```
import tensorflow as tf
print(tf.__version__)
```

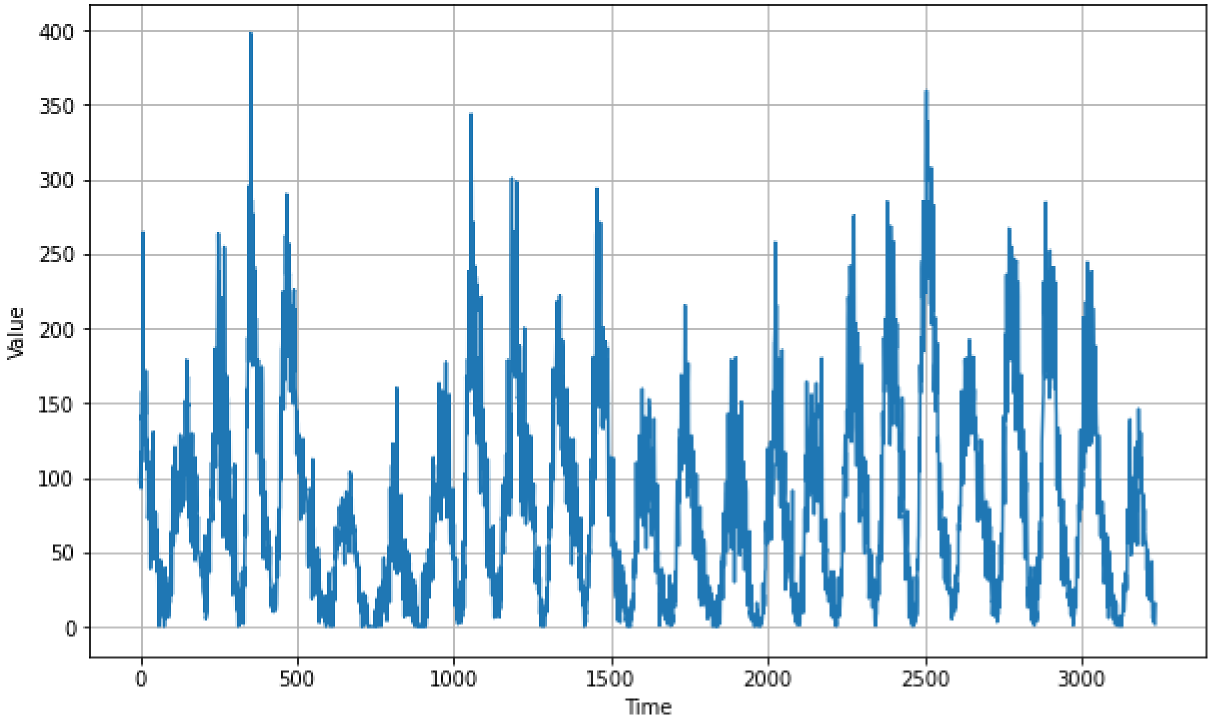
```
2.3.0
```

```
import numpy as np
import matplotlib.pyplot as plt
#the matplotlib function that'll plot our data
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(True)
```

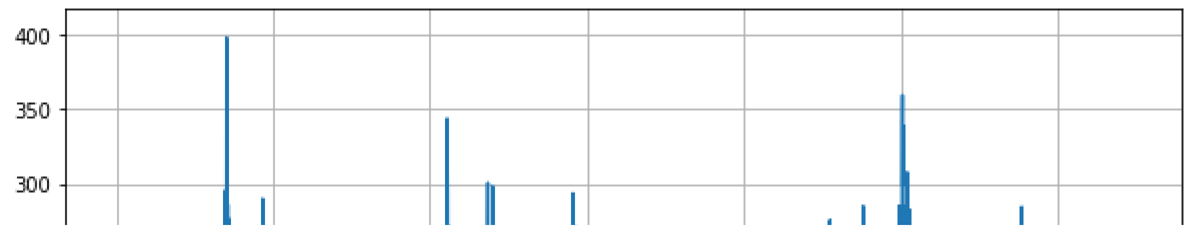
```
!wget --no-check-certificate \
    https://storage.googleapis.com/laurencemoroney-blog.appspot.com/Sunspots.csv \
    -O /tmp/sunspots.csv
```

```
--2020-09-24 18:45:55--  https://storage.googleapis.com/laurencemoroney-blog.appspot.co
Resolving storage.googleapis.com (storage.googleapis.com)... 74.125.142.128, 74.125.20.
Connecting to storage.googleapis.com (storage.googleapis.com)|74.125.142.128|:443... co
HTTP request sent, awaiting response... 200 OK
Length: 70827 (69K) [application/octet-stream]
Saving to: ‘/tmp/sunspots.csv’

/tmp/sunspots.csv   100%[===================>]  69.17K  --.-KB/s    in 0s

2020-09-24 18:45:55 (154 MB/s) - ‘/tmp/sunspots.csv’ saved [70827/70827]
```

```
import csv
time_step = []
sunspots = []

with open('/tmp/sunspots.csv') as csvfile:
  #get data and ignore header
  reader = csv.reader(csvfile, delimiter=',')
  next(reader)
  for row in reader:
    #data present as time_Step, date, monthly_mean, sunspot No
    sunspots.append(float(row[2]))
    time_step.append(int(row[0]))

series = np.array(sunspots)
time = np.array(time_step)
plt.figure(figsize=(10, 6))
plot_series(time, series)
```



```
series = np.array(sunspots)
time = np.array(time_step)
plt.figure(figsize=(10, 6))
plot_series(time, series)
```



```
#splitting data appropriately (3.5k rows in total)
split_time = 3000
time_train = time[:split_time]
x_train = series[:split_time]
time_valid = time[split_time:]
x_valid = series[split_time:]

window_size = 30
batch_size = 32
shuffle_buffer_size = 1000
```

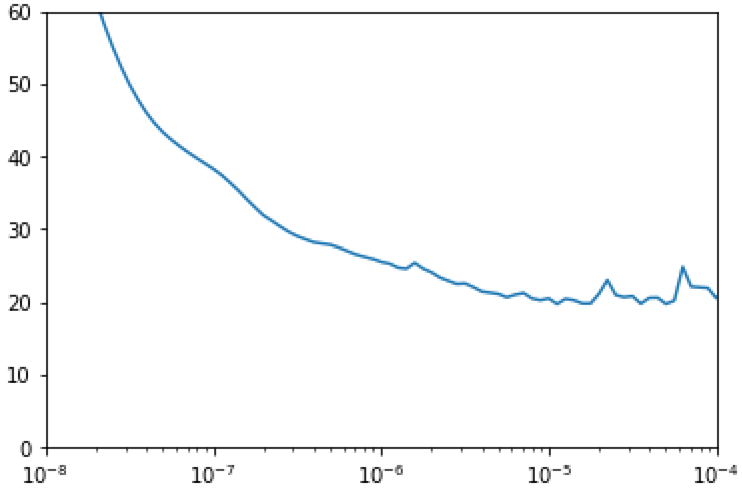
```
#same method
def windowed_dataset(series, window_size, batch_size, shuffle_buffer):
    series = tf.expand_dims(series, axis=-1)
    ds = tf.data.Dataset.from_tensor_slices(series)
    ds = ds.window(window_size + 1, shift=1, drop_remainder=True)
    ds = ds.flat_map(lambda w: w.batch(window_size + 1))
    ds = ds.shuffle(shuffle_buffer)
    ds = ds.map(lambda w: (w[:-1], w[1:]))
    return ds.batch(batch_size).prefetch(1)


#same method
def model_forecast(model, series, window_size):
    ds = tf.data.Dataset.from_tensor_slices(series)
    ds = ds.window(window_size, shift=1, drop_remainder=True)
    ds = ds.flat_map(lambda w: w.batch(window_size))
    ds = ds.batch(32).prefetch(1)
    forecast = model.predict(ds)
    return forecast


#same dummy training to obtain the optimal learning rate
tf.keras.backend.clear_session()
tf.random.set_seed(51)
np.random.seed(51)
window_size = 64
batch_size = 256
train_set = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)
print(train_set)
print(x_train.shape)

model = tf.keras.models.Sequential([
  tf.keras.layers.Conv1D(filters=32, kernel_size=5
  tf.keras.layers.Conv1D(filters=32, kernel_size=5,
                      strides=1, padding="causal",
                      activation="relu",
                      input_shape=[None, 1]),
  tf.keras.layers.LSTM(64, return_sequences=True),
  tf.keras.layers.LSTM(64, return_sequences=True),
  tf.keras.layers.Dense(30, activation="relu"),
  tf.keras.layers.Dense(10, activation="relu"),
  tf.keras.layers.Dense(1),
  tf.keras.layers.Lambda(lambda x: x * 400)
])

lr_schedule = tf.keras.callbacks.LearningRateScheduler(
    lambda epoch: 1e-8 * 10**(epoch / 20))
optimizer = tf.keras.optimizers.SGD(lr=1e-8, momentum=0.9)
model.compile(loss=tf.keras.losses.Huber(),
              optimizer=optimizer,
              metrics=["mae"])
history = model.fit(train_set, epochs=100, callbacks=[lr_schedule])
```

```
Epoch 57/100
12/12 [==============================] - 0s 34ms/step - loss: 20.9938 - mae: 21.4874
Epoch 58/100
12/12 [==============================] - 0s 32ms/step - loss: 21.2244 - mae: 21.7176
Epoch 59/100
12/12 [==============================] - 0s 24ms/step - loss: 20.4741 - mae: 20.9674
Epoch 60/100
12/12 [==============================] - 0s 23ms/step - loss: 20.2279 - mae: 20.7212
Epoch 61/100
12/12 [==============================] - 0s 26ms/step - loss: 20.4773 - mae: 20.9706
Epoch 62/100
12/12 [==============================] - 0s 27ms/step - loss: 19.7027 - mae: 20.1955
Epoch 63/100
12/12 [==============================] - 0s 27ms/step - loss: 20.4218 - mae: 20.9151
Epoch 64/100
12/12 [==============================] - 0s 24ms/step - loss: 20.2329 - mae: 20.7262
Epoch 65/100
12/12 [==============================] - 0s 27ms/step - loss: 19.7864 - mae: 20.2793
Epoch 66/100
12/12 [==============================] - 0s 23ms/step - loss: 19.7812 - mae: 20.2743
Epoch 67/100
12/12 [==============================] - 0s 25ms/step - loss: 21.1135 - mae: 21.6067
Epoch 68/100
12/12 [==============================] - 0s 24ms/step - loss: 23.0073 - mae: 23.5012
Epoch 69/100
12/12 [==============================] - 0s 23ms/step - loss: 20.9457 - mae: 21.4389
Epoch 70/100
12/12 [==============================] - 0s 29ms/step - loss: 20.6533 - mae: 21.1463
Epoch 71/100
12/12 [==============================] - 0s 24ms/step - loss: 20.7998 - mae: 21.2931
Epoch 72/100
12/12 [==============================] - 0s 24ms/step - loss: 19.7447 - mae: 20.2372
Epoch 73/100
12/12 [==============================] - 0s 25ms/step - loss: 20.5572 - mae: 21.0501
Epoch 74/100
12/12 [==============================] - 0s 23ms/step - loss: 20.5863 - mae: 21.0790
Epoch 75/100
12/12 [==============================] - 0s 23ms/step - loss: 19.7095 - mae: 20.2021
Epoch 76/100
12/12 [==============================] - 0s 24ms/step - loss: 20.1837 - mae: 20.6766
Epoch 77/100
12/12 [==============================] - 0s 25ms/step - loss: 24.8210 - mae: 25.3148
Epoch 78/100
12/12 [==============================] - 0s 23ms/step - loss: 22.1042 - mae: 22.5977
Epoch 79/100
12/12 [==============================] - 0s 31ms/step - loss: 22.0100 - mae: 22.5033
Epoch 80/100
12/12 [==============================] - 0s 31ms/step - loss: 21.9199 - mae: 22.4136
Epoch 81/100
12/12 [==============================] - 0s 24ms/step - loss: 20.5124 - mae: 21.0056
Epoch 82/100
12/12 [==============================] - 0s 24ms/step - loss: 22.0512 - mae: 22.5451
Epoch 83/100
12/12 [==============================] - 0s 35ms/step - loss: 29.7343 - mae: 30.2293
Epoch 84/100
12/12 [==============================] - 0s 30ms/step - loss: 36.4868 - mae: 36.9831
Epoch 85/100
```

```
12/12 [==============================] - 0s 24ms/step - loss: 38.4671 - mae: 38.9636
Epoch 86/100
12/12 [==============================] - 0s 26ms/step - loss: 31.8518 - mae: 32.3478
Epoch 87/100
12/12 [==============================] - 0s 27ms/step - loss: 30.2900 - mae: 30.7852
Epoch 88/100
12/12 [==============================] - 0s 35ms/step - loss: 31.2199 - mae: 31.7152
Epoch 89/100
12/12 [==============================] - 0s 33ms/step - loss: 28.4525 - mae: 28.9476
Epoch 90/100
12/12 [==============================] - 0s 35ms/step - loss: 41.4775 - mae: 41.9745
Epoch 91/100
12/12 [==============================] - 0s 24ms/step - loss: 44.8347 - mae: 45.3317
Epoch 92/100
12/12 [==============================] - 0s 24ms/step - loss: 47.4526 - mae: 47.9502
Epoch 93/100
12/12 [==============================] - 0s 25ms/step - loss: 46.7610 - mae: 47.2587
Epoch 94/100
12/12 [==============================] - 0s 24ms/step - loss: 44.9095 - mae: 45.4069
Epoch 95/100
12/12 [==============================] - 0s 24ms/step - loss: 39.7608 - mae: 40.2579
Epoch 96/100
12/12 [==============================] - 0s 23ms/step - loss: 51.7497 - mae: 52.2477
Epoch 97/100
12/12 [==============================] - 0s 25ms/step - loss: 69.2137 - mae: 69.7124
Epoch 98/100
12/12 [==============================] - 0s 25ms/step - loss: 62.7264 - mae: 63.2247
Epoch 99/100
12/12 [==============================] - 0s 24ms/step - loss: 62.8415 - mae: 63.3402
Epoch 100/100
12/12 [==============================] - 0s 31ms/step - loss: 66.2437 - mae: 66.7421
```

```
plt.semilogx(history.history["lr"], history.history["loss"])
plt.axis([1e-8, 1e-4, 0, 60])
```

```
(1e-08, 0.0001, 0.0, 60.0)
```



```
#proper training with optimal learning rate
tf.keras.backend.clear_session()
tf.random.set_seed(51)
np.random.seed(51)
train_set = windowed_dataset(x_train, window_size=60, batch_size=100, shuffle_buffer=shuffle_
model = tf.keras.models.Sequential([
  tf.keras.layers.Conv1D(filters=60, kernel_size=5,
                      strides=1, padding="causal",
                      activation="relu",
                      input_shape=[None, 1]),
  tf.keras.layers.LSTM(60, return_sequences=True),
  tf.keras.layers.LSTM(60, return_sequences=True),
  tf.keras.layers.Dense(30, activation="relu"),
  tf.keras.layers.Dense(10, activation="relu"),
  tf.keras.layers.Dense(1),
  tf.keras.layers.Lambda(lambda x: x * 400)
])


optimizer = tf.keras.optimizers.SGD(lr=1e-5, momentum=0.9)
model.compile(loss=tf.keras.losses.Huber(),
              optimizer=optimizer,
              metrics=["mae"])
history = model.fit(train_set,epochs=500)
```

```
Epoch 1/500
30/30 [==============================] - 0s 14ms/step - loss: 38.9172 - mae: 39.4135
Epoch 2/500
30/30 [==============================] - 0s 14ms/step - loss: 25.7615 - mae: 26.2559
Epoch 3/500
30/30 [==============================] - 0s 14ms/step - loss: 22.0742 - mae: 22.5679
Epoch 4/500
30/30 [==============================] - 0s 14ms/step - loss: 20.4516 - mae: 20.9444
Epoch 5/500
30/30 [==============================] - 0s 14ms/step - loss: 19.7474 - mae: 20.2398
Epoch 6/500
30/30 [==============================] - 0s 14ms/step - loss: 19.3944 - mae: 19.8866
Epoch 7/500
30/30 [==============================] - 1s 17ms/step - loss: 18.5548 - mae: 19.0467
Epoch 8/500
30/30 [==============================] - 0s 14ms/step - loss: 18.2319 - mae: 18.7236
Epoch 9/500
30/30 [==============================] - 0s 15ms/step - loss: 18.0495 - mae: 18.5409
Epoch 10/500
30/30 [==============================] - 0s 15ms/step - loss: 17.9326 - mae: 18.4237
Epoch 11/500
30/30 [==============================] - 0s 14ms/step - loss: 18.5046 - mae: 18.9957
Epoch 12/500
30/30 [==============================] - 0s 14ms/step - loss: 17.9796 - mae: 18.4705
Epoch 13/500
30/30 [==============================] - 0s 14ms/step - loss: 17.6380 - mae: 18.1284
Epoch 14/500
30/30 [==============================] - 0s 14ms/step - loss: 17.7230 - mae: 18.2137
Epoch 15/500
30/30 [==============================] - 0s 14ms/step - loss: 17.8856 - mae: 18.3763
Epoch 16/500
30/30 [==============================] - 0s 14ms/step - loss: 17.7863 - mae: 18.2771
Epoch 17/500
30/30 [==============================] - 1s 17ms/step - loss: 17.6223 - mae: 18.1131
Epoch 18/500
30/30 [==============================] - 0s 16ms/step - loss: 17.5275 - mae: 18.0181
Epoch 19/500
30/30 [==============================] - 0s 14ms/step - loss: 17.2992 - mae: 17.7898
Epoch 20/500
30/30 [==============================] - 0s 14ms/step - loss: 17.4308 - mae: 17.9216
Epoch 21/500
30/30 [==============================] - 0s 17ms/step - loss: 17.3801 - mae: 17.8707
Epoch 22/500
30/30 [==============================] - 0s 14ms/step - loss: 17.1953 - mae: 17.6859
Epoch 23/500
30/30 [==============================] - 1s 17ms/step - loss: 17.3690 - mae: 17.8597
Epoch 24/500
30/30 [==============================] - 0s 14ms/step - loss: 17.4596 - mae: 17.9503
Epoch 25/500
30/30 [==============================] - 0s 14ms/step - loss: 17.1725 - mae: 17.6630
Epoch 26/500
30/30 [==============================] - 1s 18ms/step - loss: 17.2396 - mae: 17.7300
Epoch 27/500
30/30 [==============================] - 0s 14ms/step - loss: 17.1303 - mae: 17.6207
Epoch 28/500
30/30 [==============================] - 0s 14ms/step - loss: 17.1379 - mae: 17.6281
Epoch 29/500
```

```
30/30 [==============================] - 0s 14ms/step - loss: 17.0702 - mae: 17.5603
Epoch 30/500
30/30 [==============================] - 0s 14ms/step - loss: 17.1686 - mae: 17.6590
Epoch 31/500
30/30 [==============================] - 0s 14ms/step - loss: 17.3894 - mae: 17.8798
Epoch 32/500
30/30 [==============================] - 0s 14ms/step - loss: 16.9797 - mae: 17.4698
Epoch 33/500
30/30 [==============================] - 0s 14ms/step - loss: 17.0031 - mae: 17.4930
Epoch 34/500
30/30 [==============================] - 0s 15ms/step - loss: 16.9088 - mae: 17.3989
Epoch 35/500
30/30 [==============================] - 0s 14ms/step - loss: 17.0443 - mae: 17.5345
Epoch 36/500
30/30 [==============================] - 0s 14ms/step - loss: 16.9896 - mae: 17.4799
Epoch 37/500
30/30 [==============================] - 0s 14ms/step - loss: 16.9655 - mae: 17.4557
Epoch 38/500
30/30 [==============================] - 0s 15ms/step - loss: 16.9699 - mae: 17.4599
Epoch 39/500
30/30 [==============================] - 0s 14ms/step - loss: 17.4723 - mae: 17.9626
Epoch 40/500
30/30 [==============================] - 0s 15ms/step - loss: 17.0522 - mae: 17.5420
Epoch 41/500
30/30 [==============================] - 1s 17ms/step - loss: 16.7931 - mae: 17.2829
Epoch 42/500
30/30 [==============================] - 1s 18ms/step - loss: 16.8157 - mae: 17.3053
Epoch 43/500
30/30 [==============================] - 0s 15ms/step - loss: 16.8448 - mae: 17.3344
Epoch 44/500
30/30 [==============================] - 0s 14ms/step - loss: 17.2477 - mae: 17.7375
Epoch 45/500
30/30 [==============================] - 0s 14ms/step - loss: 16.8892 - mae: 17.3790
Epoch 46/500
30/30 [==============================] - 0s 14ms/step - loss: 16.8554 - mae: 17.3449
Epoch 47/500
30/30 [==============================] - 0s 15ms/step - loss: 16.9594 - mae: 17.4489
Epoch 48/500
30/30 [==============================] - 0s 14ms/step - loss: 16.8857 - mae: 17.3756
Epoch 49/500
30/30 [==============================] - 0s 14ms/step - loss: 16.8647 - mae: 17.3541
Epoch 50/500
30/30 [==============================] - 0s 15ms/step - loss: 16.7058 - mae: 17.1953
Epoch 51/500
30/30 [==============================] - 1s 17ms/step - loss: 16.7383 - mae: 17.2275
Epoch 52/500
30/30 [==============================] - 1s 17ms/step - loss: 16.9243 - mae: 17.4135
Epoch 53/500
30/30 [==============================] - 0s 15ms/step - loss: 16.6641 - mae: 17.1536
Epoch 54/500
30/30 [==============================] - 1s 17ms/step - loss: 16.7189 - mae: 17.2078
Epoch 55/500
30/30 [==============================] - 0s 14ms/step - loss: 16.7722 - mae: 17.2613
Epoch 56/500
30/30 [==============================] - 0s 14ms/step - loss: 16.6568 - mae: 17.1463
Epoch 57/500
30/30 [==============================] - 0s 13ms/step - loss: 16.6300 - mae: 17.1192
Epoch 58/500
```