accuracy: 0.9124
Epoch 27/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
373 - accuracy: 0.9065 - val_loss: 0.3217 - val_accuracy: 0.9133
Epoch 28/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
354 - accuracy: 0.9073 - val_loss: 0.3202 - val_accuracy: 0.9134
Epoch 29/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
336 - accuracy: 0.9076 - val_loss: 0.3187 - val_accuracy: 0.9135
Epoch 30/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
319 - accuracy: 0.9080 - val_loss: 0.3173 - val_accuracy: 0.9141
Epoch 31/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
303 - accuracy: 0.9087 - val_loss: 0.3160 - val_accuracy: 0.9141
Epoch 32/85
60000/60000 [==============================] - 1s 19us/step - loss: 0.3
288 - accuracy: 0.9086 - val_loss: 0.3145 - val_accuracy: 0.9149
Epoch 33/85
60000/60000 [==============================] - 1s 17us/step - loss: 0.3
```

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```
274 - accuracy: 0.9095 - val_loss: 0.3136 - val_accuracy: 0.9150
Epoch 34/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
259 - accuracy: 0.9097 - val_loss: 0.3124 - val_accuracy: 0.9150
Epoch 35/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
246 - accuracy: 0.9100 - val_loss: 0.3111 - val_accuracy: 0.9159
Epoch 36/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
233 - accuracy: 0.9104 - val_loss: 0.3102 - val_accuracy: 0.9159
Epoch 37/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
221 - accuracy: 0.9103 - val_loss: 0.3091 - val_accuracy: 0.9157
Epoch 38/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
209 - accuracy: 0.9106 - val_loss: 0.3083 - val_accuracy: 0.9161
Epoch 39/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
198 - accuracy: 0.9111 - val_loss: 0.3072 - val_accuracy: 0.9167
Epoch 40/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
187 - accuracy: 0.9111 - val_loss: 0.3064 - val_accuracy: 0.9165
Epoch 41/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
176 - accuracy: 0.9116 - val_loss: 0.3055 - val_accuracy: 0.9165
Epoch 42/85
60000/60000 [==============================] - 1s 15us/step - loss: 0.3
166 - accuracy: 0.9120 - val_loss: 0.3050 - val_accuracy: 0.9164
Epoch 43/85
60000/60000 [==============================] - 1s 15us/step - loss: 0.3
156 - accuracy: 0.9120 - val_loss: 0.3041 - val_accuracy: 0.9171
Epoch 44/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
147 - accuracy: 0.9124 - val_loss: 0.3032 - val_accuracy: 0.9170
Epoch 45/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
138 - accuracy: 0.9126 - val_loss: 0.3025 - val_accuracy: 0.9171
Epoch 46/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
```

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```
129 - accuracy: 0.9130 - val_loss: 0.3017 - val_accuracy: 0.9173
Epoch 47/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
120 - accuracy: 0.9133 - val_loss: 0.3011 - val_accuracy: 0.9170
Epoch 48/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
112 - accuracy: 0.9136 - val_loss: 0.3005 - val_accuracy: 0.9179
Epoch 49/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
104 - accuracy: 0.9138 - val_loss: 0.2996 - val_accuracy: 0.9178
Epoch 50/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
096 - accuracy: 0.9139 - val_loss: 0.2991 - val_accuracy: 0.9177
Epoch 51/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
089 - accuracy: 0.9143 - val_loss: 0.2984 - val_accuracy: 0.9177
Epoch 52/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
082 - accuracy: 0.9143 - val_loss: 0.2981 - val_accuracy: 0.9182
Epoch 53/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
074 - accuracy: 0.9145 - val_loss: 0.2975 - val_accuracy: 0.9186
Epoch 54/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
067 - accuracy: 0.9147 - val_loss: 0.2967 - val_accuracy: 0.9183
Epoch 55/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
060 - accuracy: 0.9147 - val_loss: 0.2964 - val_accuracy: 0.9188
Epoch 56/85
60000/60000 [==============================] - 1s 18us/step - loss: 0.3
054 - accuracy: 0.9149 - val_loss: 0.2958 - val_accuracy: 0.9184
Epoch 57/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
047 - accuracy: 0.9153 - val_loss: 0.2956 - val_accuracy: 0.9187
Epoch 58/85
60000/60000 [==============================] - 1s 15us/step - loss: 0.3
041 - accuracy: 0.9153 - val_loss: 0.2948 - val_accuracy: 0.9192
Epoch 59/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.3
```

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```
035 - accuracy: 0.9153 - val_loss: 0.2943 - val_accuracy: 0.9192
Epoch 60/85
60000/60000 [==============================] - 1s 15us/step - loss: 0.3
029 - accuracy: 0.9158 - val_loss: 0.2940 - val_accuracy: 0.9195
Epoch 61/85
60000/60000 [==============================] - 1s 15us/step - loss: 0.3
023 - accuracy: 0.9157 - val_loss: 0.2933 - val_accuracy: 0.9195
Epoch 62/85
60000/60000 [==============================] - 1s 15us/step - loss: 0.3
018 - accuracy: 0.9156 - val_loss: 0.2930 - val_accuracy: 0.9191
Epoch 63/85
60000/60000 [==============================] - 1s 15us/step - loss: 0.3
012 - accuracy: 0.9159 - val_loss: 0.2925 - val_accuracy: 0.9193
Epoch 64/85
60000/60000 [==============================] - 1s 15us/step - loss: 0.3
007 - accuracy: 0.9160 - val_loss: 0.2923 - val_accuracy: 0.9204
Epoch 65/85
60000/60000 [==============================] - 1s 15us/step - loss: 0.3
002 - accuracy: 0.9162 - val_loss: 0.2918 - val_accuracy: 0.9199
Epoch 66/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.2
996 - accuracy: 0.9165 - val_loss: 0.2914 - val_accuracy: 0.9193
Epoch 67/85
60000/60000 [==============================] - 1s 17us/step - loss: 0.2
991 - accuracy: 0.9164 - val_loss: 0.2912 - val_accuracy: 0.9200
Epoch 68/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.2
986 - accuracy: 0.9169 - val_loss: 0.2909 - val_accuracy: 0.9203
Epoch 69/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.2
982 - accuracy: 0.9169 - val_loss: 0.2905 - val_accuracy: 0.9203
Epoch 70/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.2
976 - accuracy: 0.9171 - val_loss: 0.2904 - val_accuracy: 0.9201
Epoch 71/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.2
972 - accuracy: 0.9171 - val_loss: 0.2897 - val_accuracy: 0.9203
Epoch 72/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.2
```

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```
967 - accuracy: 0.9172 - val_loss: 0.2893 - val_accuracy: 0.9210
Epoch 73/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.2
963 - accuracy: 0.9174 - val_loss: 0.2890 - val_accuracy: 0.9209
Epoch 74/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.2
959 - accuracy: 0.9175 - val_loss: 0.2890 - val_accuracy: 0.9211
Epoch 75/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.2
954 - accuracy: 0.9177 - val_loss: 0.2885 - val_accuracy: 0.9205
Epoch 76/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.2
950 - accuracy: 0.9179 - val_loss: 0.2882 - val_accuracy: 0.9207
Epoch 77/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.2
946 - accuracy: 0.9179 - val_loss: 0.2877 - val_accuracy: 0.9209
Epoch 78/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.2
942 - accuracy: 0.9180 - val_loss: 0.2875 - val_accuracy: 0.9213
Epoch 79/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.2
938 - accuracy: 0.9182 - val_loss: 0.2873 - val_accuracy: 0.9213
Epoch 80/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.2
934 - accuracy: 0.9181 - val_loss: 0.2871 - val_accuracy: 0.9203
Epoch 81/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.2
930 - accuracy: 0.9183 - val_loss: 0.2866 - val_accuracy: 0.9215
Epoch 82/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.2
927 - accuracy: 0.9184 - val_loss: 0.2864 - val_accuracy: 0.9215
Epoch 83/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.2
923 - accuracy: 0.9184 - val_loss: 0.2861 - val_accuracy: 0.9216
Epoch 84/85
60000/60000 [==============================] - 1s 16us/step - loss: 0.2
919 - accuracy: 0.9187 - val_loss: 0.2860 - val_accuracy: 0.9214
Epoch 85/85
```

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```
60000/60000 [==============================] - 1s 17us/step - loss: 0.2
915 - accuracy: 0.9189 - val_loss: 0.2856 - val_accuracy: 0.9215
```

1.1.1.3 Number of Epochs vs Train Loss & Validation Loss

In [15]:
```
A1M1_score = arch1_model1.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A1M1_score[0])
print('Test accuracy:', A1M1_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in histrory.history we will have a list of length equal
 to number of epochs

vy = A1M1_history.history['val_loss']
ty = A1M1_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.2856153622478247
Test accuracy: 0.921500027179718
```

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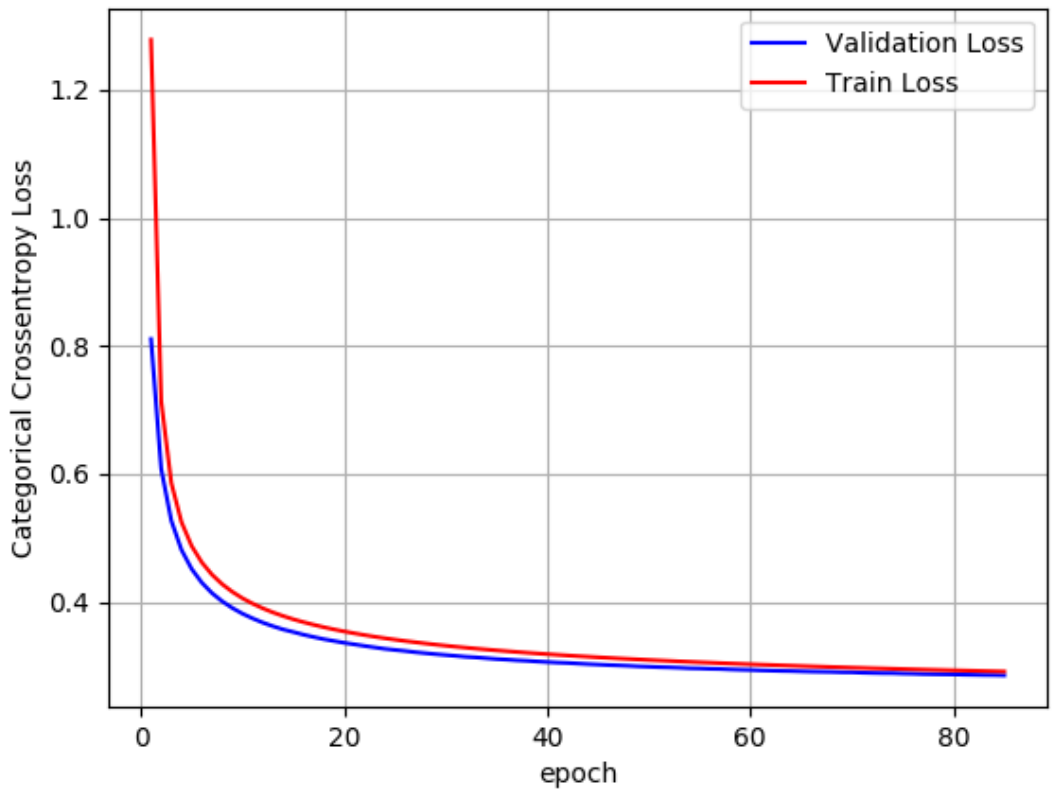

1.1.2 Model 2 : MLP + Sigmoid Activation + SGD Optimizer

1.1.2.1 Constructing the Neural Network

In [16]:
```
# Multilayer perceptron

model_sigmoid = Sequential()
model_sigmoid.add(Dense(512, activation='sigmoid', input_shape=(input_d
```

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```
im,)))
model_sigmoid.add(Dense(128, activation='sigmoid'))
model_sigmoid.add(Dense(output_dim, activation='softmax'))

model_sigmoid.summary()
```

```
Model: "sequential_2"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_2 (Dense)              (None, 512)               401920
_________________________________________________________________
dense_3 (Dense)              (None, 128)               65664
_________________________________________________________________
dense_4 (Dense)              (None, 10)                1290
=================================================================
Total params: 468,874
Trainable params: 468,874
Non-trainable params: 0
_________________________________________________________________
```

1.1.2.2 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [17]:
```
model_sigmoid.compile(optimizer='sgd', loss='categorical_crossentropy',
 metrics=['accuracy'])

A1M2_history = model_sigmoid.fit(X_train, Y_train, batch_size=batch_siz
e, epochs=nb_epoch, verbose=1, \
                                 validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 3s 53us/step - loss: 2.2
674 - accuracy: 0.2467 - val_loss: 2.2187 - val_accuracy: 0.4493
Epoch 2/85
60000/60000 [==============================] - 3s 51us/step - loss: 2.1
729 - accuracy: 0.4515 - val_loss: 2.1172 - val_accuracy: 0.5245
Epoch 3/85
```

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```
60000/60000 [==============================] - 3s 51us/step - loss: 2.0
541 - accuracy: 0.5650 - val_loss: 1.9738 - val_accuracy: 0.5881
Epoch 4/85
60000/60000 [==============================] - 3s 52us/step - loss: 1.8
867 - accuracy: 0.6222 - val_loss: 1.7765 - val_accuracy: 0.6899
Epoch 5/85
60000/60000 [==============================] - 3s 52us/step - loss: 1.6
719 - accuracy: 0.6700 - val_loss: 1.5434 - val_accuracy: 0.7108
Epoch 6/85
60000/60000 [==============================] - 3s 53us/step - loss: 1.4
421 - accuracy: 0.7106 - val_loss: 1.3190 - val_accuracy: 0.7319
Epoch 7/85
60000/60000 [==============================] - 3s 58us/step - loss: 1.2
353 - accuracy: 0.7444 - val_loss: 1.1306 - val_accuracy: 0.7629
Epoch 8/85
60000/60000 [==============================] - 3s 53us/step - loss: 1.0
688 - accuracy: 0.7697 - val_loss: 0.9851 - val_accuracy: 0.7917
Epoch 9/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.9
412 - accuracy: 0.7911 - val_loss: 0.8745 - val_accuracy: 0.7964
Epoch 10/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.8
440 - accuracy: 0.8043 - val_loss: 0.7889 - val_accuracy: 0.8188
Epoch 11/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.7
689 - accuracy: 0.8170 - val_loss: 0.7230 - val_accuracy: 0.8299
Epoch 12/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.7
094 - accuracy: 0.8270 - val_loss: 0.6691 - val_accuracy: 0.8351
Epoch 13/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.6
616 - accuracy: 0.8343 - val_loss: 0.6259 - val_accuracy: 0.8438
Epoch 14/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.6
224 - accuracy: 0.8412 - val_loss: 0.5903 - val_accuracy: 0.8524
Epoch 15/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.5
897 - accuracy: 0.8478 - val_loss: 0.5600 - val_accuracy: 0.8557
Epoch 16/85
```

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```
60000/60000 [==============================] - 4s 59us/step - loss: 0.5
620 - accuracy: 0.8537 - val_loss: 0.5345 - val_accuracy: 0.8631
Epoch 17/85
60000/60000 [==============================] - 3s 56us/step - loss: 0.5
382 - accuracy: 0.8593 - val_loss: 0.5125 - val_accuracy: 0.8678
Epoch 18/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.5
177 - accuracy: 0.8635 - val_loss: 0.4928 - val_accuracy: 0.8719
Epoch 19/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.4
998 - accuracy: 0.8680 - val_loss: 0.4755 - val_accuracy: 0.8765
Epoch 20/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.4
840 - accuracy: 0.8714 - val_loss: 0.4609 - val_accuracy: 0.8794
Epoch 21/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.4
700 - accuracy: 0.8749 - val_loss: 0.4477 - val_accuracy: 0.8825
Epoch 22/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.4
574 - accuracy: 0.8772 - val_loss: 0.4366 - val_accuracy: 0.8850
Epoch 23/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.4
463 - accuracy: 0.8798 - val_loss: 0.4256 - val_accuracy: 0.8860
Epoch 24/85
60000/60000 [==============================] - 3s 57us/step - loss: 0.4
364 - accuracy: 0.8822 - val_loss: 0.4160 - val_accuracy: 0.8880
Epoch 25/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.4
274 - accuracy: 0.8840 - val_loss: 0.4075 - val_accuracy: 0.8894
Epoch 26/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.4
191 - accuracy: 0.8855 - val_loss: 0.4002 - val_accuracy: 0.8911
Epoch 27/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.4
117 - accuracy: 0.8868 - val_loss: 0.3929 - val_accuracy: 0.8917
Epoch 28/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.4
050 - accuracy: 0.8889 - val_loss: 0.3869 - val_accuracy: 0.8943
Epoch 29/85
```

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```
60000/60000 [==============================] - 3s 53us/step - loss: 0.3
987 - accuracy: 0.8901 - val_loss: 0.3808 - val_accuracy: 0.8939
Epoch 30/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.3
928 - accuracy: 0.8913 - val_loss: 0.3758 - val_accuracy: 0.8954
Epoch 31/85
60000/60000 [==============================] - 3s 57us/step - loss: 0.3
876 - accuracy: 0.8924 - val_loss: 0.3706 - val_accuracy: 0.8973
Epoch 32/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.3
827 - accuracy: 0.8936 - val_loss: 0.3659 - val_accuracy: 0.8976
Epoch 33/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.3
781 - accuracy: 0.8947 - val_loss: 0.3616 - val_accuracy: 0.8980
Epoch 34/85
60000/60000 [==============================] - 3s 57us/step - loss: 0.3
737 - accuracy: 0.8952 - val_loss: 0.3581 - val_accuracy: 0.8999
Epoch 35/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.3
697 - accuracy: 0.8961 - val_loss: 0.3540 - val_accuracy: 0.9005
Epoch 36/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.3
660 - accuracy: 0.8971 - val_loss: 0.3512 - val_accuracy: 0.9006
Epoch 37/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.3
623 - accuracy: 0.8981 - val_loss: 0.3479 - val_accuracy: 0.9002
Epoch 38/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.3
588 - accuracy: 0.8988 - val_loss: 0.3444 - val_accuracy: 0.9032ss: 0.3
601 -
Epoch 39/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.3
558 - accuracy: 0.8993 - val_loss: 0.3404 - val_accuracy: 0.9030
Epoch 40/85
60000/60000 [==============================] - 3s 56us/step - loss: 0.3
528 - accuracy: 0.8998 - val_loss: 0.3378 - val_accuracy: 0.9035
Epoch 41/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.3
498 - accuracy: 0.9009 - val_loss: 0.3354 - val_accuracy: 0.9044
```

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```
Epoch 42/85
60000/60000 [==============================] - 3s 56us/step - loss: 0.3
472 - accuracy: 0.9015 - val_loss: 0.3331 - val_accuracy: 0.9051
Epoch 43/85
60000/60000 [==============================] - 4s 60us/step - loss: 0.3
445 - accuracy: 0.9023 - val_loss: 0.3311 - val_accuracy: 0.9047
Epoch 44/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.3
420 - accuracy: 0.9028 - val_loss: 0.3283 - val_accuracy: 0.9051
Epoch 45/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.3
396 - accuracy: 0.9034 - val_loss: 0.3260 - val_accuracy: 0.9054
Epoch 46/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.3
373 - accuracy: 0.9041 - val_loss: 0.3237 - val_accuracy: 0.9062
Epoch 47/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.3
350 - accuracy: 0.9044 - val_loss: 0.3223 - val_accuracy: 0.9064
Epoch 48/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.3
328 - accuracy: 0.9051 - val_loss: 0.3199 - val_accuracy: 0.9073
Epoch 49/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.3
308 - accuracy: 0.9054 - val_loss: 0.3183 - val_accuracy: 0.9077
Epoch 50/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.3
288 - accuracy: 0.9061 - val_loss: 0.3163 - val_accuracy: 0.9076
Epoch 51/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.3
268 - accuracy: 0.9063 - val_loss: 0.3151 - val_accuracy: 0.9077
Epoch 52/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.3
250 - accuracy: 0.9068 - val_loss: 0.3126 - val_accuracy: 0.9091
Epoch 53/85
60000/60000 [==============================] - 3s 57us/step - loss: 0.3
231 - accuracy: 0.9075 - val_loss: 0.3108 - val_accuracy: 0.9099
Epoch 54/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.3
215 - accuracy: 0.9079 - val_loss: 0.3097 - val_accuracy: 0.9102
```

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```
Epoch 55/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.3
198 - accuracy: 0.9081 - val_loss: 0.3077 - val_accuracy: 0.9108
Epoch 56/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.3
182 - accuracy: 0.9083 - val_loss: 0.3066 - val_accuracy: 0.9109
Epoch 57/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.3
165 - accuracy: 0.9088 - val_loss: 0.3044 - val_accuracy: 0.9115
Epoch 58/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.3
150 - accuracy: 0.9091 - val_loss: 0.3042 - val_accuracy: 0.9111
Epoch 59/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.3
135 - accuracy: 0.9097 - val_loss: 0.3026 - val_accuracy: 0.9119
Epoch 60/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.3
120 - accuracy: 0.9103 - val_loss: 0.3016 - val_accuracy: 0.9115
Epoch 61/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.3
106 - accuracy: 0.9103 - val_loss: 0.2997 - val_accuracy: 0.9132
Epoch 62/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.3
093 - accuracy: 0.9111 - val_loss: 0.2985 - val_accuracy: 0.9134
Epoch 63/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.3
078 - accuracy: 0.9116 - val_loss: 0.2973 - val_accuracy: 0.9130
Epoch 64/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.3
065 - accuracy: 0.9115 - val_loss: 0.2964 - val_accuracy: 0.9141
Epoch 65/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.3
053 - accuracy: 0.9121 - val_loss: 0.2949 - val_accuracy: 0.9146
Epoch 66/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.3
040 - accuracy: 0.9123 - val_loss: 0.2937 - val_accuracy: 0.9152
Epoch 67/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.3
028 - accuracy: 0.9126 - val_loss: 0.2929 - val_accuracy: 0.9152
```

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```
Epoch 68/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.3
016 - accuracy: 0.9130 - val_loss: 0.2923 - val_accuracy: 0.9146
Epoch 69/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.3
004 - accuracy: 0.9133 - val_loss: 0.2903 - val_accuracy: 0.9160
Epoch 70/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.2
993 - accuracy: 0.9135 - val_loss: 0.2898 - val_accuracy: 0.9157
Epoch 71/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.2
981 - accuracy: 0.9138 - val_loss: 0.2887 - val_accuracy: 0.9166
Epoch 72/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.2
970 - accuracy: 0.9140 - val_loss: 0.2876 - val_accuracy: 0.9172
Epoch 73/85
60000/60000 [==============================] - 3s 57us/step - loss: 0.2
959 - accuracy: 0.9147 - val_loss: 0.2865 - val_accuracy: 0.9175
Epoch 74/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.2
949 - accuracy: 0.9148 - val_loss: 0.2853 - val_accuracy: 0.9179
Epoch 75/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.2
939 - accuracy: 0.9152 - val_loss: 0.2847 - val_accuracy: 0.9182
Epoch 76/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.2
928 - accuracy: 0.9154 - val_loss: 0.2838 - val_accuracy: 0.9174
Epoch 77/85
60000/60000 [==============================] - 3s 57us/step - loss: 0.2
918 - accuracy: 0.9157 - val_loss: 0.2829 - val_accuracy: 0.9181
Epoch 78/85
60000/60000 [==============================] - 3s 56us/step - loss: 0.2
907 - accuracy: 0.9160 - val_loss: 0.2826 - val_accuracy: 0.9178
Epoch 79/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.2
899 - accuracy: 0.9165 - val_loss: 0.2815 - val_accuracy: 0.9182
Epoch 80/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.2
889 - accuracy: 0.9164 - val_loss: 0.2808 - val_accuracy: 0.9190
```

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```
Epoch 81/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.2
880 - accuracy: 0.9164 - val_loss: 0.2795 - val_accuracy: 0.9195
Epoch 82/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.2
870 - accuracy: 0.9169 - val_loss: 0.2785 - val_accuracy: 0.9197
Epoch 83/85
60000/60000 [==============================] - 4s 61us/step - loss: 0.2
860 - accuracy: 0.9170 - val_loss: 0.2777 - val_accuracy: 0.9196
Epoch 84/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.2
852 - accuracy: 0.9173 - val_loss: 0.2771 - val_accuracy: 0.9198
Epoch 85/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.2
843 - accuracy: 0.9174 - val_loss: 0.2764 - val_accuracy: 0.9197
```

1.1.2.3 Number of Epochs vs Train Loss & Validation Loss

In [18]:

```
A1M2_score = model_sigmoid.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A1M2_score[0])
print('Test accuracy:', A1M2_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy
```

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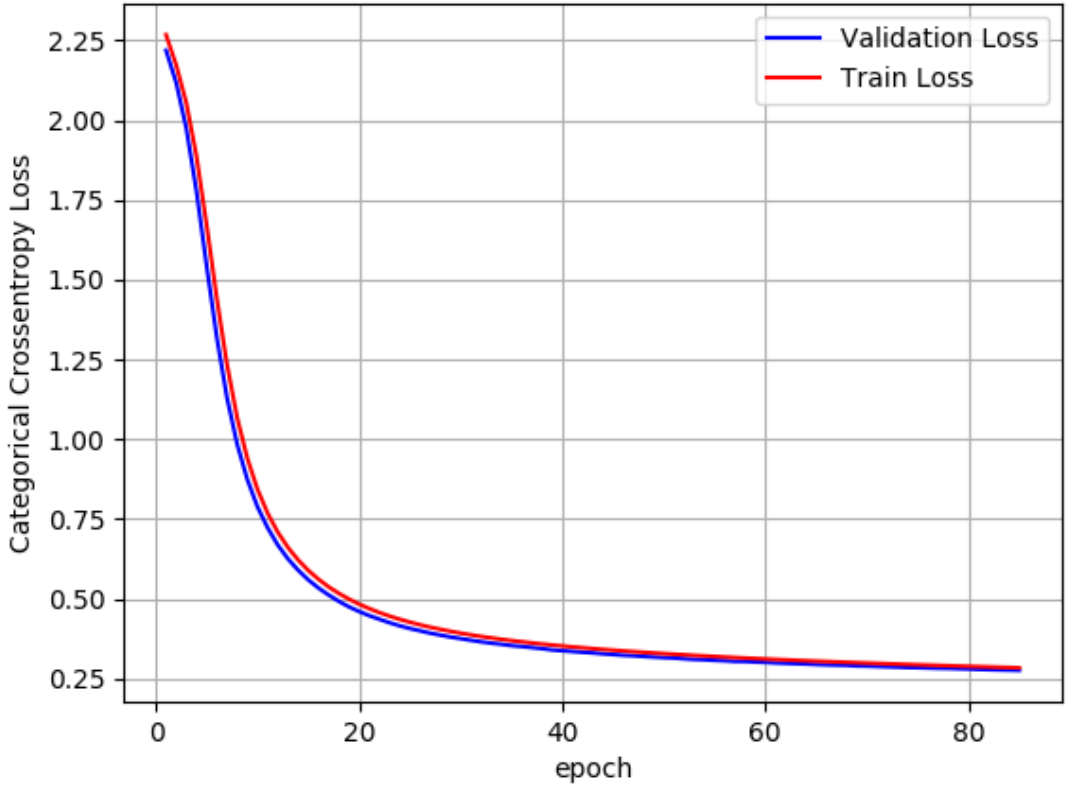
```
# loss : training loss
# acc : train accuracy
# for each key in histrory.histrory we will have a list of length equal
 to number of epochs

vy = A1M2_history.history['val_loss']
ty = A1M2_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.2764148581951857
Test accuracy: 0.919700026512146
```



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1.1.2.4 Violin Plots for Hidden Layers in Models Trained

In [19]:
```
w_after = model_sigmoid.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
out_w = w_after[4].flatten().reshape(-1,1)

fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 3, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 1')

plt.subplot(1, 3, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 2 ')

plt.subplot(1, 3, 3)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Output Layer ')
plt.show()
```

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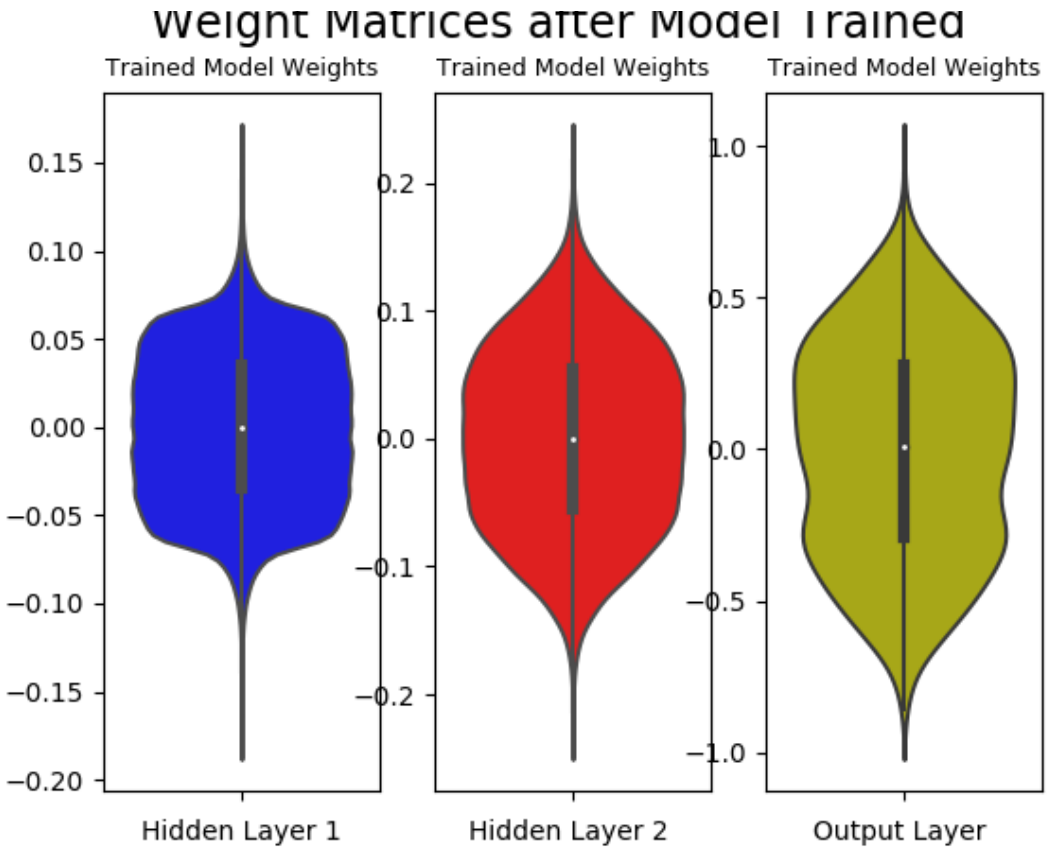

1.1.3 Model 3 : MLP + Sigmoid Activation + ADAM Optimizer

1.1.3.1 Constructing the Neural Network

In [20]:
```
model_sigmoid = Sequential()
model_sigmoid.add(Dense(512, activation='sigmoid', input_shape=(input_d
im,)))
model_sigmoid.add(Dense(128, activation='sigmoid'))
model_sigmoid.add(Dense(output_dim, activation='softmax'))
```

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```
model_sigmoid.summary()
```

```
Model: "sequential_3"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_5 (Dense)              (None, 512)               401920
_________________________________________________________________
dense_6 (Dense)              (None, 128)               65664
_________________________________________________________________
dense_7 (Dense)              (None, 10)                1290
=================================================================
Total params: 468,874
Trainable params: 468,874
Non-trainable params: 0
_________________________________________________________________
```

1.1.3.2 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [21]:
```
model_sigmoid.compile(optimizer='adam', loss='categorical_crossentropy'
, metrics=['accuracy'])

A1M3_history = model_sigmoid.fit(X_train, Y_train, batch_size=batch_siz
e, epochs=nb_epoch, verbose=1, \
                                 validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 5s 80us/step - loss: 0.5
264 - accuracy: 0.8603 - val_loss: 0.2464 - val_accuracy: 0.9276
Epoch 2/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.2
164 - accuracy: 0.9367 - val_loss: 0.1855 - val_accuracy: 0.9440
Epoch 3/85
60000/60000 [==============================] - 5s 77us/step - loss: 0.1
611 - accuracy: 0.9524 - val_loss: 0.1424 - val_accuracy: 0.9571
Epoch 4/85
```

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```
60000/60000 [==============================] - 5s 83us/step - loss: 0.1
240 - accuracy: 0.9635 - val_loss: 0.1189 - val_accuracy: 0.9628
Epoch 5/85
60000/60000 [==============================] - 5s 78us/step - loss: 0.0
988 - accuracy: 0.9712 - val_loss: 0.1005 - val_accuracy: 0.9682
Epoch 6/85
60000/60000 [==============================] - 5s 80us/step - loss: 0.0
793 - accuracy: 0.9763 - val_loss: 0.1105 - val_accuracy: 0.9661
Epoch 7/85
60000/60000 [==============================] - 5s 77us/step - loss: 0.0
655 - accuracy: 0.9808 - val_loss: 0.0806 - val_accuracy: 0.9740
Epoch 8/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
536 - accuracy: 0.9839 - val_loss: 0.0803 - val_accuracy: 0.9760
Epoch 9/85
60000/60000 [==============================] - 5s 77us/step - loss: 0.0
426 - accuracy: 0.9876 - val_loss: 0.0709 - val_accuracy: 0.9782
Epoch 10/85
60000/60000 [==============================] - 5s 78us/step - loss: 0.0
347 - accuracy: 0.9899 - val_loss: 0.0712 - val_accuracy: 0.9771
Epoch 11/85
60000/60000 [==============================] - 5s 82us/step - loss: 0.0
277 - accuracy: 0.9926 - val_loss: 0.0675 - val_accuracy: 0.9783
Epoch 12/85
60000/60000 [==============================] - 5s 79us/step - loss: 0.0
231 - accuracy: 0.9935 - val_loss: 0.0679 - val_accuracy: 0.9788
Epoch 13/85
60000/60000 [==============================] - 5s 82us/step - loss: 0.0
180 - accuracy: 0.9958 - val_loss: 0.0627 - val_accuracy: 0.9806
Epoch 14/85
60000/60000 [==============================] - 5s 79us/step - loss: 0.0
156 - accuracy: 0.9963 - val_loss: 0.0642 - val_accuracy: 0.9806
Epoch 15/85
60000/60000 [==============================] - 5s 77us/step - loss: 0.0
113 - accuracy: 0.9974 - val_loss: 0.0642 - val_accuracy: 0.9805
Epoch 16/85
60000/60000 [==============================] - 5s 83us/step - loss: 0.0
091 - accuracy: 0.9981 - val_loss: 0.0671 - val_accuracy: 0.9801
Epoch 17/85
```

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```
60000/60000 [==============================] - 5s 78us/step - loss: 0.0
075 - accuracy: 0.9984 - val_loss: 0.0746 - val_accuracy: 0.9798
Epoch 18/85
60000/60000 [==============================] - 5s 79us/step - loss: 0.0
056 - accuracy: 0.9990 - val_loss: 0.0648 - val_accuracy: 0.9823
Epoch 19/85
60000/60000 [==============================] - 5s 80us/step - loss: 0.0
040 - accuracy: 0.9994 - val_loss: 0.0708 - val_accuracy: 0.9808
Epoch 20/85
60000/60000 [==============================] - 5s 81us/step - loss: 0.0
035 - accuracy: 0.9995 - val_loss: 0.0757 - val_accuracy: 0.9794
Epoch 21/85
60000/60000 [==============================] - 5s 81us/step - loss: 0.0
048 - accuracy: 0.9988 - val_loss: 0.0734 - val_accuracy: 0.9818
Epoch 22/85
60000/60000 [==============================] - 5s 79us/step - loss: 0.0
058 - accuracy: 0.9984 - val_loss: 0.0818 - val_accuracy: 0.9809
Epoch 23/85
60000/60000 [==============================] - 5s 82us/step - loss: 0.0
025 - accuracy: 0.9995 - val_loss: 0.0758 - val_accuracy: 0.9824
Epoch 24/85
60000/60000 [==============================] - 5s 77us/step - loss: 0.0
017 - accuracy: 0.9997 - val_loss: 0.0715 - val_accuracy: 0.9831
Epoch 25/85
60000/60000 [==============================] - 5s 78us/step - loss: 7.6
160e-04 - accuracy: 0.9999 - val_loss: 0.0703 - val_accuracy: 0.9833
Epoch 26/85
60000/60000 [==============================] - 5s 78us/step - loss: 0.0
055 - accuracy: 0.9983 - val_loss: 0.0964 - val_accuracy: 0.9762
Epoch 27/85
60000/60000 [==============================] - 5s 79us/step - loss: 0.0
060 - accuracy: 0.9980 - val_loss: 0.0821 - val_accuracy: 0.9810
Epoch 28/85
60000/60000 [==============================] - 5s 82us/step - loss: 0.0
011 - accuracy: 0.9998 - val_loss: 0.0800 - val_accuracy: 0.9821
Epoch 29/85
60000/60000 [==============================] - 5s 77us/step - loss: 8.4
934e-04 - accuracy: 0.9999 - val_loss: 0.0745 - val_accuracy: 0.9824
Epoch 30/85
```

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```
60000/60000 [==============================] - 5s 83us/step - loss: 6.3
219e-04 - accuracy: 0.9999 - val_loss: 0.0771 - val_accuracy: 0.9833
Epoch 31/85
60000/60000 [==============================] - 5s 79us/step - loss: 0.0
023 - accuracy: 0.9995 - val_loss: 0.0815 - val_accuracy: 0.9829
Epoch 32/85
60000/60000 [==============================] - 5s 80us/step - loss: 0.0
065 - accuracy: 0.9979 - val_loss: 0.0910 - val_accuracy: 0.9800
Epoch 33/85
60000/60000 [==============================] - 5s 78us/step - loss: 0.0
021 - accuracy: 0.9994 - val_loss: 0.0800 - val_accuracy: 0.9827
Epoch 34/85
60000/60000 [==============================] - 5s 77us/step - loss: 2.3
950e-04 - accuracy: 1.0000 - val_loss: 0.0790 - val_accuracy: 0.9834
Epoch 35/85
60000/60000 [==============================] - 5s 82us/step - loss: 1.3
576e-04 - accuracy: 1.0000 - val_loss: 0.0791 - val_accuracy: 0.9832
Epoch 36/85
60000/60000 [==============================] - 5s 84us/step - loss: 1.1
151e-04 - accuracy: 1.0000 - val_loss: 0.0787 - val_accuracy: 0.9837
Epoch 37/85
60000/60000 [==============================] - 5s 80us/step - loss: 1.0
142e-04 - accuracy: 1.0000 - val_loss: 0.0794 - val_accuracy: 0.9831
Epoch 38/85
60000/60000 [==============================] - 5s 77us/step - loss: 0.0
088 - accuracy: 0.9971 - val_loss: 0.0951 - val_accuracy: 0.9792
Epoch 39/85
60000/60000 [==============================] - 5s 77us/step - loss: 0.0
022 - accuracy: 0.9993 - val_loss: 0.0904 - val_accuracy: 0.9809
Epoch 40/85
60000/60000 [==============================] - 5s 78us/step - loss: 4.0
878e-04 - accuracy: 0.9999 - val_loss: 0.0780 - val_accuracy: 0.9842
Epoch 41/85
60000/60000 [==============================] - 5s 83us/step - loss: 1.1
165e-04 - accuracy: 1.0000 - val_loss: 0.0795 - val_accuracy: 0.9842
Epoch 42/85
60000/60000 [==============================] - 5s 87us/step - loss: 8.6
745e-05 - accuracy: 1.0000 - val_loss: 0.0799 - val_accuracy: 0.9841
Epoch 43/85
```

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```
60000/60000 [==============================] - 5s 88us/step - loss: 7.2
171e-05 - accuracy: 1.0000 - val_loss: 0.0804 - val_accuracy: 0.9842
Epoch 44/85
60000/60000 [==============================] - 5s 81us/step - loss: 6.2
436e-05 - accuracy: 1.0000 - val_loss: 0.0810 - val_accuracy: 0.9843
Epoch 45/85
60000/60000 [==============================] - 5s 79us/step - loss: 5.3
923e-05 - accuracy: 1.0000 - val_loss: 0.0814 - val_accuracy: 0.9845
Epoch 46/85
60000/60000 [==============================] - 5s 77us/step - loss: 4.8
295e-05 - accuracy: 1.0000 - val_loss: 0.0818 - val_accuracy: 0.9848
Epoch 47/85
60000/60000 [==============================] - 5s 77us/step - loss: 4.1
259e-05 - accuracy: 1.0000 - val_loss: 0.0824 - val_accuracy: 0.9845
Epoch 48/85
60000/60000 [==============================] - 5s 82us/step - loss: 3.5
638e-05 - accuracy: 1.0000 - val_loss: 0.0835 - val_accuracy: 0.9843
Epoch 49/85
60000/60000 [==============================] - 5s 78us/step - loss: 3.1
527e-05 - accuracy: 1.0000 - val_loss: 0.0838 - val_accuracy: 0.9844
Epoch 50/85
60000/60000 [==============================] - 5s 83us/step - loss: 2.7
614e-05 - accuracy: 1.0000 - val_loss: 0.0849 - val_accuracy: 0.9847
Epoch 51/85
60000/60000 [==============================] - 5s 80us/step - loss: 2.3
543e-05 - accuracy: 1.0000 - val_loss: 0.0856 - val_accuracy: 0.9845
Epoch 52/85
60000/60000 [==============================] - 5s 80us/step - loss: 2.4
366e-05 - accuracy: 1.0000 - val_loss: 0.1000 - val_accuracy: 0.9811
Epoch 53/85
60000/60000 [==============================] - 5s 78us/step - loss: 0.0
116 - accuracy: 0.9964 - val_loss: 0.0900 - val_accuracy: 0.9812
Epoch 54/85
60000/60000 [==============================] - 5s 86us/step - loss: 8.4
253e-04 - accuracy: 0.9998 - val_loss: 0.0861 - val_accuracy: 0.9833
Epoch 55/85
60000/60000 [==============================] - 5s 77us/step - loss: 1.0
444e-04 - accuracy: 1.0000 - val_loss: 0.0861 - val_accuracy: 0.9837
Epoch 56/85
```

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```
60000/60000 [==============================] - 5s 79us/step - loss: 6.3
622e-05 - accuracy: 1.0000 - val_loss: 0.0862 - val_accuracy: 0.9839
Epoch 57/85
60000/60000 [==============================] - 5s 77us/step - loss: 4.8
993e-05 - accuracy: 1.0000 - val_loss: 0.0871 - val_accuracy: 0.9843
Epoch 58/85
60000/60000 [==============================] - 5s 77us/step - loss: 4.0
632e-05 - accuracy: 1.0000 - val_loss: 0.0873 - val_accuracy: 0.9845
Epoch 59/85
60000/60000 [==============================] - 5s 76us/step - loss: 3.3
976e-05 - accuracy: 1.0000 - val_loss: 0.0877 - val_accuracy: 0.9844
Epoch 60/85
60000/60000 [==============================] - 5s 78us/step - loss: 2.9
136e-05 - accuracy: 1.0000 - val_loss: 0.0886 - val_accuracy: 0.9846
Epoch 61/85
60000/60000 [==============================] - 5s 85us/step - loss: 2.5
174e-05 - accuracy: 1.0000 - val_loss: 0.0887 - val_accuracy: 0.9847
Epoch 62/85
60000/60000 [==============================] - 5s 78us/step - loss: 2.1
793e-05 - accuracy: 1.0000 - val_loss: 0.0892 - val_accuracy: 0.9845
Epoch 63/85
60000/60000 [==============================] - 5s 79us/step - loss: 1.8
807e-05 - accuracy: 1.0000 - val_loss: 0.0897 - val_accuracy: 0.9843
Epoch 64/85
60000/60000 [==============================] - 5s 81us/step - loss: 1.6
633e-05 - accuracy: 1.0000 - val_loss: 0.0898 - val_accuracy: 0.9846
Epoch 65/85
60000/60000 [==============================] - 5s 78us/step - loss: 1.4
380e-05 - accuracy: 1.0000 - val_loss: 0.0906 - val_accuracy: 0.9844
Epoch 66/85
60000/60000 [==============================] - 5s 77us/step - loss: 1.2
625e-05 - accuracy: 1.0000 - val_loss: 0.0914 - val_accuracy: 0.9841
Epoch 67/85
60000/60000 [==============================] - 5s 77us/step - loss: 1.0
923e-05 - accuracy: 1.0000 - val_loss: 0.0916 - val_accuracy: 0.9846
Epoch 68/85
60000/60000 [==============================] - 5s 83us/step - loss: 9.3
797e-06 - accuracy: 1.0000 - val_loss: 0.0927 - val_accuracy: 0.9844
Epoch 69/85
```

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```
60000/60000 [==============================] - 5s 80us/step - loss: 7.9
021e-06 - accuracy: 1.0000 - val_loss: 0.0930 - val_accuracy: 0.9845
Epoch 70/85
60000/60000 [==============================] - 5s 83us/step - loss: 6.7
475e-06 - accuracy: 1.0000 - val_loss: 0.0937 - val_accuracy: 0.9844
Epoch 71/85
60000/60000 [==============================] - 5s 91us/step - loss: 5.8
046e-06 - accuracy: 1.0000 - val_loss: 0.0950 - val_accuracy: 0.9846
Epoch 72/85
60000/60000 [==============================] - 5s 78us/step - loss: 4.6
838e-06 - accuracy: 1.0000 - val_loss: 0.0959 - val_accuracy: 0.9845
Epoch 73/85
60000/60000 [==============================] - 5s 81us/step - loss: 3.9
492e-06 - accuracy: 1.0000 - val_loss: 0.0970 - val_accuracy: 0.9845
Epoch 74/85
60000/60000 [==============================] - 5s 79us/step - loss: 0.0
032 - accuracy: 0.9989 - val_loss: 0.1364 - val_accuracy: 0.9728
Epoch 75/85
60000/60000 [==============================] - 5s 79us/step - loss: 0.0
068 - accuracy: 0.9977 - val_loss: 0.0969 - val_accuracy: 0.9826
Epoch 76/85
60000/60000 [==============================] - 5s 78us/step - loss: 3.2
438e-04 - accuracy: 0.9999 - val_loss: 0.0911 - val_accuracy: 0.9833
Epoch 77/85
60000/60000 [==============================] - 5s 82us/step - loss: 4.8
236e-05 - accuracy: 1.0000 - val_loss: 0.0918 - val_accuracy: 0.9838
Epoch 78/85
60000/60000 [==============================] - 5s 79us/step - loss: 2.9
443e-05 - accuracy: 1.0000 - val_loss: 0.0924 - val_accuracy: 0.9841
Epoch 79/85
60000/60000 [==============================] - 5s 78us/step - loss: 2.3
225e-05 - accuracy: 1.0000 - val_loss: 0.0929 - val_accuracy: 0.9836
Epoch 80/85
60000/60000 [==============================] - 5s 81us/step - loss: 1.8
893e-05 - accuracy: 1.0000 - val_loss: 0.0938 - val_accuracy: 0.9839
Epoch 81/85
60000/60000 [==============================] - 5s 78us/step - loss: 1.5
665e-05 - accuracy: 1.0000 - val_loss: 0.0943 - val_accuracy: 0.9837
Epoch 82/85
```

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```
60000/60000 [==============================] - 5s 78us/step - loss: 1.3
163e-05 - accuracy: 1.0000 - val_loss: 0.0953 - val_accuracy: 0.9840
Epoch 83/85
60000/60000 [==============================] - 5s 78us/step - loss: 1.1
222e-05 - accuracy: 1.0000 - val_loss: 0.0956 - val_accuracy: 0.9839
Epoch 84/85
60000/60000 [==============================] - 5s 83us/step - loss: 9.5
620e-06 - accuracy: 1.0000 - val_loss: 0.0967 - val_accuracy: 0.9840
Epoch 85/85
60000/60000 [==============================] - 5s 78us/step - loss: 8.2
819e-06 - accuracy: 1.0000 - val_loss: 0.0970 - val_accuracy: 0.9840
```

1.1.3.3 Number of Epochs vs Train Loss & Validation Loss

In [22]:

```
A1M3_score = model_sigmoid.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A1M3_score[0])
print('Test accuracy:', A1M3_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in histrory.history we will have a list of length equal
 to number of epochs
```

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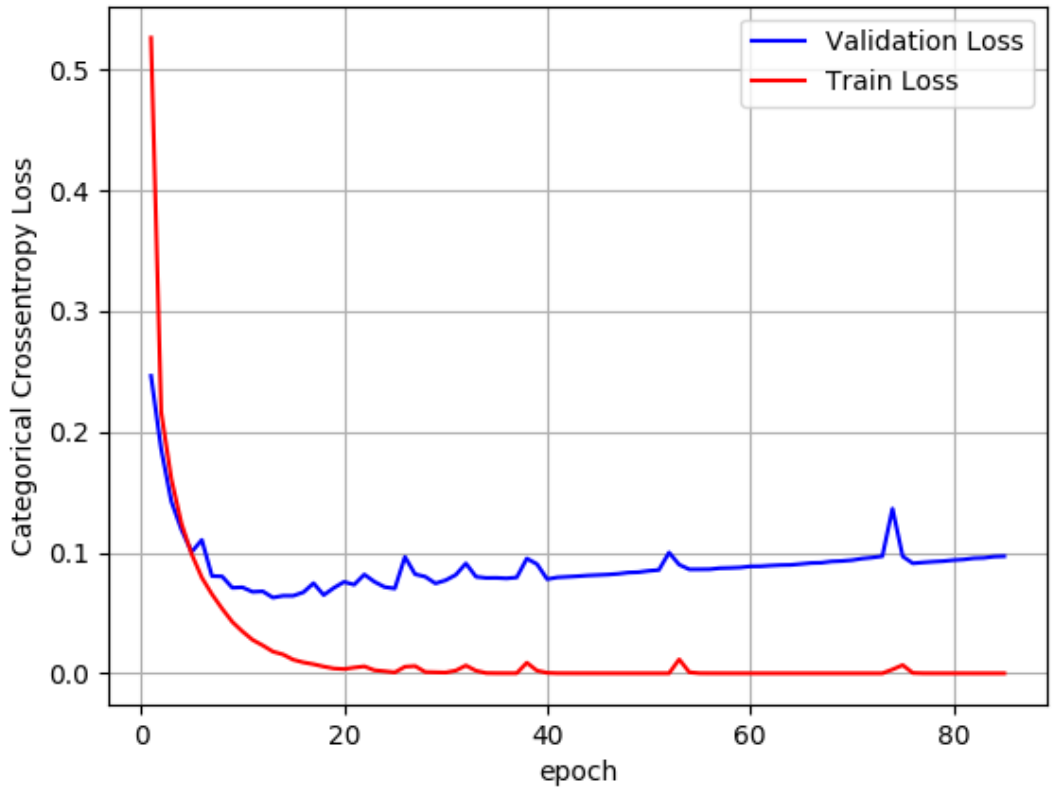
```
vy = A1M3_history.history['val_loss']
ty = A1M3_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.09699102172313358
Test accuracy: 0.984000027179718
```



1.1.3.4 Violin Plots for Hidden Layers in Models Trained

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In [23]:
```
w_after = model_sigmoid.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
out_w = w_after[4].flatten().reshape(-1,1)

fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 3, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 1')

plt.subplot(1, 3, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 2 ')

plt.subplot(1, 3, 3)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Output Layer ')
plt.show()
```

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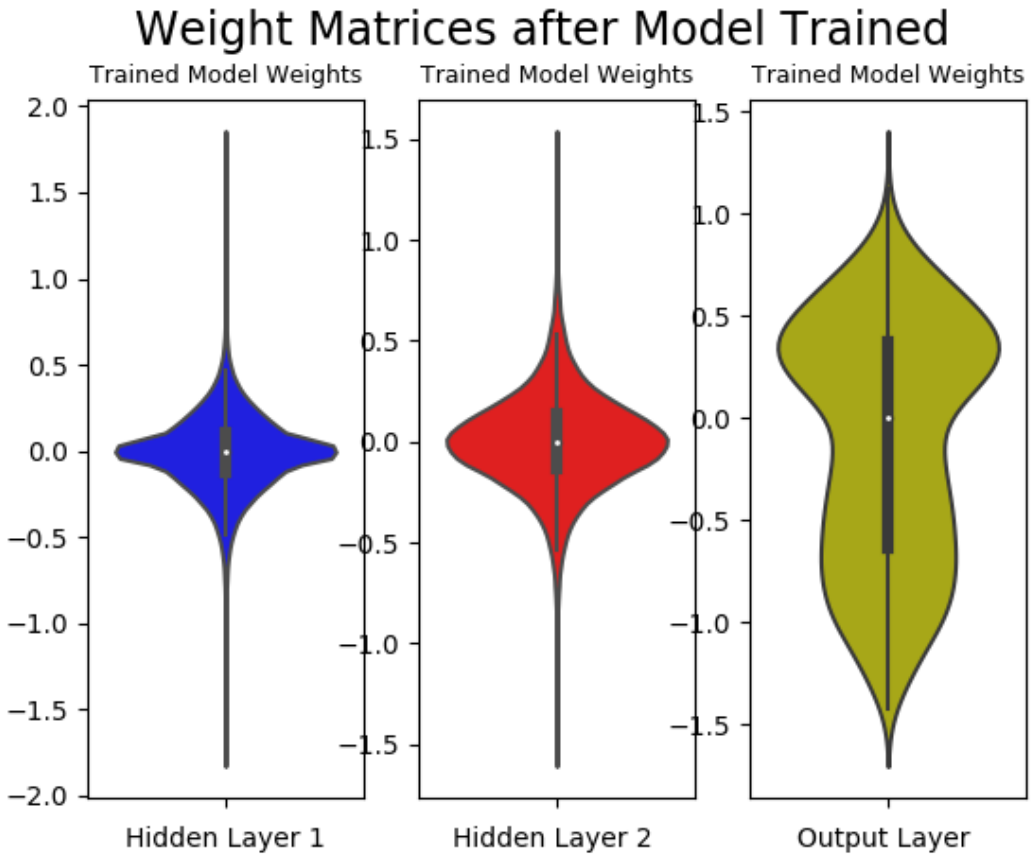

1.1.4 Model 4 : MLP + ReLU Activation + SGD Optimizer

1.1.4.1 Constructing the Neural Network

In [24]:
```
# Multilayer perceptron

# https://arxiv.org/pdf/1707.09725.pdf#page=95
# for relu layers
# If we sample weights from a normal distribution N(0,σ) we satisfy thi
```

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```
s condition with σ=√(2/(ni).
# h1 =>  σ=√(2/(fan_in) = 0.062  => N(0,σ) = N(0,0.062)
# h2 =>  σ=√(2/(fan_in) = 0.125  => N(0,σ) = N(0,0.125)
# out =>  σ=√(2/(fan_in+1) = 0.120  => N(0,σ) = N(0,0.120)

model_relu = Sequential()
model_relu.add(Dense(512, activation='relu', input_shape=(input_dim,),
 \
                     kernel_initializer=RandomNormal(mean=0.0, stddev=
0.062, seed=None)))
model_relu.add(Dense(128, activation='relu', \
                     kernel_initializer=RandomNormal(mean=0.0, stddev=
0.125, seed=None)) )
model_relu.add(Dense(output_dim, activation='softmax'))

model_relu.summary()
```

```
Model: "sequential_4"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_8 (Dense)              (None, 512)               401920
_________________________________________________________________
dense_9 (Dense)              (None, 128)               65664
_________________________________________________________________
dense_10 (Dense)             (None, 10)                1290
=================================================================
Total params: 468,874
Trainable params: 468,874
Non-trainable params: 0
_________________________________________________________________
```

1.1.4.2 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [25]:
```
model_relu.compile(optimizer='sgd', loss='categorical_crossentropy', me
trics=['accuracy'])

A1M4_history = model_relu.fit(X_train, Y_train, batch_size=batch_size,
```

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```
epochs=nb_epoch, verbose=1, \
                            validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 3s 56us/step - loss: 0.7
811 - accuracy: 0.7820 - val_loss: 0.3999 - val_accuracy: 0.8938
Epoch 2/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.3
628 - accuracy: 0.9005 - val_loss: 0.3058 - val_accuracy: 0.9141
Epoch 3/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.2
974 - accuracy: 0.9160 - val_loss: 0.2670 - val_accuracy: 0.9251
Epoch 4/85
60000/60000 [==============================] - 3s 57us/step - loss: 0.2
625 - accuracy: 0.9256 - val_loss: 0.2446 - val_accuracy: 0.9309
Epoch 5/85
60000/60000 [==============================] - 3s 57us/step - loss: 0.2
382 - accuracy: 0.9321 - val_loss: 0.2237 - val_accuracy: 0.9352
Epoch 6/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.2
197 - accuracy: 0.9378 - val_loss: 0.2102 - val_accuracy: 0.9386
Epoch 7/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.2
046 - accuracy: 0.9421 - val_loss: 0.1972 - val_accuracy: 0.9422
Epoch 8/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.1
919 - accuracy: 0.9455 - val_loss: 0.1876 - val_accuracy: 0.9453
Epoch 9/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.1
806 - accuracy: 0.9496 - val_loss: 0.1794 - val_accuracy: 0.9475
Epoch 10/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.1
710 - accuracy: 0.9520 - val_loss: 0.1719 - val_accuracy: 0.9491
Epoch 11/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.1
621 - accuracy: 0.9539 - val_loss: 0.1650 - val_accuracy: 0.9500
Epoch 12/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.1
544 - accuracy: 0.9563 - val_loss: 0.1590 - val_accuracy: 0.9527
```

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```
Epoch 13/85

60000/60000 [==============================] - 3s 54us/step - loss: 0.1
473 - accuracy: 0.9582 - val_loss: 0.1534 - val_accuracy: 0.9533
Epoch 14/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.1
411 - accuracy: 0.9605 - val_loss: 0.1476 - val_accuracy: 0.9555
Epoch 15/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.1
349 - accuracy: 0.9623 - val_loss: 0.1434 - val_accuracy: 0.9578
Epoch 16/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.1
294 - accuracy: 0.9647 - val_loss: 0.1388 - val_accuracy: 0.9584
Epoch 17/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.1
246 - accuracy: 0.9655 - val_loss: 0.1348 - val_accuracy: 0.9599
Epoch 18/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.1
198 - accuracy: 0.9669 - val_loss: 0.1312 - val_accuracy: 0.9610
Epoch 19/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.1
153 - accuracy: 0.9683 - val_loss: 0.1274 - val_accuracy: 0.9618
Epoch 20/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.1
113 - accuracy: 0.9693 - val_loss: 0.1255 - val_accuracy: 0.9631
Epoch 21/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.1
075 - accuracy: 0.9707 - val_loss: 0.1218 - val_accuracy: 0.9633
Epoch 22/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.1
038 - accuracy: 0.9719 - val_loss: 0.1194 - val_accuracy: 0.9652
Epoch 23/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.1
004 - accuracy: 0.9726 - val_loss: 0.1166 - val_accuracy: 0.9655
Epoch 24/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.0
974 - accuracy: 0.9734 - val_loss: 0.1142 - val_accuracy: 0.9662
Epoch 25/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.0
941 - accuracy: 0.9744 - val_loss: 0.1127 - val_accuracy: 0.9666
Epoch 26/85
```

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```
Epoch 26/85

60000/60000 [==============================] - 3s 58us/step - loss: 0.0
913 - accuracy: 0.9751 - val_loss: 0.1098 - val_accuracy: 0.9671
Epoch 27/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
884 - accuracy: 0.9755 - val_loss: 0.1073 - val_accuracy: 0.9675
Epoch 28/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.0
858 - accuracy: 0.9767 - val_loss: 0.1067 - val_accuracy: 0.9679
Epoch 29/85
60000/60000 [==============================] - 3s 57us/step - loss: 0.0
833 - accuracy: 0.9769 - val_loss: 0.1039 - val_accuracy: 0.9684
Epoch 30/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.0
809 - accuracy: 0.9782 - val_loss: 0.1032 - val_accuracy: 0.9695
Epoch 31/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
786 - accuracy: 0.9789 - val_loss: 0.1021 - val_accuracy: 0.9690
Epoch 32/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.0
765 - accuracy: 0.9796 - val_loss: 0.1004 - val_accuracy: 0.9697
Epoch 33/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
743 - accuracy: 0.9804 - val_loss: 0.0982 - val_accuracy: 0.9699
Epoch 34/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.0
723 - accuracy: 0.9809 - val_loss: 0.0981 - val_accuracy: 0.9700
Epoch 35/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
704 - accuracy: 0.9814 - val_loss: 0.0964 - val_accuracy: 0.9707
Epoch 36/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
685 - accuracy: 0.9819 - val_loss: 0.0951 - val_accuracy: 0.9711
Epoch 37/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.0
668 - accuracy: 0.9826 - val_loss: 0.0941 - val_accuracy: 0.9707
Epoch 38/85
60000/60000 [==============================] - 4s 60us/step - loss: 0.0
650 - accuracy: 0.9829 - val_loss: 0.0928 - val_accuracy: 0.9717
Epoch 39/85
```

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```
Epoch 39/85

60000/60000 [==============================] - 3s 55us/step - loss: 0.0
634 - accuracy: 0.9836 - val_loss: 0.0918 - val_accuracy: 0.9723
Epoch 40/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
617 - accuracy: 0.9841 - val_loss: 0.0907 - val_accuracy: 0.9720
Epoch 41/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
602 - accuracy: 0.9846 - val_loss: 0.0897 - val_accuracy: 0.9727
Epoch 42/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
587 - accuracy: 0.9851 - val_loss: 0.0883 - val_accuracy: 0.9733
Epoch 43/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
573 - accuracy: 0.9854 - val_loss: 0.0902 - val_accuracy: 0.9717
Epoch 44/85
60000/60000 [==============================] - 3s 56us/step - loss: 0.0
558 - accuracy: 0.9860 - val_loss: 0.0872 - val_accuracy: 0.9738
Epoch 45/85
60000/60000 [==============================] - 3s 56us/step - loss: 0.0
546 - accuracy: 0.9862 - val_loss: 0.0870 - val_accuracy: 0.9728
Epoch 46/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
533 - accuracy: 0.9865 - val_loss: 0.0860 - val_accuracy: 0.9739
Epoch 47/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.0
521 - accuracy: 0.9868 - val_loss: 0.0855 - val_accuracy: 0.9739
Epoch 48/85
60000/60000 [==============================] - 4s 58us/step - loss: 0.0
509 - accuracy: 0.9871 - val_loss: 0.0851 - val_accuracy: 0.9740
Epoch 49/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
496 - accuracy: 0.9875 - val_loss: 0.0848 - val_accuracy: 0.9731
Epoch 50/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
486 - accuracy: 0.9878 - val_loss: 0.0833 - val_accuracy: 0.9747
Epoch 51/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
473 - accuracy: 0.9883 - val_loss: 0.0820 - val_accuracy: 0.9748
Epoch 52/85
```

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```
Epoch 52/85

60000/60000 [==============================] - 3s 54us/step - loss: 0.0
464 - accuracy: 0.9887 - val_loss: 0.0822 - val_accuracy: 0.9752
Epoch 53/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
453 - accuracy: 0.9891 - val_loss: 0.0824 - val_accuracy: 0.9750
Epoch 54/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.0
444 - accuracy: 0.9891 - val_loss: 0.0811 - val_accuracy: 0.9750
Epoch 55/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
433 - accuracy: 0.9898 - val_loss: 0.0804 - val_accuracy: 0.9756
Epoch 56/85
60000/60000 [==============================] - 3s 51us/step - loss: 0.0
424 - accuracy: 0.9899 - val_loss: 0.0802 - val_accuracy: 0.9754
Epoch 57/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.0
415 - accuracy: 0.9901 - val_loss: 0.0795 - val_accuracy: 0.9763
Epoch 58/85
60000/60000 [==============================] - 3s 52us/step - loss: 0.0
406 - accuracy: 0.9905 - val_loss: 0.0790 - val_accuracy: 0.9761
Epoch 59/85
60000/60000 [==============================] - 3s 51us/step - loss: 0.0
397 - accuracy: 0.9906 - val_loss: 0.0786 - val_accuracy: 0.9760
Epoch 60/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
388 - accuracy: 0.9910 - val_loss: 0.0783 - val_accuracy: 0.9760
Epoch 61/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.0
381 - accuracy: 0.9911 - val_loss: 0.0784 - val_accuracy: 0.9755
Epoch 62/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
373 - accuracy: 0.9913 - val_loss: 0.0783 - val_accuracy: 0.9759
Epoch 63/85
60000/60000 [==============================] - 3s 56us/step - loss: 0.0
365 - accuracy: 0.9917 - val_loss: 0.0768 - val_accuracy: 0.9767
Epoch 64/85
60000/60000 [==============================] - 3s 56us/step - loss: 0.0
357 - accuracy: 0.9918 - val_loss: 0.0780 - val_accuracy: 0.9759
Epoch 65/85
```

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```
Epoch 65/85

60000/60000 [==============================] - 3s 53us/step - loss: 0.0
349 - accuracy: 0.9922 - val_loss: 0.0770 - val_accuracy: 0.9760
Epoch 66/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
343 - accuracy: 0.9923 - val_loss: 0.0777 - val_accuracy: 0.9760
Epoch 67/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
335 - accuracy: 0.9924 - val_loss: 0.0760 - val_accuracy: 0.9760
Epoch 68/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.0
329 - accuracy: 0.9929 - val_loss: 0.0761 - val_accuracy: 0.9767
Epoch 69/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
322 - accuracy: 0.9930 - val_loss: 0.0754 - val_accuracy: 0.9768
Epoch 70/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
315 - accuracy: 0.9933 - val_loss: 0.0756 - val_accuracy: 0.9771
Epoch 71/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.0
308 - accuracy: 0.9934 - val_loss: 0.0757 - val_accuracy: 0.9769
Epoch 72/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
302 - accuracy: 0.9935 - val_loss: 0.0747 - val_accuracy: 0.9765
Epoch 73/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.0
296 - accuracy: 0.9938 - val_loss: 0.0741 - val_accuracy: 0.9770
Epoch 74/85
60000/60000 [==============================] - 3s 56us/step - loss: 0.0
291 - accuracy: 0.9939 - val_loss: 0.0738 - val_accuracy: 0.9768
Epoch 75/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
285 - accuracy: 0.9942 - val_loss: 0.0737 - val_accuracy: 0.9770
Epoch 76/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
279 - accuracy: 0.9943 - val_loss: 0.0744 - val_accuracy: 0.9766
Epoch 77/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.0
274 - accuracy: 0.9945 - val_loss: 0.0739 - val_accuracy: 0.9769
Epoch 78/85
```

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```
Epoch 78/85

60000/60000 [==============================] - 3s 57us/step - loss: 0.0
269 - accuracy: 0.9946 - val_loss: 0.0736 - val_accuracy: 0.9771
Epoch 79/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.0
264 - accuracy: 0.9947 - val_loss: 0.0745 - val_accuracy: 0.9766
Epoch 80/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.0
259 - accuracy: 0.9950 - val_loss: 0.0729 - val_accuracy: 0.9773
Epoch 81/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
253 - accuracy: 0.9953 - val_loss: 0.0726 - val_accuracy: 0.9772
Epoch 82/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
248 - accuracy: 0.9953 - val_loss: 0.0736 - val_accuracy: 0.9771
Epoch 83/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
244 - accuracy: 0.9955 - val_loss: 0.0722 - val_accuracy: 0.9770
Epoch 84/85
60000/60000 [==============================] - 3s 55us/step - loss: 0.0
240 - accuracy: 0.9956 - val_loss: 0.0728 - val_accuracy: 0.9770
Epoch 85/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
235 - accuracy: 0.9956 - val_loss: 0.0722 - val_accuracy: 0.9771
```

1.1.4.3 Number of Epochs vs Train Loss & Validation Loss

In [26]:

```
A1M4_score = model_relu.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A1M4_score[0])
print('Test accuracy:', A1M4_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

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```
# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in history.history we will have a list of length equal t
o number of epochs

vy = A1M4_history.history['val_loss']
ty = A1M4_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.07220969564230181
Test accuracy: 0.9771000146865845
```

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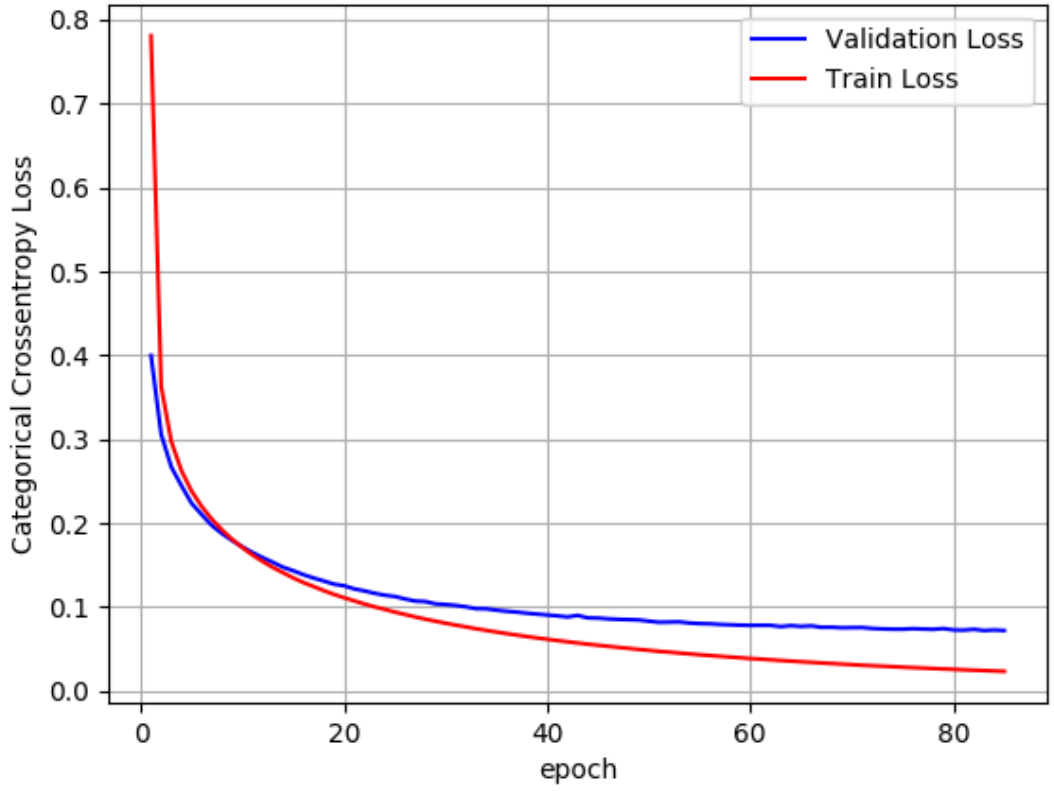

1.1.4.4 Violin Plots for Hidden Layers in Models Trained

In [27]:
```
w_after = model_relu.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
out_w = w_after[4].flatten().reshape(-1,1)
```

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```
fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 3, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 1')

plt.subplot(1, 3, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 2 ')

plt.subplot(1, 3, 3)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Output Layer ')
plt.show()
```

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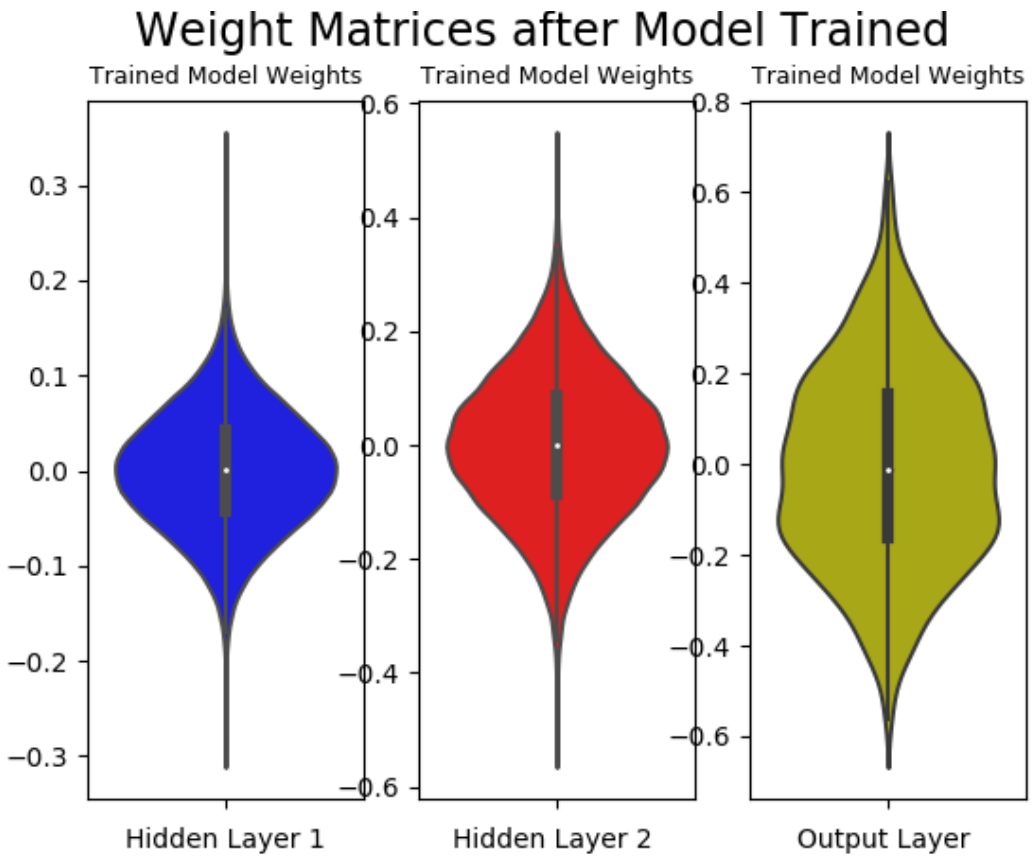

1.1.5 Model 5 : MLP + ReLU Activation + ADAM Optimizer

1.1.5.1 Constructing the Neural Network

In [28]:
```
model_relu = Sequential()
model_relu.add(Dense(512, activation='relu', input_shape=(input_dim,),\
                     kernel_initializer=RandomNormal(mean=0.0, stddev=
0.062, seed=None)))
model_relu.add(Dense(128, activation='relu', \
                     kernel_initializer=RandomNormal(mean=0.0, stddev=
```

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```
0.125, seed=None)) )
model_relu.add(Dense(output_dim, activation='softmax'))

print(model_relu.summary())
```

```
Model: "sequential_5"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_11 (Dense)             (None, 512)               401920
_________________________________________________________________
dense_12 (Dense)             (None, 128)               65664
_________________________________________________________________
dense_13 (Dense)             (None, 10)                1290
=================================================================
Total params: 468,874
Trainable params: 468,874
Non-trainable params: 0
_________________________________________________________________
None
```

1.1.5.2 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [29]:
```
model_relu.compile(optimizer='adam', loss='categorical_crossentropy', m
etrics=['accuracy'])

A1M5_history = model_relu.fit(X_train, Y_train, batch_size=batch_size,
epochs=nb_epoch, verbose=1, \
                              validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 5s 88us/step - loss: 0.2
334 - accuracy: 0.9294 - val_loss: 0.1094 - val_accuracy: 0.9668
Epoch 2/85
60000/60000 [==============================] - 6s 93us/step - loss: 0.0
868 - accuracy: 0.9739 - val_loss: 0.0837 - val_accuracy: 0.9734
Epoch 3/85
60000/60000 [==============================] - 5s 87us/step - loss: 0.0
```

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```
530 - accuracy: 0.9834 - val_loss: 0.0750 - val_accuracy: 0.9758
Epoch 4/85
60000/60000 [==============================] - 5s 82us/step - loss: 0.0
376 - accuracy: 0.9883 - val_loss: 0.0676 - val_accuracy: 0.9786
Epoch 5/85
60000/60000 [==============================] - 5s 84us/step - loss: 0.0
256 - accuracy: 0.9921 - val_loss: 0.0679 - val_accuracy: 0.9800
Epoch 6/85
60000/60000 [==============================] - 5s 82us/step - loss: 0.0
195 - accuracy: 0.9938 - val_loss: 0.0710 - val_accuracy: 0.9784
Epoch 7/85
60000/60000 [==============================] - 5s 86us/step - loss: 0.0
153 - accuracy: 0.9953 - val_loss: 0.0821 - val_accuracy: 0.9779
Epoch 8/85
60000/60000 [==============================] - 5s 84us/step - loss: 0.0
162 - accuracy: 0.9945 - val_loss: 0.0825 - val_accuracy: 0.9782
Epoch 9/85
60000/60000 [==============================] - 5s 83us/step - loss: 0.0
145 - accuracy: 0.9953 - val_loss: 0.0800 - val_accuracy: 0.9793
Epoch 10/85
60000/60000 [==============================] - 5s 83us/step - loss: 0.0
139 - accuracy: 0.9954 - val_loss: 0.0755 - val_accuracy: 0.9808
Epoch 11/85
60000/60000 [==============================] - 5s 88us/step - loss: 0.0
076 - accuracy: 0.9980 - val_loss: 0.0801 - val_accuracy: 0.9826
Epoch 12/85
60000/60000 [==============================] - 5s 83us/step - loss: 0.0
107 - accuracy: 0.9962 - val_loss: 0.0782 - val_accuracy: 0.9816
Epoch 13/85
60000/60000 [==============================] - 5s 85us/step - loss: 0.0
110 - accuracy: 0.9963 - val_loss: 0.0832 - val_accuracy: 0.9800
Epoch 14/85
60000/60000 [==============================] - 6s 94us/step - loss: 0.0
093 - accuracy: 0.9969 - val_loss: 0.1103 - val_accuracy: 0.9770
Epoch 15/85
60000/60000 [==============================] - 5s 84us/step - loss: 0.0
101 - accuracy: 0.9966 - val_loss: 0.0814 - val_accuracy: 0.9807
Epoch 16/85
60000/60000 [==============================] - 5s 86us/step - loss: 0.0
```

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```
079 - accuracy: 0.9976 - val_loss: 0.0957 - val_accuracy: 0.9798
Epoch 17/85
60000/60000 [==============================] - 5s 84us/step - loss: 0.0
078 - accuracy: 0.9974 - val_loss: 0.0902 - val_accuracy: 0.9823
Epoch 18/85
60000/60000 [==============================] - 5s 87us/step - loss: 0.0
052 - accuracy: 0.9983 - val_loss: 0.1122 - val_accuracy: 0.9781
Epoch 19/85
60000/60000 [==============================] - 5s 85us/step - loss: 0.0
073 - accuracy: 0.9976 - val_loss: 0.0960 - val_accuracy: 0.9813
Epoch 20/85
60000/60000 [==============================] - 5s 91us/step - loss: 0.0
082 - accuracy: 0.9971 - val_loss: 0.1032 - val_accuracy: 0.9802
Epoch 21/85
60000/60000 [==============================] - 5s 86us/step - loss: 0.0
077 - accuracy: 0.9976 - val_loss: 0.0984 - val_accuracy: 0.9814
Epoch 22/85
60000/60000 [==============================] - 5s 84us/step - loss: 0.0
045 - accuracy: 0.9987 - val_loss: 0.0940 - val_accuracy: 0.9828
Epoch 23/85
60000/60000 [==============================] - 5s 85us/step - loss: 0.0
044 - accuracy: 0.9986 - val_loss: 0.0932 - val_accuracy: 0.9836
Epoch 24/85
60000/60000 [==============================] - 5s 89us/step - loss: 0.0
088 - accuracy: 0.9972 - val_loss: 0.1176 - val_accuracy: 0.9787
Epoch 25/85
60000/60000 [==============================] - 5s 83us/step - loss: 0.0
061 - accuracy: 0.9981 - val_loss: 0.0972 - val_accuracy: 0.9810
Epoch 26/85
60000/60000 [==============================] - 5s 89us/step - loss: 0.0
053 - accuracy: 0.9984 - val_loss: 0.1019 - val_accuracy: 0.9832
Epoch 27/85
60000/60000 [==============================] - 5s 88us/step - loss: 0.0
059 - accuracy: 0.9982 - val_loss: 0.0903 - val_accuracy: 0.9835
Epoch 28/85
60000/60000 [==============================] - 6s 92us/step - loss: 0.0
030 - accuracy: 0.9991 - val_loss: 0.0945 - val_accuracy: 0.9825
Epoch 29/85
60000/60000 [==============================] - 5s 87us/step - loss: 0.0
```

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```
075 - accuracy: 0.9978 - val_loss: 0.1087 - val_accuracy: 0.9816
Epoch 30/85
60000/60000 [==============================] - 5s 84us/step - loss: 0.0
051 - accuracy: 0.9984 - val_loss: 0.1016 - val_accuracy: 0.9829
Epoch 31/85
60000/60000 [==============================] - 5s 85us/step - loss: 0.0
017 - accuracy: 0.9995 - val_loss: 0.0991 - val_accuracy: 0.9832
Epoch 32/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0042 - accuracy: 0.9987 - val_loss: 0.1059 - val_accuracy: 0.9826
Epoch 33/85
60000/60000 [==============================] - 7s 117us/step - loss: 0.
0073 - accuracy: 0.9976 - val_loss: 0.1337 - val_accuracy: 0.9800
Epoch 34/85
60000/60000 [==============================] - 6s 103us/step - loss: 0.
0060 - accuracy: 0.9981 - val_loss: 0.1048 - val_accuracy: 0.9819
Epoch 35/85
60000/60000 [==============================] - 5s 90us/step - loss: 0.0
052 - accuracy: 0.9984 - val_loss: 0.1170 - val_accuracy: 0.9809
Epoch 36/85
60000/60000 [==============================] - 5s 90us/step - loss: 0.0
038 - accuracy: 0.9990 - val_loss: 0.0946 - val_accuracy: 0.9837
Epoch 37/85
60000/60000 [==============================] - 6s 93us/step - loss: 0.0
021 - accuracy: 0.9993 - val_loss: 0.0974 - val_accuracy: 0.9835
Epoch 38/85
60000/60000 [==============================] - 5s 89us/step - loss: 0.0
029 - accuracy: 0.9990 - val_loss: 0.1017 - val_accuracy: 0.9823
Epoch 39/85
60000/60000 [==============================] - 6s 94us/step - loss: 0.0
079 - accuracy: 0.9979 - val_loss: 0.1049 - val_accuracy: 0.9814
Epoch 40/85
60000/60000 [==============================] - 6s 92us/step - loss: 0.0
057 - accuracy: 0.9981 - val_loss: 0.1109 - val_accuracy: 0.9820
Epoch 41/85
60000/60000 [==============================] - 5s 82us/step - loss: 0.0
046 - accuracy: 0.9986 - val_loss: 0.1079 - val_accuracy: 0.9829
Epoch 42/85
60000/60000 [==============================] - 5s 81us/step - loss: 0.0
```

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```
010 - accuracy: 0.9996 - val_loss: 0.1124 - val_accuracy: 0.9813
Epoch 43/85
60000/60000 [==============================] - 5s 80us/step - loss: 5.2
840e-04 - accuracy: 0.9998 - val_loss: 0.0940 - val_accuracy: 0.9848
Epoch 44/85
60000/60000 [==============================] - 5s 85us/step - loss: 0.0
063 - accuracy: 0.9981 - val_loss: 0.1329 - val_accuracy: 0.9805
Epoch 45/85
60000/60000 [==============================] - 5s 82us/step - loss: 0.0
075 - accuracy: 0.9977 - val_loss: 0.1399 - val_accuracy: 0.9788
Epoch 46/85
60000/60000 [==============================] - 5s 81us/step - loss: 0.0
055 - accuracy: 0.9984 - val_loss: 0.1242 - val_accuracy: 0.9827
Epoch 47/85
60000/60000 [==============================] - 5s 86us/step - loss: 0.0
046 - accuracy: 0.9986 - val_loss: 0.1300 - val_accuracy: 0.9822
Epoch 48/85
60000/60000 [==============================] - 5s 81us/step - loss: 0.0
019 - accuracy: 0.9993 - val_loss: 0.1414 - val_accuracy: 0.9823
Epoch 49/85
60000/60000 [==============================] - 5s 81us/step - loss: 0.0
064 - accuracy: 0.9984 - val_loss: 0.1455 - val_accuracy: 0.9784
Epoch 50/85
60000/60000 [==============================] - 5s 84us/step - loss: 0.0
047 - accuracy: 0.9987 - val_loss: 0.1301 - val_accuracy: 0.9810
Epoch 51/85
60000/60000 [==============================] - 5s 83us/step - loss: 0.0
029 - accuracy: 0.9991 - val_loss: 0.1224 - val_accuracy: 0.9833
Epoch 52/85
60000/60000 [==============================] - 5s 81us/step - loss: 0.0
030 - accuracy: 0.9992 - val_loss: 0.1200 - val_accuracy: 0.9827
Epoch 53/85
60000/60000 [==============================] - 5s 87us/step - loss: 0.0
044 - accuracy: 0.9990 - val_loss: 0.1296 - val_accuracy: 0.9831
Epoch 54/85
60000/60000 [==============================] - 5s 84us/step - loss: 0.0
020 - accuracy: 0.9995 - val_loss: 0.1321 - val_accuracy: 0.9817
Epoch 55/85
60000/60000 [==============================] - 5s 82us/step - loss: 0.0
```

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```
040 - accuracy: 0.9989 - val_loss: 0.1321 - val_accuracy: 0.9819
Epoch 56/85
60000/60000 [==============================] - 5s 81us/step - loss: 0.0
052 - accuracy: 0.9985 - val_loss: 0.1746 - val_accuracy: 0.9775
Epoch 57/85
60000/60000 [==============================] - 5s 84us/step - loss: 0.0
028 - accuracy: 0.9991 - val_loss: 0.1451 - val_accuracy: 0.9808
Epoch 58/85
60000/60000 [==============================] - 5s 80us/step - loss: 0.0
045 - accuracy: 0.9987 - val_loss: 0.1466 - val_accuracy: 0.9813
Epoch 59/85
60000/60000 [==============================] - 5s 87us/step - loss: 0.0
024 - accuracy: 0.9993 - val_loss: 0.1336 - val_accuracy: 0.9827
Epoch 60/85
60000/60000 [==============================] - 5s 87us/step - loss: 0.0
019 - accuracy: 0.9995 - val_loss: 0.1467 - val_accuracy: 0.9814
Epoch 61/85
60000/60000 [==============================] - 5s 92us/step - loss: 0.0
048 - accuracy: 0.9988 - val_loss: 0.1419 - val_accuracy: 0.9821
Epoch 62/85
60000/60000 [==============================] - 5s 91us/step - loss: 0.0
015 - accuracy: 0.9995 - val_loss: 0.1361 - val_accuracy: 0.9838
Epoch 63/85
60000/60000 [==============================] - 5s 90us/step - loss: 9.0
020e-04 - accuracy: 0.9998 - val_loss: 0.1509 - val_accuracy: 0.9813
Epoch 64/85
60000/60000 [==============================] - 5s 89us/step - loss: 0.0
077 - accuracy: 0.9982 - val_loss: 0.1623 - val_accuracy: 0.9800
Epoch 65/85
60000/60000 [==============================] - 6s 96us/step - loss: 0.0
057 - accuracy: 0.9985 - val_loss: 0.1721 - val_accuracy: 0.9800
Epoch 66/85
60000/60000 [==============================] - 5s 88us/step - loss: 0.0
044 - accuracy: 0.9988 - val_loss: 0.1541 - val_accuracy: 0.9815
Epoch 67/85
60000/60000 [==============================] - 5s 77us/step - loss: 0.0
035 - accuracy: 0.9992 - val_loss: 0.1617 - val_accuracy: 0.9812
Epoch 68/85
60000/60000 [==============================] - 5s 80us/step - loss: 0.0
```

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```
037 - accuracy: 0.9991 - val_loss: 0.1499 - val_accuracy: 0.9830
Epoch 69/85
60000/60000 [==============================] - 4s 74us/step - loss: 7.9
428e-04 - accuracy: 0.9998 - val_loss: 0.1497 - val_accuracy: 0.9829
Epoch 70/85
60000/60000 [==============================] - 5s 77us/step - loss: 0.0
016 - accuracy: 0.9996 - val_loss: 0.1483 - val_accuracy: 0.9839
Epoch 71/85
60000/60000 [==============================] - 4s 75us/step - loss: 6.6
593e-04 - accuracy: 0.9999 - val_loss: 0.1507 - val_accuracy: 0.9836
Epoch 72/85
60000/60000 [==============================] - 5s 82us/step - loss: 0.0
063 - accuracy: 0.9983 - val_loss: 0.1882 - val_accuracy: 0.9789
Epoch 73/85
60000/60000 [==============================] - 6s 94us/step - loss: 0.0
051 - accuracy: 0.9986 - val_loss: 0.1481 - val_accuracy: 0.9820
Epoch 74/85
60000/60000 [==============================] - 5s 87us/step - loss: 0.0
047 - accuracy: 0.9991 - val_loss: 0.1658 - val_accuracy: 0.9820
Epoch 75/85
60000/60000 [==============================] - 5s 89us/step - loss: 0.0
019 - accuracy: 0.9994 - val_loss: 0.1524 - val_accuracy: 0.9831
Epoch 76/85
60000/60000 [==============================] - 5s 87us/step - loss: 7.7
828e-04 - accuracy: 0.9998 - val_loss: 0.1422 - val_accuracy: 0.9834
Epoch 77/85
60000/60000 [==============================] - 5s 86us/step - loss: 3.2
083e-04 - accuracy: 0.9999 - val_loss: 0.1432 - val_accuracy: 0.9841
Epoch 78/85
60000/60000 [==============================] - 6s 95us/step - loss: 2.1
673e-05 - accuracy: 1.0000 - val_loss: 0.1391 - val_accuracy: 0.9839
Epoch 79/85
60000/60000 [==============================] - 5s 85us/step - loss: 5.1
294e-06 - accuracy: 1.0000 - val_loss: 0.1381 - val_accuracy: 0.9841
Epoch 80/85
60000/60000 [==============================] - 6s 94us/step - loss: 2.9
939e-06 - accuracy: 1.0000 - val_loss: 0.1379 - val_accuracy: 0.9841
Epoch 81/85
60000/60000 [==============================] - 5s 90us/step - loss: 2.3
```

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```
845e-06 - accuracy: 1.0000 - val_loss: 0.1378 - val_accuracy: 0.9842
Epoch 82/85
60000/60000 [==============================] - 5s 84us/step - loss: 1.9
544e-06 - accuracy: 1.0000 - val_loss: 0.1378 - val_accuracy: 0.9841
Epoch 83/85
60000/60000 [==============================] - 5s 87us/step - loss: 1.6
313e-06 - accuracy: 1.0000 - val_loss: 0.1378 - val_accuracy: 0.9841
Epoch 84/85
60000/60000 [==============================] - 6s 96us/step - loss: 1.3
677e-06 - accuracy: 1.0000 - val_loss: 0.1378 - val_accuracy: 0.9841
Epoch 85/85
60000/60000 [==============================] - 5s 84us/step - loss: 1.1
550e-06 - accuracy: 1.0000 - val_loss: 0.1379 - val_accuracy: 0.9841
```

1.1.5.3 Number of Epochs vs Train Loss & Validation Loss

In [30]:

```
A1M5_score = model_relu.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A1M5_score[0])
print('Test accuracy:', A1M5_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
```

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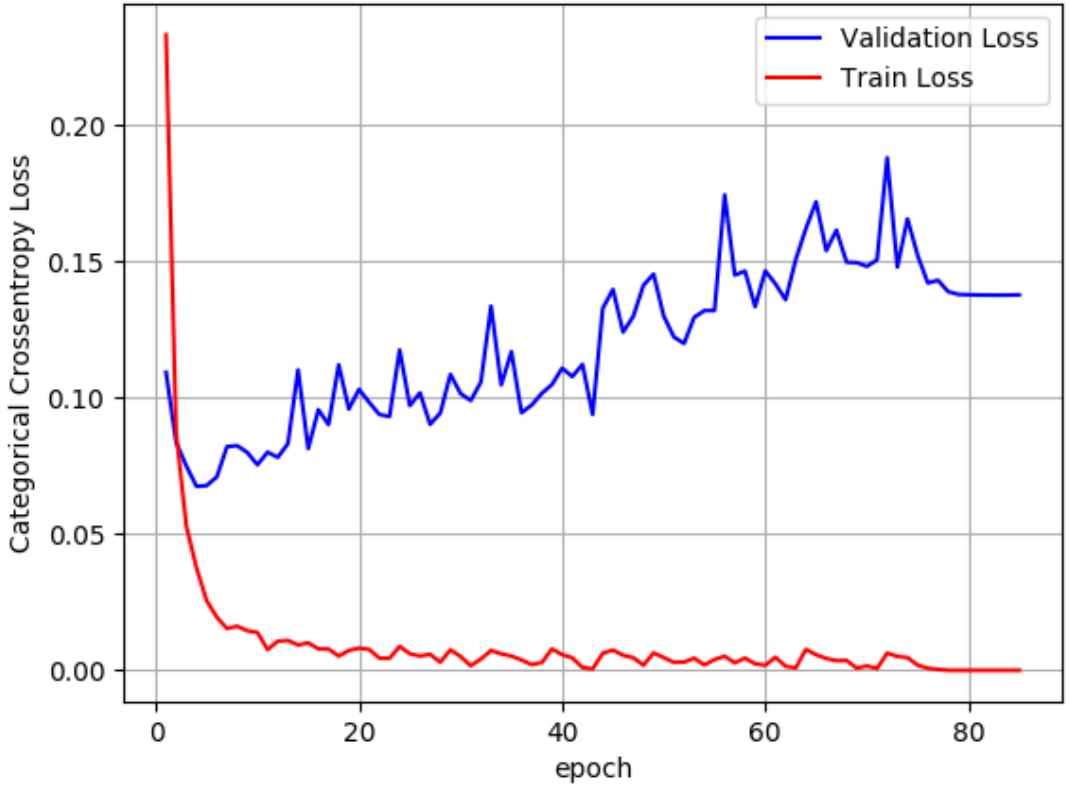
```
# acc : train accuracy
# for each key in histrory.histrory we will have a list of length equal
 to number of epochs


vy = A1M5_history.history['val_loss']
ty = A1M5_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.13787572476952978
Test accuracy: 0.9840999841690063
```



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1.1.5.4 Violin Plots for Hidden Layers in the Models Trained

In [31]:
```
w_after = model_relu.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
out_w = w_after[4].flatten().reshape(-1,1)

fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 3, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 1')

plt.subplot(1, 3, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 2 ')

plt.subplot(1, 3, 3)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Output Layer ')
plt.show()
```

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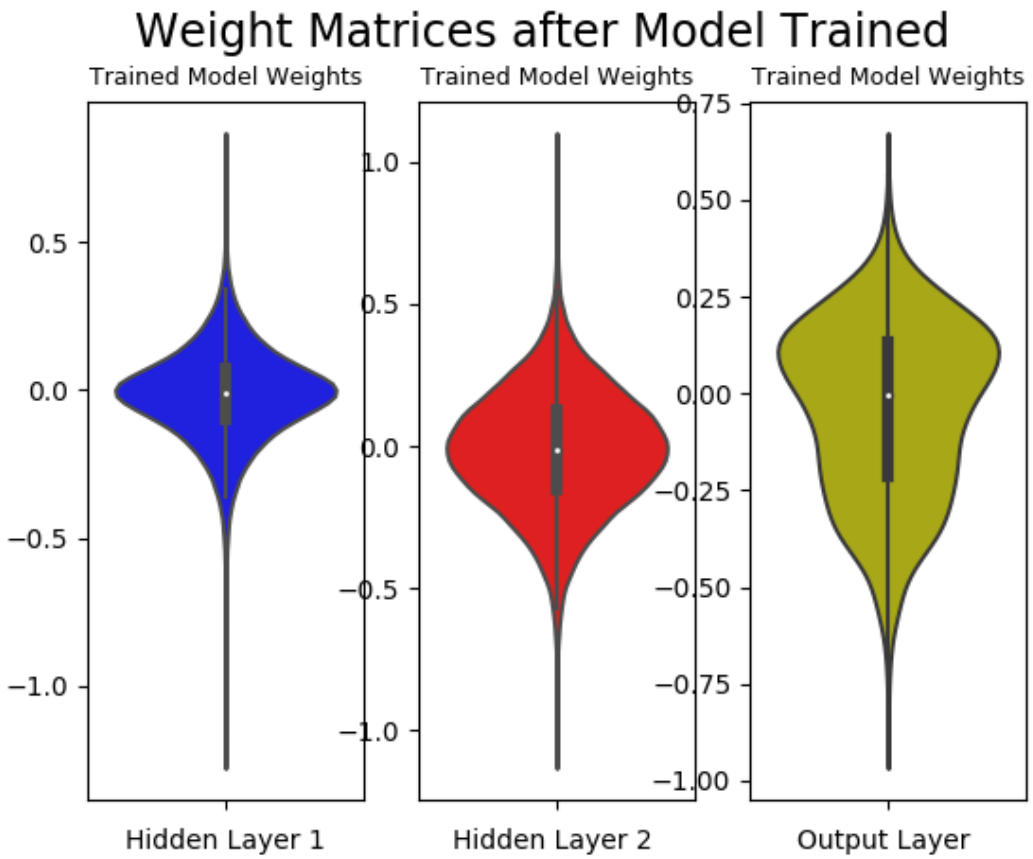

1.1.6 Model 6 : MLP + Batch-Normalization on Hidden Layers + Adam Optimizer

1.1.6.1 Constructing the Neural Network

In [32]:
```
# Multilayer perceptron

# https://intoli.com/blog/neural-network-initialization/
# If we sample weights from a normal distribution N(0,σ) we satisfy thi
```

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```
s condition with σ=√(2/(ni+ni+1).
# h1 =>  σ=√(2/(ni+ni+1) = 0.039  => N(0,σ) = N(0,0.039)
# h2 =>  σ=√(2/(ni+ni+1) = 0.055  => N(0,σ) = N(0,0.055)
# h1 =>  σ=√(2/(ni+ni+1) = 0.120  => N(0,σ) = N(0,0.120)

from keras.layers.normalization import BatchNormalization

model_batch = Sequential()

model_batch.add(Dense(512, activation='sigmoid', input_shape=(input_dim
,), \
                      kernel_initializer=RandomNormal(mean=0.0, stddev=
0.039, seed=None)))
model_batch.add(BatchNormalization())

model_batch.add(Dense(128, activation='sigmoid', \
                      kernel_initializer=RandomNormal(mean=0.0, stddev=
0.55, seed=None)) )
model_batch.add(BatchNormalization())

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

model_batch.summary()
```

```
Model: "sequential_6"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_14 (Dense)             (None, 512)               401920
_________________________________________________________________
batch_normalization_1 (Batch (None, 512)               2048
_________________________________________________________________
dense_15 (Dense)             (None, 128)               65664
_________________________________________________________________
batch_normalization_2 (Batch (None, 128)               512
_________________________________________________________________
dense_16 (Dense)             (None, 10)                1290
=================================================================
Total params: 471,434
Trainable params: 470,154
```

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```
Non-trainable params: 1,280
_________________________________________________________________
```

1.1.6.2 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [33]:
```
model_batch.compile(optimizer='adam', loss='categorical_crossentropy',
metrics=['accuracy'])

A1M6_history = model_batch.fit(X_train, Y_train, batch_size=batch_size,
 epochs=nb_epoch, verbose=1, \
                              validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 8s 140us/step - loss: 0.
3006 - accuracy: 0.9113 - val_loss: 0.2054 - val_accuracy: 0.9408
Epoch 2/85
60000/60000 [==============================] - 7s 122us/step - loss: 0.
1727 - accuracy: 0.9497 - val_loss: 0.1737 - val_accuracy: 0.9497
Epoch 3/85
60000/60000 [==============================] - 7s 123us/step - loss: 0.
1370 - accuracy: 0.9590 - val_loss: 0.1463 - val_accuracy: 0.9558
Epoch 4/85
60000/60000 [==============================] - 7s 118us/step - loss: 0.
1128 - accuracy: 0.9660 - val_loss: 0.1393 - val_accuracy: 0.9583
Epoch 5/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
0946 - accuracy: 0.9718 - val_loss: 0.1194 - val_accuracy: 0.9639
Epoch 6/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0771 - accuracy: 0.9768 - val_loss: 0.1163 - val_accuracy: 0.9669
Epoch 7/85
60000/60000 [==============================] - 8s 125us/step - loss: 0.
0702 - accuracy: 0.9777 - val_loss: 0.1230 - val_accuracy: 0.9620
Epoch 8/85
60000/60000 [==============================] - 7s 123us/step - loss: 0.
0605 - accuracy: 0.9812 - val_loss: 0.1115 - val_accuracy: 0.9679
Epoch 9/85
```

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```
60000/60000 [==============================] - 7s 114us/step - loss: 0.
0516 - accuracy: 0.9837 - val_loss: 0.1134 - val_accuracy: 0.9641
Epoch 10/85
60000/60000 [==============================] - 7s 118us/step - loss: 0.
0467 - accuracy: 0.9851 - val_loss: 0.1106 - val_accuracy: 0.9677
Epoch 11/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0390 - accuracy: 0.9877 - val_loss: 0.1048 - val_accuracy: 0.9677
Epoch 12/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
0343 - accuracy: 0.9892 - val_loss: 0.0998 - val_accuracy: 0.9688
Epoch 13/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0324 - accuracy: 0.9892 - val_loss: 0.1010 - val_accuracy: 0.9710
Epoch 14/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0287 - accuracy: 0.9906 - val_loss: 0.0974 - val_accuracy: 0.9728
Epoch 15/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0233 - accuracy: 0.9926 - val_loss: 0.0930 - val_accuracy: 0.9721
Epoch 16/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0221 - accuracy: 0.9929 - val_loss: 0.1050 - val_accuracy: 0.9721
Epoch 17/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0215 - accuracy: 0.9930 - val_loss: 0.0979 - val_accuracy: 0.9720
Epoch 18/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0216 - accuracy: 0.9930 - val_loss: 0.1054 - val_accuracy: 0.9723
Epoch 19/85
60000/60000 [==============================] - 7s 114us/step - loss: 0.
0183 - accuracy: 0.9936 - val_loss: 0.0962 - val_accuracy: 0.9751
Epoch 20/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0135 - accuracy: 0.9957 - val_loss: 0.1002 - val_accuracy: 0.9744
Epoch 21/85
60000/60000 [==============================] - 7s 113us/step - loss: 0.
0132 - accuracy: 0.9955 - val_loss: 0.0980 - val_accuracy: 0.9752
Epoch 22/85
```

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```
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0137 - accuracy: 0.9955 - val_loss: 0.1030 - val_accuracy: 0.9736
Epoch 23/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
0151 - accuracy: 0.9949 - val_loss: 0.1065 - val_accuracy: 0.9746
Epoch 24/85
60000/60000 [==============================] - 7s 122us/step - loss: 0.
0159 - accuracy: 0.9948 - val_loss: 0.1006 - val_accuracy: 0.9738
Epoch 25/85
60000/60000 [==============================] - 7s 117us/step - loss: 0.
0120 - accuracy: 0.9962 - val_loss: 0.0975 - val_accuracy: 0.9765
Epoch 26/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
0117 - accuracy: 0.9965 - val_loss: 0.1057 - val_accuracy: 0.9738
Epoch 27/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
0119 - accuracy: 0.9959 - val_loss: 0.0992 - val_accuracy: 0.9763
Epoch 28/85
60000/60000 [==============================] - 7s 123us/step - loss: 0.
0108 - accuracy: 0.9967 - val_loss: 0.0977 - val_accuracy: 0.9752
Epoch 29/85
60000/60000 [==============================] - 7s 117us/step - loss: 0.
0113 - accuracy: 0.9962 - val_loss: 0.1018 - val_accuracy: 0.9759
Epoch 30/85
60000/60000 [==============================] - 8s 127us/step - loss: 0.
0114 - accuracy: 0.9963 - val_loss: 0.1083 - val_accuracy: 0.9745
Epoch 31/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0105 - accuracy: 0.9966 - val_loss: 0.1084 - val_accuracy: 0.9752
Epoch 32/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
0080 - accuracy: 0.9973 - val_loss: 0.1064 - val_accuracy: 0.9757
Epoch 33/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0084 - accuracy: 0.9972 - val_loss: 0.1017 - val_accuracy: 0.9762
Epoch 34/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
0118 - accuracy: 0.9960 - val_loss: 0.1124 - val_accuracy: 0.9743
Epoch 35/85
```

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```
60000/60000 [==============================] - 7s 121us/step - loss: 0.
0081 - accuracy: 0.9975 - val_loss: 0.0957 - val_accuracy: 0.9770
Epoch 36/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0082 - accuracy: 0.9972 - val_loss: 0.1010 - val_accuracy: 0.9781
Epoch 37/85
60000/60000 [==============================] - 7s 122us/step - loss: 0.
0088 - accuracy: 0.9971 - val_loss: 0.0992 - val_accuracy: 0.9769
Epoch 38/85
60000/60000 [==============================] - 7s 118us/step - loss: 0.
0082 - accuracy: 0.9972 - val_loss: 0.1058 - val_accuracy: 0.9763
Epoch 39/85
60000/60000 [==============================] - 7s 122us/step - loss: 0.
0080 - accuracy: 0.9974 - val_loss: 0.1112 - val_accuracy: 0.9747
Epoch 40/85
60000/60000 [==============================] - 7s 117us/step - loss: 0.
0061 - accuracy: 0.9981 - val_loss: 0.0993 - val_accuracy: 0.9781
Epoch 41/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
0060 - accuracy: 0.9981 - val_loss: 0.1067 - val_accuracy: 0.9768
Epoch 42/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0056 - accuracy: 0.9981 - val_loss: 0.1111 - val_accuracy: 0.9771
Epoch 43/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
0065 - accuracy: 0.9977 - val_loss: 0.1082 - val_accuracy: 0.9770
Epoch 44/85
60000/60000 [==============================] - 7s 119us/step - loss: 0.
0070 - accuracy: 0.9977 - val_loss: 0.1056 - val_accuracy: 0.9759
Epoch 45/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
0086 - accuracy: 0.9971 - val_loss: 0.1153 - val_accuracy: 0.9770
Epoch 46/85
60000/60000 [==============================] - 8s 128us/step - loss: 0.
0090 - accuracy: 0.9969 - val_loss: 0.1065 - val_accuracy: 0.9790
Epoch 47/85
60000/60000 [==============================] - 7s 118us/step - loss: 0.
0063 - accuracy: 0.9979 - val_loss: 0.1148 - val_accuracy: 0.9763
Epoch 48/85
```

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```
60000/60000 [==============================] - 7s 124us/step - loss: 0.
0050 - accuracy: 0.9982 - val_loss: 0.1039 - val_accuracy: 0.9785
Epoch 49/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0047 - accuracy: 0.9984 - val_loss: 0.1216 - val_accuracy: 0.9770
Epoch 50/85
60000/60000 [==============================] - 7s 125us/step - loss: 0.
0051 - accuracy: 0.9983 - val_loss: 0.1206 - val_accuracy: 0.9768
Epoch 51/85
60000/60000 [==============================] - 7s 124us/step - loss: 0.
0079 - accuracy: 0.9974 - val_loss: 0.1269 - val_accuracy: 0.9762
Epoch 52/85
60000/60000 [==============================] - 8s 134us/step - loss: 0.
0088 - accuracy: 0.9969 - val_loss: 0.1219 - val_accuracy: 0.9752
Epoch 53/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
0071 - accuracy: 0.9974 - val_loss: 0.1184 - val_accuracy: 0.9754
Epoch 54/85
60000/60000 [==============================] - 7s 123us/step - loss: 0.
0042 - accuracy: 0.9986 - val_loss: 0.1180 - val_accuracy: 0.9759
Epoch 55/85
60000/60000 [==============================] - 7s 122us/step - loss: 0.
0050 - accuracy: 0.9983 - val_loss: 0.1196 - val_accuracy: 0.9765
Epoch 56/85
60000/60000 [==============================] - 8s 125us/step - loss: 0.
0042 - accuracy: 0.9985 - val_loss: 0.1217 - val_accuracy: 0.9762
Epoch 57/85
60000/60000 [==============================] - 7s 119us/step - loss: 0.
0050 - accuracy: 0.9983 - val_loss: 0.1154 - val_accuracy: 0.9777
Epoch 58/85
60000/60000 [==============================] - 7s 118us/step - loss: 0.
0065 - accuracy: 0.9979 - val_loss: 0.1256 - val_accuracy: 0.9764
Epoch 59/85
60000/60000 [==============================] - 7s 124us/step - loss: 0.
0044 - accuracy: 0.9984 - val_loss: 0.1134 - val_accuracy: 0.9781
Epoch 60/85
60000/60000 [==============================] - 7s 119us/step - loss: 0.
0051 - accuracy: 0.9983 - val_loss: 0.1374 - val_accuracy: 0.9748
Epoch 61/85
```

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```
60000/60000 [==============================] - 8s 131us/step - loss: 0.
0051 - accuracy: 0.9982 - val_loss: 0.1341 - val_accuracy: 0.9775
Epoch 62/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
0048 - accuracy: 0.9984 - val_loss: 0.1275 - val_accuracy: 0.9784
Epoch 63/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
0046 - accuracy: 0.9983 - val_loss: 0.1196 - val_accuracy: 0.9773
Epoch 64/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0038 - accuracy: 0.9987 - val_loss: 0.1216 - val_accuracy: 0.9777
Epoch 65/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
0060 - accuracy: 0.9980 - val_loss: 0.1199 - val_accuracy: 0.9779
Epoch 66/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0049 - accuracy: 0.9982 - val_loss: 0.1169 - val_accuracy: 0.9779
Epoch 67/85
60000/60000 [==============================] - 7s 118us/step - loss: 0.
0048 - accuracy: 0.9984 - val_loss: 0.1203 - val_accuracy: 0.9773
Epoch 68/85
60000/60000 [==============================] - 8s 126us/step - loss: 0.
0037 - accuracy: 0.9987 - val_loss: 0.1254 - val_accuracy: 0.9783
Epoch 69/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0038 - accuracy: 0.9987 - val_loss: 0.1206 - val_accuracy: 0.9788
Epoch 70/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0048 - accuracy: 0.9984 - val_loss: 0.1219 - val_accuracy: 0.9797
Epoch 71/85
60000/60000 [==============================] - 8s 130us/step - loss: 0.
0038 - accuracy: 0.9987 - val_loss: 0.1372 - val_accuracy: 0.9781
Epoch 72/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
0051 - accuracy: 0.9981 - val_loss: 0.1243 - val_accuracy: 0.9792
Epoch 73/85
60000/60000 [==============================] - 7s 118us/step - loss: 0.
0051 - accuracy: 0.9982 - val_loss: 0.1314 - val_accuracy: 0.9777
Epoch 74/85
```

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```
60000/60000 [==============================] - 7s 123us/step - loss: 0.
0053 - accuracy: 0.9980 - val_loss: 0.1307 - val_accuracy: 0.9774
Epoch 75/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
0054 - accuracy: 0.9981 - val_loss: 0.1161 - val_accuracy: 0.9795
Epoch 76/85
60000/60000 [==============================] - 7s 124us/step - loss: 0.
0040 - accuracy: 0.9988 - val_loss: 0.1138 - val_accuracy: 0.9805
Epoch 77/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
0036 - accuracy: 0.9988 - val_loss: 0.1101 - val_accuracy: 0.9806
Epoch 78/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
0030 - accuracy: 0.9989 - val_loss: 0.1163 - val_accuracy: 0.9800
Epoch 79/85
60000/60000 [==============================] - 7s 123us/step - loss: 0.
0061 - accuracy: 0.9980 - val_loss: 0.1191 - val_accuracy: 0.9774
Epoch 80/85
60000/60000 [==============================] - 7s 123us/step - loss: 0.
0041 - accuracy: 0.9987 - val_loss: 0.1193 - val_accuracy: 0.9800
Epoch 81/85
60000/60000 [==============================] - 7s 122us/step - loss: 0.
0025 - accuracy: 0.9991 - val_loss: 0.1220 - val_accuracy: 0.9783
Epoch 82/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
0045 - accuracy: 0.9985 - val_loss: 0.1297 - val_accuracy: 0.9765
Epoch 83/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
0043 - accuracy: 0.9986 - val_loss: 0.1255 - val_accuracy: 0.9770
Epoch 84/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
0029 - accuracy: 0.9991 - val_loss: 0.1237 - val_accuracy: 0.9787
Epoch 85/85
60000/60000 [==============================] - 8s 130us/step - loss: 0.
0042 - accuracy: 0.9987 - val_loss: 0.1269 - val_accuracy: 0.9774
```

1.1.6.3 Number of Epochs vs Train Loss & Validation Loss

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In [34]:
```
A1M6_score = model_batch.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A1M6_score[0])
print('Test accuracy:', A1M6_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in histrory.history we will have a list of length equal
 to number of epochs

vy = A1M6_history.history['val_loss']
ty = A1M6_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.12687595786054823
Test accuracy: 0.977400004863739
```

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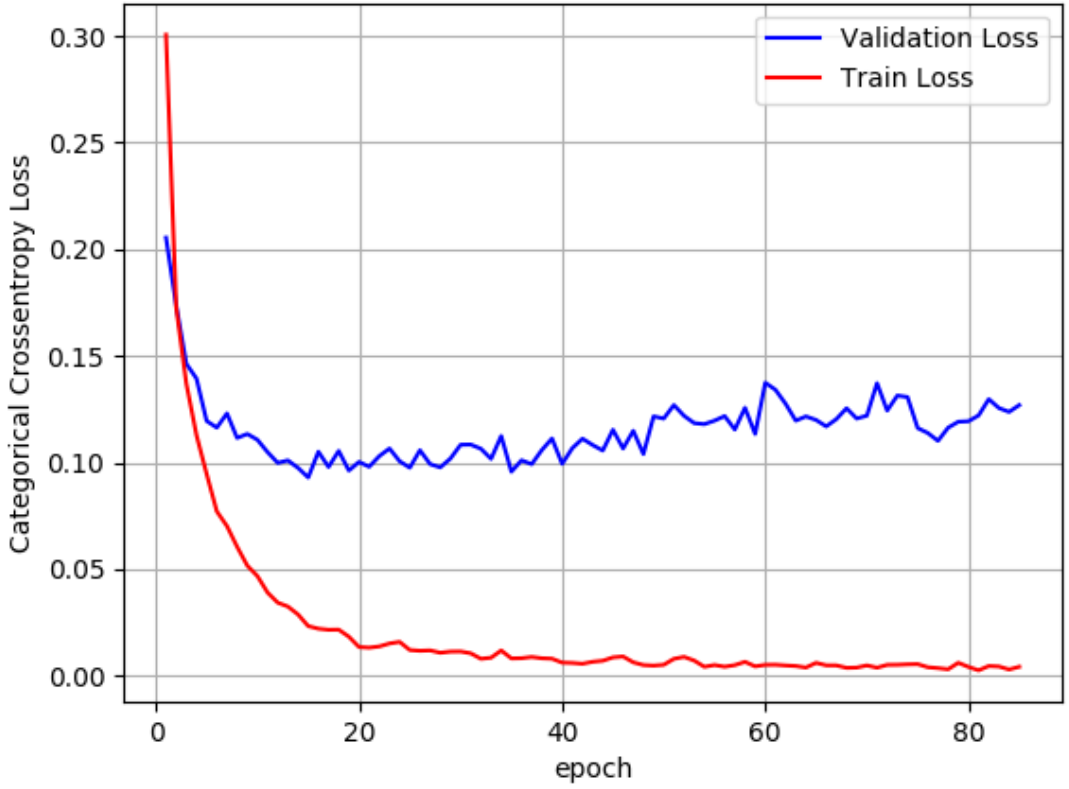

1.1.6.4 Violin Plots for Hidden Layers in Models Trained

In [35]:
```
w_after = model_batch.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
out_w = w_after[4].flatten().reshape(-1,1)
```

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```
fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 3, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 1')

plt.subplot(1, 3, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 2 ')

plt.subplot(1, 3, 3)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Output Layer ')
plt.show()
```

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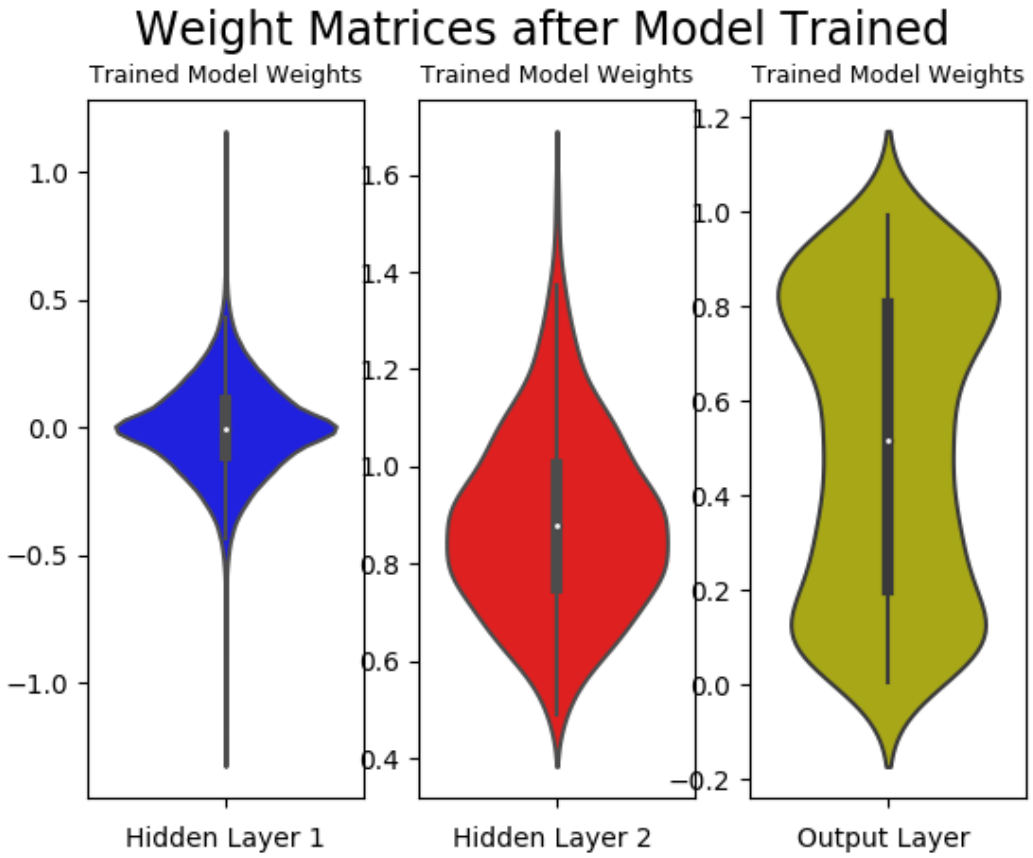

1.1.7 Model 7 : MLP + Batch Normalization + Dropout + Adam Optimizer

1.1.7.1 Constructing the Neural Network

In [36]:
```
# https://stackoverflow.com/questions/34716454/where-do-i-call-the-batc
hnormalization-function-in-keras

from keras.layers import Dropout
```

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```
model_drop = Sequential()

model_drop.add(Dense(512, activation='sigmoid', input_shape=(input_dim
,), \
                     kernel_initializer=RandomNormal(mean=0.0, stddev=
0.039, seed=None)))
model_drop.add(BatchNormalization())
model_drop.add(Dropout(0.5))

model_drop.add(Dense(128, activation='sigmoid', \
                     kernel_initializer=RandomNormal(mean=0.0, stddev=
0.55, seed=None)) )
model_drop.add(BatchNormalization())
model_drop.add(Dropout(0.5))

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

model_drop.summary()
```

```
Model: "sequential_7"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_17 (Dense)             (None, 512)               401920
_________________________________________________________________
batch_normalization_3 (Batch (None, 512)               2048
_________________________________________________________________
dropout_1 (Dropout)          (None, 512)               0
_________________________________________________________________
dense_18 (Dense)             (None, 128)               65664
_________________________________________________________________
batch_normalization_4 (Batch (None, 128)               512
_________________________________________________________________
dropout_2 (Dropout)          (None, 128)               0
_________________________________________________________________
dense_19 (Dense)             (None, 10)                1290
=================================================================
Total params: 471,434
Trainable params: 470,154
Non-trainable params: 1,280
```

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1.1.7.2 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [37]:
```
model_drop.compile(optimizer='adam', loss='categorical_crossentropy', m
etrics=['accuracy'])

A1M7_history = model_drop.fit(X_train, Y_train, batch_size=batch_size,
epochs=nb_epoch, verbose=1, \
                              validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 8s 133us/step - loss: 0.
6706 - accuracy: 0.7932 - val_loss: 0.2857 - val_accuracy: 0.9147
Epoch 2/85
60000/60000 [==============================] - 7s 117us/step - loss: 0.
4309 - accuracy: 0.8688 - val_loss: 0.2515 - val_accuracy: 0.9245
Epoch 3/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
3819 - accuracy: 0.8838 - val_loss: 0.2302 - val_accuracy: 0.9317
Epoch 4/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
3552 - accuracy: 0.8916 - val_loss: 0.2186 - val_accuracy: 0.9336
Epoch 5/85
60000/60000 [==============================] - 7s 117us/step - loss: 0.
3360 - accuracy: 0.8987 - val_loss: 0.2089 - val_accuracy: 0.9369
Epoch 6/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
3170 - accuracy: 0.9031 - val_loss: 0.2041 - val_accuracy: 0.9387
Epoch 7/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
3064 - accuracy: 0.9070 - val_loss: 0.1908 - val_accuracy: 0.9427
Epoch 8/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
2966 - accuracy: 0.9111 - val_loss: 0.1813 - val_accuracy: 0.9458
Epoch 9/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
2824 - accuracy: 0.9145 - val_loss: 0.1821 - val_accuracy: 0.9472
```

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```
Epoch 10/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
2687 - accuracy: 0.9179 - val_loss: 0.1679 - val_accuracy: 0.9511
Epoch 11/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
2607 - accuracy: 0.9213 - val_loss: 0.1628 - val_accuracy: 0.9534
Epoch 12/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
2501 - accuracy: 0.9251 - val_loss: 0.1538 - val_accuracy: 0.9547
Epoch 13/85
60000/60000 [==============================] - 7s 119us/step - loss: 0.
2387 - accuracy: 0.9282 - val_loss: 0.1426 - val_accuracy: 0.9576
Epoch 14/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
2296 - accuracy: 0.9311 - val_loss: 0.1353 - val_accuracy: 0.9599
Epoch 15/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
2179 - accuracy: 0.9332 - val_loss: 0.1291 - val_accuracy: 0.9605
Epoch 16/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
2090 - accuracy: 0.9373 - val_loss: 0.1305 - val_accuracy: 0.9598
Epoch 17/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
1992 - accuracy: 0.9402 - val_loss: 0.1224 - val_accuracy: 0.9632
Epoch 18/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
1894 - accuracy: 0.9429 - val_loss: 0.1178 - val_accuracy: 0.9650
Epoch 19/85
60000/60000 [==============================] - 7s 118us/step - loss: 0.
1851 - accuracy: 0.9434 - val_loss: 0.1128 - val_accuracy: 0.9662
Epoch 20/85
60000/60000 [==============================] - 7s 122us/step - loss: 0.
1758 - accuracy: 0.9464 - val_loss: 0.1082 - val_accuracy: 0.9689
Epoch 21/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
1697 - accuracy: 0.9492 - val_loss: 0.1025 - val_accuracy: 0.9697
Epoch 22/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
1624 - accuracy: 0.9517 - val_loss: 0.0989 - val_accuracy: 0.9715
```

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```
Epoch 23/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
1586 - accuracy: 0.9522 - val_loss: 0.1003 - val_accuracy: 0.9699
Epoch 24/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
1535 - accuracy: 0.9536 - val_loss: 0.0981 - val_accuracy: 0.9708
Epoch 25/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
1488 - accuracy: 0.9560 - val_loss: 0.0956 - val_accuracy: 0.9714
Epoch 26/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
1453 - accuracy: 0.9562 - val_loss: 0.0936 - val_accuracy: 0.9738
Epoch 27/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
1375 - accuracy: 0.9581 - val_loss: 0.0891 - val_accuracy: 0.9747
Epoch 28/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
1351 - accuracy: 0.9598 - val_loss: 0.0871 - val_accuracy: 0.9745
Epoch 29/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
1318 - accuracy: 0.9602 - val_loss: 0.0893 - val_accuracy: 0.9744
Epoch 30/85
60000/60000 [==============================] - 7s 123us/step - loss: 0.
1267 - accuracy: 0.9614 - val_loss: 0.0864 - val_accuracy: 0.9752
Epoch 31/85
60000/60000 [==============================] - 7s 117us/step - loss: 0.
1222 - accuracy: 0.9627 - val_loss: 0.0833 - val_accuracy: 0.9761
Epoch 32/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
1188 - accuracy: 0.9646 - val_loss: 0.0825 - val_accuracy: 0.9770
Epoch 33/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
1161 - accuracy: 0.9639 - val_loss: 0.0836 - val_accuracy: 0.9765
Epoch 34/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
1146 - accuracy: 0.9653 - val_loss: 0.0796 - val_accuracy: 0.9775
Epoch 35/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
1132 - accuracy: 0.9659 - val_loss: 0.0802 - val_accuracy: 0.9768
```

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```
Epoch 36/85
60000/60000 [==============================] - 7s 122us/step - loss: 0.
1105 - accuracy: 0.9669 - val_loss: 0.0771 - val_accuracy: 0.9776
Epoch 37/85
60000/60000 [==============================] - 8s 136us/step - loss: 0.
1065 - accuracy: 0.9669 - val_loss: 0.0764 - val_accuracy: 0.9788
Epoch 38/85
60000/60000 [==============================] - 7s 122us/step - loss: 0.
1025 - accuracy: 0.9680 - val_loss: 0.0761 - val_accuracy: 0.9788
Epoch 39/85
60000/60000 [==============================] - 8s 126us/step - loss: 0.
1020 - accuracy: 0.9695 - val_loss: 0.0762 - val_accuracy: 0.9781
Epoch 40/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
0957 - accuracy: 0.9706 - val_loss: 0.0788 - val_accuracy: 0.9775
Epoch 41/85
60000/60000 [==============================] - 8s 128us/step - loss: 0.
0977 - accuracy: 0.9703 - val_loss: 0.0746 - val_accuracy: 0.9800
Epoch 42/85
60000/60000 [==============================] - 7s 124us/step - loss: 0.
0955 - accuracy: 0.9705 - val_loss: 0.0717 - val_accuracy: 0.9803
Epoch 43/85
60000/60000 [==============================] - 8s 130us/step - loss: 0.
0893 - accuracy: 0.9724 - val_loss: 0.0727 - val_accuracy: 0.9797
Epoch 44/85
60000/60000 [==============================] - 7s 124us/step - loss: 0.
0906 - accuracy: 0.9724 - val_loss: 0.0716 - val_accuracy: 0.9804
Epoch 45/85
60000/60000 [==============================] - 7s 117us/step - loss: 0.
0872 - accuracy: 0.9727 - val_loss: 0.0727 - val_accuracy: 0.9804
Epoch 46/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0867 - accuracy: 0.9726 - val_loss: 0.0686 - val_accuracy: 0.9798
Epoch 47/85
60000/60000 [==============================] - 7s 124us/step - loss: 0.
0867 - accuracy: 0.9733 - val_loss: 0.0708 - val_accuracy: 0.9808
Epoch 48/85
60000/60000 [==============================] - 8s 129us/step - loss: 0.
0815 - accuracy: 0.9749 - val_loss: 0.0703 - val_accuracy: 0.9806
```

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```
Epoch 49/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
0821 - accuracy: 0.9747 - val_loss: 0.0698 - val_accuracy: 0.9810
Epoch 50/85
60000/60000 [==============================] - 7s 123us/step - loss: 0.
0814 - accuracy: 0.9751 - val_loss: 0.0701 - val_accuracy: 0.9819
Epoch 51/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0791 - accuracy: 0.9747 - val_loss: 0.0689 - val_accuracy: 0.9817
Epoch 52/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
0792 - accuracy: 0.9764 - val_loss: 0.0690 - val_accuracy: 0.9817
Epoch 53/85
60000/60000 [==============================] - 7s 123us/step - loss: 0.
0751 - accuracy: 0.9762 - val_loss: 0.0685 - val_accuracy: 0.9818
Epoch 54/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
0735 - accuracy: 0.9775 - val_loss: 0.0668 - val_accuracy: 0.9818
Epoch 55/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
0717 - accuracy: 0.9775 - val_loss: 0.0671 - val_accuracy: 0.9814
Epoch 56/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
0713 - accuracy: 0.9777 - val_loss: 0.0647 - val_accuracy: 0.9825
Epoch 57/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
0705 - accuracy: 0.9783 - val_loss: 0.0662 - val_accuracy: 0.9832
Epoch 58/85
60000/60000 [==============================] - 7s 117us/step - loss: 0.
0701 - accuracy: 0.9783 - val_loss: 0.0702 - val_accuracy: 0.9818
Epoch 59/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
0672 - accuracy: 0.9790 - val_loss: 0.0694 - val_accuracy: 0.9815
Epoch 60/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
0695 - accuracy: 0.9790 - val_loss: 0.0697 - val_accuracy: 0.9811
Epoch 61/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
0685 - accuracy: 0.9786 - val_loss: 0.0679 - val_accuracy: 0.9807
```

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```
Epoch 62/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0630 - accuracy: 0.9806 - val_loss: 0.0699 - val_accuracy: 0.9813
Epoch 63/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0627 - accuracy: 0.9798 - val_loss: 0.0694 - val_accuracy: 0.9818
Epoch 64/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
0621 - accuracy: 0.9808 - val_loss: 0.0671 - val_accuracy: 0.9828
Epoch 65/85
60000/60000 [==============================] - 7s 119us/step - loss: 0.
0611 - accuracy: 0.9808 - val_loss: 0.0694 - val_accuracy: 0.9823
Epoch 66/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
0603 - accuracy: 0.9811 - val_loss: 0.0698 - val_accuracy: 0.9820
Epoch 67/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0593 - accuracy: 0.9814 - val_loss: 0.0709 - val_accuracy: 0.9824
Epoch 68/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
0588 - accuracy: 0.9821 - val_loss: 0.0711 - val_accuracy: 0.9829
Epoch 69/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
0572 - accuracy: 0.9826 - val_loss: 0.0694 - val_accuracy: 0.9831
Epoch 70/85
60000/60000 [==============================] - 8s 127us/step - loss: 0.
0587 - accuracy: 0.9816 - val_loss: 0.0677 - val_accuracy: 0.9828
Epoch 71/85
60000/60000 [==============================] - 8s 131us/step - loss: 0.
0568 - accuracy: 0.9829 - val_loss: 0.0668 - val_accuracy: 0.9826
Epoch 72/85
60000/60000 [==============================] - 8s 128us/step - loss: 0.
0558 - accuracy: 0.9821 - val_loss: 0.0684 - val_accuracy: 0.9832
Epoch 73/85
60000/60000 [==============================] - 7s 124us/step - loss: 0.
0560 - accuracy: 0.9827 - val_loss: 0.0671 - val_accuracy: 0.9832
Epoch 74/85
60000/60000 [==============================] - 8s 130us/step - loss: 0.
0552 - accuracy: 0.9830 - val_loss: 0.0687 - val_accuracy: 0.9819
```

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```
Epoch 75/85
60000/60000 [==============================] - 7s 124us/step - loss: 0.
0543 - accuracy: 0.9829 - val_loss: 0.0674 - val_accuracy: 0.9828
Epoch 76/85
60000/60000 [==============================] - 8s 131us/step - loss: 0.
0515 - accuracy: 0.9836 - val_loss: 0.0684 - val_accuracy: 0.9830
Epoch 77/85
60000/60000 [==============================] - 8s 128us/step - loss: 0.
0523 - accuracy: 0.9843 - val_loss: 0.0665 - val_accuracy: 0.9834
Epoch 78/85
60000/60000 [==============================] - 8s 125us/step - loss: 0.
0506 - accuracy: 0.9847 - val_loss: 0.0647 - val_accuracy: 0.9836
Epoch 79/85
60000/60000 [==============================] - 8s 130us/step - loss: 0.
0495 - accuracy: 0.9847 - val_loss: 0.0708 - val_accuracy: 0.9819
Epoch 80/85
60000/60000 [==============================] - 8s 130us/step - loss: 0.
0497 - accuracy: 0.9852 - val_loss: 0.0671 - val_accuracy: 0.9831
Epoch 81/85
60000/60000 [==============================] - 7s 124us/step - loss: 0.
0471 - accuracy: 0.9854 - val_loss: 0.0677 - val_accuracy: 0.9834
Epoch 82/85
60000/60000 [==============================] - 8s 130us/step - loss: 0.
0493 - accuracy: 0.9842 - val_loss: 0.0689 - val_accuracy: 0.9827
Epoch 83/85
60000/60000 [==============================] - 7s 122us/step - loss: 0.
0457 - accuracy: 0.9855 - val_loss: 0.0696 - val_accuracy: 0.9824
Epoch 84/85
60000/60000 [==============================] - 8s 131us/step - loss: 0.
0471 - accuracy: 0.9848 - val_loss: 0.0683 - val_accuracy: 0.9833
Epoch 85/85
60000/60000 [==============================] - 8s 130us/step - loss: 0.
0450 - accuracy: 0.9859 - val_loss: 0.0667 - val_accuracy: 0.9833
```

1.1.7.3 Number of Epochs vs Train Loss & Validation Loss

In [38]:
```
A1M7_score = model_drop.evaluate(X_test, Y_test, verbose=0)
```

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```
print('Test score:', A1M7_score[0])
print('Test accuracy:', A1M7_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in histrory.histrory we will have a list of length equal
 to number of epochs

vy = A1M7_history.history['val_loss']
ty = A1M7_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.06671037031442392
Test accuracy: 0.983299970626831
```

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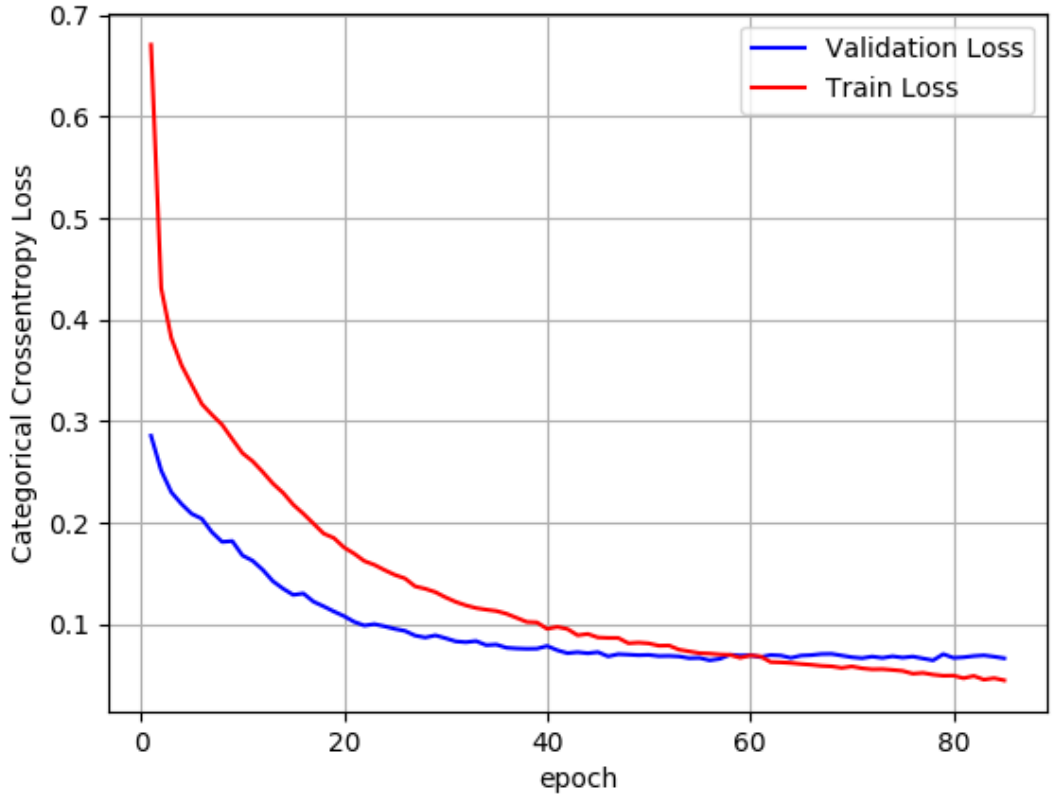

1.1.7.4 Violin Plots for Hidden Layers in Models Trained

In [39]:
```
w_after = model_drop.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
out_w = w_after[4].flatten().reshape(-1,1)
```

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```
fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 3, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 1')

plt.subplot(1, 3, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 2 ')

plt.subplot(1, 3, 3)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Output Layer ')
plt.show()
```

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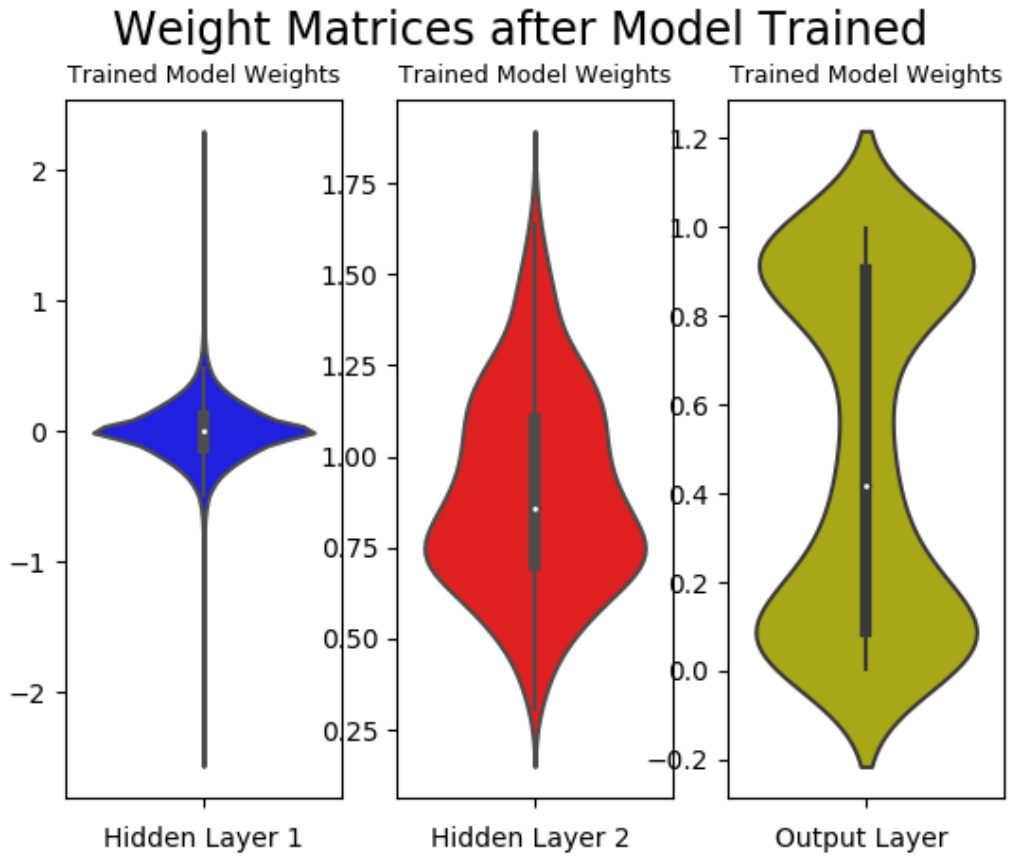

1.1.7.5 Hyper-parameter tuning of Keras Models using Sklearn

In [40]:
```
from keras.optimizers import Adam,RMSprop,SGD
def best_hyperparameters(activ):

    model = Sequential()
    model.add(Dense(512, activation=activ, input_shape=(input_dim,),\
                    kernel_initializer=RandomNormal(mean=0.0, stddev=0.
062, seed=None)))
    model.add(Dense(128, activation=activ, kernel_initializer=RandomNor
```

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```
mal(mean=0.0, stddev=0.125, seed=None)) )
    model.add(Dense(output_dim, activation='softmax'))


    model.compile(loss='categorical_crossentropy', metrics=['accuracy'
], optimizer='adam')

    return model
```

In [41]:

```
# https://machinelearningmastery.com/grid-search-hyperparameters-deep-l
earning-models-python-keras/

from datetime import datetime
start = datetime.now()

activ = ['sigmoid','relu']

from keras.wrappers.scikit_learn import KerasClassifier
from sklearn.model_selection import GridSearchCV

model = KerasClassifier(build_fn=best_hyperparameters, epochs=nb_epoch,
 batch_size=batch_size, verbose=0)
param_grid = dict(activ=activ)

# if you are using CPU
# grid = GridSearchCV(estimator=model, param_grid=param_grid, n_jobs=-
1)
# if you are using GPU dont use the n_jobs parameter

grid = GridSearchCV(estimator=model, param_grid=param_grid,cv=3,n_jobs=
-1)
grid_result = grid.fit(X_train, Y_train)

print('Time taken :', datetime.now() - start)
```

```
Time taken : 0:25:27.627696
```

In [42]:

```
print("Best: %f using %s" % (grid_result.best_score_, grid_result.best_
params_))
```

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```
means = grid_result.cv_results_['mean_test_score']
stds = grid_result.cv_results_['std_test_score']
params = grid_result.cv_results_['params']
for mean, stdev, param in zip(means, stds, params):
    print("%f (%f) with: %r" % (mean, stdev, param))
```

```
Best: 0.982000 using {'activ': 'relu'}
0.978717 (0.001226) with: {'activ': 'sigmoid'}
0.982000 (0.000795) with: {'activ': 'relu'}
```

Since we are obtaining the Best Results with ReLU as the activation function, and also because it doesn't have the disadvantages faced by sigmoid or tanh activations, we will only employ ReLU for our remaining models. Also since we know that the Adam Optimizer converges much much faster than the SGD, we only employ Adam for our remaining architectures. However, we will still experiment with the addition of Batch Normalization and Dropout Layers.

1.2 Architecture 2 :- 784-500-125-10

1.2.1 Model 1 : MLP + Adam Optimizer

1.2.1.1 Constructing the Neural Network

In [43]:
```
from keras.layers import Dropout
from keras.initializers import RandomUniform

# for ReLU Layers
# Using He-Uniform Weight Initialization
# h1 =>  σ=√(6/(fan_in) = 0.0874 (minval & maxval)
# h2 =>  σ=√(6/(fan_in) = 0.109 (minval & maxval)

arch2_model1 = Sequential()

arch2_model1.add(Dense(500, activation='relu', input_shape=(input_dim
,),\
```

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```
                        kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))

arch2_model1.add(Dense(125, activation='relu', \
                         kernel_initializer=RandomUniform(minval= -0.109,
 maxval=0.109, seed=None)) )

arch2_model1.add(Dense(output_dim, activation='softmax'))
arch2_model1.summary()
```

```
Model: "sequential_9"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_23 (Dense)             (None, 500)               392500
_________________________________________________________________
dense_24 (Dense)             (None, 125)               62625
_________________________________________________________________
dense_25 (Dense)             (None, 10)                1260
=================================================================
Total params: 456,385
Trainable params: 456,385
Non-trainable params: 0
_________________________________________________________________
```

1.2.1.2 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [44]:
```
arch2_model1.compile(optimizer='adam', loss='categorical_crossentropy',
 metrics=['accuracy'])

A2M1_history = arch2_model1.fit(X_train, Y_train, batch_size=batch_size
, epochs=nb_epoch, verbose=1, \
                             validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 5s 81us/step - loss: 0.2
392 - accuracy: 0.9301 - val_loss: 0.1197 - val_accuracy: 0.9639
```

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```
Epoch 2/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
853 - accuracy: 0.9742 - val_loss: 0.1072 - val_accuracy: 0.9659
Epoch 3/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
556 - accuracy: 0.9828 - val_loss: 0.0740 - val_accuracy: 0.9765
Epoch 4/85
60000/60000 [==============================] - 5s 80us/step - loss: 0.0
381 - accuracy: 0.9874 - val_loss: 0.0692 - val_accuracy: 0.9781
Epoch 5/85
60000/60000 [==============================] - 5s 77us/step - loss: 0.0
270 - accuracy: 0.9914 - val_loss: 0.0715 - val_accuracy: 0.9787
Epoch 6/85
60000/60000 [==============================] - 5s 75us/step - loss: 0.0
210 - accuracy: 0.9929 - val_loss: 0.0637 - val_accuracy: 0.9816
Epoch 7/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
173 - accuracy: 0.9942 - val_loss: 0.0680 - val_accuracy: 0.9809
Epoch 8/85
60000/60000 [==============================] - 5s 81us/step - loss: 0.0
124 - accuracy: 0.9960 - val_loss: 0.0895 - val_accuracy: 0.9757
Epoch 9/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
136 - accuracy: 0.9955 - val_loss: 0.1129 - val_accuracy: 0.9692
Epoch 10/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
146 - accuracy: 0.9951 - val_loss: 0.0769 - val_accuracy: 0.9785
Epoch 11/85
60000/60000 [==============================] - 5s 84us/step - loss: 0.0
082 - accuracy: 0.9972 - val_loss: 0.0765 - val_accuracy: 0.9799
Epoch 12/85
60000/60000 [==============================] - 5s 75us/step - loss: 0.0
082 - accuracy: 0.9974 - val_loss: 0.0805 - val_accuracy: 0.9802
Epoch 13/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
118 - accuracy: 0.9959 - val_loss: 0.0908 - val_accuracy: 0.9775
Epoch 14/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
129 - accuracy: 0.9955 - val_loss: 0.0899 - val_accuracy: 0.9793
```

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```
Epoch 15/85
60000/60000 [==============================] - 5s 82us/step - loss: 0.0
054 - accuracy: 0.9983 - val_loss: 0.0823 - val_accuracy: 0.9817
Epoch 16/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
073 - accuracy: 0.9975 - val_loss: 0.0816 - val_accuracy: 0.9817
Epoch 17/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
064 - accuracy: 0.9976 - val_loss: 0.0985 - val_accuracy: 0.9814
Epoch 18/85
60000/60000 [==============================] - 5s 75us/step - loss: 0.0
056 - accuracy: 0.9984 - val_loss: 0.1106 - val_accuracy: 0.9776
Epoch 19/85
60000/60000 [==============================] - 5s 80us/step - loss: 0.0
083 - accuracy: 0.9972 - val_loss: 0.0839 - val_accuracy: 0.9820
Epoch 20/85
60000/60000 [==============================] - 5s 77us/step - loss: 0.0
060 - accuracy: 0.9980 - val_loss: 0.1115 - val_accuracy: 0.9806
Epoch 21/85
60000/60000 [==============================] - 5s 80us/step - loss: 0.0
085 - accuracy: 0.9973 - val_loss: 0.1107 - val_accuracy: 0.9783
Epoch 22/85
60000/60000 [==============================] - 5s 77us/step - loss: 0.0
051 - accuracy: 0.9984 - val_loss: 0.0860 - val_accuracy: 0.9823
Epoch 23/85
60000/60000 [==============================] - 5s 77us/step - loss: 0.0
034 - accuracy: 0.9989 - val_loss: 0.0938 - val_accuracy: 0.9824
Epoch 24/85
60000/60000 [==============================] - 5s 81us/step - loss: 0.0
084 - accuracy: 0.9972 - val_loss: 0.1065 - val_accuracy: 0.9798
Epoch 25/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
094 - accuracy: 0.9972 - val_loss: 0.0910 - val_accuracy: 0.9825
Epoch 26/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
039 - accuracy: 0.9986 - val_loss: 0.0921 - val_accuracy: 0.9832
Epoch 27/85
60000/60000 [==============================] - 5s 77us/step - loss: 0.0
036 - accuracy: 0.9988 - val_loss: 0.1016 - val_accuracy: 0.9825
```

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```
Epoch 28/85
60000/60000 [==============================] - 5s 82us/step - loss: 0.0
044 - accuracy: 0.9987 - val_loss: 0.0956 - val_accuracy: 0.9812
Epoch 29/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
046 - accuracy: 0.9984 - val_loss: 0.1059 - val_accuracy: 0.9806
Epoch 30/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
038 - accuracy: 0.9987 - val_loss: 0.1024 - val_accuracy: 0.9806
Epoch 31/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
064 - accuracy: 0.9979 - val_loss: 0.1073 - val_accuracy: 0.9813
Epoch 32/85
60000/60000 [==============================] - 5s 80us/step - loss: 0.0
039 - accuracy: 0.9988 - val_loss: 0.1078 - val_accuracy: 0.9803
Epoch 33/85
60000/60000 [==============================] - 5s 78us/step - loss: 0.0
060 - accuracy: 0.9980 - val_loss: 0.1106 - val_accuracy: 0.9806
Epoch 34/85
60000/60000 [==============================] - 5s 77us/step - loss: 0.0
052 - accuracy: 0.9984 - val_loss: 0.1088 - val_accuracy: 0.9809
Epoch 35/85
60000/60000 [==============================] - 5s 80us/step - loss: 0.0
024 - accuracy: 0.9991 - val_loss: 0.1003 - val_accuracy: 0.9836
Epoch 36/85
60000/60000 [==============================] - 5s 80us/step - loss: 0.0
043 - accuracy: 0.9987 - val_loss: 0.1160 - val_accuracy: 0.9809
Epoch 37/85
60000/60000 [==============================] - 5s 80us/step - loss: 0.0
050 - accuracy: 0.9984 - val_loss: 0.1270 - val_accuracy: 0.9808
Epoch 38/85
60000/60000 [==============================] - 5s 83us/step - loss: 0.0
019 - accuracy: 0.9995 - val_loss: 0.0920 - val_accuracy: 0.9846
Epoch 39/85
60000/60000 [==============================] - 5s 78us/step - loss: 1.3
870e-04 - accuracy: 1.0000 - val_loss: 0.0932 - val_accuracy: 0.9851
Epoch 40/85
60000/60000 [==============================] - 5s 85us/step - loss: 0.0
059 - accuracy: 0.9982 - val_loss: 0.1273 - val_accuracy: 0.9807
```

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```
Epoch 41/85
60000/60000 [==============================] - 5s 86us/step - loss: 0.0
110 - accuracy: 0.9966 - val_loss: 0.1098 - val_accuracy: 0.9830
Epoch 42/85
60000/60000 [==============================] - 5s 80us/step - loss: 0.0
024 - accuracy: 0.9991 - val_loss: 0.1143 - val_accuracy: 0.9829
Epoch 43/85
60000/60000 [==============================] - 5s 79us/step - loss: 0.0
054 - accuracy: 0.9983 - val_loss: 0.1070 - val_accuracy: 0.9835
Epoch 44/85
60000/60000 [==============================] - 6s 93us/step - loss: 0.0
021 - accuracy: 0.9993 - val_loss: 0.1120 - val_accuracy: 0.9822
Epoch 45/85
60000/60000 [==============================] - 5s 79us/step - loss: 0.0
016 - accuracy: 0.9995 - val_loss: 0.0976 - val_accuracy: 0.9842
Epoch 46/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
056 - accuracy: 0.9984 - val_loss: 0.1404 - val_accuracy: 0.9800
Epoch 47/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
066 - accuracy: 0.9980 - val_loss: 0.1155 - val_accuracy: 0.9817
Epoch 48/85
60000/60000 [==============================] - 5s 81us/step - loss: 0.0
031 - accuracy: 0.9992 - val_loss: 0.1015 - val_accuracy: 0.9844
Epoch 49/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
026 - accuracy: 0.9991 - val_loss: 0.1081 - val_accuracy: 0.9837
Epoch 50/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
019 - accuracy: 0.9995 - val_loss: 0.0978 - val_accuracy: 0.9855
Epoch 51/85
60000/60000 [==============================] - 5s 87us/step - loss: 1.0
598e-04 - accuracy: 1.0000 - val_loss: 0.0930 - val_accuracy: 0.9860
Epoch 52/85
60000/60000 [==============================] - 5s 83us/step - loss: 1.7
977e-05 - accuracy: 1.0000 - val_loss: 0.0934 - val_accuracy: 0.9861
Epoch 53/85
60000/60000 [==============================] - 5s 78us/step - loss: 8.8
916e-06 - accuracy: 1.0000 - val_loss: 0.0933 - val_accuracy: 0.9862
```

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```
Epoch 54/85
60000/60000 [==============================] - 5s 83us/step - loss: 6.7
554e-06 - accuracy: 1.0000 - val_loss: 0.0935 - val_accuracy: 0.9863
Epoch 55/85
60000/60000 [==============================] - 5s 79us/step - loss: 5.4
622e-06 - accuracy: 1.0000 - val_loss: 0.0939 - val_accuracy: 0.9862
Epoch 56/85
60000/60000 [==============================] - 5s 82us/step - loss: 4.4
625e-06 - accuracy: 1.0000 - val_loss: 0.0942 - val_accuracy: 0.9864
Epoch 57/85
60000/60000 [==============================] - 5s 83us/step - loss: 3.6
837e-06 - accuracy: 1.0000 - val_loss: 0.0947 - val_accuracy: 0.9863
Epoch 58/85
60000/60000 [==============================] - 5s 80us/step - loss: 3.0
481e-06 - accuracy: 1.0000 - val_loss: 0.0950 - val_accuracy: 0.9863
Epoch 59/85
60000/60000 [==============================] - 5s 80us/step - loss: 2.5
140e-06 - accuracy: 1.0000 - val_loss: 0.0954 - val_accuracy: 0.9865
Epoch 60/85
60000/60000 [==============================] - 5s 76us/step - loss: 2.0
746e-06 - accuracy: 1.0000 - val_loss: 0.0960 - val_accuracy: 0.9864
Epoch 61/85
60000/60000 [==============================] - 6s 101us/step - loss: 1.
7087e-06 - accuracy: 1.0000 - val_loss: 0.0966 - val_accuracy: 0.9867
Epoch 62/85
60000/60000 [==============================] - 5s 76us/step - loss: 1.4
056e-06 - accuracy: 1.0000 - val_loss: 0.0972 - val_accuracy: 0.9868
Epoch 63/85
60000/60000 [==============================] - 5s 76us/step - loss: 1.1
480e-06 - accuracy: 1.0000 - val_loss: 0.0978 - val_accuracy: 0.9868
Epoch 64/85
60000/60000 [==============================] - 5s 76us/step - loss: 9.3
603e-07 - accuracy: 1.0000 - val_loss: 0.0984 - val_accuracy: 0.9867
Epoch 65/85
60000/60000 [==============================] - 5s 81us/step - loss: 7.6
311e-07 - accuracy: 1.0000 - val_loss: 0.0991 - val_accuracy: 0.9868
Epoch 66/85
60000/60000 [==============================] - 5s 76us/step - loss: 6.1
474e-07 - accuracy: 1.0000 - val_loss: 0.1001 - val_accuracy: 0.9869
```

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```
Epoch 67/85
60000/60000 [==============================] - 5s 76us/step - loss: 4.9
739e-07 - accuracy: 1.0000 - val_loss: 0.1009 - val_accuracy: 0.9868
Epoch 68/85
60000/60000 [==============================] - 5s 81us/step - loss: 3.9
884e-07 - accuracy: 1.0000 - val_loss: 0.1015 - val_accuracy: 0.9869
Epoch 69/85
60000/60000 [==============================] - 5s 77us/step - loss: 3.2
251e-07 - accuracy: 1.0000 - val_loss: 0.1026 - val_accuracy: 0.9867
Epoch 70/85
60000/60000 [==============================] - 5s 75us/step - loss: 2.5
884e-07 - accuracy: 1.0000 - val_loss: 0.1034 - val_accuracy: 0.9867
Epoch 71/85
60000/60000 [==============================] - 5s 79us/step - loss: 2.0
674e-07 - accuracy: 1.0000 - val_loss: 0.1044 - val_accuracy: 0.9867
Epoch 72/85
60000/60000 [==============================] - 5s 77us/step - loss: 1.6
556e-07 - accuracy: 1.0000 - val_loss: 0.1055 - val_accuracy: 0.9867
Epoch 73/85
60000/60000 [==============================] - 5s 83us/step - loss: 1.3
300e-07 - accuracy: 1.0000 - val_loss: 0.1062 - val_accuracy: 0.9868
Epoch 74/85
60000/60000 [==============================] - 6s 94us/step - loss: 1.0
696e-07 - accuracy: 1.0000 - val_loss: 0.1072 - val_accuracy: 0.9868
Epoch 75/85
60000/60000 [==============================] - 5s 80us/step - loss: 8.5
622e-08 - accuracy: 1.0000 - val_loss: 0.1083 - val_accuracy: 0.9869
Epoch 76/85
60000/60000 [==============================] - 5s 82us/step - loss: 6.9
052e-08 - accuracy: 1.0000 - val_loss: 0.1093 - val_accuracy: 0.9868
Epoch 77/85
60000/60000 [==============================] - 5s 89us/step - loss: 5.5
355e-08 - accuracy: 1.0000 - val_loss: 0.1101 - val_accuracy: 0.9869
Epoch 78/85
60000/60000 [==============================] - 5s 82us/step - loss: 4.4
837e-08 - accuracy: 1.0000 - val_loss: 0.1112 - val_accuracy: 0.9868
Epoch 79/85
60000/60000 [==============================] - 5s 78us/step - loss: 3.6
412e-08 - accuracy: 1.0000 - val_loss: 0.1121 - val_accuracy: 0.9870
```

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```
Epoch 80/85
60000/60000 [==============================] - 5s 81us/step - loss: 2.9
633e-08 - accuracy: 1.0000 - val_loss: 0.1131 - val_accuracy: 0.9866
Epoch 81/85
60000/60000 [==============================] - 5s 88us/step - loss: 2.4
194e-08 - accuracy: 1.0000 - val_loss: 0.1140 - val_accuracy: 0.9869
Epoch 82/85
60000/60000 [==============================] - 5s 85us/step - loss: 1.9
950e-08 - accuracy: 1.0000 - val_loss: 0.1150 - val_accuracy: 0.9870
Epoch 83/85
60000/60000 [==============================] - 5s 84us/step - loss: 1.6
584e-08 - accuracy: 1.0000 - val_loss: 0.1158 - val_accuracy: 0.9870
Epoch 84/85
60000/60000 [==============================] - 5s 85us/step - loss: 1.3
767e-08 - accuracy: 1.0000 - val_loss: 0.1170 - val_accuracy: 0.9871
Epoch 85/85
60000/60000 [==============================] - 5s 82us/step - loss: 1.1
484e-08 - accuracy: 1.0000 - val_loss: 0.1176 - val_accuracy: 0.9870
```

1.2.1.3 Number of Epochs vs Train Loss & Validation Loss

In [45]:

```python
A2M1_score = arch2_model1.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A2M1_score[0])
print('Test accuracy:', A2M1_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
```

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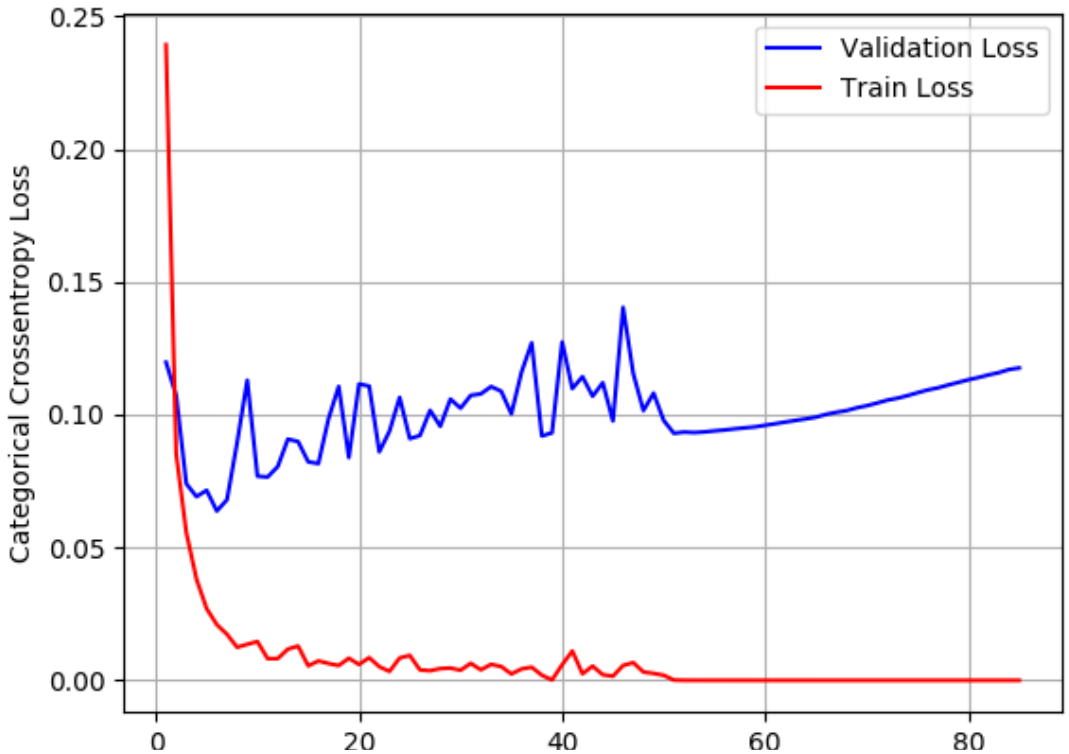
```
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in history.history we will have a list of length equal t
o number of epochs

vy = A2M1_history.history['val_loss']
ty = A2M1_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.11757605352995124
Test accuracy: 0.9869999885559082
```



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epoch

1.2.1.4 Violin Plots for Hidden Layers in Models Trained

In [46]:
```
w_after = arch2_model1.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
out_w = w_after[4].flatten().reshape(-1,1)

fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 3, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 1')

plt.subplot(1, 3, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 2 ')

plt.subplot(1, 3, 3)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Output Layer ')
plt.show()
```

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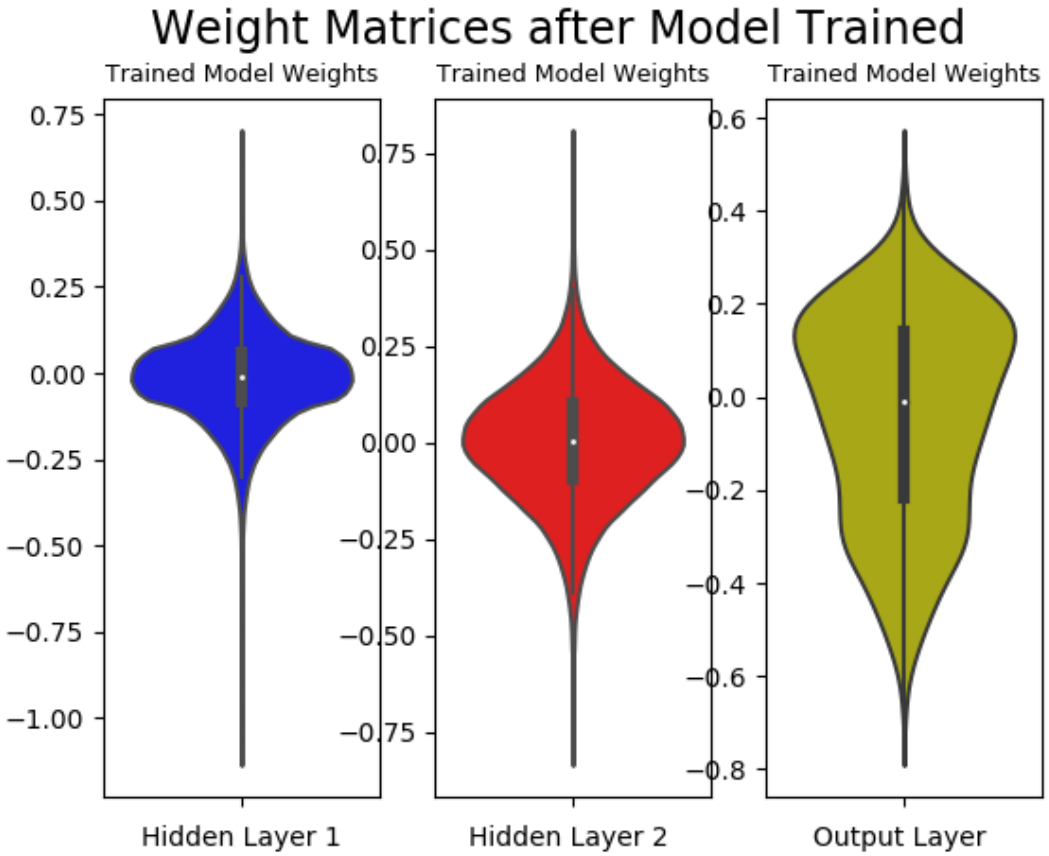

1.2.2 Model 2 : MLP + BatchNormalization + Adam Optimizer

1.2.2.1 Constructing the Neural Network

In [47]:
```
arch2_model2 = Sequential()

arch2_model2.add(Dense(500, activation='relu', input_shape=(input_dim
,),\
                       kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))
```

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```
arch2_model2.add(BatchNormalization())

arch2_model2.add(Dense(125, activation='relu', \
                       kernel_initializer=RandomUniform(minval= -0.109,
 maxval=0.109, seed=None)) )
arch2_model2.add(BatchNormalization())

arch2_model2.add(Dense(output_dim, activation='softmax'))
arch2_model2.summary()
```

```
Model: "sequential_10"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_26 (Dense)             (None, 500)               392500
_________________________________________________________________
batch_normalization_5 (Batch (None, 500)               2000
_________________________________________________________________
dense_27 (Dense)             (None, 125)               62625
_________________________________________________________________
batch_normalization_6 (Batch (None, 125)               500
_________________________________________________________________
dense_28 (Dense)             (None, 10)                1260
=================================================================
Total params: 458,885
Trainable params: 457,635
Non-trainable params: 1,250
_________________________________________________________________
```

1.2.2.2 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [48]:
```
arch2_model2.compile(optimizer='adam', loss='categorical_crossentropy',
 metrics=['accuracy'])

A2M2_history = arch2_model2.fit(X_train, Y_train, batch_size=batch_size
, epochs=nb_epoch, verbose=1, \
                             validation_data=(X_test, Y_test))
```

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```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 7s 114us/step - loss: 0.
1894 - accuracy: 0.9431 - val_loss: 0.0972 - val_accuracy: 0.9708
Epoch 2/85
60000/60000 [==============================] - 6s 103us/step - loss: 0.
0696 - accuracy: 0.9789 - val_loss: 0.0827 - val_accuracy: 0.9742
Epoch 3/85
60000/60000 [==============================] - 6s 107us/step - loss: 0.
0456 - accuracy: 0.9860 - val_loss: 0.0721 - val_accuracy: 0.9775
Epoch 4/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0325 - accuracy: 0.9897 - val_loss: 0.0729 - val_accuracy: 0.9782
Epoch 5/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0258 - accuracy: 0.9919 - val_loss: 0.0837 - val_accuracy: 0.9759
Epoch 6/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0205 - accuracy: 0.9935 - val_loss: 0.0935 - val_accuracy: 0.9726
Epoch 7/85
60000/60000 [==============================] - 6s 107us/step - loss: 0.
0199 - accuracy: 0.9930 - val_loss: 0.0857 - val_accuracy: 0.9750
Epoch 8/85
60000/60000 [==============================] - 6s 105us/step - loss: 0.
0162 - accuracy: 0.9947 - val_loss: 0.0850 - val_accuracy: 0.9750
Epoch 9/85
60000/60000 [==============================] - 6s 107us/step - loss: 0.
0142 - accuracy: 0.9953 - val_loss: 0.0914 - val_accuracy: 0.9759
Epoch 10/85
60000/60000 [==============================] - 6s 107us/step - loss: 0.
0138 - accuracy: 0.9954 - val_loss: 0.0656 - val_accuracy: 0.9815
Epoch 11/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0111 - accuracy: 0.9964 - val_loss: 0.0787 - val_accuracy: 0.9796
Epoch 12/85
60000/60000 [==============================] - 7s 108us/step - loss: 0.
0137 - accuracy: 0.9953 - val_loss: 0.0780 - val_accuracy: 0.9794
Epoch 13/85
60000/60000 [==============================] - 6s 105us/step - loss: 0.
```

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```
0103 - accuracy: 0.9966 - val_loss: 0.0789 - val_accuracy: 0.9803
Epoch 14/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0097 - accuracy: 0.9967 - val_loss: 0.0799 - val_accuracy: 0.9806
Epoch 15/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0099 - accuracy: 0.9966 - val_loss: 0.0822 - val_accuracy: 0.9799
Epoch 16/85
60000/60000 [==============================] - 6s 106us/step - loss: 0.
0099 - accuracy: 0.9966 - val_loss: 0.0881 - val_accuracy: 0.9778
Epoch 17/85
60000/60000 [==============================] - 6s 100us/step - loss: 0.
0085 - accuracy: 0.9972 - val_loss: 0.0824 - val_accuracy: 0.9797
Epoch 18/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0094 - accuracy: 0.9969 - val_loss: 0.0768 - val_accuracy: 0.9794
Epoch 19/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0076 - accuracy: 0.9973 - val_loss: 0.0752 - val_accuracy: 0.9820
Epoch 20/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0065 - accuracy: 0.9977 - val_loss: 0.0788 - val_accuracy: 0.9809
Epoch 21/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0054 - accuracy: 0.9984 - val_loss: 0.0959 - val_accuracy: 0.9802
Epoch 22/85
60000/60000 [==============================] - 7s 114us/step - loss: 0.
0051 - accuracy: 0.9983 - val_loss: 0.0814 - val_accuracy: 0.9815
Epoch 23/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0041 - accuracy: 0.9988 - val_loss: 0.0806 - val_accuracy: 0.9812
Epoch 24/85
60000/60000 [==============================] - 6s 105us/step - loss: 0.
0071 - accuracy: 0.9975 - val_loss: 0.0938 - val_accuracy: 0.9809
Epoch 25/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0085 - accuracy: 0.9971 - val_loss: 0.0892 - val_accuracy: 0.9803
Epoch 26/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
```

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```
0046 - accuracy: 0.9986 - val_loss: 0.0821 - val_accuracy: 0.9818
Epoch 27/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0049 - accuracy: 0.9983 - val_loss: 0.0845 - val_accuracy: 0.9829
Epoch 28/85
60000/60000 [==============================] - 6s 105us/step - loss: 0.
0045 - accuracy: 0.9985 - val_loss: 0.0866 - val_accuracy: 0.9818
Epoch 29/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0035 - accuracy: 0.9988 - val_loss: 0.0951 - val_accuracy: 0.9789
Epoch 30/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0051 - accuracy: 0.9984 - val_loss: 0.0871 - val_accuracy: 0.9820
Epoch 31/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0046 - accuracy: 0.9984 - val_loss: 0.0967 - val_accuracy: 0.9806
Epoch 32/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0053 - accuracy: 0.9984 - val_loss: 0.0972 - val_accuracy: 0.9799
Epoch 33/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
0034 - accuracy: 0.9988 - val_loss: 0.0869 - val_accuracy: 0.9832
Epoch 34/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0033 - accuracy: 0.9989 - val_loss: 0.0888 - val_accuracy: 0.9808
Epoch 35/85
60000/60000 [==============================] - 6s 106us/step - loss: 0.
0043 - accuracy: 0.9986 - val_loss: 0.0983 - val_accuracy: 0.9806
Epoch 36/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0055 - accuracy: 0.9981 - val_loss: 0.0899 - val_accuracy: 0.9808
Epoch 37/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0030 - accuracy: 0.9990 - val_loss: 0.0936 - val_accuracy: 0.9803
Epoch 38/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0032 - accuracy: 0.9990 - val_loss: 0.0812 - val_accuracy: 0.9824
Epoch 39/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
```

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```
0047 - accuracy: 0.9984 - val_loss: 0.0919 - val_accuracy: 0.9818
Epoch 40/85
60000/60000 [==============================] - 6s 107us/step - loss: 0.
0055 - accuracy: 0.9981 - val_loss: 0.0952 - val_accuracy: 0.9808
Epoch 41/85
60000/60000 [==============================] - 6s 105us/step - loss: 0.
0033 - accuracy: 0.9989 - val_loss: 0.0841 - val_accuracy: 0.9829
Epoch 42/85
60000/60000 [==============================] - 6s 105us/step - loss: 0.
0022 - accuracy: 0.9993 - val_loss: 0.0826 - val_accuracy: 0.9829
Epoch 43/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0029 - accuracy: 0.9991 - val_loss: 0.0832 - val_accuracy: 0.9829
Epoch 44/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0041 - accuracy: 0.9987 - val_loss: 0.1044 - val_accuracy: 0.9796
Epoch 45/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0047 - accuracy: 0.9985 - val_loss: 0.0840 - val_accuracy: 0.9827
Epoch 46/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0036 - accuracy: 0.9988 - val_loss: 0.0889 - val_accuracy: 0.9835
Epoch 47/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0020 - accuracy: 0.9992 - val_loss: 0.0898 - val_accuracy: 0.9833
Epoch 48/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0023 - accuracy: 0.9994 - val_loss: 0.0922 - val_accuracy: 0.9817
Epoch 49/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0018 - accuracy: 0.9995 - val_loss: 0.0882 - val_accuracy: 0.9831
Epoch 50/85
60000/60000 [==============================] - 7s 108us/step - loss: 0.
0025 - accuracy: 0.9992 - val_loss: 0.0937 - val_accuracy: 0.9823
Epoch 51/85
60000/60000 [==============================] - 6s 105us/step - loss: 0.
0027 - accuracy: 0.9991 - val_loss: 0.0943 - val_accuracy: 0.9829
Epoch 52/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
```

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```
0036 - accuracy: 0.9990 - val_loss: 0.0905 - val_accuracy: 0.9830
Epoch 53/85
60000/60000 [==============================] - 6s 107us/step - loss: 0.
0029 - accuracy: 0.9989 - val_loss: 0.0878 - val_accuracy: 0.9842
Epoch 54/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0020 - accuracy: 0.9994 - val_loss: 0.0820 - val_accuracy: 0.9834
Epoch 55/85
60000/60000 [==============================] - 6s 107us/step - loss: 0.
0036 - accuracy: 0.9987 - val_loss: 0.0960 - val_accuracy: 0.9809
Epoch 56/85
60000/60000 [==============================] - 6s 102us/step - loss: 0.
0022 - accuracy: 0.9993 - val_loss: 0.0840 - val_accuracy: 0.9849
Epoch 57/85
60000/60000 [==============================] - 6s 106us/step - loss: 0.
0014 - accuracy: 0.9997 - val_loss: 0.0835 - val_accuracy: 0.9847
Epoch 58/85
60000/60000 [==============================] - 6s 103us/step - loss: 0.
0020 - accuracy: 0.9995 - val_loss: 0.0959 - val_accuracy: 0.9838
Epoch 59/85
60000/60000 [==============================] - 6s 106us/step - loss: 0.
0033 - accuracy: 0.9990 - val_loss: 0.0848 - val_accuracy: 0.9833
Epoch 60/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0024 - accuracy: 0.9993 - val_loss: 0.0864 - val_accuracy: 0.9827
Epoch 61/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0024 - accuracy: 0.9992 - val_loss: 0.0861 - val_accuracy: 0.9841
Epoch 62/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0027 - accuracy: 0.9991 - val_loss: 0.0969 - val_accuracy: 0.9815
Epoch 63/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0019 - accuracy: 0.9994 - val_loss: 0.0890 - val_accuracy: 0.9837
Epoch 64/85
60000/60000 [==============================] - 6s 103us/step - loss: 0.
0022 - accuracy: 0.9992 - val_loss: 0.0868 - val_accuracy: 0.9840
Epoch 65/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
```

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```
0024 - accuracy: 0.9993 - val_loss: 0.0833 - val_accuracy: 0.9849
Epoch 66/85
60000/60000 [==============================] - 6s 103us/step - loss: 0.
0025 - accuracy: 0.9992 - val_loss: 0.0781 - val_accuracy: 0.9858
Epoch 67/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0020 - accuracy: 0.9993 - val_loss: 0.0887 - val_accuracy: 0.9838
Epoch 68/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0024 - accuracy: 0.9992 - val_loss: 0.0780 - val_accuracy: 0.9874
Epoch 69/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0017 - accuracy: 0.9993 - val_loss: 0.0834 - val_accuracy: 0.9861
Epoch 70/85
60000/60000 [==============================] - 7s 108us/step - loss: 0.
0017 - accuracy: 0.9995 - val_loss: 0.0870 - val_accuracy: 0.9863
Epoch 71/85
60000/60000 [==============================] - 6s 102us/step - loss: 0.
0038 - accuracy: 0.9988 - val_loss: 0.0889 - val_accuracy: 0.9835
Epoch 72/85
60000/60000 [==============================] - 6s 106us/step - loss: 0.
0030 - accuracy: 0.9991 - val_loss: 0.0849 - val_accuracy: 0.9848
Epoch 73/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0012 - accuracy: 0.9996 - val_loss: 0.0921 - val_accuracy: 0.9847
Epoch 74/85
60000/60000 [==============================] - 6s 104us/step - loss: 7.
3458e-04 - accuracy: 0.9998 - val_loss: 0.0862 - val_accuracy: 0.9853
Epoch 75/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0017 - accuracy: 0.9994 - val_loss: 0.0976 - val_accuracy: 0.9848
Epoch 76/85
60000/60000 [==============================] - 7s 114us/step - loss: 0.
0024 - accuracy: 0.9991 - val_loss: 0.0929 - val_accuracy: 0.9843
Epoch 77/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0027 - accuracy: 0.9992 - val_loss: 0.0931 - val_accuracy: 0.9855
Epoch 78/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
```

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```
0015 - accuracy: 0.9996 - val_loss: 0.0958 - val_accuracy: 0.9850
Epoch 79/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0012 - accuracy: 0.9997 - val_loss: 0.0898 - val_accuracy: 0.9849
Epoch 80/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0020 - accuracy: 0.9993 - val_loss: 0.1036 - val_accuracy: 0.9830
Epoch 81/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0018 - accuracy: 0.9995 - val_loss: 0.1069 - val_accuracy: 0.9844
Epoch 82/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0018 - accuracy: 0.9994 - val_loss: 0.0943 - val_accuracy: 0.9847
Epoch 83/85
60000/60000 [==============================] - 6s 106us/step - loss: 9.
1271e-04 - accuracy: 0.9998 - val_loss: 0.0984 - val_accuracy: 0.9822
Epoch 84/85
60000/60000 [==============================] - 6s 105us/step - loss: 0.
0012 - accuracy: 0.9995 - val_loss: 0.1071 - val_accuracy: 0.9813
Epoch 85/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0031 - accuracy: 0.9990 - val_loss: 0.1126 - val_accuracy: 0.9822
```

1.2.2.3 Number of Epochs vs Train Loss & Validation Loss

In [49]:

```
A2M2_score = arch2_model2.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A2M2_score[0])
print('Test accuracy:', A2M2_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
```

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```
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in history.history we will have a list of length equal t
o number of epochs

vy = A2M2_history.history['val_loss']
ty = A2M2_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.11263822395573155
Test accuracy: 0.982200026512146
```

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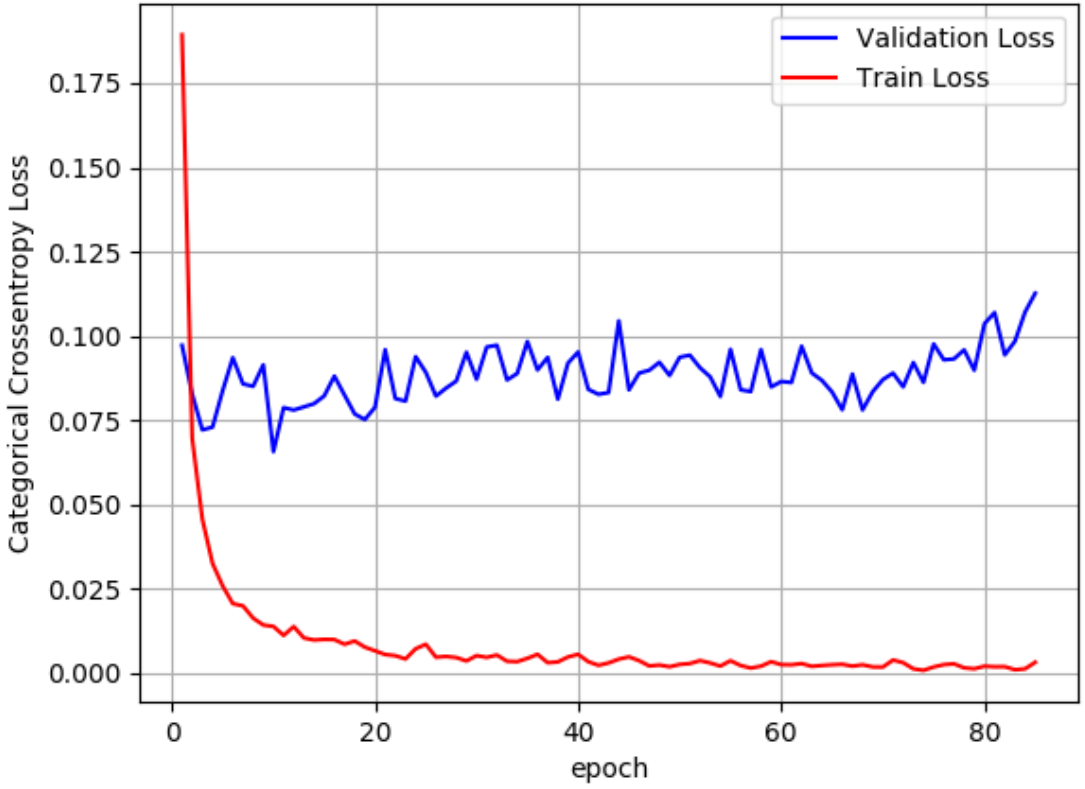

1.2.2.4 Violin Plots for Hidden Layers in Models Trained

In [50]:
```
w_after = arch2_model2.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
out_w = w_after[4].flatten().reshape(-1,1)
```

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```
fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 3, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 1')

plt.subplot(1, 3, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 2 ')

plt.subplot(1, 3, 3)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Output Layer ')
plt.show()
```

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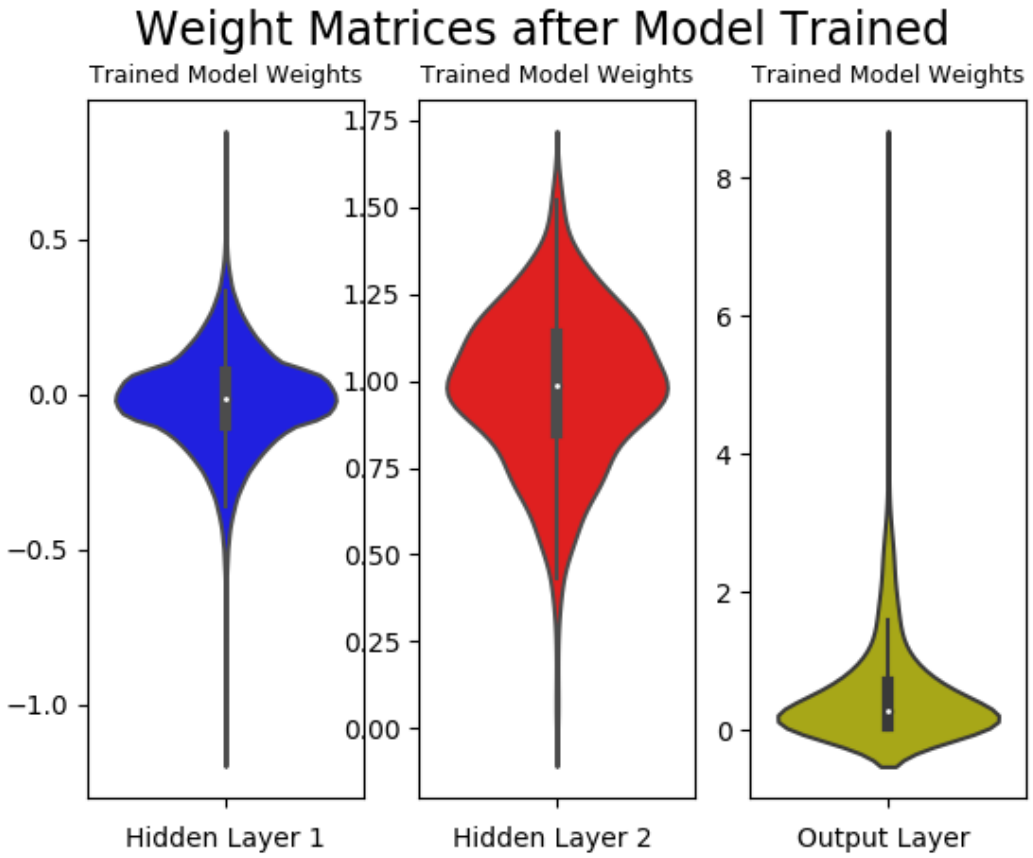

1.2.3 Model 3 : MLP + BatchNormalization + Dropout + Adam Optimizer

1.2.3.1 Hyperparameter Tuning for Dropout

In [51]:
```
def A2M3_best_hyperparameters(dropout):
    arch2_model3 = Sequential()

    arch2_model3.add(Dense(500, activation='relu', input_shape=(input_d
im,),\
```

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```
                        kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))
    arch2_model3.add(BatchNormalization())
    arch2_model3.add(Dropout(dropout))

    arch2_model3.add(Dense(125, activation='relu', \
                         kernel_initializer=RandomUniform(minval= -0.109,
 maxval=0.109, seed=None)) )
    arch2_model3.add(BatchNormalization())
    arch2_model3.add(Dropout(dropout))

    arch2_model3.add(Dense(output_dim, activation='softmax'))

    arch2_model3.compile(loss='categorical_crossentropy', metrics=['acc
uracy'], optimizer='adam')

    return arch2_model3
```

In [52]:

```
from datetime import datetime
from keras.layers.normalization import BatchNormalization
from keras.layers import Dropout
start = datetime.now()

dropout = []

for d in range(1,10):
    dropout.append(d/10)

from keras.wrappers.scikit_learn import KerasClassifier
from sklearn.model_selection import GridSearchCV

model = KerasClassifier(build_fn=A2M3_best_hyperparameters, epochs=nb_e
poch, batch_size=batch_size, verbose=0)
param_grid = dict(dropout=dropout)

# if you are using CPU
# grid = GridSearchCV(estimator=model, param_grid=param_grid, n_jobs=-
1)
# if you are using GPU dont use the n_jobs parameter
```

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```
grid_1 = GridSearchCV(estimator=model, param_grid=param_grid,cv=3,n_job
s=-1)
grid_result1 = grid_1.fit(X_train, Y_train)

print('Time taken :', datetime.now() - start)
```

```
Time taken : 2:11:58.078499
```

In [67]:
```
print("Best: %f using %s" % (grid_result1.best_score_, grid_result1.bes
t_params_))
means = grid_result1.cv_results_['mean_test_score']
stds = grid_result1.cv_results_['std_test_score']
params = grid_result1.cv_results_['params']
for mean, stdev, param in zip(means, stds, params):
    print("%f (%f) with: %r" % (mean, stdev, param))
```

```
Best: 0.982283 using {'dropout': 0.3}
0.981167 (0.001212) with: {'dropout': 0.1}
0.981367 (0.001259) with: {'dropout': 0.2}
0.982283 (0.001100) with: {'dropout': 0.3}
0.981683 (0.001133) with: {'dropout': 0.4}
0.981367 (0.000781) with: {'dropout': 0.5}
0.981033 (0.000903) with: {'dropout': 0.6}
0.979767 (0.000759) with: {'dropout': 0.7}
0.974950 (0.000980) with: {'dropout': 0.8}
0.958567 (0.001837) with: {'dropout': 0.9}
```

1.2.3.2 Constructing the Neural Network

In [54]:
```
arch2_model3 = Sequential()

arch2_model3.add(Dense(500, activation='relu', input_shape=(input_dim
,),\
                       kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))
arch2_model3.add(BatchNormalization())
arch2_model3.add(Dropout(0.3))
```

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```
arch2_model3.add(Dense(125, activation='relu', \
                       kernel_initializer=RandomUniform(minval= -0.109,
 maxval=0.109, seed=None)) )
arch2_model3.add(BatchNormalization())
arch2_model3.add(Dropout(0.3))

arch2_model3.add(Dense(output_dim, activation='softmax'))
arch2_model3.summary()
```

```
Model: "sequential_12"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_32 (Dense)             (None, 500)               392500
_________________________________________________________________
batch_normalization_9 (Batch (None, 500)               2000
_________________________________________________________________
dropout_5 (Dropout)          (None, 500)               0
_________________________________________________________________
dense_33 (Dense)             (None, 125)               62625
_________________________________________________________________
batch_normalization_10 (Batc (None, 125)               500
_________________________________________________________________
dropout_6 (Dropout)          (None, 125)               0
_________________________________________________________________
dense_34 (Dense)             (None, 10)                1260
=================================================================
Total params: 458,885
Trainable params: 457,635
Non-trainable params: 1,250
_________________________________________________________________
```

1.2.3.3 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [55]:
```
arch2_model3.compile(optimizer='adam', loss='categorical_crossentropy',
 metrics=['accuracy'])
```

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```
A2M3_history = arch2_model3.fit(X_train, Y_train, batch_size=batch_size
, epochs=nb_epoch, verbose=1, \
                              validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 8s 134us/step - loss: 0.
2904 - accuracy: 0.9118 - val_loss: 0.1116 - val_accuracy: 0.9661
Epoch 2/85
60000/60000 [==============================] - 8s 129us/step - loss: 0.
1333 - accuracy: 0.9587 - val_loss: 0.0862 - val_accuracy: 0.9730
Epoch 3/85
60000/60000 [==============================] - 7s 118us/step - loss: 0.
1030 - accuracy: 0.9682 - val_loss: 0.0818 - val_accuracy: 0.9727
Epoch 4/85
60000/60000 [==============================] - 7s 124us/step - loss: 0.
0850 - accuracy: 0.9732 - val_loss: 0.0730 - val_accuracy: 0.9779
Epoch 5/85
60000/60000 [==============================] - 7s 124us/step - loss: 0.
0725 - accuracy: 0.9769 - val_loss: 0.0638 - val_accuracy: 0.9819
Epoch 6/85
60000/60000 [==============================] - 8s 132us/step - loss: 0.
0622 - accuracy: 0.9798 - val_loss: 0.0635 - val_accuracy: 0.9810
Epoch 7/85
60000/60000 [==============================] - 8s 128us/step - loss: 0.
0588 - accuracy: 0.9809 - val_loss: 0.0640 - val_accuracy: 0.9829
Epoch 8/85
60000/60000 [==============================] - 8s 126us/step - loss: 0.
0520 - accuracy: 0.9833 - val_loss: 0.0643 - val_accuracy: 0.9808
Epoch 9/85
60000/60000 [==============================] - 7s 117us/step - loss: 0.
0485 - accuracy: 0.9840 - val_loss: 0.0695 - val_accuracy: 0.9808
Epoch 10/85
60000/60000 [==============================] - 8s 125us/step - loss: 0.
0431 - accuracy: 0.9856 - val_loss: 0.0641 - val_accuracy: 0.9808
Epoch 11/85
60000/60000 [==============================] - 8s 125us/step - loss: 0.
0434 - accuracy: 0.9854 - val_loss: 0.0653 - val_accuracy: 0.9809
Epoch 12/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
```

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```
0393 - accuracy: 0.9869 - val_loss: 0.0664 - val_accuracy: 0.9813
Epoch 13/85
60000/60000 [==============================] - 7s 125us/step - loss: 0.
0366 - accuracy: 0.9880 - val_loss: 0.0558 - val_accuracy: 0.9845
Epoch 14/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
0323 - accuracy: 0.9891 - val_loss: 0.0601 - val_accuracy: 0.9838
Epoch 15/85
60000/60000 [==============================] - 8s 126us/step - loss: 0.
0337 - accuracy: 0.9894 - val_loss: 0.0605 - val_accuracy: 0.9839
Epoch 16/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
0307 - accuracy: 0.9901 - val_loss: 0.0575 - val_accuracy: 0.9830
Epoch 17/85
60000/60000 [==============================] - 8s 127us/step - loss: 0.
0282 - accuracy: 0.9906 - val_loss: 0.0591 - val_accuracy: 0.9831
Epoch 18/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0313 - accuracy: 0.9897 - val_loss: 0.0578 - val_accuracy: 0.9840
Epoch 19/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0299 - accuracy: 0.9901 - val_loss: 0.0593 - val_accuracy: 0.9836
Epoch 20/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0268 - accuracy: 0.9910 - val_loss: 0.0623 - val_accuracy: 0.9842
Epoch 21/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0239 - accuracy: 0.9918 - val_loss: 0.0592 - val_accuracy: 0.9838
Epoch 22/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0244 - accuracy: 0.9919 - val_loss: 0.0655 - val_accuracy: 0.9830
Epoch 23/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0241 - accuracy: 0.9921 - val_loss: 0.0591 - val_accuracy: 0.9843
Epoch 24/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0227 - accuracy: 0.9921 - val_loss: 0.0586 - val_accuracy: 0.9838
Epoch 25/85
60000/60000 [==============================] - 7s 114us/step - loss: 0.
```

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```
0238 - accuracy: 0.9923 - val_loss: 0.0562 - val_accuracy: 0.9848
Epoch 26/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0211 - accuracy: 0.9933 - val_loss: 0.0556 - val_accuracy: 0.9846
Epoch 27/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0188 - accuracy: 0.9937 - val_loss: 0.0601 - val_accuracy: 0.9843
Epoch 28/85
60000/60000 [==============================] - 7s 113us/step - loss: 0.
0189 - accuracy: 0.9935 - val_loss: 0.0585 - val_accuracy: 0.9835
Epoch 29/85
60000/60000 [==============================] - 7s 114us/step - loss: 0.
0174 - accuracy: 0.9938 - val_loss: 0.0641 - val_accuracy: 0.9828
Epoch 30/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0186 - accuracy: 0.9939 - val_loss: 0.0641 - val_accuracy: 0.9840
Epoch 31/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0175 - accuracy: 0.9939 - val_loss: 0.0693 - val_accuracy: 0.9832
Epoch 32/85
60000/60000 [==============================] - 7s 119us/step - loss: 0.
0174 - accuracy: 0.9941 - val_loss: 0.0616 - val_accuracy: 0.9842
Epoch 33/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0178 - accuracy: 0.9939 - val_loss: 0.0655 - val_accuracy: 0.9842
Epoch 34/85
60000/60000 [==============================] - 7s 113us/step - loss: 0.
0168 - accuracy: 0.9946 - val_loss: 0.0597 - val_accuracy: 0.9841
Epoch 35/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0166 - accuracy: 0.9942 - val_loss: 0.0652 - val_accuracy: 0.9839
Epoch 36/85
60000/60000 [==============================] - 7s 125us/step - loss: 0.
0189 - accuracy: 0.9935 - val_loss: 0.0618 - val_accuracy: 0.9840
Epoch 37/85
60000/60000 [==============================] - 7s 123us/step - loss: 0.
0161 - accuracy: 0.9942 - val_loss: 0.0623 - val_accuracy: 0.9848
Epoch 38/85
60000/60000 [==============================] - 7s 122us/step - loss: 0.
```

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```
0142 - accuracy: 0.9949 - val_loss: 0.0641 - val_accuracy: 0.9842
Epoch 39/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0142 - accuracy: 0.9949 - val_loss: 0.0611 - val_accuracy: 0.9841
Epoch 40/85
60000/60000 [==============================] - 7s 117us/step - loss: 0.
0142 - accuracy: 0.9951 - val_loss: 0.0623 - val_accuracy: 0.9837
Epoch 41/85
60000/60000 [==============================] - 7s 122us/step - loss: 0.
0148 - accuracy: 0.9951 - val_loss: 0.0652 - val_accuracy: 0.9852
Epoch 42/85
60000/60000 [==============================] - 7s 118us/step - loss: 0.
0153 - accuracy: 0.9948 - val_loss: 0.0586 - val_accuracy: 0.9856
Epoch 43/85
60000/60000 [==============================] - 8s 127us/step - loss: 0.
0142 - accuracy: 0.9953 - val_loss: 0.0634 - val_accuracy: 0.9853
Epoch 44/85
60000/60000 [==============================] - 8s 135us/step - loss: 0.
0135 - accuracy: 0.9956 - val_loss: 0.0634 - val_accuracy: 0.9843
Epoch 45/85
60000/60000 [==============================] - 7s 122us/step - loss: 0.
0149 - accuracy: 0.9947 - val_loss: 0.0598 - val_accuracy: 0.9845
Epoch 46/85
60000/60000 [==============================] - 7s 118us/step - loss: 0.
0135 - accuracy: 0.9954 - val_loss: 0.0661 - val_accuracy: 0.9845
Epoch 47/85
60000/60000 [==============================] - 7s 122us/step - loss: 0.
0133 - accuracy: 0.9955 - val_loss: 0.0646 - val_accuracy: 0.9848
Epoch 48/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
0156 - accuracy: 0.9952 - val_loss: 0.0599 - val_accuracy: 0.9854
Epoch 49/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
0110 - accuracy: 0.9962 - val_loss: 0.0610 - val_accuracy: 0.9859
Epoch 50/85
60000/60000 [==============================] - 7s 113us/step - loss: 0.
0105 - accuracy: 0.9968 - val_loss: 0.0594 - val_accuracy: 0.9860
Epoch 51/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
```

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```
0114 - accuracy: 0.9963 - val_loss: 0.0643 - val_accuracy: 0.9850
Epoch 52/85
60000/60000 [==============================] - 7s 118us/step - loss: 0.
0123 - accuracy: 0.9962 - val_loss: 0.0678 - val_accuracy: 0.9859
Epoch 53/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0122 - accuracy: 0.9956 - val_loss: 0.0646 - val_accuracy: 0.9853
Epoch 54/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0107 - accuracy: 0.9964 - val_loss: 0.0619 - val_accuracy: 0.9847
Epoch 55/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0106 - accuracy: 0.9965 - val_loss: 0.0682 - val_accuracy: 0.9834
Epoch 56/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0113 - accuracy: 0.9962 - val_loss: 0.0652 - val_accuracy: 0.9851
Epoch 57/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0101 - accuracy: 0.9966 - val_loss: 0.0690 - val_accuracy: 0.9845
Epoch 58/85
60000/60000 [==============================] - 6s 107us/step - loss: 0.
0107 - accuracy: 0.9963 - val_loss: 0.0632 - val_accuracy: 0.9846
Epoch 59/85
60000/60000 [==============================] - 6s 107us/step - loss: 0.
0110 - accuracy: 0.9963 - val_loss: 0.0627 - val_accuracy: 0.9860
Epoch 60/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0117 - accuracy: 0.9961 - val_loss: 0.0677 - val_accuracy: 0.9857
Epoch 61/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0102 - accuracy: 0.9964 - val_loss: 0.0621 - val_accuracy: 0.9851
Epoch 62/85
60000/60000 [==============================] - 7s 114us/step - loss: 0.
0089 - accuracy: 0.9967 - val_loss: 0.0598 - val_accuracy: 0.9862
Epoch 63/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
0089 - accuracy: 0.9971 - val_loss: 0.0594 - val_accuracy: 0.9859
Epoch 64/85
60000/60000 [==============================] - 7s 113us/step - loss: 0.
```

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```
0104 - accuracy: 0.9965 - val_loss: 0.0671 - val_accuracy: 0.9853
Epoch 65/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0095 - accuracy: 0.9969 - val_loss: 0.0693 - val_accuracy: 0.9848
Epoch 66/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0093 - accuracy: 0.9966 - val_loss: 0.0669 - val_accuracy: 0.9854
Epoch 67/85
60000/60000 [==============================] - 7s 113us/step - loss: 0.
0099 - accuracy: 0.9967 - val_loss: 0.0592 - val_accuracy: 0.9866
Epoch 68/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0092 - accuracy: 0.9969 - val_loss: 0.0708 - val_accuracy: 0.9847
Epoch 69/85
60000/60000 [==============================] - 7s 114us/step - loss: 0.
0083 - accuracy: 0.9973 - val_loss: 0.0666 - val_accuracy: 0.9864
Epoch 70/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0083 - accuracy: 0.9971 - val_loss: 0.0720 - val_accuracy: 0.9850
Epoch 71/85
60000/60000 [==============================] - 7s 113us/step - loss: 0.
0090 - accuracy: 0.9972 - val_loss: 0.0715 - val_accuracy: 0.9850
Epoch 72/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0088 - accuracy: 0.9968 - val_loss: 0.0706 - val_accuracy: 0.9857
Epoch 73/85
60000/60000 [==============================] - 7s 114us/step - loss: 0.
0079 - accuracy: 0.9974 - val_loss: 0.0695 - val_accuracy: 0.9861
Epoch 74/85
60000/60000 [==============================] - 7s 113us/step - loss: 0.
0081 - accuracy: 0.9975 - val_loss: 0.0688 - val_accuracy: 0.9852
Epoch 75/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0089 - accuracy: 0.9972 - val_loss: 0.0712 - val_accuracy: 0.9855
Epoch 76/85
60000/60000 [==============================] - 7s 114us/step - loss: 0.
0094 - accuracy: 0.9968 - val_loss: 0.0750 - val_accuracy: 0.9850
Epoch 77/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
```

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```
0085 - accuracy: 0.9972 - val_loss: 0.0715 - val_accuracy: 0.9850
Epoch 78/85
60000/60000 [==============================] - 6s 107us/step - loss: 0.
0085 - accuracy: 0.9969 - val_loss: 0.0701 - val_accuracy: 0.9842
Epoch 79/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0084 - accuracy: 0.9970 - val_loss: 0.0635 - val_accuracy: 0.9856
Epoch 80/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0091 - accuracy: 0.9969 - val_loss: 0.0650 - val_accuracy: 0.9852
Epoch 81/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0084 - accuracy: 0.9974 - val_loss: 0.0743 - val_accuracy: 0.9847
Epoch 82/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0086 - accuracy: 0.9971 - val_loss: 0.0625 - val_accuracy: 0.9851
Epoch 83/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0078 - accuracy: 0.9974 - val_loss: 0.0752 - val_accuracy: 0.9855
Epoch 84/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0085 - accuracy: 0.9971 - val_loss: 0.0725 - val_accuracy: 0.9857
Epoch 85/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0070 - accuracy: 0.9977 - val_loss: 0.0670 - val_accuracy: 0.9855
```

1.2.3.4 Number of Epochs vs Train Loss & Validation Loss

In [56]:
```
A2M3_score = arch2_model3.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A2M3_score[0])
print('Test accuracy:', A2M3_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

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```
# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in history.history we will have a list of length equal t
o number of epochs

vy = A2M3_history.history['val_loss']
ty = A2M3_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.06704683752219424
Test accuracy: 0.9854999780654907
```

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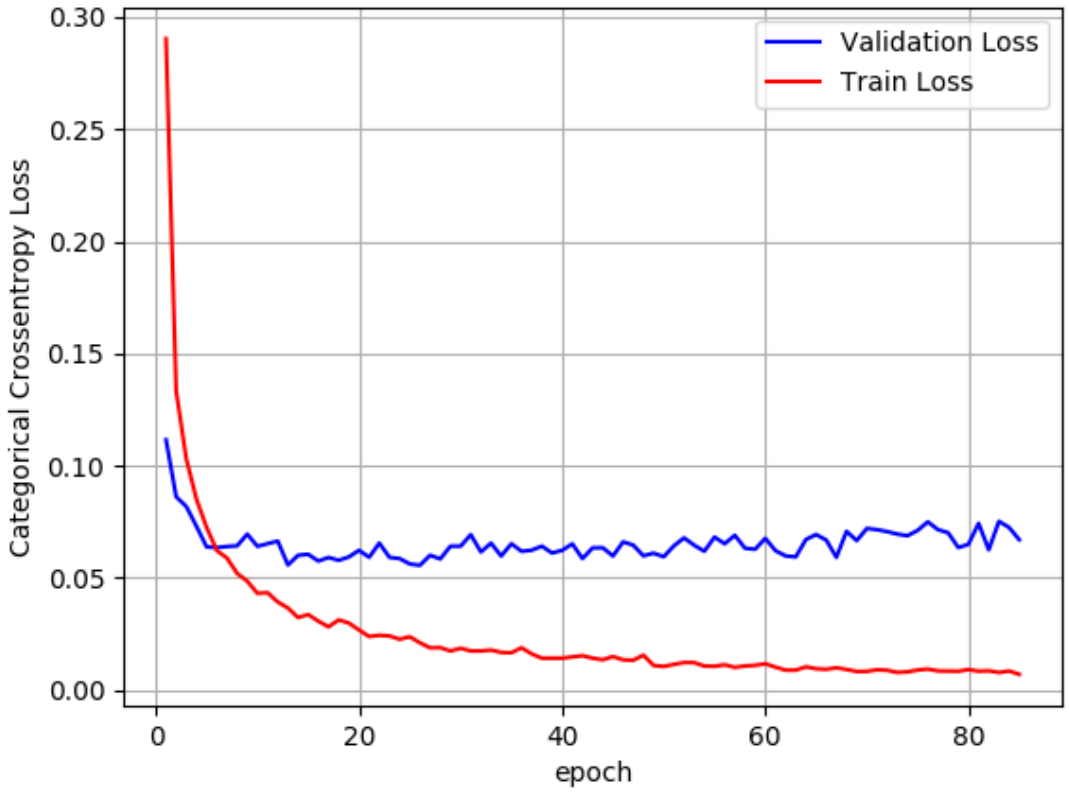

1.2.3.5 Violin Plots for Hidden Layers in Models Trained

In [57]:
```
w_after = arch2_model3.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
out_w = w_after[4].flatten().reshape(-1,1)
```

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```
fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 3, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 1')

plt.subplot(1, 3, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 2 ')

plt.subplot(1, 3, 3)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Output Layer ')
plt.show()
```

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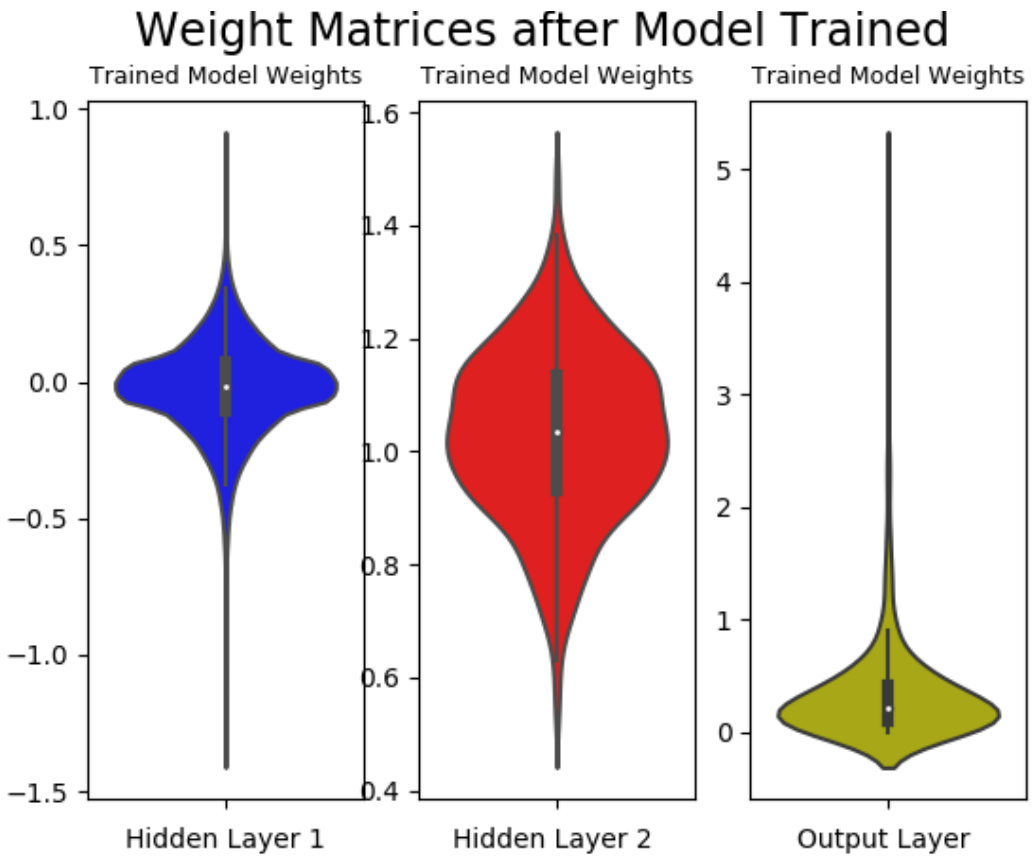

1.3 Architecture 3 :- 784-256-64-10

1.3.1 Model 1 : MLP + Adam Optimizer

1.3.1.1 Constructing the Neural Network

In [58]:
```
arch3_model1 = Sequential()

arch3_model1.add(Dense(256, activation='relu', input_shape=(input_dim
```

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```
,),\
                        kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))

arch3_model1.add(Dense(64, activation='relu', \
                         kernel_initializer=RandomUniform(minval= -0.153,
 maxval=0.153, seed=None)) )

arch3_model1.add(Dense(output_dim, activation='softmax'))
arch3_model1.summary()
```

```
Model: "sequential_13"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_35 (Dense)             (None, 256)               200960
_________________________________________________________________
dense_36 (Dense)             (None, 64)                16448
_________________________________________________________________
dense_37 (Dense)             (None, 10)                650
=================================================================
Total params: 218,058
Trainable params: 218,058
Non-trainable params: 0
_________________________________________________________________
```

1.3.1.2 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [59]:
```
arch3_model1.compile(optimizer='adam', loss='categorical_crossentropy',
 metrics=['accuracy'])

A3M1_history = arch3_model1.fit(X_train, Y_train, batch_size=batch_size
, epochs=nb_epoch, verbose=1, \
                             validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 3s 53us/step - loss: 0.2
```

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```
862 - accuracy: 0.9180 - val_loss: 0.1263 - val_accuracy: 0.9638
Epoch 2/85
60000/60000 [==============================] - 3s 47us/step - loss: 0.1
051 - accuracy: 0.9683 - val_loss: 0.0927 - val_accuracy: 0.9719
Epoch 3/85
60000/60000 [==============================] - 3s 48us/step - loss: 0.0
686 - accuracy: 0.9789 - val_loss: 0.0808 - val_accuracy: 0.9752
Epoch 4/85
60000/60000 [==============================] - 3s 46us/step - loss: 0.0
486 - accuracy: 0.9849 - val_loss: 0.0767 - val_accuracy: 0.9773
Epoch 5/85
60000/60000 [==============================] - 3s 45us/step - loss: 0.0
364 - accuracy: 0.9885 - val_loss: 0.0679 - val_accuracy: 0.9790
Epoch 6/85
60000/60000 [==============================] - 3s 44us/step - loss: 0.0
284 - accuracy: 0.9912 - val_loss: 0.0751 - val_accuracy: 0.9771
Epoch 7/85
60000/60000 [==============================] - 3s 46us/step - loss: 0.0
202 - accuracy: 0.9938 - val_loss: 0.0655 - val_accuracy: 0.9808
Epoch 8/85
60000/60000 [==============================] - 3s 49us/step - loss: 0.0
183 - accuracy: 0.9941 - val_loss: 0.0814 - val_accuracy: 0.9764
Epoch 9/85
60000/60000 [==============================] - 3s 48us/step - loss: 0.0
143 - accuracy: 0.9956 - val_loss: 0.0715 - val_accuracy: 0.9810
Epoch 10/85
60000/60000 [==============================] - 3s 48us/step - loss: 0.0
108 - accuracy: 0.9965 - val_loss: 0.0868 - val_accuracy: 0.9774
Epoch 11/85
60000/60000 [==============================] - 3s 46us/step - loss: 0.0
130 - accuracy: 0.9961 - val_loss: 0.0726 - val_accuracy: 0.9802
Epoch 12/85
60000/60000 [==============================] - 3s 43us/step - loss: 0.0
101 - accuracy: 0.9966 - val_loss: 0.0777 - val_accuracy: 0.9810
Epoch 13/85
60000/60000 [==============================] - 3s 45us/step - loss: 0.0
108 - accuracy: 0.9966 - val_loss: 0.0784 - val_accuracy: 0.9790
Epoch 14/85
60000/60000 [==============================] - 3s 49us/step - loss: 0.0
```

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```
087 - accuracy: 0.9974 - val_loss: 0.0838 - val_accuracy: 0.9801
Epoch 15/85
60000/60000 [==============================] - 3s 51us/step - loss: 0.0
052 - accuracy: 0.9984 - val_loss: 0.0879 - val_accuracy: 0.9799
Epoch 16/85
60000/60000 [==============================] - 3s 48us/step - loss: 0.0
051 - accuracy: 0.9986 - val_loss: 0.1037 - val_accuracy: 0.9767
Epoch 17/85
60000/60000 [==============================] - 3s 45us/step - loss: 0.0
090 - accuracy: 0.9969 - val_loss: 0.1044 - val_accuracy: 0.9761
Epoch 18/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.0
118 - accuracy: 0.9960 - val_loss: 0.0839 - val_accuracy: 0.9804
Epoch 19/85
60000/60000 [==============================] - 3s 50us/step - loss: 0.0
073 - accuracy: 0.9976 - val_loss: 0.0964 - val_accuracy: 0.9810
Epoch 20/85
60000/60000 [==============================] - 3s 56us/step - loss: 0.0
060 - accuracy: 0.9981 - val_loss: 0.0900 - val_accuracy: 0.9816
Epoch 21/85
60000/60000 [==============================] - 3s 46us/step - loss: 0.0
068 - accuracy: 0.9978 - val_loss: 0.0809 - val_accuracy: 0.9823
Epoch 22/85
60000/60000 [==============================] - 3s 46us/step - loss: 0.0
025 - accuracy: 0.9994 - val_loss: 0.0991 - val_accuracy: 0.9804
Epoch 23/85
60000/60000 [==============================] - 3s 54us/step - loss: 0.0
064 - accuracy: 0.9979 - val_loss: 0.1137 - val_accuracy: 0.9789
Epoch 24/85
60000/60000 [==============================] - 3s 50us/step - loss: 0.0
083 - accuracy: 0.9973 - val_loss: 0.1085 - val_accuracy: 0.9808
Epoch 25/85
60000/60000 [==============================] - 3s 49us/step - loss: 0.0
039 - accuracy: 0.9989 - val_loss: 0.1049 - val_accuracy: 0.9806
Epoch 26/85
60000/60000 [==============================] - 3s 51us/step - loss: 0.0
041 - accuracy: 0.9987 - val_loss: 0.1094 - val_accuracy: 0.9811
Epoch 27/85
60000/60000 [==============================] - 3s 44us/step - loss: 0.0
```

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```
065 - accuracy: 0.9977 - val_loss: 0.1072 - val_accuracy: 0.9806
Epoch 28/85
60000/60000 [==============================] - 3s 47us/step - loss: 0.0
052 - accuracy: 0.9984 - val_loss: 0.1110 - val_accuracy: 0.9811
Epoch 29/85
60000/60000 [==============================] - 3s 43us/step - loss: 0.0
040 - accuracy: 0.9988 - val_loss: 0.1152 - val_accuracy: 0.9796
Epoch 30/85
60000/60000 [==============================] - 3s 42us/step - loss: 0.0
051 - accuracy: 0.9986 - val_loss: 0.1036 - val_accuracy: 0.9824
Epoch 31/85
60000/60000 [==============================] - 3s 43us/step - loss: 0.0
019 - accuracy: 0.9995 - val_loss: 0.1166 - val_accuracy: 0.9802
Epoch 32/85
60000/60000 [==============================] - 3s 42us/step - loss: 0.0
054 - accuracy: 0.9982 - val_loss: 0.1272 - val_accuracy: 0.9812
Epoch 33/85
60000/60000 [==============================] - 3s 44us/step - loss: 0.0
077 - accuracy: 0.9977 - val_loss: 0.1354 - val_accuracy: 0.9774
Epoch 34/85
60000/60000 [==============================] - 3s 47us/step - loss: 0.0
052 - accuracy: 0.9982 - val_loss: 0.1068 - val_accuracy: 0.9817
Epoch 35/85
60000/60000 [==============================] - 3s 52us/step - loss: 0.0
021 - accuracy: 0.9994 - val_loss: 0.1094 - val_accuracy: 0.9830
Epoch 36/85
60000/60000 [==============================] - 3s 50us/step - loss: 0.0
022 - accuracy: 0.9992 - val_loss: 0.1354 - val_accuracy: 0.9801
Epoch 37/85
60000/60000 [==============================] - 3s 47us/step - loss: 0.0
061 - accuracy: 0.9979 - val_loss: 0.1298 - val_accuracy: 0.9798
Epoch 38/85
60000/60000 [==============================] - 3s 43us/step - loss: 0.0
023 - accuracy: 0.9993 - val_loss: 0.1228 - val_accuracy: 0.9809
Epoch 39/85
60000/60000 [==============================] - 3s 42us/step - loss: 0.0
051 - accuracy: 0.9983 - val_loss: 0.1451 - val_accuracy: 0.9775
Epoch 40/85
60000/60000 [==============================] - 3s 42us/step - loss: 0.0
```

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```
050 - accuracy: 0.9985 - val_loss: 0.1295 - val_accuracy: 0.9807
Epoch 41/85
60000/60000 [==============================] - 3s 47us/step - loss: 0.0
018 - accuracy: 0.9994 - val_loss: 0.1235 - val_accuracy: 0.9803
Epoch 42/85
60000/60000 [==============================] - 3s 44us/step - loss: 0.0
041 - accuracy: 0.9986 - val_loss: 0.1526 - val_accuracy: 0.9780
Epoch 43/85
60000/60000 [==============================] - 3s 43us/step - loss: 0.0
058 - accuracy: 0.9981 - val_loss: 0.1214 - val_accuracy: 0.9815
Epoch 44/85
60000/60000 [==============================] - 3s 43us/step - loss: 0.0
011 - accuracy: 0.9997 - val_loss: 0.1316 - val_accuracy: 0.9809
Epoch 45/85
60000/60000 [==============================] - 3s 43us/step - loss: 0.0
025 - accuracy: 0.9994 - val_loss: 0.1200 - val_accuracy: 0.9825
Epoch 46/85
60000/60000 [==============================] - 3s 46us/step - loss: 0.0
045 - accuracy: 0.9985 - val_loss: 0.1243 - val_accuracy: 0.9805
Epoch 47/85
60000/60000 [==============================] - 3s 46us/step - loss: 0.0
044 - accuracy: 0.9987 - val_loss: 0.1594 - val_accuracy: 0.9778
Epoch 48/85
60000/60000 [==============================] - 3s 42us/step - loss: 0.0
054 - accuracy: 0.9983 - val_loss: 0.1403 - val_accuracy: 0.9797
Epoch 49/85
60000/60000 [==============================] - 3s 43us/step - loss: 0.0
031 - accuracy: 0.9990 - val_loss: 0.1385 - val_accuracy: 0.9795
Epoch 50/85
60000/60000 [==============================] - 3s 46us/step - loss: 0.0
031 - accuracy: 0.9990 - val_loss: 0.1194 - val_accuracy: 0.9827
Epoch 51/85
60000/60000 [==============================] - 3s 42us/step - loss: 9.5
775e-04 - accuracy: 0.9998 - val_loss: 0.1298 - val_accuracy: 0.9820
Epoch 52/85
60000/60000 [==============================] - 3s 43us/step - loss: 0.0
019 - accuracy: 0.9994 - val_loss: 0.1380 - val_accuracy: 0.9805
Epoch 53/85
60000/60000 [==============================] - 3s 45us/step - loss: 0.0
```

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```
063 - accuracy: 0.9981 - val_loss: 0.1468 - val_accuracy: 0.9800
Epoch 54/85
60000/60000 [==============================] - 3s 48us/step - loss: 0.0
067 - accuracy: 0.9980 - val_loss: 0.1326 - val_accuracy: 0.9815
Epoch 55/85
60000/60000 [==============================] - 3s 45us/step - loss: 0.0
025 - accuracy: 0.9992 - val_loss: 0.1106 - val_accuracy: 0.9827
Epoch 56/85
60000/60000 [==============================] - 3s 48us/step - loss: 6.9
829e-04 - accuracy: 0.9998 - val_loss: 0.1126 - val_accuracy: 0.9837
Epoch 57/85
60000/60000 [==============================] - 3s 45us/step - loss: 9.4
933e-05 - accuracy: 1.0000 - val_loss: 0.1229 - val_accuracy: 0.9831
Epoch 58/85
60000/60000 [==============================] - 3s 46us/step - loss: 0.0
051 - accuracy: 0.9982 - val_loss: 0.1436 - val_accuracy: 0.9802
Epoch 59/85
60000/60000 [==============================] - 3s 52us/step - loss: 0.0
037 - accuracy: 0.9988 - val_loss: 0.1446 - val_accuracy: 0.9800
Epoch 60/85
60000/60000 [==============================] - 3s 46us/step - loss: 0.0
051 - accuracy: 0.9987 - val_loss: 0.1227 - val_accuracy: 0.9814
Epoch 61/85
60000/60000 [==============================] - 3s 43us/step - loss: 0.0
018 - accuracy: 0.9995 - val_loss: 0.1323 - val_accuracy: 0.9828
Epoch 62/85
60000/60000 [==============================] - 3s 42us/step - loss: 0.0
014 - accuracy: 0.9996 - val_loss: 0.1320 - val_accuracy: 0.9843
Epoch 63/85
60000/60000 [==============================] - 3s 43us/step - loss: 2.9
146e-04 - accuracy: 0.9999 - val_loss: 0.1249 - val_accuracy: 0.9837
Epoch 64/85
60000/60000 [==============================] - 3s 43us/step - loss: 0.0
052 - accuracy: 0.9986 - val_loss: 0.1839 - val_accuracy: 0.9776
Epoch 65/85
60000/60000 [==============================] - 3s 47us/step - loss: 0.0
075 - accuracy: 0.9978 - val_loss: 0.1342 - val_accuracy: 0.9793
Epoch 66/85
60000/60000 [==============================] - 3s 44us/step - loss: 0.0
```

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```
015 - accuracy: 0.9995 - val_loss: 0.1149 - val_accuracy: 0.9828
Epoch 67/85
60000/60000 [==============================] - 3s 43us/step - loss: 5.2
134e-04 - accuracy: 0.9999 - val_loss: 0.1265 - val_accuracy: 0.9823
Epoch 68/85
60000/60000 [==============================] - 3s 43us/step - loss: 5.6
725e-04 - accuracy: 0.9998 - val_loss: 0.1160 - val_accuracy: 0.9849
Epoch 69/85
60000/60000 [==============================] - 3s 44us/step - loss: 0.0
021 - accuracy: 0.9993 - val_loss: 0.1537 - val_accuracy: 0.9798
Epoch 70/85
60000/60000 [==============================] - 3s 42us/step - loss: 0.0
080 - accuracy: 0.9975 - val_loss: 0.1325 - val_accuracy: 0.9817
Epoch 71/85
60000/60000 [==============================] - 3s 45us/step - loss: 0.0
024 - accuracy: 0.9993 - val_loss: 0.1102 - val_accuracy: 0.9827
Epoch 72/85
60000/60000 [==============================] - 3s 57us/step - loss: 9.1
425e-04 - accuracy: 0.9998 - val_loss: 0.1275 - val_accuracy: 0.9829
Epoch 73/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.0
028 - accuracy: 0.9991 - val_loss: 0.1383 - val_accuracy: 0.9809
Epoch 74/85
60000/60000 [==============================] - 3s 51us/step - loss: 0.0
026 - accuracy: 0.9991 - val_loss: 0.1485 - val_accuracy: 0.9825
Epoch 75/85
60000/60000 [==============================] - 3s 47us/step - loss: 0.0
027 - accuracy: 0.9992 - val_loss: 0.1563 - val_accuracy: 0.9802
Epoch 76/85
60000/60000 [==============================] - 3s 44us/step - loss: 0.0
037 - accuracy: 0.9989 - val_loss: 0.1509 - val_accuracy: 0.9819
Epoch 77/85
60000/60000 [==============================] - 3s 43us/step - loss: 0.0
036 - accuracy: 0.9989 - val_loss: 0.1391 - val_accuracy: 0.9838
Epoch 78/85
60000/60000 [==============================] - 3s 42us/step - loss: 0.0
015 - accuracy: 0.9995 - val_loss: 0.1342 - val_accuracy: 0.9819
Epoch 79/85
60000/60000 [==============================] - 2s 40us/step - loss: 1.2
```

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```
305e-04 - accuracy: 1.0000 - val_loss: 0.1389 - val_accuracy: 0.9815
Epoch 80/85
60000/60000 [==============================] - 3s 42us/step - loss: 4.2
418e-04 - accuracy: 0.9999 - val_loss: 0.1550 - val_accuracy: 0.9820
Epoch 81/85
60000/60000 [==============================] - 3s 44us/step - loss: 0.0
082 - accuracy: 0.9977 - val_loss: 0.1666 - val_accuracy: 0.9795
Epoch 82/85
60000/60000 [==============================] - 2s 42us/step - loss: 0.0
028 - accuracy: 0.9993 - val_loss: 0.1437 - val_accuracy: 0.9822
Epoch 83/85
60000/60000 [==============================] - 2s 41us/step - loss: 0.0
014 - accuracy: 0.9995 - val_loss: 0.1388 - val_accuracy: 0.9829
Epoch 84/85
60000/60000 [==============================] - 2s 41us/step - loss: 0.0
028 - accuracy: 0.9992 - val_loss: 0.1489 - val_accuracy: 0.9817
Epoch 85/85
60000/60000 [==============================] - 2s 39us/step - loss: 0.0
024 - accuracy: 0.9993 - val_loss: 0.1540 - val_accuracy: 0.9821
```

1.3.1.3 Number of Epochs vs Train Loss & Validation Loss

In [60]:

```
A3M1_score = arch3_model1.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A3M1_score[0])
print('Test accuracy:', A3M1_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
```

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```
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in history.history we will have a list of length equal t
o number of epochs

vy = A3M1_history.history['val_loss']
ty = A3M1_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.1539675504027916
Test accuracy: 0.9821000099182129
```

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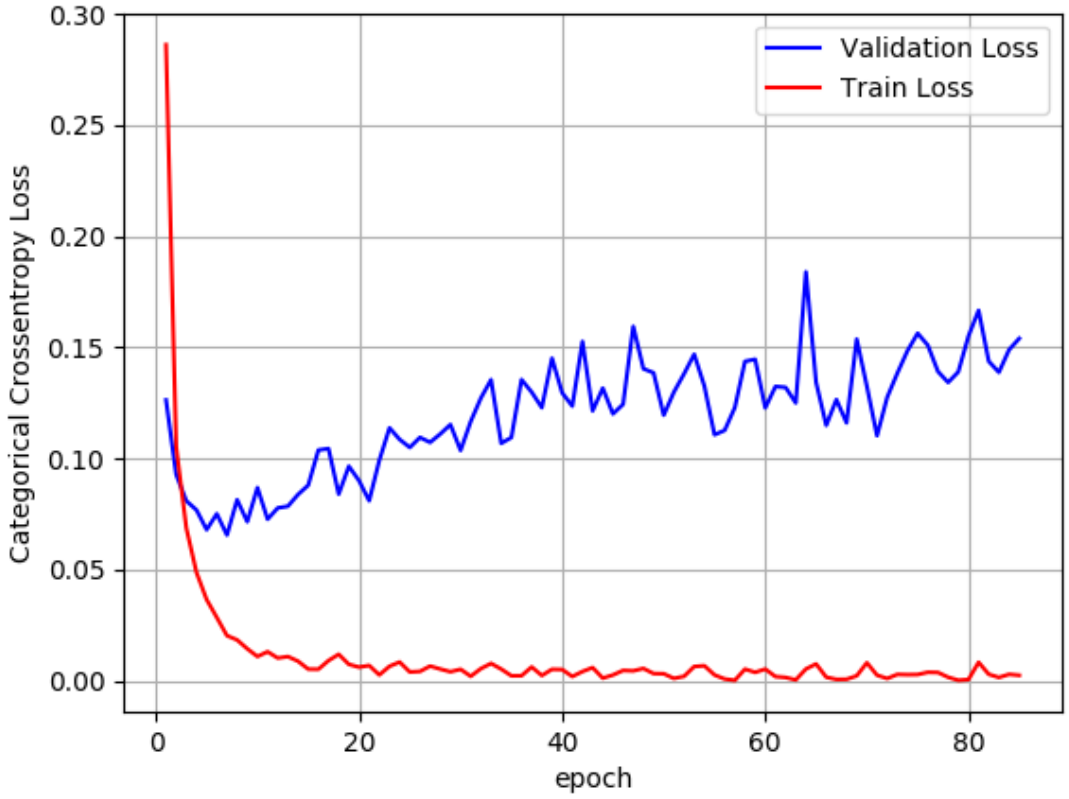

1.3.1.4 Violin Plots for Hidden Layers in the Models Trained

In [61]:
```
w_after = arch3_model1.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
out_w = w_after[4].flatten().reshape(-1,1)
```

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```
fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 3, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 1')

plt.subplot(1, 3, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 2 ')

plt.subplot(1, 3, 3)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Output Layer ')
plt.show()
```

```
/Users/dhruvnarayanan/opt/anaconda3/lib/python3.7/site-packages/ipykern
el_launcher.py:7: RuntimeWarning: More than 20 figures have been opene
d. Figures created through the pyplot interface (`matplotlib.pyplot.fig
ure`) are retained until explicitly closed and may consume too much mem
ory. (To control this warning, see the rcParam `figure.max_open_warning
`).
  import sys
```

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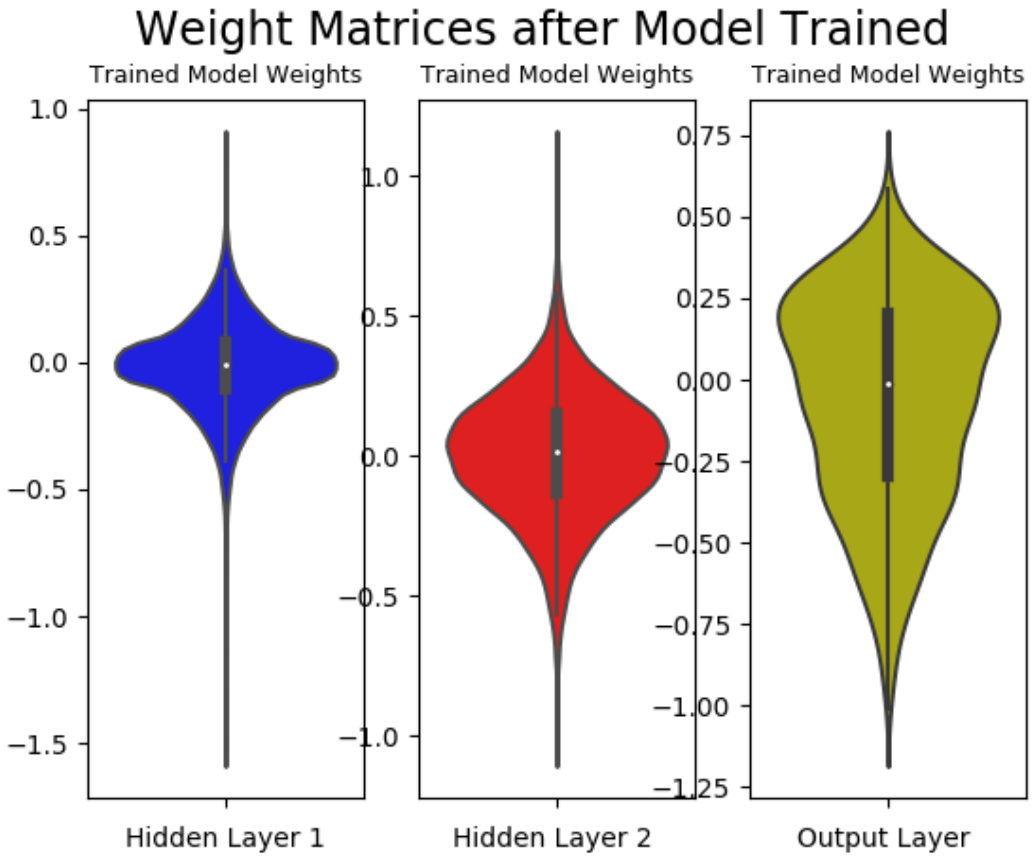

1.3.2 Model 2 : MLP + BatchNormalization + Adam Optimizer

1.3.2.1 Constructing the Neural Network

In [62]:
```
arch3_model2 = Sequential()

arch3_model2.add(Dense(256, activation='relu', input_shape=(input_dim
,),\
```

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```
                        kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))
arch3_model2.add(BatchNormalization())

arch3_model2.add(Dense(64, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.153,
 maxval=0.153, seed=None)) )
arch3_model2.add(BatchNormalization())

arch3_model2.add(Dense(output_dim, activation='softmax'))
arch3_model2.summary()
```

```
Model: "sequential_14"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_38 (Dense)             (None, 256)               200960
_________________________________________________________________
batch_normalization_11 (Batc (None, 256)               1024
_________________________________________________________________
dense_39 (Dense)             (None, 64)                16448
_________________________________________________________________
batch_normalization_12 (Batc (None, 64)                256
_________________________________________________________________
dense_40 (Dense)             (None, 10)                650
=================================================================
Total params: 219,338
Trainable params: 218,698
Non-trainable params: 640
_________________________________________________________________
```

1.3.2.2 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [63]:
```
arch3_model2.compile(optimizer='adam', loss='categorical_crossentropy',
 metrics=['accuracy'])

A3M2_history = arch3_model2.fit(X_train, Y_train, batch_size=batch_size
```

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```
, epochs=nb_epoch, verbose=1, \
                              validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 4s 70us/step - loss: 0.2
299 - accuracy: 0.9331 - val_loss: 0.1170 - val_accuracy: 0.9656
Epoch 2/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
853 - accuracy: 0.9751 - val_loss: 0.0903 - val_accuracy: 0.9717
Epoch 3/85
60000/60000 [==============================] - 4s 60us/step - loss: 0.0
574 - accuracy: 0.9821 - val_loss: 0.0897 - val_accuracy: 0.9725
Epoch 4/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.0
414 - accuracy: 0.9876 - val_loss: 0.0867 - val_accuracy: 0.9735
Epoch 5/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
319 - accuracy: 0.9898 - val_loss: 0.0809 - val_accuracy: 0.9772
Epoch 6/85
60000/60000 [==============================] - 3s 57us/step - loss: 0.0
273 - accuracy: 0.9908 - val_loss: 0.0871 - val_accuracy: 0.9739
Epoch 7/85
60000/60000 [==============================] - 4s 62us/step - loss: 0.0
239 - accuracy: 0.9921 - val_loss: 0.0831 - val_accuracy: 0.9769
Epoch 8/85
60000/60000 [==============================] - 4s 60us/step - loss: 0.0
190 - accuracy: 0.9938 - val_loss: 0.0832 - val_accuracy: 0.9773
Epoch 9/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
151 - accuracy: 0.9953 - val_loss: 0.0836 - val_accuracy: 0.9768
Epoch 10/85
60000/60000 [==============================] - 3s 57us/step - loss: 0.0
151 - accuracy: 0.9952 - val_loss: 0.0987 - val_accuracy: 0.9744
Epoch 11/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
142 - accuracy: 0.9954 - val_loss: 0.0864 - val_accuracy: 0.9767
Epoch 12/85
60000/60000 [==============================] - 4s 61us/step - loss: 0.0
093 - accuracy: 0.9970 - val_loss: 0.0828 - val_accuracy: 0.9779
```

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```
Epoch 13/85

60000/60000 [==============================] - 4s 59us/step - loss: 0.0
115 - accuracy: 0.9962 - val_loss: 0.0897 - val_accuracy: 0.9787
Epoch 14/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
129 - accuracy: 0.9958 - val_loss: 0.0884 - val_accuracy: 0.9786
Epoch 15/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
105 - accuracy: 0.9964 - val_loss: 0.0911 - val_accuracy: 0.9773
Epoch 16/85
60000/60000 [==============================] - 4s 61us/step - loss: 0.0
093 - accuracy: 0.9967 - val_loss: 0.0938 - val_accuracy: 0.9780
Epoch 17/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
104 - accuracy: 0.9965 - val_loss: 0.0873 - val_accuracy: 0.9789
Epoch 18/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
074 - accuracy: 0.9977 - val_loss: 0.0940 - val_accuracy: 0.9793
Epoch 19/85
60000/60000 [==============================] - 3s 57us/step - loss: 0.0
089 - accuracy: 0.9970 - val_loss: 0.0871 - val_accuracy: 0.9794
Epoch 20/85
60000/60000 [==============================] - 3s 57us/step - loss: 0.0
068 - accuracy: 0.9979 - val_loss: 0.0868 - val_accuracy: 0.9798
Epoch 21/85
60000/60000 [==============================] - 4s 64us/step - loss: 0.0
080 - accuracy: 0.9973 - val_loss: 0.0776 - val_accuracy: 0.9810
Epoch 22/85
60000/60000 [==============================] - 4s 60us/step - loss: 0.0
063 - accuracy: 0.9978 - val_loss: 0.0859 - val_accuracy: 0.9785
Epoch 23/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
078 - accuracy: 0.9973 - val_loss: 0.0951 - val_accuracy: 0.9798
Epoch 24/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
059 - accuracy: 0.9980 - val_loss: 0.0891 - val_accuracy: 0.9801
Epoch 25/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
060 - accuracy: 0.9981 - val_loss: 0.0854 - val_accuracy: 0.9813
Epoch 26/85
```

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```
Epoch 26/85

60000/60000 [==============================] - 3s 57us/step - loss: 0.0
049 - accuracy: 0.9985 - val_loss: 0.0851 - val_accuracy: 0.9827
Epoch 27/85
60000/60000 [==============================] - 4s 62us/step - loss: 0.0
047 - accuracy: 0.9985 - val_loss: 0.1022 - val_accuracy: 0.9789
Epoch 28/85
60000/60000 [==============================] - 4s 58us/step - loss: 0.0
052 - accuracy: 0.9984 - val_loss: 0.0974 - val_accuracy: 0.9792
Epoch 29/85
60000/60000 [==============================] - 3s 57us/step - loss: 0.0
068 - accuracy: 0.9977 - val_loss: 0.0978 - val_accuracy: 0.9803
Epoch 30/85
60000/60000 [==============================] - 3s 57us/step - loss: 0.0
093 - accuracy: 0.9966 - val_loss: 0.1011 - val_accuracy: 0.9793
Epoch 31/85
60000/60000 [==============================] - 4s 60us/step - loss: 0.0
051 - accuracy: 0.9985 - val_loss: 0.1005 - val_accuracy: 0.9792
Epoch 32/85
60000/60000 [==============================] - 4s 58us/step - loss: 0.0
033 - accuracy: 0.9989 - val_loss: 0.1005 - val_accuracy: 0.9788
Epoch 33/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
035 - accuracy: 0.9990 - val_loss: 0.0877 - val_accuracy: 0.9818
Epoch 34/85
60000/60000 [==============================] - 4s 64us/step - loss: 0.0
046 - accuracy: 0.9984 - val_loss: 0.1043 - val_accuracy: 0.9804
Epoch 35/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.0
053 - accuracy: 0.9983 - val_loss: 0.1130 - val_accuracy: 0.9779
Epoch 36/85
60000/60000 [==============================] - 4s 63us/step - loss: 0.0
031 - accuracy: 0.9990 - val_loss: 0.0885 - val_accuracy: 0.9824
Epoch 37/85
60000/60000 [==============================] - 4s 60us/step - loss: 0.0
047 - accuracy: 0.9983 - val_loss: 0.1048 - val_accuracy: 0.9791
Epoch 38/85
60000/60000 [==============================] - 4s 61us/step - loss: 0.0
038 - accuracy: 0.9988 - val_loss: 0.0945 - val_accuracy: 0.9810
Epoch 39/85
```

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```
Epoch 39/85

60000/60000 [==============================] - 4s 60us/step - loss: 0.0
039 - accuracy: 0.9988 - val_loss: 0.0992 - val_accuracy: 0.9813
Epoch 40/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
039 - accuracy: 0.9988 - val_loss: 0.0991 - val_accuracy: 0.9795
Epoch 41/85
60000/60000 [==============================] - 4s 58us/step - loss: 0.0
036 - accuracy: 0.9990 - val_loss: 0.0954 - val_accuracy: 0.9826
Epoch 42/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
036 - accuracy: 0.9989 - val_loss: 0.1058 - val_accuracy: 0.9809
Epoch 43/85
60000/60000 [==============================] - 4s 62us/step - loss: 0.0
039 - accuracy: 0.9987 - val_loss: 0.1006 - val_accuracy: 0.9816
Epoch 44/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
042 - accuracy: 0.9987 - val_loss: 0.1176 - val_accuracy: 0.9790
Epoch 45/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.0
045 - accuracy: 0.9986 - val_loss: 0.1040 - val_accuracy: 0.9802
Epoch 46/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.0
034 - accuracy: 0.9988 - val_loss: 0.1026 - val_accuracy: 0.9803
Epoch 47/85
60000/60000 [==============================] - 4s 62us/step - loss: 0.0
030 - accuracy: 0.9990 - val_loss: 0.0989 - val_accuracy: 0.9802
Epoch 48/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
025 - accuracy: 0.9992 - val_loss: 0.1036 - val_accuracy: 0.9810
Epoch 49/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.0
020 - accuracy: 0.9995 - val_loss: 0.0951 - val_accuracy: 0.9818
Epoch 50/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.0
041 - accuracy: 0.9988 - val_loss: 0.0979 - val_accuracy: 0.9807
Epoch 51/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.0
035 - accuracy: 0.9988 - val_loss: 0.0971 - val_accuracy: 0.9818
Epoch 52/85
```

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```
Epoch 52/85

60000/60000 [==============================] - 4s 62us/step - loss: 0.0
025 - accuracy: 0.9990 - val_loss: 0.0987 - val_accuracy: 0.9824
Epoch 53/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
018 - accuracy: 0.9995 - val_loss: 0.0944 - val_accuracy: 0.9815
Epoch 54/85
60000/60000 [==============================] - 4s 60us/step - loss: 0.0
027 - accuracy: 0.9992 - val_loss: 0.0954 - val_accuracy: 0.9808
Epoch 55/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.0
033 - accuracy: 0.9989 - val_loss: 0.1261 - val_accuracy: 0.9790
Epoch 56/85
60000/60000 [==============================] - 3s 57us/step - loss: 0.0
040 - accuracy: 0.9985 - val_loss: 0.1012 - val_accuracy: 0.9813
Epoch 57/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
024 - accuracy: 0.9991 - val_loss: 0.0934 - val_accuracy: 0.9819
Epoch 58/85
60000/60000 [==============================] - 4s 61us/step - loss: 0.0
019 - accuracy: 0.9995 - val_loss: 0.0945 - val_accuracy: 0.9823
Epoch 59/85
60000/60000 [==============================] - 3s 57us/step - loss: 0.0
020 - accuracy: 0.9994 - val_loss: 0.0988 - val_accuracy: 0.9824
Epoch 60/85
60000/60000 [==============================] - 3s 57us/step - loss: 0.0
023 - accuracy: 0.9993 - val_loss: 0.1098 - val_accuracy: 0.9807
Epoch 61/85
60000/60000 [==============================] - 4s 61us/step - loss: 0.0
031 - accuracy: 0.9988 - val_loss: 0.0974 - val_accuracy: 0.9821
Epoch 62/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
037 - accuracy: 0.9986 - val_loss: 0.1053 - val_accuracy: 0.9809
Epoch 63/85
60000/60000 [==============================] - 3s 57us/step - loss: 0.0
036 - accuracy: 0.9987 - val_loss: 0.1058 - val_accuracy: 0.9809
Epoch 64/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
028 - accuracy: 0.9992 - val_loss: 0.0997 - val_accuracy: 0.9814
Epoch 65/85
```

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```
Epoch 65/85

60000/60000 [==============================] - 3s 58us/step - loss: 0.0
019 - accuracy: 0.9995 - val_loss: 0.1017 - val_accuracy: 0.9810
Epoch 66/85
60000/60000 [==============================] - 3s 57us/step - loss: 0.0
019 - accuracy: 0.9994 - val_loss: 0.1004 - val_accuracy: 0.9817
Epoch 67/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
019 - accuracy: 0.9994 - val_loss: 0.1048 - val_accuracy: 0.9802
Epoch 68/85
60000/60000 [==============================] - 4s 61us/step - loss: 0.0
021 - accuracy: 0.9992 - val_loss: 0.1068 - val_accuracy: 0.9809
Epoch 69/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.0
025 - accuracy: 0.9992 - val_loss: 0.0995 - val_accuracy: 0.9830
Epoch 70/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.0
025 - accuracy: 0.9993 - val_loss: 0.1023 - val_accuracy: 0.9828
Epoch 71/85
60000/60000 [==============================] - 4s 61us/step - loss: 0.0
010 - accuracy: 0.9997 - val_loss: 0.0846 - val_accuracy: 0.9851
Epoch 72/85
60000/60000 [==============================] - 3s 57us/step - loss: 0.0
021 - accuracy: 0.9993 - val_loss: 0.0974 - val_accuracy: 0.9830
Epoch 73/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
018 - accuracy: 0.9994 - val_loss: 0.0984 - val_accuracy: 0.9826
Epoch 74/85
60000/60000 [==============================] - 4s 60us/step - loss: 0.0
030 - accuracy: 0.9991 - val_loss: 0.0994 - val_accuracy: 0.9814
Epoch 75/85
60000/60000 [==============================] - 4s 61us/step - loss: 0.0
030 - accuracy: 0.9992 - val_loss: 0.1019 - val_accuracy: 0.9823
Epoch 76/85
60000/60000 [==============================] - 4s 61us/step - loss: 0.0
017 - accuracy: 0.9993 - val_loss: 0.0995 - val_accuracy: 0.9828
Epoch 77/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
013 - accuracy: 0.9996 - val_loss: 0.1033 - val_accuracy: 0.9823
Epoch 78/85
```

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```
Epoch 78/85

60000/60000 [==============================] - 3s 57us/step - loss: 0.0
014 - accuracy: 0.9995 - val_loss: 0.1036 - val_accuracy: 0.9830
Epoch 79/85
60000/60000 [==============================] - 4s 64us/step - loss: 0.0
028 - accuracy: 0.9990 - val_loss: 0.1042 - val_accuracy: 0.9825
Epoch 80/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
017 - accuracy: 0.9994 - val_loss: 0.0909 - val_accuracy: 0.9842
Epoch 81/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
022 - accuracy: 0.9993 - val_loss: 0.1000 - val_accuracy: 0.9831
Epoch 82/85
60000/60000 [==============================] - 4s 59us/step - loss: 0.0
029 - accuracy: 0.9990 - val_loss: 0.1068 - val_accuracy: 0.9816
Epoch 83/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
021 - accuracy: 0.9992 - val_loss: 0.1021 - val_accuracy: 0.9827
Epoch 84/85
60000/60000 [==============================] - 3s 58us/step - loss: 0.0
013 - accuracy: 0.9996 - val_loss: 0.1056 - val_accuracy: 0.9826
Epoch 85/85
60000/60000 [==============================] - 4s 62us/step - loss: 0.0
021 - accuracy: 0.9992 - val_loss: 0.1048 - val_accuracy: 0.9819
```

1.3.2.3 Number of Epochs vs Train Loss & Validation Loss

In [65]:
```
import warnings
warnings.filterwarnings("ignore")

A3M2_score = arch3_model2.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A3M2_score[0])
print('Test accuracy:', A3M2_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')
```

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in history.history we will have a list of length equal t
o number of epochs

vy = A3M2_history.history['val_loss']
ty = A3M2_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.1048331060788921
Test accuracy: 0.9818999767303467
```

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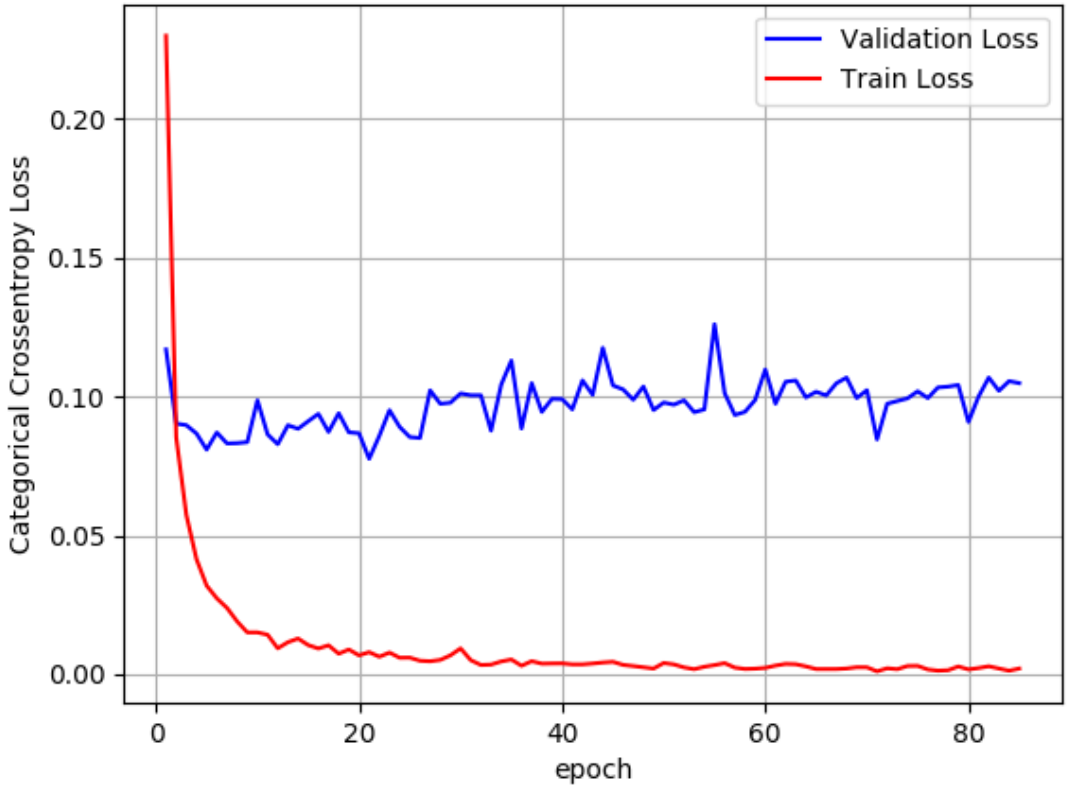

1.3.2.4 Violin Plots for Hidden Layers in the Models Trained

In [66]:
```
warnings.filterwarnings("ignore")

w_after = arch3_model2.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
```

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```
out_w = w_after[4].flatten().reshape(-1,1)

fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 3, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 1')

plt.subplot(1, 3, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 2 ')

plt.subplot(1, 3, 3)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Output Layer ')
plt.show()
```

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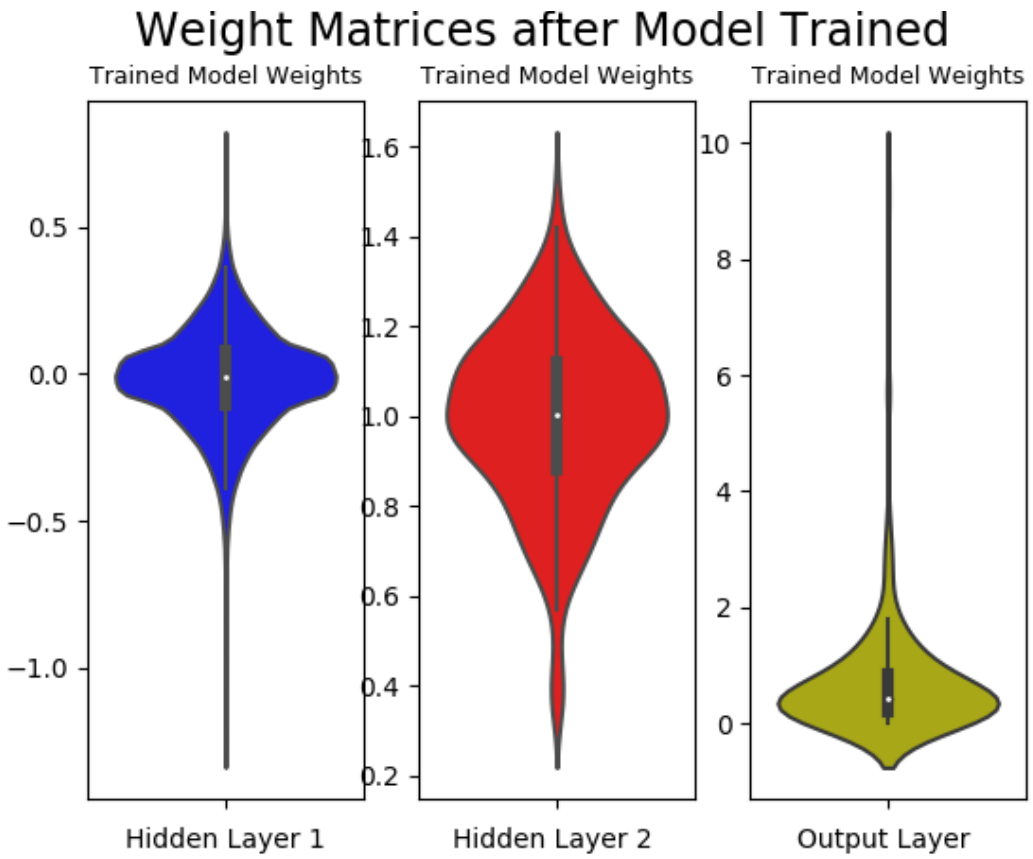

1.3.3 Model 3 : MLP + BatchNormalization + Dropout + Adam Optimizer

1.3.3.1 Hyperparameter Tuning for Dropout

In [68]:
```
def A3M3_best_hyperparameters(dropout):
    arch3_model3 = Sequential()

    arch3_model3.add(Dense(256, activation='relu', input_shape=(input_d
im,),\
```

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```
                        kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))
    arch3_model3.add(BatchNormalization())
    arch3_model3.add(Dropout(dropout))

    arch3_model3.add(Dense(64, activation='relu', \
                         kernel_initializer=RandomUniform(minval= -0.153,
 maxval=0.153, seed=None)) )
    arch3_model3.add(BatchNormalization())
    arch3_model3.add(Dropout(dropout))

    arch3_model3.add(Dense(output_dim, activation='softmax'))

    arch3_model3.compile(loss='categorical_crossentropy', metrics=['acc
uracy'], optimizer='adam')

    return arch3_model3
```

In [69]:

```
start = datetime.now()

dropout = []

for d in range(1,10):
    dropout.append(d/10)

model = KerasClassifier(build_fn=A3M3_best_hyperparameters, epochs=nb_e
poch, batch_size=batch_size, verbose=0)
param_grid = dict(dropout=dropout)

# if you are using CPU
# grid = GridSearchCV(estimator=model, param_grid=param_grid, n_jobs=-
1)
# if you are using GPU dont use the n_jobs parameter

grid_2 = GridSearchCV(estimator=model, param_grid=param_grid,cv=3,n_job
s=-1)
grid_result2 = grid_2.fit(X_train, Y_train)

print('Time taken :', datetime.now() - start)
```

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```
Time taken : 1:04:10.298202
```

In [70]:
```
print("Best: %f using %s" % (grid_result2.best_score_, grid_result2.bes
t_params_))
means = grid_result2.cv_results_['mean_test_score']
stds = grid_result2.cv_results_['std_test_score']
params = grid_result2.cv_results_['params']
for mean, stdev, param in zip(means, stds, params):
    print("%f (%f) with: %r" % (mean, stdev, param))
```

```
Best: 0.980750 using {'dropout': 0.3}
0.979300 (0.001089) with: {'dropout': 0.1}
0.980217 (0.001474) with: {'dropout': 0.2}
0.980750 (0.000748) with: {'dropout': 0.3}
0.979617 (0.000980) with: {'dropout': 0.4}
0.978850 (0.000286) with: {'dropout': 0.5}
0.976450 (0.000942) with: {'dropout': 0.6}
0.973783 (0.001014) with: {'dropout': 0.7}
0.963700 (0.000935) with: {'dropout': 0.8}
0.936917 (0.002500) with: {'dropout': 0.9}
```

1.3.3.2 Constructing the Neural Network

In [13]:
```
from keras.layers.normalization import BatchNormalization
from keras.layers import Dropout

arch3_model3 = Sequential()

arch3_model3.add(Dense(256, activation='relu', input_shape=(input_dim
,),\
                       kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))
arch3_model3.add(BatchNormalization())
arch3_model3.add(Dropout(0.3))

arch3_model3.add(Dense(64, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.153,
```

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```
 maxval=0.153, seed=None)) )
arch3_model3.add(BatchNormalization())
arch3_model3.add(Dropout(0.3))

arch3_model3.add(Dense(output_dim, activation='softmax'))
arch3_model3.summary()
```

```
Model: "sequential_1"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_1 (Dense)              (None, 256)               200960
_________________________________________________________________
batch_normalization_1 (Batch (None, 256)               1024
_________________________________________________________________
dropout_1 (Dropout)          (None, 256)               0
_________________________________________________________________
dense_2 (Dense)              (None, 64)                16448
_________________________________________________________________
batch_normalization_2 (Batch (None, 64)                256
_________________________________________________________________
dropout_2 (Dropout)          (None, 64)                0
_________________________________________________________________
dense_3 (Dense)              (None, 10)                650
=================================================================
Total params: 219,338
Trainable params: 218,698
Non-trainable params: 640
_________________________________________________________________
```

1.3.3.3 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [14]:
```
arch3_model3.compile(optimizer='adam', loss='categorical_crossentropy',
 metrics=['accuracy'])

A3M3_history = arch3_model3.fit(X_train, Y_train, batch_size=batch_size
, epochs=nb_epoch, verbose=1, \
                              validation_data=(X_test, Y_test))
```

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```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 5s 90us/step - loss: 0.3
820 - accuracy: 0.8863 - val_loss: 0.1421 - val_accuracy: 0.9591
Epoch 2/85
60000/60000 [==============================] - 5s 77us/step - loss: 0.1
779 - accuracy: 0.9473 - val_loss: 0.1111 - val_accuracy: 0.9659
Epoch 3/85
60000/60000 [==============================] - 5s 75us/step - loss: 0.1
382 - accuracy: 0.9586 - val_loss: 0.0979 - val_accuracy: 0.9685
Epoch 4/85
60000/60000 [==============================] - 4s 73us/step - loss: 0.1
159 - accuracy: 0.9651 - val_loss: 0.0820 - val_accuracy: 0.9752
Epoch 5/85
60000/60000 [==============================] - 5s 77us/step - loss: 0.0
986 - accuracy: 0.9695 - val_loss: 0.0783 - val_accuracy: 0.9760
Epoch 6/85
60000/60000 [==============================] - 4s 74us/step - loss: 0.0
914 - accuracy: 0.9717 - val_loss: 0.0798 - val_accuracy: 0.9748
Epoch 7/85
60000/60000 [==============================] - 4s 72us/step - loss: 0.0
804 - accuracy: 0.9747 - val_loss: 0.0750 - val_accuracy: 0.9761
Epoch 8/85
60000/60000 [==============================] - 4s 71us/step - loss: 0.0
748 - accuracy: 0.9765 - val_loss: 0.0694 - val_accuracy: 0.9778
Epoch 9/85
60000/60000 [==============================] - 4s 75us/step - loss: 0.0
675 - accuracy: 0.9783 - val_loss: 0.0666 - val_accuracy: 0.9793
Epoch 10/85
60000/60000 [==============================] - 4s 75us/step - loss: 0.0
681 - accuracy: 0.9783 - val_loss: 0.0642 - val_accuracy: 0.9790
Epoch 11/85
60000/60000 [==============================] - 4s 73us/step - loss: 0.0
620 - accuracy: 0.9801 - val_loss: 0.0632 - val_accuracy: 0.9811
Epoch 12/85
60000/60000 [==============================] - 4s 73us/step - loss: 0.0
587 - accuracy: 0.9813 - val_loss: 0.0602 - val_accuracy: 0.9824
Epoch 13/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
```

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```
546 - accuracy: 0.9825 - val_loss: 0.0648 - val_accuracy: 0.9813
Epoch 14/85
60000/60000 [==============================] - 4s 72us/step - loss: 0.0
515 - accuracy: 0.9833 - val_loss: 0.0703 - val_accuracy: 0.9790
Epoch 15/85
60000/60000 [==============================] - 4s 72us/step - loss: 0.0
483 - accuracy: 0.9845 - val_loss: 0.0627 - val_accuracy: 0.9821
Epoch 16/85
60000/60000 [==============================] - 5s 75us/step - loss: 0.0
474 - accuracy: 0.9849 - val_loss: 0.0585 - val_accuracy: 0.9825
Epoch 17/85
60000/60000 [==============================] - 4s 72us/step - loss: 0.0
464 - accuracy: 0.9853 - val_loss: 0.0567 - val_accuracy: 0.9823
Epoch 18/85
60000/60000 [==============================] - 4s 73us/step - loss: 0.0
417 - accuracy: 0.9863 - val_loss: 0.0565 - val_accuracy: 0.9824
Epoch 19/85
60000/60000 [==============================] - 4s 70us/step - loss: 0.0
406 - accuracy: 0.9864 - val_loss: 0.0612 - val_accuracy: 0.9817
Epoch 20/85
60000/60000 [==============================] - 4s 70us/step - loss: 0.0
354 - accuracy: 0.9880 - val_loss: 0.0634 - val_accuracy: 0.9819
Epoch 21/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
384 - accuracy: 0.9870 - val_loss: 0.0616 - val_accuracy: 0.9831
Epoch 22/85
60000/60000 [==============================] - 4s 73us/step - loss: 0.0
373 - accuracy: 0.9875 - val_loss: 0.0552 - val_accuracy: 0.9851
Epoch 23/85
60000/60000 [==============================] - 5s 77us/step - loss: 0.0
361 - accuracy: 0.9877 - val_loss: 0.0603 - val_accuracy: 0.9833
Epoch 24/85
60000/60000 [==============================] - 4s 71us/step - loss: 0.0
335 - accuracy: 0.9889 - val_loss: 0.0579 - val_accuracy: 0.9848
Epoch 25/85
60000/60000 [==============================] - 4s 68us/step - loss: 0.0
337 - accuracy: 0.9891 - val_loss: 0.0549 - val_accuracy: 0.9848
Epoch 26/85
60000/60000 [==============================] - 4s 70us/step - loss: 0.0
```

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```
321 - accuracy: 0.9896 - val_loss: 0.0559 - val_accuracy: 0.9848
Epoch 27/85
60000/60000 [==============================] - 4s 70us/step - loss: 0.0
326 - accuracy: 0.9891 - val_loss: 0.0598 - val_accuracy: 0.9841
Epoch 28/85
60000/60000 [==============================] - 5s 75us/step - loss: 0.0
304 - accuracy: 0.9902 - val_loss: 0.0615 - val_accuracy: 0.9829
Epoch 29/85
60000/60000 [==============================] - 5s 78us/step - loss: 0.0
296 - accuracy: 0.9901 - val_loss: 0.0598 - val_accuracy: 0.9829
Epoch 30/85
60000/60000 [==============================] - 4s 71us/step - loss: 0.0
303 - accuracy: 0.9897 - val_loss: 0.0616 - val_accuracy: 0.9825
Epoch 31/85
60000/60000 [==============================] - 4s 72us/step - loss: 0.0
279 - accuracy: 0.9911 - val_loss: 0.0582 - val_accuracy: 0.9850
Epoch 32/85
60000/60000 [==============================] - 5s 76us/step - loss: 0.0
277 - accuracy: 0.9904 - val_loss: 0.0583 - val_accuracy: 0.9840
Epoch 33/85
60000/60000 [==============================] - 4s 72us/step - loss: 0.0
266 - accuracy: 0.9914 - val_loss: 0.0614 - val_accuracy: 0.9834
Epoch 34/85
60000/60000 [==============================] - 5s 75us/step - loss: 0.0
266 - accuracy: 0.9909 - val_loss: 0.0603 - val_accuracy: 0.9824
Epoch 35/85
60000/60000 [==============================] - 4s 70us/step - loss: 0.0
241 - accuracy: 0.9924 - val_loss: 0.0587 - val_accuracy: 0.9843
Epoch 36/85
60000/60000 [==============================] - 4s 72us/step - loss: 0.0
260 - accuracy: 0.9909 - val_loss: 0.0615 - val_accuracy: 0.9841
Epoch 37/85
60000/60000 [==============================] - 4s 72us/step - loss: 0.0
250 - accuracy: 0.9915 - val_loss: 0.0582 - val_accuracy: 0.9843
Epoch 38/85
60000/60000 [==============================] - 4s 72us/step - loss: 0.0
232 - accuracy: 0.9923 - val_loss: 0.0572 - val_accuracy: 0.9856
Epoch 39/85
60000/60000 [==============================] - 4s 74us/step - loss: 0.0
```

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```
223 - accuracy: 0.9923 - val_loss: 0.0571 - val_accuracy: 0.9855
Epoch 40/85
60000/60000 [==============================] - 4s 71us/step - loss: 0.0
237 - accuracy: 0.9919 - val_loss: 0.0618 - val_accuracy: 0.9832
Epoch 41/85
60000/60000 [==============================] - 4s 72us/step - loss: 0.0
246 - accuracy: 0.9923 - val_loss: 0.0613 - val_accuracy: 0.9844
Epoch 42/85
60000/60000 [==============================] - 4s 70us/step - loss: 0.0
227 - accuracy: 0.9929 - val_loss: 0.0574 - val_accuracy: 0.9848
Epoch 43/85
60000/60000 [==============================] - 5s 78us/step - loss: 0.0
231 - accuracy: 0.9927 - val_loss: 0.0612 - val_accuracy: 0.9826
Epoch 44/85
60000/60000 [==============================] - 4s 73us/step - loss: 0.0
208 - accuracy: 0.9932 - val_loss: 0.0669 - val_accuracy: 0.9842
Epoch 45/85
60000/60000 [==============================] - 4s 71us/step - loss: 0.0
209 - accuracy: 0.9929 - val_loss: 0.0632 - val_accuracy: 0.9839
Epoch 46/85
60000/60000 [==============================] - 4s 73us/step - loss: 0.0
215 - accuracy: 0.9926 - val_loss: 0.0636 - val_accuracy: 0.9837
Epoch 47/85
60000/60000 [==============================] - 4s 71us/step - loss: 0.0
224 - accuracy: 0.9926 - val_loss: 0.0651 - val_accuracy: 0.9833
Epoch 48/85
60000/60000 [==============================] - 4s 73us/step - loss: 0.0
207 - accuracy: 0.9931 - val_loss: 0.0599 - val_accuracy: 0.9852
Epoch 49/85
60000/60000 [==============================] - 4s 74us/step - loss: 0.0
182 - accuracy: 0.9935 - val_loss: 0.0596 - val_accuracy: 0.9847
Epoch 50/85
60000/60000 [==============================] - 4s 72us/step - loss: 0.0
206 - accuracy: 0.9930 - val_loss: 0.0615 - val_accuracy: 0.9847
Epoch 51/85
60000/60000 [==============================] - 4s 73us/step - loss: 0.0
213 - accuracy: 0.9931 - val_loss: 0.0617 - val_accuracy: 0.9842
Epoch 52/85
60000/60000 [==============================] - 4s 73us/step - loss: 0.0
```

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```
185 - accuracy: 0.9934 - val_loss: 0.0589 - val_accuracy: 0.9846
Epoch 53/85
60000/60000 [==============================] - 5s 77us/step - loss: 0.0
190 - accuracy: 0.9941 - val_loss: 0.0608 - val_accuracy: 0.9851
Epoch 54/85
60000/60000 [==============================] - 4s 74us/step - loss: 0.0
183 - accuracy: 0.9939 - val_loss: 0.0643 - val_accuracy: 0.9851
Epoch 55/85
60000/60000 [==============================] - 4s 71us/step - loss: 0.0
191 - accuracy: 0.9937 - val_loss: 0.0674 - val_accuracy: 0.9845
Epoch 56/85
60000/60000 [==============================] - 4s 71us/step - loss: 0.0
195 - accuracy: 0.9936 - val_loss: 0.0649 - val_accuracy: 0.9844
Epoch 57/85
60000/60000 [==============================] - 4s 72us/step - loss: 0.0
190 - accuracy: 0.9940 - val_loss: 0.0660 - val_accuracy: 0.9855
Epoch 58/85
60000/60000 [==============================] - 4s 71us/step - loss: 0.0
151 - accuracy: 0.9947 - val_loss: 0.0629 - val_accuracy: 0.9840
Epoch 59/85
60000/60000 [==============================] - 4s 72us/step - loss: 0.0
147 - accuracy: 0.9951 - val_loss: 0.0619 - val_accuracy: 0.9844
Epoch 60/85
60000/60000 [==============================] - 4s 75us/step - loss: 0.0
161 - accuracy: 0.9947 - val_loss: 0.0649 - val_accuracy: 0.9841
Epoch 61/85
60000/60000 [==============================] - 4s 70us/step - loss: 0.0
179 - accuracy: 0.9941 - val_loss: 0.0665 - val_accuracy: 0.9842
Epoch 62/85
60000/60000 [==============================] - 4s 71us/step - loss: 0.0
170 - accuracy: 0.9941 - val_loss: 0.0619 - val_accuracy: 0.9849
Epoch 63/85
60000/60000 [==============================] - 4s 72us/step - loss: 0.0
184 - accuracy: 0.9937 - val_loss: 0.0623 - val_accuracy: 0.9851
Epoch 64/85
60000/60000 [==============================] - 4s 70us/step - loss: 0.0
174 - accuracy: 0.9947 - val_loss: 0.0644 - val_accuracy: 0.9850
Epoch 65/85
60000/60000 [==============================] - 4s 73us/step - loss: 0.0
```

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```
149 - accuracy: 0.9950 - val_loss: 0.0620 - val_accuracy: 0.9853
Epoch 66/85
60000/60000 [==============================] - 4s 72us/step - loss: 0.0
167 - accuracy: 0.9944 - val_loss: 0.0623 - val_accuracy: 0.9858
Epoch 67/85
60000/60000 [==============================] - 4s 75us/step - loss: 0.0
162 - accuracy: 0.9944 - val_loss: 0.0689 - val_accuracy: 0.9837
Epoch 68/85
60000/60000 [==============================] - 4s 72us/step - loss: 0.0
156 - accuracy: 0.9947 - val_loss: 0.0661 - val_accuracy: 0.9850
Epoch 69/85
60000/60000 [==============================] - 4s 70us/step - loss: 0.0
155 - accuracy: 0.9947 - val_loss: 0.0637 - val_accuracy: 0.9858
Epoch 70/85
60000/60000 [==============================] - 4s 71us/step - loss: 0.0
160 - accuracy: 0.9945 - val_loss: 0.0602 - val_accuracy: 0.9864
Epoch 71/85
60000/60000 [==============================] - 4s 71us/step - loss: 0.0
156 - accuracy: 0.9945 - val_loss: 0.0640 - val_accuracy: 0.9856
Epoch 72/85
60000/60000 [==============================] - 4s 74us/step - loss: 0.0
150 - accuracy: 0.9950 - val_loss: 0.0600 - val_accuracy: 0.9860
Epoch 73/85
60000/60000 [==============================] - 4s 74us/step - loss: 0.0
149 - accuracy: 0.9949 - val_loss: 0.0666 - val_accuracy: 0.9846
Epoch 74/85
60000/60000 [==============================] - 4s 72us/step - loss: 0.0
136 - accuracy: 0.9958 - val_loss: 0.0673 - val_accuracy: 0.9852
Epoch 75/85
60000/60000 [==============================] - 4s 73us/step - loss: 0.0
140 - accuracy: 0.9949 - val_loss: 0.0643 - val_accuracy: 0.9856
Epoch 76/85
60000/60000 [==============================] - 4s 70us/step - loss: 0.0
151 - accuracy: 0.9950 - val_loss: 0.0706 - val_accuracy: 0.9840
Epoch 77/85
60000/60000 [==============================] - 4s 72us/step - loss: 0.0
141 - accuracy: 0.9954 - val_loss: 0.0744 - val_accuracy: 0.9836
Epoch 78/85
60000/60000 [==============================] - 4s 75us/step - loss: 0.0
```

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```
140 - accuracy: 0.9953 - val_loss: 0.0743 - val_accuracy: 0.9839
Epoch 79/85
60000/60000 [==============================] - 4s 75us/step - loss: 0.0
145 - accuracy: 0.9953 - val_loss: 0.0683 - val_accuracy: 0.9840
Epoch 80/85
60000/60000 [==============================] - 4s 70us/step - loss: 0.0
141 - accuracy: 0.9952 - val_loss: 0.0663 - val_accuracy: 0.9832
Epoch 81/85
60000/60000 [==============================] - 4s 72us/step - loss: 0.0
156 - accuracy: 0.9952 - val_loss: 0.0648 - val_accuracy: 0.9839
Epoch 82/85
60000/60000 [==============================] - 5s 75us/step - loss: 0.0
139 - accuracy: 0.9952 - val_loss: 0.0670 - val_accuracy: 0.9847
Epoch 83/85
60000/60000 [==============================] - 4s 73us/step - loss: 0.0
139 - accuracy: 0.9953 - val_loss: 0.0625 - val_accuracy: 0.9855
Epoch 84/85
60000/60000 [==============================] - 4s 71us/step - loss: 0.0
123 - accuracy: 0.9962 - val_loss: 0.0629 - val_accuracy: 0.9859
Epoch 85/85
60000/60000 [==============================] - 4s 70us/step - loss: 0.0
127 - accuracy: 0.9955 - val_loss: 0.0683 - val_accuracy: 0.9851
```

1.3.3.4 Number of Epochs vs Train Loss & Validation Loss

In [15]:

```
import warnings
warnings.filterwarnings("ignore")

A3M3_score = arch3_model3.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A3M3_score[0])
print('Test accuracy:', A3M3_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

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```
# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in history.history we will have a list of length equal t
o number of epochs

vy = A3M3_history.history['val_loss']
ty = A3M3_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.06828610219557331
Test accuracy: 0.9850999712944031
```

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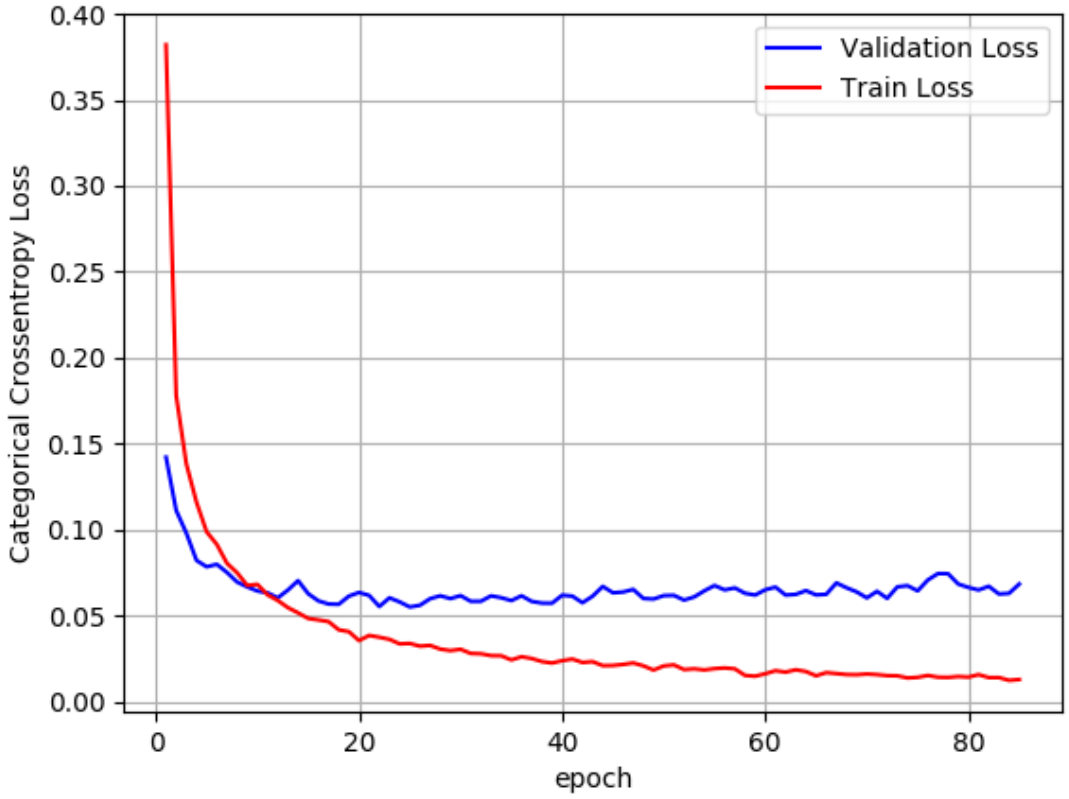

1.3.3.5 Violin Plots for Hidden Layers in the Models Trained

In [16]:
```
warnings.filterwarnings("ignore")

w_after = arch3_model3.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
```

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```
out_w = w_after[4].flatten().reshape(-1,1)

fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 3, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 1')

plt.subplot(1, 3, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Hidden Layer 2 ')

plt.subplot(1, 3, 3)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 9)
plt.xlabel('Output Layer ')
plt.show()
```

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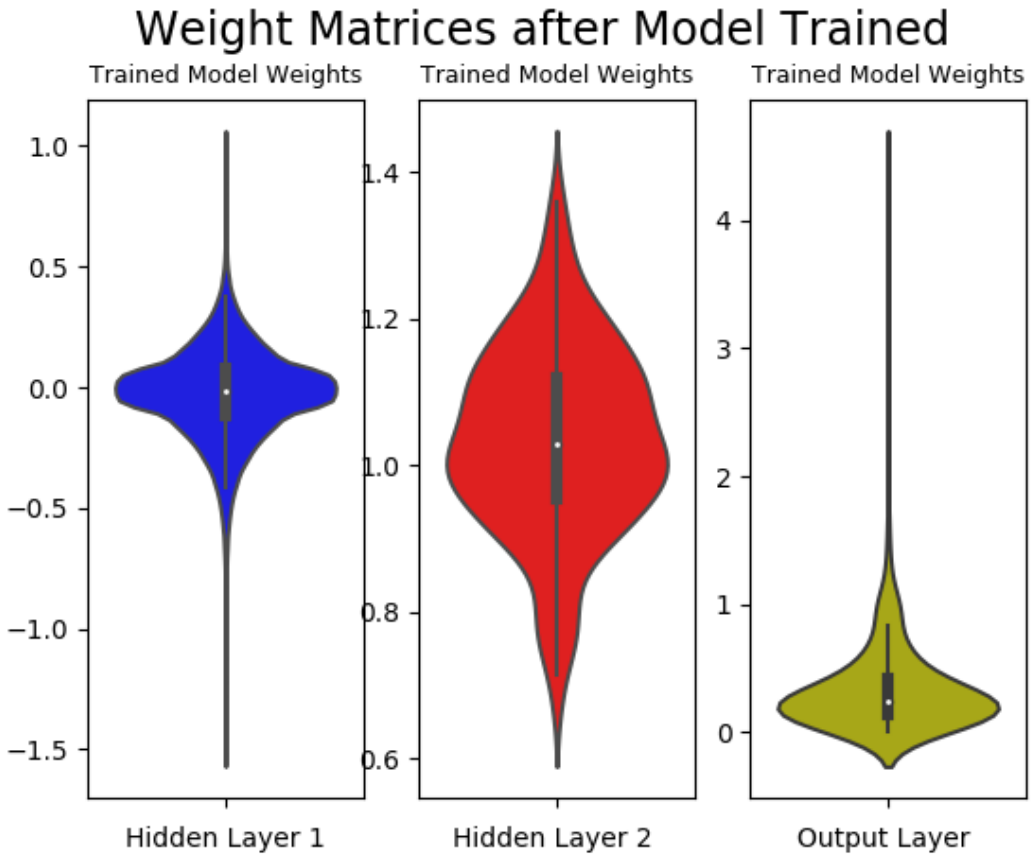

2. Number of Hidden Layers in the Neural Network = 3

2.1 Architecture 4 :- 784-512-256-128-10

2.1.1 Model 1 : MLP + Adam Optimizer

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2.1.1.1 Constructing the Neural Network

In [47]:
```
arch4_model1 = Sequential()

arch4_model1.add(Dense(512, activation='relu', input_shape=(input_dim
,),\
                       kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))

arch4_model1.add(Dense(256, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.108,
 maxval=0.108, seed=None)) )

arch4_model1.add(Dense(128, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.153,
 maxval=0.153, seed=None)) )

arch4_model1.add(Dense(output_dim, activation='softmax'))
arch4_model1.summary()
```

```
Model: "sequential_7"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_24 (Dense)             (None, 512)               401920
_________________________________________________________________
dense_25 (Dense)             (None, 256)               131328
_________________________________________________________________
dense_26 (Dense)             (None, 128)               32896
_________________________________________________________________
dense_27 (Dense)             (None, 10)                1290
=================================================================
Total params: 567,434
Trainable params: 567,434
Non-trainable params: 0
_________________________________________________________________
```

2.1.1.2 Running the Neural Network on Train & Validation Datasets for 85 Epochs

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In [48]:
```
arch4_model1.compile(optimizer='adam', loss='categorical_crossentropy',
 metrics=['accuracy'])

A4M1_history = arch4_model1.fit(X_train, Y_train, batch_size=batch_size
, epochs=nb_epoch, verbose=1, \
                              validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 6s 107us/step - loss: 0.
2245 - accuracy: 0.9320 - val_loss: 0.0950 - val_accuracy: 0.9716
Epoch 2/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0822 - accuracy: 0.9743 - val_loss: 0.0905 - val_accuracy: 0.9708
Epoch 3/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0531 - accuracy: 0.9833 - val_loss: 0.0704 - val_accuracy: 0.9783
Epoch 4/85
60000/60000 [==============================] - 6s 106us/step - loss: 0.
0383 - accuracy: 0.9875 - val_loss: 0.0807 - val_accuracy: 0.9771
Epoch 5/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0338 - accuracy: 0.9891 - val_loss: 0.0726 - val_accuracy: 0.9786
Epoch 6/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0254 - accuracy: 0.9918 - val_loss: 0.0789 - val_accuracy: 0.9770
Epoch 7/85
60000/60000 [==============================] - 7s 118us/step - loss: 0.
0215 - accuracy: 0.9929 - val_loss: 0.0685 - val_accuracy: 0.9828
Epoch 8/85
60000/60000 [==============================] - 8s 136us/step - loss: 0.
0204 - accuracy: 0.9934 - val_loss: 0.0750 - val_accuracy: 0.9815
Epoch 9/85
60000/60000 [==============================] - 8s 136us/step - loss: 0.
0144 - accuracy: 0.9953 - val_loss: 0.0818 - val_accuracy: 0.9806
Epoch 10/85
60000/60000 [==============================] - 6s 105us/step - loss: 0.
0159 - accuracy: 0.9946 - val_loss: 0.0868 - val_accuracy: 0.9792
Epoch 11/85
```

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```
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0161 - accuracy: 0.9949 - val_loss: 0.0778 - val_accuracy: 0.9818
Epoch 12/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0141 - accuracy: 0.9952 - val_loss: 0.0948 - val_accuracy: 0.9810
Epoch 13/85
60000/60000 [==============================] - 6s 101us/step - loss: 0.
0119 - accuracy: 0.9963 - val_loss: 0.0904 - val_accuracy: 0.9807
Epoch 14/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0120 - accuracy: 0.9963 - val_loss: 0.0969 - val_accuracy: 0.9802
Epoch 15/85
60000/60000 [==============================] - 6s 101us/step - loss: 0.
0114 - accuracy: 0.9965 - val_loss: 0.0919 - val_accuracy: 0.9809
Epoch 16/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0092 - accuracy: 0.9969 - val_loss: 0.0824 - val_accuracy: 0.9833
Epoch 17/85
60000/60000 [==============================] - 6s 106us/step - loss: 0.
0116 - accuracy: 0.9961 - val_loss: 0.0829 - val_accuracy: 0.9839
Epoch 18/85
60000/60000 [==============================] - 7s 119us/step - loss: 0.
0091 - accuracy: 0.9969 - val_loss: 0.0843 - val_accuracy: 0.9828
Epoch 19/85
60000/60000 [==============================] - 6s 96us/step - loss: 0.0
080 - accuracy: 0.9975 - val_loss: 0.0986 - val_accuracy: 0.9825
Epoch 20/85
60000/60000 [==============================] - 6s 100us/step - loss: 0.
0093 - accuracy: 0.9970 - val_loss: 0.0939 - val_accuracy: 0.9809
Epoch 21/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0072 - accuracy: 0.9979 - val_loss: 0.0968 - val_accuracy: 0.9814
Epoch 22/85
60000/60000 [==============================] - 7s 119us/step - loss: 0.
0070 - accuracy: 0.9979 - val_loss: 0.0876 - val_accuracy: 0.9836
Epoch 23/85
60000/60000 [==============================] - 8s 139us/step - loss: 0.
0087 - accuracy: 0.9973 - val_loss: 0.0824 - val_accuracy: 0.9824
Epoch 24/85
```

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```
60000/60000 [==============================] - 7s 114us/step - loss: 0.
0067 - accuracy: 0.9977 - val_loss: 0.0868 - val_accuracy: 0.9819
Epoch 25/85
60000/60000 [==============================] - 8s 138us/step - loss: 0.
0095 - accuracy: 0.9970 - val_loss: 0.1026 - val_accuracy: 0.9806
Epoch 26/85
60000/60000 [==============================] - 6s 103us/step - loss: 0.
0073 - accuracy: 0.9980 - val_loss: 0.0784 - val_accuracy: 0.9836
Epoch 27/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0030 - accuracy: 0.9991 - val_loss: 0.0996 - val_accuracy: 0.9836
Epoch 28/85
60000/60000 [==============================] - 7s 113us/step - loss: 0.
0081 - accuracy: 0.9975 - val_loss: 0.0960 - val_accuracy: 0.9826
Epoch 29/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0056 - accuracy: 0.9982 - val_loss: 0.1252 - val_accuracy: 0.9768
Epoch 30/85
60000/60000 [==============================] - 6s 107us/step - loss: 0.
0063 - accuracy: 0.9983 - val_loss: 0.0911 - val_accuracy: 0.9830
Epoch 31/85
60000/60000 [==============================] - 6s 97us/step - loss: 0.0
046 - accuracy: 0.9986 - val_loss: 0.1270 - val_accuracy: 0.9783
Epoch 32/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0104 - accuracy: 0.9973 - val_loss: 0.1013 - val_accuracy: 0.9802
Epoch 33/85
60000/60000 [==============================] - 6s 106us/step - loss: 0.
0037 - accuracy: 0.9988 - val_loss: 0.1101 - val_accuracy: 0.9823
Epoch 34/85
60000/60000 [==============================] - 7s 123us/step - loss: 0.
0027 - accuracy: 0.9993 - val_loss: 0.0971 - val_accuracy: 0.9836
Epoch 35/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
0065 - accuracy: 0.9982 - val_loss: 0.0924 - val_accuracy: 0.9827
Epoch 36/85
60000/60000 [==============================] - 9s 143us/step - loss: 0.
0071 - accuracy: 0.9980 - val_loss: 0.1022 - val_accuracy: 0.9829
Epoch 37/85
```

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```
60000/60000 [==============================] - 12s 207us/step - loss:
0.0032 - accuracy: 0.9994 - val_loss: 0.1106 - val_accuracy: 0.9807
Epoch 38/85
60000/60000 [==============================] - 8s 136us/step - loss: 0.
0040 - accuracy: 0.9989 - val_loss: 0.0976 - val_accuracy: 0.9834
Epoch 39/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0049 - accuracy: 0.9987 - val_loss: 0.1206 - val_accuracy: 0.9813
Epoch 40/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0084 - accuracy: 0.9974 - val_loss: 0.1052 - val_accuracy: 0.9816
Epoch 41/85
60000/60000 [==============================] - 8s 131us/step - loss: 0.
0063 - accuracy: 0.9983 - val_loss: 0.1069 - val_accuracy: 0.9818
Epoch 42/85
60000/60000 [==============================] - 8s 135us/step - loss: 0.
0031 - accuracy: 0.9991 - val_loss: 0.1070 - val_accuracy: 0.9830
Epoch 43/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0033 - accuracy: 0.9992 - val_loss: 0.1026 - val_accuracy: 0.9834
Epoch 44/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0021 - accuracy: 0.9994 - val_loss: 0.0990 - val_accuracy: 0.9838
Epoch 45/85
60000/60000 [==============================] - 8s 133us/step - loss: 0.
0072 - accuracy: 0.9981 - val_loss: 0.1204 - val_accuracy: 0.9806
Epoch 46/85
60000/60000 [==============================] - 7s 114us/step - loss: 0.
0051 - accuracy: 0.9987 - val_loss: 0.1121 - val_accuracy: 0.9841
Epoch 47/85
60000/60000 [==============================] - 6s 103us/step - loss: 0.
0046 - accuracy: 0.9985 - val_loss: 0.1297 - val_accuracy: 0.9815
Epoch 48/85
60000/60000 [==============================] - 6s 95us/step - loss: 0.0
033 - accuracy: 0.9992 - val_loss: 0.1397 - val_accuracy: 0.9812
Epoch 49/85
60000/60000 [==============================] - 6s 94us/step - loss: 0.0
026 - accuracy: 0.9993 - val_loss: 0.1340 - val_accuracy: 0.9823
Epoch 50/85
```

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```
60000/60000 [==============================] - 6s 103us/step - loss: 0.
0040 - accuracy: 0.9990 - val_loss: 0.1022 - val_accuracy: 0.9855
Epoch 51/85
60000/60000 [==============================] - 6s 101us/step - loss: 0.
0052 - accuracy: 0.9985 - val_loss: 0.1088 - val_accuracy: 0.9830
Epoch 52/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0032 - accuracy: 0.9991 - val_loss: 0.1286 - val_accuracy: 0.9830
Epoch 53/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0035 - accuracy: 0.9989 - val_loss: 0.1225 - val_accuracy: 0.9826
Epoch 54/85
60000/60000 [==============================] - 7s 113us/step - loss: 0.
0057 - accuracy: 0.9987 - val_loss: 0.1395 - val_accuracy: 0.9810
Epoch 55/85
60000/60000 [==============================] - 8s 127us/step - loss: 0.
0062 - accuracy: 0.9983 - val_loss: 0.1105 - val_accuracy: 0.9833
Epoch 56/85
60000/60000 [==============================] - 6s 99us/step - loss: 0.0
034 - accuracy: 0.9990 - val_loss: 0.1169 - val_accuracy: 0.9834
Epoch 57/85
60000/60000 [==============================] - 7s 113us/step - loss: 0.
0012 - accuracy: 0.9997 - val_loss: 0.1057 - val_accuracy: 0.9849
Epoch 58/85
60000/60000 [==============================] - 6s 97us/step - loss: 2.8
645e-04 - accuracy: 0.9999 - val_loss: 0.1156 - val_accuracy: 0.9850
Epoch 59/85
60000/60000 [==============================] - 6s 105us/step - loss: 7.
1869e-04 - accuracy: 0.9999 - val_loss: 0.1198 - val_accuracy: 0.9844
Epoch 60/85
60000/60000 [==============================] - 8s 136us/step - loss: 0.
0069 - accuracy: 0.9982 - val_loss: 0.1746 - val_accuracy: 0.9791
Epoch 61/85
60000/60000 [==============================] - 7s 123us/step - loss: 0.
0099 - accuracy: 0.9977 - val_loss: 0.1208 - val_accuracy: 0.9818
Epoch 62/85
60000/60000 [==============================] - 8s 129us/step - loss: 0.
0037 - accuracy: 0.9990 - val_loss: 0.1253 - val_accuracy: 0.9824
Epoch 63/85
```

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```
60000/60000 [==============================] - 8s 126us/step - loss: 0.
0012 - accuracy: 0.9996 - val_loss: 0.1204 - val_accuracy: 0.9825
Epoch 64/85
60000/60000 [==============================] - 7s 124us/step - loss: 0.
0026 - accuracy: 0.9993 - val_loss: 0.1315 - val_accuracy: 0.9829
Epoch 65/85
60000/60000 [==============================] - 6s 99us/step - loss: 0.0
040 - accuracy: 0.9989 - val_loss: 0.1285 - val_accuracy: 0.9830
Epoch 66/85
60000/60000 [==============================] - 6s 106us/step - loss: 0.
0044 - accuracy: 0.9989 - val_loss: 0.1138 - val_accuracy: 0.9840
Epoch 67/85
60000/60000 [==============================] - 7s 113us/step - loss: 0.
0037 - accuracy: 0.9993 - val_loss: 0.1216 - val_accuracy: 0.9836
Epoch 68/85
60000/60000 [==============================] - 8s 136us/step - loss: 0.
0018 - accuracy: 0.9995 - val_loss: 0.1304 - val_accuracy: 0.9847
Epoch 69/85
60000/60000 [==============================] - 6s 100us/step - loss: 0.
0029 - accuracy: 0.9992 - val_loss: 0.1381 - val_accuracy: 0.9826
Epoch 70/85
60000/60000 [==============================] - 6s 92us/step - loss: 0.0
044 - accuracy: 0.9989 - val_loss: 0.1413 - val_accuracy: 0.9813
Epoch 71/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
0055 - accuracy: 0.9987 - val_loss: 0.1354 - val_accuracy: 0.9830
Epoch 72/85
60000/60000 [==============================] - 8s 127us/step - loss: 0.
0018 - accuracy: 0.9995 - val_loss: 0.1168 - val_accuracy: 0.9851
Epoch 73/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0028 - accuracy: 0.9993 - val_loss: 0.1321 - val_accuracy: 0.9829
Epoch 74/85
60000/60000 [==============================] - 6s 106us/step - loss: 0.
0039 - accuracy: 0.9989 - val_loss: 0.1177 - val_accuracy: 0.9848
Epoch 75/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0031 - accuracy: 0.9992 - val_loss: 0.1393 - val_accuracy: 0.9830
Epoch 76/85
```

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```
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0050 - accuracy: 0.9989 - val_loss: 0.1231 - val_accuracy: 0.9847
Epoch 77/85
60000/60000 [==============================] - 6s 103us/step - loss: 8.
8610e-04 - accuracy: 0.9998 - val_loss: 0.1240 - val_accuracy: 0.9852
Epoch 78/85
60000/60000 [==============================] - 6s 101us/step - loss: 3.
3190e-04 - accuracy: 0.9999 - val_loss: 0.1198 - val_accuracy: 0.9854
Epoch 79/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0011 - accuracy: 0.9998 - val_loss: 0.1439 - val_accuracy: 0.9827
Epoch 80/85
60000/60000 [==============================] - 6s 107us/step - loss: 0.
0021 - accuracy: 0.9995 - val_loss: 0.1393 - val_accuracy: 0.9850
Epoch 81/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0054 - accuracy: 0.9986 - val_loss: 0.1502 - val_accuracy: 0.9811
Epoch 82/85
60000/60000 [==============================] - 6s 103us/step - loss: 0.
0050 - accuracy: 0.9988 - val_loss: 0.1344 - val_accuracy: 0.9830
Epoch 83/85
60000/60000 [==============================] - 6s 102us/step - loss: 0.
0024 - accuracy: 0.9994 - val_loss: 0.1361 - val_accuracy: 0.9837
Epoch 84/85
60000/60000 [==============================] - 6s 94us/step - loss: 0.0
065 - accuracy: 0.9982 - val_loss: 0.1325 - val_accuracy: 0.9840
Epoch 85/85
60000/60000 [==============================] - 6s 94us/step - loss: 0.0
022 - accuracy: 0.9995 - val_loss: 0.1345 - val_accuracy: 0.9852
```

2.1.1.3 Number of Epochs vs Train Loss & Validation Loss

In [49]:
```
A4M1_score = arch4_model1.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A4M1_score[0])
print('Test accuracy:', A4M1_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')
```

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the parameter val
idation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in history.history we will have a list of length equal t
o number of epochs

vy = A4M1_history.history['val_loss']
ty = A4M1_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.13447041057337014
Test accuracy: 0.9851999878883362
```

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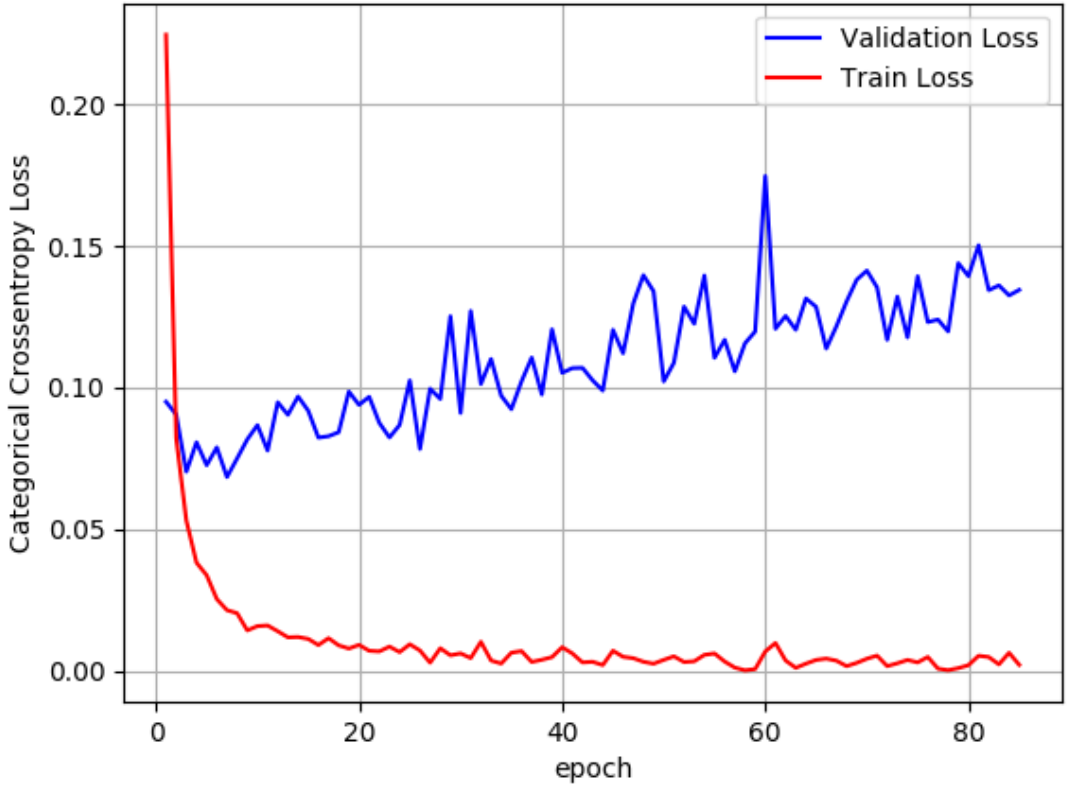

2.1.1.4 Violin Plots for Hidden Layers in the Models Trained

In [50]:
```
warnings.filterwarnings("ignore")

w_after = arch4_model1.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
```

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```
h3_w = w_after[4].flatten().reshape(-1,1)
out_w = w_after[6].flatten().reshape(-1,1)

fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 4, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Hidden Layer 1')

plt.subplot(1, 4, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Hidden Layer 2 ')

plt.subplot(1,4, 3)
ax = sns.violinplot(y=h3_w, color='g')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Hidden Layer 3 ')

plt.subplot(1, 4, 4)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Output Layer ')
plt.show()
```

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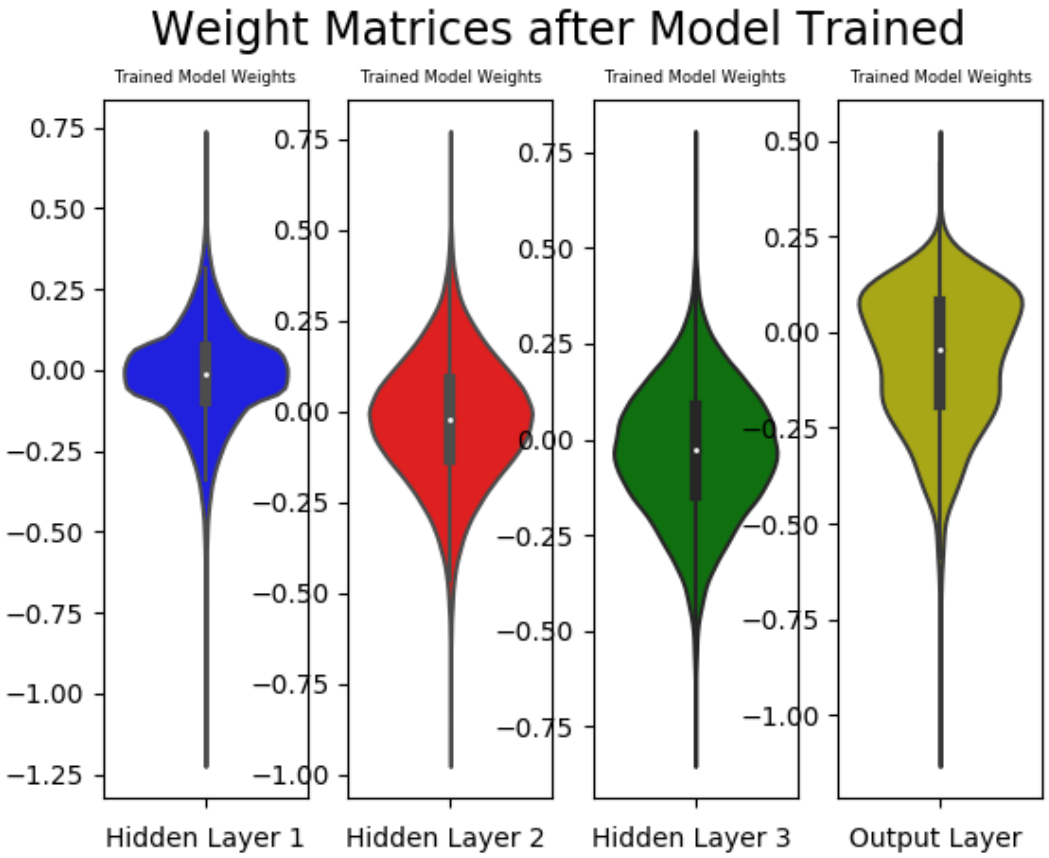

2.1.2 Model 2 : MLP + BatchNormalization + Adam Optimizer

2.1.2.1 Constructing the Neural Network

In [54]:
```
arch4_model2 = Sequential()

arch4_model2.add(Dense(512, activation='relu', input_shape=(input_dim
,),\
                       kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))
```

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```
arch4_model2.add(BatchNormalization())

arch4_model2.add(Dense(256, activation='relu', \
                       kernel_initializer=RandomUniform(minval= -0.108,
 maxval=0.108, seed=None)) )
arch4_model2.add(BatchNormalization())

arch4_model2.add(Dense(128, activation='relu', \
                       kernel_initializer=RandomUniform(minval= -0.153,
 maxval=0.153, seed=None)) )
arch4_model2.add(BatchNormalization())

arch4_model2.add(Dense(output_dim, activation='softmax'))
arch4_model2.summary()
```

```
Model: "sequential_10"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_36 (Dense)             (None, 512)               401920
_________________________________________________________________
batch_normalization_18 (Batc (None, 512)               2048
_________________________________________________________________
dense_37 (Dense)             (None, 256)               131328
_________________________________________________________________
batch_normalization_19 (Batc (None, 256)               1024
_________________________________________________________________
dense_38 (Dense)             (None, 128)               32896
_________________________________________________________________
batch_normalization_20 (Batc (None, 128)               512
_________________________________________________________________
dense_39 (Dense)             (None, 10)                1290
=================================================================
Total params: 571,018
Trainable params: 569,226
Non-trainable params: 1,792
_________________________________________________________________
```

2.1.2.2 Running the Neural Network on Train & Validation Datasets for 85 Epochs

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In [55]:
```
arch4_model2.compile(optimizer='adam', loss='categorical_crossentropy',
 metrics=['accuracy'])

A4M2_history = arch4_model2.fit(X_train, Y_train, batch_size=batch_size
, epochs=nb_epoch, verbose=1, \
                              validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 10s 171us/step - loss:
0.1944 - accuracy: 0.9409 - val_loss: 0.0935 - val_accuracy: 0.9706
Epoch 2/85
60000/60000 [==============================] - 9s 149us/step - loss: 0.
0717 - accuracy: 0.9783 - val_loss: 0.1014 - val_accuracy: 0.9688
Epoch 3/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0483 - accuracy: 0.9848 - val_loss: 0.0997 - val_accuracy: 0.9708
Epoch 4/85
60000/60000 [==============================] - 9s 154us/step - loss: 0.
0388 - accuracy: 0.9876 - val_loss: 0.0756 - val_accuracy: 0.9774
Epoch 5/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0291 - accuracy: 0.9901 - val_loss: 0.0772 - val_accuracy: 0.9777
Epoch 6/85
60000/60000 [==============================] - 9s 156us/step - loss: 0.
0260 - accuracy: 0.9912 - val_loss: 0.0783 - val_accuracy: 0.9780
Epoch 7/85
60000/60000 [==============================] - 10s 162us/step - loss:
0.0237 - accuracy: 0.9923 - val_loss: 0.0862 - val_accuracy: 0.9756
Epoch 8/85
60000/60000 [==============================] - 9s 158us/step - loss: 0.
0224 - accuracy: 0.9926 - val_loss: 0.0787 - val_accuracy: 0.9780
Epoch 9/85
60000/60000 [==============================] - 9s 154us/step - loss: 0.
0159 - accuracy: 0.9946 - val_loss: 0.0792 - val_accuracy: 0.9772
Epoch 10/85
60000/60000 [==============================] - 9s 149us/step - loss: 0.
0183 - accuracy: 0.9939 - val_loss: 0.0863 - val_accuracy: 0.9775
```

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```
Epoch 11/85
60000/60000 [==============================] - 9s 153us/step - loss: 0.
0164 - accuracy: 0.9945 - val_loss: 0.0764 - val_accuracy: 0.9798
Epoch 12/85
60000/60000 [==============================] - 9s 157us/step - loss: 0.
0118 - accuracy: 0.9961 - val_loss: 0.0892 - val_accuracy: 0.9783
Epoch 13/85
60000/60000 [==============================] - 9s 156us/step - loss: 0.
0128 - accuracy: 0.9956 - val_loss: 0.0839 - val_accuracy: 0.9804
Epoch 14/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0133 - accuracy: 0.9956 - val_loss: 0.0844 - val_accuracy: 0.9792
Epoch 15/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0120 - accuracy: 0.9959 - val_loss: 0.0771 - val_accuracy: 0.9799
Epoch 16/85
60000/60000 [==============================] - 9s 153us/step - loss: 0.
0087 - accuracy: 0.9972 - val_loss: 0.0760 - val_accuracy: 0.9825
Epoch 17/85
60000/60000 [==============================] - 9s 149us/step - loss: 0.
0108 - accuracy: 0.9965 - val_loss: 0.0829 - val_accuracy: 0.9788
Epoch 18/85
60000/60000 [==============================] - 9s 153us/step - loss: 0.
0130 - accuracy: 0.9957 - val_loss: 0.0819 - val_accuracy: 0.9812
Epoch 19/85
60000/60000 [==============================] - 9s 156us/step - loss: 0.
0089 - accuracy: 0.9971 - val_loss: 0.0702 - val_accuracy: 0.9824
Epoch 20/85
60000/60000 [==============================] - 9s 154us/step - loss: 0.
0086 - accuracy: 0.9972 - val_loss: 0.0724 - val_accuracy: 0.9826
Epoch 21/85
60000/60000 [==============================] - 9s 154us/step - loss: 0.
0075 - accuracy: 0.9975 - val_loss: 0.0819 - val_accuracy: 0.9801
Epoch 22/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0095 - accuracy: 0.9967 - val_loss: 0.0869 - val_accuracy: 0.9804
Epoch 23/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0085 - accuracy: 0.9973 - val_loss: 0.0693 - val_accuracy: 0.9844
```

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```
Epoch 24/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0081 - accuracy: 0.9976 - val_loss: 0.0842 - val_accuracy: 0.9808
Epoch 25/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0070 - accuracy: 0.9976 - val_loss: 0.0797 - val_accuracy: 0.9827
Epoch 26/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0065 - accuracy: 0.9980 - val_loss: 0.0892 - val_accuracy: 0.9802
Epoch 27/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0073 - accuracy: 0.9978 - val_loss: 0.0912 - val_accuracy: 0.9812
Epoch 28/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0056 - accuracy: 0.9983 - val_loss: 0.0857 - val_accuracy: 0.9825
Epoch 29/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0046 - accuracy: 0.9985 - val_loss: 0.0775 - val_accuracy: 0.9830
Epoch 30/85
60000/60000 [==============================] - 10s 170us/step - loss:
0.0083 - accuracy: 0.9975 - val_loss: 0.0861 - val_accuracy: 0.9824
Epoch 31/85
60000/60000 [==============================] - 11s 191us/step - loss:
0.0069 - accuracy: 0.9977 - val_loss: 0.0827 - val_accuracy: 0.9822
Epoch 32/85
60000/60000 [==============================] - 11s 185us/step - loss:
0.0054 - accuracy: 0.9981 - val_loss: 0.0898 - val_accuracy: 0.9812
Epoch 33/85
60000/60000 [==============================] - 10s 162us/step - loss:
0.0036 - accuracy: 0.9989 - val_loss: 0.0811 - val_accuracy: 0.9816
Epoch 34/85
60000/60000 [==============================] - 9s 146us/step - loss: 0.
0068 - accuracy: 0.9976 - val_loss: 0.0648 - val_accuracy: 0.9845
Epoch 35/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0053 - accuracy: 0.9983 - val_loss: 0.0895 - val_accuracy: 0.9826
Epoch 36/85
60000/60000 [==============================] - 9s 153us/step - loss: 0.
0040 - accuracy: 0.9989 - val_loss: 0.0750 - val_accuracy: 0.9833
```

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```
Epoch 37/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0055 - accuracy: 0.9983 - val_loss: 0.0803 - val_accuracy: 0.9834
Epoch 38/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0060 - accuracy: 0.9981 - val_loss: 0.0780 - val_accuracy: 0.9832
Epoch 39/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0039 - accuracy: 0.9989 - val_loss: 0.0868 - val_accuracy: 0.9823
Epoch 40/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0026 - accuracy: 0.9992 - val_loss: 0.0898 - val_accuracy: 0.9828
Epoch 41/85
60000/60000 [==============================] - 10s 162us/step - loss:
0.0052 - accuracy: 0.9983 - val_loss: 0.0891 - val_accuracy: 0.9824
Epoch 42/85
60000/60000 [==============================] - 9s 146us/step - loss: 0.
0057 - accuracy: 0.9983 - val_loss: 0.0852 - val_accuracy: 0.9813
Epoch 43/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0039 - accuracy: 0.9988 - val_loss: 0.0798 - val_accuracy: 0.9838
Epoch 44/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0058 - accuracy: 0.9981 - val_loss: 0.0837 - val_accuracy: 0.9828
Epoch 45/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0037 - accuracy: 0.9987 - val_loss: 0.0982 - val_accuracy: 0.9828
Epoch 46/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0045 - accuracy: 0.9985 - val_loss: 0.0900 - val_accuracy: 0.9825
Epoch 47/85
60000/60000 [==============================] - 9s 153us/step - loss: 0.
0030 - accuracy: 0.9991 - val_loss: 0.0837 - val_accuracy: 0.9833
Epoch 48/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0028 - accuracy: 0.9992 - val_loss: 0.0920 - val_accuracy: 0.9825
Epoch 49/85
60000/60000 [==============================] - 9s 153us/step - loss: 0.
0034 - accuracy: 0.9989 - val_loss: 0.0773 - val_accuracy: 0.9838
```

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```
Epoch 50/85
60000/60000 [==============================] - 9s 153us/step - loss: 0.
0037 - accuracy: 0.9988 - val_loss: 0.0911 - val_accuracy: 0.9821
Epoch 51/85
60000/60000 [==============================] - 9s 146us/step - loss: 0.
0050 - accuracy: 0.9985 - val_loss: 0.0882 - val_accuracy: 0.9816
Epoch 52/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0037 - accuracy: 0.9987 - val_loss: 0.0770 - val_accuracy: 0.9837
Epoch 53/85
60000/60000 [==============================] - 9s 154us/step - loss: 0.
0024 - accuracy: 0.9992 - val_loss: 0.0818 - val_accuracy: 0.9842
Epoch 54/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0041 - accuracy: 0.9986 - val_loss: 0.0855 - val_accuracy: 0.9835
Epoch 55/85
60000/60000 [==============================] - 9s 149us/step - loss: 0.
0021 - accuracy: 0.9994 - val_loss: 0.0754 - val_accuracy: 0.9861
Epoch 56/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0014 - accuracy: 0.9995 - val_loss: 0.0893 - val_accuracy: 0.9840
Epoch 57/85
60000/60000 [==============================] - 9s 149us/step - loss: 0.
0028 - accuracy: 0.9990 - val_loss: 0.0960 - val_accuracy: 0.9838
Epoch 58/85
60000/60000 [==============================] - 9s 146us/step - loss: 0.
0036 - accuracy: 0.9988 - val_loss: 0.0856 - val_accuracy: 0.9846
Epoch 59/85
60000/60000 [==============================] - 9s 154us/step - loss: 0.
0040 - accuracy: 0.9987 - val_loss: 0.0865 - val_accuracy: 0.9842
Epoch 60/85
60000/60000 [==============================] - 9s 149us/step - loss: 0.
0029 - accuracy: 0.9990 - val_loss: 0.0830 - val_accuracy: 0.9847
Epoch 61/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0033 - accuracy: 0.9990 - val_loss: 0.0942 - val_accuracy: 0.9846
Epoch 62/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0031 - accuracy: 0.9988 - val_loss: 0.0940 - val_accuracy: 0.9829
```

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```
Epoch 63/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0020 - accuracy: 0.9994 - val_loss: 0.0845 - val_accuracy: 0.9839
Epoch 64/85
60000/60000 [==============================] - 9s 157us/step - loss: 0.
0026 - accuracy: 0.9992 - val_loss: 0.0891 - val_accuracy: 0.9843
Epoch 65/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0025 - accuracy: 0.9993 - val_loss: 0.0846 - val_accuracy: 0.9851
Epoch 66/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0040 - accuracy: 0.9987 - val_loss: 0.0929 - val_accuracy: 0.9844
Epoch 67/85
60000/60000 [==============================] - 9s 145us/step - loss: 0.
0029 - accuracy: 0.9991 - val_loss: 0.0911 - val_accuracy: 0.9840
Epoch 68/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0019 - accuracy: 0.9994 - val_loss: 0.0844 - val_accuracy: 0.9850
Epoch 69/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0024 - accuracy: 0.9993 - val_loss: 0.0954 - val_accuracy: 0.9832
Epoch 70/85
60000/60000 [==============================] - 9s 154us/step - loss: 0.
0027 - accuracy: 0.9992 - val_loss: 0.0916 - val_accuracy: 0.9837
Epoch 71/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0020 - accuracy: 0.9994 - val_loss: 0.0904 - val_accuracy: 0.9838
Epoch 72/85
60000/60000 [==============================] - 9s 154us/step - loss: 0.
0021 - accuracy: 0.9995 - val_loss: 0.0893 - val_accuracy: 0.9849
Epoch 73/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0036 - accuracy: 0.9987 - val_loss: 0.0873 - val_accuracy: 0.9840
Epoch 74/85
60000/60000 [==============================] - 9s 153us/step - loss: 0.
0028 - accuracy: 0.9992 - val_loss: 0.0892 - val_accuracy: 0.9835
Epoch 75/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0038 - accuracy: 0.9989 - val_loss: 0.0931 - val_accuracy: 0.9839
```

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```
Epoch 76/85
60000/60000 [==============================] - 9s 153us/step - loss: 0.
0025 - accuracy: 0.9991 - val_loss: 0.0816 - val_accuracy: 0.9853
Epoch 77/85
60000/60000 [==============================] - 9s 153us/step - loss: 0.
0031 - accuracy: 0.9991 - val_loss: 0.0835 - val_accuracy: 0.9850
Epoch 78/85
60000/60000 [==============================] - 9s 149us/step - loss: 0.
0025 - accuracy: 0.9993 - val_loss: 0.0812 - val_accuracy: 0.9837
Epoch 79/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0014 - accuracy: 0.9997 - val_loss: 0.0819 - val_accuracy: 0.9836
Epoch 80/85
60000/60000 [==============================] - 9s 149us/step - loss: 0.
0020 - accuracy: 0.9992 - val_loss: 0.0887 - val_accuracy: 0.9831
Epoch 81/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0013 - accuracy: 0.9995 - val_loss: 0.0884 - val_accuracy: 0.9836
Epoch 82/85
60000/60000 [==============================] - 9s 156us/step - loss: 0.
0014 - accuracy: 0.9996 - val_loss: 0.0841 - val_accuracy: 0.9853
Epoch 83/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0025 - accuracy: 0.9992 - val_loss: 0.0941 - val_accuracy: 0.9831
Epoch 84/85
60000/60000 [==============================] - 10s 162us/step - loss:
0.0025 - accuracy: 0.9992 - val_loss: 0.0910 - val_accuracy: 0.9843
Epoch 85/85
60000/60000 [==============================] - 9s 146us/step - loss: 0.
0024 - accuracy: 0.9992 - val_loss: 0.0853 - val_accuracy: 0.9852
```

2.1.2.3 Number of Epochs vs Train Loss & Validation Loss

In [56]:
```
warnings.filterwarnings("ignore")

A4M2_score = arch4_model2.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A4M2_score[0])
print('Test accuracy:', A4M2_score[1])
```

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```
fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in history.history we will have a list of length equal t
o number of epochs

vy = A4M2_history.history['val_loss']
ty = A4M2_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.08532992944723572
Test accuracy: 0.9851999878883362
```

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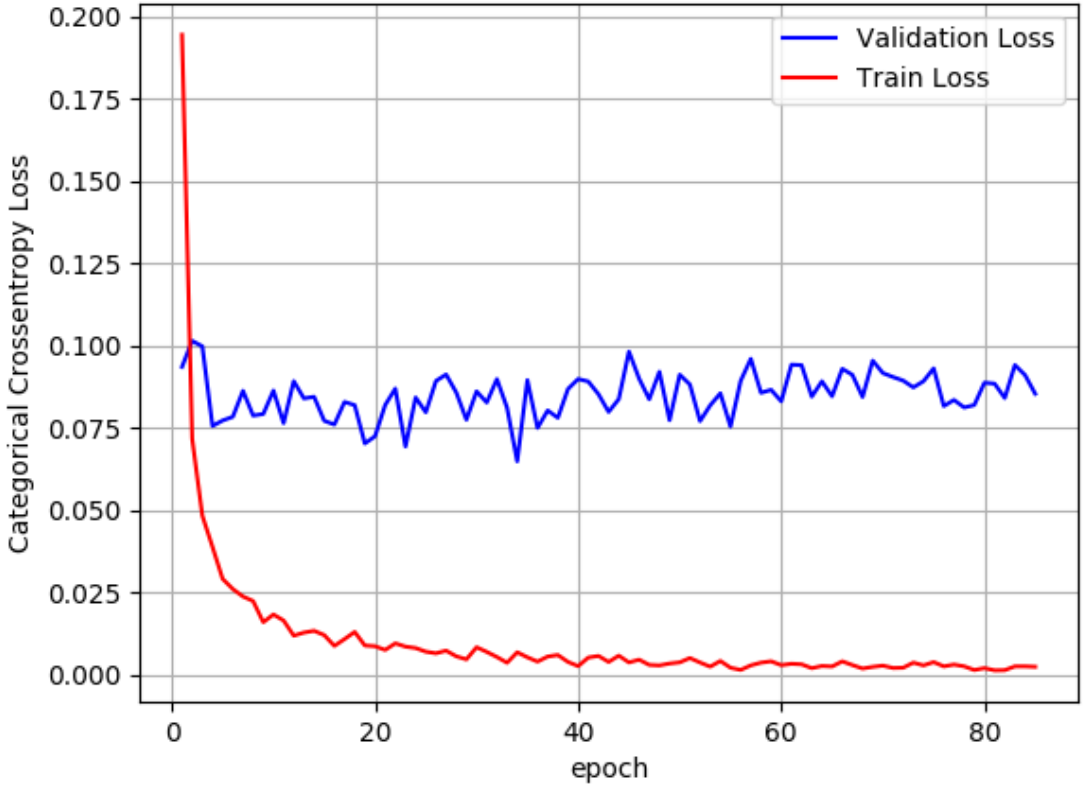

2.1.2.4 Violin Plots for Hidden Layers in the Models Trained

In [57]:
```
w_after = arch4_model2.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
h3_w = w_after[4].flatten().reshape(-1,1)
out_w = w_after[6].flatten().reshape(-1,1)
```

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```
fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 4, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Hidden Layer 1')

plt.subplot(1, 4, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Hidden Layer 2 ')

plt.subplot(1,4, 3)
ax = sns.violinplot(y=h3_w, color='g')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Hidden Layer 3 ')

plt.subplot(1, 4, 4)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Output Layer ')
plt.show()
```

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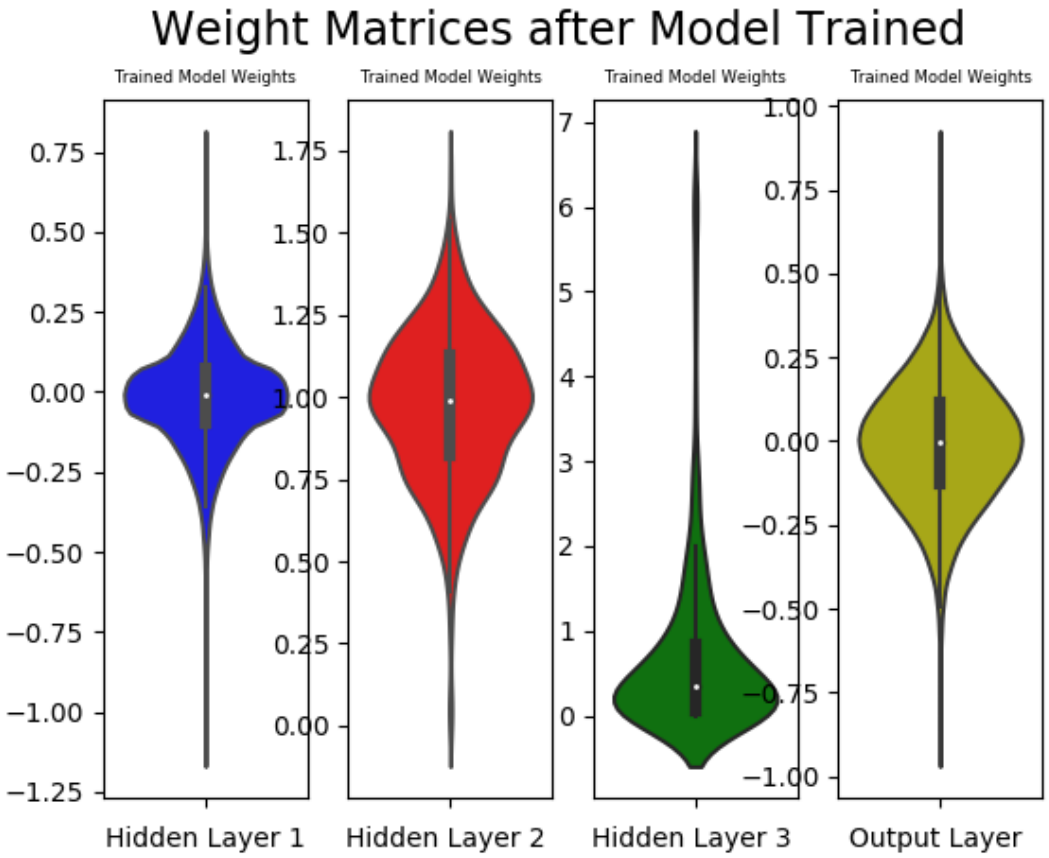

2.1.3 Model 3 : MLP + BatchNormalization + Dropout + Adam Optimizer

2.1.3.1 Hyperparameter Tuning for Dropout

In [25]:
```
def A4M3_best_hyperparameters(dropout):
    arch4_model3 = Sequential()

    arch4_model3.add(Dense(512, activation='relu', input_shape=(input_d
im,),\
```

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```
                        kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))
    arch4_model3.add(BatchNormalization())
    arch4_model3.add(Dropout(dropout))

    arch4_model3.add(Dense(256, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.108,
 maxval=0.108, seed=None)) )
    arch4_model3.add(BatchNormalization())
    arch4_model3.add(Dropout(dropout))

    arch4_model3.add(Dense(128, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.153,
 maxval=0.153, seed=None)) )
    arch4_model3.add(BatchNormalization())
    arch4_model3.add(Dropout(dropout))

    arch4_model3.add(Dense(output_dim, activation='softmax'))

    arch4_model3.compile(loss='categorical_crossentropy', metrics=['acc
uracy'], optimizer='adam')

    return arch4_model3
```

In [26]:

```
from datetime import datetime
start = datetime.now()

dropout = []

for d in range(1,10):
    dropout.append(d/10)

from keras.wrappers.scikit_learn import KerasClassifier
from sklearn.model_selection import GridSearchCV

model = KerasClassifier(build_fn=A4M3_best_hyperparameters, epochs=nb_e
poch, batch_size=batch_size, verbose=0)
param_grid = dict(dropout=dropout)
```

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```
# if you are using CPU
# grid = GridSearchCV(estimator=model, param_grid=param_grid, n_jobs=-
1)
# if you are using GPU dont use the n_jobs parameter

grid_3 = GridSearchCV(estimator=model, param_grid=param_grid,cv=3,n_job
s=-1)
grid_result3 = grid_3.fit(X_train, Y_train)

print('Time taken :', datetime.now() - start)
```

```
Time taken : 2:38:58.557040
```

In [27]:

```
print("Best: %f using %s" % (grid_result3.best_score_, grid_result3.bes
t_params_))
means = grid_result3.cv_results_['mean_test_score']
stds = grid_result3.cv_results_['std_test_score']
params = grid_result3.cv_results_['params']
for mean, stdev, param in zip(means, stds, params):
    print("%f (%f) with: %r" % (mean, stdev, param))
```

```
Best: 0.982333 using {'dropout': 0.3}
0.981300 (0.001297) with: {'dropout': 0.1}
0.981617 (0.000595) with: {'dropout': 0.2}
0.982333 (0.001351) with: {'dropout': 0.3}
0.982150 (0.001227) with: {'dropout': 0.4}
0.982333 (0.001342) with: {'dropout': 0.5}
0.981200 (0.000531) with: {'dropout': 0.6}
0.979550 (0.000726) with: {'dropout': 0.7}
0.974850 (0.001035) with: {'dropout': 0.8}
0.952950 (0.001168) with: {'dropout': 0.9}
```

2.1.3.2 Constructing the Neural Network

In [58]:

```
arch4_model3 = Sequential()

arch4_model3.add(Dense(512, activation='relu', input_shape=(input_dim
,),\
```

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```
                        kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))
arch4_model3.add(BatchNormalization())
arch4_model3.add(Dropout(0.3))

arch4_model3.add(Dense(256, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.108,
 maxval=0.108, seed=None)) )
arch4_model3.add(BatchNormalization())
arch4_model3.add(Dropout(0.3))

arch4_model3.add(Dense(128, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.153,
 maxval=0.153, seed=None)) )
arch4_model3.add(BatchNormalization())
arch4_model3.add(Dropout(0.3))

arch4_model3.add(Dense(output_dim, activation='softmax'))
arch4_model3.summary()
```

```
Model: "sequential_11"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_40 (Dense)             (None, 512)               401920
_________________________________________________________________
batch_normalization_21 (Batc (None, 512)               2048
_________________________________________________________________
dropout_9 (Dropout)          (None, 512)               0
_________________________________________________________________
dense_41 (Dense)             (None, 256)               131328
_________________________________________________________________
batch_normalization_22 (Batc (None, 256)               1024
_________________________________________________________________
dropout_10 (Dropout)         (None, 256)               0
_________________________________________________________________
dense_42 (Dense)             (None, 128)               32896
_________________________________________________________________
batch_normalization_23 (Batc (None, 128)               512
_________________________________________________________________
```

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```
dropout_11 (Dropout)         (None, 128)               0
_________________________________________________________________
dense_43 (Dense)             (None, 10)                1290
=================================================================
Total params: 571,018
Trainable params: 569,226
Non-trainable params: 1,792
_________________________________________________________________
```

2.1.3.3 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [59]:
```
arch4_model3.compile(optimizer='adam', loss='categorical_crossentropy',
 metrics=['accuracy'])

A4M3_history = arch4_model3.fit(X_train, Y_train, batch_size=batch_size
, epochs=nb_epoch, verbose=1, \
                              validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 10s 167us/step - loss:
0.3439 - accuracy: 0.8951 - val_loss: 0.1178 - val_accuracy: 0.9654
Epoch 2/85
60000/60000 [==============================] - 9s 153us/step - loss: 0.
1560 - accuracy: 0.9519 - val_loss: 0.0893 - val_accuracy: 0.9721
Epoch 3/85
60000/60000 [==============================] - 9s 156us/step - loss: 0.
1142 - accuracy: 0.9653 - val_loss: 0.0842 - val_accuracy: 0.9740
Epoch 4/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0978 - accuracy: 0.9699 - val_loss: 0.0754 - val_accuracy: 0.9770
Epoch 5/85
60000/60000 [==============================] - 9s 154us/step - loss: 0.
0830 - accuracy: 0.9740 - val_loss: 0.0716 - val_accuracy: 0.9780
Epoch 6/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0741 - accuracy: 0.9766 - val_loss: 0.0695 - val_accuracy: 0.9794
Epoch 7/85
```

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```
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0690 - accuracy: 0.9779 - val_loss: 0.0590 - val_accuracy: 0.9809
Epoch 8/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0608 - accuracy: 0.9805 - val_loss: 0.0613 - val_accuracy: 0.9816
Epoch 9/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0580 - accuracy: 0.9815 - val_loss: 0.0625 - val_accuracy: 0.9821
Epoch 10/85
60000/60000 [==============================] - 9s 157us/step - loss: 0.
0522 - accuracy: 0.9826 - val_loss: 0.0630 - val_accuracy: 0.9815
Epoch 11/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0489 - accuracy: 0.9847 - val_loss: 0.0630 - val_accuracy: 0.9814
Epoch 12/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0455 - accuracy: 0.9848 - val_loss: 0.0592 - val_accuracy: 0.9831
Epoch 13/85
60000/60000 [==============================] - 9s 153us/step - loss: 0.
0453 - accuracy: 0.9853 - val_loss: 0.0622 - val_accuracy: 0.9812
Epoch 14/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0438 - accuracy: 0.9854 - val_loss: 0.0613 - val_accuracy: 0.9831
Epoch 15/85
60000/60000 [==============================] - 9s 146us/step - loss: 0.
0393 - accuracy: 0.9870 - val_loss: 0.0564 - val_accuracy: 0.9834
Epoch 16/85
60000/60000 [==============================] - 10s 162us/step - loss:
0.0363 - accuracy: 0.9876 - val_loss: 0.0603 - val_accuracy: 0.9835
Epoch 17/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0360 - accuracy: 0.9883 - val_loss: 0.0646 - val_accuracy: 0.9823
Epoch 18/85
60000/60000 [==============================] - 9s 146us/step - loss: 0.
0353 - accuracy: 0.9887 - val_loss: 0.0626 - val_accuracy: 0.9831
Epoch 19/85
60000/60000 [==============================] - 10s 162us/step - loss:
0.0321 - accuracy: 0.9898 - val_loss: 0.0619 - val_accuracy: 0.9835
Epoch 20/85
```

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```
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0309 - accuracy: 0.9900 - val_loss: 0.0597 - val_accuracy: 0.9830
Epoch 21/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0299 - accuracy: 0.9903 - val_loss: 0.0607 - val_accuracy: 0.9828
Epoch 22/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0282 - accuracy: 0.9908 - val_loss: 0.0611 - val_accuracy: 0.9835
Epoch 23/85
60000/60000 [==============================] - 9s 157us/step - loss: 0.
0277 - accuracy: 0.9907 - val_loss: 0.0602 - val_accuracy: 0.9839
Epoch 24/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0270 - accuracy: 0.9905 - val_loss: 0.0588 - val_accuracy: 0.9842
Epoch 25/85
60000/60000 [==============================] - 9s 149us/step - loss: 0.
0263 - accuracy: 0.9911 - val_loss: 0.0608 - val_accuracy: 0.9854
Epoch 26/85
60000/60000 [==============================] - 10s 159us/step - loss:
0.0241 - accuracy: 0.9922 - val_loss: 0.0572 - val_accuracy: 0.9856
Epoch 27/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0229 - accuracy: 0.9927 - val_loss: 0.0646 - val_accuracy: 0.9830
Epoch 28/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0253 - accuracy: 0.9915 - val_loss: 0.0595 - val_accuracy: 0.9847
Epoch 29/85
60000/60000 [==============================] - 10s 165us/step - loss:
0.0234 - accuracy: 0.9926 - val_loss: 0.0569 - val_accuracy: 0.9862
Epoch 30/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0215 - accuracy: 0.9922 - val_loss: 0.0646 - val_accuracy: 0.9842
Epoch 31/85
60000/60000 [==============================] - 9s 154us/step - loss: 0.
0210 - accuracy: 0.9933 - val_loss: 0.0605 - val_accuracy: 0.9850
Epoch 32/85
60000/60000 [==============================] - 10s 170us/step - loss:
0.0225 - accuracy: 0.9927 - val_loss: 0.0657 - val_accuracy: 0.9841
Epoch 33/85
```

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```
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0185 - accuracy: 0.9938 - val_loss: 0.0562 - val_accuracy: 0.9860
Epoch 34/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0189 - accuracy: 0.9941 - val_loss: 0.0623 - val_accuracy: 0.9844
Epoch 35/85
60000/60000 [==============================] - 9s 157us/step - loss: 0.
0198 - accuracy: 0.9933 - val_loss: 0.0633 - val_accuracy: 0.9847
Epoch 36/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0181 - accuracy: 0.9941 - val_loss: 0.0563 - val_accuracy: 0.9870
Epoch 37/85
60000/60000 [==============================] - 9s 157us/step - loss: 0.
0164 - accuracy: 0.9946 - val_loss: 0.0624 - val_accuracy: 0.9856
Epoch 38/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0173 - accuracy: 0.9944 - val_loss: 0.0635 - val_accuracy: 0.9848
Epoch 39/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0185 - accuracy: 0.9939 - val_loss: 0.0588 - val_accuracy: 0.9854
Epoch 40/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0174 - accuracy: 0.9941 - val_loss: 0.0573 - val_accuracy: 0.9855
Epoch 41/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0144 - accuracy: 0.9948 - val_loss: 0.0599 - val_accuracy: 0.9869
Epoch 42/85
60000/60000 [==============================] - 10s 159us/step - loss:
0.0156 - accuracy: 0.9948 - val_loss: 0.0658 - val_accuracy: 0.9851
Epoch 43/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0195 - accuracy: 0.9937 - val_loss: 0.0604 - val_accuracy: 0.9860
Epoch 44/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0159 - accuracy: 0.9947 - val_loss: 0.0600 - val_accuracy: 0.9862
Epoch 45/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0145 - accuracy: 0.9948 - val_loss: 0.0604 - val_accuracy: 0.9860
Epoch 46/85
```

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```
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0135 - accuracy: 0.9952 - val_loss: 0.0669 - val_accuracy: 0.9851
Epoch 47/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0153 - accuracy: 0.9951 - val_loss: 0.0631 - val_accuracy: 0.9857
Epoch 48/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0163 - accuracy: 0.9948 - val_loss: 0.0589 - val_accuracy: 0.9863
Epoch 49/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0146 - accuracy: 0.9950 - val_loss: 0.0589 - val_accuracy: 0.9859
Epoch 50/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0157 - accuracy: 0.9946 - val_loss: 0.0637 - val_accuracy: 0.9856
Epoch 51/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0139 - accuracy: 0.9952 - val_loss: 0.0556 - val_accuracy: 0.9871
Epoch 52/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0121 - accuracy: 0.9960 - val_loss: 0.0596 - val_accuracy: 0.9867
Epoch 53/85
60000/60000 [==============================] - 9s 149us/step - loss: 0.
0120 - accuracy: 0.9960 - val_loss: 0.0652 - val_accuracy: 0.9851
Epoch 54/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0127 - accuracy: 0.9956 - val_loss: 0.0579 - val_accuracy: 0.9873
Epoch 55/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0131 - accuracy: 0.9960 - val_loss: 0.0602 - val_accuracy: 0.9866
Epoch 56/85
60000/60000 [==============================] - 9s 146us/step - loss: 0.
0130 - accuracy: 0.9959 - val_loss: 0.0579 - val_accuracy: 0.9863
Epoch 57/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0124 - accuracy: 0.9961 - val_loss: 0.0597 - val_accuracy: 0.9854
Epoch 58/85
60000/60000 [==============================] - 9s 146us/step - loss: 0.
0127 - accuracy: 0.9957 - val_loss: 0.0604 - val_accuracy: 0.9866
Epoch 59/85
```

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```
60000/60000 [==============================] - 9s 154us/step - loss: 0.
0125 - accuracy: 0.9957 - val_loss: 0.0576 - val_accuracy: 0.9867
Epoch 60/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0121 - accuracy: 0.9960 - val_loss: 0.0617 - val_accuracy: 0.9862
Epoch 61/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0124 - accuracy: 0.9957 - val_loss: 0.0610 - val_accuracy: 0.9867
Epoch 62/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0113 - accuracy: 0.9961 - val_loss: 0.0603 - val_accuracy: 0.9857
Epoch 63/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0107 - accuracy: 0.9963 - val_loss: 0.0608 - val_accuracy: 0.9861
Epoch 64/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0116 - accuracy: 0.9961 - val_loss: 0.0658 - val_accuracy: 0.9856
Epoch 65/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0117 - accuracy: 0.9960 - val_loss: 0.0562 - val_accuracy: 0.9872
Epoch 66/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0100 - accuracy: 0.9967 - val_loss: 0.0632 - val_accuracy: 0.9867
Epoch 67/85
60000/60000 [==============================] - 9s 153us/step - loss: 0.
0102 - accuracy: 0.9965 - val_loss: 0.0589 - val_accuracy: 0.9862
Epoch 68/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0103 - accuracy: 0.9968 - val_loss: 0.0585 - val_accuracy: 0.9874
Epoch 69/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0107 - accuracy: 0.9964 - val_loss: 0.0650 - val_accuracy: 0.9862
Epoch 70/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0102 - accuracy: 0.9966 - val_loss: 0.0613 - val_accuracy: 0.9869
Epoch 71/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0098 - accuracy: 0.9968 - val_loss: 0.0641 - val_accuracy: 0.9864
Epoch 72/85
```

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```
60000/60000 [==============================] - 9s 153us/step - loss: 0.
0120 - accuracy: 0.9963 - val_loss: 0.0650 - val_accuracy: 0.9859
Epoch 73/85
60000/60000 [==============================] - 9s 146us/step - loss: 0.
0100 - accuracy: 0.9965 - val_loss: 0.0717 - val_accuracy: 0.9842
Epoch 74/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0107 - accuracy: 0.9965 - val_loss: 0.0628 - val_accuracy: 0.9865
Epoch 75/85
60000/60000 [==============================] - 9s 154us/step - loss: 0.
0086 - accuracy: 0.9973 - val_loss: 0.0611 - val_accuracy: 0.9867
Epoch 76/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0087 - accuracy: 0.9969 - val_loss: 0.0635 - val_accuracy: 0.9870
Epoch 77/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0096 - accuracy: 0.9969 - val_loss: 0.0619 - val_accuracy: 0.9867
Epoch 78/85
60000/60000 [==============================] - 9s 149us/step - loss: 0.
0096 - accuracy: 0.9968 - val_loss: 0.0620 - val_accuracy: 0.9874
Epoch 79/85
60000/60000 [==============================] - 9s 156us/step - loss: 0.
0089 - accuracy: 0.9974 - val_loss: 0.0572 - val_accuracy: 0.9869
Epoch 80/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0096 - accuracy: 0.9969 - val_loss: 0.0590 - val_accuracy: 0.9867
Epoch 81/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0089 - accuracy: 0.9971 - val_loss: 0.0617 - val_accuracy: 0.9866
Epoch 82/85
60000/60000 [==============================] - 9s 157us/step - loss: 0.
0092 - accuracy: 0.9970 - val_loss: 0.0685 - val_accuracy: 0.9856
Epoch 83/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0095 - accuracy: 0.9970 - val_loss: 0.0654 - val_accuracy: 0.9864
Epoch 84/85
60000/60000 [==============================] - 10s 159us/step - loss:
0.0083 - accuracy: 0.9973 - val_loss: 0.0685 - val_accuracy: 0.9867
Epoch 85/85
```

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```
60000/60000 [==============================] - 10s 159us/step - loss:
0.0097 - accuracy: 0.9968 - val_loss: 0.0677 - val_accuracy: 0.9844
```

2.1.3.4 Number of Epochs vs Train Loss & Validation Loss

In [60]:
```
warnings.filterwarnings("ignore")

A4M3_score = arch4_model3.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A4M3_score[0])
print('Test accuracy:', A4M3_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in history.history we will have a list of length equal t
o number of epochs

vy = A4M3_history.history['val_loss']
ty = A4M3_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.06769079408217712
Test accuracy: 0.9843999743461609
```

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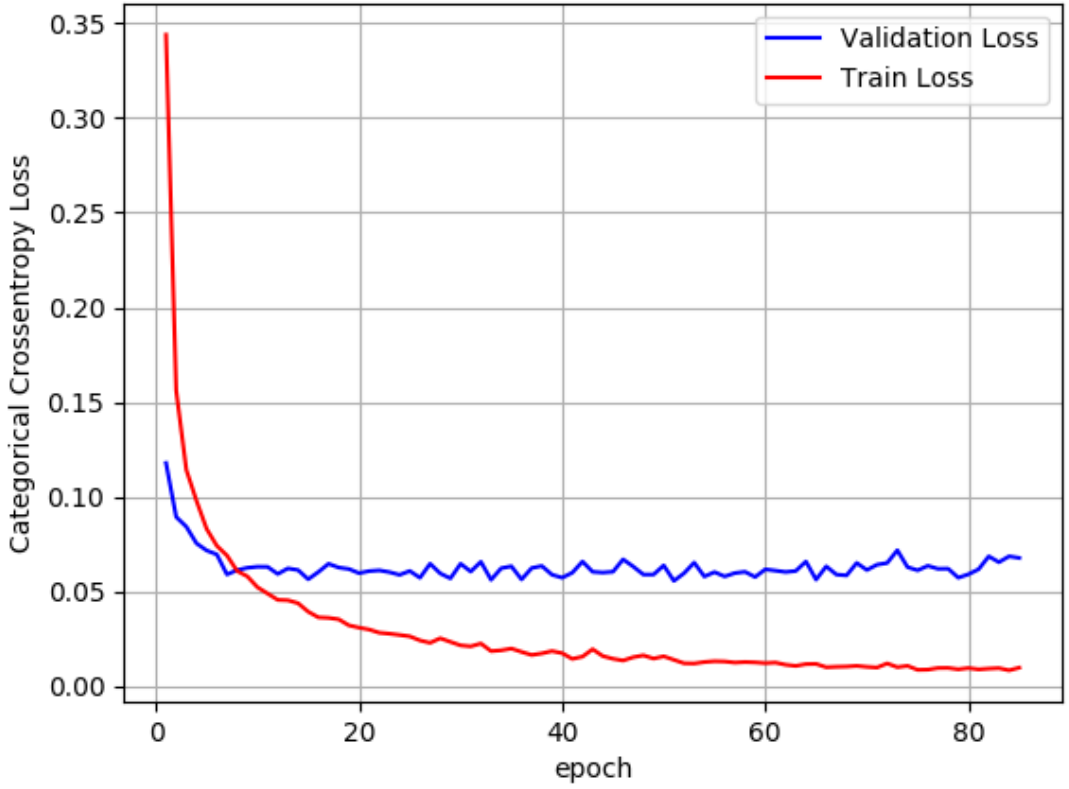

2.1.3.5 Violin Plots for Hidden Layers in the Models Trained

In [61]:
```
w_after = arch4_model3.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
h3_w = w_after[4].flatten().reshape(-1,1)
out_w = w_after[6].flatten().reshape(-1,1)
```

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```
fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 4, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Hidden Layer 1')

plt.subplot(1, 4, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Hidden Layer 2 ')

plt.subplot(1,4, 3)
ax = sns.violinplot(y=h3_w, color='g')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Hidden Layer 3 ')

plt.subplot(1, 4, 4)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Output Layer ')
plt.show()
```

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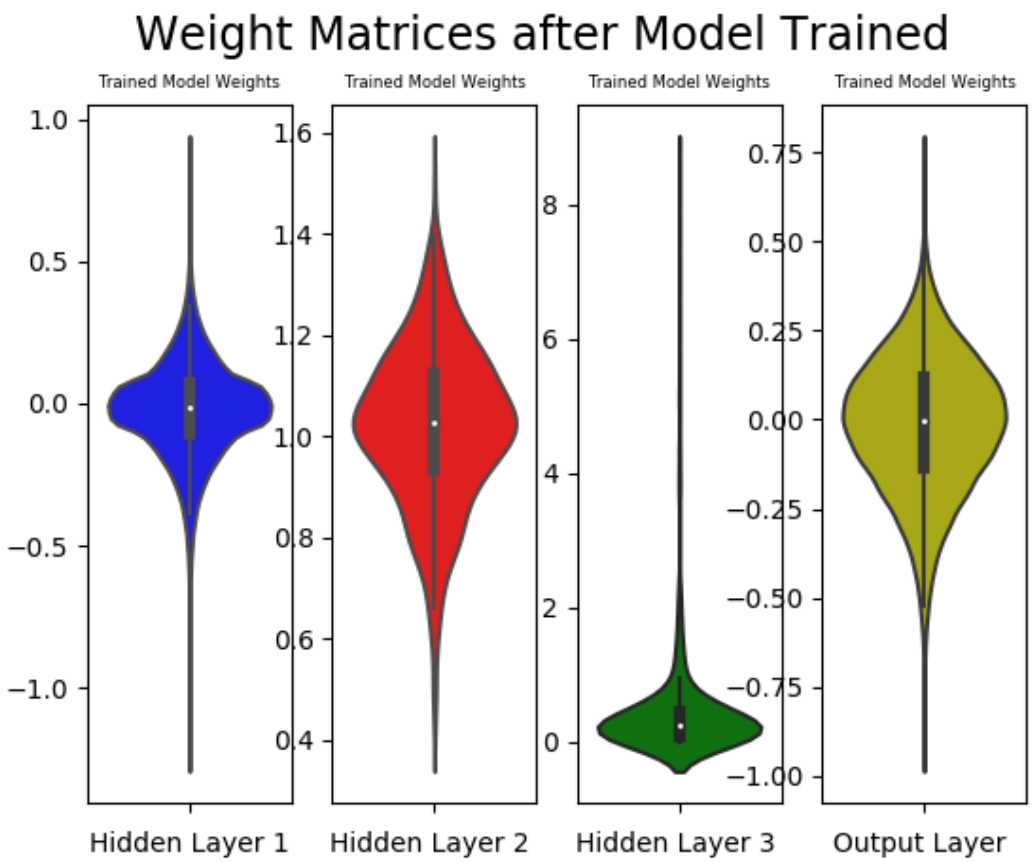

2.2 Architecture 5 :- 784-500-250-125-10

2.2.1 Model 1 : MLP + Adam Optimizer

2.2.1.1 Constructing the Neural Network

In [32]:
```
arch5_model1 = Sequential()
```

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```
arch5_model1.add(Dense(500, activation='relu', input_shape=(input_dim
,),\
                       kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))

arch5_model1.add(Dense(250, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.109,
 maxval=0.109, seed=None)) )

arch5_model1.add(Dense(125, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.155,
 maxval=0.155, seed=None)) )

arch5_model1.add(Dense(output_dim, activation='softmax'))
arch5_model1.summary()
```

```
Model: "sequential_6"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_20 (Dense)             (None, 500)               392500
_________________________________________________________________
dense_21 (Dense)             (None, 250)               125250
_________________________________________________________________
dense_22 (Dense)             (None, 125)               31375
_________________________________________________________________
dense_23 (Dense)             (None, 10)                1260
=================================================================
Total params: 550,385
Trainable params: 550,385
Non-trainable params: 0
_________________________________________________________________
```

2.2.1.2 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [33]:
```
arch5_model1.compile(optimizer='adam', loss='categorical_crossentropy',
 metrics=['accuracy'])
```

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```
A5M1_history = arch5_model1.fit(X_train, Y_train, batch_size=batch_size
, epochs=nb_epoch, verbose=1, \
                              validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 6s 105us/step - loss: 0.
2251 - accuracy: 0.9333 - val_loss: 0.1030 - val_accuracy: 0.9681
Epoch 2/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0824 - accuracy: 0.9742 - val_loss: 0.0824 - val_accuracy: 0.9759
Epoch 3/85
60000/60000 [==============================] - 6s 105us/step - loss: 0.
0538 - accuracy: 0.9829 - val_loss: 0.0931 - val_accuracy: 0.9700
Epoch 4/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0399 - accuracy: 0.9869 - val_loss: 0.0848 - val_accuracy: 0.9741
Epoch 5/85
60000/60000 [==============================] - 6s 103us/step - loss: 0.
0319 - accuracy: 0.9895 - val_loss: 0.0725 - val_accuracy: 0.9792
Epoch 6/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0238 - accuracy: 0.9924 - val_loss: 0.0718 - val_accuracy: 0.9794
Epoch 7/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0221 - accuracy: 0.9926 - val_loss: 0.0734 - val_accuracy: 0.9802
Epoch 8/85
60000/60000 [==============================] - 6s 101us/step - loss: 0.
0175 - accuracy: 0.9944 - val_loss: 0.0868 - val_accuracy: 0.9776
Epoch 9/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0160 - accuracy: 0.9947 - val_loss: 0.0718 - val_accuracy: 0.9804
Epoch 10/85
60000/60000 [==============================] - 6s 102us/step - loss: 0.
0171 - accuracy: 0.9944 - val_loss: 0.0925 - val_accuracy: 0.9753
Epoch 11/85
60000/60000 [==============================] - 6s 102us/step - loss: 0.
0123 - accuracy: 0.9960 - val_loss: 0.0714 - val_accuracy: 0.9831
Epoch 12/85

60000/60000 [==============================] - 7s 112us/step - loss: 0.
```

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```
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0146 - accuracy: 0.9953 - val_loss: 0.0895 - val_accuracy: 0.9797
Epoch 13/85
60000/60000 [==============================] - 6s 106us/step - loss: 0.
0102 - accuracy: 0.9967 - val_loss: 0.1050 - val_accuracy: 0.9778
Epoch 14/85
60000/60000 [==============================] - 6s 103us/step - loss: 0.
0150 - accuracy: 0.9953 - val_loss: 0.0748 - val_accuracy: 0.9827
Epoch 15/85
60000/60000 [==============================] - 6s 107us/step - loss: 0.
0084 - accuracy: 0.9975 - val_loss: 0.0921 - val_accuracy: 0.9794
Epoch 16/85
60000/60000 [==============================] - 6s 105us/step - loss: 0.
0115 - accuracy: 0.9966 - val_loss: 0.0808 - val_accuracy: 0.9824
Epoch 17/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0099 - accuracy: 0.9966 - val_loss: 0.0944 - val_accuracy: 0.9799
Epoch 18/85
60000/60000 [==============================] - 6s 107us/step - loss: 0.
0085 - accuracy: 0.9974 - val_loss: 0.0844 - val_accuracy: 0.9825
Epoch 19/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0090 - accuracy: 0.9972 - val_loss: 0.0913 - val_accuracy: 0.9820
Epoch 20/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0075 - accuracy: 0.9977 - val_loss: 0.1037 - val_accuracy: 0.9791
Epoch 21/85
60000/60000 [==============================] - 6s 105us/step - loss: 0.
0091 - accuracy: 0.9972 - val_loss: 0.0916 - val_accuracy: 0.9819
Epoch 22/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0096 - accuracy: 0.9972 - val_loss: 0.1008 - val_accuracy: 0.9801
Epoch 23/85
60000/60000 [==============================] - 6s 106us/step - loss: 0.
0054 - accuracy: 0.9982 - val_loss: 0.0846 - val_accuracy: 0.9837
Epoch 24/85
60000/60000 [==============================] - 6s 107us/step - loss: 0.
0081 - accuracy: 0.9973 - val_loss: 0.0915 - val_accuracy: 0.9824
Epoch 25/85

60000/60000 [==============================] - 6s 108us/step - loss: 0.
```

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```
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0081 - accuracy: 0.9976 - val_loss: 0.0790 - val_accuracy: 0.9830
Epoch 26/85
60000/60000 [==============================] - 6s 103us/step - loss: 0.
0040 - accuracy: 0.9989 - val_loss: 0.0949 - val_accuracy: 0.9803
Epoch 27/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0070 - accuracy: 0.9980 - val_loss: 0.1030 - val_accuracy: 0.9791
Epoch 28/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0079 - accuracy: 0.9974 - val_loss: 0.0896 - val_accuracy: 0.9833
Epoch 29/85
60000/60000 [==============================] - 6s 105us/step - loss: 0.
0059 - accuracy: 0.9984 - val_loss: 0.0823 - val_accuracy: 0.9836
Epoch 30/85
60000/60000 [==============================] - 6s 102us/step - loss: 0.
0082 - accuracy: 0.9979 - val_loss: 0.0897 - val_accuracy: 0.9830
Epoch 31/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0052 - accuracy: 0.9987 - val_loss: 0.0852 - val_accuracy: 0.9839
Epoch 32/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0052 - accuracy: 0.9984 - val_loss: 0.0915 - val_accuracy: 0.9821
Epoch 33/85
60000/60000 [==============================] - 6s 106us/step - loss: 0.
0076 - accuracy: 0.9977 - val_loss: 0.1197 - val_accuracy: 0.9770
Epoch 34/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0040 - accuracy: 0.9989 - val_loss: 0.0878 - val_accuracy: 0.9829
Epoch 35/85
60000/60000 [==============================] - 6s 106us/step - loss: 0.
0019 - accuracy: 0.9995 - val_loss: 0.0954 - val_accuracy: 0.9842
Epoch 36/85
60000/60000 [==============================] - 6s 100us/step - loss: 0.
0055 - accuracy: 0.9981 - val_loss: 0.1272 - val_accuracy: 0.9771
Epoch 37/85
60000/60000 [==============================] - 6s 104us/step - loss: 0.
0100 - accuracy: 0.9969 - val_loss: 0.0909 - val_accuracy: 0.9821
Epoch 38/85

60000/60000 [==============================] - 6s 96us/step - loss: 0.0
```

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```
60000/60000 [==============================] - 6s 96us/step - loss: 0.0
053 - accuracy: 0.9984 - val_loss: 0.0866 - val_accuracy: 0.9843
Epoch 39/85
60000/60000 [==============================] - 6s 100us/step - loss: 0.
0044 - accuracy: 0.9986 - val_loss: 0.0969 - val_accuracy: 0.9837
Epoch 40/85
60000/60000 [==============================] - 6s 98us/step - loss: 0.0
036 - accuracy: 0.9988 - val_loss: 0.0815 - val_accuracy: 0.9827
Epoch 41/85
60000/60000 [==============================] - 6s 100us/step - loss: 0.
0050 - accuracy: 0.9986 - val_loss: 0.0987 - val_accuracy: 0.9829
Epoch 42/85
60000/60000 [==============================] - 6s 96us/step - loss: 0.0
042 - accuracy: 0.9987 - val_loss: 0.1231 - val_accuracy: 0.9791
Epoch 43/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0081 - accuracy: 0.9977 - val_loss: 0.1093 - val_accuracy: 0.9813
Epoch 44/85
60000/60000 [==============================] - 6s 102us/step - loss: 0.
0043 - accuracy: 0.9988 - val_loss: 0.1006 - val_accuracy: 0.9831
Epoch 45/85
60000/60000 [==============================] - 6s 107us/step - loss: 2.
3267e-04 - accuracy: 0.9999 - val_loss: 0.0873 - val_accuracy: 0.9848
Epoch 46/85
60000/60000 [==============================] - 6s 103us/step - loss: 5.
5793e-05 - accuracy: 1.0000 - val_loss: 0.0883 - val_accuracy: 0.9849
Epoch 47/85
60000/60000 [==============================] - 6s 106us/step - loss: 1.
4682e-05 - accuracy: 1.0000 - val_loss: 0.0892 - val_accuracy: 0.9855
Epoch 48/85
60000/60000 [==============================] - 7s 109us/step - loss: 1.
0130e-05 - accuracy: 1.0000 - val_loss: 0.0905 - val_accuracy: 0.9856
Epoch 49/85
60000/60000 [==============================] - 6s 104us/step - loss: 7.
4715e-06 - accuracy: 1.0000 - val_loss: 0.0917 - val_accuracy: 0.9857
Epoch 50/85
60000/60000 [==============================] - 7s 114us/step - loss: 5.
6423e-06 - accuracy: 1.0000 - val_loss: 0.0929 - val_accuracy: 0.9857
Epoch 51/85

60000/60000 [==============================] - 6s 107us/step - loss: 4.
```

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```
60000/60000 [==============================] - 6s 107us/step - loss: 4.
3059e-06 - accuracy: 1.0000 - val_loss: 0.0942 - val_accuracy: 0.9857
Epoch 52/85
60000/60000 [==============================] - 6s 105us/step - loss: 3.
3052e-06 - accuracy: 1.0000 - val_loss: 0.0956 - val_accuracy: 0.9857
Epoch 53/85
60000/60000 [==============================] - 7s 110us/step - loss: 2.
5386e-06 - accuracy: 1.0000 - val_loss: 0.0969 - val_accuracy: 0.9858
Epoch 54/85
60000/60000 [==============================] - 6s 108us/step - loss: 1.
9349e-06 - accuracy: 1.0000 - val_loss: 0.0985 - val_accuracy: 0.9859
Epoch 55/85
60000/60000 [==============================] - 6s 100us/step - loss: 1.
4705e-06 - accuracy: 1.0000 - val_loss: 0.1001 - val_accuracy: 0.9858
Epoch 56/85
60000/60000 [==============================] - 6s 97us/step - loss: 1.1
120e-06 - accuracy: 1.0000 - val_loss: 0.1017 - val_accuracy: 0.9857
Epoch 57/85
60000/60000 [==============================] - 6s 96us/step - loss: 8.3
941e-07 - accuracy: 1.0000 - val_loss: 0.1033 - val_accuracy: 0.9857
Epoch 58/85
60000/60000 [==============================] - 6s 98us/step - loss: 6.3
032e-07 - accuracy: 1.0000 - val_loss: 0.1051 - val_accuracy: 0.9858
Epoch 59/85
60000/60000 [==============================] - 6s 105us/step - loss: 4.
6884e-07 - accuracy: 1.0000 - val_loss: 0.1070 - val_accuracy: 0.9860
Epoch 60/85
60000/60000 [==============================] - 6s 104us/step - loss: 3.
4673e-07 - accuracy: 1.0000 - val_loss: 0.1090 - val_accuracy: 0.9859
Epoch 61/85
60000/60000 [==============================] - 7s 110us/step - loss: 2.
5578e-07 - accuracy: 1.0000 - val_loss: 0.1112 - val_accuracy: 0.9859
Epoch 62/85
60000/60000 [==============================] - 6s 103us/step - loss: 1.
8968e-07 - accuracy: 1.0000 - val_loss: 0.1134 - val_accuracy: 0.9859
Epoch 63/85
60000/60000 [==============================] - 6s 104us/step - loss: 1.
4014e-07 - accuracy: 1.0000 - val_loss: 0.1157 - val_accuracy: 0.9859
Epoch 64/85

60000/60000 [==============================] - 7s 109us/step - loss: 1.
```

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```
60000/60000 [==============================] - 7s 109us/step - loss: 1.
0331e-07 - accuracy: 1.0000 - val_loss: 0.1180 - val_accuracy: 0.9860
Epoch 65/85
60000/60000 [==============================] - 7s 109us/step - loss: 7.
6840e-08 - accuracy: 1.0000 - val_loss: 0.1203 - val_accuracy: 0.9860
Epoch 66/85
60000/60000 [==============================] - 6s 103us/step - loss: 5.
7395e-08 - accuracy: 1.0000 - val_loss: 0.1225 - val_accuracy: 0.9861
Epoch 67/85
60000/60000 [==============================] - 6s 106us/step - loss: 4.
3094e-08 - accuracy: 1.0000 - val_loss: 0.1248 - val_accuracy: 0.9861
Epoch 68/85
60000/60000 [==============================] - 7s 110us/step - loss: 3.
2775e-08 - accuracy: 1.0000 - val_loss: 0.1269 - val_accuracy: 0.9862
Epoch 69/85
60000/60000 [==============================] - 6s 106us/step - loss: 2.
4837e-08 - accuracy: 1.0000 - val_loss: 0.1290 - val_accuracy: 0.9862
Epoch 70/85
60000/60000 [==============================] - 6s 107us/step - loss: 1.
9185e-08 - accuracy: 1.0000 - val_loss: 0.1309 - val_accuracy: 0.9863
Epoch 71/85
60000/60000 [==============================] - 6s 108us/step - loss: 1.
4929e-08 - accuracy: 1.0000 - val_loss: 0.1327 - val_accuracy: 0.9863
Epoch 72/85
60000/60000 [==============================] - 6s 104us/step - loss: 1.
1754e-08 - accuracy: 1.0000 - val_loss: 0.1344 - val_accuracy: 0.9863
Epoch 73/85
60000/60000 [==============================] - 6s 104us/step - loss: 9.
4155e-09 - accuracy: 1.0000 - val_loss: 0.1359 - val_accuracy: 0.9862
Epoch 74/85
60000/60000 [==============================] - 7s 111us/step - loss: 7.
5082e-09 - accuracy: 1.0000 - val_loss: 0.1374 - val_accuracy: 0.9862
Epoch 75/85
60000/60000 [==============================] - 6s 108us/step - loss: 6.
0439e-09 - accuracy: 1.0000 - val_loss: 0.1387 - val_accuracy: 0.9863
Epoch 76/85
60000/60000 [==============================] - 6s 104us/step - loss: 4.
9849e-09 - accuracy: 1.0000 - val_loss: 0.1400 - val_accuracy: 0.9861
Epoch 77/85

60000/60000 [==============================] - 6s 103us/step - loss: 4.
```

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```
60000/60000 [==============================] - 6s 103us/step - loss: 4.
0829e-09 - accuracy: 1.0000 - val_loss: 0.1412 - val_accuracy: 0.9861
Epoch 78/85
60000/60000 [==============================] - 7s 109us/step - loss: 3.
3637e-09 - accuracy: 1.0000 - val_loss: 0.1423 - val_accuracy: 0.9860
Epoch 79/85
60000/60000 [==============================] - 6s 107us/step - loss: 2.
7994e-09 - accuracy: 1.0000 - val_loss: 0.1433 - val_accuracy: 0.9859
Epoch 80/85
60000/60000 [==============================] - 7s 111us/step - loss: 2.
3524e-09 - accuracy: 1.0000 - val_loss: 0.1443 - val_accuracy: 0.9860
Epoch 81/85
60000/60000 [==============================] - 6s 102us/step - loss: 1.
9789e-09 - accuracy: 1.0000 - val_loss: 0.1451 - val_accuracy: 0.9860
Epoch 82/85
60000/60000 [==============================] - 6s 103us/step - loss: 1.
6769e-09 - accuracy: 1.0000 - val_loss: 0.1460 - val_accuracy: 0.9859
Epoch 83/85
60000/60000 [==============================] - 6s 103us/step - loss: 1.
4444e-09 - accuracy: 1.0000 - val_loss: 0.1468 - val_accuracy: 0.9859
Epoch 84/85
60000/60000 [==============================] - 6s 108us/step - loss: 1.
2338e-09 - accuracy: 1.0000 - val_loss: 0.1474 - val_accuracy: 0.9859
Epoch 85/85
60000/60000 [==============================] - 7s 109us/step - loss: 1.
0530e-09 - accuracy: 1.0000 - val_loss: 0.1482 - val_accuracy: 0.9858
```

2.2.1.3 Number of Epochs vs Train Loss & Validation Loss

In [34]:
```
warnings.filterwarnings("ignore")

A5M1_score = arch5_model1.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A5M1_score[0])
print('Test accuracy:', A5M1_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')
```

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in history.history we will have a list of length equal t
o number of epochs

vy = A5M1_history.history['val_loss']
ty = A5M1_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.1481512006560134
Test accuracy: 0.98580002784729
```

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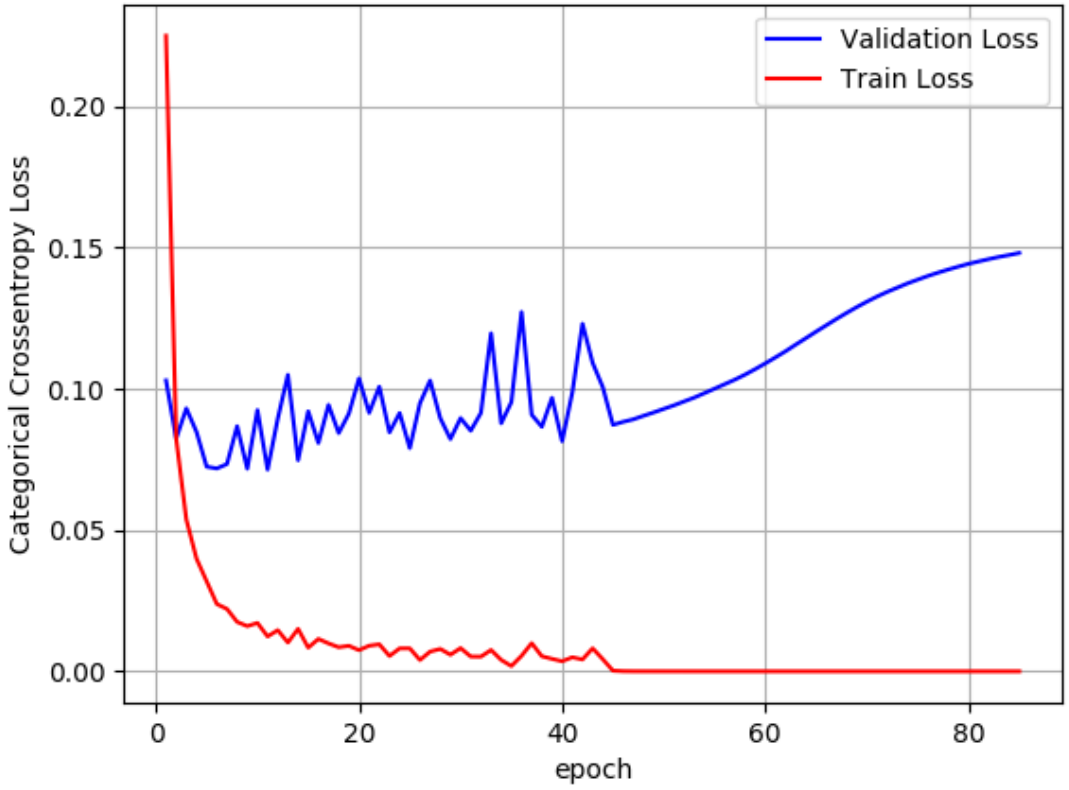

2.2.1.4 Violin Plots for Hidden Layers in the Models Trained

In [46]:
```
w_after = arch5_model1.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
h3_w = w_after[4].flatten().reshape(-1,1)
out_w = w_after[6].flatten().reshape(-1,1)
```

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```
fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 4, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Hidden Layer 1')

plt.subplot(1, 4, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Hidden Layer 2 ')

plt.subplot(1,4, 3)
ax = sns.violinplot(y=h3_w, color='g')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Hidden Layer 3 ')

plt.subplot(1, 4, 4)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Output Layer ')
plt.show()
```

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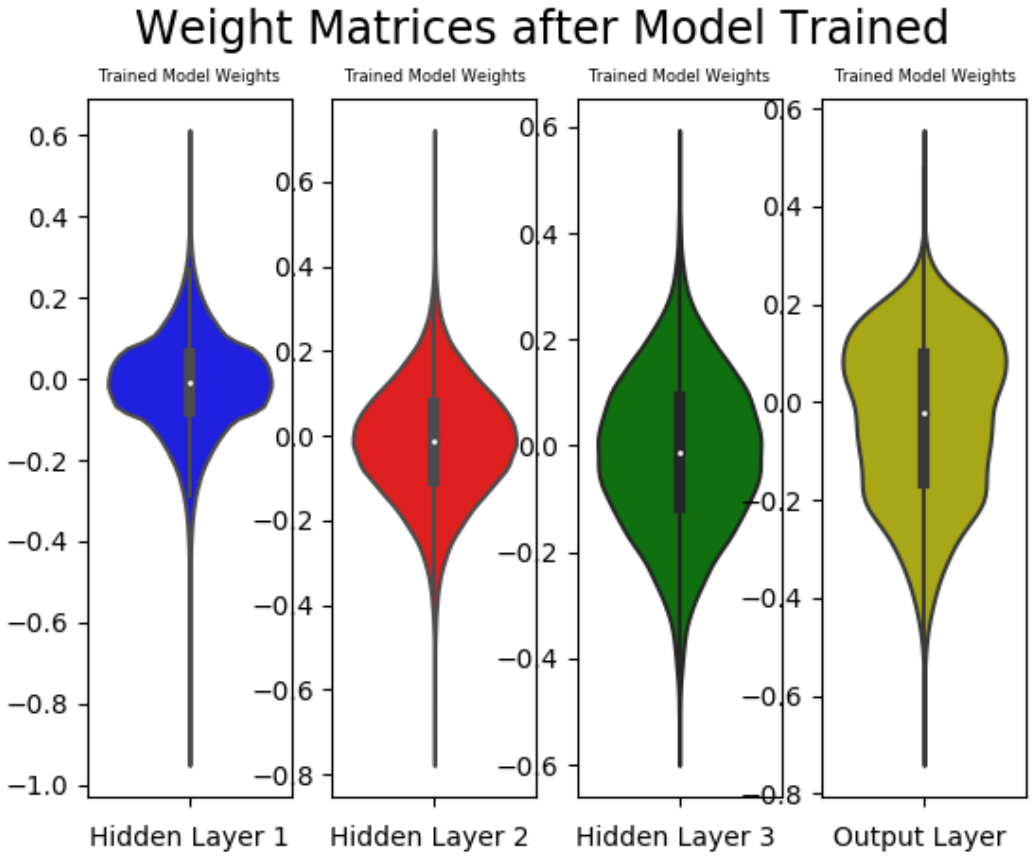

2.2.2 Model 2 : MLP + BatchNormalization + Adam Optimizer

2.2.2.1 Constructing the Neural Network

In [62]:
```
arch5_model2 = Sequential()

arch5_model2.add(Dense(500, activation='relu', input_shape=(input_dim
,),\
                       kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))
```

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```
arch5_model2.add(BatchNormalization())

arch5_model2.add(Dense(250, activation='relu', \
                       kernel_initializer=RandomUniform(minval= -0.109,
 maxval=0.109, seed=None)) )
arch5_model2.add(BatchNormalization())

arch5_model2.add(Dense(125, activation='relu', \
                       kernel_initializer=RandomUniform(minval= -0.155,
 maxval=0.155, seed=None)) )
arch5_model2.add(BatchNormalization())

arch5_model2.add(Dense(output_dim, activation='softmax'))
arch5_model2.summary()
```

```
Model: "sequential_12"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_44 (Dense)             (None, 500)               392500
_________________________________________________________________
batch_normalization_24 (Batc (None, 500)               2000
_________________________________________________________________
dense_45 (Dense)             (None, 250)               125250
_________________________________________________________________
batch_normalization_25 (Batc (None, 250)               1000
_________________________________________________________________
dense_46 (Dense)             (None, 125)               31375
_________________________________________________________________
batch_normalization_26 (Batc (None, 125)               500
_________________________________________________________________
dense_47 (Dense)             (None, 10)                1260
=================================================================
Total params: 553,885
Trainable params: 552,135
Non-trainable params: 1,750
_________________________________________________________________
```

2.2.2.2 Running the Neural Network on Train & Validation Datasets for 85 Epochs

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In [63]:
```
arch5_model2.compile(optimizer='adam', loss='categorical_crossentropy',
 metrics=['accuracy'])

A5M2_history = arch5_model2.fit(X_train, Y_train, batch_size=batch_size
, epochs=nb_epoch, verbose=1, \
                              validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 10s 159us/step - loss:
0.1936 - accuracy: 0.9420 - val_loss: 0.0958 - val_accuracy: 0.9710
Epoch 2/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0732 - accuracy: 0.9769 - val_loss: 0.0775 - val_accuracy: 0.9762
Epoch 3/85
60000/60000 [==============================] - 9s 154us/step - loss: 0.
0470 - accuracy: 0.9852 - val_loss: 0.0789 - val_accuracy: 0.9755
Epoch 4/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0394 - accuracy: 0.9874 - val_loss: 0.0857 - val_accuracy: 0.9760
Epoch 5/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0313 - accuracy: 0.9896 - val_loss: 0.0746 - val_accuracy: 0.9806
Epoch 6/85
60000/60000 [==============================] - 9s 158us/step - loss: 0.
0242 - accuracy: 0.9917 - val_loss: 0.0706 - val_accuracy: 0.9777
Epoch 7/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0218 - accuracy: 0.9929 - val_loss: 0.0897 - val_accuracy: 0.9743
Epoch 8/85
60000/60000 [==============================] - 9s 149us/step - loss: 0.
0224 - accuracy: 0.9922 - val_loss: 0.0865 - val_accuracy: 0.9763
Epoch 9/85
60000/60000 [==============================] - 9s 154us/step - loss: 0.
0164 - accuracy: 0.9944 - val_loss: 0.0785 - val_accuracy: 0.9783
Epoch 10/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0144 - accuracy: 0.9954 - val_loss: 0.0804 - val_accuracy: 0.9793
```

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```
Epoch 11/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0143 - accuracy: 0.9950 - val_loss: 0.0771 - val_accuracy: 0.9815
Epoch 12/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0133 - accuracy: 0.9958 - val_loss: 0.0912 - val_accuracy: 0.9760
Epoch 13/85
60000/60000 [==============================] - 9s 153us/step - loss: 0.
0159 - accuracy: 0.9946 - val_loss: 0.0909 - val_accuracy: 0.9784
Epoch 14/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0122 - accuracy: 0.9960 - val_loss: 0.0833 - val_accuracy: 0.9790
Epoch 15/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0116 - accuracy: 0.9962 - val_loss: 0.0732 - val_accuracy: 0.9827
Epoch 16/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0096 - accuracy: 0.9970 - val_loss: 0.0900 - val_accuracy: 0.9782
Epoch 17/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0100 - accuracy: 0.9963 - val_loss: 0.0817 - val_accuracy: 0.9789
Epoch 18/85
60000/60000 [==============================] - 8s 140us/step - loss: 0.
0100 - accuracy: 0.9966 - val_loss: 0.0748 - val_accuracy: 0.9808
Epoch 19/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0096 - accuracy: 0.9967 - val_loss: 0.0766 - val_accuracy: 0.9837
Epoch 20/85
60000/60000 [==============================] - 9s 144us/step - loss: 0.
0084 - accuracy: 0.9969 - val_loss: 0.0738 - val_accuracy: 0.9814
Epoch 21/85
60000/60000 [==============================] - 9s 142us/step - loss: 0.
0073 - accuracy: 0.9977 - val_loss: 0.0848 - val_accuracy: 0.9798
Epoch 22/85
60000/60000 [==============================] - 8s 139us/step - loss: 0.
0116 - accuracy: 0.9962 - val_loss: 0.0743 - val_accuracy: 0.9829
Epoch 23/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0081 - accuracy: 0.9970 - val_loss: 0.0800 - val_accuracy: 0.9824
```

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```
Epoch 24/85
60000/60000 [==============================] - 9s 142us/step - loss: 0.
0053 - accuracy: 0.9983 - val_loss: 0.0868 - val_accuracy: 0.9802
Epoch 25/85
60000/60000 [==============================] - 9s 144us/step - loss: 0.
0060 - accuracy: 0.9980 - val_loss: 0.0804 - val_accuracy: 0.9818
Epoch 26/85
60000/60000 [==============================] - 9s 142us/step - loss: 0.
0096 - accuracy: 0.9967 - val_loss: 0.0763 - val_accuracy: 0.9821
Epoch 27/85
60000/60000 [==============================] - 9s 142us/step - loss: 0.
0065 - accuracy: 0.9979 - val_loss: 0.0758 - val_accuracy: 0.9824
Epoch 28/85
60000/60000 [==============================] - 8s 139us/step - loss: 0.
0031 - accuracy: 0.9990 - val_loss: 0.0737 - val_accuracy: 0.9845
Epoch 29/85
60000/60000 [==============================] - 9s 144us/step - loss: 0.
0054 - accuracy: 0.9983 - val_loss: 0.0824 - val_accuracy: 0.9812
Epoch 30/85
60000/60000 [==============================] - 9s 146us/step - loss: 0.
0083 - accuracy: 0.9972 - val_loss: 0.0794 - val_accuracy: 0.9814
Epoch 31/85
60000/60000 [==============================] - 8s 141us/step - loss: 0.
0071 - accuracy: 0.9978 - val_loss: 0.0816 - val_accuracy: 0.9823
Epoch 32/85
60000/60000 [==============================] - 9s 145us/step - loss: 0.
0050 - accuracy: 0.9984 - val_loss: 0.0789 - val_accuracy: 0.9824
Epoch 33/85
60000/60000 [==============================] - 9s 145us/step - loss: 0.
0048 - accuracy: 0.9984 - val_loss: 0.0817 - val_accuracy: 0.9828
Epoch 34/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0046 - accuracy: 0.9985 - val_loss: 0.0801 - val_accuracy: 0.9831
Epoch 35/85
60000/60000 [==============================] - 9s 144us/step - loss: 0.
0042 - accuracy: 0.9985 - val_loss: 0.0810 - val_accuracy: 0.9839
Epoch 36/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0061 - accuracy: 0.9981 - val_loss: 0.0894 - val_accuracy: 0.9809
```

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```
Epoch 37/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0047 - accuracy: 0.9987 - val_loss: 0.0839 - val_accuracy: 0.9819
Epoch 38/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0050 - accuracy: 0.9984 - val_loss: 0.0780 - val_accuracy: 0.9803
Epoch 39/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0039 - accuracy: 0.9990 - val_loss: 0.0883 - val_accuracy: 0.9824
Epoch 40/85
60000/60000 [==============================] - 9s 143us/step - loss: 0.
0041 - accuracy: 0.9987 - val_loss: 0.0828 - val_accuracy: 0.9837
Epoch 41/85
60000/60000 [==============================] - 9s 142us/step - loss: 0.
0045 - accuracy: 0.9984 - val_loss: 0.0796 - val_accuracy: 0.9831
Epoch 42/85
60000/60000 [==============================] - 8s 140us/step - loss: 0.
0047 - accuracy: 0.9987 - val_loss: 0.0892 - val_accuracy: 0.9825
Epoch 43/85
60000/60000 [==============================] - 9s 145us/step - loss: 0.
0046 - accuracy: 0.9987 - val_loss: 0.0809 - val_accuracy: 0.9840
Epoch 44/85
60000/60000 [==============================] - 8s 141us/step - loss: 0.
0032 - accuracy: 0.9991 - val_loss: 0.0862 - val_accuracy: 0.9840
Epoch 45/85
60000/60000 [==============================] - 9s 143us/step - loss: 0.
0035 - accuracy: 0.9988 - val_loss: 0.0824 - val_accuracy: 0.9847
Epoch 46/85
60000/60000 [==============================] - 8s 141us/step - loss: 0.
0032 - accuracy: 0.9990 - val_loss: 0.0787 - val_accuracy: 0.9845
Epoch 47/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0036 - accuracy: 0.9989 - val_loss: 0.0937 - val_accuracy: 0.9821
Epoch 48/85
60000/60000 [==============================] - 8s 141us/step - loss: 0.
0027 - accuracy: 0.9990 - val_loss: 0.0832 - val_accuracy: 0.9824
Epoch 49/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0029 - accuracy: 0.9991 - val_loss: 0.0964 - val_accuracy: 0.9832
```

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```
Epoch 50/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0030 - accuracy: 0.9992 - val_loss: 0.0976 - val_accuracy: 0.9811
Epoch 51/85
60000/60000 [==============================] - 8s 141us/step - loss: 0.
0063 - accuracy: 0.9979 - val_loss: 0.0872 - val_accuracy: 0.9832
Epoch 52/85
60000/60000 [==============================] - 8s 140us/step - loss: 0.
0045 - accuracy: 0.9983 - val_loss: 0.0814 - val_accuracy: 0.9846
Epoch 53/85
60000/60000 [==============================] - 9s 143us/step - loss: 0.
0036 - accuracy: 0.9989 - val_loss: 0.0851 - val_accuracy: 0.9816
Epoch 54/85
60000/60000 [==============================] - 9s 146us/step - loss: 0.
0021 - accuracy: 0.9993 - val_loss: 0.0808 - val_accuracy: 0.9850
Epoch 55/85
60000/60000 [==============================] - 8s 135us/step - loss: 0.
0027 - accuracy: 0.9992 - val_loss: 0.0864 - val_accuracy: 0.9823
Epoch 56/85
60000/60000 [==============================] - 8s 137us/step - loss: 0.
0027 - accuracy: 0.9991 - val_loss: 0.0819 - val_accuracy: 0.9853
Epoch 57/85
60000/60000 [==============================] - 9s 144us/step - loss: 0.
0030 - accuracy: 0.9989 - val_loss: 0.0865 - val_accuracy: 0.9837
Epoch 58/85
60000/60000 [==============================] - 9s 146us/step - loss: 0.
0021 - accuracy: 0.9994 - val_loss: 0.0794 - val_accuracy: 0.9840
Epoch 59/85
60000/60000 [==============================] - 8s 139us/step - loss: 0.
0034 - accuracy: 0.9988 - val_loss: 0.0856 - val_accuracy: 0.9850
Epoch 60/85
60000/60000 [==============================] - 9s 143us/step - loss: 0.
0027 - accuracy: 0.9991 - val_loss: 0.0936 - val_accuracy: 0.9820
Epoch 61/85
60000/60000 [==============================] - 9s 145us/step - loss: 0.
0047 - accuracy: 0.9985 - val_loss: 0.1017 - val_accuracy: 0.9803
Epoch 62/85
60000/60000 [==============================] - 9s 143us/step - loss: 0.
0035 - accuracy: 0.9991 - val_loss: 0.0913 - val_accuracy: 0.9825
```

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```
Epoch 63/85
60000/60000 [==============================] - 9s 144us/step - loss: 0.
0028 - accuracy: 0.9991 - val_loss: 0.0897 - val_accuracy: 0.9825
Epoch 64/85
60000/60000 [==============================] - 8s 138us/step - loss: 0.
0024 - accuracy: 0.9992 - val_loss: 0.0840 - val_accuracy: 0.9837
Epoch 65/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0025 - accuracy: 0.9992 - val_loss: 0.0969 - val_accuracy: 0.9820
Epoch 66/85
60000/60000 [==============================] - 8s 138us/step - loss: 0.
0020 - accuracy: 0.9994 - val_loss: 0.0763 - val_accuracy: 0.9851
Epoch 67/85
60000/60000 [==============================] - 9s 142us/step - loss: 0.
0031 - accuracy: 0.9992 - val_loss: 0.0886 - val_accuracy: 0.9837
Epoch 68/85
60000/60000 [==============================] - 8s 139us/step - loss: 0.
0036 - accuracy: 0.9987 - val_loss: 0.0961 - val_accuracy: 0.9821
Epoch 69/85
60000/60000 [==============================] - 9s 142us/step - loss: 0.
0030 - accuracy: 0.9991 - val_loss: 0.0780 - val_accuracy: 0.9851
Epoch 70/85
60000/60000 [==============================] - 8s 141us/step - loss: 0.
0020 - accuracy: 0.9994 - val_loss: 0.0816 - val_accuracy: 0.9850
Epoch 71/85
60000/60000 [==============================] - 9s 144us/step - loss: 0.
0024 - accuracy: 0.9993 - val_loss: 0.0825 - val_accuracy: 0.9829
Epoch 72/85
60000/60000 [==============================] - 8s 140us/step - loss: 0.
0023 - accuracy: 0.9993 - val_loss: 0.0730 - val_accuracy: 0.9853
Epoch 73/85
60000/60000 [==============================] - 9s 142us/step - loss: 0.
0017 - accuracy: 0.9995 - val_loss: 0.0861 - val_accuracy: 0.9833
Epoch 74/85
60000/60000 [==============================] - 8s 141us/step - loss: 0.
0017 - accuracy: 0.9995 - val_loss: 0.0761 - val_accuracy: 0.9853
Epoch 75/85
60000/60000 [==============================] - 9s 145us/step - loss: 0.
0023 - accuracy: 0.9994 - val_loss: 0.0825 - val_accuracy: 0.9838
```

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```
Epoch 76/85
60000/60000 [==============================] - 8s 141us/step - loss: 0.
0031 - accuracy: 0.9991 - val_loss: 0.0870 - val_accuracy: 0.9830
Epoch 77/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0020 - accuracy: 0.9995 - val_loss: 0.0792 - val_accuracy: 0.9831
Epoch 78/85
60000/60000 [==============================] - 10s 161us/step - loss:
0.0027 - accuracy: 0.9992 - val_loss: 0.0829 - val_accuracy: 0.9830
Epoch 79/85
60000/60000 [==============================] - 10s 159us/step - loss:
0.0028 - accuracy: 0.9991 - val_loss: 0.0734 - val_accuracy: 0.9851
Epoch 80/85
60000/60000 [==============================] - 11s 192us/step - loss:
0.0020 - accuracy: 0.9993 - val_loss: 0.1013 - val_accuracy: 0.9806
Epoch 81/85
60000/60000 [==============================] - 12s 195us/step - loss:
0.0017 - accuracy: 0.9994 - val_loss: 0.0748 - val_accuracy: 0.9849
Epoch 82/85
60000/60000 [==============================] - 11s 189us/step - loss:
0.0014 - accuracy: 0.9995 - val_loss: 0.0825 - val_accuracy: 0.9836
Epoch 83/85
60000/60000 [==============================] - 10s 167us/step - loss:
0.0024 - accuracy: 0.9992 - val_loss: 0.0908 - val_accuracy: 0.9837
Epoch 84/85
60000/60000 [==============================] - 9s 144us/step - loss: 0.
0028 - accuracy: 0.9991 - val_loss: 0.0830 - val_accuracy: 0.9842
Epoch 85/85
60000/60000 [==============================] - 8s 140us/step - loss: 0.
0018 - accuracy: 0.9993 - val_loss: 0.0980 - val_accuracy: 0.9833
```

2.2.2.3 Number of Epochs vs Train Loss & Validation Loss

In [64]:
```
warnings.filterwarnings("ignore")

A5M2_score = arch5_model2.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A5M2_score[0])
print('Test accuracy:', A5M2_score[1])
```

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```
fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in history.history we will have a list of length equal t
o number of epochs

vy = A5M2_history.history['val_loss']
ty = A5M2_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.09802400289352353
Test accuracy: 0.983299970626831
```

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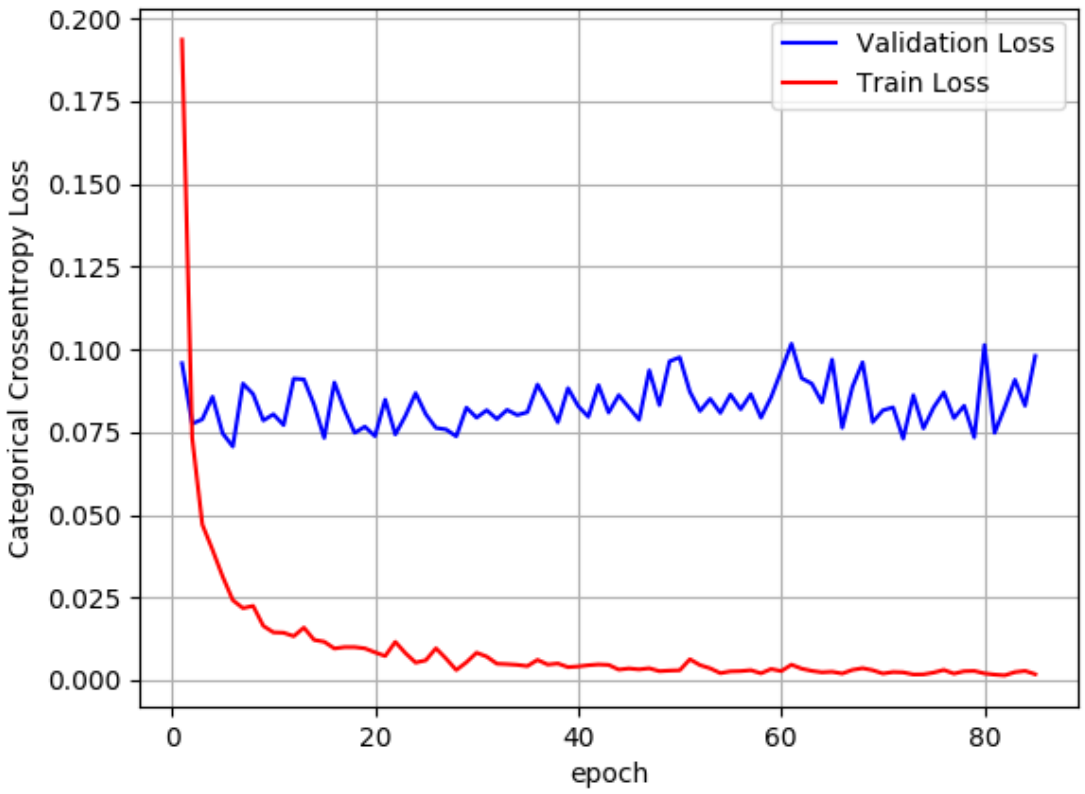

2.2.2.4 Violin Plots for Hidden Layers in the Models Trained

In [65]:
```
w_after = arch5_model2.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
h3_w = w_after[4].flatten().reshape(-1,1)
out_w = w_after[6].flatten().reshape(-1,1)
```

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```
fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 4, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Hidden Layer 1')

plt.subplot(1, 4, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Hidden Layer 2 ')

plt.subplot(1,4, 3)
ax = sns.violinplot(y=h3_w, color='g')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Hidden Layer 3 ')

plt.subplot(1, 4, 4)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Output Layer ')
plt.show()
```

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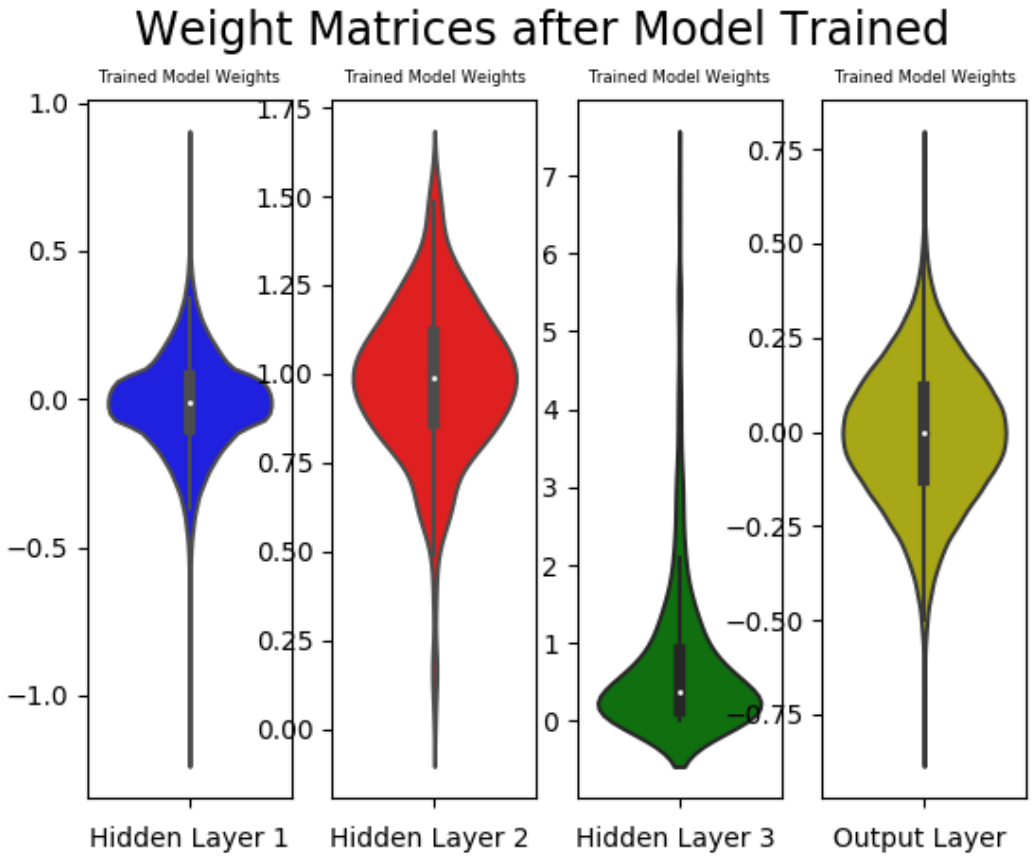

2.2.3 Model 3 : MLP + BatchNormalization + Dropout + Adam Optimizer

2.2.3.1 Hyperparameter Tuning for Dropout

In [15]:
```
from keras.layers.normalization import BatchNormalization
from keras.layers import Dropout

def A5M3_best_hyperparameters(dropout):
    arch5_model3 = Sequential()
```

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```
    arch5_model3.add(Dense(500, activation='relu', input_shape=(input_d
im,),\
                        kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))
    arch5_model3.add(BatchNormalization())
    arch5_model3.add(Dropout(dropout))

    arch5_model3.add(Dense(250, activation='relu', \
                         kernel_initializer=RandomUniform(minval= -0.109,
 maxval=0.109, seed=None)) )
    arch5_model3.add(BatchNormalization())
    arch5_model3.add(Dropout(dropout))

    arch5_model3.add(Dense(125, activation='relu', \
                         kernel_initializer=RandomUniform(minval= -0.155,
 maxval=0.155, seed=None)) )
    arch5_model3.add(BatchNormalization())
    arch5_model3.add(Dropout(dropout))

    arch5_model3.add(Dense(output_dim, activation='softmax'))

    arch5_model3.compile(optimizer='adam', loss='categorical_crossentro
py', metrics=['accuracy'])

    return arch5_model3
```

In [18]:

```
from datetime import datetime
from keras.wrappers.scikit_learn import KerasClassifier
from sklearn.model_selection import GridSearchCV

start = datetime.now()

dropout = []

for d in range(1,10):
    dropout.append(d/10)

model = KerasClassifier(build_fn=A5M3_best_hyperparameters, epochs=nb_e
```

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```
poch, batch_size=batch_size, verbose=0)
param_grid = dict(dropout=dropout)

# if you are using CPU
# grid = GridSearchCV(estimator=model, param_grid=param_grid, n_jobs=-
1)
# if you are using GPU dont use the n_jobs parameter

grid_4 = GridSearchCV(estimator=model, param_grid=param_grid,cv=3,n_job
s=-1)
grid_result4 = grid_4.fit(X_train, Y_train)

print('Time taken :', datetime.now() - start)
```

```
Time taken : 2:30:24.596214
```

In [19]:

```
print("Best: %f using %s" % (grid_result4.best_score_, grid_result4.bes
t_params_))
means = grid_result4.cv_results_['mean_test_score']
stds = grid_result4.cv_results_['std_test_score']
params = grid_result4.cv_results_['params']

for mean, stdev, param in zip(means, stds, params):
    print("%f (%f) with: %r" % (mean, stdev, param))
```

```
Best: 0.982750 using {'dropout': 0.4}
0.981600 (0.001524) with: {'dropout': 0.1}
0.981267 (0.000327) with: {'dropout': 0.2}
0.981650 (0.001205) with: {'dropout': 0.3}
0.982750 (0.001003) with: {'dropout': 0.4}
0.982117 (0.001073) with: {'dropout': 0.5}
0.981517 (0.001129) with: {'dropout': 0.6}
0.979683 (0.000710) with: {'dropout': 0.7}
0.973867 (0.001234) with: {'dropout': 0.8}
0.950283 (0.001695) with: {'dropout': 0.9}
```

2.2.3.2 Constructing the Neural Network

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In [20]:
```
arch5_model3 = Sequential()

arch5_model3.add(Dense(500, activation='relu', input_shape=(input_dim
,),\
                       kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))
arch5_model3.add(BatchNormalization())
arch5_model3.add(Dropout(0.4))

arch5_model3.add(Dense(250, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.109,
 maxval=0.109, seed=None)) )
arch5_model3.add(BatchNormalization())
arch5_model3.add(Dropout(0.4))

arch5_model3.add(Dense(125, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.155,
 maxval=0.155, seed=None)) )
arch5_model3.add(BatchNormalization())
arch5_model3.add(Dropout(0.4))

arch5_model3.add(Dense(output_dim, activation='softmax'))
arch5_model3.summary()
```

```
Model: "sequential_2"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_5 (Dense)              (None, 500)               392500
_________________________________________________________________
batch_normalization_4 (Batch (None, 500)               2000
_________________________________________________________________
dropout_4 (Dropout)          (None, 500)               0
_________________________________________________________________
dense_6 (Dense)              (None, 250)               125250
_________________________________________________________________
batch_normalization_5 (Batch (None, 250)               1000
_________________________________________________________________
dropout_5 (Dropout)          (None, 250)               0
_________________________________________________________________
```

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```
dense_7 (Dense)              (None, 125)               31375
_________________________________________________________________
batch_normalization_6 (Batch (None, 125)               500
_________________________________________________________________
dropout_6 (Dropout)          (None, 125)               0
_________________________________________________________________
dense_8 (Dense)              (None, 10)                1260
=================================================================
Total params: 553,885
Trainable params: 552,135
Non-trainable params: 1,750
_________________________________________________________________
```

2.2.3.3 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [21]:
```
arch5_model3.compile(optimizer='adam', loss='categorical_crossentropy',
 metrics=['accuracy'])

A5M3_history = arch5_model3.fit(X_train, Y_train, batch_size=batch_size
, epochs=nb_epoch, verbose=1, \
                              validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 12s 204us/step - loss:
0.4395 - accuracy: 0.8650 - val_loss: 0.1389 - val_accuracy: 0.9555
Epoch 2/85
60000/60000 [==============================] - 8s 141us/step - loss: 0.
1951 - accuracy: 0.9414 - val_loss: 0.1036 - val_accuracy: 0.9692
Epoch 3/85
60000/60000 [==============================] - 8s 136us/step - loss: 0.
1494 - accuracy: 0.9547 - val_loss: 0.0874 - val_accuracy: 0.9732
Epoch 4/85
60000/60000 [==============================] - 10s 168us/step - loss:
0.1248 - accuracy: 0.9628 - val_loss: 0.0836 - val_accuracy: 0.9759
Epoch 5/85
60000/60000 [==============================] - 10s 173us/step - loss:
0.1103 - accuracy: 0.9671 - val_loss: 0.0748 - val_accuracy: 0.9765
```

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```
Epoch 6/85
60000/60000 [==============================] - 10s 167us/step - loss:
0.1030 - accuracy: 0.9687 - val_loss: 0.0725 - val_accuracy: 0.9776
Epoch 7/85
60000/60000 [==============================] - 10s 163us/step - loss:
0.0921 - accuracy: 0.9716 - val_loss: 0.0673 - val_accuracy: 0.9797
Epoch 8/85
60000/60000 [==============================] - 9s 144us/step - loss: 0.
0863 - accuracy: 0.9729 - val_loss: 0.0623 - val_accuracy: 0.9805
Epoch 9/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0795 - accuracy: 0.9764 - val_loss: 0.0630 - val_accuracy: 0.9800
Epoch 10/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0715 - accuracy: 0.9775 - val_loss: 0.0571 - val_accuracy: 0.9824
Epoch 11/85
60000/60000 [==============================] - 8s 140us/step - loss: 0.
0669 - accuracy: 0.9792 - val_loss: 0.0588 - val_accuracy: 0.9816
Epoch 12/85
60000/60000 [==============================] - 10s 164us/step - loss:
0.0640 - accuracy: 0.9797 - val_loss: 0.0596 - val_accuracy: 0.9822
Epoch 13/85
60000/60000 [==============================] - 9s 149us/step - loss: 0.
0612 - accuracy: 0.9807 - val_loss: 0.0575 - val_accuracy: 0.9826
Epoch 14/85
60000/60000 [==============================] - 9s 156us/step - loss: 0.
0567 - accuracy: 0.9817 - val_loss: 0.0549 - val_accuracy: 0.9840
Epoch 15/85
60000/60000 [==============================] - 10s 160us/step - loss:
0.0539 - accuracy: 0.9830 - val_loss: 0.0623 - val_accuracy: 0.9822
Epoch 16/85
60000/60000 [==============================] - 12s 206us/step - loss:
0.0530 - accuracy: 0.9836 - val_loss: 0.0623 - val_accuracy: 0.9824
Epoch 17/85
60000/60000 [==============================] - 13s 217us/step - loss:
0.0495 - accuracy: 0.9844 - val_loss: 0.0539 - val_accuracy: 0.9836
Epoch 18/85
60000/60000 [==============================] - 13s 215us/step - loss:
0.0500 - accuracy: 0.9842 - val_loss: 0.0549 - val_accuracy: 0.9830
```

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```
Epoch 19/85
60000/60000 [==============================] - 11s 190us/step - loss:
0.0468 - accuracy: 0.9851 - val_loss: 0.0522 - val_accuracy: 0.9847
Epoch 20/85
60000/60000 [==============================] - 9s 143us/step - loss: 0.
0435 - accuracy: 0.9862 - val_loss: 0.0529 - val_accuracy: 0.9856
Epoch 21/85
60000/60000 [==============================] - 11s 176us/step - loss:
0.0424 - accuracy: 0.9867 - val_loss: 0.0575 - val_accuracy: 0.9835
Epoch 22/85
60000/60000 [==============================] - 9s 149us/step - loss: 0.
0410 - accuracy: 0.9868 - val_loss: 0.0540 - val_accuracy: 0.9850
Epoch 23/85
60000/60000 [==============================] - 12s 195us/step - loss:
0.0407 - accuracy: 0.9873 - val_loss: 0.0523 - val_accuracy: 0.9846
Epoch 24/85
60000/60000 [==============================] - 10s 169us/step - loss:
0.0428 - accuracy: 0.9863 - val_loss: 0.0575 - val_accuracy: 0.9837
Epoch 25/85
60000/60000 [==============================] - 10s 165us/step - loss:
0.0374 - accuracy: 0.9883 - val_loss: 0.0549 - val_accuracy: 0.9852
Epoch 26/85
60000/60000 [==============================] - 9s 158us/step - loss: 0.
0358 - accuracy: 0.9884 - val_loss: 0.0540 - val_accuracy: 0.9846
Epoch 27/85
60000/60000 [==============================] - 8s 140us/step - loss: 0.
0365 - accuracy: 0.9888 - val_loss: 0.0475 - val_accuracy: 0.9857
Epoch 28/85
60000/60000 [==============================] - 8s 141us/step - loss: 0.
0335 - accuracy: 0.9890 - val_loss: 0.0522 - val_accuracy: 0.9849
Epoch 29/85
60000/60000 [==============================] - 9s 156us/step - loss: 0.
0329 - accuracy: 0.9890 - val_loss: 0.0568 - val_accuracy: 0.9849
Epoch 30/85
60000/60000 [==============================] - 9s 154us/step - loss: 0.
0325 - accuracy: 0.9895 - val_loss: 0.0574 - val_accuracy: 0.9845
Epoch 31/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0322 - accuracy: 0.9897 - val_loss: 0.0575 - val_accuracy: 0.9848
```

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```
Epoch 32/85
60000/60000 [==============================] - 9s 142us/step - loss: 0.
0310 - accuracy: 0.9905 - val_loss: 0.0531 - val_accuracy: 0.9852
Epoch 33/85
60000/60000 [==============================] - 8s 140us/step - loss: 0.
0288 - accuracy: 0.9903 - val_loss: 0.0572 - val_accuracy: 0.9852
Epoch 34/85
60000/60000 [==============================] - 8s 139us/step - loss: 0.
0291 - accuracy: 0.9906 - val_loss: 0.0586 - val_accuracy: 0.9845
Epoch 35/85
60000/60000 [==============================] - 8s 140us/step - loss: 0.
0297 - accuracy: 0.9904 - val_loss: 0.0595 - val_accuracy: 0.9849
Epoch 36/85
60000/60000 [==============================] - 8s 141us/step - loss: 0.
0287 - accuracy: 0.9904 - val_loss: 0.0575 - val_accuracy: 0.9849
Epoch 37/85
60000/60000 [==============================] - 9s 156us/step - loss: 0.
0275 - accuracy: 0.9910 - val_loss: 0.0535 - val_accuracy: 0.9845
Epoch 38/85
60000/60000 [==============================] - 10s 171us/step - loss:
0.0253 - accuracy: 0.9918 - val_loss: 0.0532 - val_accuracy: 0.9865
Epoch 39/85
60000/60000 [==============================] - 10s 164us/step - loss:
0.0258 - accuracy: 0.9917 - val_loss: 0.0560 - val_accuracy: 0.9867
Epoch 40/85
60000/60000 [==============================] - 10s 171us/step - loss:
0.0260 - accuracy: 0.9915 - val_loss: 0.0609 - val_accuracy: 0.9841
Epoch 41/85
60000/60000 [==============================] - 9s 157us/step - loss: 0.
0247 - accuracy: 0.9917 - val_loss: 0.0570 - val_accuracy: 0.9864
Epoch 42/85
60000/60000 [==============================] - 10s 165us/step - loss:
0.0236 - accuracy: 0.9922 - val_loss: 0.0541 - val_accuracy: 0.9866
Epoch 43/85
60000/60000 [==============================] - 10s 171us/step - loss:
0.0237 - accuracy: 0.9924 - val_loss: 0.0607 - val_accuracy: 0.9856
Epoch 44/85
60000/60000 [==============================] - 10s 163us/step - loss:
0.0226 - accuracy: 0.9930 - val_loss: 0.0569 - val_accuracy: 0.9864
```

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```
Epoch 45/85
60000/60000 [==============================] - 13s 217us/step - loss:
0.0240 - accuracy: 0.9923 - val_loss: 0.0570 - val_accuracy: 0.9857
Epoch 46/85
60000/60000 [==============================] - 10s 164us/step - loss:
0.0223 - accuracy: 0.9929 - val_loss: 0.0600 - val_accuracy: 0.9845
Epoch 47/85
60000/60000 [==============================] - 11s 181us/step - loss:
0.0226 - accuracy: 0.9927 - val_loss: 0.0591 - val_accuracy: 0.9849
Epoch 48/85
60000/60000 [==============================] - 9s 156us/step - loss: 0.
0227 - accuracy: 0.9924 - val_loss: 0.0585 - val_accuracy: 0.9852
Epoch 49/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0216 - accuracy: 0.9929 - val_loss: 0.0520 - val_accuracy: 0.9865
Epoch 50/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0202 - accuracy: 0.9933 - val_loss: 0.0546 - val_accuracy: 0.9863
Epoch 51/85
60000/60000 [==============================] - 10s 160us/step - loss:
0.0197 - accuracy: 0.9936 - val_loss: 0.0583 - val_accuracy: 0.9858
Epoch 52/85
60000/60000 [==============================] - 12s 200us/step - loss:
0.0197 - accuracy: 0.9938 - val_loss: 0.0594 - val_accuracy: 0.9857
Epoch 53/85
60000/60000 [==============================] - 10s 159us/step - loss:
0.0207 - accuracy: 0.9929 - val_loss: 0.0547 - val_accuracy: 0.9866
Epoch 54/85
60000/60000 [==============================] - 10s 166us/step - loss:
0.0183 - accuracy: 0.9938 - val_loss: 0.0575 - val_accuracy: 0.9864
Epoch 55/85
60000/60000 [==============================] - 11s 186us/step - loss:
0.0193 - accuracy: 0.9935 - val_loss: 0.0584 - val_accuracy: 0.9857
Epoch 56/85
60000/60000 [==============================] - 10s 173us/step - loss:
0.0184 - accuracy: 0.9942 - val_loss: 0.0588 - val_accuracy: 0.9862
Epoch 57/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0184 - accuracy: 0.9942 - val_loss: 0.0646 - val_accuracy: 0.9857
```

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```
Epoch 58/85
60000/60000 [==============================] - 9s 157us/step - loss: 0.
0186 - accuracy: 0.9936 - val_loss: 0.0622 - val_accuracy: 0.9854
Epoch 59/85
60000/60000 [==============================] - 8s 138us/step - loss: 0.
0185 - accuracy: 0.9940 - val_loss: 0.0602 - val_accuracy: 0.9853
Epoch 60/85
60000/60000 [==============================] - 10s 161us/step - loss:
0.0182 - accuracy: 0.9939 - val_loss: 0.0641 - val_accuracy: 0.9848
Epoch 61/85
60000/60000 [==============================] - 9s 157us/step - loss: 0.
0156 - accuracy: 0.9951 - val_loss: 0.0579 - val_accuracy: 0.9858
Epoch 62/85
60000/60000 [==============================] - 10s 167us/step - loss:
0.0168 - accuracy: 0.9948 - val_loss: 0.0595 - val_accuracy: 0.9848
Epoch 63/85
60000/60000 [==============================] - 11s 187us/step - loss:
0.0176 - accuracy: 0.9942 - val_loss: 0.0566 - val_accuracy: 0.9853
Epoch 64/85
60000/60000 [==============================] - 12s 204us/step - loss:
0.0152 - accuracy: 0.9950 - val_loss: 0.0617 - val_accuracy: 0.9859
Epoch 65/85
60000/60000 [==============================] - 12s 202us/step - loss:
0.0158 - accuracy: 0.9948 - val_loss: 0.0620 - val_accuracy: 0.9859
Epoch 66/85
60000/60000 [==============================] - 12s 192us/step - loss:
0.0178 - accuracy: 0.9945 - val_loss: 0.0588 - val_accuracy: 0.9863
Epoch 67/85
60000/60000 [==============================] - 12s 201us/step - loss:
0.0165 - accuracy: 0.9944 - val_loss: 0.0563 - val_accuracy: 0.9862
Epoch 68/85
60000/60000 [==============================] - 10s 170us/step - loss:
0.0159 - accuracy: 0.9949 - val_loss: 0.0616 - val_accuracy: 0.9853
Epoch 69/85
60000/60000 [==============================] - 10s 169us/step - loss:
0.0155 - accuracy: 0.9948 - val_loss: 0.0607 - val_accuracy: 0.9860
Epoch 70/85
60000/60000 [==============================] - 11s 186us/step - loss:
0.0169 - accuracy: 0.9946 - val_loss: 0.0571 - val_accuracy: 0.9864
```

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```
Epoch 71/85
60000/60000 [==============================] - 12s 197us/step - loss:
0.0155 - accuracy: 0.9949 - val_loss: 0.0602 - val_accuracy: 0.9872
Epoch 72/85
60000/60000 [==============================] - 11s 176us/step - loss:
0.0149 - accuracy: 0.9952 - val_loss: 0.0618 - val_accuracy: 0.9853
Epoch 73/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0142 - accuracy: 0.9954 - val_loss: 0.0593 - val_accuracy: 0.9863
Epoch 74/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0148 - accuracy: 0.9950 - val_loss: 0.0584 - val_accuracy: 0.9868
Epoch 75/85
60000/60000 [==============================] - 11s 180us/step - loss:
0.0148 - accuracy: 0.9953 - val_loss: 0.0555 - val_accuracy: 0.9864
Epoch 76/85
60000/60000 [==============================] - 11s 179us/step - loss:
0.0157 - accuracy: 0.9949 - val_loss: 0.0574 - val_accuracy: 0.9872
Epoch 77/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0136 - accuracy: 0.9956 - val_loss: 0.0580 - val_accuracy: 0.9859
Epoch 78/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0123 - accuracy: 0.9959 - val_loss: 0.0604 - val_accuracy: 0.9852
Epoch 79/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0147 - accuracy: 0.9951 - val_loss: 0.0656 - val_accuracy: 0.9855
Epoch 80/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0140 - accuracy: 0.9956 - val_loss: 0.0661 - val_accuracy: 0.9856
Epoch 81/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0148 - accuracy: 0.9948 - val_loss: 0.0617 - val_accuracy: 0.9865
Epoch 82/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0139 - accuracy: 0.9957 - val_loss: 0.0641 - val_accuracy: 0.9867
Epoch 83/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0135 - accuracy: 0.9959 - val_loss: 0.0630 - val_accuracy: 0.9854
```

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```
Epoch 84/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0132 - accuracy: 0.9955 - val_loss: 0.0622 - val_accuracy: 0.9858
Epoch 85/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
0134 - accuracy: 0.9957 - val_loss: 0.0669 - val_accuracy: 0.9860
```

2.2.3.4 Number of Epochs vs Train Loss & Validation Loss

In [22]:

```
import warnings
warnings.filterwarnings("ignore")

A5M3_score = arch5_model3.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A5M3_score[0])
print('Test accuracy:', A5M3_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in history.history we will have a list of length equal t
o number of epochs

vy = A5M3_history.history['val_loss']
```

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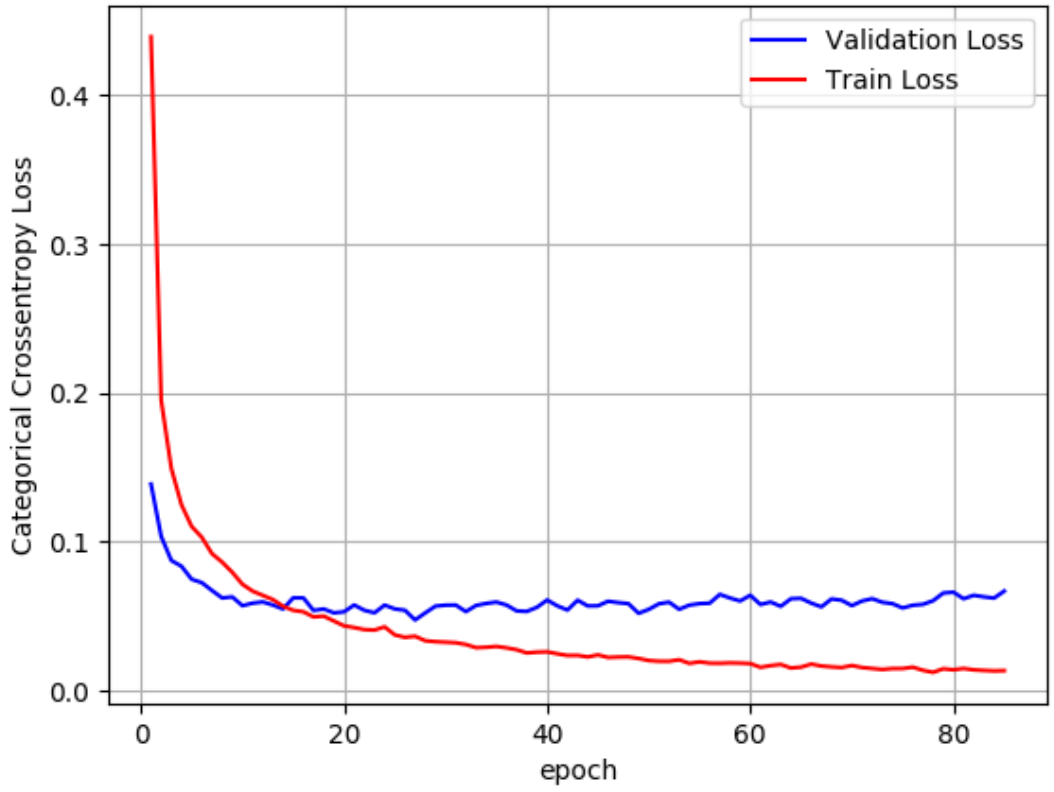
```
ty = A5M3_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.06687827669550607
Test accuracy: 0.9860000014305115
```



2.2.3.5 Violin Plots for Hidden Layers in the Models Trained

In [23]:
```
w_after = arch5_model3.get_weights()
```

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```
h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
h3_w = w_after[4].flatten().reshape(-1,1)
out_w = w_after[6].flatten().reshape(-1,1)

fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 4, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Hidden Layer 1')

plt.subplot(1, 4, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Hidden Layer 2 ')

plt.subplot(1,4, 3)
ax = sns.violinplot(y=h3_w, color='g')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Hidden Layer 3 ')

plt.subplot(1, 4, 4)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 6)
plt.xlabel('Output Layer ')
plt.show()
```

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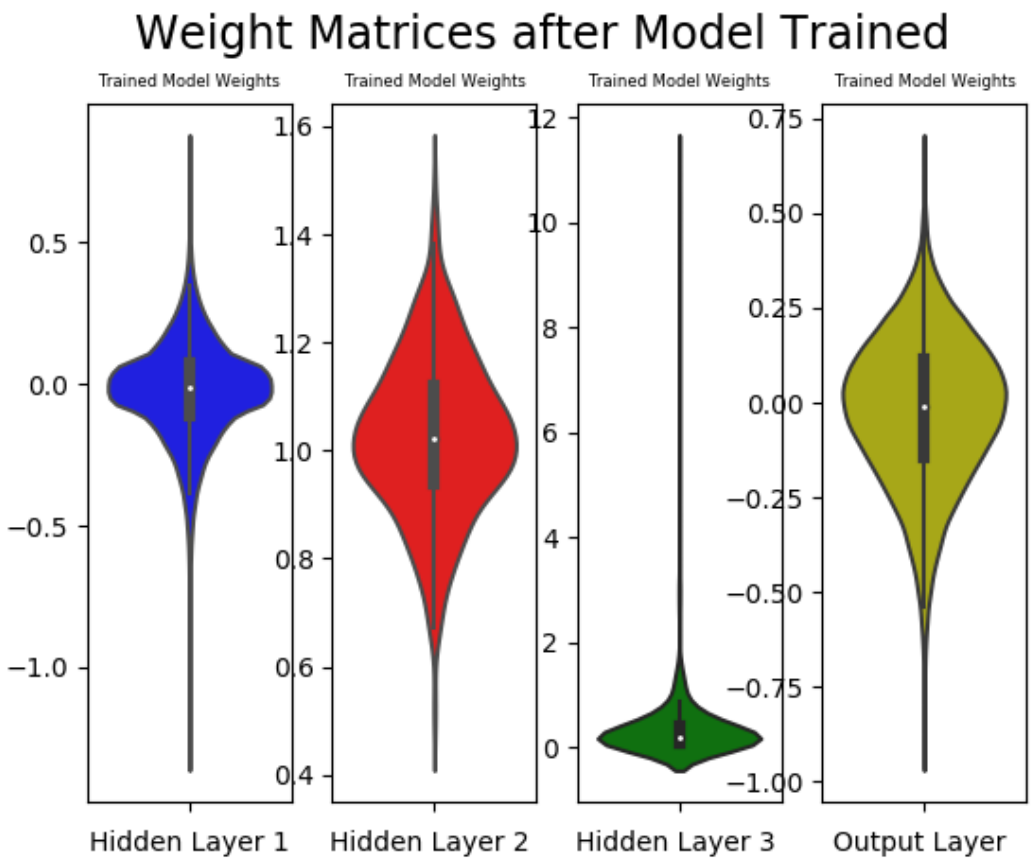

3. Number of Hidden Layers in the Neural Network = 5

3.1 Architecture 6 :- 784-512-256-128-64-32-10

3.1.1 Model 1 : MLP + Adam Optimizer

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3.1.1.1 Constructing the Neural Network

In [25]:
```
arch6_model1 = Sequential()

arch6_model1.add(Dense(512, activation='relu', input_shape=(input_dim
,),\
                       kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))

arch6_model1.add(Dense(256, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.108,
 maxval=0.108, seed=None)) )

arch6_model1.add(Dense(128, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.153,
 maxval=0.153, seed=None)) )

arch6_model1.add(Dense(64, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.216,
 maxval=0.216, seed=None)) )

arch6_model1.add(Dense(32, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.306,
 maxval=0.306, seed=None)) )

arch6_model1.add(Dense(output_dim, activation='softmax'))
arch6_model1.summary()
```

```
Model: "sequential_4"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_15 (Dense)             (None, 512)               401920
_________________________________________________________________
dense_16 (Dense)             (None, 256)               131328
_________________________________________________________________
dense_17 (Dense)             (None, 128)               32896
_________________________________________________________________
dense_18 (Dense)             (None, 64)                8256
```

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```
_________________________________________________________________
dense_19 (Dense)             (None, 32)                2080
_________________________________________________________________
dense_20 (Dense)             (None, 10)                330
=================================================================
Total params: 576,810
Trainable params: 576,810
Non-trainable params: 0
_________________________________________________________________
```

3.1.1.2 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [26]:
```
arch6_model1.compile(optimizer='adam', loss='categorical_crossentropy',
 metrics=['accuracy'])

A6M1_history = arch6_model1.fit(X_train, Y_train, batch_size=batch_size
, epochs=nb_epoch, verbose=1, \
                              validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 7s 124us/step - loss: 0.
2485 - accuracy: 0.9264 - val_loss: 0.1041 - val_accuracy: 0.9689
Epoch 2/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0891 - accuracy: 0.9728 - val_loss: 0.0853 - val_accuracy: 0.9733
Epoch 3/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0610 - accuracy: 0.9811 - val_loss: 0.0725 - val_accuracy: 0.9768
Epoch 4/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0438 - accuracy: 0.9860 - val_loss: 0.0660 - val_accuracy: 0.9799
Epoch 5/85
60000/60000 [==============================] - 7s 117us/step - loss: 0.
0364 - accuracy: 0.9878 - val_loss: 0.0760 - val_accuracy: 0.9785
Epoch 6/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0292 - accuracy: 0.9905 - val_loss: 0.0772 - val_accuracy: 0.9790
```

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```
Epoch 7/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0294 - accuracy: 0.9904 - val_loss: 0.0784 - val_accuracy: 0.9771
Epoch 8/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0214 - accuracy: 0.9931 - val_loss: 0.0885 - val_accuracy: 0.9763
Epoch 9/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0212 - accuracy: 0.9932 - val_loss: 0.0795 - val_accuracy: 0.9790
Epoch 10/85
60000/60000 [==============================] - 7s 119us/step - loss: 0.
0203 - accuracy: 0.9936 - val_loss: 0.0878 - val_accuracy: 0.9755
Epoch 11/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0175 - accuracy: 0.9944 - val_loss: 0.0913 - val_accuracy: 0.9789
Epoch 12/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
0160 - accuracy: 0.9948 - val_loss: 0.0767 - val_accuracy: 0.9822
Epoch 13/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
0159 - accuracy: 0.9949 - val_loss: 0.0798 - val_accuracy: 0.9795
Epoch 14/85
60000/60000 [==============================] - 7s 113us/step - loss: 0.
0123 - accuracy: 0.9960 - val_loss: 0.0944 - val_accuracy: 0.9781
Epoch 15/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0165 - accuracy: 0.9955 - val_loss: 0.0739 - val_accuracy: 0.9808
Epoch 16/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0112 - accuracy: 0.9966 - val_loss: 0.0957 - val_accuracy: 0.9813
Epoch 17/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
0151 - accuracy: 0.9958 - val_loss: 0.0960 - val_accuracy: 0.9770
Epoch 18/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0107 - accuracy: 0.9966 - val_loss: 0.0860 - val_accuracy: 0.9817
Epoch 19/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
0099 - accuracy: 0.9970 - val_loss: 0.0878 - val_accuracy: 0.9817
```

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```
Epoch 20/85
60000/60000 [==============================] - 7s 113us/step - loss: 0.
0105 - accuracy: 0.9969 - val_loss: 0.0762 - val_accuracy: 0.9825
Epoch 21/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0085 - accuracy: 0.9978 - val_loss: 0.0802 - val_accuracy: 0.9836
Epoch 22/85
60000/60000 [==============================] - 7s 108us/step - loss: 0.
0103 - accuracy: 0.9969 - val_loss: 0.0933 - val_accuracy: 0.9813
Epoch 23/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0077 - accuracy: 0.9977 - val_loss: 0.0815 - val_accuracy: 0.9845
Epoch 24/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0078 - accuracy: 0.9978 - val_loss: 0.1012 - val_accuracy: 0.9802
Epoch 25/85
60000/60000 [==============================] - 7s 114us/step - loss: 0.
0123 - accuracy: 0.9963 - val_loss: 0.0930 - val_accuracy: 0.9798
Epoch 26/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0097 - accuracy: 0.9970 - val_loss: 0.1024 - val_accuracy: 0.9798
Epoch 27/85
60000/60000 [==============================] - 6s 107us/step - loss: 0.
0070 - accuracy: 0.9978 - val_loss: 0.0984 - val_accuracy: 0.9812
Epoch 28/85
60000/60000 [==============================] - 7s 113us/step - loss: 0.
0069 - accuracy: 0.9979 - val_loss: 0.1223 - val_accuracy: 0.9780
Epoch 29/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0094 - accuracy: 0.9973 - val_loss: 0.0873 - val_accuracy: 0.9824
Epoch 30/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0043 - accuracy: 0.9987 - val_loss: 0.0905 - val_accuracy: 0.9836
Epoch 31/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0067 - accuracy: 0.9982 - val_loss: 0.1349 - val_accuracy: 0.9750
Epoch 32/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0088 - accuracy: 0.9979 - val_loss: 0.0930 - val_accuracy: 0.9824
```

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```
Epoch 33/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
0079 - accuracy: 0.9979 - val_loss: 0.0870 - val_accuracy: 0.9827
Epoch 34/85
60000/60000 [==============================] - 7s 113us/step - loss: 0.
0060 - accuracy: 0.9983 - val_loss: 0.0921 - val_accuracy: 0.9817
Epoch 35/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0044 - accuracy: 0.9989 - val_loss: 0.0956 - val_accuracy: 0.9836
Epoch 36/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0043 - accuracy: 0.9989 - val_loss: 0.0862 - val_accuracy: 0.9833
Epoch 37/85
60000/60000 [==============================] - 7s 124us/step - loss: 0.
0056 - accuracy: 0.9984 - val_loss: 0.1055 - val_accuracy: 0.9806
Epoch 38/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0069 - accuracy: 0.9981 - val_loss: 0.1059 - val_accuracy: 0.9848
Epoch 39/85
60000/60000 [==============================] - 7s 113us/step - loss: 0.
0095 - accuracy: 0.9976 - val_loss: 0.0859 - val_accuracy: 0.9829
Epoch 40/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0052 - accuracy: 0.9987 - val_loss: 0.0916 - val_accuracy: 0.9842
Epoch 41/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0041 - accuracy: 0.9987 - val_loss: 0.1129 - val_accuracy: 0.9799
Epoch 42/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
0045 - accuracy: 0.9987 - val_loss: 0.0966 - val_accuracy: 0.9830
Epoch 43/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0032 - accuracy: 0.9993 - val_loss: 0.0862 - val_accuracy: 0.9840
Epoch 44/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
0042 - accuracy: 0.9988 - val_loss: 0.1149 - val_accuracy: 0.9829
Epoch 45/85
60000/60000 [==============================] - 7s 113us/step - loss: 0.
0057 - accuracy: 0.9988 - val_loss: 0.0865 - val_accuracy: 0.9839
```

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```
Epoch 46/85
60000/60000 [==============================] - 7s 114us/step - loss: 0.
0064 - accuracy: 0.9982 - val_loss: 0.1069 - val_accuracy: 0.9831
Epoch 47/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0057 - accuracy: 0.9985 - val_loss: 0.1053 - val_accuracy: 0.9811
Epoch 48/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0020 - accuracy: 0.9993 - val_loss: 0.0901 - val_accuracy: 0.9857
Epoch 49/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0019 - accuracy: 0.9995 - val_loss: 0.1302 - val_accuracy: 0.9806
Epoch 50/85
60000/60000 [==============================] - 7s 118us/step - loss: 0.
0064 - accuracy: 0.9984 - val_loss: 0.0985 - val_accuracy: 0.9841
Epoch 51/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0053 - accuracy: 0.9986 - val_loss: 0.0840 - val_accuracy: 0.9833
Epoch 52/85
60000/60000 [==============================] - 7s 118us/step - loss: 0.
0018 - accuracy: 0.9995 - val_loss: 0.1136 - val_accuracy: 0.9829
Epoch 53/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0056 - accuracy: 0.9984 - val_loss: 0.1066 - val_accuracy: 0.9823
Epoch 54/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0053 - accuracy: 0.9987 - val_loss: 0.1024 - val_accuracy: 0.9845
Epoch 55/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0026 - accuracy: 0.9994 - val_loss: 0.0967 - val_accuracy: 0.9851
Epoch 56/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0029 - accuracy: 0.9993 - val_loss: 0.1062 - val_accuracy: 0.9843
Epoch 57/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0048 - accuracy: 0.9988 - val_loss: 0.1301 - val_accuracy: 0.9787
Epoch 58/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0067 - accuracy: 0.9983 - val_loss: 0.1061 - val_accuracy: 0.9839
```

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```
Epoch 59/85
60000/60000 [==============================] - 7s 118us/step - loss: 0.
0011 - accuracy: 0.9997 - val_loss: 0.1138 - val_accuracy: 0.9859
Epoch 60/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0051 - accuracy: 0.9989 - val_loss: 0.1124 - val_accuracy: 0.9829
Epoch 61/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0060 - accuracy: 0.9983 - val_loss: 0.1046 - val_accuracy: 0.9851
Epoch 62/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0020 - accuracy: 0.9995 - val_loss: 0.1179 - val_accuracy: 0.9826
Epoch 63/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
0041 - accuracy: 0.9989 - val_loss: 0.1249 - val_accuracy: 0.9819
Epoch 64/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0074 - accuracy: 0.9981 - val_loss: 0.1088 - val_accuracy: 0.9837
Epoch 65/85
60000/60000 [==============================] - 6s 107us/step - loss: 0.
0035 - accuracy: 0.9992 - val_loss: 0.1002 - val_accuracy: 0.9837
Epoch 66/85
60000/60000 [==============================] - 7s 111us/step - loss: 0.
0021 - accuracy: 0.9994 - val_loss: 0.1065 - val_accuracy: 0.9836
Epoch 67/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0051 - accuracy: 0.9988 - val_loss: 0.0998 - val_accuracy: 0.9838
Epoch 68/85
60000/60000 [==============================] - 7s 116us/step - loss: 0.
0013 - accuracy: 0.9996 - val_loss: 0.1154 - val_accuracy: 0.9840
Epoch 69/85
60000/60000 [==============================] - 6s 108us/step - loss: 0.
0036 - accuracy: 0.9992 - val_loss: 0.1117 - val_accuracy: 0.9813
Epoch 70/85
60000/60000 [==============================] - 7s 114us/step - loss: 0.
0018 - accuracy: 0.9995 - val_loss: 0.1255 - val_accuracy: 0.9825
Epoch 71/85
60000/60000 [==============================] - 7s 118us/step - loss: 0.
0042 - accuracy: 0.9990 - val_loss: 0.1347 - val_accuracy: 0.9800
```

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```
Epoch 72/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0046 - accuracy: 0.9990 - val_loss: 0.1207 - val_accuracy: 0.9840
Epoch 73/85
60000/60000 [==============================] - 7s 110us/step - loss: 0.
0034 - accuracy: 0.9991 - val_loss: 0.1167 - val_accuracy: 0.9822
Epoch 74/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
0039 - accuracy: 0.9991 - val_loss: 0.1135 - val_accuracy: 0.9805
Epoch 75/85
60000/60000 [==============================] - 7s 115us/step - loss: 0.
0025 - accuracy: 0.9991 - val_loss: 0.1014 - val_accuracy: 0.9838
Epoch 76/85
60000/60000 [==============================] - 7s 112us/step - loss: 6.
3771e-04 - accuracy: 0.9998 - val_loss: 0.1033 - val_accuracy: 0.9829
Epoch 77/85
60000/60000 [==============================] - 7s 113us/step - loss: 0.
0035 - accuracy: 0.9992 - val_loss: 0.1224 - val_accuracy: 0.9830
Epoch 78/85
60000/60000 [==============================] - 7s 112us/step - loss: 0.
0062 - accuracy: 0.9985 - val_loss: 0.1082 - val_accuracy: 0.9833
Epoch 79/85
60000/60000 [==============================] - 7s 109us/step - loss: 0.
0049 - accuracy: 0.9987 - val_loss: 0.1164 - val_accuracy: 0.9849
Epoch 80/85
60000/60000 [==============================] - 7s 114us/step - loss: 0.
0016 - accuracy: 0.9997 - val_loss: 0.1060 - val_accuracy: 0.9847
Epoch 81/85
60000/60000 [==============================] - 7s 111us/step - loss: 7.
8858e-05 - accuracy: 1.0000 - val_loss: 0.1134 - val_accuracy: 0.9853
Epoch 82/85
60000/60000 [==============================] - 7s 110us/step - loss: 1.
1759e-05 - accuracy: 1.0000 - val_loss: 0.1163 - val_accuracy: 0.9855
Epoch 83/85
60000/60000 [==============================] - 7s 117us/step - loss: 6.
7827e-06 - accuracy: 1.0000 - val_loss: 0.1191 - val_accuracy: 0.9856
Epoch 84/85
60000/60000 [==============================] - 7s 115us/step - loss: 4.
4719e-06 - accuracy: 1.0000 - val_loss: 0.1216 - val_accuracy: 0.9856
```

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```
Epoch 85/85
60000/60000 [==============================] - 7s 114us/step - loss: 3.
0914e-06 - accuracy: 1.0000 - val_loss: 0.1241 - val_accuracy: 0.9854
```

3.1.1.3 Number of Epochs vs Train Loss & Validation Loss

In [27]:

```
warnings.filterwarnings("ignore")

A6M1_score = arch6_model1.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A6M1_score[0])
print('Test accuracy:', A6M1_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in history.history we will have a list of length equal t
o number of epochs

vy = A6M1_history.history['val_loss']
ty = A6M1_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.12406139864550833
Test accuracy: 0.9854000210762024
```

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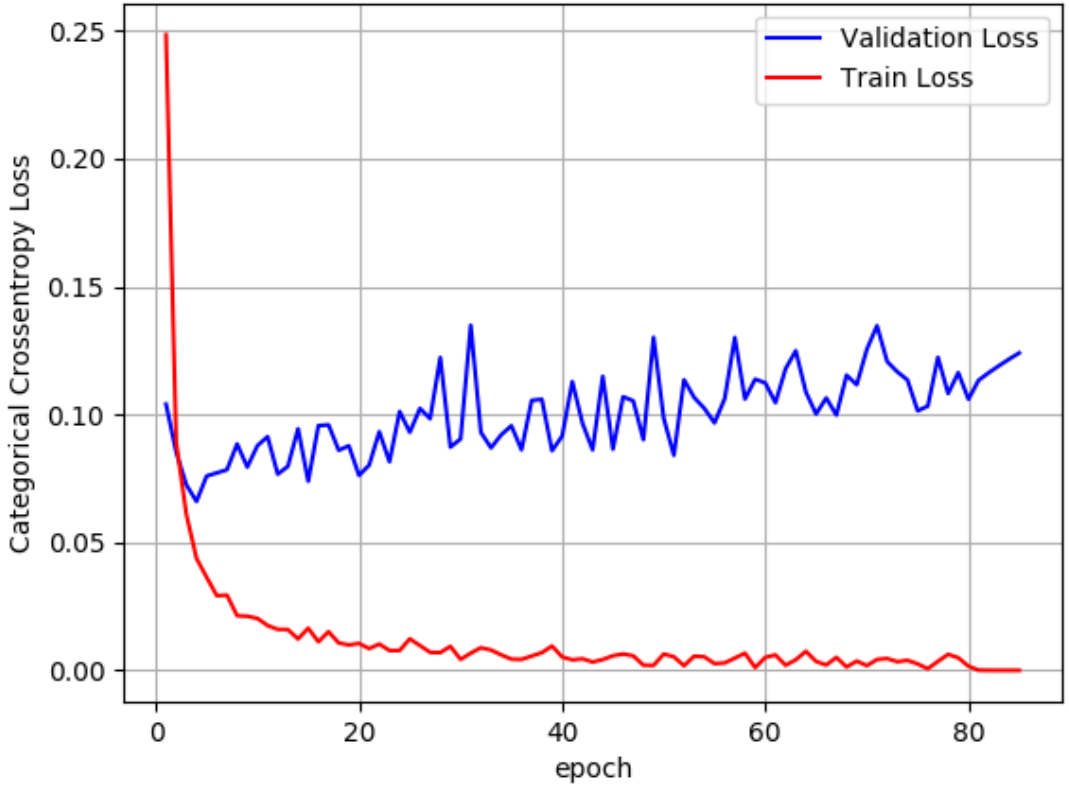
```
Test accuracy: 0.9854000210702024
```



3.1.1.4 Violin Plots for Hidden Layers in the Models Trained

In [30]:
```
w_after = arch6_model1.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
h3_w = w_after[4].flatten().reshape(-1,1)
h4_w = w_after[6].flatten().reshape(-1,1)
```

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```
h5_w = w_after[8].flatten().reshape(-1,1)
out_w = w_after[10].flatten().reshape(-1,1)

fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 6, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL1')

plt.subplot(1, 6, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL2 ')

plt.subplot(1, 6, 3)
ax = sns.violinplot(y=h3_w, color='g')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL3 ')

plt.subplot(1, 6, 4)
ax = sns.violinplot(y=h4_w, color='m')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL4 ')

plt.subplot(1, 6, 5)
ax = sns.violinplot(y=h5_w, color='c')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL5 ')

plt.subplot(1, 6, 6)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('Out')
plt.show()
```

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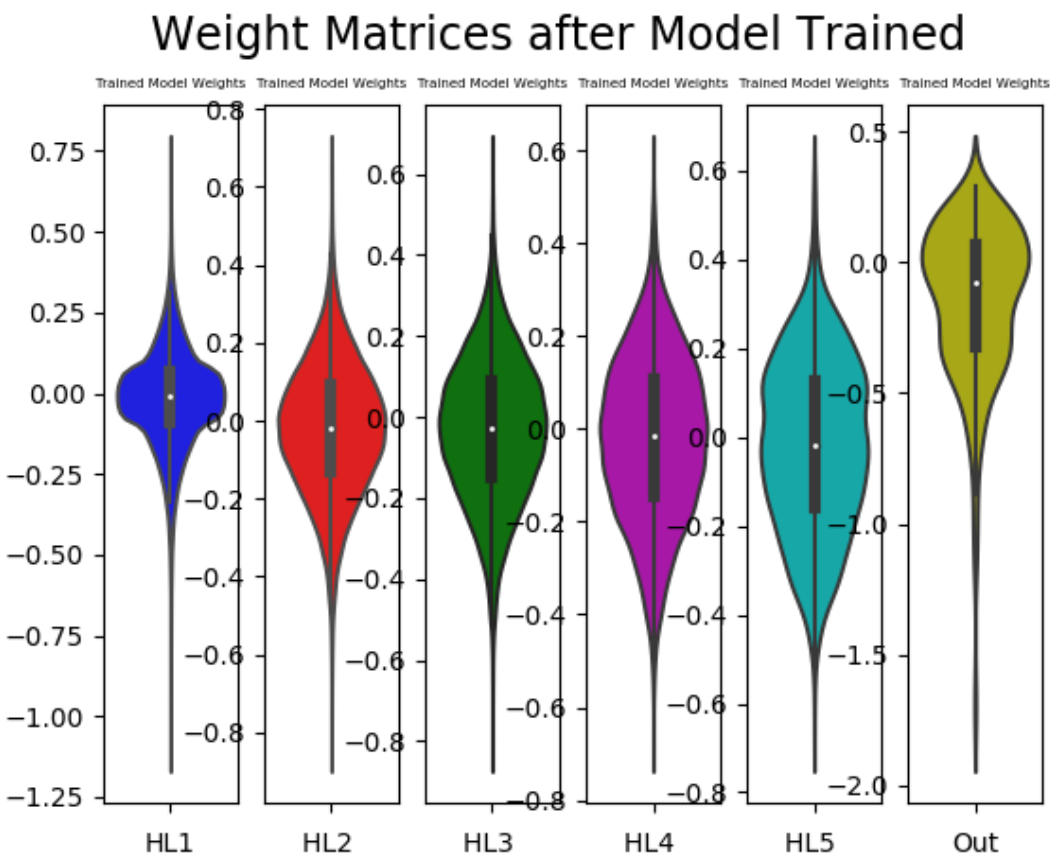

3.1.2 Model 2 : MLP + BatchNormalization + Adam Optimizer

3.1.2.1 Constructing the Neural Network

In [32]:
```
arch6_model2 = Sequential()

arch6_model2.add(Dense(512, activation='relu', input_shape=(input_dim
,),\
                       kernel_initializer=RandomUniform(minval= -0.087,
```

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```
maxval = 0.087, seed=None)))
arch6_model2.add(BatchNormalization())

arch6_model2.add(Dense(256, activation='relu', \
                       kernel_initializer=RandomUniform(minval= -0.108,
 maxval=0.108, seed=None)) )
arch6_model2.add(BatchNormalization())

arch6_model2.add(Dense(128, activation='relu', \
                       kernel_initializer=RandomUniform(minval= -0.153,
 maxval=0.153, seed=None)) )
arch6_model2.add(BatchNormalization())

arch6_model2.add(Dense(64, activation='relu', \
                       kernel_initializer=RandomUniform(minval= -0.216,
 maxval=0.216, seed=None)) )
arch6_model2.add(BatchNormalization())

arch6_model2.add(Dense(32, activation='relu', \
                       kernel_initializer=RandomUniform(minval= -0.306,
 maxval=0.306, seed=None)) )
arch6_model2.add(BatchNormalization())

arch6_model2.add(Dense(output_dim, activation='softmax'))
arch6_model2.summary()
```

```
Model: "sequential_6"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_27 (Dense)             (None, 512)               401920
_________________________________________________________________
batch_normalization_12 (Batc (None, 512)               2048
_________________________________________________________________
dense_28 (Dense)             (None, 256)               131328
_________________________________________________________________
batch_normalization_13 (Batc (None, 256)               1024
_________________________________________________________________
dense_29 (Dense)             (None, 128)               32896
_________________________________________________________________
```

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```
batch_normalization_14 (Batc (None, 128)               512
_________________________________________________________________
dense_30 (Dense)             (None, 64)                8256
_________________________________________________________________
batch_normalization_15 (Batc (None, 64)                256
_________________________________________________________________
dense_31 (Dense)             (None, 32)                2080
_________________________________________________________________
batch_normalization_16 (Batc (None, 32)                128
_________________________________________________________________
dense_32 (Dense)             (None, 10)                330
=================================================================
Total params: 580,778
Trainable params: 578,794
Non-trainable params: 1,984
_________________________________________________________________
```

3.1.2.2 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [33]:
```
arch6_model2.compile(optimizer='adam', loss='categorical_crossentropy',
 metrics=['accuracy'])

A6M2_history = arch6_model2.fit(X_train, Y_train, batch_size=batch_size
, epochs=nb_epoch, verbose=1, \
                              validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 11s 187us/step - loss:
0.2625 - accuracy: 0.9283 - val_loss: 0.1095 - val_accuracy: 0.9661
Epoch 2/85
60000/60000 [==============================] - 10s 168us/step - loss:
0.0931 - accuracy: 0.9720 - val_loss: 0.0864 - val_accuracy: 0.9734
Epoch 3/85
60000/60000 [==============================] - 10s 172us/step - loss:
0.0664 - accuracy: 0.9794 - val_loss: 0.0927 - val_accuracy: 0.9714
Epoch 4/85
60000/60000 [==============================] - 8s 140us/step - loss: 0.
```

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```
0478 - accuracy: 0.9849 - val_loss: 0.1013 - val_accuracy: 0.9705
Epoch 5/85
60000/60000 [==============================] - 9s 145us/step - loss: 0.
0436 - accuracy: 0.9862 - val_loss: 0.0940 - val_accuracy: 0.9732
Epoch 6/85
60000/60000 [==============================] - 9s 143us/step - loss: 0.
0376 - accuracy: 0.9879 - val_loss: 0.0661 - val_accuracy: 0.9800
Epoch 7/85
60000/60000 [==============================] - 9s 143us/step - loss: 0.
0326 - accuracy: 0.9892 - val_loss: 0.0854 - val_accuracy: 0.9742
Epoch 8/85
60000/60000 [==============================] - 8s 141us/step - loss: 0.
0274 - accuracy: 0.9909 - val_loss: 0.0737 - val_accuracy: 0.9788
Epoch 9/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0258 - accuracy: 0.9917 - val_loss: 0.0734 - val_accuracy: 0.9790
Epoch 10/85
60000/60000 [==============================] - 12s 195us/step - loss:
0.0237 - accuracy: 0.9923 - val_loss: 0.0688 - val_accuracy: 0.9813
Epoch 11/85
60000/60000 [==============================] - 10s 166us/step - loss:
0.0195 - accuracy: 0.9934 - val_loss: 0.0812 - val_accuracy: 0.9784
Epoch 12/85
60000/60000 [==============================] - 10s 159us/step - loss:
0.0176 - accuracy: 0.9940 - val_loss: 0.0757 - val_accuracy: 0.9795
Epoch 13/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0183 - accuracy: 0.9942 - val_loss: 0.0753 - val_accuracy: 0.9817
Epoch 14/85
60000/60000 [==============================] - 9s 158us/step - loss: 0.
0175 - accuracy: 0.9941 - val_loss: 0.0821 - val_accuracy: 0.9799
Epoch 15/85
60000/60000 [==============================] - 9s 150us/step - loss: 0.
0159 - accuracy: 0.9946 - val_loss: 0.0812 - val_accuracy: 0.9789
Epoch 16/85
60000/60000 [==============================] - 9s 157us/step - loss: 0.
0164 - accuracy: 0.9947 - val_loss: 0.0862 - val_accuracy: 0.9793
Epoch 17/85
60000/60000 [==============================] - 10s 160us/step - loss:
```

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```
0.0158 - accuracy: 0.9944 - val_loss: 0.0722 - val_accuracy: 0.9813
Epoch 18/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0113 - accuracy: 0.9962 - val_loss: 0.0698 - val_accuracy: 0.9821
Epoch 19/85
60000/60000 [==============================] - 9s 157us/step - loss: 0.
0133 - accuracy: 0.9954 - val_loss: 0.0881 - val_accuracy: 0.9772
Epoch 20/85
60000/60000 [==============================] - 10s 162us/step - loss:
0.0127 - accuracy: 0.9958 - val_loss: 0.0822 - val_accuracy: 0.9797
Epoch 21/85
60000/60000 [==============================] - 10s 160us/step - loss:
0.0122 - accuracy: 0.9959 - val_loss: 0.0748 - val_accuracy: 0.9818
Epoch 22/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0117 - accuracy: 0.9962 - val_loss: 0.0854 - val_accuracy: 0.9811
Epoch 23/85
60000/60000 [==============================] - 10s 161us/step - loss:
0.0081 - accuracy: 0.9976 - val_loss: 0.0850 - val_accuracy: 0.9799
Epoch 24/85
60000/60000 [==============================] - 10s 160us/step - loss:
0.0099 - accuracy: 0.9967 - val_loss: 0.0944 - val_accuracy: 0.9781
Epoch 25/85
60000/60000 [==============================] - 9s 153us/step - loss: 0.
0116 - accuracy: 0.9966 - val_loss: 0.0904 - val_accuracy: 0.9780
Epoch 26/85
60000/60000 [==============================] - 9s 154us/step - loss: 0.
0098 - accuracy: 0.9968 - val_loss: 0.0904 - val_accuracy: 0.9790
Epoch 27/85
60000/60000 [==============================] - 10s 160us/step - loss:
0.0090 - accuracy: 0.9972 - val_loss: 0.0882 - val_accuracy: 0.9815
Epoch 28/85
60000/60000 [==============================] - 9s 158us/step - loss: 0.
0085 - accuracy: 0.9975 - val_loss: 0.0906 - val_accuracy: 0.9801
Epoch 29/85
60000/60000 [==============================] - 9s 158us/step - loss: 0.
0094 - accuracy: 0.9967 - val_loss: 0.0801 - val_accuracy: 0.9808
Epoch 30/85
60000/60000 [==============================] - 9s 156us/step - loss: 0.
```

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```
0071 - accuracy: 0.9977 - val_loss: 0.0775 - val_accuracy: 0.9830
Epoch 31/85
60000/60000 [==============================] - 10s 163us/step - loss:
0.0071 - accuracy: 0.9978 - val_loss: 0.0832 - val_accuracy: 0.9824
Epoch 32/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0056 - accuracy: 0.9983 - val_loss: 0.0844 - val_accuracy: 0.9825
Epoch 33/85
60000/60000 [==============================] - 10s 163us/step - loss:
0.0091 - accuracy: 0.9970 - val_loss: 0.1027 - val_accuracy: 0.9783
Epoch 34/85
60000/60000 [==============================] - 9s 153us/step - loss: 0.
0105 - accuracy: 0.9968 - val_loss: 0.0825 - val_accuracy: 0.9811
Epoch 35/85
60000/60000 [==============================] - 9s 156us/step - loss: 0.
0067 - accuracy: 0.9978 - val_loss: 0.0844 - val_accuracy: 0.9815
Epoch 36/85
60000/60000 [==============================] - 9s 149us/step - loss: 0.
0058 - accuracy: 0.9982 - val_loss: 0.0829 - val_accuracy: 0.9819
Epoch 37/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0061 - accuracy: 0.9980 - val_loss: 0.0770 - val_accuracy: 0.9829
Epoch 38/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0066 - accuracy: 0.9978 - val_loss: 0.0737 - val_accuracy: 0.9828
Epoch 39/85
60000/60000 [==============================] - 9s 149us/step - loss: 0.
0064 - accuracy: 0.9977 - val_loss: 0.0824 - val_accuracy: 0.9818
Epoch 40/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0053 - accuracy: 0.9983 - val_loss: 0.0777 - val_accuracy: 0.9818
Epoch 41/85
60000/60000 [==============================] - 9s 149us/step - loss: 0.
0050 - accuracy: 0.9983 - val_loss: 0.0775 - val_accuracy: 0.9822
Epoch 42/85
60000/60000 [==============================] - 9s 147us/step - loss: 0.
0053 - accuracy: 0.9985 - val_loss: 0.0690 - val_accuracy: 0.9850
Epoch 43/85
60000/60000 [==============================] - 9s 148us/step - loss: 0.
```

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```
0056 - accuracy: 0.9980 - val_loss: 0.0804 - val_accuracy: 0.9824
Epoch 44/85
60000/60000 [==============================] - 10s 159us/step - loss:
0.0063 - accuracy: 0.9979 - val_loss: 0.0801 - val_accuracy: 0.9831
Epoch 45/85
60000/60000 [==============================] - 10s 162us/step - loss:
0.0065 - accuracy: 0.9979 - val_loss: 0.0754 - val_accuracy: 0.9832
Epoch 46/85
60000/60000 [==============================] - 10s 159us/step - loss:
0.0050 - accuracy: 0.9983 - val_loss: 0.0717 - val_accuracy: 0.9835
Epoch 47/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0044 - accuracy: 0.9987 - val_loss: 0.0749 - val_accuracy: 0.9828
Epoch 48/85
60000/60000 [==============================] - 9s 157us/step - loss: 0.
0048 - accuracy: 0.9984 - val_loss: 0.0883 - val_accuracy: 0.9823
Epoch 49/85
60000/60000 [==============================] - 9s 156us/step - loss: 0.
0055 - accuracy: 0.9982 - val_loss: 0.0803 - val_accuracy: 0.9822
Epoch 50/85
60000/60000 [==============================] - 9s 157us/step - loss: 0.
0048 - accuracy: 0.9984 - val_loss: 0.0837 - val_accuracy: 0.9822
Epoch 51/85
60000/60000 [==============================] - 9s 154us/step - loss: 0.
0057 - accuracy: 0.9981 - val_loss: 0.0844 - val_accuracy: 0.9810
Epoch 52/85
60000/60000 [==============================] - 10s 162us/step - loss:
0.0055 - accuracy: 0.9983 - val_loss: 0.0769 - val_accuracy: 0.9838
Epoch 53/85
60000/60000 [==============================] - 9s 158us/step - loss: 0.
0050 - accuracy: 0.9985 - val_loss: 0.0777 - val_accuracy: 0.9840
Epoch 54/85
60000/60000 [==============================] - 9s 156us/step - loss: 0.
0034 - accuracy: 0.9989 - val_loss: 0.0914 - val_accuracy: 0.9807
Epoch 55/85
60000/60000 [==============================] - 11s 186us/step - loss:
0.0046 - accuracy: 0.9985 - val_loss: 0.0886 - val_accuracy: 0.9802
Epoch 56/85
60000/60000 [==============================] - 9s 158us/step - loss: 0.
```

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```
0046 - accuracy: 0.9984 - val_loss: 0.0860 - val_accuracy: 0.9824
Epoch 57/85
60000/60000 [==============================] - 10s 160us/step - loss:
0.0051 - accuracy: 0.9984 - val_loss: 0.0855 - val_accuracy: 0.9820
Epoch 58/85
60000/60000 [==============================] - 9s 157us/step - loss: 0.
0036 - accuracy: 0.9990 - val_loss: 0.0850 - val_accuracy: 0.9818
Epoch 59/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0035 - accuracy: 0.9989 - val_loss: 0.0813 - val_accuracy: 0.9839
Epoch 60/85
60000/60000 [==============================] - 9s 156us/step - loss: 0.
0040 - accuracy: 0.9988 - val_loss: 0.0731 - val_accuracy: 0.9843
Epoch 61/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0033 - accuracy: 0.9989 - val_loss: 0.0698 - val_accuracy: 0.9860
Epoch 62/85
60000/60000 [==============================] - 10s 158us/step - loss:
0.0032 - accuracy: 0.9989 - val_loss: 0.0780 - val_accuracy: 0.9834
Epoch 63/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0049 - accuracy: 0.9985 - val_loss: 0.0840 - val_accuracy: 0.9826
Epoch 64/85
60000/60000 [==============================] - 9s 156us/step - loss: 0.
0042 - accuracy: 0.9986 - val_loss: 0.0816 - val_accuracy: 0.9818
Epoch 65/85
60000/60000 [==============================] - 10s 160us/step - loss:
0.0037 - accuracy: 0.9988 - val_loss: 0.0795 - val_accuracy: 0.9845
Epoch 66/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0027 - accuracy: 0.9992 - val_loss: 0.0847 - val_accuracy: 0.9825
Epoch 67/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0050 - accuracy: 0.9984 - val_loss: 0.0902 - val_accuracy: 0.9805
Epoch 68/85
60000/60000 [==============================] - 9s 157us/step - loss: 0.
0032 - accuracy: 0.9990 - val_loss: 0.0784 - val_accuracy: 0.9839
Epoch 69/85
60000/60000 [==============================] - 9s 156us/step - loss: 0.
```

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```
0025 - accuracy: 0.9994 - val_loss: 0.0721 - val_accuracy: 0.9848
Epoch 70/85
60000/60000 [==============================] - 10s 161us/step - loss:
0.0029 - accuracy: 0.9990 - val_loss: 0.0802 - val_accuracy: 0.9830
Epoch 71/85
60000/60000 [==============================] - 9s 152us/step - loss: 0.
0025 - accuracy: 0.9991 - val_loss: 0.0832 - val_accuracy: 0.9827
Epoch 72/85
60000/60000 [==============================] - 9s 158us/step - loss: 0.
0035 - accuracy: 0.9990 - val_loss: 0.0928 - val_accuracy: 0.9820
Epoch 73/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0037 - accuracy: 0.9987 - val_loss: 0.0963 - val_accuracy: 0.9816
Epoch 74/85
60000/60000 [==============================] - 9s 153us/step - loss: 0.
0026 - accuracy: 0.9992 - val_loss: 0.0777 - val_accuracy: 0.9852
Epoch 75/85
60000/60000 [==============================] - 9s 153us/step - loss: 0.
0029 - accuracy: 0.9991 - val_loss: 0.0872 - val_accuracy: 0.9828
Epoch 76/85
60000/60000 [==============================] - 9s 158us/step - loss: 0.
0040 - accuracy: 0.9987 - val_loss: 0.0893 - val_accuracy: 0.9824
Epoch 77/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0022 - accuracy: 0.9993 - val_loss: 0.0925 - val_accuracy: 0.9832
Epoch 78/85
60000/60000 [==============================] - 11s 175us/step - loss:
0.0027 - accuracy: 0.9992 - val_loss: 0.0894 - val_accuracy: 0.9839
Epoch 79/85
60000/60000 [==============================] - 12s 196us/step - loss:
0.0026 - accuracy: 0.9992 - val_loss: 0.0887 - val_accuracy: 0.9833
Epoch 80/85
60000/60000 [==============================] - 11s 176us/step - loss:
0.0033 - accuracy: 0.9990 - val_loss: 0.0999 - val_accuracy: 0.9811
Epoch 81/85
60000/60000 [==============================] - 11s 181us/step - loss:
0.0032 - accuracy: 0.9992 - val_loss: 0.0899 - val_accuracy: 0.9823
Epoch 82/85
60000/60000 [==============================] - 10s 173us/step - loss:
```

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```
0.0028 - accuracy: 0.9992 - val_loss: 0.0870 - val_accuracy: 0.9817
Epoch 83/85
60000/60000 [==============================] - 11s 180us/step - loss:
0.0020 - accuracy: 0.9994 - val_loss: 0.0837 - val_accuracy: 0.9832
Epoch 84/85
60000/60000 [==============================] - 11s 178us/step - loss:
0.0032 - accuracy: 0.9990 - val_loss: 0.0850 - val_accuracy: 0.9824
Epoch 85/85
60000/60000 [==============================] - 11s 180us/step - loss:
0.0030 - accuracy: 0.9991 - val_loss: 0.0873 - val_accuracy: 0.9837
```

3.1.2.3 Number of Epochs vs Train Loss & Validation Loss

In [34]:

```
warnings.filterwarnings("ignore")

A6M2_score = arch6_model2.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A6M2_score[0])
print('Test accuracy:', A6M2_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in history.history we will have a list of length equal t
```

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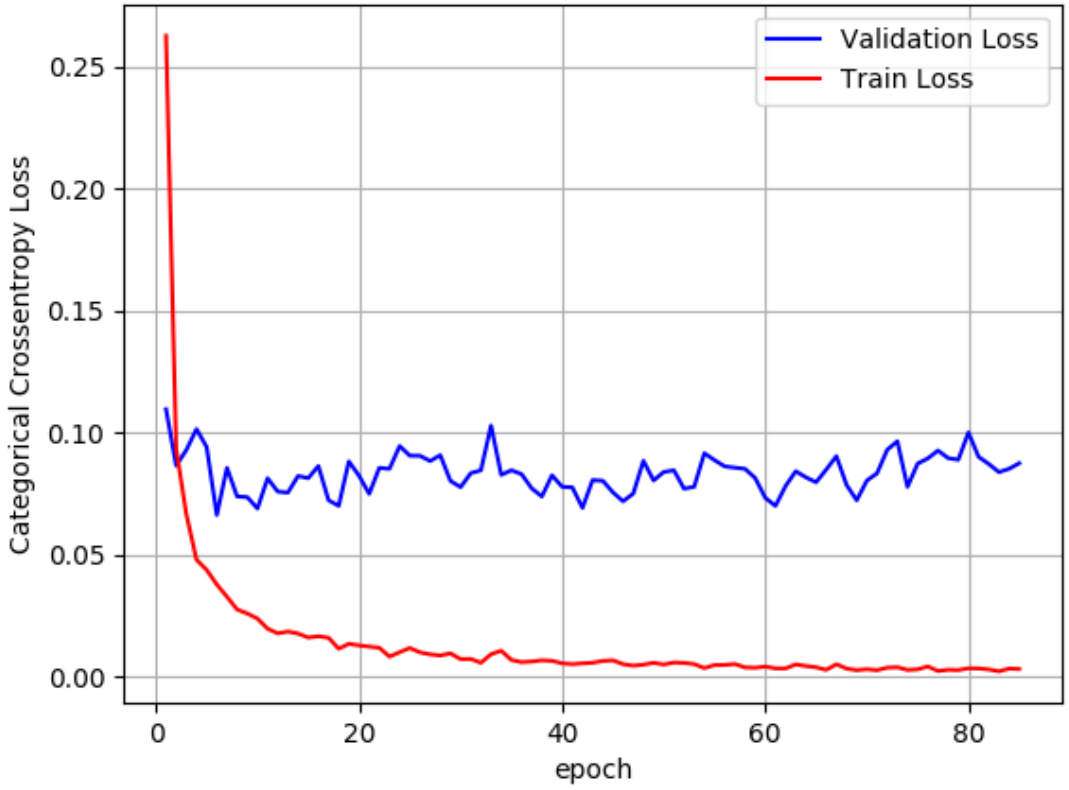
```
o number of epochs

vy = A6M2_history.history['val_loss']
ty = A6M2_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.0873116682912103
Test accuracy: 0.9836999773979187
```



3.1.2.4 Violin Plots for Hidden Layers in the Models Trained

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In [35]:
```
w_after = arch6_model2.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
h3_w = w_after[4].flatten().reshape(-1,1)
h4_w = w_after[6].flatten().reshape(-1,1)
h5_w = w_after[8].flatten().reshape(-1,1)
out_w = w_after[10].flatten().reshape(-1,1)

fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 6, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL1')

plt.subplot(1, 6, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL2 ')

plt.subplot(1, 6, 3)
ax = sns.violinplot(y=h3_w, color='g')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL3 ')

plt.subplot(1, 6, 4)
ax = sns.violinplot(y=h4_w, color='m')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL4 ')

plt.subplot(1, 6, 5)
ax = sns.violinplot(y=h5_w, color='c')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL5 ')

plt.subplot(1, 6, 6)
ax = sns.violinplot(y=out_w,color='y')
```

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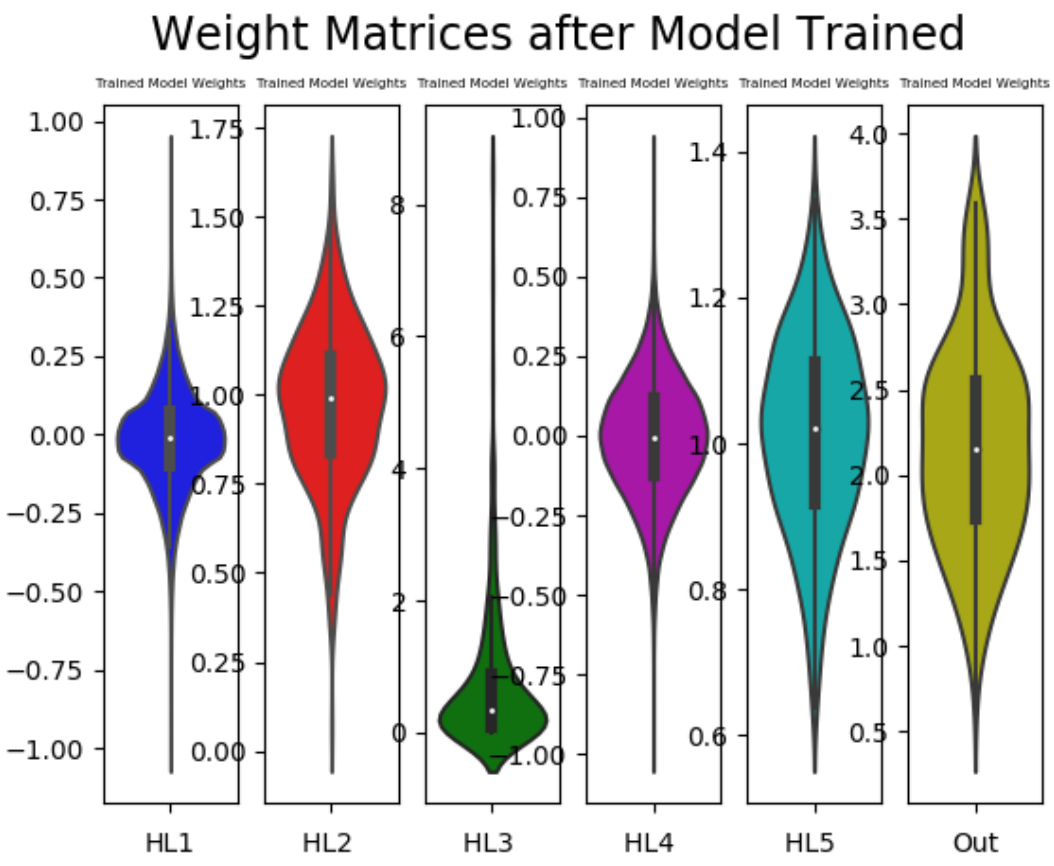
```
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('Out')
plt.show()
```



3.1.3 Model 3 : MLP + BatchNormalization + Dropout + Adam Optimizer

3.1.3.1 Hyperparameter Tuning for Dropout

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In [38]:
```
def A6M3_best_hyperparameters(dropout):
    arch6_model3 = Sequential()

    arch6_model3.add(Dense(512, activation='relu', input_shape=(input_d
im,),\
                       kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))
    arch6_model3.add(BatchNormalization())
    arch6_model3.add(Dropout(dropout))

    arch6_model3.add(Dense(256, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.108,
 maxval=0.108, seed=None)) )
    arch6_model3.add(BatchNormalization())
    arch6_model3.add(Dropout(dropout))

    arch6_model3.add(Dense(128, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.153,
 maxval=0.153, seed=None)) )
    arch6_model3.add(BatchNormalization())
    arch6_model3.add(Dropout(dropout))

    arch6_model3.add(Dense(64, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.216,
 maxval=0.216, seed=None)) )
    arch6_model3.add(BatchNormalization())
    arch6_model3.add(Dropout(dropout))

    arch6_model3.add(Dense(32, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.306,
 maxval=0.306, seed=None)) )
    arch6_model3.add(BatchNormalization())
    arch6_model3.add(Dropout(dropout))

    arch6_model3.add(Dense(output_dim, activation='softmax'))

    arch6_model3.compile(optimizer='adam', loss='categorical_crossentro
py', metrics=['accuracy'])
```

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```
    return arch6_model3
```

In [39]:
```
start = datetime.now()

dropout = []

for d in range(1,10):
    dropout.append(d/10)

model = KerasClassifier(build_fn=A6M3_best_hyperparameters, epochs=nb_e
poch, batch_size=batch_size, verbose=0)
param_grid = dict(dropout=dropout)

# if you are using CPU
# grid = GridSearchCV(estimator=model, param_grid=param_grid, n_jobs=-
1)
# if you are using GPU dont use the n_jobs parameter

grid_5 = GridSearchCV(estimator=model, param_grid=param_grid,cv=3,n_job
s=-1)
grid_result5 = grid_5.fit(X_train, Y_train)

print('Time taken :', datetime.now() - start)
```

```
Time taken : 2:48:16.857742
```

In [40]:
```
print("Best: %f using %s" % (grid_result5.best_score_, grid_result5.bes
t_params_))
means = grid_result5.cv_results_['mean_test_score']
stds = grid_result5.cv_results_['std_test_score']
params = grid_result5.cv_results_['params']

for mean, stdev, param in zip(means, stds, params):
    print("%f (%f) with: %r" % (mean, stdev, param))
```

```
Best: 0.982650 using {'dropout': 0.3}
0.981700 (0.001657) with: {'dropout': 0.1}
0.982567 (0.000674) with: {'dropout': 0.2}
0.982650 (0.000389) with: {'dropout': 0.3}
```

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```
0.982650 (0.000389) with: {'dropout': 0.3}
0.981967 (0.001426) with: {'dropout': 0.4}
0.981850 (0.001346) with: {'dropout': 0.5}
0.979950 (0.000991) with: {'dropout': 0.6}
0.975450 (0.001258) with: {'dropout': 0.7}
0.850083 (0.075527) with: {'dropout': 0.8}
0.444717 (0.055117) with: {'dropout': 0.9}
```

3.1.3.2 Constructing the Neural Network

In [41]:
```
arch6_model3 = Sequential()

arch6_model3.add(Dense(512, activation='relu', input_shape=(input_dim
,),\
                       kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))
arch6_model3.add(BatchNormalization())
arch6_model3.add(Dropout(0.3))

arch6_model3.add(Dense(256, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.108,
 maxval=0.108, seed=None)) )
arch6_model3.add(BatchNormalization())
arch6_model3.add(Dropout(0.3))

arch6_model3.add(Dense(128, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.153,
 maxval=0.153, seed=None)) )
arch6_model3.add(BatchNormalization())
arch6_model3.add(Dropout(0.3))

arch6_model3.add(Dense(64, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.216,
 maxval=0.216, seed=None)) )
arch6_model3.add(BatchNormalization())
arch6_model3.add(Dropout(0.3))

arch6_model3.add(Dense(32, activation='relu', \
```

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```
                        kernel_initializer=RandomUniform(minval= -0.306,
 maxval=0.306, seed=None)) )
arch6_model3.add(BatchNormalization())
arch6_model3.add(Dropout(0.3))

arch6_model3.add(Dense(output_dim, activation='softmax'))
arch6_model3.summary()
```

```
Model: "sequential_8"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_39 (Dense)             (None, 512)               401920
_________________________________________________________________
batch_normalization_22 (Batc (None, 512)               2048
_________________________________________________________________
dropout_12 (Dropout)         (None, 512)               0
_________________________________________________________________
dense_40 (Dense)             (None, 256)               131328
_________________________________________________________________
batch_normalization_23 (Batc (None, 256)               1024
_________________________________________________________________
dropout_13 (Dropout)         (None, 256)               0
_________________________________________________________________
dense_41 (Dense)             (None, 128)               32896
_________________________________________________________________
batch_normalization_24 (Batc (None, 128)               512
_________________________________________________________________
dropout_14 (Dropout)         (None, 128)               0
_________________________________________________________________
dense_42 (Dense)             (None, 64)                8256
_________________________________________________________________
batch_normalization_25 (Batc (None, 64)                256
_________________________________________________________________
dropout_15 (Dropout)         (None, 64)                0
_________________________________________________________________
dense_43 (Dense)             (None, 32)                2080
_________________________________________________________________
batch_normalization_26 (Batc (None, 32)                128
_________________________________________________________________
```

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```
dropout_16 (Dropout)         (None, 32)                0
_________________________________________________________________
dense_44 (Dense)             (None, 10)                330
=================================================================
Total params: 580,778
Trainable params: 578,794
Non-trainable params: 1,984
_________________________________________________________________
```

3.1.3.3 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [42]:
```
arch6_model3.compile(optimizer='adam', loss='categorical_crossentropy',
 metrics=['accuracy'])

A6M3_history = arch6_model3.fit(X_train, Y_train, batch_size=batch_size
, epochs=nb_epoch, verbose=1, \
                              validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 11s 191us/step - loss:
0.6732 - accuracy: 0.8017 - val_loss: 0.1684 - val_accuracy: 0.9495
Epoch 2/85
60000/60000 [==============================] - 10s 162us/step - loss:
0.2437 - accuracy: 0.9358 - val_loss: 0.1169 - val_accuracy: 0.9662
Epoch 3/85
60000/60000 [==============================] - 10s 171us/step - loss:
0.1910 - accuracy: 0.9504 - val_loss: 0.0970 - val_accuracy: 0.9727
Epoch 4/85
60000/60000 [==============================] - 10s 163us/step - loss:
0.1544 - accuracy: 0.9594 - val_loss: 0.1033 - val_accuracy: 0.9722
Epoch 5/85
60000/60000 [==============================] - 10s 163us/step - loss:
0.1363 - accuracy: 0.9645 - val_loss: 0.0905 - val_accuracy: 0.9745
Epoch 6/85
60000/60000 [==============================] - 10s 163us/step - loss:
0.1218 - accuracy: 0.9683 - val_loss: 0.0844 - val_accuracy: 0.9773
Epoch 7/85
```

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```
60000/60000 [==============================] - 10s 159us/step - loss:
0.1159 - accuracy: 0.9692 - val_loss: 0.0865 - val_accuracy: 0.9773
Epoch 8/85
60000/60000 [==============================] - 10s 168us/step - loss:
0.1052 - accuracy: 0.9723 - val_loss: 0.0803 - val_accuracy: 0.9800
Epoch 9/85
60000/60000 [==============================] - 10s 165us/step - loss:
0.0950 - accuracy: 0.9744 - val_loss: 0.0753 - val_accuracy: 0.9804
Epoch 10/85
60000/60000 [==============================] - 11s 180us/step - loss:
0.0908 - accuracy: 0.9762 - val_loss: 0.0744 - val_accuracy: 0.9807
Epoch 11/85
60000/60000 [==============================] - 11s 175us/step - loss:
0.0811 - accuracy: 0.9783 - val_loss: 0.0684 - val_accuracy: 0.9821
Epoch 12/85
60000/60000 [==============================] - 12s 201us/step - loss:
0.0805 - accuracy: 0.9787 - val_loss: 0.0679 - val_accuracy: 0.9828
Epoch 13/85
60000/60000 [==============================] - 11s 180us/step - loss:
0.0742 - accuracy: 0.9798 - val_loss: 0.0685 - val_accuracy: 0.9825
Epoch 14/85
60000/60000 [==============================] - 10s 160us/step - loss:
0.0708 - accuracy: 0.9809 - val_loss: 0.0610 - val_accuracy: 0.9844
Epoch 15/85
60000/60000 [==============================] - 10s 167us/step - loss:
0.0688 - accuracy: 0.9819 - val_loss: 0.0567 - val_accuracy: 0.9848
Epoch 16/85
60000/60000 [==============================] - 10s 160us/step - loss:
0.0643 - accuracy: 0.9825 - val_loss: 0.0646 - val_accuracy: 0.9836
Epoch 17/85
60000/60000 [==============================] - 10s 164us/step - loss:
0.0642 - accuracy: 0.9829 - val_loss: 0.0642 - val_accuracy: 0.9827
Epoch 18/85
60000/60000 [==============================] - 10s 164us/step - loss:
0.0582 - accuracy: 0.9847 - val_loss: 0.0631 - val_accuracy: 0.9835
Epoch 19/85
60000/60000 [==============================] - 10s 162us/step - loss:
0.0537 - accuracy: 0.9857 - val_loss: 0.0651 - val_accuracy: 0.9838
Epoch 20/85
```

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```
60000/60000 [==============================] - 10s 165us/step - loss:
0.0555 - accuracy: 0.9854 - val_loss: 0.0657 - val_accuracy: 0.9830
Epoch 21/85
60000/60000 [==============================] - 10s 167us/step - loss:
0.0524 - accuracy: 0.9860 - val_loss: 0.0568 - val_accuracy: 0.9856
Epoch 22/85
60000/60000 [==============================] - 10s 164us/step - loss:
0.0527 - accuracy: 0.9858 - val_loss: 0.0602 - val_accuracy: 0.9851
Epoch 23/85
60000/60000 [==============================] - 10s 170us/step - loss:
0.0494 - accuracy: 0.9868 - val_loss: 0.0598 - val_accuracy: 0.9858
Epoch 24/85
60000/60000 [==============================] - 10s 164us/step - loss:
0.0455 - accuracy: 0.9876 - val_loss: 0.0625 - val_accuracy: 0.9839
Epoch 25/85
60000/60000 [==============================] - 10s 170us/step - loss:
0.0429 - accuracy: 0.9883 - val_loss: 0.0637 - val_accuracy: 0.9858
Epoch 26/85
60000/60000 [==============================] - 10s 167us/step - loss:
0.0466 - accuracy: 0.9872 - val_loss: 0.0699 - val_accuracy: 0.9842
Epoch 27/85
60000/60000 [==============================] - 10s 160us/step - loss:
0.0419 - accuracy: 0.9882 - val_loss: 0.0682 - val_accuracy: 0.9843
Epoch 28/85
60000/60000 [==============================] - 10s 167us/step - loss:
0.0393 - accuracy: 0.9894 - val_loss: 0.0657 - val_accuracy: 0.9843
Epoch 29/85
60000/60000 [==============================] - 10s 165us/step - loss:
0.0384 - accuracy: 0.9894 - val_loss: 0.0598 - val_accuracy: 0.9853
Epoch 30/85
60000/60000 [==============================] - 10s 160us/step - loss:
0.0390 - accuracy: 0.9896 - val_loss: 0.0616 - val_accuracy: 0.9854
Epoch 31/85
60000/60000 [==============================] - 10s 167us/step - loss:
0.0373 - accuracy: 0.9897 - val_loss: 0.0660 - val_accuracy: 0.9843
Epoch 32/85
60000/60000 [==============================] - 10s 165us/step - loss:
0.0347 - accuracy: 0.9904 - val_loss: 0.0663 - val_accuracy: 0.9845
Epoch 33/85
```

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```
60000/60000 [==============================] - 10s 160us/step - loss:
0.0355 - accuracy: 0.9903 - val_loss: 0.0603 - val_accuracy: 0.9861
Epoch 34/85
60000/60000 [==============================] - 10s 167us/step - loss:
0.0348 - accuracy: 0.9904 - val_loss: 0.0637 - val_accuracy: 0.9840
Epoch 35/85
60000/60000 [==============================] - 10s 161us/step - loss:
0.0325 - accuracy: 0.9909 - val_loss: 0.0674 - val_accuracy: 0.9843
Epoch 36/85
60000/60000 [==============================] - 11s 176us/step - loss:
0.0311 - accuracy: 0.9915 - val_loss: 0.0634 - val_accuracy: 0.9857
Epoch 37/85
60000/60000 [==============================] - 12s 196us/step - loss:
0.0326 - accuracy: 0.9914 - val_loss: 0.0557 - val_accuracy: 0.9872
Epoch 38/85
60000/60000 [==============================] - 11s 184us/step - loss:
0.0305 - accuracy: 0.9917 - val_loss: 0.0631 - val_accuracy: 0.9871
Epoch 39/85
60000/60000 [==============================] - 11s 183us/step - loss:
0.0296 - accuracy: 0.9920 - val_loss: 0.0622 - val_accuracy: 0.9868
Epoch 40/85
60000/60000 [==============================] - 10s 166us/step - loss:
0.0285 - accuracy: 0.9928 - val_loss: 0.0620 - val_accuracy: 0.9860
Epoch 41/85
60000/60000 [==============================] - 10s 163us/step - loss:
0.0280 - accuracy: 0.9922 - val_loss: 0.0617 - val_accuracy: 0.9856
Epoch 42/85
60000/60000 [==============================] - 10s 167us/step - loss:
0.0284 - accuracy: 0.9921 - val_loss: 0.0621 - val_accuracy: 0.9852
Epoch 43/85
60000/60000 [==============================] - 10s 164us/step - loss:
0.0285 - accuracy: 0.9924 - val_loss: 0.0640 - val_accuracy: 0.9854
Epoch 44/85
60000/60000 [==============================] - 10s 166us/step - loss:
0.0271 - accuracy: 0.9926 - val_loss: 0.0599 - val_accuracy: 0.9873
Epoch 45/85
60000/60000 [==============================] - 10s 166us/step - loss:
0.0284 - accuracy: 0.9920 - val_loss: 0.0608 - val_accuracy: 0.9865
Epoch 46/85
```

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```
60000/60000 [==============================] - 10s 163us/step - loss:
0.0253 - accuracy: 0.9930 - val_loss: 0.0638 - val_accuracy: 0.9860
Epoch 47/85
60000/60000 [==============================] - 10s 171us/step - loss:
0.0211 - accuracy: 0.9940 - val_loss: 0.0636 - val_accuracy: 0.9865
Epoch 48/85
60000/60000 [==============================] - 10s 162us/step - loss:
0.0254 - accuracy: 0.9930 - val_loss: 0.0688 - val_accuracy: 0.9851
Epoch 49/85
60000/60000 [==============================] - 10s 169us/step - loss:
0.0278 - accuracy: 0.9926 - val_loss: 0.0633 - val_accuracy: 0.9861
Epoch 50/85
60000/60000 [==============================] - 10s 167us/step - loss:
0.0264 - accuracy: 0.9927 - val_loss: 0.0592 - val_accuracy: 0.9870
Epoch 51/85
60000/60000 [==============================] - 10s 162us/step - loss:
0.0222 - accuracy: 0.9937 - val_loss: 0.0646 - val_accuracy: 0.9859
Epoch 52/85
60000/60000 [==============================] - 10s 170us/step - loss:
0.0230 - accuracy: 0.9932 - val_loss: 0.0650 - val_accuracy: 0.9858
Epoch 53/85
60000/60000 [==============================] - 10s 165us/step - loss:
0.0245 - accuracy: 0.9933 - val_loss: 0.0674 - val_accuracy: 0.9857
Epoch 54/85
60000/60000 [==============================] - 10s 161us/step - loss:
0.0230 - accuracy: 0.9938 - val_loss: 0.0627 - val_accuracy: 0.9866
Epoch 55/85
60000/60000 [==============================] - 10s 164us/step - loss:
0.0221 - accuracy: 0.9940 - val_loss: 0.0674 - val_accuracy: 0.9858
Epoch 56/85
60000/60000 [==============================] - 10s 159us/step - loss:
0.0223 - accuracy: 0.9935 - val_loss: 0.0650 - val_accuracy: 0.9871
Epoch 57/85
60000/60000 [==============================] - 10s 164us/step - loss:
0.0254 - accuracy: 0.9932 - val_loss: 0.0672 - val_accuracy: 0.9856
Epoch 58/85
60000/60000 [==============================] - 10s 170us/step - loss:
0.0219 - accuracy: 0.9940 - val_loss: 0.0644 - val_accuracy: 0.9867
Epoch 59/85
```

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```
60000/60000 [==============================] - 10s 164us/step - loss:
0.0201 - accuracy: 0.9944 - val_loss: 0.0615 - val_accuracy: 0.9866
Epoch 60/85
60000/60000 [==============================] - 10s 166us/step - loss:
0.0190 - accuracy: 0.9946 - val_loss: 0.0641 - val_accuracy: 0.9864
Epoch 61/85
60000/60000 [==============================] - 10s 168us/step - loss:
0.0200 - accuracy: 0.9946 - val_loss: 0.0665 - val_accuracy: 0.9866
Epoch 62/85
60000/60000 [==============================] - 10s 161us/step - loss:
0.0188 - accuracy: 0.9949 - val_loss: 0.0661 - val_accuracy: 0.9860
Epoch 63/85
60000/60000 [==============================] - 10s 166us/step - loss:
0.0201 - accuracy: 0.9946 - val_loss: 0.0703 - val_accuracy: 0.9856
Epoch 64/85
60000/60000 [==============================] - 10s 170us/step - loss:
0.0199 - accuracy: 0.9946 - val_loss: 0.0674 - val_accuracy: 0.9857
Epoch 65/85
60000/60000 [==============================] - 10s 161us/step - loss:
0.0206 - accuracy: 0.9945 - val_loss: 0.0653 - val_accuracy: 0.9866
Epoch 66/85
60000/60000 [==============================] - 10s 164us/step - loss:
0.0192 - accuracy: 0.9945 - val_loss: 0.0598 - val_accuracy: 0.9872
Epoch 67/85
60000/60000 [==============================] - 10s 163us/step - loss:
0.0179 - accuracy: 0.9951 - val_loss: 0.0658 - val_accuracy: 0.9875
Epoch 68/85
60000/60000 [==============================] - 10s 164us/step - loss:
0.0180 - accuracy: 0.9949 - val_loss: 0.0740 - val_accuracy: 0.9851
Epoch 69/85
60000/60000 [==============================] - 10s 164us/step - loss:
0.0181 - accuracy: 0.9948 - val_loss: 0.0667 - val_accuracy: 0.9864
Epoch 70/85
60000/60000 [==============================] - 10s 168us/step - loss:
0.0173 - accuracy: 0.9954 - val_loss: 0.0643 - val_accuracy: 0.9877
Epoch 71/85
60000/60000 [==============================] - 10s 160us/step - loss:
0.0165 - accuracy: 0.9954 - val_loss: 0.0718 - val_accuracy: 0.9864
Epoch 72/85
```

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```
60000/60000 [==============================] - 9s 153us/step - loss: 0.
0177 - accuracy: 0.9951 - val_loss: 0.0622 - val_accuracy: 0.9875
Epoch 73/85
60000/60000 [==============================] - 9s 149us/step - loss: 0.
0178 - accuracy: 0.9952 - val_loss: 0.0696 - val_accuracy: 0.9856
Epoch 74/85
60000/60000 [==============================] - 9s 151us/step - loss: 0.
0156 - accuracy: 0.9956 - val_loss: 0.0706 - val_accuracy: 0.9862
Epoch 75/85
60000/60000 [==============================] - 10s 165us/step - loss:
0.0183 - accuracy: 0.9950 - val_loss: 0.0622 - val_accuracy: 0.9870
Epoch 76/85
60000/60000 [==============================] - 13s 217us/step - loss:
0.0165 - accuracy: 0.9955 - val_loss: 0.0646 - val_accuracy: 0.9864
Epoch 77/85
60000/60000 [==============================] - 11s 179us/step - loss:
0.0163 - accuracy: 0.9952 - val_loss: 0.0744 - val_accuracy: 0.9869
Epoch 78/85
60000/60000 [==============================] - 10s 163us/step - loss:
0.0170 - accuracy: 0.9950 - val_loss: 0.0729 - val_accuracy: 0.9854
Epoch 79/85
60000/60000 [==============================] - 10s 168us/step - loss:
0.0173 - accuracy: 0.9950 - val_loss: 0.0632 - val_accuracy: 0.9862
Epoch 80/85
60000/60000 [==============================] - 10s 160us/step - loss:
0.0157 - accuracy: 0.9957 - val_loss: 0.0623 - val_accuracy: 0.9872
Epoch 81/85
60000/60000 [==============================] - 10s 165us/step - loss:
0.0150 - accuracy: 0.9957 - val_loss: 0.0644 - val_accuracy: 0.9872
Epoch 82/85
60000/60000 [==============================] - 10s 169us/step - loss:
0.0172 - accuracy: 0.9951 - val_loss: 0.0650 - val_accuracy: 0.9863
Epoch 83/85
60000/60000 [==============================] - 10s 164us/step - loss:
0.0166 - accuracy: 0.9951 - val_loss: 0.0665 - val_accuracy: 0.9868
Epoch 84/85
60000/60000 [==============================] - 10s 167us/step - loss:
0.0146 - accuracy: 0.9960 - val_loss: 0.0654 - val_accuracy: 0.9867
Epoch 85/85
```

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```
60000/60000 [==============================] - 10s 160us/step - loss:
0.0148 - accuracy: 0.9958 - val_loss: 0.0727 - val_accuracy: 0.9871
```

3.1.3.4 Number of Epochs vs Train Loss & Validation Loss

In [43]:
```
warnings.filterwarnings("ignore")

A6M3_score = arch6_model3.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A6M3_score[0])
print('Test accuracy:', A6M3_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in history.history we will have a list of length equal t
o number of epochs

vy = A6M3_history.history['val_loss']
ty = A6M3_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.07269650230827392
Test accuracy: 0.9871000051498413
```

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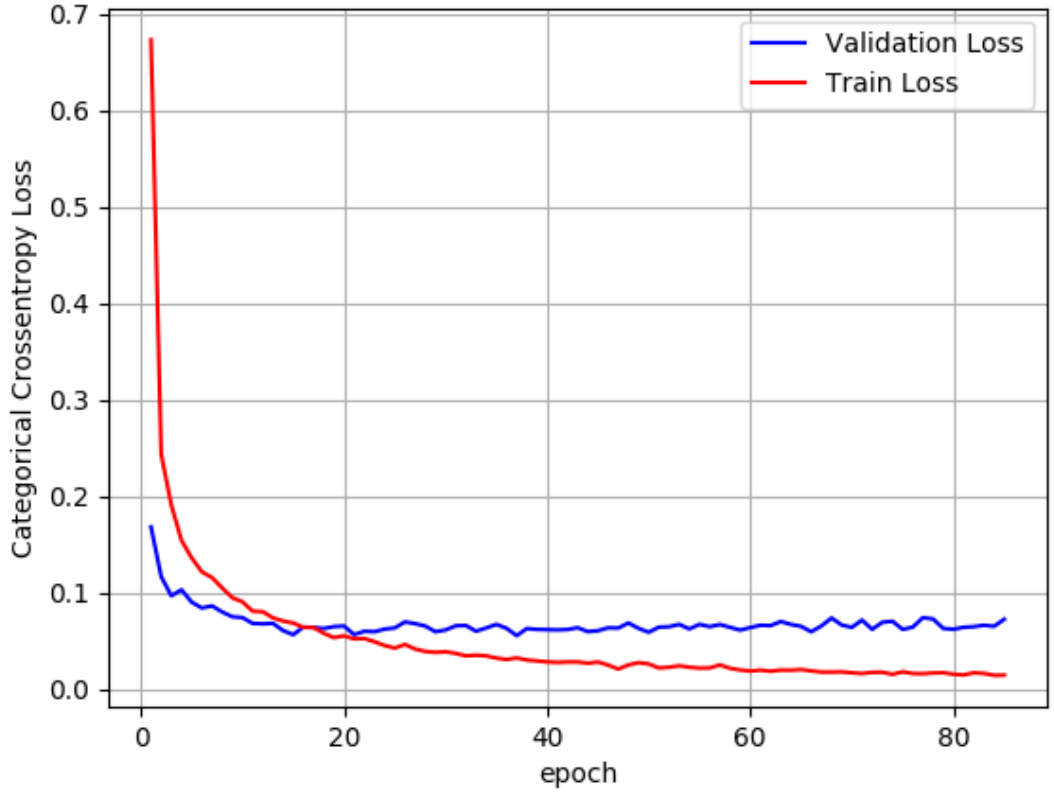

3.1.3.5 Violin Plots for Hidden Layers in the Models Trained

In [44]:
```
w_after = arch6_model3.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
h3_w = w_after[4].flatten().reshape(-1,1)
h4_w = w_after[6].flatten().reshape(-1,1)
h5_w = w_after[8].flatten().reshape(-1,1)
```

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```
out_w = w_after[10].flatten().reshape(-1,1)

fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 6, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL1')

plt.subplot(1, 6, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL2 ')

plt.subplot(1, 6, 3)
ax = sns.violinplot(y=h3_w, color='g')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL3 ')

plt.subplot(1, 6, 4)
ax = sns.violinplot(y=h4_w, color='m')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL4 ')

plt.subplot(1, 6, 5)
ax = sns.violinplot(y=h5_w, color='c')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL5 ')

plt.subplot(1, 6, 6)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('Out')
plt.show()
```

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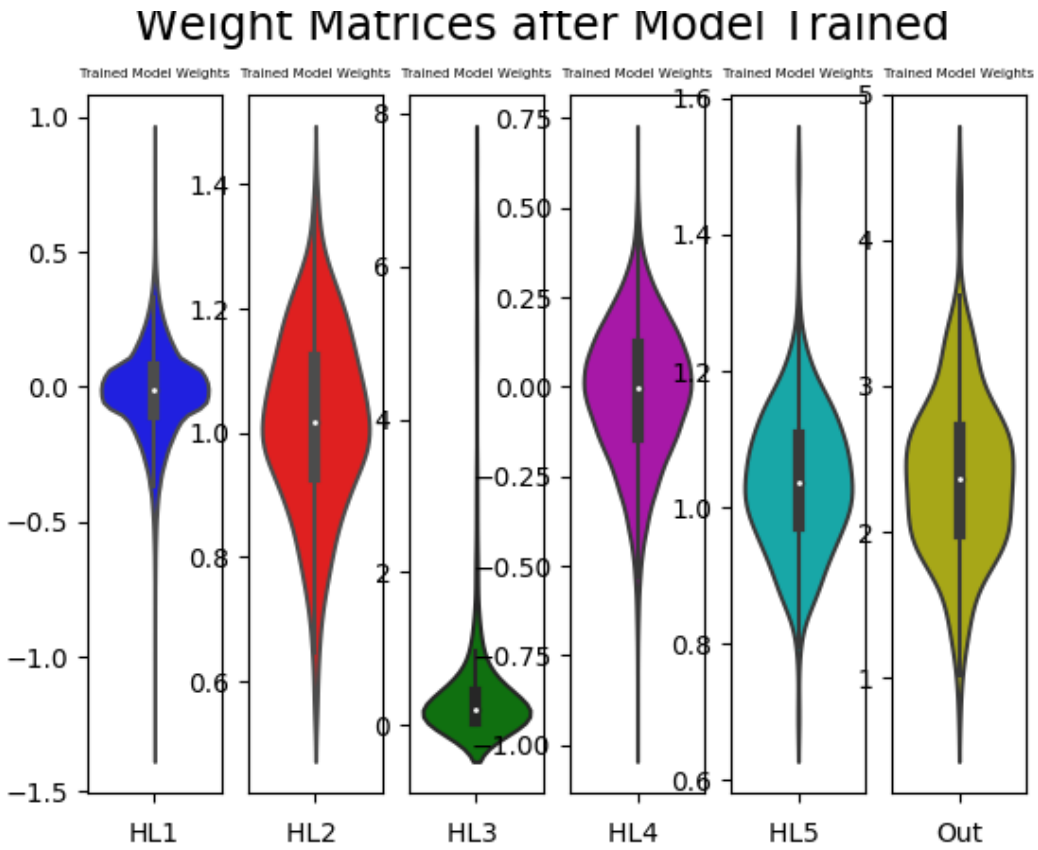

3.2 Architecture 7 :- 784-360-512-256-128-64-10

3.2.1 Model 1 : MLP + Adam Optimizer

3.2.1.1 Constructing the Neural Network

In [45]:
```
arch7_model1 = Sequential()

arch7_model1.add(Dense(360, activation='relu', input_shape=(input_dim
```

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```
,),\
                        kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))

arch7_model1.add(Dense(512, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.128,
 maxval=0.128, seed=None)) )

arch7_model1.add(Dense(256, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.108,
 maxval=0.108, seed=None)) )

arch7_model1.add(Dense(128, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.153,
 maxval=0.153, seed=None)) )

arch7_model1.add(Dense(64, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.216,
 maxval=0.216, seed=None)) )

arch7_model1.add(Dense(output_dim, activation='softmax'))
arch7_model1.summary()
```

```
Model: "sequential_9"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_45 (Dense)             (None, 360)               282600
_________________________________________________________________
dense_46 (Dense)             (None, 512)               184832
_________________________________________________________________
dense_47 (Dense)             (None, 256)               131328
_________________________________________________________________
dense_48 (Dense)             (None, 128)               32896
_________________________________________________________________
dense_49 (Dense)             (None, 64)                8256
_________________________________________________________________
dense_50 (Dense)             (None, 10)                650
=================================================================
Total params: 640,562
```

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```
Trainable params: 640,562
Non-trainable params: 0
_________________________________________________________________
```

3.2.1.2 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [46]:
```
arch7_model1.compile(optimizer='adam', loss='categorical_crossentropy',
 metrics=['accuracy'])

A7M1_history = arch7_model1.fit(X_train, Y_train, batch_size=batch_size
, epochs=nb_epoch, verbose=1, \
                              validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 7s 124us/step - loss: 0.
2350 - accuracy: 0.9298 - val_loss: 0.1096 - val_accuracy: 0.9668
Epoch 2/85
60000/60000 [==============================] - 8s 128us/step - loss: 0.
0924 - accuracy: 0.9718 - val_loss: 0.1099 - val_accuracy: 0.9671
Epoch 3/85
60000/60000 [==============================] - 8s 129us/step - loss: 0.
0622 - accuracy: 0.9805 - val_loss: 0.0938 - val_accuracy: 0.9695
Epoch 4/85
60000/60000 [==============================] - 8s 134us/step - loss: 0.
0480 - accuracy: 0.9847 - val_loss: 0.0995 - val_accuracy: 0.9734
Epoch 5/85
60000/60000 [==============================] - 7s 125us/step - loss: 0.
0366 - accuracy: 0.9883 - val_loss: 0.0864 - val_accuracy: 0.9764
Epoch 6/85
60000/60000 [==============================] - 7s 122us/step - loss: 0.
0332 - accuracy: 0.9898 - val_loss: 0.0753 - val_accuracy: 0.9786
Epoch 7/85
60000/60000 [==============================] - 8s 129us/step - loss: 0.
0272 - accuracy: 0.9916 - val_loss: 0.0669 - val_accuracy: 0.9813
Epoch 8/85
60000/60000 [==============================] - 7s 124us/step - loss: 0.
0258 - accuracy: 0.9915 - val_loss: 0.0912 - val_accuracy: 0.9779
```

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```
Epoch 9/85
60000/60000 [==============================] - 8s 129us/step - loss: 0.
0241 - accuracy: 0.9926 - val_loss: 0.0826 - val_accuracy: 0.9785
Epoch 10/85
60000/60000 [==============================] - 7s 119us/step - loss: 0.
0184 - accuracy: 0.9939 - val_loss: 0.0931 - val_accuracy: 0.9768
Epoch 11/85
60000/60000 [==============================] - 7s 125us/step - loss: 0.
0165 - accuracy: 0.9947 - val_loss: 0.0912 - val_accuracy: 0.9791
Epoch 12/85
60000/60000 [==============================] - 8s 125us/step - loss: 0.
0204 - accuracy: 0.9937 - val_loss: 0.0928 - val_accuracy: 0.9804
Epoch 13/85
60000/60000 [==============================] - 8s 128us/step - loss: 0.
0166 - accuracy: 0.9951 - val_loss: 0.0758 - val_accuracy: 0.9818
Epoch 14/85
60000/60000 [==============================] - 8s 138us/step - loss: 0.
0144 - accuracy: 0.9957 - val_loss: 0.0767 - val_accuracy: 0.9827
Epoch 15/85
60000/60000 [==============================] - 9s 142us/step - loss: 0.
0152 - accuracy: 0.9954 - val_loss: 0.1147 - val_accuracy: 0.9772
Epoch 16/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
0112 - accuracy: 0.9964 - val_loss: 0.0814 - val_accuracy: 0.9832
Epoch 17/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
0133 - accuracy: 0.9961 - val_loss: 0.0994 - val_accuracy: 0.9796
Epoch 18/85
60000/60000 [==============================] - 8s 135us/step - loss: 0.
0135 - accuracy: 0.9960 - val_loss: 0.0903 - val_accuracy: 0.9818
Epoch 19/85
60000/60000 [==============================] - 8s 126us/step - loss: 0.
0121 - accuracy: 0.9966 - val_loss: 0.0817 - val_accuracy: 0.9815
Epoch 20/85
60000/60000 [==============================] - 8s 129us/step - loss: 0.
0096 - accuracy: 0.9973 - val_loss: 0.0883 - val_accuracy: 0.9817
Epoch 21/85
60000/60000 [==============================] - 8s 129us/step - loss: 0.
0094 - accuracy: 0.9972 - val_loss: 0.1030 - val_accuracy: 0.9804
```

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```
Epoch 22/85
60000/60000 [==============================] - 7s 123us/step - loss: 0.
0108 - accuracy: 0.9969 - val_loss: 0.1010 - val_accuracy: 0.9807
Epoch 23/85
60000/60000 [==============================] - 8s 133us/step - loss: 0.
0099 - accuracy: 0.9971 - val_loss: 0.0963 - val_accuracy: 0.9808
Epoch 24/85
60000/60000 [==============================] - 7s 120us/step - loss: 0.
0098 - accuracy: 0.9969 - val_loss: 0.0974 - val_accuracy: 0.9802
Epoch 25/85
60000/60000 [==============================] - 7s 125us/step - loss: 0.
0079 - accuracy: 0.9980 - val_loss: 0.1030 - val_accuracy: 0.9810
Epoch 26/85
60000/60000 [==============================] - 7s 122us/step - loss: 0.
0105 - accuracy: 0.9972 - val_loss: 0.0870 - val_accuracy: 0.9833
Epoch 27/85
60000/60000 [==============================] - 7s 124us/step - loss: 0.
0059 - accuracy: 0.9984 - val_loss: 0.1046 - val_accuracy: 0.9829
Epoch 28/85
60000/60000 [==============================] - 8s 126us/step - loss: 0.
0087 - accuracy: 0.9977 - val_loss: 0.0963 - val_accuracy: 0.9799
Epoch 29/85
60000/60000 [==============================] - 8s 125us/step - loss: 0.
0087 - accuracy: 0.9976 - val_loss: 0.1032 - val_accuracy: 0.9828
Epoch 30/85
60000/60000 [==============================] - 7s 124us/step - loss: 0.
0084 - accuracy: 0.9977 - val_loss: 0.0957 - val_accuracy: 0.9815
Epoch 31/85
60000/60000 [==============================] - 8s 131us/step - loss: 0.
0068 - accuracy: 0.9980 - val_loss: 0.1038 - val_accuracy: 0.9812
Epoch 32/85
60000/60000 [==============================] - 8s 125us/step - loss: 0.
0080 - accuracy: 0.9979 - val_loss: 0.0960 - val_accuracy: 0.9825
Epoch 33/85
60000/60000 [==============================] - 8s 125us/step - loss: 0.
0054 - accuracy: 0.9986 - val_loss: 0.1156 - val_accuracy: 0.9815
Epoch 34/85
60000/60000 [==============================] - 8s 131us/step - loss: 0.
0062 - accuracy: 0.9984 - val_loss: 0.0982 - val_accuracy: 0.9841
```

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```
Epoch 35/85
60000/60000 [==============================] - 8s 129us/step - loss: 0.
0065 - accuracy: 0.9982 - val_loss: 0.1417 - val_accuracy: 0.9762
Epoch 36/85
60000/60000 [==============================] - 7s 123us/step - loss: 0.
0095 - accuracy: 0.9974 - val_loss: 0.1036 - val_accuracy: 0.9824
Epoch 37/85
60000/60000 [==============================] - 8s 131us/step - loss: 0.
0087 - accuracy: 0.9978 - val_loss: 0.1056 - val_accuracy: 0.9833
Epoch 38/85
60000/60000 [==============================] - 8s 129us/step - loss: 0.
0049 - accuracy: 0.9988 - val_loss: 0.1181 - val_accuracy: 0.9819
Epoch 39/85
60000/60000 [==============================] - 7s 125us/step - loss: 0.
0025 - accuracy: 0.9993 - val_loss: 0.1202 - val_accuracy: 0.9825
Epoch 40/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
0066 - accuracy: 0.9985 - val_loss: 0.1141 - val_accuracy: 0.9831
Epoch 41/85
60000/60000 [==============================] - 8s 127us/step - loss: 0.
0089 - accuracy: 0.9976 - val_loss: 0.1190 - val_accuracy: 0.9826
Epoch 42/85
60000/60000 [==============================] - 8s 132us/step - loss: 0.
0080 - accuracy: 0.9978 - val_loss: 0.0943 - val_accuracy: 0.9818
Epoch 43/85
60000/60000 [==============================] - 7s 125us/step - loss: 0.
0045 - accuracy: 0.9987 - val_loss: 0.1197 - val_accuracy: 0.9814
Epoch 44/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
0048 - accuracy: 0.9988 - val_loss: 0.1064 - val_accuracy: 0.9822
Epoch 45/85
60000/60000 [==============================] - 8s 128us/step - loss: 0.
0073 - accuracy: 0.9981 - val_loss: 0.0919 - val_accuracy: 0.9838
Epoch 46/85
60000/60000 [==============================] - 8s 135us/step - loss: 0.
0049 - accuracy: 0.9989 - val_loss: 0.1483 - val_accuracy: 0.9820
Epoch 47/85
60000/60000 [==============================] - 8s 126us/step - loss: 0.
0080 - accuracy: 0.9980 - val_loss: 0.1114 - val_accuracy: 0.9826
```

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```
Epoch 48/85
60000/60000 [==============================] - 7s 123us/step - loss: 0.
0045 - accuracy: 0.9987 - val_loss: 0.1293 - val_accuracy: 0.9839
Epoch 49/85
60000/60000 [==============================] - 8s 135us/step - loss: 0.
0056 - accuracy: 0.9989 - val_loss: 0.1116 - val_accuracy: 0.9846
Epoch 50/85
60000/60000 [==============================] - 8s 130us/step - loss: 0.
0041 - accuracy: 0.9989 - val_loss: 0.1138 - val_accuracy: 0.9843
Epoch 51/85
60000/60000 [==============================] - 8s 128us/step - loss: 0.
0069 - accuracy: 0.9985 - val_loss: 0.1057 - val_accuracy: 0.9843
Epoch 52/85
60000/60000 [==============================] - 7s 124us/step - loss: 0.
0059 - accuracy: 0.9985 - val_loss: 0.1046 - val_accuracy: 0.9837
Epoch 53/85
60000/60000 [==============================] - 8s 133us/step - loss: 0.
0039 - accuracy: 0.9991 - val_loss: 0.1052 - val_accuracy: 0.9849
Epoch 54/85
60000/60000 [==============================] - 8s 128us/step - loss: 0.
0053 - accuracy: 0.9985 - val_loss: 0.1293 - val_accuracy: 0.9819
Epoch 55/85
60000/60000 [==============================] - 8s 133us/step - loss: 0.
0069 - accuracy: 0.9981 - val_loss: 0.1137 - val_accuracy: 0.9845
Epoch 56/85
60000/60000 [==============================] - 7s 123us/step - loss: 0.
0018 - accuracy: 0.9995 - val_loss: 0.1468 - val_accuracy: 0.9841
Epoch 57/85
60000/60000 [==============================] - 8s 133us/step - loss: 0.
0054 - accuracy: 0.9988 - val_loss: 0.1236 - val_accuracy: 0.9832
Epoch 58/85
60000/60000 [==============================] - 7s 125us/step - loss: 0.
0080 - accuracy: 0.9983 - val_loss: 0.1200 - val_accuracy: 0.9839
Epoch 59/85
60000/60000 [==============================] - 8s 133us/step - loss: 0.
0048 - accuracy: 0.9990 - val_loss: 0.1029 - val_accuracy: 0.9858
Epoch 60/85
60000/60000 [==============================] - 7s 125us/step - loss: 0.
0039 - accuracy: 0.9991 - val_loss: 0.1577 - val_accuracy: 0.9835
```

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```
Epoch 61/85
60000/60000 [==============================] - 8s 130us/step - loss: 0.
0075 - accuracy: 0.9983 - val_loss: 0.1135 - val_accuracy: 0.9825
Epoch 62/85
60000/60000 [==============================] - 7s 123us/step - loss: 0.
0025 - accuracy: 0.9993 - val_loss: 0.1397 - val_accuracy: 0.9842
Epoch 63/85
60000/60000 [==============================] - 7s 123us/step - loss: 0.
0051 - accuracy: 0.9990 - val_loss: 0.1385 - val_accuracy: 0.9841
Epoch 64/85
60000/60000 [==============================] - 8s 130us/step - loss: 0.
0024 - accuracy: 0.9995 - val_loss: 0.1254 - val_accuracy: 0.9857
Epoch 65/85
60000/60000 [==============================] - 8s 131us/step - loss: 1.
5415e-04 - accuracy: 1.0000 - val_loss: 0.1439 - val_accuracy: 0.9859
Epoch 66/85
60000/60000 [==============================] - 8s 126us/step - loss: 2.
1316e-04 - accuracy: 1.0000 - val_loss: 0.1541 - val_accuracy: 0.9852
Epoch 67/85
60000/60000 [==============================] - 7s 124us/step - loss: 0.
0130 - accuracy: 0.9972 - val_loss: 0.1723 - val_accuracy: 0.9800
Epoch 68/85
60000/60000 [==============================] - 8s 127us/step - loss: 0.
0094 - accuracy: 0.9976 - val_loss: 0.1032 - val_accuracy: 0.9837
Epoch 69/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
0043 - accuracy: 0.9991 - val_loss: 0.1042 - val_accuracy: 0.9849
Epoch 70/85
60000/60000 [==============================] - 8s 126us/step - loss: 0.
0020 - accuracy: 0.9994 - val_loss: 0.1137 - val_accuracy: 0.9841
Epoch 71/85
60000/60000 [==============================] - 7s 120us/step - loss: 2.
9477e-04 - accuracy: 0.9999 - val_loss: 0.1473 - val_accuracy: 0.9837
Epoch 72/85
60000/60000 [==============================] - 8s 125us/step - loss: 0.
0069 - accuracy: 0.9984 - val_loss: 0.1315 - val_accuracy: 0.9832
Epoch 73/85
60000/60000 [==============================] - 7s 119us/step - loss: 0.
0056 - accuracy: 0.9988 - val_loss: 0.1363 - val_accuracy: 0.9814
```

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```
Epoch 74/85
60000/60000 [==============================] - 7s 123us/step - loss: 0.
0048 - accuracy: 0.9989 - val_loss: 0.1398 - val_accuracy: 0.9821
Epoch 75/85
60000/60000 [==============================] - 8s 129us/step - loss: 0.
0035 - accuracy: 0.9992 - val_loss: 0.1648 - val_accuracy: 0.9826
Epoch 76/85
60000/60000 [==============================] - 7s 122us/step - loss: 0.
0064 - accuracy: 0.9986 - val_loss: 0.1046 - val_accuracy: 0.9825
Epoch 77/85
60000/60000 [==============================] - 7s 121us/step - loss: 0.
0031 - accuracy: 0.9992 - val_loss: 0.1262 - val_accuracy: 0.9826
Epoch 78/85
60000/60000 [==============================] - 8s 126us/step - loss: 0.
0028 - accuracy: 0.9994 - val_loss: 0.1225 - val_accuracy: 0.9834
Epoch 79/85
60000/60000 [==============================] - 7s 123us/step - loss: 4.
4208e-04 - accuracy: 0.9999 - val_loss: 0.1853 - val_accuracy: 0.9852
Epoch 80/85
60000/60000 [==============================] - 8s 130us/step - loss: 8.
7459e-06 - accuracy: 1.0000 - val_loss: 0.1961 - val_accuracy: 0.9850
Epoch 81/85
60000/60000 [==============================] - 8s 126us/step - loss: 1.
2484e-06 - accuracy: 1.0000 - val_loss: 0.2030 - val_accuracy: 0.9850
Epoch 82/85
60000/60000 [==============================] - 8s 127us/step - loss: 7.
4935e-07 - accuracy: 1.0000 - val_loss: 0.2086 - val_accuracy: 0.9850
Epoch 83/85
60000/60000 [==============================] - 7s 123us/step - loss: 4.
9969e-07 - accuracy: 1.0000 - val_loss: 0.2138 - val_accuracy: 0.9851
Epoch 84/85
60000/60000 [==============================] - 8s 127us/step - loss: 3.
4848e-07 - accuracy: 1.0000 - val_loss: 0.2191 - val_accuracy: 0.9851
Epoch 85/85
60000/60000 [==============================] - 7s 122us/step - loss: 2.
4953e-07 - accuracy: 1.0000 - val_loss: 0.2239 - val_accuracy: 0.9851
```

3.2.1.3 Number of Epochs vs Train Loss & Validation Loss

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In [47]:
```
warnings.filterwarnings("ignore")

A7M1_score = arch7_model1.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A7M1_score[0])
print('Test accuracy:', A7M1_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in history.history we will have a list of length equal t
o number of epochs

vy = A7M1_history.history['val_loss']
ty = A7M1_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.2239265702778512
Test accuracy: 0.9850999712944031
```

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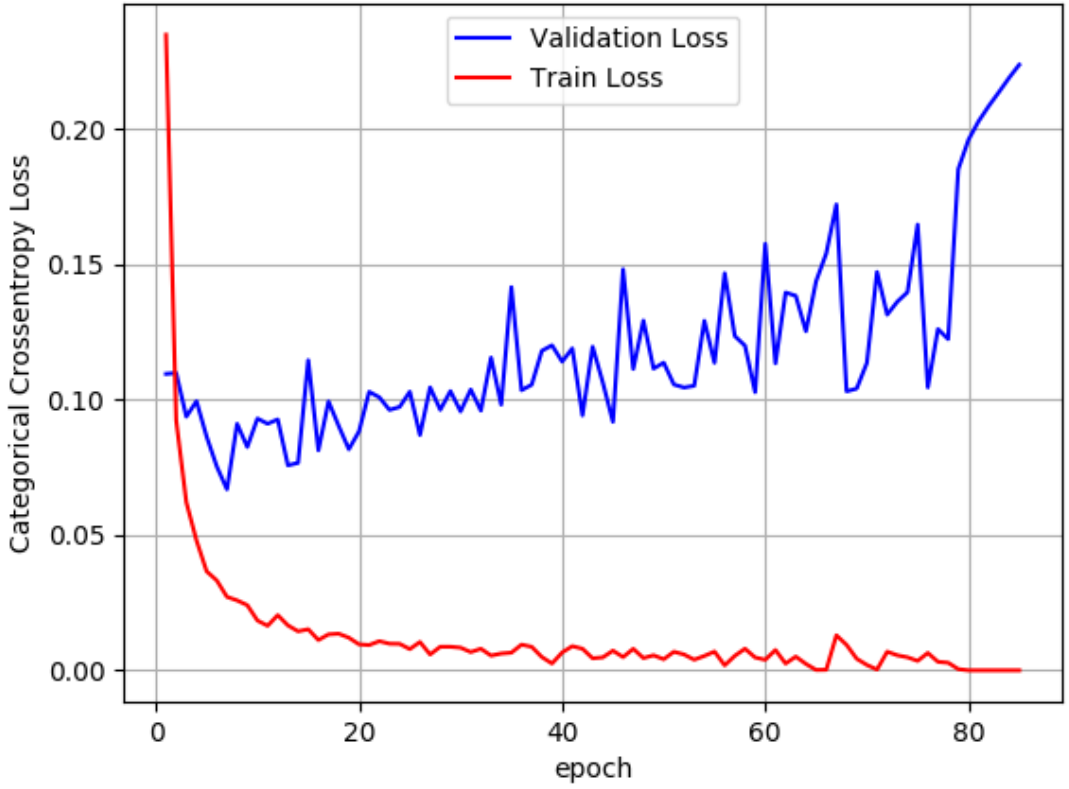

3.2.1.4 Violin Plots for Hidden Layers in the Models Trained

In [48]:
```
w_after = arch7_model1.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
h3_w = w_after[4].flatten().reshape(-1,1)
h4_w = w_after[6].flatten().reshape(-1,1)
```

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```
h5_w = w_after[8].flatten().reshape(-1,1)
out_w = w_after[10].flatten().reshape(-1,1)

fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 6, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL1')

plt.subplot(1, 6, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL2 ')

plt.subplot(1, 6, 3)
ax = sns.violinplot(y=h3_w, color='g')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL3 ')

plt.subplot(1, 6, 4)
ax = sns.violinplot(y=h4_w, color='m')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL4 ')

plt.subplot(1, 6, 5)
ax = sns.violinplot(y=h5_w, color='c')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL5 ')

plt.subplot(1, 6, 6)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('Out')
plt.show()
```

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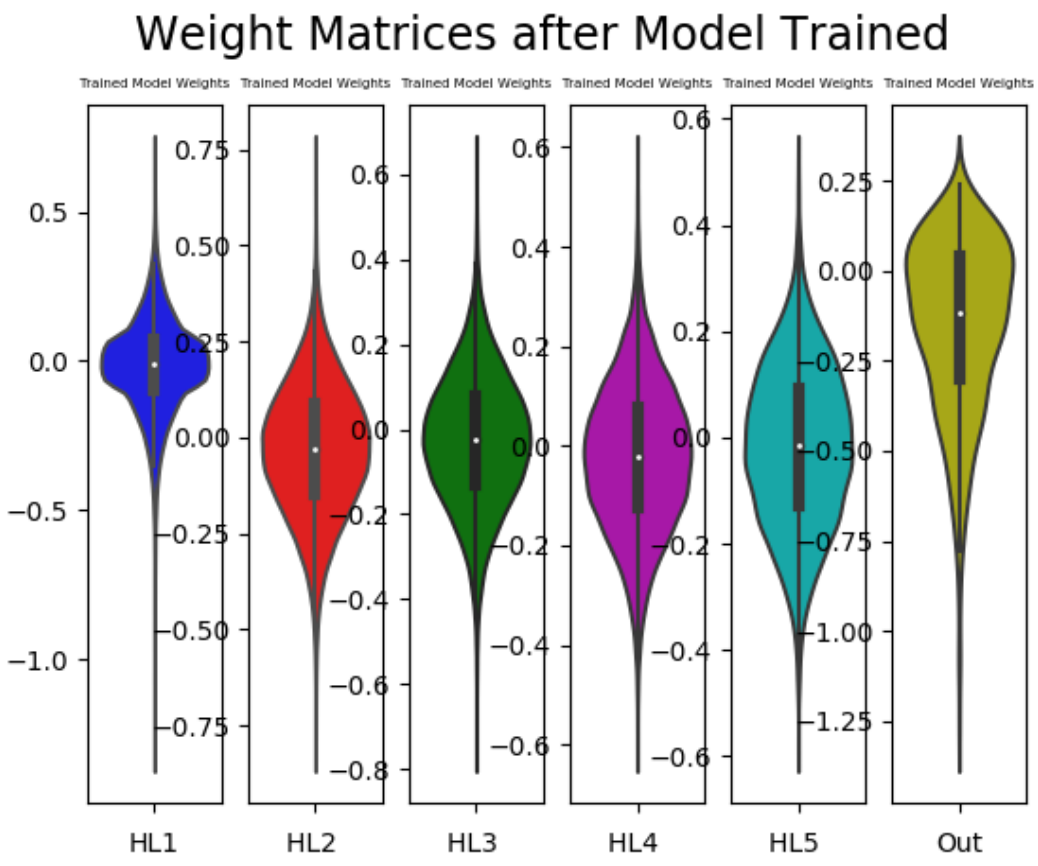

3.2.2 Model 2 : MLP + BatchNormalization + Adam Optimizer

3.2.2.1 Constructing the Neural Network

In [49]:
```
arch7_model2 = Sequential()

arch7_model2.add(Dense(360, activation='relu', input_shape=(input_dim
,),\
                       kernel_initializer=RandomUniform(minval= -0.087,
```

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```
maxval = 0.087, seed=None)))
arch7_model2.add(BatchNormalization())

arch7_model2.add(Dense(512, activation='relu', \
                       kernel_initializer=RandomUniform(minval= -0.128,
 maxval=0.128, seed=None)) )
arch7_model2.add(BatchNormalization())

arch7_model2.add(Dense(256, activation='relu', \
                       kernel_initializer=RandomUniform(minval= -0.108,
 maxval=0.108, seed=None)) )
arch7_model2.add(BatchNormalization())

arch7_model2.add(Dense(128, activation='relu', \
                       kernel_initializer=RandomUniform(minval= -0.153,
 maxval=0.153, seed=None)) )
arch7_model2.add(BatchNormalization())

arch7_model2.add(Dense(64, activation='relu', \
                       kernel_initializer=RandomUniform(minval= -0.216,
 maxval=0.216, seed=None)) )
arch7_model2.add(BatchNormalization())

arch7_model2.add(Dense(output_dim, activation='softmax'))
arch7_model2.summary()
```

```
Model: "sequential_10"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_51 (Dense)             (None, 360)               282600
_________________________________________________________________
batch_normalization_27 (Batc (None, 360)               1440
_________________________________________________________________
dense_52 (Dense)             (None, 512)               184832
_________________________________________________________________
batch_normalization_28 (Batc (None, 512)               2048
_________________________________________________________________
dense_53 (Dense)             (None, 256)               131328
_________________________________________________________________
```

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```
batch_normalization_29 (Batc (None, 256)               1024
_________________________________________________________________
dense_54 (Dense)             (None, 128)               32896
_________________________________________________________________
batch_normalization_30 (Batc (None, 128)               512
_________________________________________________________________
dense_55 (Dense)             (None, 64)                8256
_________________________________________________________________
batch_normalization_31 (Batc (None, 64)                256
_________________________________________________________________
dense_56 (Dense)             (None, 10)                650
=================================================================
Total params: 645,842
Trainable params: 643,202
Non-trainable params: 2,640
_________________________________________________________________
```

3.2.2.2 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [50]:
```
arch7_model2.compile(optimizer='adam', loss='categorical_crossentropy',
 metrics=['accuracy'])

A7M2_history = arch7_model2.fit(X_train, Y_train, batch_size=batch_size
, epochs=nb_epoch, verbose=1, \
                             validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 12s 199us/step - loss:
0.2217 - accuracy: 0.9344 - val_loss: 0.1084 - val_accuracy: 0.9668
Epoch 2/85
60000/60000 [==============================] - 11s 185us/step - loss:
0.0859 - accuracy: 0.9730 - val_loss: 0.0879 - val_accuracy: 0.9716
Epoch 3/85
60000/60000 [==============================] - 10s 173us/step - loss:
0.0644 - accuracy: 0.9796 - val_loss: 0.0866 - val_accuracy: 0.9723
Epoch 4/85
60000/60000 [==============================] - 10s 164us/step - loss:
```

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```
0.0474 - accuracy: 0.9850 - val_loss: 0.0836 - val_accuracy: 0.9760
Epoch 5/85
60000/60000 [==============================] - 10s 172us/step - loss:
0.0396 - accuracy: 0.9868 - val_loss: 0.0930 - val_accuracy: 0.9730
Epoch 6/85
60000/60000 [==============================] - 10s 170us/step - loss:
0.0349 - accuracy: 0.9892 - val_loss: 0.0819 - val_accuracy: 0.9769
Epoch 7/85
60000/60000 [==============================] - 10s 168us/step - loss:
0.0295 - accuracy: 0.9900 - val_loss: 0.0903 - val_accuracy: 0.9727
Epoch 8/85
60000/60000 [==============================] - 11s 176us/step - loss:
0.0305 - accuracy: 0.9899 - val_loss: 0.0705 - val_accuracy: 0.9805
Epoch 9/85
60000/60000 [==============================] - 10s 171us/step - loss:
0.0224 - accuracy: 0.9927 - val_loss: 0.0815 - val_accuracy: 0.9762
Epoch 10/85
60000/60000 [==============================] - 10s 164us/step - loss:
0.0235 - accuracy: 0.9924 - val_loss: 0.0762 - val_accuracy: 0.9770
Epoch 11/85
60000/60000 [==============================] - 10s 172us/step - loss:
0.0193 - accuracy: 0.9937 - val_loss: 0.0872 - val_accuracy: 0.9767
Epoch 12/85
60000/60000 [==============================] - 10s 171us/step - loss:
0.0198 - accuracy: 0.9933 - val_loss: 0.0927 - val_accuracy: 0.9779
Epoch 13/85
60000/60000 [==============================] - 10s 168us/step - loss:
0.0175 - accuracy: 0.9945 - val_loss: 0.0863 - val_accuracy: 0.9776
Epoch 14/85
60000/60000 [==============================] - 11s 182us/step - loss:
0.0168 - accuracy: 0.9944 - val_loss: 0.0706 - val_accuracy: 0.9819
Epoch 15/85
60000/60000 [==============================] - 11s 178us/step - loss:
0.0202 - accuracy: 0.9935 - val_loss: 0.0715 - val_accuracy: 0.9814
Epoch 16/85
60000/60000 [==============================] - 10s 169us/step - loss:
0.0151 - accuracy: 0.9948 - val_loss: 0.0729 - val_accuracy: 0.9816
Epoch 17/85
60000/60000 [==============================] - 11s 183us/step - loss:
```

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```
0.0156 - accuracy: 0.9949 - val_loss: 0.0793 - val_accuracy: 0.9812
Epoch 18/85
60000/60000 [==============================] - 10s 170us/step - loss:
0.0109 - accuracy: 0.9965 - val_loss: 0.0898 - val_accuracy: 0.9778
Epoch 19/85
60000/60000 [==============================] - 10s 172us/step - loss:
0.0144 - accuracy: 0.9953 - val_loss: 0.0733 - val_accuracy: 0.9822
Epoch 20/85
60000/60000 [==============================] - 10s 171us/step - loss:
0.0106 - accuracy: 0.9964 - val_loss: 0.0824 - val_accuracy: 0.9797
Epoch 21/85
60000/60000 [==============================] - 10s 164us/step - loss:
0.0150 - accuracy: 0.9948 - val_loss: 0.0743 - val_accuracy: 0.9818
Epoch 22/85
60000/60000 [==============================] - 10s 170us/step - loss:
0.0097 - accuracy: 0.9969 - val_loss: 0.0751 - val_accuracy: 0.9828
Epoch 23/85
60000/60000 [==============================] - 10s 167us/step - loss:
0.0087 - accuracy: 0.9974 - val_loss: 0.0763 - val_accuracy: 0.9816
Epoch 24/85
60000/60000 [==============================] - 11s 179us/step - loss:
0.0100 - accuracy: 0.9967 - val_loss: 0.0838 - val_accuracy: 0.9803
Epoch 25/85
60000/60000 [==============================] - 11s 177us/step - loss:
0.0106 - accuracy: 0.9965 - val_loss: 0.0748 - val_accuracy: 0.9808
Epoch 26/85
60000/60000 [==============================] - 10s 170us/step - loss:
0.0099 - accuracy: 0.9969 - val_loss: 0.0786 - val_accuracy: 0.9815
Epoch 27/85
60000/60000 [==============================] - 10s 164us/step - loss:
0.0088 - accuracy: 0.9970 - val_loss: 0.0730 - val_accuracy: 0.9825
Epoch 28/85
60000/60000 [==============================] - 10s 171us/step - loss:
0.0060 - accuracy: 0.9979 - val_loss: 0.0741 - val_accuracy: 0.9823
Epoch 29/85
60000/60000 [==============================] - 10s 171us/step - loss:
0.0085 - accuracy: 0.9972 - val_loss: 0.0676 - val_accuracy: 0.9847
Epoch 30/85
60000/60000 [==============================] - 10s 164us/step - loss:
```

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```
0.0089 - accuracy: 0.9973 - val_loss: 0.0833 - val_accuracy: 0.9816
Epoch 31/85
60000/60000 [==============================] - 10s 173us/step - loss:
0.0079 - accuracy: 0.9975 - val_loss: 0.0763 - val_accuracy: 0.9824
Epoch 32/85
60000/60000 [==============================] - 10s 164us/step - loss:
0.0085 - accuracy: 0.9973 - val_loss: 0.0824 - val_accuracy: 0.9807
Epoch 33/85
60000/60000 [==============================] - 11s 176us/step - loss:
0.0083 - accuracy: 0.9974 - val_loss: 0.0811 - val_accuracy: 0.9809
Epoch 34/85
60000/60000 [==============================] - 10s 172us/step - loss:
0.0066 - accuracy: 0.9979 - val_loss: 0.0806 - val_accuracy: 0.9821
Epoch 35/85
60000/60000 [==============================] - 10s 165us/step - loss:
0.0075 - accuracy: 0.9980 - val_loss: 0.0751 - val_accuracy: 0.9838
Epoch 36/85
60000/60000 [==============================] - 10s 170us/step - loss:
0.0060 - accuracy: 0.9980 - val_loss: 0.0708 - val_accuracy: 0.9829
Epoch 37/85
60000/60000 [==============================] - 10s 170us/step - loss:
0.0055 - accuracy: 0.9982 - val_loss: 0.0742 - val_accuracy: 0.9846
Epoch 38/85
60000/60000 [==============================] - 10s 170us/step - loss:
0.0075 - accuracy: 0.9976 - val_loss: 0.0789 - val_accuracy: 0.9806
Epoch 39/85
60000/60000 [==============================] - 10s 169us/step - loss:
0.0063 - accuracy: 0.9977 - val_loss: 0.0805 - val_accuracy: 0.9824
Epoch 40/85
60000/60000 [==============================] - 10s 167us/step - loss:
0.0072 - accuracy: 0.9981 - val_loss: 0.0848 - val_accuracy: 0.9824
Epoch 41/85
60000/60000 [==============================] - 10s 170us/step - loss:
0.0052 - accuracy: 0.9985 - val_loss: 0.0799 - val_accuracy: 0.9824
Epoch 42/85
60000/60000 [==============================] - 10s 168us/step - loss:
0.0054 - accuracy: 0.9980 - val_loss: 0.0796 - val_accuracy: 0.9822
Epoch 43/85
60000/60000 [==============================] - 10s 165us/step - loss:
```

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```
0.0064 - accuracy: 0.9979 - val_loss: 0.0886 - val_accuracy: 0.9812
Epoch 44/85
60000/60000 [==============================] - 10s 169us/step - loss:
0.0042 - accuracy: 0.9987 - val_loss: 0.0792 - val_accuracy: 0.9823
Epoch 45/85
60000/60000 [==============================] - 10s 169us/step - loss:
0.0057 - accuracy: 0.9984 - val_loss: 0.0790 - val_accuracy: 0.9840
Epoch 46/85
60000/60000 [==============================] - 11s 177us/step - loss:
0.0072 - accuracy: 0.9979 - val_loss: 0.0838 - val_accuracy: 0.9819
Epoch 47/85
60000/60000 [==============================] - 10s 166us/step - loss:
0.0060 - accuracy: 0.9981 - val_loss: 0.0744 - val_accuracy: 0.9831
Epoch 48/85
60000/60000 [==============================] - 10s 167us/step - loss:
0.0047 - accuracy: 0.9984 - val_loss: 0.0689 - val_accuracy: 0.9835
Epoch 49/85
60000/60000 [==============================] - 11s 176us/step - loss:
0.0046 - accuracy: 0.9987 - val_loss: 0.0676 - val_accuracy: 0.9847
Epoch 50/85
60000/60000 [==============================] - 10s 169us/step - loss:
0.0047 - accuracy: 0.9986 - val_loss: 0.0721 - val_accuracy: 0.9846
Epoch 51/85
60000/60000 [==============================] - 10s 169us/step - loss:
0.0059 - accuracy: 0.9981 - val_loss: 0.0714 - val_accuracy: 0.9840
Epoch 52/85
60000/60000 [==============================] - 10s 169us/step - loss:
0.0049 - accuracy: 0.9984 - val_loss: 0.0817 - val_accuracy: 0.9824
Epoch 53/85
60000/60000 [==============================] - 10s 163us/step - loss:
0.0037 - accuracy: 0.9990 - val_loss: 0.0686 - val_accuracy: 0.9850
Epoch 54/85
60000/60000 [==============================] - 10s 172us/step - loss:
0.0035 - accuracy: 0.9988 - val_loss: 0.0838 - val_accuracy: 0.9824
Epoch 55/85
60000/60000 [==============================] - 10s 160us/step - loss:
0.0055 - accuracy: 0.9982 - val_loss: 0.0789 - val_accuracy: 0.9824
Epoch 56/85
60000/60000 [==============================] - 9s 154us/step - loss: 0.
```

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```
0044 - accuracy: 0.9984 - val_loss: 0.0878 - val_accuracy: 0.9810
Epoch 57/85
60000/60000 [==============================] - 10s 159us/step - loss:
0.0034 - accuracy: 0.9989 - val_loss: 0.0804 - val_accuracy: 0.9828
Epoch 58/85
60000/60000 [==============================] - 10s 161us/step - loss:
0.0055 - accuracy: 0.9983 - val_loss: 0.0875 - val_accuracy: 0.9828
Epoch 59/85
60000/60000 [==============================] - 9s 157us/step - loss: 0.
0046 - accuracy: 0.9986 - val_loss: 0.0897 - val_accuracy: 0.9797
Epoch 60/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
0032 - accuracy: 0.9991 - val_loss: 0.0757 - val_accuracy: 0.9829
Epoch 61/85
60000/60000 [==============================] - 10s 164us/step - loss:
0.0038 - accuracy: 0.9988 - val_loss: 0.0743 - val_accuracy: 0.9847
Epoch 62/85
60000/60000 [==============================] - 10s 162us/step - loss:
0.0024 - accuracy: 0.9992 - val_loss: 0.0828 - val_accuracy: 0.9835
Epoch 63/85
60000/60000 [==============================] - 10s 162us/step - loss:
0.0032 - accuracy: 0.9991 - val_loss: 0.0970 - val_accuracy: 0.9802
Epoch 64/85
60000/60000 [==============================] - 10s 159us/step - loss:
0.0030 - accuracy: 0.9992 - val_loss: 0.0767 - val_accuracy: 0.9827
Epoch 65/85
60000/60000 [==============================] - 10s 162us/step - loss:
0.0038 - accuracy: 0.9988 - val_loss: 0.0793 - val_accuracy: 0.9841
Epoch 66/85
60000/60000 [==============================] - 10s 160us/step - loss:
0.0044 - accuracy: 0.9987 - val_loss: 0.0909 - val_accuracy: 0.9815
Epoch 67/85
60000/60000 [==============================] - 9s 156us/step - loss: 0.
0043 - accuracy: 0.9987 - val_loss: 0.0878 - val_accuracy: 0.9829
Epoch 68/85
60000/60000 [==============================] - 10s 161us/step - loss:
0.0040 - accuracy: 0.9987 - val_loss: 0.0886 - val_accuracy: 0.9826
Epoch 69/85
60000/60000 [==============================] - 9s 155us/step - loss: 0.
```

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```
0035 - accuracy: 0.9989 - val_loss: 0.0836 - val_accuracy: 0.9837
Epoch 70/85
60000/60000 [==============================] - 10s 160us/step - loss:
0.0027 - accuracy: 0.9990 - val_loss: 0.0927 - val_accuracy: 0.9822
Epoch 71/85
60000/60000 [==============================] - 9s 157us/step - loss: 0.
0022 - accuracy: 0.9993 - val_loss: 0.0935 - val_accuracy: 0.9840
Epoch 72/85
60000/60000 [==============================] - 10s 171us/step - loss:
0.0038 - accuracy: 0.9989 - val_loss: 0.1048 - val_accuracy: 0.9801
Epoch 73/85
60000/60000 [==============================] - 10s 172us/step - loss:
0.0034 - accuracy: 0.9992 - val_loss: 0.0916 - val_accuracy: 0.9822
Epoch 74/85
60000/60000 [==============================] - 10s 166us/step - loss:
0.0043 - accuracy: 0.9988 - val_loss: 0.0840 - val_accuracy: 0.9846
Epoch 75/85
60000/60000 [==============================] - 10s 170us/step - loss:
0.0022 - accuracy: 0.9993 - val_loss: 0.0771 - val_accuracy: 0.9856
Epoch 76/85
60000/60000 [==============================] - 10s 169us/step - loss:
0.0017 - accuracy: 0.9994 - val_loss: 0.0792 - val_accuracy: 0.9858
Epoch 77/85
60000/60000 [==============================] - 10s 171us/step - loss:
0.0031 - accuracy: 0.9992 - val_loss: 0.0927 - val_accuracy: 0.9820
Epoch 78/85
60000/60000 [==============================] - 10s 163us/step - loss:
0.0042 - accuracy: 0.9988 - val_loss: 0.0815 - val_accuracy: 0.9844
Epoch 79/85
60000/60000 [==============================] - 10s 170us/step - loss:
0.0032 - accuracy: 0.9988 - val_loss: 0.0800 - val_accuracy: 0.9859
Epoch 80/85
60000/60000 [==============================] - 10s 163us/step - loss:
0.0019 - accuracy: 0.9996 - val_loss: 0.0781 - val_accuracy: 0.9853
Epoch 81/85
60000/60000 [==============================] - 10s 164us/step - loss:
0.0029 - accuracy: 0.9991 - val_loss: 0.0956 - val_accuracy: 0.9819
Epoch 82/85
60000/60000 [==============================] - 10s 165us/step - loss:
```

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```
0.0034 - accuracy: 0.9991 - val_loss: 0.0826 - val_accuracy: 0.9834
Epoch 83/85
60000/60000 [==============================] - 10s 168us/step - loss:
0.0021 - accuracy: 0.9993 - val_loss: 0.0816 - val_accuracy: 0.9842
Epoch 84/85
60000/60000 [==============================] - 10s 161us/step - loss:
0.0018 - accuracy: 0.9994 - val_loss: 0.0806 - val_accuracy: 0.9849
Epoch 85/85
60000/60000 [==============================] - 11s 176us/step - loss:
0.0019 - accuracy: 0.9995 - val_loss: 0.0801 - val_accuracy: 0.9862
```

3.2.2.3 Number of Epochs vs Train Loss & Validation Loss

In [51]:

```
warnings.filterwarnings("ignore")

A7M2_score = arch7_model2.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A7M2_score[0])
print('Test accuracy:', A7M2_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in history.history we will have a list of length equal t
```

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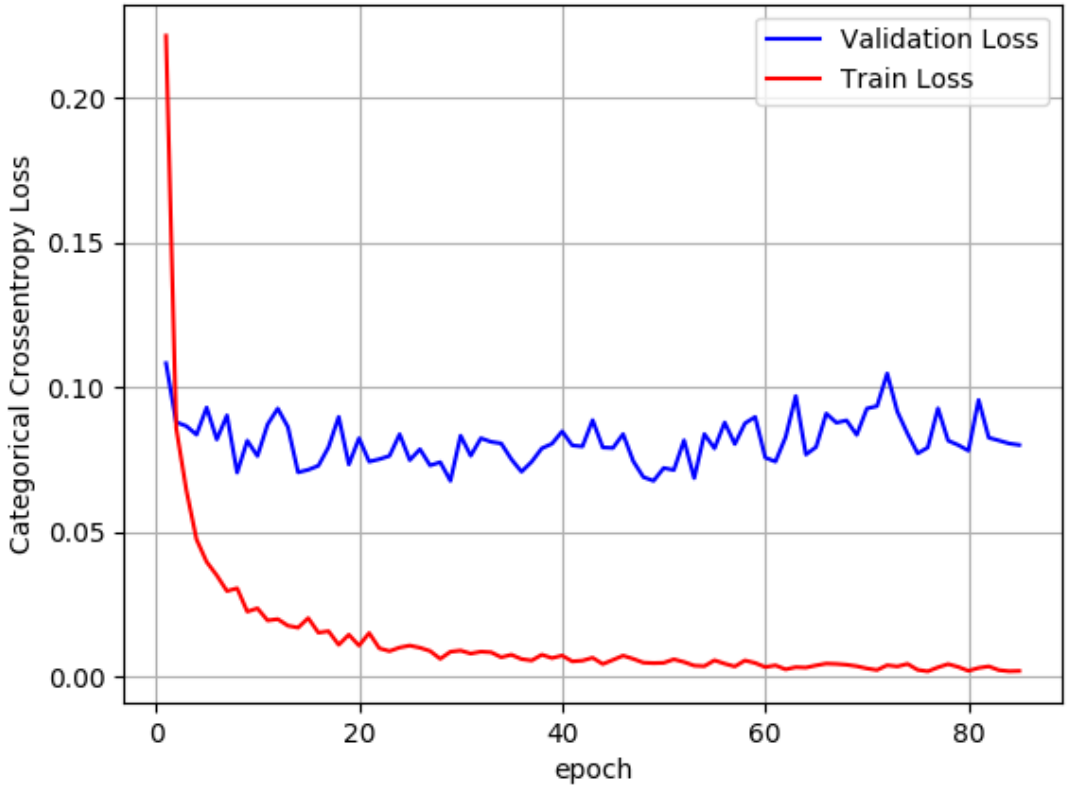
```
o number of epochs

vy = A7M2_history.history['val_loss']
ty = A7M2_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

```
Test score: 0.08006006373140116
Test accuracy: 0.9861999750137329
```



3.2.2.4 Violin Plots for Hidden Layers in the Models Trained

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In [52]:
```
w_after = arch7_model2.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
h3_w = w_after[4].flatten().reshape(-1,1)
h4_w = w_after[6].flatten().reshape(-1,1)
h5_w = w_after[8].flatten().reshape(-1,1)
out_w = w_after[10].flatten().reshape(-1,1)

fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 6, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL1')

plt.subplot(1, 6, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL2 ')

plt.subplot(1, 6, 3)
ax = sns.violinplot(y=h3_w, color='g')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL3 ')

plt.subplot(1, 6, 4)
ax = sns.violinplot(y=h4_w, color='m')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL4 ')

plt.subplot(1, 6, 5)
ax = sns.violinplot(y=h5_w, color='c')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL5 ')

plt.subplot(1, 6, 6)
ax = sns.violinplot(y=out_w,color='y')
```

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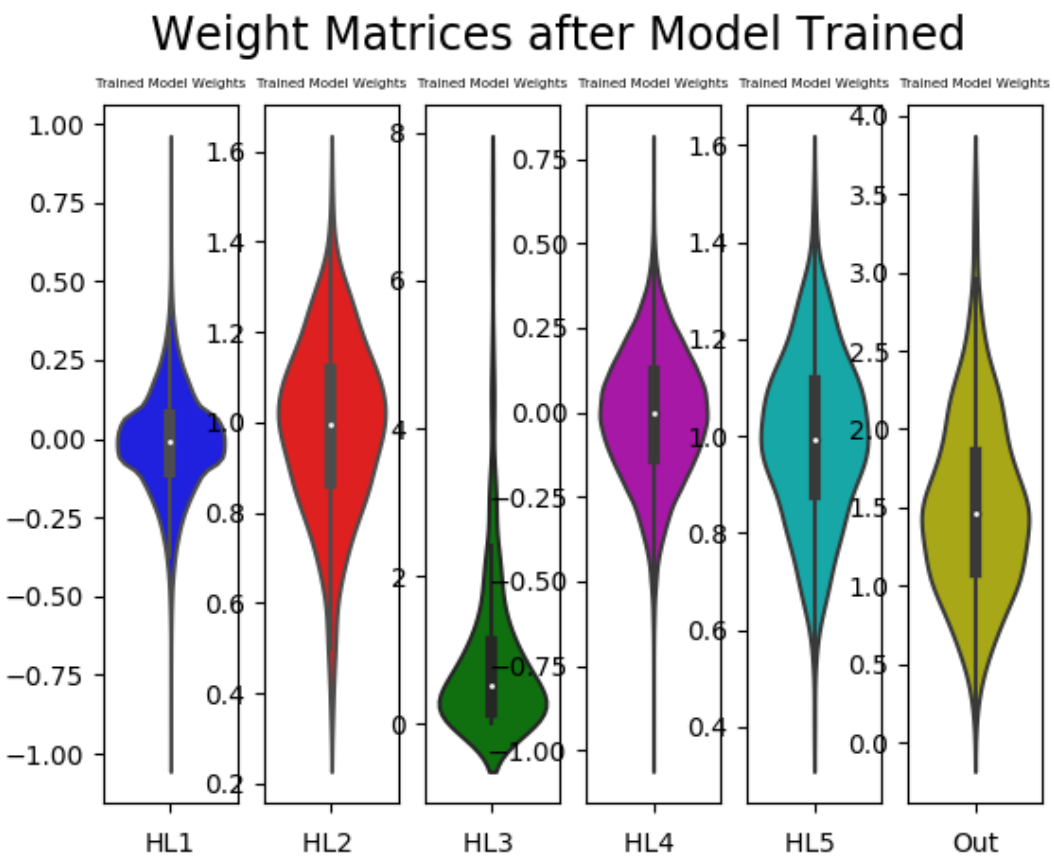
```
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('Out')
plt.show()
```



3.2.3 Model 3 : MLP + BatchNormalization + Dropout + Adam Optimizer

3.2.3.1 Hyperparameter Tuning for Dropout

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In [53]:
```
def A7M3_best_hyperparameters(dropout):

    arch7_model3 = Sequential()

    arch7_model3.add(Dense(360, activation='relu', input_shape=(input_d
im,),\
                        kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))
    arch7_model3.add(BatchNormalization())
    arch7_model3.add(Dropout(dropout))

    arch7_model3.add(Dense(512, activation='relu', \
                         kernel_initializer=RandomUniform(minval= -0.128,
 maxval=0.128, seed=None)) )
    arch7_model3.add(BatchNormalization())
    arch7_model3.add(Dropout(dropout))

    arch7_model3.add(Dense(256, activation='relu', \
                         kernel_initializer=RandomUniform(minval= -0.108,
 maxval=0.108, seed=None)) )
    arch7_model3.add(BatchNormalization())
    arch7_model3.add(Dropout(dropout))

    arch7_model3.add(Dense(128, activation='relu', \
                         kernel_initializer=RandomUniform(minval= -0.153,
 maxval=0.153, seed=None)) )
    arch7_model3.add(BatchNormalization())
    arch7_model3.add(Dropout(dropout))

    arch7_model3.add(Dense(64, activation='relu', \
                         kernel_initializer=RandomUniform(minval= -0.216,
 maxval=0.216, seed=None)) )
    arch7_model3.add(BatchNormalization())
    arch7_model3.add(Dropout(dropout))

    arch7_model3.add(Dense(output_dim, activation='softmax'))

    arch7_model3.compile(optimizer='adam', loss='categorical_crossentro
py', metrics=['accuracy'])
```

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```
    return arch7_model3
```

In [54]:
```
from datetime import datetime
start = datetime.now()

dropout = []

for d in range(1,10):
    dropout.append(d/10)

from keras.wrappers.scikit_learn import KerasClassifier
from sklearn.model_selection import GridSearchCV

model = KerasClassifier(build_fn=A7M3_best_hyperparameters, epochs=nb_e
poch, batch_size=batch_size, verbose=0)
param_grid = dict(dropout=dropout)

# if you are using CPU
# grid = GridSearchCV(estimator=model, param_grid=param_grid, n_jobs=-
1)
# if you are using GPU dont use the n_jobs parameter

grid_6 = GridSearchCV(estimator=model, param_grid=param_grid,cv=3,n_job
s=-1)
grid_result6 = grid_6.fit(X_train, Y_train)

print('Time taken :', datetime.now() - start)
```

```
Time taken : 3:19:49.626629
```

In [55]:
```
print("Best: %f using %s" % (grid_result6.best_score_, grid_result6.bes
t_params_))
means = grid_result6.cv_results_['mean_test_score']
stds = grid_result6.cv_results_['std_test_score']
params = grid_result6.cv_results_['params']
for mean, stdev, param in zip(means, stds, params):
    print("%f (%f) with: %r" % (mean, stdev, param))
```

```
Best: 0.082283 using {'dropout': 0.3}
```

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```
Best: 0.982283 using {'dropout': 0.3}
0.982017 (0.001226) with: {'dropout': 0.1}
0.981667 (0.000425) with: {'dropout': 0.2}
0.982283 (0.000473) with: {'dropout': 0.3}
0.981583 (0.001000) with: {'dropout': 0.4}
0.981683 (0.000539) with: {'dropout': 0.5}
0.979600 (0.000319) with: {'dropout': 0.6}
0.976050 (0.000604) with: {'dropout': 0.7}
0.940000 (0.031638) with: {'dropout': 0.8}
0.327250 (0.018375) with: {'dropout': 0.9}
```

3.2.3.2 Constructing the Neural Network

In [56]:

```
arch7_model3 = Sequential()

arch7_model3.add(Dense(360, activation='relu', input_shape=(input_dim
,),\
                       kernel_initializer=RandomUniform(minval= -0.087,
maxval = 0.087, seed=None)))
arch7_model3.add(BatchNormalization())
arch7_model3.add(Dropout(0.3))

arch7_model3.add(Dense(512, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.128,
 maxval=0.128, seed=None)) )
arch7_model3.add(BatchNormalization())
arch7_model3.add(Dropout(0.3))

arch7_model3.add(Dense(256, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.108,
 maxval=0.108, seed=None)) )
arch7_model3.add(BatchNormalization())
arch7_model3.add(Dropout(0.3))

arch7_model3.add(Dense(128, activation='relu', \
                        kernel_initializer=RandomUniform(minval= -0.153,
 maxval=0.153, seed=None)) )
arch7_model3.add(BatchNormalization())
```

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```
arch7_model3.add(Dropout(0.3))

arch7_model3.add(Dense(64, activation='relu', \
                       kernel_initializer=RandomUniform(minval= -0.216,
 maxval=0.216, seed=None)) )
arch7_model3.add(BatchNormalization())
arch7_model3.add(Dropout(0.3))

arch7_model3.add(Dense(output_dim, activation='softmax'))
arch7_model3.summary()
```

```
Model: "sequential_12"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_63 (Dense)             (None, 360)               282600
_________________________________________________________________
batch_normalization_37 (Batc (None, 360)               1440
_________________________________________________________________
dropout_22 (Dropout)         (None, 360)               0
_________________________________________________________________
dense_64 (Dense)             (None, 512)               184832
_________________________________________________________________
batch_normalization_38 (Batc (None, 512)               2048
_________________________________________________________________
dropout_23 (Dropout)         (None, 512)               0
_________________________________________________________________
dense_65 (Dense)             (None, 256)               131328
_________________________________________________________________
batch_normalization_39 (Batc (None, 256)               1024
_________________________________________________________________
dropout_24 (Dropout)         (None, 256)               0
_________________________________________________________________
dense_66 (Dense)             (None, 128)               32896
_________________________________________________________________
batch_normalization_40 (Batc (None, 128)               512
_________________________________________________________________
dropout_25 (Dropout)         (None, 128)               0
_________________________________________________________________
dense_67 (Dense)             (None, 64)                8256
```

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```
_________________________________________________________________
batch_normalization_41 (Batc (None, 64)                256
_________________________________________________________________
dropout_26 (Dropout)         (None, 64)                0
_________________________________________________________________
dense_68 (Dense)             (None, 10)                650
=================================================================
Total params: 645,842
Trainable params: 643,202
Non-trainable params: 2,640
_________________________________________________________________
```

3.2.3.3 Running the Neural Network on Train & Validation Datasets for 85 Epochs

In [57]:
```
arch7_model3.compile(optimizer='adam', loss='categorical_crossentropy',
 metrics=['accuracy'])

A7M3_history = arch7_model3.fit(X_train, Y_train, batch_size=batch_size
, epochs=nb_epoch, verbose=1, \
                             validation_data=(X_test, Y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/85
60000/60000 [==============================] - 14s 234us/step - loss:
0.5253 - accuracy: 0.8410 - val_loss: 0.1621 - val_accuracy: 0.9535
Epoch 2/85
60000/60000 [==============================] - 11s 191us/step - loss:
0.2111 - accuracy: 0.9398 - val_loss: 0.1126 - val_accuracy: 0.9667
Epoch 3/85
60000/60000 [==============================] - 11s 180us/step - loss:
0.1668 - accuracy: 0.9524 - val_loss: 0.0886 - val_accuracy: 0.9730
Epoch 4/85
60000/60000 [==============================] - 11s 184us/step - loss:
0.1378 - accuracy: 0.9600 - val_loss: 0.0857 - val_accuracy: 0.9754
Epoch 5/85
60000/60000 [==============================] - 11s 186us/step - loss:
0.1226 - accuracy: 0.9649 - val_loss: 0.0754 - val_accuracy: 0.9783
Epoch 6/85
```

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```
60000/60000 [==============================] - 11s 179us/step - loss:
0.1063 - accuracy: 0.9692 - val_loss: 0.0788 - val_accuracy: 0.9771
Epoch 7/85
60000/60000 [==============================] - 11s 190us/step - loss:
0.0979 - accuracy: 0.9721 - val_loss: 0.0715 - val_accuracy: 0.9791
Epoch 8/85
60000/60000 [==============================] - 11s 179us/step - loss:
0.0877 - accuracy: 0.9747 - val_loss: 0.0727 - val_accuracy: 0.9803
Epoch 9/85
60000/60000 [==============================] - 11s 179us/step - loss:
0.0817 - accuracy: 0.9763 - val_loss: 0.0719 - val_accuracy: 0.9806
Epoch 10/85
60000/60000 [==============================] - 11s 186us/step - loss:
0.0785 - accuracy: 0.9772 - val_loss: 0.0649 - val_accuracy: 0.9825
Epoch 11/85
60000/60000 [==============================] - 11s 185us/step - loss:
0.0723 - accuracy: 0.9782 - val_loss: 0.0743 - val_accuracy: 0.9802
Epoch 12/85
60000/60000 [==============================] - 11s 181us/step - loss:
0.0670 - accuracy: 0.9797 - val_loss: 0.0687 - val_accuracy: 0.9812
Epoch 13/85
60000/60000 [==============================] - 11s 184us/step - loss:
0.0688 - accuracy: 0.9799 - val_loss: 0.0601 - val_accuracy: 0.9830
Epoch 14/85
60000/60000 [==============================] - 11s 182us/step - loss:
0.0612 - accuracy: 0.9821 - val_loss: 0.0598 - val_accuracy: 0.9843
Epoch 15/85
60000/60000 [==============================] - 11s 181us/step - loss:
0.0602 - accuracy: 0.9826 - val_loss: 0.0679 - val_accuracy: 0.9821
Epoch 16/85
60000/60000 [==============================] - 11s 184us/step - loss:
0.0586 - accuracy: 0.9828 - val_loss: 0.0648 - val_accuracy: 0.9821
Epoch 17/85
60000/60000 [==============================] - 12s 196us/step - loss:
0.0549 - accuracy: 0.9845 - val_loss: 0.0603 - val_accuracy: 0.9823
Epoch 18/85
60000/60000 [==============================] - 11s 185us/step - loss:
0.0508 - accuracy: 0.9852 - val_loss: 0.0696 - val_accuracy: 0.9814
Epoch 19/85
```

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```
60000/60000 [==============================] - 11s 181us/step - loss:
0.0505 - accuracy: 0.9853 - val_loss: 0.0587 - val_accuracy: 0.9844
Epoch 20/85
60000/60000 [==============================] - 11s 179us/step - loss:
0.0474 - accuracy: 0.9861 - val_loss: 0.0587 - val_accuracy: 0.9849
Epoch 21/85
60000/60000 [==============================] - 11s 185us/step - loss:
0.0467 - accuracy: 0.9858 - val_loss: 0.0588 - val_accuracy: 0.9839
Epoch 22/85
60000/60000 [==============================] - 11s 179us/step - loss:
0.0400 - accuracy: 0.9880 - val_loss: 0.0580 - val_accuracy: 0.9860
Epoch 23/85
60000/60000 [==============================] - 11s 178us/step - loss:
0.0424 - accuracy: 0.9873 - val_loss: 0.0587 - val_accuracy: 0.9851
Epoch 24/85
60000/60000 [==============================] - 11s 176us/step - loss:
0.0428 - accuracy: 0.9875 - val_loss: 0.0555 - val_accuracy: 0.9838
Epoch 25/85
60000/60000 [==============================] - 10s 173us/step - loss:
0.0384 - accuracy: 0.9884 - val_loss: 0.0608 - val_accuracy: 0.9845
Epoch 26/85
60000/60000 [==============================] - 10s 174us/step - loss:
0.0382 - accuracy: 0.9887 - val_loss: 0.0642 - val_accuracy: 0.9845
Epoch 27/85
60000/60000 [==============================] - 11s 184us/step - loss:
0.0365 - accuracy: 0.9892 - val_loss: 0.0635 - val_accuracy: 0.9839
Epoch 28/85
60000/60000 [==============================] - 11s 180us/step - loss:
0.0356 - accuracy: 0.9894 - val_loss: 0.0623 - val_accuracy: 0.9839
Epoch 29/85
60000/60000 [==============================] - 11s 183us/step - loss:
0.0350 - accuracy: 0.9898 - val_loss: 0.0550 - val_accuracy: 0.9851
Epoch 30/85
60000/60000 [==============================] - 11s 178us/step - loss:
0.0343 - accuracy: 0.9898 - val_loss: 0.0626 - val_accuracy: 0.9852
Epoch 31/85
60000/60000 [==============================] - 11s 178us/step - loss:
0.0334 - accuracy: 0.9898 - val_loss: 0.0647 - val_accuracy: 0.9850
Epoch 32/85
```

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```
60000/60000 [==============================] - 11s 180us/step - loss:
0.0319 - accuracy: 0.9902 - val_loss: 0.0577 - val_accuracy: 0.9867
Epoch 33/85
60000/60000 [==============================] - 11s 177us/step - loss:
0.0330 - accuracy: 0.9905 - val_loss: 0.0575 - val_accuracy: 0.9859
Epoch 34/85
60000/60000 [==============================] - 11s 177us/step - loss:
0.0313 - accuracy: 0.9910 - val_loss: 0.0594 - val_accuracy: 0.9852
Epoch 35/85
60000/60000 [==============================] - 11s 188us/step - loss:
0.0299 - accuracy: 0.9912 - val_loss: 0.0596 - val_accuracy: 0.9857
Epoch 36/85
60000/60000 [==============================] - 11s 187us/step - loss:
0.0305 - accuracy: 0.9911 - val_loss: 0.0559 - val_accuracy: 0.9860
Epoch 37/85
60000/60000 [==============================] - 11s 176us/step - loss:
0.0289 - accuracy: 0.9913 - val_loss: 0.0588 - val_accuracy: 0.9852
Epoch 38/85
60000/60000 [==============================] - 11s 189us/step - loss:
0.0311 - accuracy: 0.9904 - val_loss: 0.0610 - val_accuracy: 0.9860
Epoch 39/85
60000/60000 [==============================] - 13s 216us/step - loss:
0.0281 - accuracy: 0.9916 - val_loss: 0.0595 - val_accuracy: 0.9854
Epoch 40/85
60000/60000 [==============================] - 11s 178us/step - loss:
0.0265 - accuracy: 0.9921 - val_loss: 0.0577 - val_accuracy: 0.9870
Epoch 41/85
60000/60000 [==============================] - 11s 180us/step - loss:
0.0277 - accuracy: 0.9918 - val_loss: 0.0554 - val_accuracy: 0.9873
Epoch 42/85
60000/60000 [==============================] - 11s 181us/step - loss:
0.0256 - accuracy: 0.9922 - val_loss: 0.0553 - val_accuracy: 0.9858
Epoch 43/85
60000/60000 [==============================] - 11s 182us/step - loss:
0.0260 - accuracy: 0.9921 - val_loss: 0.0593 - val_accuracy: 0.9863
Epoch 44/85
60000/60000 [==============================] - 11s 191us/step - loss:
0.0239 - accuracy: 0.9927 - val_loss: 0.0651 - val_accuracy: 0.9848
Epoch 45/85
```

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```
60000/60000 [==============================] - 10s 174us/step - loss:
0.0248 - accuracy: 0.9926 - val_loss: 0.0603 - val_accuracy: 0.9864
Epoch 46/85
60000/60000 [==============================] - 10s 174us/step - loss:
0.0219 - accuracy: 0.9935 - val_loss: 0.0650 - val_accuracy: 0.9856
Epoch 47/85
60000/60000 [==============================] - 11s 190us/step - loss:
0.0222 - accuracy: 0.9932 - val_loss: 0.0621 - val_accuracy: 0.9864
Epoch 48/85
60000/60000 [==============================] - 11s 176us/step - loss:
0.0228 - accuracy: 0.9933 - val_loss: 0.0626 - val_accuracy: 0.9848
Epoch 49/85
60000/60000 [==============================] - 11s 177us/step - loss:
0.0228 - accuracy: 0.9934 - val_loss: 0.0648 - val_accuracy: 0.9860
Epoch 50/85
60000/60000 [==============================] - 11s 178us/step - loss:
0.0227 - accuracy: 0.9931 - val_loss: 0.0607 - val_accuracy: 0.9863
Epoch 51/85
60000/60000 [==============================] - 10s 174us/step - loss:
0.0210 - accuracy: 0.9938 - val_loss: 0.0617 - val_accuracy: 0.9871
Epoch 52/85
60000/60000 [==============================] - 10s 173us/step - loss:
0.0194 - accuracy: 0.9942 - val_loss: 0.0619 - val_accuracy: 0.9856
Epoch 53/85
60000/60000 [==============================] - 11s 177us/step - loss:
0.0177 - accuracy: 0.9948 - val_loss: 0.0575 - val_accuracy: 0.9878
Epoch 54/85
60000/60000 [==============================] - 12s 193us/step - loss:
0.0203 - accuracy: 0.9937 - val_loss: 0.0633 - val_accuracy: 0.9860
Epoch 55/85
60000/60000 [==============================] - 10s 171us/step - loss:
0.0198 - accuracy: 0.9941 - val_loss: 0.0600 - val_accuracy: 0.9869
Epoch 56/85
60000/60000 [==============================] - 13s 219us/step - loss:
0.0193 - accuracy: 0.9942 - val_loss: 0.0605 - val_accuracy: 0.9856
Epoch 57/85
60000/60000 [==============================] - 14s 239us/step - loss:
0.0196 - accuracy: 0.9944 - val_loss: 0.0640 - val_accuracy: 0.9862
Epoch 58/85
```

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```
60000/60000 [==============================] - 14s 239us/step - loss:
0.0178 - accuracy: 0.9945 - val_loss: 0.0631 - val_accuracy: 0.9858
Epoch 59/85
60000/60000 [==============================] - 12s 205us/step - loss:
0.0221 - accuracy: 0.9933 - val_loss: 0.0567 - val_accuracy: 0.9876
Epoch 60/85
60000/60000 [==============================] - 11s 181us/step - loss:
0.0189 - accuracy: 0.9943 - val_loss: 0.0614 - val_accuracy: 0.9864
Epoch 61/85
60000/60000 [==============================] - 11s 178us/step - loss:
0.0177 - accuracy: 0.9946 - val_loss: 0.0643 - val_accuracy: 0.9854
Epoch 62/85
60000/60000 [==============================] - 11s 183us/step - loss:
0.0177 - accuracy: 0.9943 - val_loss: 0.0626 - val_accuracy: 0.9870
Epoch 63/85
60000/60000 [==============================] - 11s 186us/step - loss:
0.0190 - accuracy: 0.9942 - val_loss: 0.0608 - val_accuracy: 0.9869
Epoch 64/85
60000/60000 [==============================] - 11s 184us/step - loss:
0.0174 - accuracy: 0.9949 - val_loss: 0.0608 - val_accuracy: 0.9867
Epoch 65/85
60000/60000 [==============================] - 11s 183us/step - loss:
0.0176 - accuracy: 0.9945 - val_loss: 0.0560 - val_accuracy: 0.9880
Epoch 66/85
60000/60000 [==============================] - 11s 180us/step - loss:
0.0169 - accuracy: 0.9944 - val_loss: 0.0648 - val_accuracy: 0.9860
Epoch 67/85
60000/60000 [==============================] - 11s 185us/step - loss:
0.0169 - accuracy: 0.9949 - val_loss: 0.0646 - val_accuracy: 0.9866
Epoch 68/85
60000/60000 [==============================] - 11s 180us/step - loss:
0.0146 - accuracy: 0.9959 - val_loss: 0.0643 - val_accuracy: 0.9883
Epoch 69/85
60000/60000 [==============================] - 11s 180us/step - loss:
0.0197 - accuracy: 0.9940 - val_loss: 0.0571 - val_accuracy: 0.9868
Epoch 70/85
60000/60000 [==============================] - 11s 191us/step - loss:
0.0159 - accuracy: 0.9953 - val_loss: 0.0622 - val_accuracy: 0.9861
Epoch 71/85
```

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```
60000/60000 [==============================] - 11s 186us/step - loss:
0.0148 - accuracy: 0.9955 - val_loss: 0.0602 - val_accuracy: 0.9866
Epoch 72/85
60000/60000 [==============================] - 11s 178us/step - loss:
0.0171 - accuracy: 0.9950 - val_loss: 0.0602 - val_accuracy: 0.9868
Epoch 73/85
60000/60000 [==============================] - 11s 177us/step - loss:
0.0154 - accuracy: 0.9954 - val_loss: 0.0595 - val_accuracy: 0.9872
Epoch 74/85
60000/60000 [==============================] - 11s 178us/step - loss:
0.0151 - accuracy: 0.9954 - val_loss: 0.0604 - val_accuracy: 0.9862
Epoch 75/85
60000/60000 [==============================] - 12s 202us/step - loss:
0.0162 - accuracy: 0.9950 - val_loss: 0.0613 - val_accuracy: 0.9872
Epoch 76/85
60000/60000 [==============================] - 15s 248us/step - loss:
0.0161 - accuracy: 0.9952 - val_loss: 0.0621 - val_accuracy: 0.9870
Epoch 77/85
60000/60000 [==============================] - 15s 253us/step - loss:
0.0135 - accuracy: 0.9958 - val_loss: 0.0557 - val_accuracy: 0.9880
Epoch 78/85
60000/60000 [==============================] - 15s 256us/step - loss:
0.0142 - accuracy: 0.9957 - val_loss: 0.0598 - val_accuracy: 0.9859
Epoch 79/85
60000/60000 [==============================] - 15s 255us/step - loss:
0.0149 - accuracy: 0.9955 - val_loss: 0.0586 - val_accuracy: 0.9877
Epoch 80/85
60000/60000 [==============================] - 15s 257us/step - loss:
0.0135 - accuracy: 0.9959 - val_loss: 0.0626 - val_accuracy: 0.9860
Epoch 81/85
60000/60000 [==============================] - 12s 195us/step - loss:
0.0136 - accuracy: 0.9960 - val_loss: 0.0635 - val_accuracy: 0.9867
Epoch 82/85
60000/60000 [==============================] - 10s 174us/step - loss:
0.0137 - accuracy: 0.9960 - val_loss: 0.0646 - val_accuracy: 0.9858
Epoch 83/85
60000/60000 [==============================] - 11s 182us/step - loss:
0.0133 - accuracy: 0.9959 - val_loss: 0.0658 - val_accuracy: 0.9864
Epoch 84/85
```

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```
60000/60000 [==============================] - 11s 181us/step - loss:
0.0144 - accuracy: 0.9958 - val_loss: 0.0642 - val_accuracy: 0.9861
Epoch 85/85
60000/60000 [==============================] - 11s 186us/step - loss:
0.0121 - accuracy: 0.9963 - val_loss: 0.0642 - val_accuracy: 0.9874
```

3.2.3.4 Number of Epochs vs Train Loss & Validation Loss

In [58]:

```
warnings.filterwarnings("ignore")

A7M3_score = arch7_model3.evaluate(X_test, Y_test, verbose=0)
print('Test score:', A7M3_score[0])
print('Test accuracy:', A7M3_score[1])

fig,ax = plt.subplots(1,1)
ax.set_xlabel('epoch') ; ax.set_ylabel('Categorical Crossentropy Loss')

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

# print(history.history.keys())
# dict_keys(['val_loss', 'val_acc', 'loss', 'acc'])
# history = model_drop.fit(X_train, Y_train, batch_size=batch_size, epo
chs=nb_epoch, verbose=1, validation_data=(X_test, Y_test))

# we will get val_loss and val_acc only when you pass the paramter vali
dation_data
# val_loss : validation loss
# val_acc : validation accuracy

# loss : training loss
# acc : train accuracy
# for each key in history.history we will have a list of length equal t
o number of epochs

vy = A7M3_history.history['val_loss']
ty = A7M3_history.history['loss']
plt_dynamic(x, vy, ty, ax)
```

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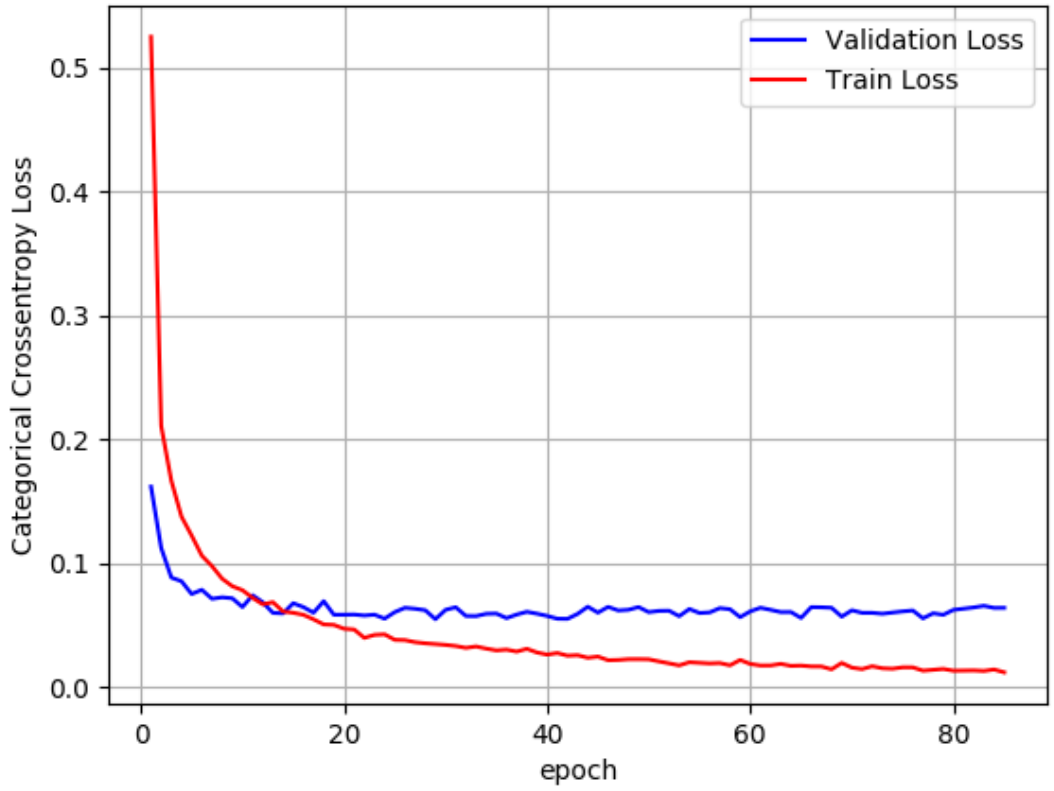
```
Test score: 0.06421894468564132
Test accuracy: 0.9873999953269958
```



3.2.3.5 Violin Plots for Hidden Layers in the Models Trained

In [59]:
```
w_after = arch7_model3.get_weights()

h1_w = w_after[0].flatten().reshape(-1,1)
h2_w = w_after[2].flatten().reshape(-1,1)
```

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```
h3_w = w_after[4].flatten().reshape(-1,1)
h4_w = w_after[6].flatten().reshape(-1,1)
h5_w = w_after[8].flatten().reshape(-1,1)
out_w = w_after[10].flatten().reshape(-1,1)

fig = plt.figure()
fig.suptitle('Weight Matrices after Model Trained', fontsize=17)

plt.subplot(1, 6, 1)
ax = sns.violinplot(y=h1_w,color='b')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL1')

plt.subplot(1, 6, 2)
ax = sns.violinplot(y=h2_w, color='r')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL2 ')

plt.subplot(1, 6, 3)
ax = sns.violinplot(y=h3_w, color='g')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL3 ')

plt.subplot(1, 6, 4)
ax = sns.violinplot(y=h4_w, color='m')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL4 ')

plt.subplot(1, 6, 5)
ax = sns.violinplot(y=h5_w, color='c')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('HL5 ')

plt.subplot(1, 6, 6)
ax = sns.violinplot(y=out_w,color='y')
ax.set_title('Trained Model Weights',fontsize= 5)
plt.xlabel('Out')
plt.show()
```

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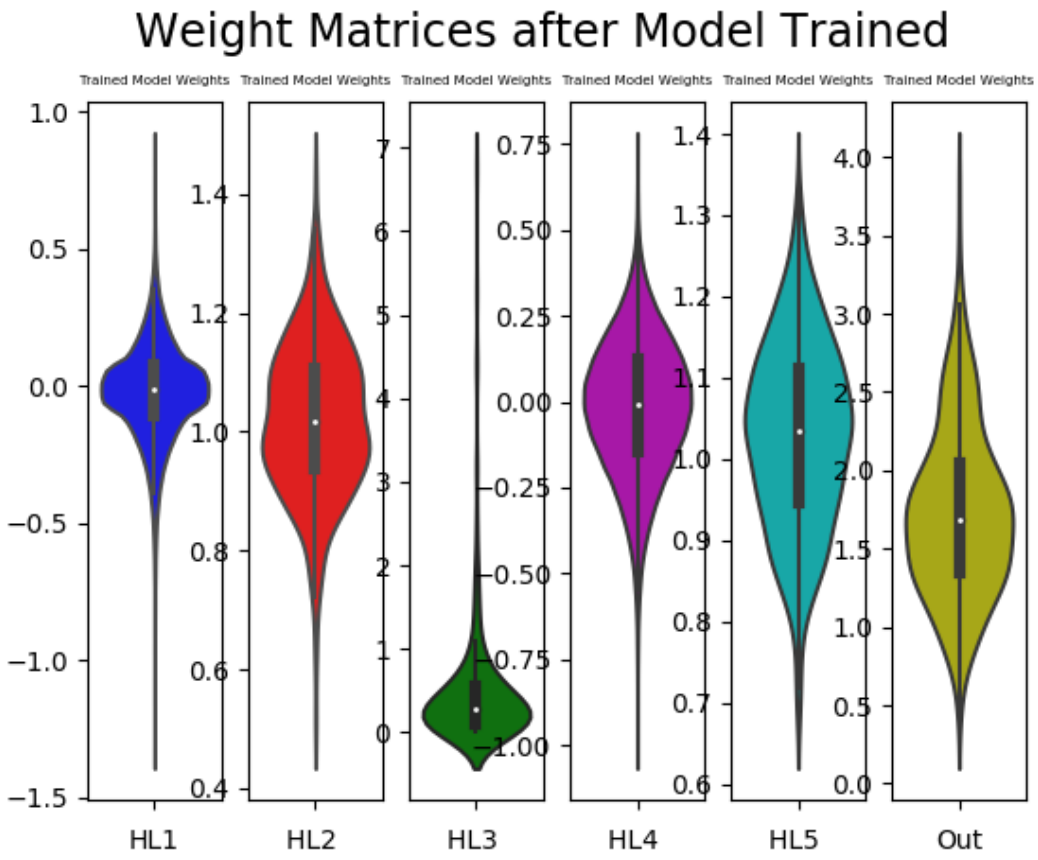

4. Conclusion

The MNIST Dataset is a dataset of Handwritten Characters pertaining to 10 integers from 0 to 9, which is used for Training in the case of Many Image Processing Tasks. We have an input square image of size (28 px* 28 px), which makes the corresponding vector that we obtain to be 784-dimensional. After this, we obtain a Matrix of this dimensionality where each cell in the Matrix corresponds to an integral number from 0 to 255 -> The Higher is the value of this number, the darker that particular pixel value is.

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There are a total of 60,000 Training Datapoints and a total of 10,000 Test Datapoints in MNIST. We build various models in order to try and minimize our Test Accuracy and Test Log Loss values. We train each of our models on a total of 85 epochs so that the value is not too small for SGD type Optimizations to try and achieve convergence.

First, we work on an architecture with 2 Hidden Layers (784-512-128-10) and employ all of our possible Activations (sigmoid and ReLU) and optimizations on top of it, after which we can easily realise that a ReLU Activation and an Adam Optimizer is going to give us the best result, which is the reason why we only employ these model types on our remaining architectures. We work on 3 models for each of the architectures that we build : Simple Model with ReLU and Adam, a model with Batch Normalization added and the other also having a Dropout Value. For all of these cases, we are carrying out weight initialization with the help of He-Uniform, which is a very good technique for ReLUs as well as Leaky ReLUs.

We know that Batch Normalization acts as a Weak Regularizer, which is the reason that we also need a Dropout value. We could have added a Dropout value only in the deeper layers of a Neural Network, however, we add the same after every layer in this case. Dropout Value is a Hyperparameter that we tune with the help of GridSearchCV (integrating both keras as well as sklearn).

A couple of important parameters is the number of layers in a Neural Network as well as the number of neurons in each layer. Since our input is 784 dimensional and the output softmax is 10 dimensional, these numbers will remain constant. But we can try various values ie. each layer would have a neuron count in the range of (10-784).There is no clear consensus on what is the best way to make this decision, except to try out various architectures. That is the reason why we try multiple architectures across 2,3 and 5 hidden layers.

We are training all the models on a fix number of 85 epochs for each model for better comparison. However, for each model we also compare the Loss Value across different epoch numbers for Train and Validation Datasets, so as to the Epoch Number for which this loss is minimum. Along with this, we also need to ensure that the gap between the Train and Validation curves in this plot is not too big, which would indicate overfitting in such a scenario. After this, we also plot the weight distribution across different hidden layers and the output layer with the help of a violin plot.

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The Summary of each of our models that we have built so far is as shown below :

In [6]:
```
from prettytable import PrettyTable

x=PrettyTable()
x.field_names=["Arch #","Model","Test Accuracy","Test Log Loss"]

print ("Metrics for a 2 Hidden Layer Architecture - 784-512-128-10 afte
r 85 Epochs :")
print("="*100)

x.add_row(["Arch 1","Softmax Classifier (Single Layer)", "92.15%","0.28
56"])
x.add_row(["Arch 1","MLP + Sigmoid + SGD", "91.97%","0.2764"])
x.add_row(["Arch 1","MLP + Sigmoid + Adam", "98.40%","0.0970"])
x.add_row(["Arch 1","MLP + ReLU (He-Normal) + SGD", "97.71%","0.0722"])
x.add_row(["Arch 1","MLP + ReLU (He-Normal) + Adam", "98.41%","0.1379"
])
x.add_row(["Arch 1","MLP + ReLU (He-Normal) + BN + Adam", "97.74%","0.1
269"])
x.add_row(["Arch 1","MLP + ReLU (He-Normal) + BN + Dropout + Adam", "9
8.33%","0.0667"])

print(x)

print('-'*100)

y=PrettyTable()
y.field_names=["Arch #","Architecture","Model","Test Accuracy","Test Lo
g Loss"]

print ("Metrics for other 2 Hidden Layer Architectures after 85 Epochs
 :")
print("="*100)

y.add_row(["Arch 2","784-500-125-10","MLP + ReLU (He-Uniform) + Adam",
"98.70%","0.1176"])
y.add_row(["Arch 2","784-500-125-10","MLP + ReLU (He-Uniform) + BN + Ad
am", "98.22%","0.1126"])
```

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```
y.add_row(["Arch 2","784-500-125-10","MLP + ReLU (He-Uniform) + BN + Dr
opout + Adam", "98.55%","0.0670"])
y.add_row(["Arch 3","784-256-64-10","MLP + ReLU (He-Uniform) + Adam",
"98.21%","0.1540"])
y.add_row(["Arch 3","784-500-125-10","MLP + ReLU (He-Uniform) + BN + Ad
am", "98.22%","0.1126"])
y.add_row(["Arch 3","784-500-125-10","MLP + ReLU (He-Uniform) + BN + Dr
opout + Adam", "98.55%","0.0670"])
print(y)

print('-'*100)

z=PrettyTable()
z.field_names=["Arch #","Architecture","Model","Test Accuracy","Test Lo
g Loss"]

print ("Metrics for 3 Hidden Layer Architectures after 85 Epochs :")
print("="*100)

z.add_row(["Arch 4","784-512-256-128-10","MLP + ReLU (He-Uniform) + Ada
m", "98.52%","0.1345"])
z.add_row(["Arch 4","784-512-256-128-10","MLP + ReLU (He-Uniform) + BN
 + Adam", "98.52%","0.0853"])
z.add_row(["Arch 4","784-512-256-128-10","MLP + ReLU (He-Uniform) + BN
 + Dropout + Adam", "98.44%","0.0677"])
z.add_row(["Arch 5","784-500-250-125-10","MLP + ReLU (He-Uniform) + Ada
m", "98.58%","0.1482"])
z.add_row(["Arch 5","784-500-250-125-10","MLP + ReLU (He-Uniform) + BN
 + Adam", "98.33%","0.0980"])
z.add_row(["Arch 5","784-500-250-125-10","MLP + ReLU (He-Uniform) + BN
 + Dropout + Adam", "98.60%","0.0669"])
print(z)

print('-'*100)

a=PrettyTable()
a.field_names=["Arch #","Architecture","Model","Test Accuracy","Test Lo
g Loss"]
```

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```
print ("Metrics for 5 Hidden Layer Architectures after 85 Epochs :")
print("="*100)

a.add_row(["Arch 6","784-512-256-128-64-32-10","MLP + ReLU (He-Uniform)
 + Adam", "98.54%","0.1241"])
a.add_row(["Arch 6","784-512-256-128-64-32-10","MLP + ReLU (He-Uniform)
 + BN + Adam", "98.37%","0.0873"])
a.add_row(["Arch 6","784-512-256-128-64-32-10","MLP + ReLU (He-Uniform)
 + BN + Dropout + Adam", "98.71%","0.0727"])
a.add_row(["Arch 7","784-360-512-256-128-64-10","MLP + ReLU (He-Unifor
m) + Adam", "98.51%","0.2239"])
a.add_row(["Arch 7","784-360-512-256-128-64-10","MLP + ReLU (He-Unifor
m) + BN + Adam", "98.62%","0.0801"])
a.add_row(["Arch 7","784-360-512-256-128-64-10","MLP + ReLU (He-Unifor
m) + BN + Dropout + Adam", "98.74%","0.0642"])
print(a)
```

```
Metrics for a 2 Hidden Layer Architecture - 784-512-128-10 after 85 Epo
chs :
=====================================================================
==============================
+--------+-----------------------------------------------+--------------
-+---------------+
| Arch # |                     Model                     | Test Accuracy
| Test Log Loss |
+--------+-----------------------------------------------+--------------
-+---------------+
| Arch 1 |      Softmax Classifier (Single Layer)        |     92.15%
|     0.2856     |
| Arch 1 |             MLP + Sigmoid + SGD               |     91.97%
|     0.2764     |
| Arch 1 |             MLP + Sigmoid + Adam              |     98.40%
|     0.0970     |
| Arch 1 |         MLP + ReLU (He-Normal) + SGD          |     97.71%
|     0.0722     |
| Arch 1 |        MLP + ReLU (He-Normal) + Adam          |     98.41%
|     0.1379     |
| Arch 1 |      MLP + ReLU (He-Normal) + BN + Adam       |     97.74%
|     0.1269     |
| Arch 1 | MLP + ReLU (He-Normal) + BN + Dropout + Adam |     98.33%
```

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```
|     0.0667    |
+--------+-----------------------------------------------+--------------
-+---------------+
-----------------------------------------------------------------------
-----------------------------
Metrics for other 2 Hidden Layer Architectures after 85 Epochs :
=======================================================================
============================
+--------+----------------+---------------------------------------------
---+---------------+---------------+

| Arch # |  Architecture  |                      Model
   | Test Accuracy | Test Log Loss |
+--------+----------------+---------------------------------------------
---+---------------+---------------+
| Arch 2 | 784-500-125-10 |         MLP + ReLU (He-Uniform) + Adam
   |     98.70%    |     0.1176    |
| Arch 2 | 784-500-125-10 |      MLP + ReLU (He-Uniform) + BN + Adam
   |     98.22%    |     0.1126    |
| Arch 2 | 784-500-125-10 | MLP + ReLU (He-Uniform) + BN + Dropout + Ad
am |     98.55%    |     0.0670    |
| Arch 3 | 784-256-64-10  |         MLP + ReLU (He-Uniform) + Adam
   |     98.21%    |     0.1540    |
| Arch 3 | 784-500-125-10 |      MLP + ReLU (He-Uniform) + BN + Adam
   |     98.22%    |     0.1126    |
| Arch 3 | 784-500-125-10 | MLP + ReLU (He-Uniform) + BN + Dropout + Ad
am |     98.55%    |     0.0670    |
+--------+----------------+---------------------------------------------
---+---------------+---------------+
-----------------------------------------------------------------------
-----------------------------
Metrics for 3 Hidden Layer Architectures after 85 Epochs :
=======================================================================
============================
+--------+--------------------+----------------------------------------
-------+---------------+---------------+
| Arch # |    Architecture    |                      Model
       | Test Accuracy | Test Log Loss |
+--------+--------------------+----------------------------------------
-------+---------------+---------------+
| Arch 4 | 784-512-256-128-10 |         MLP + ReLU (He-Uniform) + Adam
```

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```
| Arch 4 | 784-512-256-128-10 |         MLP + ReLU (He-Uniform) + Adam
       |     98.52%    |     0.1345    |
| Arch 4 | 784-512-256-128-10 |      MLP + ReLU (He-Uniform) + BN + Ada
m      |     98.52%    |     0.0853    |
| Arch 4 | 784-512-256-128-10 | MLP + ReLU (He-Uniform) + BN + Dropout
+ Adam |     98.44%    |     0.0677    |
| Arch 5 | 784-500-250-125-10 |         MLP + ReLU (He-Uniform) + Adam
       |     98.58%    |     0.1482    |
| Arch 5 | 784-500-250-125-10 |      MLP + ReLU (He-Uniform) + BN + Ada
m      |     98.33%    |     0.0980    |

| Arch 5 | 784-500-250-125-10 | MLP + ReLU (He-Uniform) + BN + Dropout
+ Adam |     98.60%    |     0.0669    |
+--------+--------------------+---------------------------------------
-------+---------------+---------------+
-----------------------------------------------------------------------
-----------------------------
Metrics for 5 Hidden Layer Architectures after 85 Epochs :
=======================================================================
==============================
+--------+---------------------------+--------------------------------
--------------+---------------+---------------+
| Arch # |        Architecture       |                     Model
              | Test Accuracy | Test Log Loss |
+--------+---------------------------+--------------------------------
--------------+---------------+---------------+
| Arch 6 |  784-512-256-128-64-32-10 |         MLP + ReLU (He-Uniform)
+ Adam        |     98.54%    |     0.1241    |
| Arch 6 |  784-512-256-128-64-32-10 |      MLP + ReLU (He-Uniform) + B
N + Adam      |     98.37%    |     0.0873    |
| Arch 6 |  784-512-256-128-64-32-10 | MLP + ReLU (He-Uniform) + BN + D
ropout + Adam |     98.71%    |     0.0727    |
| Arch 7 | 784-360-512-256-128-64-10 |         MLP + ReLU (He-Uniform)
+ Adam        |     98.51%    |     0.2239    |
| Arch 7 | 784-360-512-256-128-64-10 |      MLP + ReLU (He-Uniform) + B
N + Adam      |     98.62%    |     0.0801    |
| Arch 7 | 784-360-512-256-128-64-10 | MLP + ReLU (He-Uniform) + BN + D
ropout + Adam |     98.74%    |     0.0642    |
+--------+---------------------------+--------------------------------
--------------+---------------+---------------+
```

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