RNN_scratch

July 10, 2018

In [174]:
```
import numpy as np
import tensorflow as tf
import matplotlib.pyplot as plt
%matplotlib inline
```

In [3]:
```
num_inputs = 2
num_neurons = 3
```

In [4]:
```
x0 = tf.placeholder(tf.float32, [None, num_inputs])
x1 = tf.placeholder(tf.float32, [None, num_inputs])
```

In [5]:
```
Wx = tf.random_normal(shape=[num_inputs, num_neurons])
Wy = tf.random_normal(shape=[num_neurons, num_neurons])
b = tf.zeros([1, num_neurons])
```

In [6]:
```
# graphs
y0 = tf.tanh(tf.matmul(x0, Wx) + b)
# feedback + present
y1 = tf.tanh(tf.matmul(y0, Wy) + tf.matmul(x1, Wx) + b)
```

In [7]:
```
# intialize variables
init = tf.global_variables_initializer()
```

In [8]:
```
# create data
# time stamp at t = 0
x0_batch = np.array([ [0, 1], [2, 3], [4, 5] ])
# time stamp at t = t + 1 = 1
x1_batch = np.array([ [100, 101], [102, 103], [104, 105] ])
```

In [9]:
```
with tf.Session() as sess:
    sess.run(init)

    y0_output_vals, y1_output_vals = sess.run([y0, y1],
                    feed_dict = {x0:x0_batch, x1:x1_batch})
```

In [10]:
```
y0_output_vals
```

Out[10]:
```
array([[ 0.46511364, -0.921773  ,  0.9284943 ],
       [ 0.96557266, -0.9307549 ,  0.9783266 ],
       [ 0.9983207 , -0.93873835,  0.993547  ]], dtype=float32)
```

```
In [11]: y1_output_vals

Out[11]: array([[ 1.        , -0.99936646,  1.        ],
                [ 1.        , -0.9977223 ,  1.        ],
                [ 1.        , -0.99780226,  1.        ]], dtype=float32)
```

0.1 Vanishing Gradients

While backpropagating, in deeper networks, gradients get smaller and at some point, they stop changing significantly.

GRU and LSTM can be used to fix them (in RNN)

Depends on activation function choice.

Like **sigmoid:**

$$\sigma(z) = \frac{1}{1 + e^{-z}}$$

It saturates both positive and negative values.

Solution:

Use **ReLU** (doesn't saturate positive values.) Problem: for -ve numbers, always 0.

Solution:

Use **Leaky ReLU.**

Others: **ELU** (Exponential Linear Unit)

Another solution: Use Batch Normalization, Gradient Clipping (cut off gradients to be b/w -1 and 1 : example)

0.2 Introduction to RNN using TF API

Problem: Time series. ($sin(t)$, t = time)

```
In [30]: import numpy as np
         import tensorflow as tf
         import matplotlib.pyplot as plt
         %matplotlib inline
```

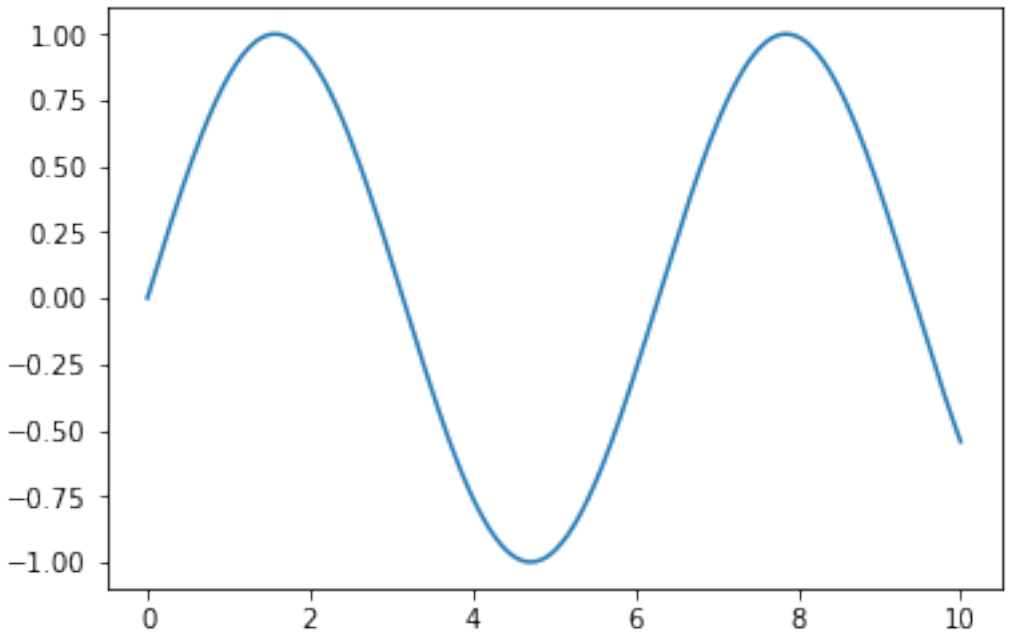
```
In [17]: class TimeSeriesData():
             def __init__(self, num_points, xmin, xmax):
                 # creates data
                 self.xmin = xmin
                 self.xmax = xmax
                 self.num_points = num_points
                 self.resolution = (self.xmax - self.xmin)/(self.num_points)
                 self.x_data = np.linspace(self.xmin, self.xmax, self.num_points)
                 self.y_true = np.sin(self.x_data)

             def ret_true(self, x_series):
                 return np.sin(x_series)

             def next_batch(self, batch_size, steps, return_batch_ts=False):
                 # grab random starting point for each batch
```

```
        rand_start = np.random.rand(batch_size, 1)
        # convert to be on time series
        ts_start = rand_start * (self.xmax - self.xmin - \
                                 (steps * self.resolution))
        # create batch series : x axis
        batch_ts = ts_start + np.arange(0.0, steps + 1) * \
        self.resolution
        # create y data for each x axis point
        y_batch = np.sin(batch_ts)
        # formatting for RNN
        if return_batch_ts:
            return y_batch[:, :-1].reshape(-1, steps, 1), \
        y_batch[:, 1:].reshape(-1, steps, 1), batch_ts
        else:
            # returns at t = t and t = t + 1
            return y_batch[:, :-1].reshape(-1, steps, 1), \
        y_batch[:, 1:].reshape(-1, steps, 1)
```

In [18]:
```
ts_data = TimeSeriesData(250, 0, 10)
```

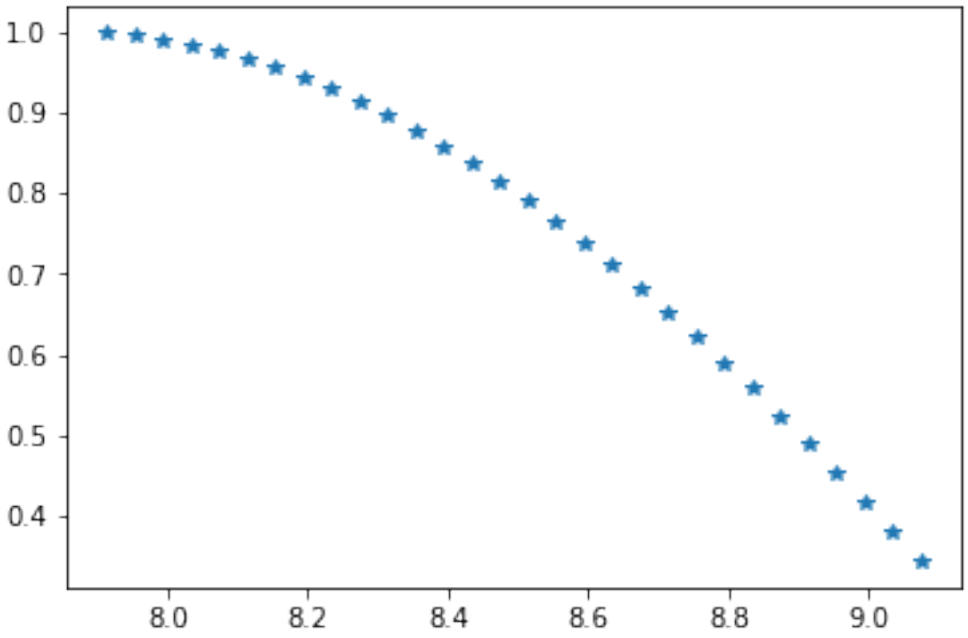
In [20]:
```
plt.plot(ts_data.x_data, ts_data.y_true)
```

Out[20]:
```
[<matplotlib.lines.Line2D at 0x7f285e27d780>]
```

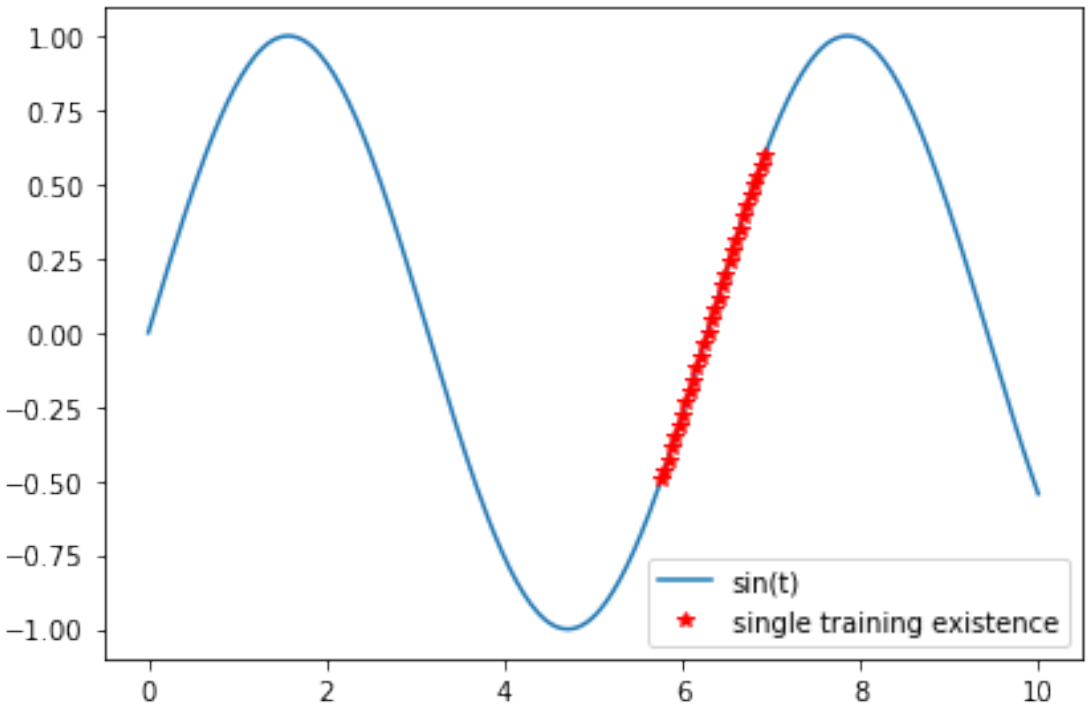


In [21]:
```
num_timesteps = 30 # number of steps in each batch
```

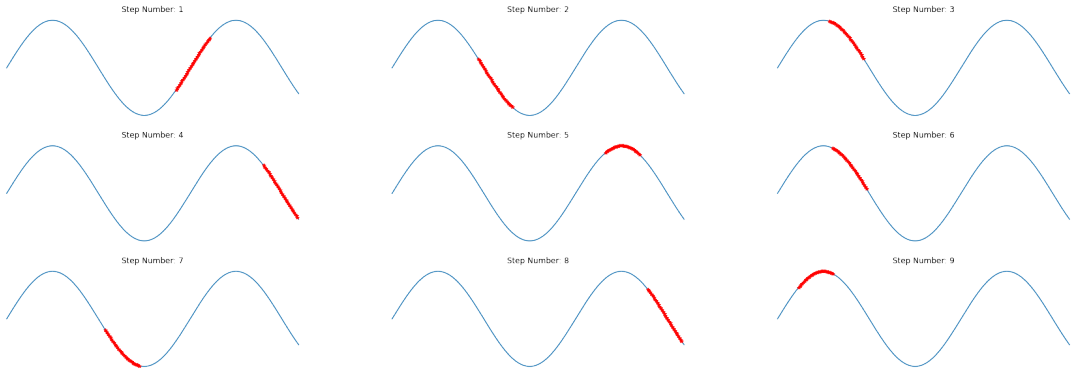
```
In [40]: def generateNextBatch(num_timesteps):
             y1, y2, ts = ts_data.next_batch(1, num_timesteps, True)
             return y1, y2, ts

In [28]: ts.shape
         # needs to be flattened

Out[28]: (1, 30, 1)

In [31]: plt.plot(ts.flatten()[1:], y2.flatten(), '*')

Out[31]: [<matplotlib.lines.Line2D at 0x7f285c74dcf8>]
```



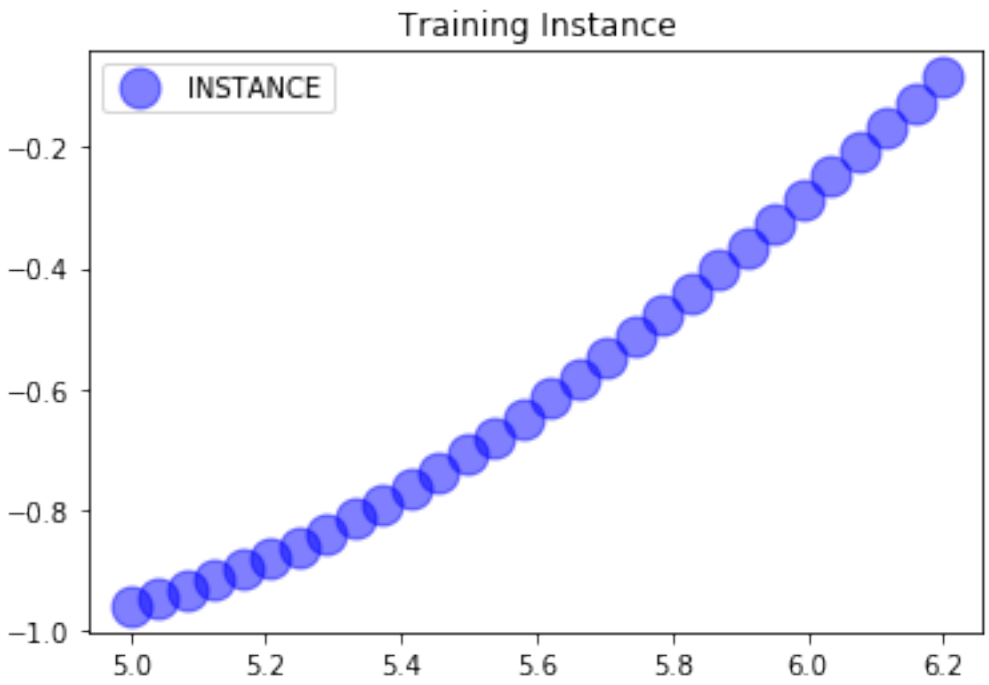

```
In [42]: y1, y2, ts = generateNextBatch(30)
         plt.plot(ts_data.x_data, ts_data.y_true, label='sin(t)')
         plt.plot(ts.flatten()[1:], y2.flatten(), '*', c = 'r', label='single training existen
         plt.legend()
         plt.tight_layout()
```



In [76]:
```
import math

        plt.figure(figsize=[30,10])
        num_cols = 3
        num_images = 9
        num_rows = math.ceil(num_images / num_cols)

        for i in range(0, num_images):
            plt.subplot(num_rows, num_cols, i+1)
            plt.axis('off')
            y1, y2, ts = generateNextBatch(30)
            plt.plot(ts_data.x_data, ts_data.y_true, label='sin(t)')
            plt.plot(ts.flatten()[1:], y2.flatten(), '*', c = 'r', label='single training exis
            plt.title("Step Number: " + str(i + 1))
```

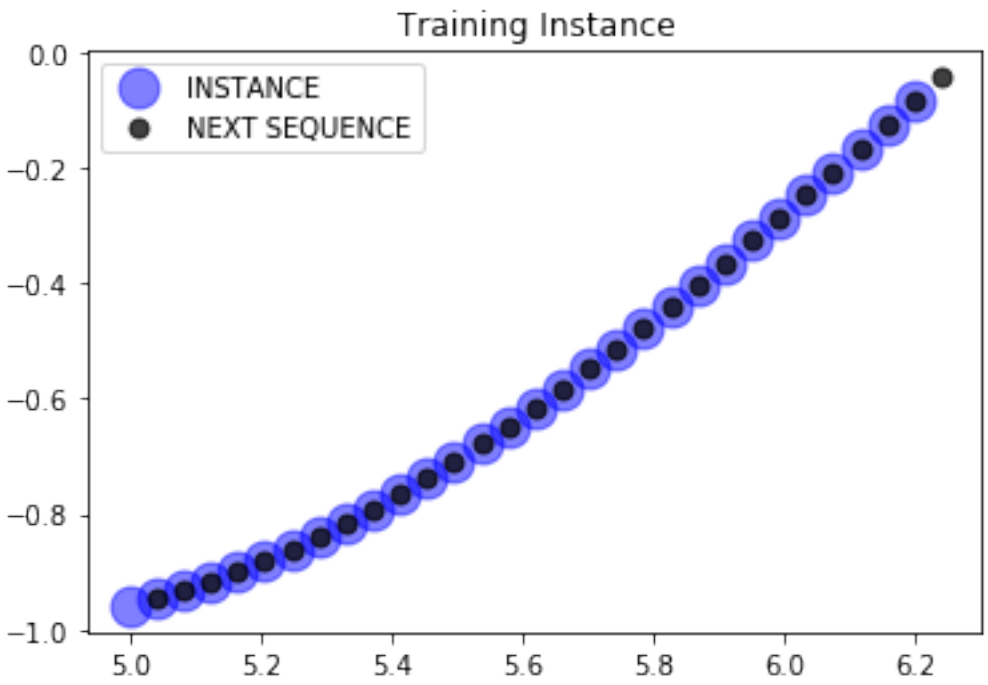



```
In [56]: train_instance = np.linspace(5, 5 + ts_data.resolution * \
                            (num_timesteps + 1), num_timesteps + 1)

In [57]: train_instance

Out[57]: array([5.        , 5.04133333, 5.08266667, 5.124     , 5.16533333,
                5.20666667, 5.248     , 5.28933333, 5.33066667, 5.372     ,
                5.41333333, 5.45466667, 5.496     , 5.53733333, 5.57866667,
                5.62      , 5.66133333, 5.70266667, 5.744     , 5.78533333,
                5.82666667, 5.868     , 5.90933333, 5.95066667, 5.992     ,
                6.03333333, 6.07466667, 6.116     , 6.15733333, 6.19866667,
                6.24      ])

In [71]: plt.title('Training Instance')

         plt.plot(train_instance[:-1], ts_data.ret_true(train_instance[:-1]),
                  'bo', markerSize=15, alpha=0.5, label='INSTANCE')

         plt.legend()

Out[71]: <matplotlib.legend.Legend at 0x7f282c417ac8>
```



We want to predict one time step ahead of it. [Goal]

```
In [74]: plt.title('Training Instance')

         plt.plot(train_instance[:-1], ts_data.ret_true(train_instance[:-1]),
                 'bo', markerSize=15, alpha=0.5, label='INSTANCE')
         # doing for next time step (1: )
         plt.plot(train_instance[1:], ts_data.ret_true(train_instance[1:]),
                 'ko', markerSize=7, alpha=0.75, label='NEXT SEQUENCE')

         plt.legend()

Out[74]: <matplotlib.legend.Legend at 0x7f282d6b00b8>
```



Creating Model using Tensorflow

```
In [175]: # usually necessary when a graph has already been created
          # not needed here but worth it.
          tf.reset_default_graph()

In [176]: num_inputs = 1

In [177]: num_neurons = 100 # number of neurons in a layer

In [178]: num_outputs = 1

In [196]: lr = 0.001 # learning rate
          batch_size = 1
          num_train_iterations = 2000 # 2000 steps

In [180]: X = tf.placeholder(dtype=tf.float32, shape=[None, num_timesteps, \
                                                       num_inputs])

In [181]: Y = tf.placeholder(dtype=tf.float32, shape=[None, num_timesteps, \
                                                       num_outputs])

In [89]: # Recurrent Neural Network Cell Layer

In [182]: cell = tf.contrib.rnn.BasicRNNCell(num_units=num_neurons,
                                              activation=tf.nn.relu)
          # output projection wrapper
          cell = tf.contrib.rnn.OutputProjectionWrapper(cell, output_size=num_outputs)
```

```
In [183]: outputs, states = tf.nn.dynamic_rnn(cell, X, dtype=tf.float32)

In [184]: # MSE
          loss = tf.reduce_mean(tf.square(outputs - Y))

In [185]: # optimizer - adam
          optimizer = tf.train.AdamOptimizer(learning_rate=lr)

          # optimizer minimzes the loss calculated above
          train = optimizer.minimize(loss)

          # initialize all variables
          init = tf.global_variables_initializer()

In [97]: # if using gpu
         # uncomment the following line
         # gpu_options = tf.GPUOptions(per_process_gpu_memory_fraction = 0.85)

In [186]: saver = tf.train.Saver() # saves model

In [197]: with tf.Session() as sess:
              sess.run(init)

              for iteration in range(num_train_iterations):
                  X_batch, Y_batch = ts_data.next_batch(batch_size, num_timesteps)

                  sess.run(train, feed_dict = {X:X_batch, Y:Y_batch})

                  if iteration % 100 == 0:
                      mse = loss.eval(feed_dict={X:X_batch, Y:Y_batch})
                      print(iteration, "\tMSE", mse)

              saver.save(sess, "./rnn_time_series_codealong")
```

```
0         MSE 0.54810894
100         MSE 0.20570844
200         MSE 0.0068678525
300         MSE 0.003448643
400         MSE 0.008003245
500         MSE 0.0062846127
600         MSE 6.705546e-05
700         MSE 0.016843755
800         MSE 0.00018747394
900         MSE 0.0028962297
1000         MSE 0.0023182756
1100         MSE 0.0018538045
1200         MSE 0.00010784715
1300         MSE 0.0142185
1400         MSE 0.0135010965
```

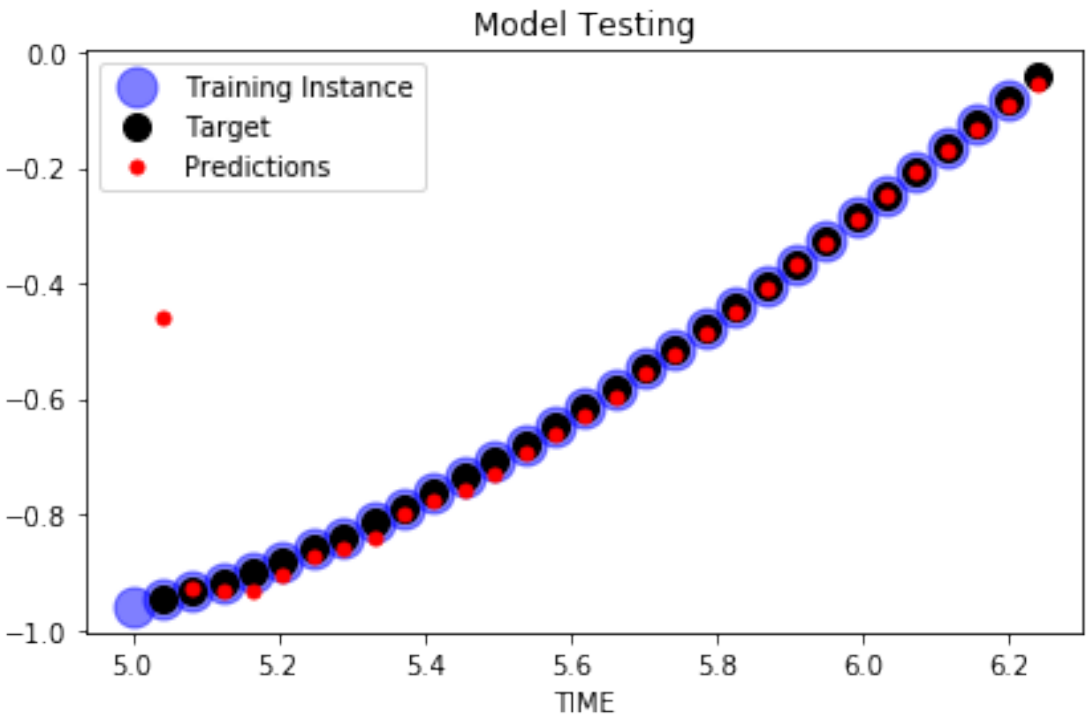
```
1500         MSE 0.0065394198
1600         MSE 0.008510323
1700         MSE 0.001088756
1800         MSE 0.01031712
1900         MSE 0.0007852756
```

```
In [198]: with tf.Session() as sess:
              saver.restore(sess, "./rnn_time_series_codealong")
              X_new = np.sin(np.array(train_instance[:-1].reshape(-1,
                                  num_timesteps, num_inputs)))
              y_pred = sess.run(outputs, feed_dict={X:X_new})
```

```
INFO:tensorflow:Restoring parameters from ./rnn_time_series_codealong
```

Testing Model

```
In [199]: plt.title("Model Testing")

          # training instance
          plt.plot(train_instance[:-1], np.sin(train_instance[:-1]),
                   "bo", markerSize=15, alpha=0.5, label="Training Instance")
          # ground truth values (np.sin(training instance))
          plt.plot(train_instance[1:], np.sin(train_instance[1:]),
                   "ko", markerSize=10, label="Target")
          # models prediction
          plt.plot(train_instance[1:], y_pred[0,:,0], 'r.',
                   markerSize=10, label='Predictions')

          plt.xlabel("TIME")
          plt.legend()
          plt.tight_layout()
```

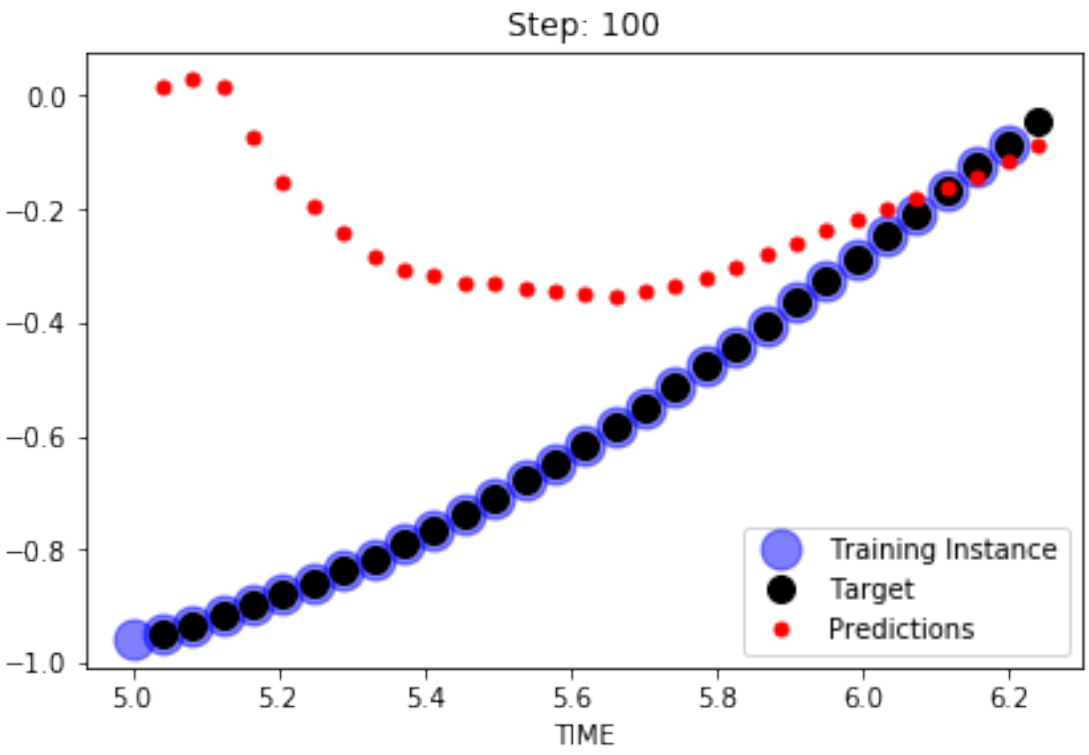



```
In [190]: def testing_model(steps):
              batch_size = 1
              with tf.Session() as sess:
                  sess.run(init)

                  for iteration in range(steps):
                      X_batch, Y_batch = ts_data.next_batch(batch_size, num_timesteps)

                      sess.run(train, feed_dict = {X:X_batch, Y:Y_batch})

                      if iteration % 100 == 0:
                          mse = loss.eval(feed_dict={X:X_batch, Y:Y_batch})
                          # print(iteration, "\tMSE", mse)

                  saver.save(sess, "./rnn_time_series_codealong")

              with tf.Session() as sess:
                  saver.restore(sess, "./rnn_time_series_codealong")
                  X_new = np.sin(np.array(train_instance[:-1].reshape(-1,
                                          num_timesteps, num_inputs)))
                  y_pred = sess.run(outputs, feed_dict={X:X_new})

          #     plt.title("Model Testing")
```

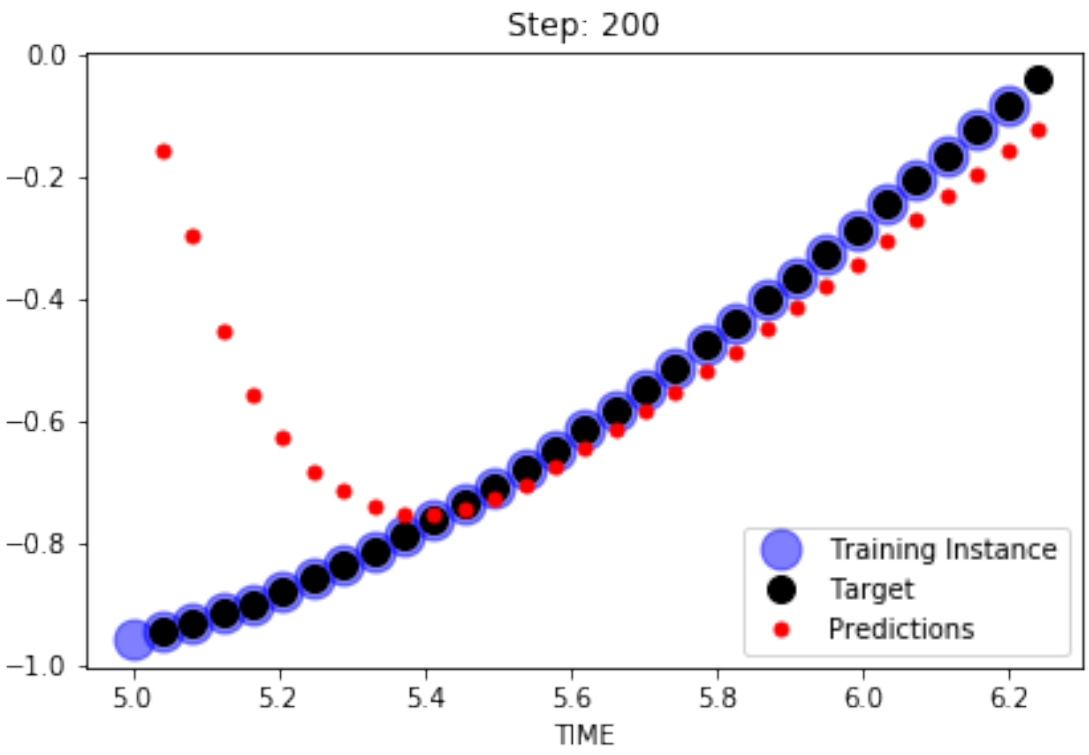
```
            return y_pred
```

In [195]:
```
# plt.figure(figsize=[100, 30])

num_cols = 1
num_images = 9
num_rows = math.ceil(num_images / num_cols)

step = 100
i = 0
while(step <= 2000):
    # plt.subplot(num_rows, num_cols, i+1)

    y_pred = testing_model(step)

#     print(y_pred.shape)
    print(step)
    # y1, y2, ts = generateNextBatch(30)
    plt.plot(train_instance[:-1], np.sin(train_instance[:-1]),
        "bo", markerSize=15, alpha=0.5, label="Training Instance")
    # ground truth values (np.sin(training instance))
    plt.plot(train_instance[1:], np.sin(train_instance[1:]),
            "ko", markerSize=10, label="Target")
    # models prediction
    plt.plot(train_instance[1:], y_pred[0,:,0], 'r.',
            markerSize=10, label='Predictions')

    plt.xlabel("TIME")
    plt.legend()
    plt.tight_layout()
    plt.title("Step: " + str(step))
    plt.show()
    step += 100
    i += 1
# training instance
```

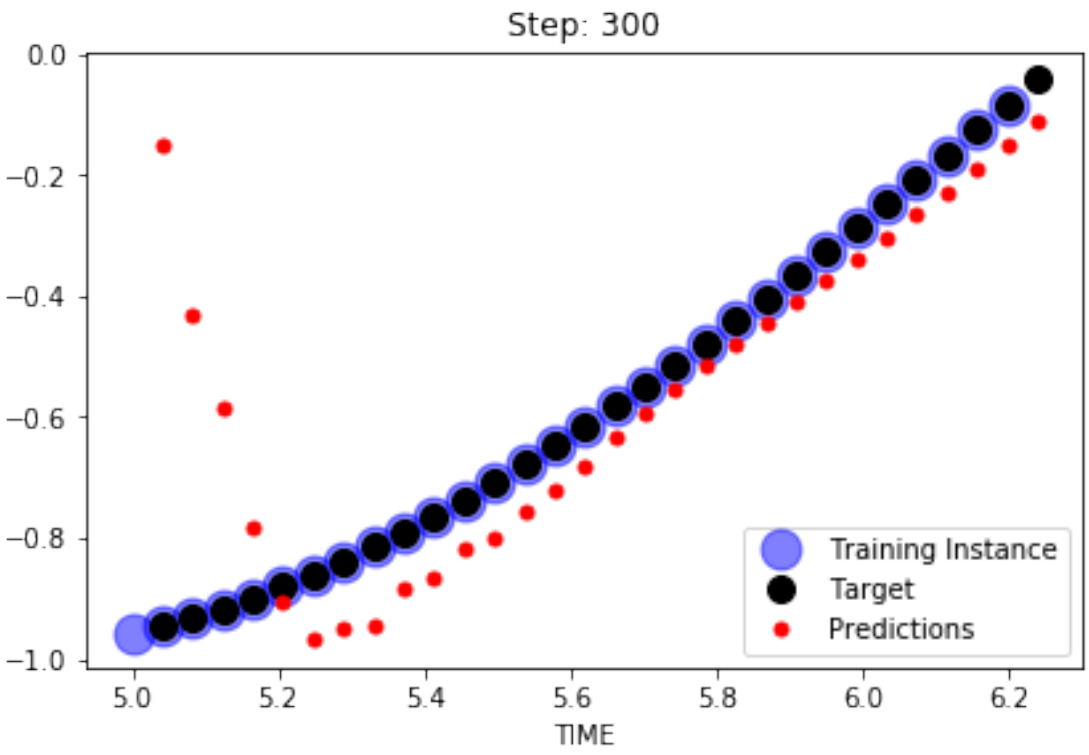
```
INFO:tensorflow:Restoring parameters from ./rnn_time_series_codealong
100
```



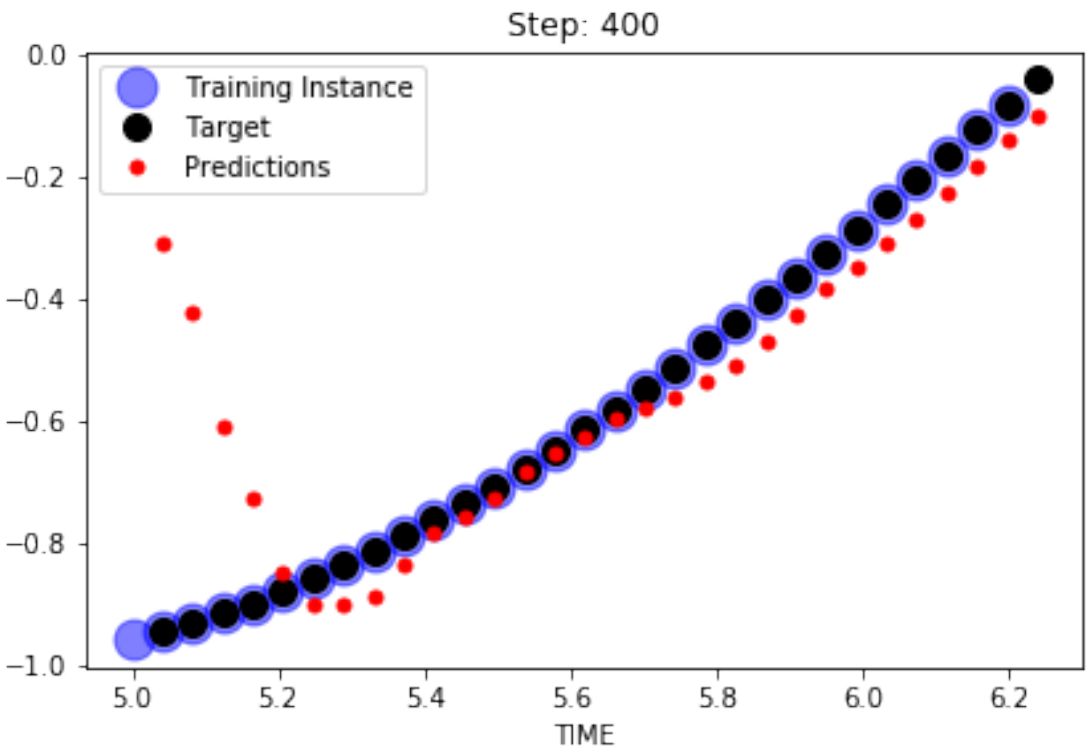

```
INFO:tensorflow:Restoring parameters from ./rnn_time_series_codealong
200
```



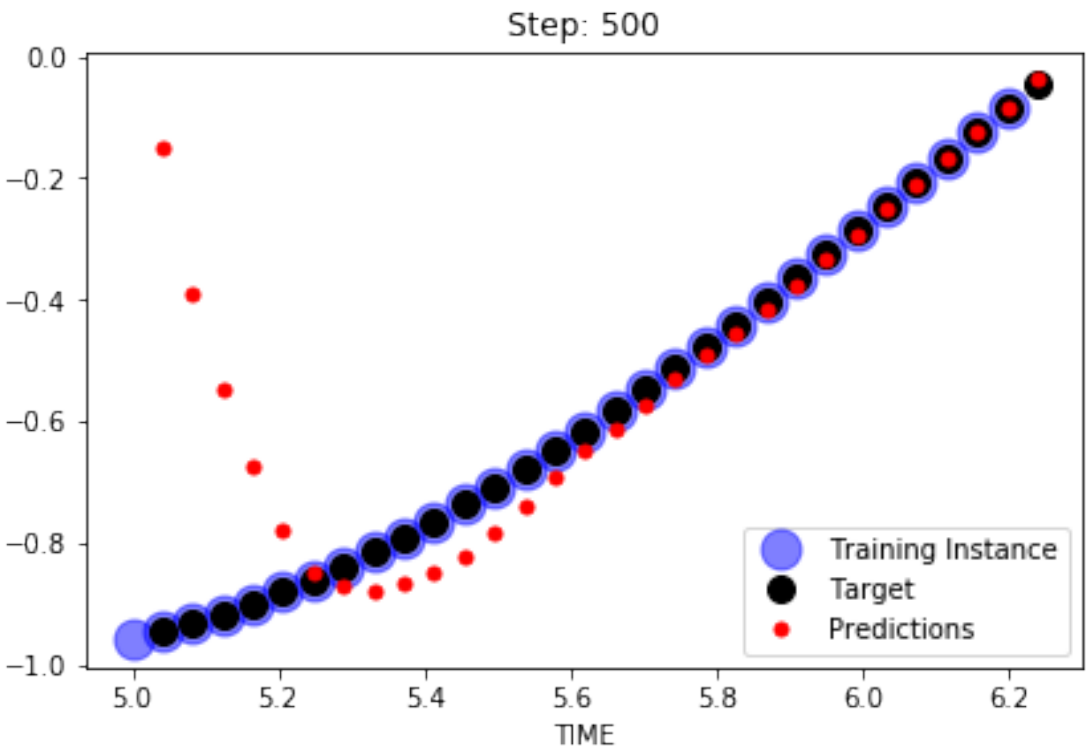

```
INFO:tensorflow:Restoring parameters from ./rnn_time_series_codealong
300
```



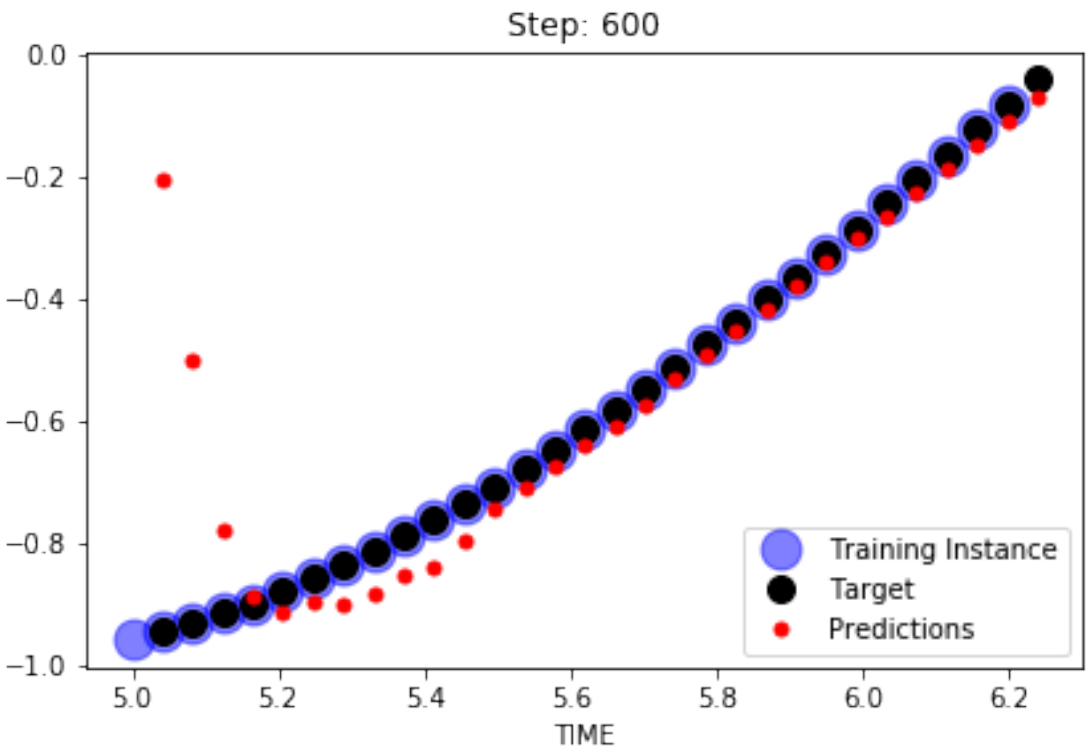

```
INFO:tensorflow:Restoring parameters from ./rnn_time_series_codealong
400
```



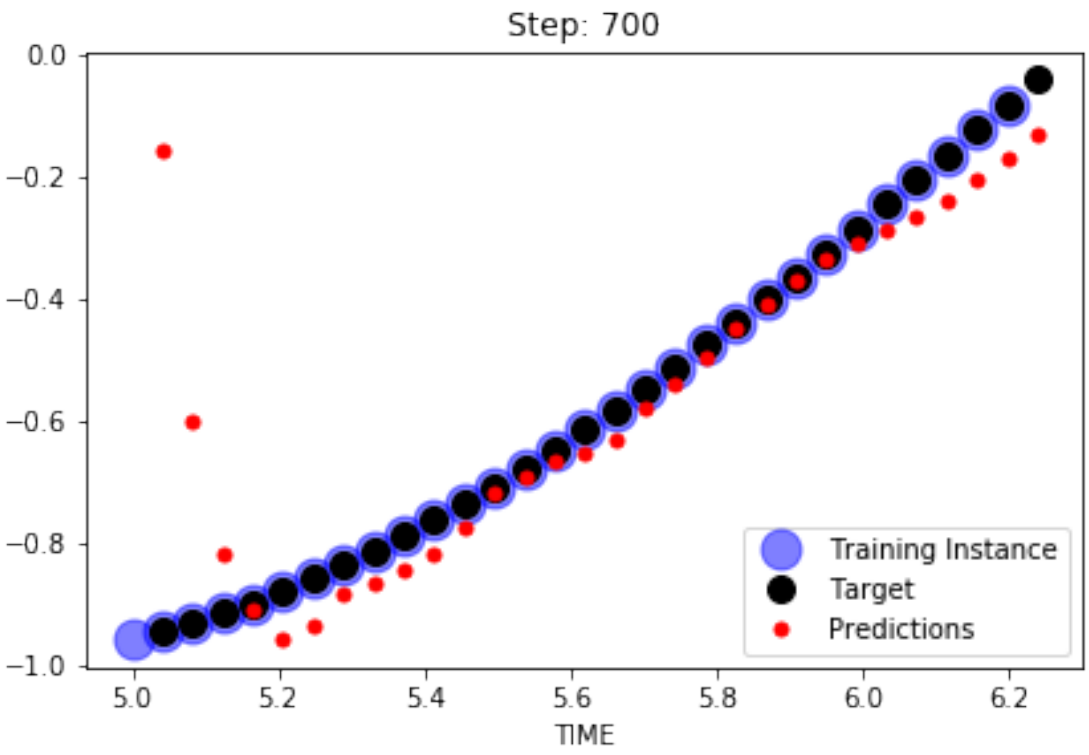

```
INFO:tensorflow:Restoring parameters from ./rnn_time_series_codealong
500
```



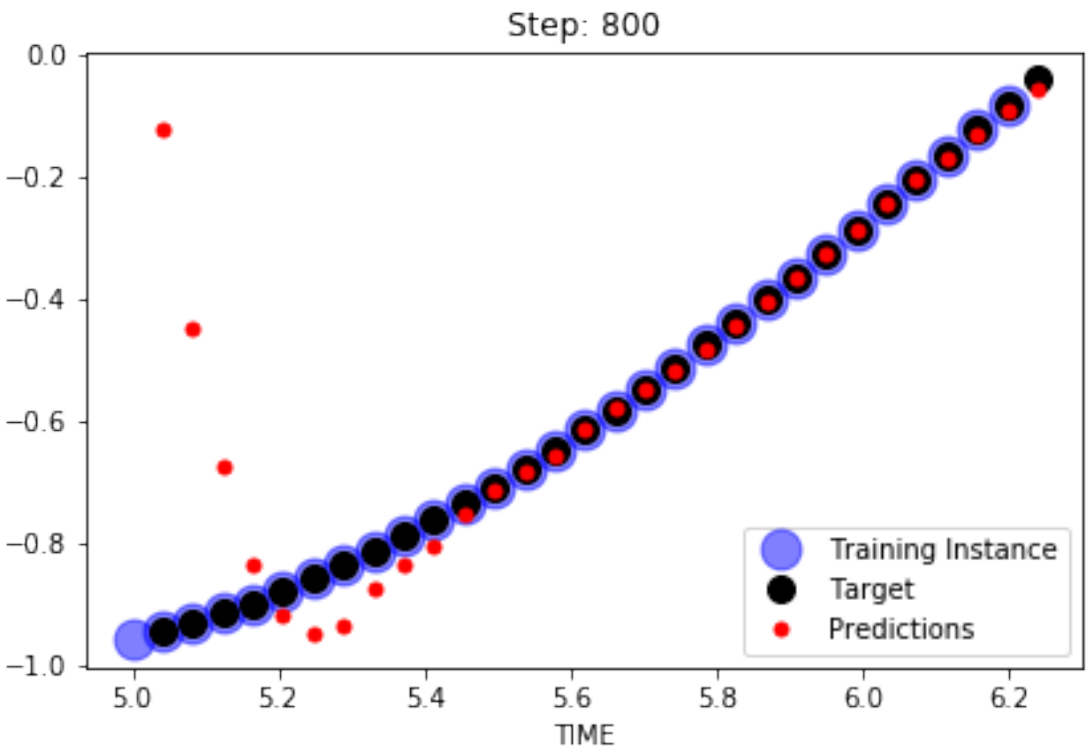

```
INFO:tensorflow:Restoring parameters from ./rnn_time_series_codealong
600
```



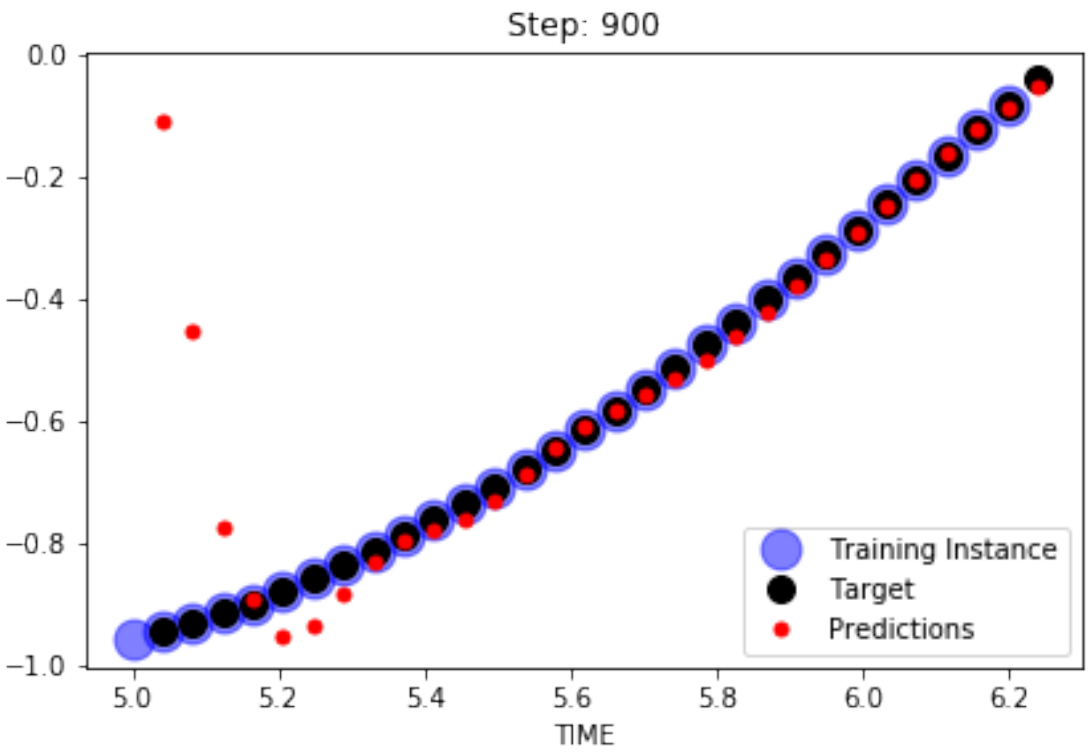

```
INFO:tensorflow:Restoring parameters from ./rnn_time_series_codealong
700
```



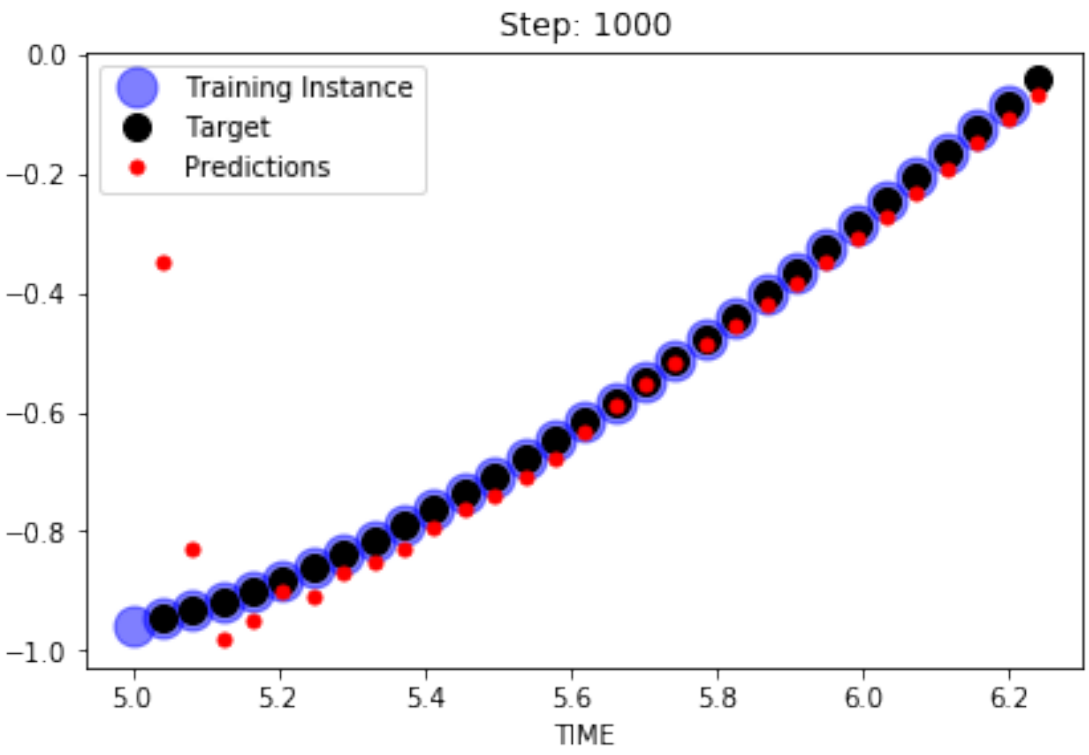

```
INFO:tensorflow:Restoring parameters from ./rnn_time_series_codealong
800
```



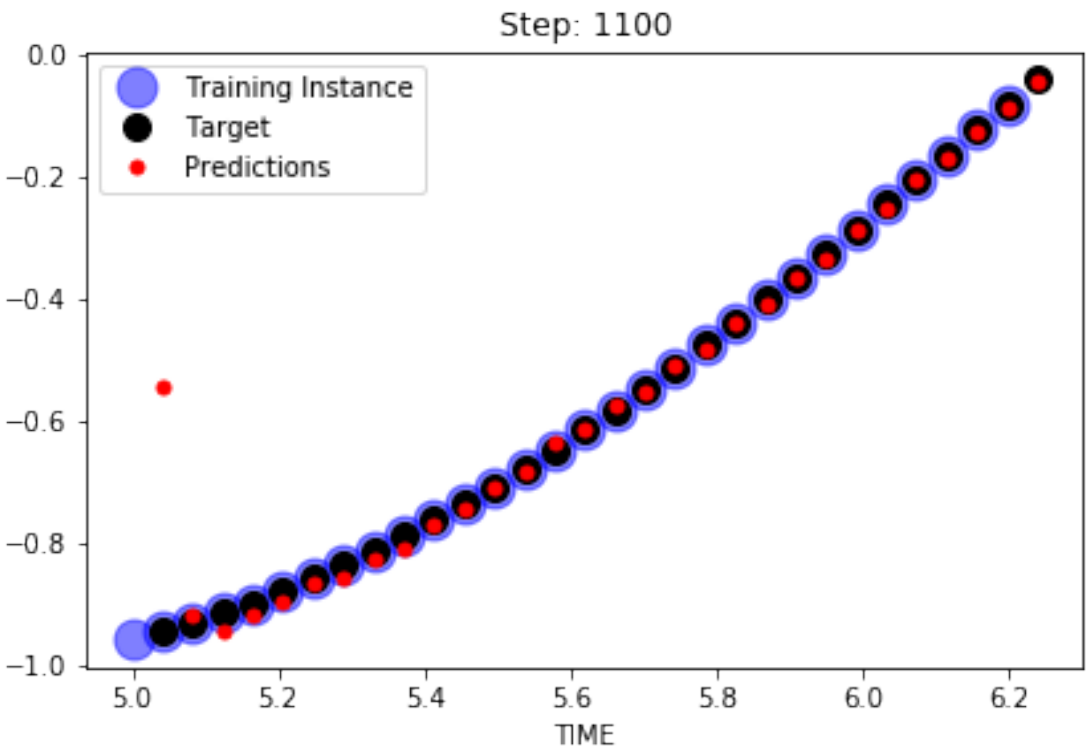

```
INFO:tensorflow:Restoring parameters from ./rnn_time_series_codealong
900
```



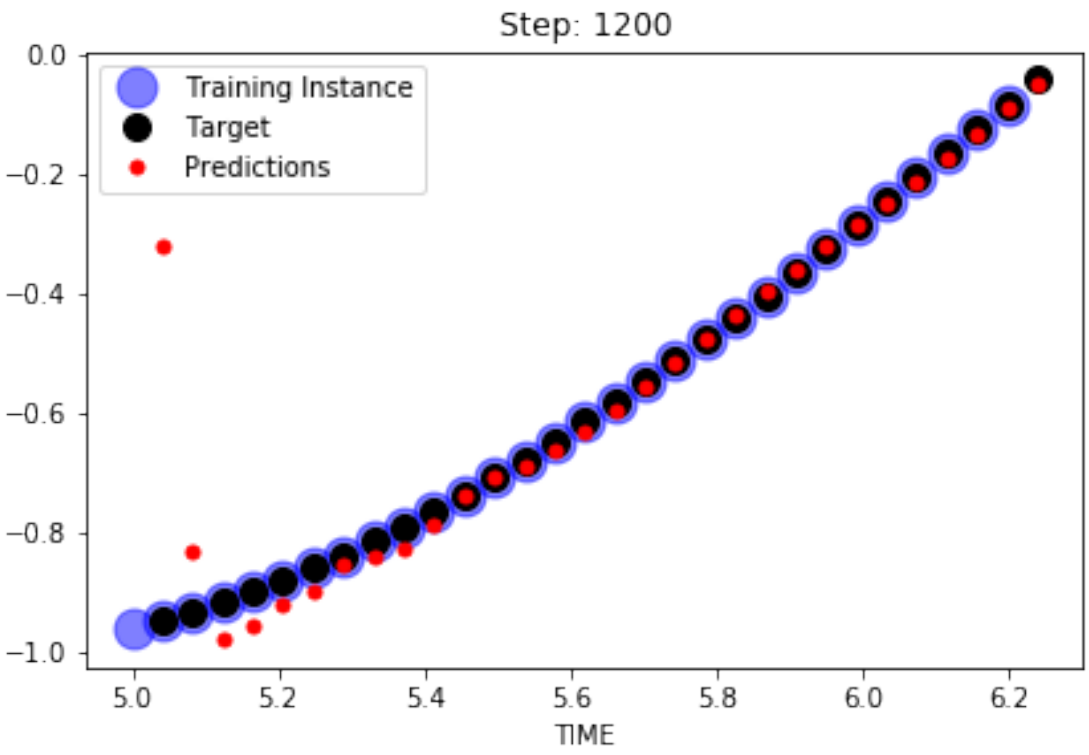

```
INFO:tensorflow:Restoring parameters from ./rnn_time_series_codealong
1000
```



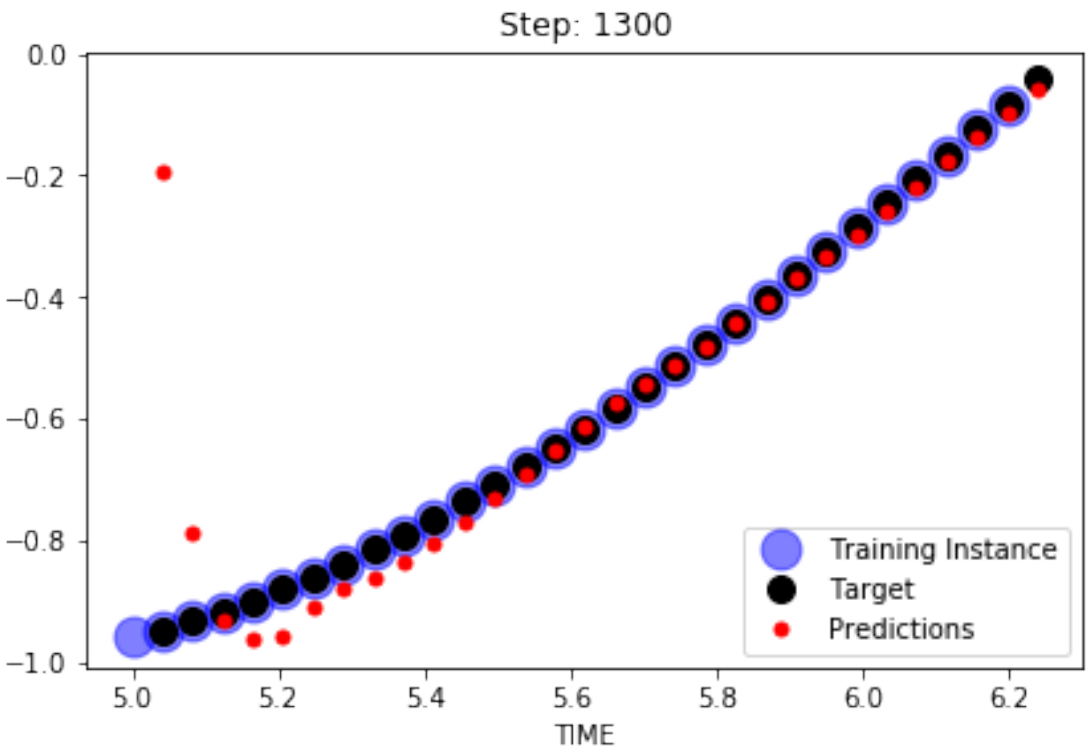

```
INFO:tensorflow:Restoring parameters from ./rnn_time_series_codealong
1100
```



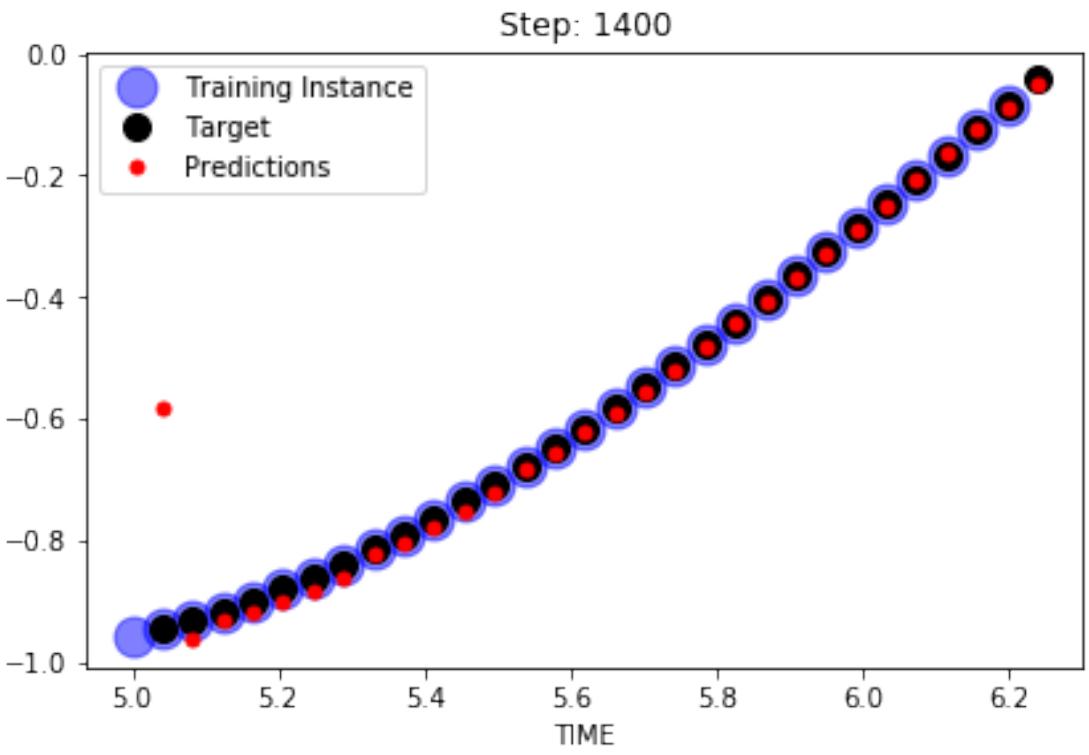

```
INFO:tensorflow:Restoring parameters from ./rnn_time_series_codealong
1200
```



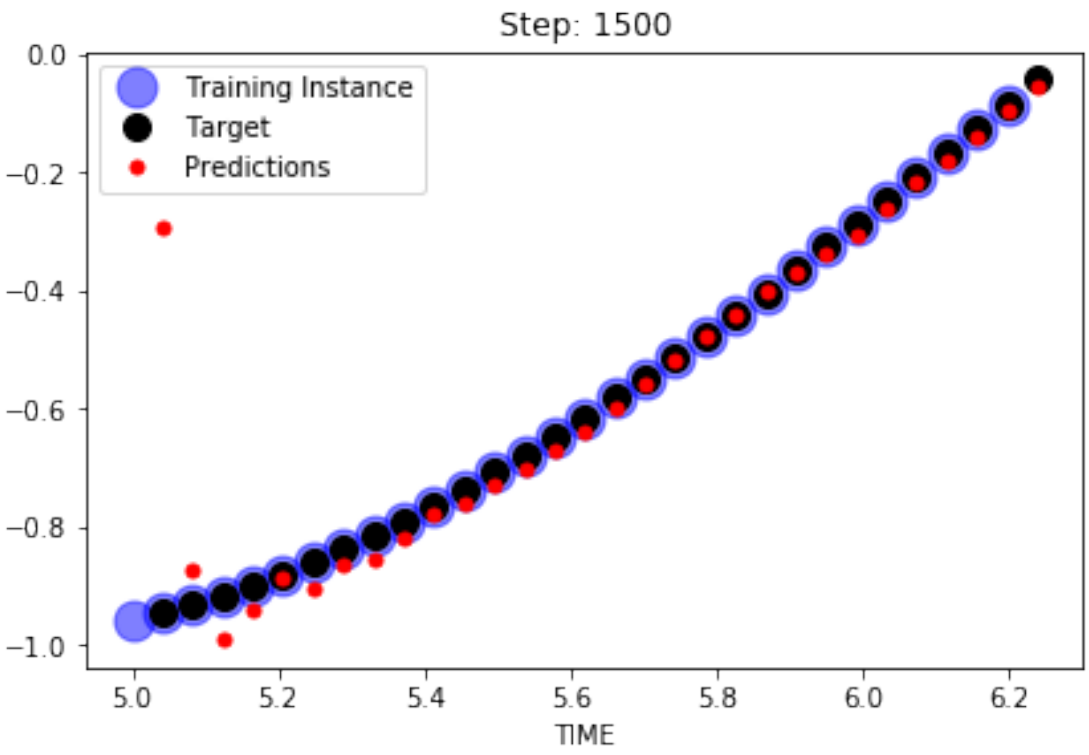

```
INFO:tensorflow:Restoring parameters from ./rnn_time_series_codealong
1300
```



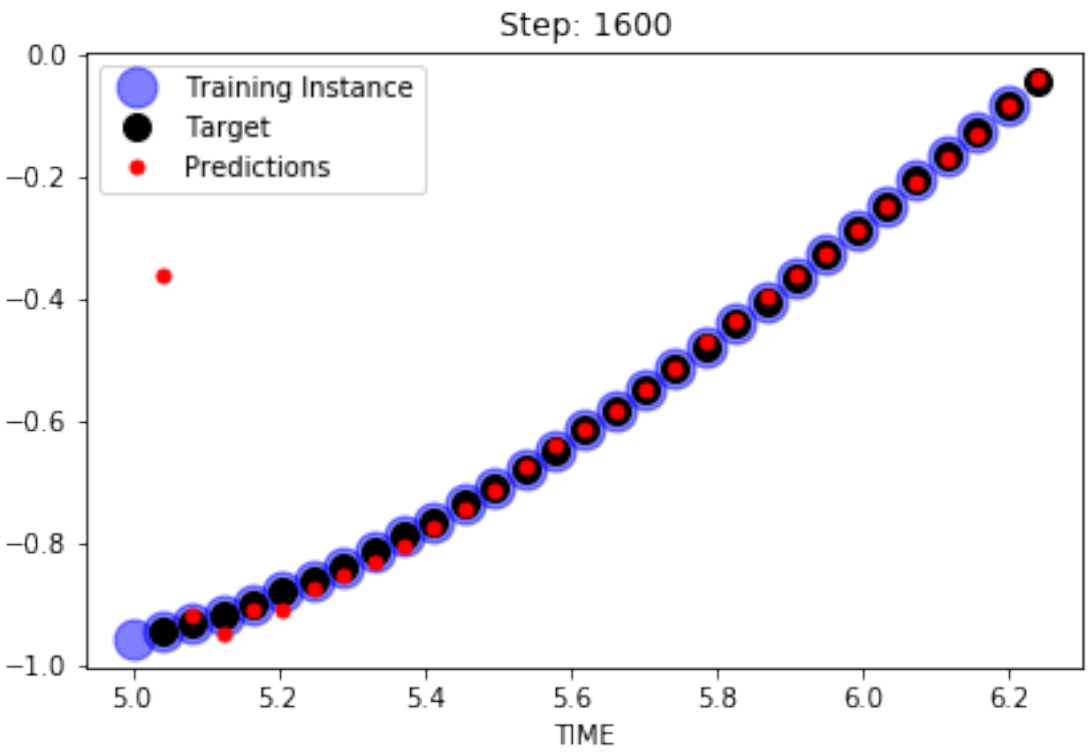

```
INFO:tensorflow:Restoring parameters from ./rnn_time_series_codealong
1400
```



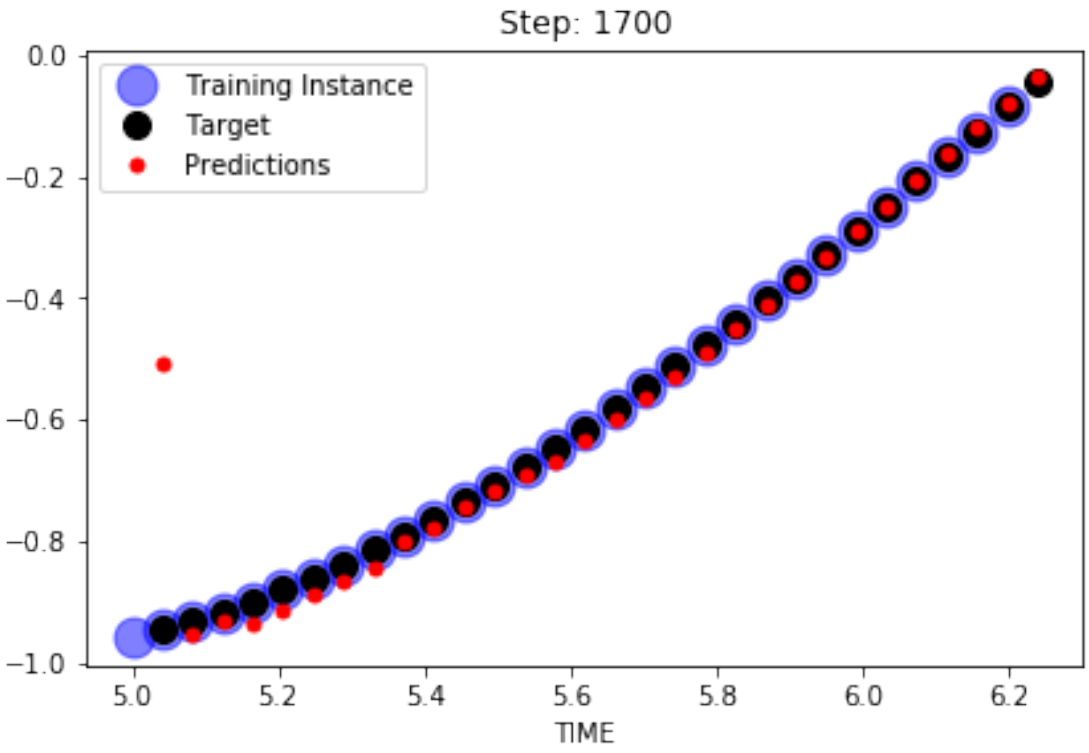

```
INFO:tensorflow:Restoring parameters from ./rnn_time_series_codealong
1500
```



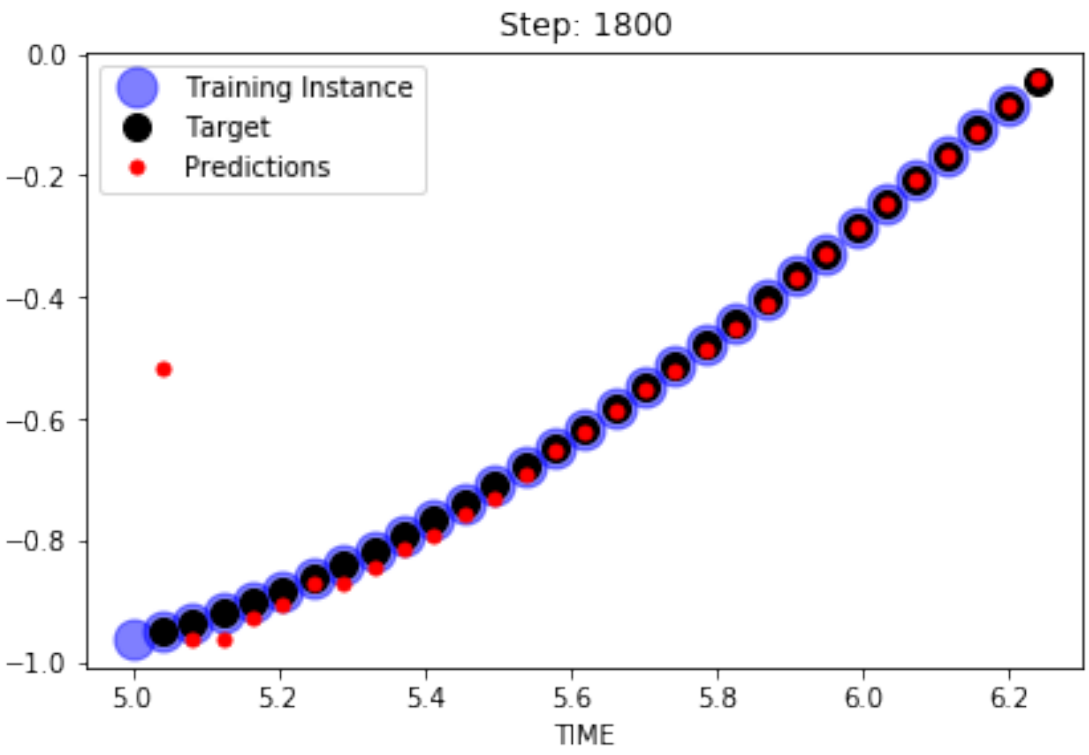

```
INFO:tensorflow:Restoring parameters from ./rnn_time_series_codealong
1600
```



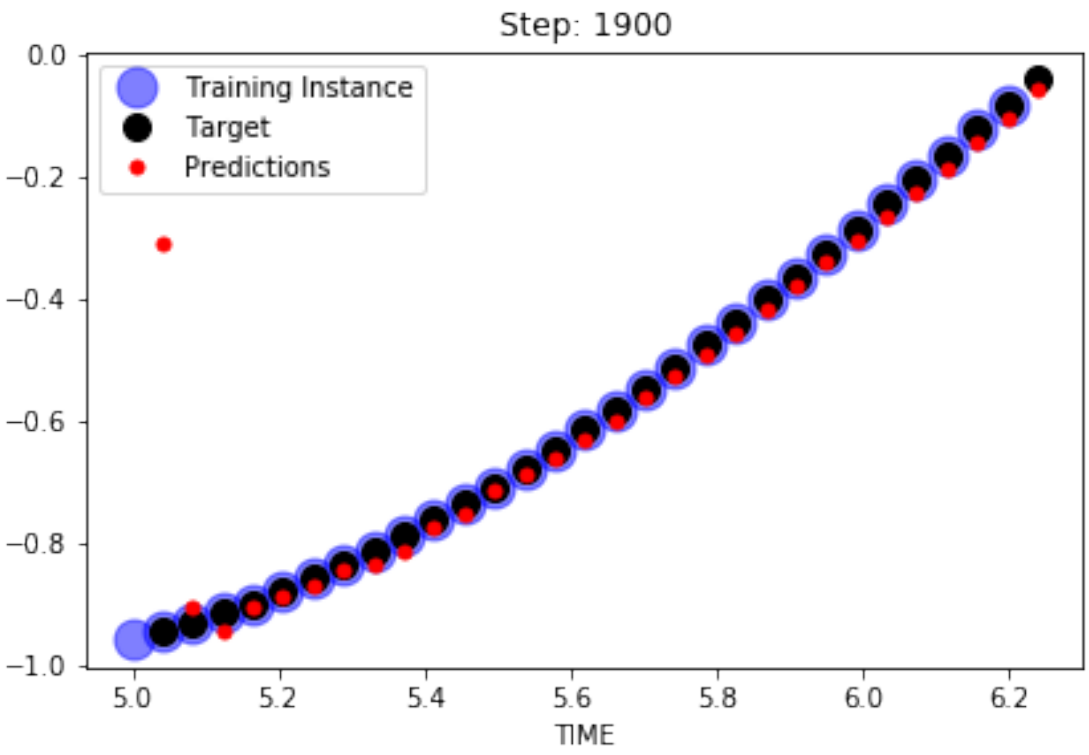

```
INFO:tensorflow:Restoring parameters from ./rnn_time_series_codealong
1700
```



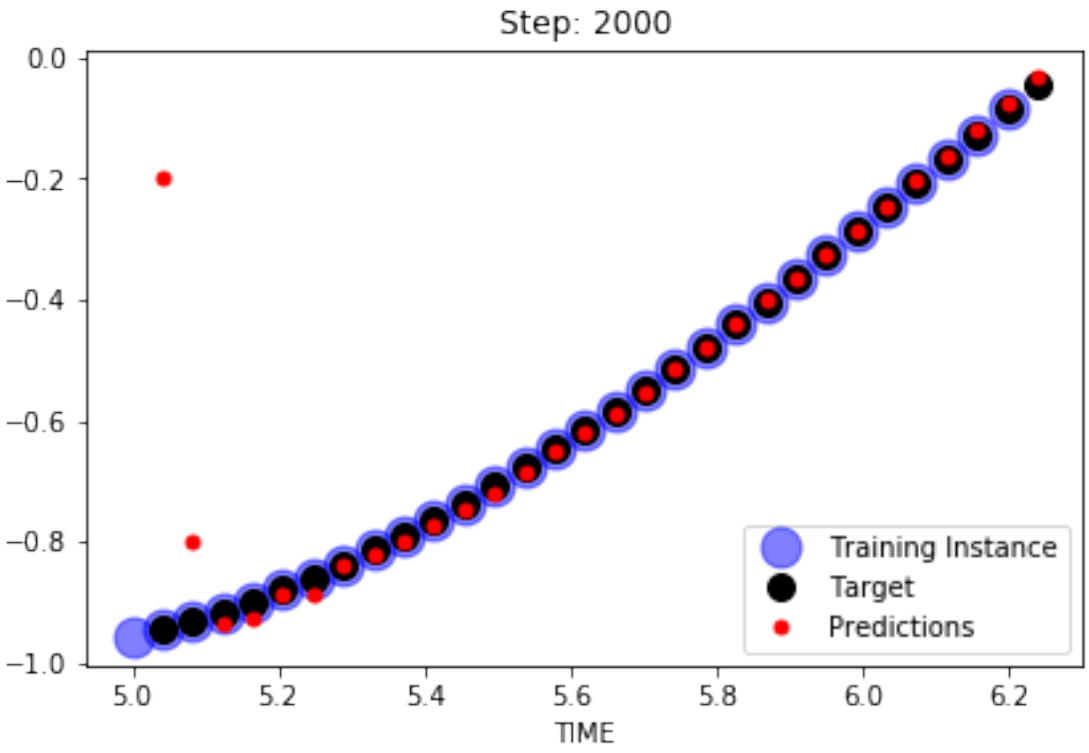

```
INFO:tensorflow:Restoring parameters from ./rnn_time_series_codealong
1800
```




```
INFO:tensorflow:Restoring parameters from ./rnn_time_series_codealong
1900
```




```
INFO:tensorflow:Restoring parameters from ./rnn_time_series_codealong
2000
```


Step: 2000
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
5.0
5.2
5.4
5.6
5.8
6.0
6.2
TIME
Training Instance
Target
Predictions