```
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```

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

```
2.0.0-beta1
```

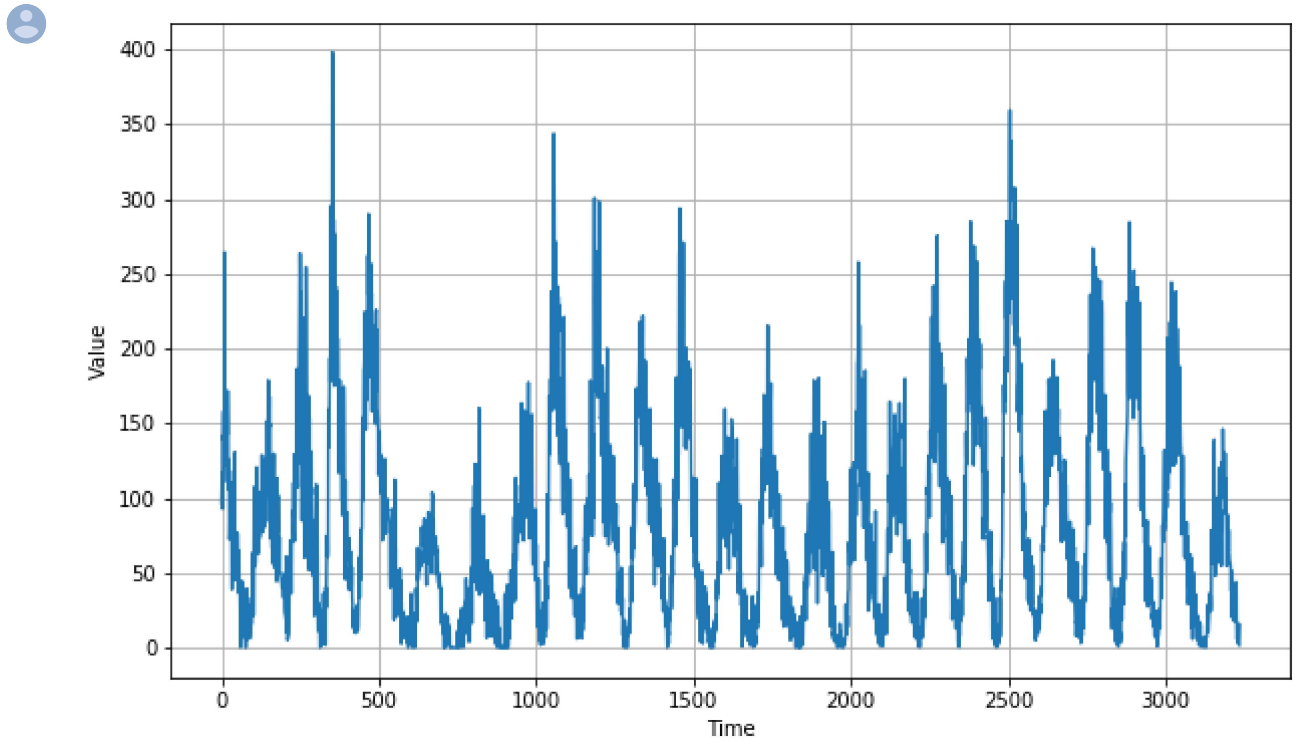
```
import numpy as np
import matplotlib.pyplot as plt
def plot_series(time, series, format="-", start=0, end=None):
    plt.plot(time[start:end], series[start:end], format)
    plt.xlabel("Time")
    plt.ylabel("Value")
    plt.grid(True)
```

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

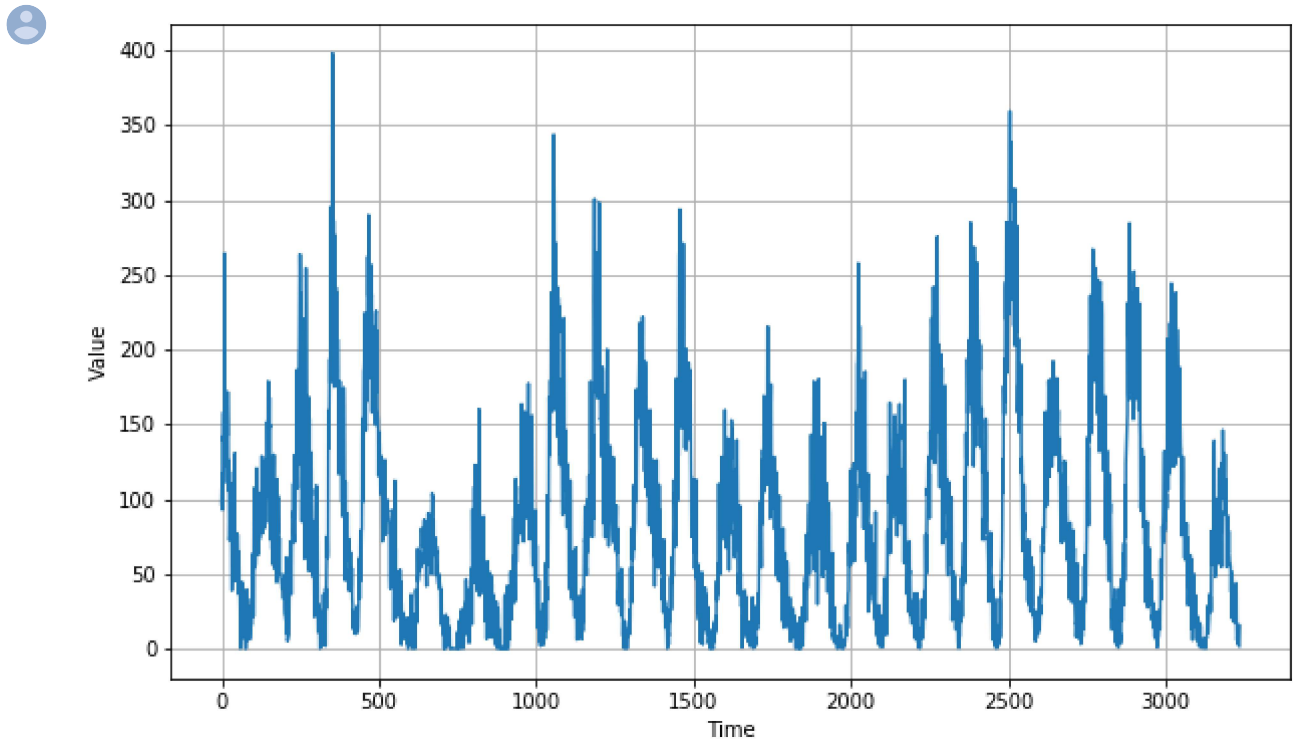
```
--2019-07-02 23:12:41-- https://storage.googleapis.com/laurencemoroney-blog.appspot
Resolving storage.googleapis.com (storage.googleapis.com)... 172.217.194.128, 2404:6
Connecting to storage.googleapis.com (storage.googleapis.com)|172.217.194.128|:443..
HTTP request sent, awaiting response... 200 OK
Length: 70827 (69K) [application/octet-stream]
Saving to: '/tmp/sunspots.csv'

/tmp/sunspots.csv   100%[===================>]  69.17K  --.-KB/s    in 0.001s

2019-07-02 23:12:42 (116 MB/s) - '/tmp/sunspots.csv' saved [70827/70827]
```

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

with open('/tmp/sunspots.csv') as csvfile:
    reader = csv.reader(csvfile, delimiter=',')
    next(reader)
    for row in reader:
        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)
```


```
split_time = 3000
time_train = time[:split_time]
x_train = series[: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



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)


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


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,
                         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"])
```

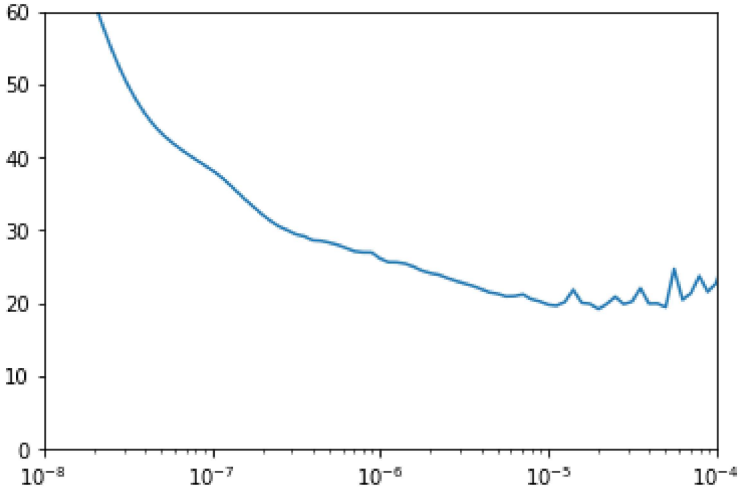
```
history = model.fit(train_set, epochs=100, callbacks=[lr_schedule])
```

```
12/12 [==============================] - 4s 332ms/step - loss: 21.8298 - mae: 22.295
Epoch 65/100
12/12 [==============================] - 4s 334ms/step - loss: 20.0344 - mae: 20.501
Epoch 66/100
12/12 [==============================] - 4s 338ms/step - loss: 19.8413 - mae: 20.355
Epoch 67/100
12/12 [==============================] - 4s 335ms/step - loss: 19.2233 - mae: 19.637
Epoch 68/100
12/12 [==============================] - 4s 335ms/step - loss: 19.8518 - mae: 20.347
Epoch 69/100
12/12 [==============================] - 4s 334ms/step - loss: 20.8911 - mae: 21.333
Epoch 70/100
12/12 [==============================] - 4s 332ms/step - loss: 19.7789 - mae: 20.311
Epoch 71/100
12/12 [==============================] - 4s 336ms/step - loss: 20.0997 - mae: 20.661
Epoch 72/100
12/12 [==============================] - 4s 336ms/step - loss: 22.0256 - mae: 22.500
Epoch 73/100
12/12 [==============================] - 4s 343ms/step - loss: 20.1406 - mae: 20.391
Epoch 74/100
12/12 [==============================] - 4s 340ms/step - loss: 19.8856 - mae: 20.405
Epoch 75/100
12/12 [==============================] - 4s 326ms/step - loss: 19.3671 - mae: 19.915
Epoch 76/100
12/12 [==============================] - 4s 335ms/step - loss: 24.5668 - mae: 25.179
Epoch 77/100
12/12 [==============================] - 4s 334ms/step - loss: 20.3807 - mae: 20.905
Epoch 78/100
12/12 [==============================] - 4s 336ms/step - loss: 21.3236 - mae: 21.812
Epoch 79/100
12/12 [==============================] - 4s 324ms/step - loss: 23.4973 - mae: 24.180
Epoch 80/100
12/12 [==============================] - 4s 330ms/step - loss: 21.4505 - mae: 22.000
Epoch 81/100
12/12 [==============================] - 4s 329ms/step - loss: 22.8129 - mae: 23.191
Epoch 82/100
12/12 [==============================] - 4s 328ms/step - loss: 26.1930 - mae: 26.792
Epoch 83/100
12/12 [==============================] - 4s 333ms/step - loss: 27.5889 - mae: 27.690
Epoch 84/100
12/12 [==============================] - 4s 329ms/step - loss: 57.0122 - mae: 56.486
Epoch 85/100
12/12 [==============================] - 4s 323ms/step - loss: 57.7061 - mae: 58.153
Epoch 86/100
12/12 [==============================] - 4s 325ms/step - loss: 51.5218 - mae: 51.774
Epoch 87/100
12/12 [==============================] - 4s 326ms/step - loss: 49.4597 - mae: 49.131
Epoch 88/100
12/12 [==============================] - 4s 326ms/step - loss: 63.3244 - mae: 60.374
Epoch 89/100
12/12 [==============================] - 4s 330ms/step - loss: 59.7555 - mae: 60.170
Epoch 90/100
12/12 [==============================] - 4s 328ms/step - loss: 55.3084 - mae: 55.520
Epoch 91/100
12/12 [==============================] - 4s 322ms/step - loss: 54.5066 - mae: 54.750
Epoch 92/100
12/12 [==============================] - 4s 323ms/step - loss: 53.7672 - mae: 54.010
Epoch 93/100
12/12 [==============================] - 4s 330ms/step - loss: 52.6478 - mae: 52.922
Epoch 94/100
12/12 [==============================] - 4s 321ms/step - loss: 57.2889 - mae: 56.923
Epoch 95/100
```

```
Epoch 95/100
12/12 [==============================] - 4s 335ms/step - loss: 59.4641 - mae: 59.746
Epoch 96/100
12/12 [==============================] - 4s 333ms/step - loss: 56.2535 - mae: 56.536
Epoch 97/100
12/12 [==============================] - 4s 334ms/step - loss: 57.8982 - mae: 58.136
Epoch 98/100
12/12 [==============================] - 4s 331ms/step - loss: 58.4549 - mae: 58.690
Epoch 99/100
12/12 [==============================] - 4s 332ms/step - loss: 54.5750 - mae: 54.809
Epoch 100/100
12/12 [==============================] - 4s 322ms/step - loss: 54.9520 - mae: 55.192
```

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

```
[1e-08, 0.0001, 0, 60]
```




```
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_b
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 [==============================] - 7s 227ms/step - loss: 37.8896 - mae: 38.605
Epoch 2/500
30/30 [==============================] - 4s 128ms/step - loss: 24.3137 - mae: 24.847
Epoch 3/500
30/30 [==============================] - 4s 124ms/step - loss: 21.0376 - mae: 21.541
Epoch 4/500
30/30 [==============================] - 4s 124ms/step - loss: 20.2604 - mae: 20.755
Epoch 5/500
30/30 [==============================] - 4s 124ms/step - loss: 19.6226 - mae: 20.115
Epoch 6/500
30/30 [==============================] - 4s 125ms/step - loss: 19.2406 - mae: 19.716
Epoch 7/500
30/30 [==============================] - 4s 126ms/step - loss: 18.8684 - mae: 19.357
Epoch 8/500
30/30 [==============================] - 4s 123ms/step - loss: 18.6414 - mae: 19.130
Epoch 9/500
30/30 [==============================] - 4s 124ms/step - loss: 18.3319 - mae: 18.818
Epoch 10/500
30/30 [==============================] - 4s 127ms/step - loss: 18.0562 - mae: 18.539
Epoch 11/500
30/30 [==============================] - 4s 124ms/step - loss: 17.9810 - mae: 18.453
Epoch 12/500
30/30 [==============================] - 4s 124ms/step - loss: 18.1221 - mae: 18.599
Epoch 13/500
30/30 [==============================] - 4s 123ms/step - loss: 18.0651 - mae: 18.525
Epoch 14/500
30/30 [==============================] - 4s 124ms/step - loss: 17.7861 - mae: 18.270
Epoch 15/500
30/30 [==============================] - 4s 125ms/step - loss: 17.8317 - mae: 18.297
Epoch 16/500
30/30 [==============================] - 4s 122ms/step - loss: 17.8733 - mae: 18.350
Epoch 17/500
30/30 [==============================] - 4s 123ms/step - loss: 17.8476 - mae: 18.336
Epoch 18/500
30/30 [==============================] - 4s 124ms/step - loss: 17.4424 - mae: 17.924
Epoch 19/500
30/30 [==============================] - 4s 127ms/step - loss: 17.3558 - mae: 17.834
Epoch 20/500
30/30 [==============================] - 4s 124ms/step - loss: 17.6471 - mae: 18.125
Epoch 21/500
30/30 [==============================] - 4s 124ms/step - loss: 17.5979 - mae: 18.085
Epoch 22/500
30/30 [==============================] - 4s 127ms/step - loss: 17.2557 - mae: 17.738
Epoch 23/500
30/30 [==============================] - 4s 127ms/step - loss: 17.4762 - mae: 17.953
Epoch 24/500
30/30 [==============================] - 4s 126ms/step - loss: 17.4770 - mae: 17.942
Epoch 25/500
30/30 [==============================] - 4s 123ms/step - loss: 17.5380 - mae: 18.013
Epoch 26/500
30/30 [==============================] - 4s 125ms/step - loss: 17.2549 - mae: 17.734
Epoch 27/500
30/30 [==============================] - 4s 127ms/step - loss: 17.1579 - mae: 17.635
Epoch 28/500
30/30 [==============================] - 4s 125ms/step - loss: 17.2286 - mae: 17.713
Epoch 29/500
30/30 [==============================] - 4s 125ms/step - loss: 17.0821 - mae: 17.560
Epoch 30/500
30/30 [==============================] - 4s 124ms/step - loss: 17.1587 - mae: 17.640
Epoch 31/500
```

```
30/30 [==============================] - 4s 123ms/step - loss: 17.1101 - mae: 17.591
Epoch 32/500
30/30 [==============================] - 4s 125ms/step - loss: 17.0714 - mae: 17.555
Epoch 33/500
30/30 [==============================] - 4s 124ms/step - loss: 17.0534 - mae: 17.537
Epoch 34/500
30/30 [==============================] - 4s 125ms/step - loss: 17.0213 - mae: 17.506
Epoch 35/500
30/30 [==============================] - 4s 125ms/step - loss: 16.9862 - mae: 17.467
Epoch 36/500
30/30 [==============================] - 4s 123ms/step - loss: 16.9095 - mae: 17.382
Epoch 37/500
30/30 [==============================] - 4s 124ms/step - loss: 17.1090 - mae: 17.595
Epoch 38/500
30/30 [==============================] - 4s 125ms/step - loss: 16.9883 - mae: 17.464
Epoch 39/500
30/30 [==============================] - 4s 122ms/step - loss: 17.0849 - mae: 17.570
Epoch 40/500
30/30 [==============================] - 4s 123ms/step - loss: 16.8545 - mae: 17.337
Epoch 41/500
30/30 [==============================] - 4s 124ms/step - loss: 16.9221 - mae: 17.405
Epoch 42/500
30/30 [==============================] - 4s 124ms/step - loss: 16.9210 - mae: 17.392
Epoch 43/500
30/30 [==============================] - 4s 125ms/step - loss: 17.1371 - mae: 17.614
Epoch 44/500
30/30 [==============================] - 4s 126ms/step - loss: 16.8160 - mae: 17.297
Epoch 45/500
30/30 [==============================] - 4s 124ms/step - loss: 16.8466 - mae: 17.328
Epoch 46/500
30/30 [==============================] - 4s 128ms/step - loss: 16.8060 - mae: 17.288
Epoch 47/500
30/30 [==============================] - 4s 126ms/step - loss: 16.8747 - mae: 17.359
Epoch 48/500
30/30 [==============================] - 4s 125ms/step - loss: 16.7896 - mae: 17.272
Epoch 49/500
30/30 [==============================] - 4s 124ms/step - loss: 16.7441 - mae: 17.225
Epoch 50/500
30/30 [==============================] - 4s 123ms/step - loss: 16.7234 - mae: 17.205
Epoch 51/500
30/30 [==============================] - 4s 124ms/step - loss: 16.7007 - mae: 17.183
Epoch 52/500
30/30 [==============================] - 4s 121ms/step - loss: 16.7465 - mae: 17.226
Epoch 53/500
30/30 [==============================] - 4s 122ms/step - loss: 16.7266 - mae: 17.207
Epoch 54/500
30/30 [==============================] - 4s 122ms/step - loss: 16.6735 - mae: 17.155
Epoch 55/500
30/30 [==============================] - 4s 123ms/step - loss: 16.6545 - mae: 17.136
Epoch 56/500
30/30 [==============================] - 4s 121ms/step - loss: 16.7774 - mae: 17.251
Epoch 57/500
30/30 [==============================] - 4s 122ms/step - loss: 16.9464 - mae: 17.431
Epoch 58/500
30/30 [==============================] - 4s 121ms/step - loss: 16.6419 - mae: 17.124
Epoch 59/500
30/30 [==============================] - 4s 121ms/step - loss: 16.7839 - mae: 17.267
Epoch 60/500
30/30 [==============================] - 4s 123ms/step - loss: 16.6947 - mae: 17.179
Epoch 61/500
30/30 [==============================] - 4s 121ms/step - loss: 16.5983 - mae: 17.080
Epoch 62/500
```