ansi_regression-final

April 17, 2018

1 ANSI Application analysis

```
In [1]: import numpy
        import pandas
        import matplotlib
        import matplotlib.pyplot as plotter
        from scipy.stats import pearsonr, probplot
        from sklearn.metrics import mean_squared_error, mean_absolute_error, f1_score
        matplotlib.rcParams['agg.path.chunksize'] = 10000
```

```
In [2]: def view_boxplot(df):
            %matplotlib
            df.boxplot()
            plotter.show()
```

1.1 CPU data

```
In [3]: cpu_df = pandas.read_csv('data/ansi_final/ansi_final_cpu.csv', index_col='Time').drop(
```

```
In [4]: #cpu_df.columns
```

```
In [5]: cpu_df = cpu_df.clip(lower=0, upper=1000)
        #view_boxplot(cpu_df)
```

1.2 Network TX

```
In [6]: txnet_df = pandas.read_csv('data/ansi_final/ansi_final_network_tx.csv', index_col='Time
```

```
In [7]: #txnet_df.columns
```

```
In [8]: txnet_df = txnet_df.clip(lower=0, upper=50000)
        #view_boxplot(txnet_df)
```

1.3 Network RX

```
In [9]: rxnet_df = pandas.read_csv('data/ansi_final/ansi_final_network_rx.csv', index_col='Time
```

```
In [10]: #rxnet_df.columns
```

```
In [11]: rxnet_df = rxnet_df.clip(lower=0, upper=15000)
         #view_boxplot(rxnet_df)
```

1.4 Disk IO data

```
In [12]: disk_df = pandas.read_csv('data/ansi_final/ansi_final_disk_io.csv', index_col='Time')
```

```
In [13]: #disk_df.columns
```

```
In [14]: disk_df = disk_df.clip(lower=0, upper=4000)
         #view_boxplot(disk_df)
```

1.5 Context switching

```
In [15]: context_df = pandas.read_csv('data/ansi_final/ansi_final_context.csv', index_col='Tim
```

```
In [16]: #context_df.columns
```

```
In [17]: context_df = context_df.clip(lower=0, upper=5000)
         #view_boxplot(context_df)
```

1.6 Seperate into proper dataframes for each node

```
In [18]: dframes = [cpu_df, txnet_df, rxnet_df, context_df, disk_df]
         node = {}

         for i in range(1,13):
             frames = []

             for dframe in dframes:
                 columns = list(filter(lambda x: f'bb{i}l' in x, dframe.columns))
                 frames.append(dframe[columns])

             node[i] = pandas.concat(frames, join='inner', axis=1).fillna(0)[:68300]
```

```
In [19]: for i in range(1,13):
             print(node[i].shape)

         for i in range(len(node[1].columns)):
             print(f"{i}: {node[1].columns[i]}")
```

```
(68300, 29)
(68300, 29)
(68300, 29)
(68300, 29)
(68300, 29)
(68300, 29)
(68300, 29)
(68300, 29)
(68300, 29)
(68300, 29)
(68300, 29)
```

```
(68300, 29)
0: cpu_value host bb1localdomain type_instance idle
1: cpu_value host bb1localdomain type_instance interrupt
2: cpu_value host bb1localdomain type_instance nice
3: cpu_value host bb1localdomain type_instance softirq
4: cpu_value host bb1localdomain type_instance steal
5: cpu_value host bb1localdomain type_instance system
6: cpu_value host bb1localdomain type_instance user
7: cpu_value host bb1localdomain type_instance wait
8: interface_tx host bb1localdomain instance lo type if_dropped
9: interface_tx host bb1localdomain instance lo type if_errors
10: interface_tx host bb1localdomain instance lo type if_octets
11: interface_tx host bb1localdomain instance lo type if_packets
12: interface_tx host bb1localdomain instance wlan0 type if_dropped
13: interface_tx host bb1localdomain instance wlan0 type if_errors
14: interface_tx host bb1localdomain instance wlan0 type if_octets
15: interface_tx host bb1localdomain instance wlan0 type if_packets
16: interface_rx host bb1localdomain instance lo type if_dropped
17: interface_rx host bb1localdomain instance lo type if_errors
18: interface_rx host bb1localdomain instance lo type if_octets
19: interface_rx host bb1localdomain instance lo type if_packets
20: interface_rx host bb1localdomain instance wlan0 type if_dropped
21: interface_rx host bb1localdomain instance wlan0 type if_errors
22: interface_rx host bb1localdomain instance wlan0 type if_octets
23: interface_rx host bb1localdomain instance wlan0 type if_packets
24: contextswitch_value host bb1localdomain type contextswitch
25: disk_io_time host bb1localdomain instance mmcblk1 type disk_io_time
26: disk_io_time host bb1localdomain instance mmcblk1boot0 type disk_io_time
27: disk_io_time host bb1localdomain instance mmcblk1boot1 type disk_io_time
28: disk_io_time host bb1localdomain instance mmcblk1p1 type disk_io_time
```

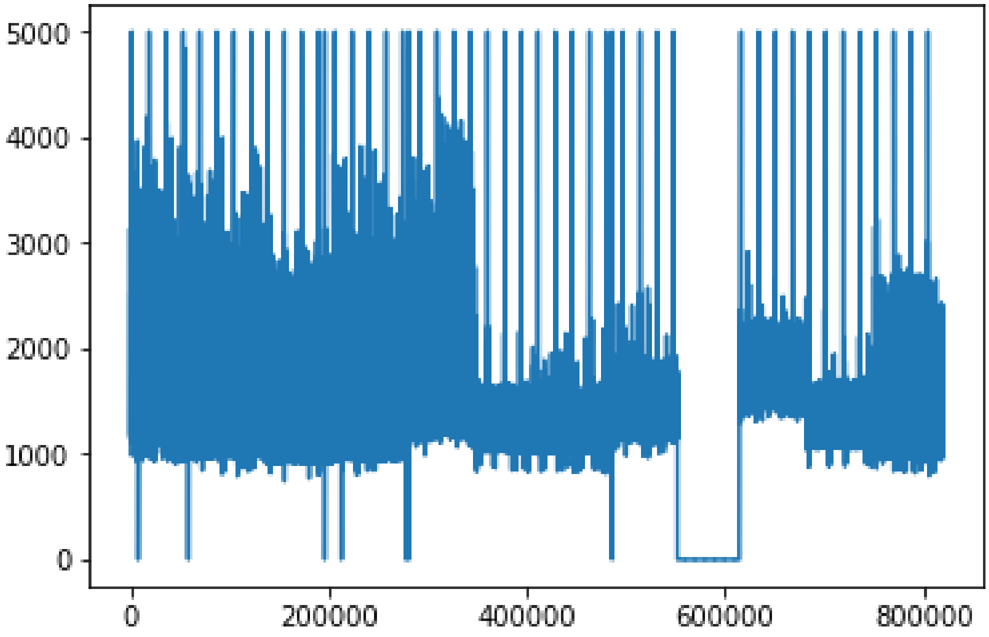
1.7 Get data

```
In [20]: data_matrices = []

         for i in range(1,13):
             data_matrices.append(node[i].as_matrix())

         data = numpy.vstack(data_matrices)
```

```
In [21]: data.shape
```

```
Out[21]: (819600, 29)
```

```
In [22]: tdata = data[:,24]
         plotter.plot(tdata.T)
         plotter.show()
         print(data.shape)
```



```
(819600, 29)
```

```
In [23]: #data = data[:,24]
```

1.8 Prepare scaler

```
In [24]: from sklearn.preprocessing import MinMaxScaler
         from sklearn.preprocessing import StandardScaler
         from sklearn.preprocessing import RobustScaler
         scaler = MinMaxScaler()

In [25]: scaler.fit(data)
         del data
```

1.9 Correrlation measurement

```
In [26]: for i in range(len(data_matrices)):

             transformed = scaler.transform(data_matrices[i])
             data_matrices[i] = transformed

         X = numpy.stack(data_matrices[:4], axis=1)
         test = numpy.stack(data_matrices[4:], axis=1)
         print(X.shape)
         print(test.shape)
```

```
(68300, 4, 29)
(68300, 8, 29)
```

```
In [27]: print(X.shape)
         LEN = X.shape[0]
         SPLIT = int(0.8*LEN)

         train_X = X[:SPLIT,:,:]
         val_X = X[SPLIT:,:,:]

         print(train_X.shape)
         print(val_X.shape)
```

```
(68300, 4, 29)
(54640, 4, 29)
(13660, 4, 29)
```

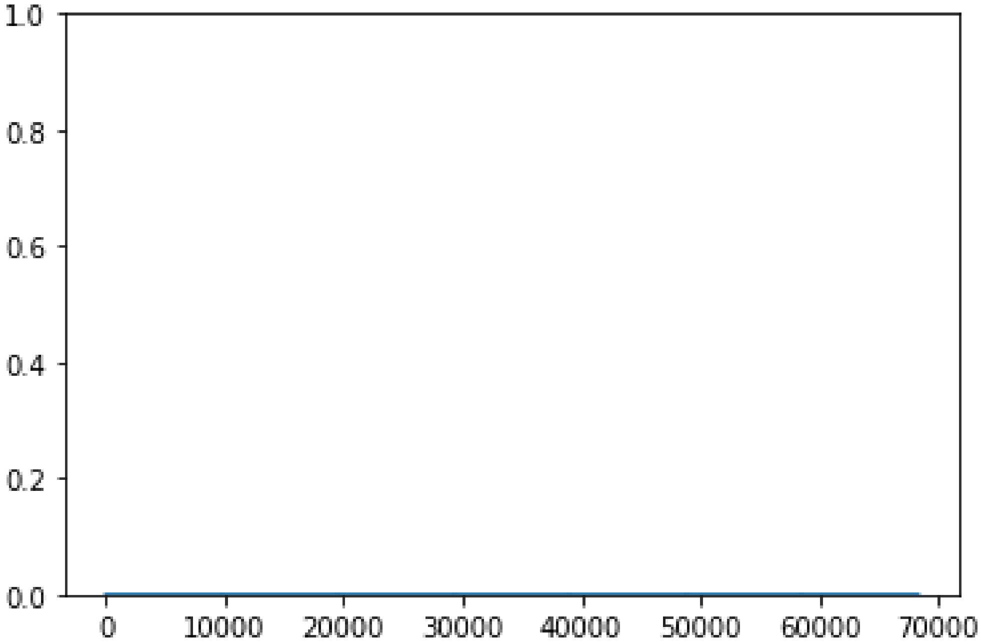
```
In [28]: test_X = numpy.transpose(test, (1,0,2))
         train_X = numpy.transpose(train_X, (1,0,2))
         val_X = numpy.transpose(val_X, (1,0,2))
         print(test_X.shape)
         print(train_X.shape)
         print(val_X.shape)
```

```
(8, 68300, 29)
(4, 54640, 29)
(4, 13660, 29)
```

```
In [29]: def flat_generator(X, tsteps = 5, ravel=1):
             i = 0

             while True:
                 batch_X = X[:,i:i+tsteps,:]
                 batch_y = X[:,i+tsteps,:]

                 if ravel:
                     batch_X = batch_X.reshape((batch_X.shape[0], -1))
                 #print(batch_X.shape)
                 #print(batch_y.shape)

                 yield batch_X, batch_y

                 i += 1
                 if i > (X.shape[1] - tsteps - 1):
                     i = 0
                     continue
```

```
In [30]: series = test_X[7,:,21]
         print(series.shape)
         plotter.ylim(0,1)
         plotter.plot(series)
         plotter.show()
         print(numpy.random.randint(29))
```

```
(68300,)
```



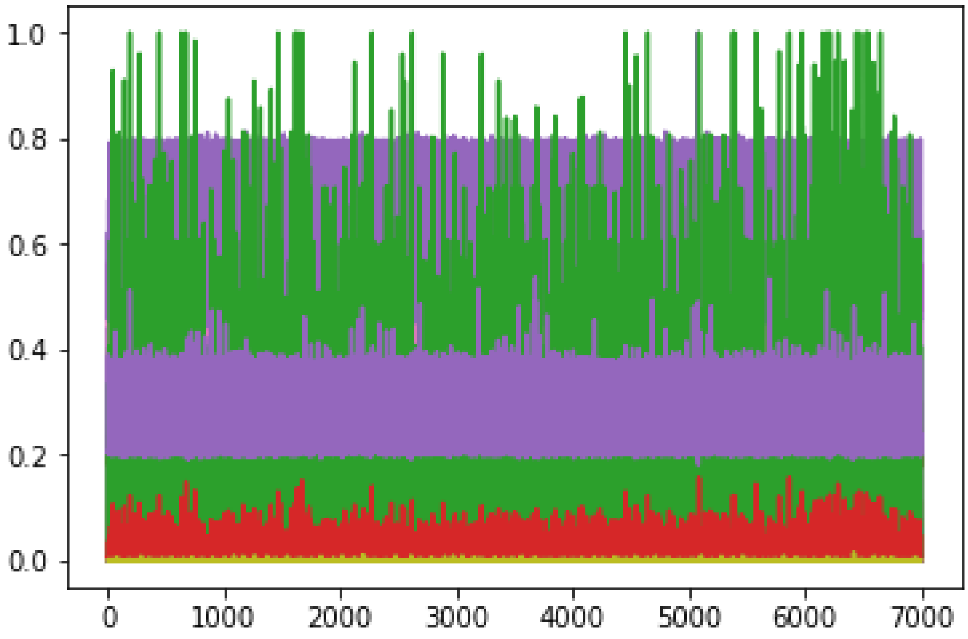
```
21
```

```
In [31]: #avg_load = test_X[3,:,:]
         #disk_io_start_late = test_X[0,:,:]
```

```
        #app_change_early = test_X[1,:,:]
        #idle_early = test_X[4,:,:]
        normal_test = test_X[7,:,:]
        synth_test = test_X[7,3000:10000,:]
```

```
In [32]: print(synth_test.shape)
         plotter.plot(synth_test[:,:])
         plotter.show()
```

```
(7000, 29)
```



```
In [33]: def get_anomaly_labels(error, window_size, technique):

             if technique == "rolling":
                 arr = pandas.Series(error)
                 means = arr.rolling(window=window_size).mean()
                 std = arr.rolling(window=window_size).std()

             if technique == "exp":
                 arr = pandas.Series(error)
                 means = arr.ewm(halflife=window_size).mean()
                 std = arr.ewm(halflife=window_size).std()

             outlier = (arr > (means + (5.0 * std))) * 1.0
             mark = numpy.zeros(arr.shape[0])
```

```
    window = 100

    for i in range(window,outlier.shape[0]):
        num = window
        outliers = numpy.sum(outlier[i-window:i])
        per = outliers/num
        if per > 0.04:
            mark[i-window:i] = outlier[i-window:i]
        else:
            mark[i] = 0.0

    #plotter.plot(0.09 * true,'r-', alpha=0.5, label="True")
    #plotter.plot(0.09 * mark,'b-', alpha=0.3, label="Prediction", linewidth=1)
    #plotter.plot(means,'b--', alpha=0.9, linewidth=0.5)
    #plotter.plot(means + (5.0 * std), 'r-', alpha=0.5, linewidth=0.5)
    #plotter.plot(error,'g-', alpha=0.5, label="Error", linewidth=0.5)
    #plotter.ylim(0,0.1)
    #plotter.legend()
    #plotter.show()

    return mark

def get_score(error, true, moving_window, name="none", dataset_name="none"):

    # For rolling window
    labels = get_anomaly_labels(error, moving_window, "rolling")
    true = true[true.shape[0]-labels.shape[0]:]
    #print(true)
    #print(labels)

    #plotter.plot(0.09 * true,'r-', alpha=0.5, label="True")
    #plotter.plot(0.09 * labels,'b-', alpha=0.5, label="Prediction")
    #plotter.plot(error,'g-', alpha=0.3, label="Error")
    #plotter.ylim(0,0.1)
    #plotter.legend()
    #plotter.show()

    print(f"For {name} and rolling window size {moving_window} and dataset name {datas
    print(f"True: {numpy.sum(true)} Labels: {numpy.sum(labels)} Overlap: {numpy.sum(nu

    # For exp window
    labels = get_anomaly_labels(error, moving_window, "exp")
    true = true[true.shape[0]-labels.shape[0]:]

    #plotter.plot(0.09 * true,'r-', alpha=0.5, label="True")
    #plotter.plot(0.09 * labels,'b-', alpha=0.5, label="Prediction")
    #plotter.plot(error,'g-', alpha=0.3, label="Error")
    #plotter.ylim(0,0.5)
    #plotter.legend()
    #plotter.show()

    print(f"For {name} and exp window size {moving_window} and dataset name {dataset_
    print(f"True: {numpy.sum(true)} Labels: {numpy.sum(labels)} Overlap: {numpy.sum(nu

def get_error(model ,dataset, ravel=1, name="none", window=10):

    test_gen = flat_generator(numpy.array([dataset]), window,0)
    error = []
    targets = []
    preds = []
    for i in range(dataset.shape[0]-(window+1)):
        _input,target = next(test_gen)
        targets.append(target.squeeze())
        #print(_input.shape)
        if ravel:
            _input = _input.ravel()[:,numpy.newaxis].T

        pred = model.predict(_input)
        #print(target.shape)
        #print(pred.shape)
        preds.append(pred.squeeze())
        error.append(mean_absolute_error(y_pred=pred, y_true=target))

    targets = numpy.vstack(targets)
    preds = numpy.vstack(preds)

    #plotter.plot(numpy.array(error), alpha=0.5, linewidth=0.5, label="error")
    #plotter.ylim(0,0.1)
    #plotter.legend()
    #plotter.plot()
    #plotter.show()

    return error


def test_anomalies(model, dataset, ravel=1, windows_list=[100], name="none", window=1


    for window_size in windows_list:

        ## For network flood:

        for i in range(1,10):

            test_set = numpy.copy(dataset)
            anomaly_range = numpy.random.randint(3000,5000)
            test_set[anomaly_range:anomaly_range+i,21:23] = 1.0
            true = numpy.zeros(test_set.shape[0])
            true[anomaly_range:anomaly_range+i] = 1.0

            error = numpy.array(get_error(model, test_set, ravel, window=window))
            fname = f"results/{name}_{window_size}_duration_{i}.npy"
            print(f"Writing {fname}")
            numpy.save(fname,error)
            numpy.save(f"results/{name}_{window_size}_duration_{i}_true.npy",true)
            #get_score(error, true, window_size, name, "network_flood")


        #noise = numpy.random.normal(size=test_set.shape, loc=0, scale=0.1)

        #test_set = numpy.clip(test_set + noise, a_min=0.0, a_max=1.0)


        #(test_set.shape)
```

1.10 Training functions

```
In [34]: from keras.models import Model
         from keras.layers import Dense, Input, Dropout, GRU
         from keras.callbacks import EarlyStopping
```

```
Using TensorFlow backend.
```

```
In [35]: def train(model, tgen, vgen, name="none"):
             estopper = EarlyStopping(patience=15, min_delta=0.0001)
             history = model.fit_generator(tgen, steps_per_epoch=1000, epochs=10000, callbacks=
             plotter.plot(history.history['loss'],label='train')
             plotter.plot(history.history['val_loss'],label='validation')
             plotter.legend()
             plotter.xlim(0,150)
             plotter.xlabel("Epochs")
             plotter.ylabel("Error")
             plotter.savefig(f"{name}_train.png", dpi=500)
             plotter.show()
             print(f"Training loss for final epoch is {history.history['loss'][-1]}")
             print(f"Validation loss for final epoch is {history.history['val_loss'][-1]}")
```

```
In [36]: def plot_running_stats(error, name="none", window_size=5, bounds=None, qq=0):
             error = numpy.array(error)
             numpy.save(f"results/{name}_error.npy", error)
```

```
window = numpy.ones(window_size)/window_size
running_mean = numpy.convolve(error, window, mode="same")
running_sigma = pandas.Series(error).rolling(window=window_size, center=True).std
difference = 3.0 * running_sigma

upper = running_mean + difference
lower = running_mean - difference

if bounds == None:
    global_mean = numpy.mean(error) * numpy.ones(error.shape[0])
    global_sigma = numpy.std(error) * numpy.ones(error.shape[0])
    bound = (5.0 * global_sigma) + global_mean

else:

    global_mean = bounds[0]
    bound = bounds[1]

anomaly = ((error > bound) * error)
anomaly = numpy.array([float('nan') if x == 0.0 else x for x in anomaly])

if qq:

    #a, b, l, s = beta.fit(error)
    probplot(error,dist="norm", plot=plotter)
    plotter.legend()
    plotter.savefig(f"{name}_qq.png",dpi=500)
    plotter.show()

    plotter.hist(error, bins=100)
    plotter.legend()
    plotter.savefig(f"{name}_hist.png")
    plotter.show()

arr = pandas.Series(error)
means = arr.rolling(window=720).mean()
std = arr.rolling(window=720).std()
outlier = (arr > (means + 5.0 * std)) * 1.0

mark = numpy.ones(arr.shape[0]) * numpy.nan

window = 100

for i in range(window,outlier.shape[0]):
    num = window
    outliers = numpy.sum(outlier[i-window:i])
    per = outliers/num
    if per > 0.04:
        mark[i-window:i] = 1.0
    else:
        mark[i] = 0.0

plotter.plot(error, 'g-', label="Error", alpha=0.4, linewidth=0.5)
plotter.ylim(0,0.2)
plotter.xlabel("time")
plotter.ylabel("Error")
plotter.legend()
plotter.savefig(f"{name}_error_plain.png", dpi=500)
plotter.show()

fig = plotter.figure()
plotter.plot(error, 'g-', alpha=0.4, label="Error", linewidth=0.5)
plotter.plot(means, 'r-.', alpha=0.9, label="Mean", linewidth=0.5)
#plotter.plot(upper,'b-', alpha=0.2, label="Upper Bound", linewidth=0.5)
plotter.plot(means + 5.0 * std,'b--', alpha=0.9, label="Bound", linewidth=0.5)
plotter.plot(0.1 * mark,'r-', alpha=0.5, label="Anomaly")
plotter.legend()
plotter.ylim(0,0.2)
plotter.xlabel("time")
plotter.ylabel("Error")
plotter.draw()
fig.savefig(f"{name}_truetestloss.png", dpi=500)
plotter.show()



arr = pandas.Series(error)
means = arr.ewm(halflife=720).mean()
std = arr.ewm(halflife=720).std()
outlier = (arr > (means + 5.0 * std)) * 1.0

mark = numpy.ones(arr.shape[0]) * numpy.nan

window = 100

for i in range(window, outlier.shape[0]):
    num = window
    outliers = numpy.sum(outlier[i-window: i])
    per = outliers/num
    if per > 0.04:
        mark[i] = 1.0
    else:
        mark[i] = 0.0

fig = plotter.figure()
plotter.plot(error, 'g-', alpha=0.4, label="Error", linewidth=0.5)
```

```
             plotter.plot(means, 'r-.', alpha=0.9, label="Mean", linewidth=0.5)
             #plotter.plot(upper,'b-', alpha=0.2, label="Upper Bound", linewidth=0.5)
             plotter.plot(means + 5.0 * std,'b--', alpha=0.9, label="Bound", linewidth=0.5)
             plotter.plot(0.1 * mark,'r-', alpha=0.5, label="Anomaly")
             plotter.legend()
             plotter.ylim(0,0.2)
             plotter.xlabel("time")
             plotter.ylabel("Error")
             plotter.draw()
             fig.savefig(f"{name}_truetestloss_exp.png", dpi=500)
             plotter.show()


             fig.clf()
             plotter.clf()
             plotter.close()
             error = numpy.array(error)
             print(f"The mean error for {name} is {numpy.mean(error)} for length {error.shape[(

             return (global_mean, bound)

In [37]: def data_test(model, dataset=test_X[0], ravel=1, write=0, name="none", window=5, bounc
             test_gen = flat_generator(numpy.array([dataset]), window,0)
             error = []
             targets = []
             preds = []
             for i in range(dataset.shape[0]-(window+1)):
                 _input,target = next(test_gen)
                 targets.append(target.squeeze())
                 if ravel:
                     _input = _input.ravel()[:,numpy.newaxis].T

                 pred = model.predict(_input)
                 #print(target.shape)
                 #print(pred.shape)
                 preds.append(pred.squeeze())
                 error.append(mean_absolute_error(y_pred=pred, y_true=target))

             targets = numpy.vstack(targets)
             preds = numpy.vstack(preds)
             return plot_running_stats(error, name=name, window_size=window, bounds=bounds, qq=

             #print(error)

In [38]: def gen_test(model, dataset=test_X[0], ravel=1, write=0, name="none"):
             test_gen = flat_generator(numpy.array([dataset]), TIMESTEPS,0)
             error = []
             targets = []
             preds = []
             for i in range(2000):
                 _input,target = next(test_gen)

                 if i != 0:
                     #print(_input.shape)
                     _input = _input.squeeze()[1:,:]
                     #print(_input.shape)
                     _input = numpy.append(pred,_input, axis=0)[numpy.newaxis,:,:]
                     #print(_input.shape)

                 targets.append(target.squeeze())
                 if ravel:
                     _input = _input.ravel()[:,numpy.newaxis].T

                 pred = model.predict(_input)
                 #print(target.shape)
                 #print(pred.shape)
                 preds.append(pred.squeeze())
                 error.append(mean_absolute_error(y_pred=pred, y_true=target))

             targets = numpy.vstack(targets)
             preds = numpy.vstack(preds)

             plotter.plot(error, 'g-', alpha=0.5)
             plotter.ylim(0,0.2)
             plotter.xlabel("time")
             plotter.ylabel("Error")
             plotter.savefig(f"{name}_testloss.png")
             plotter.show()
             error = numpy.array(error)
             print(numpy.mean(error))
             plotter.boxplot(error)
             plotter.ylim(0,0.2)
             plotter.xlabel("time")
             plotter.ylabel("Error")
             plotter.savefig(f"{name}_boxplot.png")
             plotter.show()
             if write:
                 numpy.savetxt('loss.txt', numpy.array(error))
             true_test(model,dataset,ravel=ravel,name=name)
             #print(error)

In [39]: def test(model, ravel=1, name="none", window=20):
             print(f"---------- Beginning tests for {name} ----------")
             #print(f"Testing on Disk IO begin data.")
             #bounds = data_test(model, dataset=disk_io_start_late , ravel=ravel, name=(name+"
             #print(f"Testing on Avg. load data.")
```

```
    #data_test(model, dataset=avg_load, ravel=ravel, name=(name+"_avg_load_"), window
    #print(f"Testing on app change early data.")
    #data_test(model, dataset=app_change_early, ravel=ravel, name=(name+"_app_change_
    print(f"Testing on Normal data.")
    data_test(model, dataset=normal_test, ravel=ravel, name=(name+"_normal_"), window
    #print(f"Testing on Idle early data.")
    #data_test(model, dataset=idle_early, ravel=ravel, name=(name+"_idle_early_"), wi
    #test_anomalies(model, synth_test, ravel=ravel, name=name, window=window)
    print("="*20)
    print("\r\n\r\n")
```

1.11 Train Models

```
In [40]: X = train_X
```

1.11.1 Linear Regression

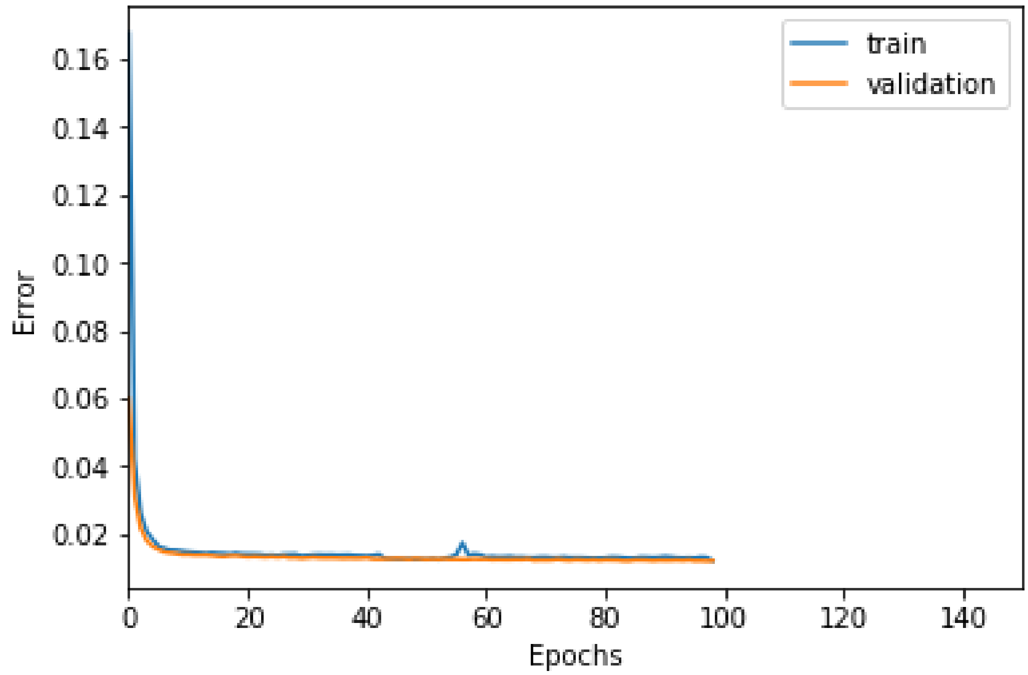
2 steps

```
In [41]: TIMESTEPS = 2
         DIM = 29
         tgen = flat_generator(X, TIMESTEPS)
         vgen = flat_generator(val_X, TIMESTEPS)
         name = "lin2"
```

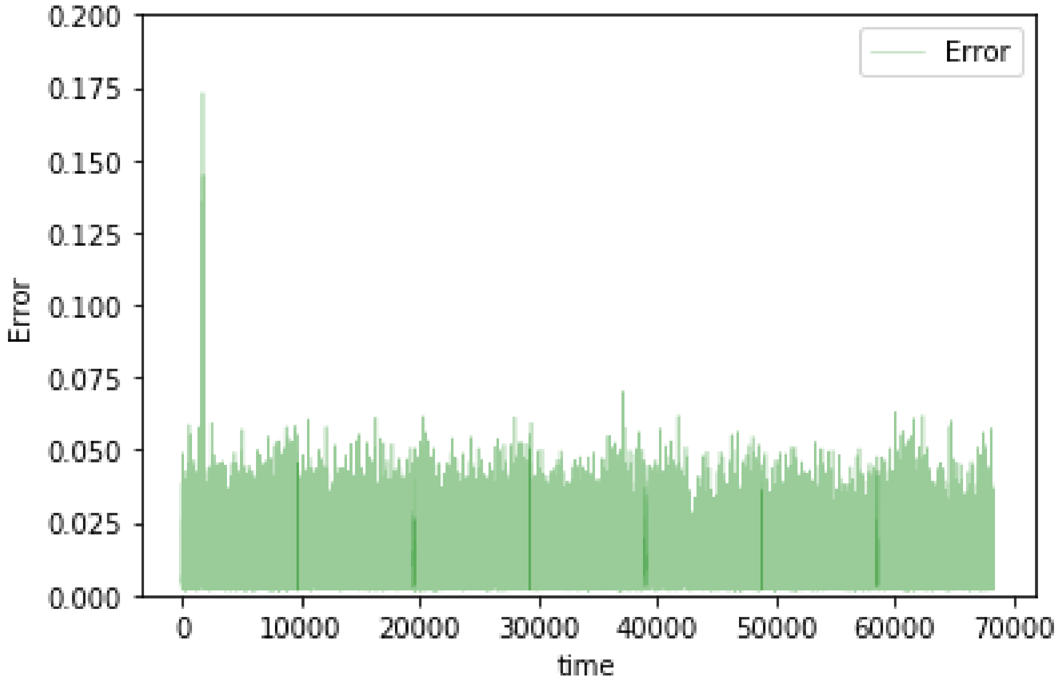
```
In [42]: input_layer = Input(shape=(TIMESTEPS*DIM,))
         output = Dense(DIM, activation='sigmoid')(input_layer)
```

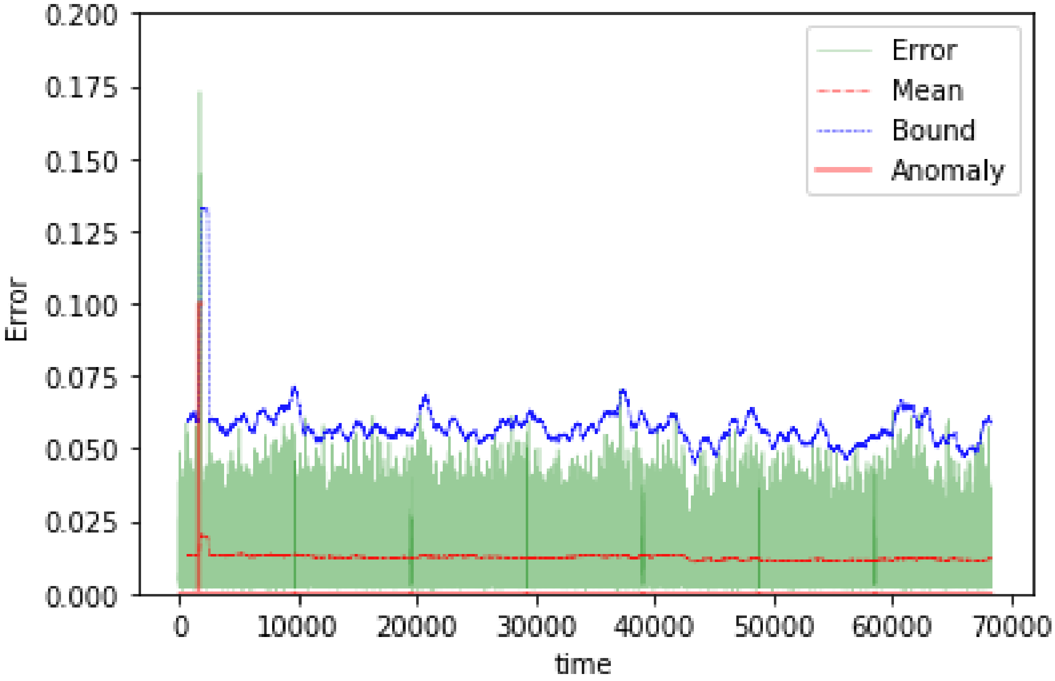
```
In [43]: model = Model(input_layer, output)
         model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

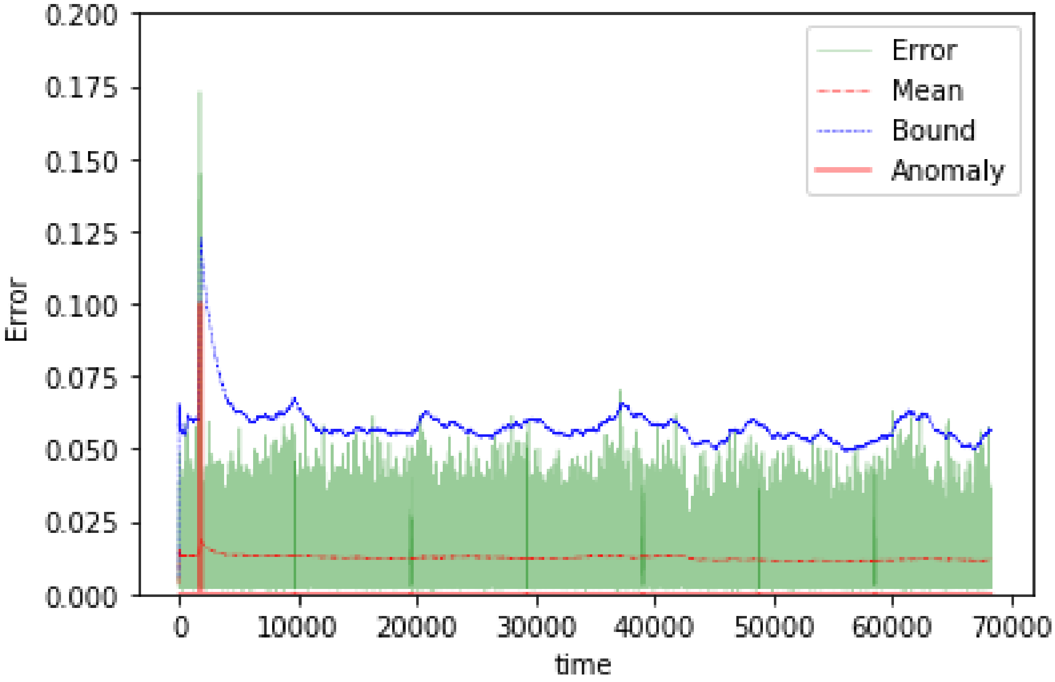
```
In [44]: train(model, tgen, vgen, name=name)
         test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.012198674850165844
Validation loss for final epoch is 0.012222263252129778
---------- Beginning tests for lin2 ----------
Testing on Normal data.
```




0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly


0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly

```
The mean error for lin2_normal_ is 0.012419262847992637 for length 68297
====================
```

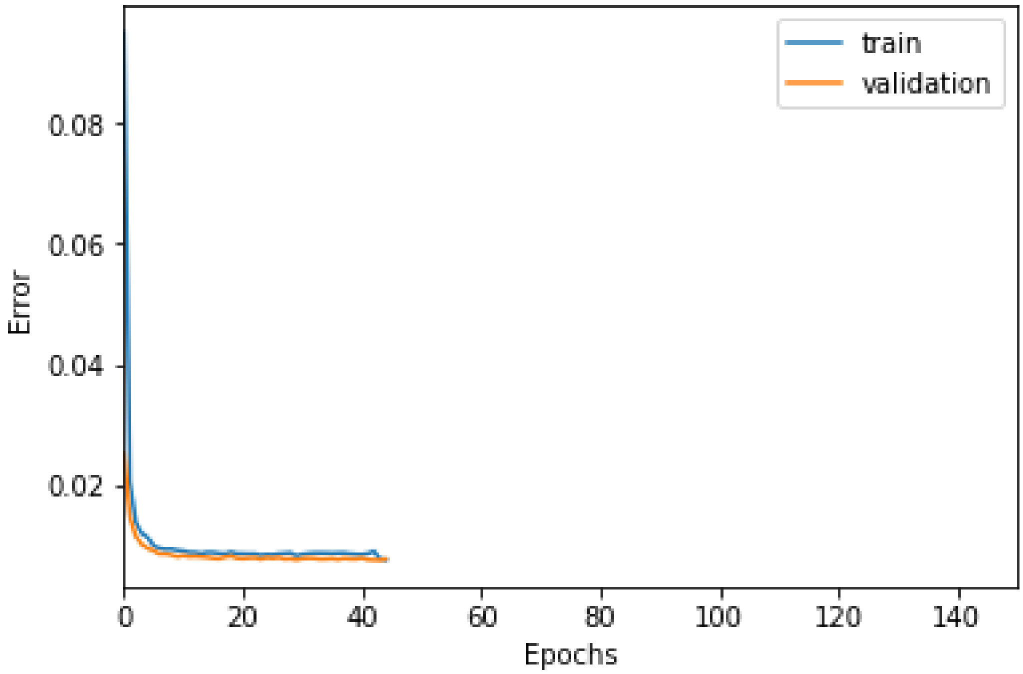
5 steps

```
In [45]: TIMESTEPS = 5
         DIM = 29
         tgen = flat_generator(X, TIMESTEPS)
         vgen = flat_generator(val_X, TIMESTEPS)
         name = "lin5"
```

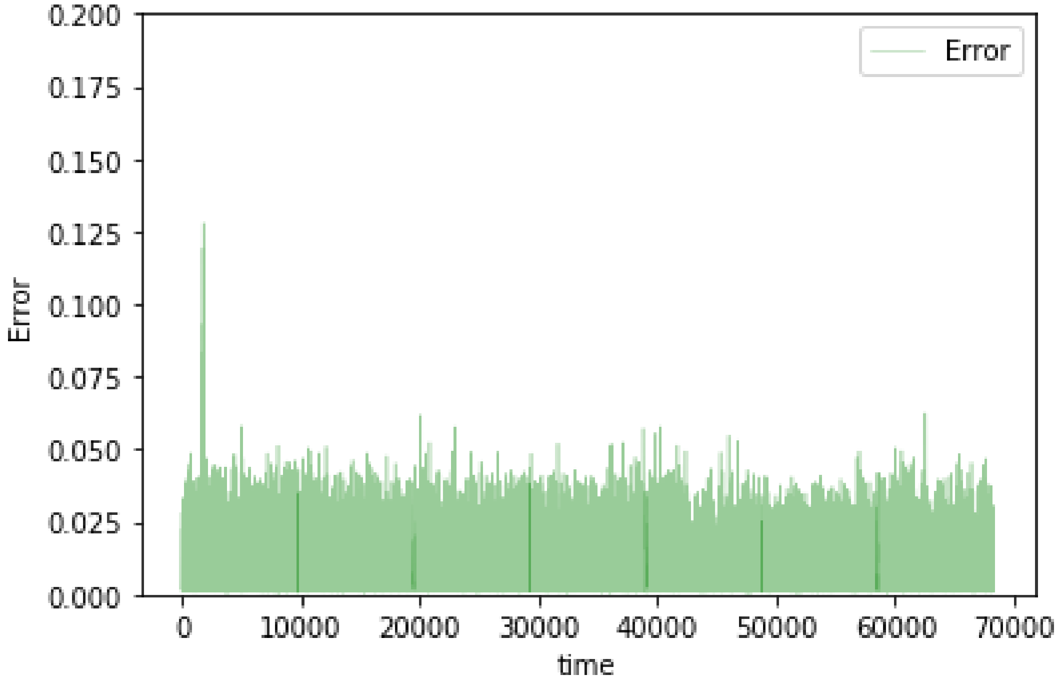
```
In [46]: input_layer = Input(shape=(TIMESTEPS*DIM,))
         output = Dense(DIM, activation='sigmoid')(input_layer)
```

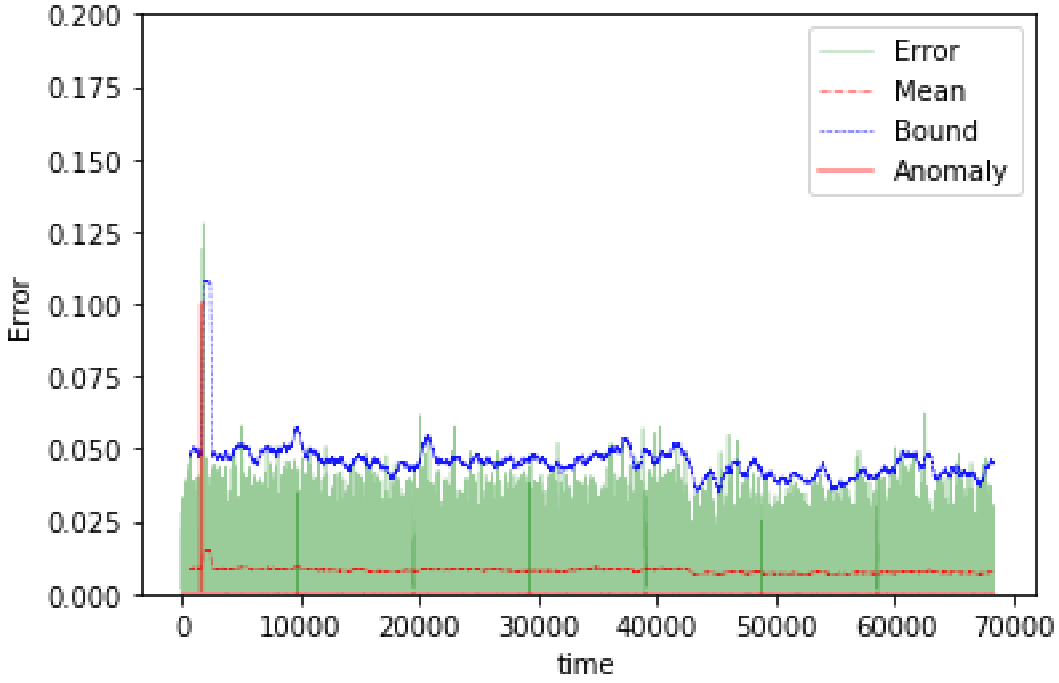
```
In [47]: model = Model(input_layer, output)
         model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

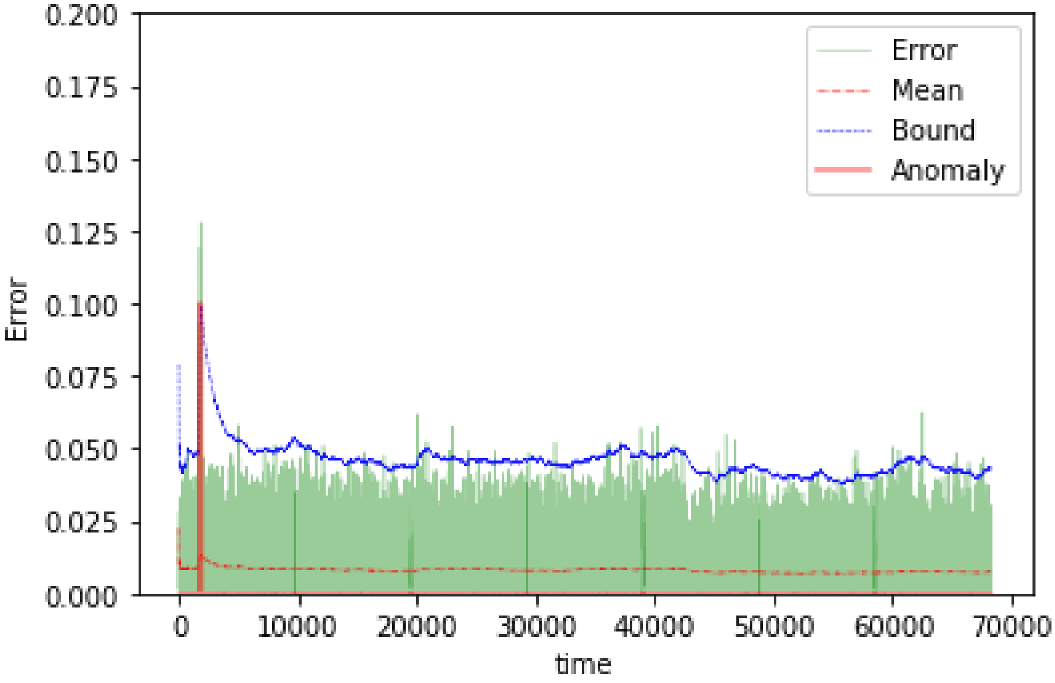
```
In [48]: train(model, tgen, vgen, name=name)
         test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.007605127180344425
Validation loss for final epoch is 0.007739097486482933
---------- Beginning tests for lin5 ----------
Testing on Normal data.
```



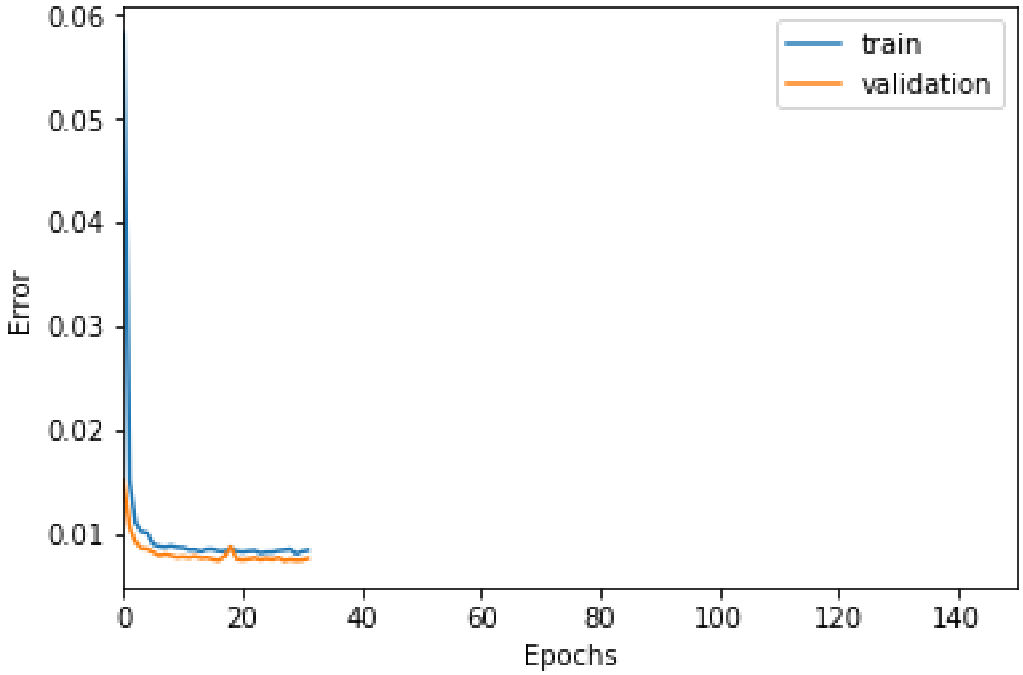




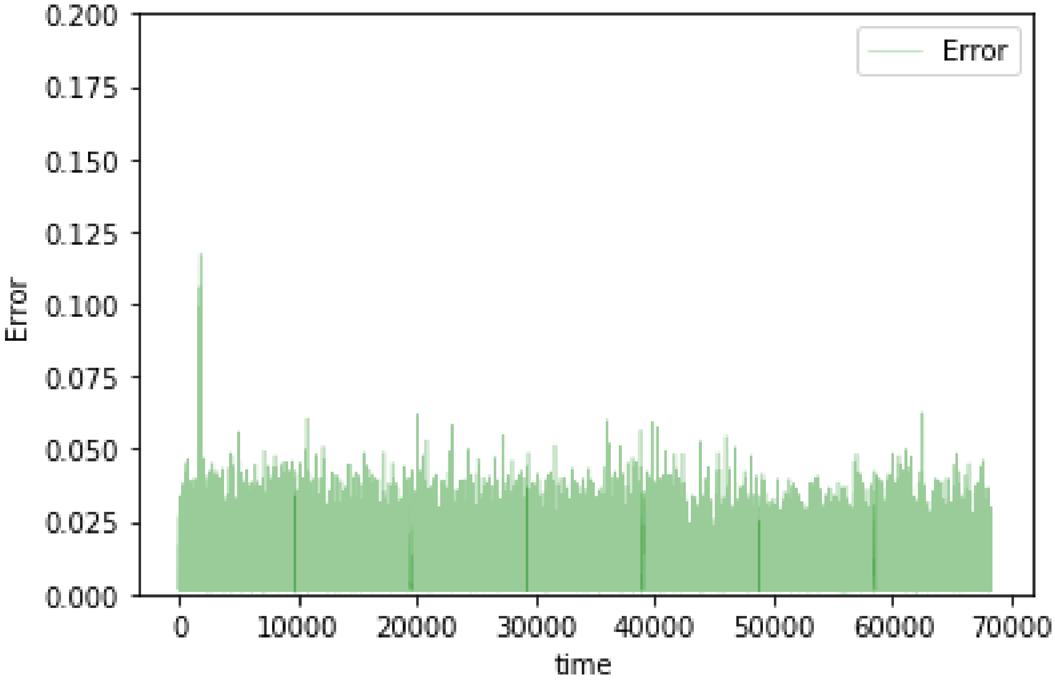
```
The mean error for lin5_normal_ is 0.008016757622511196 for length 68294
====================
```

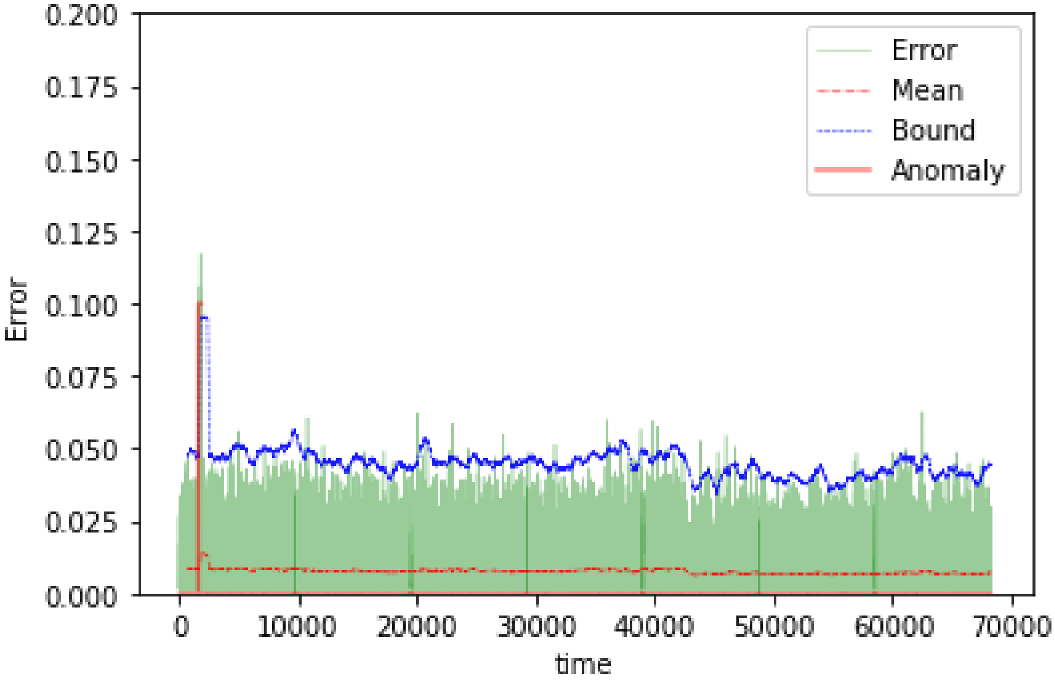
10 steps

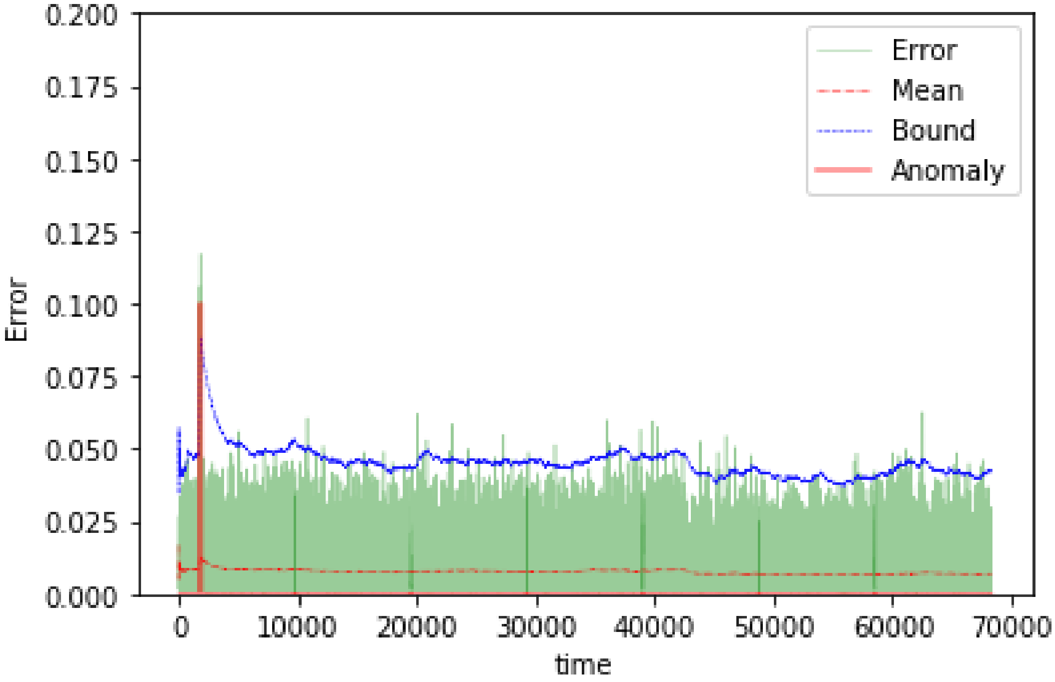
```
In [49]: TIMESTEPS = 10
         DIM = 29
         tgen = flat_generator(X, TIMESTEPS)
         vgen = flat_generator(val_X, TIMESTEPS)
         name = "lin10"

In [50]: input_layer = Input(shape=(TIMESTEPS*DIM,))
         output = Dense(DIM, activation='sigmoid')(input_layer)

In [51]: model = Model(input_layer, output)
         model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])

In [52]: train(model, tgen, vgen, name=name)
         test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008356910020927899
Validation loss for final epoch is 0.0075539354813518
---------- Beginning tests for lin10 ----------
Testing on Normal data.
```



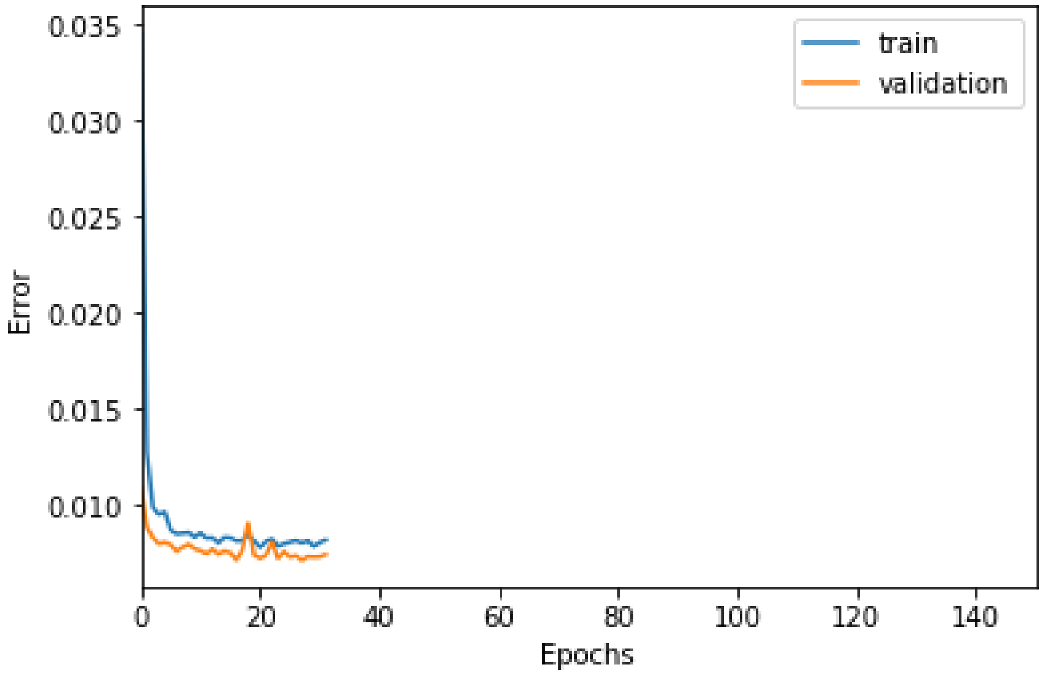

0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly


0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly

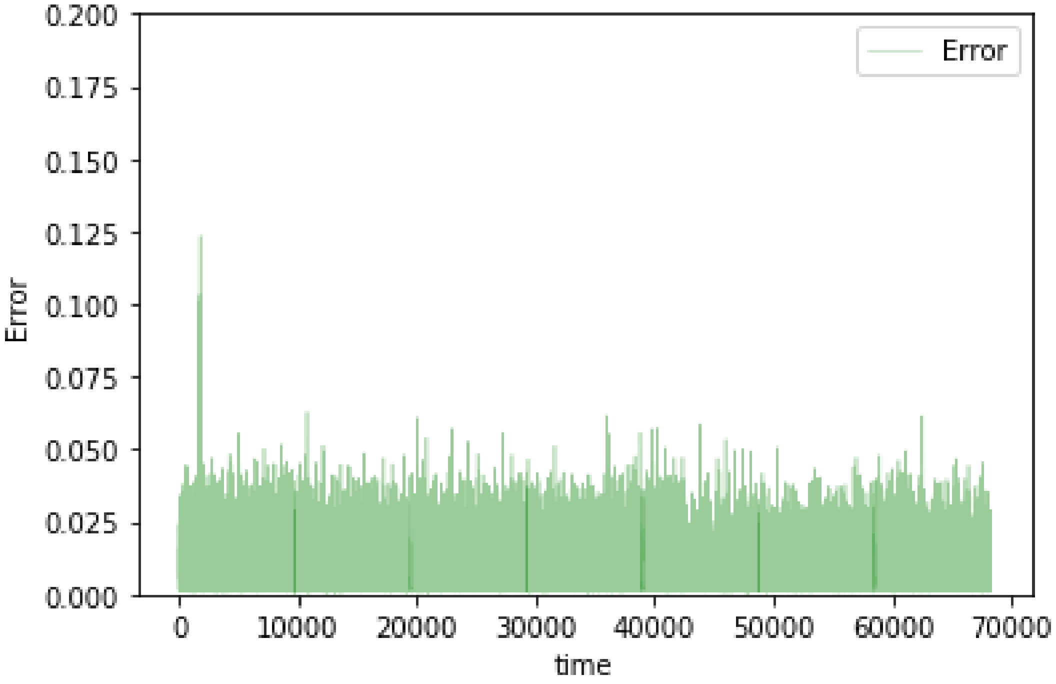
```
The mean error for lin10_normal_ is 0.0076288646433865445 for length 68289
====================
```

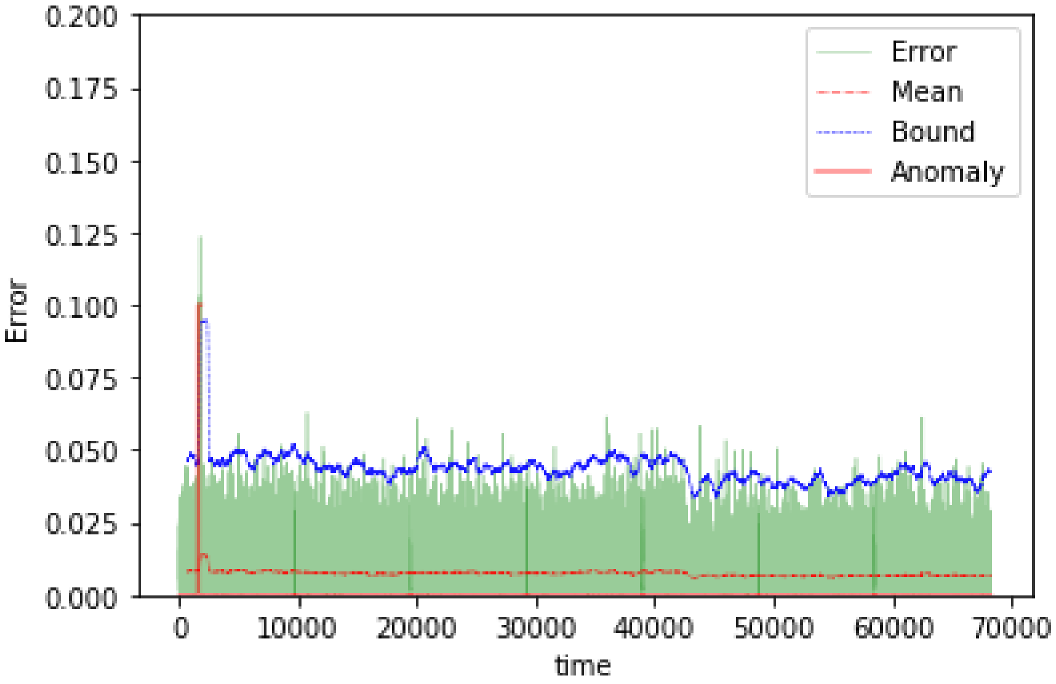
20 steps

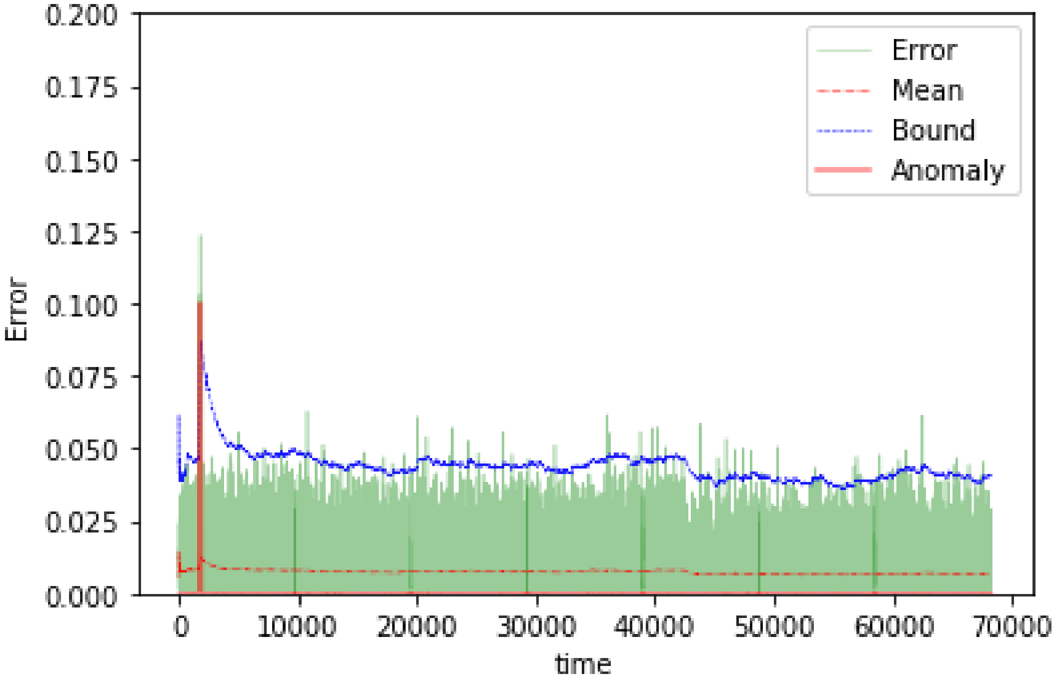
```
In [53]: TIMESTEPS = 20
         DIM = 29
         tgen = flat_generator(X, TIMESTEPS)
         vgen = flat_generator(val_X, TIMESTEPS)
         name = "lin20"

In [54]: input_layer = Input(shape=(TIMESTEPS*DIM,))
         output = Dense(DIM, activation='sigmoid')(input_layer)

In [55]: model = Model(input_layer, output)
         model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])

In [56]: train(model, tgen, vgen, name=name)
         test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008197543913614937
Validation loss for final epoch is 0.007438422540435568
---------- Beginning tests for lin20 ----------
Testing on Normal data.
```



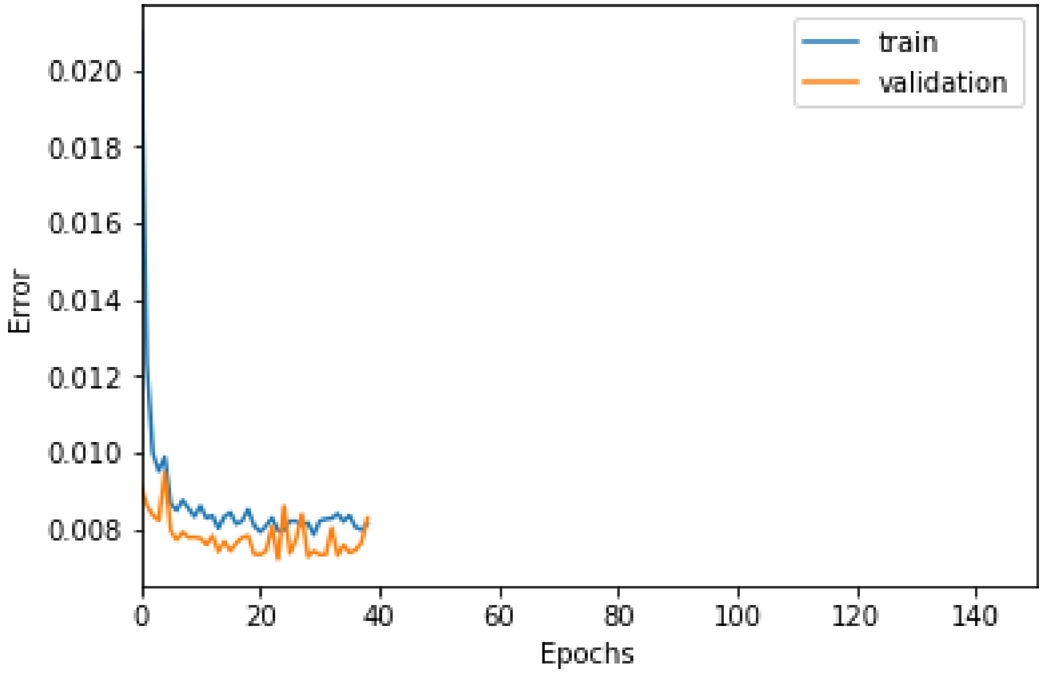




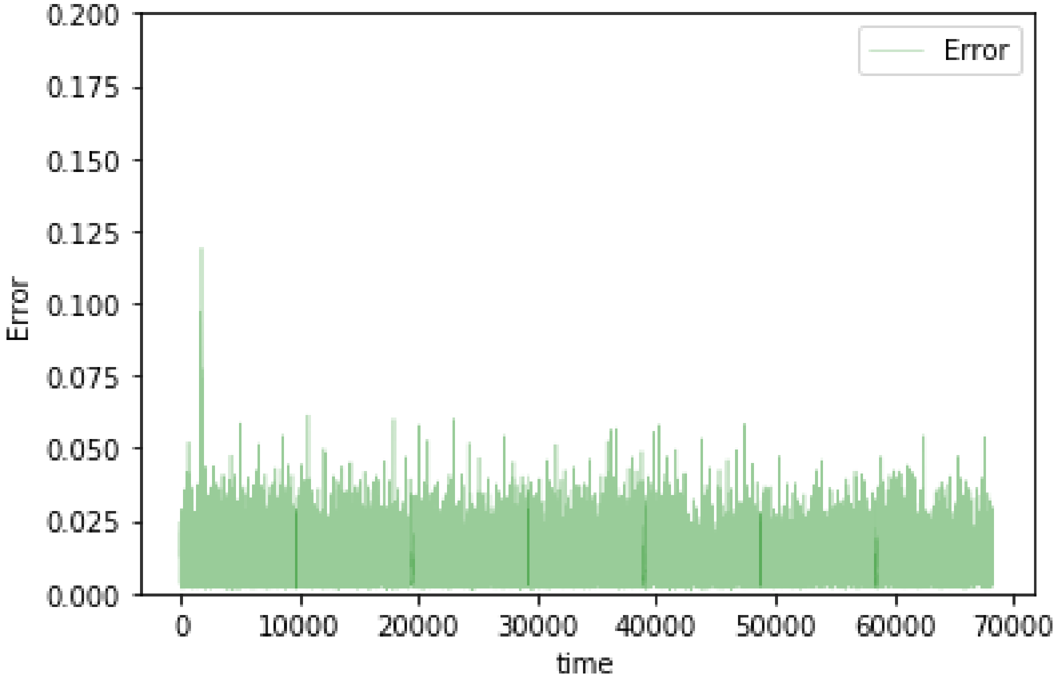
```
The mean error for lin20_normal_ is 0.0074296539402097595 for length 68279
====================
```

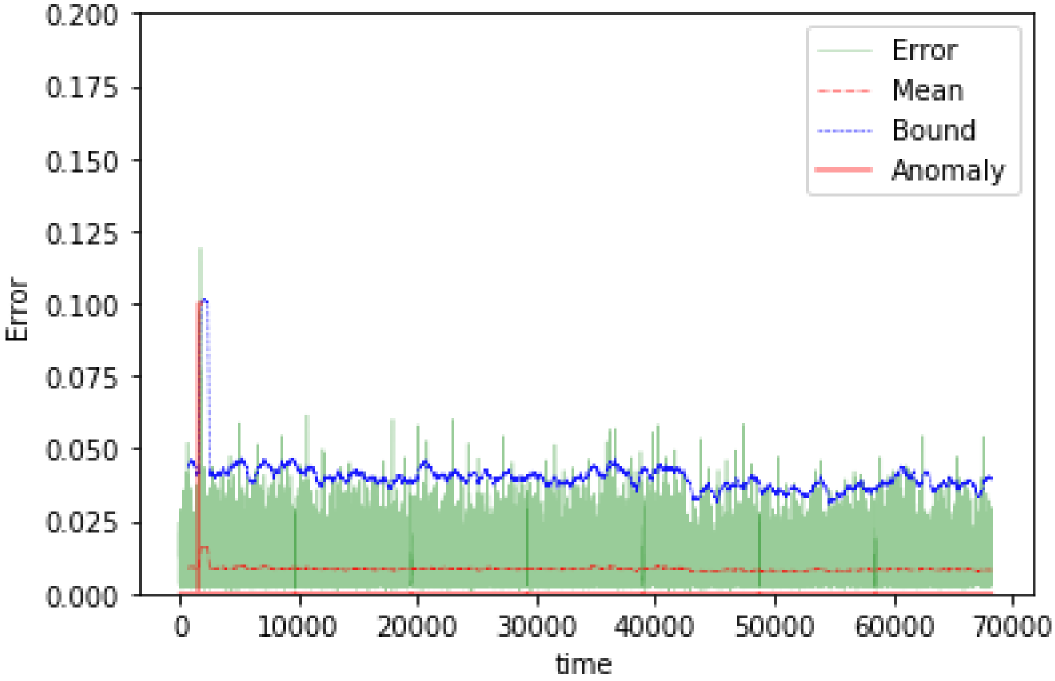
50 steps

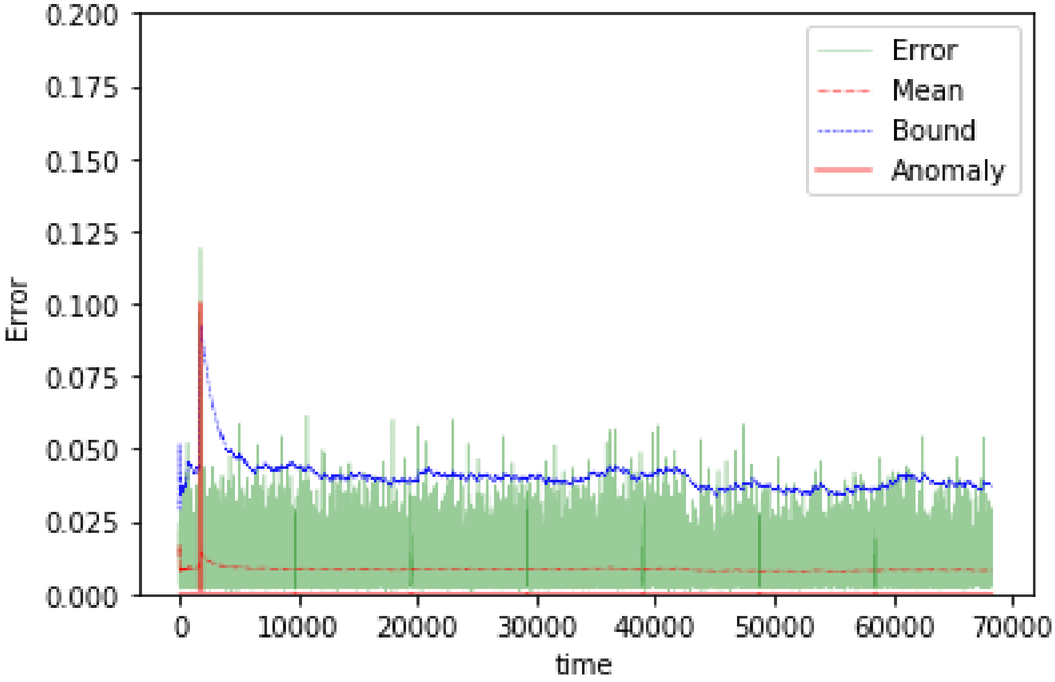
```
In [57]: TIMESTEPS = 50
         DIM = 29
         tgen = flat_generator(X, TIMESTEPS)
         vgen = flat_generator(val_X, TIMESTEPS)
         name = "lin50"

In [58]: input_layer = Input(shape=(TIMESTEPS*DIM,))
         output = Dense(DIM, activation='sigmoid')(input_layer)

In [59]: model = Model(input_layer, output)
         model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])

In [60]: train(model, tgen, vgen, name=name)
         test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008130129865370692
Validation loss for final epoch is 0.008277453483548015
---------- Beginning tests for lin50 ----------
Testing on Normal data.
```



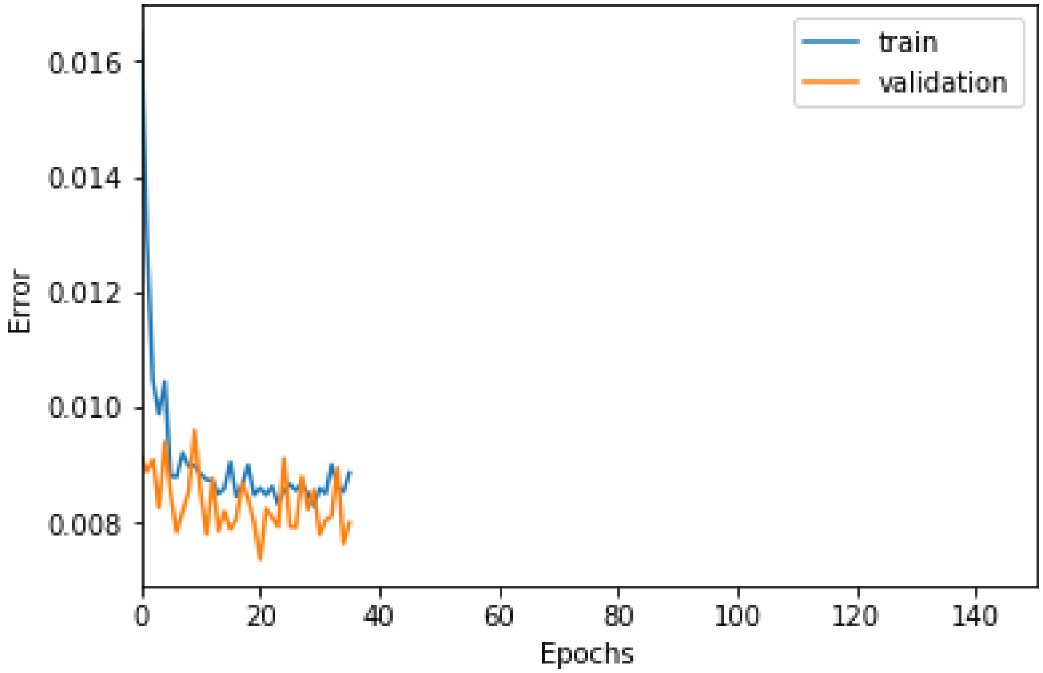

0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly


0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly

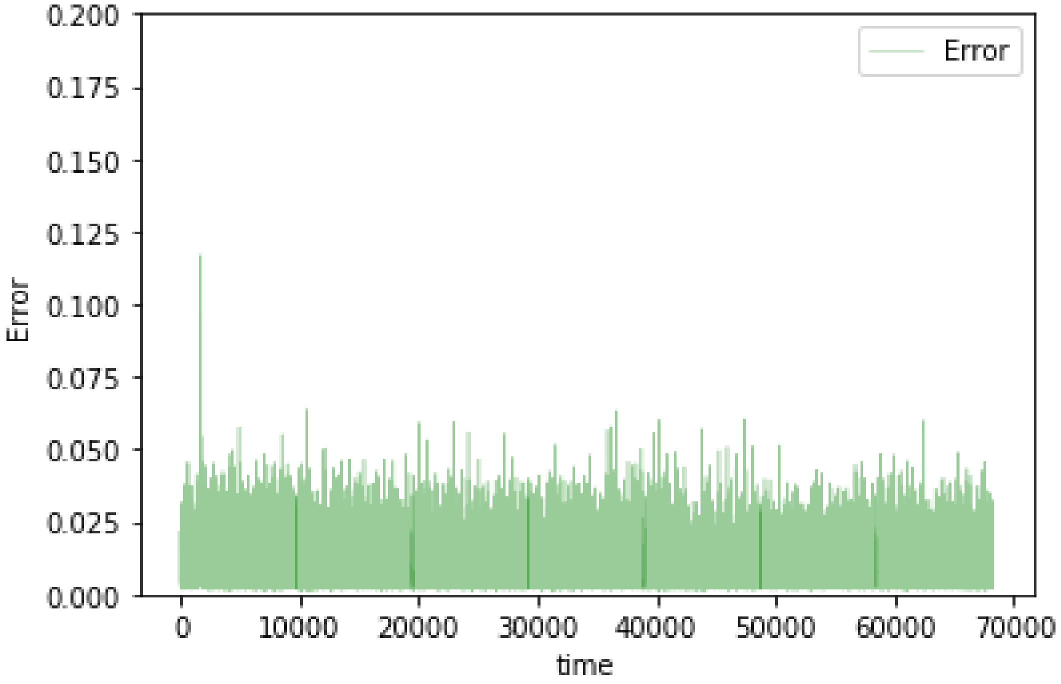
```
The mean error for lin50_normal_ is 0.008475679684637558 for length 68249
====================
```

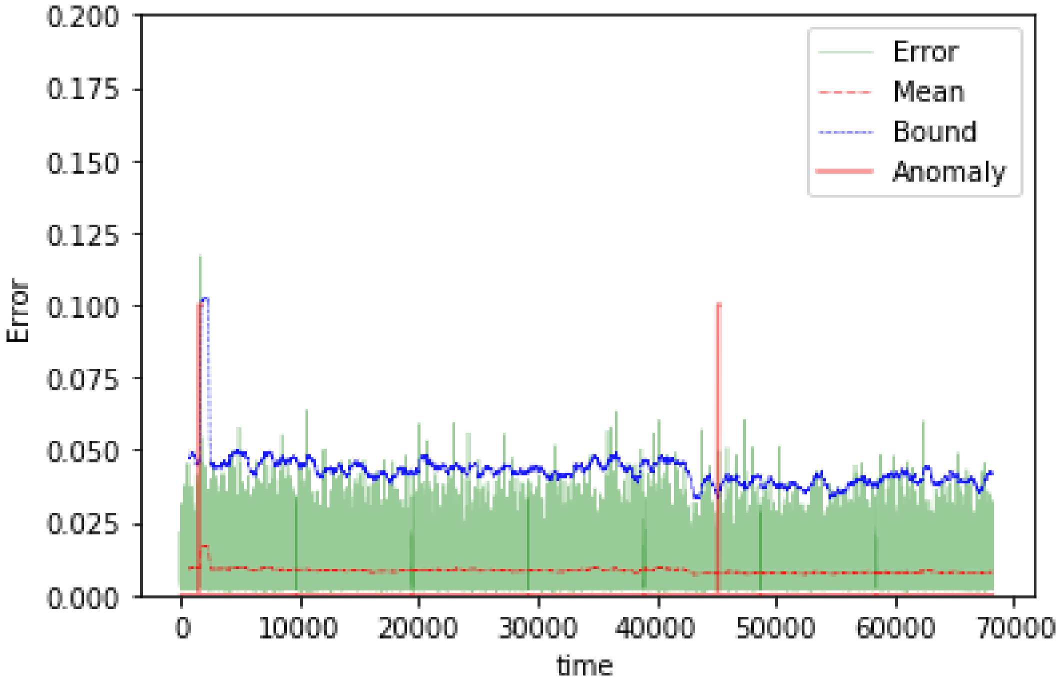
100 steps

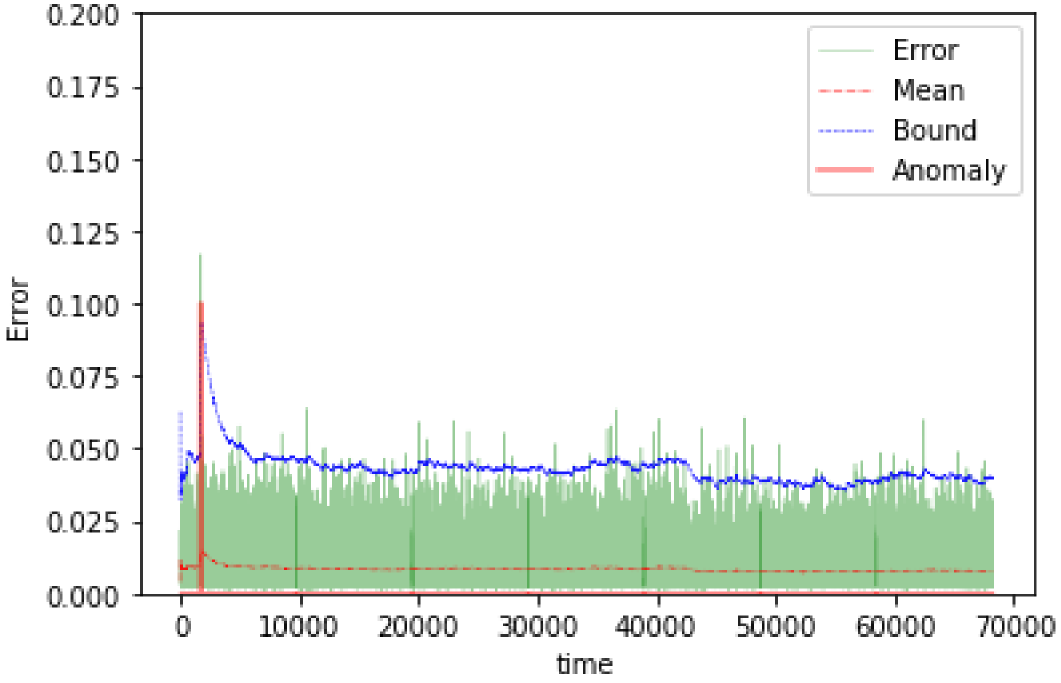
```
In [61]: TIMESTEPS = 100
         DIM = 29
         tgen = flat_generator(X, TIMESTEPS)
         vgen = flat_generator(val_X, TIMESTEPS)
         name = "lin100"

In [62]: input_layer = Input(shape=(TIMESTEPS*DIM,))
         output = Dense(DIM, activation='sigmoid')(input_layer)

In [63]: model = Model(input_layer, output)
         model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])

In [64]: train(model, tgen, vgen, name=name)
         test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008869136287132278
Validation loss for final epoch is 0.008005064548924565
---------- Beginning tests for lin100 ----------
Testing on Normal data.
```



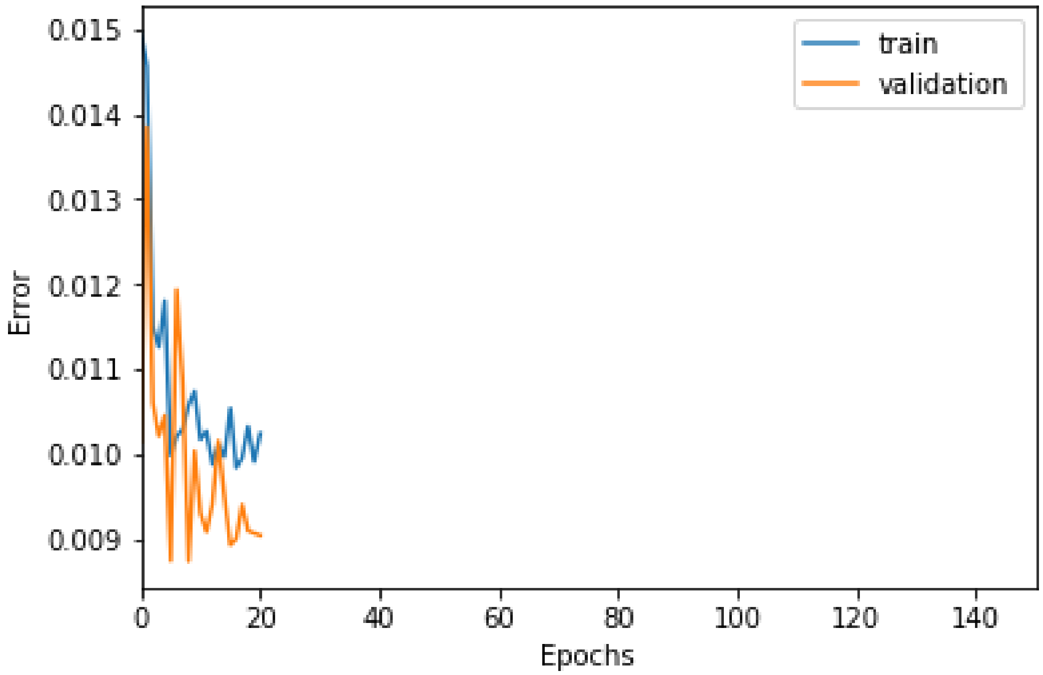




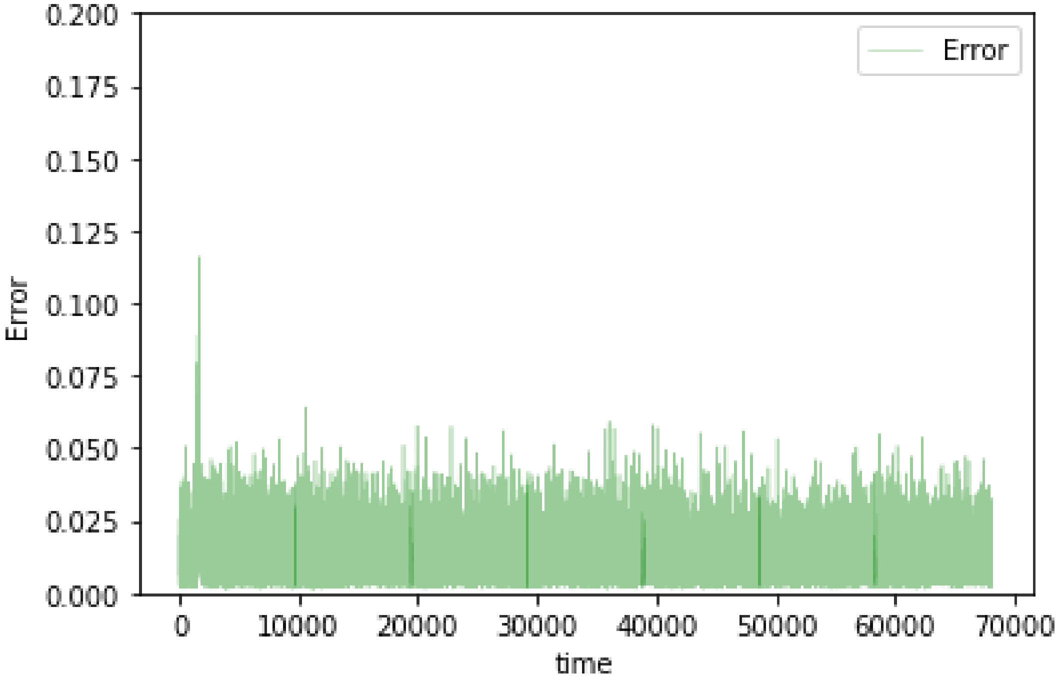
```
The mean error for lin100_normal_ is 0.008404050768236708 for length 68199
====================
```

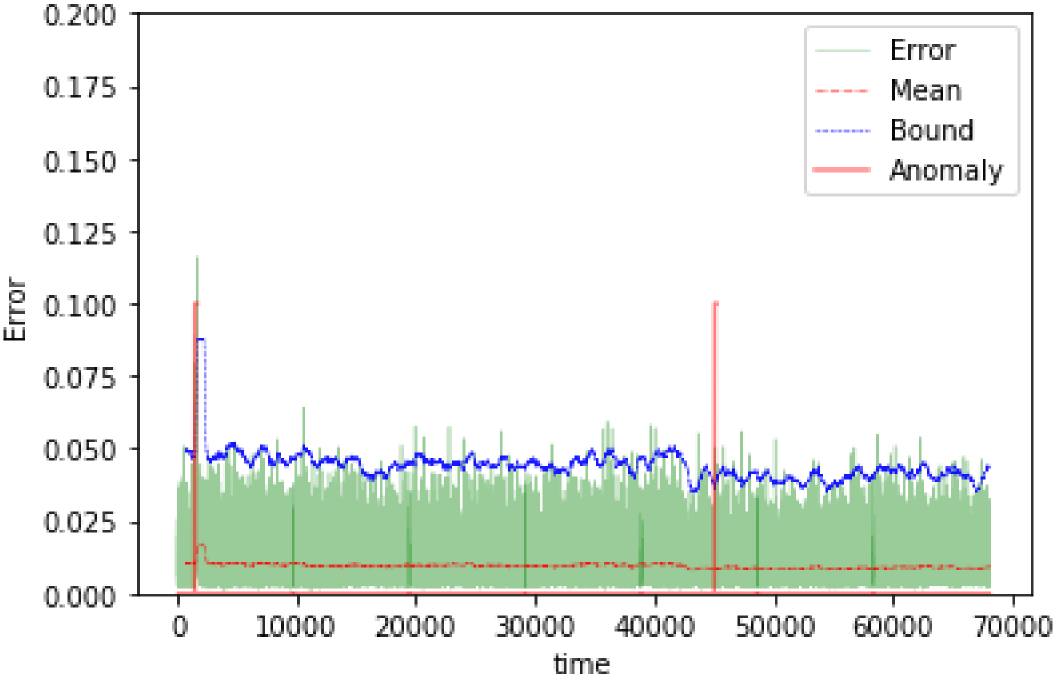
200 steps

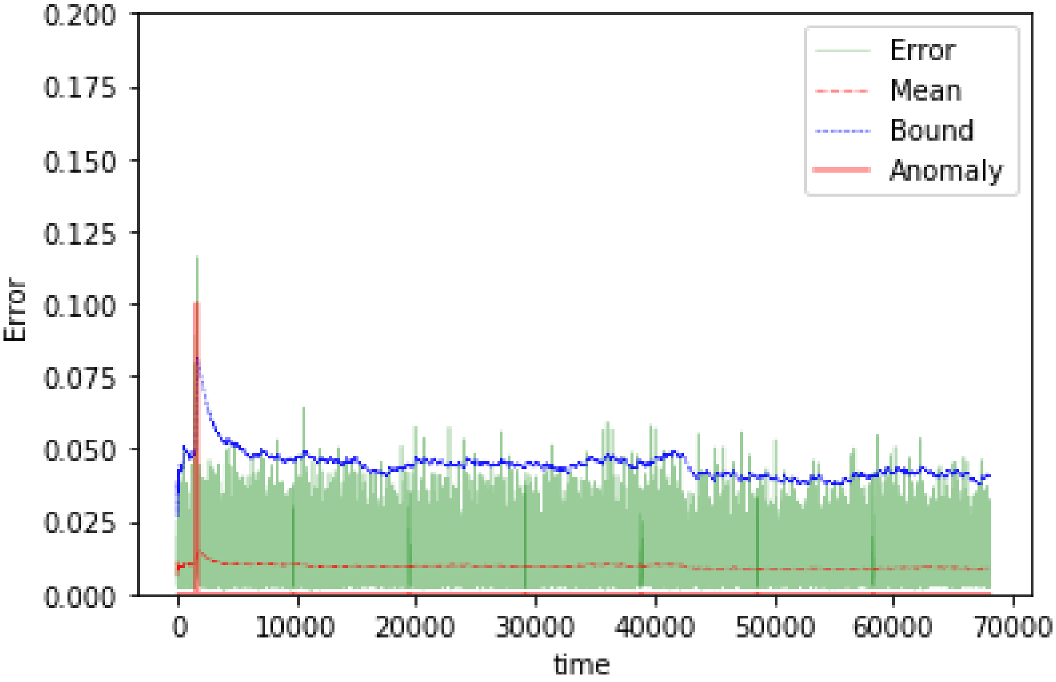
```
In [65]: TIMESTEPS = 200
         DIM = 29
         tgen = flat_generator(X, TIMESTEPS)
         vgen = flat_generator(val_X, TIMESTEPS)
         name = "lin200"

In [66]: input_layer = Input(shape=(TIMESTEPS*DIM,))
         output = Dense(DIM, activation='sigmoid')(input_layer)

In [67]: model = Model(input_layer, output)
         model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])

In [68]: train(model, tgen, vgen, name=name)
         test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.010245981639716774
Validation loss for final epoch is 0.009047726144082844
---------- Beginning tests for lin200 ----------
Testing on Normal data.
```




0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly


0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly

```
The mean error for lin200_normal_ is 0.009499800243700207 for length 68099
====================
```

1.11.2 NN with 1 hidden layer

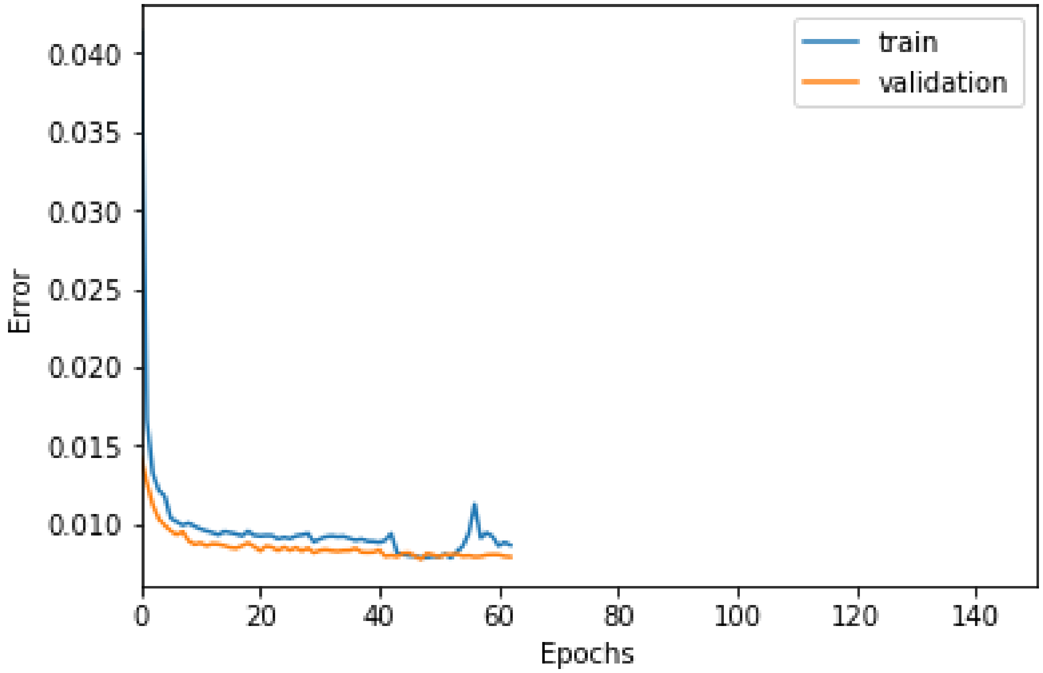
2 steps

```
In [69]: TIMESTEPS = 2
         DIM = 29
         tgen = flat_generator(X, TIMESTEPS)
         vgen = flat_generator(val_X, TIMESTEPS)
         name = "nn1_2"
```

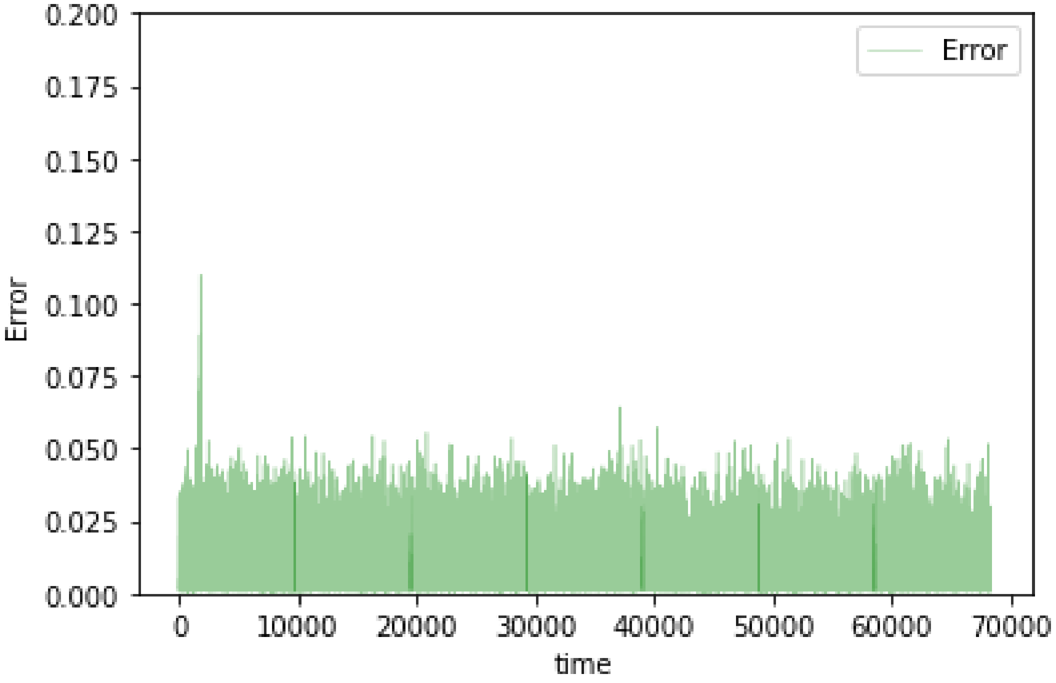
```
In [70]: input_layer = Input(shape=(TIMESTEPS*DIM,))
         hidden = Dense(100, activation='relu')(input_layer)
         output = Dense(DIM, activation='sigmoid')(hidden)
```

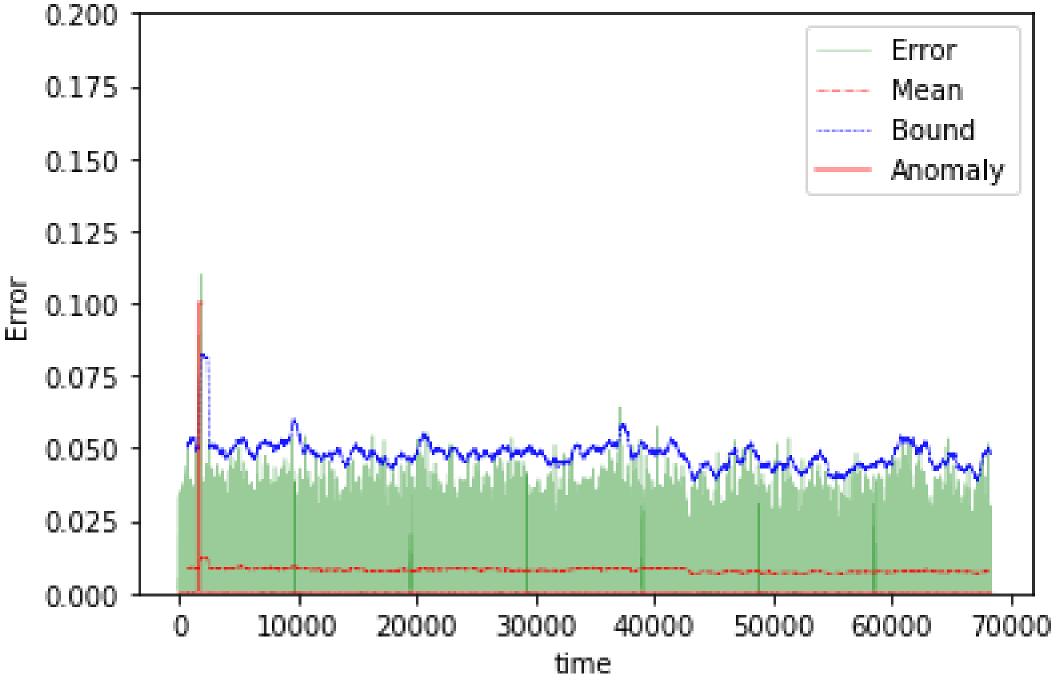
```
In [71]: model = Model(input_layer, output)
         model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

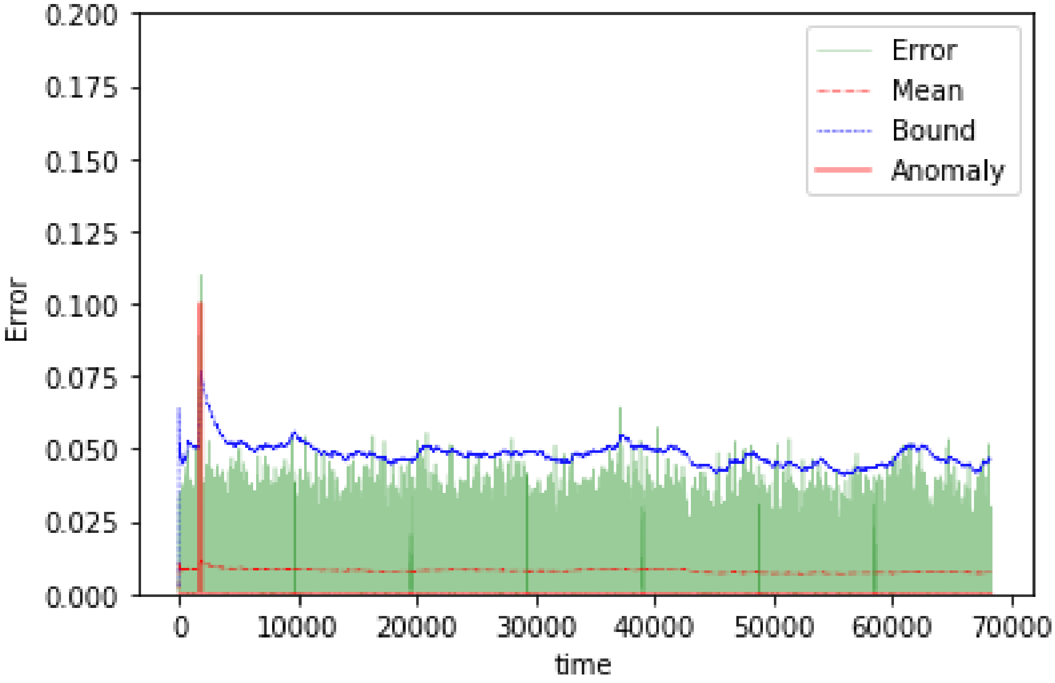
```
In [72]: train(model, tgen, vgen, name=name)
         test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008670514621073381
Validation loss for final epoch is 0.007923918919754214
---------- Beginning tests for nn1_2 ----------
Testing on Normal data.
```





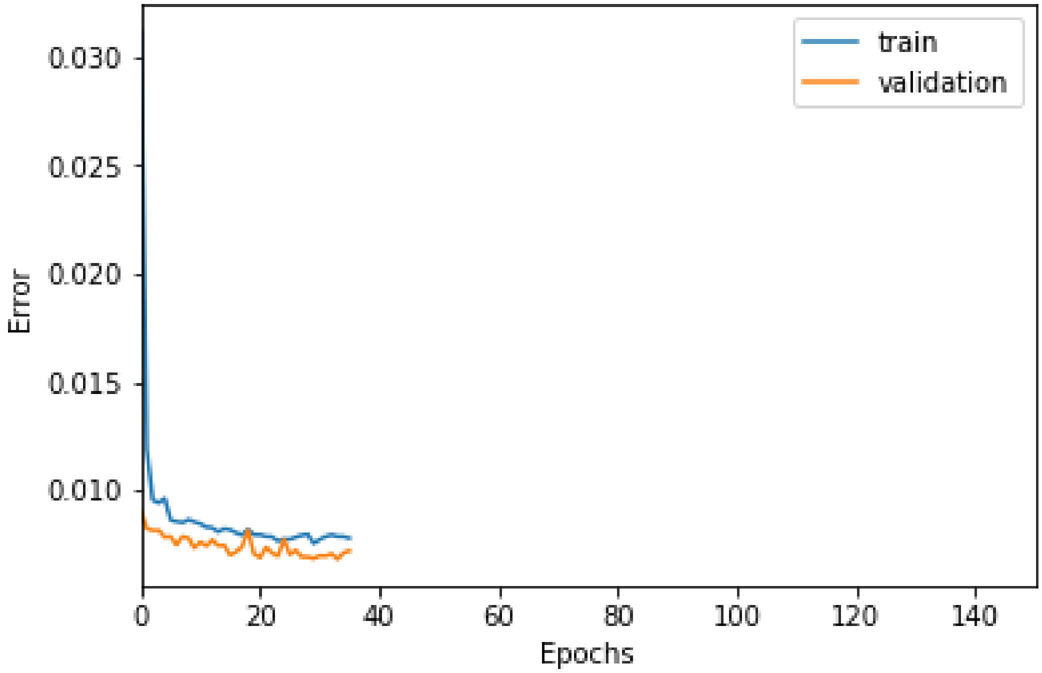


```
The mean error for nn1_2_normal_ is 0.00794332725724199 for length 68297
====================
```

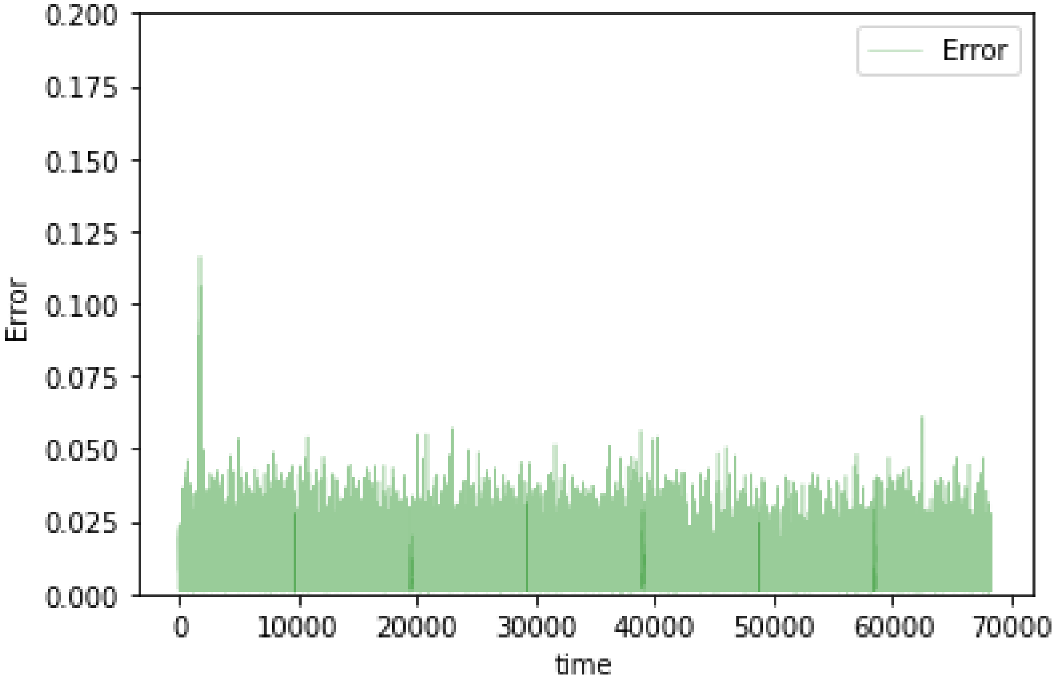
5 steps

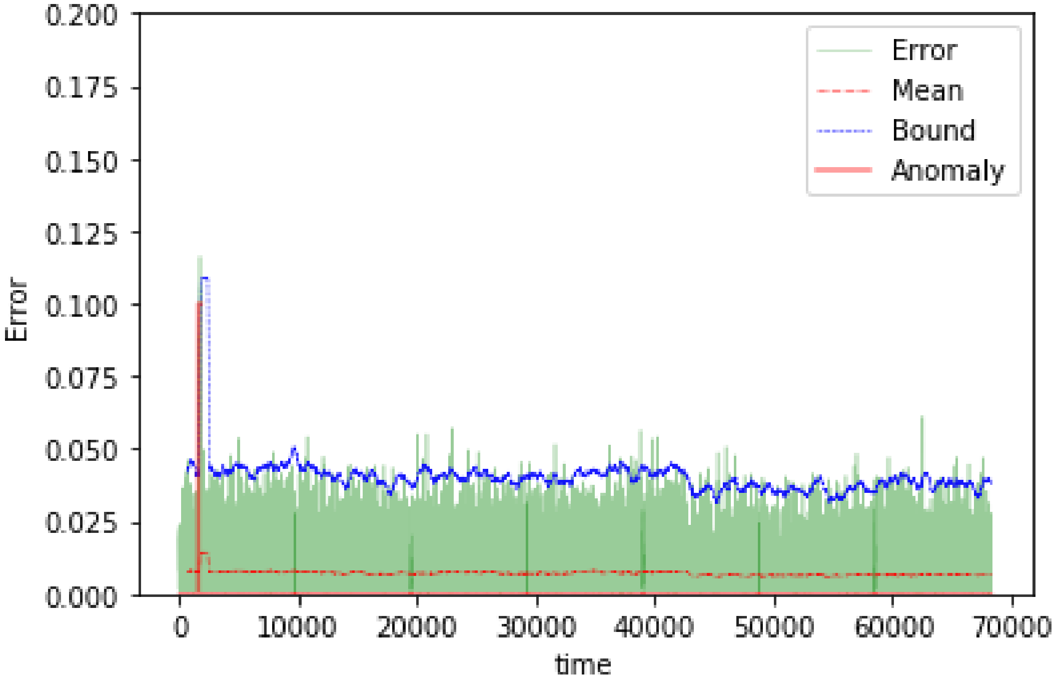
```
In [73]: TIMESTEPS = 5
         DIM = 29
         tgen = flat_generator(X, TIMESTEPS)
         vgen = flat_generator(val_X, TIMESTEPS)
         name = "nn1_5"

In [74]: input_layer = Input(shape=(TIMESTEPS*DIM,))
         hidden = Dense(100, activation='relu')(input_layer)
         output = Dense(DIM, activation='sigmoid')(hidden)

In [75]: model = Model(input_layer, output)
         model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

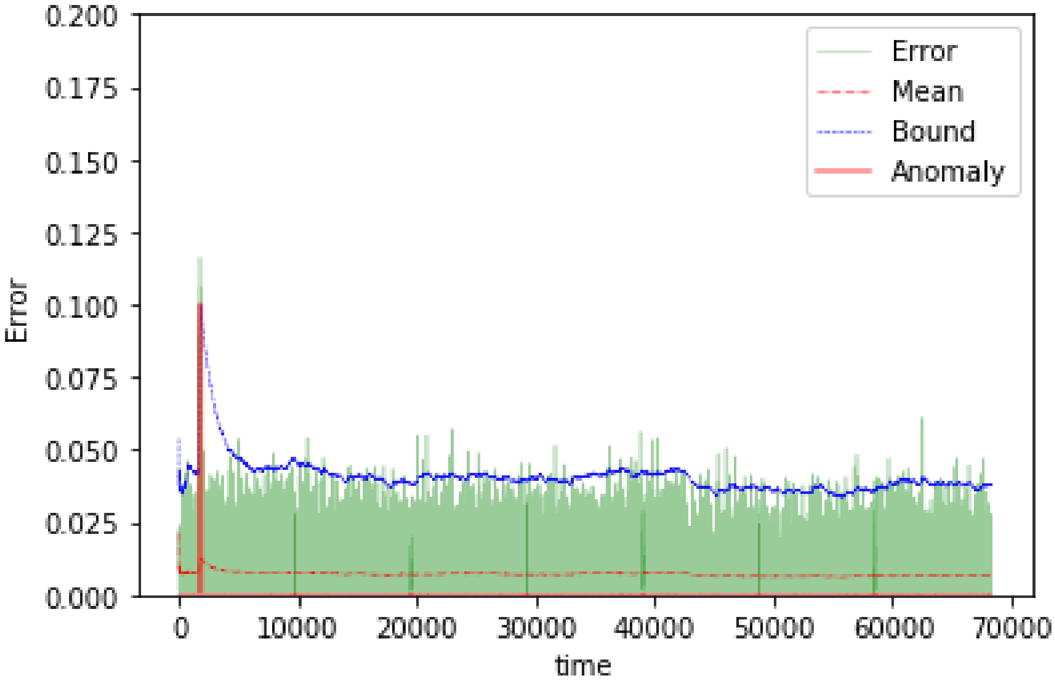
```
In [76]: train(model, tgen, vgen, name=name)
         test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.007782427513622679
Validation loss for final epoch is 0.007194245650665835
---------- Beginning tests for nn1_5 ----------
Testing on Normal data.
```


Error
Error
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
0
10000
20000
30000
40000
50000
60000
70000
time

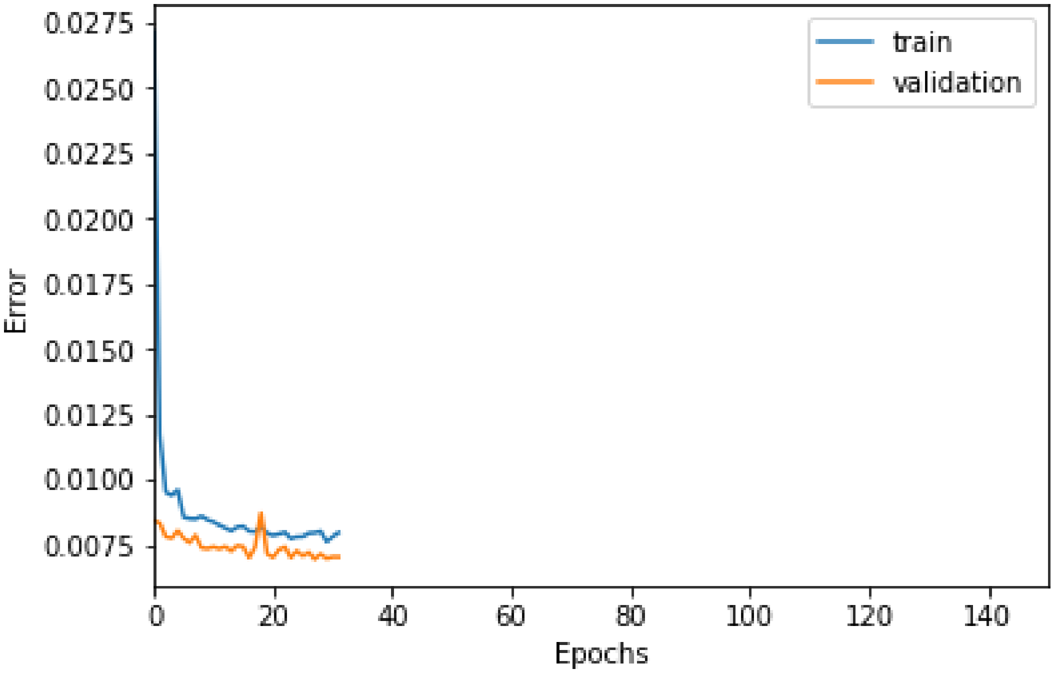

Error
Mean
Bound
Anomaly
Error
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
0
10000
20000
30000
40000
50000
60000
70000
time



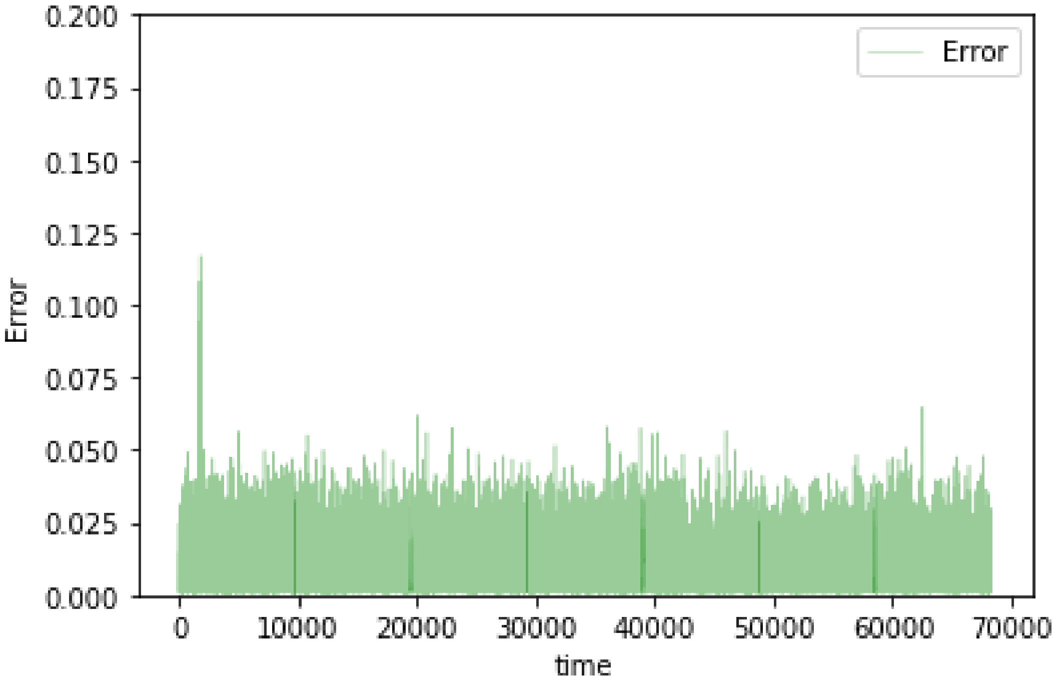
```
The mean error for nn1_5_normal_ is 0.007124384554601376 for length 68294
====================
```

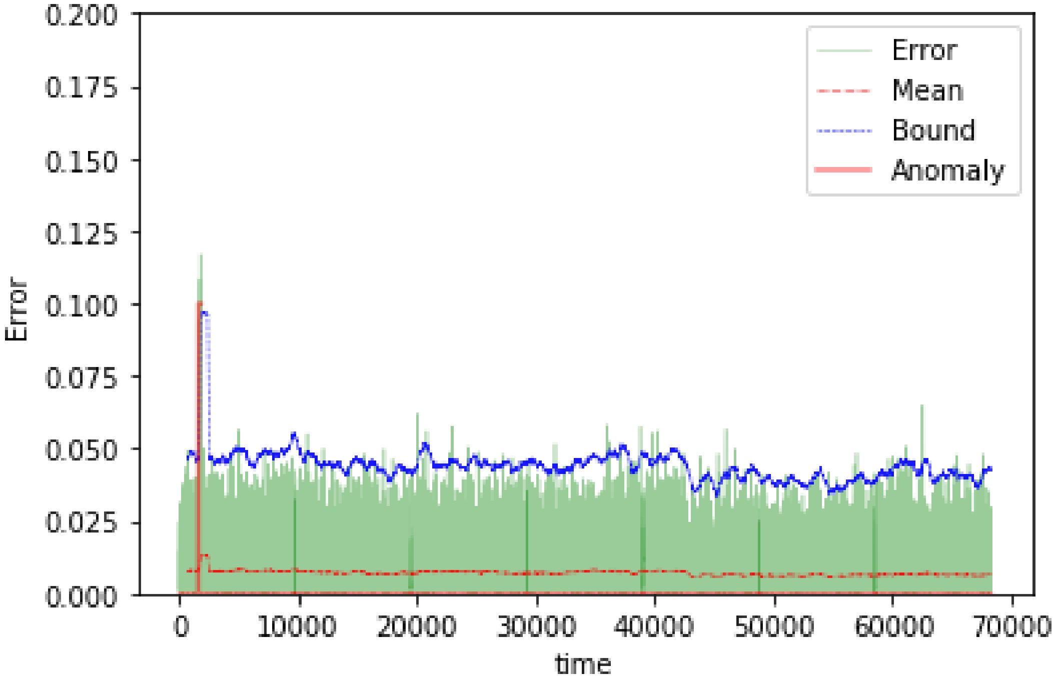
10 steps

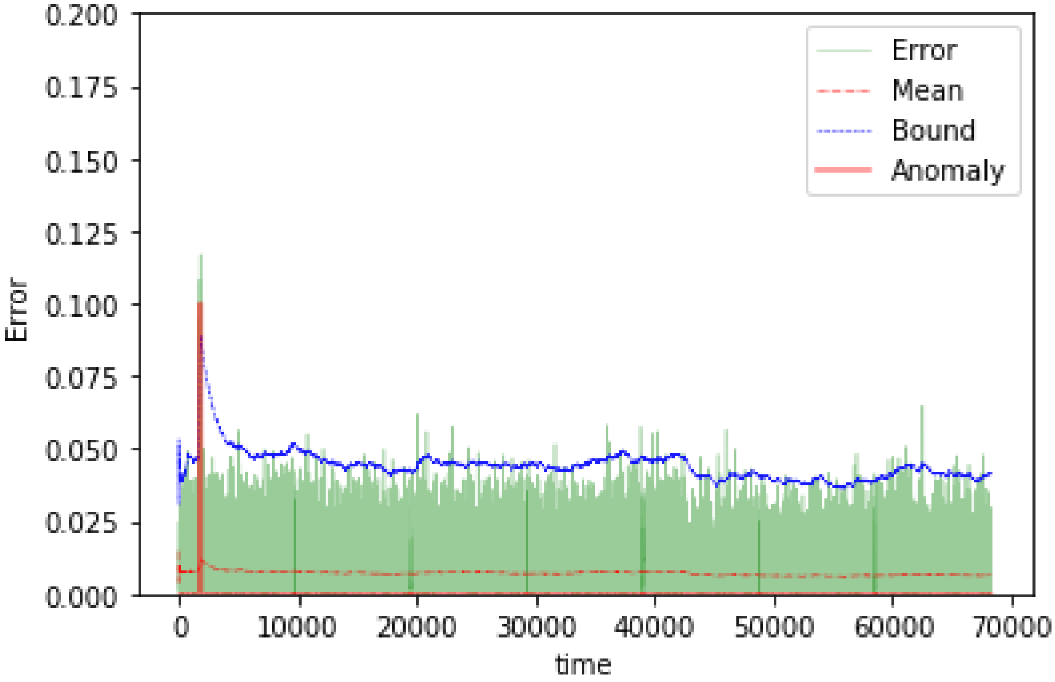
```
In [77]: TIMESTEPS = 10
         DIM = 29
         tgen = flat_generator(X, TIMESTEPS)
         vgen = flat_generator(val_X, TIMESTEPS)
         name = "nn1_10"

In [78]: input_layer = Input(shape=(TIMESTEPS*DIM,))
         hidden = Dense(100, activation='relu')(input_layer)
         output = Dense(DIM, activation='sigmoid')(hidden)

In [79]: model = Model(input_layer, output)
         model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])

In [80]: train(model, tgen, vgen, name=name)
         test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.007966320621781051
Validation loss for final epoch is 0.007032657149480656
---------- Beginning tests for nn1_10 ----------
Testing on Normal data.
```




Error
Mean
Bound
Anomaly
Error
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
0
10000
20000
30000
40000
50000
60000
70000
time


Error
Mean
Bound
Anomaly
Error
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
0
10000
20000
30000
40000
50000
60000
70000
time

```
The mean error for nn1_10_normal_ is 0.007097160318198191 for length 68289
====================
```

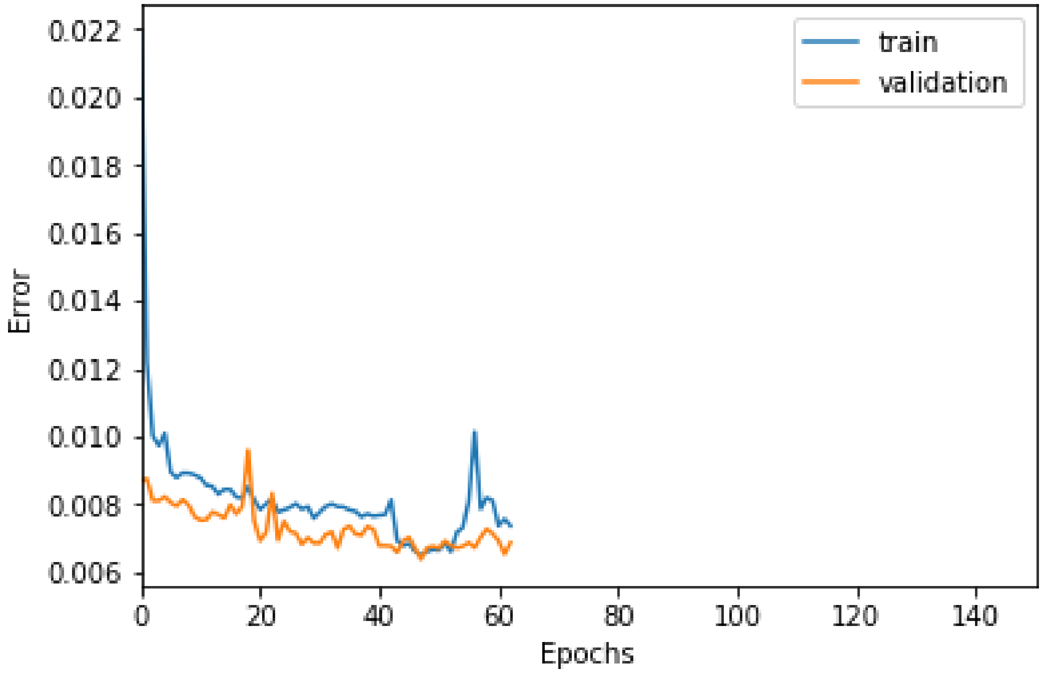
20 steps

```
In [81]: TIMESTEPS = 20
         DIM = 29
         tgen = flat_generator(X, TIMESTEPS)
         vgen = flat_generator(val_X, TIMESTEPS)
         name = "nn1_20"
```

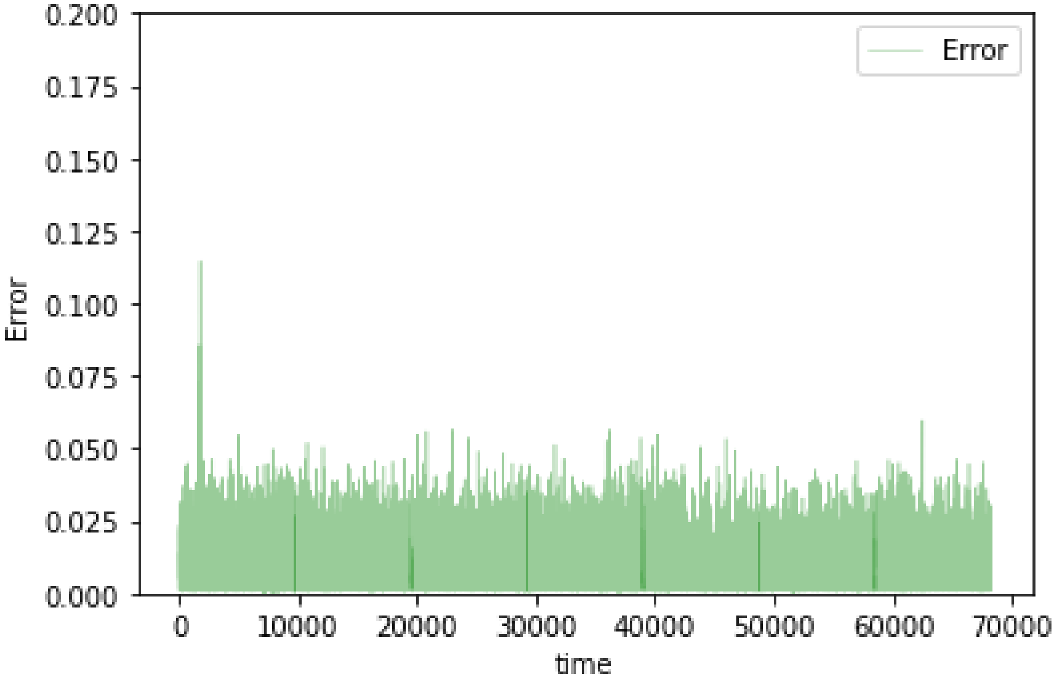
```
In [82]: input_layer = Input(shape=(TIMESTEPS*DIM,))
         hidden = Dense(100,activation='relu')(input_layer)
         output = Dense(DIM, activation='sigmoid')(hidden)
```

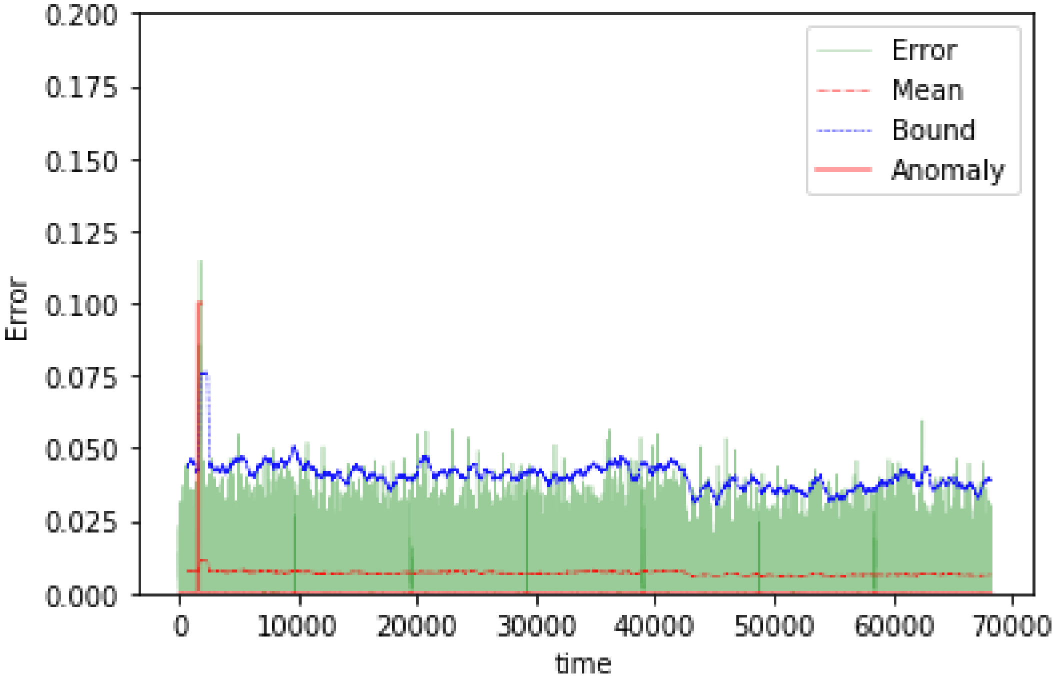
```
In [83]: model = Model(input_layer, output)
         model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

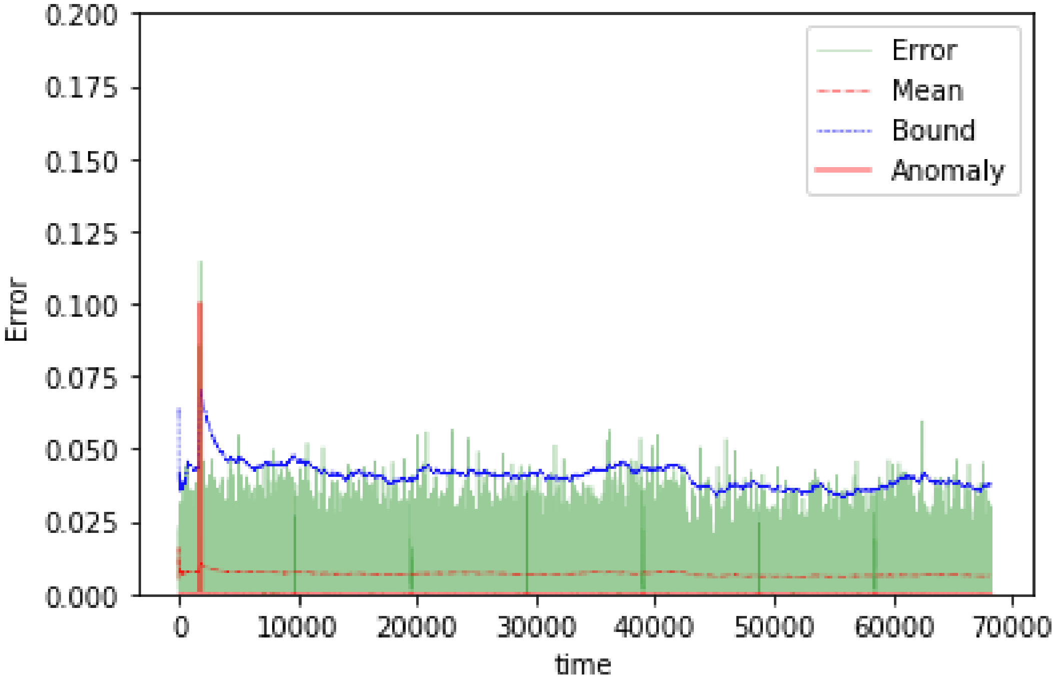
```
In [84]: train(model, tgen, vgen, name=name)
         test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.007379020310938358
Validation loss for final epoch is 0.0068768529685912655
---------- Beginning tests for nn1_20 ----------
Testing on Normal data.
```





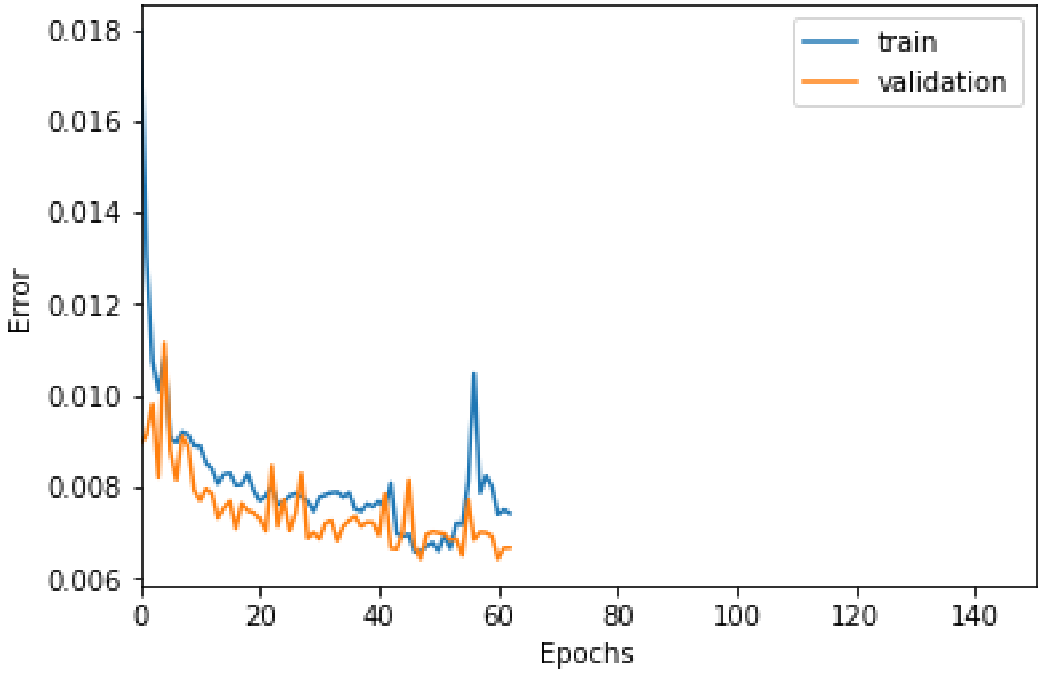


```
The mean error for nn1_20_normal_ is 0.006872599188956382 for length 68279
====================
```

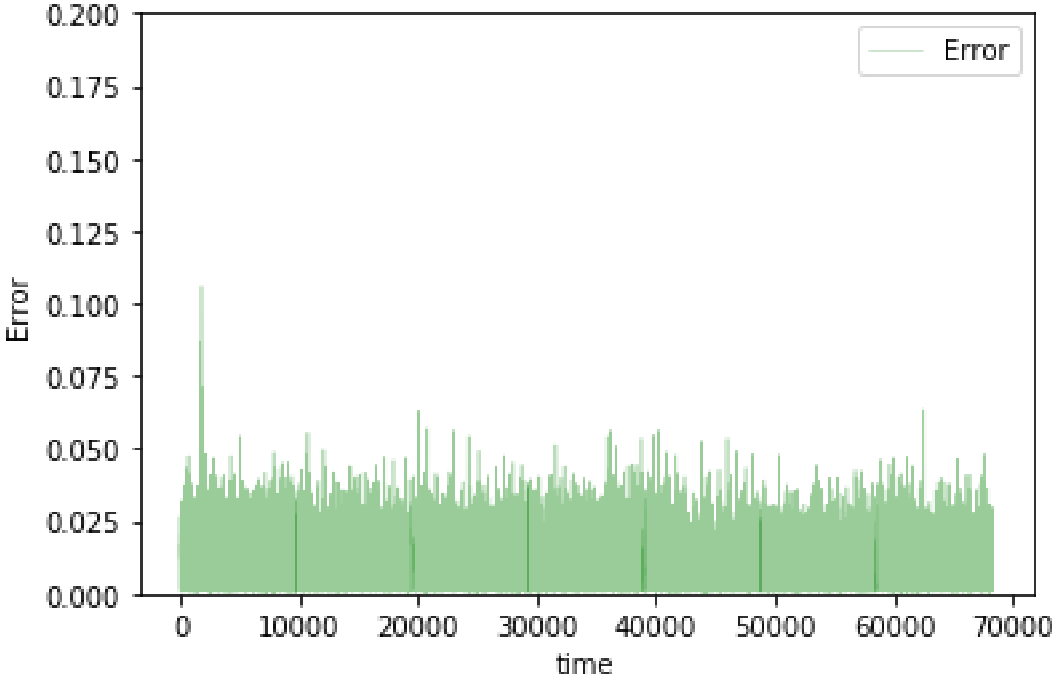
50 steps

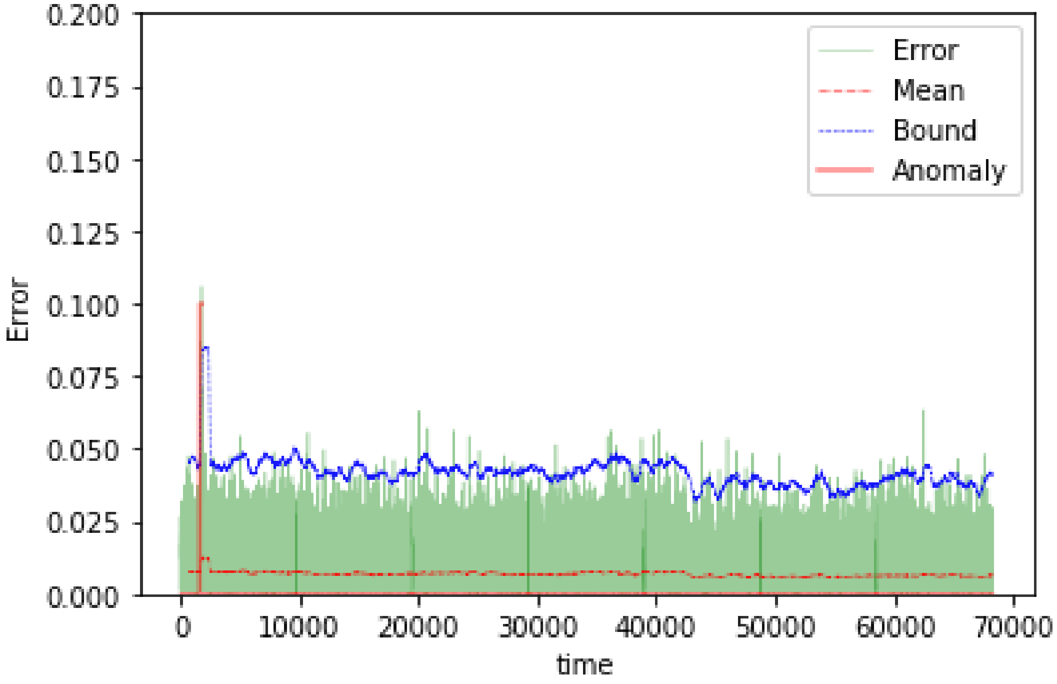
```
In [85]: TIMESTEPS = 50
         DIM = 29
         tgen = flat_generator(X, TIMESTEPS)
         vgen = flat_generator(val_X, TIMESTEPS)
         name = "nn1_50"

In [86]: input_layer = Input(shape=(TIMESTEPS*DIM,))
         hidden = Dense(100,activation='relu')(input_layer)
         output = Dense(DIM, activation='sigmoid')(hidden)

In [87]: model = Model(input_layer, output)
         model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

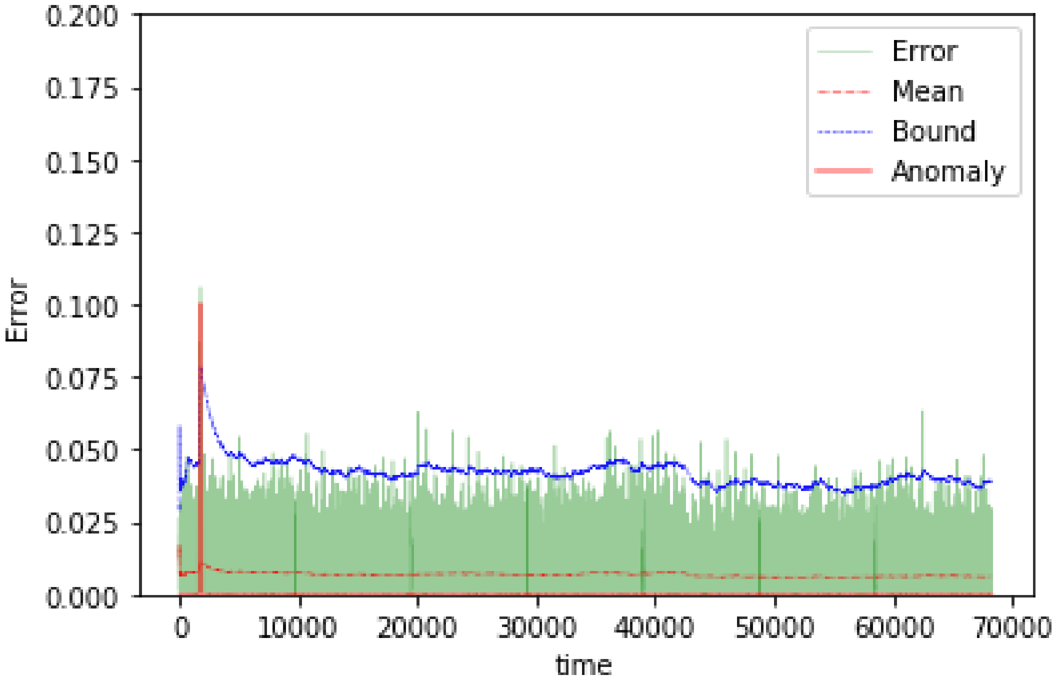
```
In [88]: train(model, tgen, vgen, name=name)
         test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.007416516275261529
Validation loss for final epoch is 0.006669080848922022
---------- Beginning tests for nn1_50 ----------
Testing on Normal data.
```


0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error

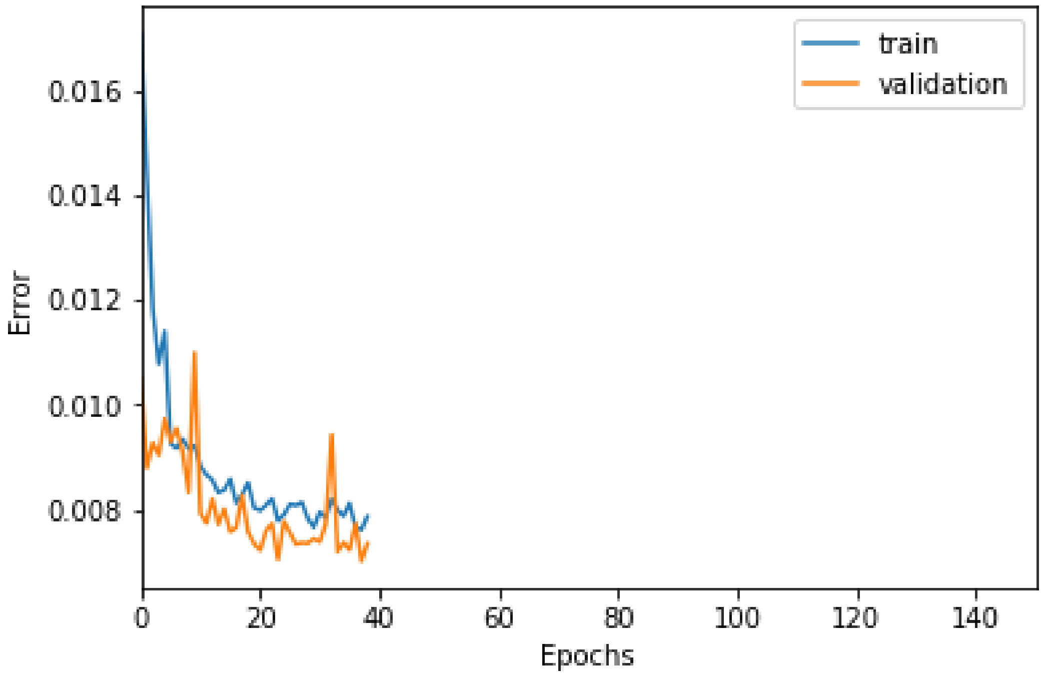

0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly



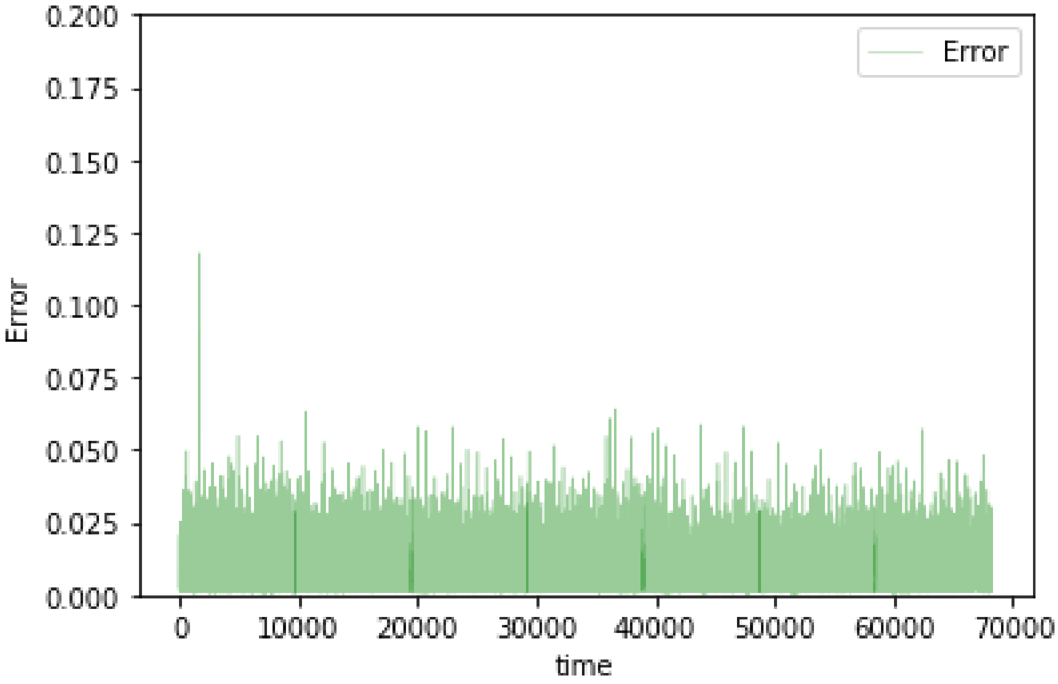
```
The mean error for nn1_50_normal_ is 0.006836222236026735 for length 68249
====================
```

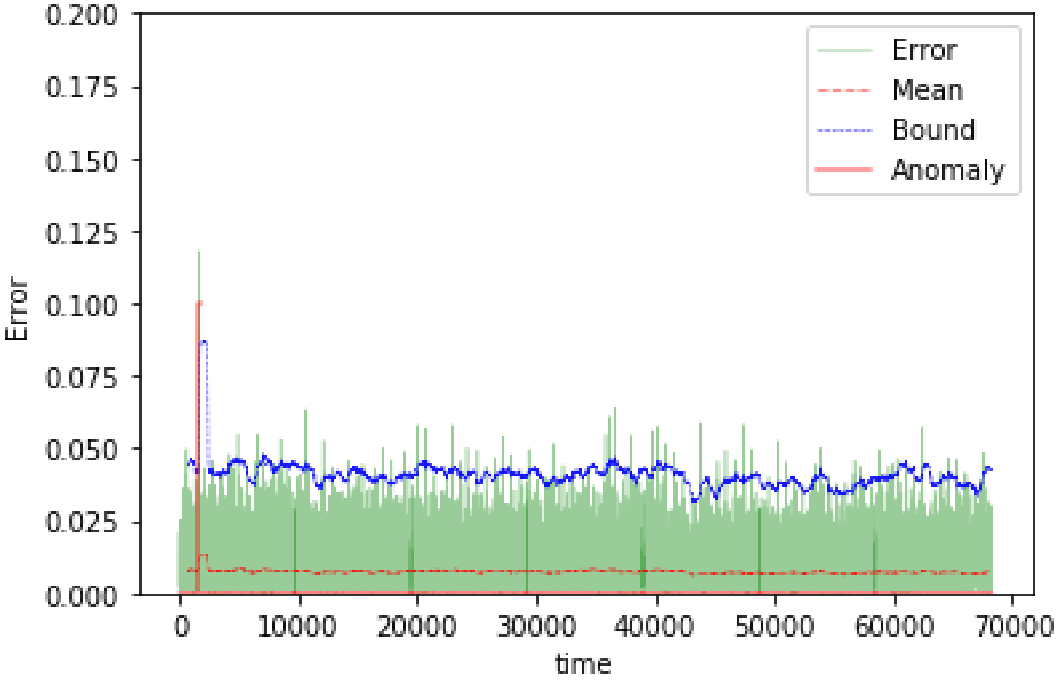
100 steps

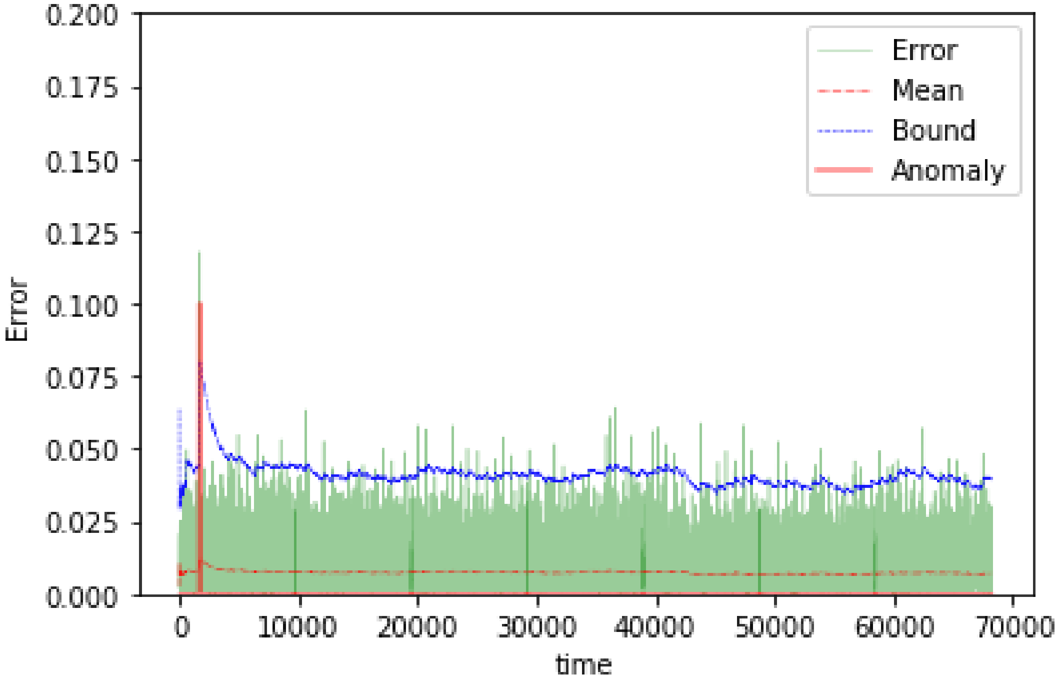
```
In [89]: TIMESTEPS = 100
         DIM = 29
         tgen = flat_generator(X, TIMESTEPS)
         vgen = flat_generator(val_X, TIMESTEPS)
         name = "nn1_100"

In [90]: input_layer = Input(shape=(TIMESTEPS*DIM,))
         hidden = Dense(100,activation='relu')(input_layer)
         output = Dense(DIM, activation='sigmoid')(hidden)

In [91]: model = Model(input_layer, output)
         model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])

In [92]: train(model, tgen, vgen, name=name)
         test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.007877720904303715
Validation loss for final epoch is 0.007362006059614941
---------- Beginning tests for nn1_100 ----------
Testing on Normal data.
```




Error
Mean
Bound
Anomaly
Error
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
0
10000
20000
30000
40000
50000
60000
70000
time


Error
Mean
Bound
Anomaly
Error
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
0
10000
20000
30000
40000
50000
60000
70000
time

```
The mean error for nn1_100_normal_ is 0.007414447175339916 for length 68199
====================
```

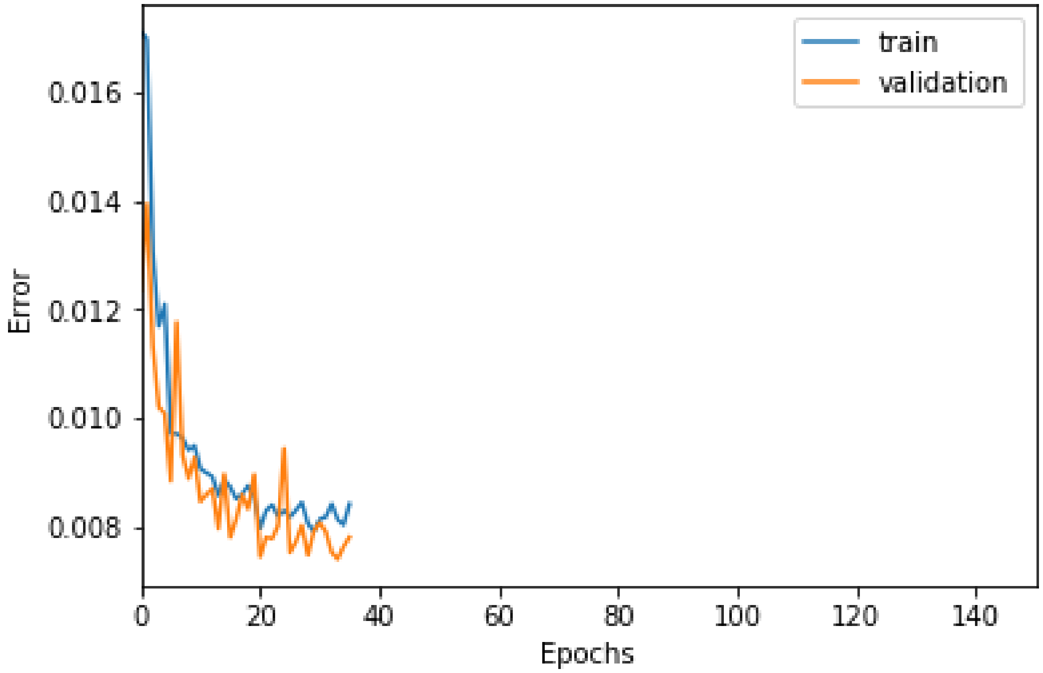
200 steps

```
In [93]: TIMESTEPS = 200
         DIM = 29
         tgen = flat_generator(X, TIMESTEPS)
         vgen = flat_generator(val_X, TIMESTEPS)
         name = "nn1_200"
```

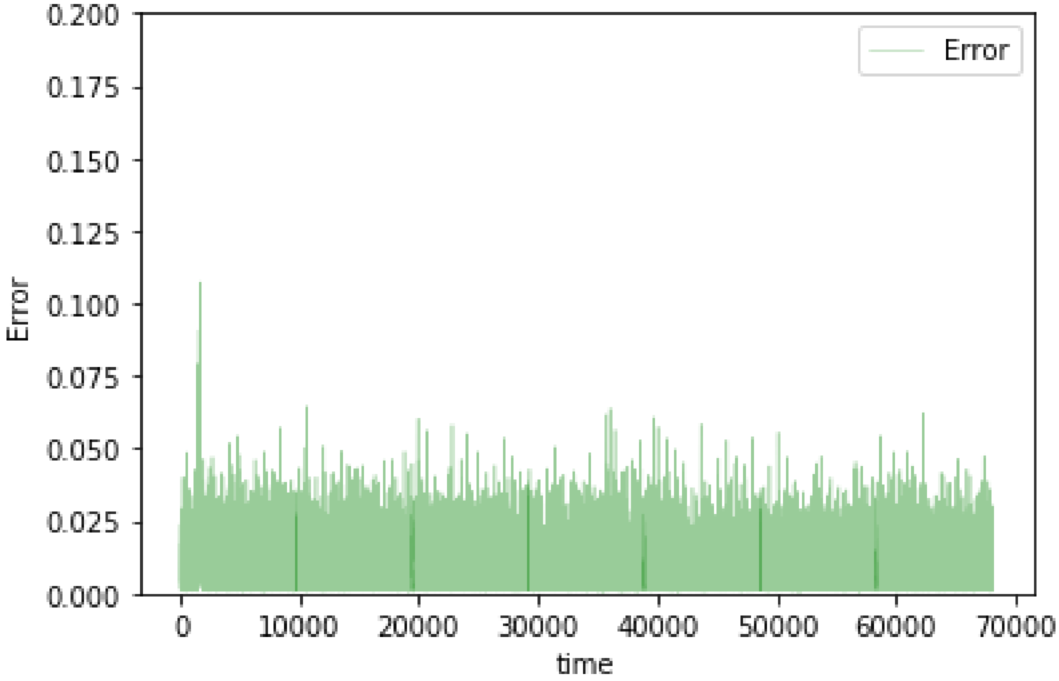
```
In [94]: input_layer = Input(shape=(TIMESTEPS*DIM,))
         hidden = Dense(100,activation='relu')(input_layer)
         output = Dense(DIM, activation='sigmoid')(hidden)
```

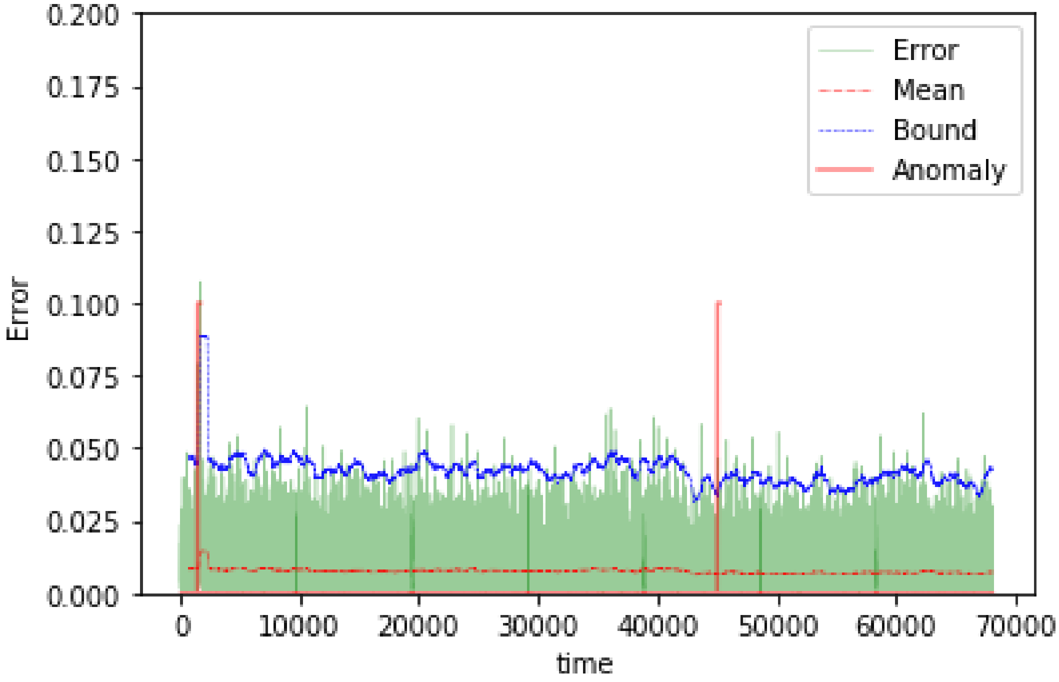
```
In [95]: model = Model(input_layer, output)
         model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

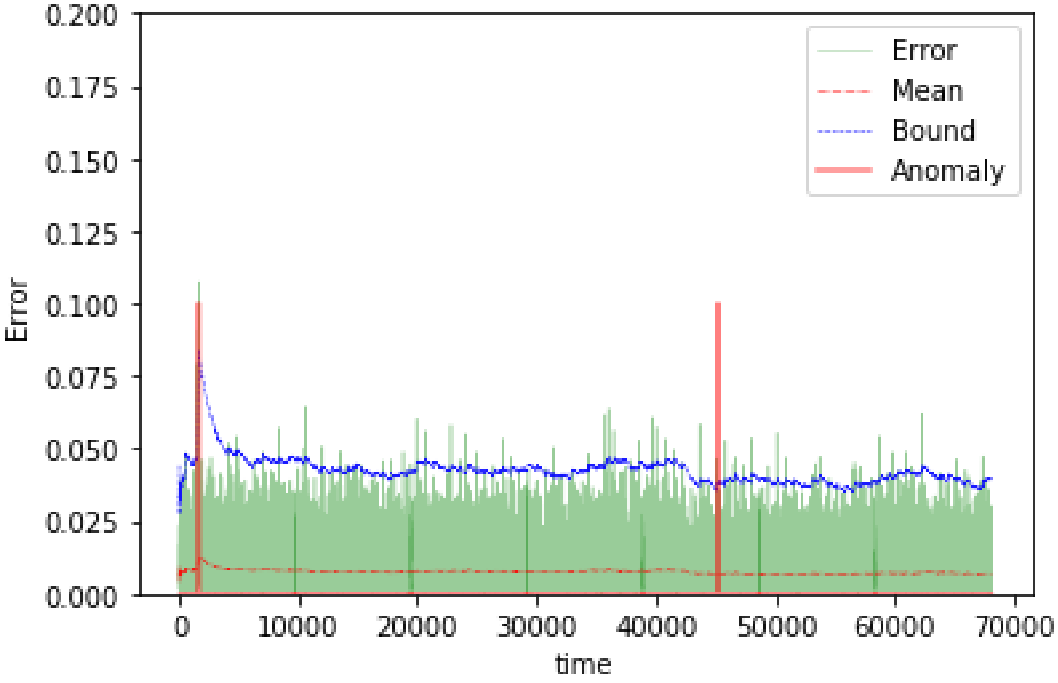
```
In [96]: train(model, tgen, vgen, name=name)
         test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008407896119635553
Validation loss for final epoch is 0.007797789694974199
---------- Beginning tests for nn1_200 ----------
Testing on Normal data.
```







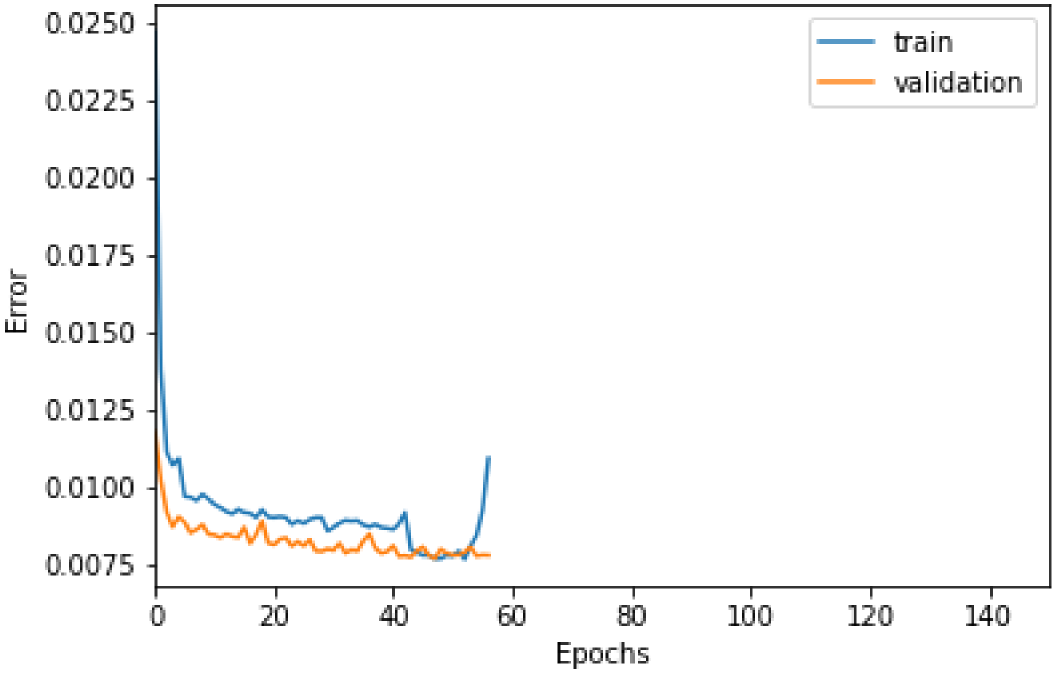
```
The mean error for nn1_200_normal_ is 0.007616529005377 1244 for length 68099
====================
```

1.11.3 NN with 2 hidden layers

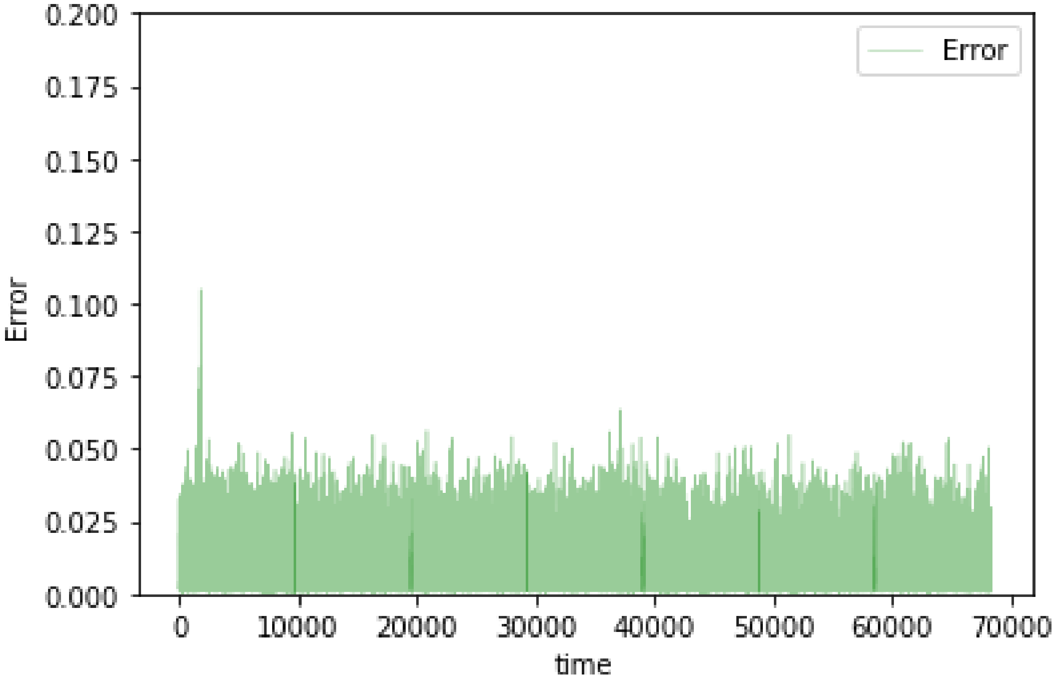
2 steps

```
In [97]: TIMESTEPS = 2
         DIM = 29
         tgen = flat_generator(X, TIMESTEPS)
         vgen = flat_generator(val_X, TIMESTEPS)
         name = "nn2_2"

In [98]: input_layer = Input(shape=(TIMESTEPS*DIM,))
         hidden = Dense(500, activation='relu')(input_layer)
         hidden = Dense(100, activation='relu')(hidden)
         output = Dense(DIM, activation='sigmoid')(hidden)
```

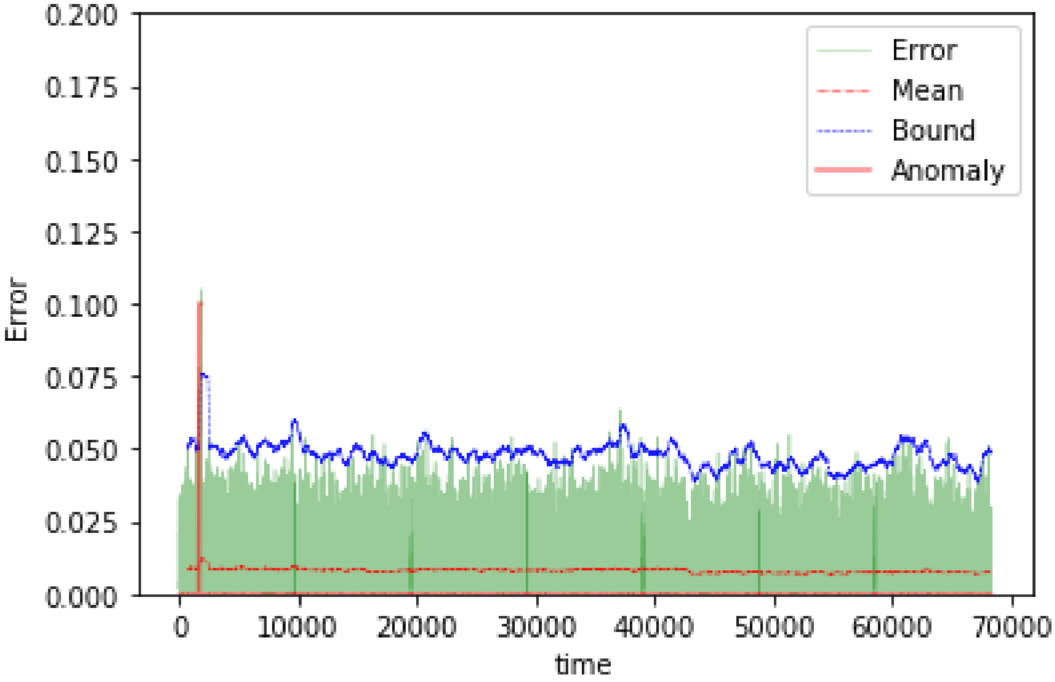
```
In [99]: model = Model(input_layer, output)
         model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])

In [100]: train(model, tgen, vgen, name=name)
          test(model, name=name, window=TIMESTEPS)
```



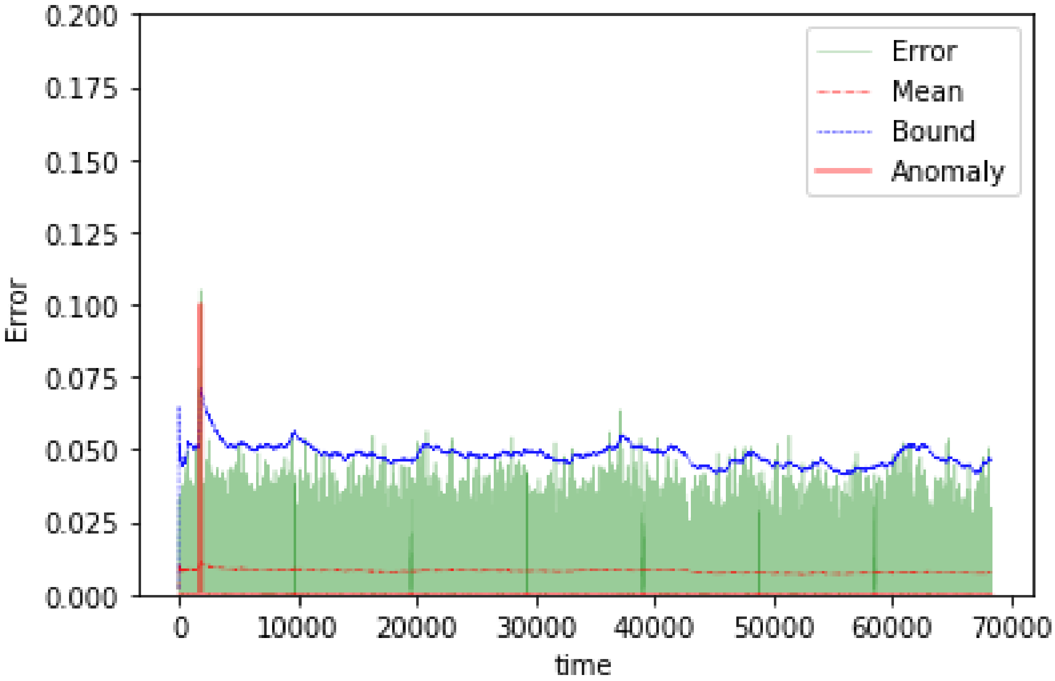
```
Training loss for final epoch is 0.010946616681409069
Validation loss for final epoch is 0.007812759321765042
---------- Beginning tests for nn2_2 ----------
Testing on Normal data.
```



Error
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
0
10000
20000
30000
40000
50000
60000
70000
time
Error



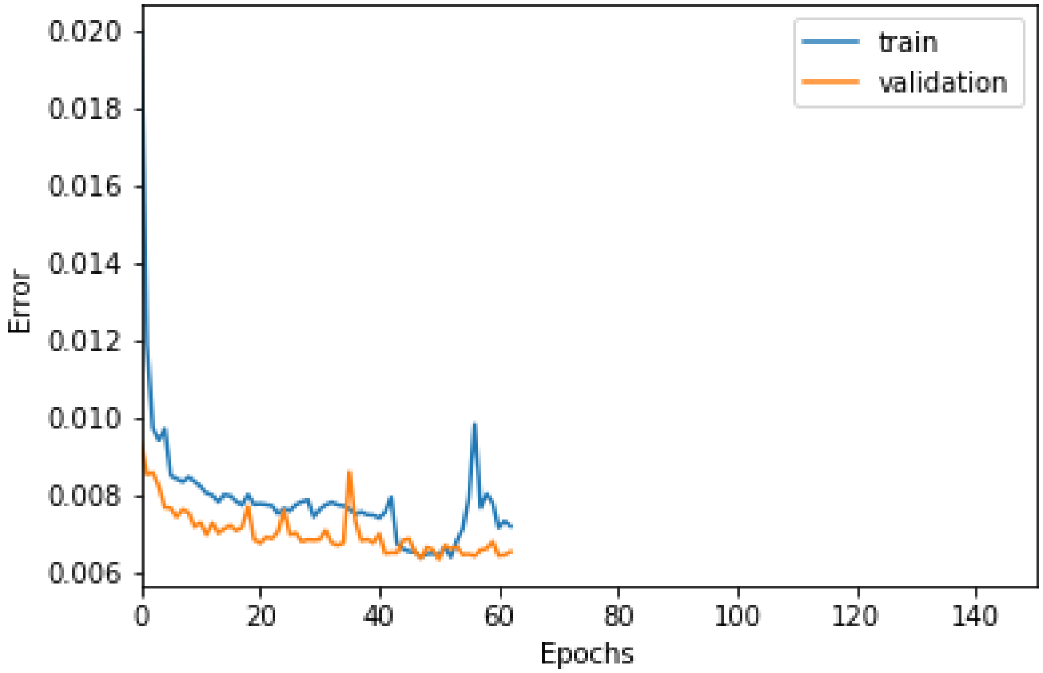
Error
Mean
Bound
Anomaly
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
0
10000
20000
30000
40000
50000
60000
70000
time
Error



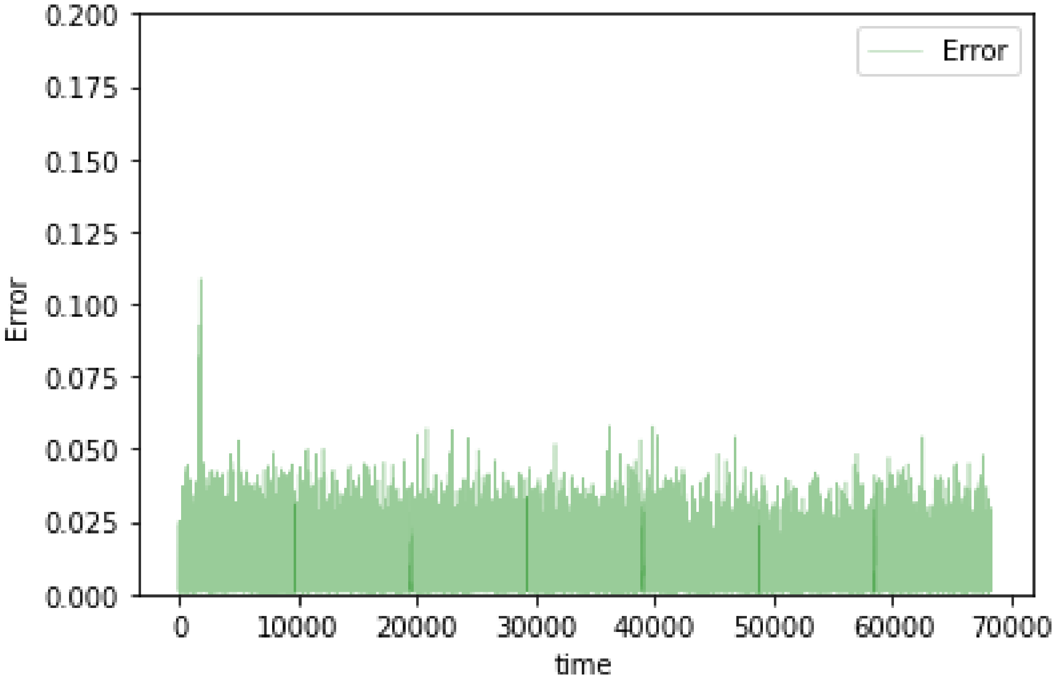
```
The mean error for nn2_2_normal_ is 0.008058119225196694 for length 68297
====================
```

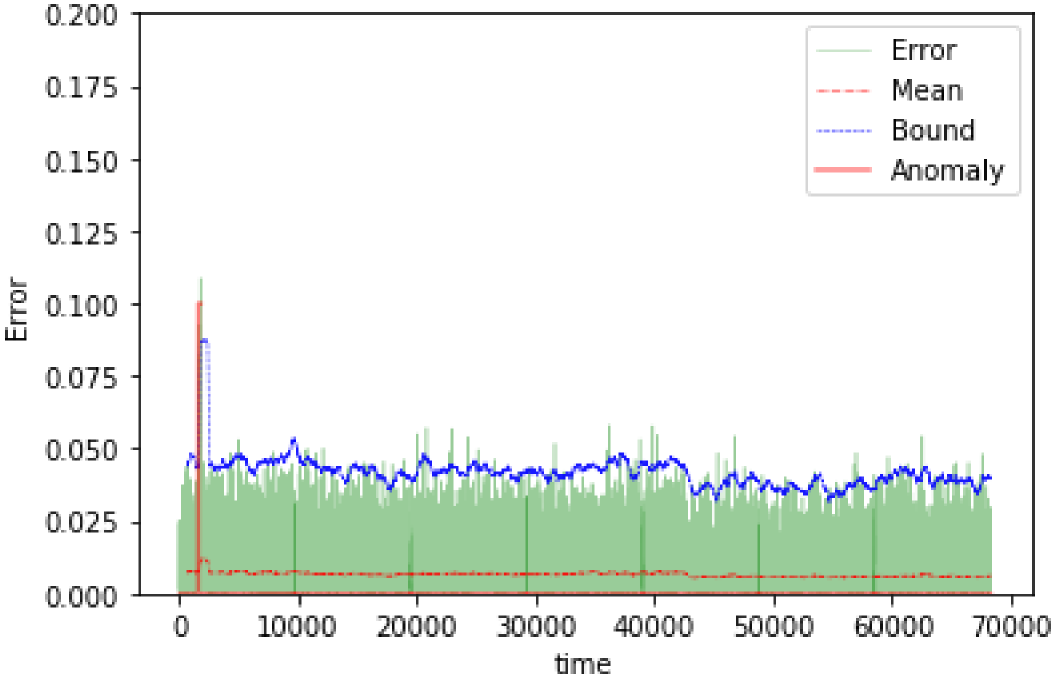
5 steps

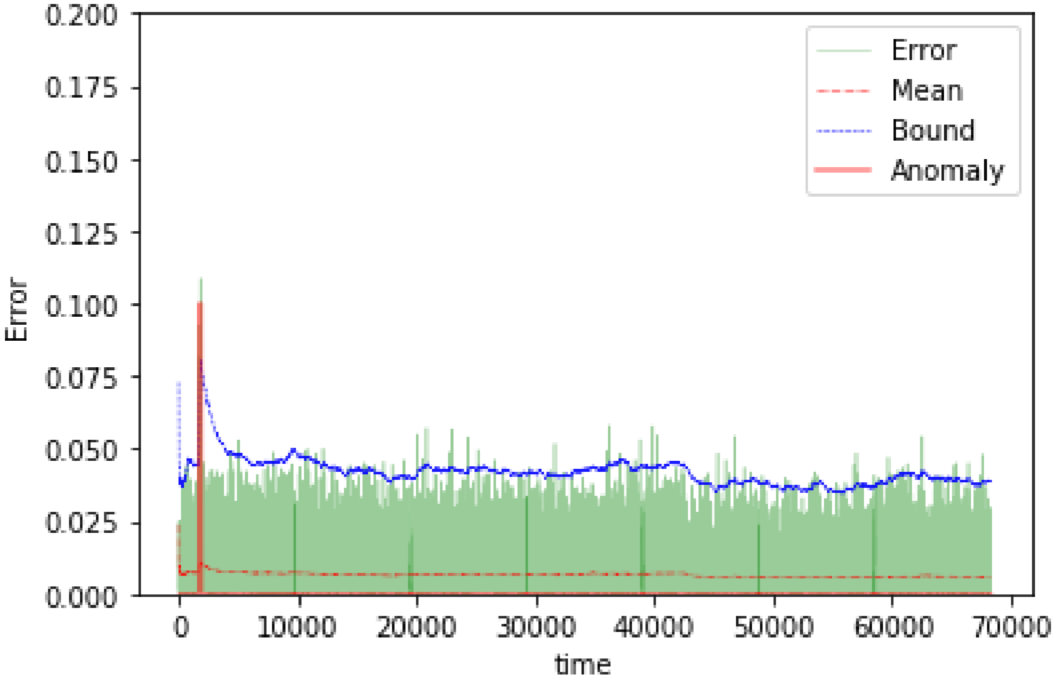
```
In [101]: TIMESTEPS = 5
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS)
          vgen = flat_generator(val_X, TIMESTEPS)
          name = "nn2_5"

In [102]: input_layer = Input(shape=(TIMESTEPS*DIM,))
          hidden = Dense(500, activation='relu')(input_layer)
          hidden = Dense(100, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)

In [103]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])

In [104]: train(model, tgen, vgen, name=name)
          test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.007203710669884458
Validation loss for final epoch is 0.00653938826546073
---------- Beginning tests for nn2_5 ----------
Testing on Normal data.
```



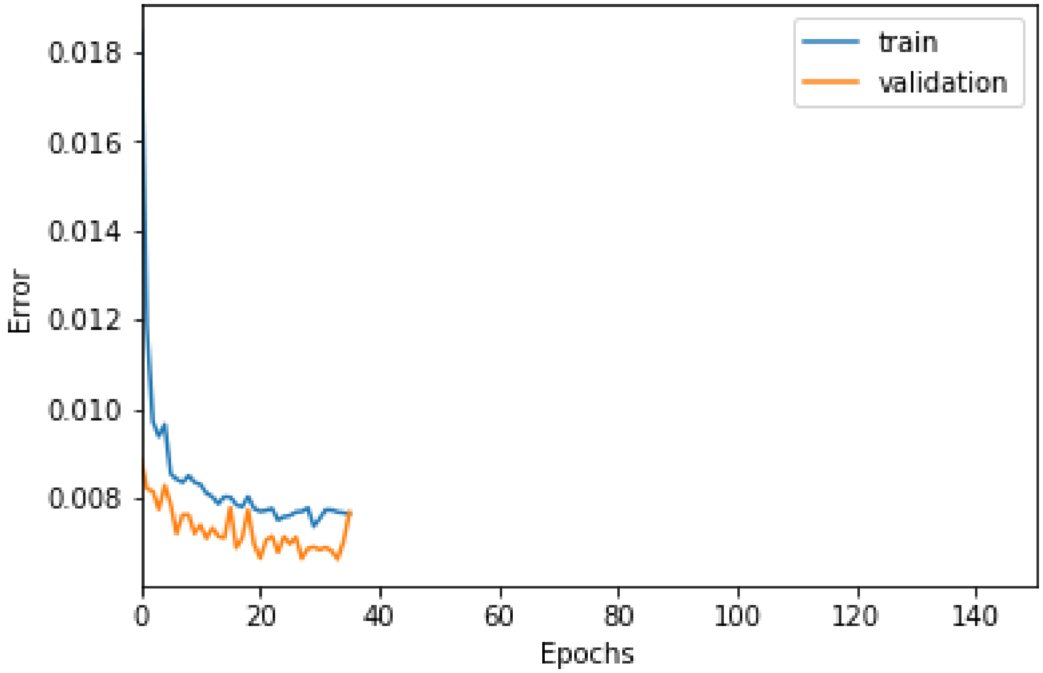

0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly


0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly

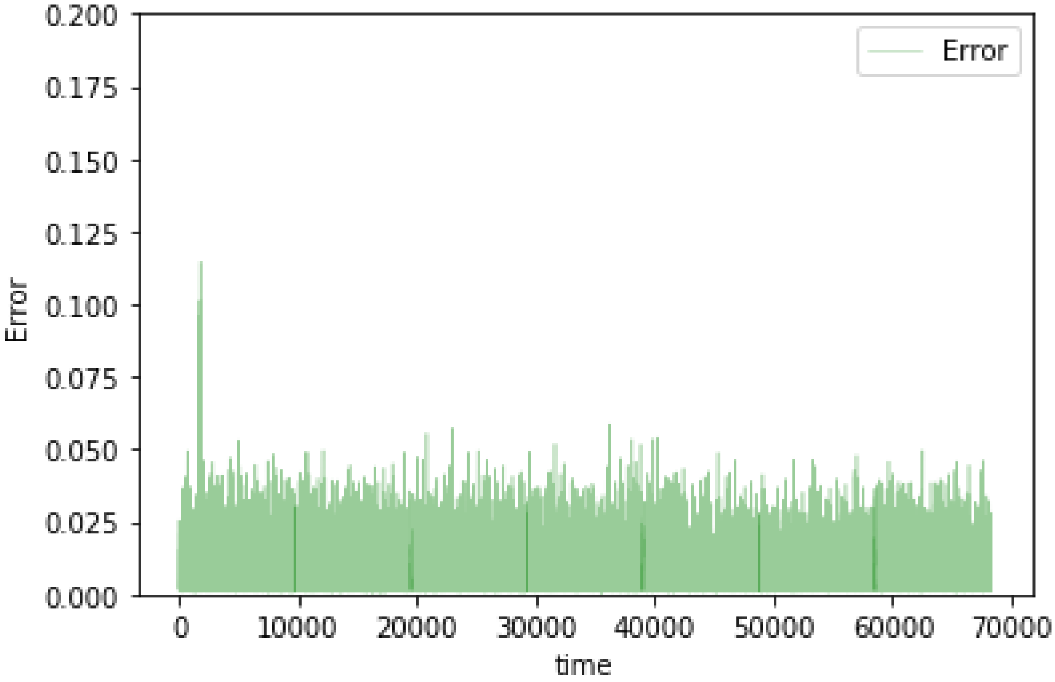
```
The mean error for nn2_5_normal_ is 0.006560263645435531 for length 68294
====================
```

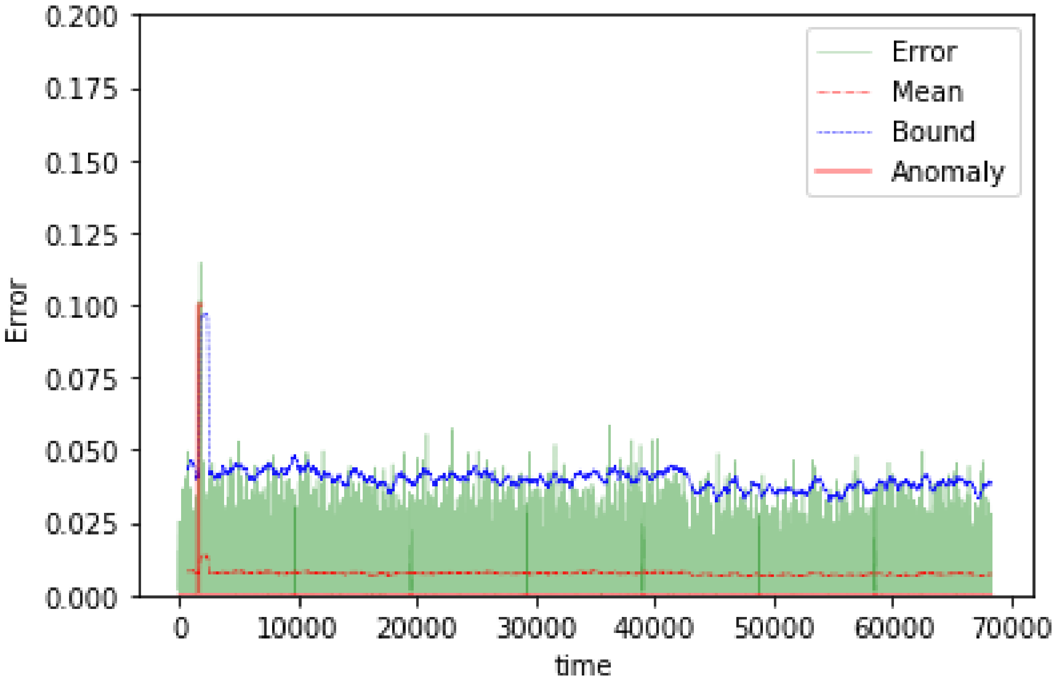
10 steps

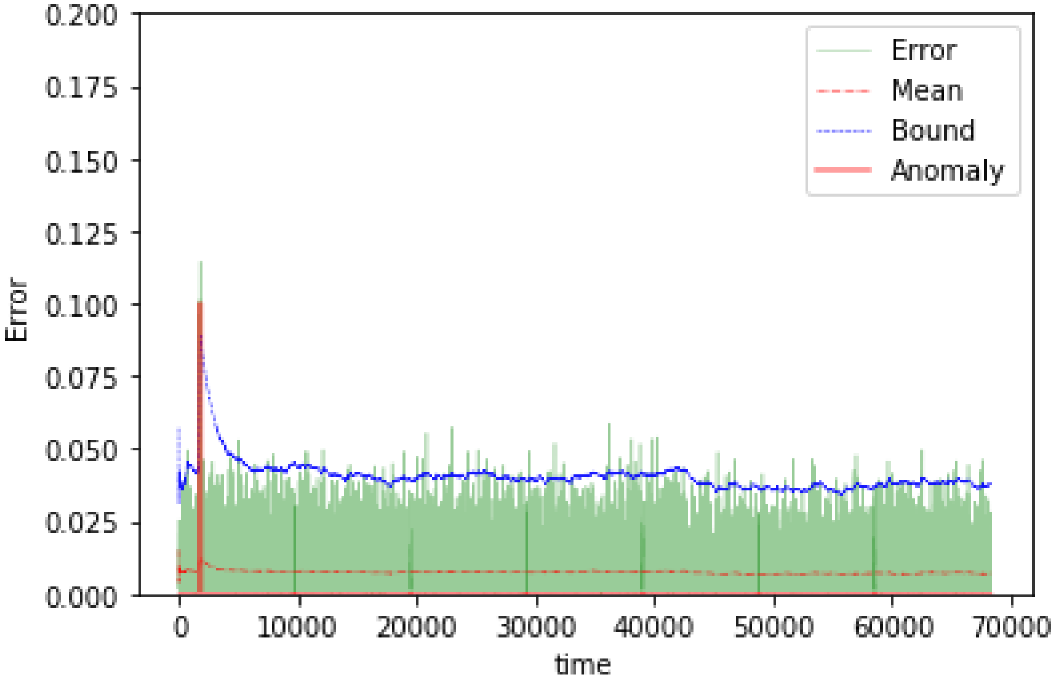
```
In [105]: TIMESTEPS = 10
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS)
          vgen = flat_generator(val_X, TIMESTEPS)
          name = "nn2_10"

In [106]: input_layer = Input(shape=(TIMESTEPS*DIM,))
          hidden = Dense(500, activation='relu')(input_layer)
          hidden = Dense(100, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)

In [107]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])

In [108]: train(model, tgen, vgen, name=name)
          test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.007645282419165596
Validation loss for final epoch is 0.007687205089488998
---------- Beginning tests for nn2_10 ----------
Testing on Normal data.
```







```
The mean error for nn2_10_normal_ is 0.007496893948005318 for length 68289
====================
```

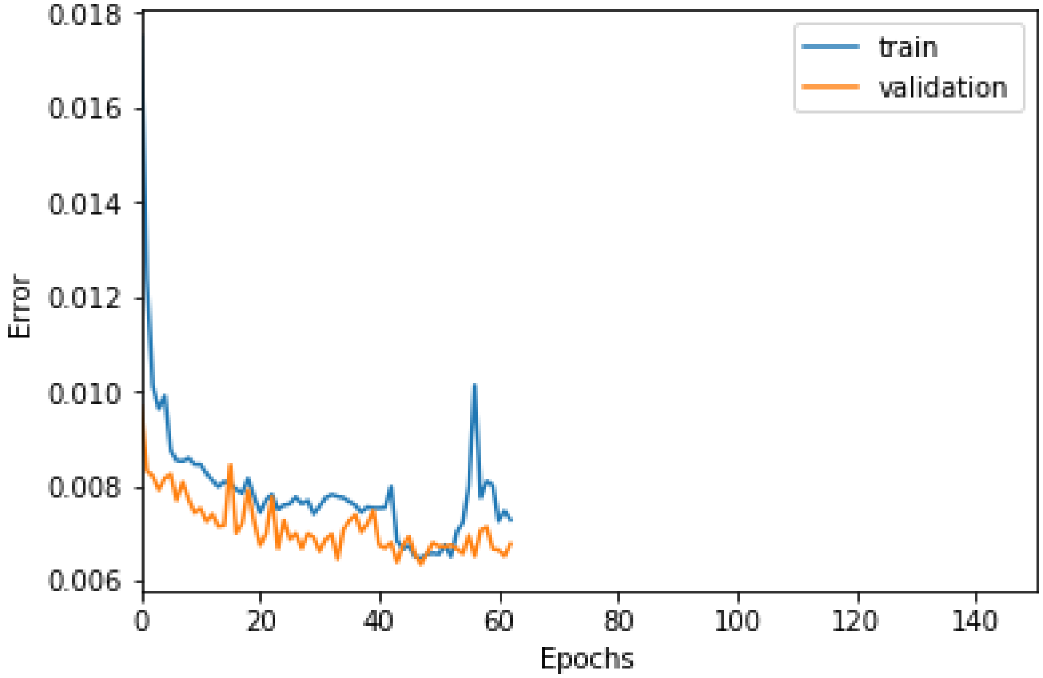
20 steps

```
In [109]: TIMESTEPS = 20
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS)
          vgen = flat_generator(val_X, TIMESTEPS)
          name = "nn2_20"
```

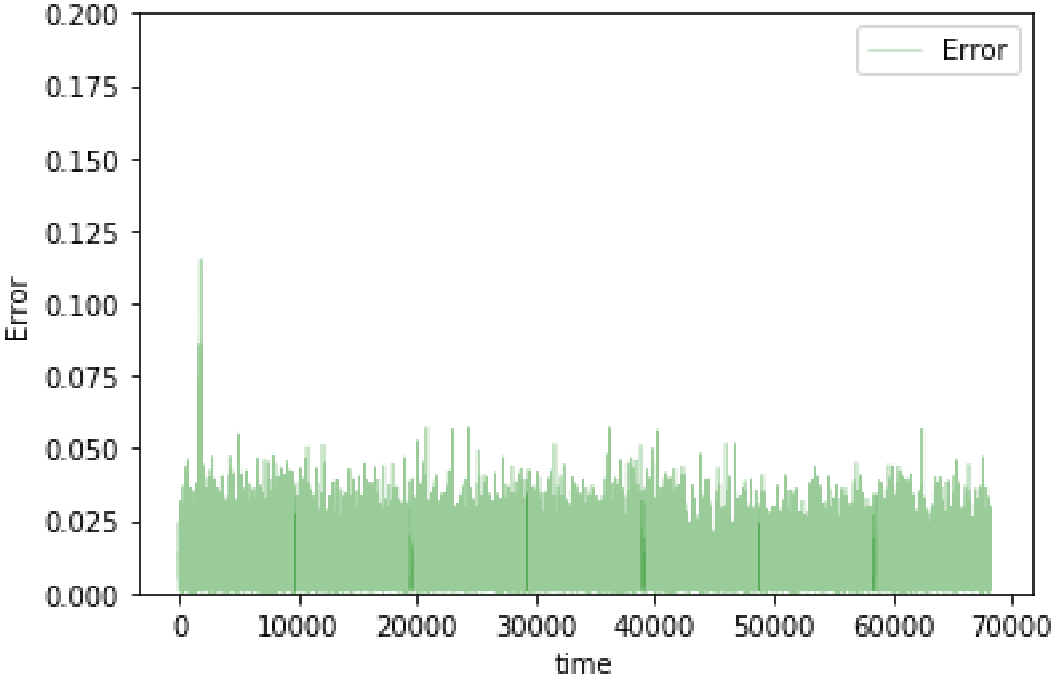
```
In [110]: input_layer = Input(shape=(TIMESTEPS*DIM,))
          hidden = Dense(500, activation='relu')(input_layer)
          hidden = Dense(100, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)
```

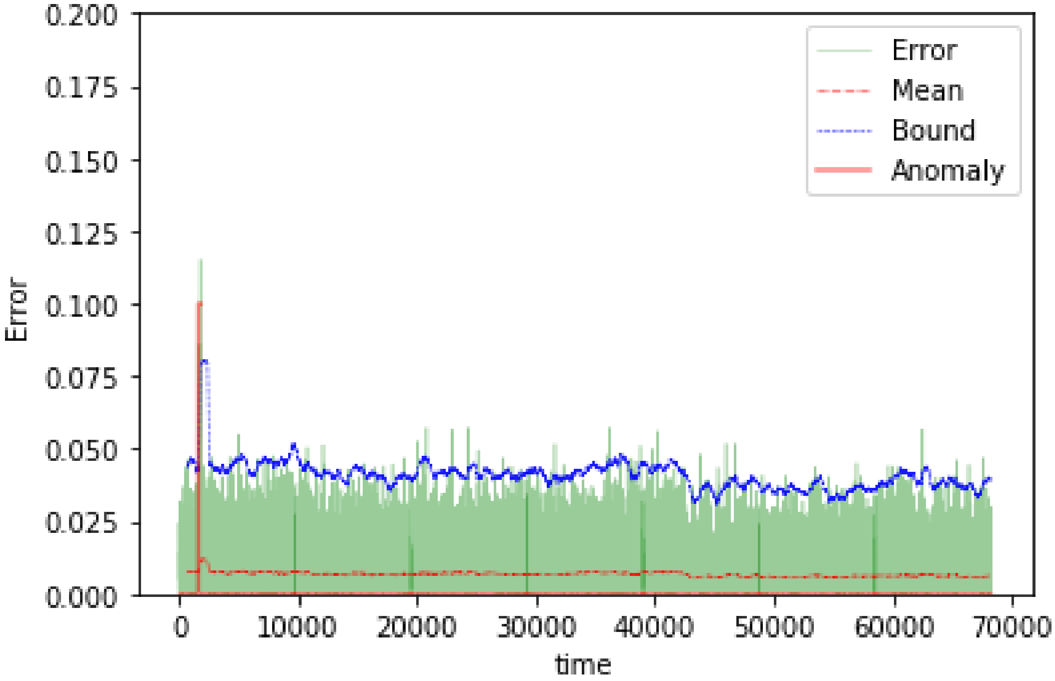
```
In [111]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

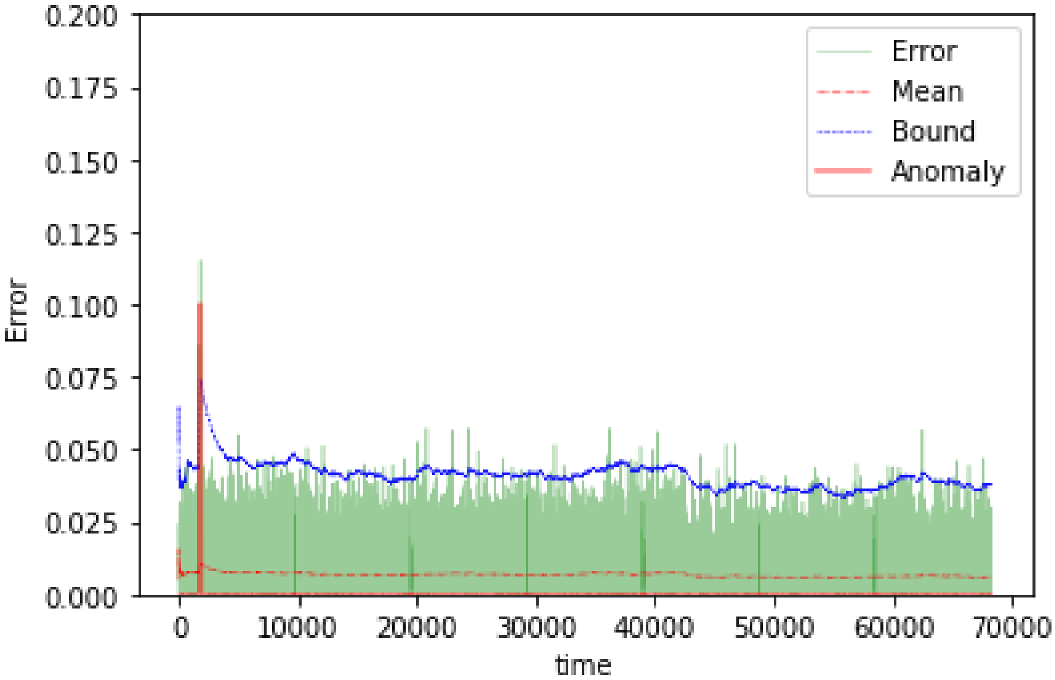
```
In [112]: train(model, tgen, vgen, name=name)
          test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.007284274581121281
Validation loss for final epoch is 0.006774859631317668
---------- Beginning tests for nn2_20 ----------
Testing on Normal data.
```


0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error

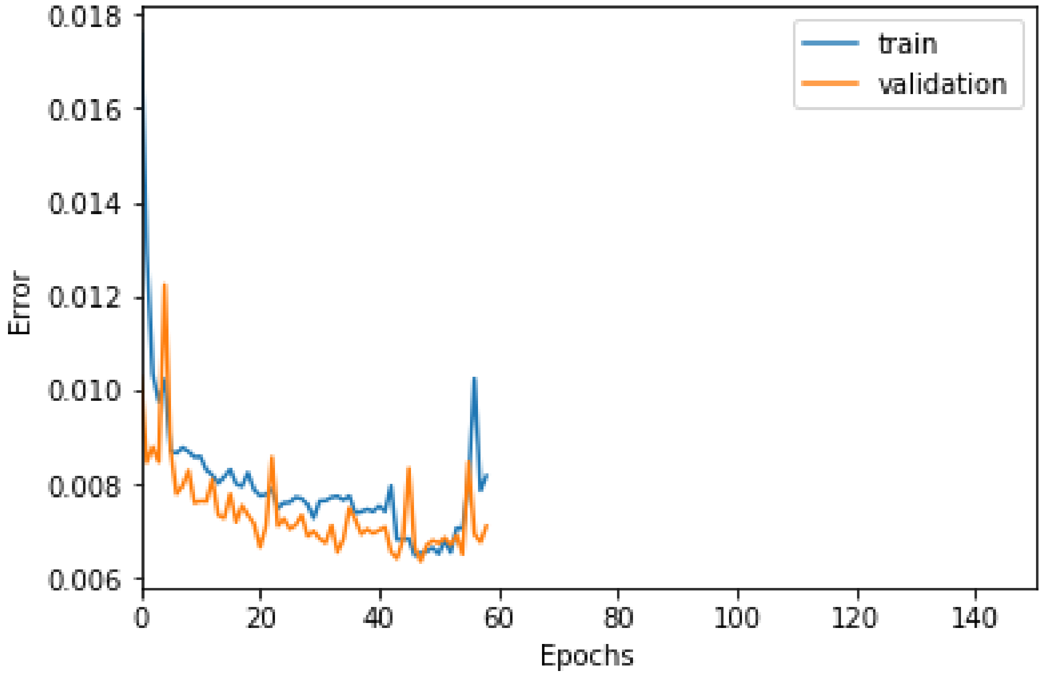

0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly



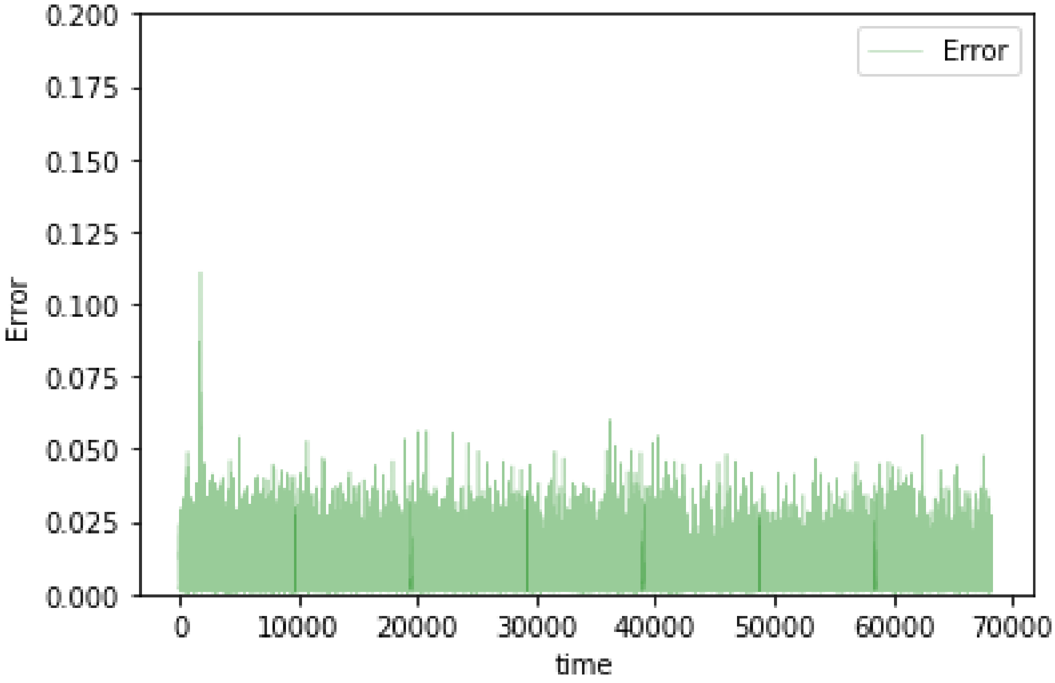
```
The mean error for nn2_20_normal_ is 0.006777428565729844 for length 68279
====================
```

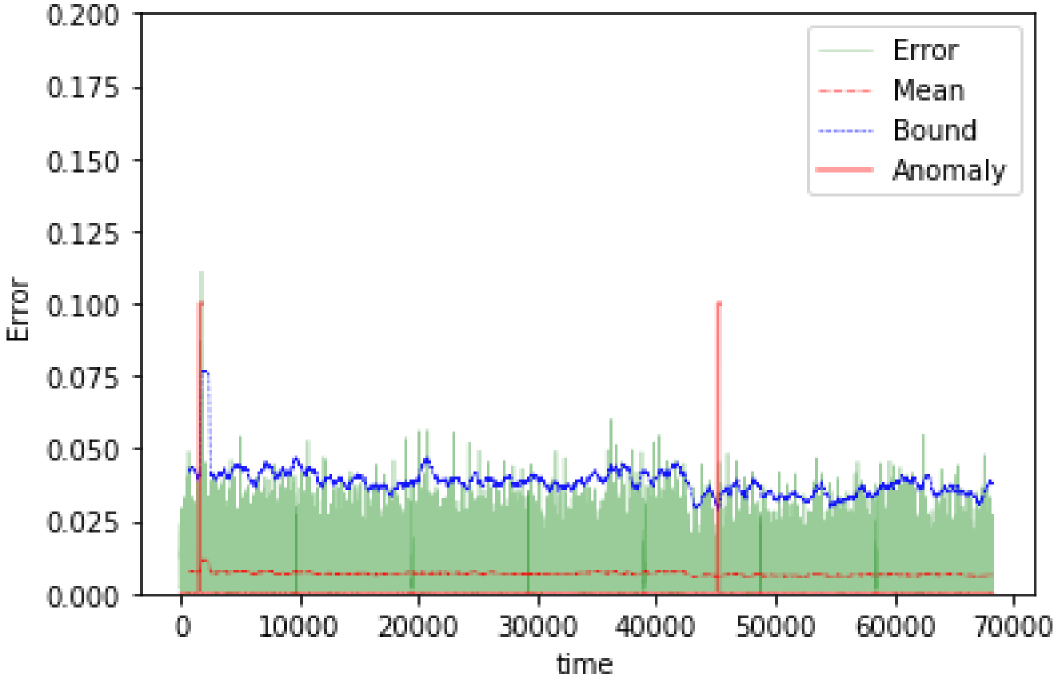
50 steps

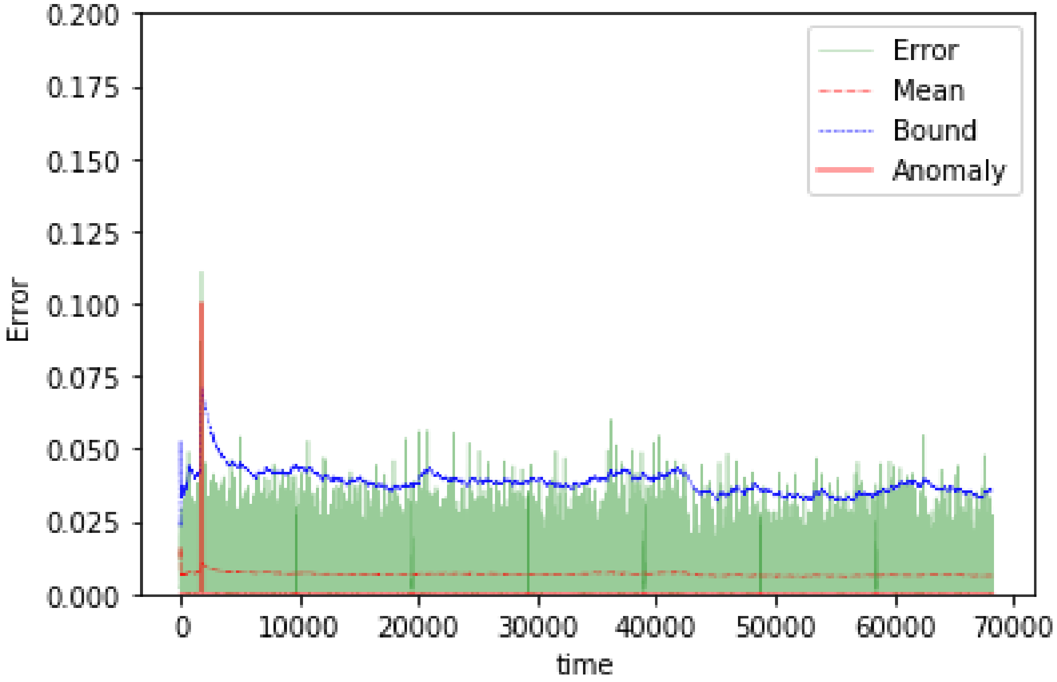
```
In [113]: TIMESTEPS = 50
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS)
          vgen = flat_generator(val_X, TIMESTEPS)
          name = "nn2_50"

In [114]: input_layer = Input(shape=(TIMESTEPS*DIM,))
          hidden = Dense(500, activation='relu')(input_layer)
          hidden = Dense(100, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)

In [115]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])

In [116]: train(model, tgen, vgen, name=name)
          test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008180279432330281
Validation loss for final epoch is 0.007108349320013076
---------- Beginning tests for nn2_50 ----------
Testing on Normal data.
```




0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly


0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly

```
The mean error for nn2_50_normal_ is 0.006799389311177419 for length 68249
====================
```

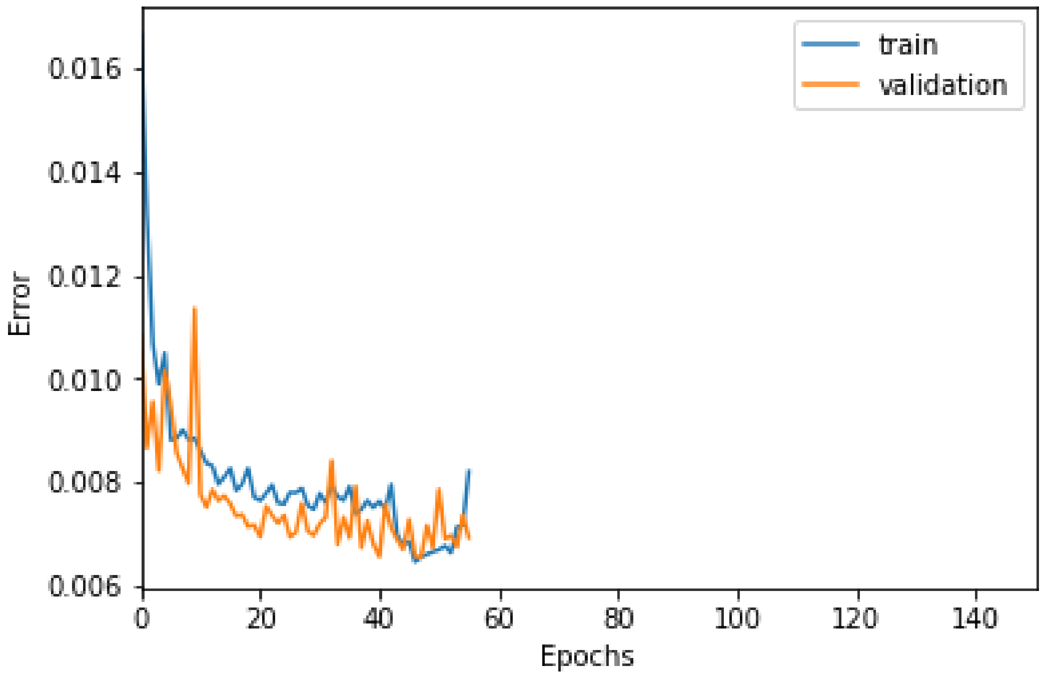
100 steps

```
In [117]: TIMESTEPS = 100
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS)
          vgen = flat_generator(val_X, TIMESTEPS)
          name = "nn2_100"
```

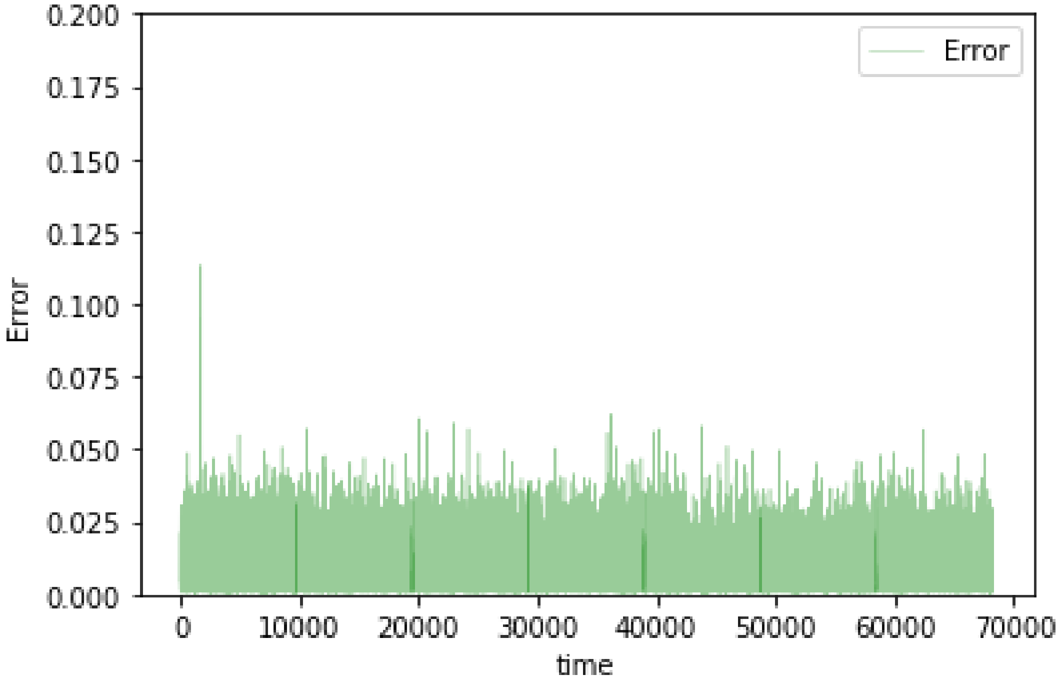
```
In [118]: input_layer = Input(shape=(TIMESTEPS*DIM,))
          hidden = Dense(500, activation='relu')(input_layer)
          hidden = Dense(100, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)
```

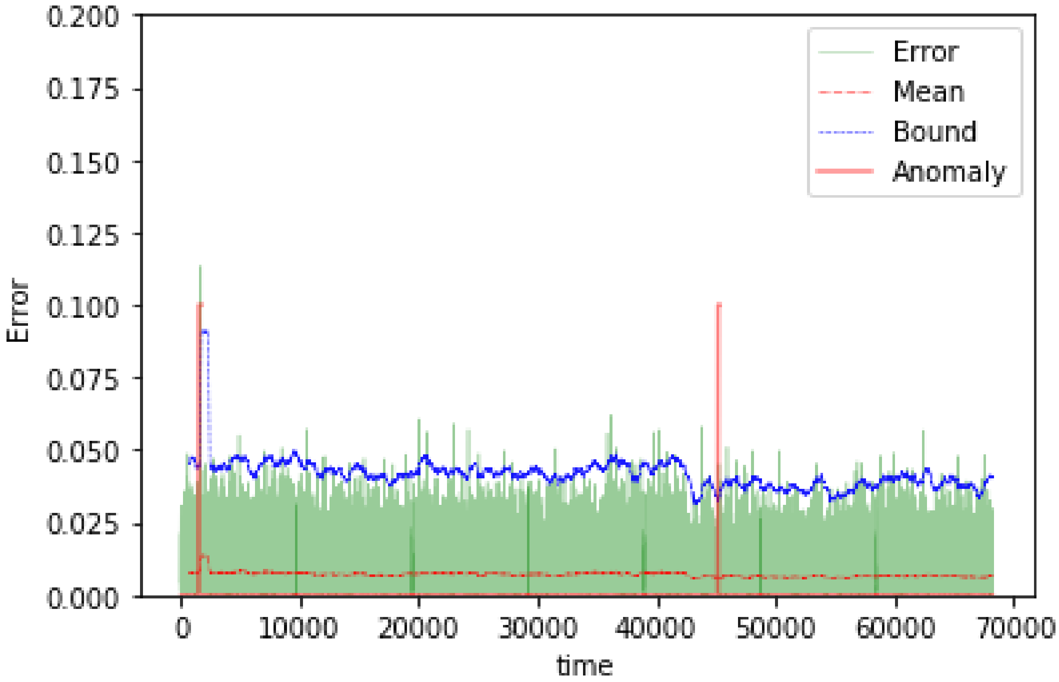
```
In [119]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

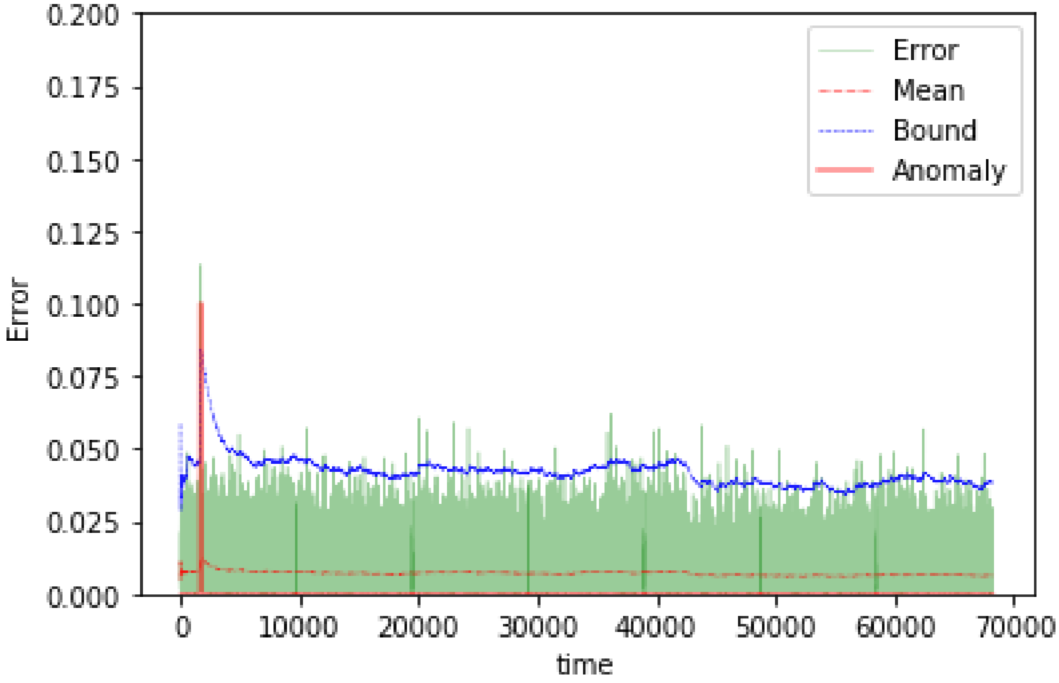
```
In [120]: train(model, tgen, vgen, name=name)
          test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008201928741880693
Validation loss for final epoch is 0.0069217113647609945
---------- Beginning tests for nn2_100 ----------
Testing on Normal data.
```





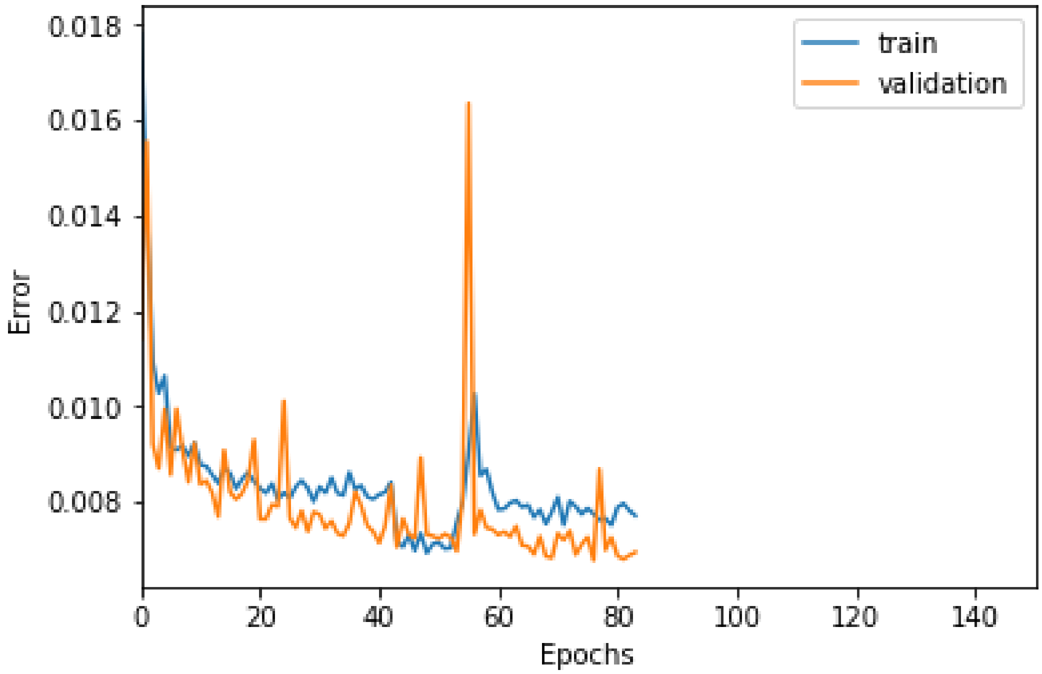


```
The mean error for nn2_100_normal_ is 0.007064809141689605 for length 68199
====================
```

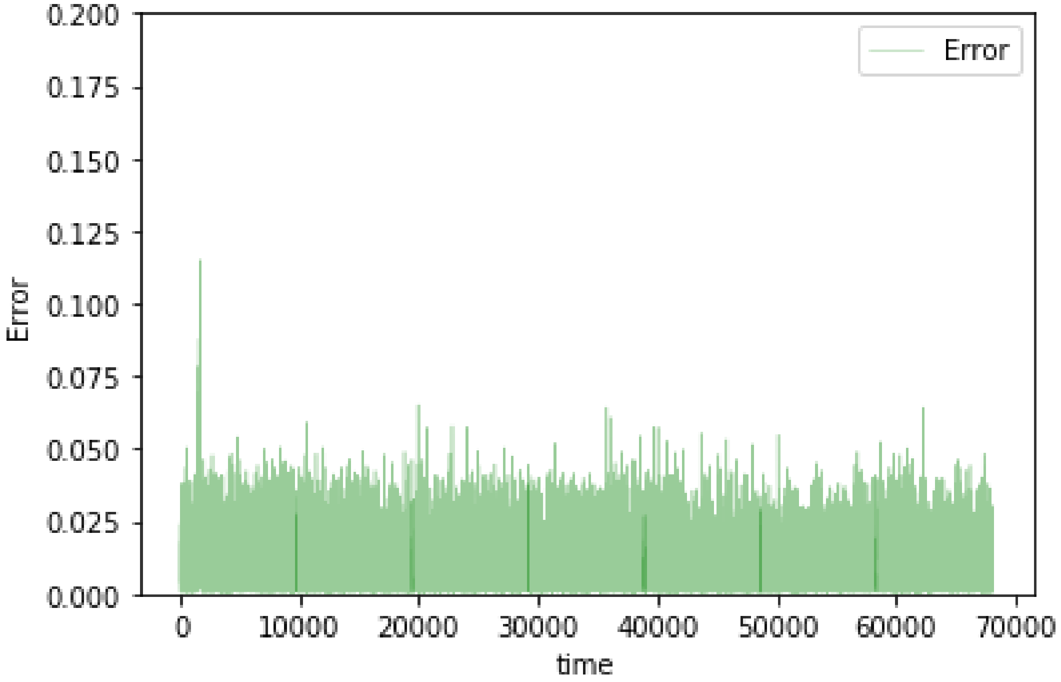
200 steps

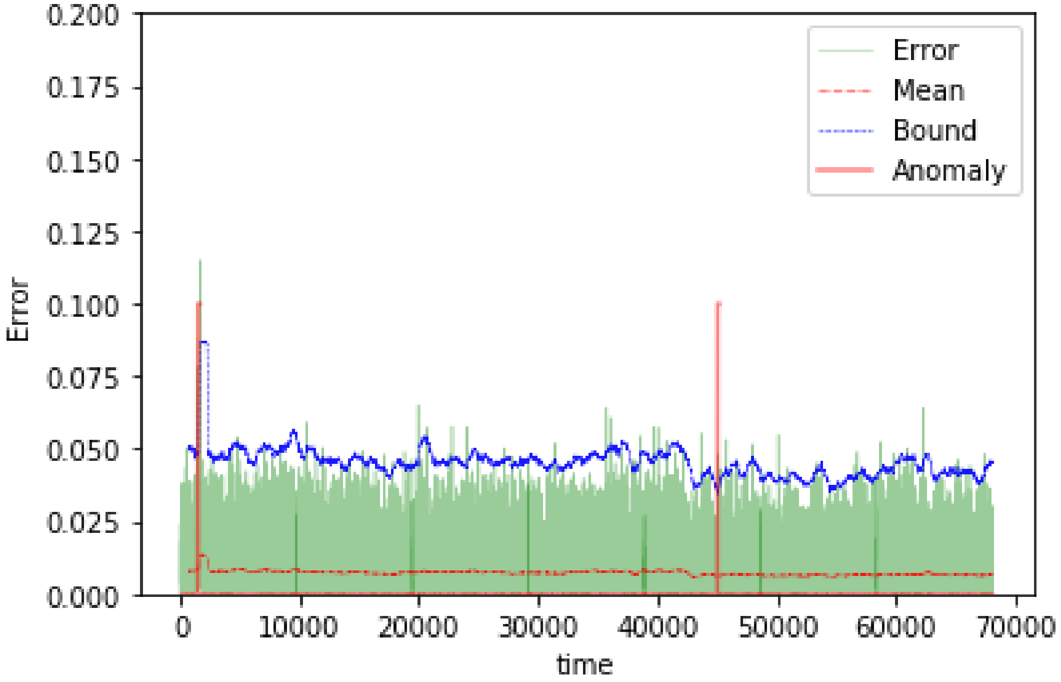
```
In [121]: TIMESTEPS = 200
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS)
          vgen = flat_generator(val_X, TIMESTEPS)
          name = "nn2_200"

In [122]: input_layer = Input(shape=(TIMESTEPS*DIM,))
          hidden = Dense(500, activation='relu')(input_layer)
          hidden = Dense(100, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)

In [123]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

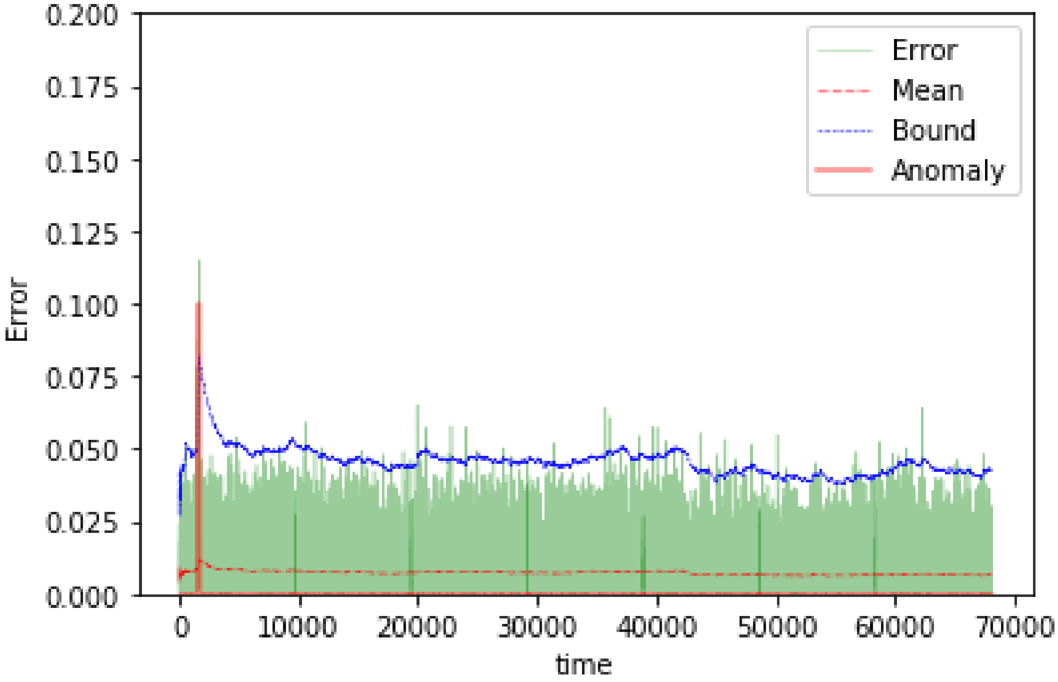
```
In [124]: train(model, tgen, vgen, name=name)
          test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.007711684601847O825
Validation loss for final epoch is 0.006946622412302531
---------- Beginning tests for nn2_200 ----------
Testing on Normal data.
```


Error
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
0
10000
20000
30000
40000
50000
60000
70000
time
Error


Error
Mean
Bound
Anomaly
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
0
10000
20000
30000
40000
50000
60000
70000
time
Error



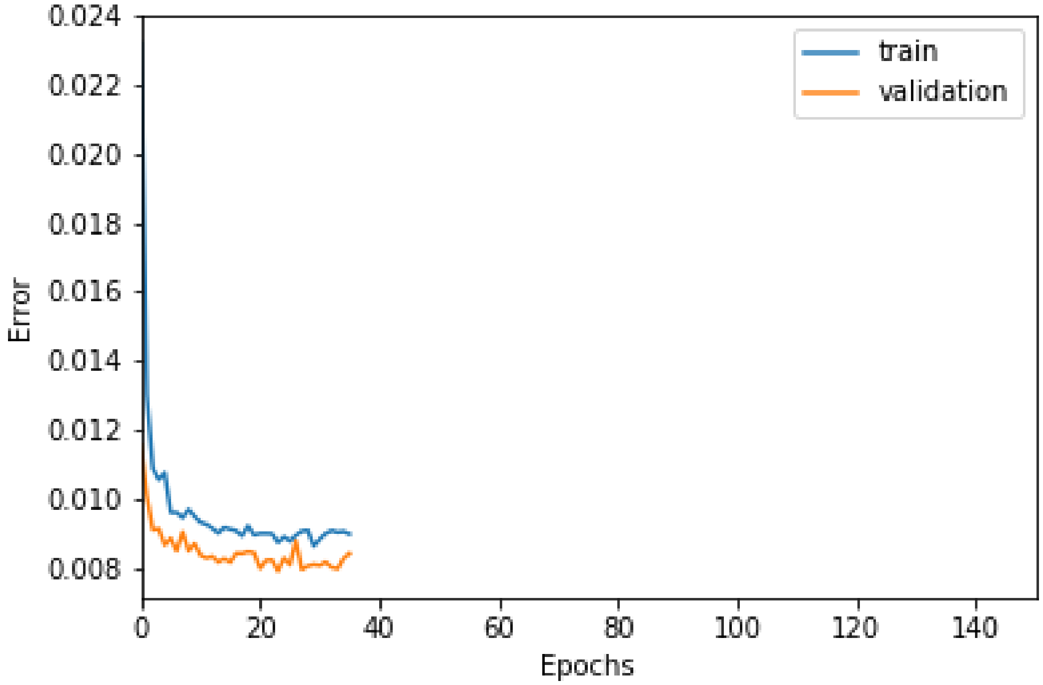
```
The mean error for nn2_200_normal_ is 0.007258977383452148 for length 68099
====================
```

1.11.4 NN with 3 hidden layers

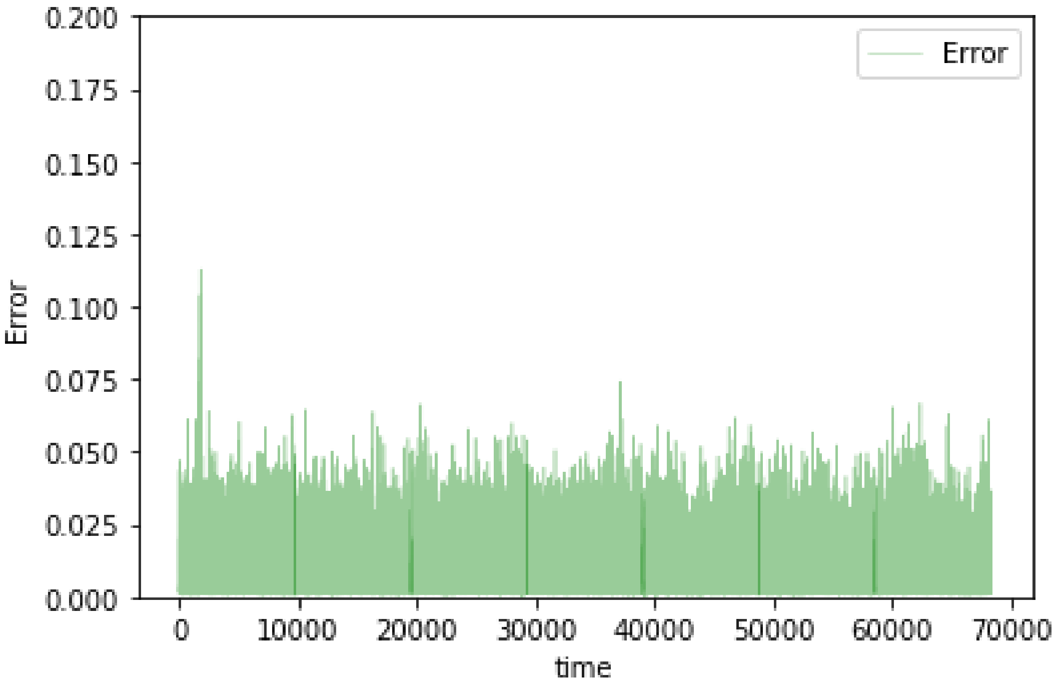
2 steps

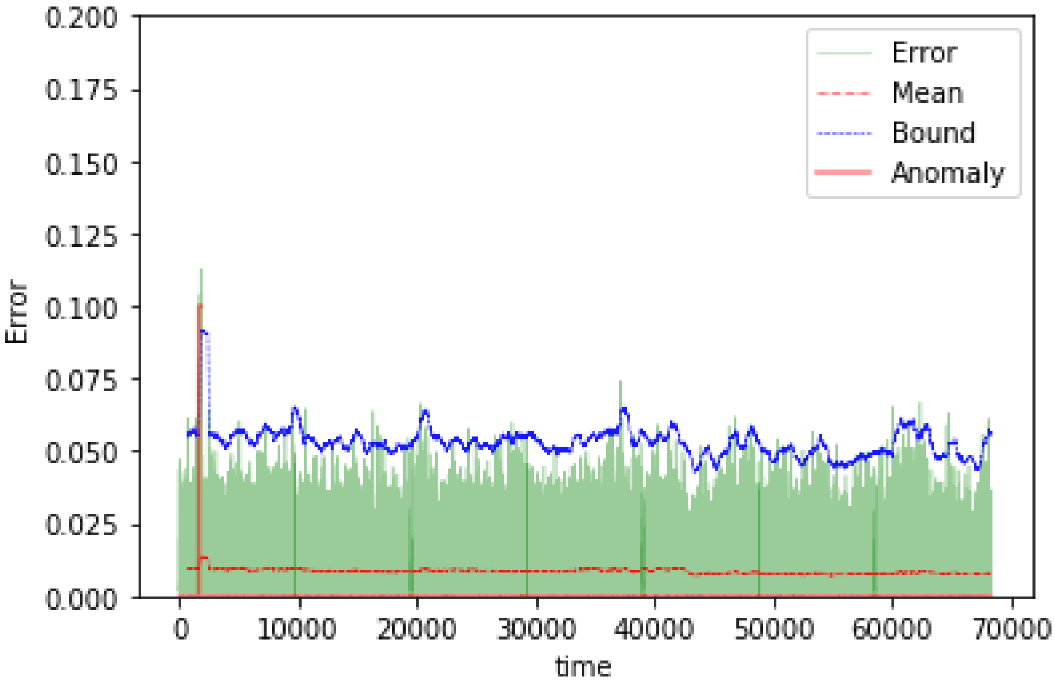
```
In [125]: TIMESTEPS = 2
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS)
          vgen = flat_generator(val_X, TIMESTEPS)
          name = "nn3_2"

In [126]: input_layer = Input(shape=(TIMESTEPS*DIM,))
          hidden = Dense(1000, activation='relu')(input_layer)
          hidden = Dense(500, activation='relu')(hidden)
          hidden = Dense(100, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)

In [127]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

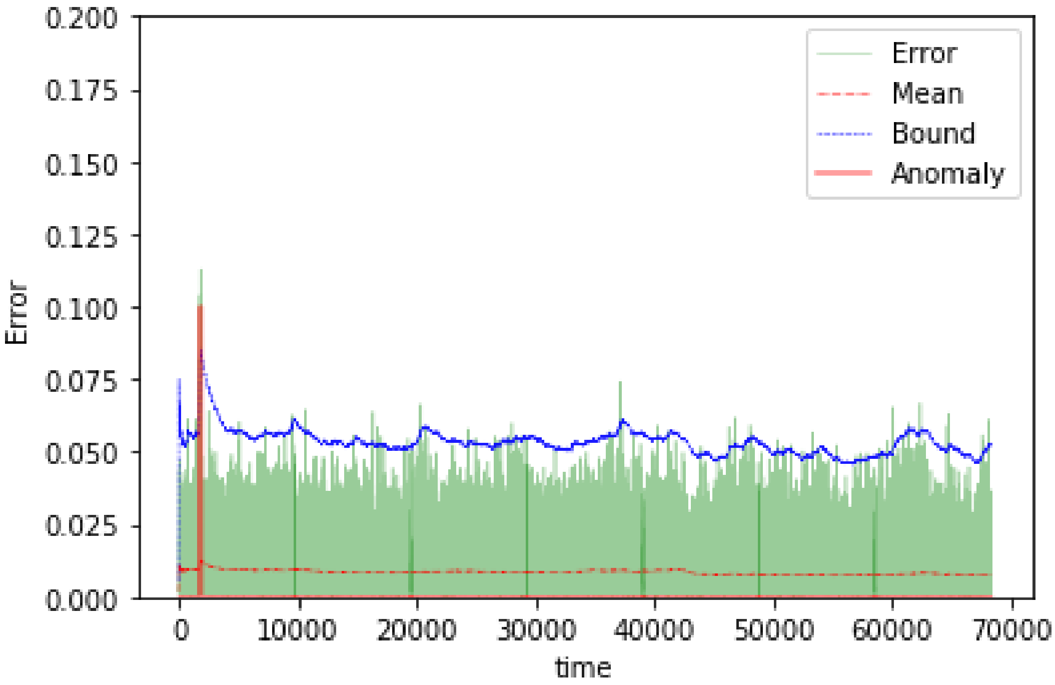
```
In [128]: train(model, tgen, vgen, name=name)
          test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008977393320878036
Validation loss for final epoch is 0.008412801611586473
---------- Beginning tests for nn3_2 ----------
Testing on Normal data.
```


0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error

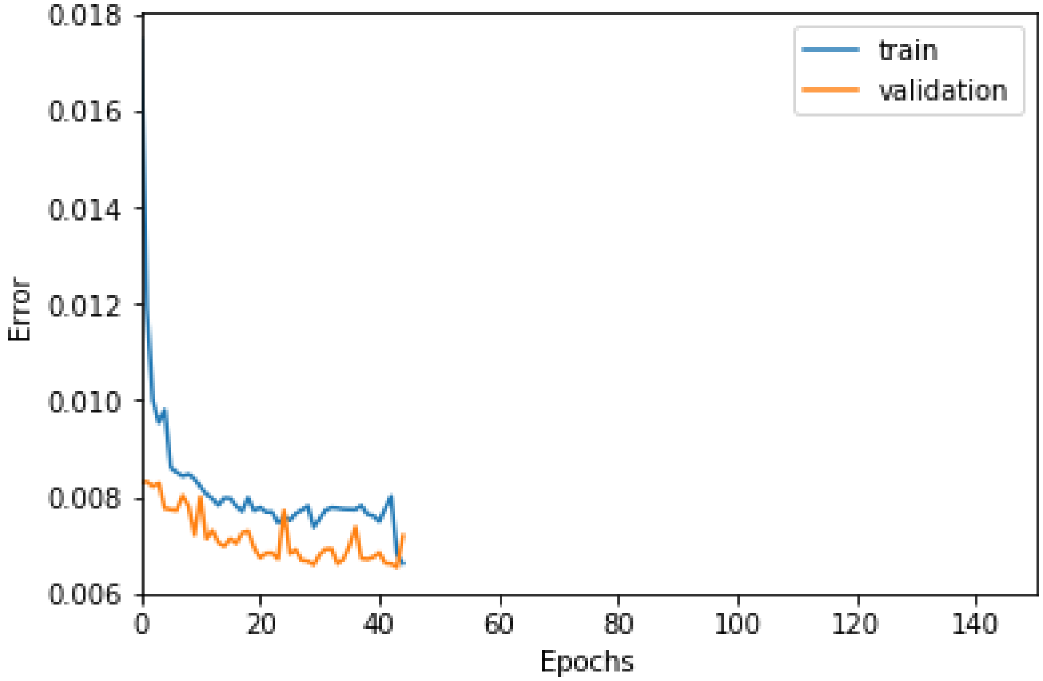

0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly



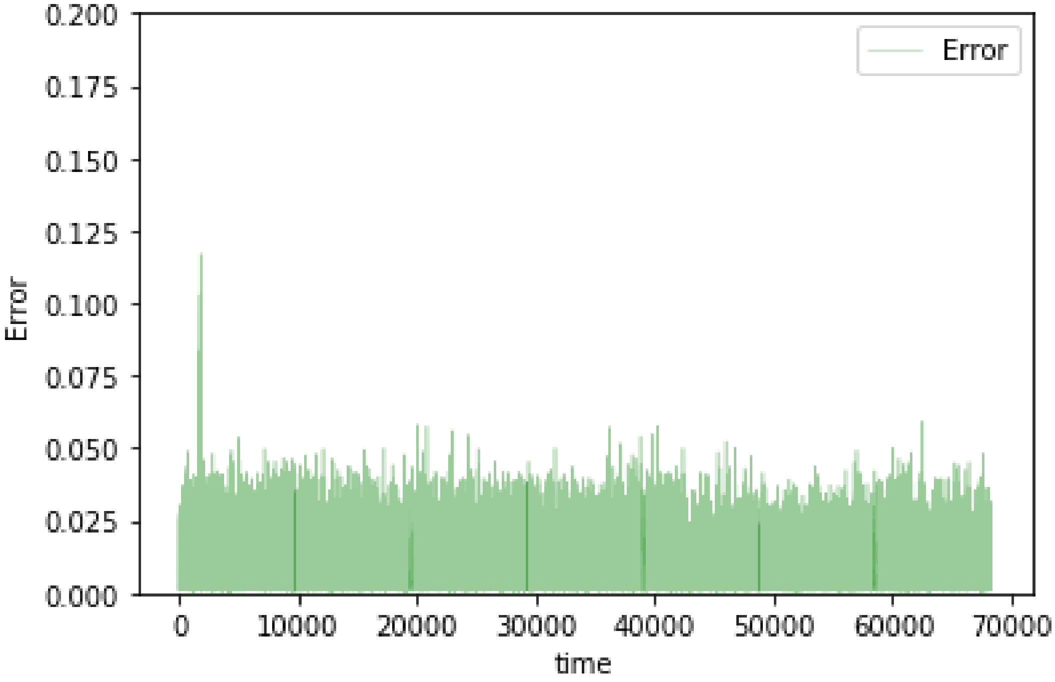
```
The mean error for nn3_2_normal_ is 0.008495754745263253 for length 68297
====================
```

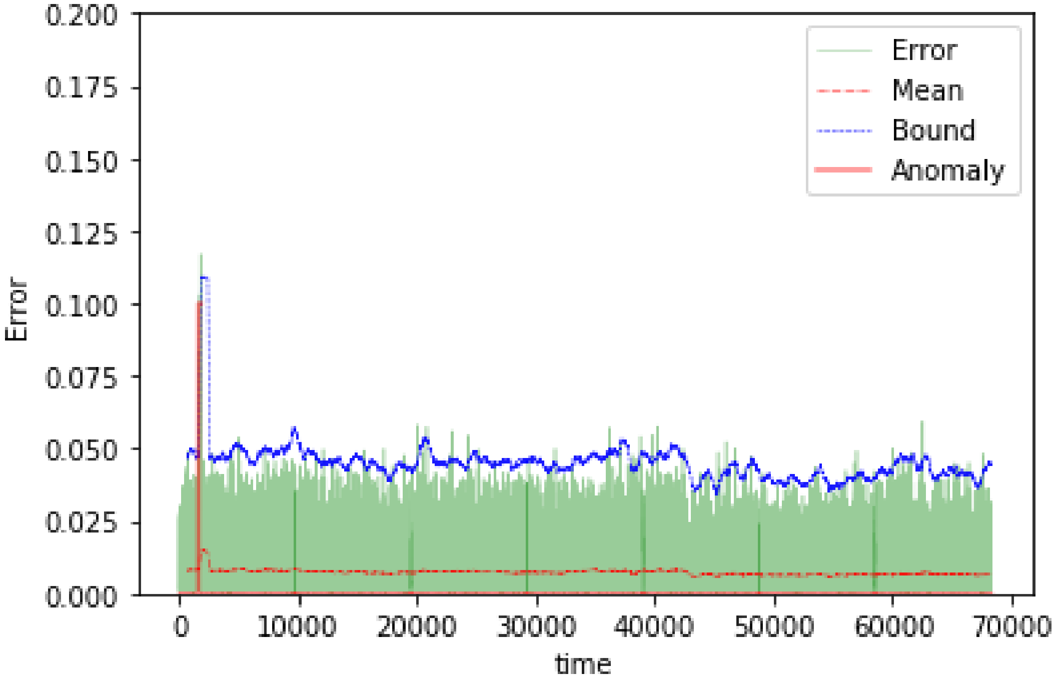
5 steps

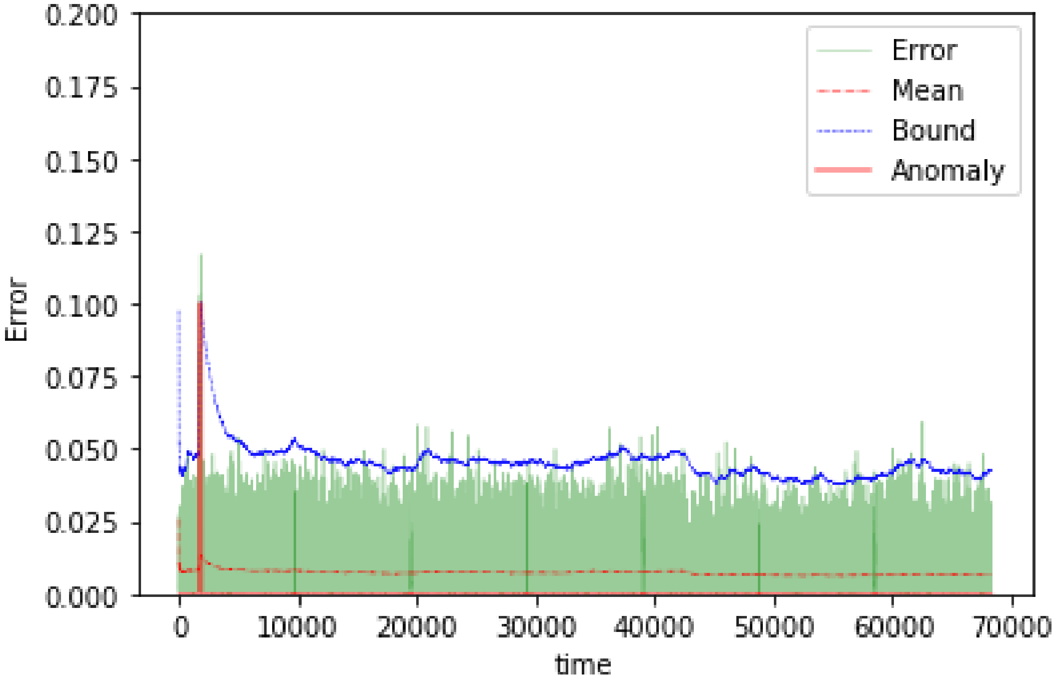
```
In [129]: TIMESTEPS = 5
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS)
          vgen = flat_generator(val_X, TIMESTEPS)
          name = "nn3_5"

In [130]: input_layer = Input(shape=(TIMESTEPS*DIM,))
          hidden = Dense(1000, activation='relu')(input_layer)
          hidden = Dense(500, activation='relu')(hidden)
          hidden = Dense(100, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)

In [131]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])

In [132]: train(model, tgen, vgen, name=name)
          test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.0066253157071769235
Validation loss for final epoch is 0.007202407631790265
---------- Beginning tests for nn3_5 ----------
Testing on Normal data.
```



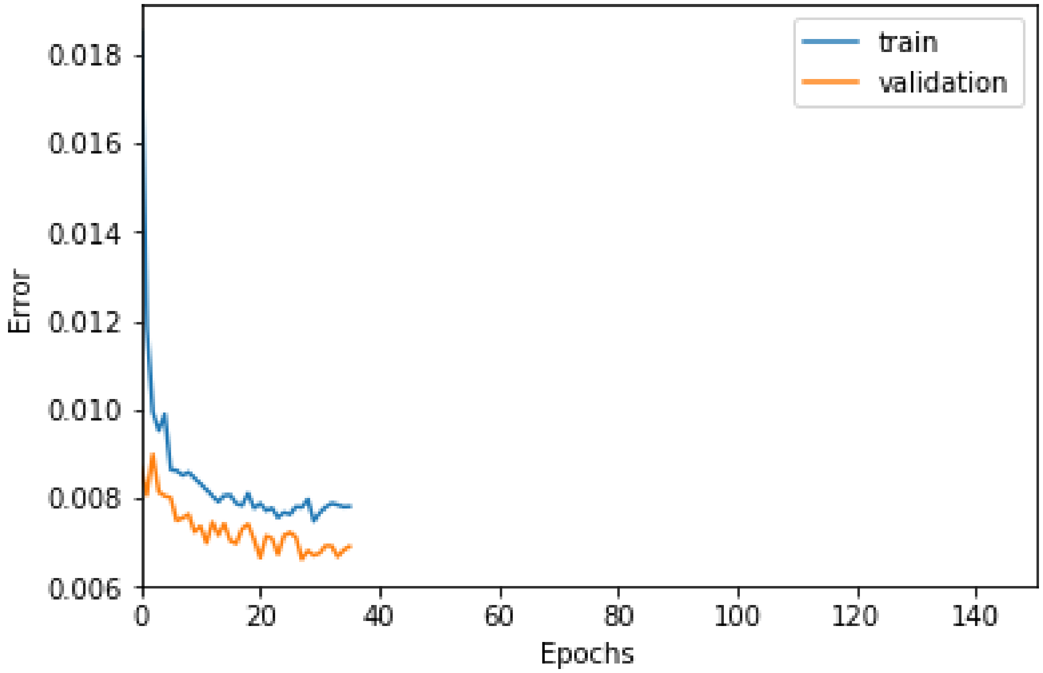

0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly


0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly

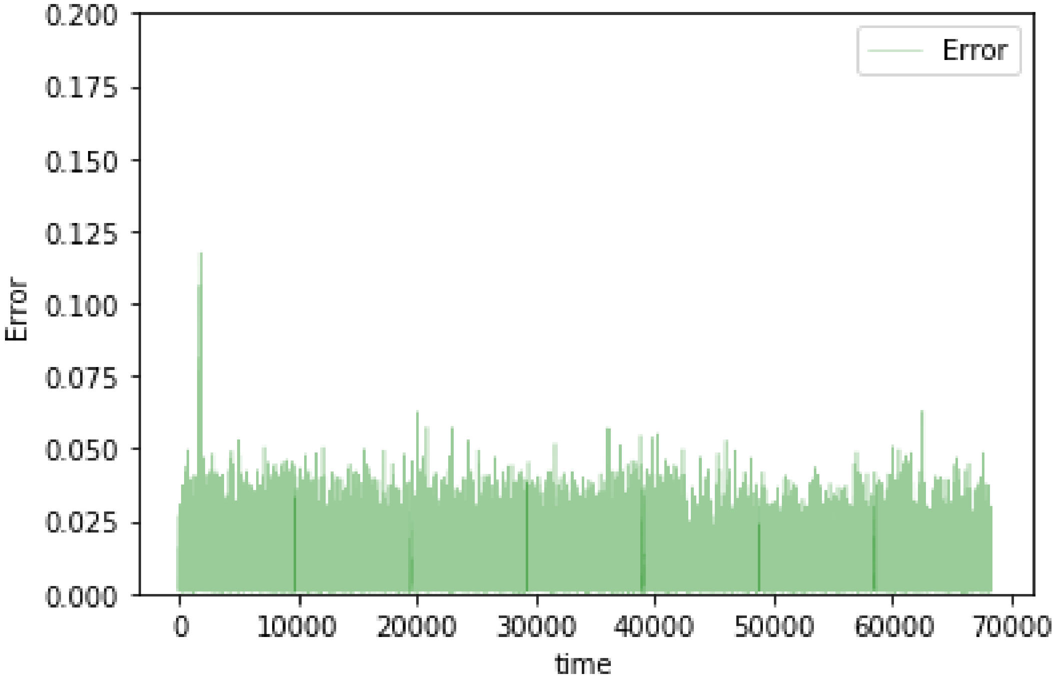
```
The mean error for nn3_5_normal_ is 0.00730327706876657 for length 68294
====================
```

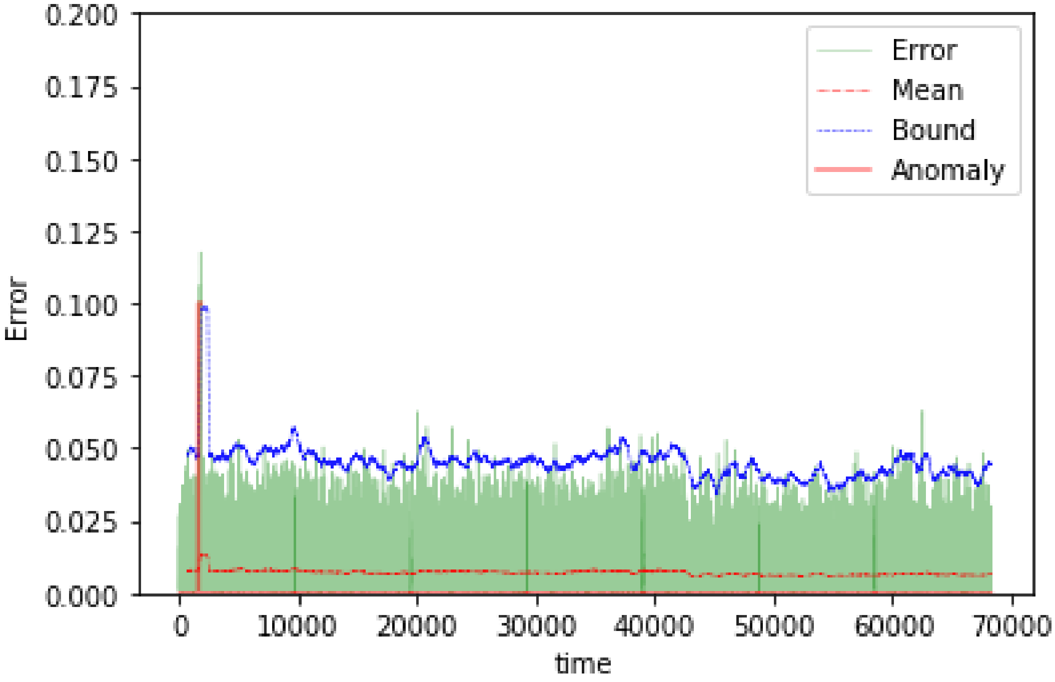
10 steps

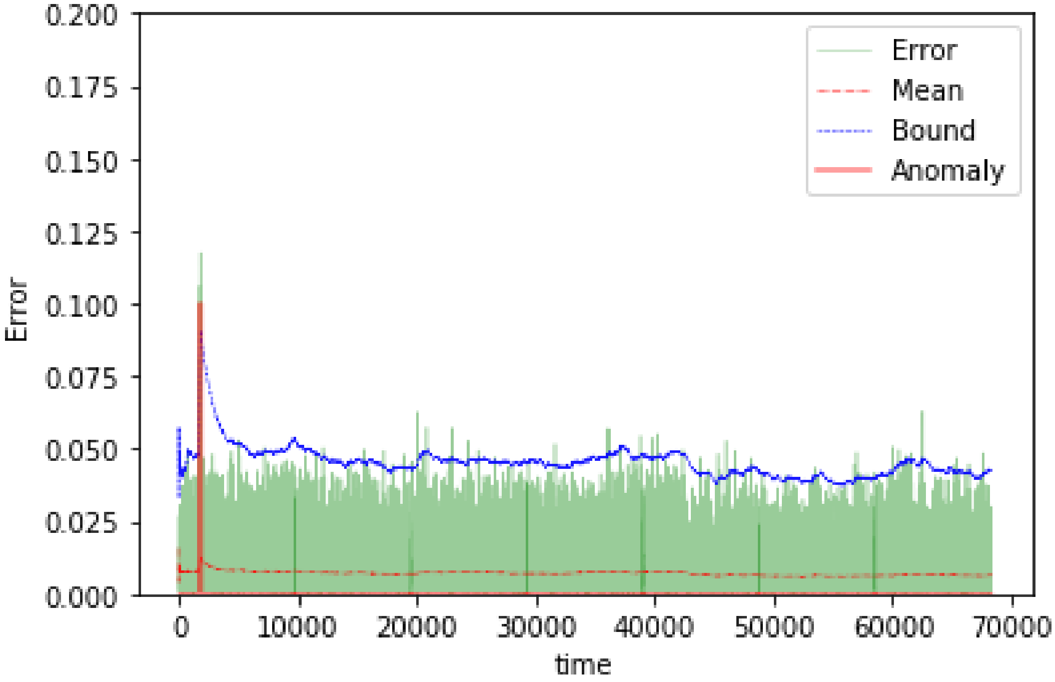
```
In [133]: TIMESTEPS = 10
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS)
          vgen = flat_generator(val_X, TIMESTEPS)
          name = "nn3_10"

In [134]: input_layer = Input(shape=(TIMESTEPS*DIM,))
          hidden = Dense(1000, activation='relu')(input_layer)
          hidden = Dense(500, activation='relu')(hidden)
          hidden = Dense(100, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)

In [135]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])

In [136]: train(model, tgen, vgen, name=name)
          test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.007812029589957092
Validation loss for final epoch is 0.0069083290459821005
---------- Beginning tests for nn3_10 ----------
Testing on Normal data.
```







```
The mean error for nn3_10_normal_ is 0.007082756702432661 for length 68289
====================
```

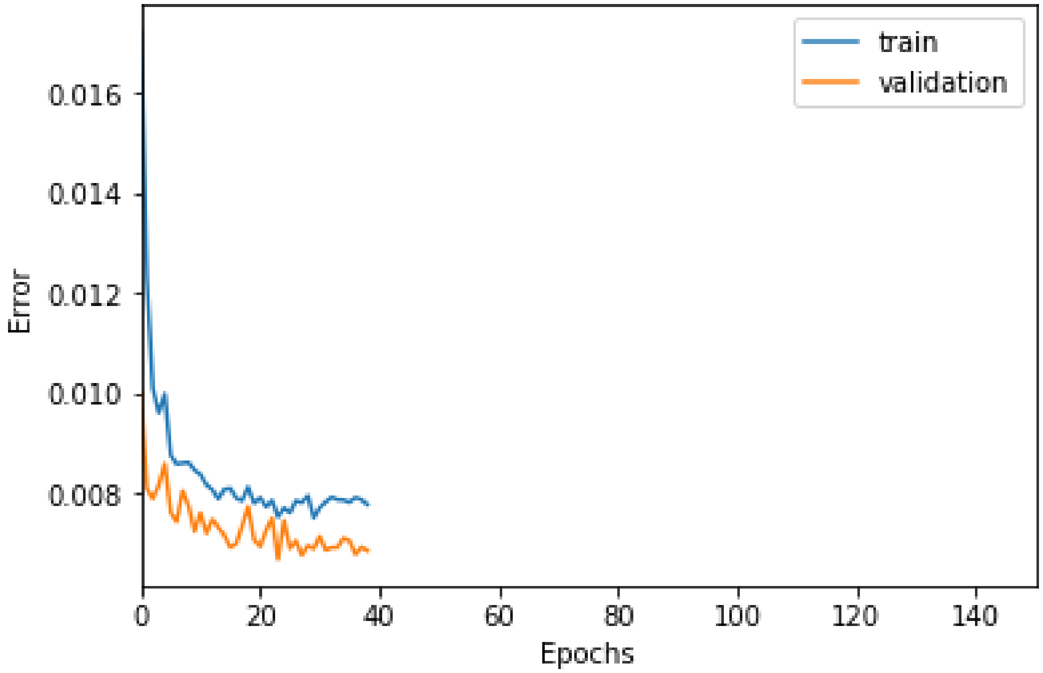
20 steps

```
In [137]: TIMESTEPS = 20
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS)
          vgen = flat_generator(val_X, TIMESTEPS)
          name = "nn3_20"
```

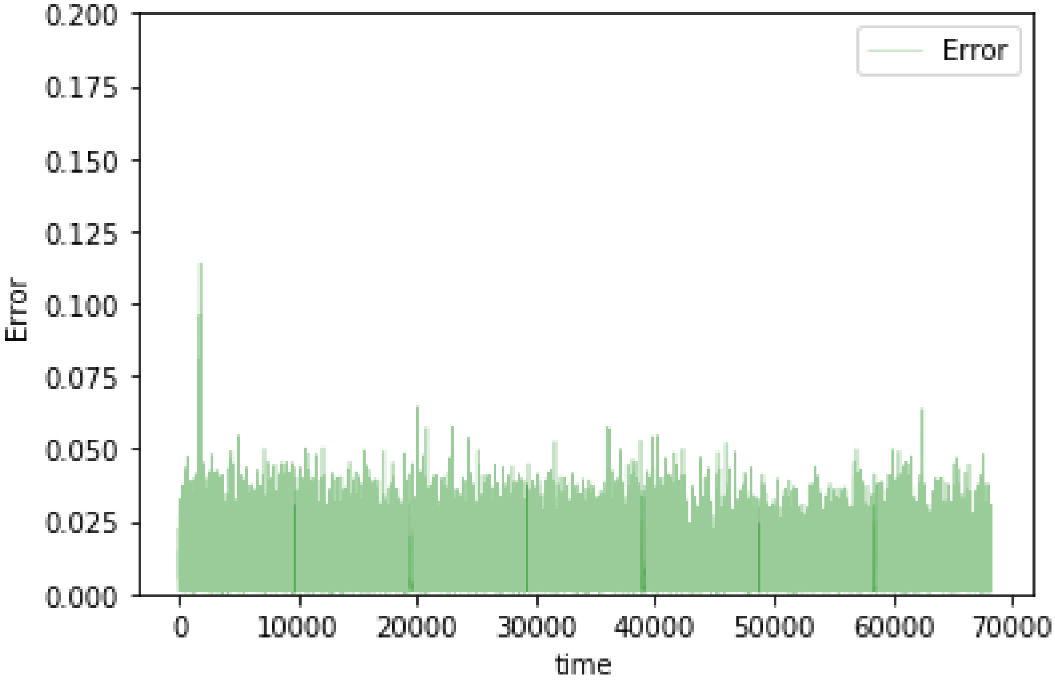
```
In [138]: input_layer = Input(shape=(TIMESTEPS*DIM,))
          hidden = Dense(1000, activation='relu')(input_layer)
          hidden = Dense(500, activation='relu')(hidden)
          hidden = Dense(100, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)
```

```
In [139]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

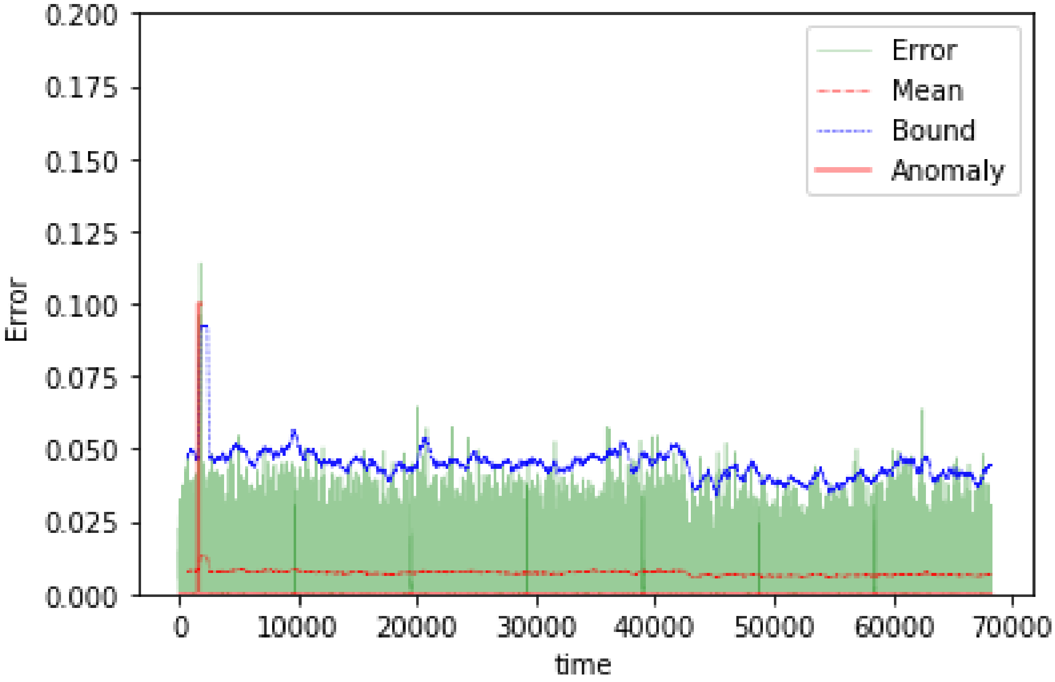
```
In [140]: train(model, tgen, vgen, name=name)
          test(model, name=name, window=TIMESTEPS)
```



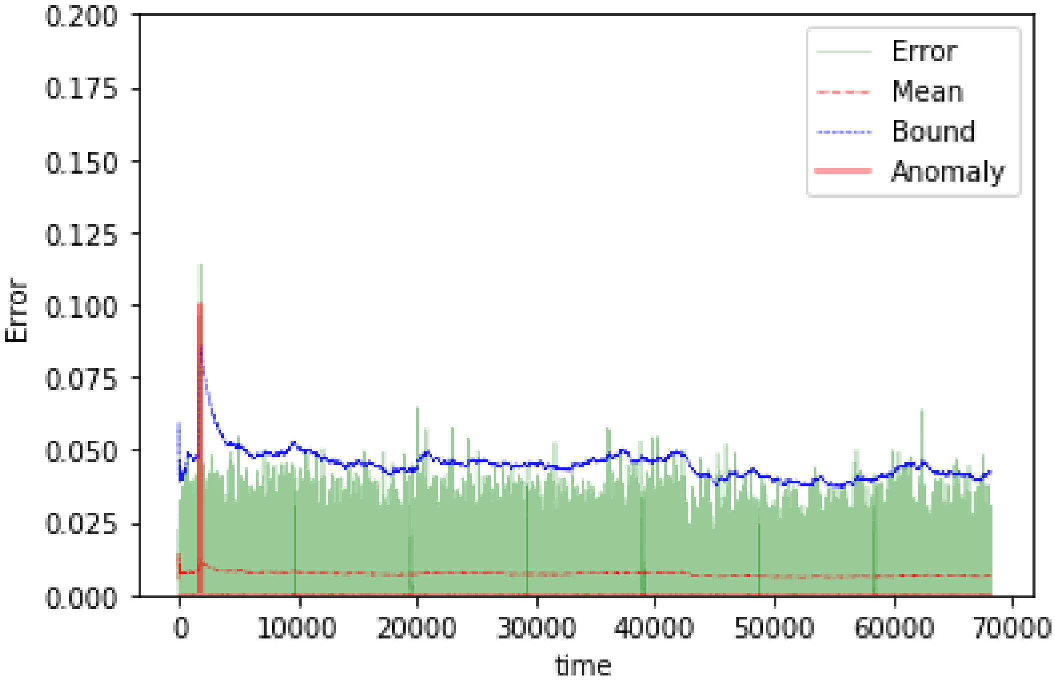
```
Training loss for final epoch is 0.007777658795122989
Validation loss for final epoch is 0.006856498639564961
---------- Beginning tests for nn3_20 ----------
Testing on Normal data.
```



0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error



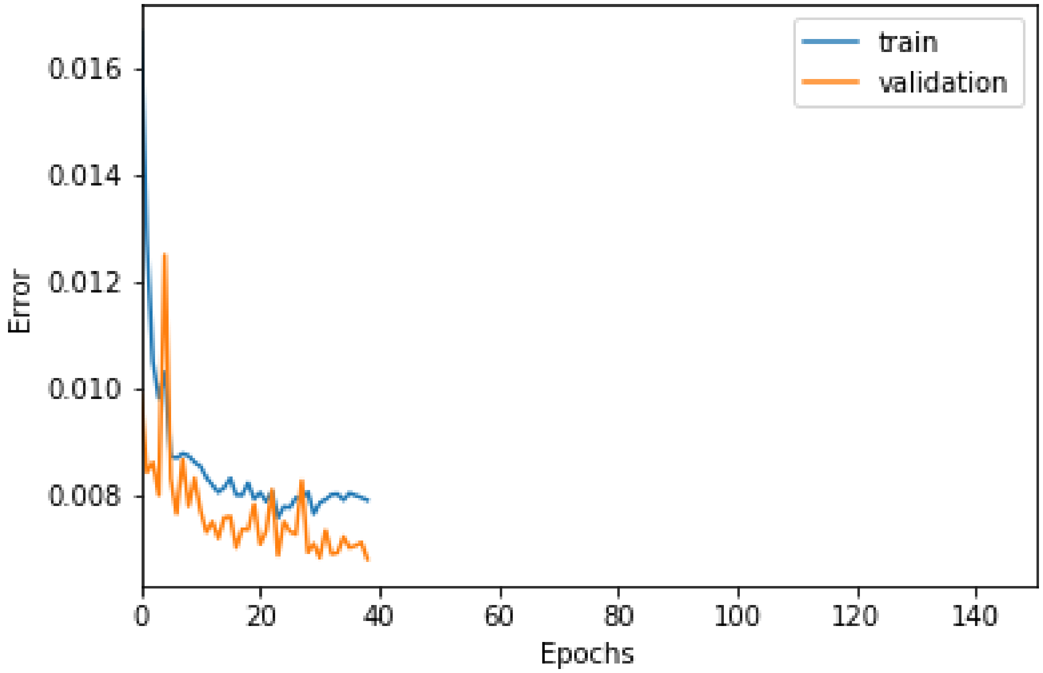
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly



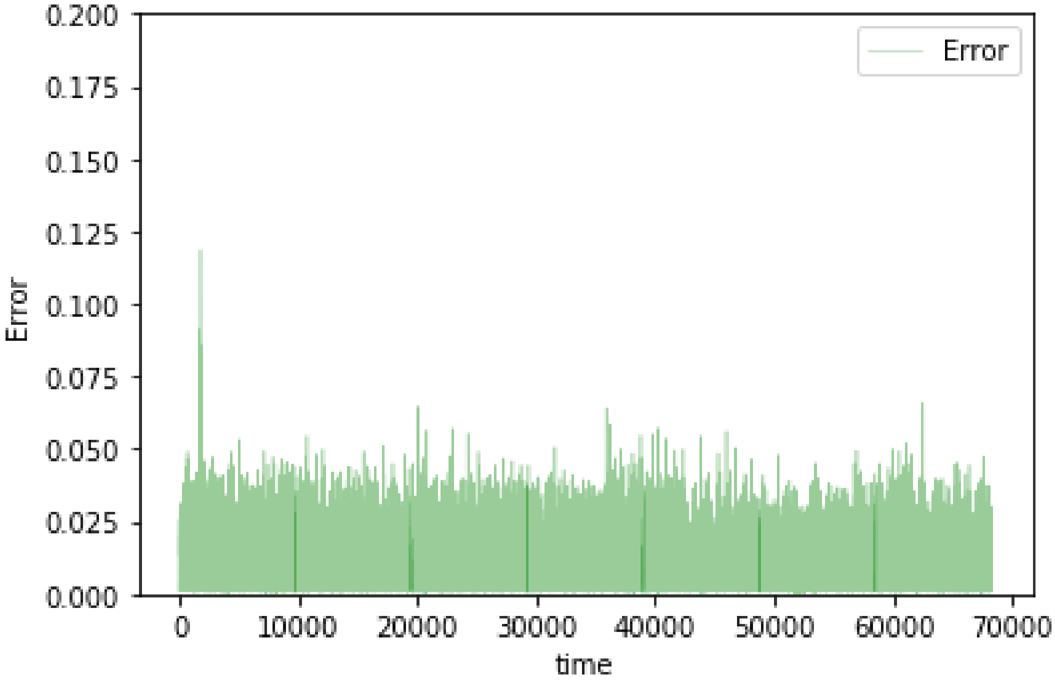
```
The mean error for nn3_20_normal_ is 0.007189139191435208 for length 68279
====================
```

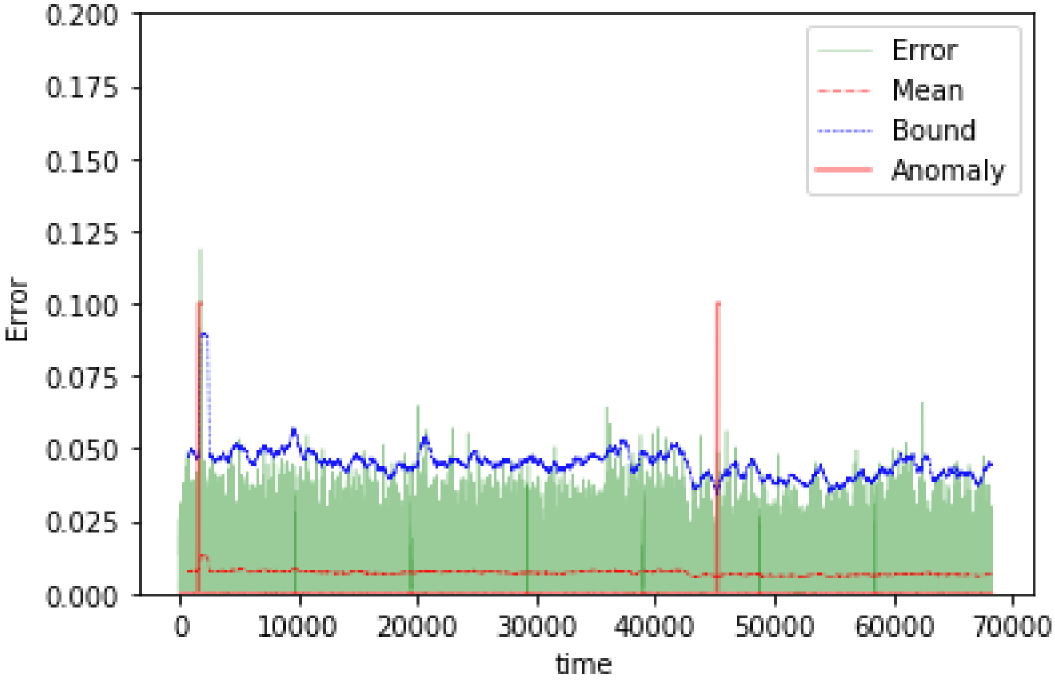
50 steps

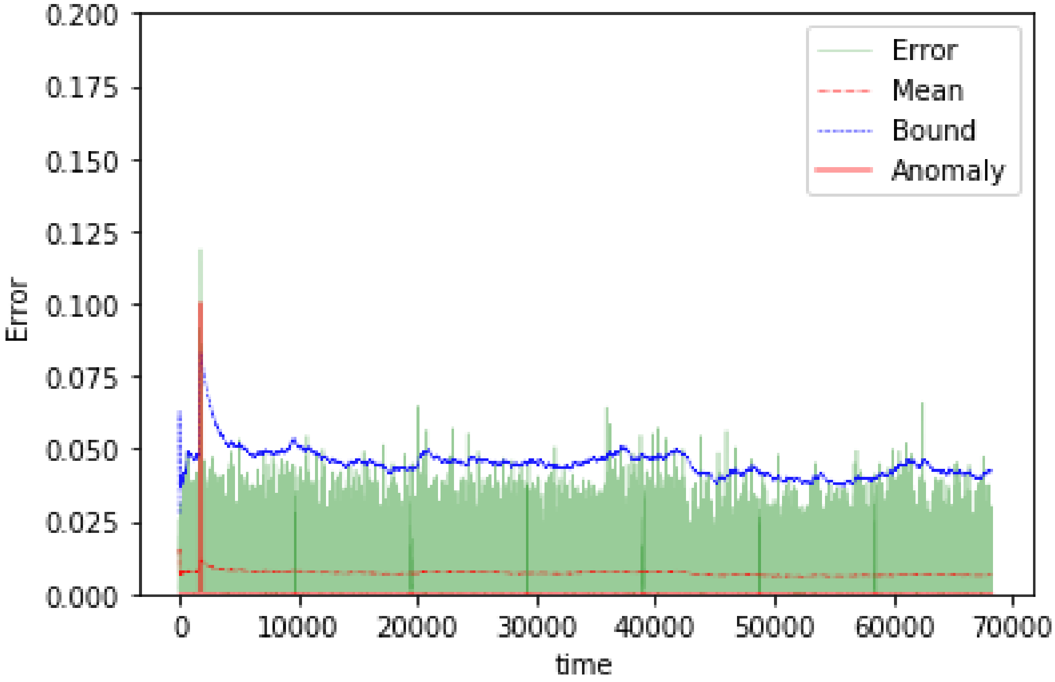
```
In [141]: TIMESTEPS = 50
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS)
          vgen = flat_generator(val_X, TIMESTEPS)
          name = "nn3_50"

In [142]: input_layer = Input(shape=(TIMESTEPS*DIM,))
          hidden = Dense(1000, activation='relu')(input_layer)
          hidden = Dense(500, activation='relu')(hidden)
          hidden = Dense(100, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)

In [143]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])

In [144]: train(model, tgen, vgen, name=name)
          test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.00790176934376359
Validation loss for final epoch is 0.006799345748266205
---------- Beginning tests for nn3_50 ----------
Testing on Normal data.
```




0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly


0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly

```
The mean error for nn3_50_normal_ is 0.007127557657232805 for length 68249
====================
```

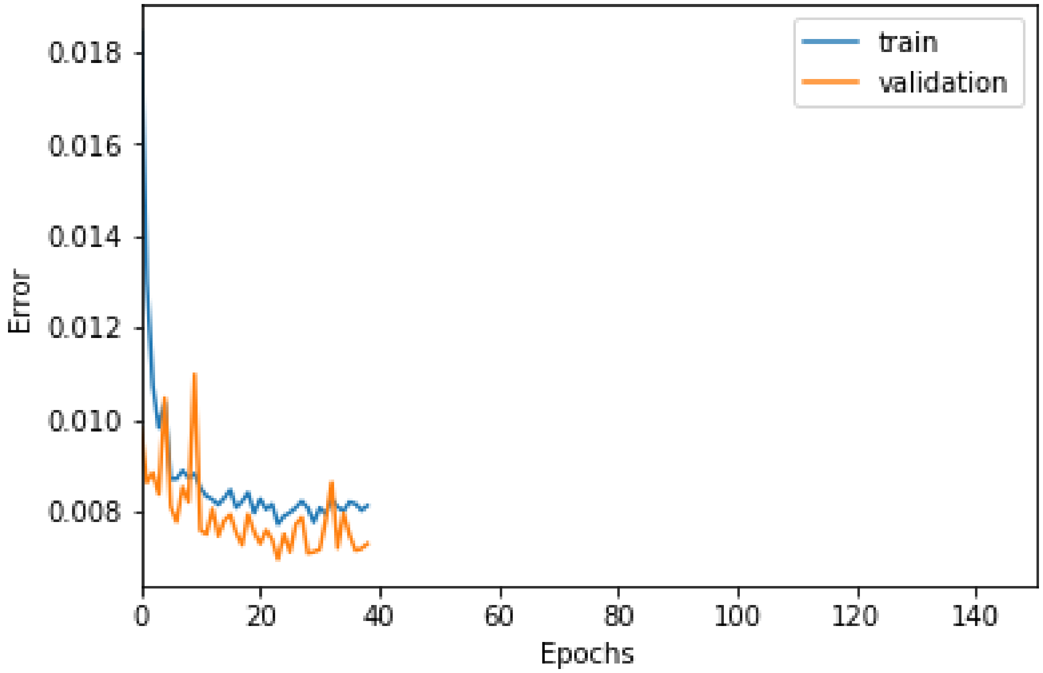
100 steps

```
In [145]: TIMESTEPS = 100
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS)
          vgen = flat_generator(val_X, TIMESTEPS)
          name = "nn3_100"
```

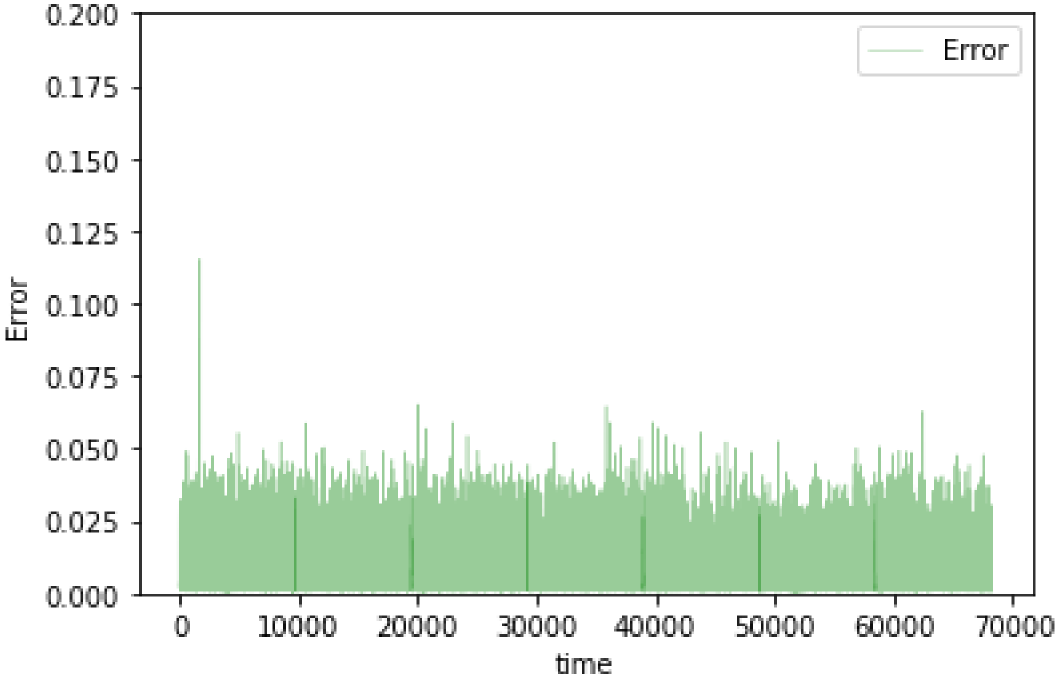
```
In [146]: input_layer = Input(shape=(TIMESTEPS*DIM,))
          hidden = Dense(1000, activation='relu')(input_layer)
          hidden = Dense(500, activation='relu')(hidden)
          hidden = Dense(100, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)
```

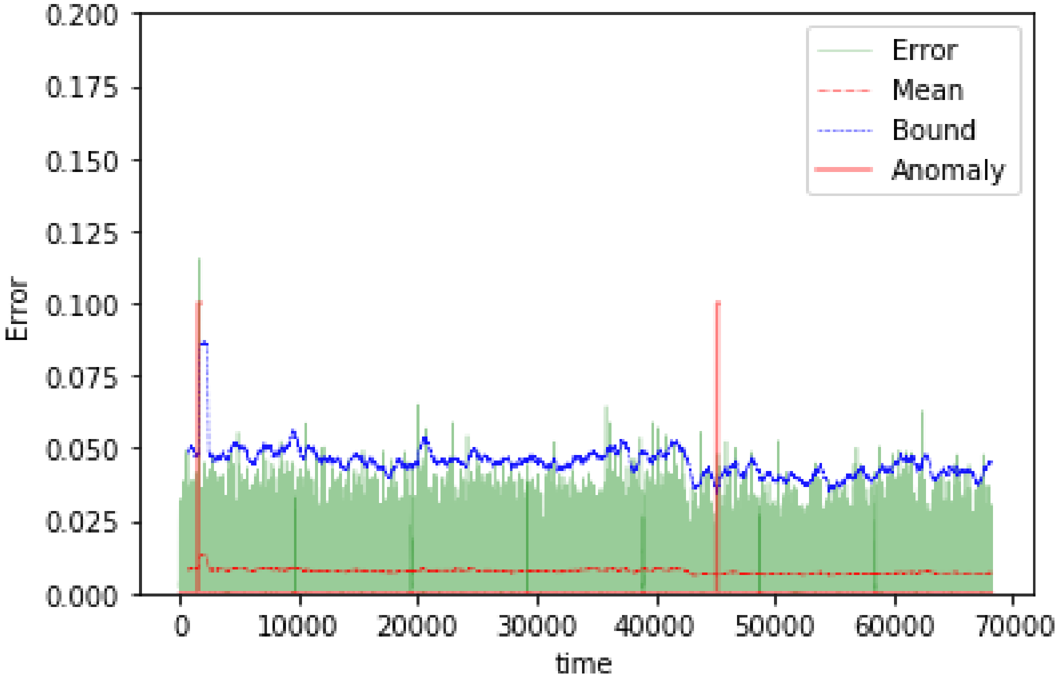
```
In [147]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

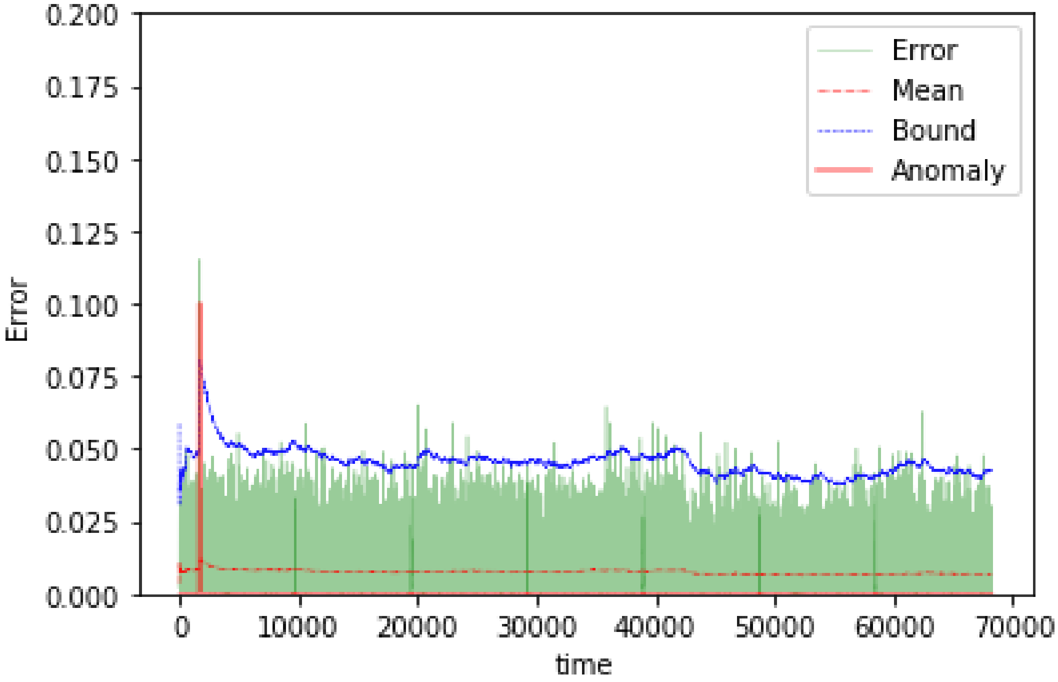
```
In [148]: train(model, tgen, vgen, name=name)
          test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.00811580884642899
Validation loss for final epoch is 0.0072851574977394196
---------- Beginning tests for nn3_100 ----------
Testing on Normal data.
```







```
The mean error for nn3_100_normal_ is 0.007538654389467203 for length 68199
====================
```

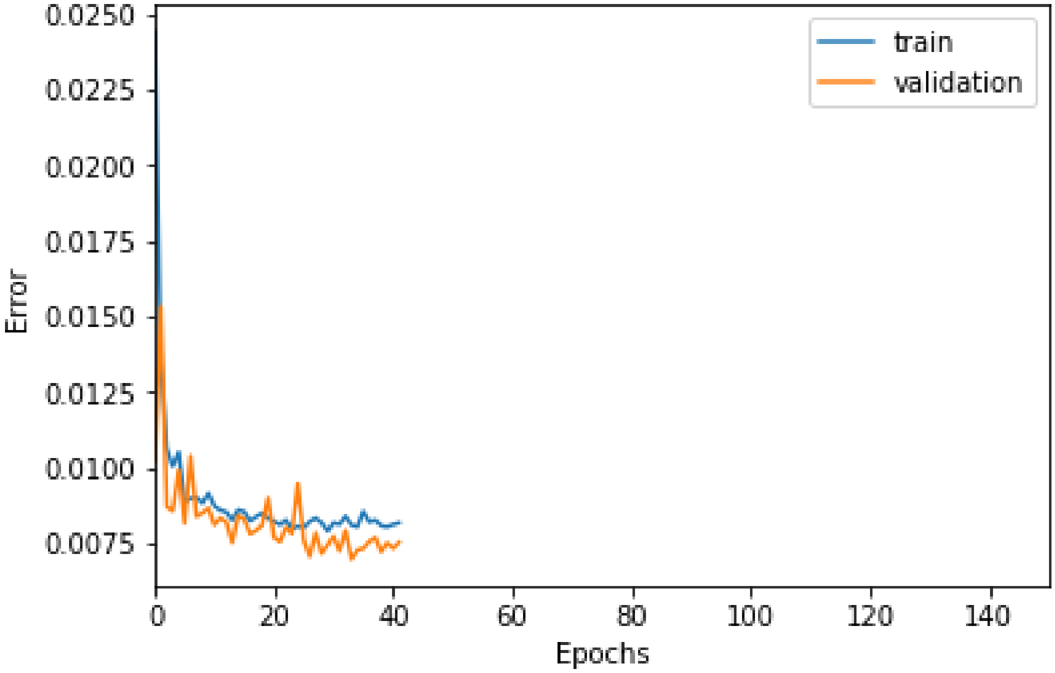
200 steps

```
In [149]: TIMESTEPS = 200
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS)
          vgen = flat_generator(val_X, TIMESTEPS)
          name = "nn3_200"
```

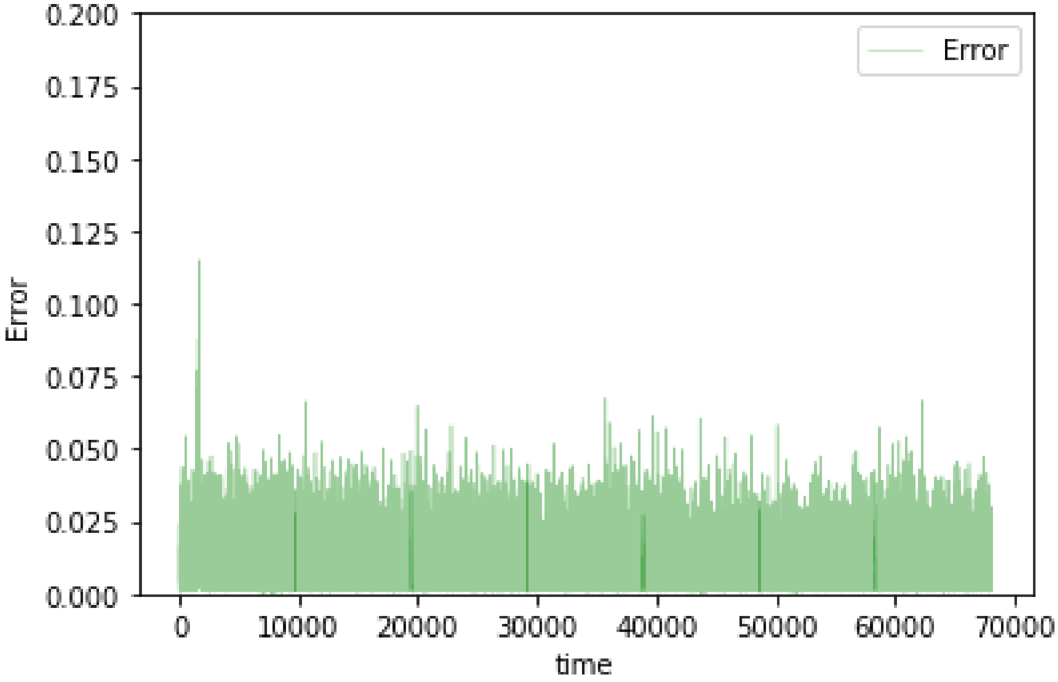
```
In [150]: input_layer = Input(shape=(TIMESTEPS*DIM,))
          hidden = Dense(1000, activation='relu')(input_layer)
          hidden = Dense(500, activation='relu')(hidden)
          hidden = Dense(100, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)
```

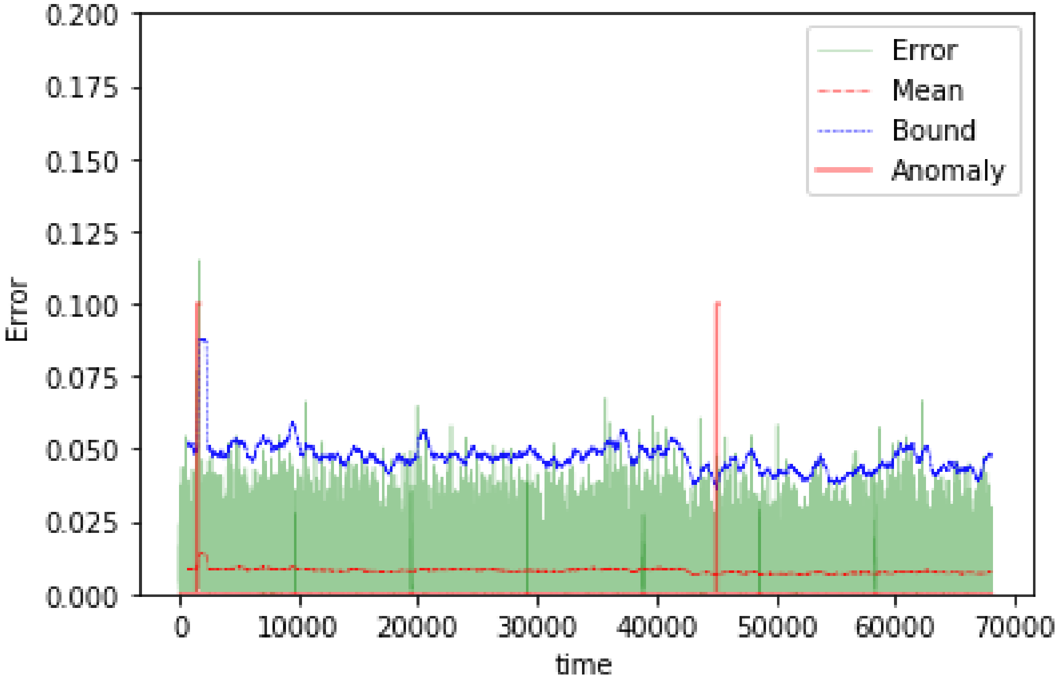
```
In [151]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

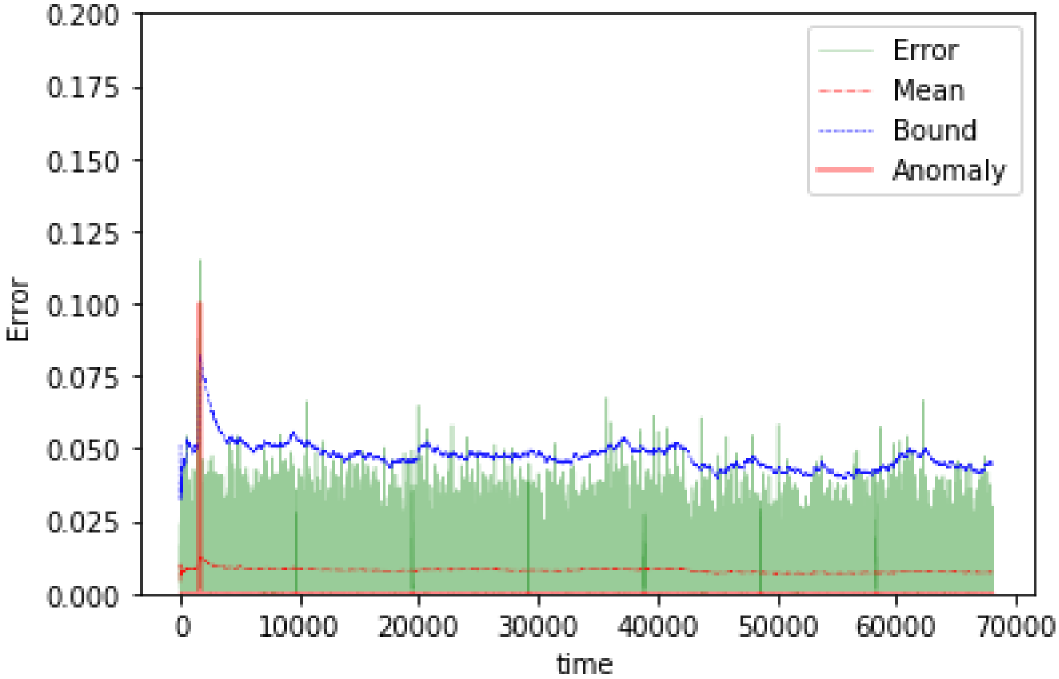
```
In [152]: train(model, tgen, vgen, name=name)
          test(model, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008189415906206705
Validation loss for final epoch is 0.007538747538812458
---------- Beginning tests for nn3_200 ----------
Testing on Normal data.
```


0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error


0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly



```
The mean error for nn3_200_normal_ is 0.007976614589910749 for length 68099
====================
```

1.11.5 RNN with 1 GRU layers

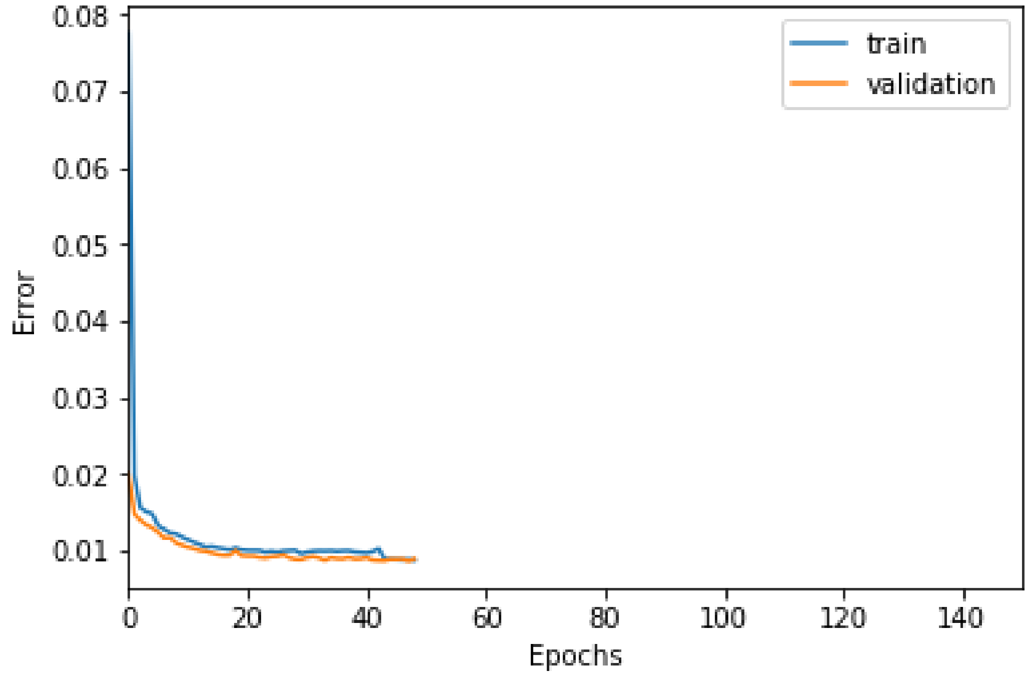
2 steps

```
In [153]: TIMESTEPS = 2
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS,0)
          vgen = flat_generator(val_X, TIMESTEPS,0)
          name = "gru1_2"
```

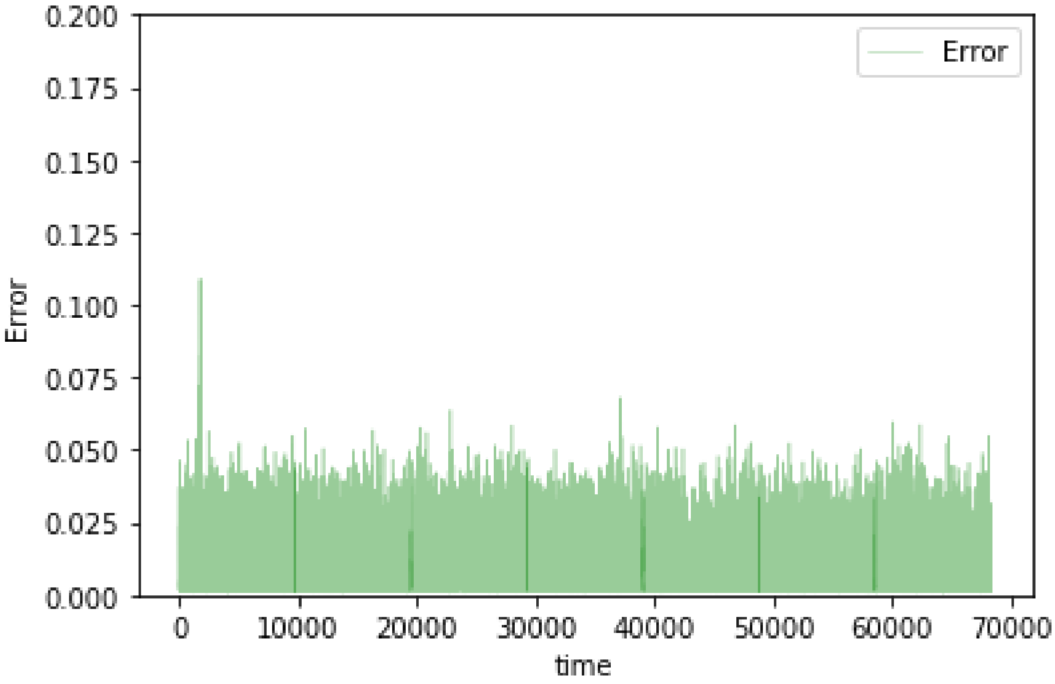
```
In [154]: input_layer = Input(shape=(TIMESTEPS,DIM))
          hidden = GRU(10, activation='relu')(input_layer)
          output = Dense(DIM, activation='sigmoid')(hidden)
```

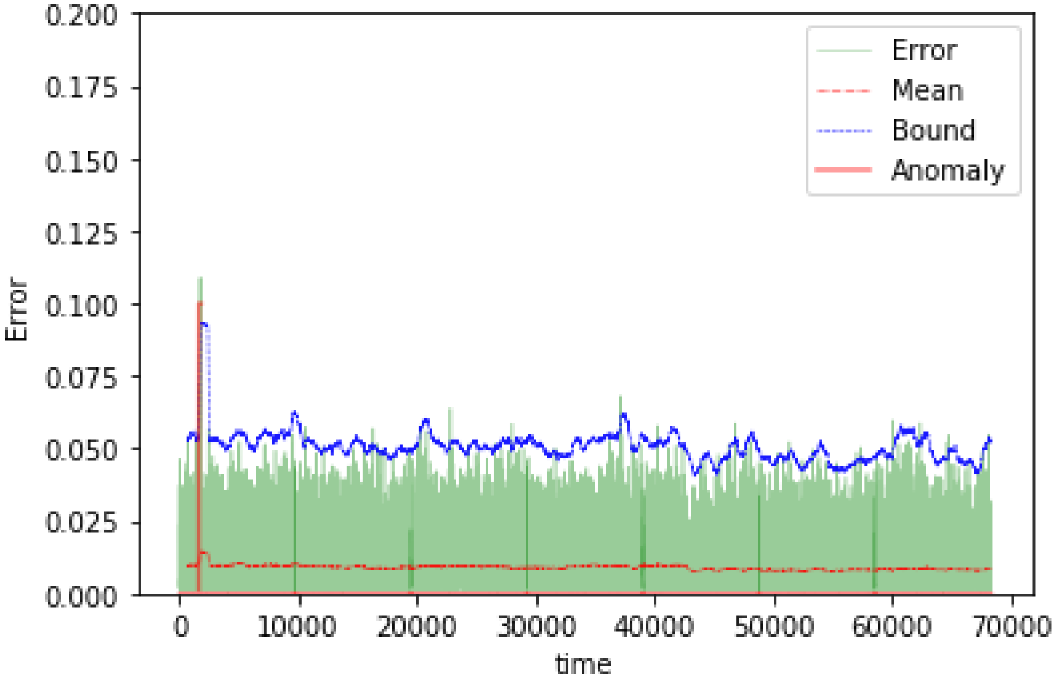
```
In [155]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

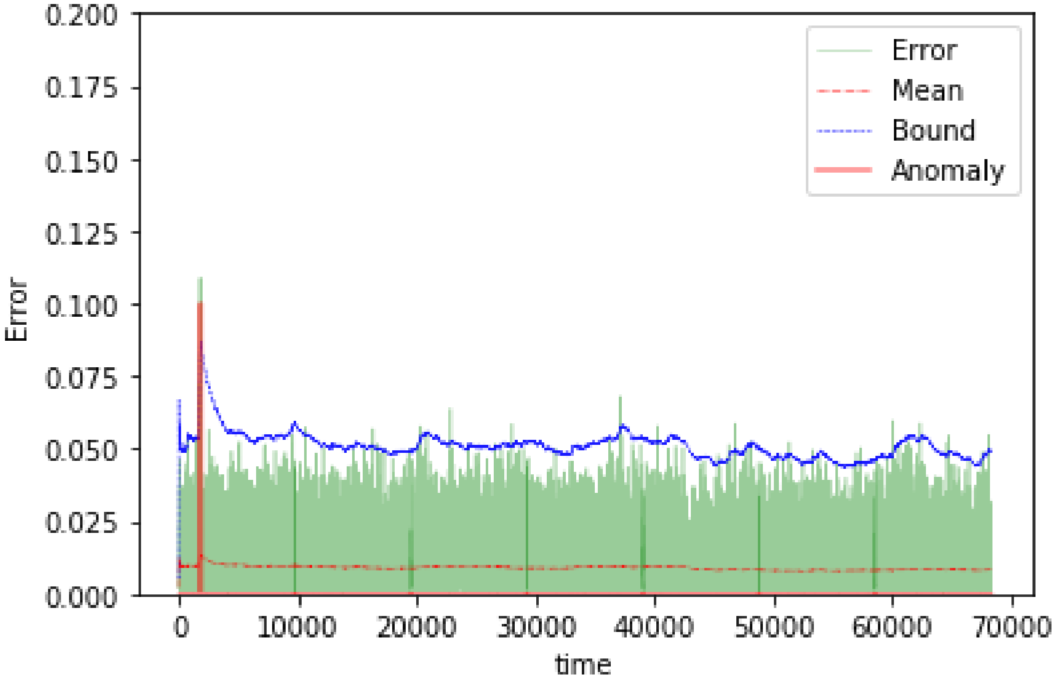
```
In [156]: train(model, tgen, vgen, name=name)
          test(model, ravel=0, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008748463535099291
Validation loss for final epoch is 0.008934514801832848
---------- Beginning tests for gru1_2 ----------
Testing on Normal data.
```




0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly


0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly

```
The mean error for gru1_2_normal_ is 0.008969316909505634 for length 68297
====================
```

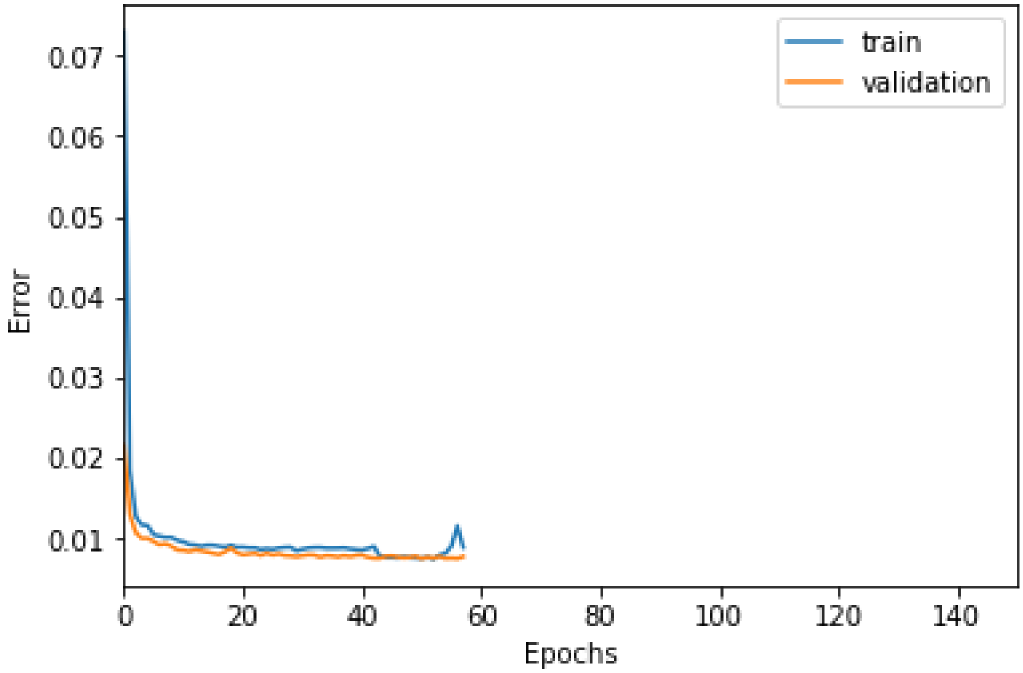
5 steps

```
In [157]: TIMESTEPS = 5
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS,0)
          vgen = flat_generator(val_X, TIMESTEPS, 0)
          name = "gru1_5"
```

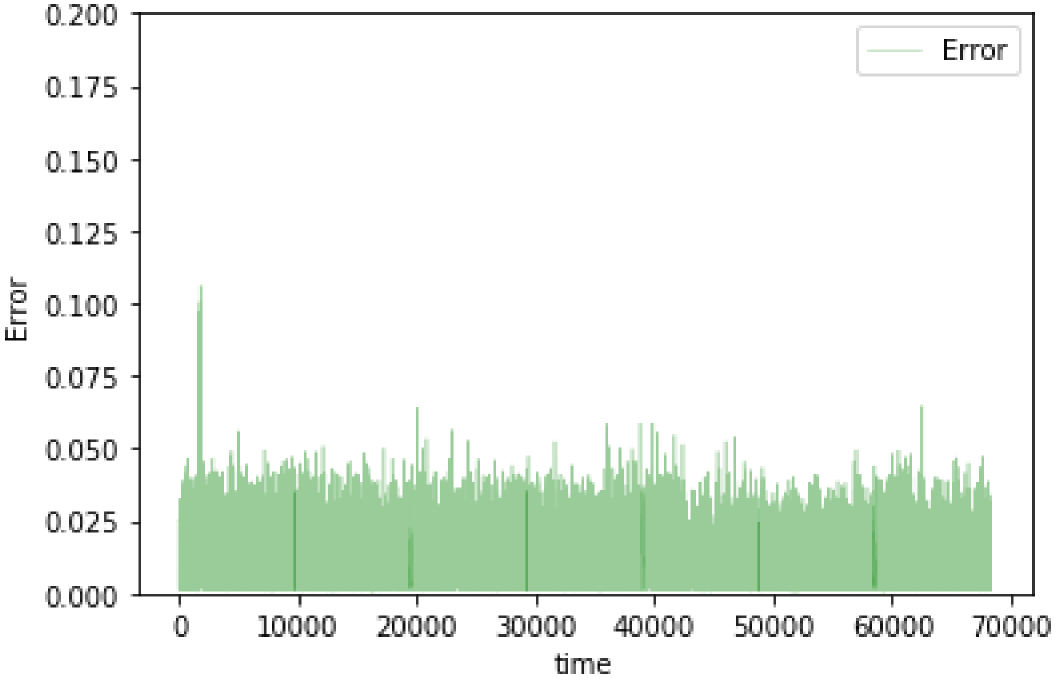
```
In [158]: input_layer = Input(shape=(TIMESTEPS,DIM))
          hidden = GRU(10, activation='relu')(input_layer)
          output = Dense(DIM, activation='sigmoid')(hidden)
```

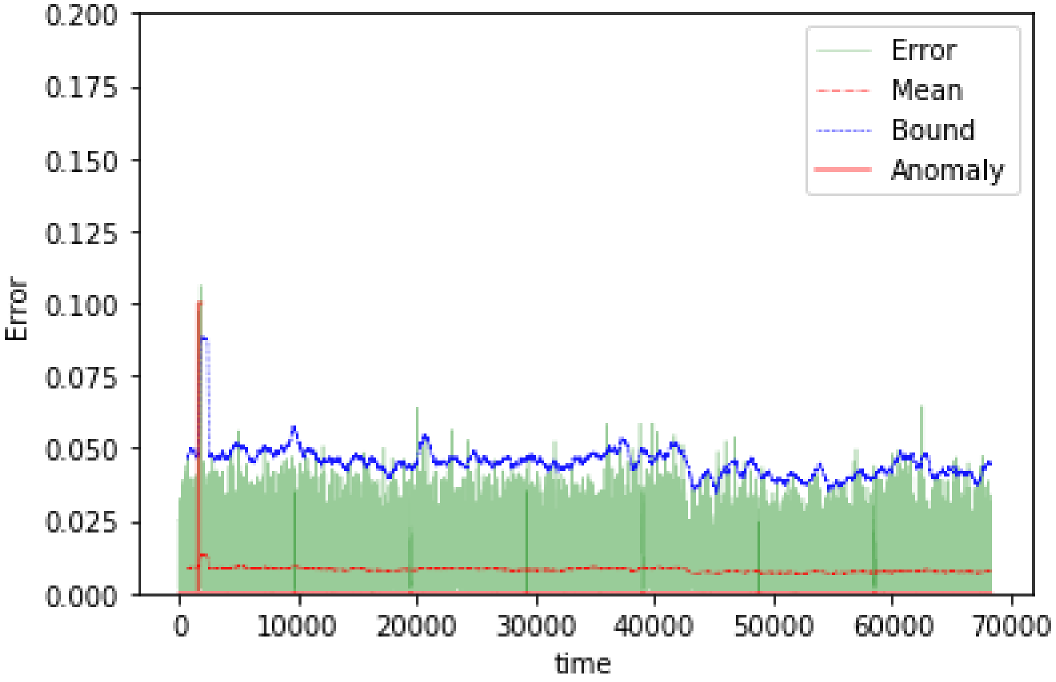
```
In [159]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

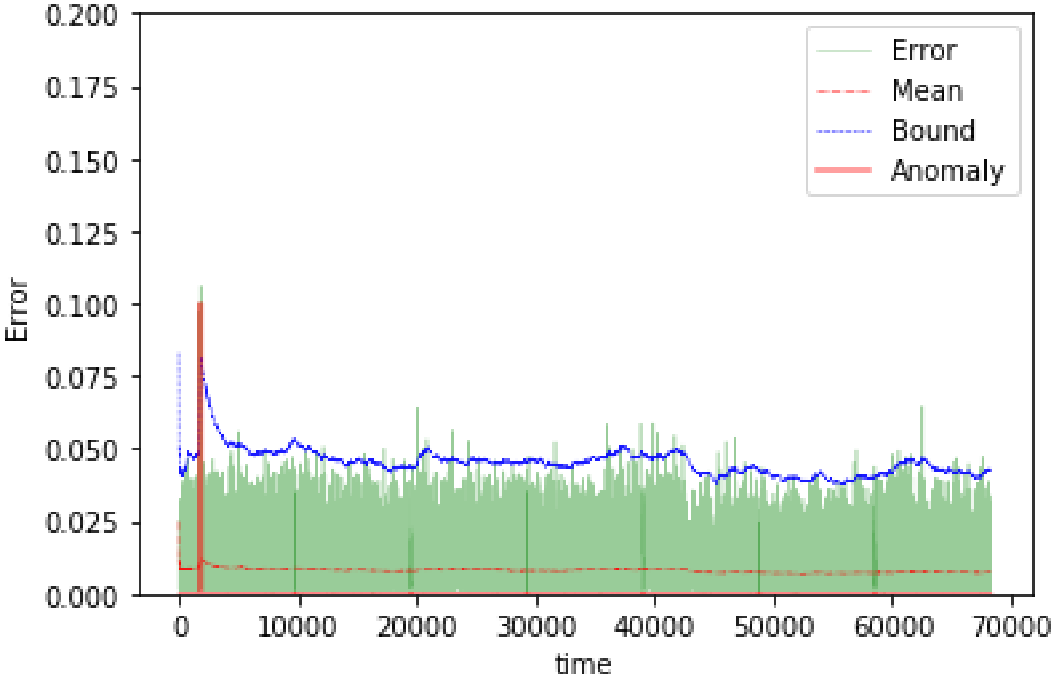
```
In [160]: train(model, tgen, vgen, name=name)
          test(model, ravel=0, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008881685076979921
Validation loss for final epoch is 0.007758386765373871
---------- Beginning tests for gru1_5 ----------
Testing on Normal data.
```





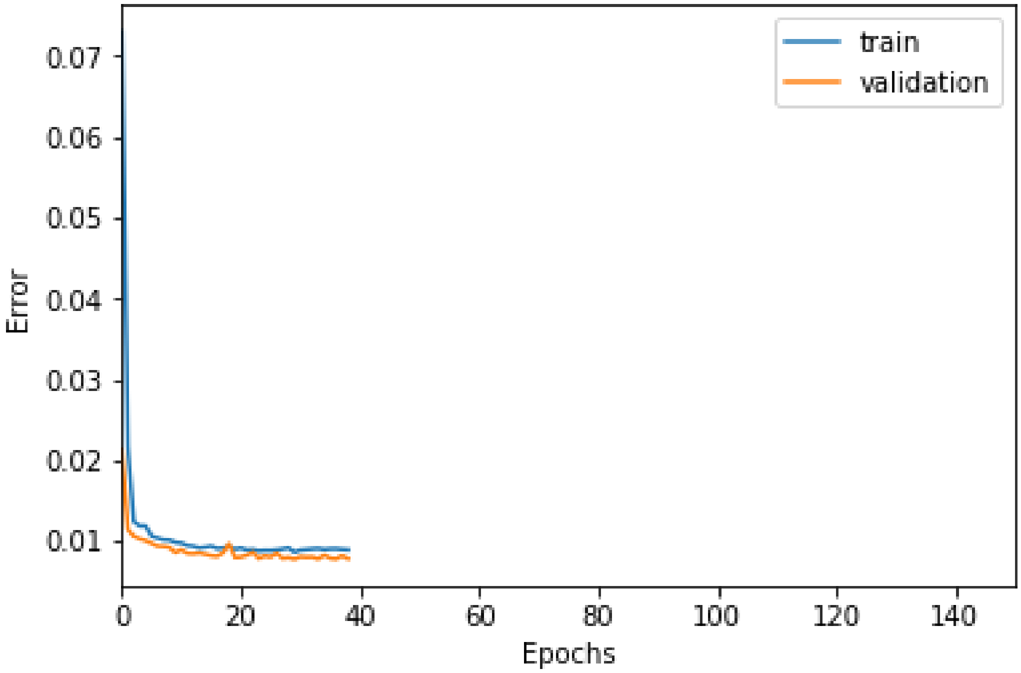


```
The mean error for gru1_5_normal_ is 0.008043153741308989 for length 68294
====================
```

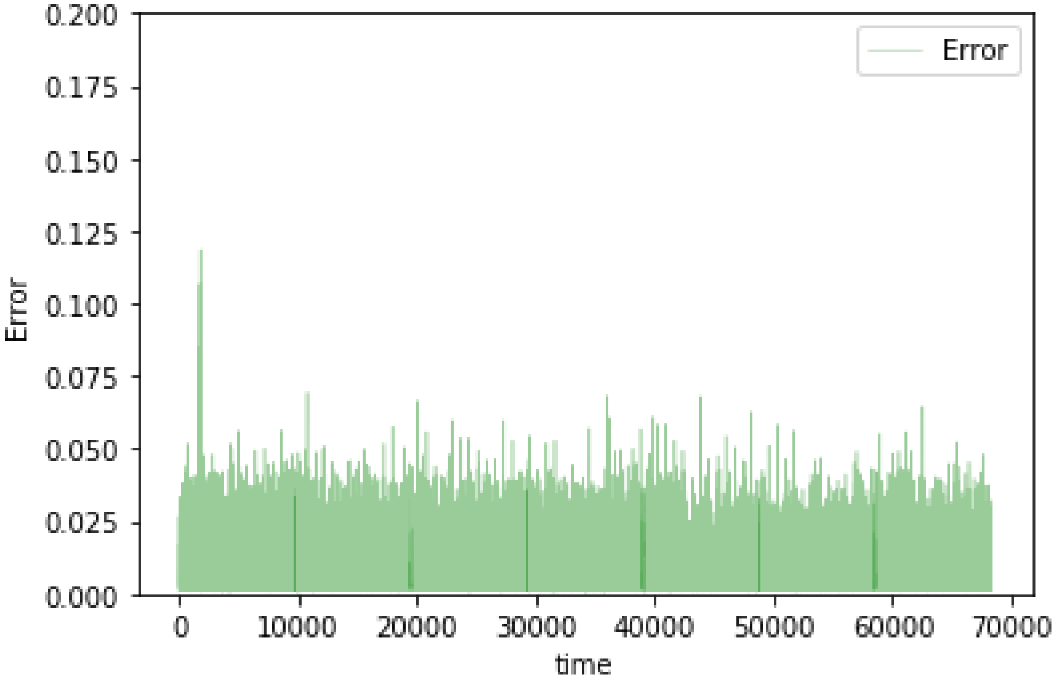
10 steps

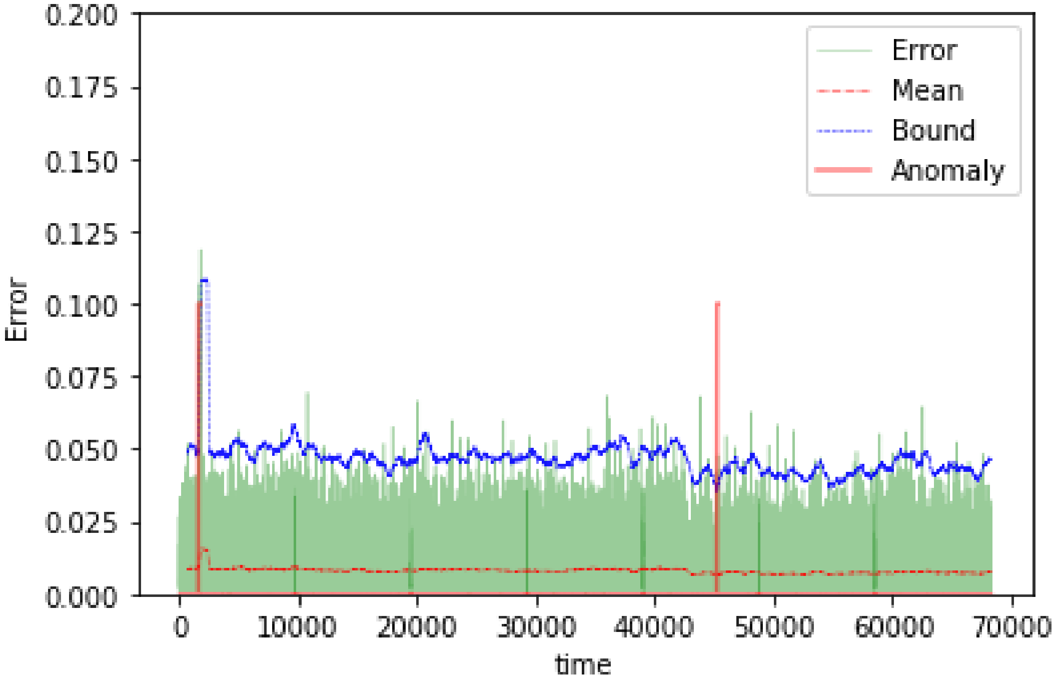
```
In [161]: TIMESTEPS = 10
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS, 0)
          vgen = flat_generator(val_X, TIMESTEPS, 0)
          name = "gru1_10"

In [162]: input_layer = Input(shape=(TIMESTEPS,DIM))
          hidden = GRU(10, activation='relu')(input_layer)
          output = Dense(DIM, activation='sigmoid')(hidden)

In [163]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

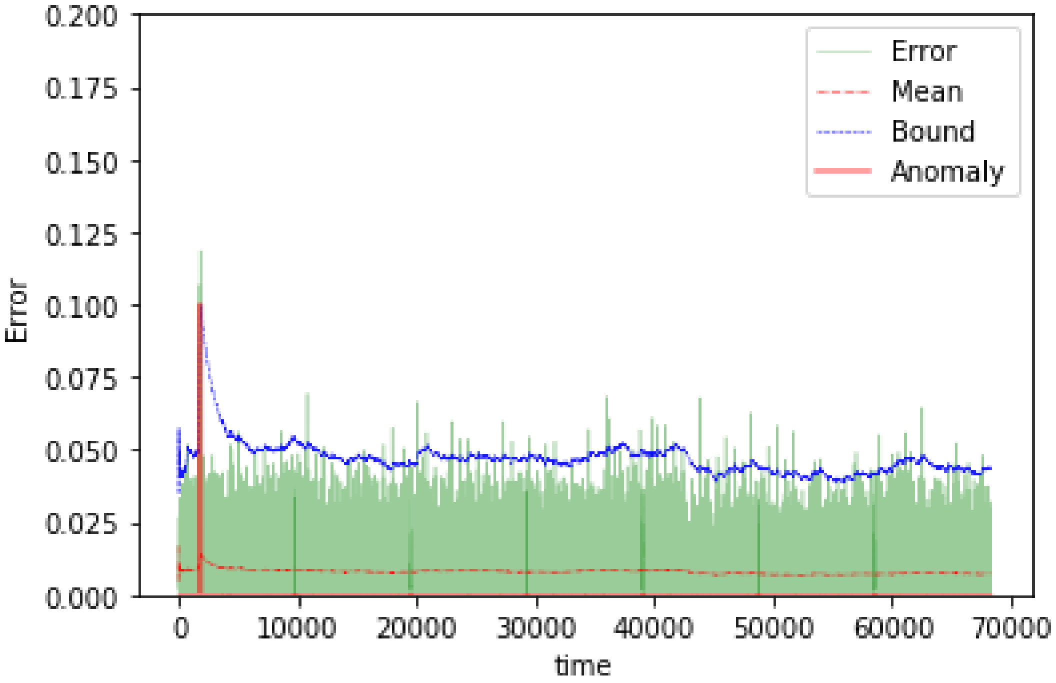
```
In [164]: train(model, tgen, vgen, name=name)
          test(model, ravel=0, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008927863472374157
Validation loss for final epoch is 0.00782537856255658
---------- Beginning tests for gru1_10 ----------
Testing on Normal data.
```


Error
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time


Error
Mean
Bound
Anomaly
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time



```
The mean error for gru1_10_normal_ is 0.00800600854095723 for length 68289
====================
```

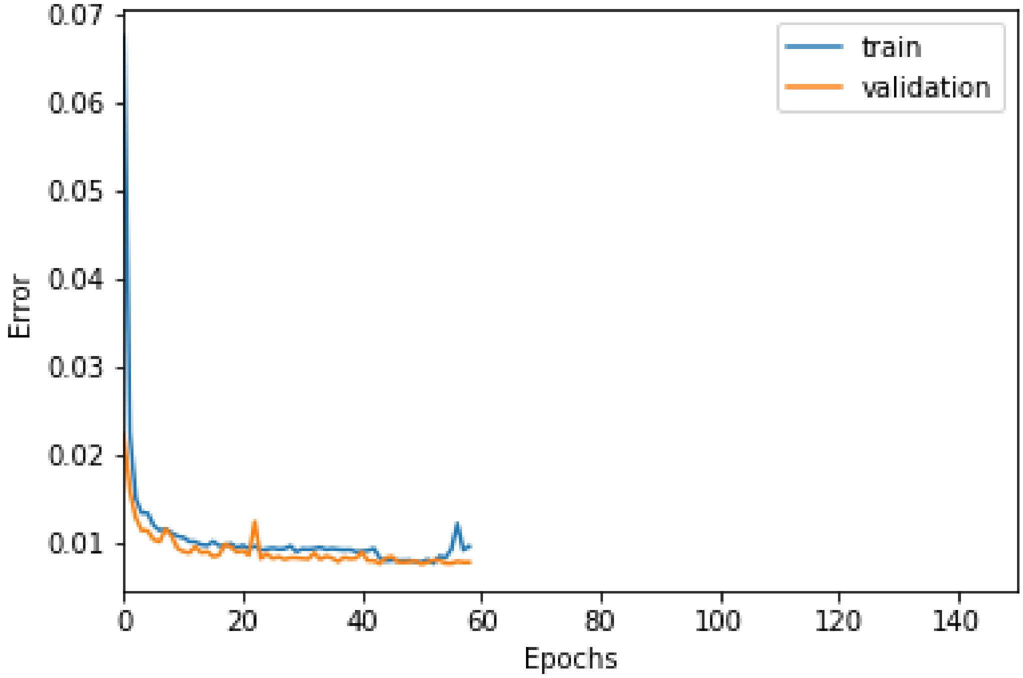
20 steps

```
In [165]: TIMESTEPS = 20
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS,0)
          vgen = flat_generator(val_X, TIMESTEPS,0)
          name = "gru1_20"
```

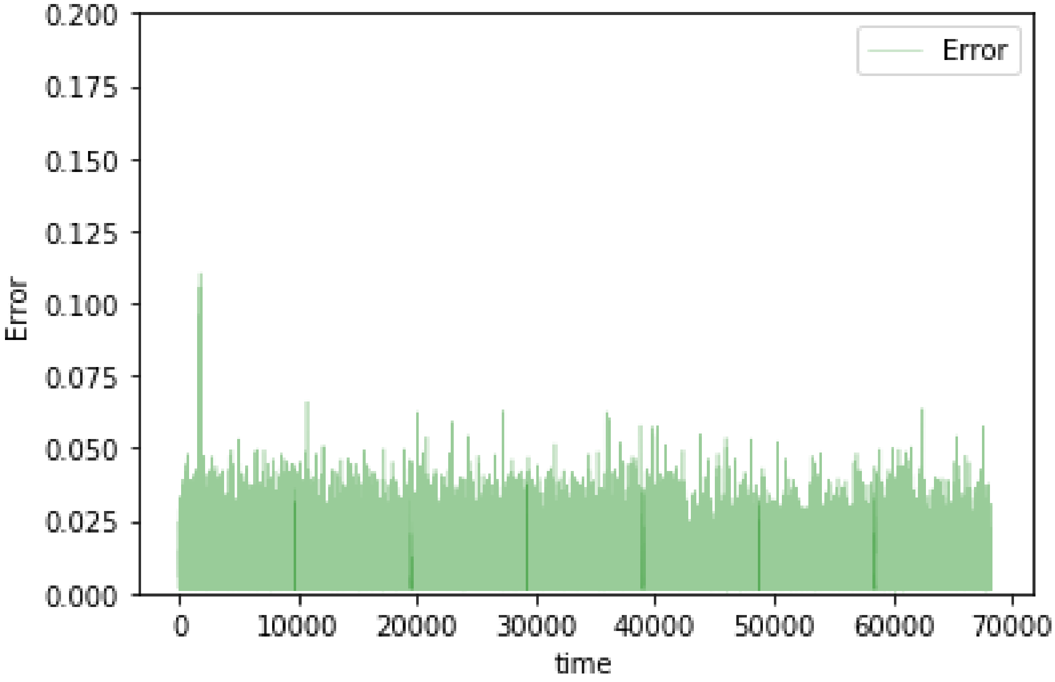
```
In [166]: input_layer = Input(shape=(TIMESTEPS,DIM))
          hidden = GRU(10, activation='relu')(input_layer)
          output = Dense(DIM, activation='sigmoid')(hidden)
```

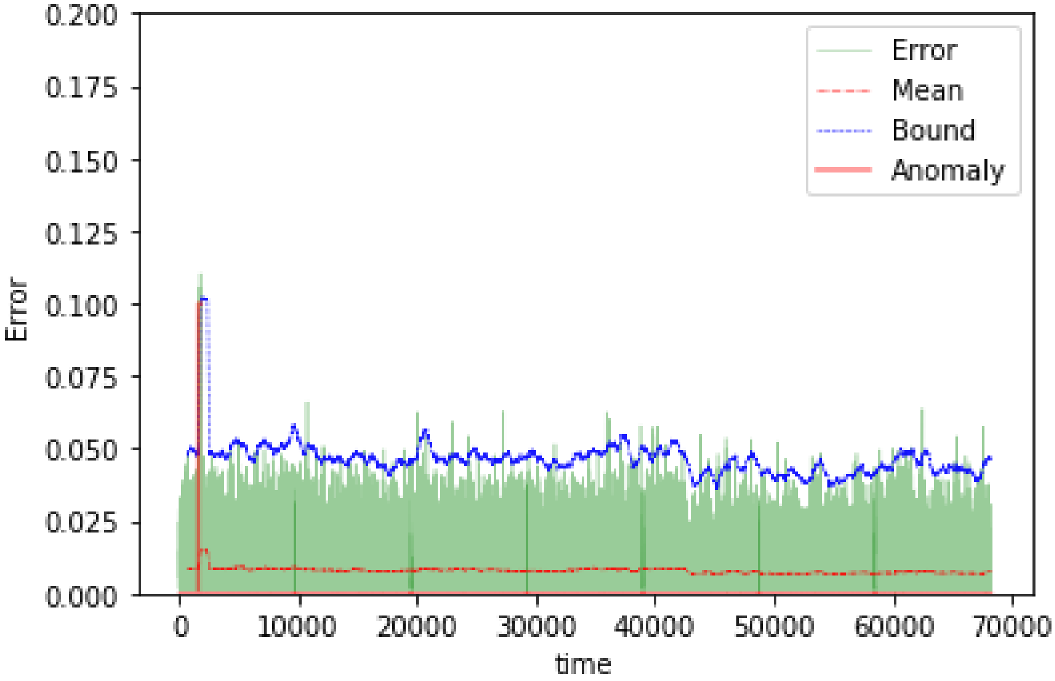
```
In [167]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

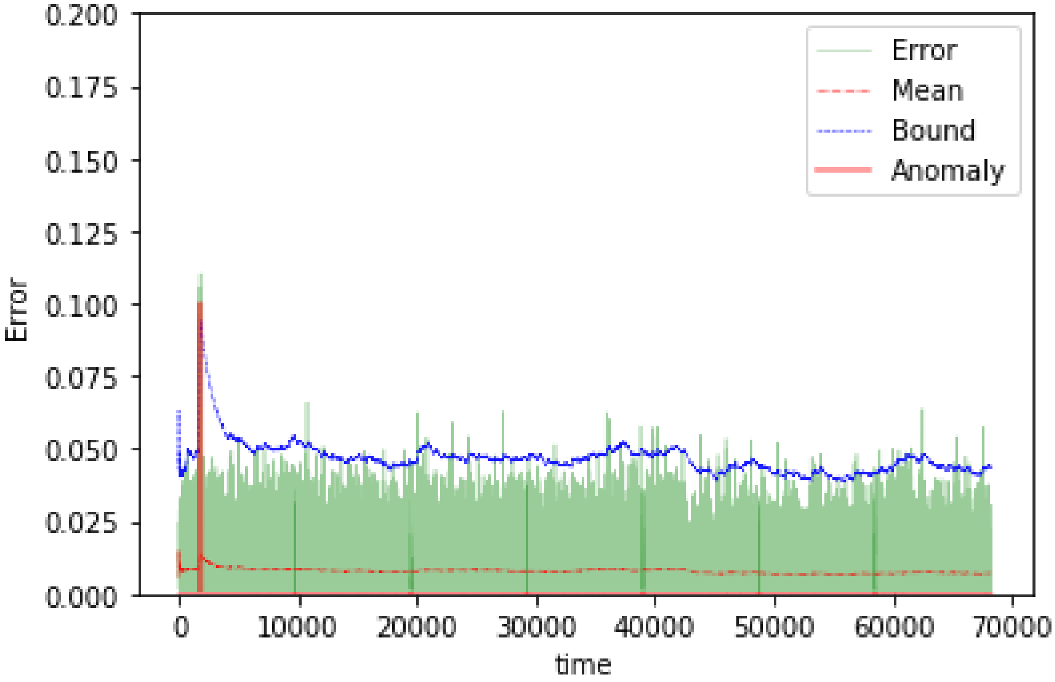
```
In [168]: train(model, tgen, vgen, name=name)
          test(model, ravel=0, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.009549152096733451
Validation loss for final epoch is 0.007743921980960295
---------- Beginning tests for gru1_20 ----------
Testing on Normal data.
```



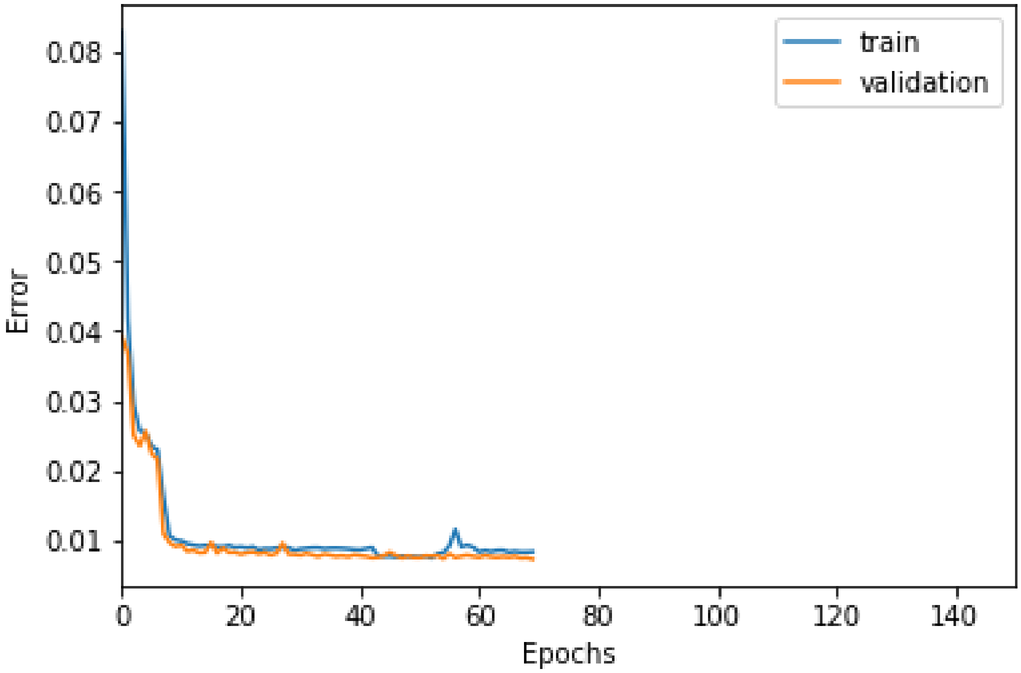

0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly


0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly

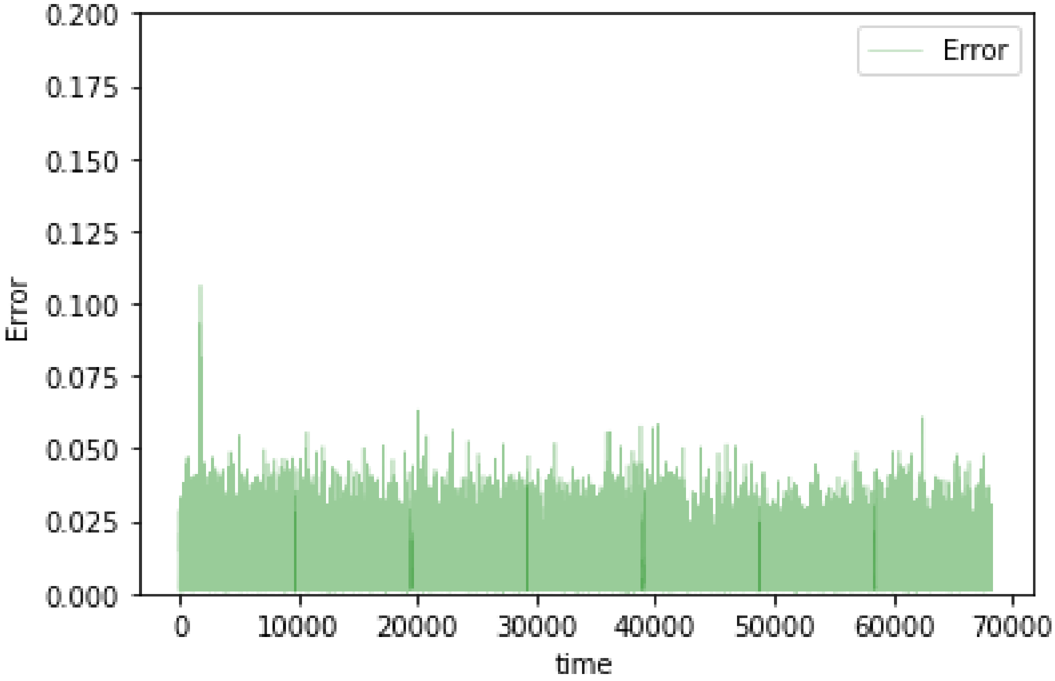
```
The mean error for gru1_20_normal_ is 0.007883864733051684 for length 68279
====================
```

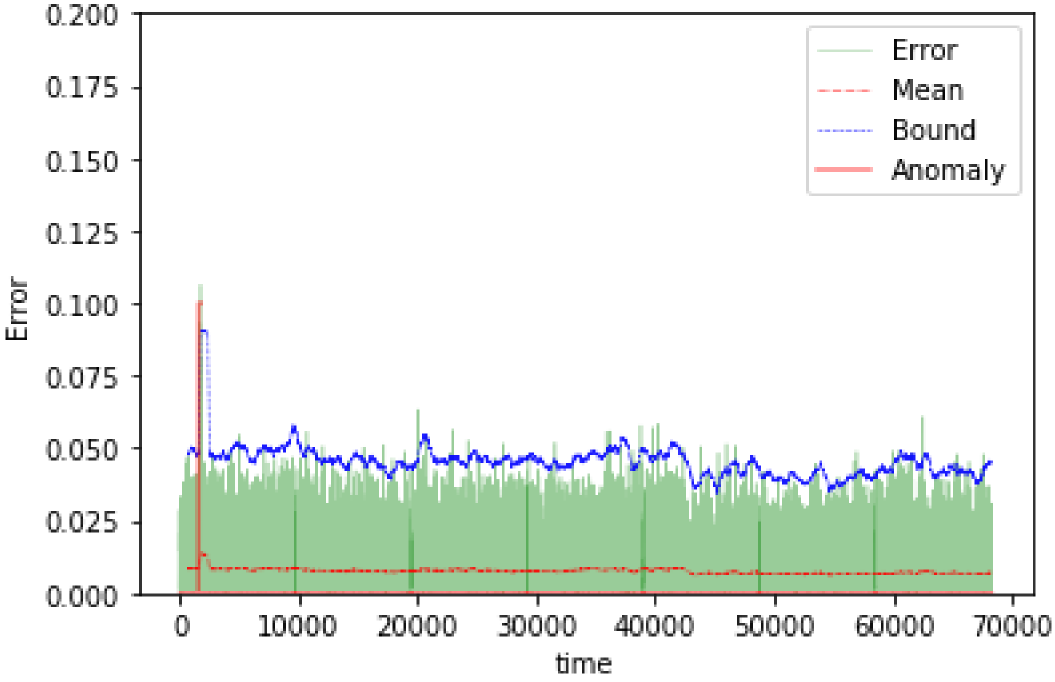
50 steps

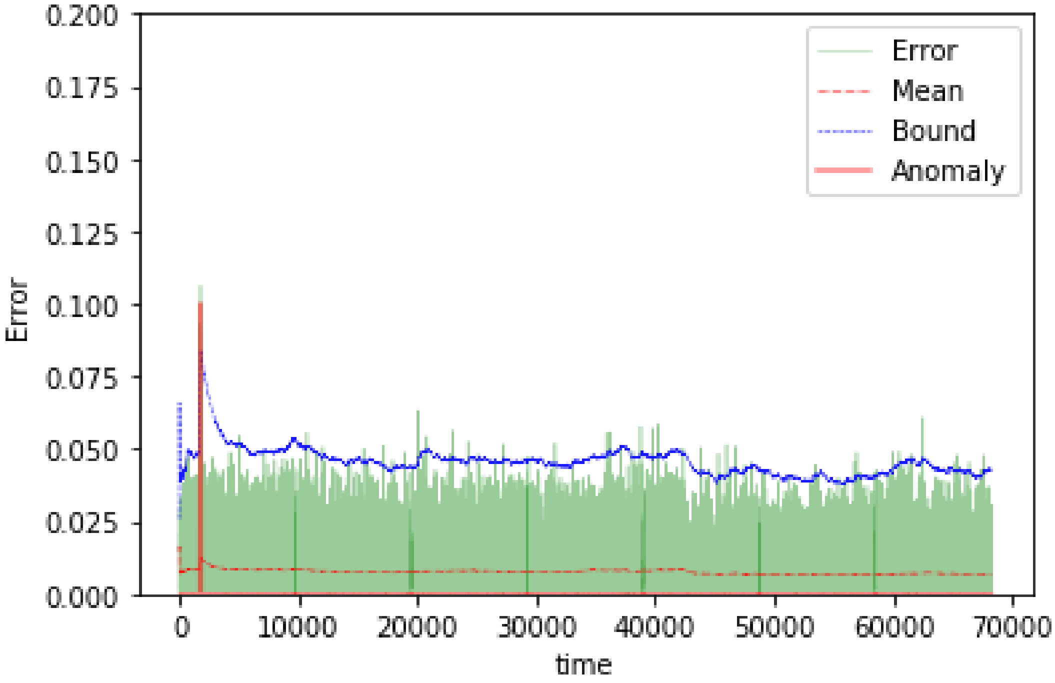
```
In [169]: TIMESTEPS = 50
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS,0)
          vgen = flat_generator(val_X, TIMESTEPS,0)
          name = "gru1_50"

In [170]: input_layer = Input(shape=(TIMESTEPS,DIM))
          hidden = GRU(10, activation='relu')(input_layer)
          output = Dense(DIM, activation='sigmoid')(hidden)

In [171]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])

In [172]: train(model, tgen, vgen, name=name)
          test(model, ravel=0, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008316080629476346
Validation loss for final epoch is 0.007262779241194948
---------- Beginning tests for gru1_50 ----------
Testing on Normal data.
```





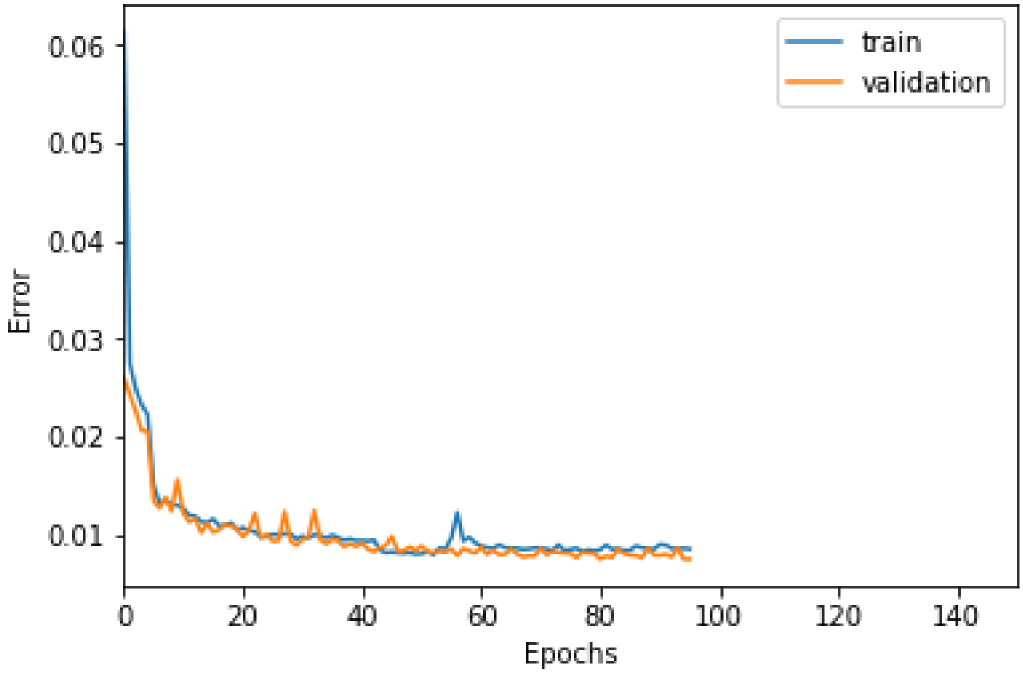


```
The mean error for gru1_50_normal_ is 0.007606780938264082 for length 68249
====================
```

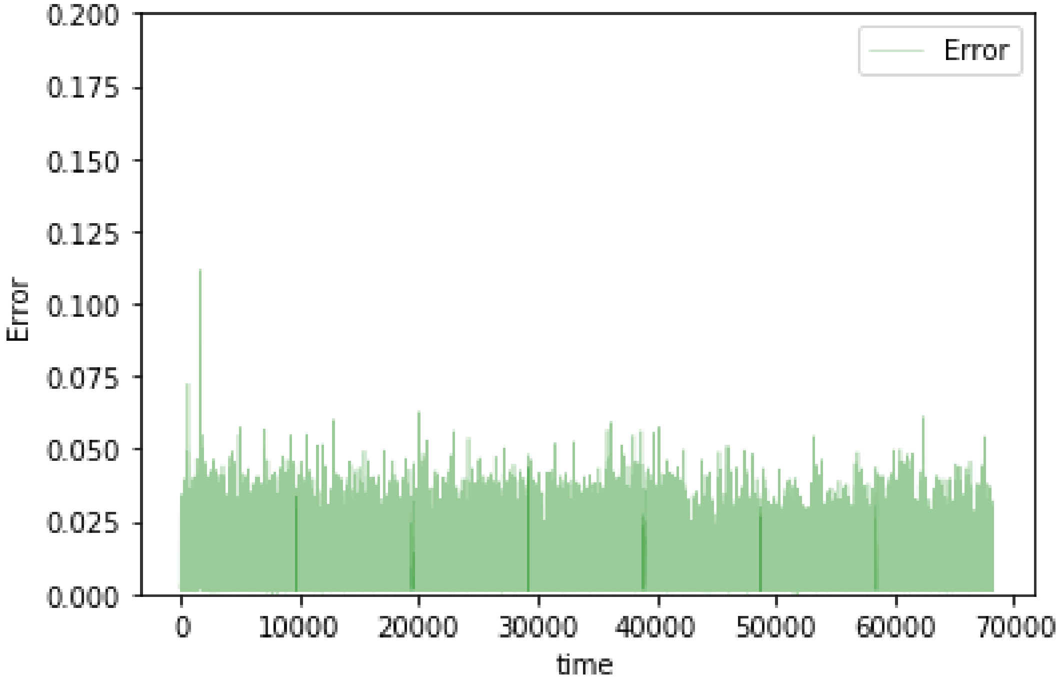
100 steps

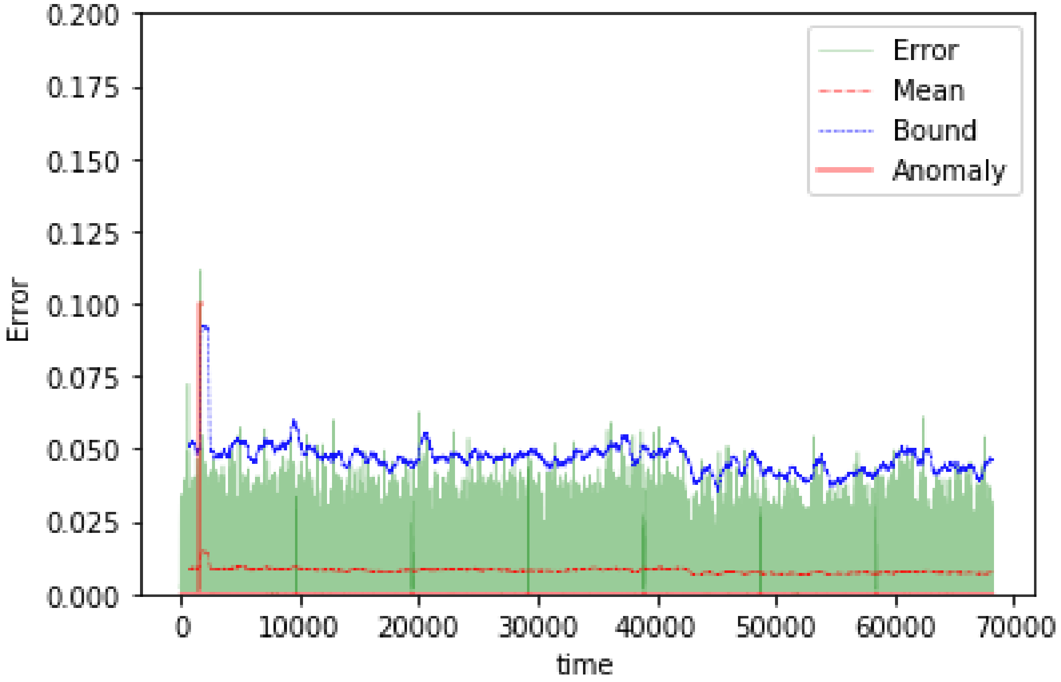
```
In [173]: TIMESTEPS = 100
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS,0)
          vgen = flat_generator(val_X, TIMESTEPS,0)
          name = "gru1_100"

In [174]: input_layer = Input(shape=(TIMESTEPS,DIM))
          hidden = GRU(10, activation='relu')(input_layer)
          output = Dense(DIM, activation='sigmoid')(hidden)

In [175]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

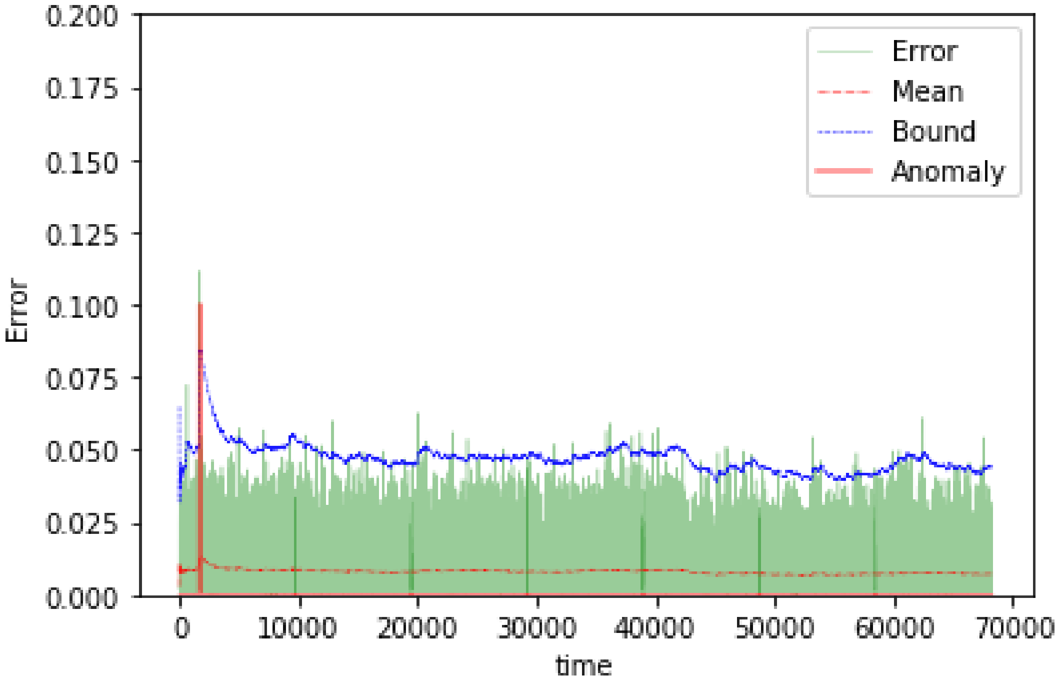
```
In [176]: train(model, tgen, vgen, name=name)
          test(model, ravel=0, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008534929826157167
Validation loss for final epoch is 0.007493695398094132
---------- Beginning tests for gru1_100 ----------
Testing on Normal data.
```


0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error

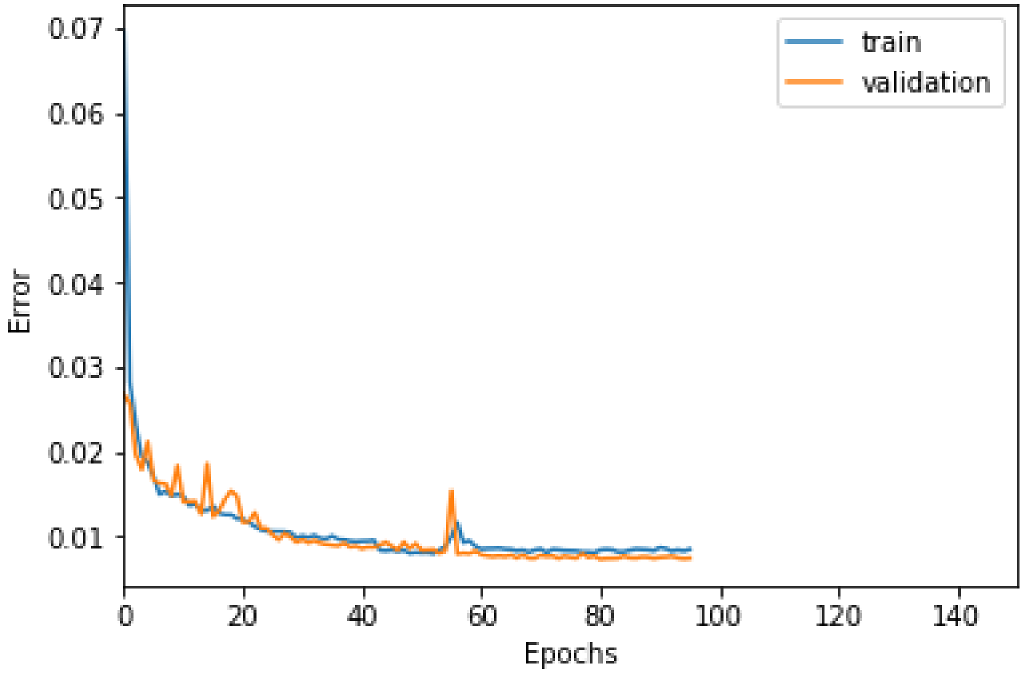

0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly



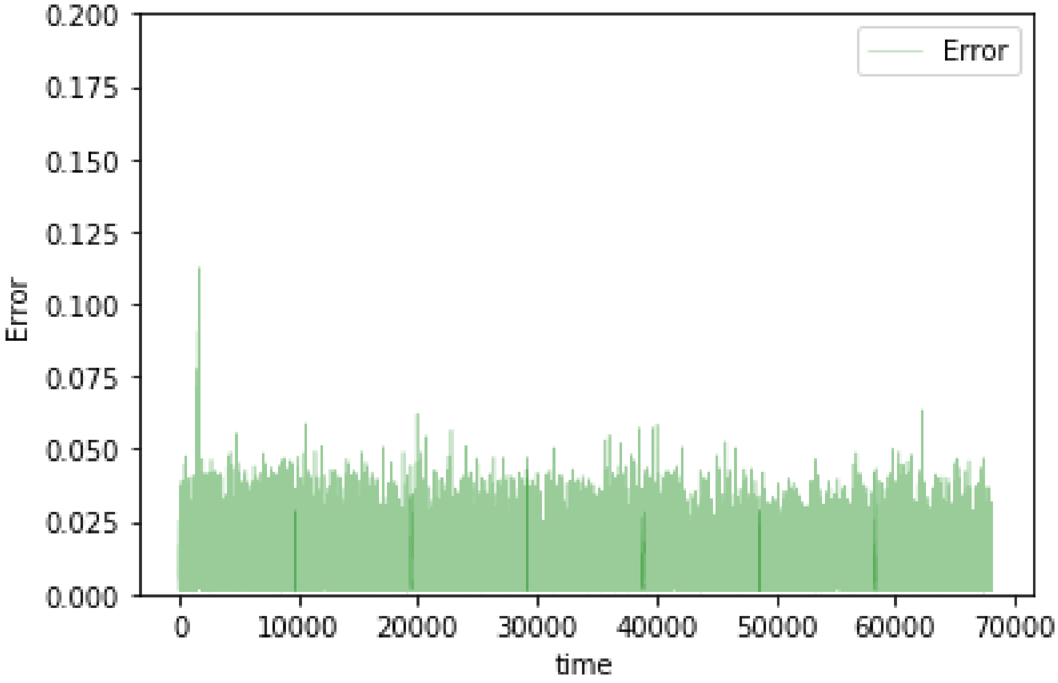
```
The mean error for gru1_100_normal_ is 0.008026211629312106 for length 68199
====================
```

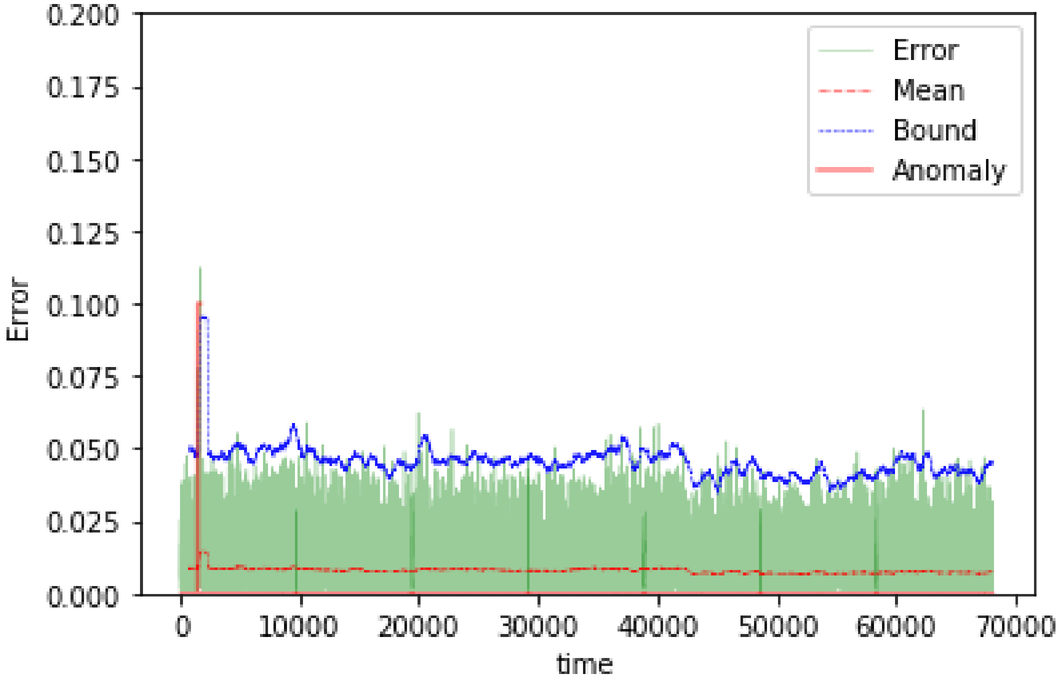
200 steps

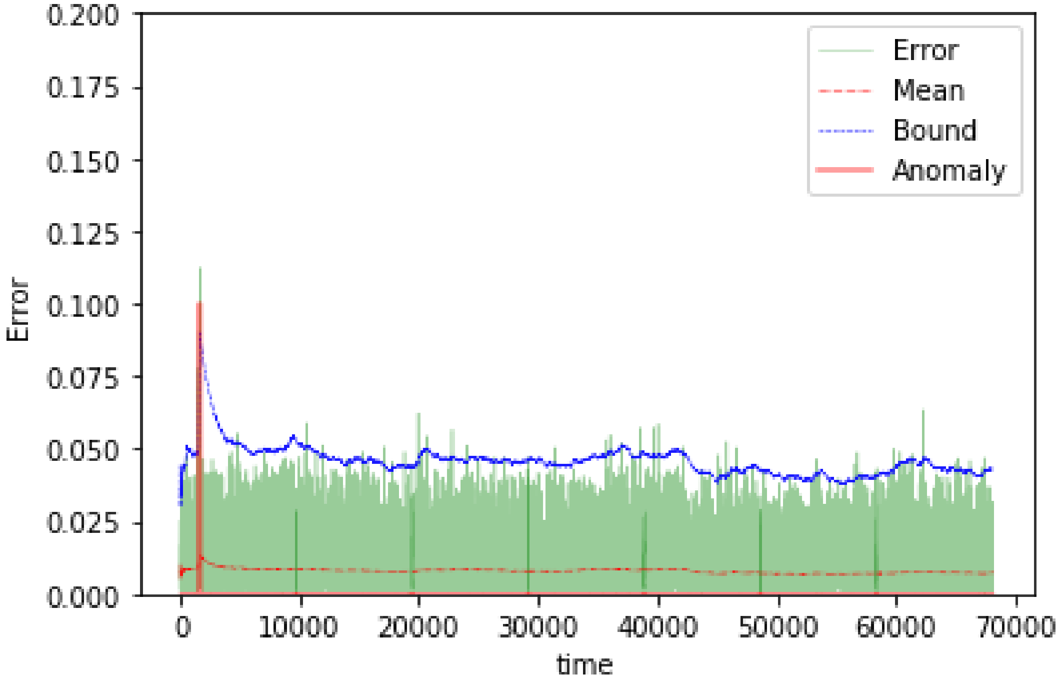
```
In [177]: TIMESTEPS = 200
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS,0)
          vgen = flat_generator(val_X, TIMESTEPS,0)
          name = "gru1_200"

In [178]: input_layer = Input(shape=(TIMESTEPS,DIM))
          hidden = GRU(10, activation='relu')(input_layer)
          output = Dense(DIM, activation='sigmoid')(hidden)

In [179]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])

In [180]: train(model, tgen, vgen, name=name)
          test(model, ravel=0, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008502582725253888
Validation loss for final epoch is 0.007460829935735091
---------- Beginning tests for gru1_200 ----------
Testing on Normal data.
```




0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly


0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly

```
The mean error for gru1_200_normal_ is 0.007934991109294428 for length 68099
====================
```

1.11.6 RNN with 2 GRU layers

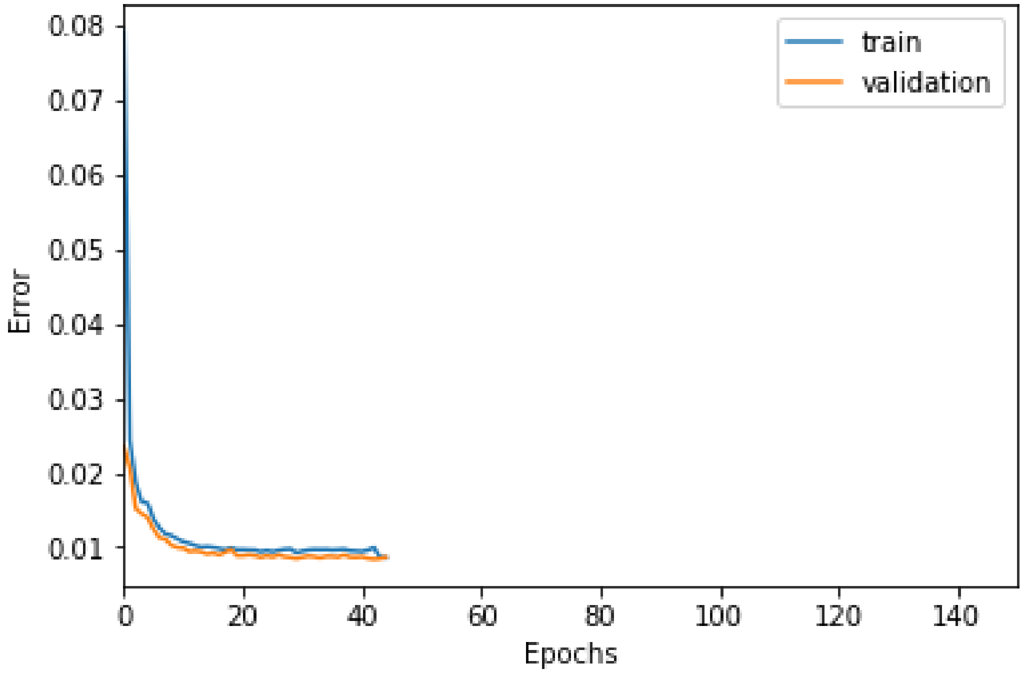
2 steps

```
In [181]: TIMESTEPS = 2
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS,0)
          vgen = flat_generator(val_X, TIMESTEPS,0)
          name = "gru2_2"
```

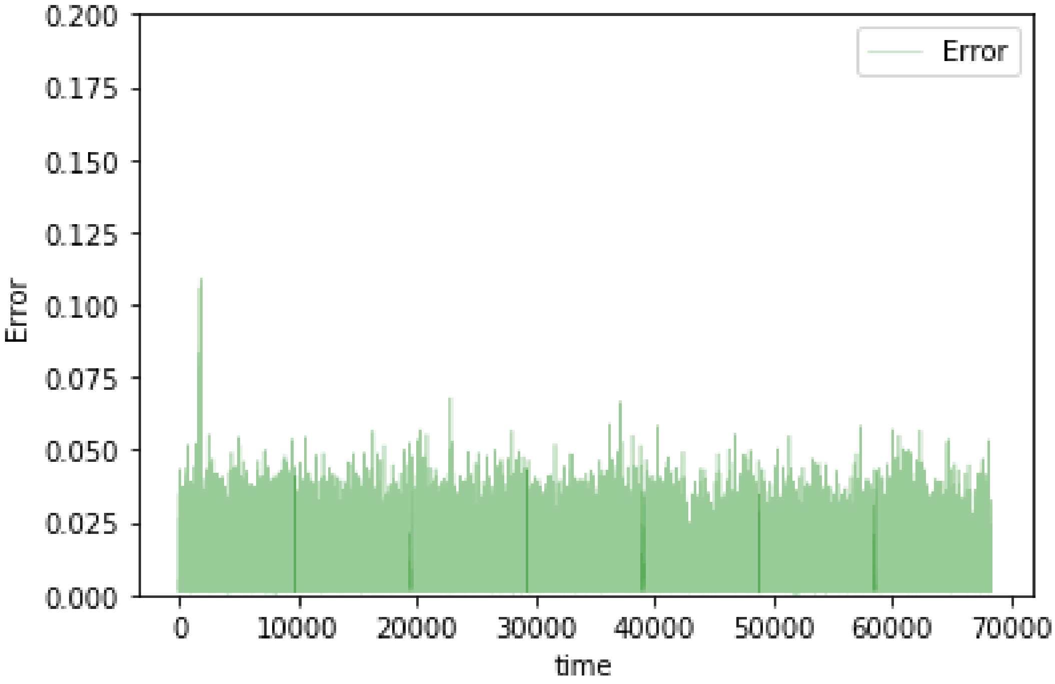
```
In [182]: input_layer = Input(shape=(TIMESTEPS,DIM))
          hidden = GRU(10, activation='relu', return_sequences=True)(input_layer)
          hidden = GRU(10, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)
```

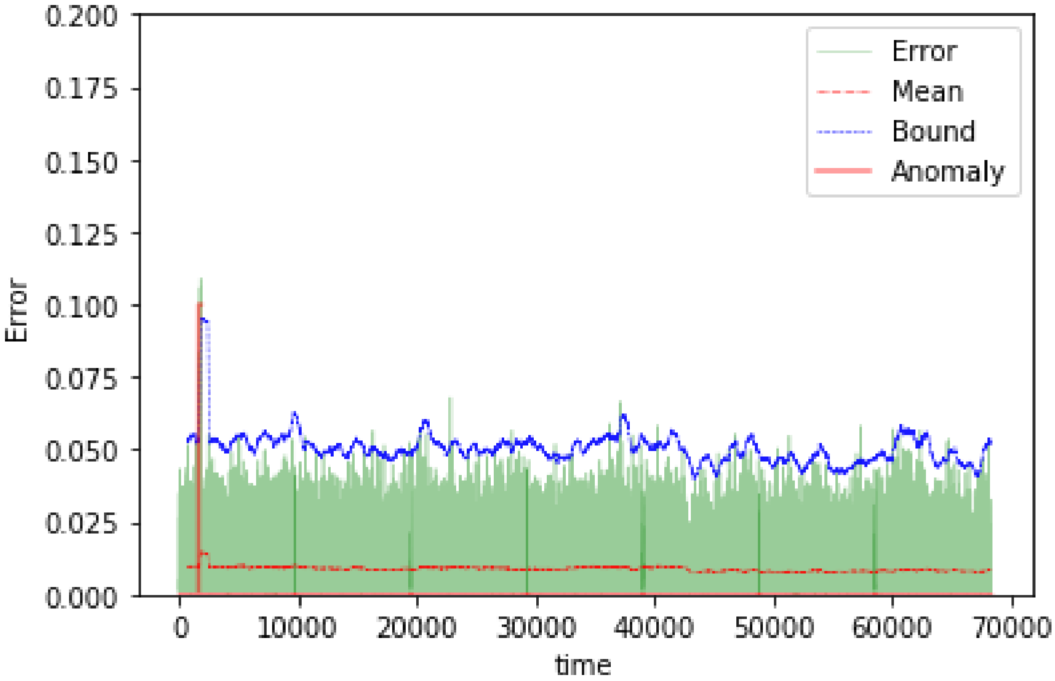
```
In [183]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

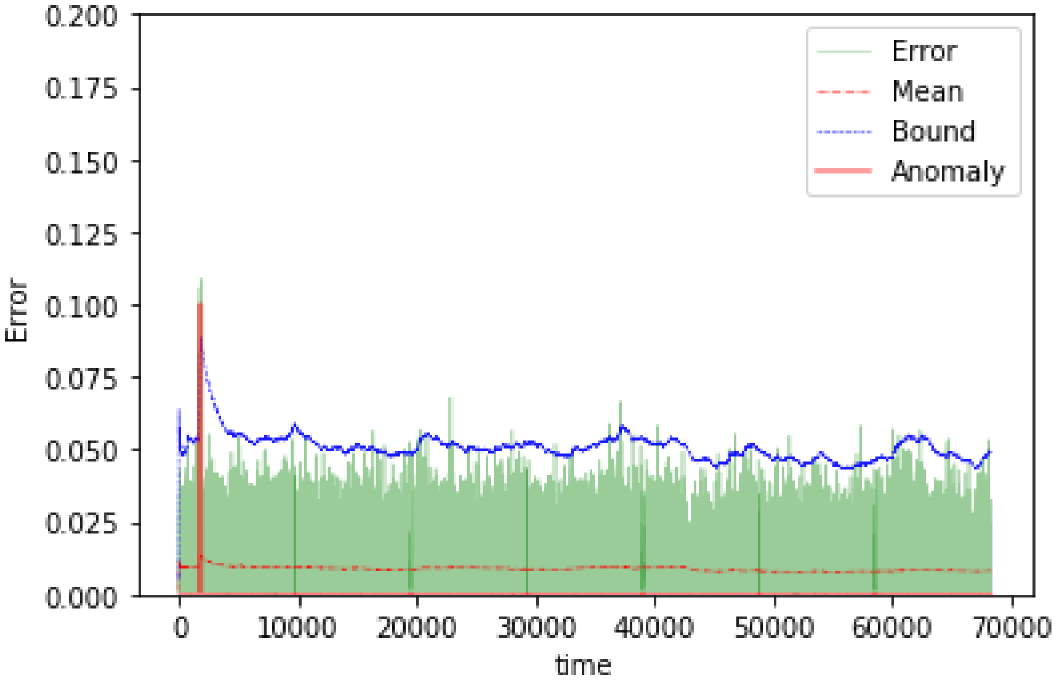
```
In [184]: train(model, tgen, vgen, name=name)
          test(model, ravel=0, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.00860491382307373
Validation loss for final epoch is 0.008674331634421833
---------- Beginning tests for gru2_2 ----------
Testing on Normal data.
```



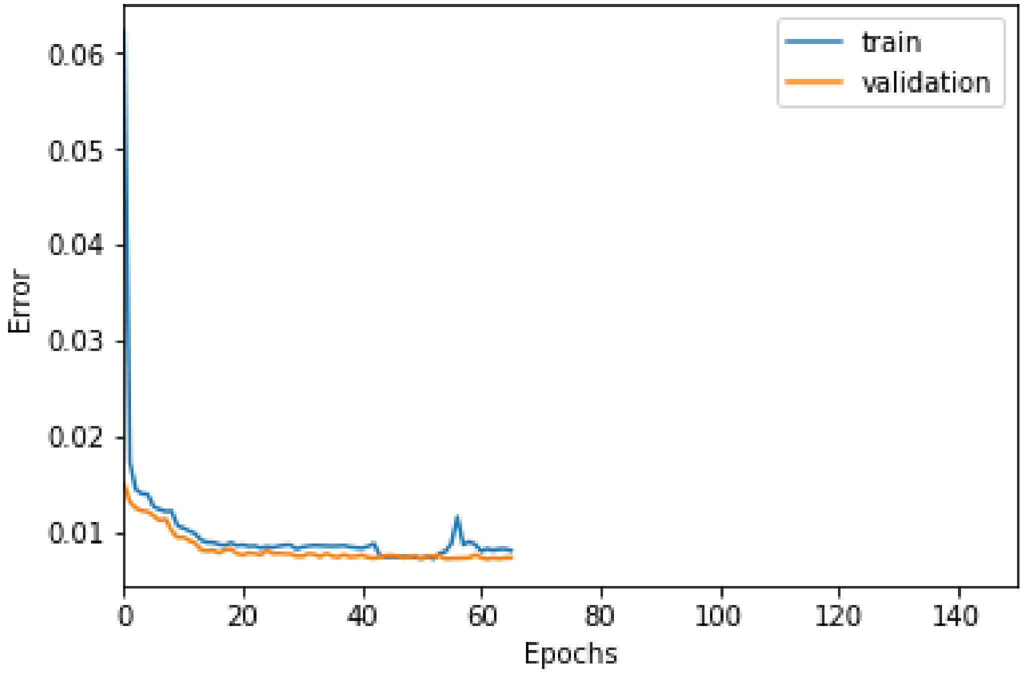




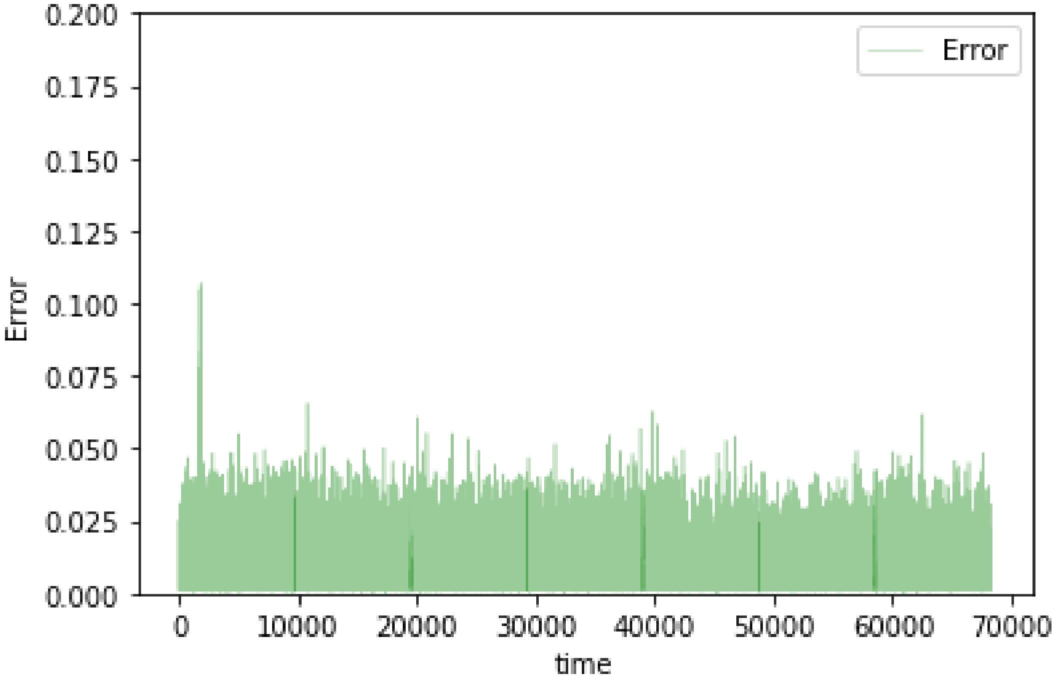
```
The mean error for gru2_2_normal_ is 0.008811361961096557 for length 68297
====================
```

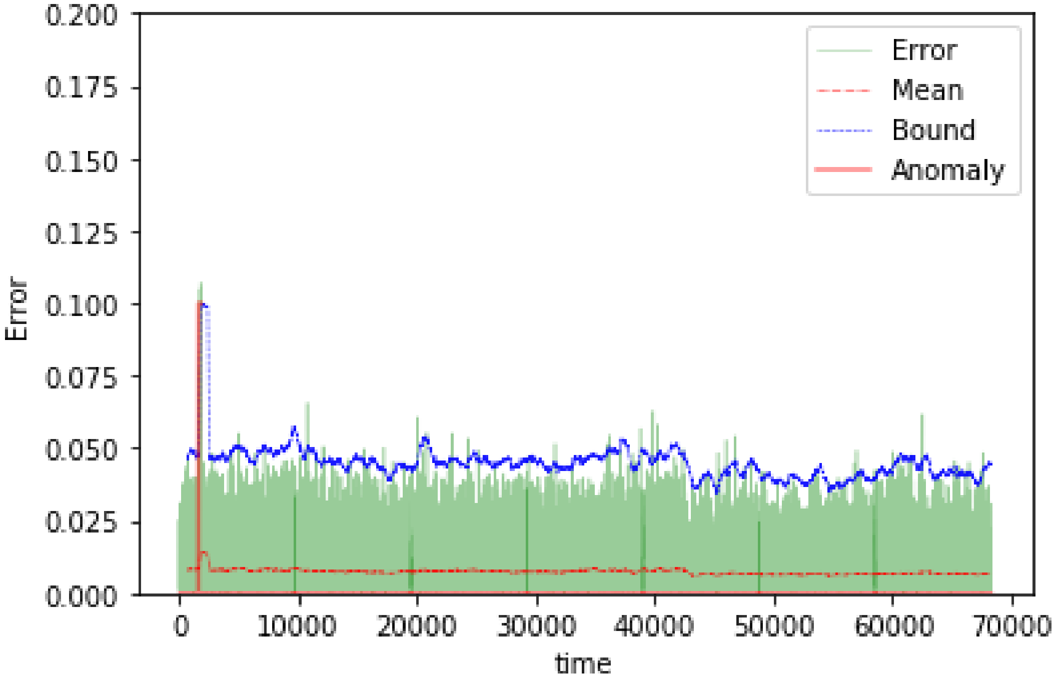
5 steps

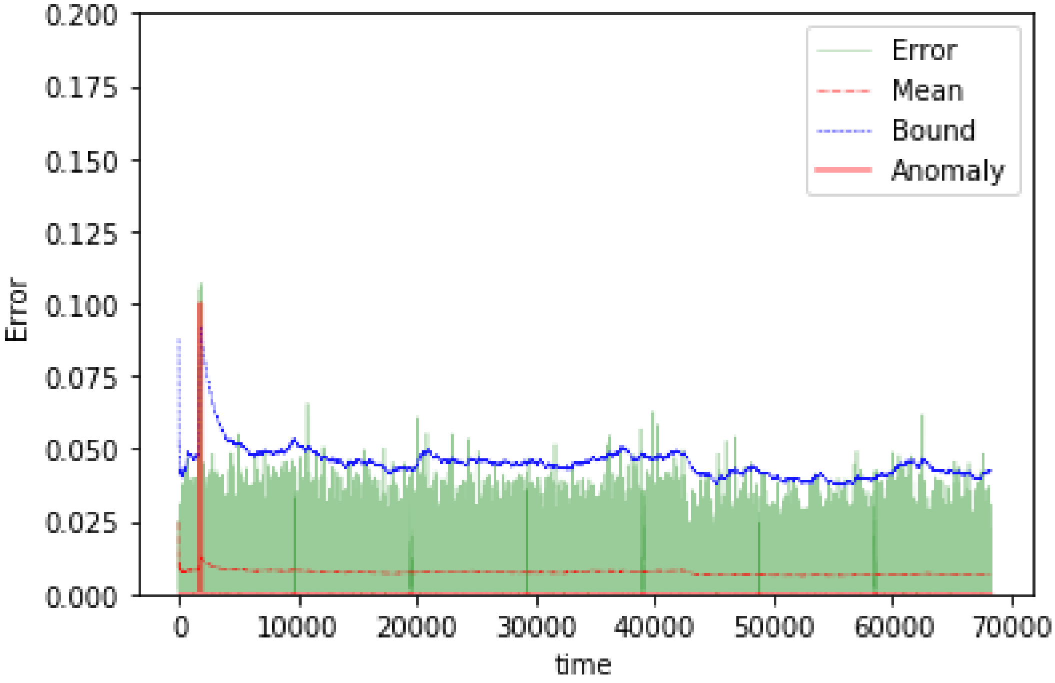
```
In [185]: TIMESTEPS = 5
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS,0)
          vgen = flat_generator(val_X, TIMESTEPS, 0)
          name = "gru2_5"

In [186]: input_layer = Input(shape=(TIMESTEPS,DIM))
          hidden = GRU(10, activation='relu', return_sequences=True)(input_layer)
          hidden = GRU(10, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)

In [187]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])

In [188]: train(model, tgen, vgen, name=name)
          test(model, ravel=0, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008050079022883438
Validation loss for final epoch is 0.007317246945557488
---------- Beginning tests for gru2_5 ----------
Testing on Normal data.
```





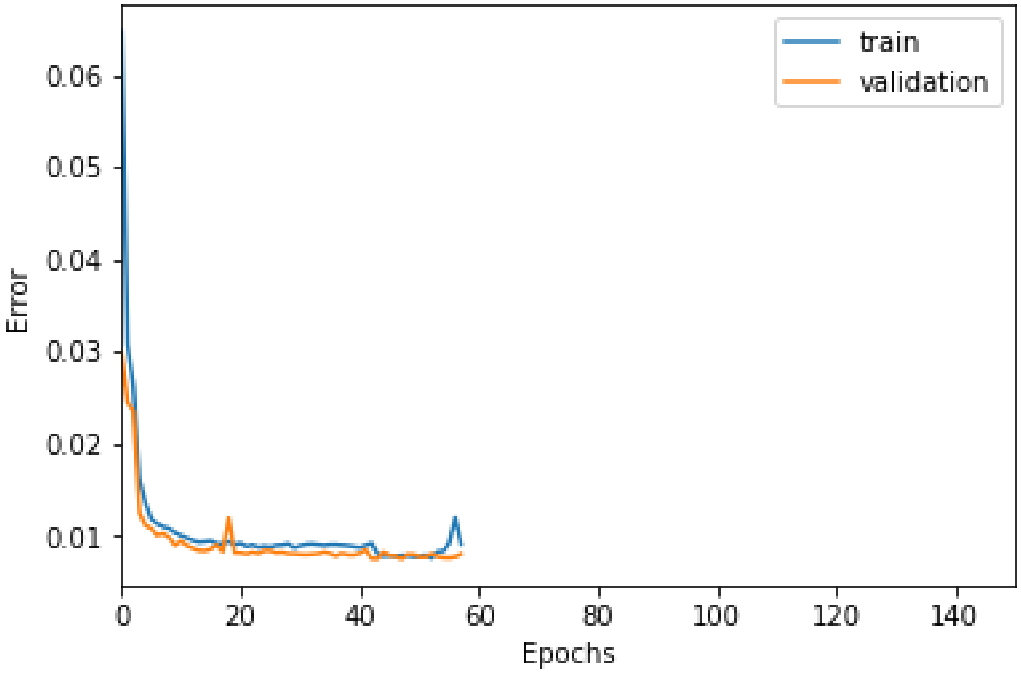


```
The mean error for gru2_5_normal_ is 0.007368053703357032 for length 68294
====================
```

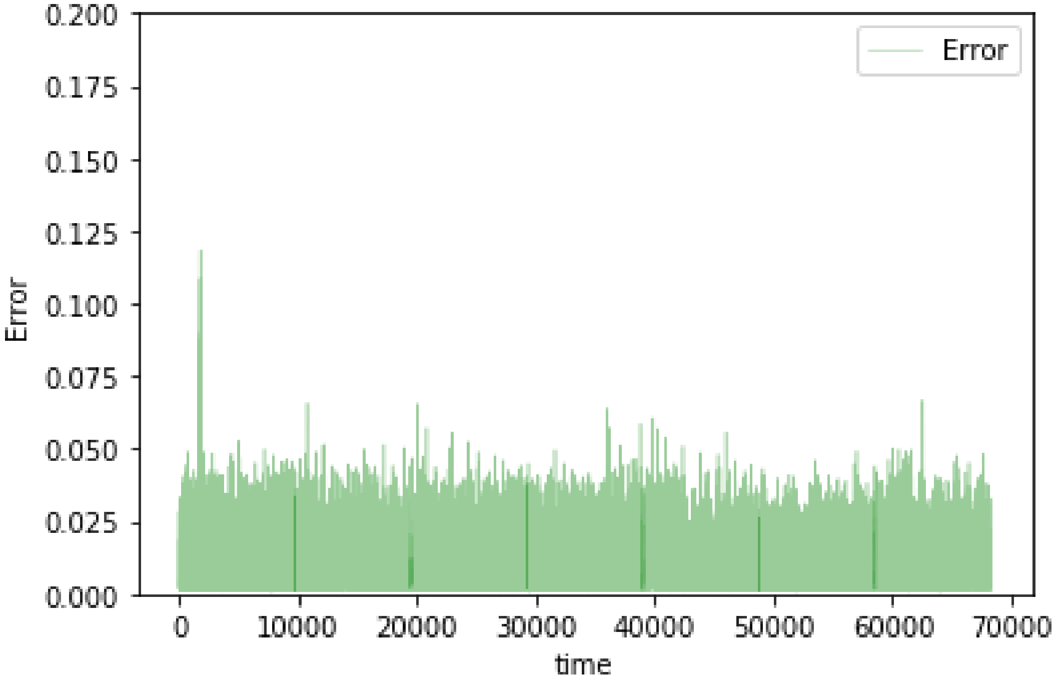
10 steps

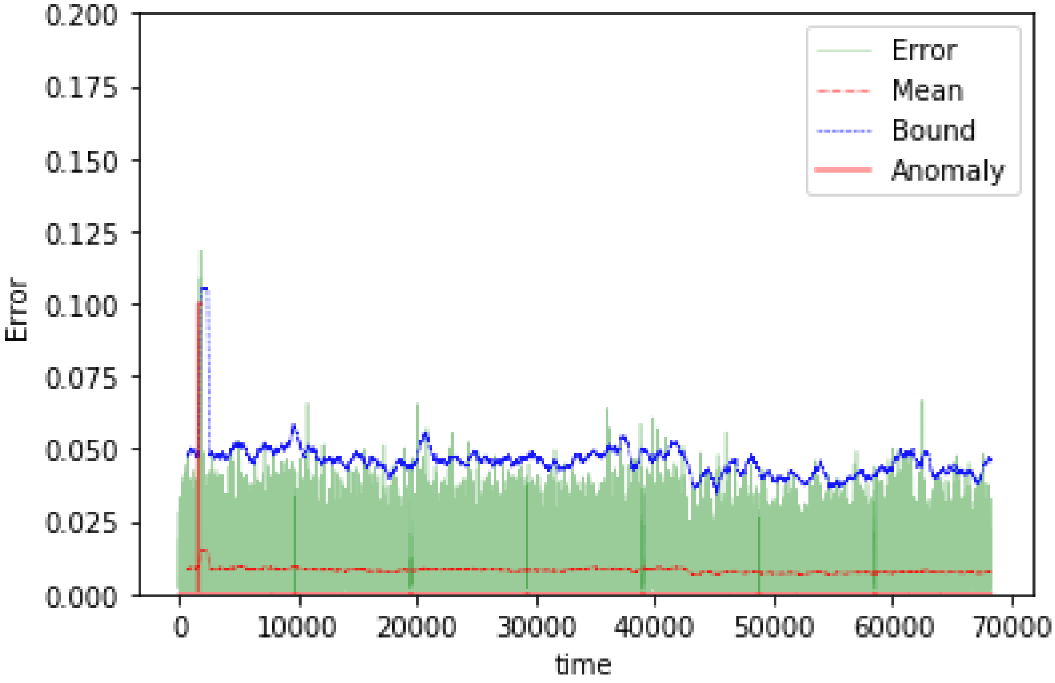
```
In [189]: TIMESTEPS = 10
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS, 0)
          vgen = flat_generator(val_X, TIMESTEPS, 0)
          name = "gru2_10"

In [190]: input_layer = Input(shape=(TIMESTEPS,DIM))
          hidden = GRU(10, activation='relu', return_sequences=True)(input_layer)
          hidden = GRU(10, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)

In [191]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

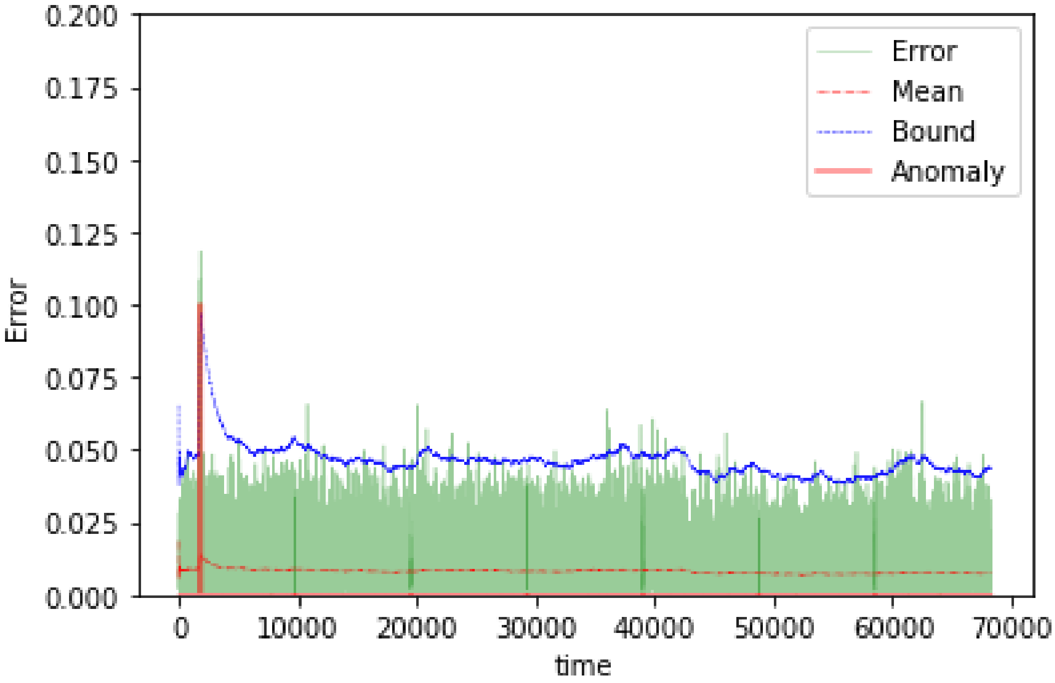
```
In [192]: train(model, tgen, vgen, name=name)
          test(model, ravel=0, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.009045016329502687
Validation loss for final epoch is 0.007995738690136932
---------- Beginning tests for gru2_10 ----------
Testing on Normal data.
```


Error
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time

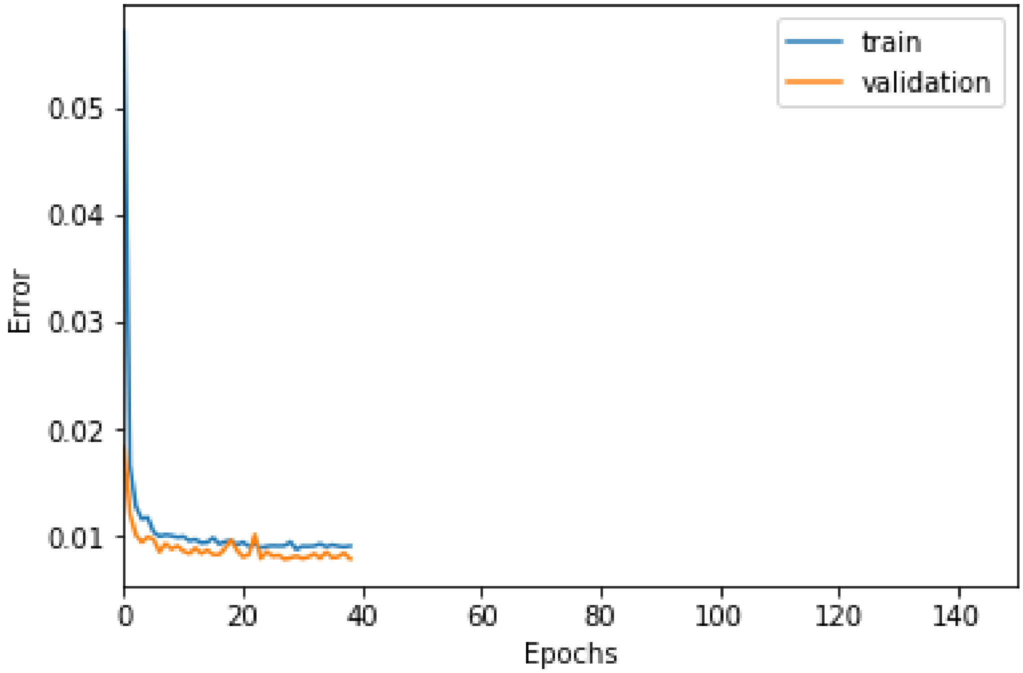

Error
Mean
Bound
Anomaly
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time



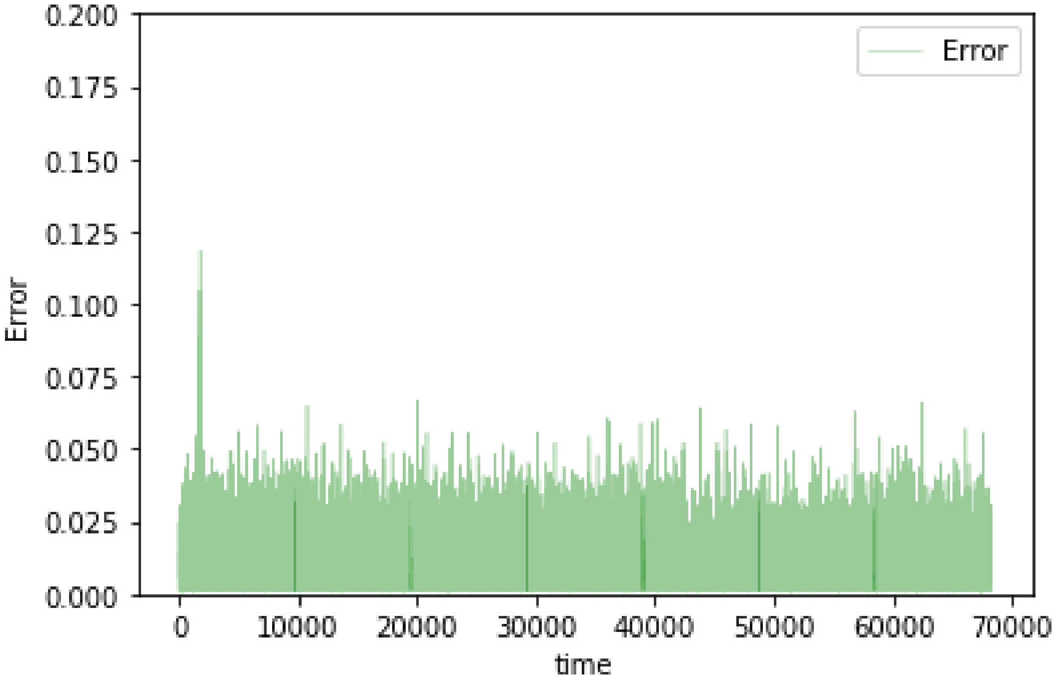
```
The mean error for gru2_10_normal_ is 0.008140157287838264 for length 68289
====================
```

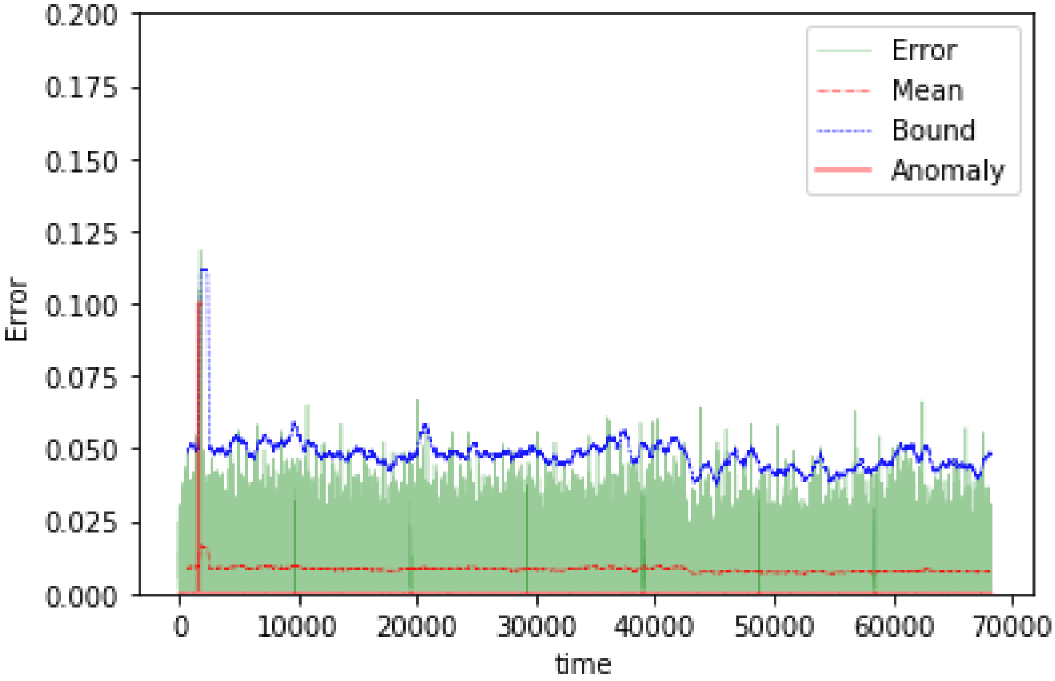
20 steps

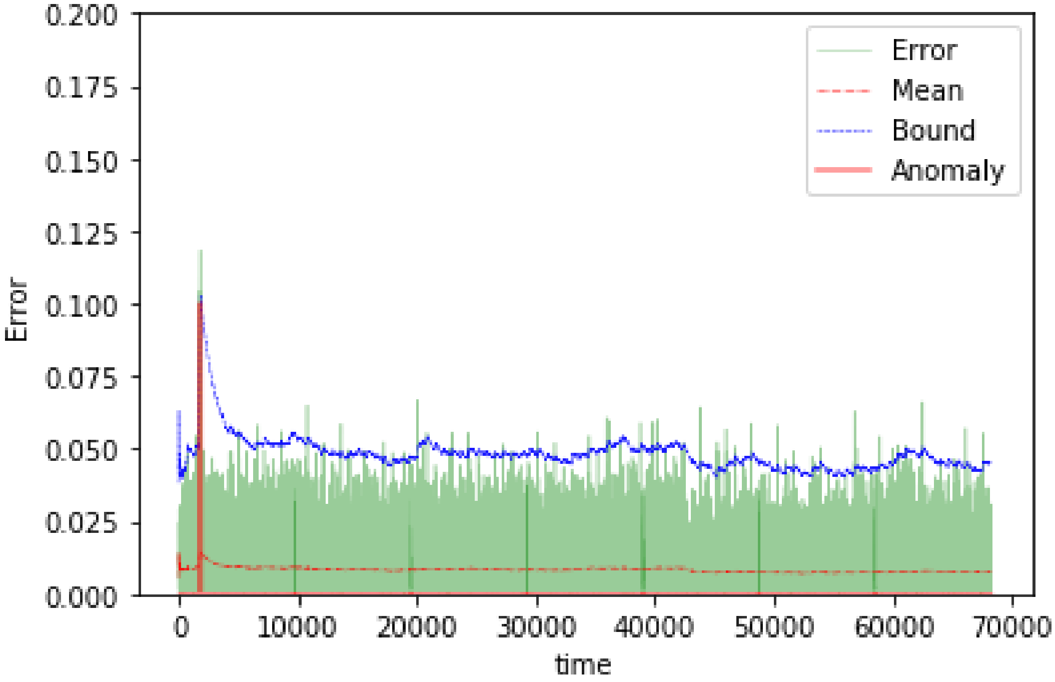
```
In [193]: TIMESTEPS = 20
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS,0)
          vgen = flat_generator(val_X, TIMESTEPS,0)
          name = "gru2_20"

In [194]: input_layer = Input(shape=(TIMESTEPS,DIM))
          hidden = GRU(10, activation='relu', return_sequences=True)(input_layer)
          hidden = GRU(10, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)

In [195]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])

In [196]: train(model, tgen, vgen, name=name)
          test(model, ravel=0, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.009110346899018624
Validation loss for final epoch is 0.007916304992511869
---------- Beginning tests for gru2_20 ----------
Testing on Normal data.
```




0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly


0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly

```
The mean error for gru2_20_normal_ is 0.008281991045037265 for length 68279
====================
```

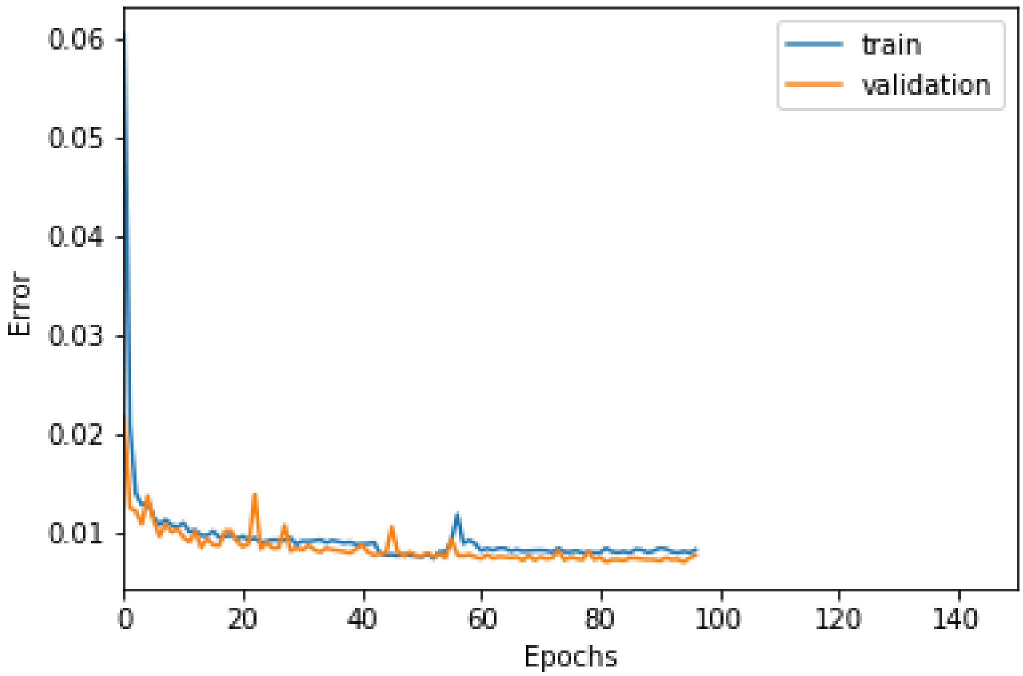
50 steps

```
In [197]: TIMESTEPS = 50
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS,0)
          vgen = flat_generator(val_X, TIMESTEPS,0)
          name = "gru2_50"
```

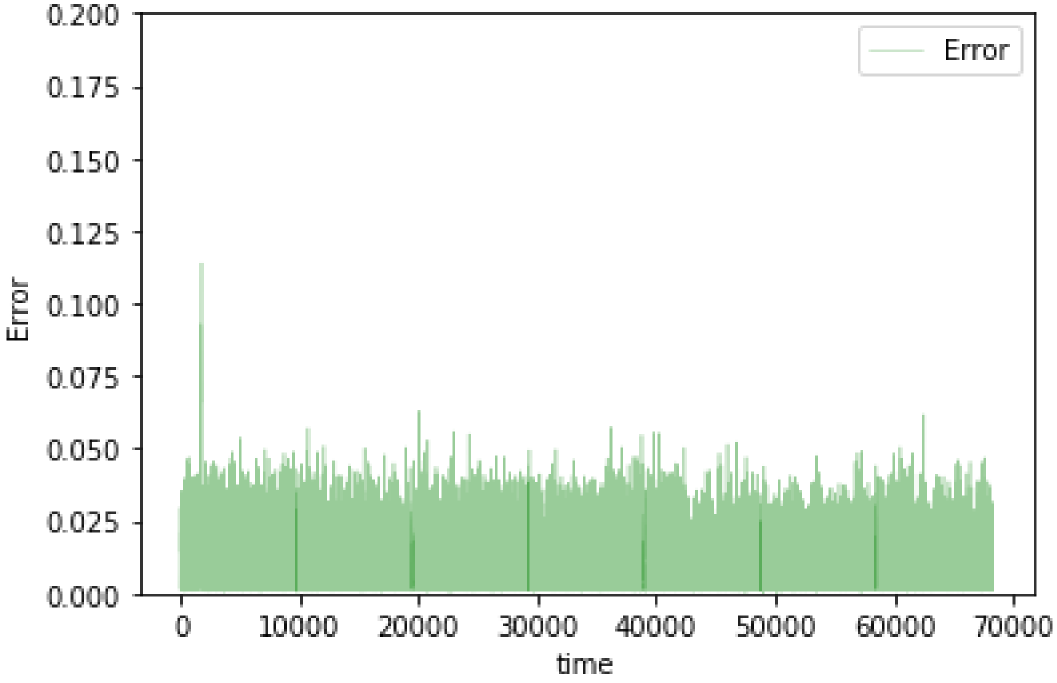
```
In [198]: input_layer = Input(shape=(TIMESTEPS,DIM))
          hidden = GRU(10, activation='relu', return_sequences=True)(input_layer)
          hidden = GRU(10, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)
```

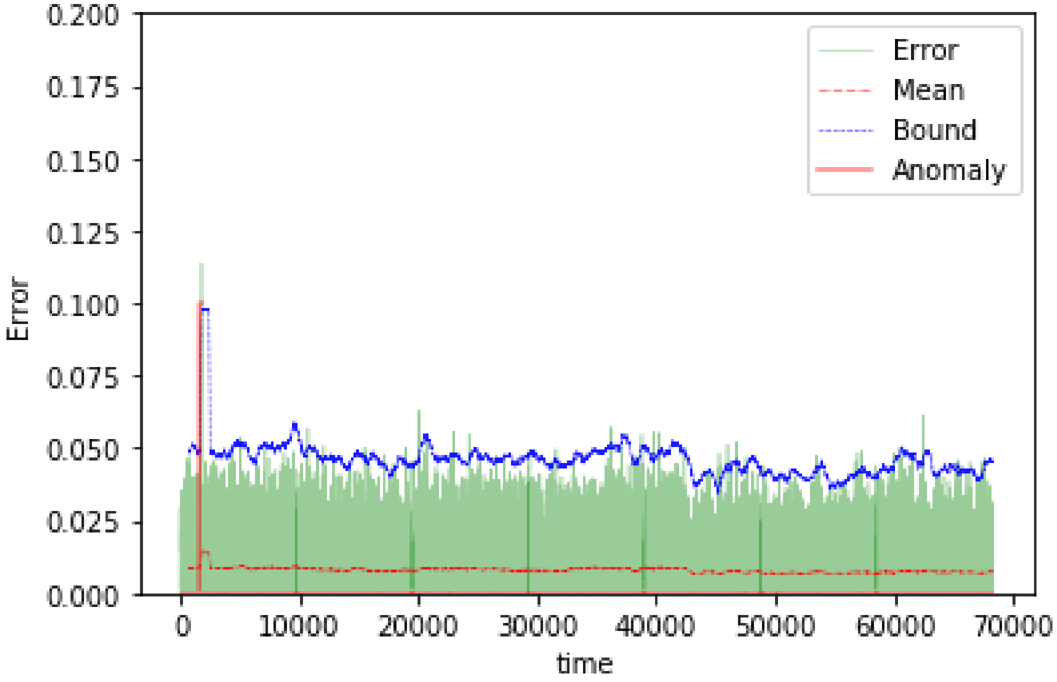
```
In [199]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

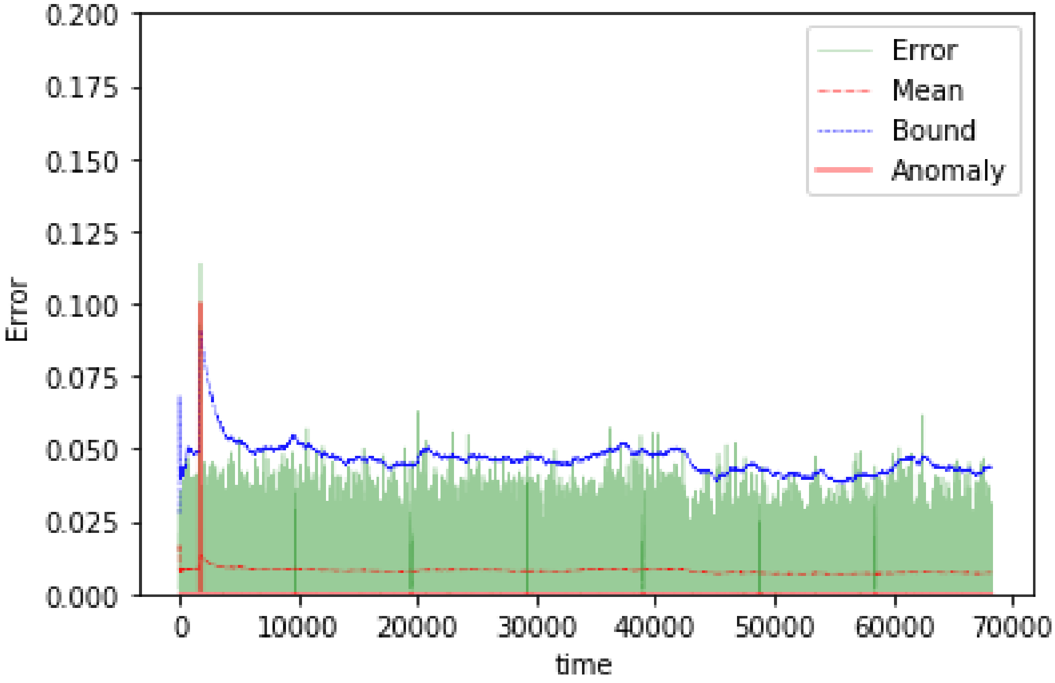
```
In [200]: train(model, tgen, vgen, name=name)
          test(model, ravel=0, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008284776615910231
Validation loss for final epoch is 0.00776666938222479
---------- Beginning tests for gru2_50 ----------
Testing on Normal data.
```





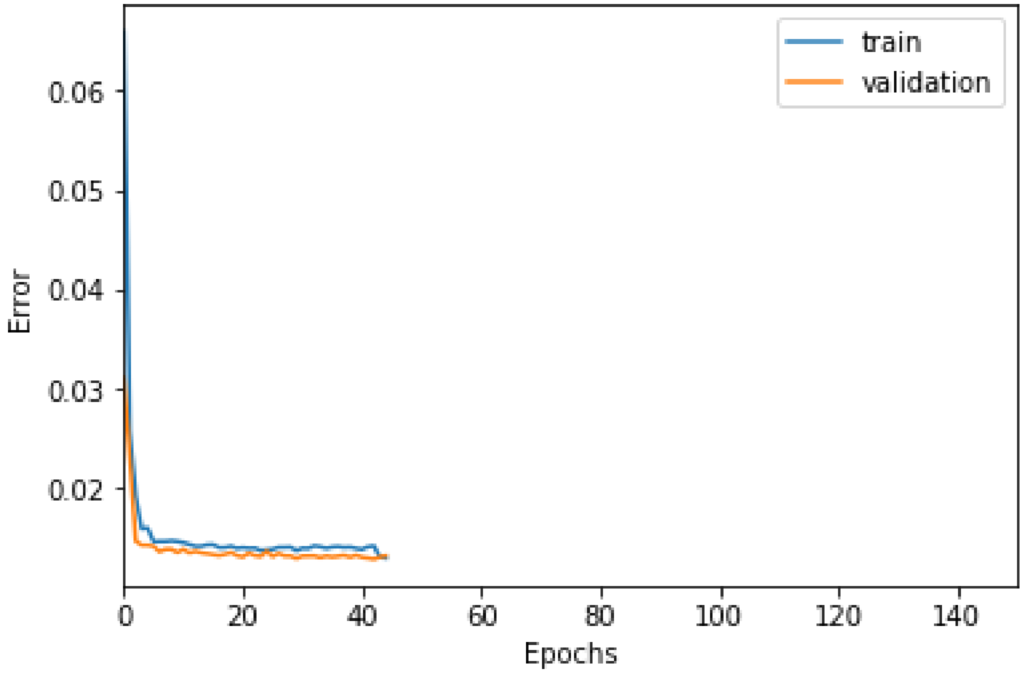


```
The mean error for gru2_50_normal_ is 0.007949994744830406 for length 68249
====================
```

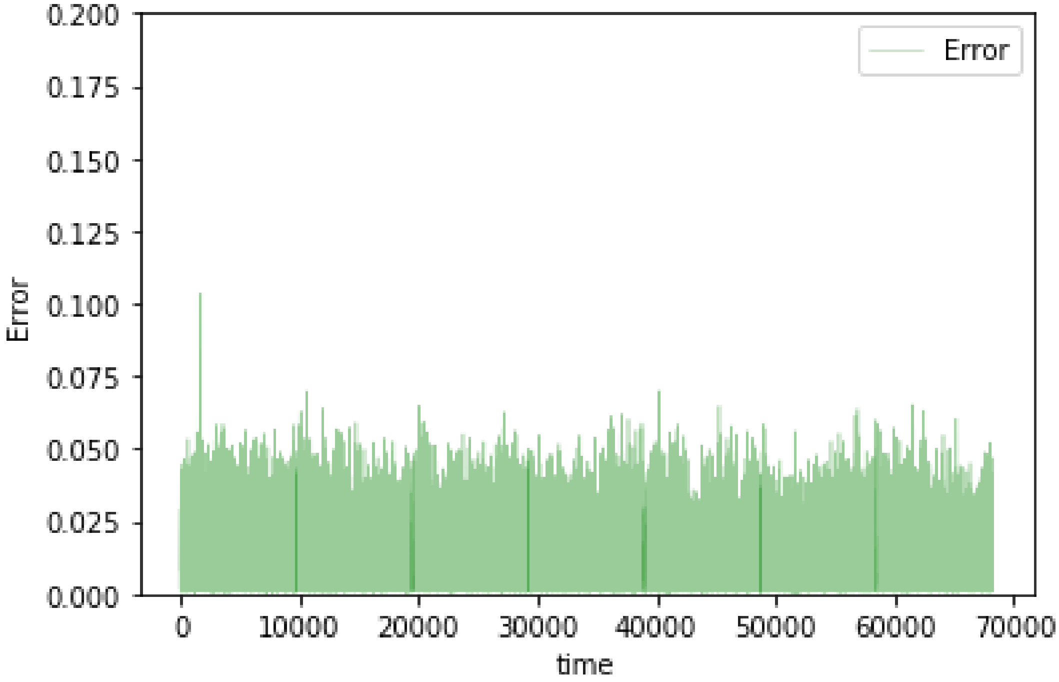
100 steps

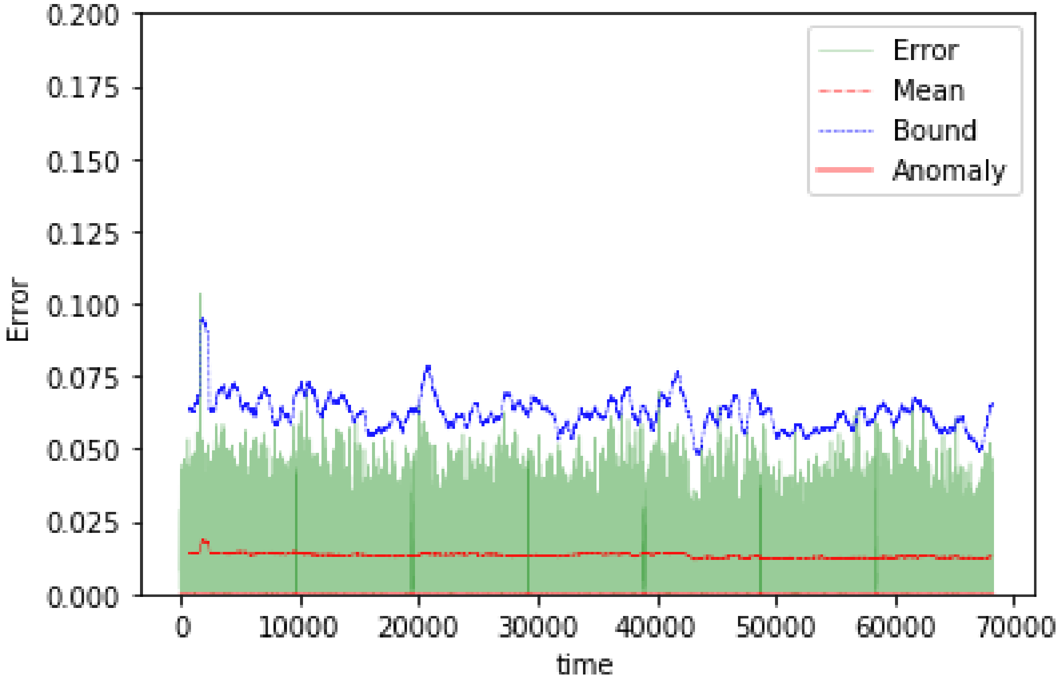
```
In [201]: TIMESTEPS = 100
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS,0)
          vgen = flat_generator(val_X, TIMESTEPS,0)
          name = "gru2_100"

In [202]: input_layer = Input(shape=(TIMESTEPS,DIM))
          hidden = GRU(10, activation='relu', return_sequences=True)(input_layer)
          hidden = GRU(10, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)

In [203]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

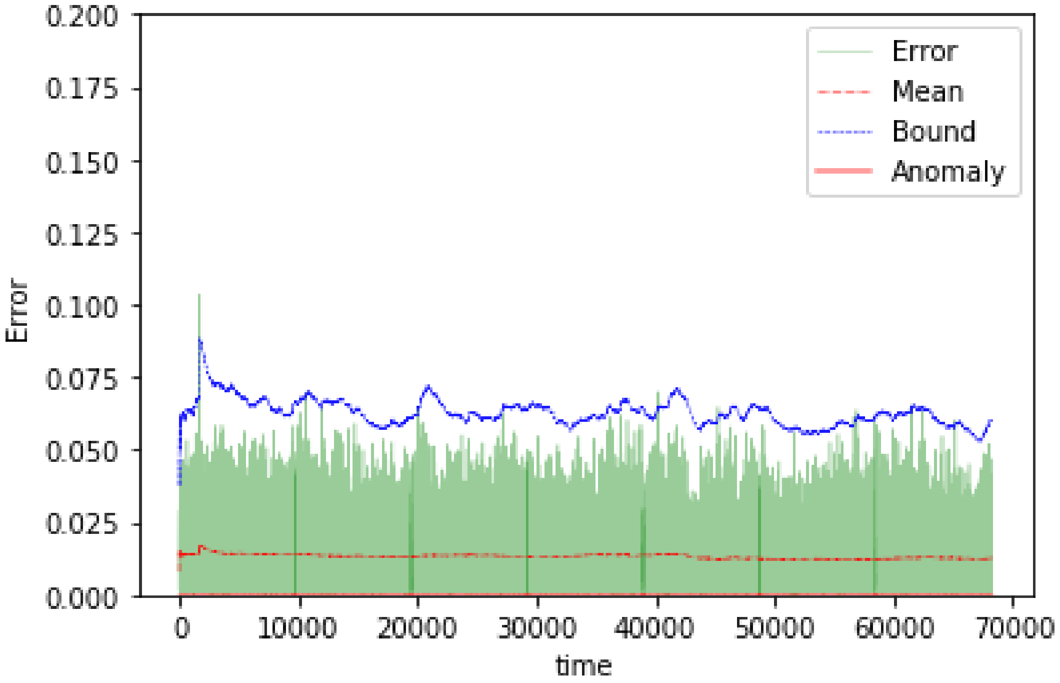
```
In [204]: train(model, tgen, vgen, name=name)
          test(model, ravel=0, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.013032213078578934
Validation loss for final epoch is 0.013238054197980091
---------- Beginning tests for gru2_100 ----------
Testing on Normal data.
```


0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error

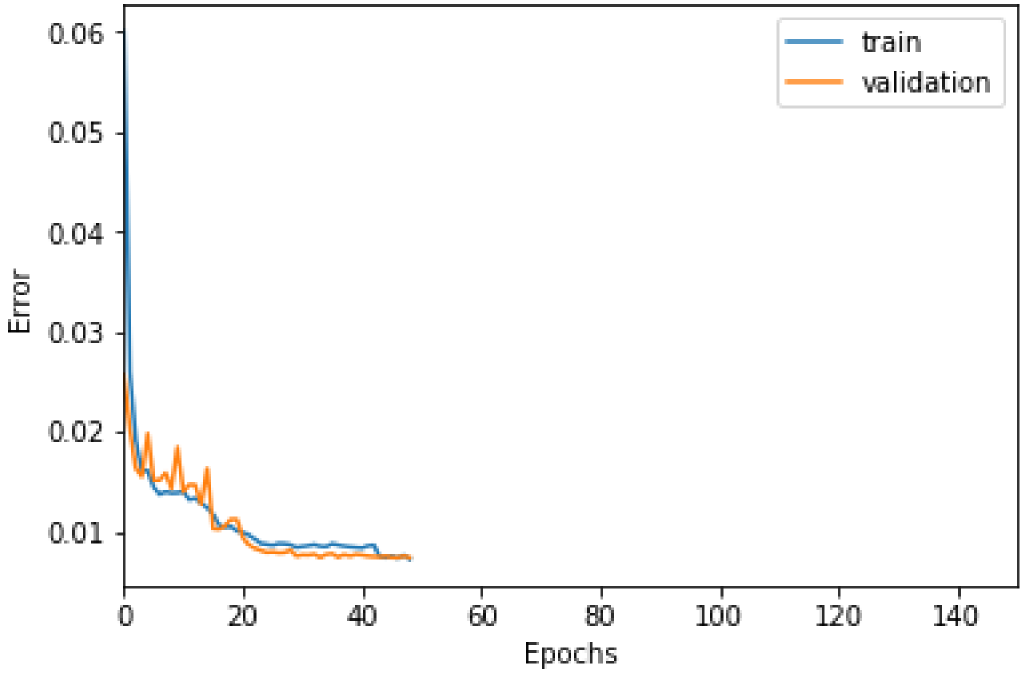

0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly



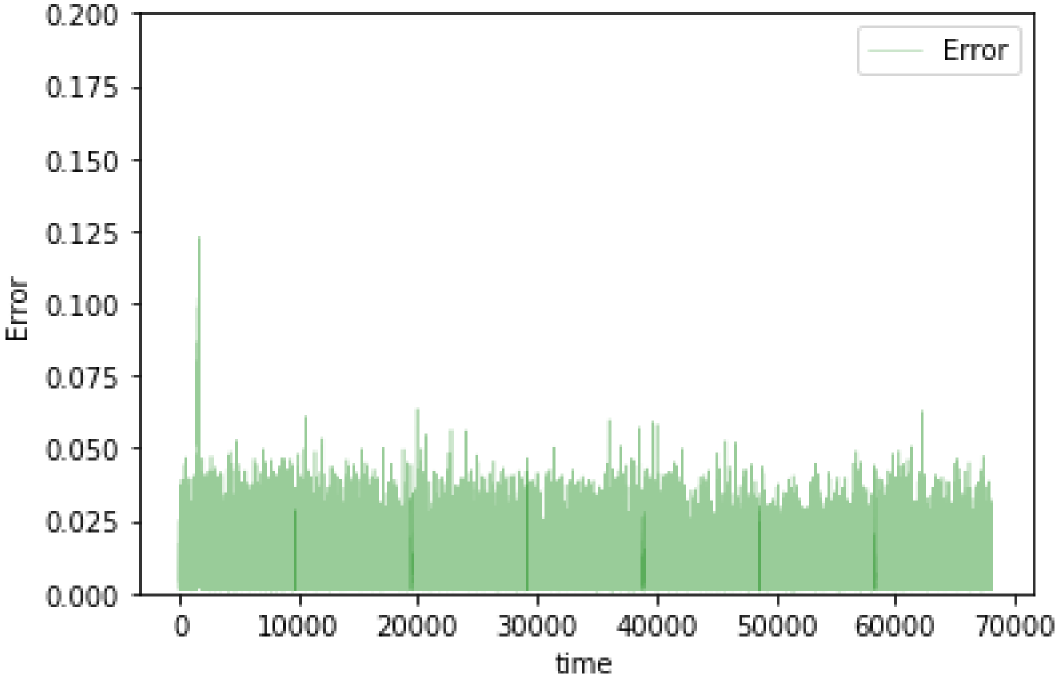
```
The mean error for gru2_100_normal_ is 0.013267289794409373 for length 68199
====================
```

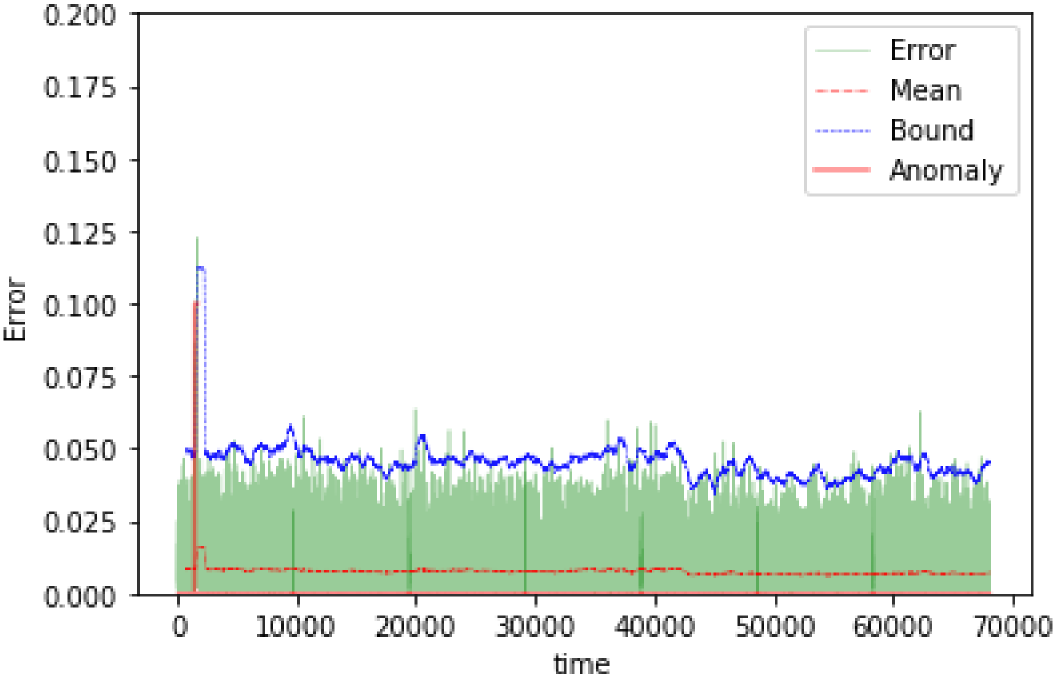
200 steps

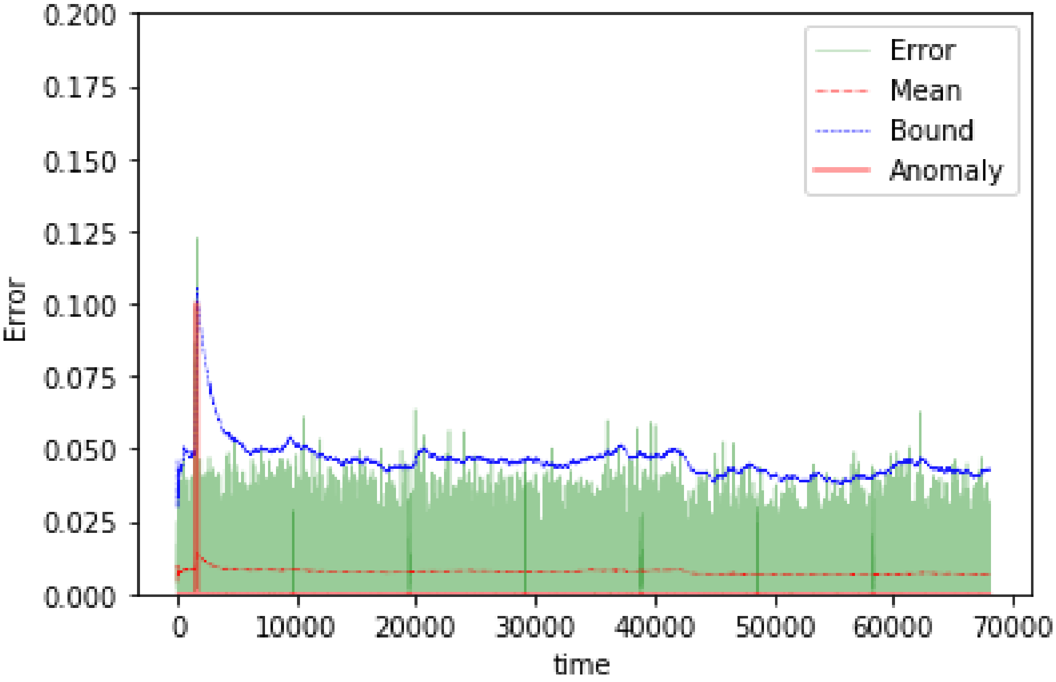
```
In [205]: TIMESTEPS = 200
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS,0)
          vgen = flat_generator(val_X, TIMESTEPS,0)
          name = "gru2_200"

In [206]: input_layer = Input(shape=(TIMESTEPS,DIM))
          hidden = GRU(10, activation='relu', return_sequences=True)(input_layer)
          hidden = GRU(10, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)

In [207]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])

In [208]: train(model, tgen, vgen, name=name)
          test(model, ravel=0, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.00723495903168805
Validation loss for final epoch is 0.007391909931669943
---------- Beginning tests for gru2_200 ----------
Testing on Normal data.
```




0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly


0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly

```
The mean error for gru2_200_normal_ is 0.007598908535110696 for length 68099
====================
```

1.11.7 RNN with 3 GRU layers

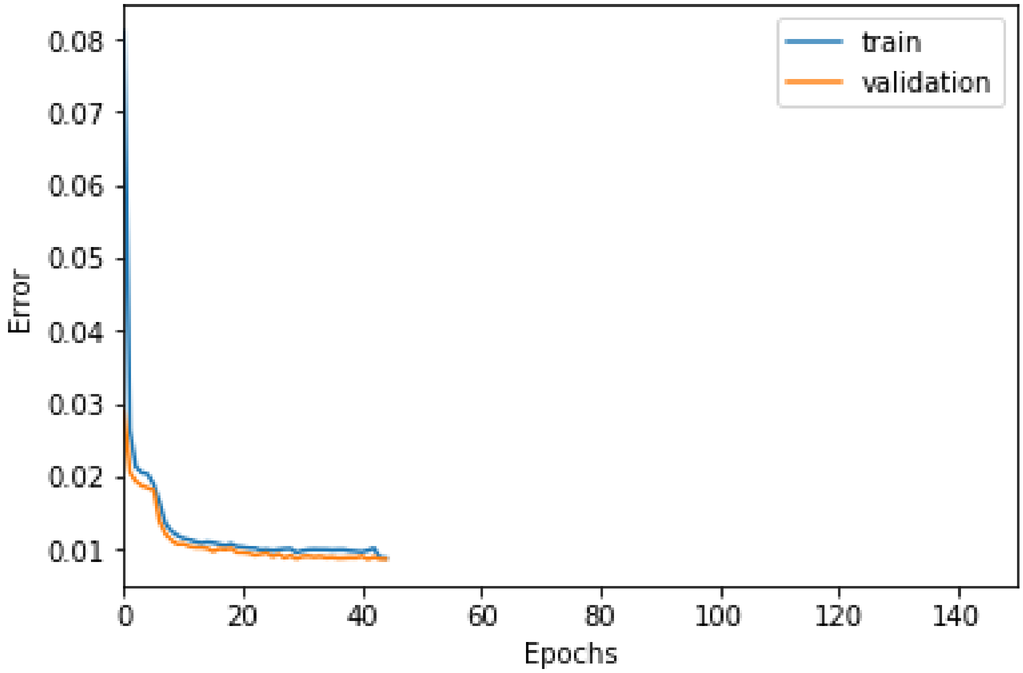
2 steps

```
In [209]: TIMESTEPS = 2
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS,0)
          vgen = flat_generator(val_X, TIMESTEPS,0)
          name = "gru3_2"
```

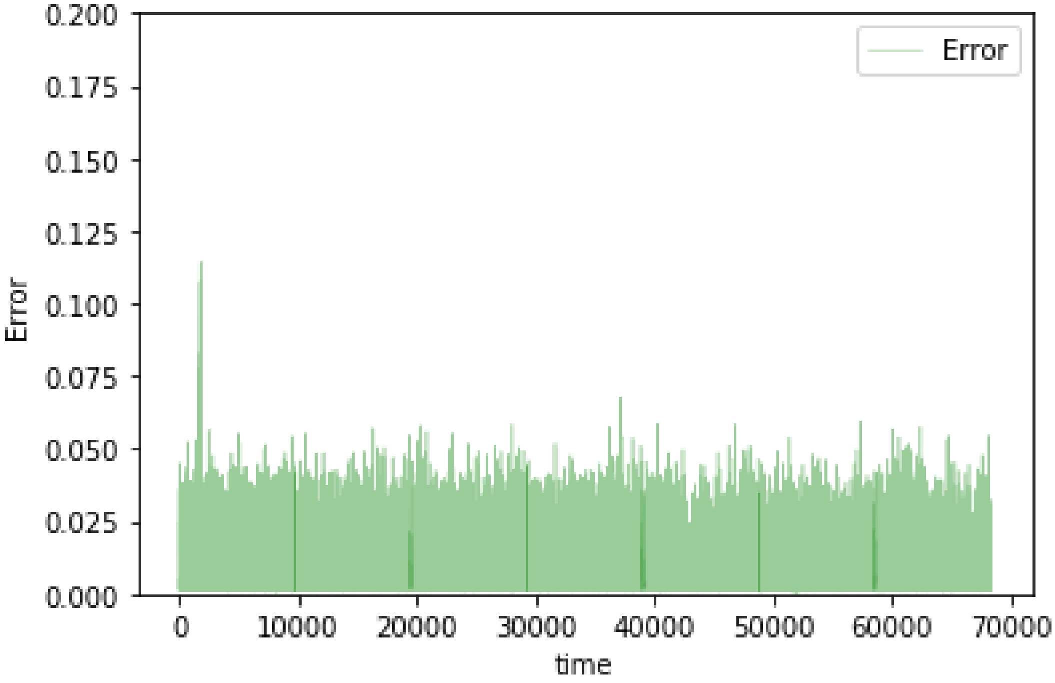
```
In [210]: input_layer = Input(shape=(TIMESTEPS,DIM))
          hidden = GRU(10, activation='relu', return_sequences=True)(input_layer)
          hidden = GRU(10, activation='relu', return_sequences=True)(hidden)
          hidden = GRU(10, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)
```

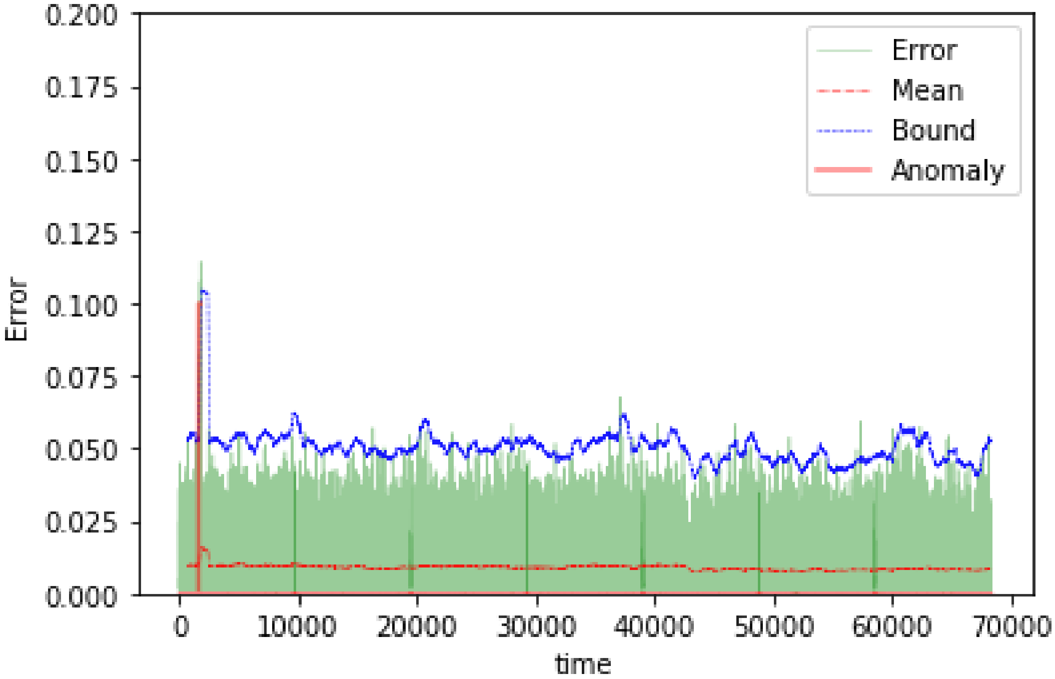
```
In [211]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

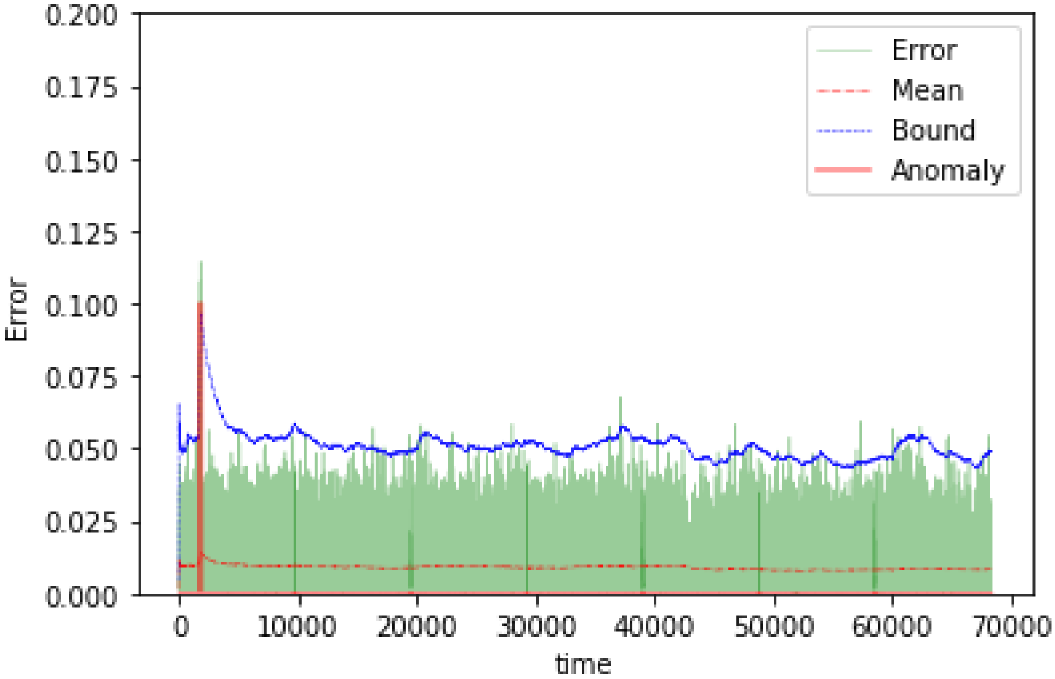
```
In [212]: train(model, tgen, vgen, name=name)
          test(model, ravel=0, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008804839166463354
Validation loss for final epoch is 0.008668052218854427
---------- Beginning tests for gru3_2 ----------
Testing on Normal data.
```







```
The mean error for gru3_2_normal_ is 0.008965031936521524 for length 68297
====================
```

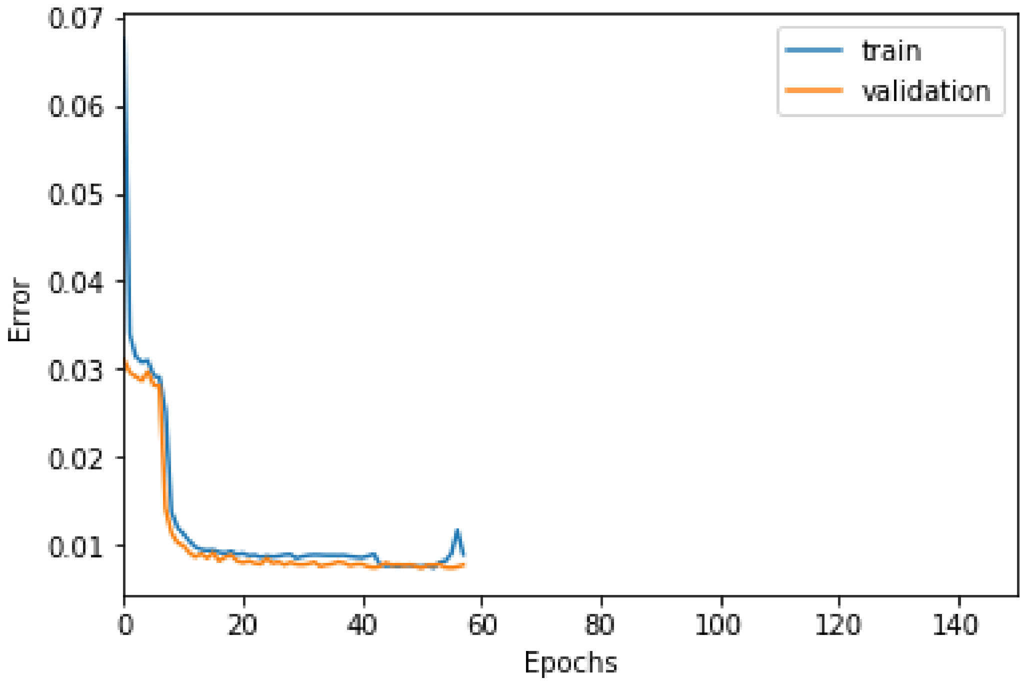
5 steps

```
In [213]: TIMESTEPS = 5
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS, 0)
          vgen = flat_generator(val_X, TIMESTEPS, 0)
          name = "gru3_5"
```

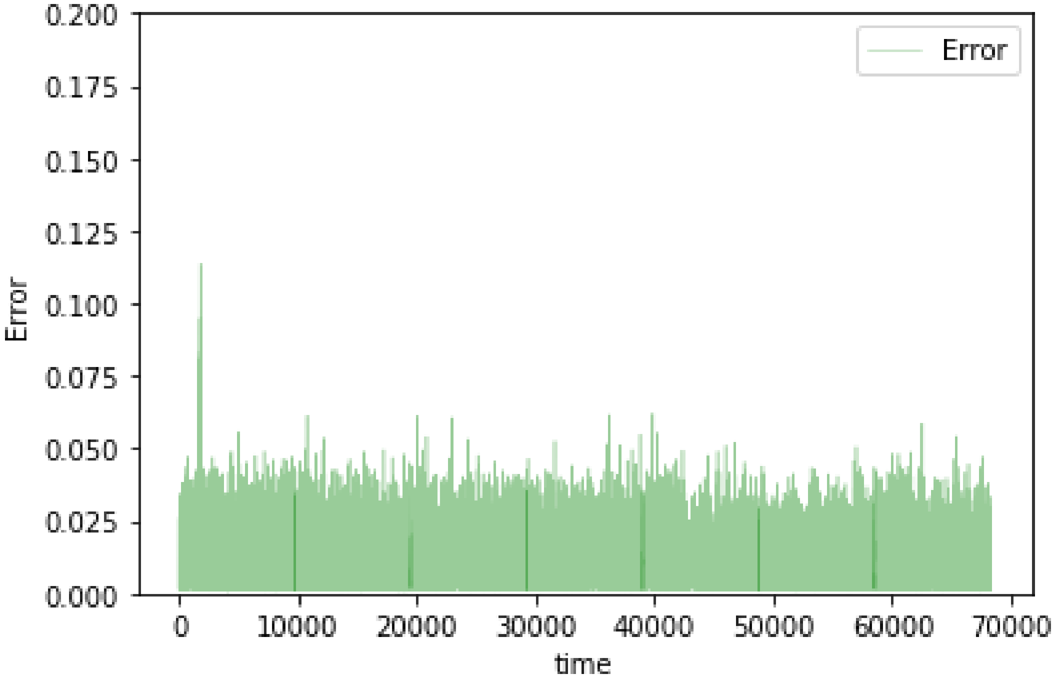
```
In [214]: input_layer = Input(shape=(TIMESTEPS,DIM))
          hidden = GRU(10, activation='relu', return_sequences=True)(input_layer)
          hidden = GRU(10, activation='relu', return_sequences=True)(hidden)
          hidden = GRU(10, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)
```

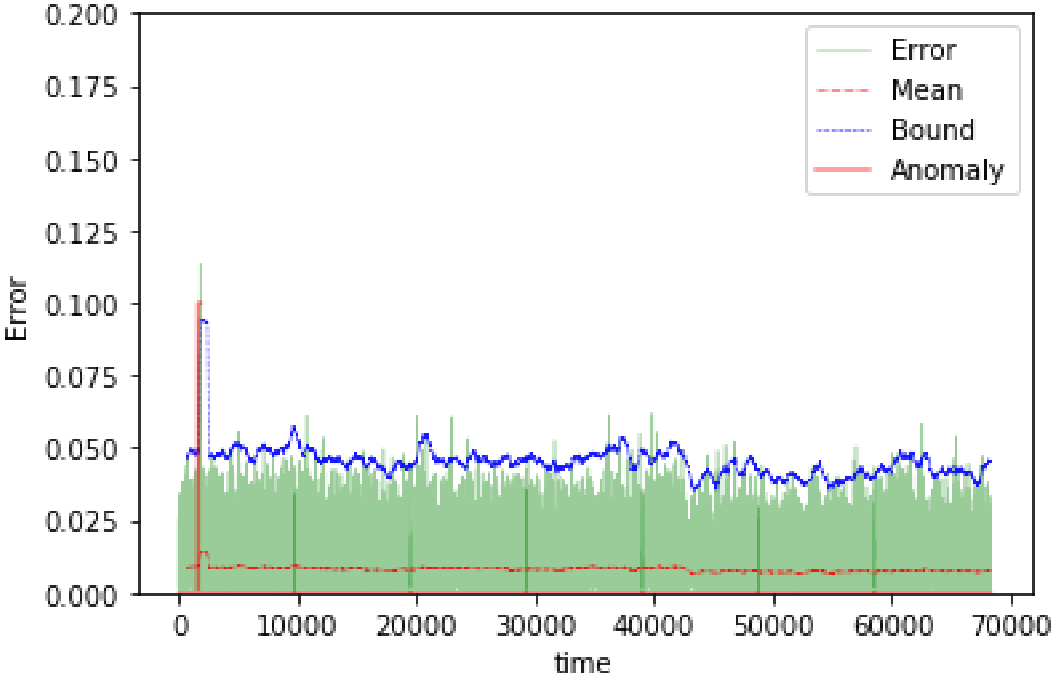
```
In [215]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

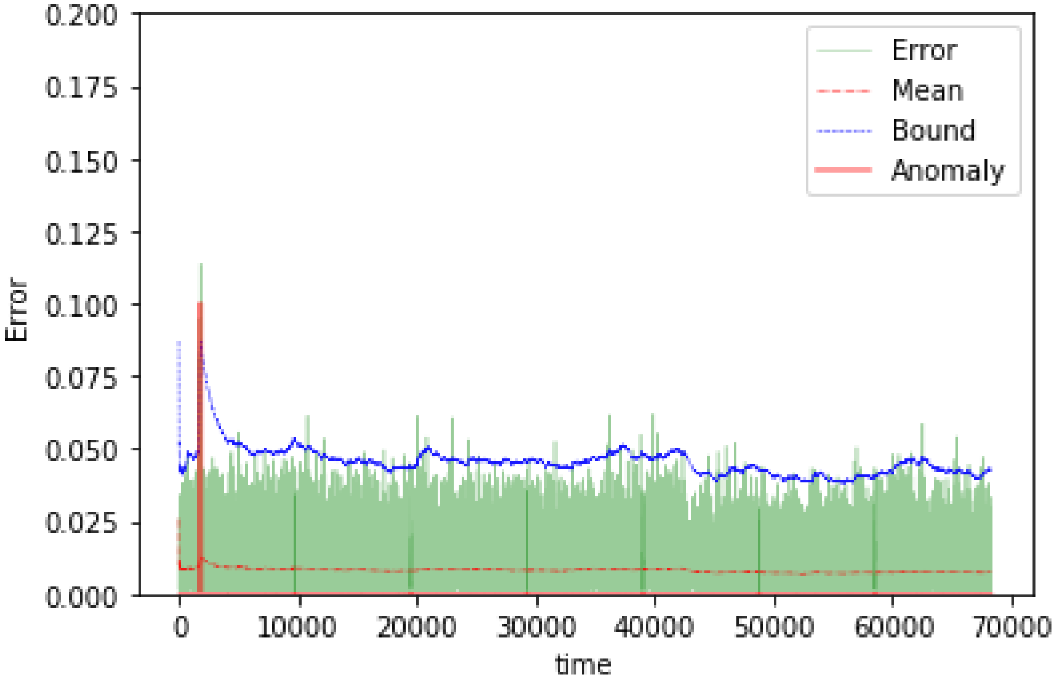
```
In [216]: train(model, tgen, vgen, name=name)
          test(model, ravel=0, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008943241923588181
Validation loss for final epoch is 0.0077513327172491 7
---------- Beginning tests for gru3_5 ----------
Testing on Normal data.
```





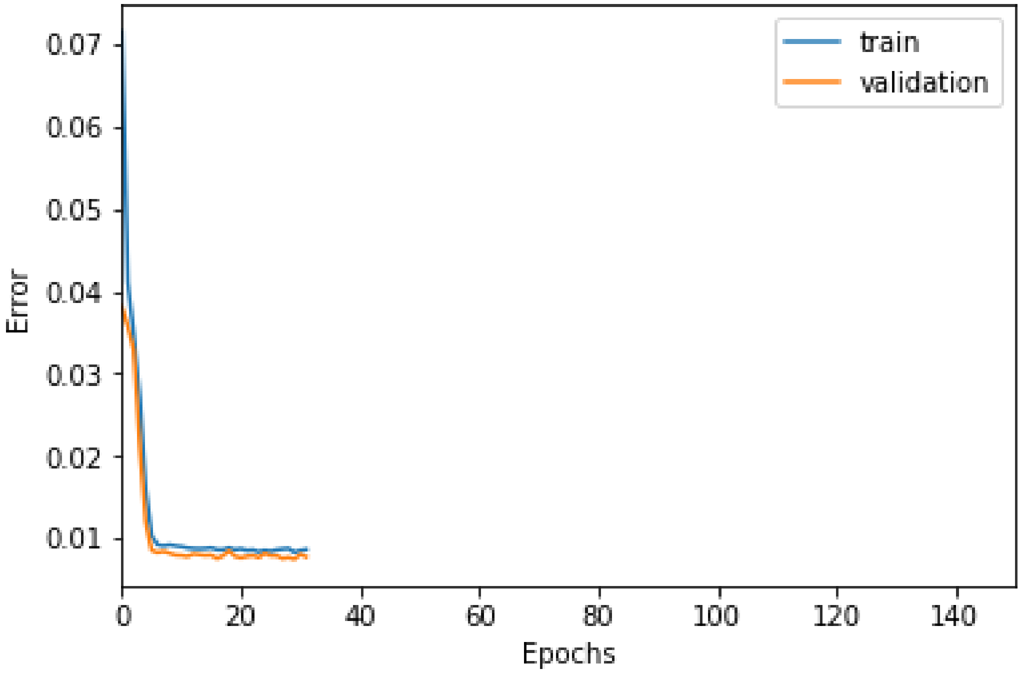


```
The mean error for gru3_5_normal_ is 0.008125028739241234 for length 68294
====================
```

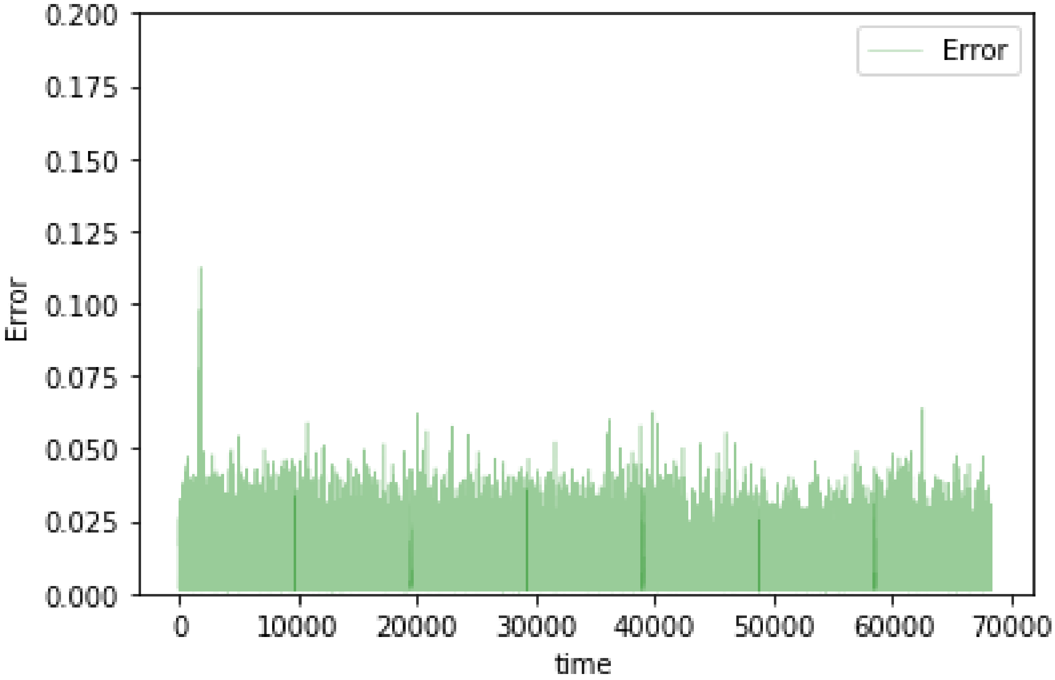
10 steps

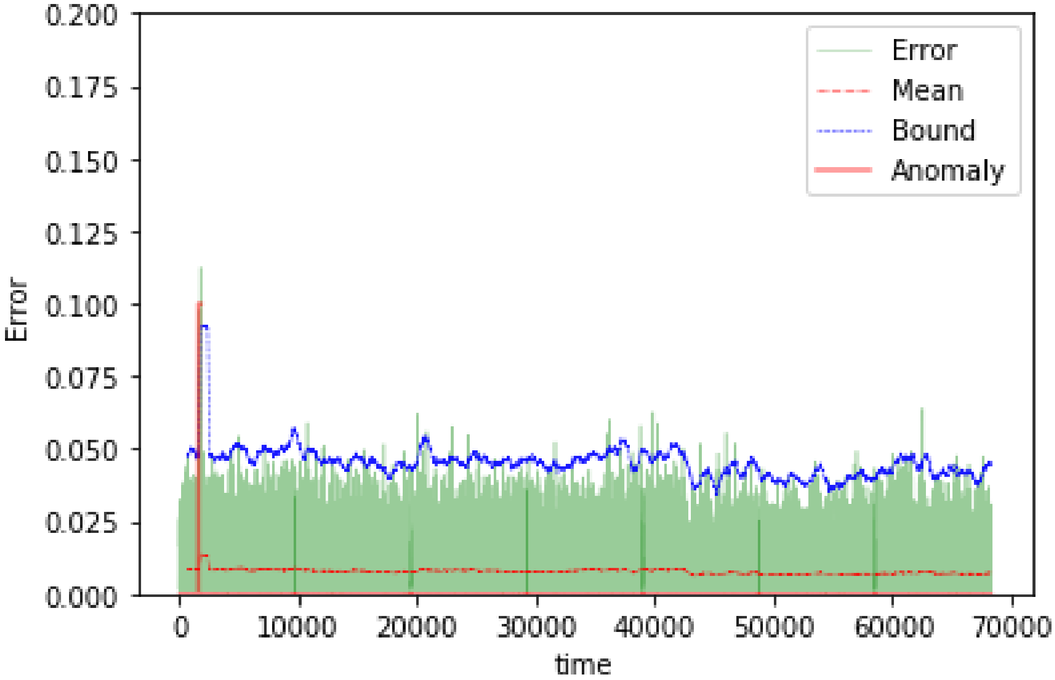
```
In [217]: TIMESTEPS = 10
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS, 0)
          vgen = flat_generator(val_X, TIMESTEPS, 0)
          name = "gru3_10"

In [218]: input_layer = Input(shape=(TIMESTEPS,DIM))
          hidden = GRU(10, activation='relu', return_sequences=True)(input_layer)
          hidden = GRU(10, activation='relu', return_sequences=True)(hidden)
          hidden = GRU(10, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)

In [219]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

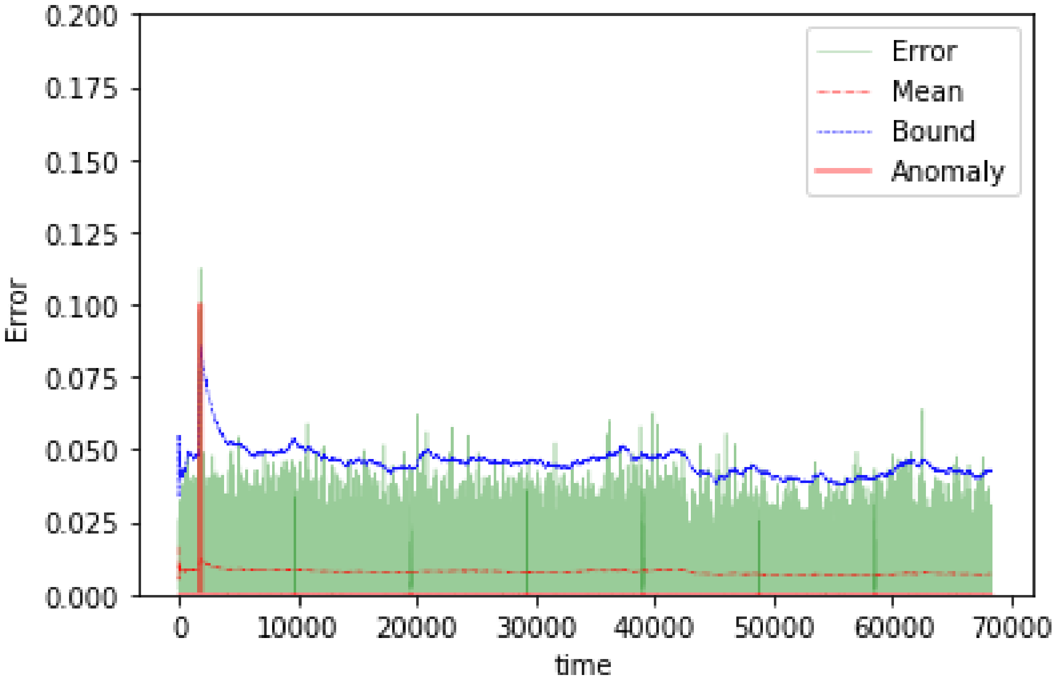
```
In [220]: train(model, tgen, vgen, name=name)
          test(model, ravel=0, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008625217507476919
Validation loss for final epoch is 0.007729742549941875
---------- Beginning tests for gru3_10 ----------
Testing on Normal data.
```


Error
Error
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
0
10000
20000
30000
40000
50000
60000
70000
time


Error
Mean
Bound
Anomaly
Error
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
0
10000
20000
30000
40000
50000
60000
70000
time



```
The mean error for gru3_10_normal_ is 0.007734519435871059 for length 68289
====================
```

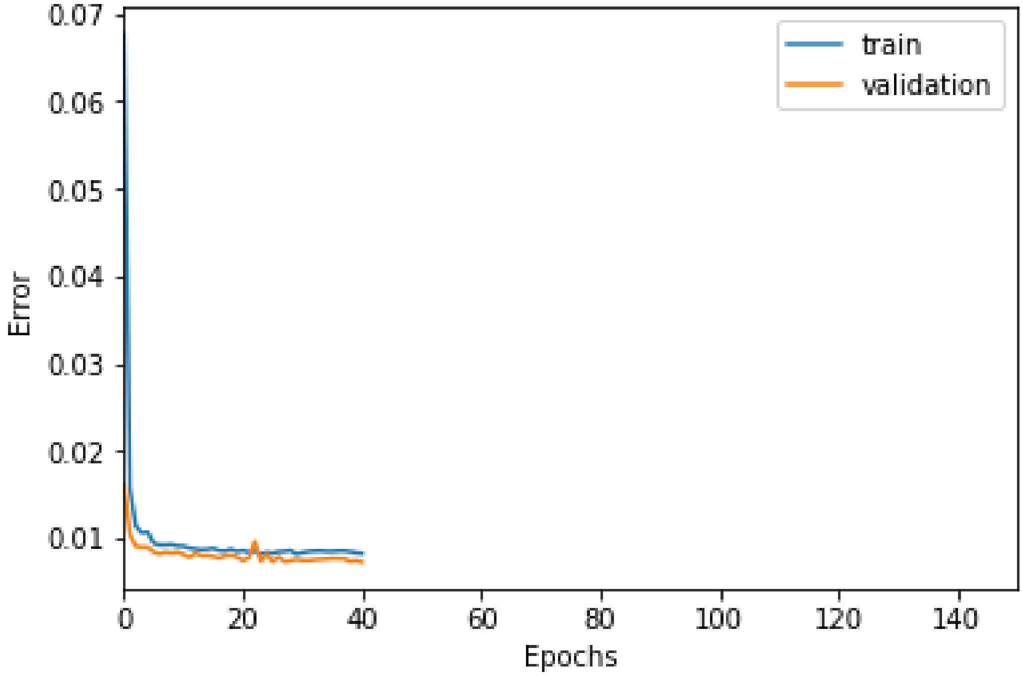
20 steps

```
In [221]: TIMESTEPS = 20
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS,0)
          vgen = flat_generator(val_X, TIMESTEPS,0)
          name = "gru3_20"
```

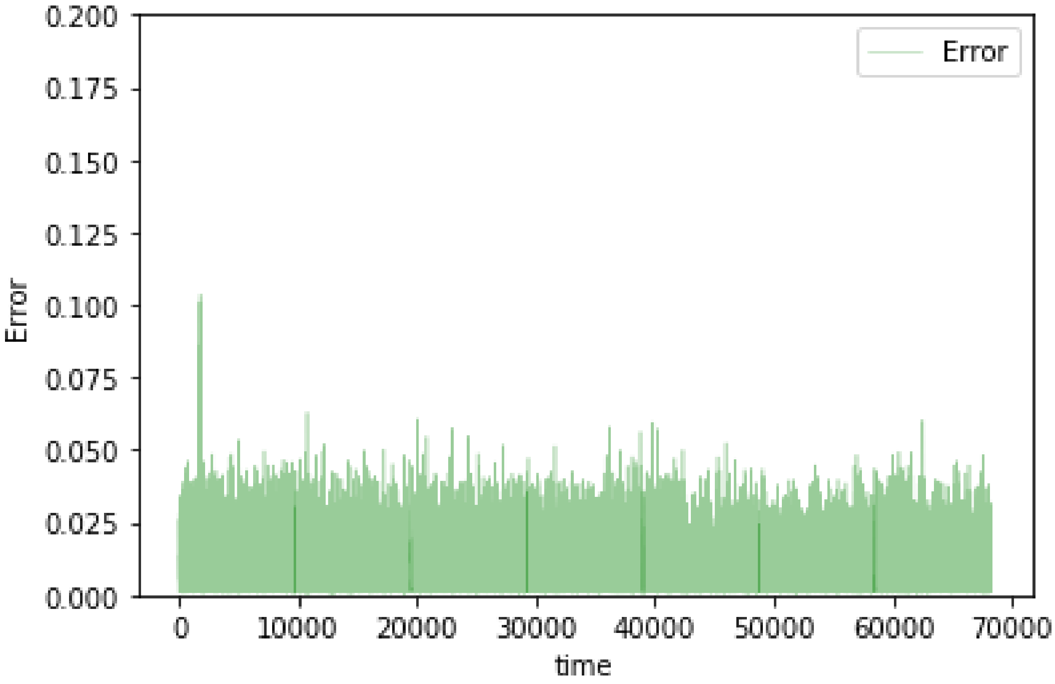
```
In [222]: input_layer = Input(shape=(TIMESTEPS,DIM))
          hidden = GRU(10, activation='relu', return_sequences=True)(input_layer)
          hidden = GRU(10, activation='relu', return_sequences=True)(hidden)
          hidden = GRU(10, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)
```

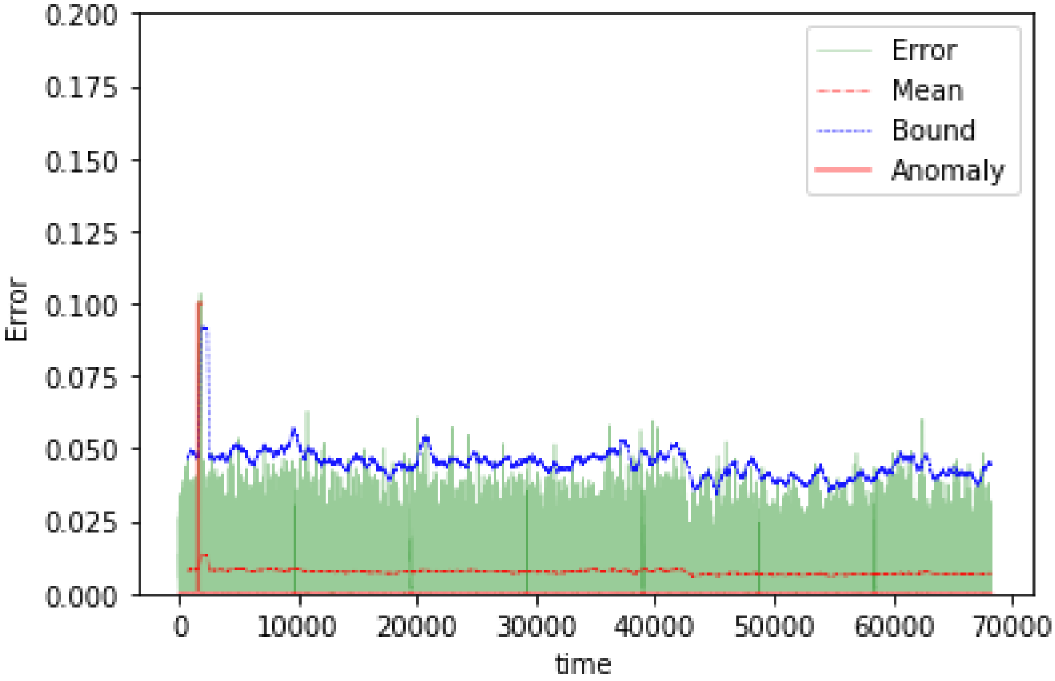
```
In [223]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

```
In [224]: train(model, tgen, vgen, name=name)
          test(model, ravel=0, name=name, window=TIMESTEPS)
```

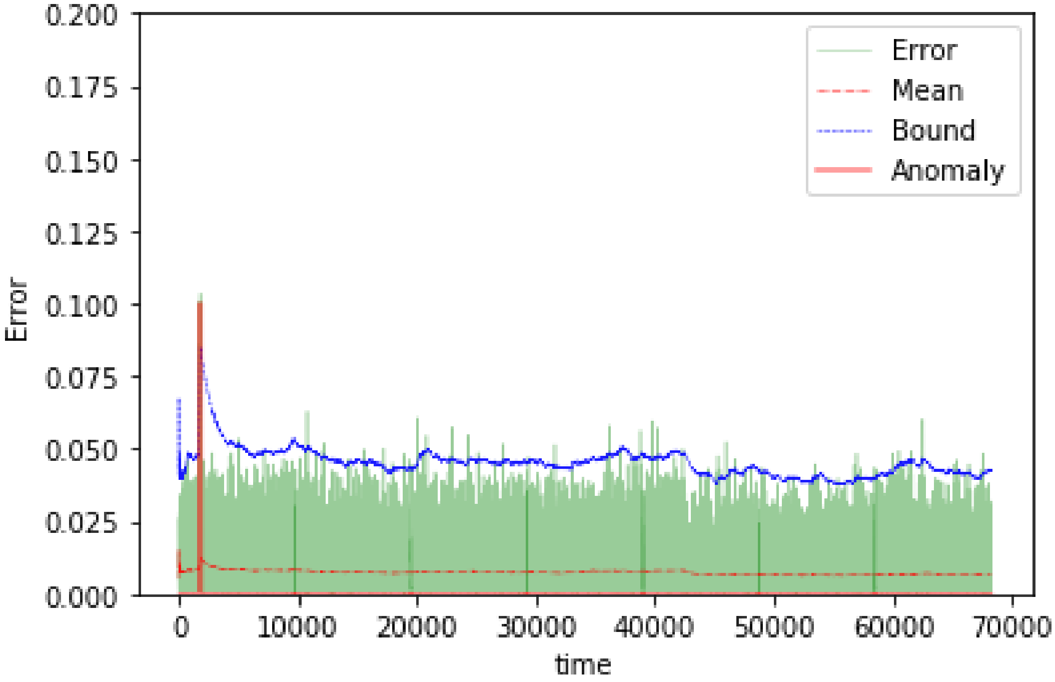


```
Training loss for final epoch is 0.008260209661326371
Validation loss for final epoch is 0.0072789703316520895
---------- Beginning tests for gru3_20 ----------
Testing on Normal data.
```





0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly



0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly

```
The mean error for gru3_20_normal_ is 0.007411721981871608 for length 68279
====================
```

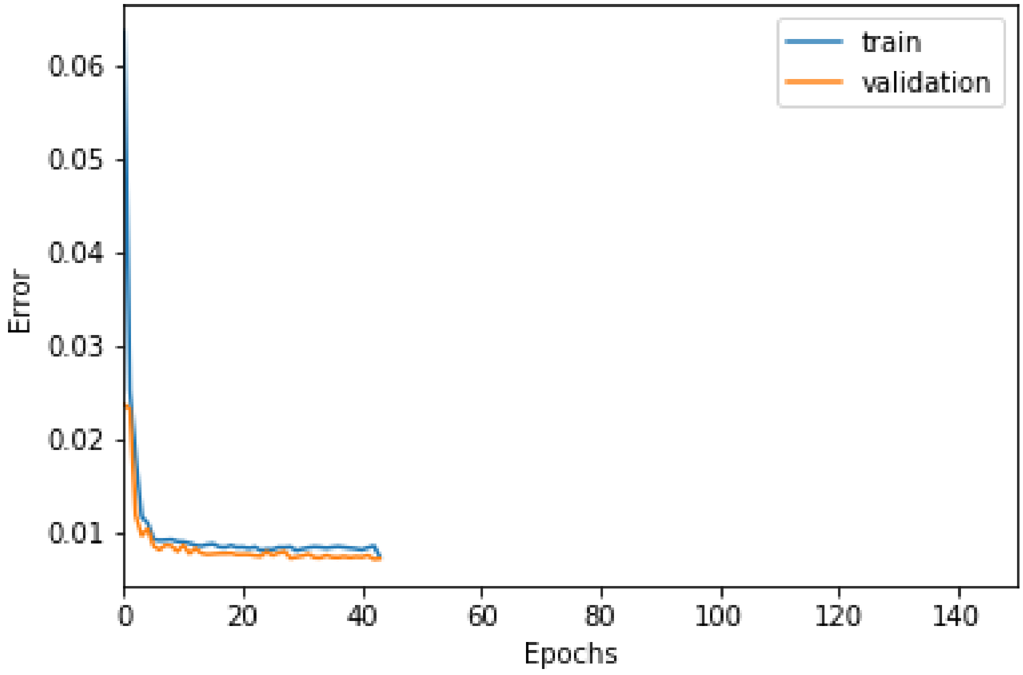
50 steps

```
In [225]: TIMESTEPS = 50
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS,0)
          vgen = flat_generator(val_X, TIMESTEPS,0)
          name = "gru3_50"
```

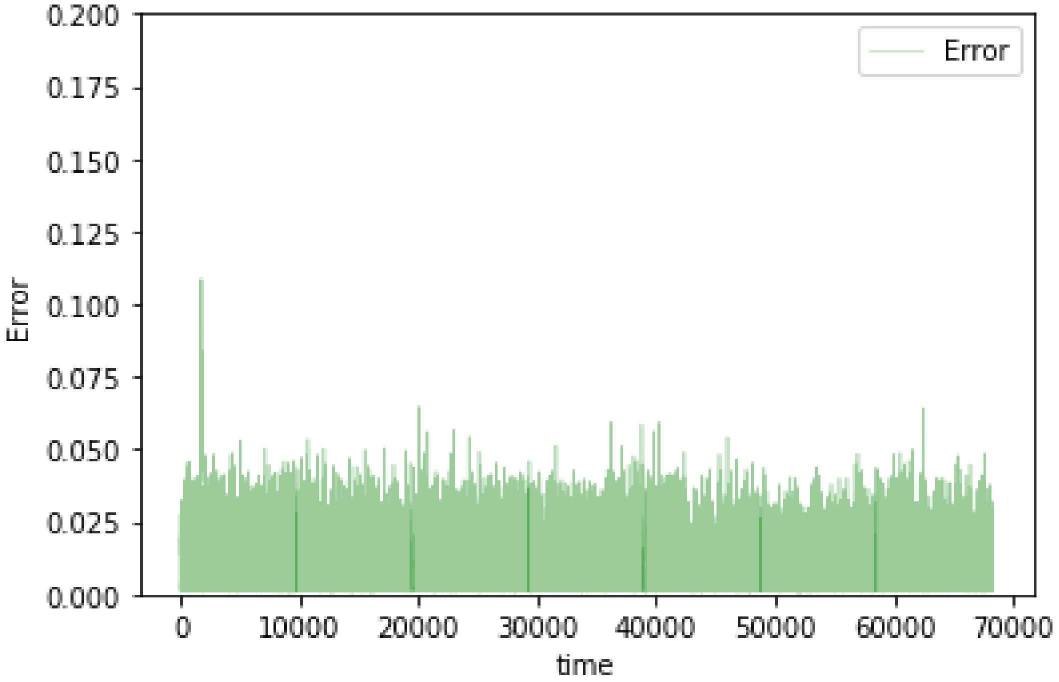
```
In [226]: input_layer = Input(shape=(TIMESTEPS,DIM))
          hidden = GRU(10, activation='relu', return_sequences=True)(input_layer)
          hidden = GRU(10, activation='relu', return_sequences=True)(hidden)
          hidden = GRU(10, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)
```

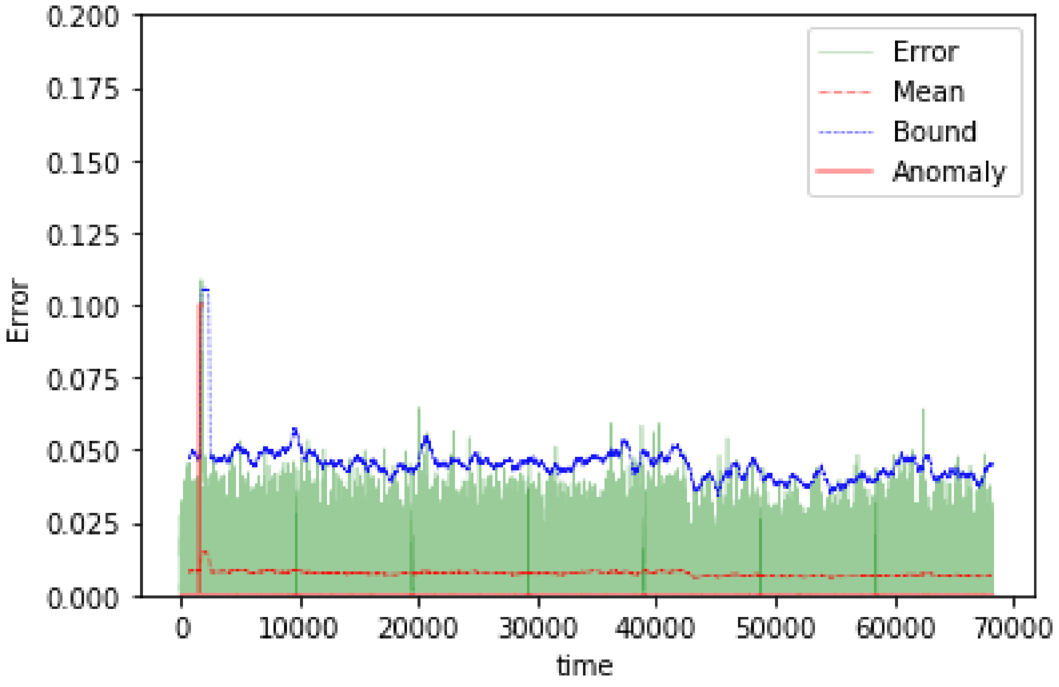
```
In [227]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

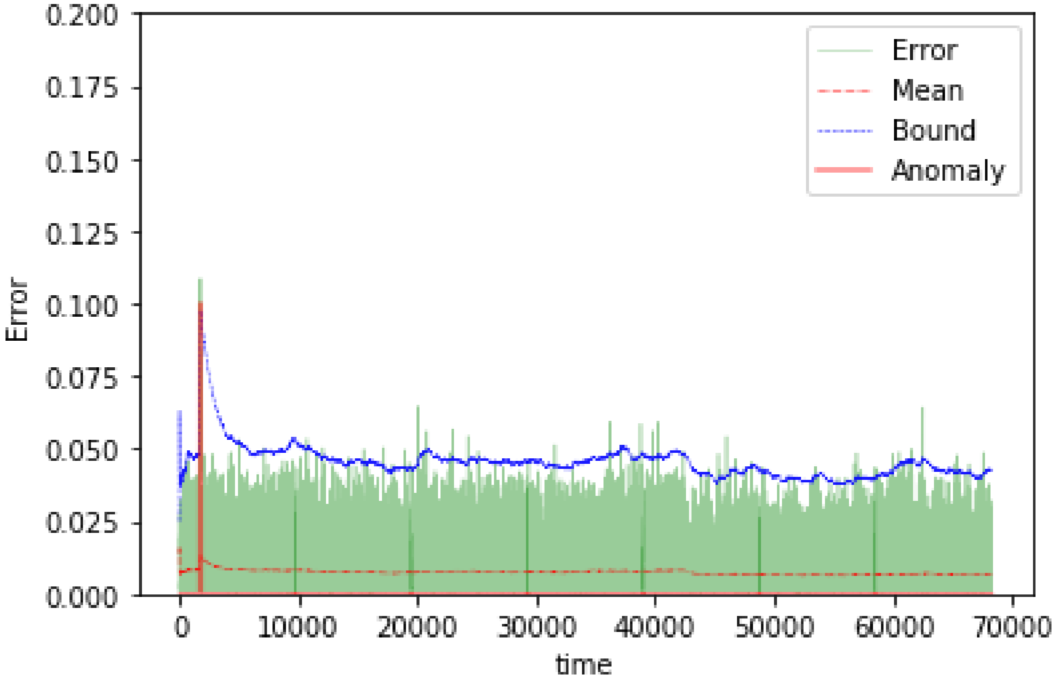
```
In [228]: train(model, tgen, vgen, name=name)
          test(model, ravel=0, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.0074368298584595325
Validation loss for final epoch is 0.007227270314469934
---------- Beginning tests for gru3_50 ----------
Testing on Normal data.
```





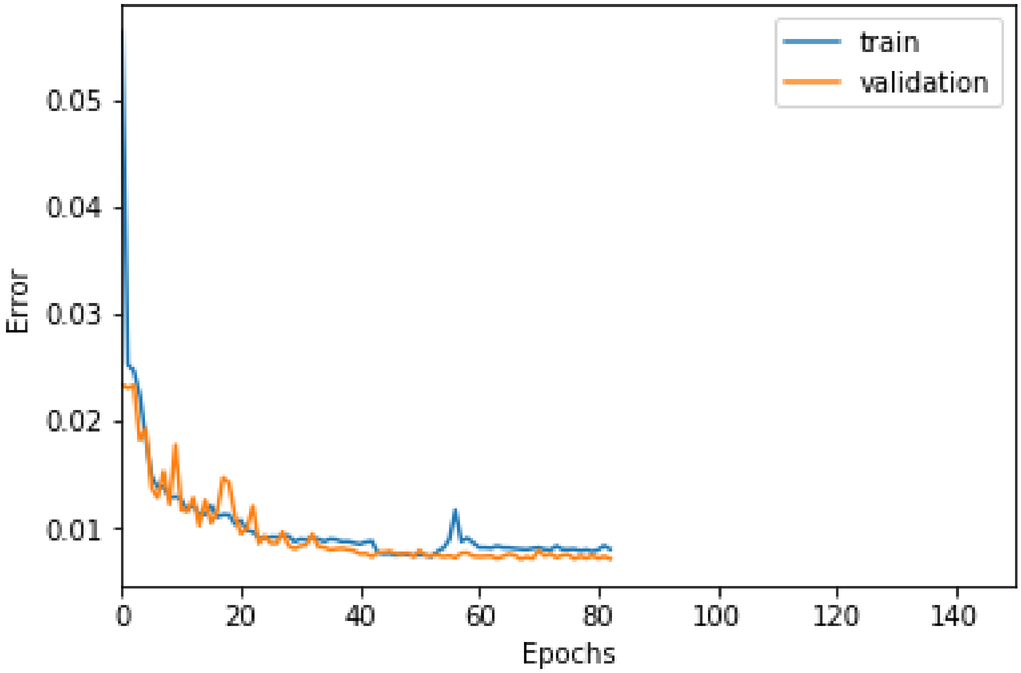


```
The mean error for gru3_50_normal_ is 0.007450785901126989 for length 68249
====================
```

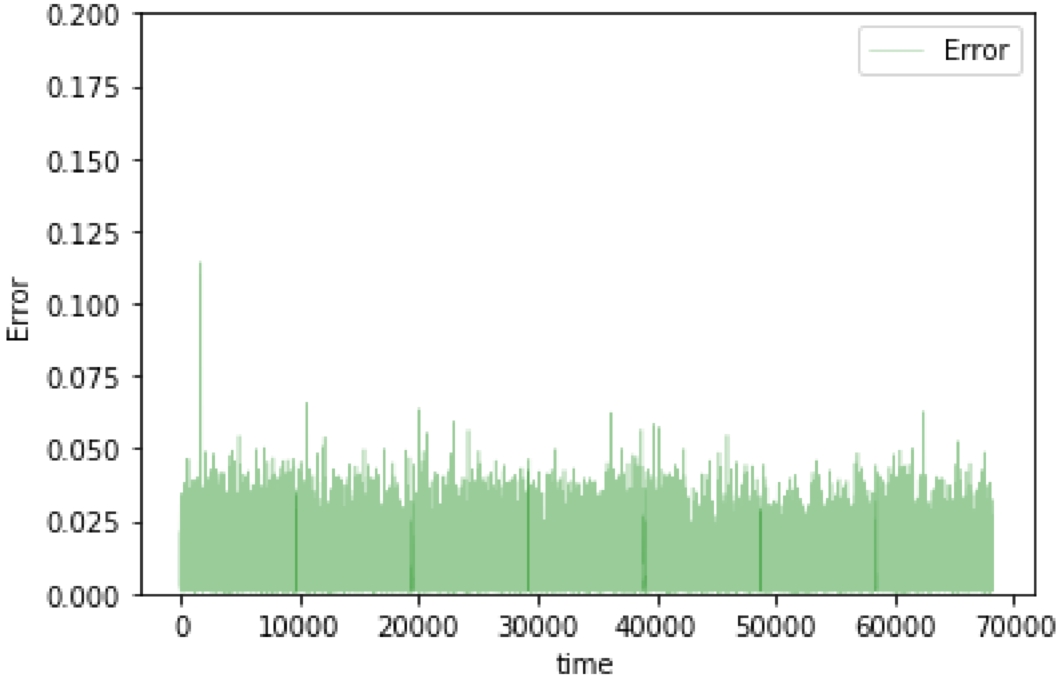
100 steps

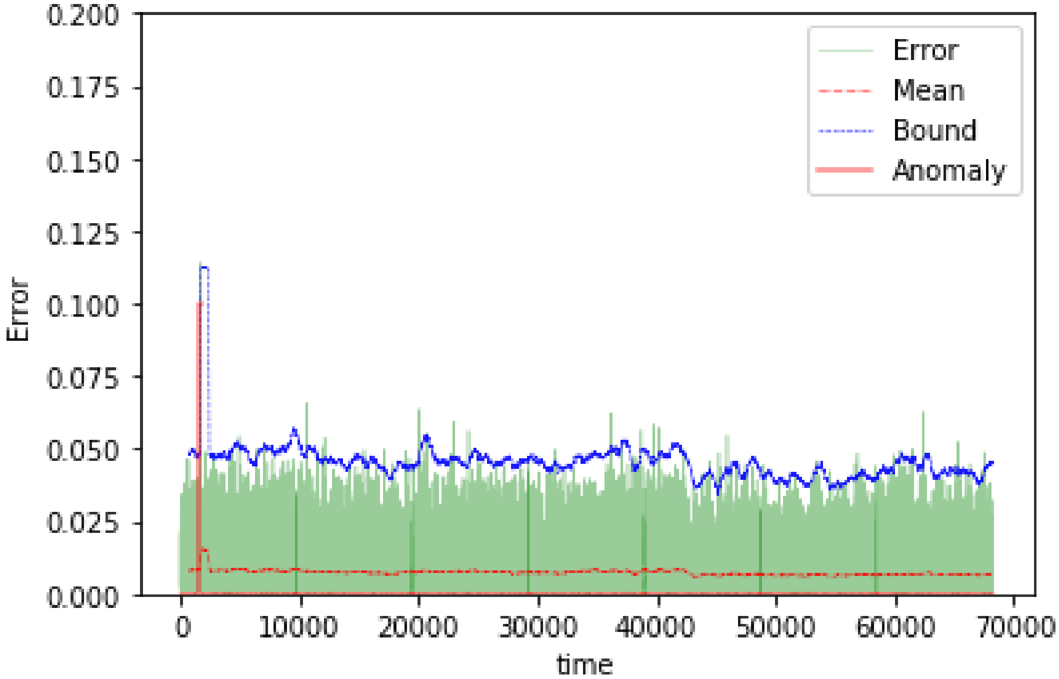
```
In [229]: TIMESTEPS = 100
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS,0)
          vgen = flat_generator(val_X, TIMESTEPS,0)
          name = "gru3_100"

In [230]: input_layer = Input(shape=(TIMESTEPS,DIM))
          hidden = GRU(10, activation='relu', return_sequences=True)(input_layer)
          hidden = GRU(10, activation='relu', return_sequences=True)(hidden)
          hidden = GRU(10, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)

In [231]: model = Model(input_layer, output)
          model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])
```

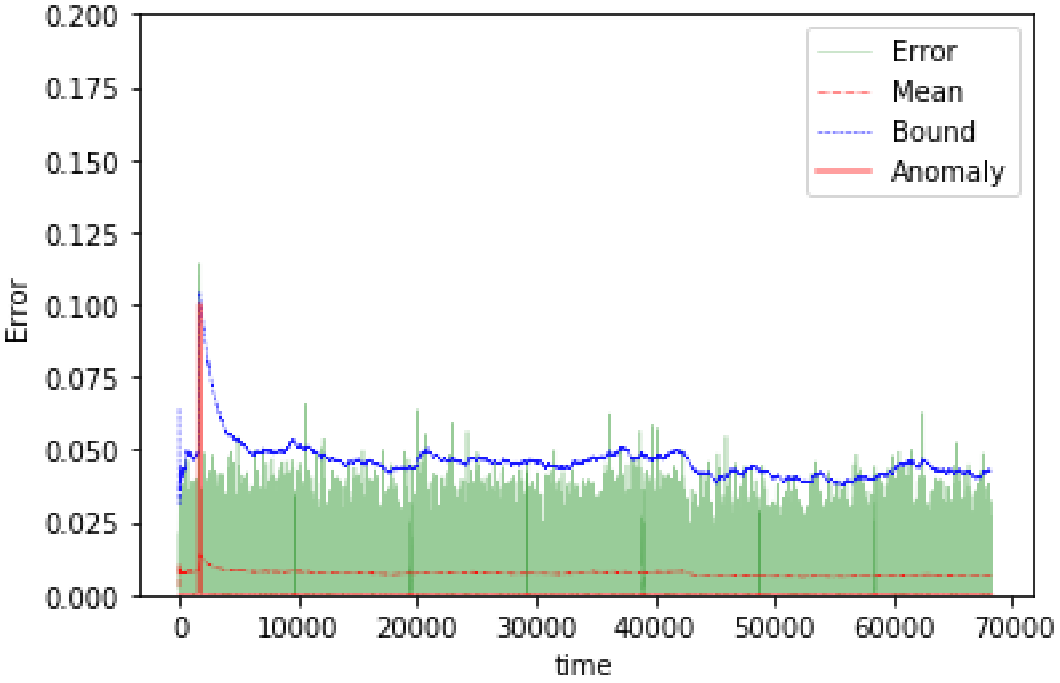
```
In [232]: train(model, tgen, vgen, name=name)
          test(model, ravel=0, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.008005085296346807
Validation loss for final epoch is 0.007108211631770246
---------- Beginning tests for gru3_100 ----------
Testing on Normal data.
```


0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error

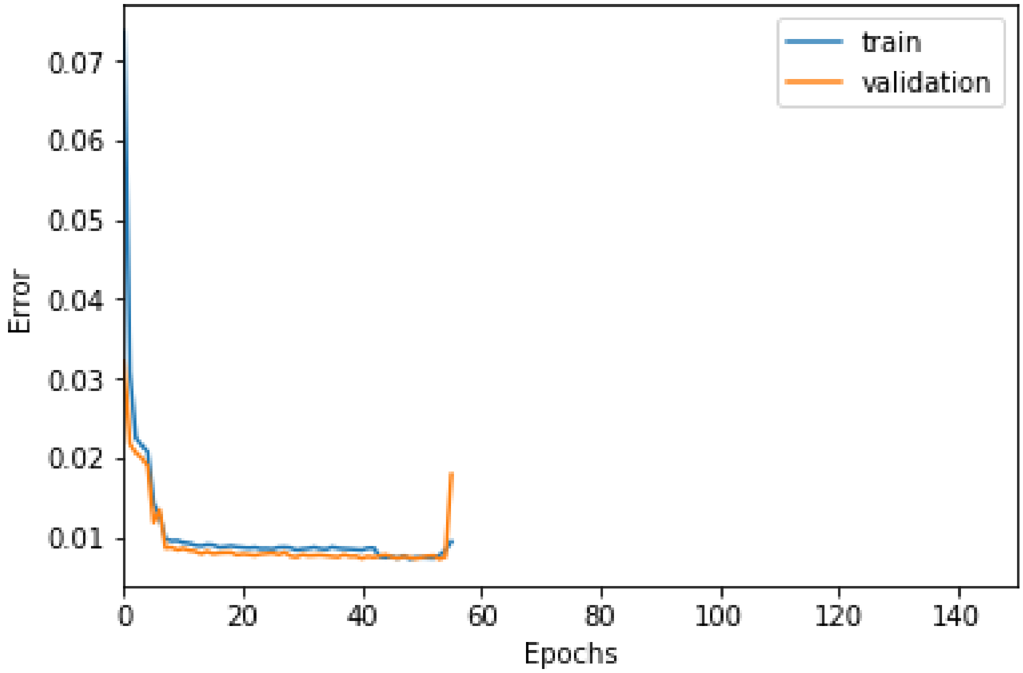

0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Error
0
10000
20000
30000
40000
50000
60000
70000
time
Error
Mean
Bound
Anomaly



```
The mean error for gru3_100_normal_ is 0.007387910047410272 for length 68199
====================
```

200 steps

```
In [233]: TIMESTEPS = 200
          DIM = 29
          tgen = flat_generator(X, TIMESTEPS,0)
          vgen = flat_generator(val_X, TIMESTEPS,0)
          name = "gru3_200"

In [234]: input_layer = Input(shape=(TIMESTEPS,DIM))
          hidden = GRU(10, activation='relu', return_sequences=True)(input_layer)
          hidden = GRU(10, activation='relu', return_sequences=True)(hidden)
          hidden = GRU(10, activation='relu')(hidden)
          output = Dense(DIM, activation='sigmoid')(hidden)

In [ ]: model = Model(input_layer, output)
        model.compile(loss='mean_absolute_error', optimizer='adam', metrics=['mae'])

In [ ]: train(model, tgen, vgen, name=name)
        test(model, ravel=0, name=name, window=TIMESTEPS)
```



```
Training loss for final epoch is 0.009387552069150843
Validation loss for final epoch is 0.017899903855286538
---------- Beginning tests for gru3_200 ----------
Testing on Normal data.
```