Created by:

Shubhnoor Gill

18BCS6061

B.E. CSE(AIML)-1

Group-B

Comparison of Activation Functions using MNIST Dataset

For this purpose, a simple ANN model was used for the MNIST dataset.

- Rectified Linear Unit(ReLU) Function
- Sigmoid Function
- Hyperbolic Tangent Function
- Swish Function
- Scaled Exponential Linear Unit (SELU) Function

The loss, validation, training accuracy for the different activation function with the respective plots is shown in this notebook.

In [1]:
```
# Importing the required libraries
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
from keras.datasets import mnist
from keras.utils import plot_model
from sklearn.model_selection import train_test_split
from keras.utils import np_utils # used for categorisation
from keras.models import Sequential
from keras.layers import Dense
from keras.optimizers import Adam
```
```
Using TensorFlow backend.
```

In [2]:
```
# Unpacking dataset into train and test
(X_train, y_train), (X_test, y_test) = mnist.load_data()
```

In [3]:
```
X_train.shape
```
Out[3]:
```
(60000, 28, 28)
```

In [4]:
```
# Data Pre-processing

n = X_train.shape[1] * X_train.shape[2] # flatten this array into a vector of  28×28=784
X_train = X_train.reshape(X_train.shape[0], n).astype('float32') #type to cast one or more of the DataF
rame's columns to column-specific types.
X_test = X_test.reshape(X_test.shape[0], n).astype('float32')
X_train = X_train / 255 # convert into fully black and fully white
X_test = X_test / 255
y_train = np_utils.to_categorical(y_train) # digits are 0-9, so we have 10 classes, one hot encoding
y_test = np_utils.to_categorical(y_test) #Converts a class vector (integers) to binary class matrix.
num_classes = y_test.shape[1]
```

In [5]:
```
X_train.shape
```
Out[5]:
```
(60000, 784)
```

In [6]:
```
X_test.shape
```
Out[6]:
```
(10000, 784)
```

Rectified Linear Unit (ReLU) Activation Function

In [7]:
```
RELU_model = Sequential()

RELU_model.add(Dense(500, input_dim=n, activation='relu'))

RELU_model.add(Dense(100, activation='relu'))

RELU_model.add(Dense(num_classes, activation='softmax'))

# Compile model

RELU_model.compile(loss='categorical_crossentropy', optimizer='adam', metrics=['accuracy'])
RELU_model.summary()
```
```
Model: "sequential_1"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_1 (Dense)              (None, 500)               392500
_________________________________________________________________
dense_2 (Dense)              (None, 100)               50100
_________________________________________________________________
dense_3 (Dense)              (None, 10)                1010
=================================================================
Total params: 443,610
Trainable params: 443,610
Non-trainable params: 0
_________________________________________________________________
```

Result of Train and Test

In [8]:
```
hist_relu=RELU_model.fit(X_train, y_train, validation_data=(X_test, y_test), epochs=10, batch_size=200)
scores_relu = RELU_model.evaluate(X_test, y_test)
print('Test loss:', scores_relu[0])
print('Test accuracy:', scores_relu[1])
```
```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 2s 35us/step - loss: 0.2723 - accuracy: 0.9215 - val_l
oss: 0.1248 - val_accuracy: 0.9632
Epoch 2/10
60000/60000 [==============================] - 2s 28us/step - loss: 0.0990 - accuracy: 0.9715 - val_l
oss: 0.0997 - val_accuracy: 0.9685
Epoch 3/10
60000/60000 [==============================] - 2s 32us/step - loss: 0.0638 - accuracy: 0.9808 - val_l
oss: 0.0719 - val_accuracy: 0.9765
Epoch 4/10
60000/60000 [==============================] - 2s 31us/step - loss: 0.0442 - accuracy: 0.9869 - val_l
oss: 0.0623 - val_accuracy: 0.9797
Epoch 5/10
60000/60000 [==============================] - 2s 28us/step - loss: 0.0310 - accuracy: 0.9904 - val_l
oss: 0.0613 - val_accuracy: 0.9811
Epoch 6/10
60000/60000 [==============================] - 2s 28us/step - loss: 0.0237 - accuracy: 0.9929 - val_l
oss: 0.0711 - val_accuracy: 0.9786
Epoch 7/10
60000/60000 [==============================] - 2s 32us/step - loss: 0.0176 - accuracy: 0.9943 - val_l
oss: 0.0657 - val_accuracy: 0.9817
Epoch 8/10
60000/60000 [==============================] - 2s 37us/step - loss: 0.0135 - accuracy: 0.9959 - val_l
oss: 0.0679 - val_accuracy: 0.9798
Epoch 9/10
60000/60000 [==============================] - 2s 33us/step - loss: 0.0122 - accuracy: 0.9964 - val_l
oss: 0.0720 - val_accuracy: 0.9805
Epoch 10/10
60000/60000 [==============================] - 2s 36us/step - loss: 0.0104 - accuracy: 0.9968 - val_l
oss: 0.0692 - val_accuracy: 0.9792
10000/10000 [==============================] - 1s 84us/step
Test loss: 0.06924099981761683
Test accuracy: 0.979200005531311
```

Sigmoid Activation Function

In [9]:
```
SIG_model = Sequential()

SIG_model.add(Dense(500, input_dim=n, activation='sigmoid'))

SIG_model.add(Dense(100, activation='sigmoid'))

SIG_model.add(Dense(num_classes, activation='softmax'))

# Compile model

SIG_model.compile(loss='categorical_crossentropy', optimizer='adam', metrics=['accuracy'])
SIG_model.summary()
```
```
Model: "sequential_2"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_4 (Dense)              (None, 500)               392500
_________________________________________________________________
dense_5 (Dense)              (None, 100)               50100
_________________________________________________________________
dense_6 (Dense)              (None, 10)                1010
=================================================================
Total params: 443,610
Trainable params: 443,610
Non-trainable params: 0
_________________________________________________________________
```

Result of Train and Test

In [10]:
```
hist_sig=SIG_model.fit(X_train, y_train, validation_data=(X_test, y_test), epochs=10, batch_size=200)
scores_sig = SIG_model.evaluate(X_test, y_test)
print('Test loss:', scores_sig[0])
print('Test accuracy:', scores_sig[1])
```
```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 2s 38us/step - loss: 0.7180 - accuracy: 0.8184 - val_l
oss: 0.3013 - val_accuracy: 0.9162
Epoch 2/10
60000/60000 [==============================] - 2s 38us/step - loss: 0.2614 - accuracy: 0.9248 - val_l
oss: 0.2189 - val_accuracy: 0.9362
Epoch 3/10
60000/60000 [==============================] - 3s 44us/step - loss: 0.1986 - accuracy: 0.9421 - val_l
oss: 0.1752 - val_accuracy: 0.9481
Epoch 4/10
60000/60000 [==============================] - 2s 36us/step - loss: 0.1582 - accuracy: 0.9535 - val_l
oss: 0.1463 - val_accuracy: 0.9555
Epoch 5/10
60000/60000 [==============================] - 2s 37us/step - loss: 0.1291 - accuracy: 0.9626 - val_l
oss: 0.1267 - val_accuracy: 0.9619
Epoch 6/10
60000/60000 [==============================] - 2s 29us/step - loss: 0.1059 - accuracy: 0.9690 - val_l
oss: 0.1075 - val_accuracy: 0.9669
Epoch 7/10
60000/60000 [==============================] - 2s 29us/step - loss: 0.0875 - accuracy: 0.9744 - val_l
oss: 0.0945 - val_accuracy: 0.9704
Epoch 8/10
60000/60000 [==============================] - 2s 33us/step - loss: 0.0735 - accuracy: 0.9790 - val_l
oss: 0.0905 - val_accuracy: 0.9727
Epoch 9/10
60000/60000 [==============================] - 2s 26us/step - loss: 0.0611 - accuracy: 0.9825 - val_l
oss: 0.0805 - val_accuracy: 0.9735
Epoch 10/10
60000/60000 [==============================] - 2s 32us/step - loss: 0.0522 - accuracy: 0.9848 - val_l
oss: 0.0764 - val_accuracy: 0.9764
10000/10000 [==============================] - 1s 77us/step
Test loss: 0.07643256488069892
Test accuracy: 0.9764000177383423
```

Hyperbolic Tangent Activation Function

In [11]:
```
HTan_model = Sequential()

HTan_model.add(Dense(500, input_dim=n, activation='tanh'))

HTan_model.add(Dense(100, activation='tanh'))

HTan_model.add(Dense(num_classes, activation='softmax'))

# Compile model

HTan_model.compile(loss='categorical_crossentropy', optimizer='adam', metrics=['accuracy'])
HTan_model.summary()
```
```
Model: "sequential_3"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_7 (Dense)              (None, 500)               392500
_________________________________________________________________
dense_8 (Dense)              (None, 100)               50100
_________________________________________________________________
dense_9 (Dense)              (None, 10)                1010
=================================================================
Total params: 443,610
Trainable params: 443,610
Non-trainable params: 0
_________________________________________________________________
```

Result of Train and Test

In [12]:
```
hist_htan=HTan_model.fit(X_train, y_train, validation_data=(X_test, y_test), epochs=10, batch_size=200)
scores_htan =HTan_model.evaluate(X_test, y_test)
print('Test loss:', scores_htan[0])
print('Test accuracy:', scores_htan[1])
```
```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 2s 37us/step - loss: 0.3003 - accuracy: 0.9115 - val_l
oss: 0.1729 - val_accuracy: 0.9491
Epoch 2/10
60000/60000 [==============================] - 2s 29us/step - loss: 0.1475 - accuracy: 0.9576 - val_l
oss: 0.1285 - val_accuracy: 0.9631
Epoch 3/10
60000/60000 [==============================] - 2s 34us/step - loss: 0.1041 - accuracy: 0.9700 - val_l
oss: 0.1025 - val_accuracy: 0.9705
Epoch 4/10
60000/60000 [==============================] - 2s 32us/step - loss: 0.0806 - accuracy: 0.9764 - val_l
oss: 0.0925 - val_accuracy: 0.9730
Epoch 5/10
60000/60000 [==============================] - 2s 29us/step - loss: 0.0616 - accuracy: 0.9821 - val_l
oss: 0.0827 - val_accuracy: 0.9749
Epoch 6/10
60000/60000 [==============================] - 2s 30us/step - loss: 0.0487 - accuracy: 0.9861 - val_l
oss: 0.0696 - val_accuracy: 0.9777
Epoch 7/10
60000/60000 [==============================] - 2s 30us/step - loss: 0.0374 - accuracy: 0.9897 - val_l
oss: 0.0783 - val_accuracy: 0.9760
Epoch 8/10
60000/60000 [==============================] - 2s 28us/step - loss: 0.0307 - accuracy: 0.9915 - val_l
oss: 0.0748 - val_accuracy: 0.9777
Epoch 9/10
60000/60000 [==============================] - 2s 28us/step - loss: 0.0235 - accuracy: 0.9943 - val_l
oss: 0.0685 - val_accuracy: 0.9792
Epoch 10/10
60000/60000 [==============================] - 2s 28us/step - loss: 0.0189 - accuracy: 0.9958 - val_l
oss: 0.0713 - val_accuracy: 0.9792
10000/10000 [==============================] - 1s 77us/step
Test loss: 0.07125129706889857
Test accuracy: 0.979200005531311
```

Swish Activation Function

In [13]:
```
def swish(x):
    return x * keras.backend.sigmoid(x)
```

In [14]:
```
SWISH_model = Sequential()

SWISH_model.add(Dense(500, input_dim=n, activation=swish))

SWISH_model.add(Dense(100, activation=swish))

SWISH_model.add(Dense(num_classes, activation='softmax'))

# Compile model

SWISH_model.compile(loss='categorical_crossentropy', optimizer='adam', metrics=['accuracy'])
SWISH_model.summary()
```
```
Model: "sequential_4"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_10 (Dense)             (None, 500)               392500
_________________________________________________________________
dense_11 (Dense)             (None, 100)               50100
_________________________________________________________________
dense_12 (Dense)             (None, 10)                1010
=================================================================
Total params: 443,610
Trainable params: 443,610
Non-trainable params: 0
_________________________________________________________________
```

Result of Train and Test

In [15]:
```
hist_swish=SWISH_model.fit(X_train, y_train, validation_data=(X_test, y_test), epochs=10, batch_size=20
0)
scores_swish =SWISH_model.evaluate(X_test, y_test)
print('Test loss:', scores_swish[0])
print('Test accuracy:', scores_swish[1])
```
```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 2s 32us/step - loss: 0.2995 - accuracy: 0.9163 - val_l
oss: 0.1398 - val_accuracy: 0.9584
Epoch 2/10
60000/60000 [==============================] - 2s 29us/step - loss: 0.1199 - accuracy: 0.9638 - val_l
oss: 0.1013 - val_accuracy: 0.9681
Epoch 3/10
60000/60000 [==============================] - 2s 30us/step - loss: 0.0765 - accuracy: 0.9767 - val_l
oss: 0.0775 - val_accuracy: 0.9752
Epoch 4/10
60000/60000 [==============================] - 2s 30us/step - loss: 0.0539 - accuracy: 0.9835 - val_l
oss: 0.0686 - val_accuracy: 0.9780
Epoch 5/10
60000/60000 [==============================] - 3s 43us/step - loss: 0.0395 - accuracy: 0.9879 - val_l
oss: 0.0629 - val_accuracy: 0.9789
Epoch 6/10
60000/60000 [==============================] - 2s 38us/step - loss: 0.0294 - accuracy: 0.9909 - val_l
oss: 0.0578 - val_accuracy: 0.9824
Epoch 7/10
60000/60000 [==============================] - 3s 47us/step - loss: 0.0219 - accuracy: 0.9935 - val_l
oss: 0.0592 - val_accuracy: 0.9816
Epoch 8/10
60000/60000 [==============================] - 2s 33us/step - loss: 0.0179 - accuracy: 0.9944 - val_l
oss: 0.0635 - val_accuracy: 0.9813
Epoch 9/10
60000/60000 [==============================] - 2s 32us/step - loss: 0.0121 - accuracy: 0.9964 - val_l
oss: 0.0614 - val_accuracy: 0.9825
Epoch 10/10
60000/60000 [==============================] - 2s 39us/step - loss: 0.0128 - accuracy: 0.9958 - val_l
oss: 0.0654 - val_accuracy: 0.9811
10000/10000 [==============================] - 1s 120us/step
Test loss: 0.06543042148059466
Test accuracy: 0.9811000227928162
```

Scaled Exponential Linear Unit (SELU) Activation Function

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

SELU_model.add(Dense(500, input_dim=n, activation='selu'))

SELU_model.add(Dense(100, activation='selu'))

SELU_model.add(Dense(num_classes, activation='softmax'))

# Compile model

SELU_model.compile(loss='categorical_crossentropy', optimizer='adam', metrics=['accuracy'])
SELU_model.summary()
```
```
Model: "sequential_5"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_13 (Dense)             (None, 500)               392500
_________________________________________________________________
dense_14 (Dense)             (None, 100)               50100
_________________________________________________________________
dense_15 (Dense)             (None, 10)                1010
=================================================================
Total params: 443,610
Trainable params: 443,610
Non-trainable params: 0
_________________________________________________________________
```

Result of Train and Test

In [17]:
```
hist_selu=SELU_model.fit(X_train, y_train, validation_data=(X_test, y_test), epochs=10, batch_size=200)
scores_selu =SELU_model.evaluate(X_test, y_test)
print('Test loss:', scores_selu[0])
print('Test accuracy:', scores_selu[1])
```
```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 2s 41us/step - loss: 0.3116 - accuracy: 0.9072 - val_l
oss: 0.1997 - val_accuracy: 0.9390
Epoch 2/10
60000/60000 [==============================] - 3s 42us/step - loss: 0.1502 - accuracy: 0.9554 - val_l
oss: 0.1314 - val_accuracy: 0.9586
Epoch 3/10
60000/60000 [==============================] - 2s 37us/step - loss: 0.1066 - accuracy: 0.9678 - val_l
oss: 0.1071 - val_accuracy: 0.9667
Epoch 4/10
60000/60000 [==============================] - 2s 32us/step - loss: 0.0819 - accuracy: 0.9745 - val_l
oss: 0.1000 - val_accuracy: 0.9688
Epoch 5/10
60000/60000 [==============================] - 2s 33us/step - loss: 0.0653 - accuracy: 0.9799 - val_l
oss: 0.0986 - val_accuracy: 0.9703
Epoch 6/10
60000/60000 [==============================] - 2s 36us/step - loss: 0.0535 - accuracy: 0.9834 - val_l
oss: 0.0893 - val_accuracy: 0.9736
Epoch 7/10
60000/60000 [==============================] - 2s 30us/step - loss: 0.0447 - accuracy: 0.9855 - val_l
oss: 0.0862 - val_accuracy: 0.9739
Epoch 8/10
60000/60000 [==============================] - 2s 29us/step - loss: 0.0374 - accuracy: 0.9876 - val_l
oss: 0.0783 - val_accuracy: 0.9775
Epoch 9/10
60000/60000 [==============================] - 2s 35us/step - loss: 0.0331 - accuracy: 0.9890 - val_l
oss: 0.0914 - val_accuracy: 0.9755
Epoch 10/10
60000/60000 [==============================] - 2s 36us/step - loss: 0.0277 - accuracy: 0.9907 - val_l
oss: 0.0961 - val_accuracy: 0.9728
10000/10000 [==============================] - 1s 83us/step
Test loss: 0.09614768207155866
Test accuracy: 0.9728000164031982
```

Comparision of all 5 Activation Functions

In [18]:
```
test_loss=[scores_relu[0],scores_sig[0],scores_htan[0],scores_swish[0],scores_selu[0]]
test_acc=[scores_relu[1],scores_sig[1],scores_htan[1],scores_swish[1],scores_selu[1]]

df_scores=pd.DataFrame({'Test Loss':test_loss,'Test Accuracy':test_acc},index=['RELU','Sigmoid','TanH',
'Swish','SELU'])
df_scores
```
Out[18]:

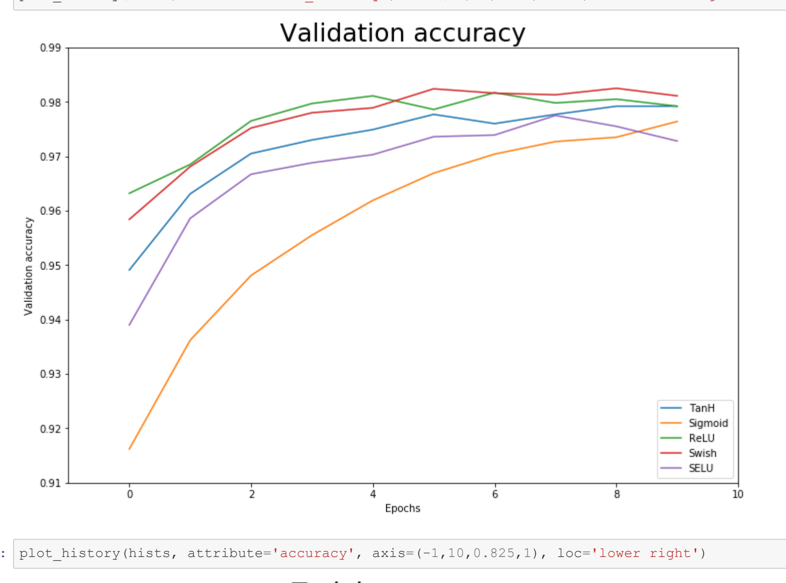
	Test Loss	Test Accuracy
RELU	0.069241	0.9792
Sigmoid	0.076433	0.9764
TanH	0.071251	0.9792
Swish	0.065430	0.9811
SELU	0.096148	0.9728

In [19]:
```
hists = [hist_htan, hist_sig, hist_relu, hist_swish, hist_selu]
```

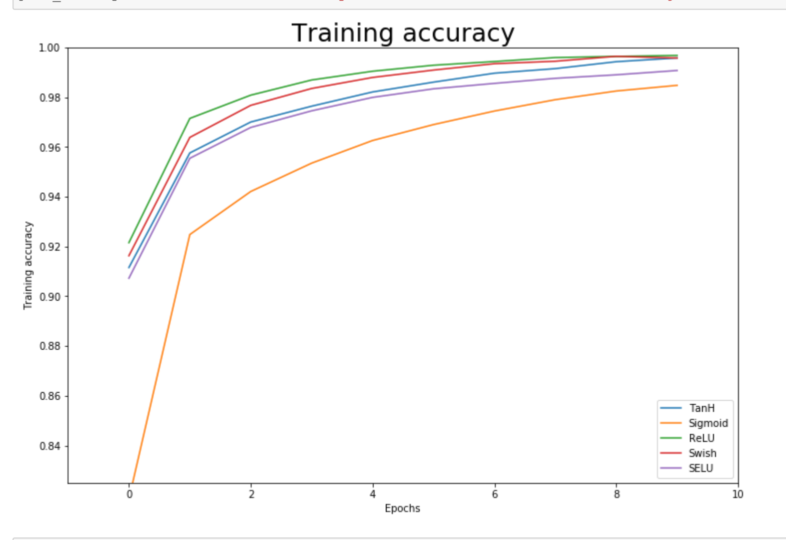
In [20]:
```
def plot_history(hists, attribute, axis=(-1,10,0.85,0.94), loc='lower right'):
    title={'val_loss': 'Validation loss', 'loss': 'Training loss', 'val_accuracy': 'Validation accurac
y', 'accuracy': 'Training accuracy'}
    num_hists=len(hists)

    plt.figure(figsize=(12, 8))
    plt.axis(axis)
    for i in range(num_hists):
        plt.plot(hists[i].history[attribute])
    plt.title(title[attribute], fontsize=25)
    plt.ylabel(title[attribute])
    plt.xlabel('Epochs')
    plt.legend(['TanH', 'Sigmoid', 'ReLU', 'Swish', 'SELU'], loc=loc)
    plt.show()
```

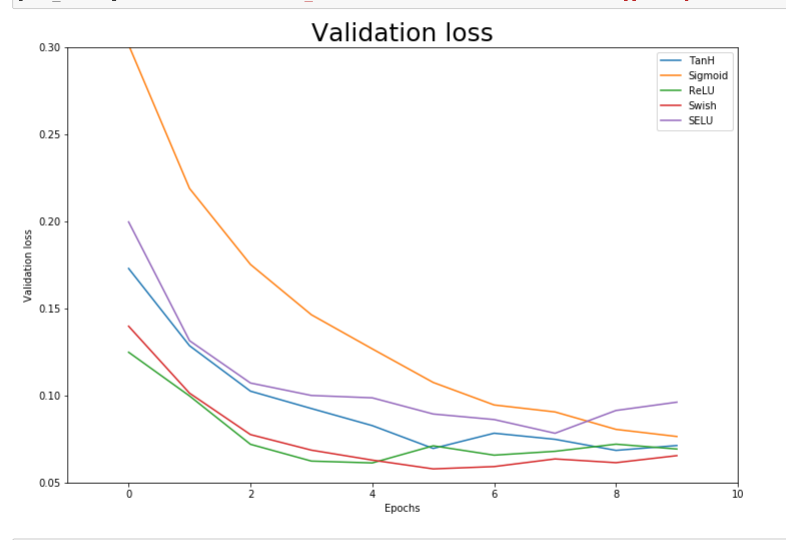
In [21]:
```
plot_history(hists, attribute='val_accuracy',axis=(-1,10,0.91,0.99), loc='lower right')
```



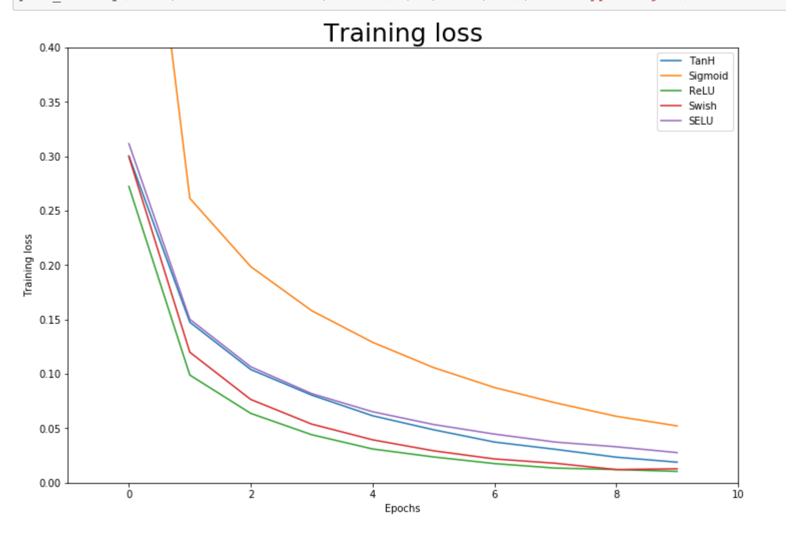
In [22]:
```
plot_history(hists, attribute='accuracy', axis=(-1,10,0.825,1), loc='lower right')
```



In [23]:
```
plot_history(hists, attribute='val_loss', axis=(-1,10,0.05,0.30), loc='upper right')
```



In [24]:
```
plot_history(hists, attribute='loss', axis=(-1,10,0.000,0.4), loc='upper right')
```



Thank You