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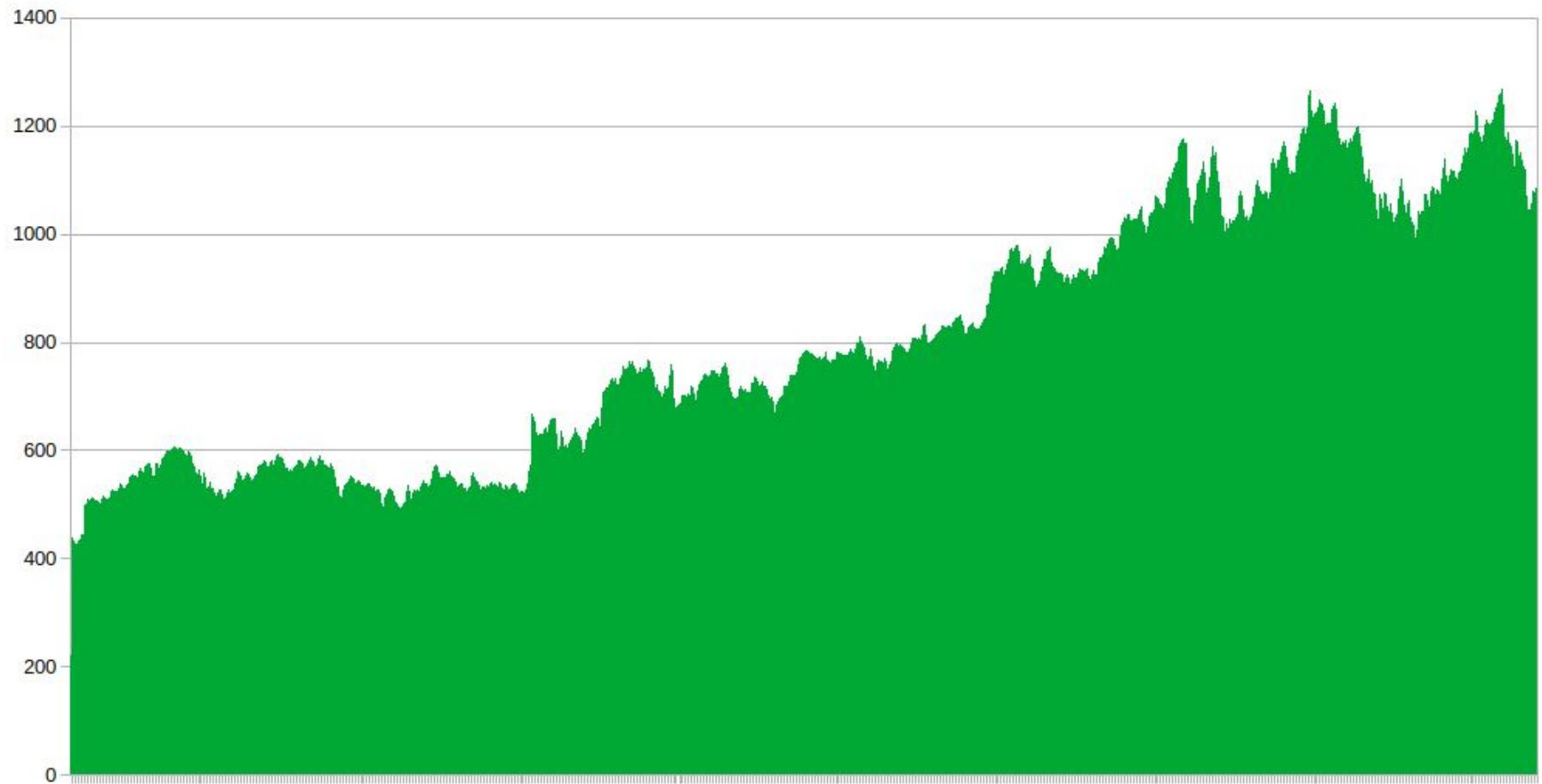


Chart Created by lmoroney@

Sammamish, WA

Monday 11:00 AM

Cloudy



61

°F | °C

Precipitation: 0%

Humidity: 79%

Wind: 5 mph

Temperature

Precipitation

Wind



Mon



75° 56°

Tue



67° 51°

Wed



64° 50°

Thu



66° 51°

Fri



73° 53°

Sat



72° 53°

Sun



65° 53°

Mon

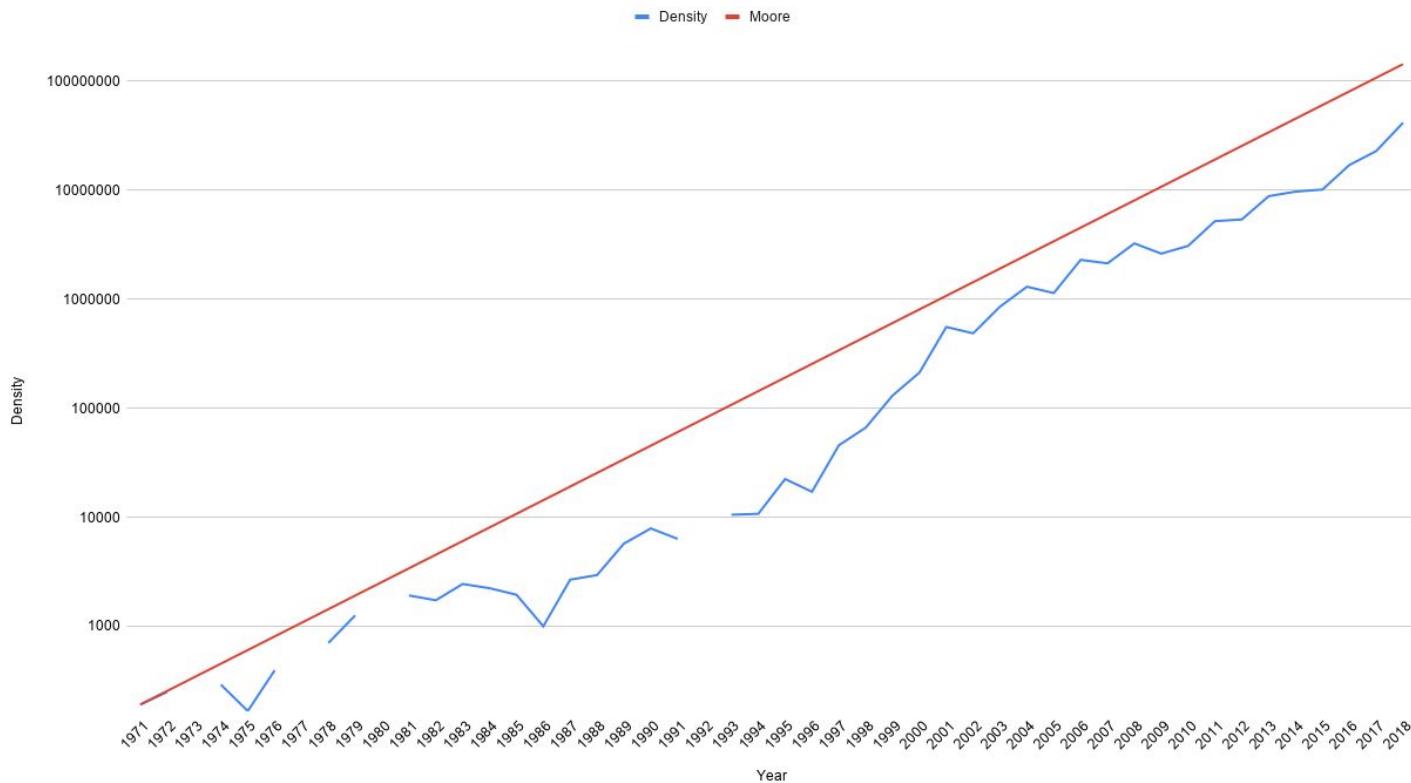


65° 53°

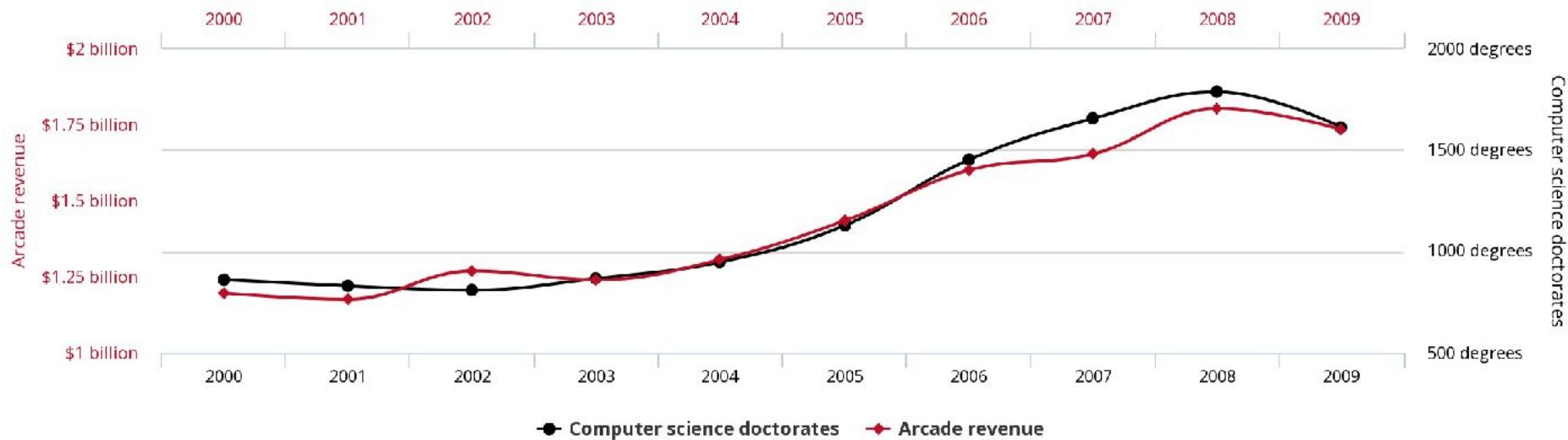
More on weather.com

Feedback

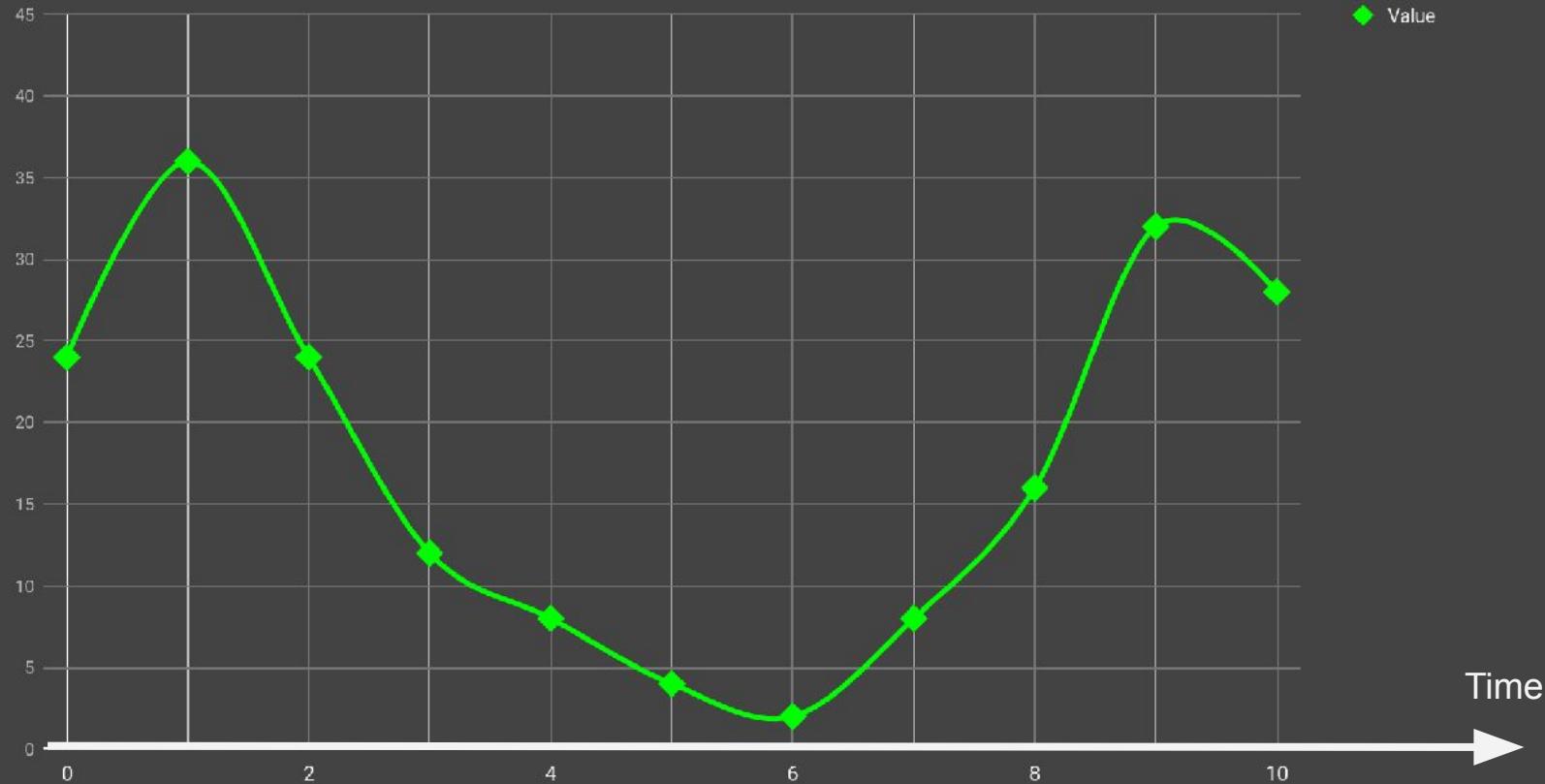
Density vs. Year



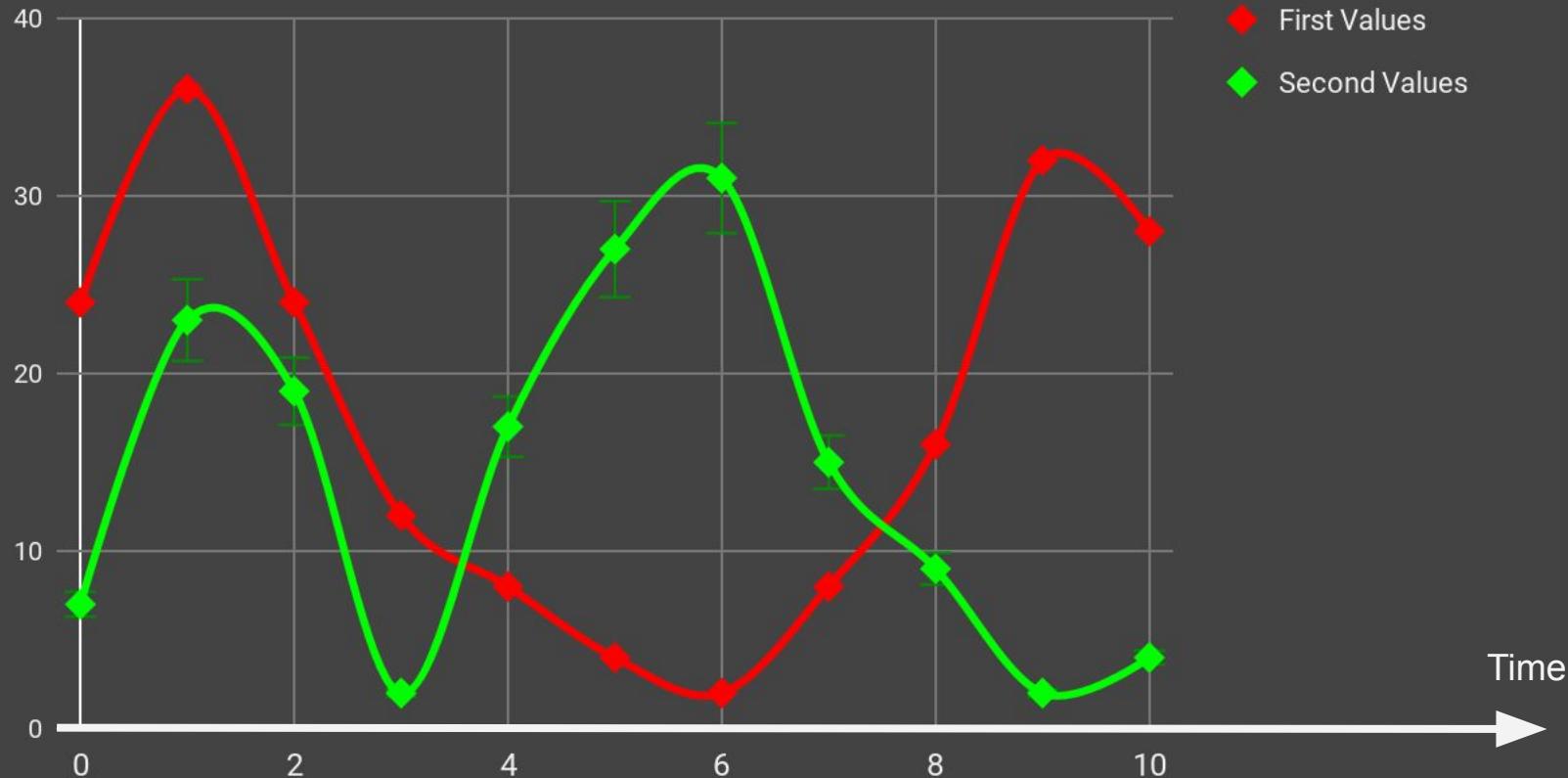
Total revenue generated by arcades
correlates with
Computer science doctorates awarded in the US



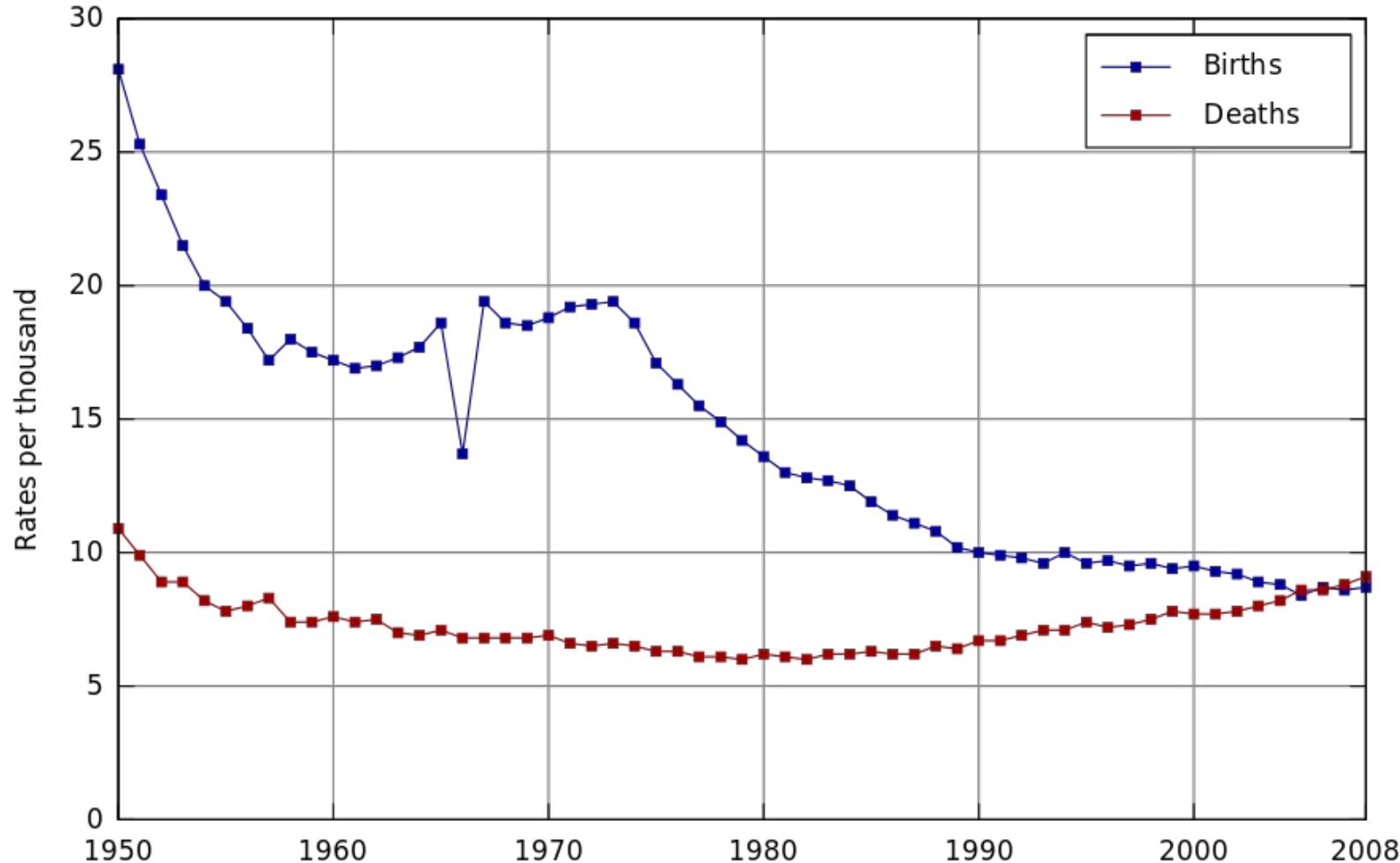
Univariate Time Series

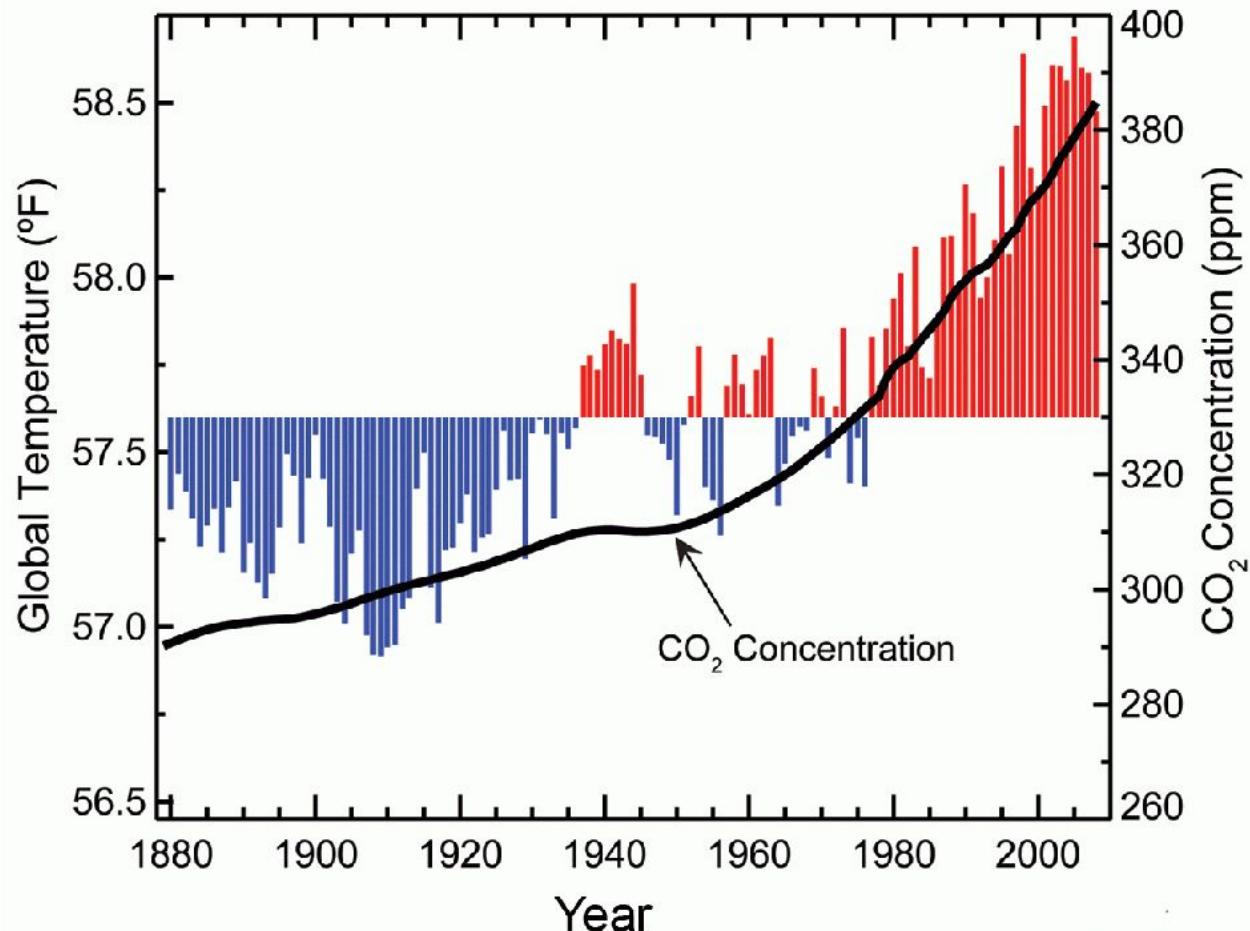


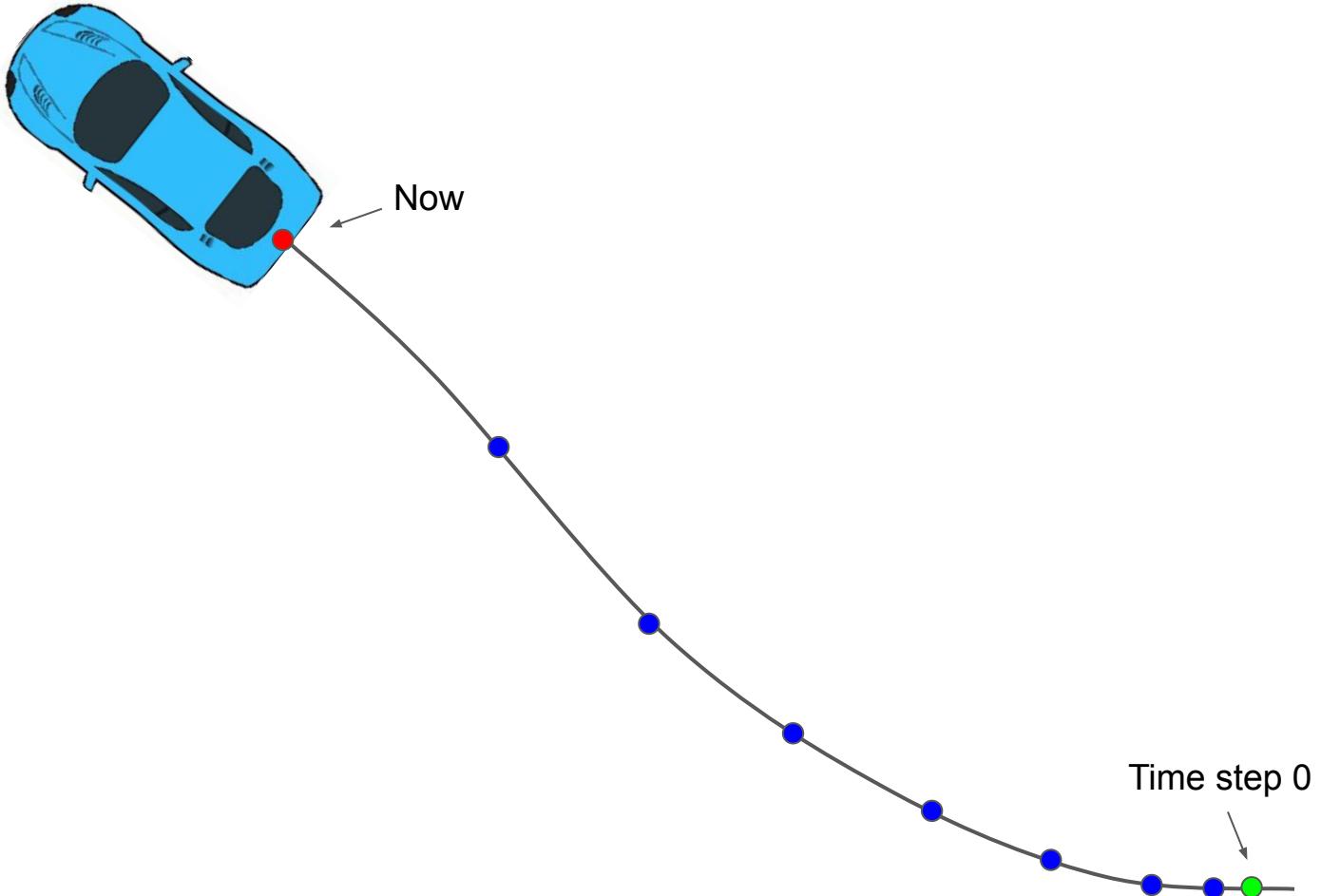
Multivariate Time Series



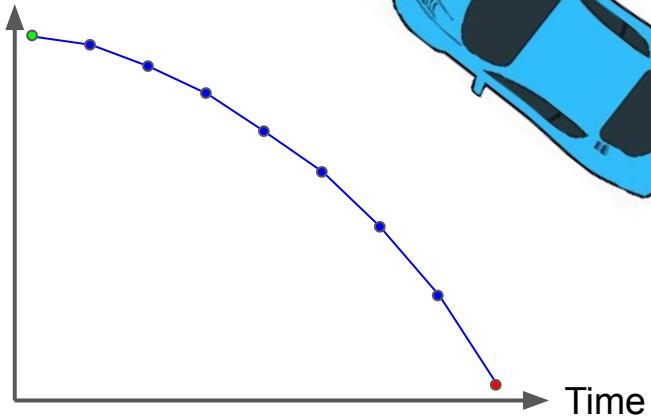
Birth and Death Rate in Japan





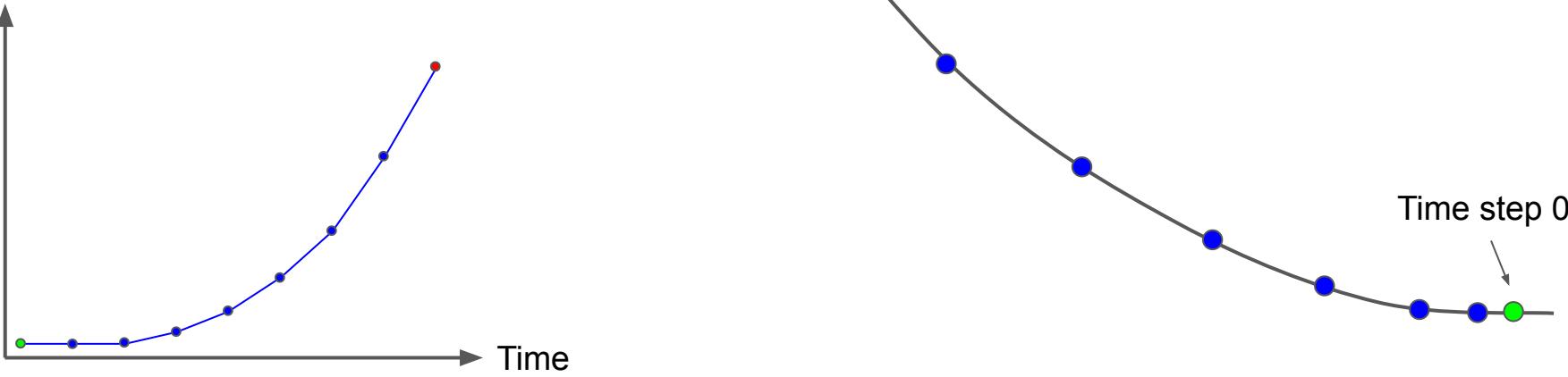


Longitude



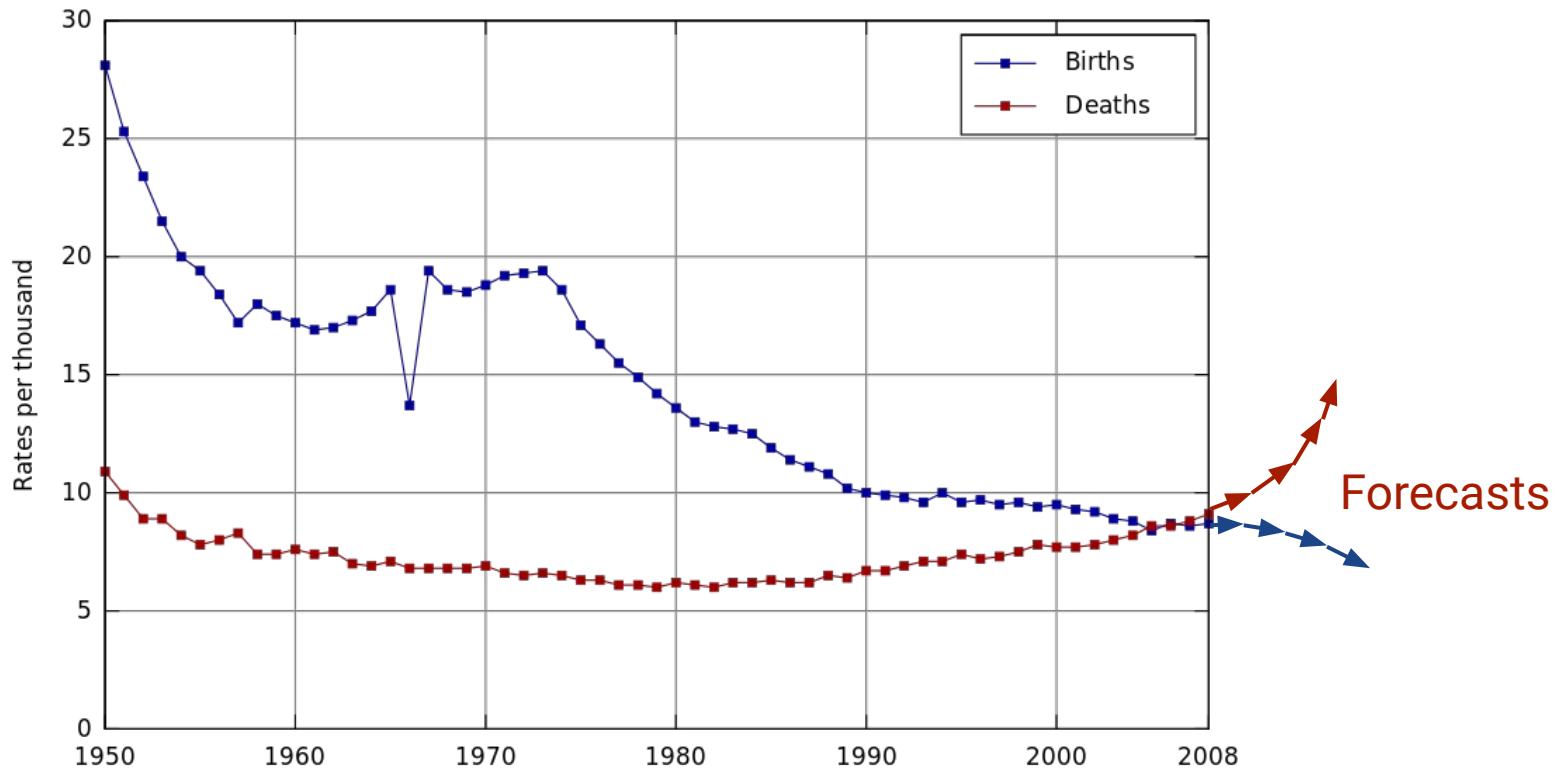
Now

Latitude

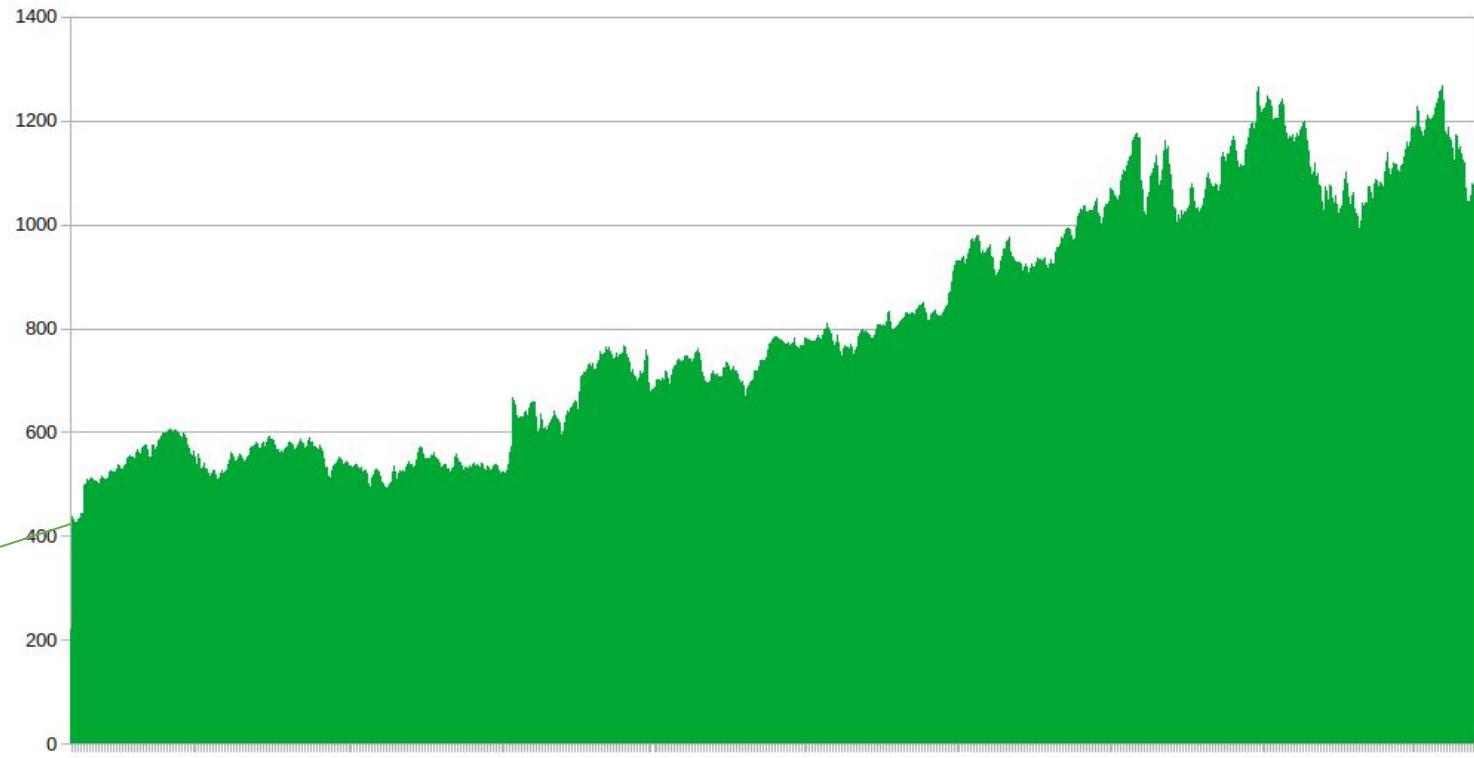


Time step 0

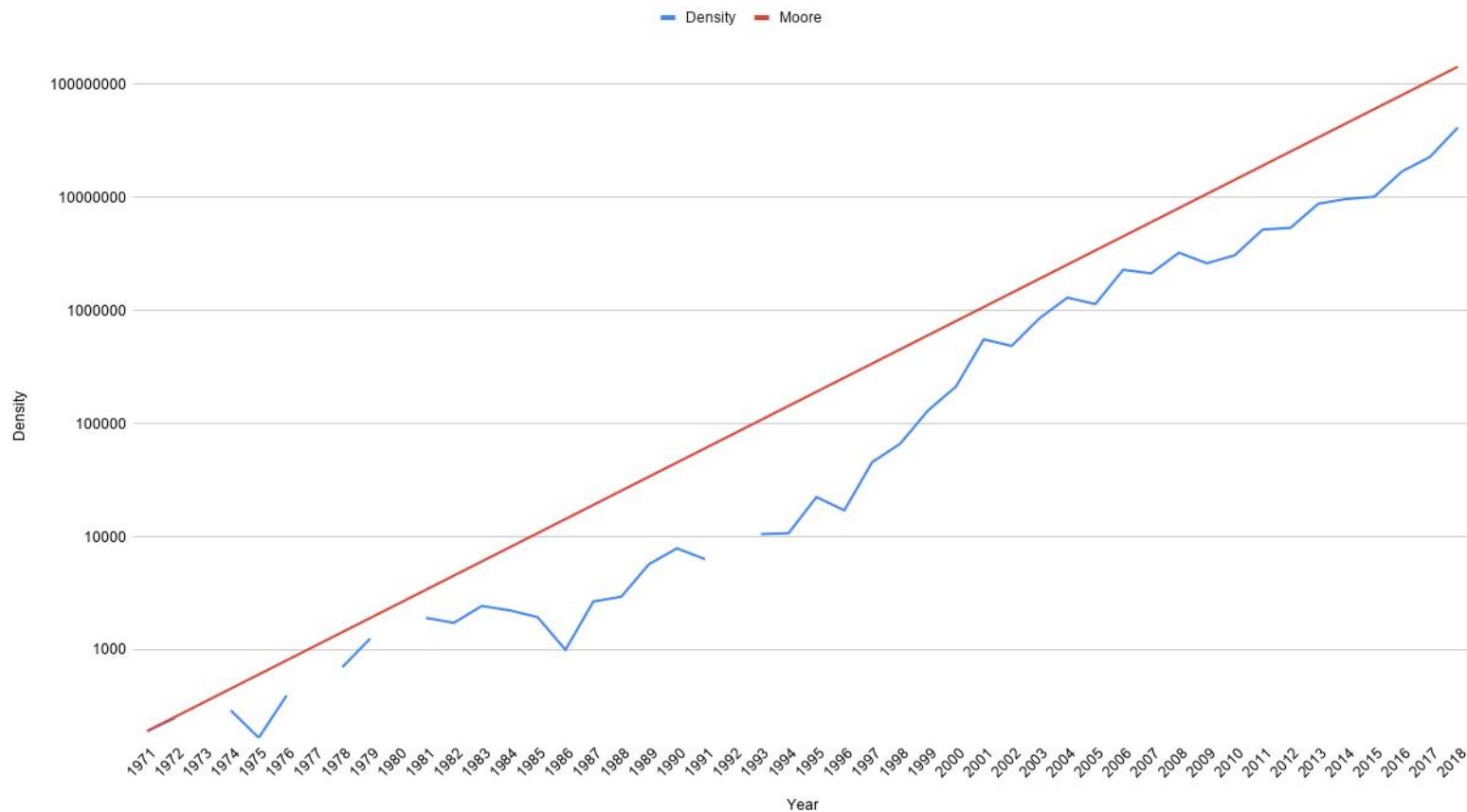
Birth and Death Rate in Japan



Imputed Data



Density vs. Year



Density vs. Year

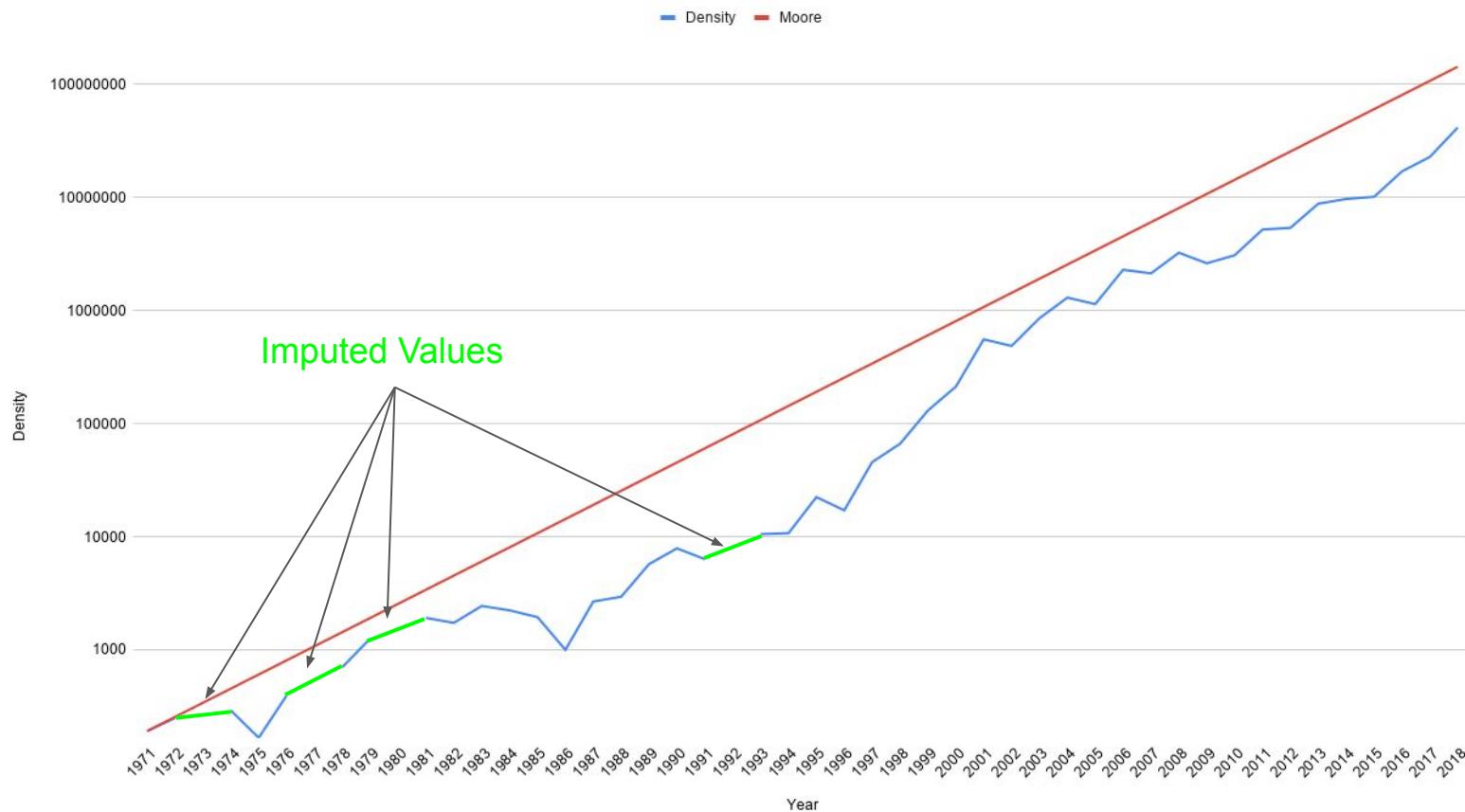
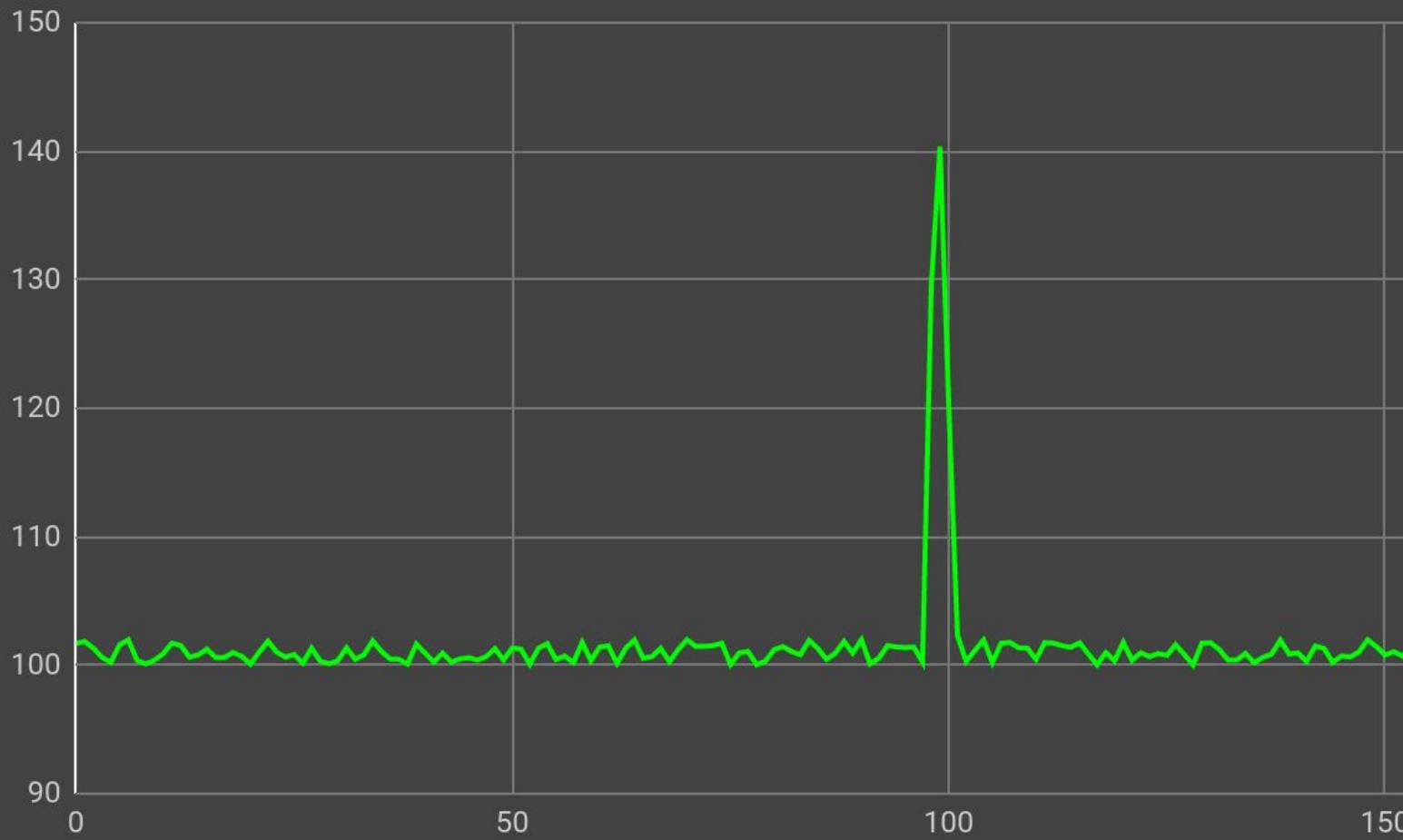
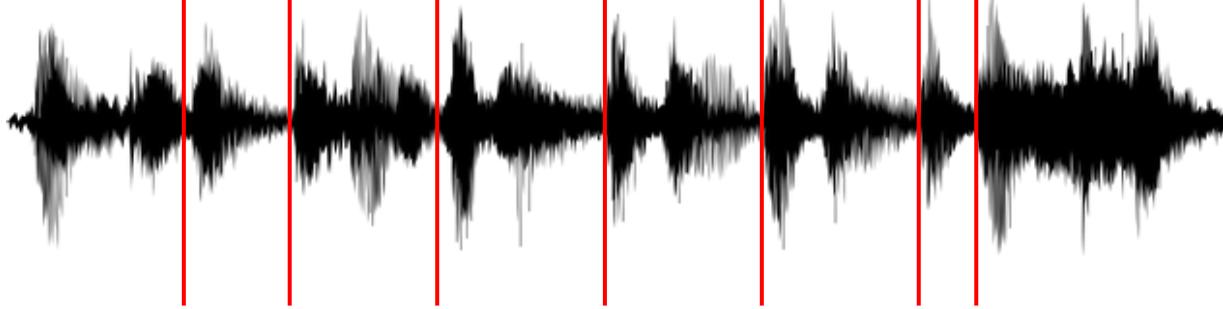


Chart Created by lmoroney@

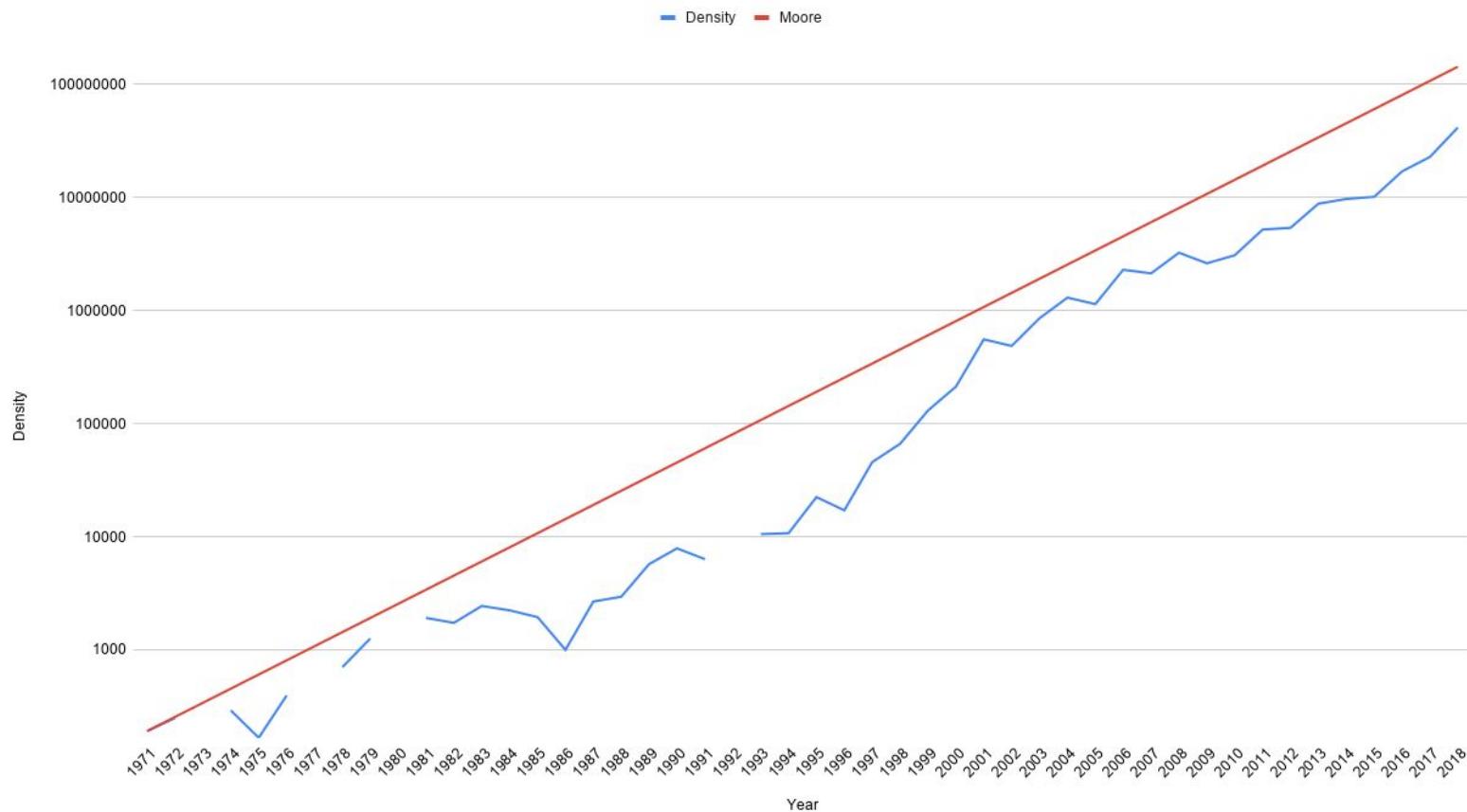


Today

we're teaching coding neural layers in Tensorflow



Density vs. Year





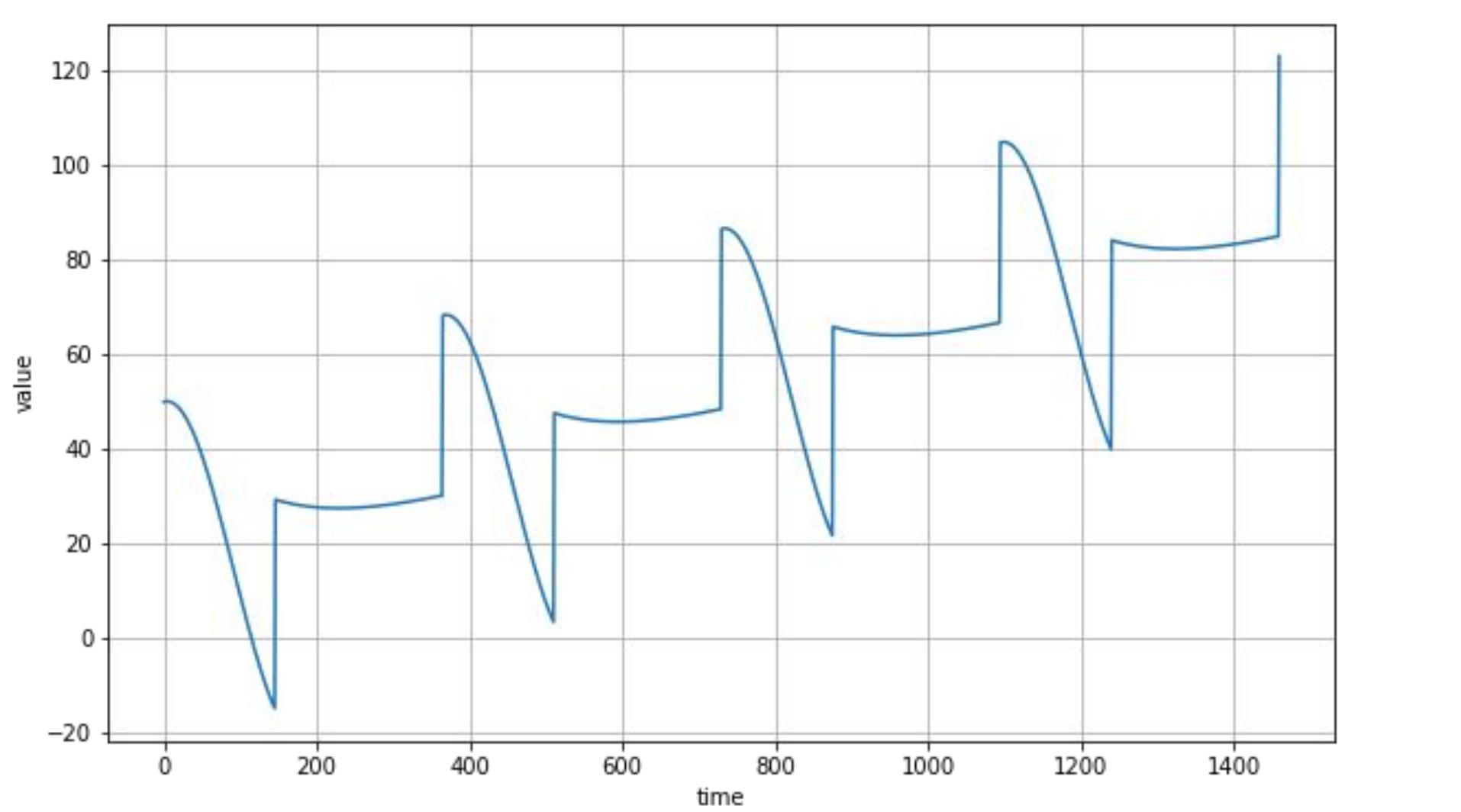
February 2010

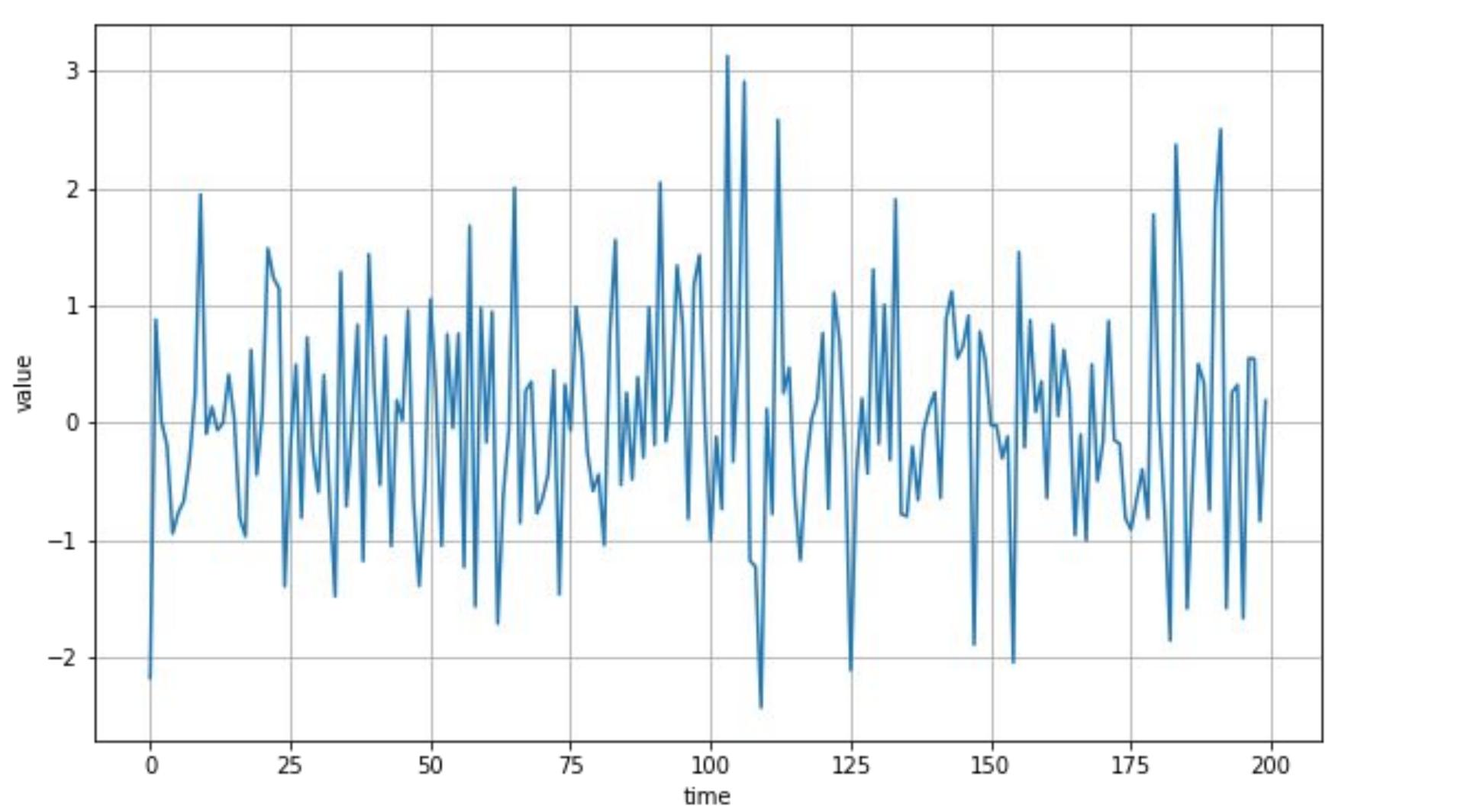
March 2010

April 2010

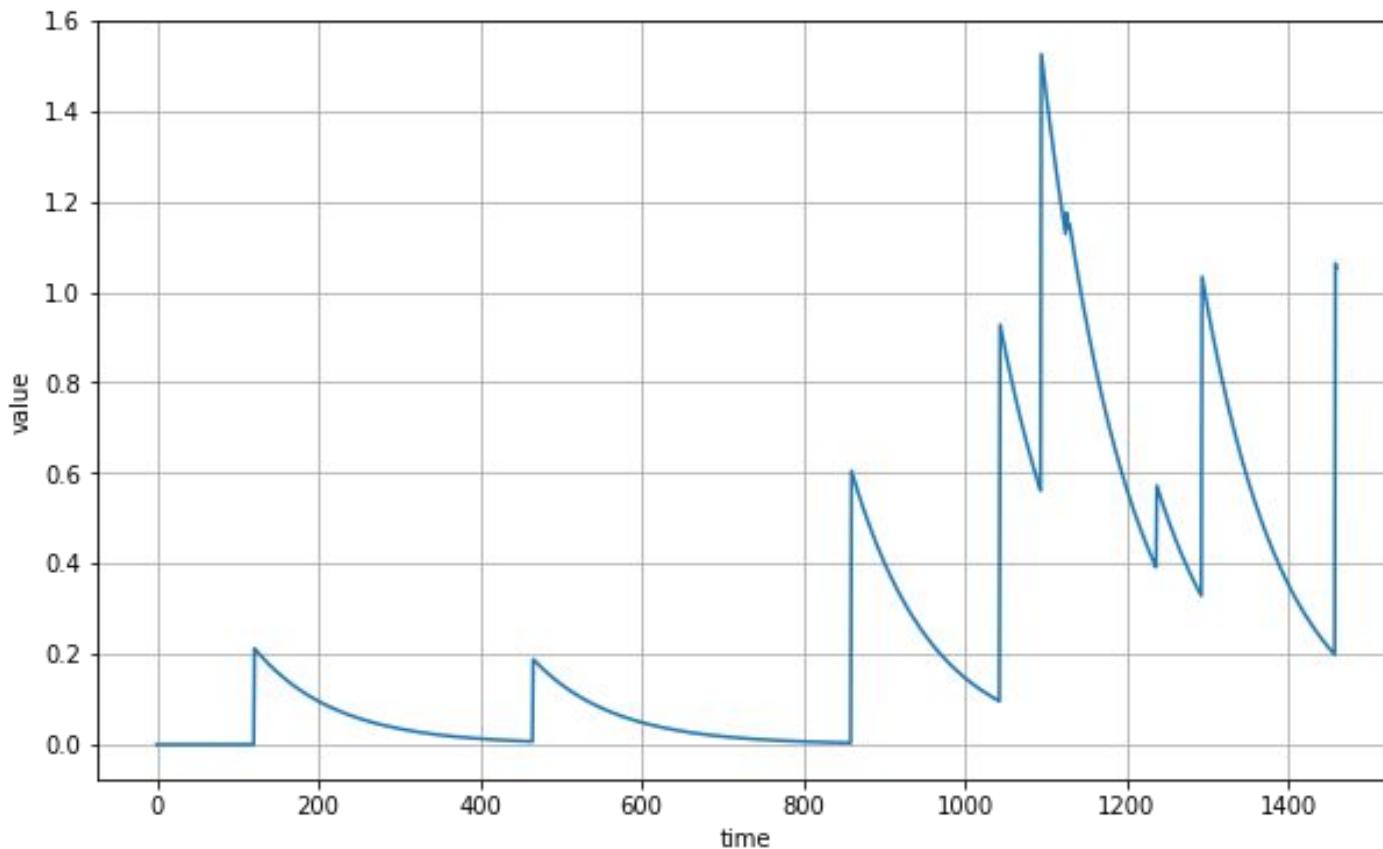
May 2010

June 2010

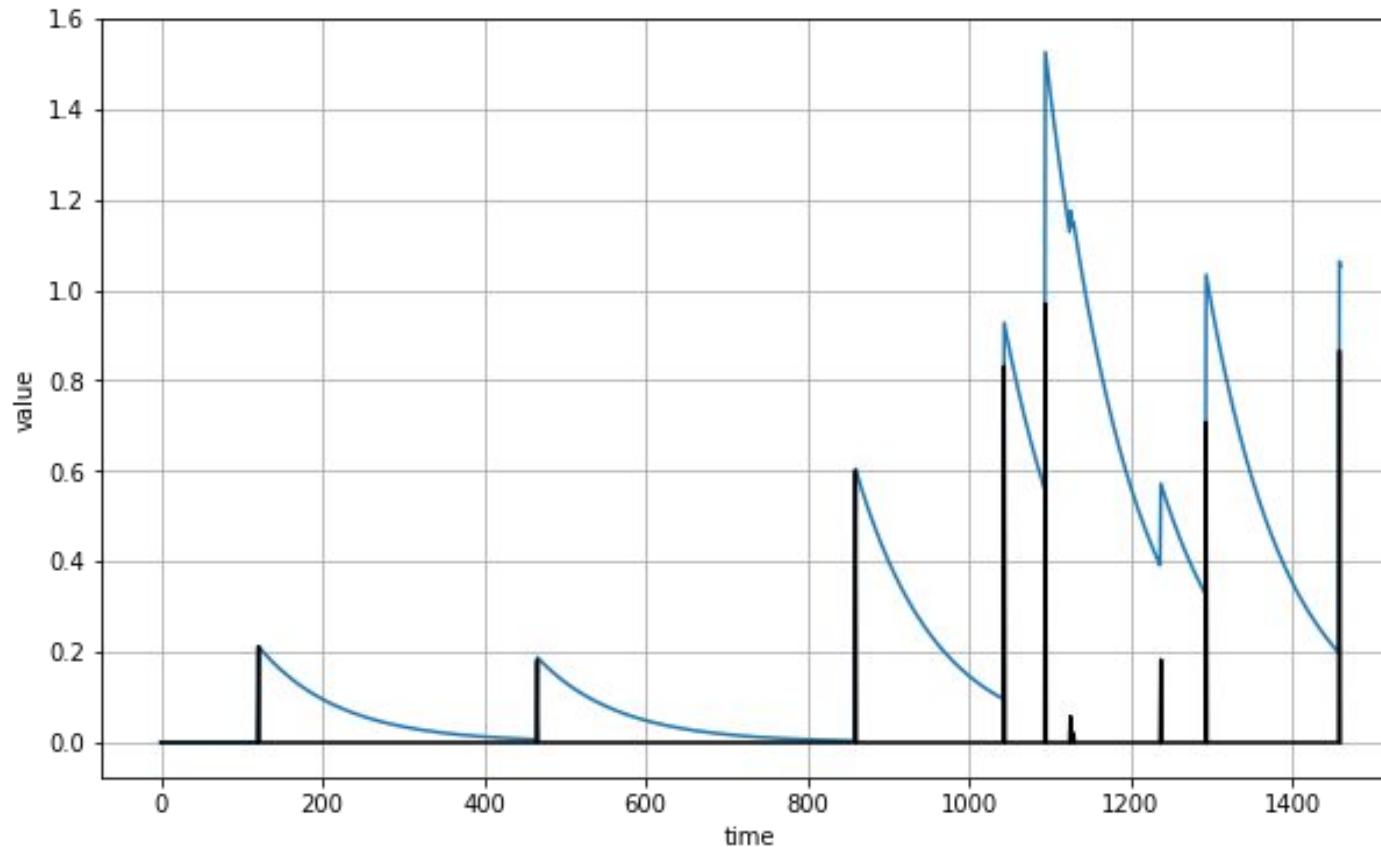




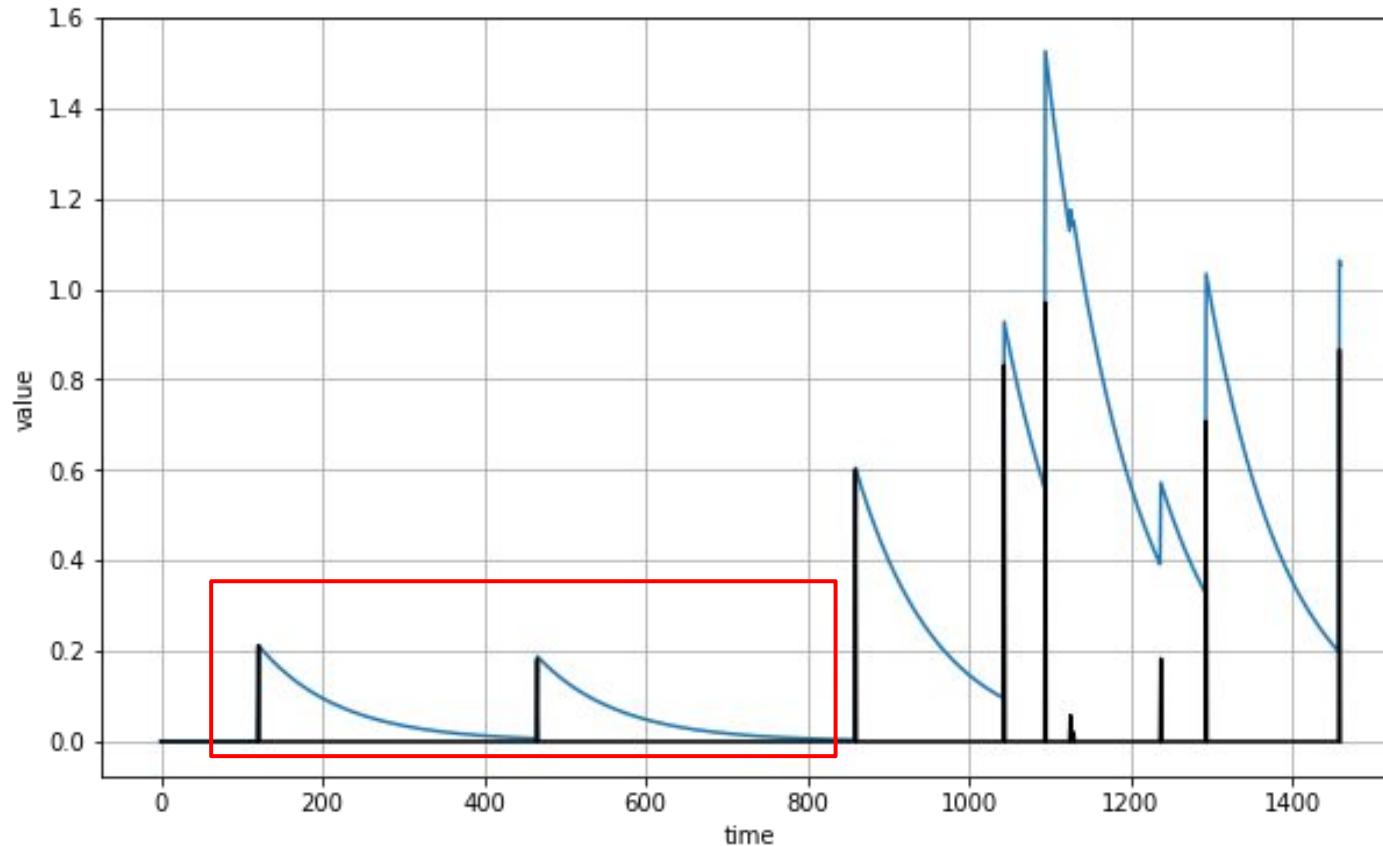
Autocorrelation



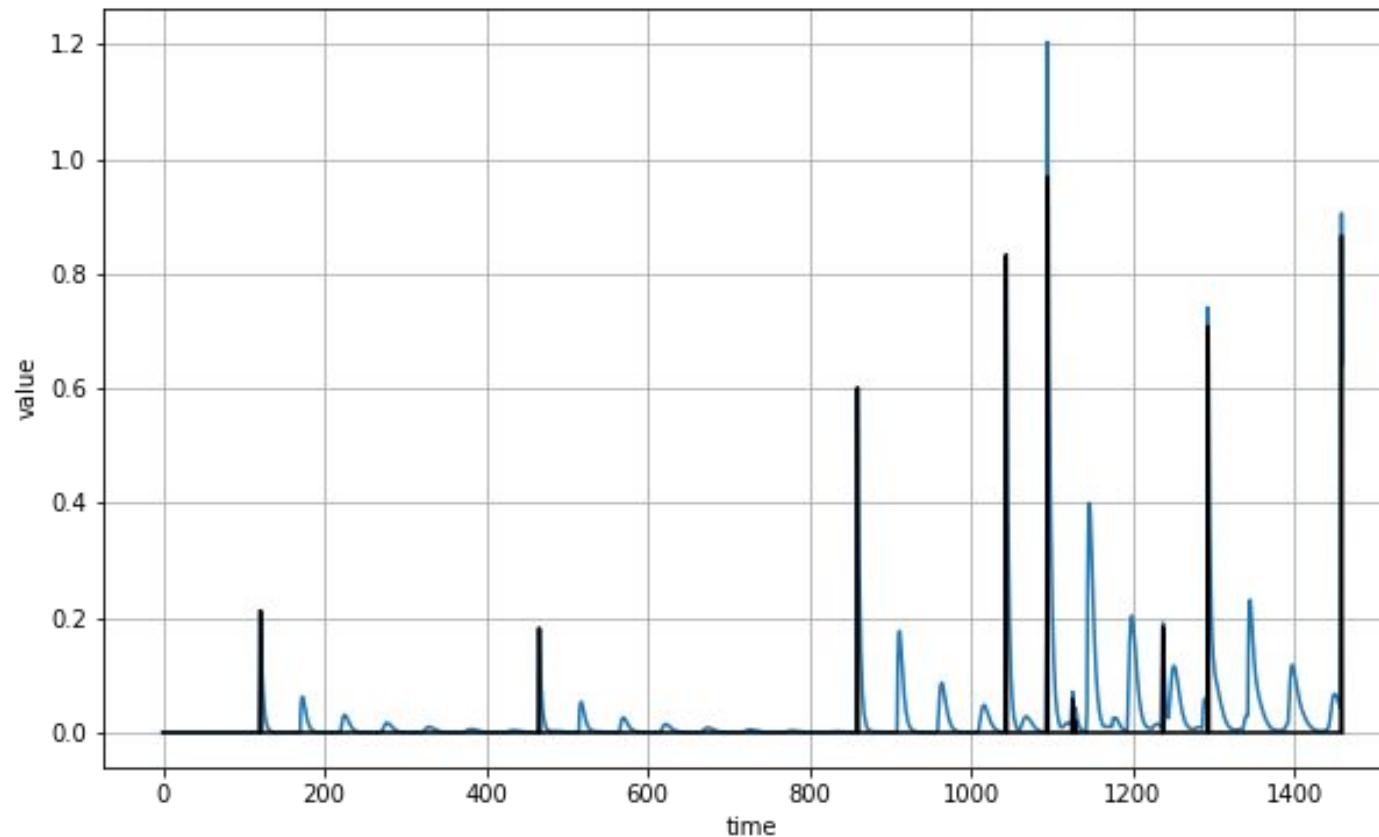
$$v(t) = 0.99 \times v(t-1) + \text{occasional spike}$$



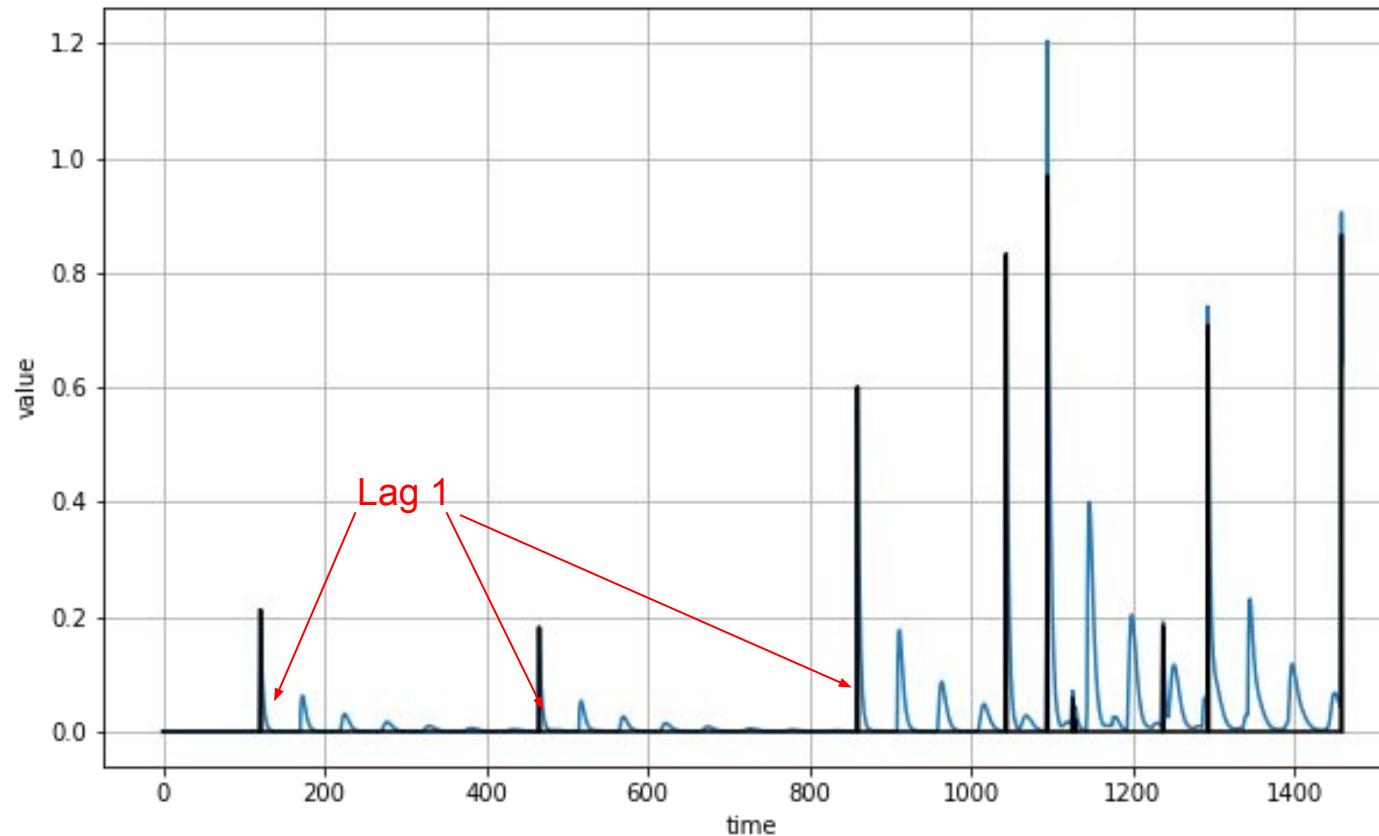
$$v(t) = 0.99 \times v(t-1) + \text{occasional spike}$$



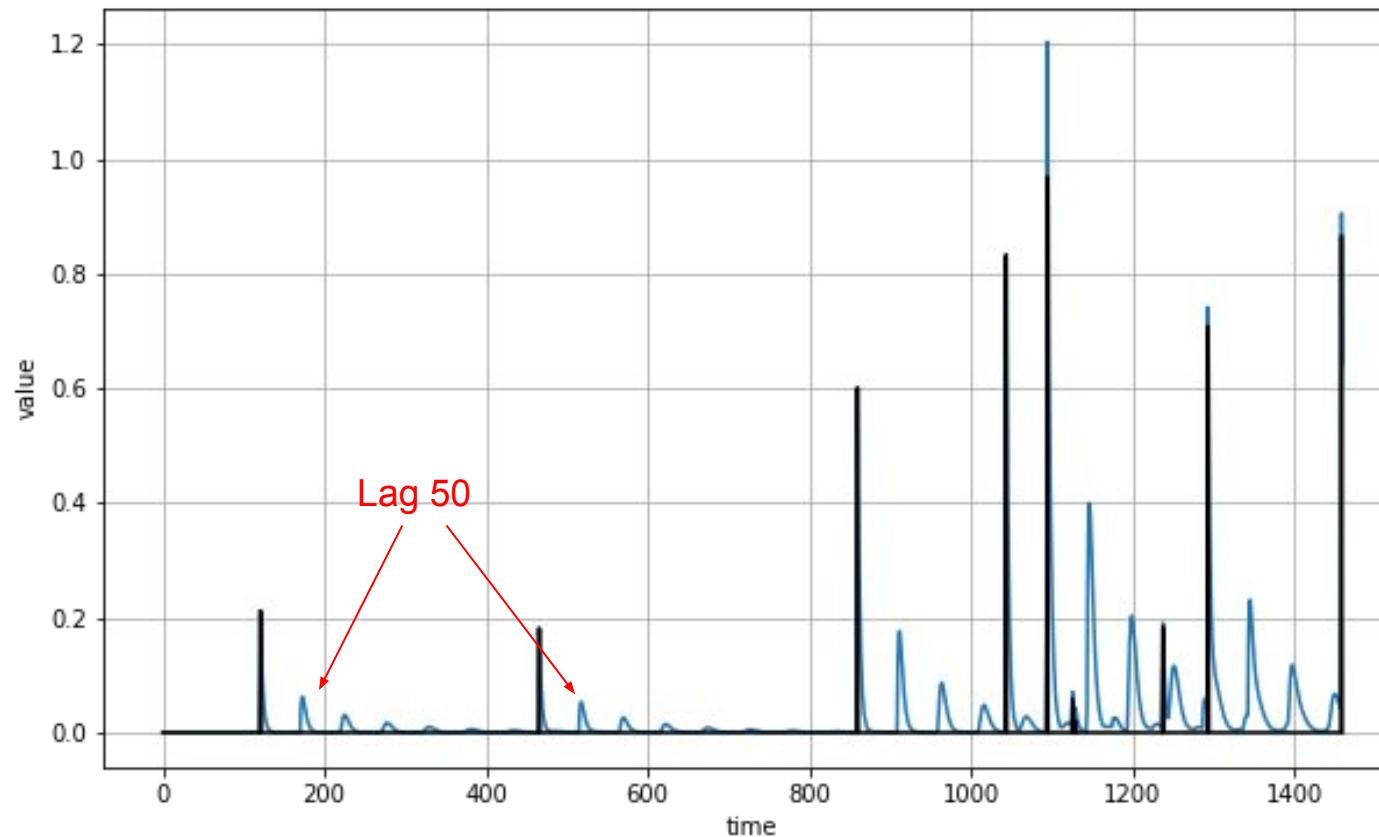
$$v(t) = 0.7 \times v(t-1) + 0.2 \times v(t-50) + \text{occasional spike}$$



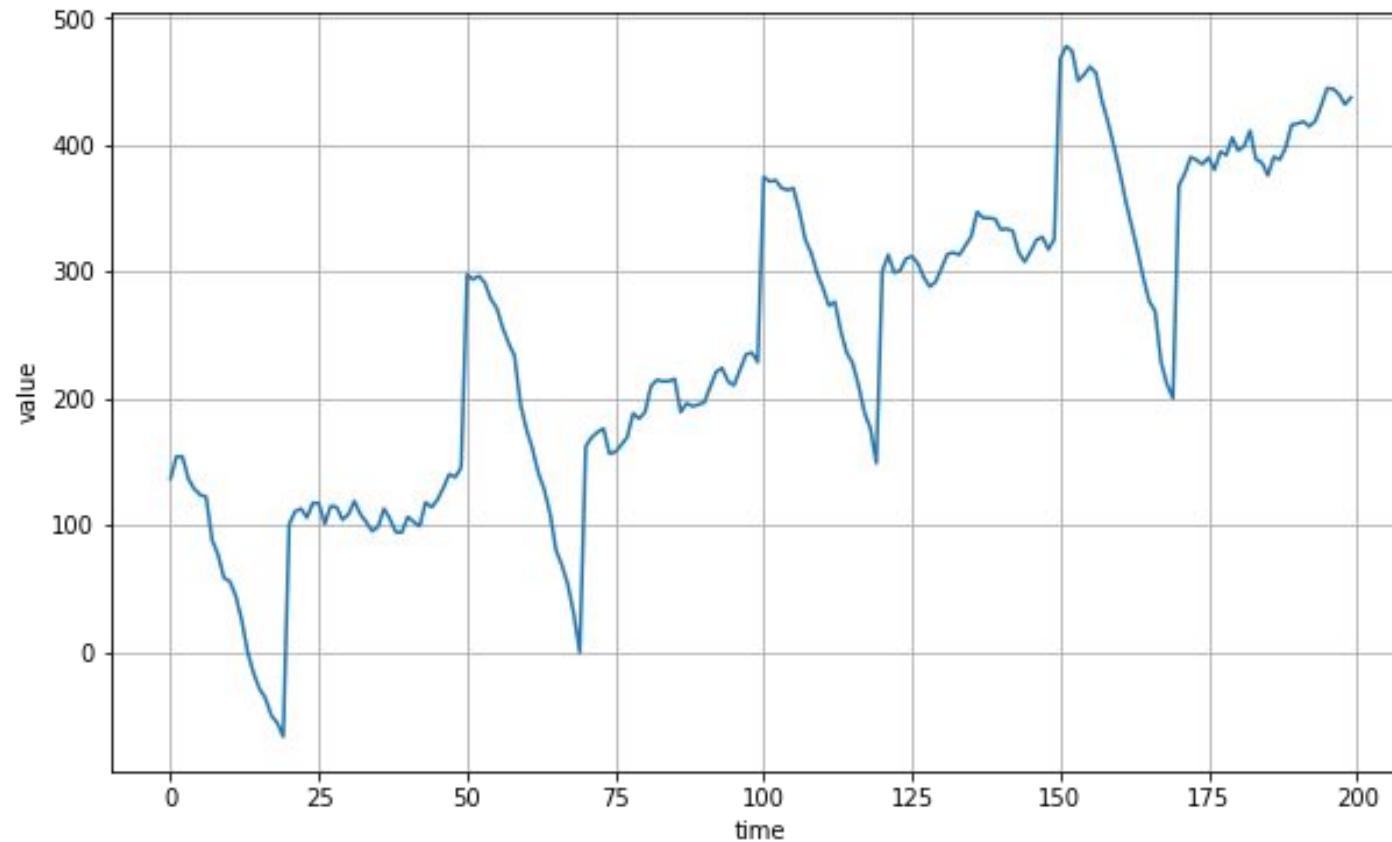
$$v(t) = 0.7 \times v(t-1) + 0.2 \times v(t-50) + \text{occasional spike}$$



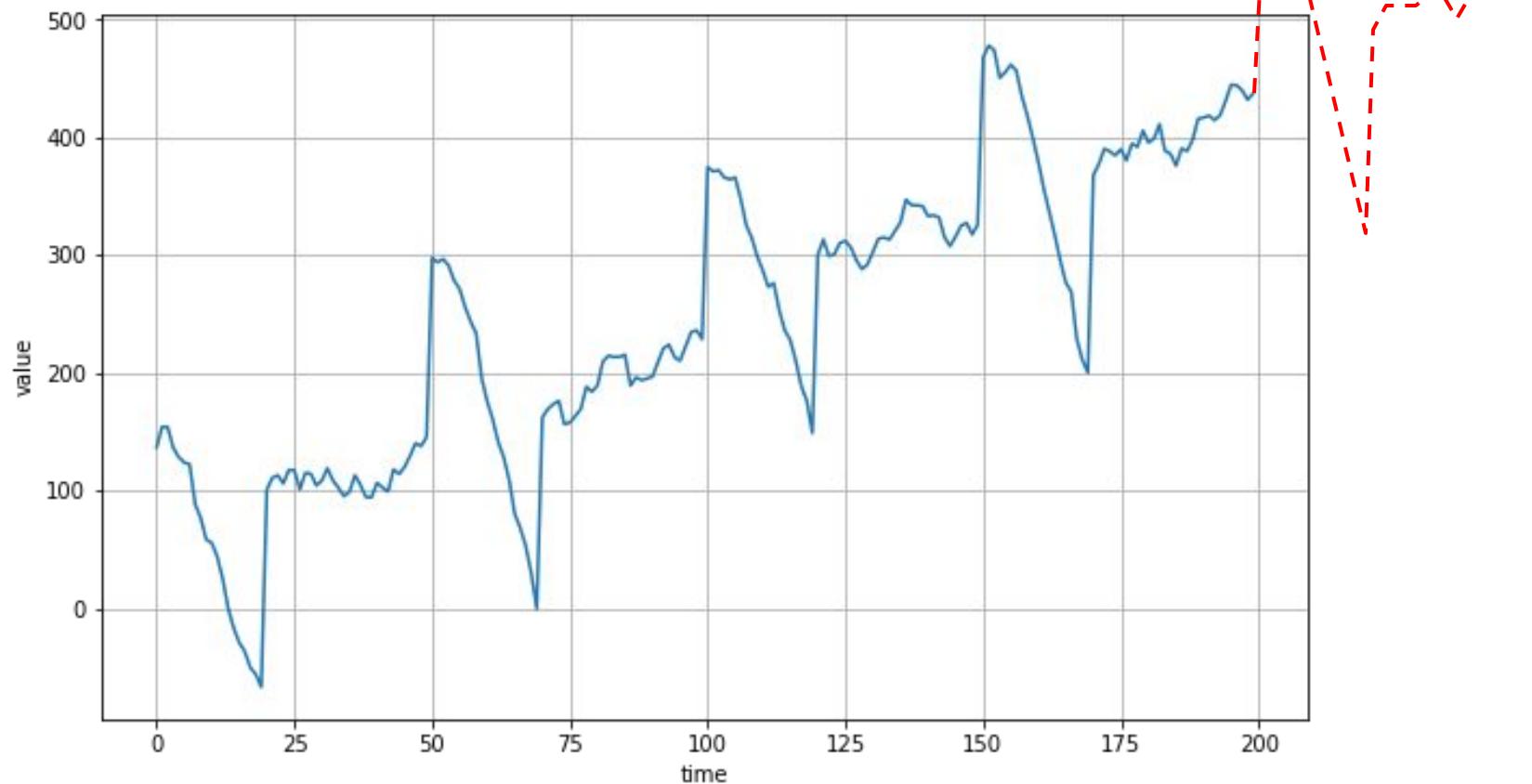
$$v(t) = 0.7 \times v(t-1) + 0.2 \times v(t-50) + \text{occasional spike}$$



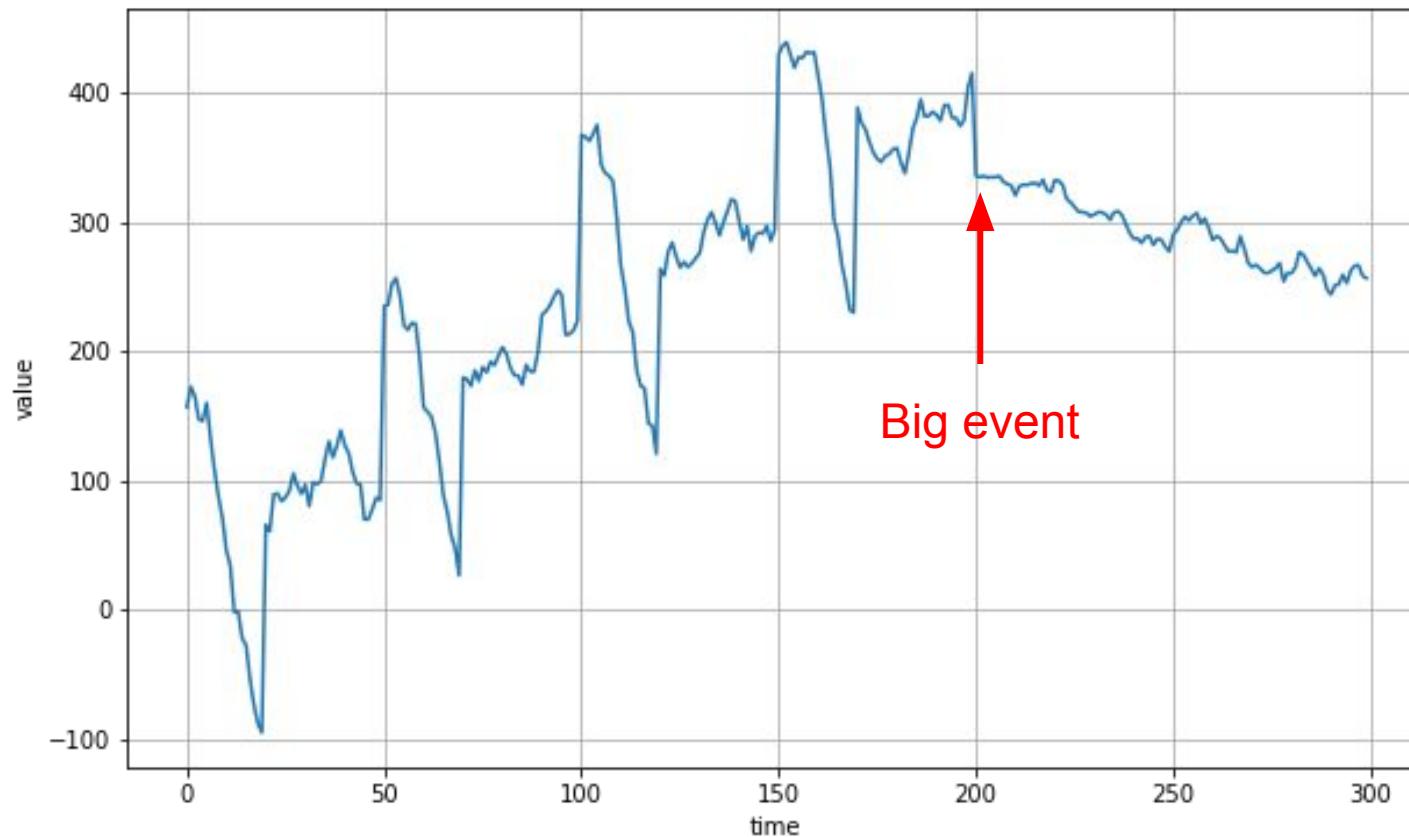
Trend + Seasonality + Autocorrelation + Noise



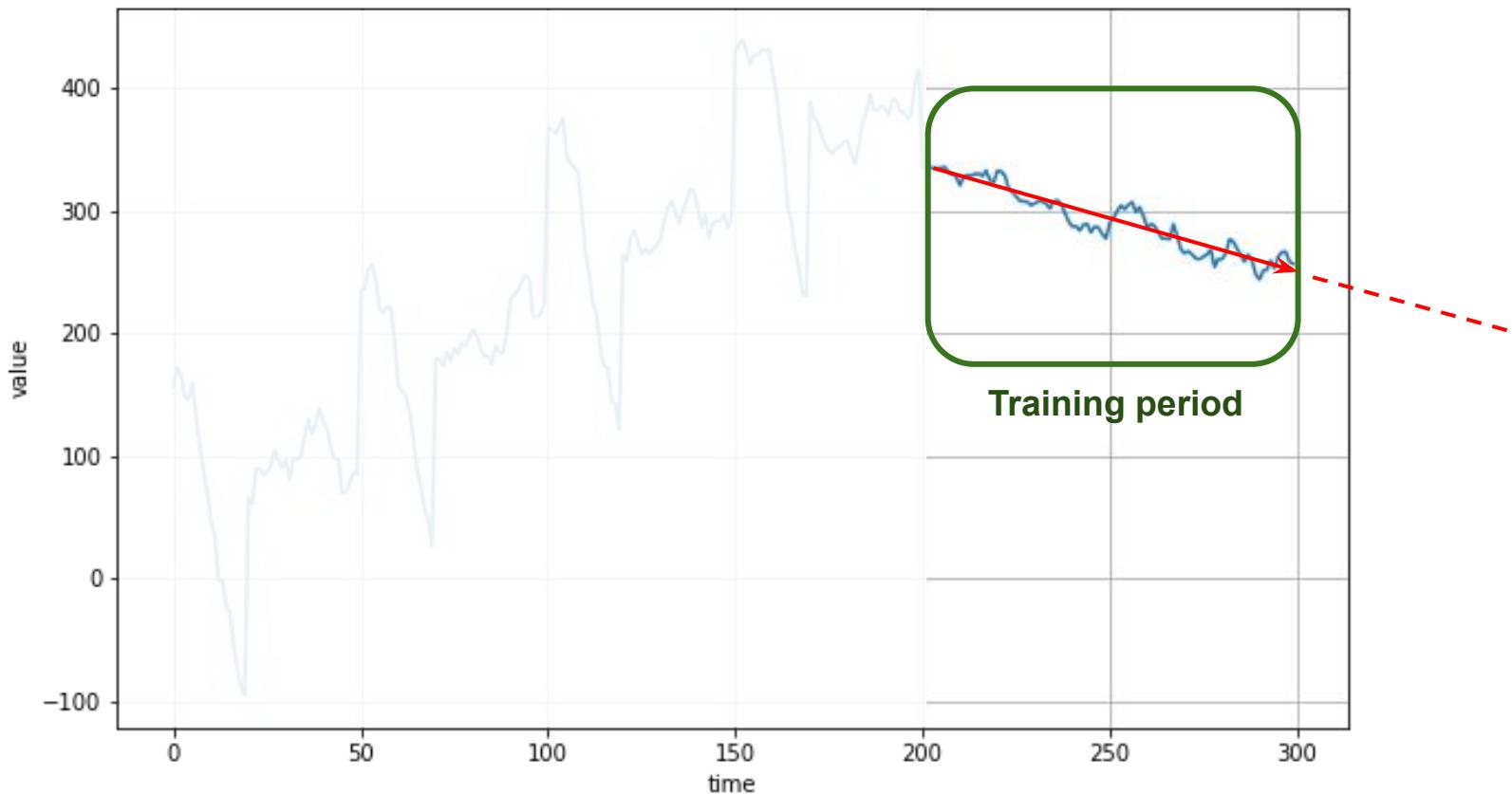
Forecast Learned Patterns



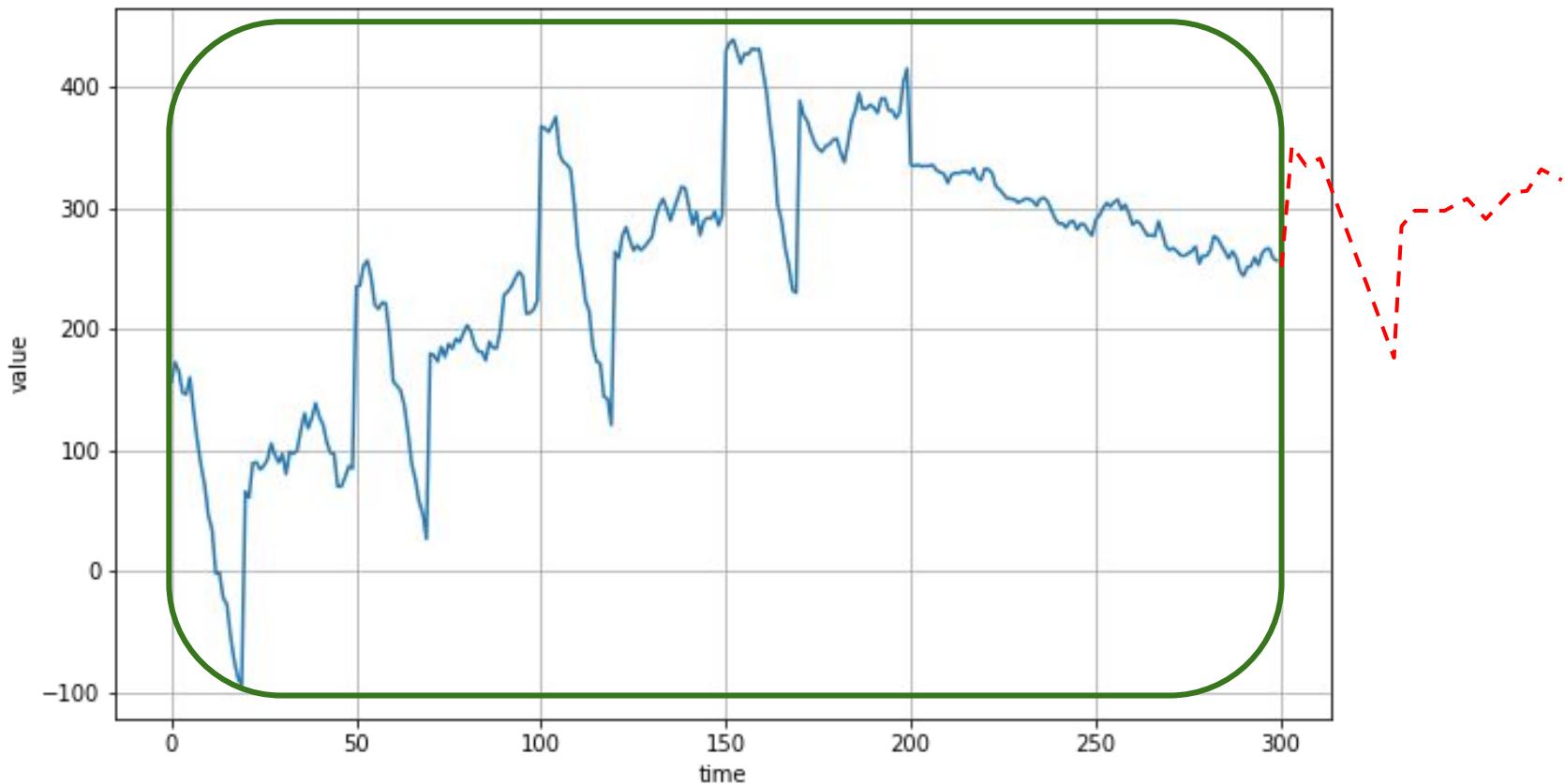
Non-Stationary Time Series



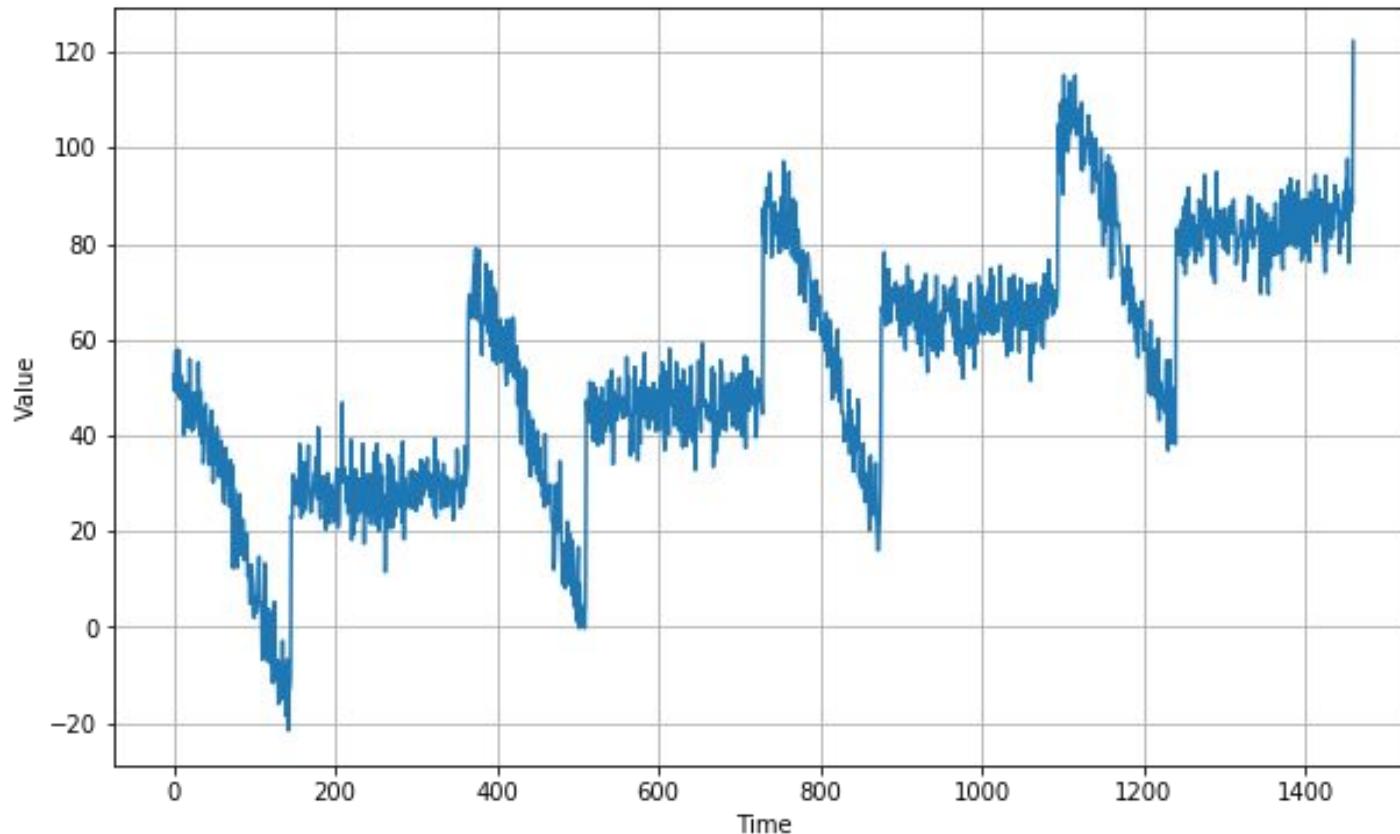
Non-Stationary Time Series



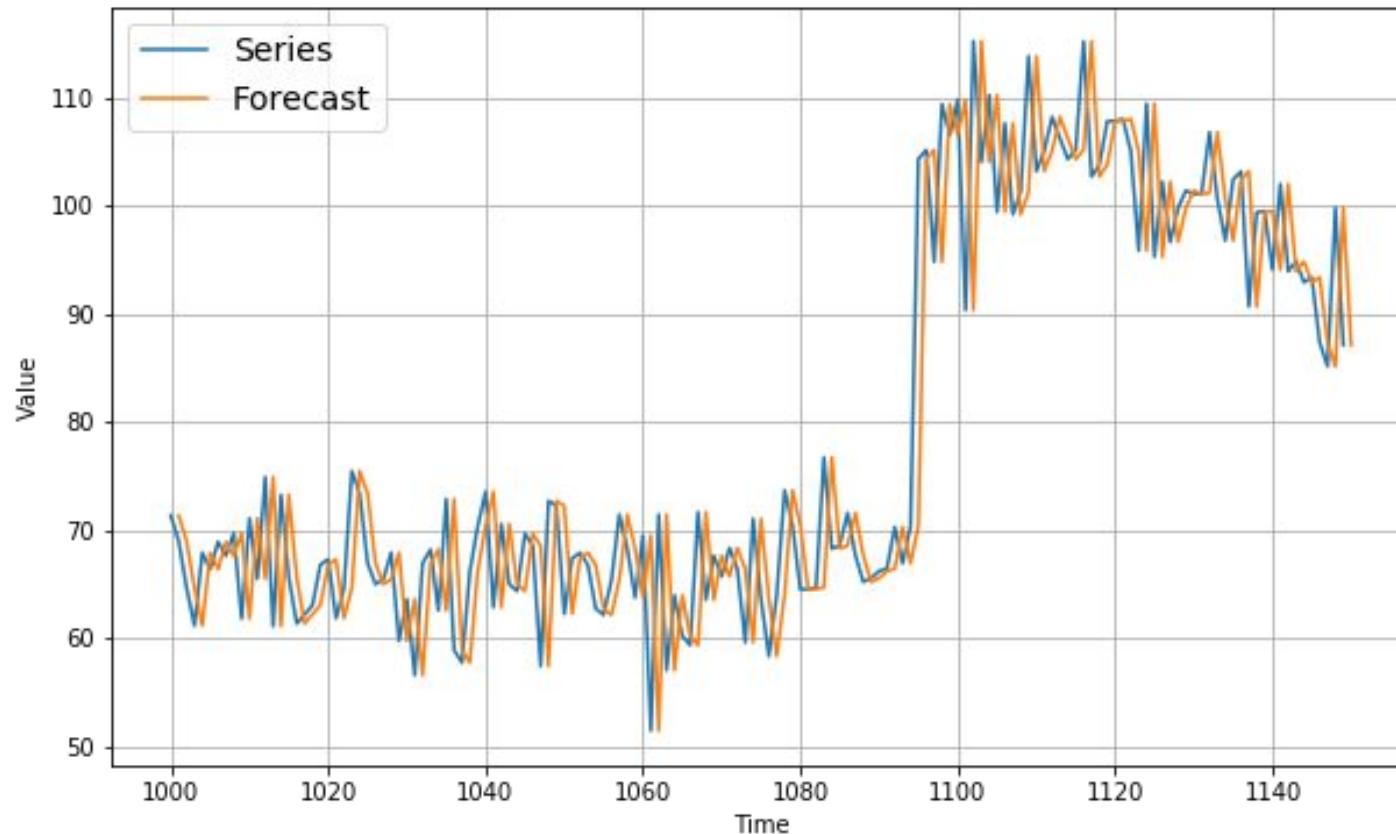
Non-Stationary Time Series



Trend + Seasonality + Noise



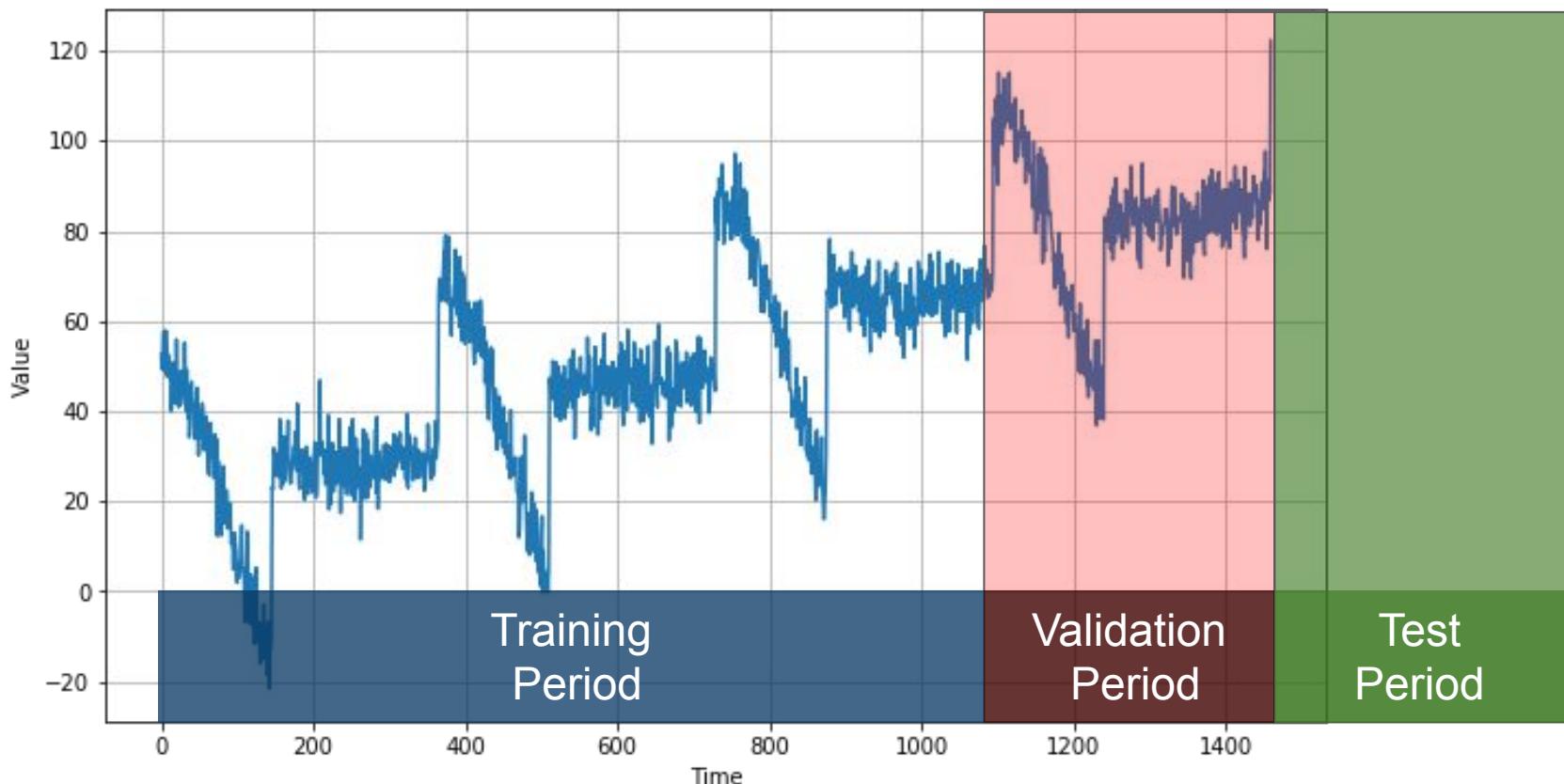
Naive Forecasting



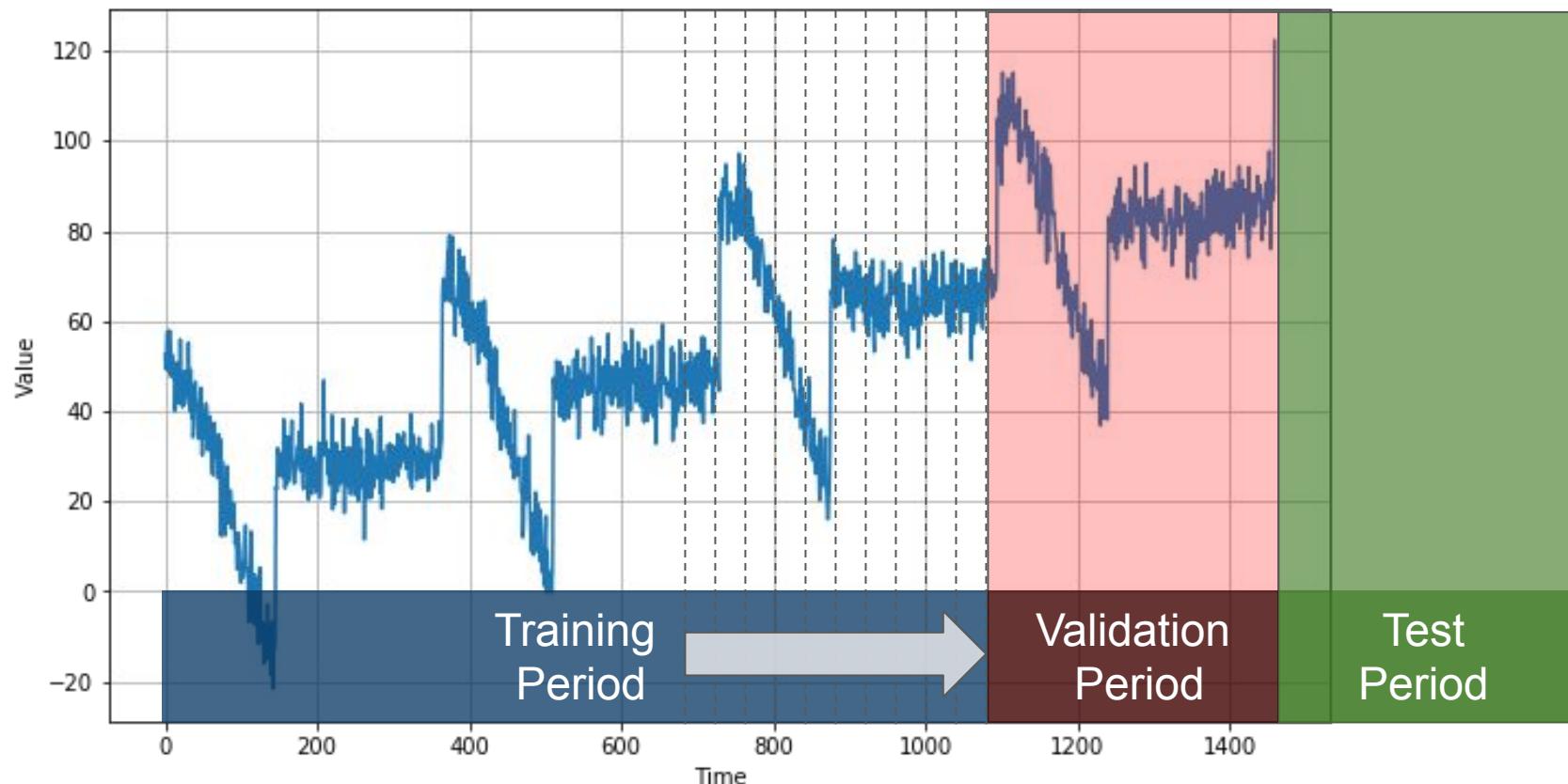
Fixed Partitioning



Fixed Partitioning



Roll-Forward Partitioning



```
errors = forecasts - actual

mse = np.square(errors).mean()

rmse = np.sqrt(mse)

mae = np.abs(errors).mean()

mape = np.abs(errors / x_valid).mean()
```



```
errors = forecasts - actual

mse = np.square(errors).mean()

rmse = np.sqrt(mse)

mae = np.abs(errors).mean()

mape = np.abs(errors / x_valid).mean()
```



```
errors = forecasts - actual

mse = np.square(errors).mean()

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rmse = np.sqrt(mse)

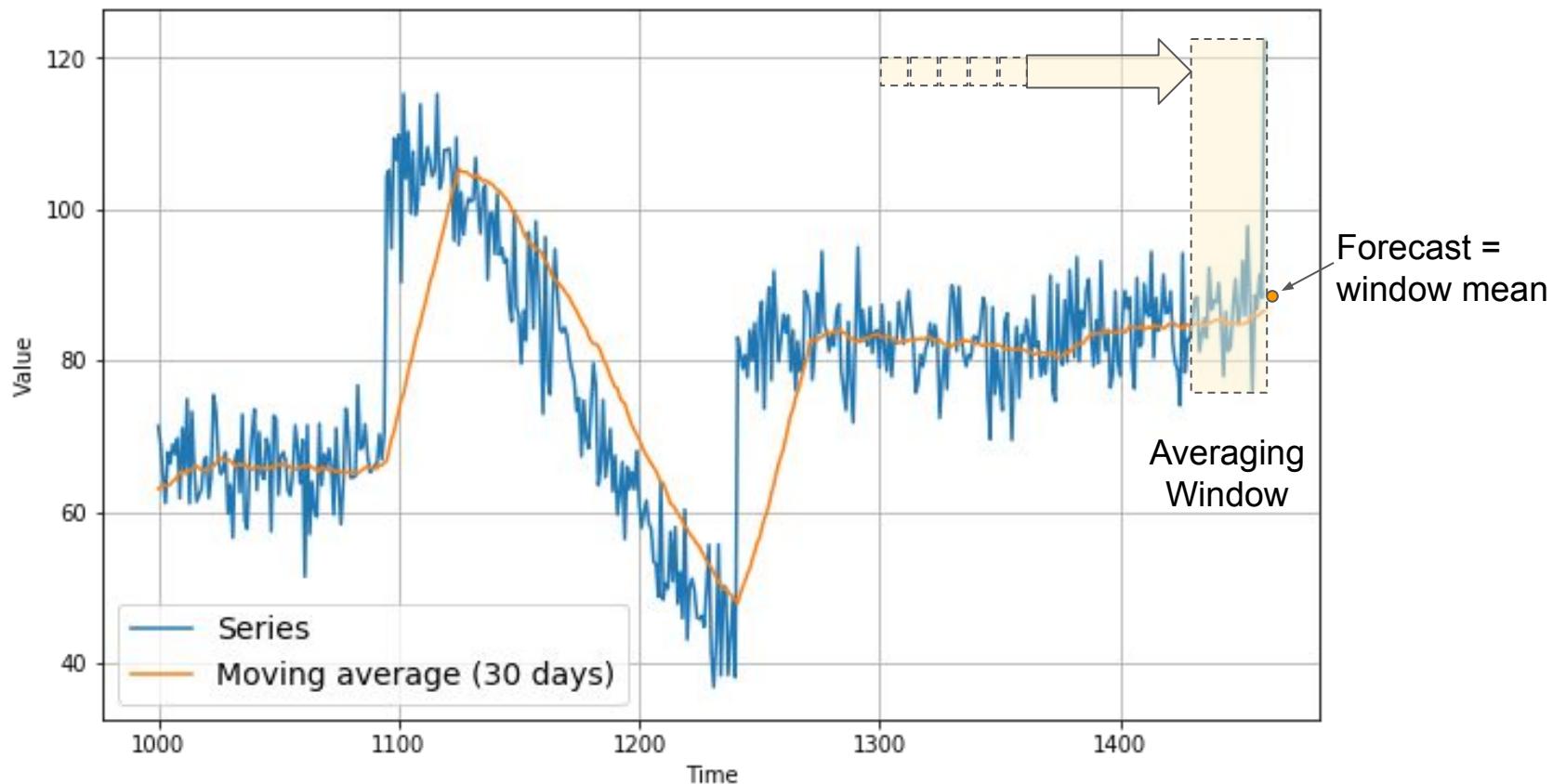
mae = np.abs(errors).mean()

mape = np.abs(errors / x_valid).mean()
```

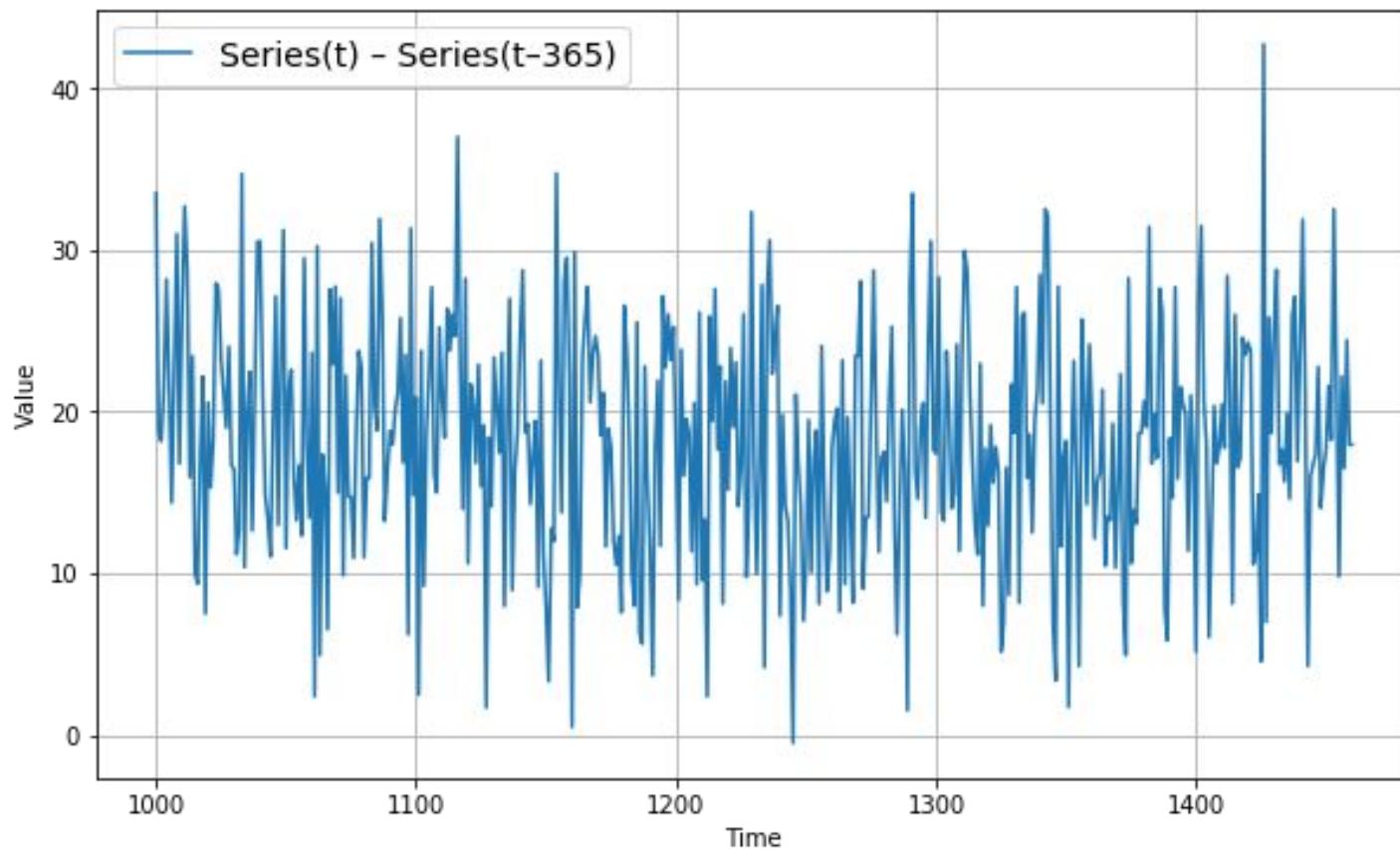
```
mae = tf.keras.metrics.mae(x_valid, naive_forecast).numpy()
```

```
5.937908515321673
```

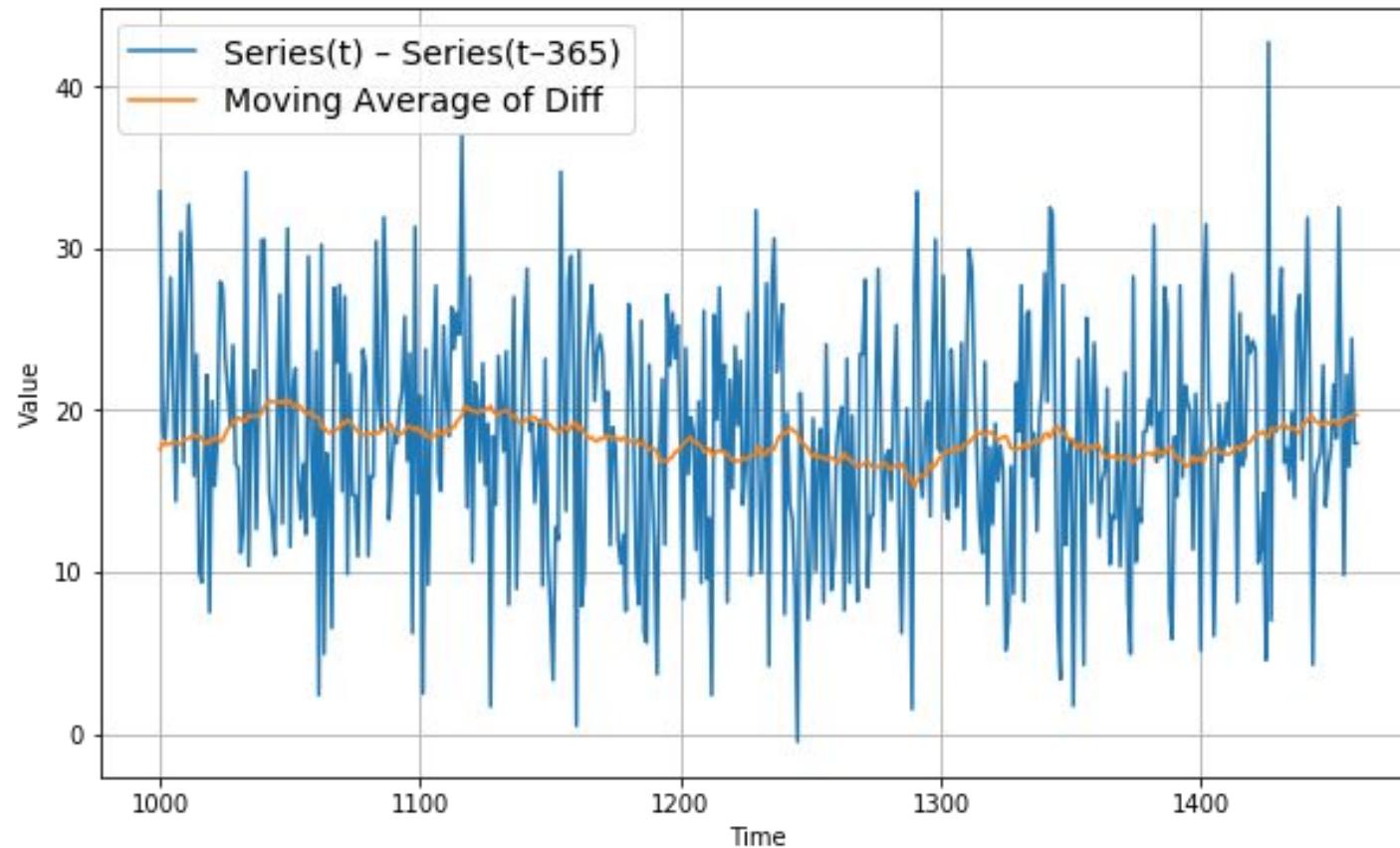
Moving Average



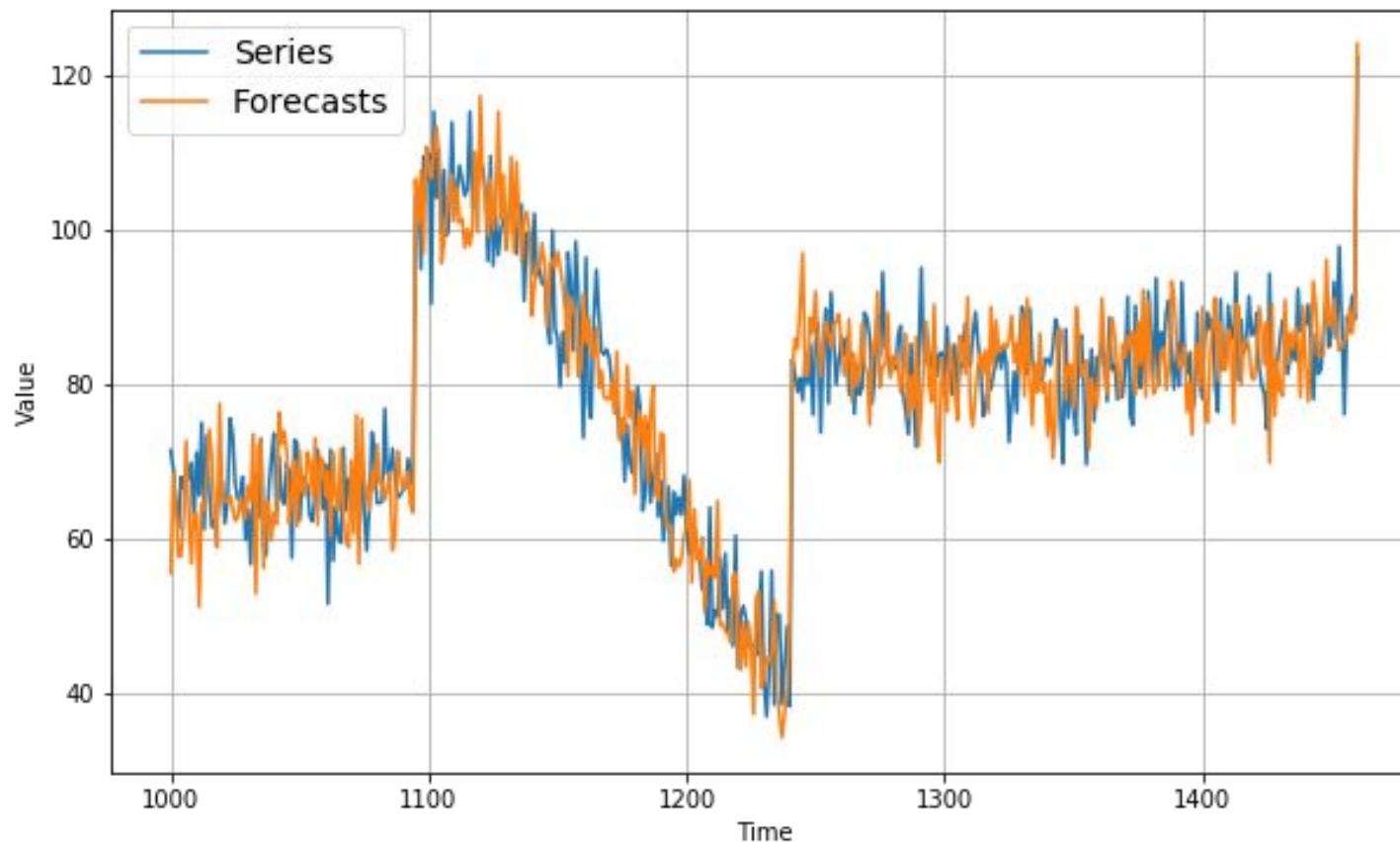
Differencing



Moving Average on Differenced Time Series

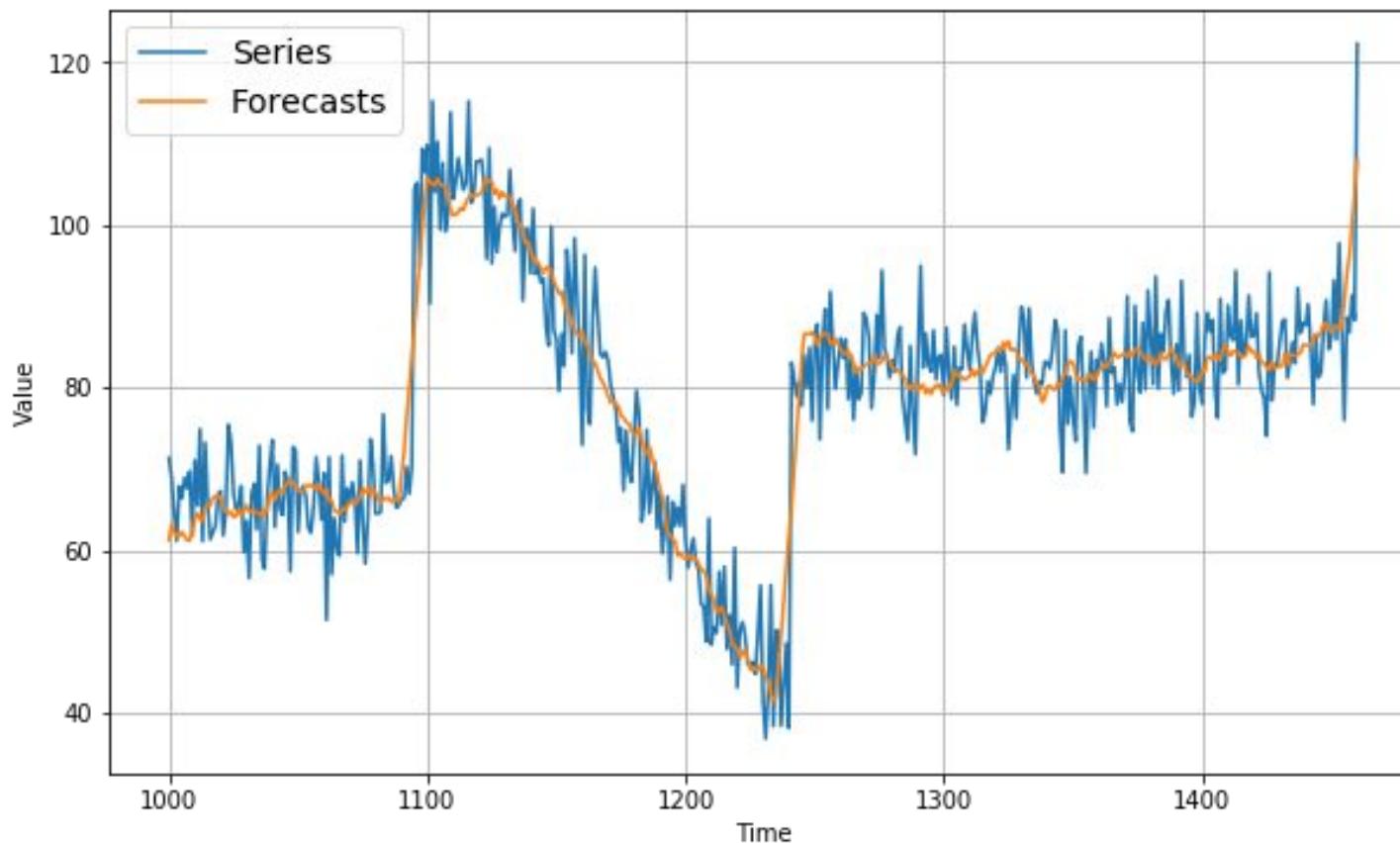


Restoring the Trend and Seasonality



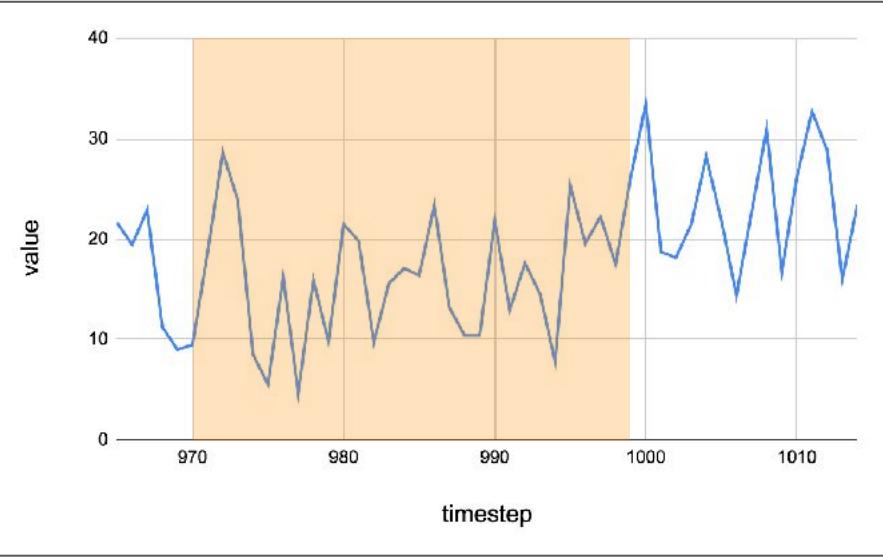
Forecasts = moving average of differenced series + series(t - 365)

Smoothing Both Past and Present Values

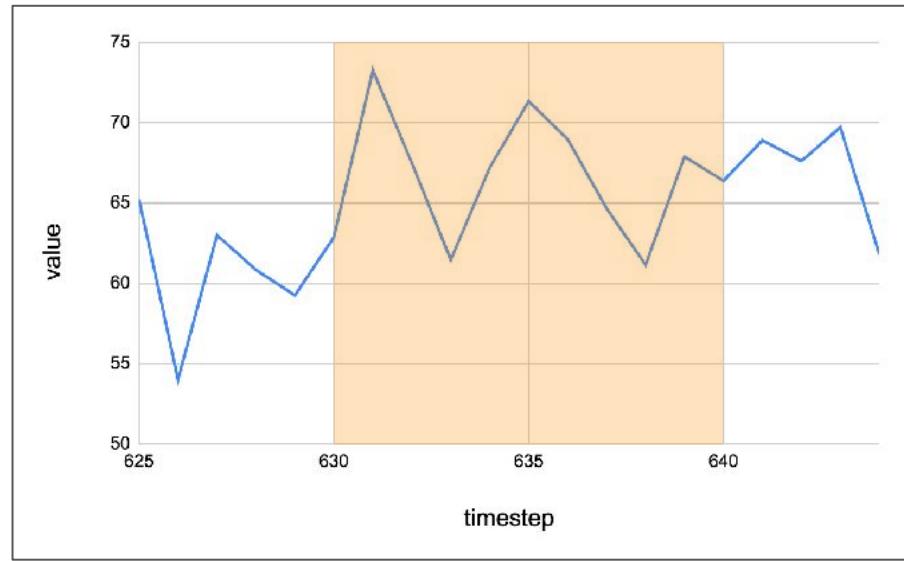


Forecasts = trailing moving average of differenced series + centered moving average of past series ($t - 365$)

Trailing Moving Average of Differenced Series
(zoomed at t_{1000} , window size = 30)



Centered Moving Average of Past Series ($t - 365$)
(zoomed at t_{635} , window size = 11)



$$TMA_{t_{1000}} = (v_{t_{970}} + v_{t_{971}} + v_{t_{972}} + \dots + v_{t_{999}}) / 30$$

\rightarrow forecast at $t_{1000} = TMA_{t_{1000}} + CMA_{t_{635}}$

$$CMA_{t_{635}} = (v_{t_{630}} + v_{t_{631}} + v_{t_{632}} + \dots + v_{t_{640}}) / 11$$

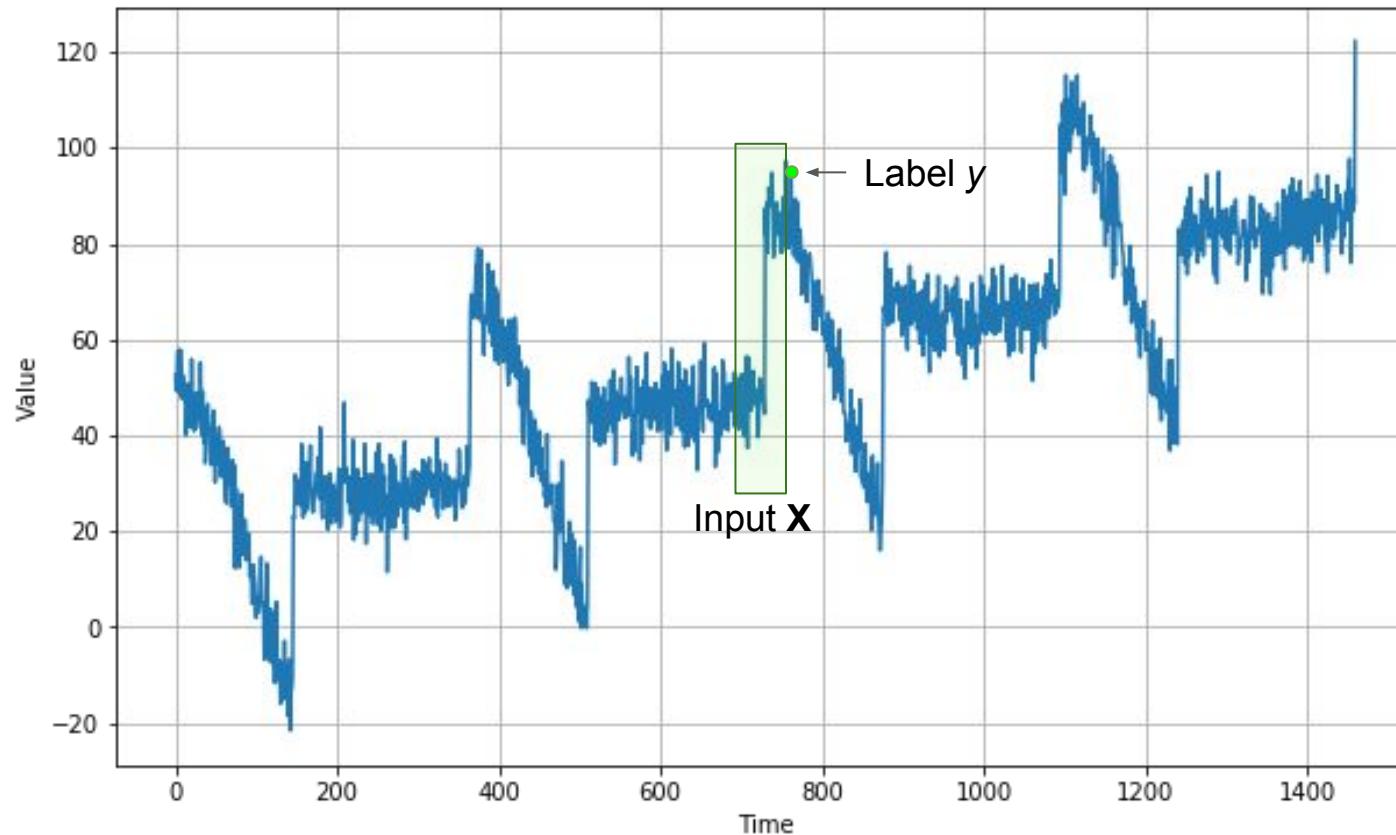
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Machine Learning on Time Windows



```
dataset = tf.data.Dataset.range(10)
for val in dataset:
    print(val.numpy())
```



```
dataset = tf.data.Dataset.range(10)
for val in dataset:
    print(val.numpy())
```

0
1
2
3
4
5
6
7
8
9

```
dataset = tf.data.Dataset.range(10)
dataset = dataset.window(5, shift=1)
for window_dataset in dataset:
    for val in window_dataset:
        print(val.numpy(), end=" ")
print()
```



```
dataset = tf.data.Dataset.range(10)
dataset = dataset.window(5, shift=1)
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    for val in window_dataset:
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    for val in window_dataset:
        print(val.numpy(), end=" ")
    print()
```

```
0 1 2 3 4
1 2 3 4 5
2 3 4 5 6
3 4 5 6 7
4 5 6 7 8
5 6 7 8 9
6 7 8 9
7 8 9
8 9
9
```



```
dataset = tf.data.Dataset.range(10)
dataset = dataset.window(5, shift=1, drop_remainder=True)
for window_dataset in dataset:
    for val in window_dataset:
        print(val.numpy(), end=" ")
print()
```



```
dataset = tf.data.Dataset.range(10)
dataset = dataset.window(5, shift=1, drop_remainder=True)
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```

```
0 1 2 3 4
1 2 3 4 5
2 3 4 5 6
3 4 5 6 7
4 5 6 7 8
5 6 7 8 9
```

```
dataset = tf.data.Dataset.range(10)
dataset = dataset.window(5, shift=1, drop_remainder=True)
dataset = dataset.flat_map(lambda window: window.batch(5))
for window in dataset:
    print(window.numpy())
```



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```

```
[0 1 2 3 4]
[1 2 3 4 5]
[2 3 4 5 6]
[3 4 5 6 7]
[4 5 6 7 8]
[5 6 7 8 9]
```

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dataset = tf.data.Dataset.range(10)
dataset = dataset.window(5, shift=1, drop_remainder=True)
dataset = dataset.flat_map(lambda window: window.batch(5))
dataset = dataset.map(lambda window: (window[:-1], window[-1]))
for x,y in dataset:
    print(x.numpy(), y.numpy())
```

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dataset = tf.data.Dataset.range(10)
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```
[0 1 2 3] [4]
[1 2 3 4] [5]
[2 3 4 5] [6]
[3 4 5 6] [7]
[4 5 6 7] [8]
[5 6 7 8] [9]
```

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dataset = tf.data.Dataset.range(10)
dataset = dataset.window(5, shift=1, drop_remainder=True)
dataset = dataset.flat_map(lambda window: window.batch(5))
dataset = dataset.map(lambda window: (window[:-1], window[-1]))
dataset = dataset.shuffle(buffer_size=10)
for x,y in dataset:
    print(x.numpy(), y.numpy())
```



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dataset = tf.data.Dataset.range(10)
dataset = dataset.window(5, shift=1, drop_remainder=True)
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```
[3 4 5 6] [7]
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dataset = dataset.flat_map(lambda window: window.batch(5))
dataset = dataset.map(lambda window: (window[:-1], window[-1]))
dataset = dataset.shuffle(buffer_size=10)
dataset = dataset.batch(2).prefetch(1)
for x,y in dataset:
    print("x = ", x.numpy())
    print("y = ", y.numpy())
```



```
dataset = tf.data.Dataset.range(10)
dataset = dataset.window(5, shift=1, drop_remainder=True)
dataset = dataset.flat_map(lambda window: window.batch(5))
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y = [[8] [5]]
x = [[3 4 5 6] [2 3 4 5]]
y = [[7] [6]]
x = [[5 6 7 8] [0 1 2 3]]
y = [[9] [4]]
```

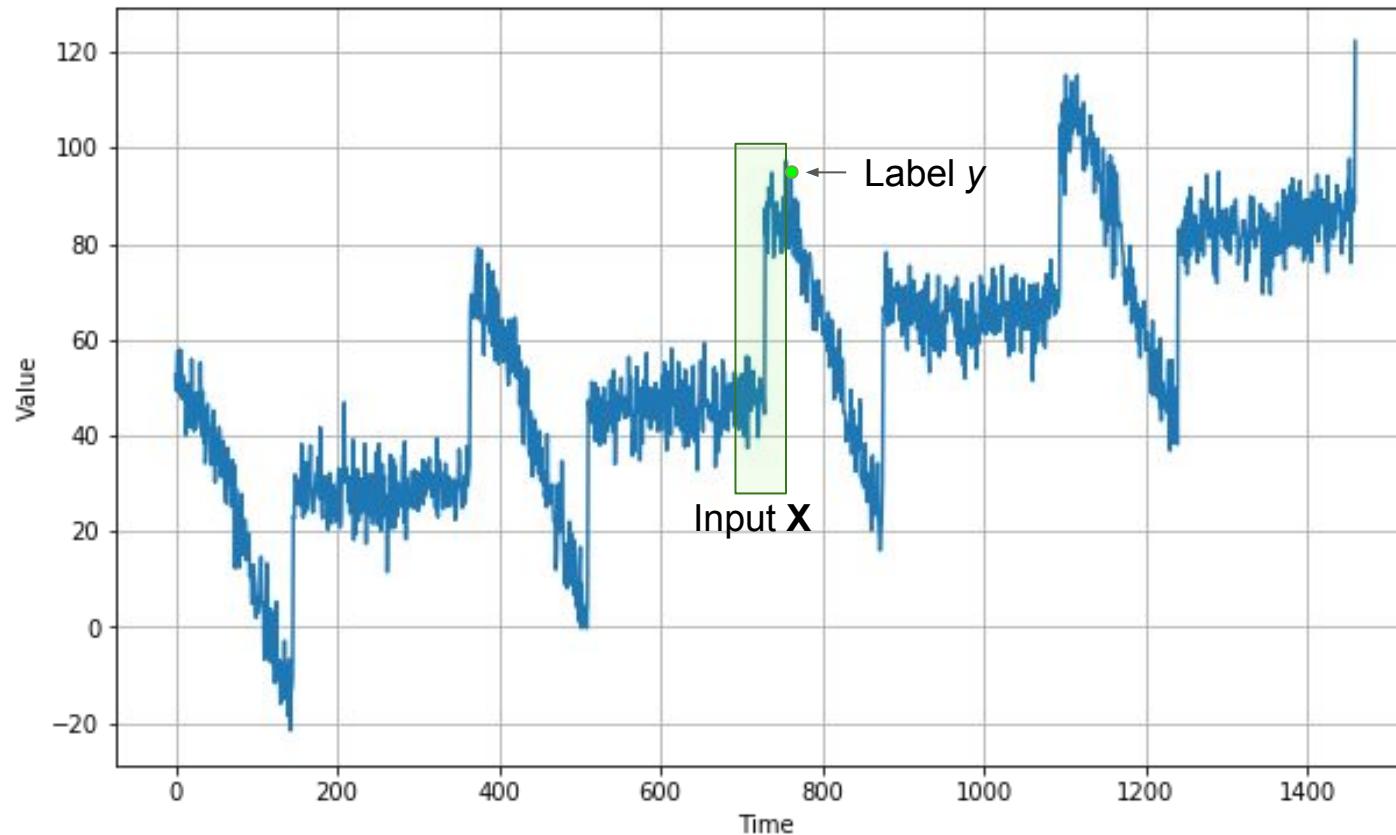
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x = [[3 4 5 6] [2 3 4 5]]
y = [[7] [6]]
x = [[5 6 7 8] [0 1 2 3]]
y = [[9] [4]]
```

Machine Learning on Time Windows



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

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

```
def windowed_dataset(series, window_size, batch_size, shuffle_buffer):
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    dataset = dataset.shuffle(shuffle_buffer)
    dataset = dataset.map(lambda window: (window[:-1], window[-1]))
    dataset = dataset.batch(batch_size).prefetch(1)
    return dataset
```

```
split_time = 1000
time_train = time[:split_time]
x_train = series[:split_time]
time_valid = time[split_time:]
x_valid = series[split_time:]
```

```
split_time = 1000
time_train = time[:split_time]
x_train = series[:split_time]
time_valid = time[split_time:]
x_valid = series[split_time:]
```



```
window_size = 20
batch_size = 32
shuffle_buffer_size = 1000

dataset = windowed_dataset(series, window_size, batch_size, shuffle_buffer_size)
l0 = tf.keras.layers.Dense(1)
model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size,)),
    l0,
])

```

```
window_size = 20
batch_size = 32
shuffle_buffer_size = 1000

dataset = windowed_dataset(series, window_size, batch_size, shuffle_buffer_size)
l0 = tf.keras.layers.Dense(1)
model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size,)),
    l0,
])

```

```
window_size = 20
batch_size = 32
shuffle_buffer_size = 1000

dataset = windowed_dataset(series, window_size, batch_size, shuffle_buffer_size)
10 = tf.keras.layers.Dense(1)
model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size,)),
    10,
])
```



```
window_size = 20
batch_size = 32
shuffle_buffer_size = 1000

dataset = windowed_dataset(series, window_size, batch_size, shuffle_buffer_size)
10 = tf.keras.layers.Dense(1)
model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size,)),
    10,
])
```



```
window_size = 20
batch_size = 32
shuffle_buffer_size = 1000

dataset = windowed_dataset(series, window_size, batch_size, shuffle_buffer_size)
l0 = tf.keras.layers.Dense(1)
model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size,)),
    l0,
])
```



```
model.compile(  
    loss="mse",  
    optimizer=tf.keras.optimizers.SGD(learning_rate=1e-6, momentum=0.9)  
)  
model.fit(dataset, epochs=100)
```

```
model.compile(  
    loss="mse",  
    optimizer=tf.keras.optimizers.SGD(learning_rate=1e-6, momentum=0.9)  
)  
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```
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    loss="mse",  
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)  
model.fit(dataset, epochs=100)
```



```
print("Layer weights {}".format(l0.get_weights()))
```

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print("Layer weights {}".format(l0.get_weights()))
```

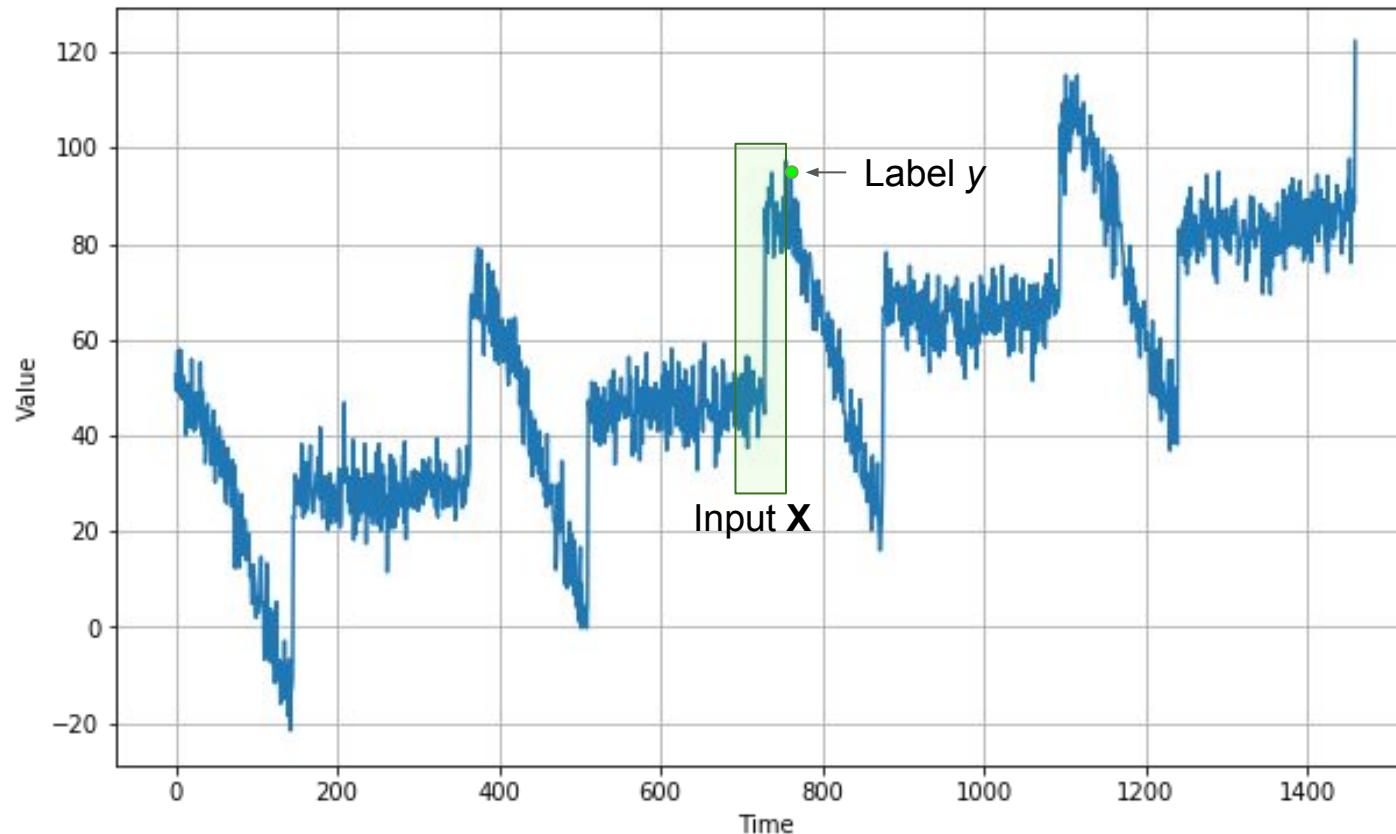
```
Layer weights [array([[ 0.01633573],  
[-0.02911791],  
[ 0.00845617],  
[-0.02175158],  
[ 0.04962169],  
[-0.03212642],  
[-0.02596855],  
[-0.00689476],  
[ 0.0616533 ],  
[-0.00668752],  
[-0.02735964],  
[ 0.0377918 ],  
[-0.02855931],  
[ 0.05299238],  
[-0.0121608 ],  
[ 0.00138755],  
[ 0.0905595 ],  
[ 0.19994621],  
[ 0.2556632 ],  
[ 0.41660047]], dtype=float32), array([0.01430958], dtype=float32)]
```

```
print("Layer weights {}".format(10.get_weights()))
```

Layer weights [array([[0.01633573],
[-0.02911791],
[0.00845617],
[-0.02175158],
[0.04962169],
[-0.03212642],
[-0.02596855],
[-0.00689476],
[0.0616533],
[-0.00668752],
[-0.02735964],
[0.0377918],
[-0.02855931],
[0.05299238],
[-0.0121608],
[0.00138755],
[0.0905595],
[0.19994621],
[0.2556632],
[0.41660047]], dtype=float32), array([0.01430958], dtype=float32)]

The diagram illustrates the structure of a layer's weights. It shows a vertical list of weight vectors, each represented by a single row of numerical values. Red arrows point from the first four vectors to labels W_{t0} , W_{t1} , W_{t2} , and W_{t3} respectively, indicating they are the weight matrices for time steps 0, 1, 2, and 3. A red arrow also points from the last vector to a label b , indicating it is the bias vector.

Machine Learning on Time Windows



```
print("Layer weights {}".format(l0.get_weights()))
```

Layer weights [array([[0.01633573],
[-0.02911791],
[0.00845617],
[-0.02175158],
[0.04962169],
[-0.03212642],
[-0.02596855],
[-0.00689476],
[0.0616533],
[-0.00668752],
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[0.0377918],
[-0.02855931],
[0.05299238],
[-0.0121608],
[0.00138755],
[0.0905595],
[0.19994621],
[0.2556632],
[0.41660047]], dtype=float32), array([0.01430958], dtype=float32)]

The diagram illustrates the structure of a layer's weights. It shows a vertical list of weight vectors. Red arrows point from the first four vectors to labels W_{t0} , W_{t1} , W_{t2} , and W_{t3} respectively. A red arrow points from the fifth vector to a label b .

```
print("Layer weights {}".format(l0.get_weights()))
```

```
Layer weights [array([[ 0.01633573],  
[-0.02911791],  
[ 0.00845617],  
[-0.02175158],  
[ 0.04962169],  
[-0.03212642],  
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[ 0.0905595 ],  
[ 0.19994621],  
[ 0.2556632 ],  
[ 0.41660047]], dtype=float32), array([0.01430958], dtype=float32)]
```

```
print(series[1:21])
model.predict(series[1:21][np.newaxis])
```



```
print(series[1:21])
model.predict(series[1:21][np.newaxis])
```

```
print(series[1:21])
model.predict(series[1:21][np.newaxis])
```

```
[49.35275  53.314735 57.711823 48.934444 48.931244 57.982895 53.897125
 47.67393  52.68371 47.591717 47.506374 50.959415 40.086178 40.919415
 46.612473 44.228207 50.720642 44.454983 41.76799 55.980938]

array([[49.08478]], dtype=float32)
```



```
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).squeeze()
```

```
forecast = []
for time in range(len(series) - window_size):
    forecast.append(model.predict(series[time:time + window_size][np.newaxis]))

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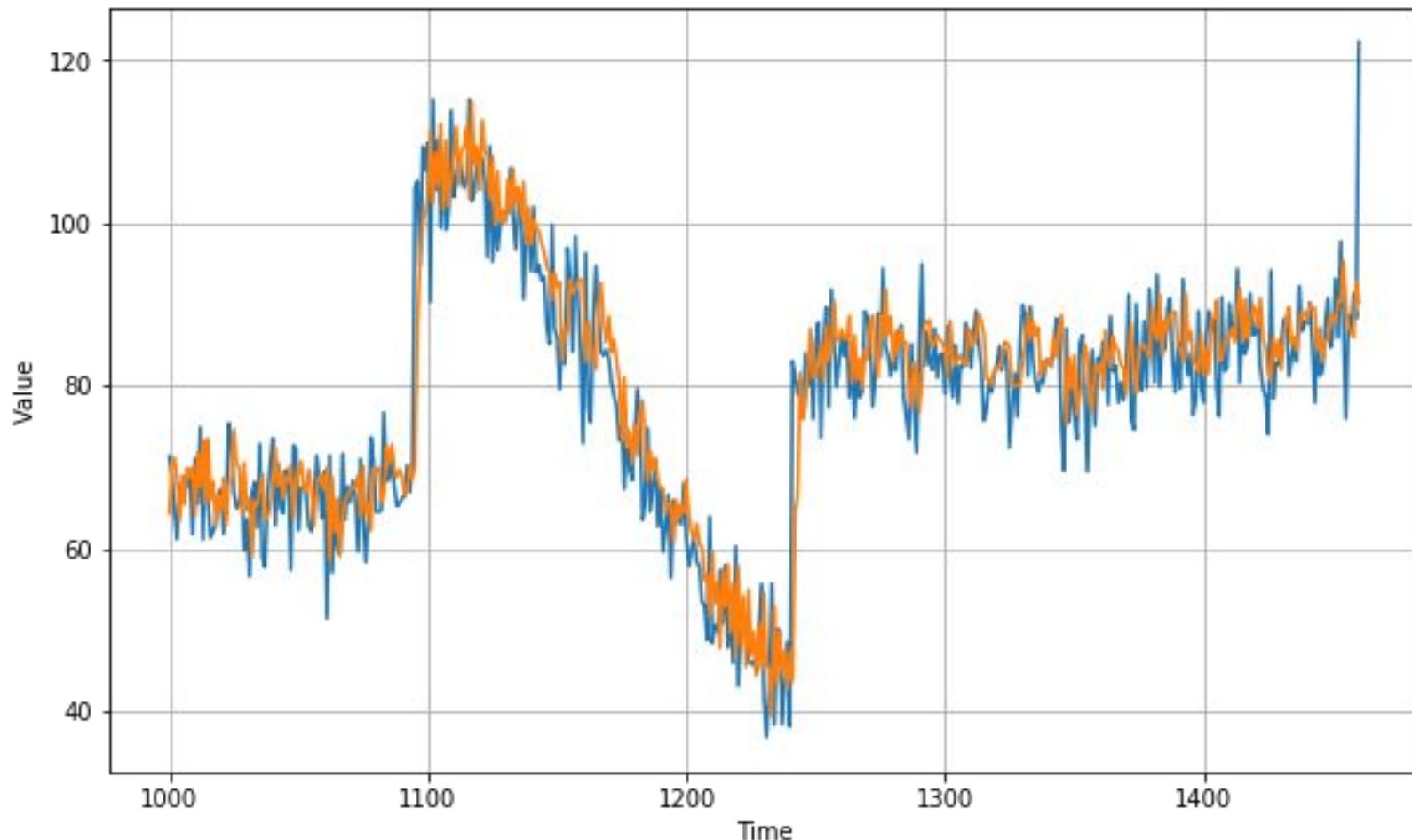
forecast = forecast[split_time - window_size:]
results = np.array(forecast).squeeze()
```



```
forecast = []
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forecast = forecast[split_time - window_size:]
results = np.array(forecast).squeeze()
```





```
tf.keras.metrics.mae(x_valid, results).numpy()
```

4.9526777

```
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size,)),
    tf.keras.layers.Dense(10, 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)
)
model.fit(dataset, epochs=100, verbose=0)
```

```
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

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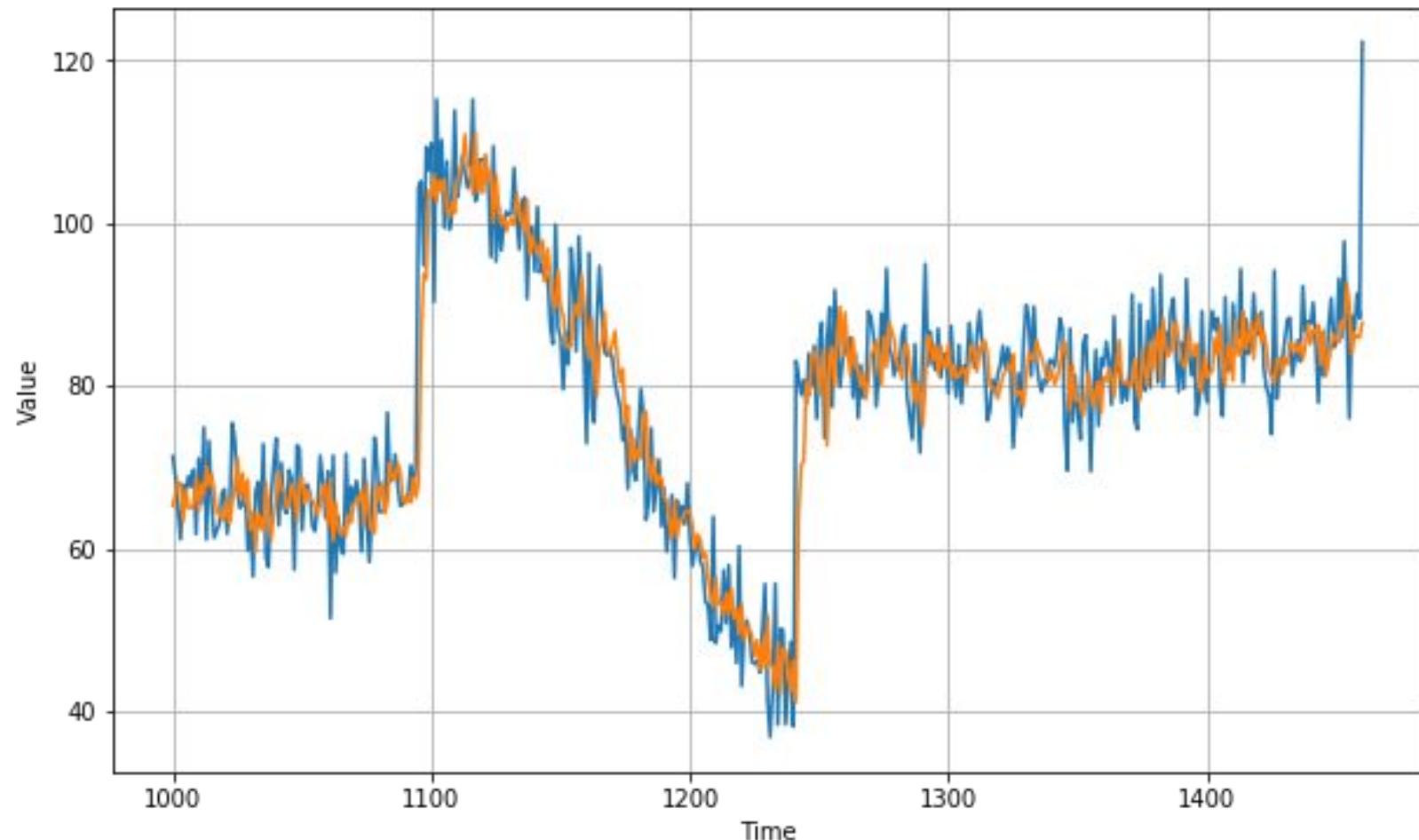
model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size,)),
    tf.keras.layers.Dense(10, activation="relu"),
    tf.keras.layers.Dense(10, activation="relu"),
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model.fit(dataset, epochs=100, verbose=0)
```



deeplearning.ai

```
tf.keras.metrics.mae(x_valid, results).numpy()
```

4.9833784

```
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

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

lr_schedule = tf.keras.callbacks.LearningRateScheduler(
    lambda epoch: 1e-8 * 10**(epoch / 20))

optimizer = tf.keras.optimizers.SGD(momentum=0.9)

model.compile(loss="mse", optimizer=optimizer)

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

```
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size,)),
    tf.keras.layers.Dense(10, activation="relu"),
    tf.keras.layers.Dense(10, activation="relu"),
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```
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    tf.keras.layers.Dense(10, activation="relu"),
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])

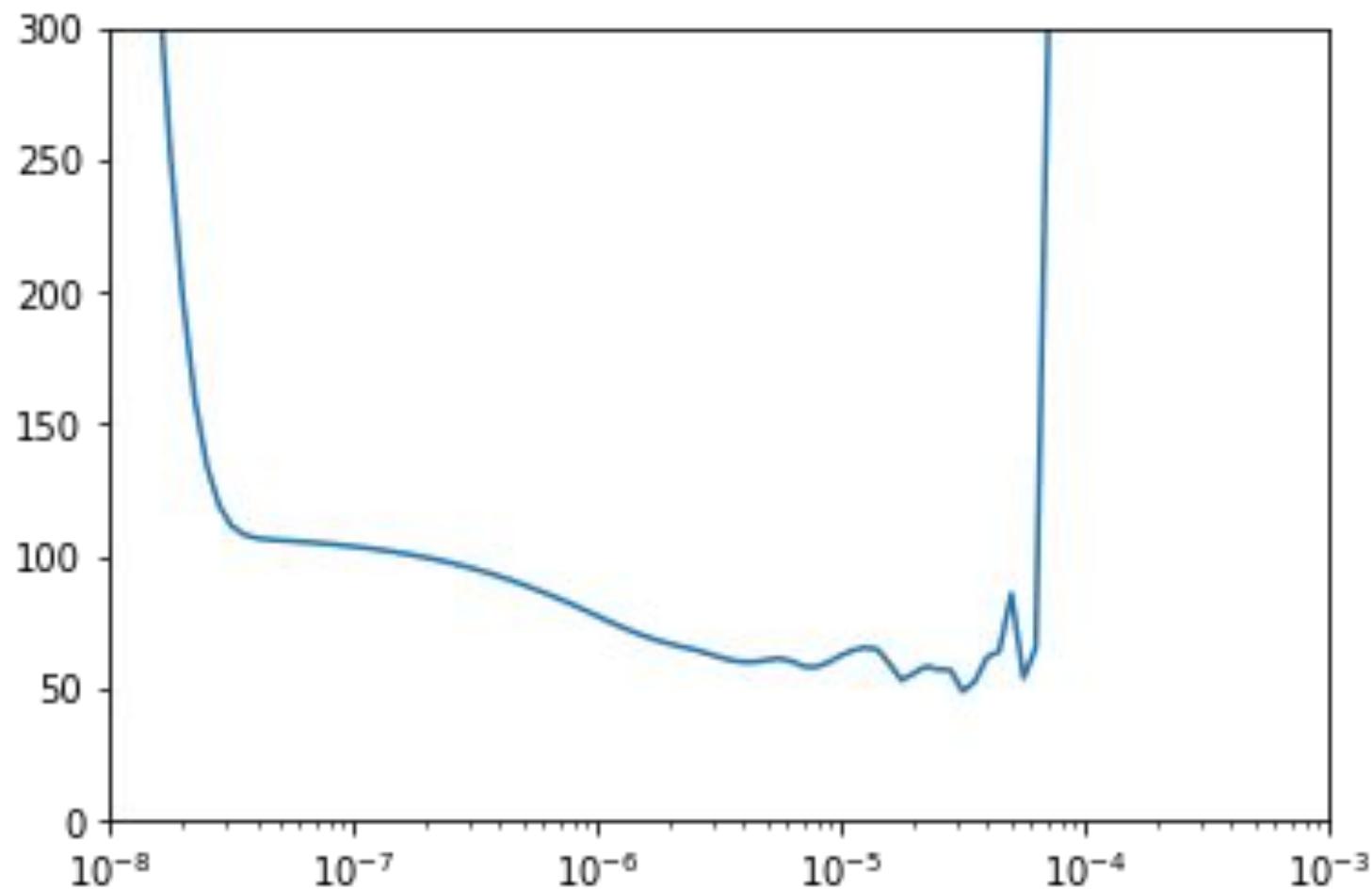
lr_schedule = tf.keras.callbacks.LearningRateScheduler(
    lambda epoch: 1e-8 * 10**(epoch / 20))

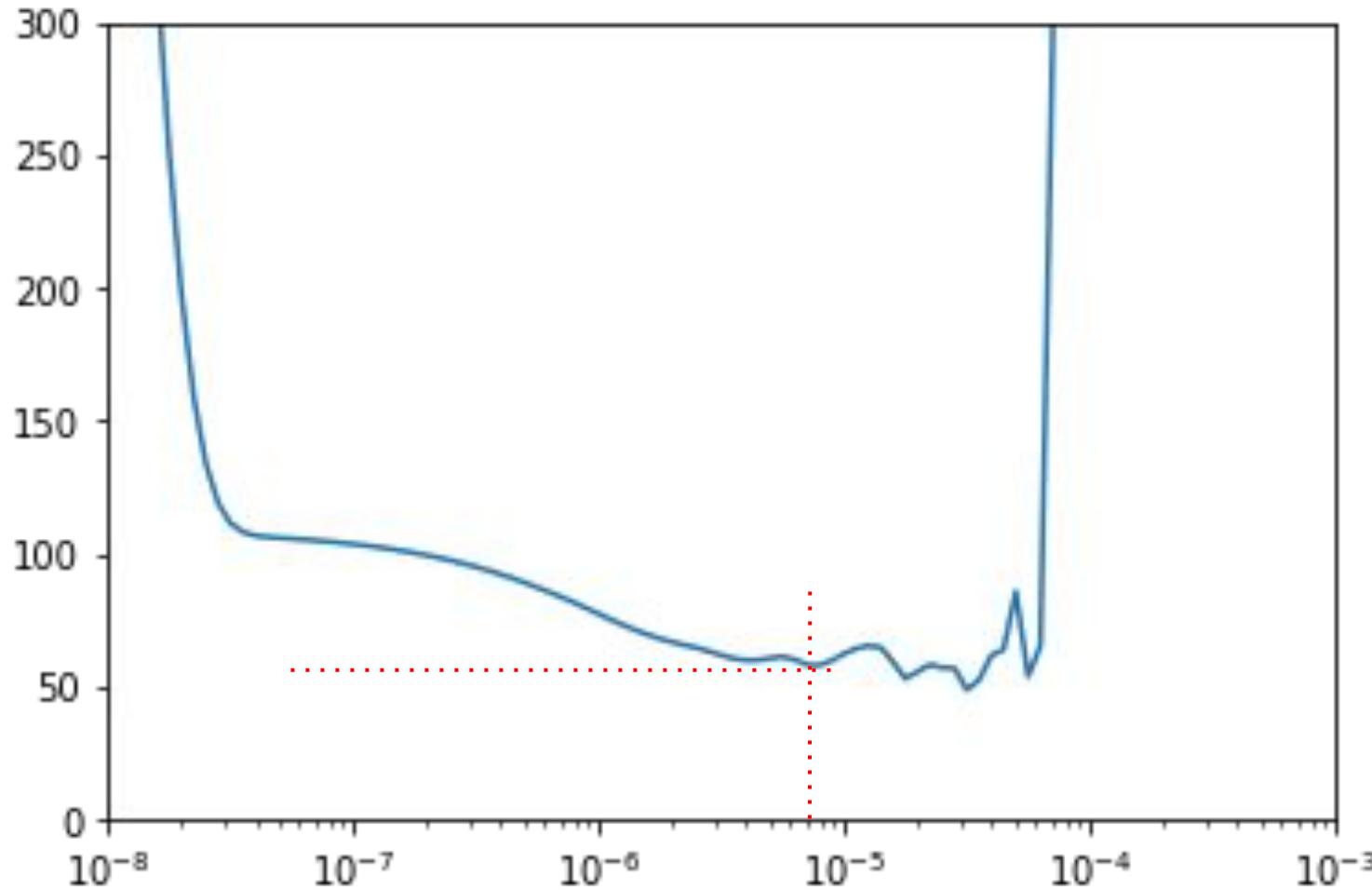
optimizer = tf.keras.optimizers.SGD(momentum=0.9)

model.compile(loss="mse", optimizer=optimizer)

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

```
lrs = 1e-8 * (10 ** (np.arange(100) / 20))
plt.semilogx(lrs, history.history["loss"])
plt.axis([1e-8, 1e-3, 0, 300])
```





```
window_size = 30
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

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

optimizer = tf.keras.optimizers.SGD(learning_rate=7e-6, momentum=0.9)

model.compile(loss="mse", optimizer=optimizer)

history = model.fit(dataset, epochs=500)
```

```
window_size = 30
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

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

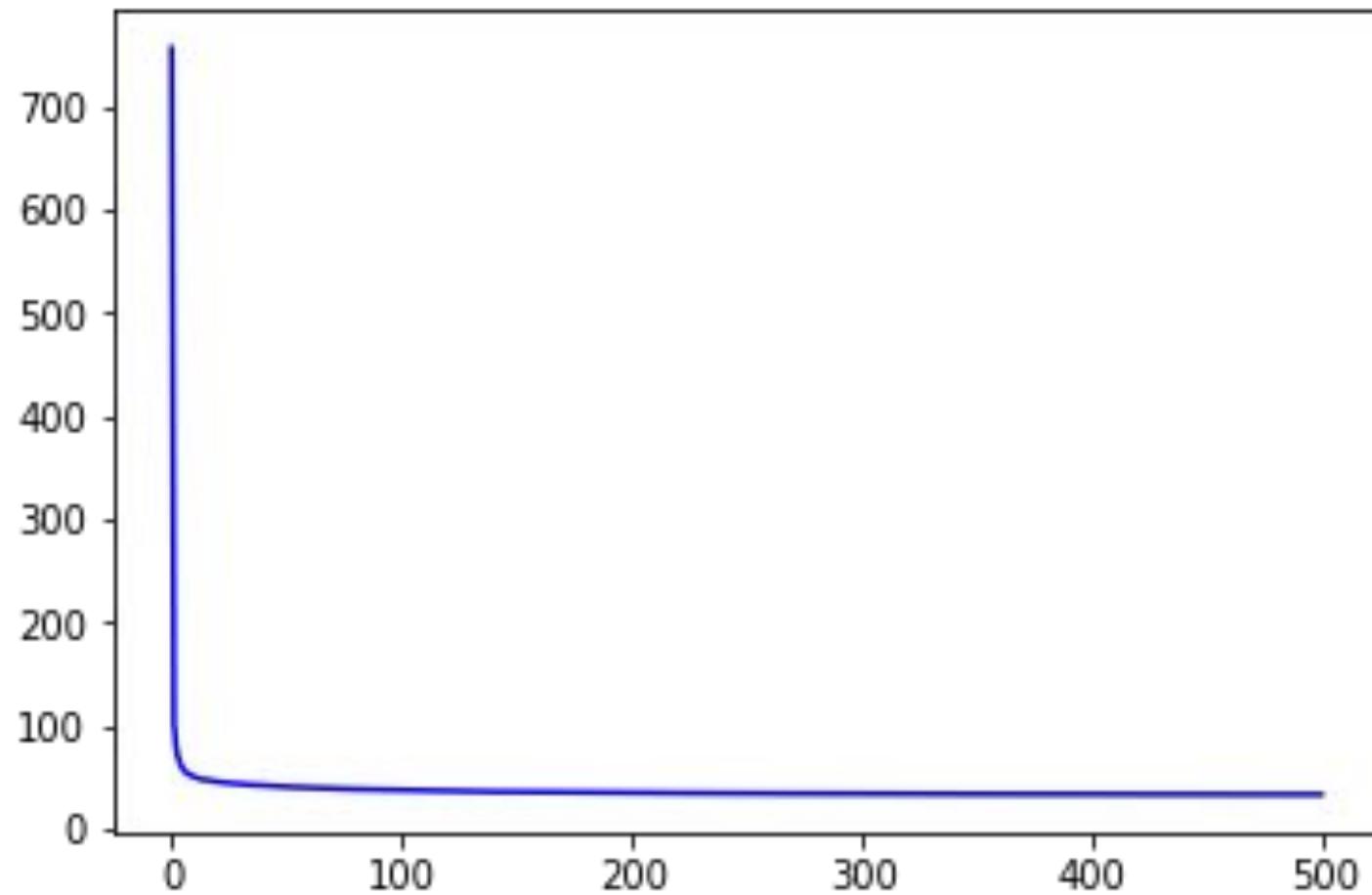
optimizer = tf.keras.optimizers.SGD(learning_rate=7e-6, momentum=0.9)

model.compile(loss="mse", optimizer=optimizer)

history = model.fit(dataset, epochs=500)
```

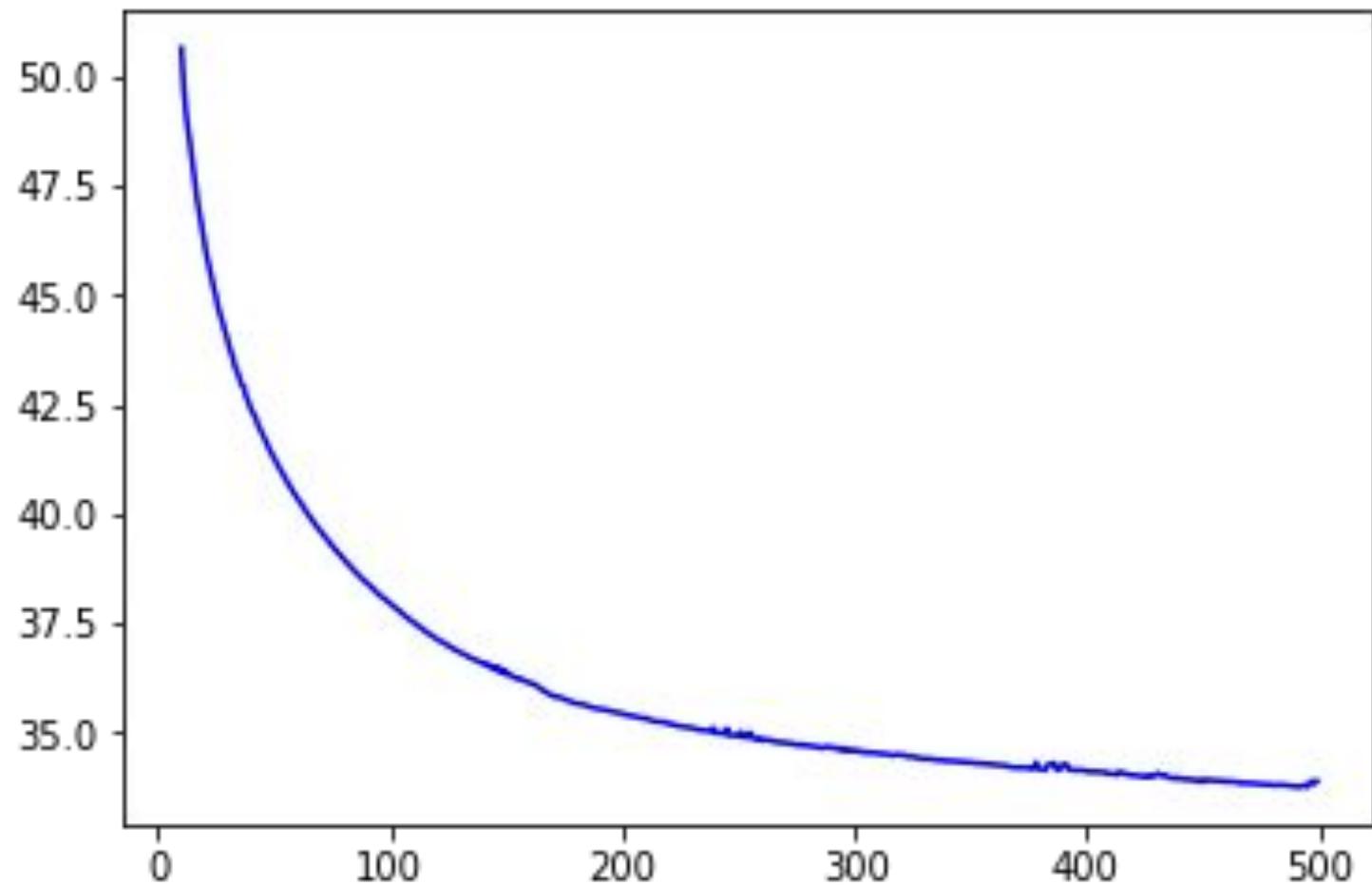
```
loss = history.history['loss']
epochs = range(len(loss))
plt.plot(epochs, loss, 'b', label='Training Loss')
plt.show()
```

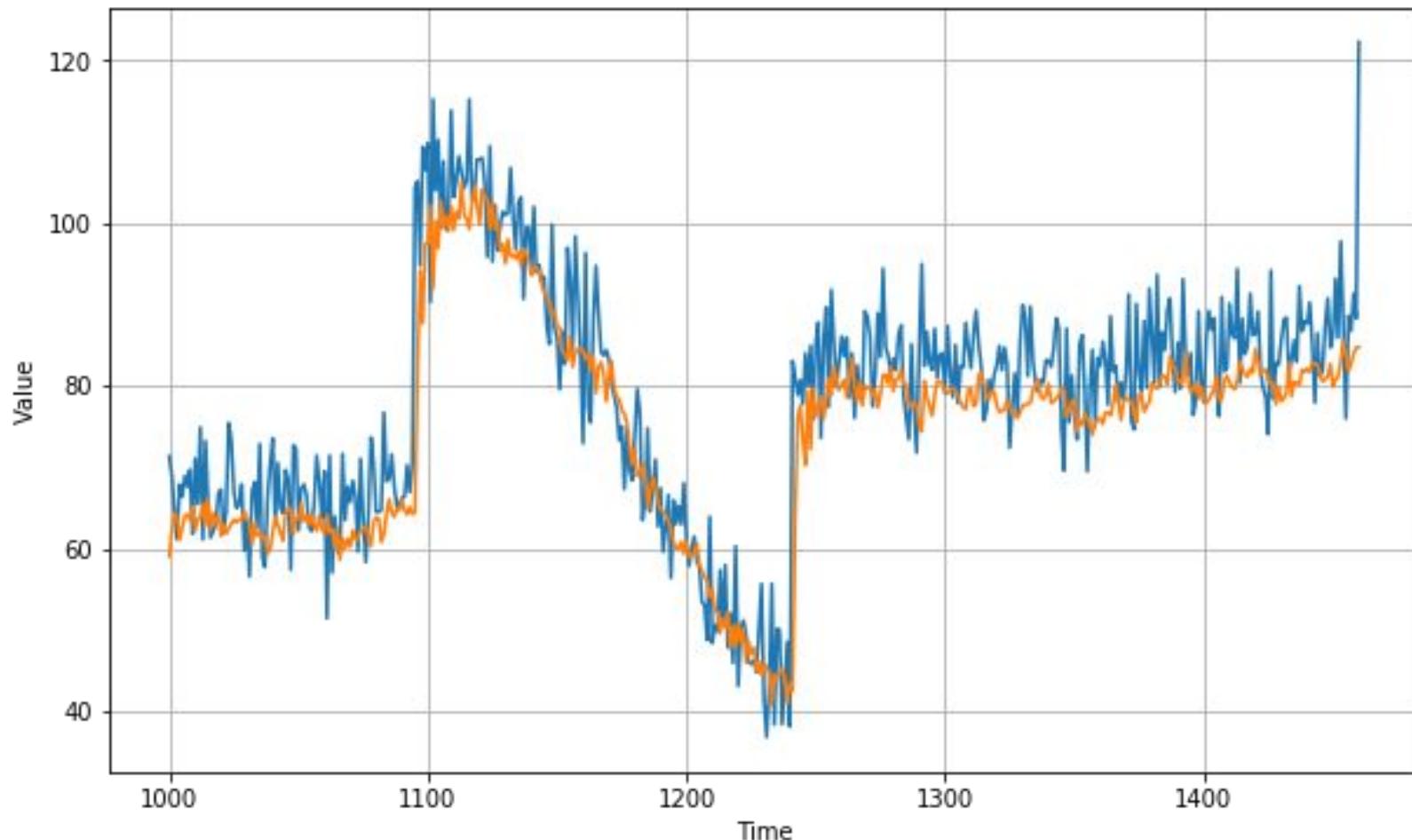




```
loss = history.history['loss']
epochs = range(10, len(loss))
plot_loss = loss[10:]
plt.plot(epochs, loss, 'b', label='Training Loss')
plt.show()
```







```
tf.keras.metrics.mae(x_valid, results).numpy()
```

4.4847784

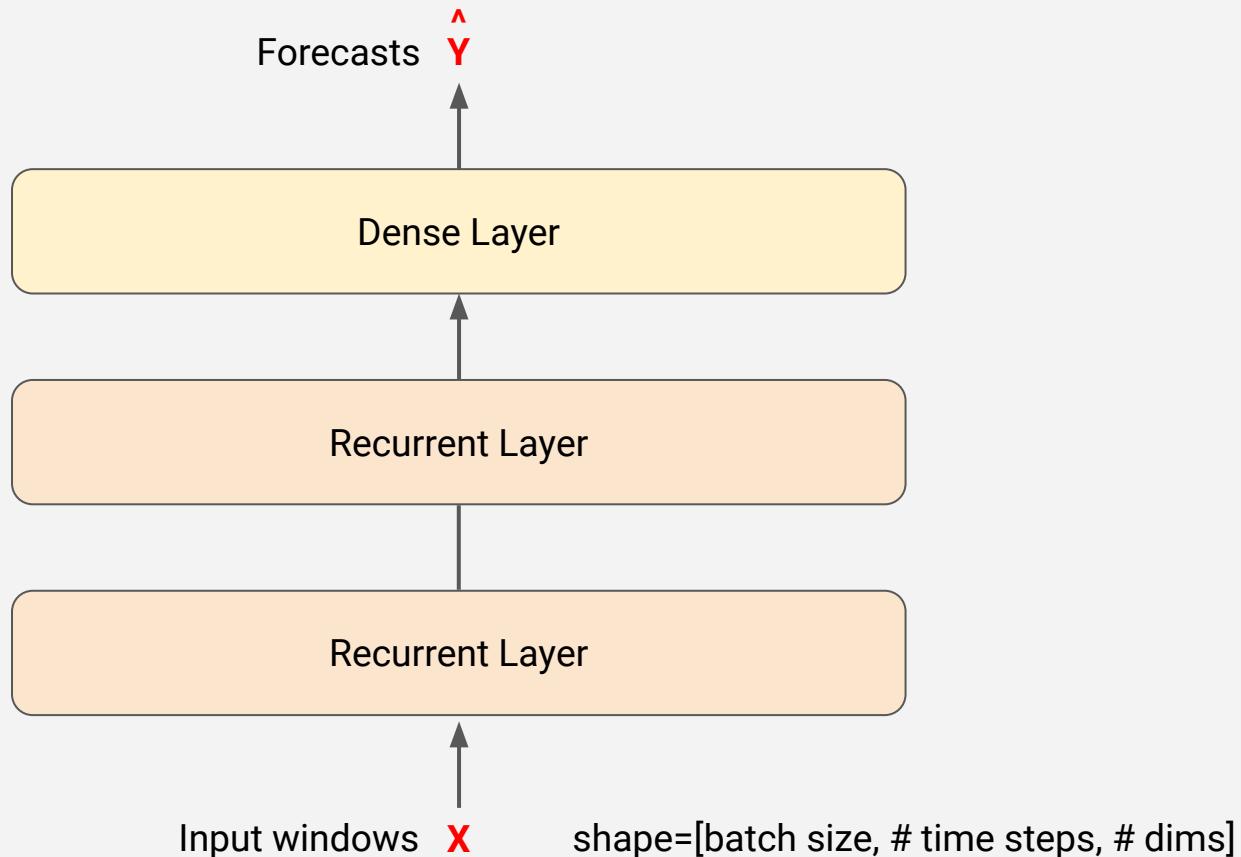
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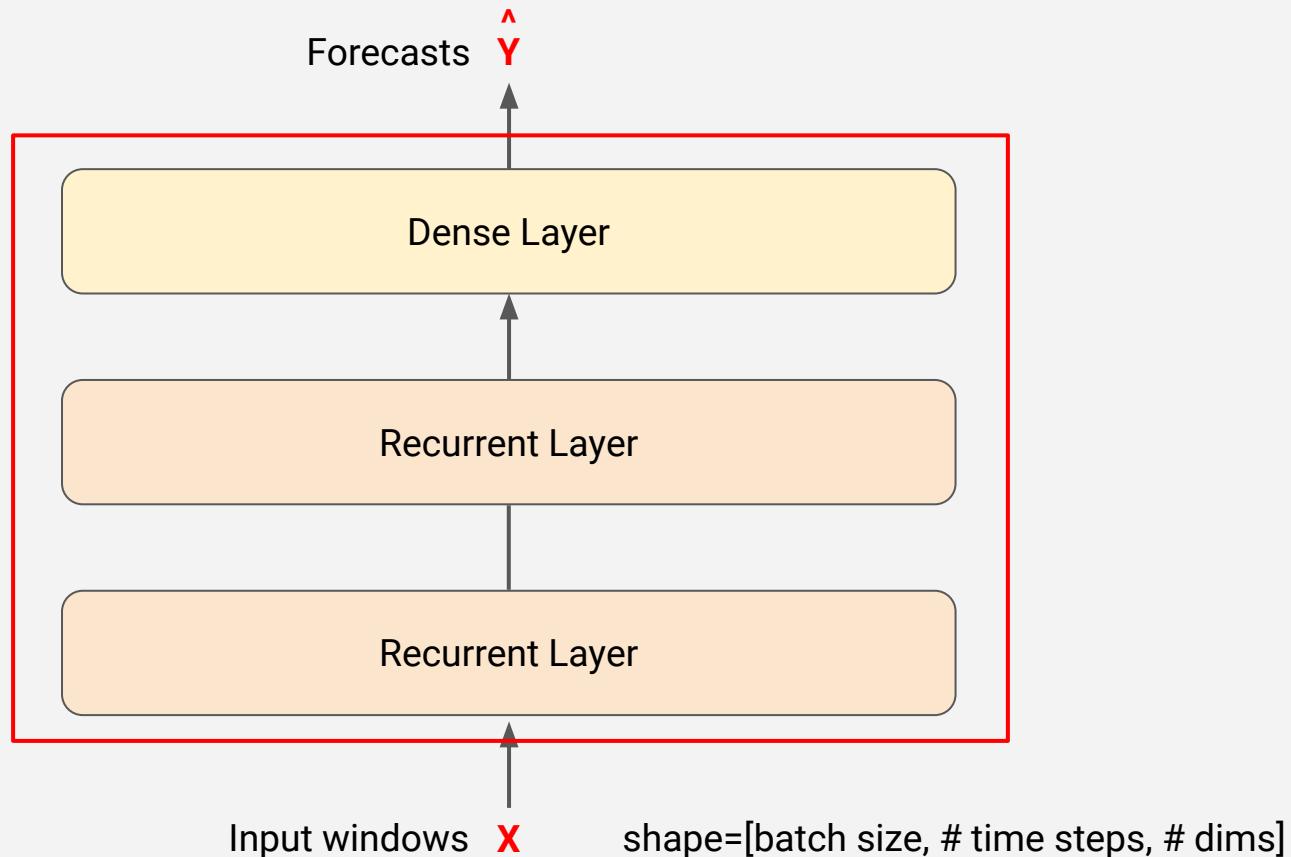
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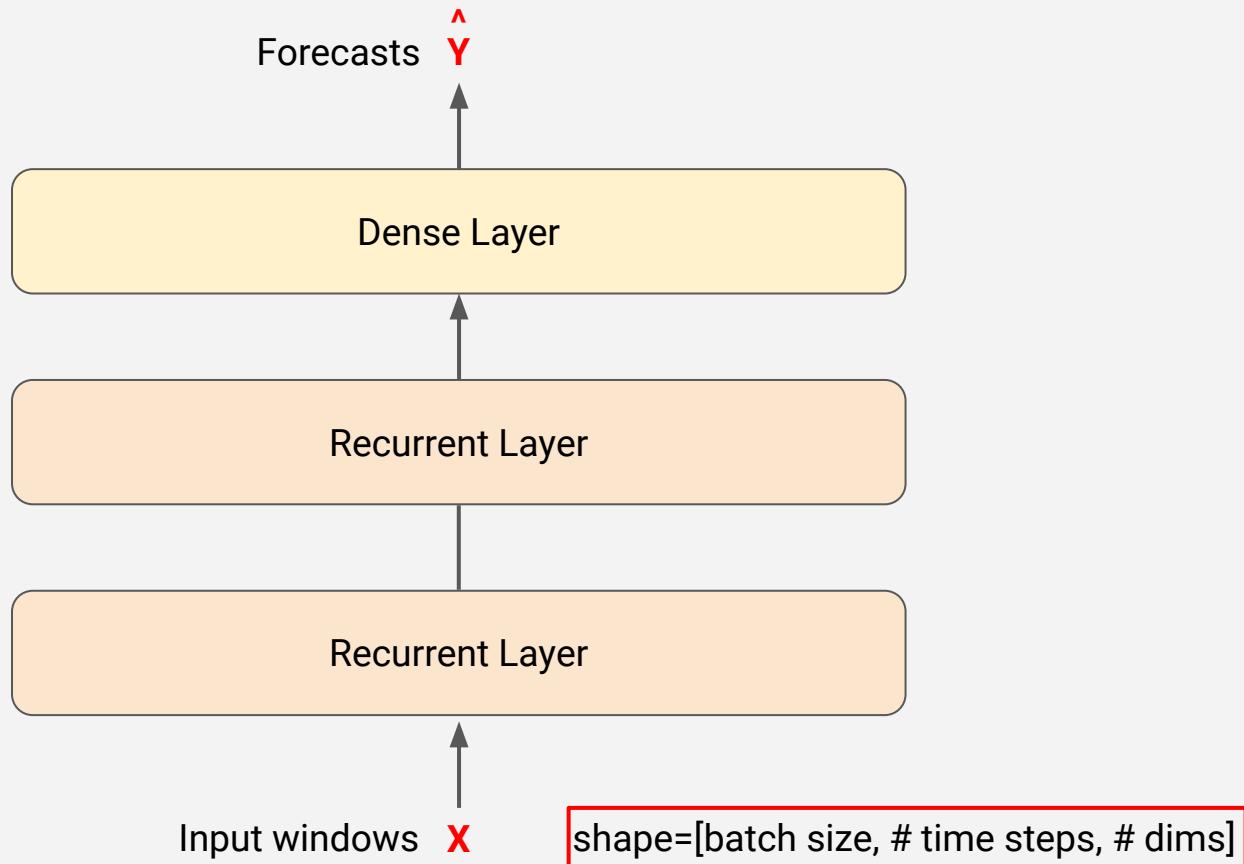
Recurrent Neural Network



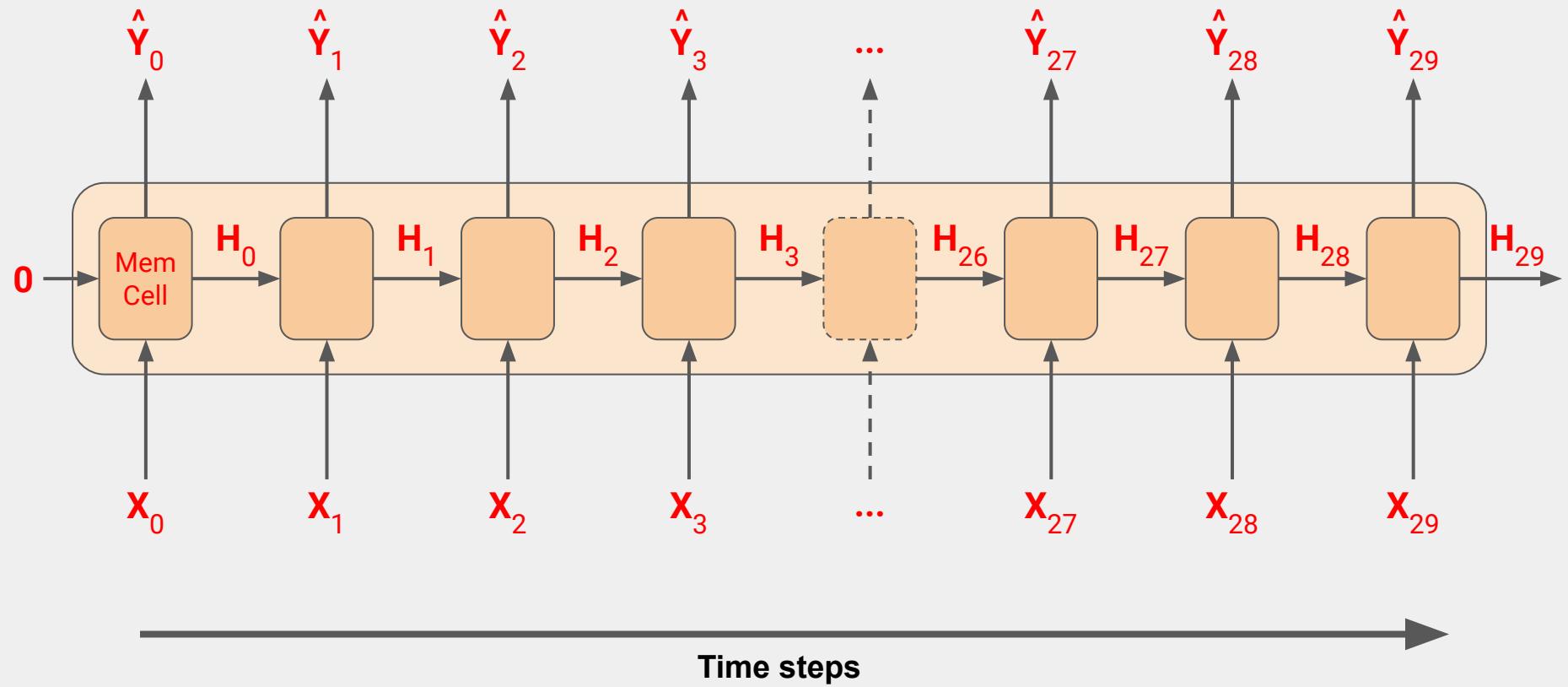
Recurrent Neural Network



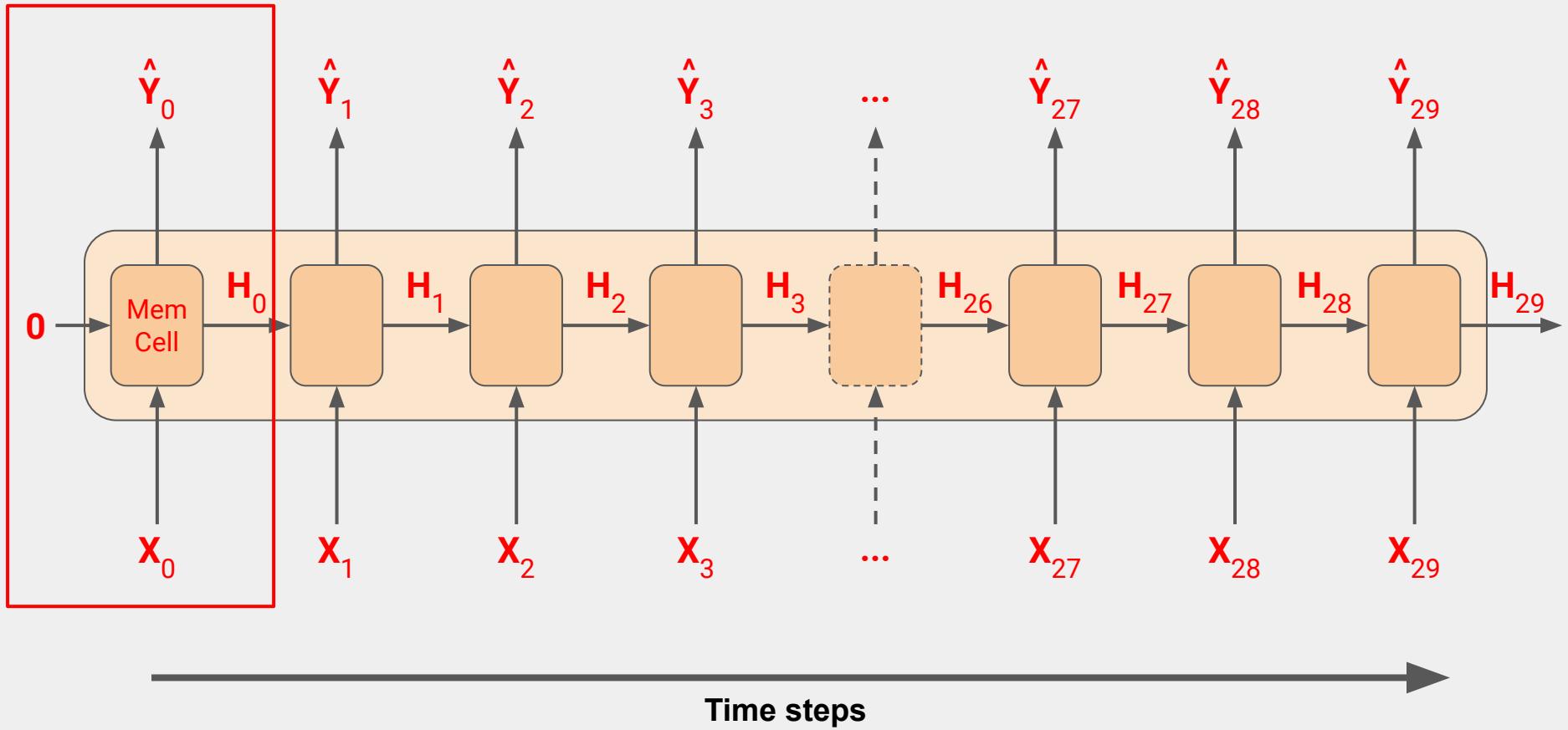
Recurrent Neural Network



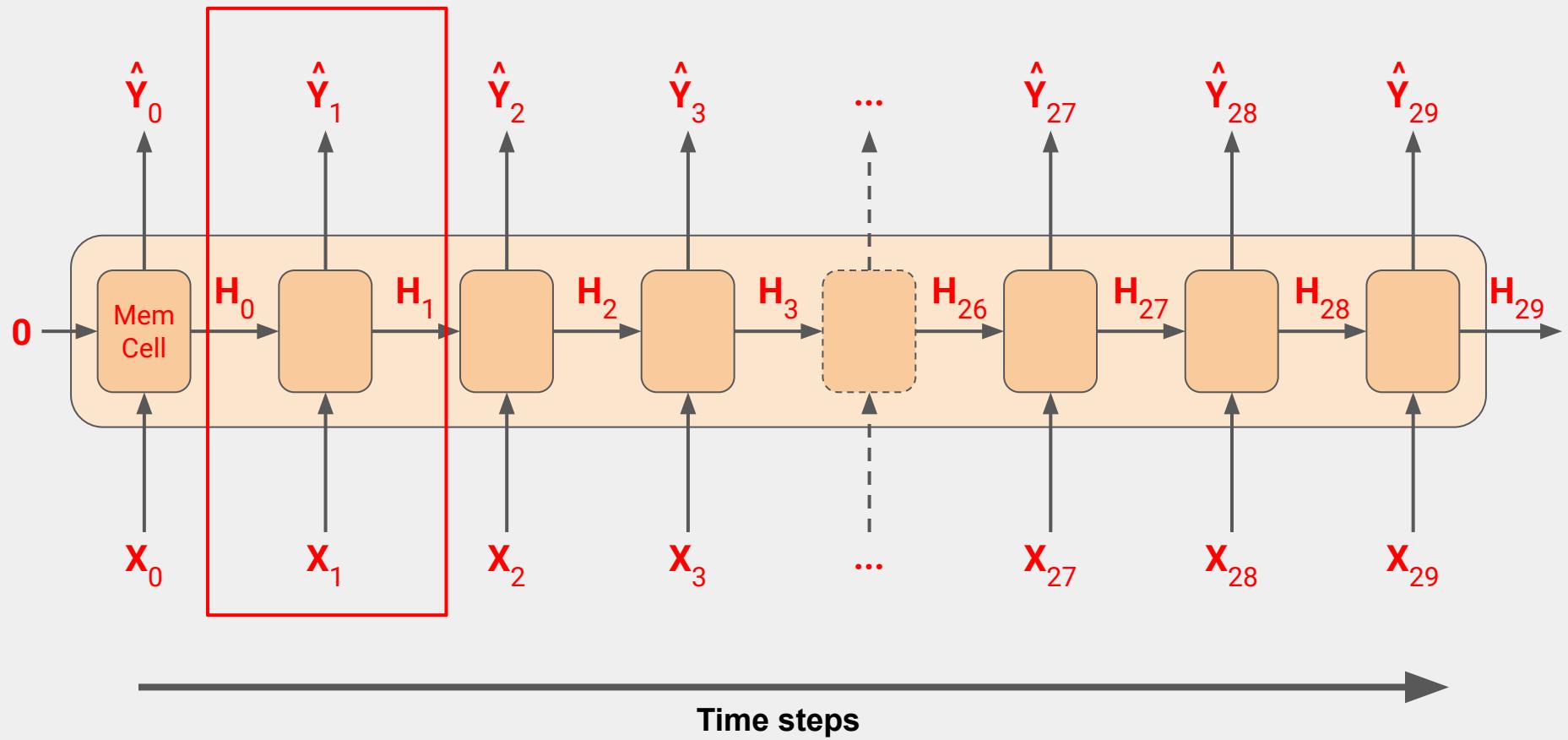
Recurrent Layer



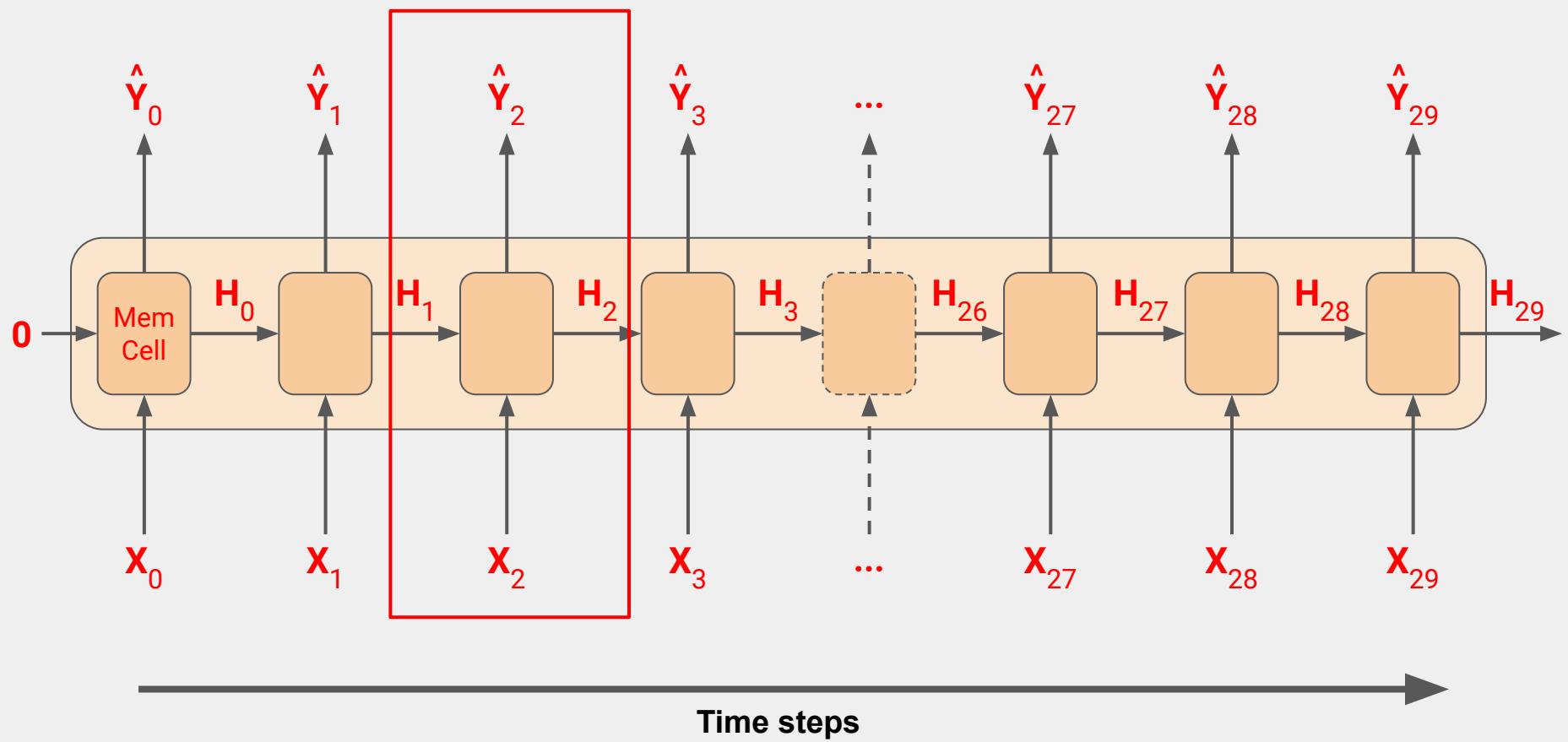
Recurrent Layer



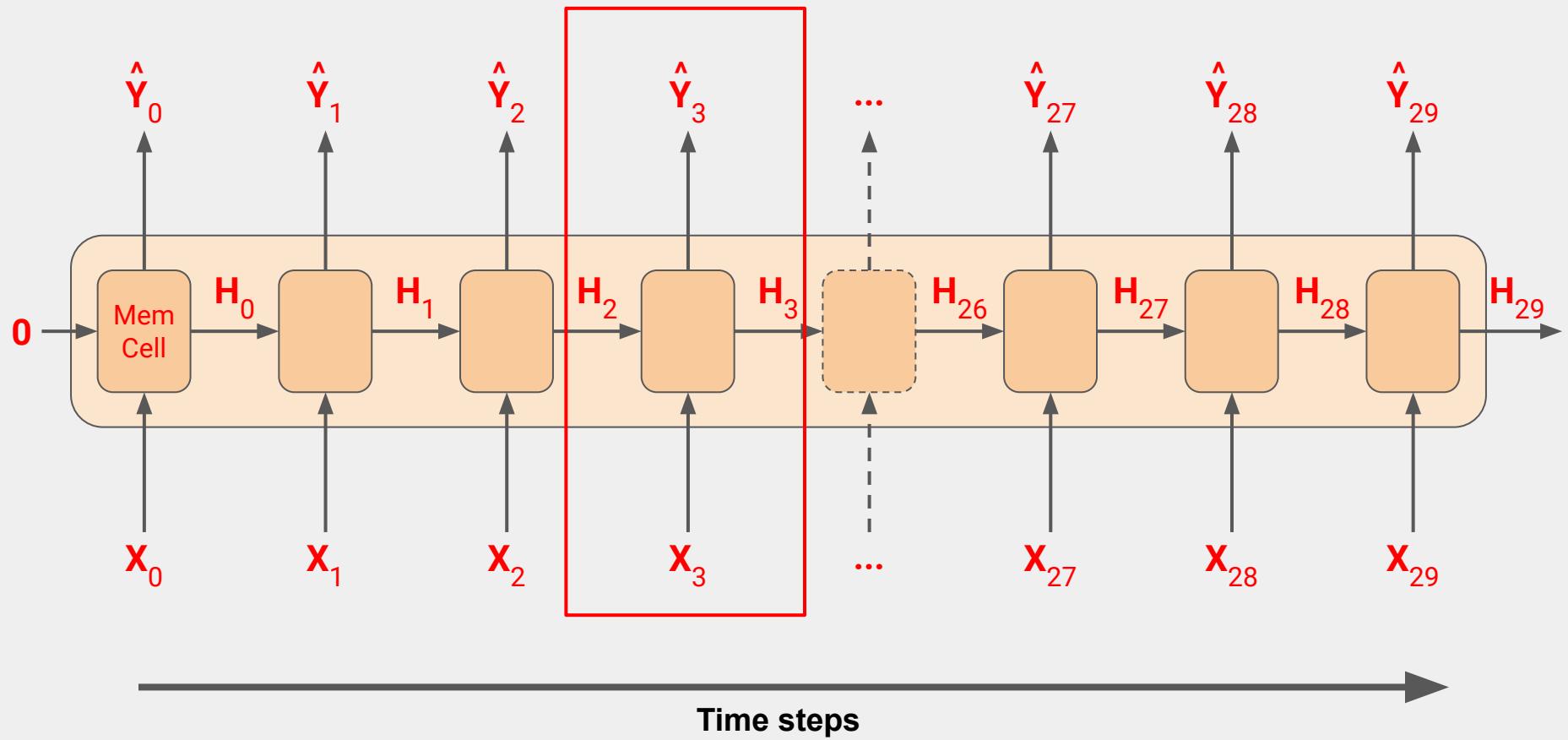
Recurrent Layer



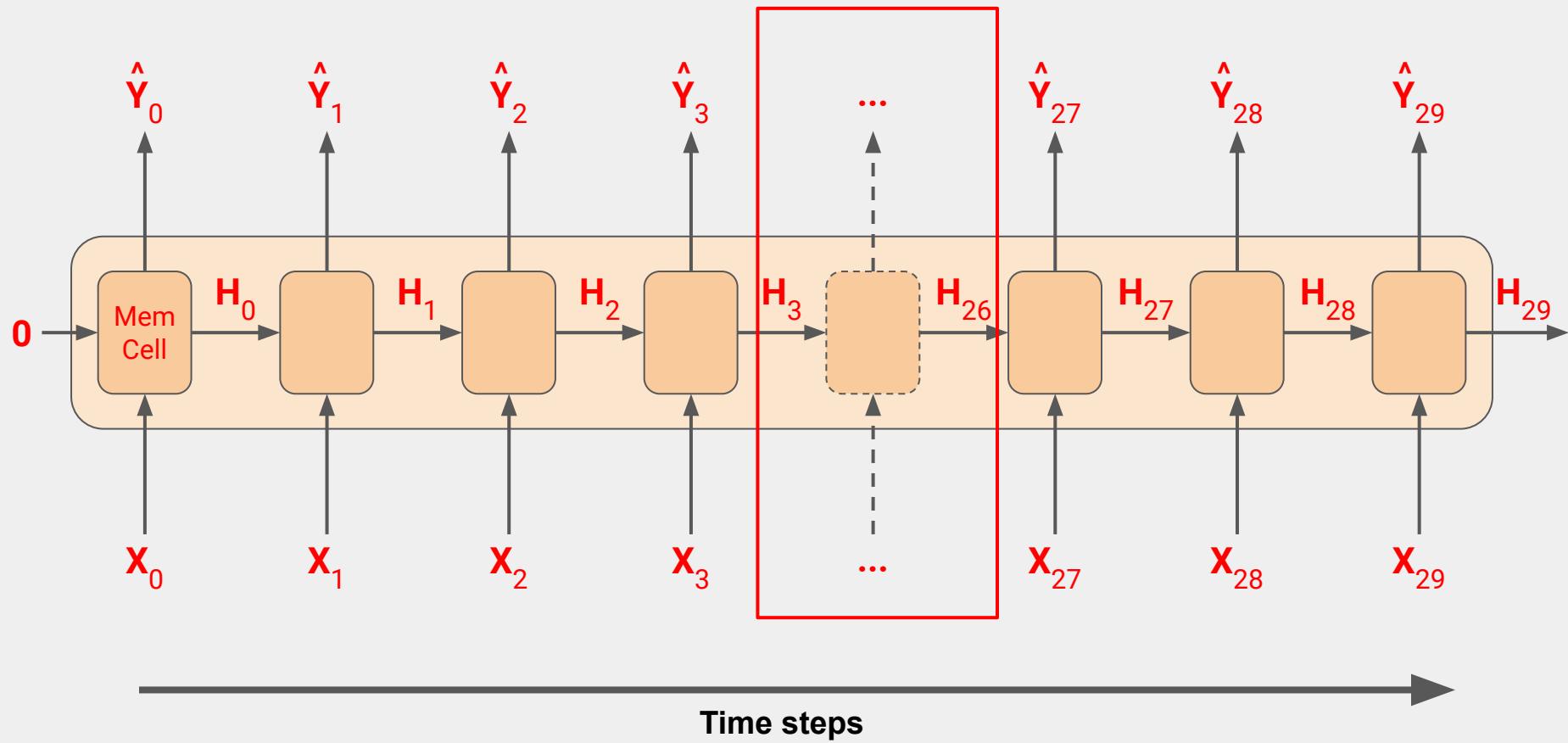
Recurrent Layer



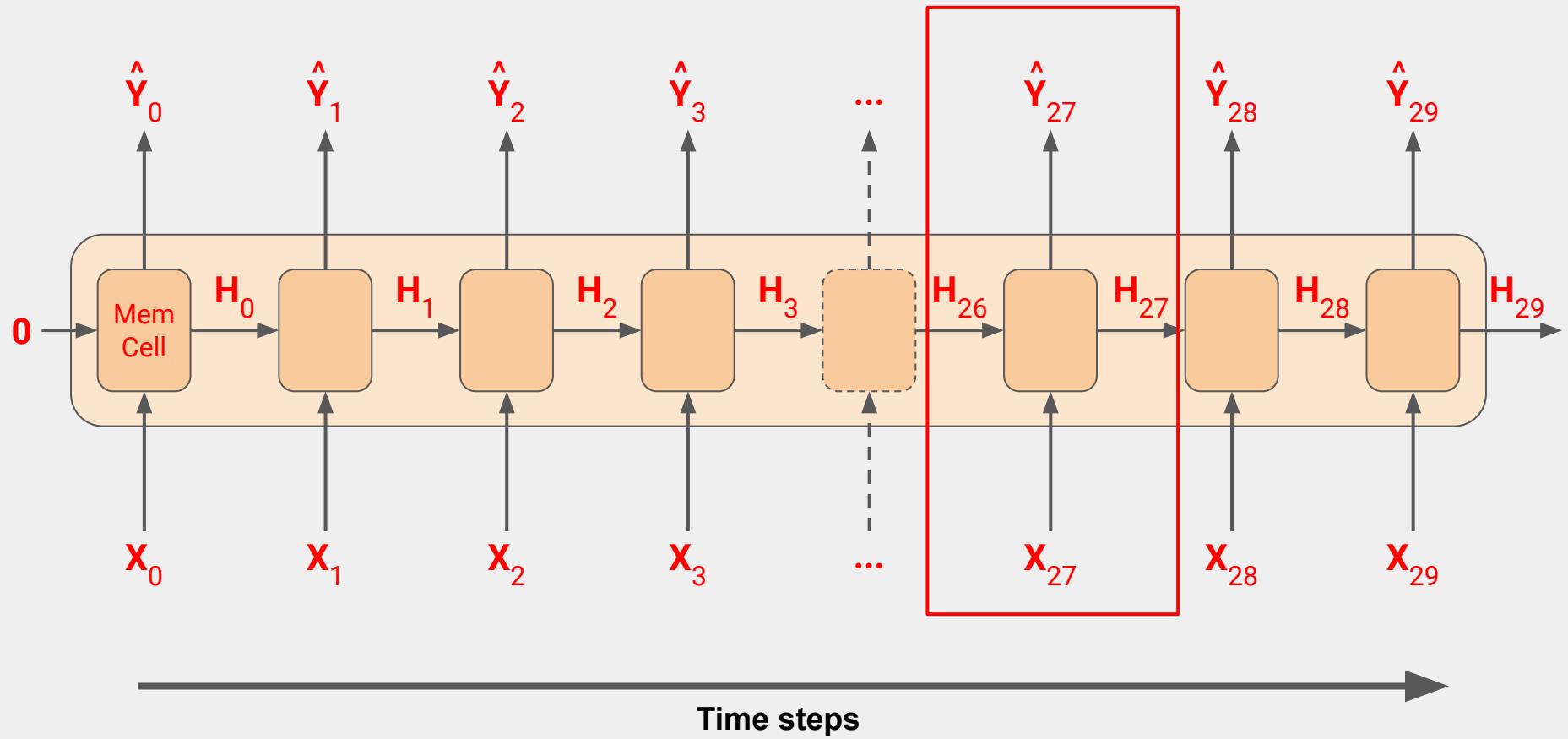
Recurrent Layer



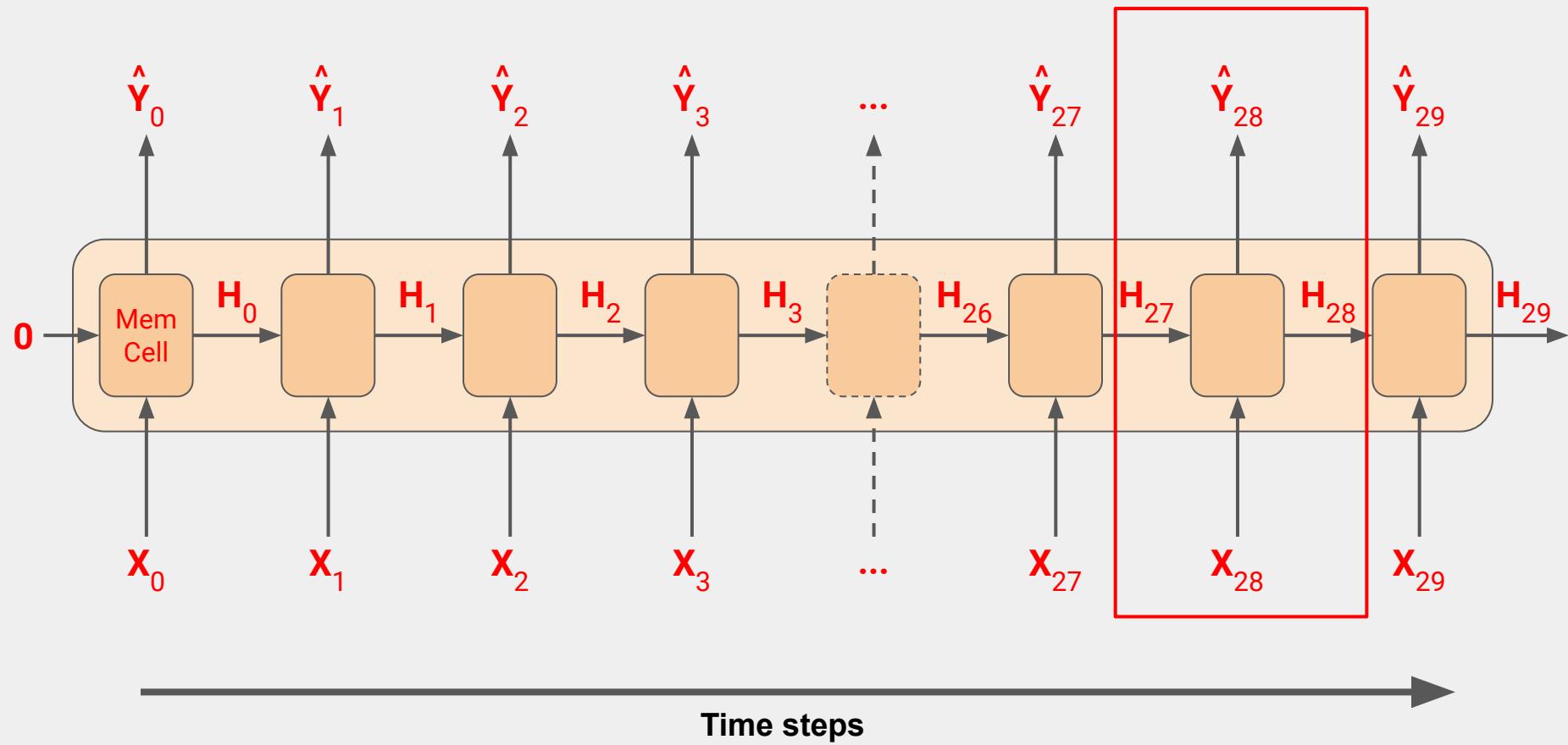
Recurrent Layer



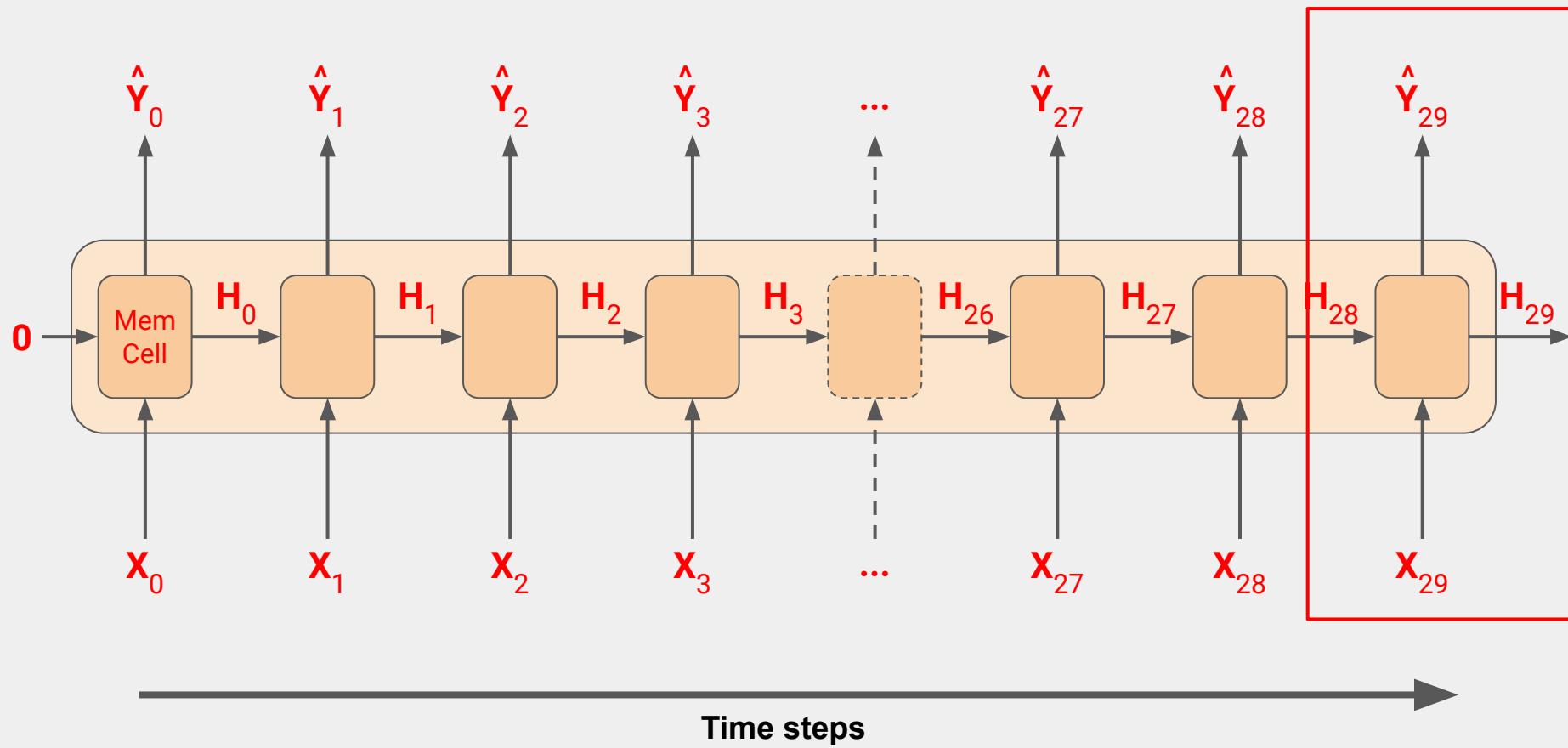
Recurrent Layer



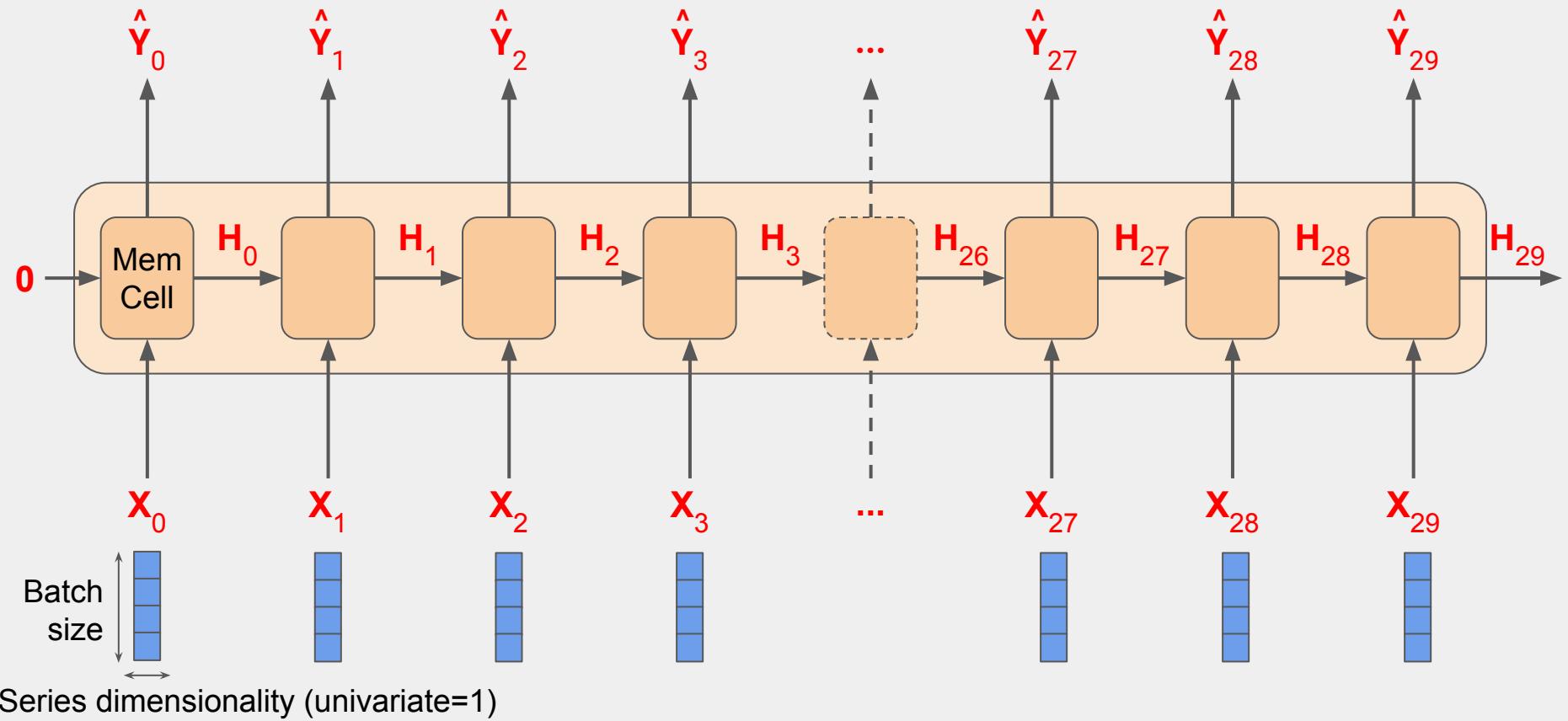
Recurrent Layer



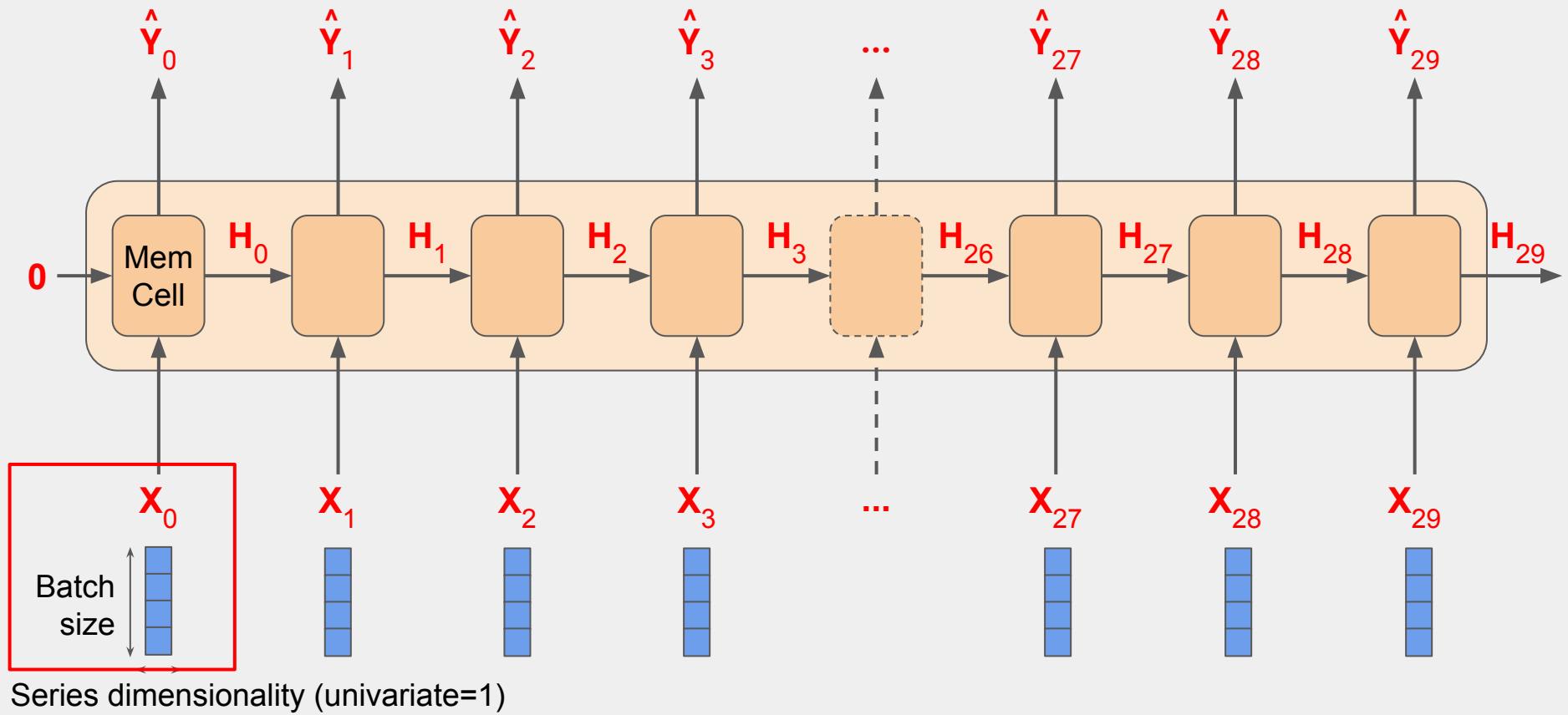
Recurrent Layer



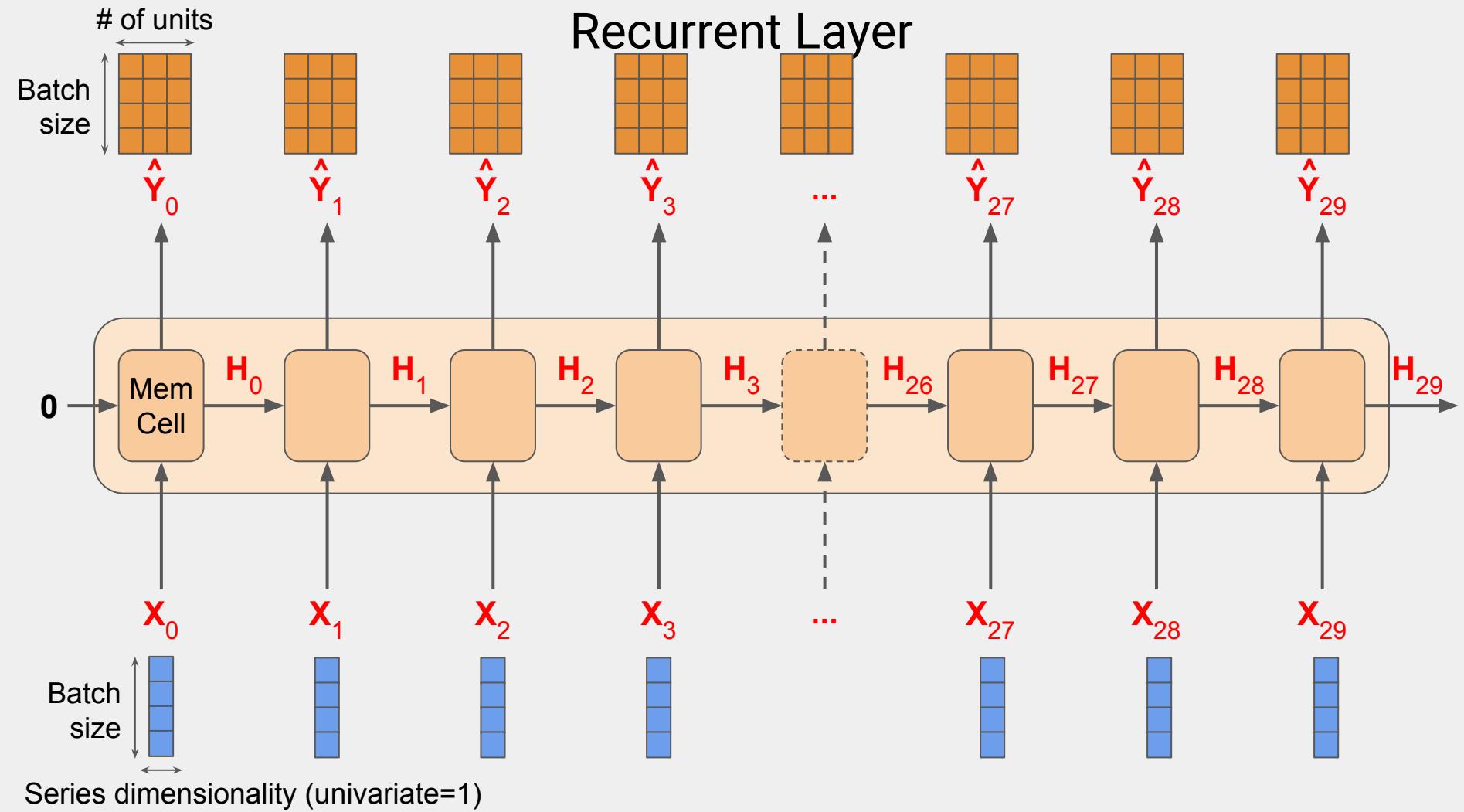
Recurrent Layer



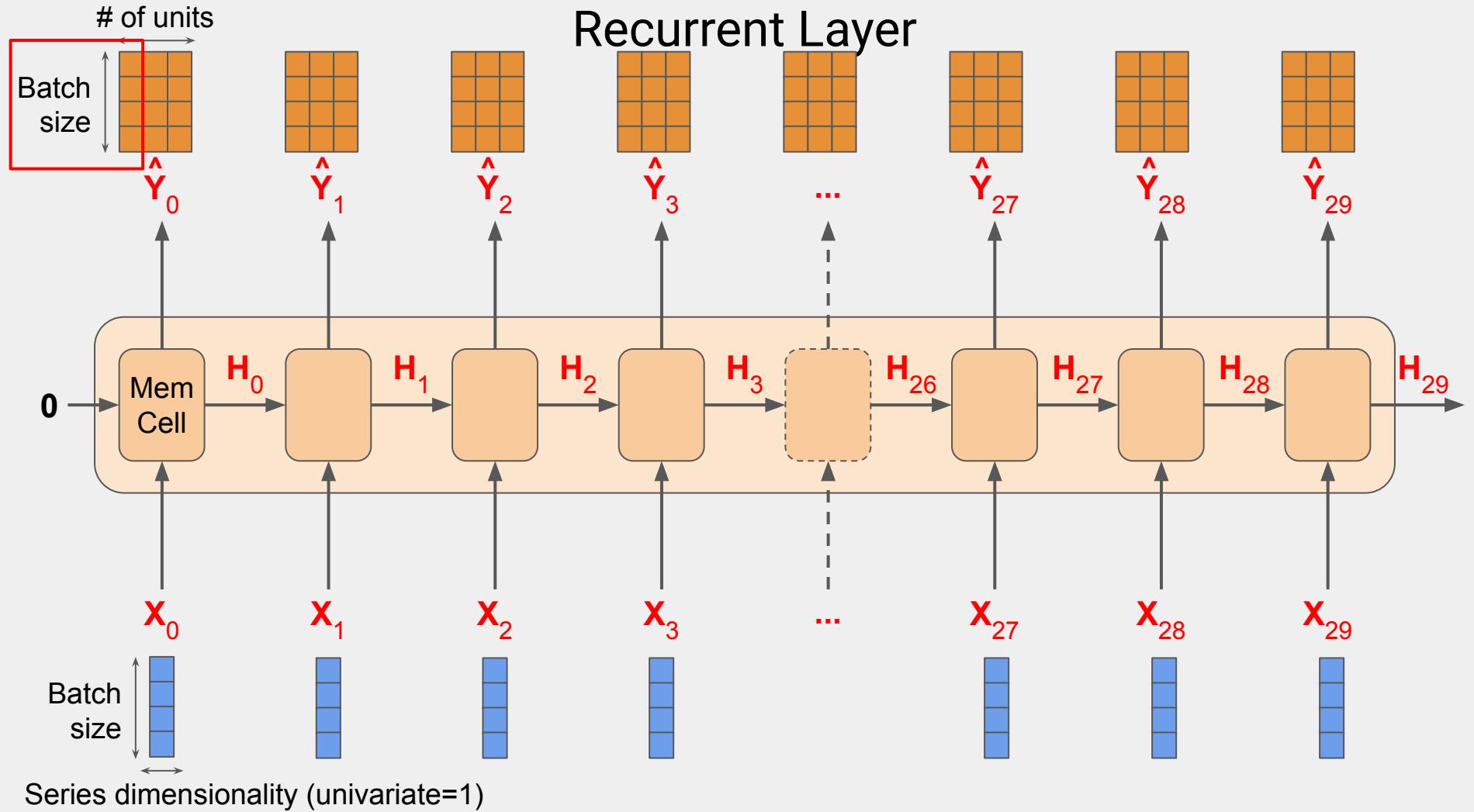
Recurrent Layer



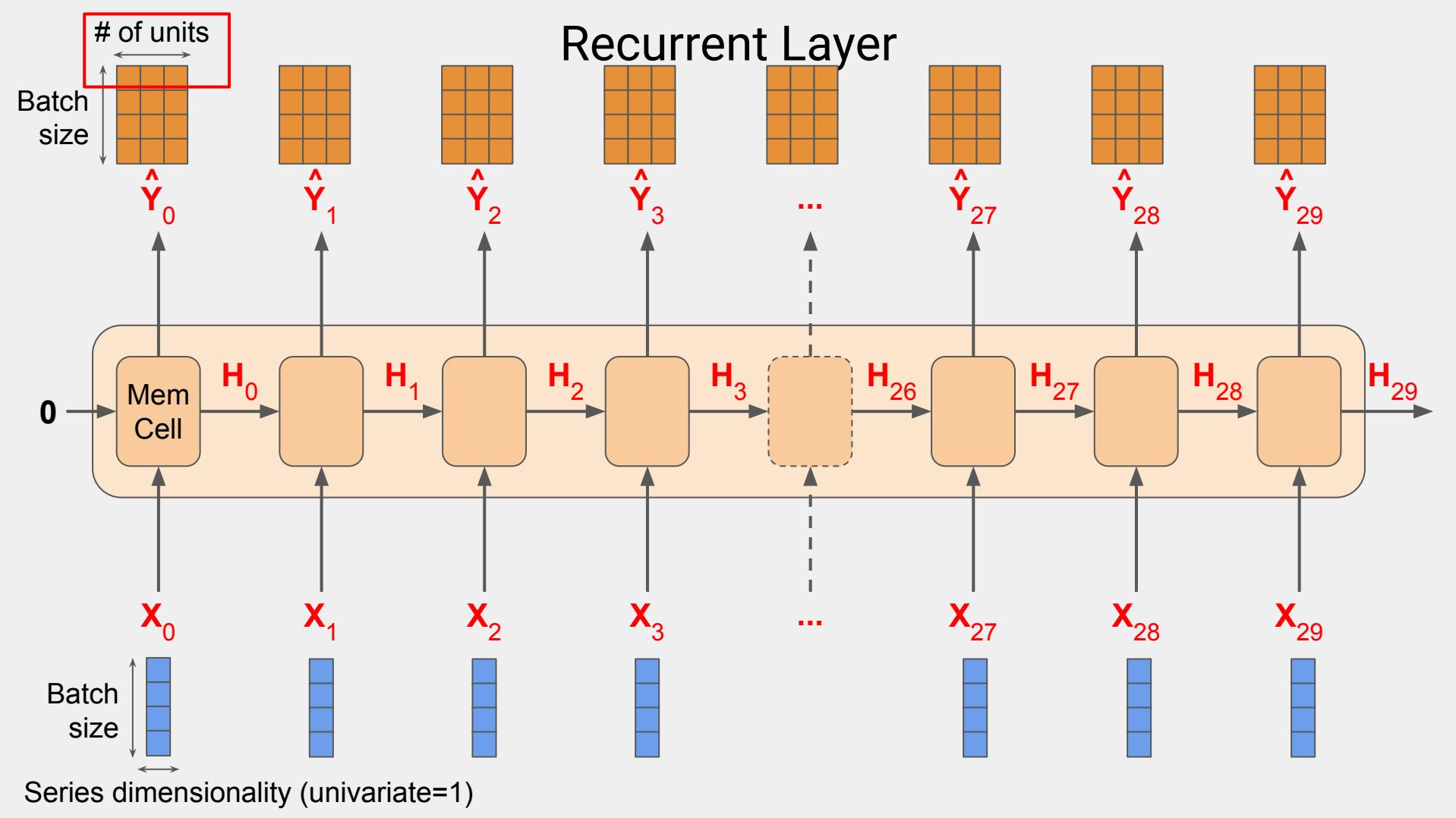
Recurrent Layer



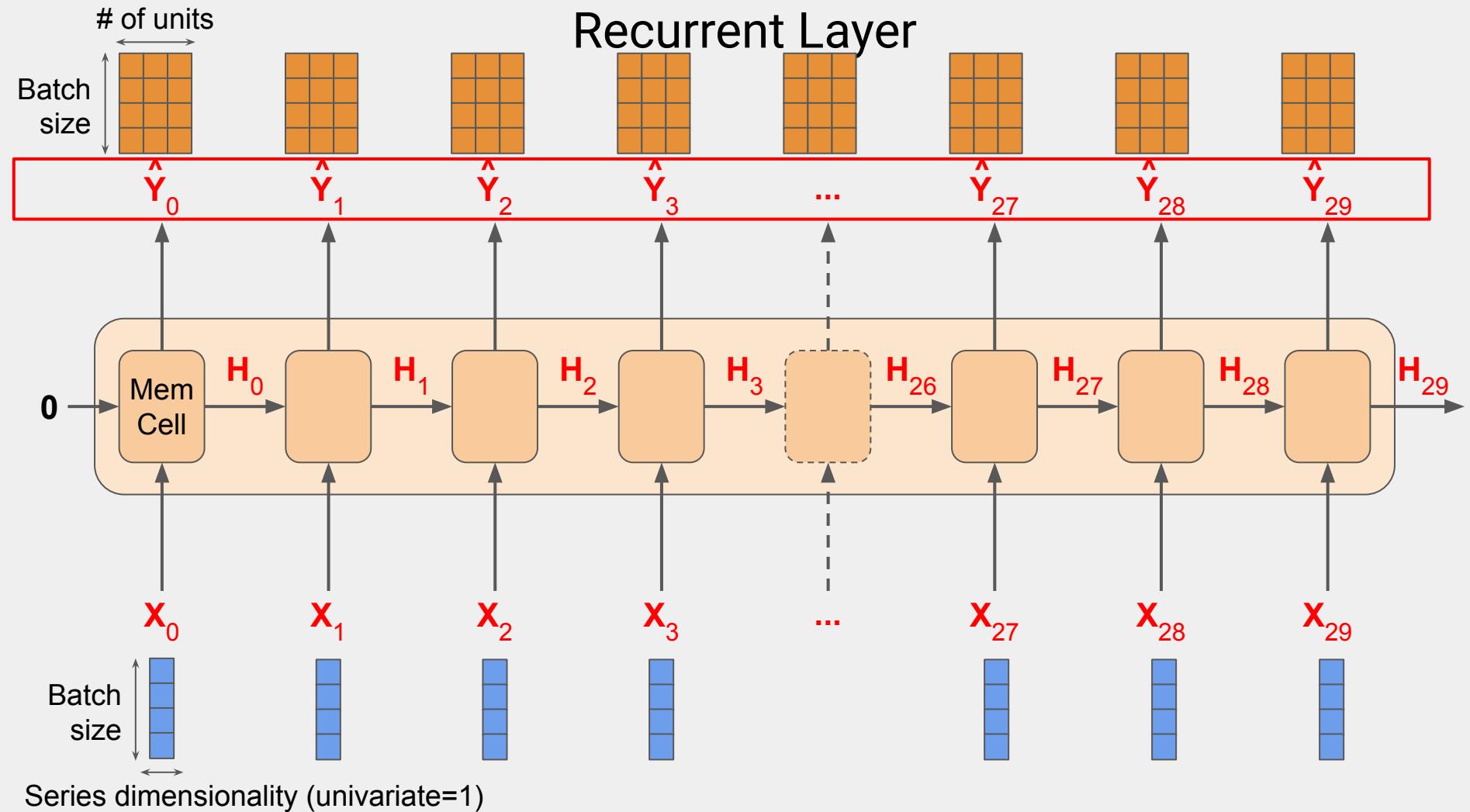
Recurrent Layer



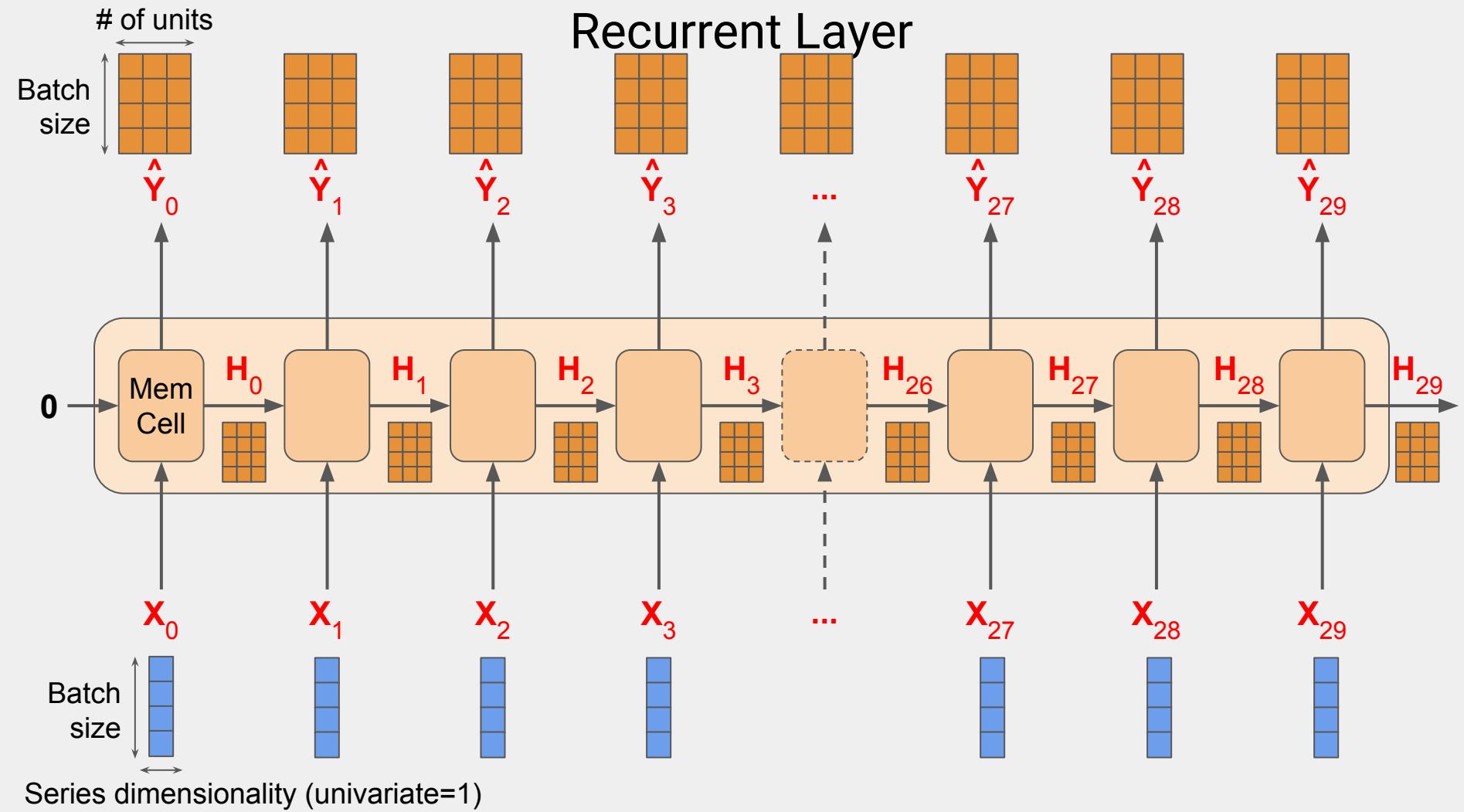
Recurrent Layer



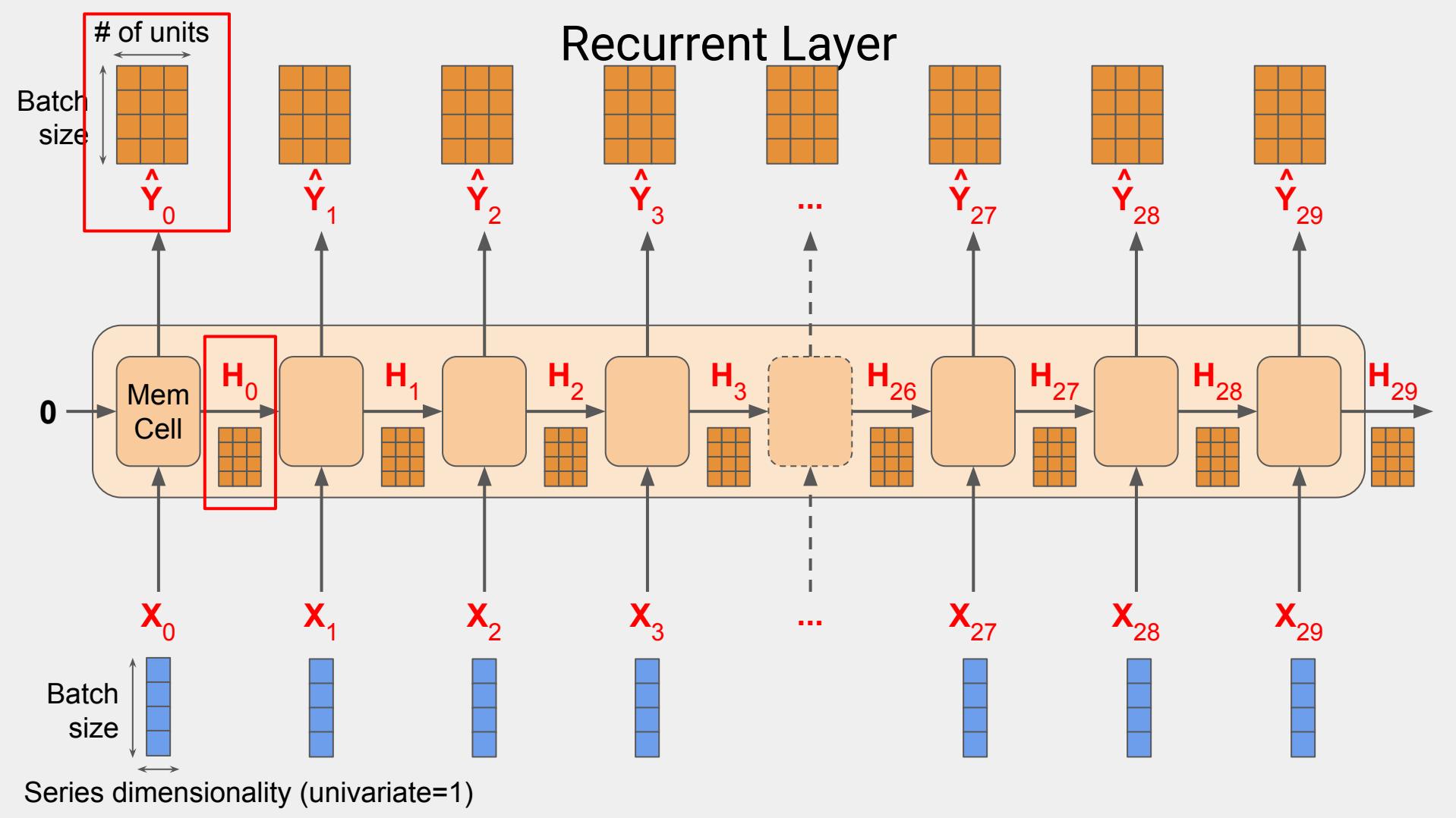
Recurrent Layer



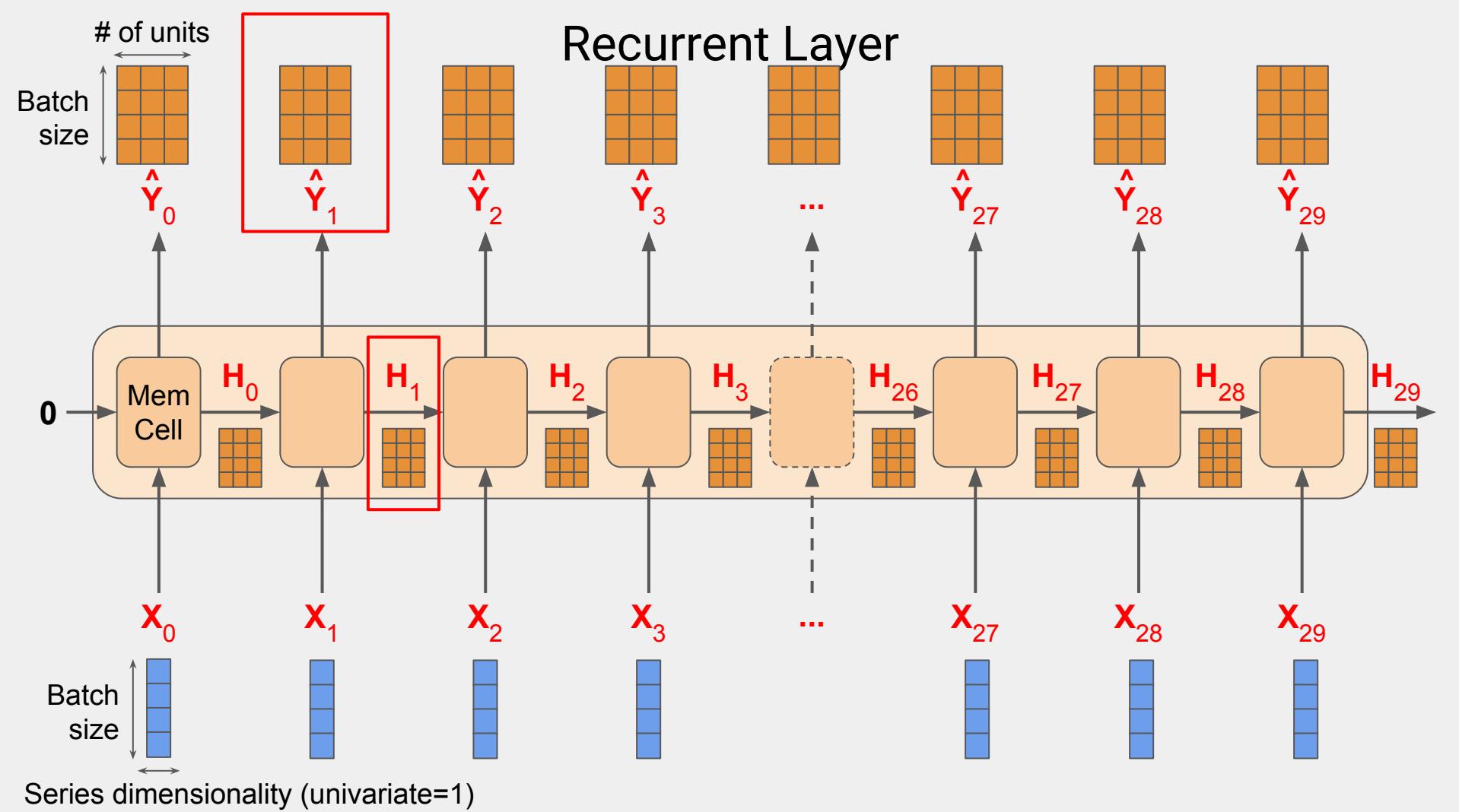
Recurrent Layer



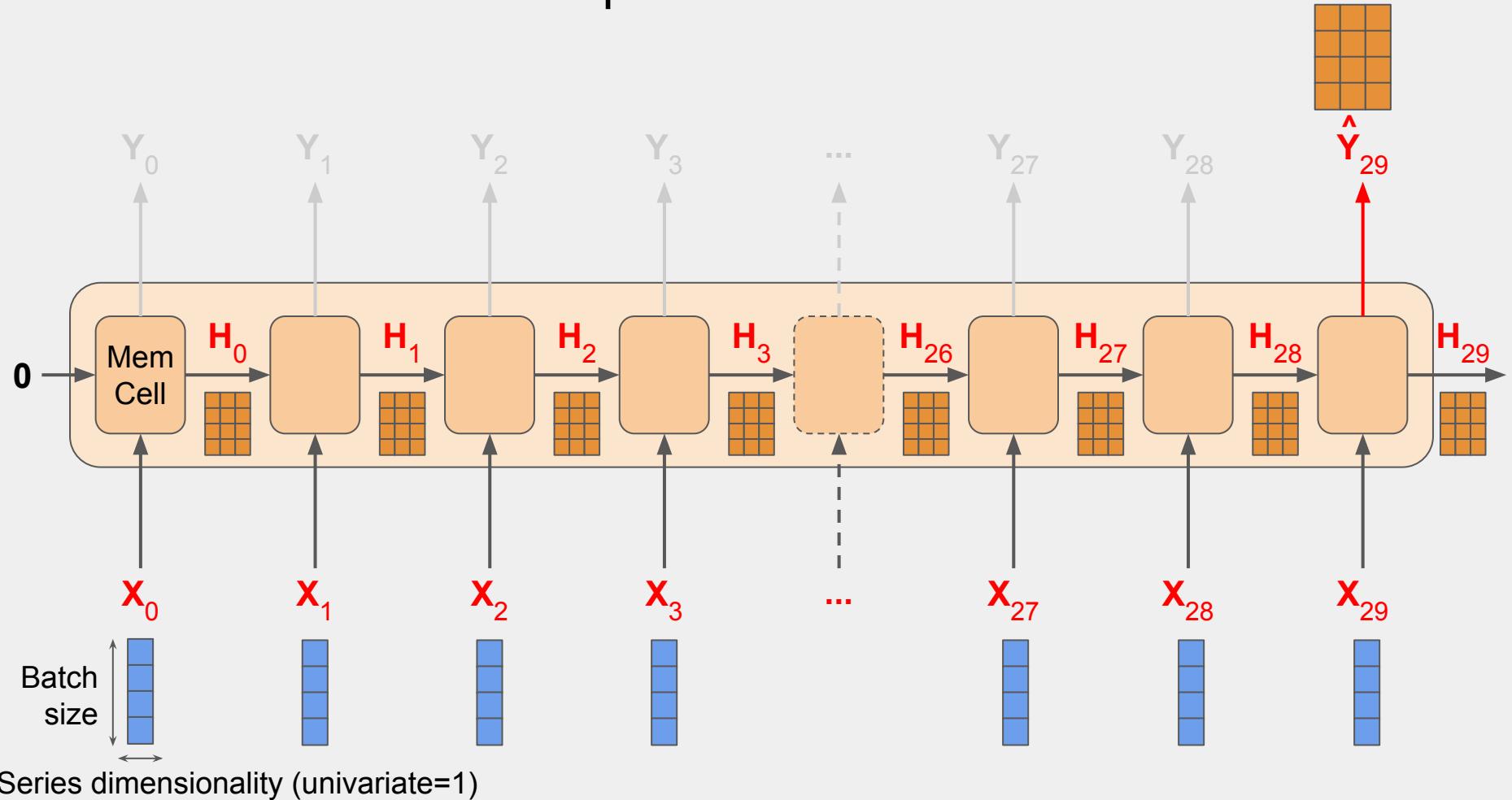
Recurrent Layer



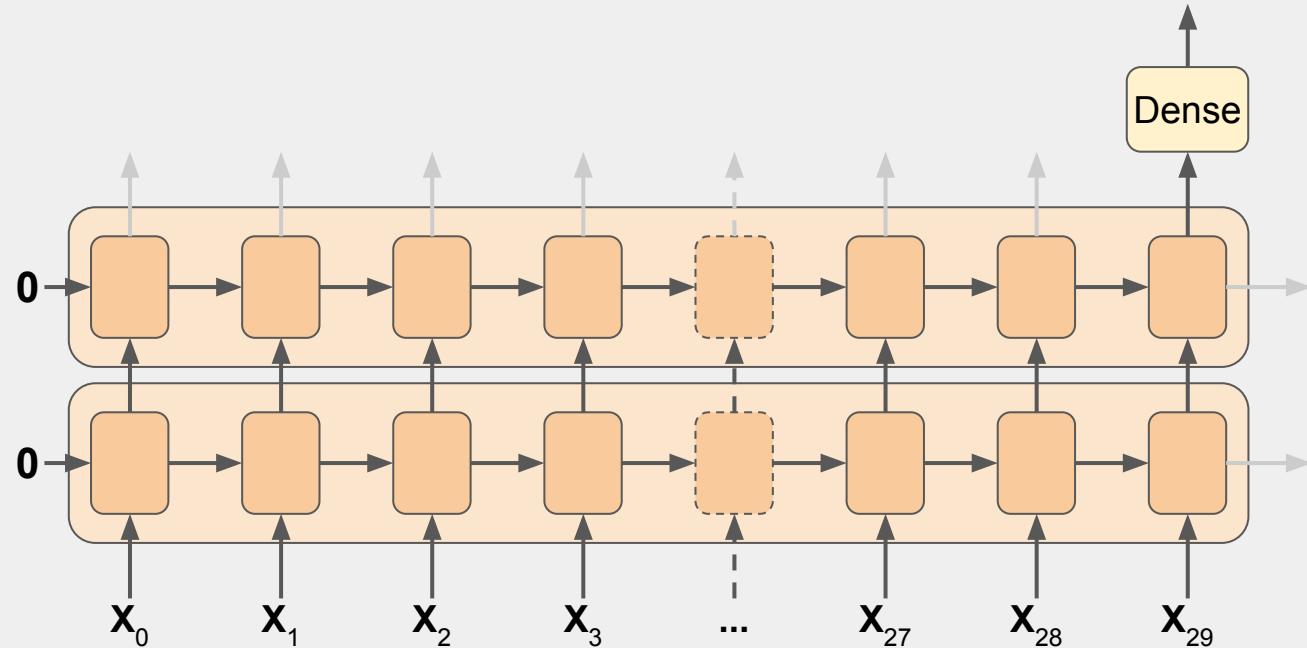
Recurrent Layer



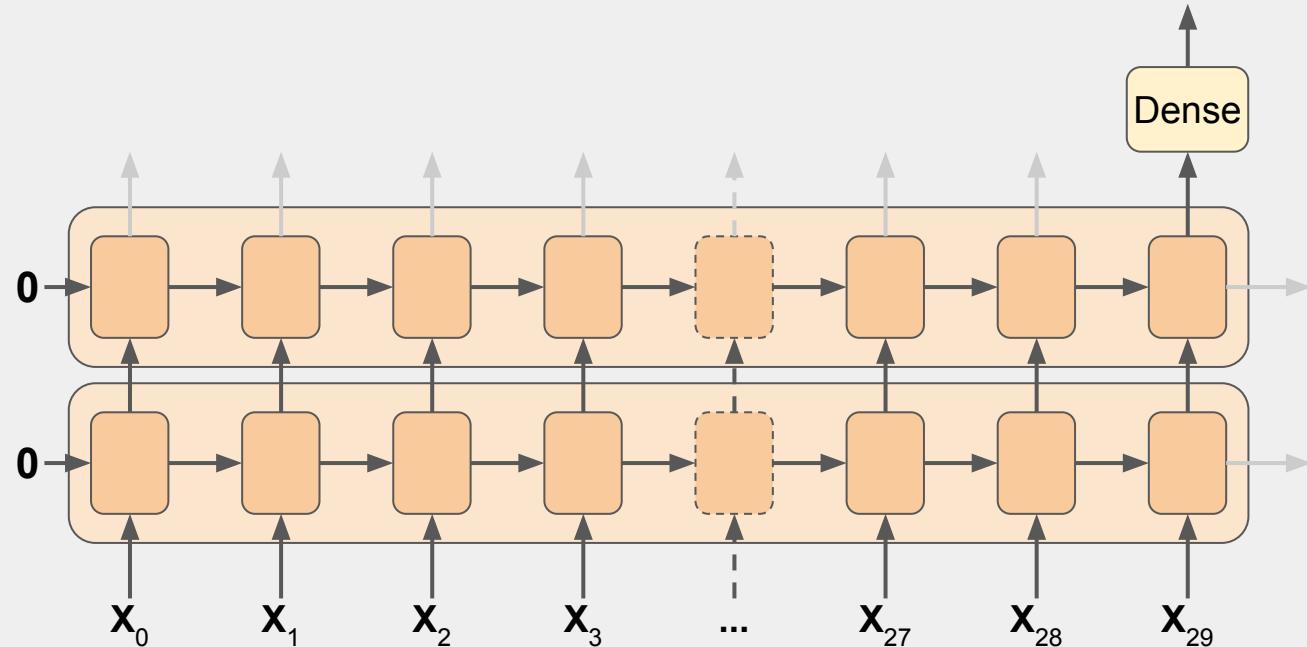
Sequence-to-Vector



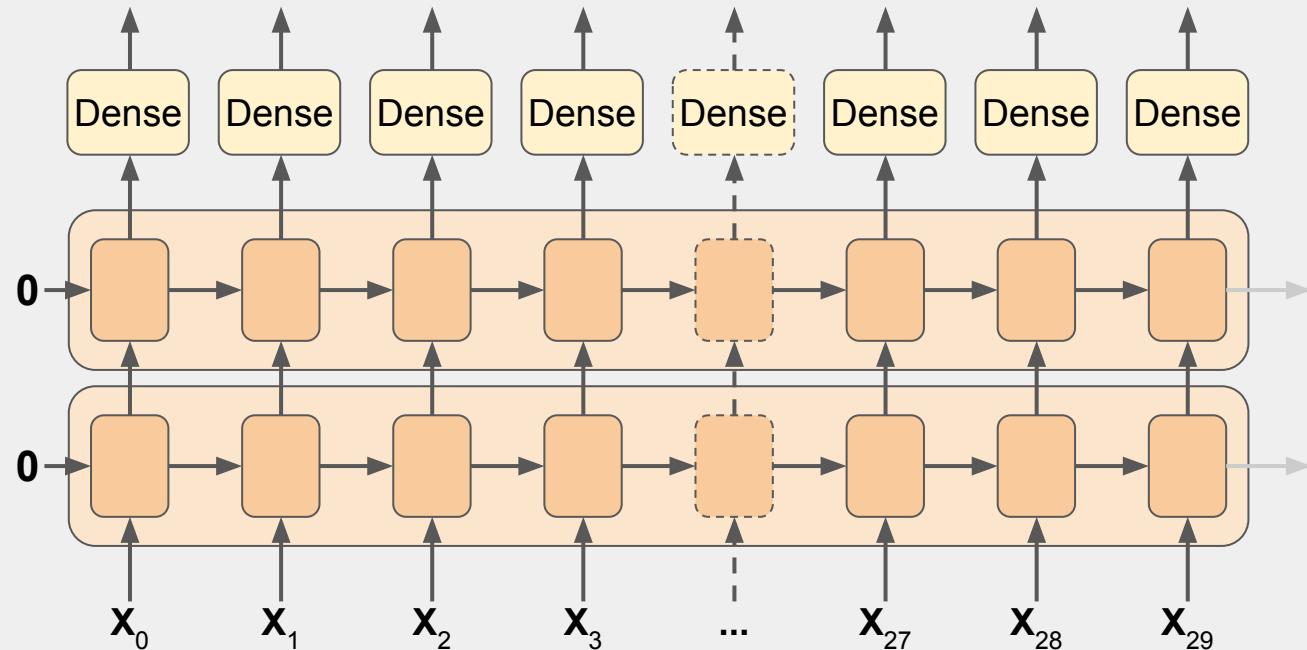
```
model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.SimpleRNN(20, return_sequences=True),
    tf.keras.layers.SimpleRNN(20),
    tf.keras.layers.Dense(1)
])
```



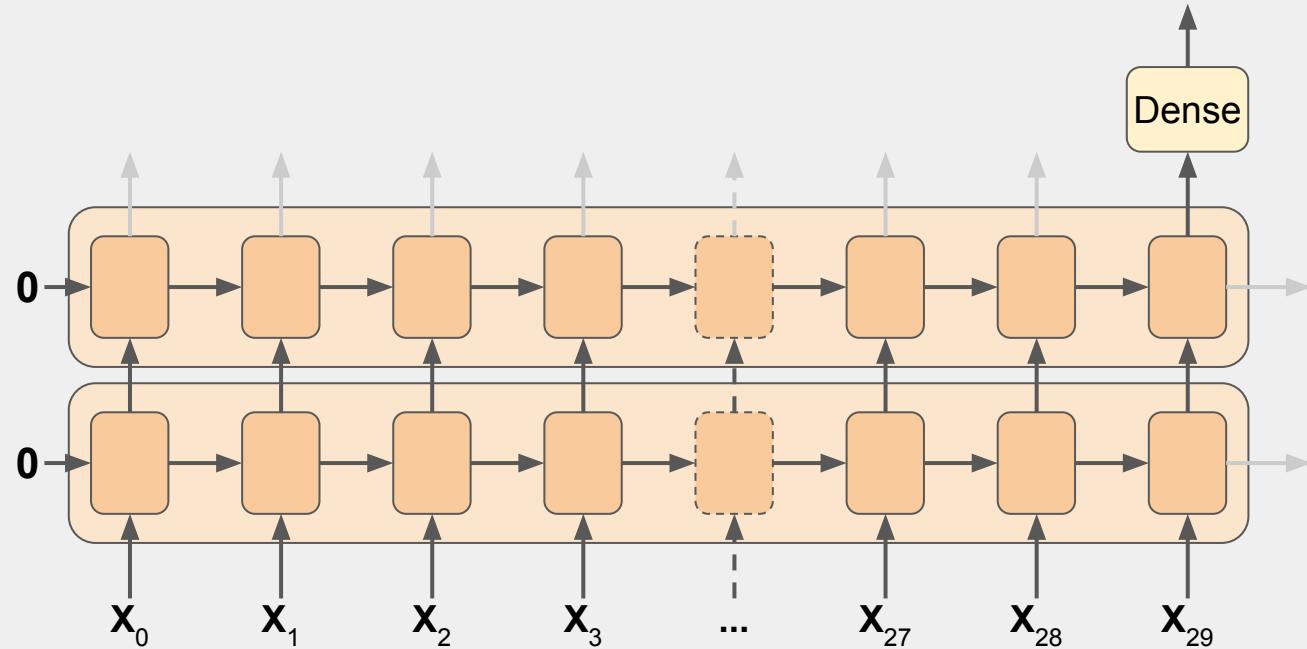
```
model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.SimpleRNN(20, return_sequences=True),
    tf.keras.layers.SimpleRNN(20),
    tf.keras.layers.Dense(1)
])
```



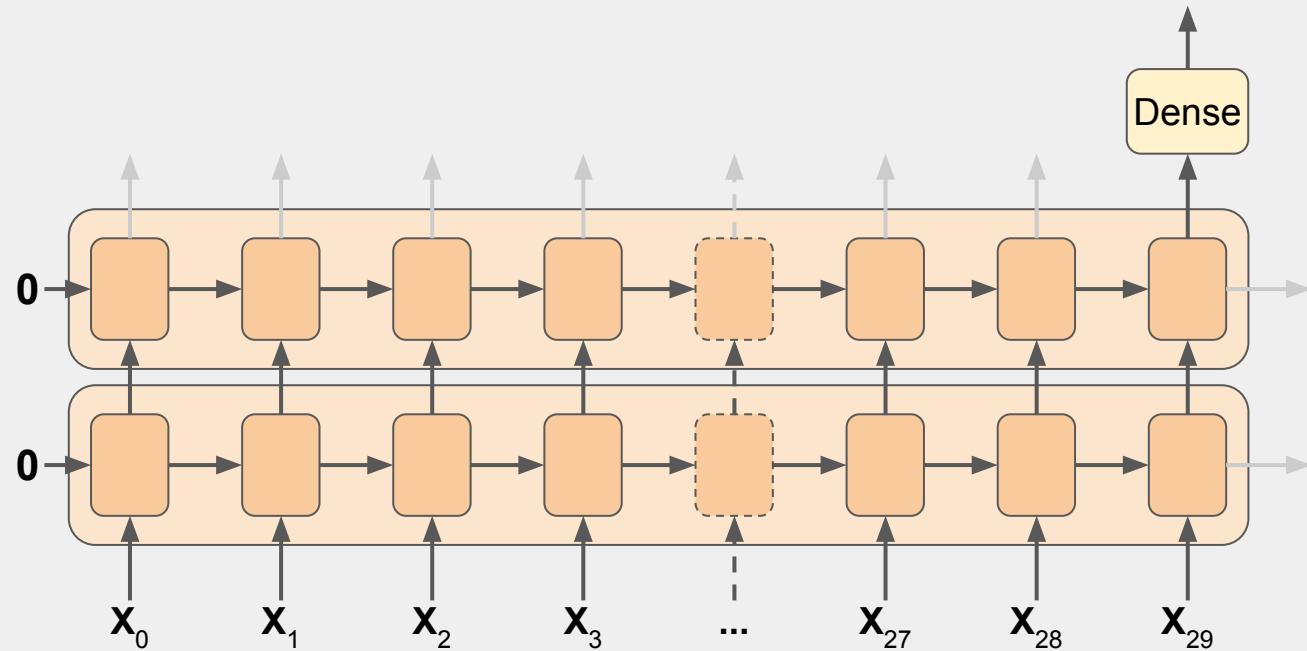
```
model = tf.keras.models.Sequential([  
    tf.keras.Input(shape=(window_size, 1)),  
    tf.keras.layers.SimpleRNN(20, return_sequences=True),  
    tf.keras.layers.SimpleRNN(20, return_sequences=True),  
    tf.keras.layers.Dense(1)  
])
```



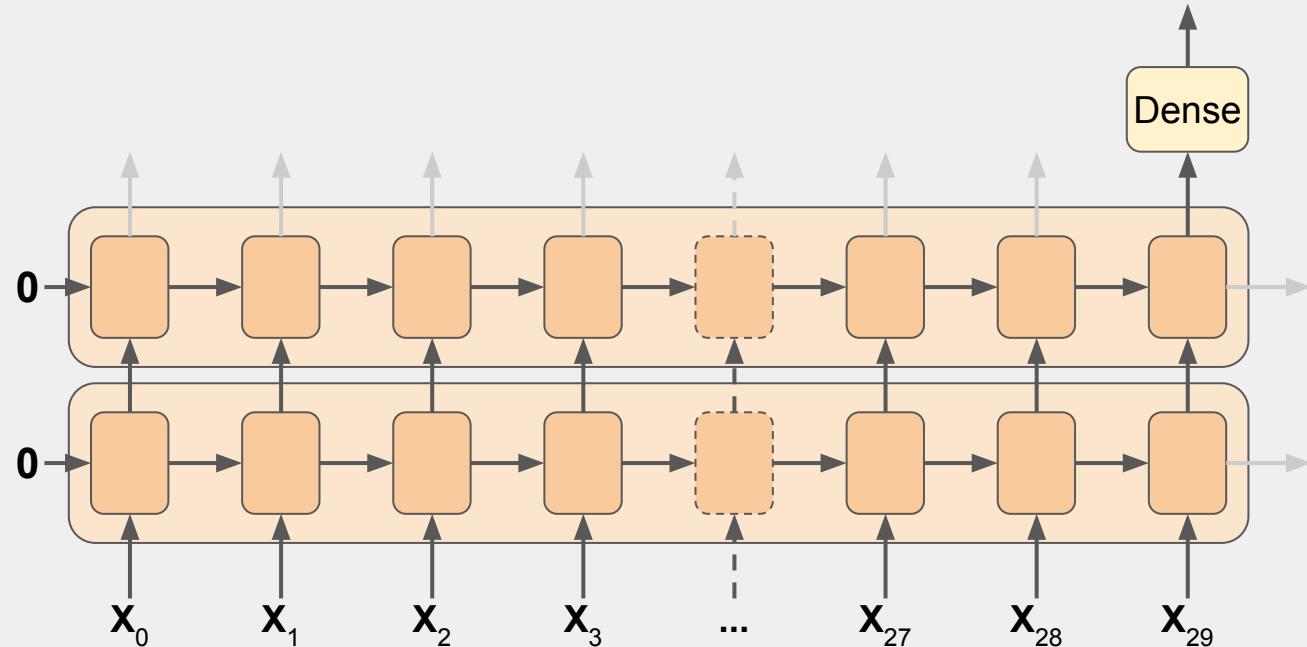
```
model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.SimpleRNN(20, return_sequences=True),
    tf.keras.layers.SimpleRNN(20),
    tf.keras.layers.Dense(1)
])
```



```
model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.SimpleRNN(20, return_sequences=True),
    tf.keras.layers.SimpleRNN(20),
    tf.keras.layers.Dense(1),
    tf.keras.layers.Lambda(lambda x: x * 100.0)
])
```



```
model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.SimpleRNN(20, return_sequences=True),
    tf.keras.layers.SimpleRNN(20),
    tf.keras.layers.Dense(1),
    tf.keras.layers.Lambda(lambda x: x * 100.0)
])
```



```
train_set = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.SimpleRNN(40, return_sequences=True),
    tf.keras.layers.SimpleRNN(40),
    tf.keras.layers.Dense(1),
    tf.keras.layers.Lambda(lambda x: x * 100.0)
])

lr_schedule = tf.keras.callbacks.LearningRateScheduler(lambda epoch: 1e-8 * 10**(epoch / 20))

optimizer = tf.keras.optimizers.SGD(learning_rate=1e-8, momentum=0.9)

model.compile(loss=tf.keras.losses.Huber(),
              optimizer=optimizer,
              metrics=[ "mae"])

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

```
train_set = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
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              optimizer=optimizer,
              metrics=[ "mae"])

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

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



```
train_set = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.SimpleRNN(40, return_sequences=True),
    tf.keras.layers.SimpleRNN(40),
    tf.keras.layers.Dense(1),
    tf.keras.layers.Lambda(lambda x: x * 100.0)
])

```

```
lr_schedule = tf.keras.callbacks.LearningRateScheduler(lambda epoch: 1e-8 * 10**(epoch / 20))
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```
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    tf.keras.Input(shape=(window_size, 1)),
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    tf.keras.layers.SimpleRNN(40),
    tf.keras.layers.Dense(1),
    tf.keras.layers.Lambda(lambda x: x * 100.0)
])

lr_schedule = tf.keras.callbacks.LearningRateScheduler(lambda epoch: 1e-8 * 10**((epoch / 20)))

optimizer = tf.keras.optimizers.SGD(learning_rate=1e-8, momentum=0.9)

model.compile(loss=tf.keras.losses.Huber(),
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              metrics=[ "mae"])

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    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.SimpleRNN(40, return_sequences=True),
    tf.keras.layers.SimpleRNN(40),
    tf.keras.layers.Dense(1),
    tf.keras.layers.Lambda(lambda x: x * 100.0)
])

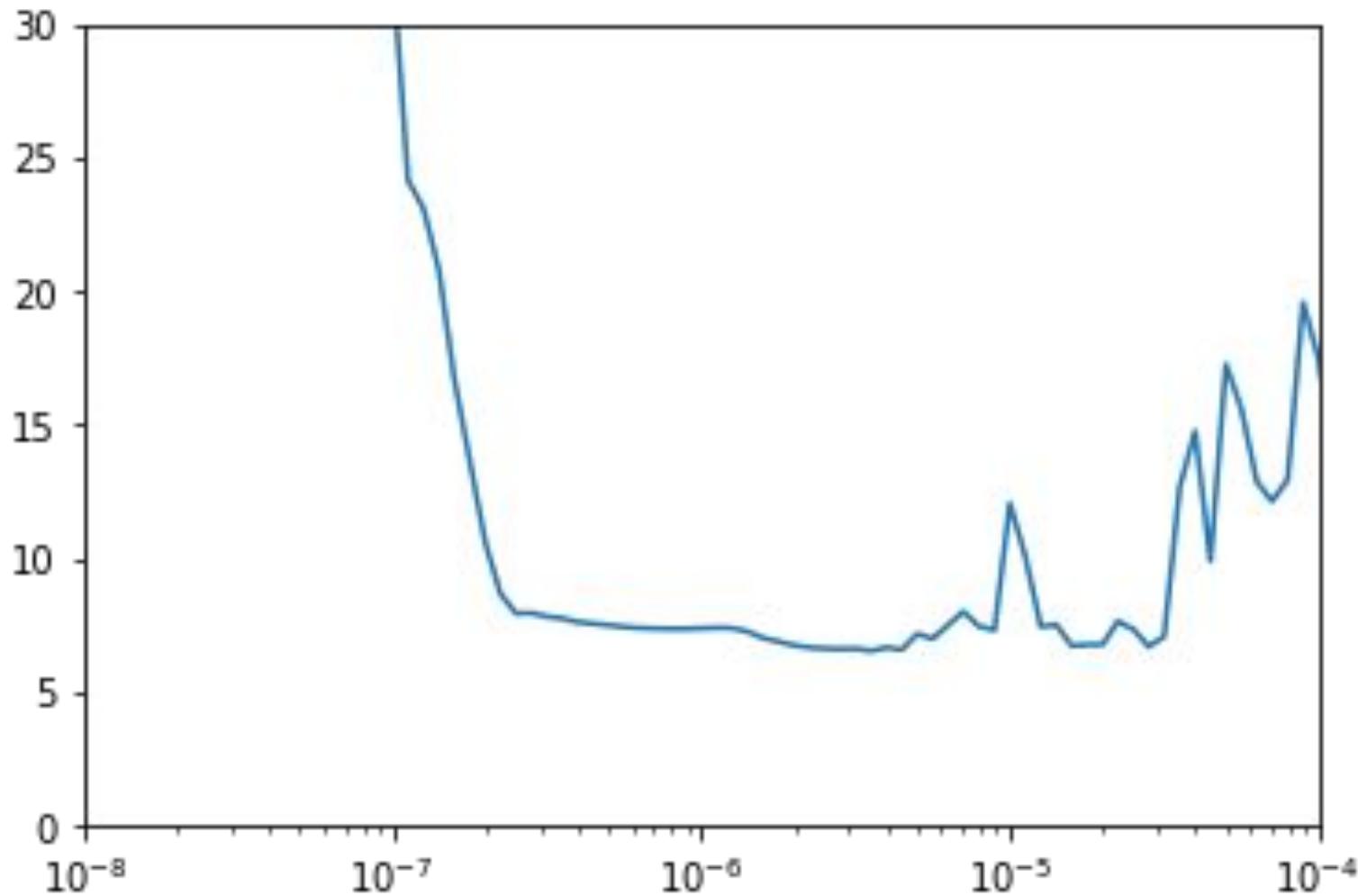
lr_schedule = tf.keras.callbacks.LearningRateScheduler(lambda epoch: 1e-8 * 10**((epoch / 20)))

optimizer = tf.keras.optimizers.SGD(learning_rate=1e-8, momentum=0.9)

model.compile(loss=tf.keras.losses.Huber(),
              optimizer=optimizer,
              metrics=["mae"])

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

https://en.wikipedia.org/wiki/Huber_loss



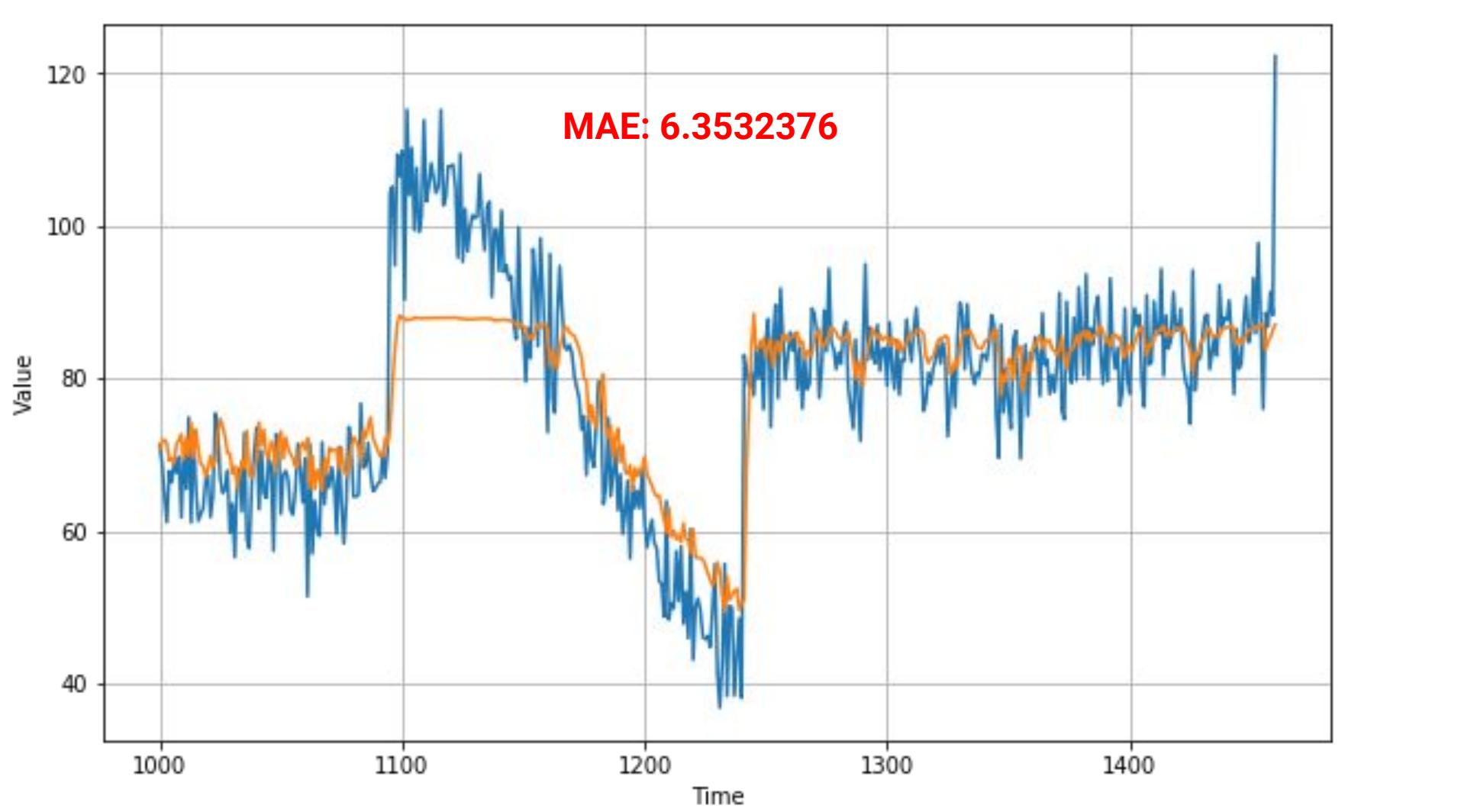
```
train_set = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.SimpleRNN(40, return_sequences=True),
    tf.keras.layers.SimpleRNN(40),
    tf.keras.layers.Dense(1),
    tf.keras.layers.Lambda(lambda x: x * 100.0)
])

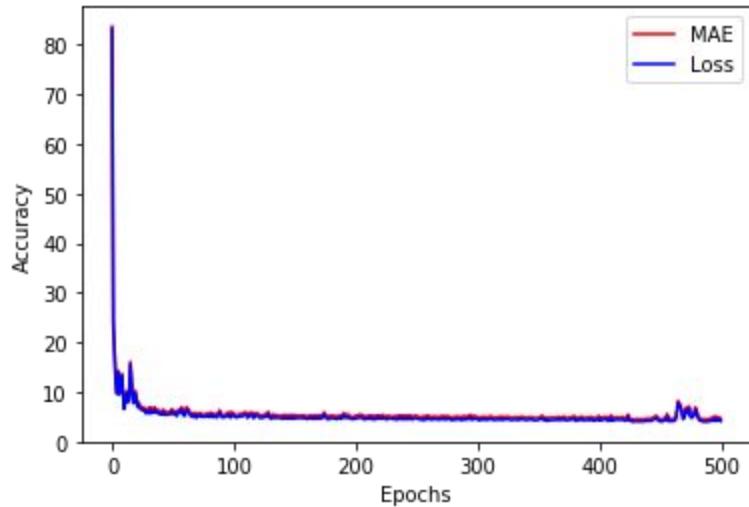
optimizer = tf.keras.optimizers.SGD(learning_rate=5e-6, momentum=0.9)
```

model.compile(loss=tf.keras.losses.Huber(),
 optimizer=optimizer,
 metrics=["mae"])

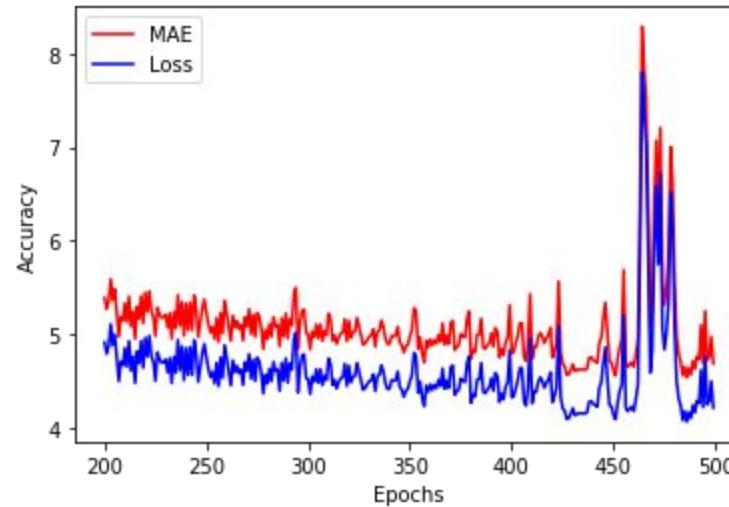
```
history = model.fit(dataset, epochs=500)
```

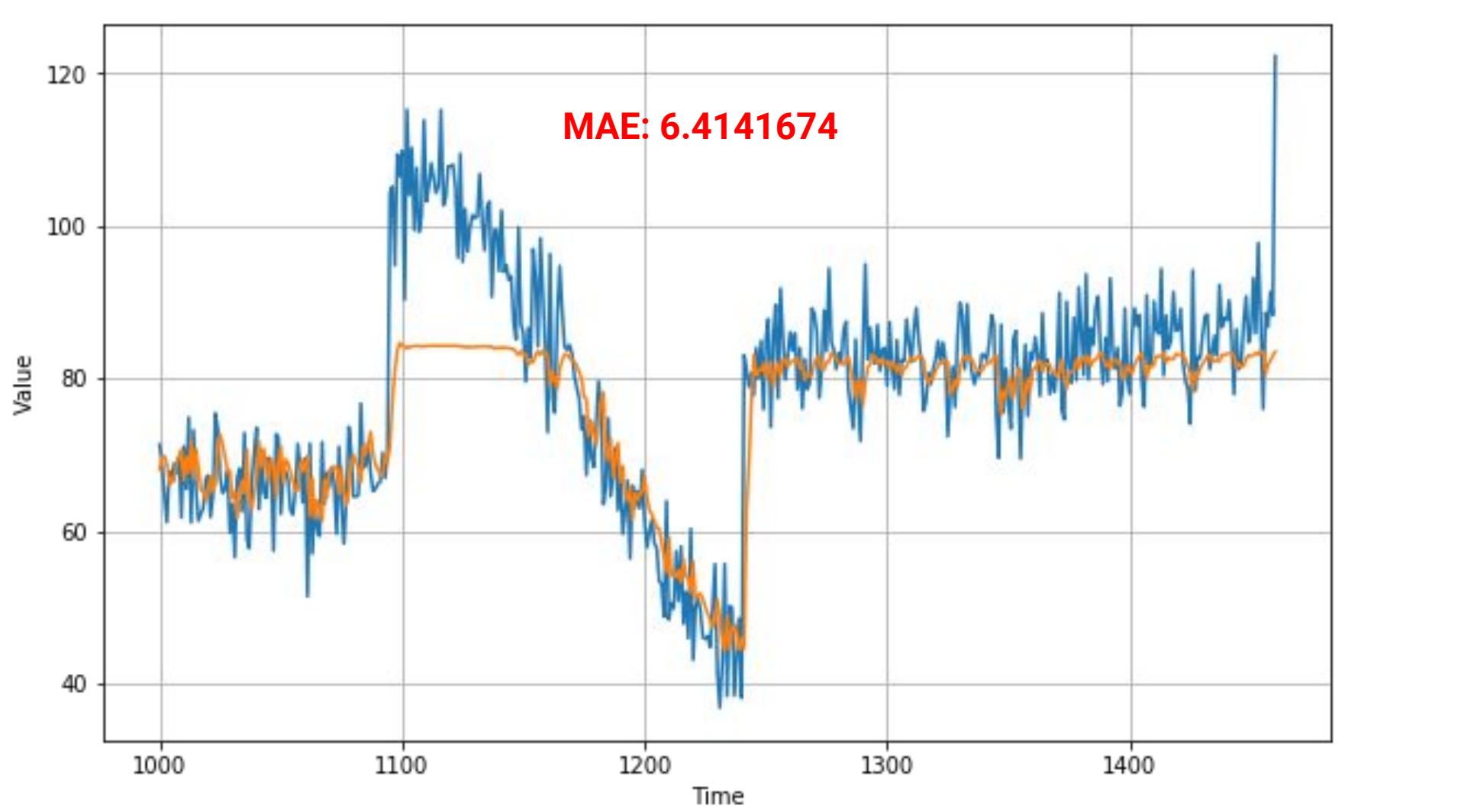


MAE and Loss

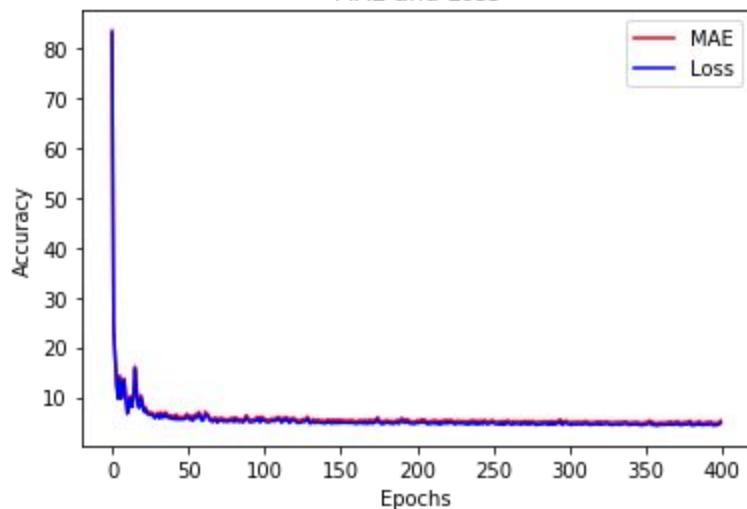


MAE and Loss

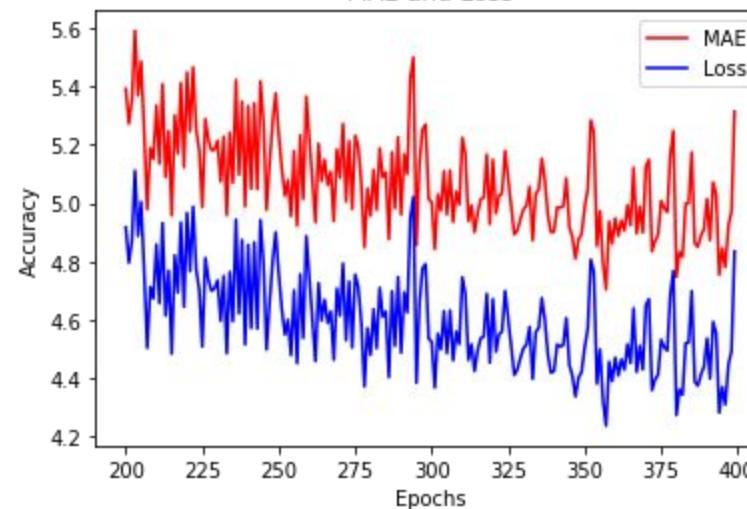


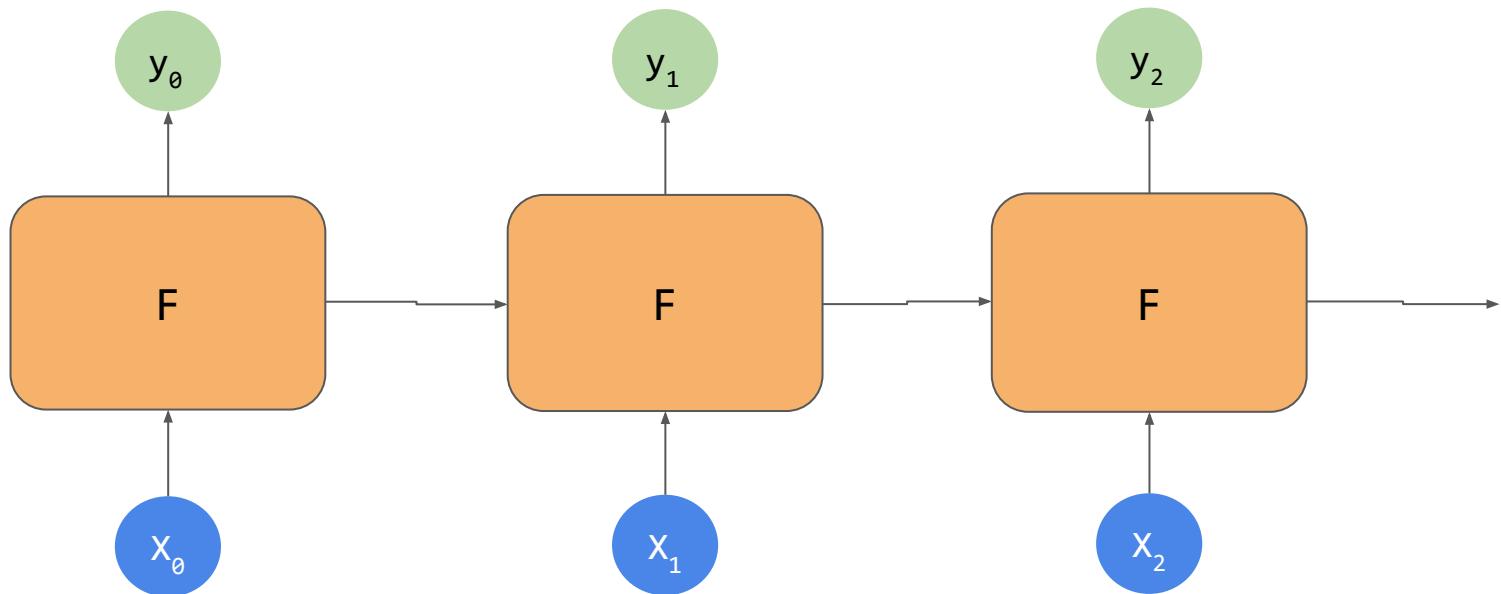


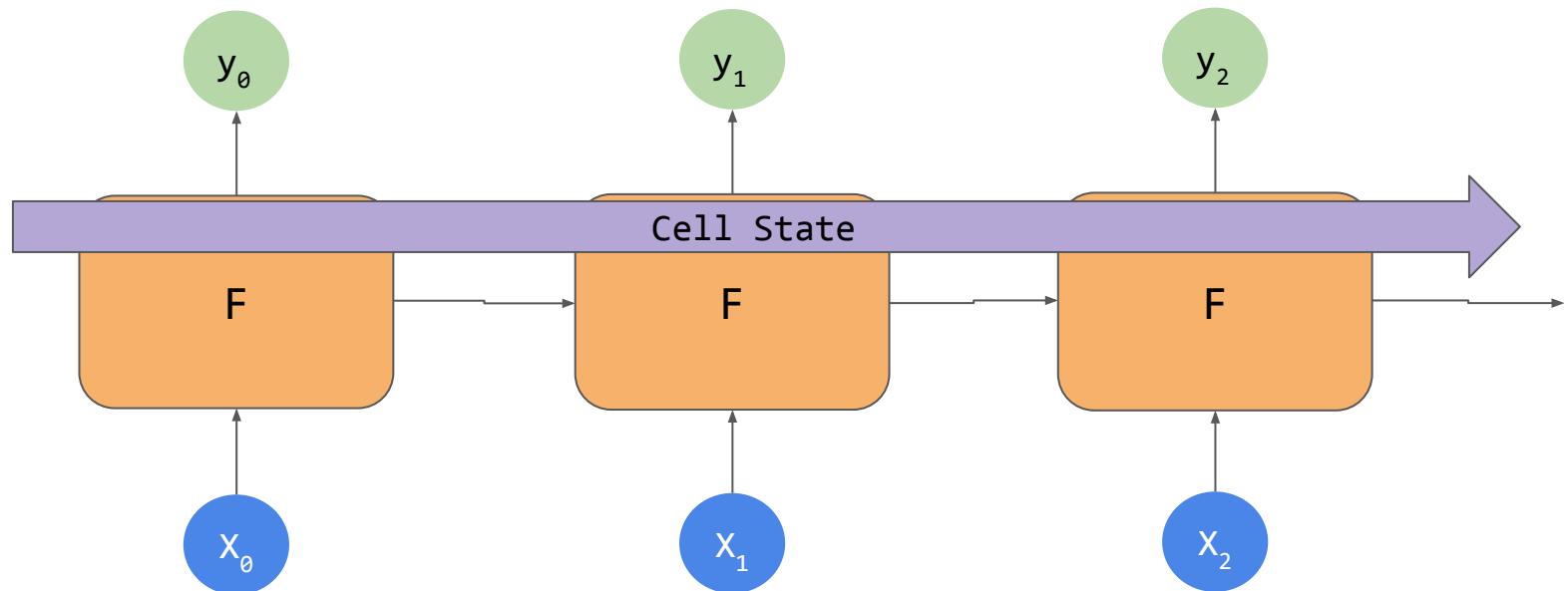
MAE and Loss

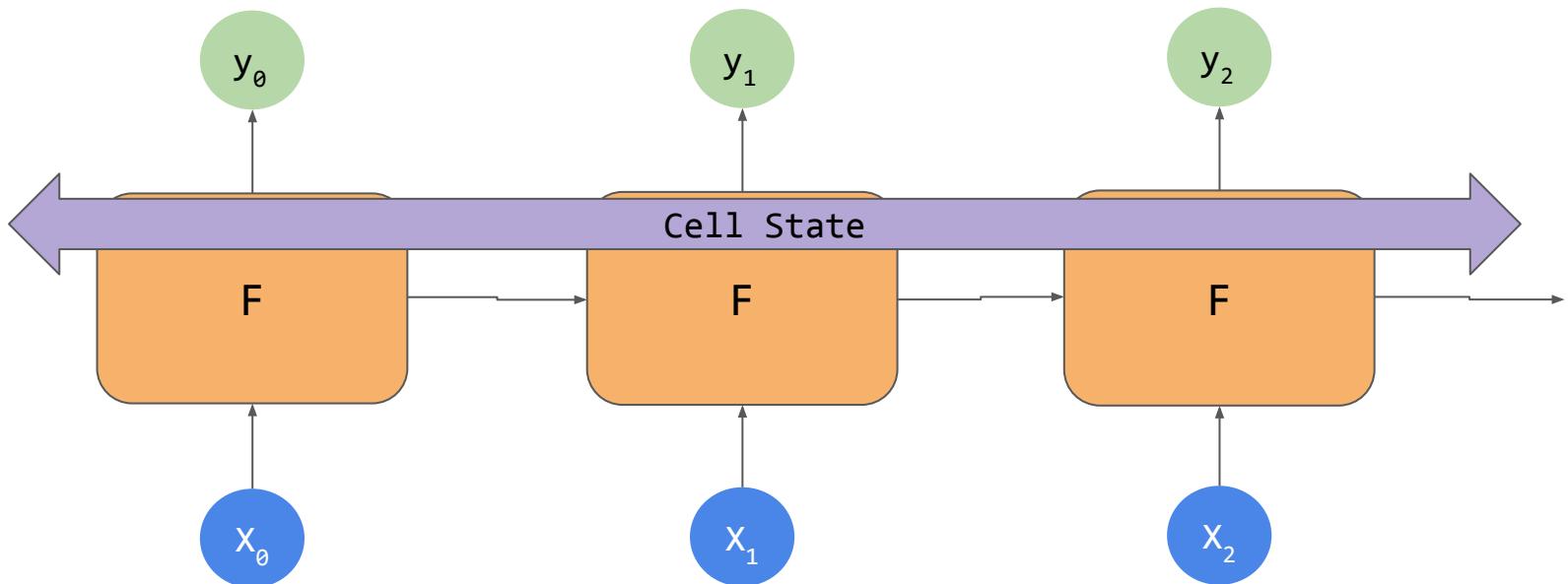


MAE and Loss









Long Short Term Memory (LSTM)

LSTM in pictures

$$\tilde{c}^{<t>} = \tanh(W_c[a^{<t-1>}, x^{<t>}] + b_c)$$

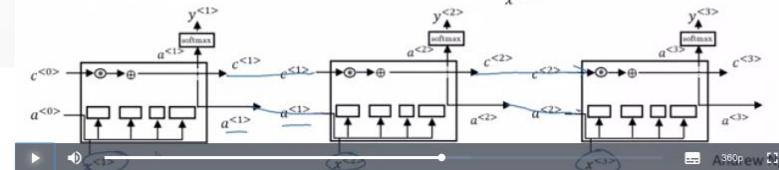
$$\Gamma_u = \sigma(W_u[a^{<t-1>}, x^{<t>}] + b_u)$$

$$\Gamma_f = \sigma(W_f[a^{<t-1>}, x^{<t>}] + b_f)$$

$$\Gamma_o = \sigma(W_o[a^{<t-1>}, x^{<t>}] + b_o)$$

$$c^{<t>} = \Gamma_u * \tilde{c}^{<t>} + \Gamma_f * c^{<t-1>}$$

$$a^{<t>} = \Gamma_o * \tanh c^{<t>}$$



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Sequence Models

★★★★★ 13393 ratings

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Sequence Models

★★★★★ 13393 ratings

Course 5 of 5 in the Specialization Deep Learning

This course will teach you how to build models for natural language, audio, and other sequence data. Thanks to deep learning, sequence algorithms are working far better than just two years ago, and this is enabling numerous exciting applications in speech recognition, music synthesis, chatbots, machine translation, natural language understanding, and many others. You will:

- Understand how to build and train Recurrent Neural Networks (RNNs), and commonly-

More

```
tf.keras.backend.clear_session()

train_set = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32)),
    tf.keras.layers.Dense(1),
    tf.keras.layers.Lambda(lambda x: x * 100.0)
])

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

history = model.fit(dataset, epochs=100)
```

```
tf.keras.backend.clear_session()
```

```
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```

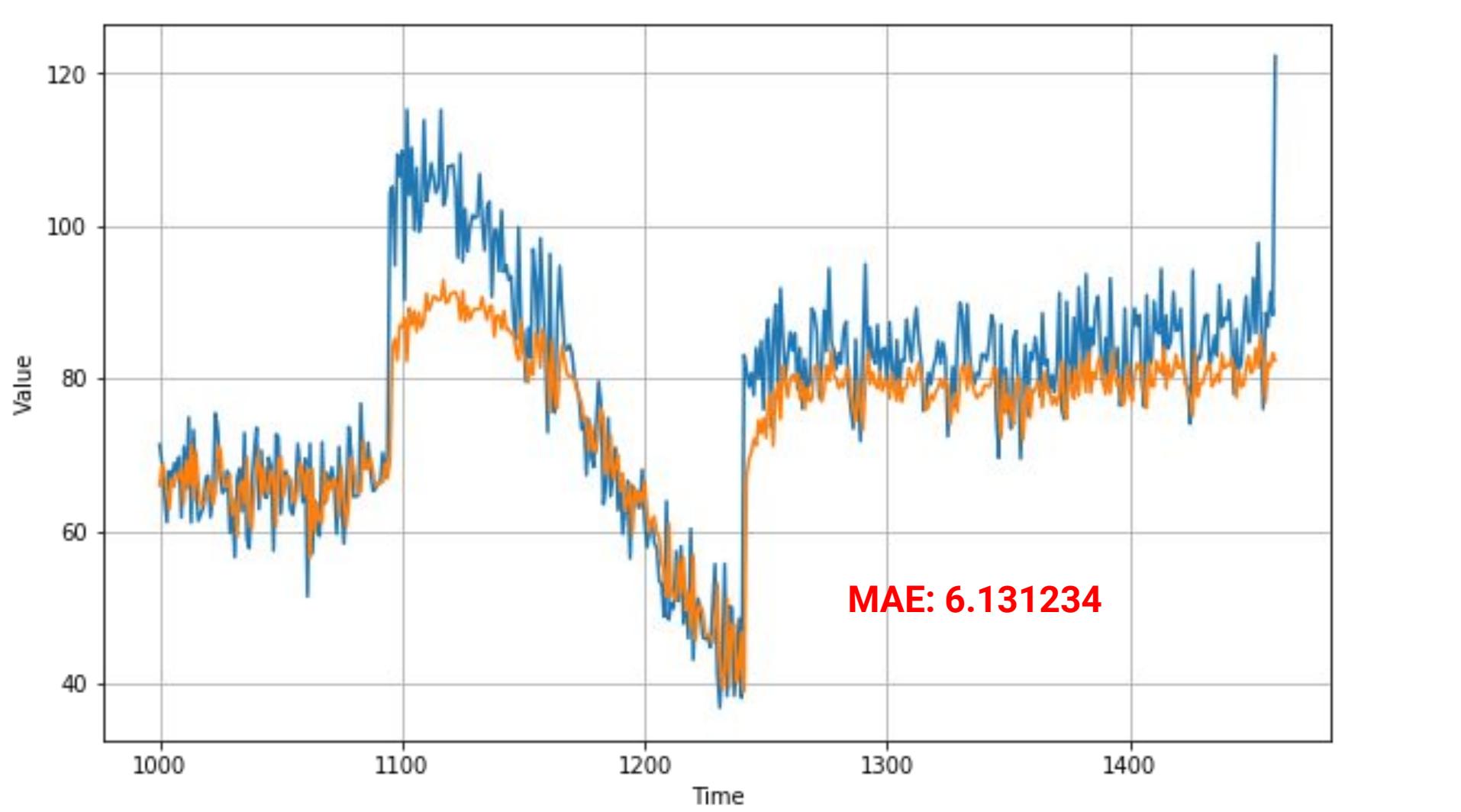
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```

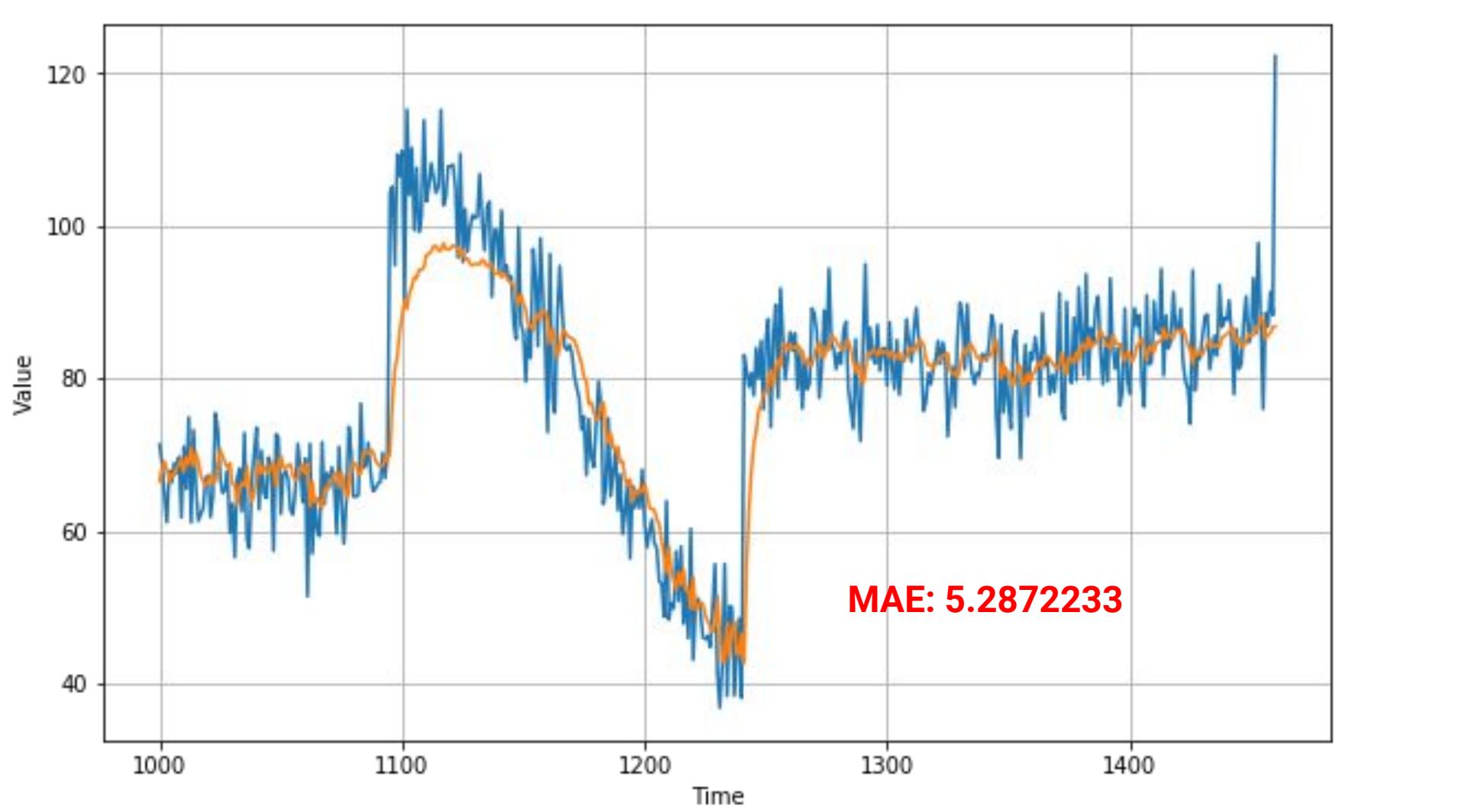
```
tf.keras.backend.clear_session()

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    tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32, return_sequences=True)),
    tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32)),
    tf.keras.layers.Dense(1),
    tf.keras.layers.Lambda(lambda x: x * 100.0)
])
model.compile(loss="mse", optimizer=tf.keras.optimizers.SGD(learning_rate=1e-6, momentum=0.9))

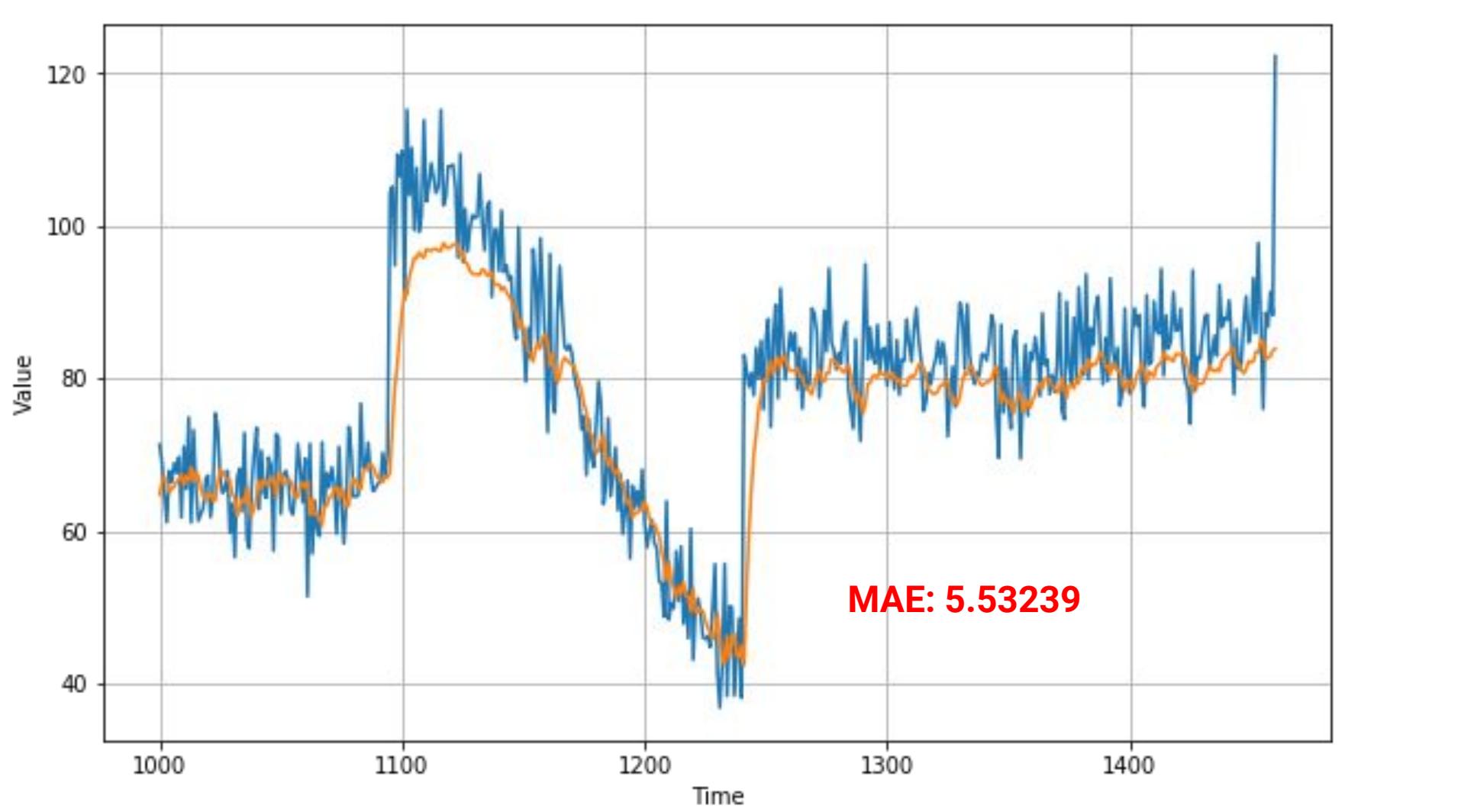
history = model.fit(dataset, epochs=100)
```

```
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    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32, return_sequences=True)),
    tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32, return_sequences=True)),
    tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32)), # This line is highlighted with a red box
    tf.keras.layers.Dense(1),
    tf.keras.layers.Lambda(lambda x: x * 100.0)
])
model.compile(loss="mse", optimizer=tf.keras.optimizers.SGD(learning_rate=1e-6, momentum=0.9))

history = model.fit(dataset, epochs=100)
```



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```
model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.Conv1D(filters=32, kernel_size=5,
                          strides=1, padding="causal",
                          activation="relu"),
    tf.keras.layers.LSTM(32, return_sequences=True),
    tf.keras.layers.LSTM(32),
    tf.keras.layers.Dense(1),
    tf.keras.layers.Lambda(lambda x: x * 200)
])
```

```
optimizer = tf.keras.optimizers.SGD(learning_rate=1e-5, momentum=0.9)
```

```
model.compile(loss=tf.keras.losses.Huber(),
               optimizer=optimizer,
               metrics=["mae"])
```

```
history = model.fit(dataset, epochs=500)
```

deeplearning.ai TensorFlow in Practice Specialization [Go To Course](#)

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Syllabus - What you will learn from this course

WEEK 1

Exploring a Larger Dataset

In the first course in this specialization, you had an introduction to TensorFlow, and how, with its high level APIs you could do basic image classification, and you learned a little bit about Convolutional Neural Networks (ConvNets). In this course you'll go deeper into using ConvNets with real-world data, and learn about techniques that you can use... [SHOW ALL](#)

8 videos (Total 18 min), 5 readings, 3 quizzes [SEE ALL](#)

WEEK 2

Augmentation: A technique to avoid overfitting

You've heard the term overfitting a number of times to this point. Overfitting is simply the concept of being over specialized in training – namely that your model is very good at classifying what it is trained for, but not so good at classifying things that it hasn't seen. In order to generalize your model more effectively, you will of course need a ... [SHOW ALL](#)

7 videos (Total 14 min), 6 readings, 3 quizzes [SEE ALL](#)

WEEK 3

Transfer Learning

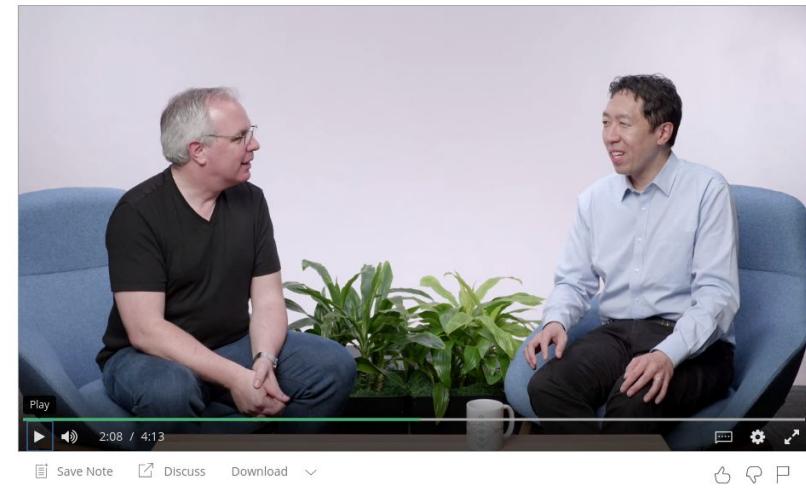
Building models for yourself is great, and can be very powerful. But, as you've seen, you can be limited by the data you have on hand. Not everybody has access to massive datasets or the compute power that's needed to train them effectively. Transfer learning can help solve this – where people with models trained on large datasets train them, ... [SHOW ALL](#)

7 videos (Total 14 min), 5 readings, 3 quizzes [SEE ALL](#)

WEEK 4

Multiclass Classifications

Introduction, A conversation with Andrew Ng



English [▼](#)

[Help Us Translate](#)

0:00 In the first course, you learned how to use TensorFlow to implement a basic neural network, going up all the way to basic Convolutional Neural Network. In this second course, you go much further. In the first week, you take the ideas you've learned, and apply them to a much bigger dataset of cats versus dogs on Kaggle. Yes so we take the full Kaggle dataset of 25,000 cats versus dogs

```
model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.Conv1D(filters=32, kernel_size=5,
                          strides=1, padding="causal",
                          activation="relu"),
    tf.keras.layers.LSTM(32, return_sequences=True),
    tf.keras.layers.LSTM(32),
    tf.keras.layers.Dense(1),
    tf.keras.layers.Lambda(lambda x: x * 200)
])
```

```
lr_schedule = tf.keras.callbacks.LearningRateScheduler(lambda epoch: 1e-8 * 10**(epoch / 20))

optimizer = tf.keras.optimizers.SGD(learning_rate=1e-8, momentum=0.9)

model.compile(loss=tf.keras.losses.Huber(),
              optimizer=optimizer,
              metrics=["mae"])

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

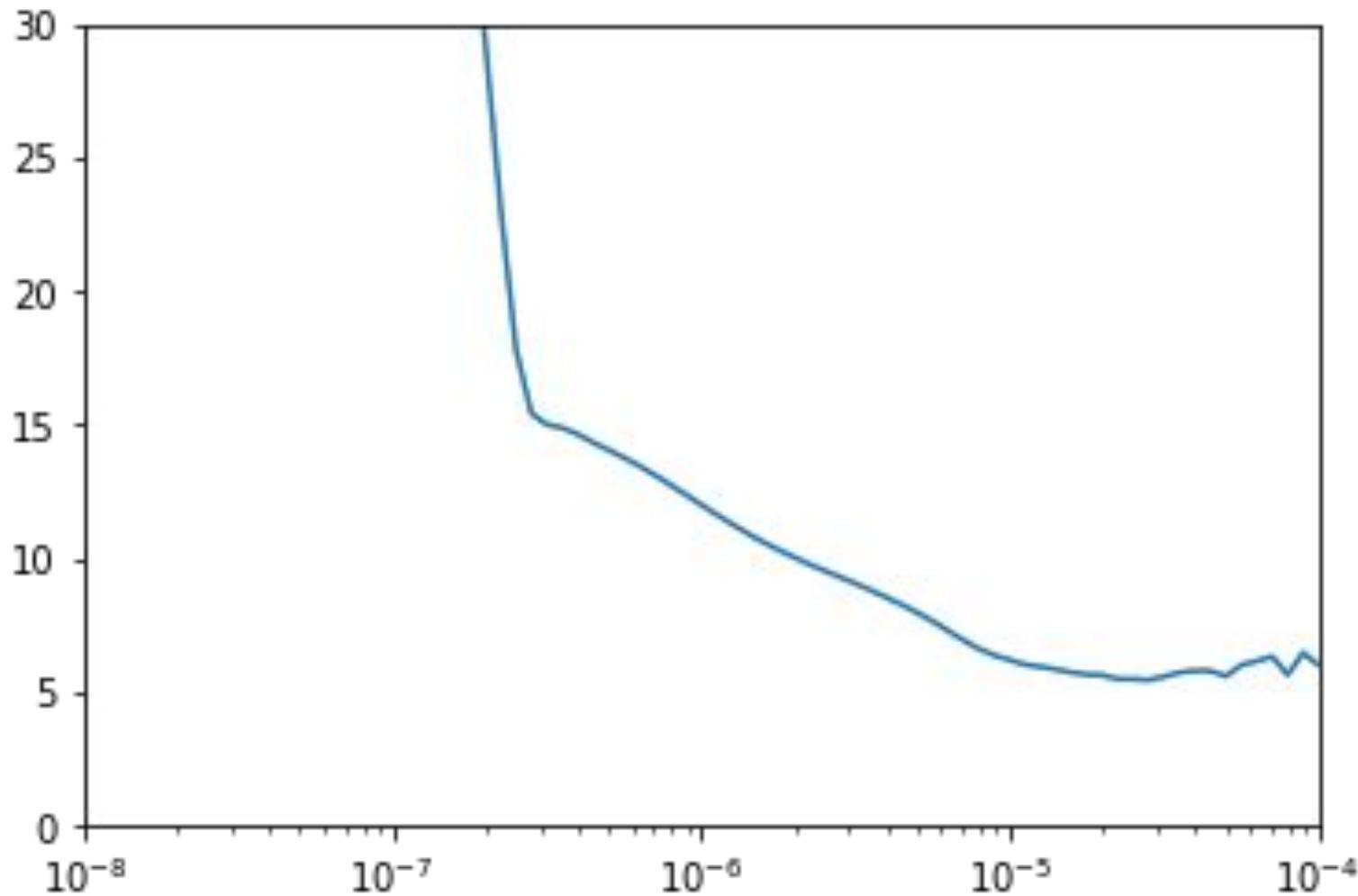
```
model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.Conv1D(filters=32, kernel_size=5,
                          strides=1, padding="causal",
                          activation="relu"),
    tf.keras.layers.LSTM(32, return_sequences=True),
    tf.keras.layers.LSTM(32),
    tf.keras.layers.Dense(1),
    tf.keras.layers.Lambda(lambda x: x * 200)
])
```

```
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model.compile(loss=tf.keras.losses.Huber(),
              optimizer=optimizer,
              metrics=["mae"])

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

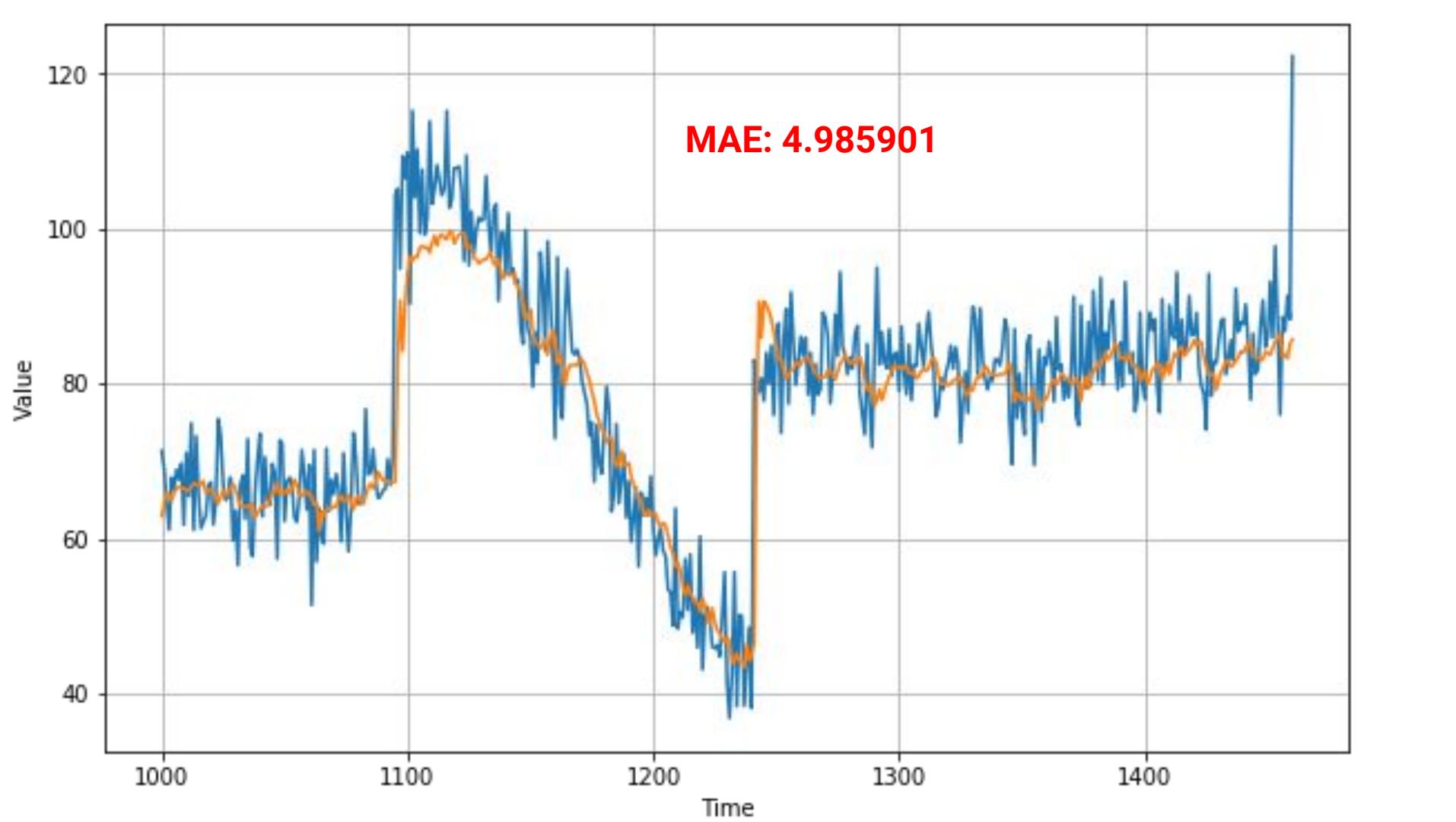


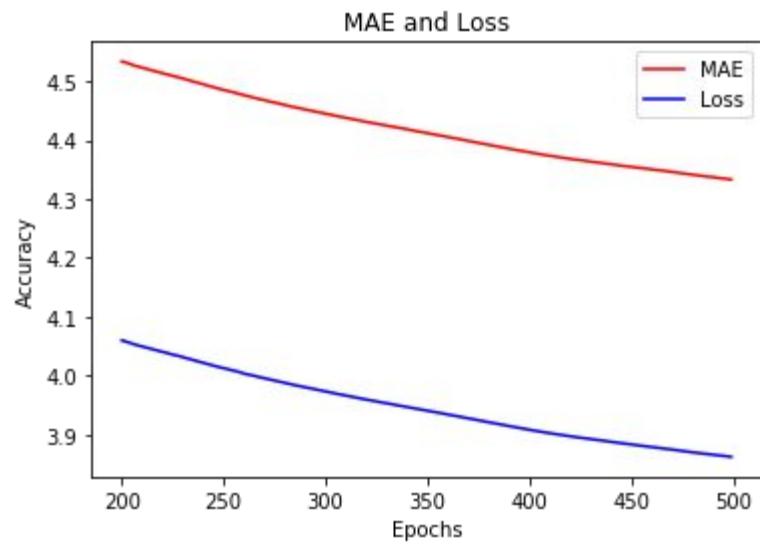
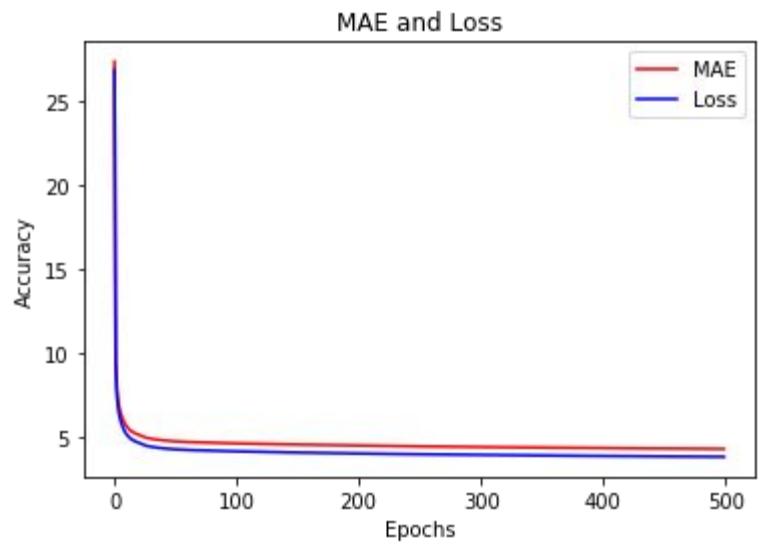
```
model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.Conv1D(filters=32, kernel_size=5,
                          strides=1, padding="causal",
                          activation="relu"),
    tf.keras.layers.LSTM(32, return_sequences=True),
    tf.keras.layers.LSTM(32),
    tf.keras.layers.Dense(1),
    tf.keras.layers.Lambda(lambda x: x * 200)
])
```

```
optimizer = tf.keras.optimizers.SGD(learning_rate=1e-5, momentum=0.9)
```

```
model.compile(loss=tf.keras.losses.Huber(),
               optimizer=optimizer,
               metrics=["mae"])
```

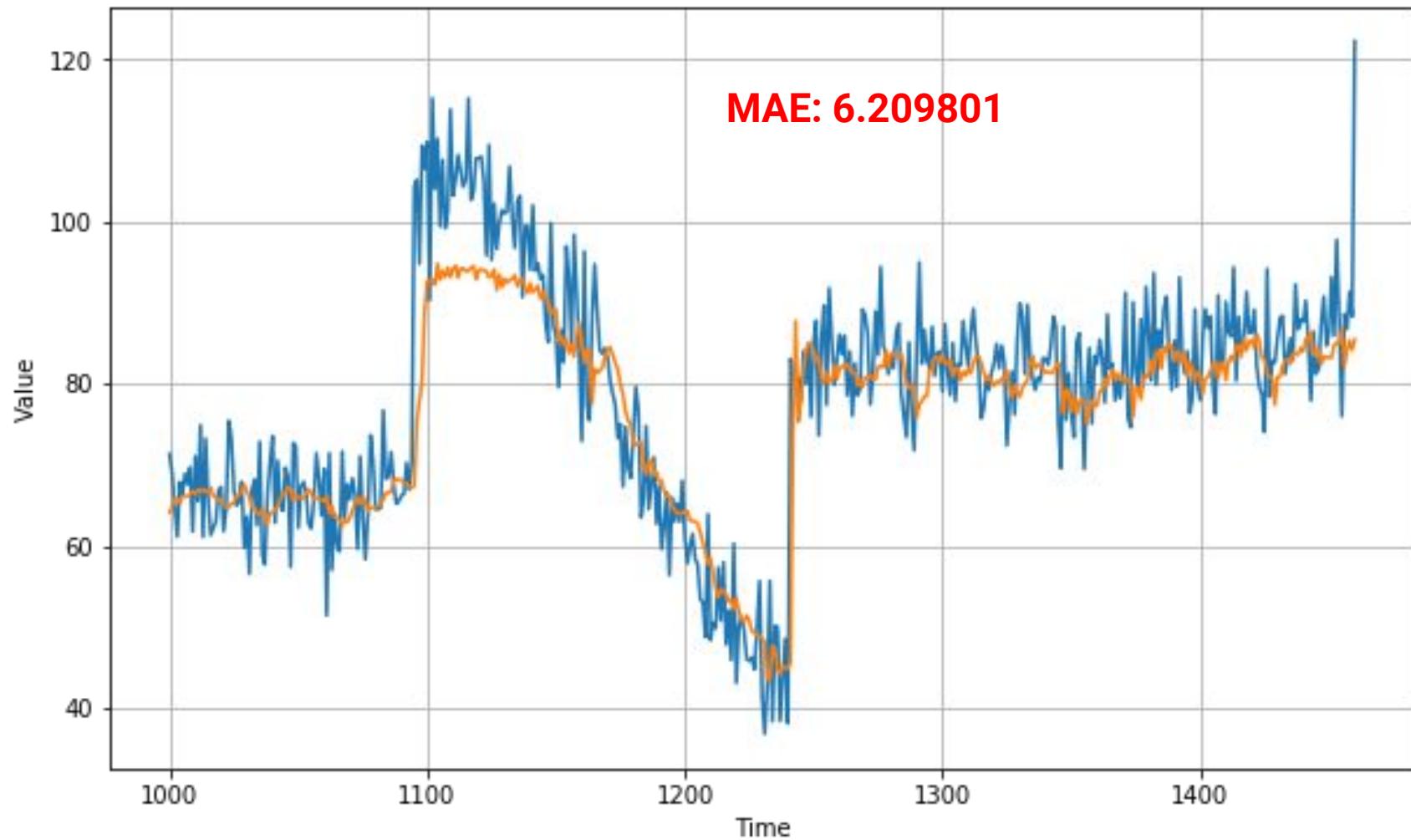
```
history = model.fit(dataset, epochs=500)
```

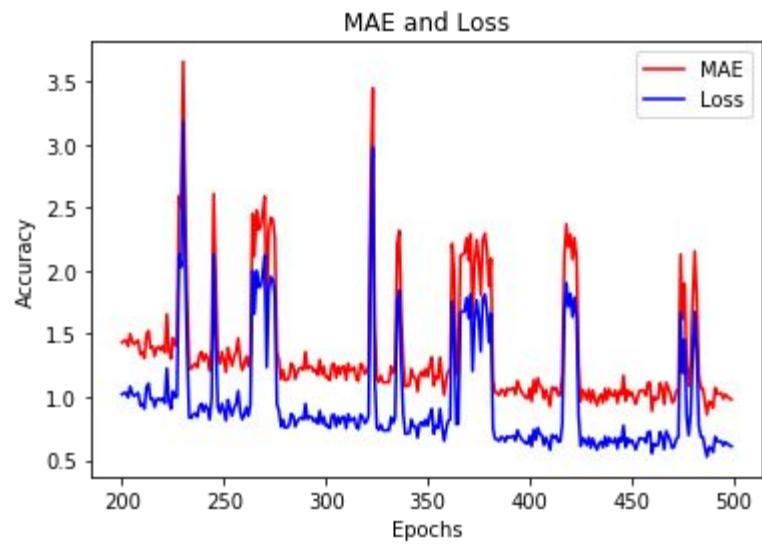
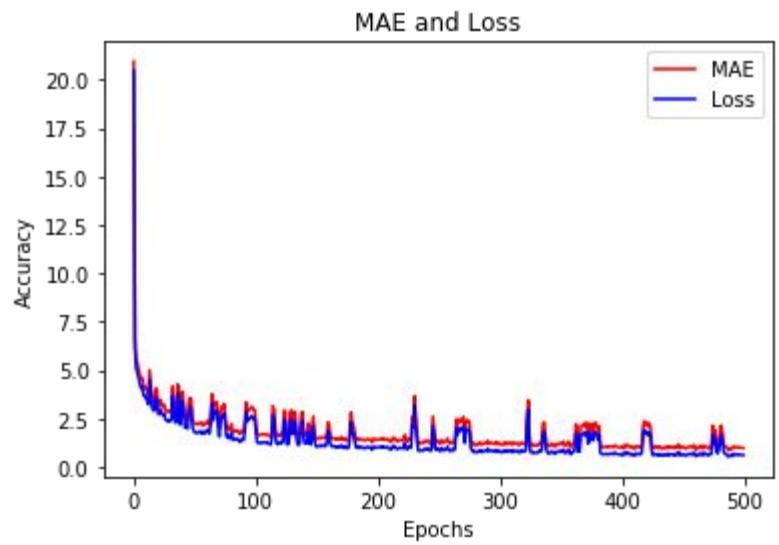




```
model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.Conv1D(filters=32, kernel_size=5,
                          strides=1, padding="causal",
                          activation="relu"),
    tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32, return_sequences=True)),
    tf.keras.layers.Bidirectional(tf.keras.layers.LSTM(32)),
    tf.keras.layers.Dense(1),
    tf.keras.layers.Lambda(lambda x: x * 200)
])
```

```
Epoch 495/500
31/31 [=====] - 2s 58ms/step - loss: 0.6491 - mae: 1.0314
Epoch 496/500
31/31 [=====] - 2s 60ms/step - loss: 0.6155 - mae: 0.9857
Epoch 497/500
31/31 [=====] - 2s 59ms/step - loss: 0.6425 - mae: 1.0207
Epoch 498/500
31/31 [=====] - 2s 59ms/step - loss: 0.6330 - mae: 1.0046
Epoch 499/500
31/31 [=====] - 2s 59ms/step - loss: 0.6155 - mae: 0.9877
Epoch 500/500
31/31 [=====] - 2s 59ms/step - loss: 0.6111 - mae: 0.9806
```





<https://www.coursera.org/learn/deep-neural-network>

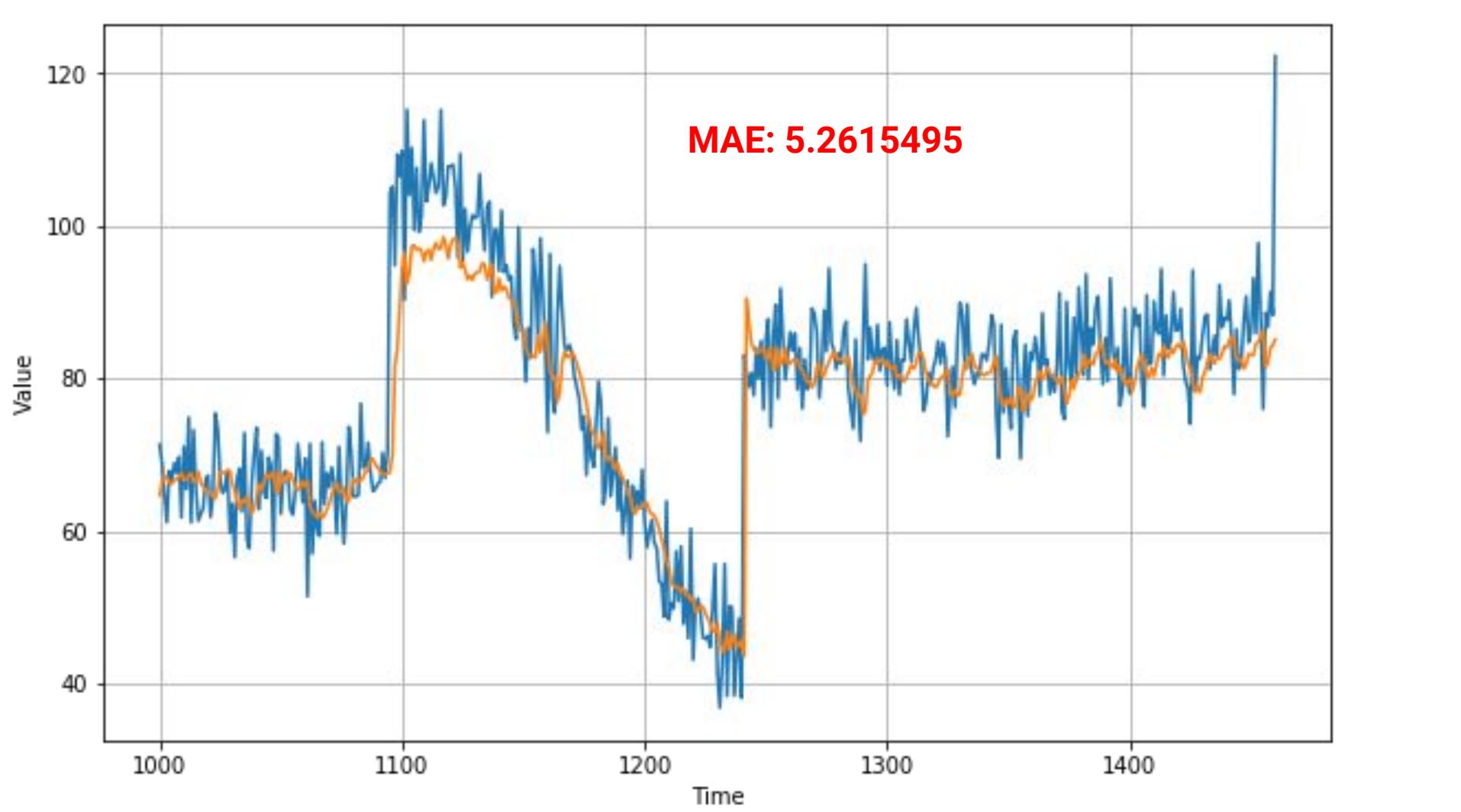
[youtube.com/watch?v=l4ISUAcvHF](https://www.youtube.com/watch?v=l4ISUAcvHF)

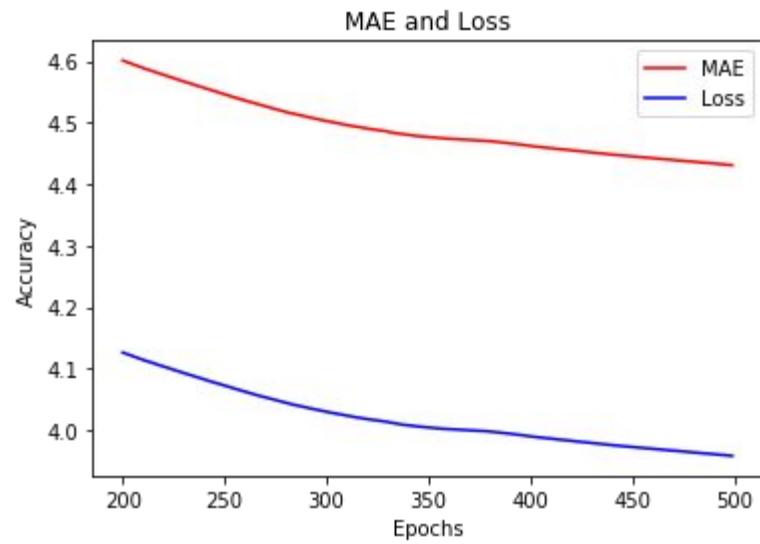
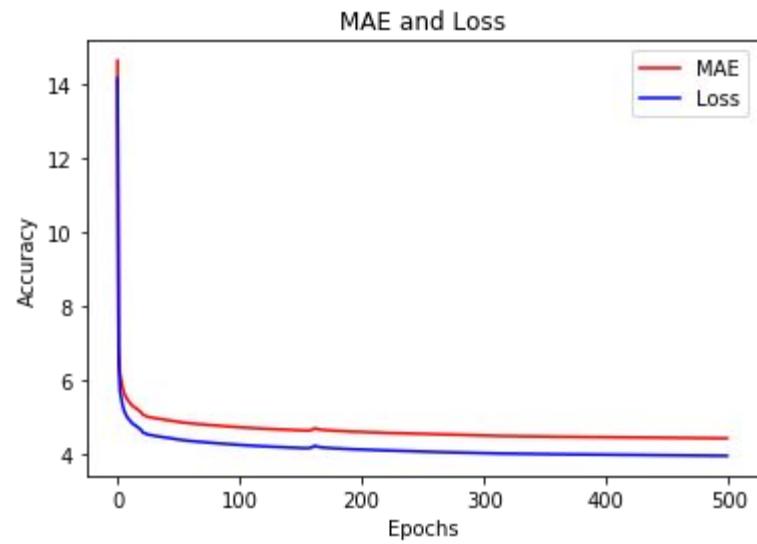


Machine Learning



Lecture 17.3 – Large Scale Machine Learning | Mini Batch Gradient Descent – [Andrew Ng]





<https://www.kaggle.com/robertvalt/sunspots>

Dataset

Sunspots

Monthly Mean Total Sunspot Number - from 1749 to July 2018

 Especuloide · updated a year ago (Version 3)

Data Kernels (5) Discussion Activity Metadata Download (22 KB) New Kernel

Usability 7.1 License CC0: Public Domain Tags No tags yet

Description

Context

Sunspots are temporary phenomena on the Sun's photosphere that appear as spots darker than the surrounding areas. They are regions of reduced surface temperature caused by concentrations of magnetic field flux that inhibit convection. Sunspots usually appear in pairs of opposite magnetic polarity. Their number varies according to the approximately 11-year solar cycle.

Source: <https://en.wikipedia.org/wiki/Sunspot>

Content :

↓

Data (22 KB)

Data Sources	About this file	Columns
 Sunspots.csv 3235 x 3	Sunspots - Monthly Mean Total Sunspot Number	# Date # Monthly Mean Total Sunspot Number

Sunspots.csv ×

	,Date,Monthly Mean Total Sunspot Number
1	,Date,Monthly Mean Total Sunspot Number
2	0,1749-01-31,96.7
3	1,1749-02-28,104.3
4	2,1749-03-31,116.7
5	3,1749-04-30,92.8
6	4,1749-05-31,141.7
7	5,1749-06-30,139.2
8	6,1749-07-31,158.0
9	7,1749-08-31,110.5
10	8,1749-09-30,126.5
11	9,1749-10-31,125.8
12	10,1749-11-30,264.3
13	11,1749-12-31,142.0
14	12,1750-01-31,122.2
15	13,1750-02-28,126.5
16	14,1750-03-31,148.7
17	15,1750-04-30,147.2
18	16,1750-05-31,150.0
19	17,1750-06-30,166.7

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



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

with open('./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]))
```



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

with open('./sunspots.csv') as csvfile:
    reader = csv.reader(csvfile, delimiter=',')
    next(reader)
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    next(reader)
    for row in reader:
        sunspots.append(float(row[2]))
        time_step.append(int(row[0]))
```

	,Date,Monthly Mean Total Sunspot Number
1	,Date,Monthly Mean Total Sunspot Number
2	0,1749-01-31,90.7
3	1,1749-02-28,104.3
4	2,1749-03-31,116.7
5	3,1749-04-30,92.8
6	4,1749-05-31,141.7
7	5,1749-06-30,139.2
8	6,1749-07-31,158.0
9	7,1749-08-31,110.5
10	8,1749-09-30,126.5
11	9,1749-10-31,125.8
12	10,1749-11-30,264.3
13	11,1749-12-31,142.0
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    next(reader)
    for row in reader:
        sunspots.append(float(row[2]))
        time_step.append(int(row[0]))
```

	Date	Monthly Mean Sunspot Number
1	0,1749-01-31	96.7
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15	14,1750-03-31	148.7
16	15,1750-04-30	147.2
17	16,1750-05-31	150.0
18	17,1750-06-30	166.7



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

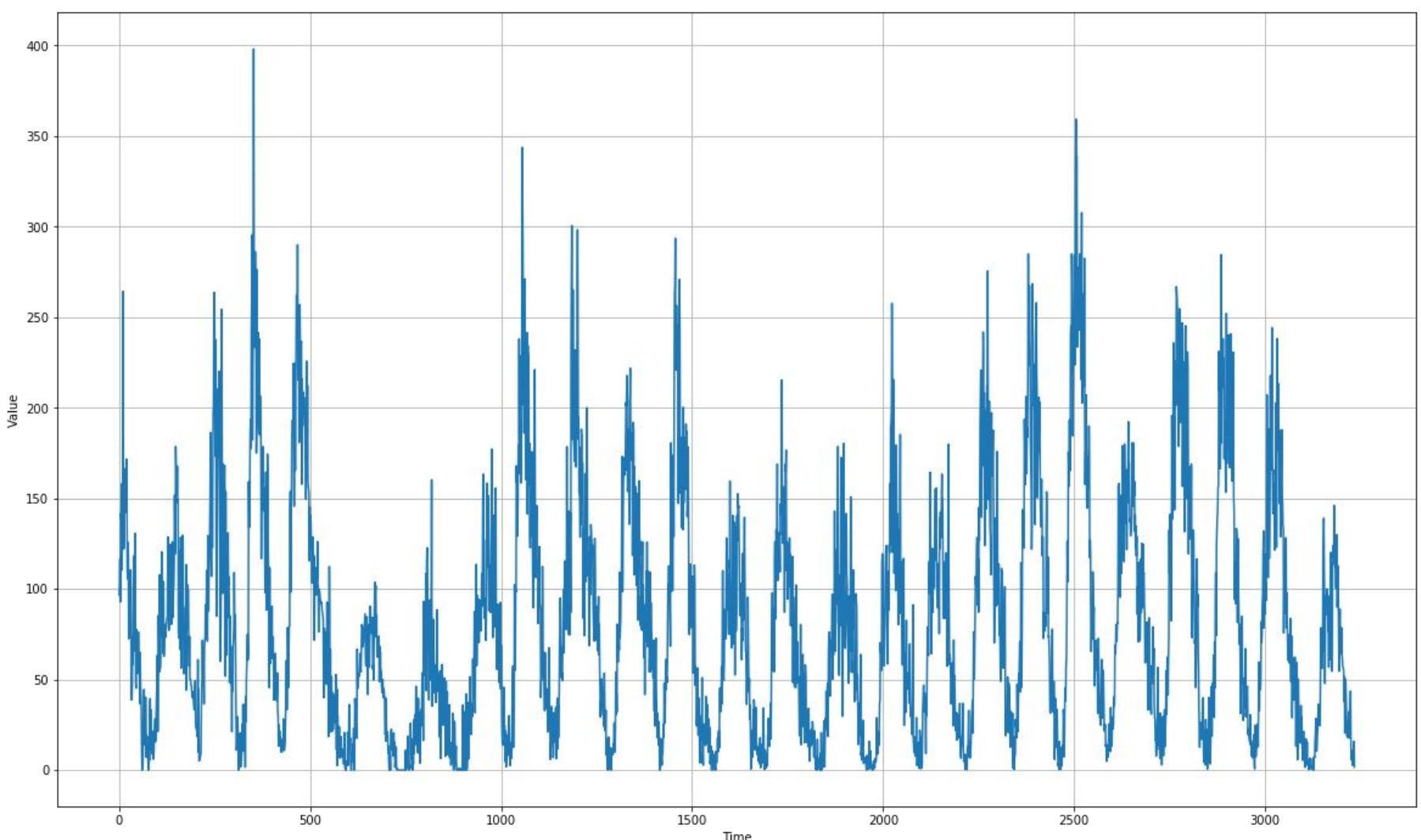
with open('./sunspots.csv') as csvfile:
    reader = csv.reader(csvfile, delimiter=',')
    next(reader)
    for row in reader:
        sunspots.append(float(row[2]))
        time_step.append(int(row[0]))
```

	Date	Monthly Mean Total Sunspot Number
1	0, 749-01-31	96.7
2	1, 749-02-28	104.3
3	2, 749-03-31	116.7
4	3, 749-04-30	92.8
5	4, 749-05-31	141.7
6	5, 749-06-30	139.2
7	6, 749-07-31	158.0
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11	10, 1749-11-30	264.3
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15	14, 1750-03-31	148.7
16	15, 1750-04-30	147.2
17	16, 1750-05-31	150.0
18	17, 1750-06-30	166.7



```
series = np.array(sunspots)
time = np.array(time_step)
```





```
split_time = 1000
time_train = time[:split_time]
x_train = series[:split_time]
time_valid = time[split_time:]
x_valid = series[split_time:]

window_size = 20
batch_size = 32
shuffle_buffer_size = 1000
```

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



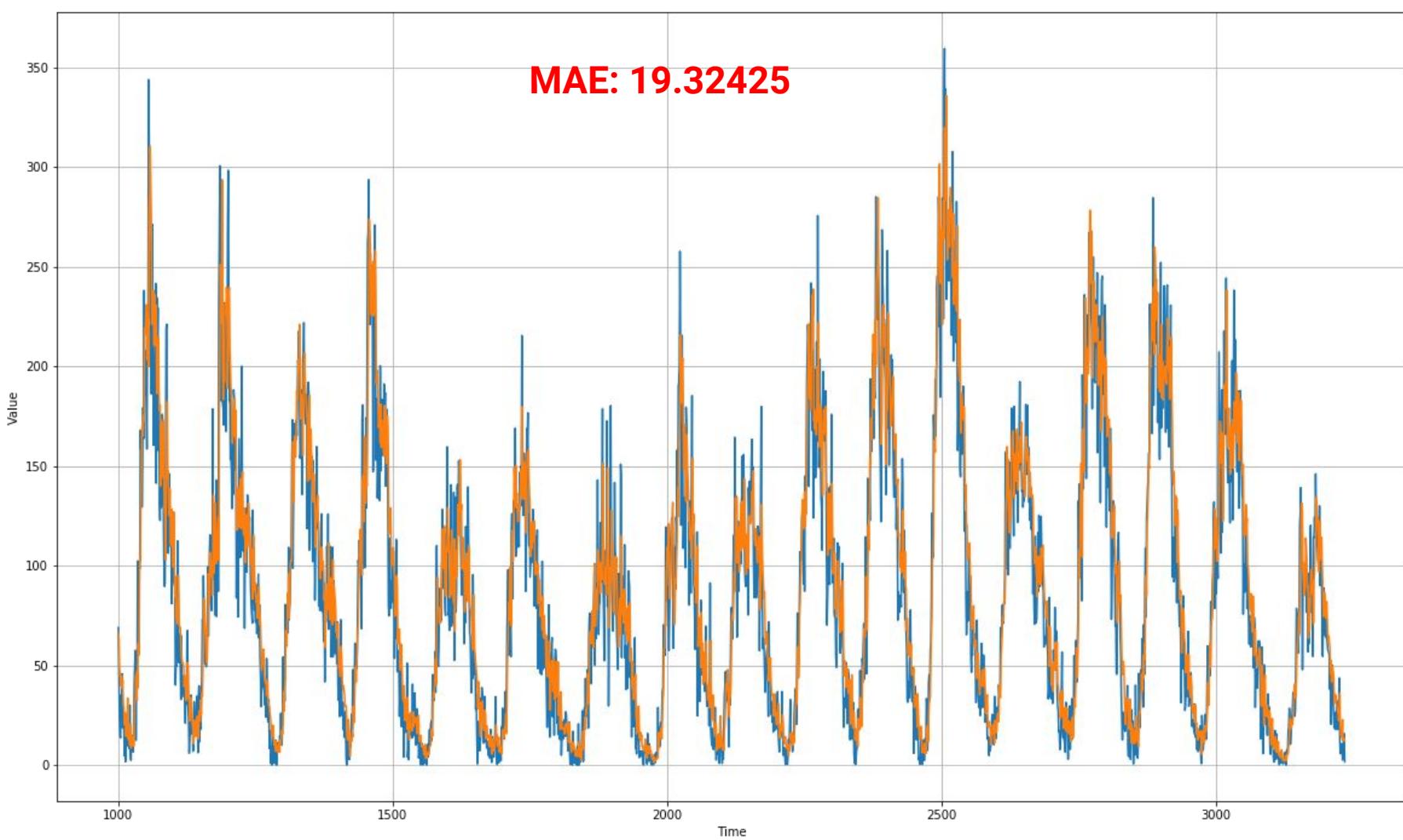
```
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

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

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

history = model.fit(dataset, epochs=100)
```

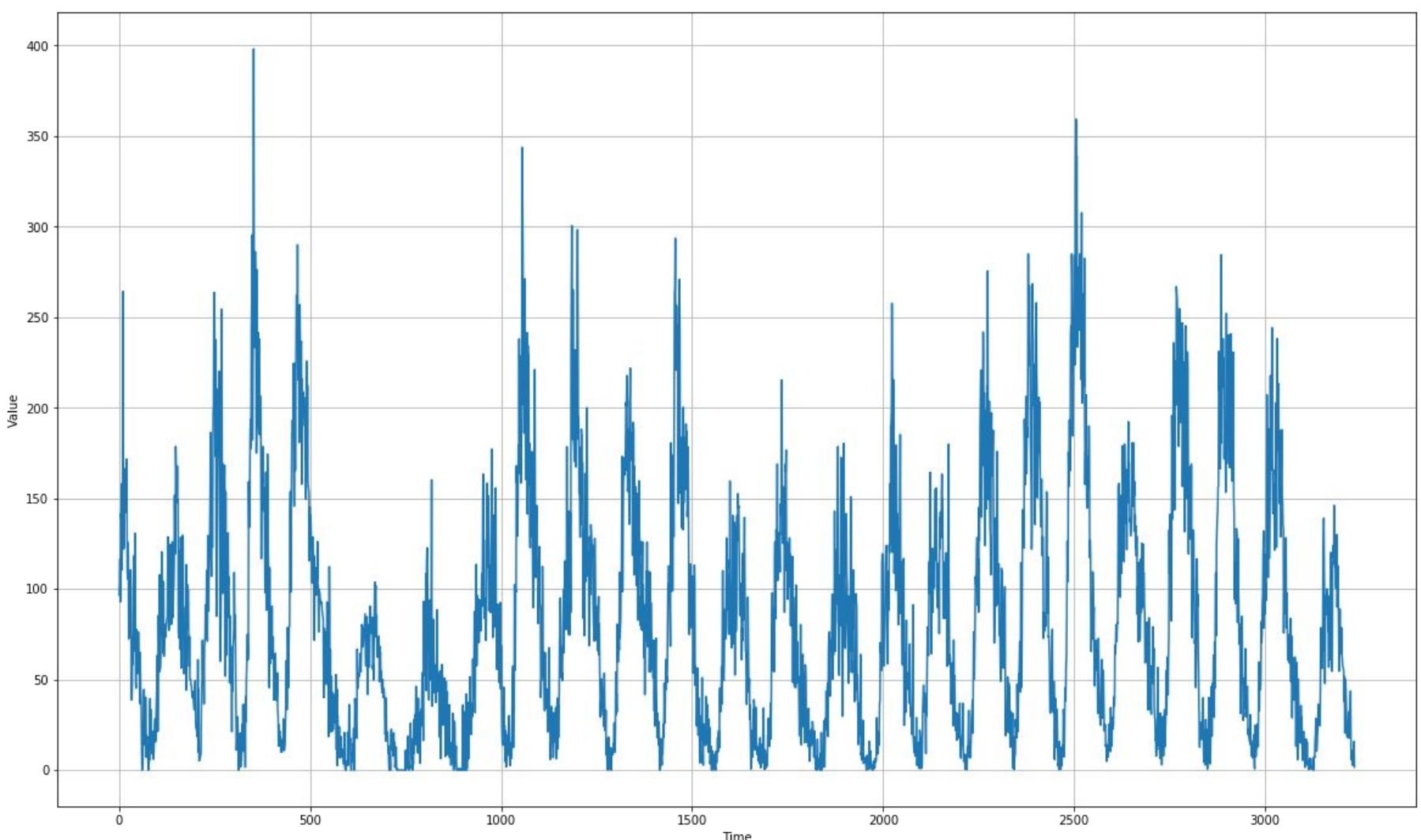
MAE: 19.32425





```
split_time = 1000
time_train = time[:split_time]
x_train = series[:split_time]
time_valid = time[split_time:]
x_valid = series[split_time:]

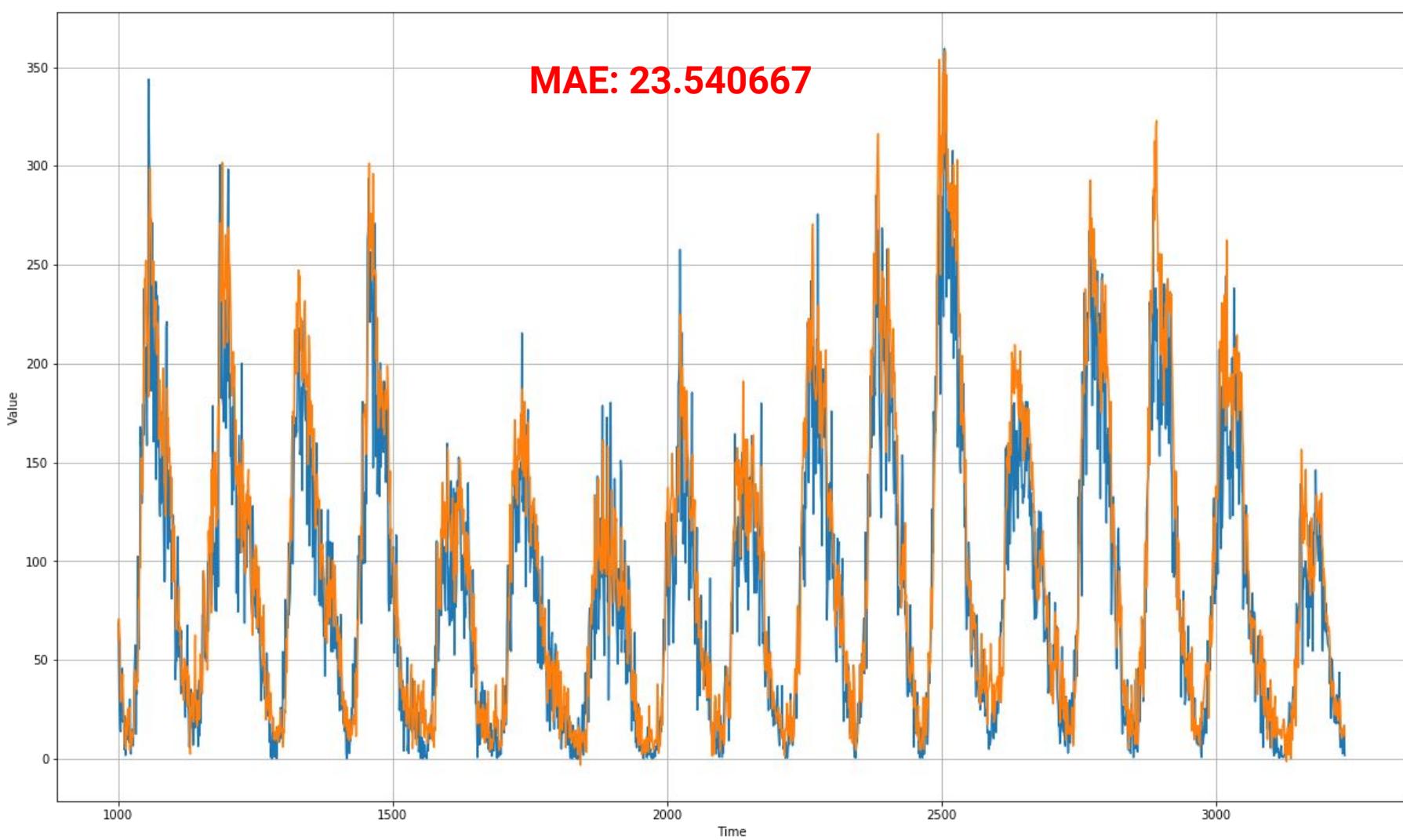
window_size = 20
batch_size = 32
shuffle_buffer_size = 1000
```

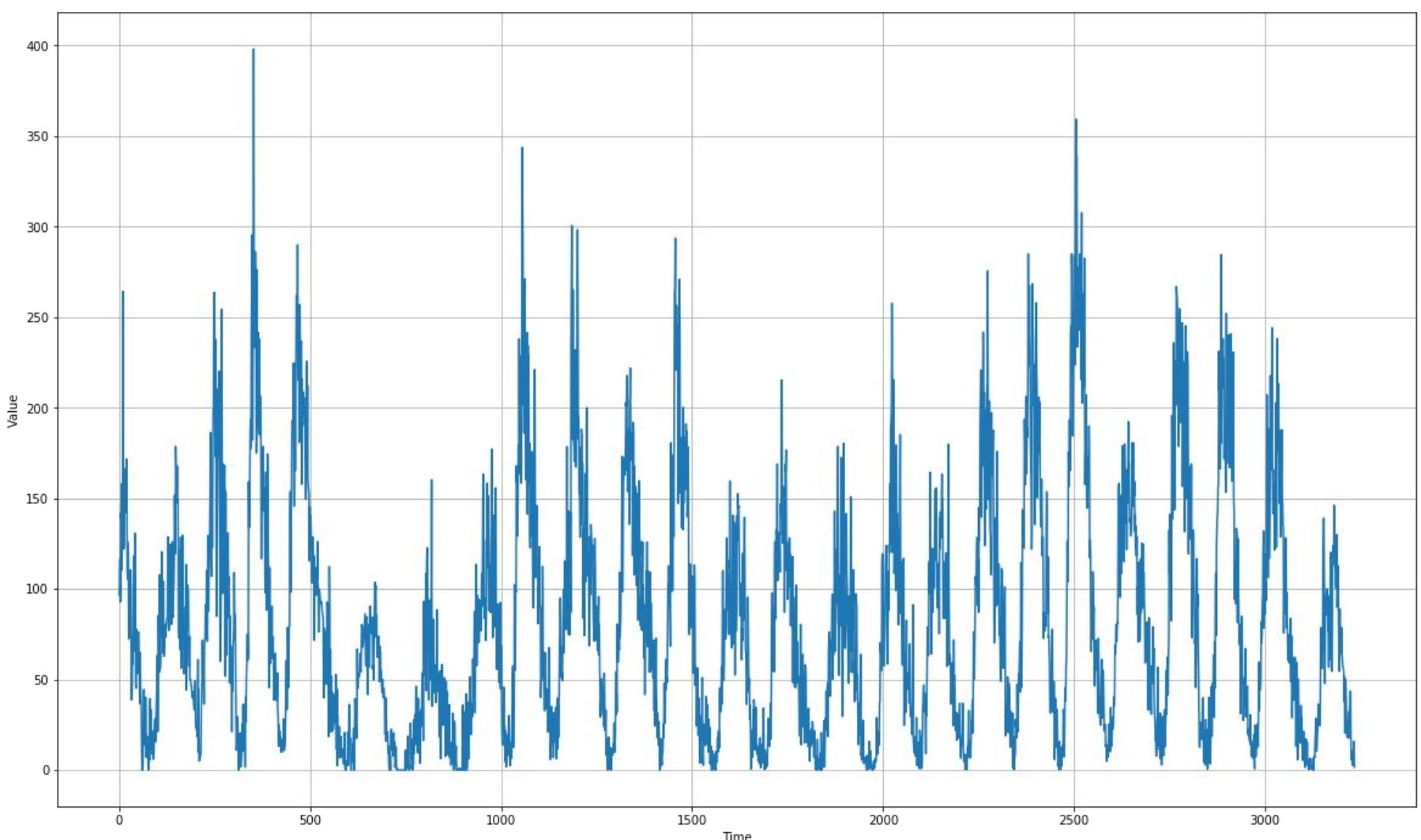


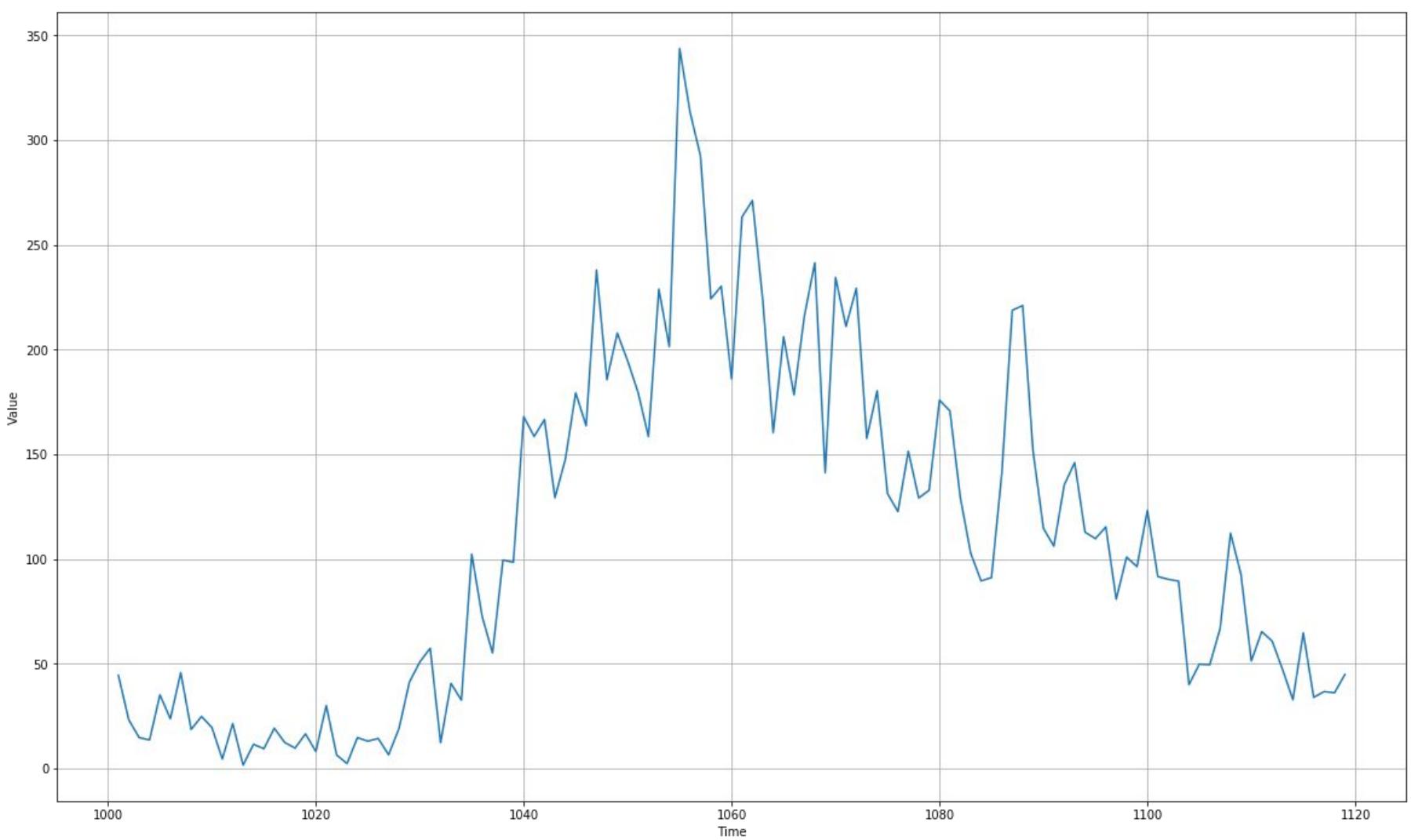
```
split_time = 1000
time_train = time[:split_time]
x_train = series[:split_time]
time_valid = time[split_time:]
x_valid = series[split_time:]

window_size = 132
batch_size = 32
shuffle_buffer_size = 1000
```

MAE: 23.540667







```
split_time = 1000
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
```

```
split_time = 1000
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
```

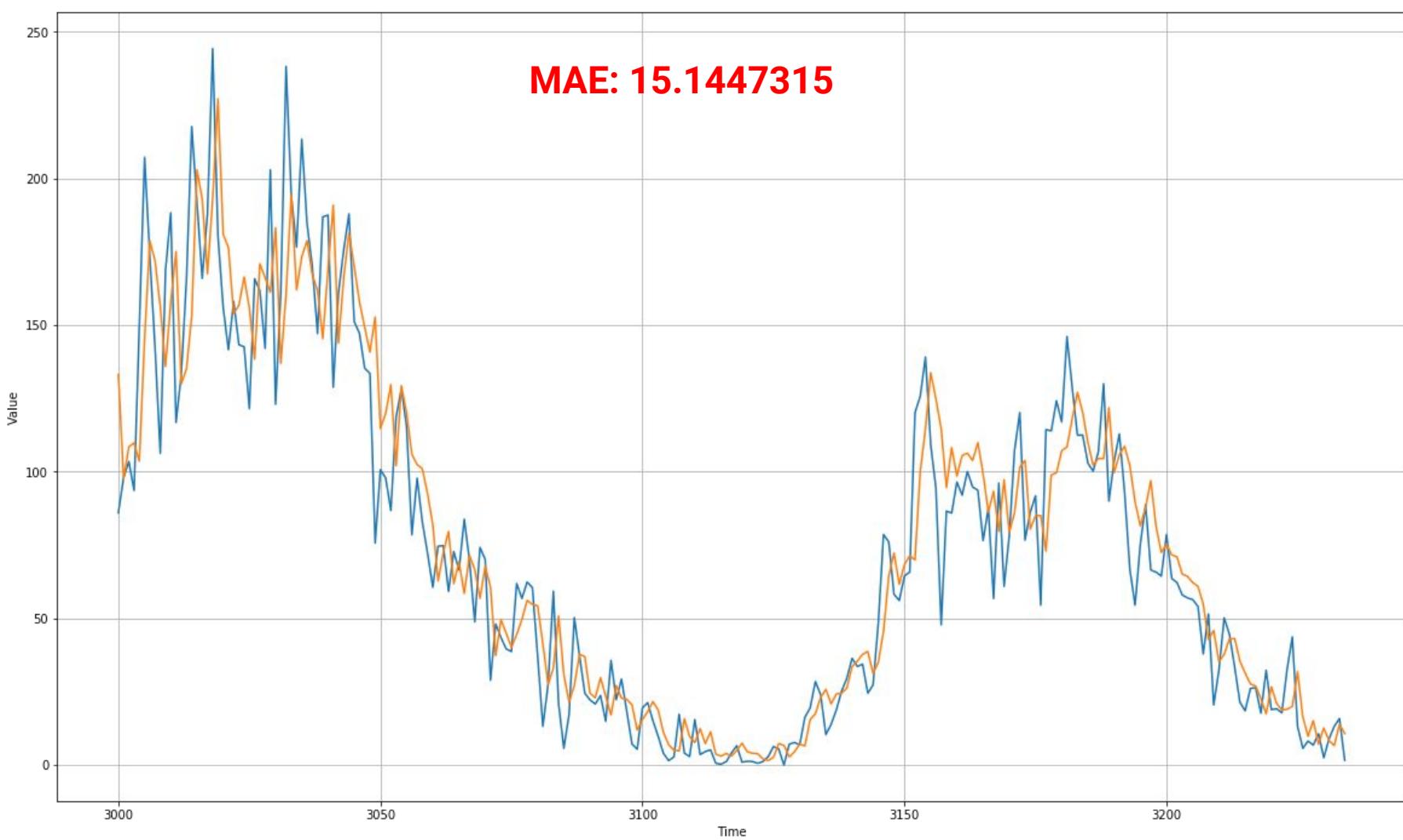


```
split_time = 3000
time_train = time[:split_time]
x_train = series[:split_time]
time_valid = time[split_time:]
x_valid = series[split_time:]

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



MAE: 15.1447315



```
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

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

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

history = model.fit(dataset, epochs=100)
```

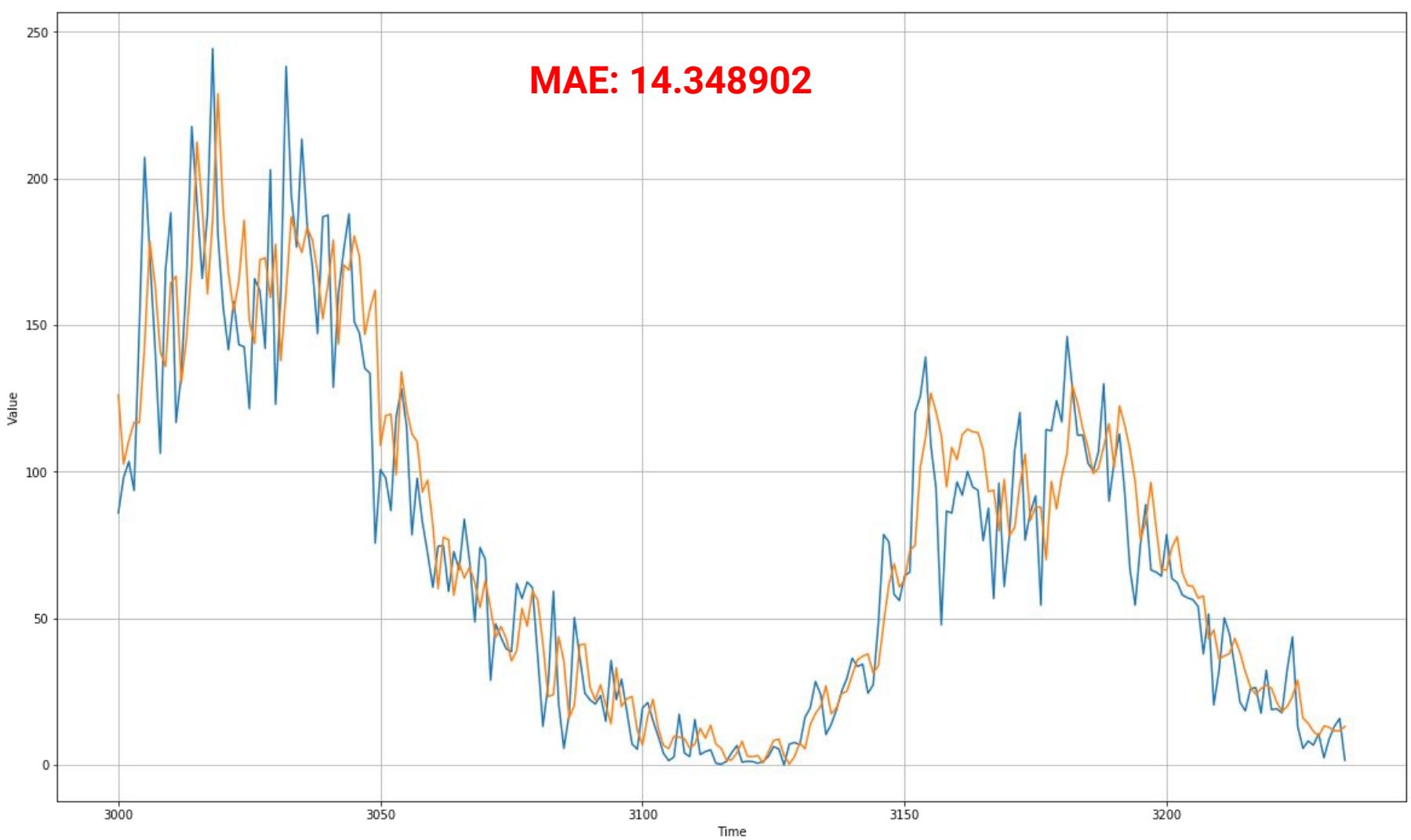
```
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size,)),
    tf.keras.layers.Dense(30, activation="relu"),
    tf.keras.layers.Dense(15, activation="relu"),
    tf.keras.layers.Dense(1, activation="relu")
])

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

history = model.fit(dataset, epochs=100)
```

MAE: 14.348902



```
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

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

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

history = model.fit(dataset, epochs=100)
```

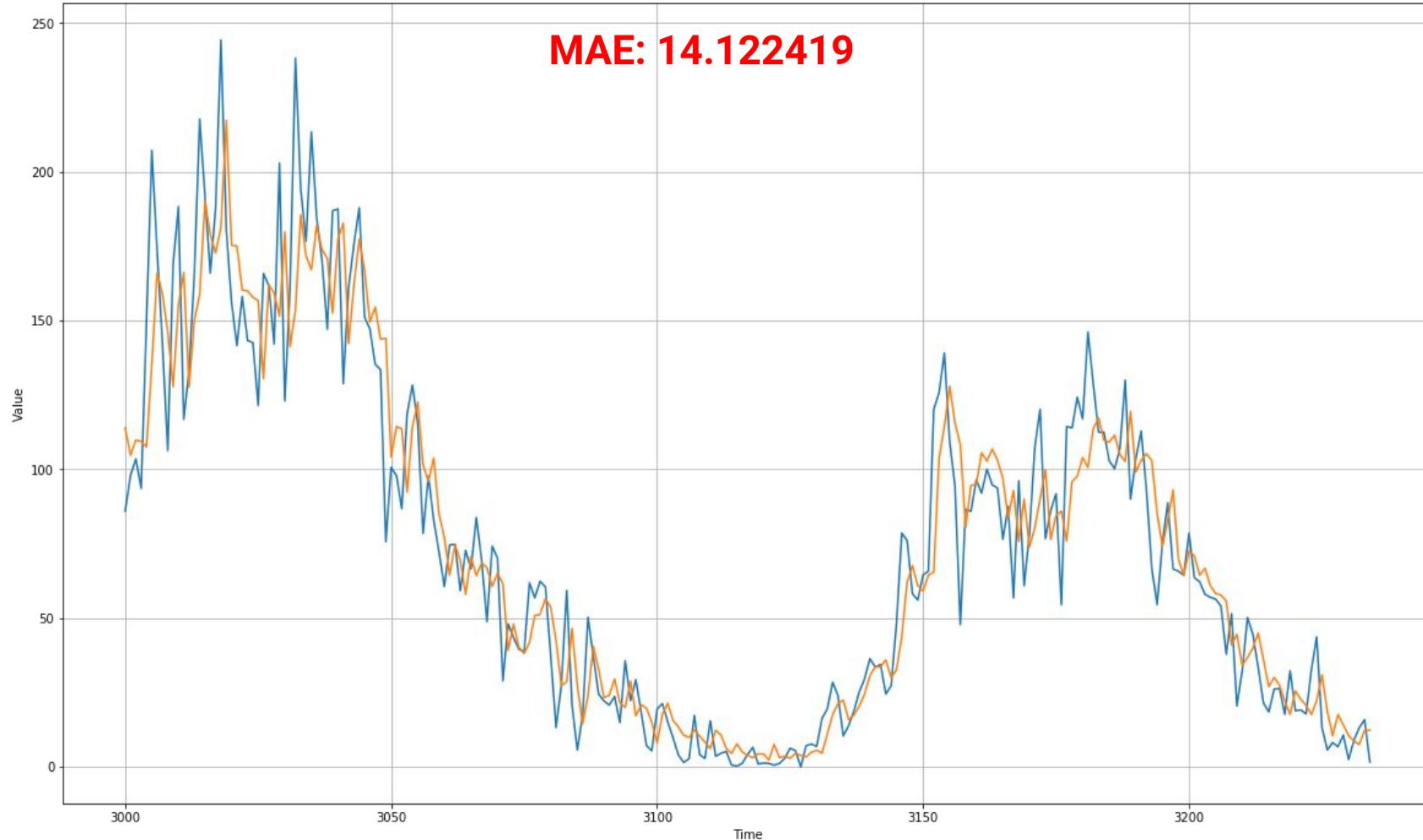
```
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

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

model.compile(loss="mse", optimizer=tf.keras.optimizers.SGD(learning_rate=1e-7, momentum=0.9))

history = model.fit(dataset, epochs=100)
```

MAE: 14.122419



```
model.predict(series[3205:3235][np.newaxis])
```



```
model.predict(series[3205:3235][np.newaxis])
```

7.0773993

(last updated 01 Jun 2019 09:42 UT)

OBSERVED MONTHLY SUNSPOT NUMBERS

2001	142.6	121.5	165.8	161.7	142.1	202.9	123.0	161.5	238.2	194.1	176.6	213.4
2002	184.6	170.2	147.1	186.9	187.5	128.8	161.0	175.6	187.9	151.2	147.2	135.3
2003	133.5	75.7	100.7	97.9	86.8	118.7	128.3	115.4	78.5	97.8	82.9	72.2
2004	60.6	74.6	74.8	59.2	72.8	66.5	83.8	69.7	48.8	74.2	70.1	28.9
2005	48.1	43.5	39.6	38.7	61.9	56.8	62.4	60.5	37.2	13.2	27.5	59.3
2006	20.9	5.7	17.3	50.3	37.2	24.5	22.2	20.8	23.7	14.9	35.7	22.3
2007	29.3	18.4	7.2	5.4	19.5	21.3	15.1	9.8	4.0	1.5	2.8	17.3
2008	4.1	2.9	15.5	3.6	4.6	5.2	0.6	0.3	1.2	4.2	6.6	1.0
2009	1.3	1.2	0.6	1.2	2.9	6.3	5.5	0.0	7.1	7.7	6.9	16.3
2010	19.5	28.5	24.0	10.4	13.9	18.8	25.2	29.6	36.4	33.6	34.4	24.5
2011	27.3	48.3	78.6	76.1	58.2	56.1	64.5	65.8	120.1	125.7	139.1	109.3
2012	94.4	47.8	86.6	85.9	96.5	92.0	100.1	94.8	93.7	76.5	87.6	56.8
2013	96.1	60.9	78.3	107.3	120.2	76.7	86.2	91.8	54.5	114.4	113.9	124.2
2014	117.0	146.1	128.7	112.5	112.5	102.9	100.2	106.9	130.0	90.0	103.6	112.9
2015	93.0	66.7	54.5	75.3	88.8	66.5	65.8	64.4	78.6	63.6	62.2	58.0
2016	57.0	56.4	54.1	37.9	51.5	20.5	32.4	50.2	44.6	33.4	21.4	18.5
2017	26.1	26.4	17.7	32.3	18.9	19.2	17.8	32.6	43.7	13.2	5.7	8.2
2018	6.8	10.7	2.5	8.9	13.1	15.6	1.6	8.7	3.3	4.9	4.9	3.1
2019	7.8	0.8	9.5	9.1	10.1							

```
split_time = 3000
window_size = 60

dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

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

model.compile(loss="mse", optimizer=tf.keras.optimizers.SGD(learning_rate=1e-7, momentum=0.9))
```



```
window_size = 60
batch_size = 64

dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.Conv1D(filters=32, kernel_size=5, strides=1,
                          padding="causal", activation="relu"),
    tf.keras.layers.LSTM(32, return_sequences=True),
    tf.keras.layers.LSTM(32),
    tf.keras.layers.Dense(30, activation="relu"),
    tf.keras.layers.Dense(10, activation="relu"),
    tf.keras.layers.Dense(1, activation="relu")
    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(learning_rate=1e-8, momentum=0.9)
model.compile(loss=tf.keras.losses.Huber(), optimizer=optimizer, metrics=["mae"])
history = model.fit(dataset, epochs=100, callbacks=[lr_schedule])
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```
window_size = 60
batch_size = 64

dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.Conv1D(filters=32, kernel_size=5, strides=1,
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    tf.keras.layers.LSTM(32),
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```

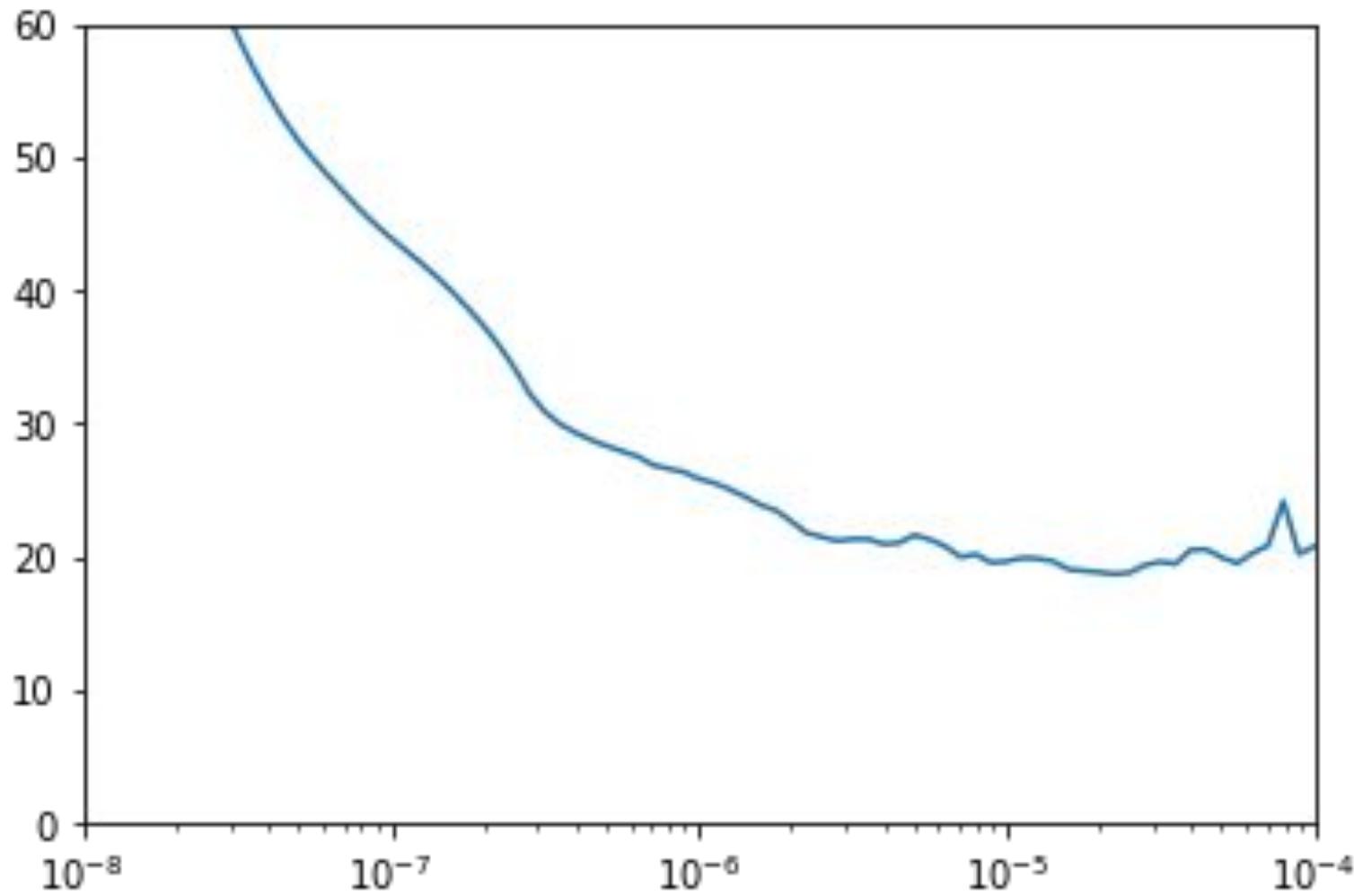


```
window_size = 60
batch_size = 64

dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.Conv1D(filters=32, kernel_size=5, strides=1,
                          padding="causal", activation="relu"),
    tf.keras.layers.LSTM(32, return_sequences=True),
    tf.keras.layers.LSTM(32),
    tf.keras.layers.Dense(30, activation="relu"),
    tf.keras.layers.Dense(10, activation="relu"),
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model.compile(loss=tf.keras.losses.Huber(), optimizer=optimizer, metrics=["mae"])
history = model.fit(dataset, epochs=100, callbacks=[lr_schedule])
```

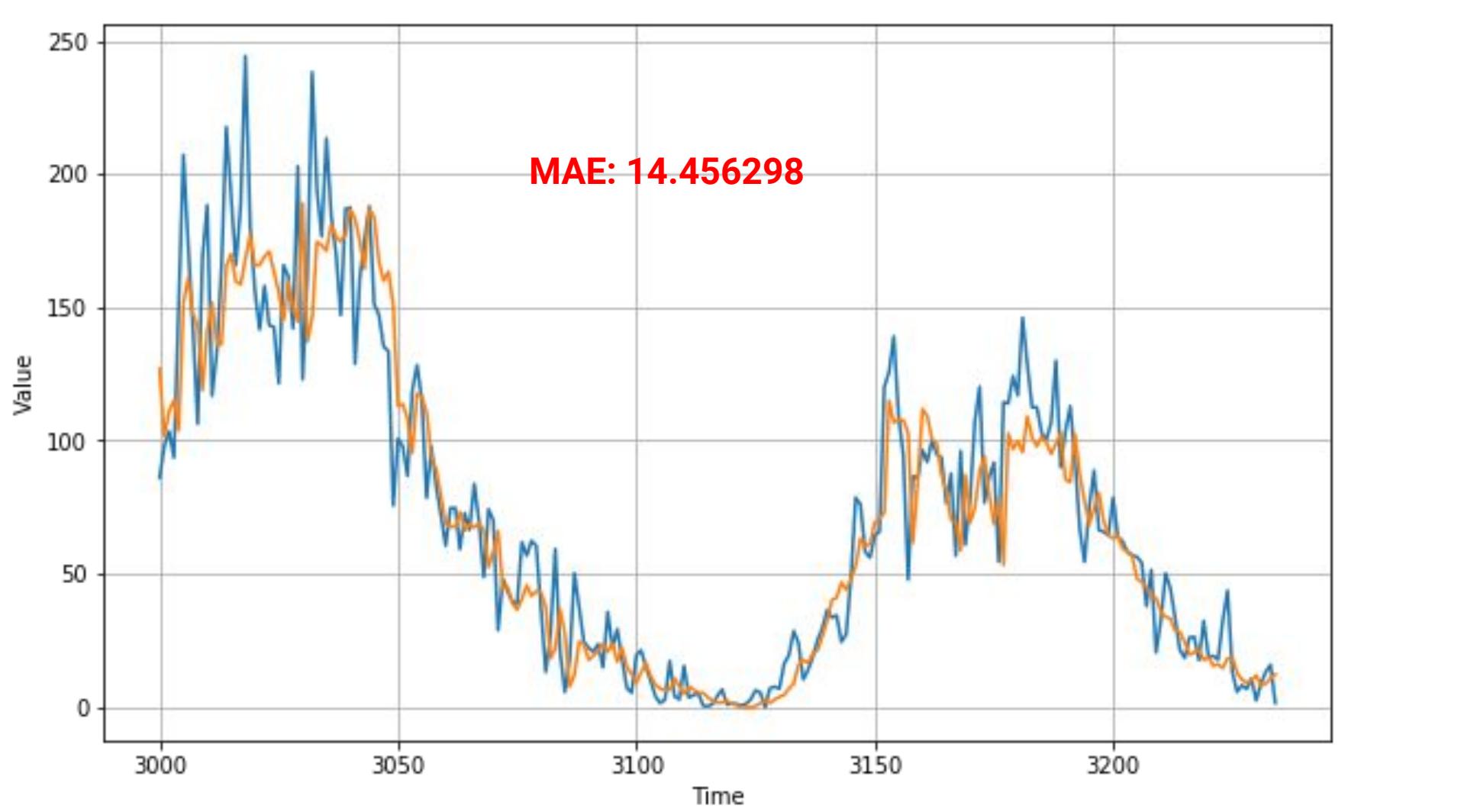


```
window_size = 60
batch_size = 64

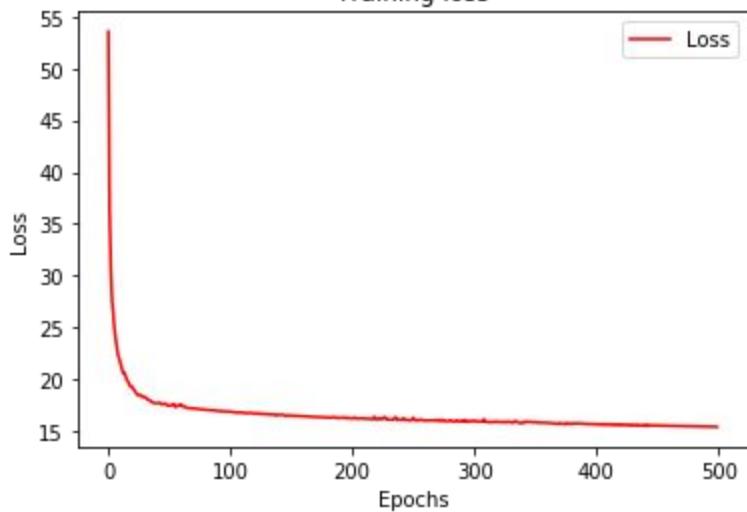
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.Conv1D(filters=32, kernel_size=5, strides=1,
                          padding="causal", activation="relu"),
    tf.keras.layers.LSTM(32, return_sequences=True),
    tf.keras.layers.LSTM(32),
    tf.keras.layers.Dense(30, activation="relu"),
    tf.keras.layers.Dense(10, activation="relu"),
    tf.keras.layers.Dense(1, activation="relu")
    tf.keras.layers.Lambda(lambda x: x * 400)
])

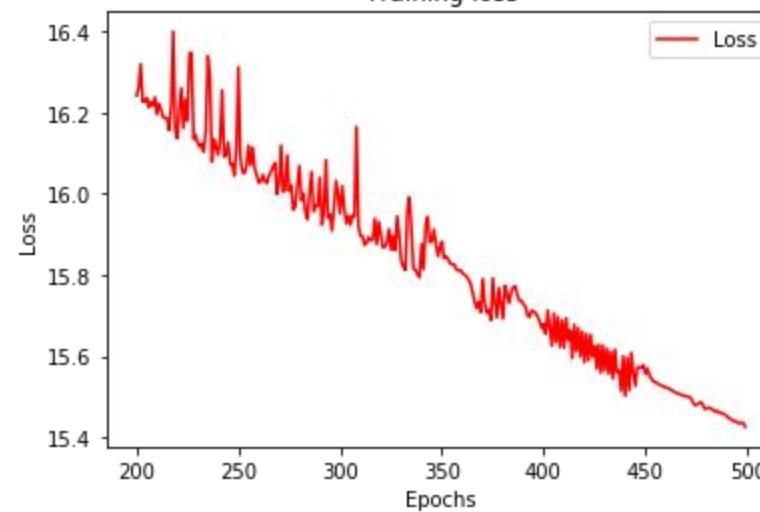
optimizer = tf.keras.optimizers.SGD(learning_rate=1e-5, momentum=0.9)
model.compile(loss=tf.keras.losses.Huber(), optimizer=optimizer, metrics=["mae"])
history = model.fit(dataset, epochs=500)
```



Training loss



Training loss

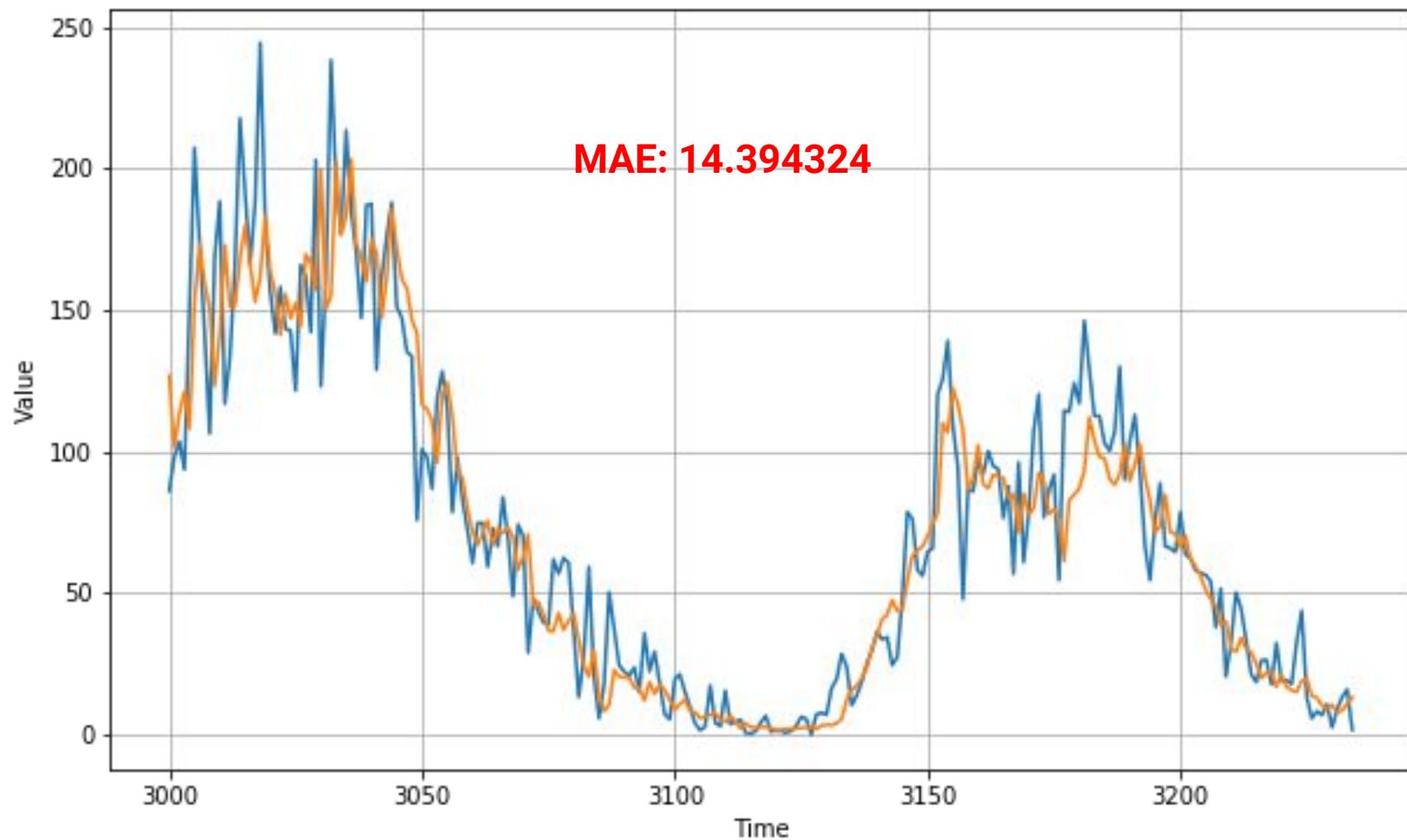


```
window_size = 60
batch_size = 256

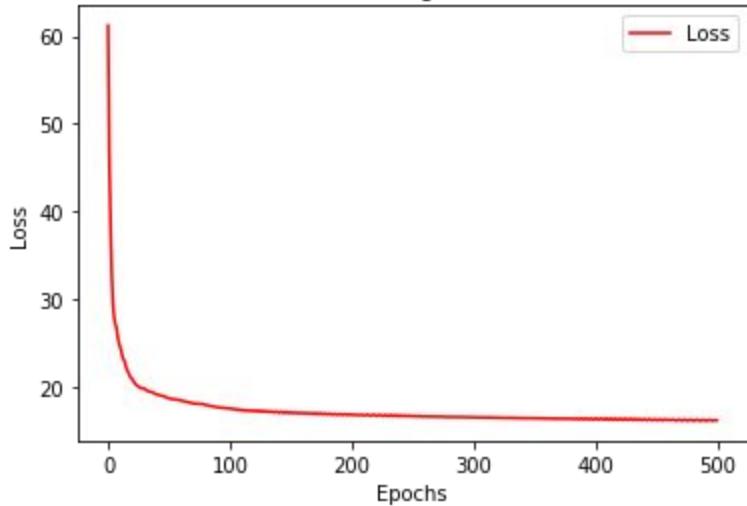
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.Conv1D(filters=32, kernel_size=5, strides=1,
                          padding="causal", activation="relu"),
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    tf.keras.layers.Lambda(lambda x: x * 400)
])

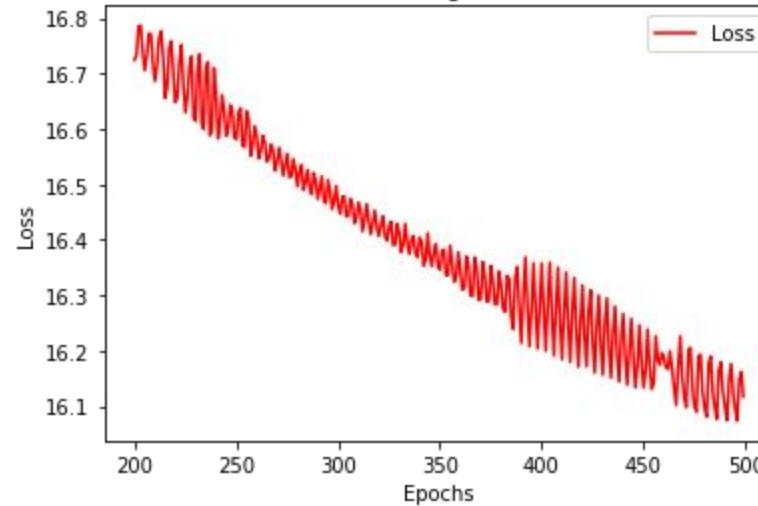
optimizer = tf.keras.optimizers.SGD(learning_rate=1e-5, momentum=0.9)
model.compile(loss=tf.keras.losses.Huber(), optimizer=optimizer, metrics=["mae"])
history = model.fit(dataset, epochs=500)
```



Training loss



Training loss



```
window_size = 60
batch_size = 250

dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.Conv1D(filters=60, kernel_size=5, strides=1,
                          padding="causal", activation="relu"),
    tf.keras.layers.LSTM(60, return_sequences=True),
    tf.keras.layers.LSTM(60),
    tf.keras.layers.Dense(30, activation="relu"),
    tf.keras.layers.Dense(10, activation="relu"),
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model.compile(loss=tf.keras.losses.Huber(), optimizer=optimizer, metrics=["mae"])
history = model.fit(dataset, epochs=500)
```

```
window_size = 60
batch_size = 250

dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.Conv1D(filters=60, kernel_size=5, strides=1,
                          padding="causal", activation="relu"),
    tf.keras.layers.LSTM(60, return_sequences=True),
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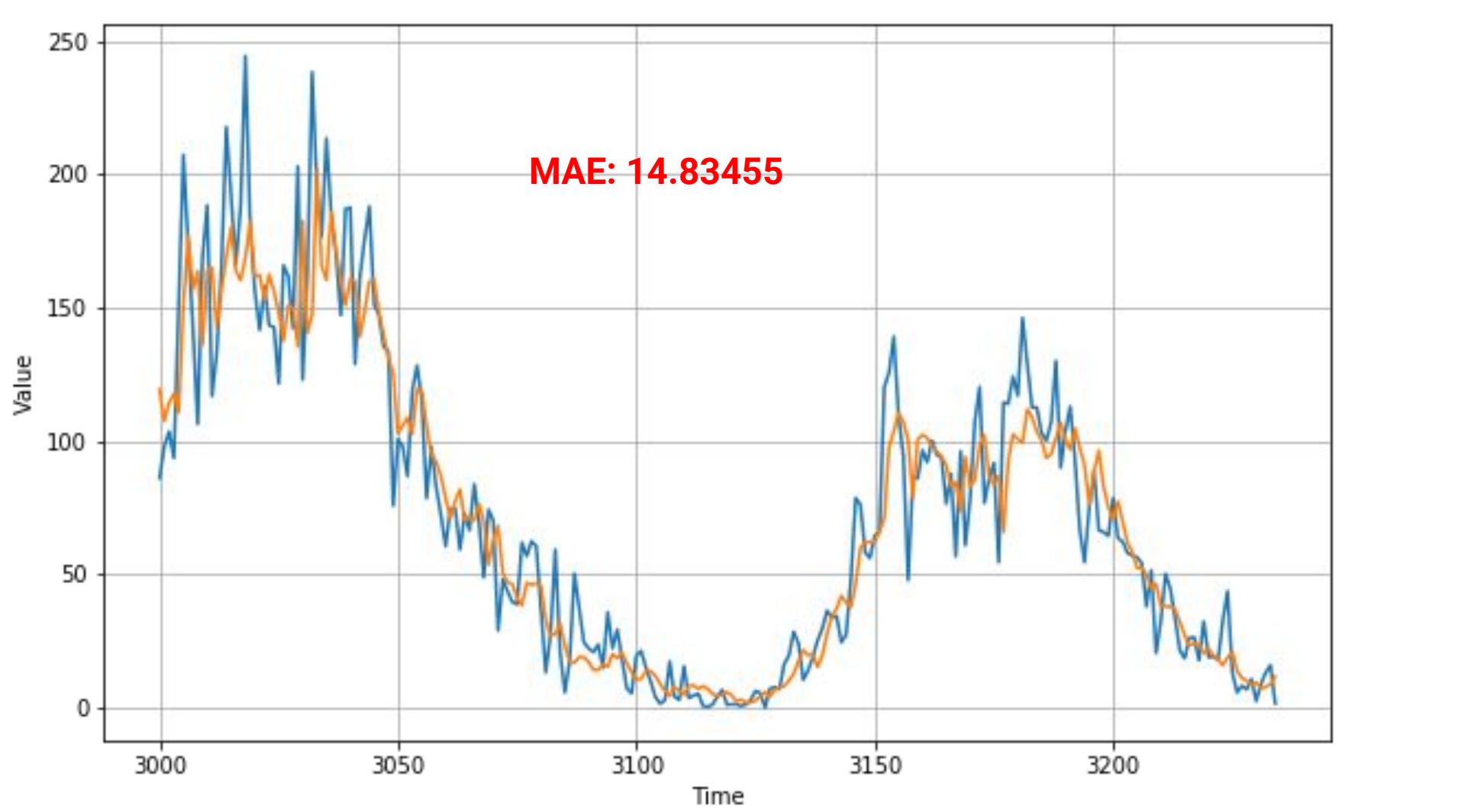
optimizer = tf.keras.optimizers.SGD(learning_rate=1e-5, momentum=0.9)
model.compile(loss=tf.keras.losses.Huber(), optimizer=optimizer, metrics=["mae"])
history = model.fit(dataset, epochs=500)
```

```
window_size = 60
batch_size = 250

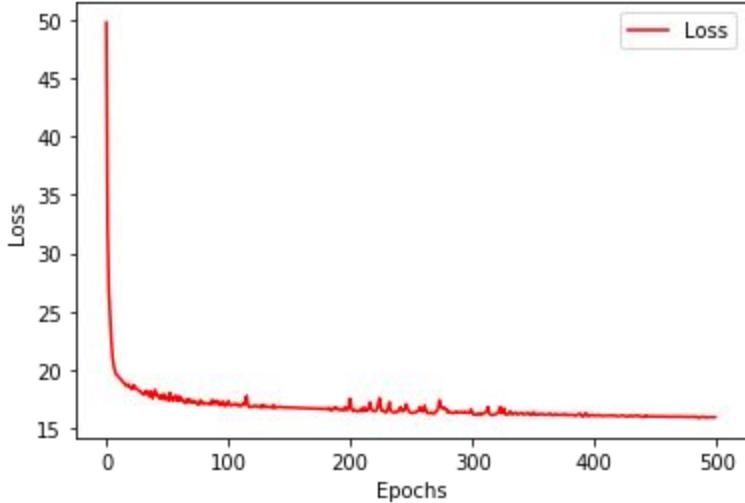
dataset = windowed_dataset(x_train, window_size, batch_size, shuffle_buffer_size)

model = tf.keras.models.Sequential([
    tf.keras.Input(shape=(window_size, 1)),
    tf.keras.layers.Conv1D(filters=60, kernel_size=5, strides=1,
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    tf.keras.layers.LSTM(60, return_sequences=True),
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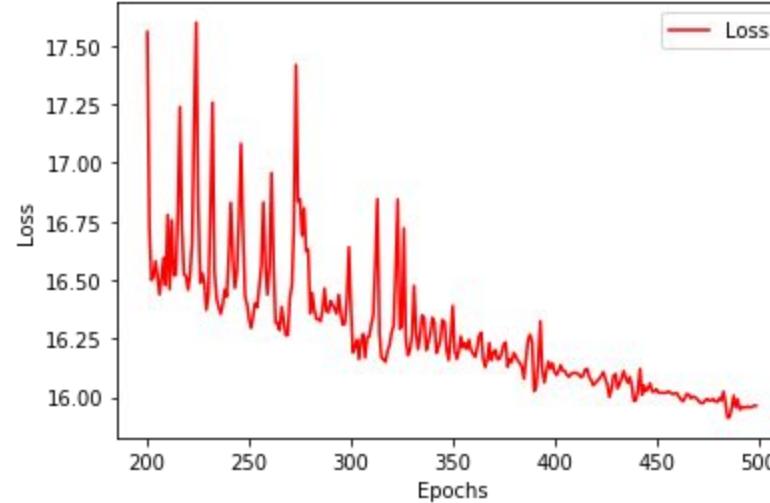
optimizer = tf.keras.optimizers.SGD(learning_rate=1e-5, momentum=0.9)
model.compile(loss=tf.keras.losses.Huber(), optimizer=optimizer, metrics=["mae"])
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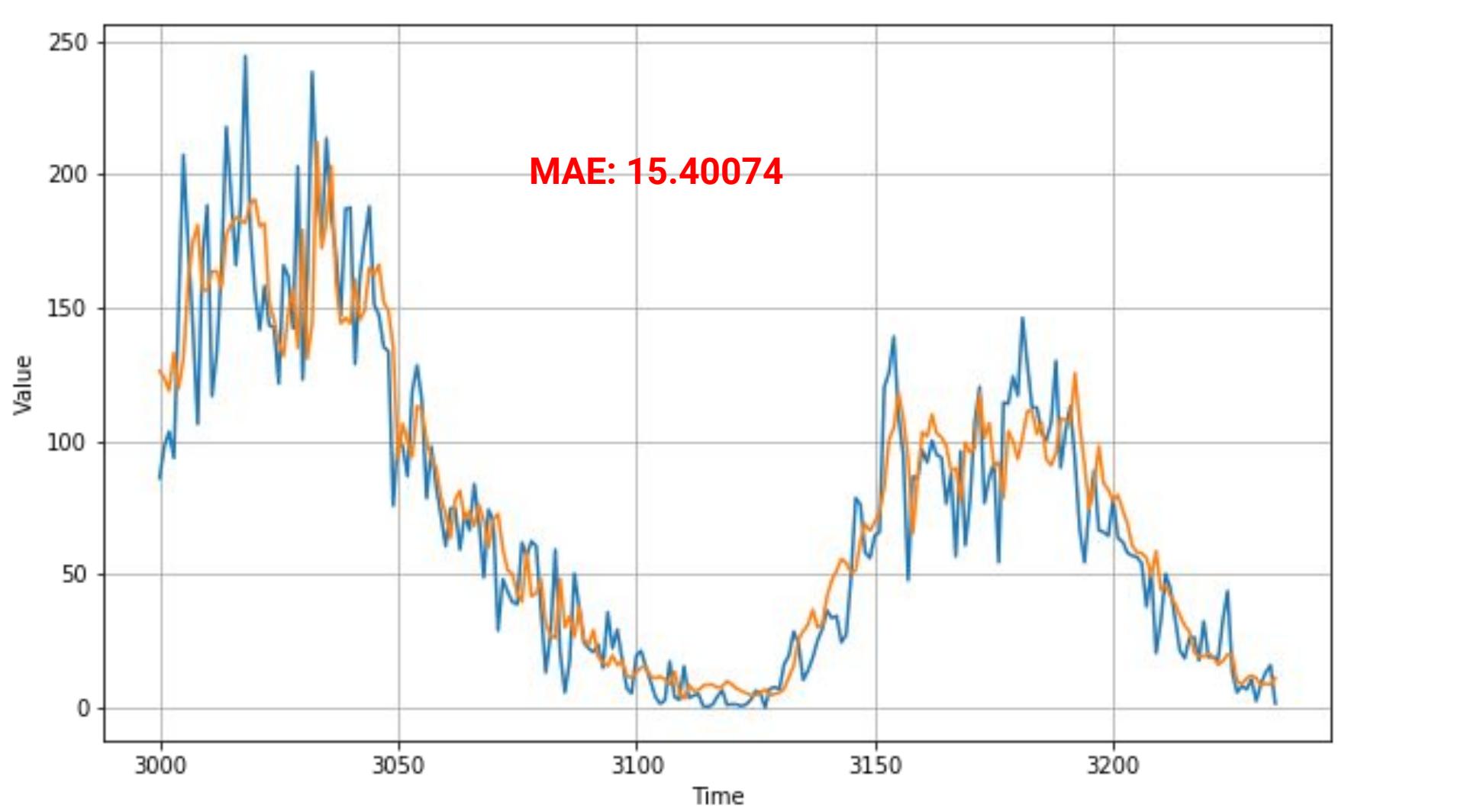


Training loss

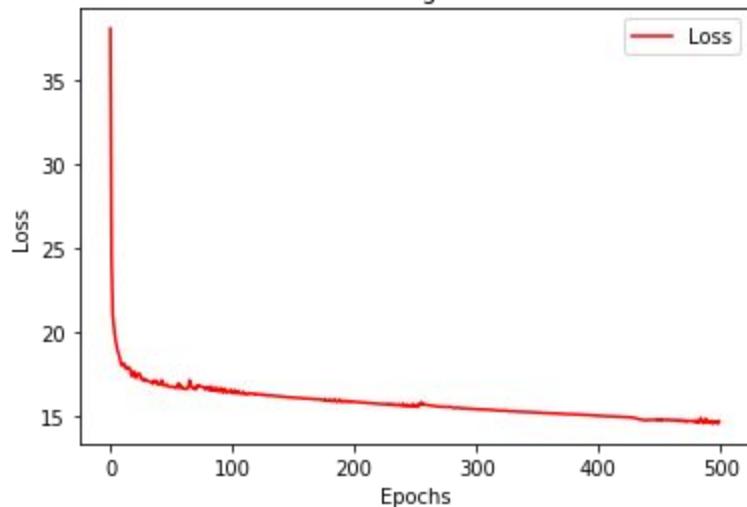


Training loss





Training loss



Training loss

