C4W2_Assignment

April 5, 2023

1 Week 2: Predicting time series

Welcome! In the previous assignment you got some exposure to working with time series data, but you didn't use machine learning techniques for your forecasts. This week you will be using a deep neural network to create forecasts to see how this technique compares with the ones you already tried out. Once again all of the data is going to be generated.

Let's get started!

[1]:
```
import numpy as np
import tensorflow as tf
import matplotlib.pyplot as plt
from dataclasses import dataclass

# import warnings
# warnings.filterwarnings('ignore')
```

1.1 Generating the data

The next cell includes a bunch of helper functions to generate and plot the time series:

[2]:
```
def plot_series(time, series, format="-", start=0, end=None):
    plt.plot(time[start:end], series[start:end], format)
    plt.xlabel("Time")
    plt.ylabel("Value")
    plt.grid(False)

def trend(time, slope=0):
    return slope * time

def seasonal_pattern(season_time):
    """Just an arbitrary pattern, you can change it if you wish"""
    return np.where(season_time < 0.1,
                    np.cos(season_time * 6 * np.pi),
                    2 / np.exp(9 * season_time))

def seasonality(time, period, amplitude=1, phase=0):
    """Repeats the same pattern at each period"""
    season_time = ((time + phase) % period) / period
```

```
    return amplitude * seasonal_pattern(season_time)

def noise(time, noise_level=1, seed=None):
    rnd = np.random.RandomState(seed)
    return rnd.randn(len(time)) * noise_level
```

You will be generating time series data that greatly resembles the one from last week but with some differences.

Notice that this time all the generation is done within a function and global variables are saved within a dataclass. This is done to avoid using global scope as it was done in during the previous week.

If you haven't used dataclasses before, they are just Python classes that provide a convenient syntax for storing data. You can read more about them in the docs.

[3]:
```
def generate_time_series():
    # The time dimension or the x-coordinate of the time series
    time = np.arange(4 * 365 + 1, dtype="float32")

    # Initial series is just a straight line with a y-intercept
    y_intercept = 10
    slope = 0.005
    series = trend(time, slope) + y_intercept

    # Adding seasonality
    amplitude = 50
    series += seasonality(time, period=365, amplitude=amplitude)

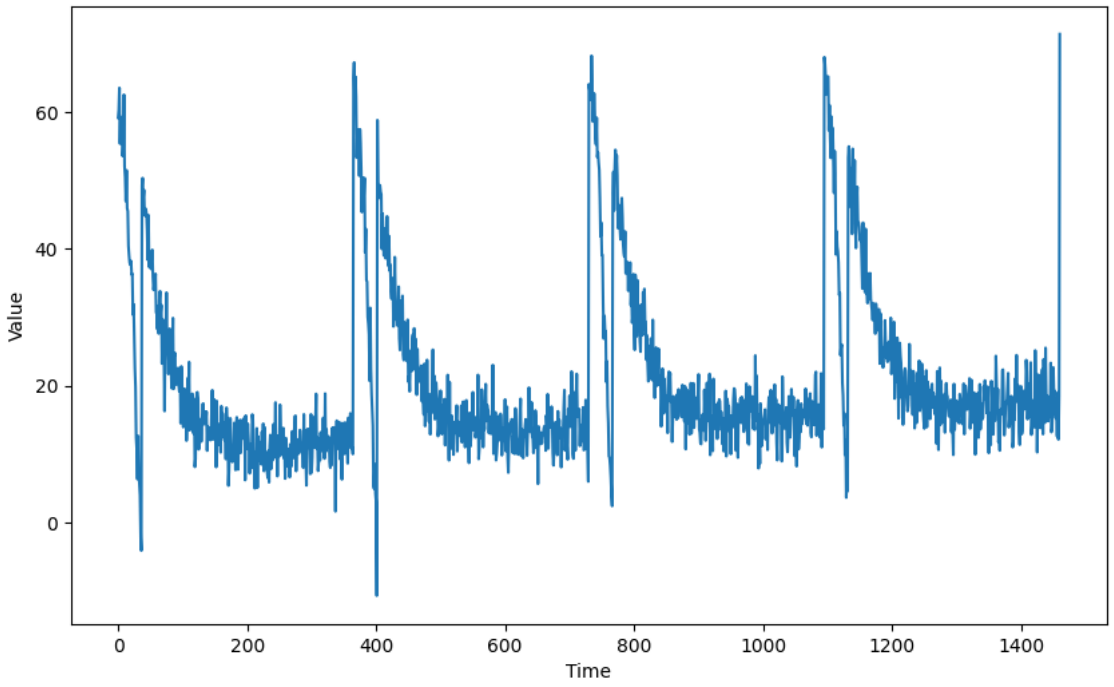
    # Adding some noise
    noise_level = 3
    series += noise(time, noise_level, seed=51)

    return time, series


# Save all "global" variables within the G class (G stands for global)
@dataclass
class G:
    TIME, SERIES = generate_time_series()
    SPLIT_TIME = 1100
    WINDOW_SIZE = 20
    BATCH_SIZE = 32
    SHUFFLE_BUFFER_SIZE = 1000


# Plot the generated series
plt.figure(figsize=(10, 6))
```

```
plot_series(G.TIME, G.SERIES)
plt.show()
```



1.2 Splitting the data

Since you already coded the `train_val_split` function during last week's assignment, this time it is provided for you:

[4]:
```
def train_val_split(time, series, time_step=G.SPLIT_TIME):

    time_train = time[:time_step]
    series_train = series[:time_step]
    time_valid = time[time_step:]
    series_valid = series[time_step:]

    return time_train, series_train, time_valid, series_valid


# Split the dataset
time_train, series_train, time_valid, series_valid = train_val_split(G.TIME, G.
 ↪SERIES)
```

1.3 Processing the data

As you saw on the lectures you can feed the data for training by creating a dataset with the appropiate processing steps such as `windowing`, `flattening`, `batching` and `shuffling`. To do so complete the `windowed_dataset` function below.

Notice that this function receives a `series`, `window_size`, `batch_size` and `shuffle_buffer` and the last three of these default to the "global" values defined earlier.

Be sure to check out the docs about `TF Datasets` if you need any help.

[5]:
```
def windowed_dataset(series, window_size=G.WINDOW_SIZE, batch_size=G.
 ↪BATCH_SIZE, shuffle_buffer=G.SHUFFLE_BUFFER_SIZE):

    ### START CODE HERE

    # Create dataset from the series
    dataset = tf.data.Dataset.from_tensor_slices(series)

    # Slice the dataset into the appropriate windows
    dataset = dataset.window(window_size + 1, shift=1, drop_remainder=True)

    # Flatten the dataset
    dataset = dataset.flat_map(lambda window: window.batch(window_size + 1))

    # Shuffle it
    dataset = dataset.shuffle(shuffle_buffer)

    # Split it into the features and labels
    dataset = dataset.map(lambda window: (window[:-1], window[-1]))

    # Batch it
    dataset = dataset.batch(batch_size).prefetch(1)

    ### END CODE HERE

    return dataset
```

To test your function you will be using a `window_size` of 1 which means that you will use each value to predict the next one. This for 5 elements since a `batch_size` of 5 is used and no shuffle since `shuffle_buffer` is set to 1.

Given this, the batch of features should be identical to the first 5 elements of the `series_train` and the batch of labels should be equal to elements 2 through 6 of the `series_train`.

[6]:
```
# Test your function with windows size of 1 and no shuffling
test_dataset = windowed_dataset(series_train, window_size=1, batch_size=5,␣
 ↪shuffle_buffer=1)

# Get the first batch of the test dataset
```

```
batch_of_features, batch_of_labels = next((iter(test_dataset)))

print(f"batch_of_features has type: {type(batch_of_features)}\n")
print(f"batch_of_labels has type: {type(batch_of_labels)}\n")
print(f"batch_of_features has shape: {batch_of_features.shape}\n")
print(f"batch_of_labels has shape: {batch_of_labels.shape}\n")
print(f"batch_of_features is equal to first five elements in the series: {np.
  ↪allclose(batch_of_features.numpy().flatten(), series_train[:5])}\n")
print(f"batch_of_labels is equal to first five labels: {np.
  ↪allclose(batch_of_labels.numpy(), series_train[1:6])}")
```

```
Metal device set to: Apple M1 Pro
batch_of_features has type: <class
'tensorflow.python.framework.ops.EagerTensor'>

batch_of_labels has type: <class 'tensorflow.python.framework.ops.EagerTensor'>

batch_of_features has shape: (5, 1)

batch_of_labels has shape: (5,)

batch_of_features is equal to first five elements in the series: True

batch_of_labels is equal to first five labels: True

2023-04-05 13:45:35.123798: I
tensorflow/core/common_runtime/pluggable_device/pluggable_device_factory.cc:305]
Could not identify NUMA node of platform GPU ID 0, defaulting to 0. Your kernel
may not have been built with NUMA support.
2023-04-05 13:45:35.124015: I
tensorflow/core/common_runtime/pluggable_device/pluggable_device_factory.cc:271]
Created TensorFlow device (/job:localhost/replica:0/task:0/device:GPU:0 with 0
MB memory) -> physical PluggableDevice (device: 0, name: METAL, pci bus id:
<undefined>)
2023-04-05 13:45:35.186275: W
tensorflow/core/platform/profile_utils/cpu_utils.cc:128] Failed to get CPU
frequency: 0 Hz
```

Expected Output:

```
batch_of_features has type: <class 'tensorflow.python.framework.ops.EagerTensor'>

batch_of_labels has type: <class 'tensorflow.python.framework.ops.EagerTensor'>

batch_of_features has shape: (5, 1)

batch_of_labels has shape: (5,)

batch_of_features is equal to first five elements in the series: True
```

```
batch_of_labels is equal to first five labels: True
```

1.4 Defining the model architecture

Now that you have a function that will process the data before it is fed into your neural network for training, it is time to define you layer architecture.

Complete the `create_model` function below. Notice that this function receives the `window_size` since this will be an important parameter for the first layer of your network.

Hint: - You will only need `Dense` layers. - Do not include `Lambda` layers. These are not required and are incompatible with the `HDF5` format which will be used to save your model for grading. - The training should be really quick so if you notice that each epoch is taking more than a few seconds, consider trying a different architecture.

[12]:
```
def create_model(window_size=G.WINDOW_SIZE):

    ### START CODE HERE

    model = tf.keras.models.Sequential([
        tf.keras.layers.Dense(20, input_shape=[window_size], activation="relu"),
        tf.keras.layers.Dense(10, activation="relu"),
        tf.keras.layers.Dense(1)
    ])

    model.compile(loss="mse", optimizer=tf.keras.optimizers.
 ↪SGD(learning_rate=1e-6, momentum=0.9))

    ### END CODE HERE

    return model
```

[13]:
```
# Apply the processing to the whole training series
dataset = windowed_dataset(series_train)

# Save an instance of the model
model = create_model()

# Train it
model.fit(dataset, epochs=100)
```

```
Epoch 1/100

2023-04-05 13:47:07.699334: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
Plugin optimizer for device_type GPU is enabled.

34/34 [==============================] - 1s 4ms/step - loss: 116.8029
Epoch 2/100
```

```
34/34 [==============================] - 0s 3ms/step - loss: 81.7779
Epoch 3/100
34/34 [==============================] - 0s 3ms/step - loss: 69.3402
Epoch 4/100
34/34 [==============================] - 0s 4ms/step - loss: 63.4508
Epoch 5/100
34/34 [==============================] - 0s 3ms/step - loss: 58.6884
Epoch 6/100
34/34 [==============================] - 0s 4ms/step - loss: 55.9619
Epoch 7/100
34/34 [==============================] - 0s 3ms/step - loss: 53.1970
Epoch 8/100
34/34 [==============================] - 0s 3ms/step - loss: 50.5827
Epoch 9/100
34/34 [==============================] - 0s 3ms/step - loss: 48.8018
Epoch 10/100
34/34 [==============================] - 0s 3ms/step - loss: 47.5132
Epoch 11/100
34/34 [==============================] - 0s 3ms/step - loss: 46.0785
Epoch 12/100
34/34 [==============================] - 0s 3ms/step - loss: 44.7797
Epoch 13/100
34/34 [==============================] - 0s 3ms/step - loss: 43.6182
Epoch 14/100
34/34 [==============================] - 0s 3ms/step - loss: 42.9689
Epoch 15/100
34/34 [==============================] - 0s 3ms/step - loss: 41.7583
Epoch 16/100
34/34 [==============================] - 0s 3ms/step - loss: 40.9174
Epoch 17/100
34/34 [==============================] - 0s 3ms/step - loss: 40.3483
Epoch 18/100
34/34 [==============================] - 0s 3ms/step - loss: 39.7833
Epoch 19/100
34/34 [==============================] - 0s 4ms/step - loss: 38.8274
Epoch 20/100
34/34 [==============================] - 0s 4ms/step - loss: 38.7147
Epoch 21/100
34/34 [==============================] - 0s 3ms/step - loss: 37.8800
Epoch 22/100
34/34 [==============================] - 0s 3ms/step - loss: 37.5357
Epoch 23/100
34/34 [==============================] - 0s 4ms/step - loss: 36.7937
Epoch 24/100
34/34 [==============================] - 0s 3ms/step - loss: 36.8055
Epoch 25/100
34/34 [==============================] - 0s 4ms/step - loss: 35.9907
Epoch 26/100
```

```
34/34 [==============================] - 0s 3ms/step - loss: 35.5612
Epoch 27/100
34/34 [==============================] - 0s 3ms/step - loss: 35.2909
Epoch 28/100
34/34 [==============================] - 0s 4ms/step - loss: 34.9496
Epoch 29/100
34/34 [==============================] - 0s 4ms/step - loss: 34.4592
Epoch 30/100
34/34 [==============================] - 0s 4ms/step - loss: 34.1466
Epoch 31/100
34/34 [==============================] - 0s 4ms/step - loss: 33.9237
Epoch 32/100
34/34 [==============================] - 0s 3ms/step - loss: 33.4726
Epoch 33/100
34/34 [==============================] - 0s 3ms/step - loss: 33.2444
Epoch 34/100
34/34 [==============================] - 0s 4ms/step - loss: 33.0400
Epoch 35/100
34/34 [==============================] - 0s 3ms/step - loss: 32.6991
Epoch 36/100
34/34 [==============================] - 0s 3ms/step - loss: 32.5008
Epoch 37/100
34/34 [==============================] - 0s 4ms/step - loss: 32.5279
Epoch 38/100
34/34 [==============================] - 0s 4ms/step - loss: 32.1407
Epoch 39/100
34/34 [==============================] - 0s 3ms/step - loss: 31.9747
Epoch 40/100
34/34 [==============================] - 0s 3ms/step - loss: 31.7316
Epoch 41/100
34/34 [==============================] - 0s 3ms/step - loss: 31.3939
Epoch 42/100
34/34 [==============================] - 0s 3ms/step - loss: 31.2206
Epoch 43/100
34/34 [==============================] - 0s 3ms/step - loss: 30.9897
Epoch 44/100
34/34 [==============================] - 0s 3ms/step - loss: 30.9006
Epoch 45/100
34/34 [==============================] - 0s 3ms/step - loss: 30.9441
Epoch 46/100
34/34 [==============================] - 0s 3ms/step - loss: 30.7004
Epoch 47/100
34/34 [==============================] - 0s 4ms/step - loss: 30.7476
Epoch 48/100
34/34 [==============================] - 0s 4ms/step - loss: 30.6203
Epoch 49/100
34/34 [==============================] - 0s 3ms/step - loss: 30.5403
Epoch 50/100
```

```
34/34 [==============================] - 0s 3ms/step - loss: 30.4960
Epoch 51/100
34/34 [==============================] - 0s 4ms/step - loss: 30.2646
Epoch 52/100
34/34 [==============================] - 0s 3ms/step - loss: 30.1550
Epoch 53/100
34/34 [==============================] - 0s 3ms/step - loss: 30.0554
Epoch 54/100
34/34 [==============================] - 0s 3ms/step - loss: 30.2125
Epoch 55/100
34/34 [==============================] - 0s 3ms/step - loss: 30.0244
Epoch 56/100
34/34 [==============================] - 0s 3ms/step - loss: 29.7802
Epoch 57/100
34/34 [==============================] - 0s 3ms/step - loss: 29.7583
Epoch 58/100
34/34 [==============================] - 0s 4ms/step - loss: 29.9044
Epoch 59/100
34/34 [==============================] - 0s 3ms/step - loss: 29.6552
Epoch 60/100
34/34 [==============================] - 0s 3ms/step - loss: 29.4785
Epoch 61/100
34/34 [==============================] - 0s 4ms/step - loss: 29.5779
Epoch 62/100
34/34 [==============================] - 0s 4ms/step - loss: 29.5944
Epoch 63/100
34/34 [==============================] - 0s 3ms/step - loss: 29.3875
Epoch 64/100
34/34 [==============================] - 0s 3ms/step - loss: 29.3888
Epoch 65/100
34/34 [==============================] - 0s 4ms/step - loss: 29.2469
Epoch 66/100
34/34 [==============================] - 0s 3ms/step - loss: 29.4825
Epoch 67/100
34/34 [==============================] - 0s 3ms/step - loss: 29.1715
Epoch 68/100
34/34 [==============================] - 0s 3ms/step - loss: 29.1445
Epoch 69/100
34/34 [==============================] - 0s 3ms/step - loss: 29.1726
Epoch 70/100
34/34 [==============================] - 0s 3ms/step - loss: 29.0032
Epoch 71/100
34/34 [==============================] - 0s 3ms/step - loss: 29.0759
Epoch 72/100
34/34 [==============================] - 0s 3ms/step - loss: 29.1336
Epoch 73/100
34/34 [==============================] - 0s 3ms/step - loss: 29.0473
Epoch 74/100
```

```
34/34 [==============================] - 0s 3ms/step - loss: 28.8184
Epoch 75/100
34/34 [==============================] - 0s 3ms/step - loss: 28.9130
Epoch 76/100
34/34 [==============================] - 0s 3ms/step - loss: 28.7958
Epoch 77/100
34/34 [==============================] - 0s 3ms/step - loss: 28.7335
Epoch 78/100
34/34 [==============================] - 0s 3ms/step - loss: 28.9381
Epoch 79/100
34/34 [==============================] - 0s 3ms/step - loss: 28.7914
Epoch 80/100
34/34 [==============================] - 0s 3ms/step - loss: 28.6995
Epoch 81/100
34/34 [==============================] - 0s 3ms/step - loss: 28.6749
Epoch 82/100
34/34 [==============================] - 0s 3ms/step - loss: 28.8203
Epoch 83/100
34/34 [==============================] - 0s 3ms/step - loss: 28.7073
Epoch 84/100
34/34 [==============================] - 0s 3ms/step - loss: 28.6978
Epoch 85/100
34/34 [==============================] - 0s 3ms/step - loss: 28.6447
Epoch 86/100
34/34 [==============================] - 0s 4ms/step - loss: 28.7096
Epoch 87/100
34/34 [==============================] - 0s 4ms/step - loss: 28.6447
Epoch 88/100
34/34 [==============================] - 0s 3ms/step - loss: 28.9399
Epoch 89/100
34/34 [==============================] - 0s 3ms/step - loss: 28.6942
Epoch 90/100
34/34 [==============================] - 0s 3ms/step - loss: 28.5295
Epoch 91/100
34/34 [==============================] - 0s 3ms/step - loss: 28.6113
Epoch 92/100
34/34 [==============================] - 0s 3ms/step - loss: 28.4422
Epoch 93/100
34/34 [==============================] - 0s 3ms/step - loss: 28.5810
Epoch 94/100
34/34 [==============================] - 0s 3ms/step - loss: 28.4548
Epoch 95/100
34/34 [==============================] - 0s 3ms/step - loss: 28.6883
Epoch 96/100
34/34 [==============================] - 0s 4ms/step - loss: 28.6446
Epoch 97/100
34/34 [==============================] - 0s 3ms/step - loss: 28.4658
Epoch 98/100
```

```
34/34 [==============================] - 0s 3ms/step - loss: 28.4389
Epoch 99/100
34/34 [==============================] - 0s 3ms/step - loss: 28.3561
Epoch 100/100
34/34 [==============================] - 0s 3ms/step - loss: 28.2683
```

[13]: <keras.callbacks.History at 0x2927cce20>

1.5 Evaluating the forecast

Now it is time to evaluate the performance of the forecast. For this you can use the `compute_metrics` function that you coded in the previous assignment:

[14]:
```
def compute_metrics(true_series, forecast):

    mse = tf.keras.metrics.mean_squared_error(true_series, forecast).numpy()
    mae = tf.keras.metrics.mean_absolute_error(true_series, forecast).numpy()

    return mse, mae
```

At this point only the model that will perform the forecast is ready but you still need to compute the actual forecast.

For this, run the cell below which uses the `generate_forecast` function to compute the forecast. This function generates the next value given a set of the previous `window_size` points for every point in the validation set.

[15]:
```
def generate_forecast(series=G.SERIES, split_time=G.SPLIT_TIME, window_size=G.
 ↪WINDOW_SIZE):
    forecast = []
    for time in range(len(series) - window_size):
        forecast.append(model.predict(series[time:time + window_size][np.
 ↪newaxis]))

    forecast = forecast[split_time-window_size:]
    results = np.array(forecast)[:, 0, 0]
    return results


# Save the forecast
dnn_forecast = generate_forecast()

# Plot it
plt.figure(figsize=(10, 6))
plot_series(time_valid, series_valid)
plot_series(time_valid, dnn_forecast)
```

```
1/1 [==============================] - 0s 36ms/step
1/1 [==============================] - 0s 10ms/step
```

```
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```

```
2023-04-05 13:47:28.064874: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:113]
Plugin optimizer for device_type GPU is enabled.
```

```
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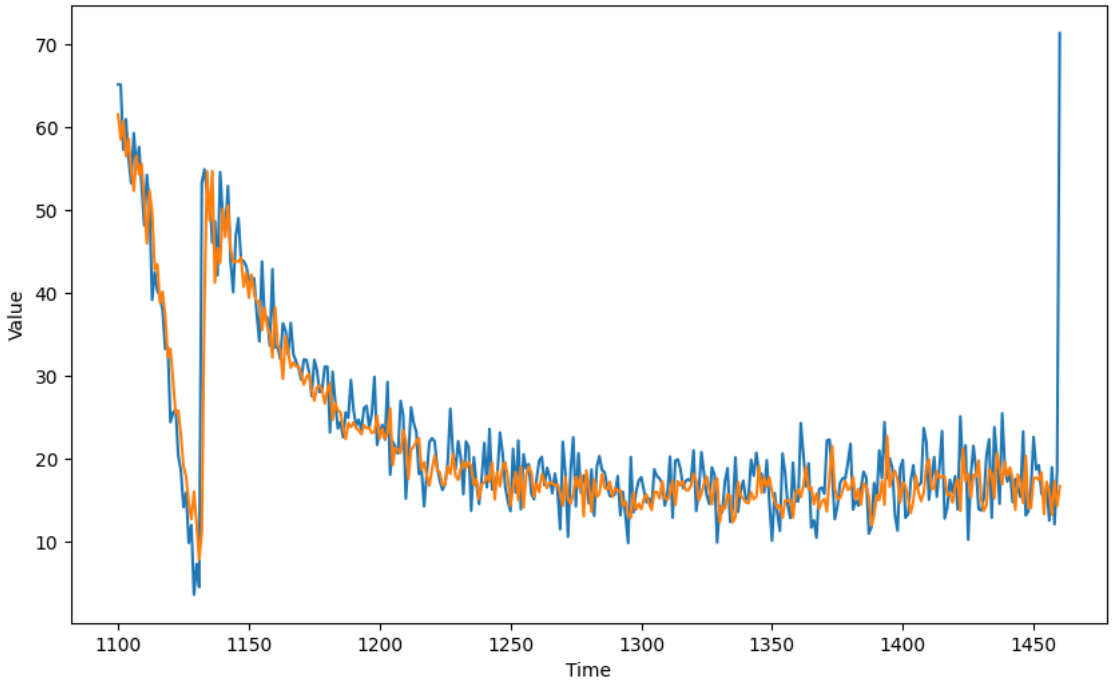

Expected Output:

A series similar to this one:

[16]:
```
mse, mae = compute_metrics(series_valid, dnn_forecast)

print(f"mse: {mse:.2f}, mae: {mae:.2f} for forecast")
```

```
mse: 28.51, mae: 3.28 for forecast
```

To pass this assignment your forecast should achieve an MSE of 30 or less.

- If your forecast didn't achieve this threshold try re-training your model with a different architecture or tweaking the optimizer's parameters.
- If your forecast did achieve this threshold run the following cell to save your model in a HDF5 file file which will be used for grading and after doing so, submit your assigment for grading.
- Make sure you didn't use `Lambda` layers in your model since these are incompatible with the `HDF5` format which will be used to save your model for grading.
- This environment includes a dummy `my_model.h5` file which is just a dummy model trained for one epoch. **To replace this file with your actual model you need to run the next cell before submitting for grading.**

[17]:
```
# Save your model in HDF5 format
model.save('my_model.h5')
```

Congratulations on finishing this week's assignment!

You have successfully implemented a neural network capable of forecasting time series while also learning how to leverage Tensorflow's Dataset class to process time series data!

Keep it up!