Time series prediction with LSTM (student notebook)

Neural networks like Long Short-Term Memory (LSTM) recurrent neural networks are able to almost seamlessly model problems with multiple input variables.

This is a great benefit in time series forecasting, where classical linear methods can be difficult to adapt to multivariate or multiple input forecasting problems.

In this lab, you will discover how you can develop an LSTM model for multivariate time series forecasting with the Keras deep learning library.

In [ ]:

```
"""
(Practical tip) Table of contents can be compiled directly in jupyter notebooks using the following code:
I set an exception: if the package is in your installation you can import it otherwise you download it
then import it.
"""
try:
    from jyquickhelper import add_notebook_menu
except:
    !pip install jyquickhelper
    from jyquickhelper import add_notebook_menu

"""
Output Table of contents to navigate easily in the notebook.
For interested readers, the package also includes Ipython magic commands to go back to this cell
wherever you are in the notebook to look for cells faster
"""
add_notebook_menu()
```

Out[ ]: run previous cell, wait for 2 seconds

Imports

In [ ]:

```
import ssl

ssl._create_default_https_context = ssl._create_unverified_context
```

In [ ]:
```
# plottinh
import matplotlib.pyplot as plt
import plotly.express as px
```

In [ ]:
```
# data
import math
import numpy as np
import pandas as pd
```

In [ ]:
```
# ML
import tensorflow as tf
from sklearn.compose import ColumnTransformer
from sklearn.impute import SimpleImputer
from sklearn.metrics import mean_squared_error
from sklearn.pipeline import FeatureUnion, Pipeline
from sklearn.preprocessing import MinMaxScaler, OneHotEncoder, StandardScaler
from tensorflow.keras import utils
from tensorflow.keras.callbacks import EarlyStopping, ModelCheckpoint
from tensorflow.keras.layers import (LSTM, AveragePooling1D, Bidirectional,
                                     Dense, Embedding, Flatten, Input,
                                     RepeatVector)
from tensorflow.keras.models import Model, load_model
```

LSTM network for uni-variate time series

LSTM can be used to model univariate time series forecasting problems.

These problems consist of a single set of observations and a model is needed to learn from the past set of observations in order to forecast the next value in the sequence.

We will demonstrate a number of variations of the LSTM model for univariate time series forecasting.

Be careful not to draw hasty conclusions about the relative performance of the models. The number of layers or neurons are highly variable between models.

Data preparation

A first example

Consider a given univariate sequence: `[10, 20, 30, 40, 50, 60, 70, 80, 90]`

We can divide the sequence into multiple input/output patterns called samples, where three time steps are used as input and one time step is used as output for the one-step prediction that is being learned.

```
 X,             y
10, 20, 30      40
20, 30, 40      50
30, 40, 50      60
...
```

The `series_to_supervised()` function below implements this behavior and will split a given univariate sequence into multiple samples where each sample has a specified number of time steps (`n_in, by default 3`) and the output has also a specified number of time steps (`n_out, by default 1`).

By default, the data to predict is the last columns.

In [ ]:

```
def series_to_supervised(data, n_in=3, n_out=1, output=None, dropnan=True):
    n_vars = 1 if type(data) is list else data.shape[1]
    output = [data.columns[-1]] if output is None else output
    df = pd.DataFrame(data)
    cols, names = list(), list()

    # input sequence (t-n, ... t-1)
    for i in range(n_in, 0, -1):
        cols += [df.shift(i)]
        names += [f"{col}(t-{i})" for col in data.columns]

    # forecast sequence (t, t+1, ... t+n)
    for i in range(0, n_out):
        cols += [df[output].shift(-i)]
        if i == 0:
            names += [f"{j}(t)" for j in output]
        else:
            names += [f"{j}(t+{i})" for j in output]

    # put it all together
```

```
    agg = pd.concat(cols, axis=1)
    agg.columns = names

    # drop rows with NaN values
    if dropnan:
        agg.dropna(inplace=True)
    return agg
```

TODO − Students

- create the time series mentioned in the first exemple.

In [ ]:
```
my_time_series = pd.DataFrame(list(range(10,100,10)))
my_time_series
```

Out[ ]:

	0
0	10
1	20
2	30
3	40
4	50
5	60
6	70
7	80
8	90

In [ ]:
```
data = series_to_supervised(my_time_series, n_in=3, n_out=1)
data.head()
```

Out[ ]:

	0(t-3)	0(t-2)	0(t-1)	0(t)
3	10.0	20.0	30.0	40
4	20.0	30.0	40.0	50
5	30.0	40.0	50.0	60
6	40.0	50.0	60.0	70
7	50.0	60.0	70.0	80

Head of the previous dataset

```
 0(t-3)  0(t-2)  0(t-1)  0(t)
3   0.0 10.0    20.0    30
4   10.0    20.0    30.0    40
5   20.0    30.0    40.0    50
6   30.0    40.0    50.0    60
7   40.0    50.0    60.0    70
```


Do the same for a more sophisticated series

In [ ]:

```
SIZE = 250
time_stamps = range(SIZE)

fct = lambda x: x*math.sin(x)
time_series = pd.DataFrame(data={"data":[fct(x) for x in range(SIZE)]})

n_features = my_time_series.shape[1] # for univariate time series
time_series
```

Out[ ]:

	data
0	0.000000
1	0.841471
2	1.818595
3	0.423360
4	-3.027210
...	...
245	-10.832078
246	200.922960
247	228.921375
248	45.818526
249	-181.063635

250 rows × 1 columns

TODO − Students

- Plot the time series generated thanks to x --> x*sin(x) with 250 timestamps
- label x and y axis

In [ ]:

```
# plot data
px.scatter(
    data_frame=time_series,
    y="data",
    labels={"data": "time series value", "index": "time"},
    title="Time series of y -> x.sin(x)",
)
```

TODO − Students

- Using `series_to_supervise` split data into samples with n_in = 6 and n_out = 1
- Put the result in variable data

In [ ]:
```
""" FILL """
n_in = 6
n_out = 1
data = series_to_supervised(data=time_series, n_in=n_in, n_out=n_out)
data.head()
```

Out[ ]:

	data(t-6)	data(t-5)	data(t-4)	data(t-3)	data(t-2)	data(t-1)	data(t)
6	0.000000	0.841471	1.818595	0.423360	-3.027210	-4.794621	-1.676493
7	0.841471	1.818595	0.423360	-3.027210	-4.794621	-1.676493	4.598906
8	1.818595	0.423360	-3.027210	-4.794621	-1.676493	4.598906	7.914866
9	0.423360	-3.027210	-4.794621	-1.676493	4.598906	7.914866	3.709066
10	-3.027210	-4.794621	-1.676493	4.598906	7.914866	3.709066	-5.440211

Head of the previous dataset

	data(t-6)	data(t-5)	data(t-4)	data(t-3)	data(t-2)	data(t-1)	data(t)
6	0.000000	0.841471	1.818595	0.423360	-3.027210	-4.794621	-1.676493
7	0.841471	1.818595	0.423360	-3.027210	-4.794621	-1.676493	4.598906
8	1.818595	0.423360	-3.027210	-4.794621	-1.676493	4.598906	7.914866
9	0.423360	-3.027210	-4.794621	-1.676493	4.598906	7.914866	3.709066
10	-3.027210	-4.794621	-1.676493	4.598906	7.914866	3.709066	-5.440211

Contrary to the approaches used so far, we cannot separate the data into TRAIN, VALID and TEST in a random way, since we are dealing with time series where the order is important.

The TRAIN data will therefore necessarily be at the beginning, then we will find the VALIDATION data and finally the TEST data.

Here are the chosen indices.

In [ ]:
```
testAndValid = 0.1

SPLIT = int(testAndValid*len(data))
idx_train = len(data)-2*SPLIT
```

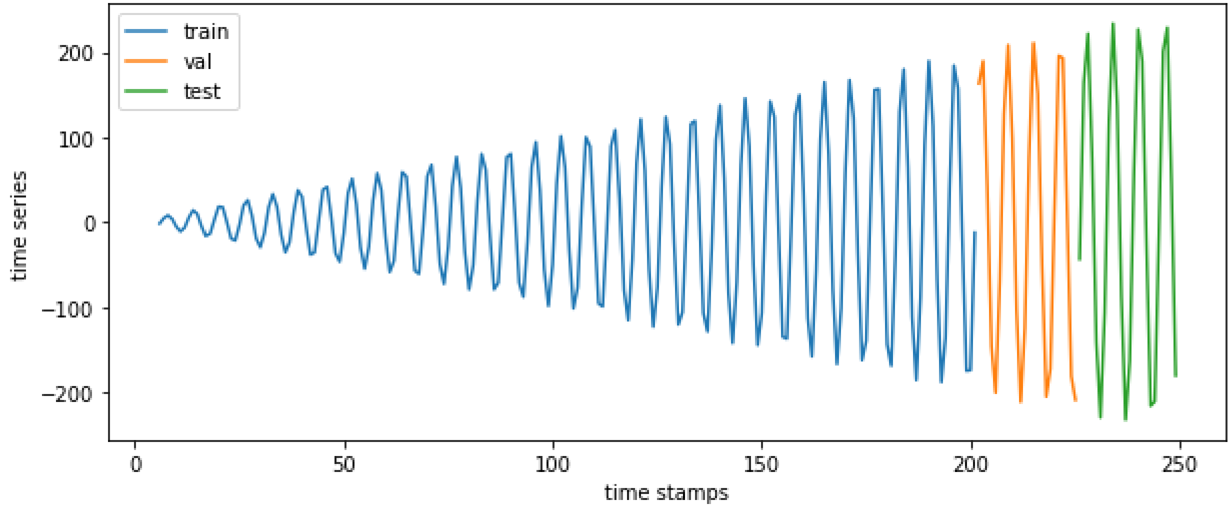
```
idx_test = len(data)-SPLIT

print(f"TRAIN=time_series[:{idx_train}]")
print(f"VALID=time_series[{idx_train}:{idx_test}]")
print(f"TEST=time_series[{idx_test}:]")

TRAIN=data[:idx_train]
VAL=data[idx_train:idx_test]
TEST=data[idx_test:]
```

```
TRAIN=time_series[:196]
VALID=time_series[196:220]
TEST=time_series[220:]
```

In [ ]:

```
plt.figure(figsize=(10, 4))
plt.plot(TRAIN["data(t)"], label="train")
plt.plot(VAL["data(t)"], label="val")
plt.plot(TEST["data(t)"], label="test")
plt.legend()
plt.xlabel("time stamps")
plt.ylabel("time series")
```

Out[ ]: Text(0, 0.5, 'time series')



TODO − Students

- complete the code for preprocessing your train/validation/test datasets.

In [ ]:

```
# split into input and outputs
train_X, train_y = TRAIN.values[:, :-n_out], TRAIN.values[:, -n_out]
val_X, val_y = VAL.values[:, :-n_out], VAL.values[:, -n_out]
test_X, test_y = TEST.values[:, :-n_out], TEST.values[:, -n_out]

# reshape input to be 3D [samples, timesteps, features]
train_X = train_X.reshape((-1, n_in, n_features))
val_X = val_X.reshape((-1, n_in, n_features))
test_X = test_X.reshape((-1, n_in, n_features))

train_X.shape, train_y.shape
```

Out[ ]:

```
((196, 6, 1), (196,))
```

train_X.shape = (196, 6, 1)

train_y.shape = (196,)

Build a first network using LSTM cells

TODO − Students

- Look carefully at the following cell
- What is the impact of the `return_sequences` parameter of the LSTM cell? (change the value: False or True and observe the shape of the output).

If `return_sequences=True` , the LSTM and the Dense layer get an extra dimension, which has value `n_in` .

In [ ]:

```
LSTM_SIZE = 16

inputs = Input(shape=(n_in, n_features))
hidden = LSTM(LSTM_SIZE, return_sequences=False, activation="relu")(inputs)
# hidden = LSTM(LSTM_SIZE, return_sequences=True, activation='relu')(inputs) # check what changing `return_sequence`
outputs = Dense(n_out, activation="linear")(hidden)
```

```
model = Model(inputs=inputs, outputs=outputs)
model.summary()
```

```
Model: "model"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 input_1 (InputLayer)        [(None, 6, 1)]            0

 lstm (LSTM)                 (None, 16)                1152

 dense (Dense)               (None, 1)                 17

=================================================================
Total params: 1,169
Trainable params: 1,169
Non-trainable params: 0
_________________________________________________________________
2022-02-03 13:20:15.360918: I tensorflow/stream_executor/cuda/cuda_gpu_executor.cc:939] successful NUMA node read fro
m SysFS had negative value (-1), but there must be at least one NUMA node, so returning NUMA node zero
2022-02-03 13:20:15.415097: W tensorflow/stream_executor/platform/default/dso_loader.cc:64] Could not load dynamic li
brary 'libcudnn.so.8'; dlerror: libcudnn.so.8: cannot open shared object file: No such file or directory
2022-02-03 13:20:15.415120: W tensorflow/core/common_runtime/gpu/gpu_device.cc:1850] Cannot dlopen some GPU librarie
s. Please make sure the missing libraries mentioned above are installed properly if you would like to use GPU. Follow
the guide at https://www.tensorflow.org/install/gpu for how to download and setup the required libraries for your pla
tform.
Skipping registering GPU devices...
2022-02-03 13:20:15.416141: I tensorflow/core/platform/cpu_feature_guard.cc:151] This TensorFlow binary is optimized
with oneAPI Deep Neural Network Library (oneDNN) to use the following CPU instructions in performance-critical operat
ions:  AVX2 FMA
To enable them in other operations, rebuild TensorFlow with the appropriate compiler flags.
```

TODO − Students

- Complete the function build_and_fit used to train your RNN model.
- compile : as usual
- fit : as usual but...
  - Be careful, you have to set the shuffle parameter to false in order to take the data in order.
  - Use the validation set to control the overfitting in the earlystopping callback

In [ ]:

```
def build_and_fit(model, X_train, y_train, X_val, y_val, X_test, y_test, patience=150, epochs=200):
```

```python
    model.compile(
        optimizer="adam",
        loss="mse",
        metrics=["mae"],
    )
    es = EarlyStopping(
        monitor="val_loss",
        patience=patience,
        verbose=1,
        restore_best_weights=True,
        mode="min",
    )
    history = model.fit(
        x=X_train,
        y=y_train,
        validation_data=(X_val, y_val),
        epochs=epochs,
        callbacks=[es],
        use_multiprocessing=True,
        workers=6,
    )  # epochs = 200
    y_pred = model.predict(X_test)

    # plot history
    plt.figure(figsize=(20, 8))

    plt.subplot(311)
    plt.plot(history.history["loss"][3:], label="loss")
    plt.plot(history.history["val_loss"][3:], label="val_loss")
    plt.legend()

    plt.subplot(312)
    plt.plot(history.history["mae"][3:], label="mae")
    plt.plot(history.history["val_mae"][3:], label="val_mae")
    plt.legend()

    plt.subplot(313)
    plt.plot(range(len(y_train)), y_train, label="train")
    plt.plot(range(len(y_train), len(y_train) + len(y_val)), y_val, label="valid")
    plt.plot(
        range(len(y_train) + len(y_val), len(y_train) + len(y_val) + len(y_pred)),
        y_test,
        label="test",
    )
```

```
    plt.plot(
        range(len(y_train) + len(y_val), len(y_train) + len(y_val) + len(y_pred)),
        y_pred,
        label="predict",
    )

    plt.legend(loc="center left")
    plt.show()

    return model


history = build_and_fit(model, train_X, train_y, val_X, val_y, test_X, test_y)
```

```
Epoch 1/200
7/7 [==============================] - 2s 59ms/step - loss: 7101.2339 - mae: 66.3495 - val_loss: 24298.4375 - val_ma
e: 142.4521
Epoch 2/200
7/7 [==============================] - 0s 8ms/step - loss: 6989.7437 - mae: 65.8553 - val_loss: 23966.7559 - val_mae:
141.4368
Epoch 3/200
7/7 [==============================] - 0s 11ms/step - loss: 6899.4243 - mae: 65.4329 - val_loss: 23673.3066 - val_ma
e: 140.5119
Epoch 4/200
7/7 [==============================] - 0s 10ms/step - loss: 6811.3877 - mae: 65.0595 - val_loss: 23411.0840 - val_ma
e: 139.6716
Epoch 5/200
7/7 [==============================] - 0s 9ms/step - loss: 6736.9980 - mae: 64.7106 - val_loss: 23156.3438 - val_mae:
138.8918
Epoch 6/200
7/7 [==============================] - 0s 13ms/step - loss: 6668.3623 - mae: 64.3808 - val_loss: 22889.9785 - val_ma
e: 138.0099
Epoch 7/200
7/7 [==============================] - 0s 11ms/step - loss: 6591.1724 - mae: 63.9740 - val_loss: 22599.0215 - val_ma
e: 137.0667
Epoch 8/200
7/7 [==============================] - 0s 14ms/step - loss: 6496.8481 - mae: 63.4771 - val_loss: 22229.4980 - val_ma
e: 135.9030
Epoch 9/200
7/7 [==============================] - 0s 10ms/step - loss: 6345.7539 - mae: 62.6829 - val_loss: 21462.8535 - val_ma
e: 133.4701
Epoch 10/200
7/7 [==============================] - 0s 12ms/step - loss: 6066.4331 - mae: 61.2305 - val_loss: 20078.3145 - val_ma
e: 128.7614
Epoch 11/200
7/7 [==============================] - 0s 10ms/step - loss: 5649.0742 - mae: 58.8348 - val_loss: 18253.3652 - val_ma
e: 121.7736
Epoch 12/200
7/7 [==============================] - 0s 11ms/step - loss: 4913.2612 - mae: 54.3636 - val_loss: 15018.2451 - val_ma
e: 107.6457
Epoch 13/200
7/7 [==============================] - 0s 8ms/step - loss: 3893.4473 - mae: 47.8118 - val_loss: 10444.9678 - val_mae:
88.7976
Epoch 14/200
7/7 [==============================] - 0s 10ms/step - loss: 2612.7014 - mae: 38.8874 - val_loss: 5874.5059 - val_mae:
64.1259
Epoch 15/200
7/7 [==============================] - 0s 10ms/step - loss: 1608.9170 - mae: 28.0861 - val_loss: 3896.5129 - val_mae:
```

```
51.1207
Epoch 16/200
7/7 [==============================] - 0s 12ms/step - loss: 782.7701 - mae: 19.9142 - val_loss: 1547.2188 - val_mae:
33.1972
Epoch 17/200
7/7 [==============================] - 0s 9ms/step - loss: 384.2574 - mae: 14.2538 - val_loss: 1167.2101 - val_mae: 2
6.5784
Epoch 18/200
7/7 [==============================] - 0s 10ms/step - loss: 270.1581 - mae: 11.3855 - val_loss: 777.2419 - val_mae: 2
0.5762
Epoch 19/200
7/7 [==============================] - 0s 9ms/step - loss: 155.1639 - mae: 8.9656 - val_loss: 315.7553 - val_mae: 14.
6766
Epoch 20/200
7/7 [==============================] - 0s 14ms/step - loss: 112.6128 - mae: 7.7363 - val_loss: 242.9045 - val_mae: 1
4.0201
Epoch 21/200
7/7 [==============================] - 0s 9ms/step - loss: 96.3965 - mae: 7.1097 - val_loss: 289.9259 - val_mae: 14.4
938
Epoch 22/200
7/7 [==============================] - 0s 8ms/step - loss: 76.9316 - mae: 6.4324 - val_loss: 344.9596 - val_mae: 16.0
441
Epoch 23/200
7/7 [==============================] - 0s 8ms/step - loss: 66.0565 - mae: 5.9564 - val_loss: 288.4574 - val_mae: 13.8
596
Epoch 24/200
7/7 [==============================] - 0s 10ms/step - loss: 57.7384 - mae: 5.6954 - val_loss: 200.7659 - val_mae: 11.
8854
Epoch 25/200
7/7 [==============================] - 0s 10ms/step - loss: 52.4524 - mae: 5.3686 - val_loss: 178.6131 - val_mae: 11.
0683
Epoch 26/200
7/7 [==============================] - 0s 8ms/step - loss: 49.5558 - mae: 5.2363 - val_loss: 142.7106 - val_mae: 10.1
592
Epoch 27/200
7/7 [==============================] - 0s 10ms/step - loss: 47.3641 - mae: 5.2076 - val_loss: 189.4663 - val_mae: 10.
8813
Epoch 28/200
7/7 [==============================] - 0s 10ms/step - loss: 43.8737 - mae: 4.9467 - val_loss: 146.1061 - val_mae: 10.
1680
Epoch 29/200
7/7 [==============================] - 0s 9ms/step - loss: 39.7621 - mae: 4.6723 - val_loss: 109.5313 - val_mae: 9.00
59
Epoch 30/200
```

```
7/7 [==============================] - 0s 8ms/step - loss: 37.7654 - mae: 4.5441 - val_loss: 106.1000 - val_mae: 8.71
90
Epoch 31/200
7/7 [==============================] - 0s 10ms/step - loss: 36.2503 - mae: 4.4601 - val_loss: 131.4766 - val_mae: 9.3
070
Epoch 32/200
7/7 [==============================] - 0s 10ms/step - loss: 35.2164 - mae: 4.3920 - val_loss: 116.8583 - val_mae: 9.1
033
Epoch 33/200
7/7 [==============================] - 0s 10ms/step - loss: 36.2437 - mae: 4.4966 - val_loss: 95.6189 - val_mae: 8.35
72
Epoch 34/200
7/7 [==============================] - 0s 11ms/step - loss: 33.8594 - mae: 4.3395 - val_loss: 108.3158 - val_mae: 8.8
975
Epoch 35/200
7/7 [==============================] - 0s 9ms/step - loss: 34.3026 - mae: 4.3682 - val_loss: 83.8716 - val_mae: 7.728
2
Epoch 36/200
7/7 [==============================] - 0s 9ms/step - loss: 30.0231 - mae: 4.0572 - val_loss: 88.2265 - val_mae: 8.011
7
Epoch 37/200
7/7 [==============================] - 0s 9ms/step - loss: 29.7190 - mae: 4.0012 - val_loss: 102.2666 - val_mae: 7.89
06
Epoch 38/200
7/7 [==============================] - 0s 9ms/step - loss: 28.6568 - mae: 3.8735 - val_loss: 78.7546 - val_mae: 7.233
2
Epoch 39/200
7/7 [==============================] - 0s 8ms/step - loss: 26.9688 - mae: 3.7989 - val_loss: 68.5760 - val_mae: 6.869
9
Epoch 40/200
7/7 [==============================] - 0s 12ms/step - loss: 26.4931 - mae: 3.7509 - val_loss: 64.3434 - val_mae: 6.57
59
Epoch 41/200
7/7 [==============================] - 0s 11ms/step - loss: 25.2542 - mae: 3.6361 - val_loss: 61.2069 - val_mae: 6.43
36
Epoch 42/200
7/7 [==============================] - 0s 11ms/step - loss: 24.5071 - mae: 3.5784 - val_loss: 59.1059 - val_mae: 6.28
26
Epoch 43/200
7/7 [==============================] - 0s 10ms/step - loss: 23.8144 - mae: 3.5171 - val_loss: 55.7903 - val_mae: 6.14
37
Epoch 44/200
7/7 [==============================] - 0s 9ms/step - loss: 23.2616 - mae: 3.4441 - val_loss: 58.8982 - val_mae: 6.370
2
```

```
Epoch 45/200
7/7 [==============================] - 0s 8ms/step - loss: 22.8991 - mae: 3.4053 - val_loss: 56.9168 - val_mae: 6.318
6
Epoch 46/200
7/7 [==============================] - 0s 10ms/step - loss: 23.1697 - mae: 3.4211 - val_loss: 49.6800 - val_mae: 5.86
78
Epoch 47/200
7/7 [==============================] - 0s 13ms/step - loss: 22.0346 - mae: 3.3474 - val_loss: 48.8839 - val_mae: 5.76
34
Epoch 48/200
7/7 [==============================] - 0s 14ms/step - loss: 21.7510 - mae: 3.2694 - val_loss: 48.4571 - val_mae: 5.75
74
Epoch 49/200
7/7 [==============================] - 0s 9ms/step - loss: 21.6661 - mae: 3.2957 - val_loss: 54.1020 - val_mae: 6.122
3
Epoch 50/200
7/7 [==============================] - 0s 11ms/step - loss: 21.6431 - mae: 3.2729 - val_loss: 45.8445 - val_mae: 5.73
08
Epoch 51/200
7/7 [==============================] - 0s 11ms/step - loss: 19.8522 - mae: 3.1754 - val_loss: 48.6131 - val_mae: 5.59
63
Epoch 52/200
7/7 [==============================] - 0s 9ms/step - loss: 19.6399 - mae: 3.1596 - val_loss: 48.7671 - val_mae: 5.812
4
Epoch 53/200
7/7 [==============================] - 0s 9ms/step - loss: 18.7511 - mae: 3.0766 - val_loss: 48.2882 - val_mae: 5.709
7
Epoch 54/200
7/7 [==============================] - 0s 9ms/step - loss: 18.4697 - mae: 3.0627 - val_loss: 58.9946 - val_mae: 5.994
1
Epoch 55/200
7/7 [==============================] - 0s 12ms/step - loss: 18.9489 - mae: 3.0837 - val_loss: 46.0864 - val_mae: 4.99
81
Epoch 56/200
7/7 [==============================] - 0s 9ms/step - loss: 17.6787 - mae: 3.0394 - val_loss: 44.9409 - val_mae: 5.236
7
Epoch 57/200
7/7 [==============================] - 0s 11ms/step - loss: 17.1148 - mae: 2.9707 - val_loss: 41.6956 - val_mae: 5.12
27
Epoch 58/200
7/7 [==============================] - 0s 8ms/step - loss: 18.0091 - mae: 3.0064 - val_loss: 41.9101 - val_mae: 5.039
1
Epoch 59/200
7/7 [==============================] - 0s 8ms/step - loss: 17.6327 - mae: 2.9115 - val_loss: 42.4102 - val_mae: 5.110
```

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7
Epoch 60/200
7/7 [==============================] - 0s 8ms/step - loss: 16.4941 - mae: 2.9283 - val_loss: 45.7992 - val_mae: 5.444
1
Epoch 61/200
7/7 [==============================] - 0s 10ms/step - loss: 15.5719 - mae: 2.7944 - val_loss: 47.9034 - val_mae: 5.45
97
Epoch 62/200
7/7 [==============================] - 0s 8ms/step - loss: 15.0956 - mae: 2.7360 - val_loss: 44.5866 - val_mae: 5.109
5
Epoch 63/200
7/7 [==============================] - 0s 10ms/step - loss: 14.9943 - mae: 2.7449 - val_loss: 45.4304 - val_mae: 5.07
82
Epoch 64/200
7/7 [==============================] - 0s 9ms/step - loss: 14.4380 - mae: 2.6735 - val_loss: 49.7746 - val_mae: 5.234
0
Epoch 65/200
7/7 [==============================] - 0s 8ms/step - loss: 14.3203 - mae: 2.6667 - val_loss: 45.3938 - val_mae: 4.895
0
Epoch 66/200
7/7 [==============================] - 0s 8ms/step - loss: 13.9592 - mae: 2.6072 - val_loss: 45.7050 - val_mae: 4.604
7
Epoch 67/200
7/7 [==============================] - 0s 8ms/step - loss: 15.2118 - mae: 2.5975 - val_loss: 44.6558 - val_mae: 4.682
1
Epoch 68/200
7/7 [==============================] - 0s 7ms/step - loss: 14.4725 - mae: 2.5383 - val_loss: 44.2135 - val_mae: 4.662
2
Epoch 69/200
7/7 [==============================] - 0s 7ms/step - loss: 13.8670 - mae: 2.6053 - val_loss: 45.0614 - val_mae: 4.587
1
Epoch 70/200
7/7 [==============================] - 0s 7ms/step - loss: 12.0359 - mae: 2.4560 - val_loss: 50.3850 - val_mae: 5.082
1
Epoch 71/200
7/7 [==============================] - 0s 8ms/step - loss: 12.1858 - mae: 2.4803 - val_loss: 42.7811 - val_mae: 4.739
1
Epoch 72/200
7/7 [==============================] - 0s 7ms/step - loss: 11.3609 - mae: 2.4045 - val_loss: 41.3613 - val_mae: 4.477
0
Epoch 73/200
7/7 [==============================] - 0s 7ms/step - loss: 10.8747 - mae: 2.3073 - val_loss: 45.0466 - val_mae: 4.765
9
Epoch 74/200
```

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7/7 [==============================] - 0s 9ms/step - loss: 10.8350 - mae: 2.3504 - val_loss: 52.8925 - val_mae: 5.481
9
Epoch 75/200
7/7 [==============================] - 0s 9ms/step - loss: 10.7354 - mae: 2.4033 - val_loss: 53.5635 - val_mae: 5.768
5
Epoch 76/200
7/7 [==============================] - 0s 8ms/step - loss: 11.0056 - mae: 2.3990 - val_loss: 45.3037 - val_mae: 5.495
4
Epoch 77/200
7/7 [==============================] - 0s 10ms/step - loss: 11.1229 - mae: 2.3756 - val_loss: 50.1381 - val_mae: 5.60
28
Epoch 78/200
7/7 [==============================] - 0s 12ms/step - loss: 10.1220 - mae: 2.3894 - val_loss: 36.5764 - val_mae: 4.31
99
Epoch 79/200
7/7 [==============================] - 0s 8ms/step - loss: 10.0316 - mae: 2.2917 - val_loss: 48.1896 - val_mae: 5.469
3
Epoch 80/200
7/7 [==============================] - 0s 7ms/step - loss: 8.9311 - mae: 2.2882 - val_loss: 47.9371 - val_mae: 5.5810
Epoch 81/200
7/7 [==============================] - 0s 7ms/step - loss: 8.4044 - mae: 2.1906 - val_loss: 35.7362 - val_mae: 4.7646
Epoch 82/200
7/7 [==============================] - 0s 8ms/step - loss: 9.1630 - mae: 2.1417 - val_loss: 43.2535 - val_mae: 5.1162
Epoch 83/200
7/7 [==============================] - 0s 7ms/step - loss: 9.5379 - mae: 2.2583 - val_loss: 42.9799 - val_mae: 4.9054
Epoch 84/200
7/7 [==============================] - 0s 9ms/step - loss: 8.8073 - mae: 2.0950 - val_loss: 33.1437 - val_mae: 4.6402
Epoch 85/200
7/7 [==============================] - 0s 9ms/step - loss: 8.6856 - mae: 2.1238 - val_loss: 31.3547 - val_mae: 4.5736
Epoch 86/200
7/7 [==============================] - 0s 25ms/step - loss: 9.5056 - mae: 2.2241 - val_loss: 54.9337 - val_mae: 5.479
0
Epoch 87/200
7/7 [==============================] - 0s 11ms/step - loss: 7.3855 - mae: 2.0591 - val_loss: 46.7825 - val_mae: 5.180
7
Epoch 88/200
7/7 [==============================] - 0s 9ms/step - loss: 16.9627 - mae: 2.7217 - val_loss: 79.4571 - val_mae: 6.556
4
Epoch 89/200
7/7 [==============================] - 0s 8ms/step - loss: 17.3256 - mae: 2.7713 - val_loss: 51.7472 - val_mae: 6.090
6
Epoch 90/200
7/7 [==============================] - 0s 8ms/step - loss: 13.5450 - mae: 2.7912 - val_loss: 36.9668 - val_mae: 5.054
2
```

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Epoch 91/200
7/7 [==============================] - 0s 8ms/step - loss: 10.3213 - mae: 2.3554 - val_loss: 26.2625 - val_mae: 4.159
2
Epoch 92/200
7/7 [==============================] - 0s 7ms/step - loss: 8.6823 - mae: 2.1743 - val_loss: 33.5126 - val_mae: 4.7135
Epoch 93/200
7/7 [==============================] - 0s 8ms/step - loss: 8.4663 - mae: 2.0711 - val_loss: 33.9089 - val_mae: 4.3671
Epoch 94/200
7/7 [==============================] - 0s 7ms/step - loss: 7.3226 - mae: 1.9484 - val_loss: 38.4329 - val_mae: 4.7251
Epoch 95/200
7/7 [==============================] - 0s 6ms/step - loss: 7.4724 - mae: 1.9903 - val_loss: 32.9663 - val_mae: 3.9388
Epoch 96/200
7/7 [==============================] - 0s 6ms/step - loss: 7.3914 - mae: 1.9236 - val_loss: 27.8066 - val_mae: 3.7104
Epoch 97/200
7/7 [==============================] - 0s 7ms/step - loss: 6.6720 - mae: 1.8450 - val_loss: 28.0270 - val_mae: 3.9102
Epoch 98/200
7/7 [==============================] - 0s 11ms/step - loss: 6.2665 - mae: 1.8015 - val_loss: 36.0762 - val_mae: 4.487
9
Epoch 99/200
7/7 [==============================] - 0s 9ms/step - loss: 6.1517 - mae: 1.7617 - val_loss: 39.1799 - val_mae: 4.7140
Epoch 100/200
7/7 [==============================] - 0s 7ms/step - loss: 5.7467 - mae: 1.7014 - val_loss: 33.8216 - val_mae: 4.4635
Epoch 101/200
7/7 [==============================] - 0s 7ms/step - loss: 5.5983 - mae: 1.7158 - val_loss: 26.8260 - val_mae: 3.9201
Epoch 102/200
7/7 [==============================] - 0s 8ms/step - loss: 5.5757 - mae: 1.7134 - val_loss: 28.1957 - val_mae: 3.8703
Epoch 103/200
7/7 [==============================] - 0s 7ms/step - loss: 5.6115 - mae: 1.7035 - val_loss: 48.5206 - val_mae: 4.4774
Epoch 104/200
7/7 [==============================] - 0s 9ms/step - loss: 5.2345 - mae: 1.6649 - val_loss: 39.4899 - val_mae: 4.5569
Epoch 105/200
7/7 [==============================] - 0s 7ms/step - loss: 4.8326 - mae: 1.6206 - val_loss: 32.6796 - val_mae: 4.3160
Epoch 106/200
7/7 [==============================] - 0s 7ms/step - loss: 4.1518 - mae: 1.5305 - val_loss: 28.8177 - val_mae: 4.0501
Epoch 107/200
7/7 [==============================] - 0s 11ms/step - loss: 5.5962 - mae: 1.6613 - val_loss: 36.5105 - val_mae: 4.355
3
Epoch 108/200
7/7 [==============================] - 0s 10ms/step - loss: 6.3159 - mae: 1.7843 - val_loss: 49.5722 - val_mae: 4.793
5
Epoch 109/200
7/7 [==============================] - 0s 10ms/step - loss: 5.9520 - mae: 1.6949 - val_loss: 36.4010 - val_mae: 4.676
2
Epoch 110/200
```

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7/7 [==============================] - 0s 10ms/step - loss: 5.7083 - mae: 1.7971 - val_loss: 31.9751 - val_mae: 4.380
2
Epoch 111/200
7/7 [==============================] - 0s 10ms/step - loss: 5.4533 - mae: 1.7729 - val_loss: 46.4696 - val_mae: 4.713
8
Epoch 112/200
7/7 [==============================] - 0s 11ms/step - loss: 5.3172 - mae: 1.7165 - val_loss: 53.5195 - val_mae: 4.986
3
Epoch 113/200
7/7 [==============================] - 0s 10ms/step - loss: 7.5595 - mae: 1.8220 - val_loss: 50.2035 - val_mae: 4.692
0
Epoch 114/200
7/7 [==============================] - 0s 10ms/step - loss: 5.6201 - mae: 1.7013 - val_loss: 40.6862 - val_mae: 4.184
3
Epoch 115/200
7/7 [==============================] - 0s 9ms/step - loss: 5.6399 - mae: 1.6738 - val_loss: 29.9518 - val_mae: 3.9230
Epoch 116/200
7/7 [==============================] - 0s 9ms/step - loss: 5.5146 - mae: 1.7650 - val_loss: 27.7507 - val_mae: 3.8339
Epoch 117/200
7/7 [==============================] - 0s 9ms/step - loss: 4.9690 - mae: 1.6536 - val_loss: 33.0390 - val_mae: 3.9233
Epoch 118/200
7/7 [==============================] - 0s 8ms/step - loss: 4.6813 - mae: 1.6114 - val_loss: 28.7472 - val_mae: 3.7722
Epoch 119/200
7/7 [==============================] - 0s 10ms/step - loss: 4.5983 - mae: 1.6087 - val_loss: 36.0049 - val_mae: 4.467
8
Epoch 120/200
7/7 [==============================] - 0s 9ms/step - loss: 4.4822 - mae: 1.5906 - val_loss: 35.0705 - val_mae: 4.3193
Epoch 121/200
7/7 [==============================] - 0s 9ms/step - loss: 3.9549 - mae: 1.4733 - val_loss: 34.6906 - val_mae: 4.3622
Epoch 122/200
7/7 [==============================] - 0s 7ms/step - loss: 5.0493 - mae: 1.5768 - val_loss: 31.1211 - val_mae: 4.0682
Epoch 123/200
7/7 [==============================] - 0s 7ms/step - loss: 4.3560 - mae: 1.5350 - val_loss: 33.7785 - val_mae: 4.3678
Epoch 124/200
7/7 [==============================] - 0s 7ms/step - loss: 4.3918 - mae: 1.5496 - val_loss: 29.3986 - val_mae: 3.9939
Epoch 125/200
7/7 [==============================] - 0s 8ms/step - loss: 4.1205 - mae: 1.4914 - val_loss: 29.9126 - val_mae: 4.0323
Epoch 126/200
7/7 [==============================] - 0s 10ms/step - loss: 4.0537 - mae: 1.4684 - val_loss: 28.9357 - val_mae: 3.845
2
Epoch 127/200
7/7 [==============================] - 0s 12ms/step - loss: 3.7913 - mae: 1.4243 - val_loss: 25.5160 - val_mae: 3.745
4
Epoch 128/200
```

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7/7 [==============================] - 0s 10ms/step - loss: 3.9974 - mae: 1.4413 - val_loss: 29.1982 - val_mae: 3.838
8
Epoch 129/200
7/7 [==============================] - 0s 11ms/step - loss: 3.7379 - mae: 1.3807 - val_loss: 32.0305 - val_mae: 4.274
9
Epoch 130/200
7/7 [==============================] - 0s 10ms/step - loss: 3.7784 - mae: 1.4161 - val_loss: 28.2094 - val_mae: 4.023
3
Epoch 131/200
7/7 [==============================] - 0s 10ms/step - loss: 3.5770 - mae: 1.3646 - val_loss: 28.0322 - val_mae: 3.931
5
Epoch 132/200
7/7 [==============================] - 0s 9ms/step - loss: 3.4896 - mae: 1.3301 - val_loss: 29.8695 - val_mae: 4.0209
Epoch 133/200
7/7 [==============================] - 0s 10ms/step - loss: 3.4030 - mae: 1.3208 - val_loss: 31.7993 - val_mae: 4.074
8
Epoch 134/200
7/7 [==============================] - 0s 10ms/step - loss: 3.3661 - mae: 1.3135 - val_loss: 34.1051 - val_mae: 4.112
4
Epoch 135/200
7/7 [==============================] - 0s 9ms/step - loss: 3.6873 - mae: 1.3486 - val_loss: 38.4753 - val_mae: 4.2959
Epoch 136/200
7/7 [==============================] - 0s 11ms/step - loss: 3.3977 - mae: 1.3161 - val_loss: 33.6548 - val_mae: 4.343
9
Epoch 137/200
7/7 [==============================] - 0s 10ms/step - loss: 3.3508 - mae: 1.3302 - val_loss: 30.6705 - val_mae: 4.038
0
Epoch 138/200
7/7 [==============================] - 0s 9ms/step - loss: 3.4915 - mae: 1.3447 - val_loss: 27.7591 - val_mae: 3.9847
Epoch 139/200
7/7 [==============================] - 0s 13ms/step - loss: 3.4087 - mae: 1.3412 - val_loss: 44.3582 - val_mae: 4.721
7
Epoch 140/200
7/7 [==============================] - 0s 7ms/step - loss: 3.5357 - mae: 1.3730 - val_loss: 41.7926 - val_mae: 4.6407
Epoch 141/200
7/7 [==============================] - 0s 8ms/step - loss: 3.4830 - mae: 1.3557 - val_loss: 34.9098 - val_mae: 4.0370
Epoch 142/200
7/7 [==============================] - 0s 8ms/step - loss: 6.1829 - mae: 1.5946 - val_loss: 36.3935 - val_mae: 4.6320
Epoch 143/200
7/7 [==============================] - 0s 7ms/step - loss: 7.1935 - mae: 1.7904 - val_loss: 38.0534 - val_mae: 4.2747
Epoch 144/200
7/7 [==============================] - 0s 8ms/step - loss: 11.5612 - mae: 1.9954 - val_loss: 56.6439 - val_mae: 4.711
9
Epoch 145/200
```

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7/7 [==============================] - 0s 7ms/step - loss: 8.8928 - mae: 1.9227 - val_loss: 33.4276 - val_mae: 4.4201
Epoch 146/200
7/7 [==============================] - 0s 10ms/step - loss: 5.3550 - mae: 1.6260 - val_loss: 33.7168 - val_mae: 4.284
4
Epoch 147/200
7/7 [==============================] - 0s 10ms/step - loss: 4.4125 - mae: 1.5422 - val_loss: 39.2856 - val_mae: 4.672
2
Epoch 148/200
7/7 [==============================] - 0s 10ms/step - loss: 3.7618 - mae: 1.4459 - val_loss: 35.3516 - val_mae: 3.862
0
Epoch 149/200
7/7 [==============================] - 0s 10ms/step - loss: 3.4776 - mae: 1.3895 - val_loss: 38.0018 - val_mae: 4.218
9
Epoch 150/200
7/7 [==============================] - 0s 9ms/step - loss: 3.1651 - mae: 1.3158 - val_loss: 36.1256 - val_mae: 4.0708
Epoch 151/200
7/7 [==============================] - 0s 9ms/step - loss: 2.9425 - mae: 1.2490 - val_loss: 31.4520 - val_mae: 4.1466
Epoch 152/200
7/7 [==============================] - 0s 11ms/step - loss: 2.8963 - mae: 1.2400 - val_loss: 28.8358 - val_mae: 3.716
3
Epoch 153/200
7/7 [==============================] - 0s 8ms/step - loss: 2.9236 - mae: 1.2399 - val_loss: 31.0430 - val_mae: 4.0161
Epoch 154/200
7/7 [==============================] - 0s 10ms/step - loss: 2.8540 - mae: 1.2468 - val_loss: 32.1124 - val_mae: 4.080
8
Epoch 155/200
7/7 [==============================] - 0s 10ms/step - loss: 2.6418 - mae: 1.1886 - val_loss: 28.9226 - val_mae: 3.744
7
Epoch 156/200
7/7 [==============================] - 0s 10ms/step - loss: 2.5605 - mae: 1.1775 - val_loss: 30.2327 - val_mae: 3.869
8
Epoch 157/200
7/7 [==============================] - 0s 9ms/step - loss: 2.5323 - mae: 1.1516 - val_loss: 29.8700 - val_mae: 3.7682
Epoch 158/200
7/7 [==============================] - 0s 8ms/step - loss: 2.8390 - mae: 1.2095 - val_loss: 31.6022 - val_mae: 4.0290
Epoch 159/200
7/7 [==============================] - 0s 9ms/step - loss: 2.5094 - mae: 1.1491 - val_loss: 28.6799 - val_mae: 3.8032
Epoch 160/200
7/7 [==============================] - 0s 8ms/step - loss: 2.7966 - mae: 1.2047 - val_loss: 27.7331 - val_mae: 3.8279
Epoch 161/200
7/7 [==============================] - 0s 8ms/step - loss: 8.9006 - mae: 1.7766 - val_loss: 41.6184 - val_mae: 4.3679
Epoch 162/200
7/7 [==============================] - 0s 6ms/step - loss: 7.5542 - mae: 1.7025 - val_loss: 34.9263 - val_mae: 4.1597
Epoch 163/200
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7/7 [==============================] - 0s 8ms/step - loss: 4.8766 - mae: 1.6183 - val_loss: 29.6338 - val_mae: 4.2015
Epoch 164/200
7/7 [==============================] - 0s 7ms/step - loss: 5.9070 - mae: 1.7097 - val_loss: 28.6029 - val_mae: 4.1496
Epoch 165/200
7/7 [==============================] - 0s 8ms/step - loss: 4.6595 - mae: 1.5544 - val_loss: 46.3514 - val_mae: 4.8248
Epoch 166/200
7/7 [==============================] - 0s 7ms/step - loss: 5.1202 - mae: 1.5687 - val_loss: 35.6553 - val_mae: 4.3970
Epoch 167/200
7/7 [==============================] - 0s 8ms/step - loss: 4.0233 - mae: 1.5179 - val_loss: 47.7748 - val_mae: 4.6228
Epoch 168/200
7/7 [==============================] - 0s 8ms/step - loss: 4.4438 - mae: 1.4313 - val_loss: 34.8889 - val_mae: 3.9728
Epoch 169/200
7/7 [==============================] - 0s 9ms/step - loss: 4.6338 - mae: 1.5487 - val_loss: 37.2709 - val_mae: 4.3945
Epoch 170/200
7/7 [==============================] - 0s 8ms/step - loss: 4.2272 - mae: 1.4478 - val_loss: 38.5795 - val_mae: 4.5106
Epoch 171/200
7/7 [==============================] - 0s 7ms/step - loss: 2.7132 - mae: 1.2046 - val_loss: 27.8951 - val_mae: 3.9933
Epoch 172/200
7/7 [==============================] - 0s 8ms/step - loss: 2.7227 - mae: 1.1918 - val_loss: 28.0220 - val_mae: 3.7662
Epoch 173/200
7/7 [==============================] - 0s 9ms/step - loss: 2.7252 - mae: 1.1843 - val_loss: 28.1490 - val_mae: 3.7318
Epoch 174/200
7/7 [==============================] - 0s 8ms/step - loss: 2.4338 - mae: 1.1105 - val_loss: 29.2231 - val_mae: 3.9123
Epoch 175/200
7/7 [==============================] - 0s 7ms/step - loss: 2.5544 - mae: 1.1652 - val_loss: 33.5721 - val_mae: 4.2534
Epoch 176/200
7/7 [==============================] - 0s 8ms/step - loss: 2.7380 - mae: 1.1907 - val_loss: 26.9158 - val_mae: 3.7710
Epoch 177/200
7/7 [==============================] - 0s 8ms/step - loss: 3.1910 - mae: 1.2711 - val_loss: 35.7935 - val_mae: 4.0757
Epoch 178/200
7/7 [==============================] - 0s 8ms/step - loss: 2.9700 - mae: 1.2780 - val_loss: 38.8904 - val_mae: 4.4066
Epoch 179/200
7/7 [==============================] - 0s 7ms/step - loss: 2.8059 - mae: 1.1984 - val_loss: 33.5945 - val_mae: 3.9510
Epoch 180/200
7/7 [==============================] - 0s 8ms/step - loss: 3.4127 - mae: 1.3503 - val_loss: 31.9517 - val_mae: 3.9908
Epoch 181/200
7/7 [==============================] - 0s 8ms/step - loss: 4.5018 - mae: 1.4330 - val_loss: 33.1217 - val_mae: 4.1157
Epoch 182/200
7/7 [==============================] - 0s 7ms/step - loss: 2.8797 - mae: 1.2641 - val_loss: 33.6574 - val_mae: 3.9053
Epoch 183/200
7/7 [==============================] - 0s 8ms/step - loss: 2.5367 - mae: 1.1886 - val_loss: 27.2624 - val_mae: 3.8120
Epoch 184/200
7/7 [==============================] - 0s 7ms/step - loss: 2.5451 - mae: 1.1640 - val_loss: 26.9461 - val_mae: 3.6794
Epoch 185/200
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7/7 [==============================] - 0s 7ms/step - loss: 2.3314 - mae: 1.1188 - val_loss: 38.5144 - val_mae: 4.3539
Epoch 186/200
7/7 [==============================] - 0s 7ms/step - loss: 2.7086 - mae: 1.2086 - val_loss: 30.2528 - val_mae: 3.8829
Epoch 187/200
7/7 [==============================] - 0s 7ms/step - loss: 2.5874 - mae: 1.1802 - val_loss: 27.2228 - val_mae: 3.8976
Epoch 188/200
7/7 [==============================] - 0s 7ms/step - loss: 2.4728 - mae: 1.1779 - val_loss: 29.9828 - val_mae: 3.9550
Epoch 189/200
7/7 [==============================] - 0s 8ms/step - loss: 2.4341 - mae: 1.1095 - val_loss: 29.4395 - val_mae: 3.8486
Epoch 190/200
7/7 [==============================] - 0s 7ms/step - loss: 2.5250 - mae: 1.0624 - val_loss: 28.7487 - val_mae: 3.8723
Epoch 191/200
7/7 [==============================] - 0s 8ms/step - loss: 2.6290 - mae: 1.1556 - val_loss: 27.1314 - val_mae: 3.8748
Epoch 192/200
7/7 [==============================] - 0s 7ms/step - loss: 2.3730 - mae: 1.1115 - val_loss: 25.2785 - val_mae: 3.7124
Epoch 193/200
7/7 [==============================] - 0s 7ms/step - loss: 2.0672 - mae: 1.0218 - val_loss: 32.8661 - val_mae: 3.8784
Epoch 194/200
7/7 [==============================] - 0s 7ms/step - loss: 2.3650 - mae: 1.0994 - val_loss: 21.9754 - val_mae: 3.4155
Epoch 195/200
7/7 [==============================] - 0s 7ms/step - loss: 2.5299 - mae: 1.1224 - val_loss: 25.3838 - val_mae: 3.6555
Epoch 196/200
7/7 [==============================] - 0s 8ms/step - loss: 2.5131 - mae: 1.1328 - val_loss: 31.5744 - val_mae: 4.0327
Epoch 197/200
7/7 [==============================] - 0s 8ms/step - loss: 2.4467 - mae: 1.0912 - val_loss: 32.0520 - val_mae: 4.0738
Epoch 198/200
7/7 [==============================] - 0s 8ms/step - loss: 2.5839 - mae: 1.1118 - val_loss: 29.6312 - val_mae: 4.0737
Epoch 199/200
7/7 [==============================] - 0s 8ms/step - loss: 2.3210 - mae: 1.0653 - val_loss: 22.8936 - val_mae: 3.5098
Epoch 200/200
7/7 [==============================] - 0s 10ms/step - loss: 2.1198 - mae: 1.0358 - val_loss: 25.7987 - val_mae: 3.585
0
```
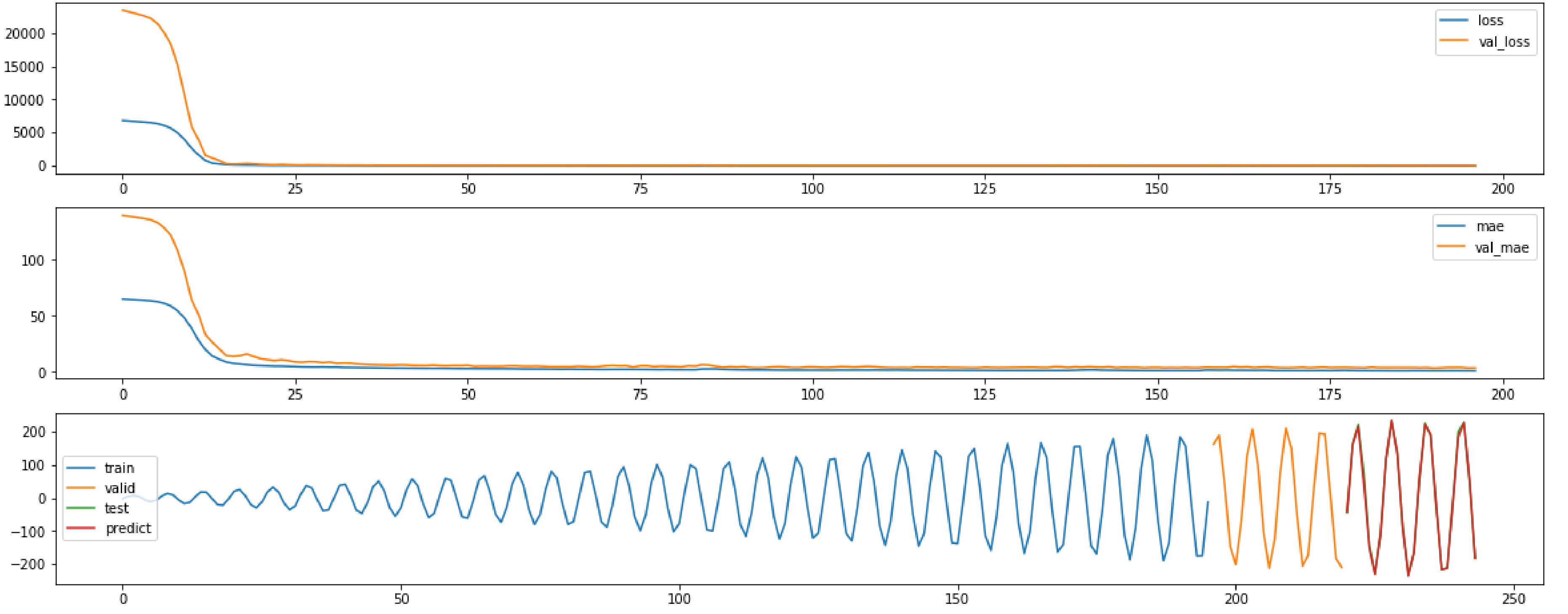



In [ ]:

```
# demonstrate prediction
start = 12
y_true = (start + n_in) * (start + n_in)
x_input = np.array([fct(x) for x in range(start, start + n_in)])
x_input = x_input.reshape((1, n_in, n_features))
yhat = model.predict(x_input, verbose=0)
print(yhat, y_true)
```

```
[[-12.219949]] 324
```

Stacked Bi-LSTM

In order to improve the performance of the model, it's possible to:

- stack LSTM with `return_sequence=True` for all levels except the last one where `return_sequence=False`
- use Bi-LSTM

TODO − Students

- Build a model stacking 3 BI-LSTM layers

In [ ]:
```
inputs = Input(shape=(n_in, n_features))
bi_lstm1 = Bidirectional(
    layer=LSTM(
        units=LSTM_SIZE,
        return_sequences=True,
        activation="relu",
    )
)(inputs)

bi_lstm2 = Bidirectional(
    layer=LSTM(
        units=LSTM_SIZE,
        return_sequences=True,
        activation="relu",
    )
)(bi_lstm1)

bi_lstm3 = Bidirectional(
    layer=LSTM(
        units=LSTM_SIZE,
        return_sequences=False,
        activation="relu",
    )
)(bi_lstm2)
outputs = Dense(n_out, activation="linear")(bi_lstm3)
model = Model(inputs=inputs, outputs=outputs)
model.summary()
# Bidirectional(LSTM(LSTM_SIZE, return_sequences=True, activation='relu'))
```

```
Model: "model_1"
_________________________________________________________________
 Layer (type)                Output Shape              Param #   
=================================================================
 input_2 (InputLayer)        [(None, 6, 1)]            0         
                                                                 
 bidirectional (Bidirectiona  (None, 6, 32)            2304      
 l)                                                              
                                                                 
 bidirectional_1 (Bidirectio  (None, 6, 32)            6272      
 nal)                                                            
                                                                 
 bidirectional_2 (Bidirectio  (None, 32)               6272      
 nal)                                                            
                                                                 
 dense_1 (Dense)             (None, 1)                 33        
                                                                 
=================================================================
Total params: 14,881
Trainable params: 14,881
Non-trainable params: 0
_________________________________________________________________
```

In [ ]:

```
model = build_and_fit(model, train_X, train_y, val_X, val_y, test_X, test_y)
```

```
Epoch 1/200
7/7 [==============================] - 5s 115ms/step - loss: 6852.0498 - mae: 65.3581 - val_loss: 23325.4219 - val_ma
e: 138.8743
Epoch 2/200
7/7 [==============================] - 0s 13ms/step - loss: 6766.2549 - mae: 64.9611 - val_loss: 22937.2168 - val_ma
e: 137.6566
Epoch 3/200
7/7 [==============================] - 0s 13ms/step - loss: 6649.4458 - mae: 64.4194 - val_loss: 22157.9434 - val_ma
e: 135.2447
Epoch 4/200
7/7 [==============================] - 0s 13ms/step - loss: 6387.9141 - mae: 63.1555 - val_loss: 20624.8672 - val_ma
e: 130.3098
Epoch 5/200
7/7 [==============================] - 0s 14ms/step - loss: 5837.9233 - mae: 60.5187 - val_loss: 17793.7324 - val_ma
e: 120.2873
Epoch 6/200
7/7 [==============================] - 0s 14ms/step - loss: 4605.4194 - mae: 53.6145 - val_loss: 11505.5312 - val_ma
e: 94.8881
Epoch 7/200
7/7 [==============================] - 0s 14ms/step - loss: 2651.3960 - mae: 38.5482 - val_loss: 4805.0859 - val_mae:
56.1267
Epoch 8/200
7/7 [==============================] - 0s 14ms/step - loss: 1310.5723 - mae: 25.9977 - val_loss: 3475.1003 - val_mae:
46.2576
Epoch 9/200
7/7 [==============================] - 0s 13ms/step - loss: 711.6000 - mae: 18.8495 - val_loss: 2052.6755 - val_mae:
34.7541
Epoch 10/200
7/7 [==============================] - 0s 14ms/step - loss: 327.6907 - mae: 12.8462 - val_loss: 946.1776 - val_mae: 2
5.4910
Epoch 11/200
7/7 [==============================] - 0s 13ms/step - loss: 140.7849 - mae: 8.4317 - val_loss: 435.8086 - val_mae: 1
6.4811
Epoch 12/200
7/7 [==============================] - 0s 14ms/step - loss: 137.4184 - mae: 7.7849 - val_loss: 403.6886 - val_mae: 1
5.8728
Epoch 13/200
7/7 [==============================] - 0s 14ms/step - loss: 100.2583 - mae: 7.3596 - val_loss: 308.3312 - val_mae: 1
5.0106
Epoch 14/200
7/7 [==============================] - 0s 13ms/step - loss: 91.5998 - mae: 6.5167 - val_loss: 342.9456 - val_mae: 14.
7394
Epoch 15/200
7/7 [==============================] - 0s 13ms/step - loss: 47.8356 - mae: 5.1606 - val_loss: 407.1275 - val_mae: 16.
```

```
1669
Epoch 16/200
7/7 [==============================] - 0s 13ms/step - loss: 46.0105 - mae: 4.8805 - val_loss: 610.6370 - val_mae: 18.
5364
Epoch 17/200
7/7 [==============================] - 0s 13ms/step - loss: 45.9449 - mae: 5.0061 - val_loss: 258.2818 - val_mae: 13.
4511
Epoch 18/200
7/7 [==============================] - 0s 14ms/step - loss: 30.0888 - mae: 4.3209 - val_loss: 153.1507 - val_mae: 9.3
899
Epoch 19/200
7/7 [==============================] - 0s 13ms/step - loss: 25.1200 - mae: 3.7207 - val_loss: 121.9400 - val_mae: 9.0
771
Epoch 20/200
7/7 [==============================] - 0s 13ms/step - loss: 15.9194 - mae: 2.9536 - val_loss: 133.0031 - val_mae: 8.8
203
Epoch 21/200
7/7 [==============================] - 0s 14ms/step - loss: 12.5748 - mae: 2.7188 - val_loss: 120.3429 - val_mae: 9.2
620
Epoch 22/200
7/7 [==============================] - 0s 13ms/step - loss: 13.7891 - mae: 2.7277 - val_loss: 124.0865 - val_mae: 9.2
082
Epoch 23/200
7/7 [==============================] - 0s 14ms/step - loss: 10.2510 - mae: 2.4222 - val_loss: 114.9563 - val_mae: 8.6
526
Epoch 24/200
7/7 [==============================] - 0s 14ms/step - loss: 6.8400 - mae: 2.0106 - val_loss: 100.1074 - val_mae: 8.05
09
Epoch 25/200
7/7 [==============================] - 0s 13ms/step - loss: 6.5647 - mae: 1.9924 - val_loss: 121.0947 - val_mae: 8.64
02
Epoch 26/200
7/7 [==============================] - 0s 13ms/step - loss: 5.4268 - mae: 1.7786 - val_loss: 115.7363 - val_mae: 8.19
55
Epoch 27/200
7/7 [==============================] - 0s 13ms/step - loss: 6.6613 - mae: 1.9332 - val_loss: 100.3828 - val_mae: 7.42
00
Epoch 28/200
7/7 [==============================] - 0s 14ms/step - loss: 5.7132 - mae: 1.7934 - val_loss: 98.2480 - val_mae: 7.744
1
Epoch 29/200
7/7 [==============================] - 0s 14ms/step - loss: 5.3257 - mae: 1.7288 - val_loss: 98.2294 - val_mae: 7.834
1
Epoch 30/200
```

```
7/7 [==============================] - 0s 13ms/step - loss: 4.8171 - mae: 1.5966 - val_loss: 104.3664 - val_mae: 7.42
44
Epoch 31/200
7/7 [==============================] - 0s 14ms/step - loss: 4.7194 - mae: 1.5797 - val_loss: 96.0026 - val_mae: 7.491
5
Epoch 32/200
7/7 [==============================] - 0s 14ms/step - loss: 4.0700 - mae: 1.5051 - val_loss: 87.2695 - val_mae: 7.264
3
Epoch 33/200
7/7 [==============================] - 0s 14ms/step - loss: 3.6121 - mae: 1.4091 - val_loss: 86.8148 - val_mae: 7.055
0
Epoch 34/200
7/7 [==============================] - 0s 14ms/step - loss: 3.8904 - mae: 1.3833 - val_loss: 79.8419 - val_mae: 6.915
0
Epoch 35/200
7/7 [==============================] - 0s 14ms/step - loss: 3.2450 - mae: 1.2926 - val_loss: 77.8456 - val_mae: 6.810
3
Epoch 36/200
7/7 [==============================] - 0s 13ms/step - loss: 3.0118 - mae: 1.2608 - val_loss: 79.0442 - val_mae: 6.776
6
Epoch 37/200
7/7 [==============================] - 0s 14ms/step - loss: 3.0114 - mae: 1.2535 - val_loss: 74.9496 - val_mae: 6.940
5
Epoch 38/200
7/7 [==============================] - 0s 13ms/step - loss: 2.9263 - mae: 1.2899 - val_loss: 72.3818 - val_mae: 6.943
0
Epoch 39/200
7/7 [==============================] - 0s 13ms/step - loss: 3.3308 - mae: 1.2803 - val_loss: 72.4922 - val_mae: 6.806
3
Epoch 40/200
7/7 [==============================] - 0s 13ms/step - loss: 3.0688 - mae: 1.2660 - val_loss: 76.6441 - val_mae: 7.068
7
Epoch 41/200
7/7 [==============================] - 0s 13ms/step - loss: 2.5934 - mae: 1.1817 - val_loss: 78.2778 - val_mae: 7.048
4
Epoch 42/200
7/7 [==============================] - 0s 13ms/step - loss: 1.9267 - mae: 1.0127 - val_loss: 74.2469 - val_mae: 6.925
6
Epoch 43/200
7/7 [==============================] - 0s 13ms/step - loss: 1.8739 - mae: 0.9689 - val_loss: 73.0244 - val_mae: 6.897
3
Epoch 44/200
7/7 [==============================] - 0s 14ms/step - loss: 1.7707 - mae: 0.9670 - val_loss: 69.4864 - val_mae: 6.589
0
```

```
Epoch 45/200
7/7 [==============================] - 0s 14ms/step - loss: 1.9097 - mae: 1.0042 - val_loss: 67.4273 - val_mae: 6.490
3
Epoch 46/200
7/7 [==============================] - 0s 13ms/step - loss: 1.7000 - mae: 0.9737 - val_loss: 66.6400 - val_mae: 6.364
6
Epoch 47/200
7/7 [==============================] - 0s 14ms/step - loss: 1.6152 - mae: 0.8923 - val_loss: 70.2104 - val_mae: 6.375
5
Epoch 48/200
7/7 [==============================] - 0s 13ms/step - loss: 1.3860 - mae: 0.8286 - val_loss: 69.5787 - val_mae: 6.501
5
Epoch 49/200
7/7 [==============================] - 0s 13ms/step - loss: 1.2770 - mae: 0.8170 - val_loss: 69.0435 - val_mae: 6.550
3
Epoch 50/200
7/7 [==============================] - 0s 13ms/step - loss: 1.2697 - mae: 0.7985 - val_loss: 67.3310 - val_mae: 6.383
0
Epoch 51/200
7/7 [==============================] - 0s 14ms/step - loss: 1.4422 - mae: 0.8500 - val_loss: 62.7135 - val_mae: 6.120
3
Epoch 52/200
7/7 [==============================] - 0s 13ms/step - loss: 1.3912 - mae: 0.8305 - val_loss: 63.2911 - val_mae: 6.263
5
Epoch 53/200
7/7 [==============================] - 0s 13ms/step - loss: 2.0079 - mae: 0.8942 - val_loss: 60.0009 - val_mae: 6.102
0
Epoch 54/200
7/7 [==============================] - 0s 13ms/step - loss: 1.6315 - mae: 0.9417 - val_loss: 81.3545 - val_mae: 7.060
8
Epoch 55/200
7/7 [==============================] - 0s 13ms/step - loss: 1.6287 - mae: 0.9413 - val_loss: 72.1254 - val_mae: 6.795
2
Epoch 56/200
7/7 [==============================] - 0s 13ms/step - loss: 1.4911 - mae: 0.9330 - val_loss: 71.2206 - val_mae: 6.726
0
Epoch 57/200
7/7 [==============================] - 0s 13ms/step - loss: 1.4152 - mae: 0.8727 - val_loss: 69.6598 - val_mae: 6.429
3
Epoch 58/200
7/7 [==============================] - 0s 13ms/step - loss: 3.0500 - mae: 1.1042 - val_loss: 66.8199 - val_mae: 6.561
9
Epoch 59/200
7/7 [==============================] - 0s 14ms/step - loss: 1.7254 - mae: 0.9350 - val_loss: 59.8062 - val_mae: 6.164
```

```
5
Epoch 60/200
7/7 [==============================] - 0s 13ms/step - loss: 1.3823 - mae: 0.8798 - val_loss: 72.5573 - val_mae: 6.654
5
Epoch 61/200
7/7 [==============================] - 0s 14ms/step - loss: 1.1972 - mae: 0.7720 - val_loss: 63.5195 - val_mae: 6.325
6
Epoch 62/200
7/7 [==============================] - 0s 14ms/step - loss: 0.9509 - mae: 0.7018 - val_loss: 64.2967 - val_mae: 6.320
7
Epoch 63/200
7/7 [==============================] - 0s 13ms/step - loss: 0.9406 - mae: 0.7208 - val_loss: 61.1452 - val_mae: 6.058
9
Epoch 64/200
7/7 [==============================] - 0s 13ms/step - loss: 0.8247 - mae: 0.6695 - val_loss: 62.1056 - val_mae: 6.204
1
Epoch 65/200
7/7 [==============================] - 0s 13ms/step - loss: 0.7075 - mae: 0.5960 - val_loss: 60.1171 - val_mae: 6.150
4
Epoch 66/200
7/7 [==============================] - 0s 13ms/step - loss: 0.6439 - mae: 0.5504 - val_loss: 65.3437 - val_mae: 6.341
7
Epoch 67/200
7/7 [==============================] - 0s 13ms/step - loss: 0.6420 - mae: 0.5643 - val_loss: 62.9020 - val_mae: 6.240
5
Epoch 68/200
7/7 [==============================] - 0s 13ms/step - loss: 0.7699 - mae: 0.5825 - val_loss: 62.8355 - val_mae: 6.366
9
Epoch 69/200
7/7 [==============================] - 0s 14ms/step - loss: 0.8260 - mae: 0.6076 - val_loss: 61.7343 - val_mae: 6.305
3
Epoch 70/200
7/7 [==============================] - 0s 13ms/step - loss: 0.5677 - mae: 0.5305 - val_loss: 60.3432 - val_mae: 6.004
0
Epoch 71/200
7/7 [==============================] - 0s 14ms/step - loss: 0.7349 - mae: 0.5575 - val_loss: 59.9144 - val_mae: 6.113
5
Epoch 72/200
7/7 [==============================] - 0s 14ms/step - loss: 0.6752 - mae: 0.5828 - val_loss: 56.2661 - val_mae: 6.011
4
Epoch 73/200
7/7 [==============================] - 0s 13ms/step - loss: 0.6149 - mae: 0.5891 - val_loss: 57.0951 - val_mae: 5.861
9
Epoch 74/200
```

```
7/7 [==============================] - 0s 13ms/step - loss: 0.6406 - mae: 0.5807 - val_loss: 59.0306 - val_mae: 6.218
5
Epoch 75/200
7/7 [==============================] - 0s 13ms/step - loss: 0.6024 - mae: 0.5640 - val_loss: 56.2747 - val_mae: 6.100
3
Epoch 76/200
7/7 [==============================] - 0s 13ms/step - loss: 0.4676 - mae: 0.4927 - val_loss: 56.3470 - val_mae: 5.995
5
Epoch 77/200
7/7 [==============================] - 0s 12ms/step - loss: 0.4293 - mae: 0.4497 - val_loss: 56.4407 - val_mae: 5.977
2
Epoch 78/200
7/7 [==============================] - 0s 13ms/step - loss: 0.4157 - mae: 0.4533 - val_loss: 62.8566 - val_mae: 6.347
2
Epoch 79/200
7/7 [==============================] - 0s 12ms/step - loss: 0.4978 - mae: 0.5178 - val_loss: 54.8716 - val_mae: 5.889
2
Epoch 80/200
7/7 [==============================] - 0s 12ms/step - loss: 0.5954 - mae: 0.5255 - val_loss: 56.1481 - val_mae: 6.130
3
Epoch 81/200
7/7 [==============================] - 0s 14ms/step - loss: 0.5231 - mae: 0.5279 - val_loss: 63.4118 - val_mae: 6.156
4
Epoch 82/200
7/7 [==============================] - 0s 13ms/step - loss: 0.6773 - mae: 0.6133 - val_loss: 56.2699 - val_mae: 6.036
4
Epoch 83/200
7/7 [==============================] - 0s 14ms/step - loss: 0.6054 - mae: 0.5824 - val_loss: 62.2997 - val_mae: 6.251
8
Epoch 84/200
7/7 [==============================] - 0s 13ms/step - loss: 0.5147 - mae: 0.5230 - val_loss: 63.6901 - val_mae: 6.317
6
Epoch 85/200
7/7 [==============================] - 0s 13ms/step - loss: 0.5471 - mae: 0.5658 - val_loss: 57.0931 - val_mae: 5.946
1
Epoch 86/200
7/7 [==============================] - 0s 14ms/step - loss: 0.5704 - mae: 0.5652 - val_loss: 64.4630 - val_mae: 6.530
1
Epoch 87/200
7/7 [==============================] - 0s 13ms/step - loss: 0.5550 - mae: 0.5742 - val_loss: 56.8215 - val_mae: 5.930
8
Epoch 88/200
7/7 [==============================] - 0s 13ms/step - loss: 0.5628 - mae: 0.5785 - val_loss: 59.8022 - val_mae: 6.107
3
```

```
Epoch 89/200
7/7 [==============================] - 0s 13ms/step - loss: 0.5601 - mae: 0.5341 - val_loss: 56.6900 - val_mae: 5.886
1
Epoch 90/200
7/7 [==============================] - 0s 14ms/step - loss: 0.6121 - mae: 0.5842 - val_loss: 53.6640 - val_mae: 5.879
7
Epoch 91/200
7/7 [==============================] - 0s 13ms/step - loss: 0.5682 - mae: 0.5619 - val_loss: 55.0022 - val_mae: 5.817
7
Epoch 92/200
7/7 [==============================] - 0s 13ms/step - loss: 0.5241 - mae: 0.5428 - val_loss: 55.1637 - val_mae: 5.964
4
Epoch 93/200
7/7 [==============================] - 0s 13ms/step - loss: 1.0383 - mae: 0.6801 - val_loss: 59.2202 - val_mae: 6.096
3
Epoch 94/200
7/7 [==============================] - 0s 13ms/step - loss: 1.1414 - mae: 0.7271 - val_loss: 57.3319 - val_mae: 5.837
5
Epoch 95/200
7/7 [==============================] - 0s 13ms/step - loss: 1.2142 - mae: 0.7511 - val_loss: 55.4936 - val_mae: 5.829
7
Epoch 96/200
7/7 [==============================] - 0s 13ms/step - loss: 1.5202 - mae: 0.8789 - val_loss: 70.3853 - val_mae: 6.607
1
Epoch 97/200
7/7 [==============================] - 0s 13ms/step - loss: 1.8696 - mae: 0.9304 - val_loss: 54.8302 - val_mae: 5.936
4
Epoch 98/200
7/7 [==============================] - 0s 13ms/step - loss: 1.2199 - mae: 0.7522 - val_loss: 49.1730 - val_mae: 5.365
3
Epoch 99/200
7/7 [==============================] - 0s 14ms/step - loss: 0.9487 - mae: 0.7274 - val_loss: 47.8300 - val_mae: 5.252
6
Epoch 100/200
7/7 [==============================] - 0s 13ms/step - loss: 0.8582 - mae: 0.6846 - val_loss: 63.7522 - val_mae: 6.235
4
Epoch 101/200
7/7 [==============================] - 0s 13ms/step - loss: 1.0292 - mae: 0.7134 - val_loss: 58.7771 - val_mae: 5.846
6
Epoch 102/200
7/7 [==============================] - 0s 13ms/step - loss: 0.6978 - mae: 0.6322 - val_loss: 49.0125 - val_mae: 5.501
1
Epoch 103/200
7/7 [==============================] - 0s 13ms/step - loss: 1.0211 - mae: 0.7060 - val_loss: 51.3081 - val_mae: 5.673
```

```
7
Epoch 104/200
7/7 [==============================] - 0s 14ms/step - loss: 1.0006 - mae: 0.7433 - val_loss: 58.7102 - val_mae: 5.916
5
Epoch 105/200
7/7 [==============================] - 0s 14ms/step - loss: 1.0404 - mae: 0.7467 - val_loss: 45.3671 - val_mae: 5.191
5
Epoch 106/200
7/7 [==============================] - 0s 14ms/step - loss: 1.6341 - mae: 0.8862 - val_loss: 41.6365 - val_mae: 5.136
6
Epoch 107/200
7/7 [==============================] - 0s 13ms/step - loss: 0.9927 - mae: 0.7588 - val_loss: 51.9471 - val_mae: 5.642
6
Epoch 108/200
7/7 [==============================] - 0s 13ms/step - loss: 0.9893 - mae: 0.7432 - val_loss: 48.1578 - val_mae: 5.254
8
Epoch 109/200
7/7 [==============================] - 0s 13ms/step - loss: 0.8775 - mae: 0.6937 - val_loss: 48.3655 - val_mae: 5.760
6
Epoch 110/200
7/7 [==============================] - 0s 13ms/step - loss: 1.7548 - mae: 0.8577 - val_loss: 59.2889 - val_mae: 6.032
2
Epoch 111/200
7/7 [==============================] - 0s 13ms/step - loss: 3.2978 - mae: 1.2973 - val_loss: 62.9466 - val_mae: 6.423
0
Epoch 112/200
7/7 [==============================] - 0s 13ms/step - loss: 5.1840 - mae: 1.5694 - val_loss: 54.1124 - val_mae: 5.479
8
Epoch 113/200
7/7 [==============================] - 0s 13ms/step - loss: 4.3850 - mae: 1.3300 - val_loss: 74.2065 - val_mae: 6.734
5
Epoch 114/200
7/7 [==============================] - 0s 13ms/step - loss: 2.7956 - mae: 1.1253 - val_loss: 44.3034 - val_mae: 5.105
7
Epoch 115/200
7/7 [==============================] - 0s 14ms/step - loss: 1.8275 - mae: 0.9974 - val_loss: 40.6376 - val_mae: 4.903
8
Epoch 116/200
7/7 [==============================] - 0s 13ms/step - loss: 1.0719 - mae: 0.7840 - val_loss: 46.5838 - val_mae: 5.258
9
Epoch 117/200
7/7 [==============================] - 0s 13ms/step - loss: 1.3744 - mae: 0.8724 - val_loss: 37.2046 - val_mae: 5.211
2
Epoch 118/200
```

```
7/7 [==============================] - 0s 13ms/step - loss: 0.9875 - mae: 0.7450 - val_loss: 47.2895 - val_mae: 5.468
5
Epoch 119/200
7/7 [==============================] - 0s 13ms/step - loss: 0.8254 - mae: 0.6452 - val_loss: 44.4363 - val_mae: 5.291
7
Epoch 120/200
7/7 [==============================] - 0s 13ms/step - loss: 0.9219 - mae: 0.7526 - val_loss: 48.7590 - val_mae: 5.429
6
Epoch 121/200
7/7 [==============================] - 0s 13ms/step - loss: 1.2746 - mae: 0.7603 - val_loss: 42.1986 - val_mae: 5.088
4
Epoch 122/200
7/7 [==============================] - 0s 13ms/step - loss: 1.1994 - mae: 0.7778 - val_loss: 39.0325 - val_mae: 4.582
2
Epoch 123/200
7/7 [==============================] - 0s 13ms/step - loss: 1.1093 - mae: 0.7381 - val_loss: 48.6244 - val_mae: 5.214
5
Epoch 124/200
7/7 [==============================] - 0s 13ms/step - loss: 1.0489 - mae: 0.6516 - val_loss: 42.1759 - val_mae: 5.074
9
Epoch 125/200
7/7 [==============================] - 0s 13ms/step - loss: 0.8155 - mae: 0.6686 - val_loss: 42.3626 - val_mae: 5.033
7
Epoch 126/200
7/7 [==============================] - 0s 13ms/step - loss: 0.9460 - mae: 0.6114 - val_loss: 47.1958 - val_mae: 5.268
8
Epoch 127/200
7/7 [==============================] - 0s 13ms/step - loss: 0.7060 - mae: 0.5969 - val_loss: 40.3470 - val_mae: 5.045
5
Epoch 128/200
7/7 [==============================] - 0s 13ms/step - loss: 0.5801 - mae: 0.5390 - val_loss: 49.1075 - val_mae: 5.273
5
Epoch 129/200
7/7 [==============================] - 0s 13ms/step - loss: 0.4757 - mae: 0.4932 - val_loss: 45.7277 - val_mae: 5.248
2
Epoch 130/200
7/7 [==============================] - 0s 14ms/step - loss: 0.3679 - mae: 0.4122 - val_loss: 43.3761 - val_mae: 5.003
3
Epoch 131/200
7/7 [==============================] - 0s 13ms/step - loss: 0.3030 - mae: 0.4221 - val_loss: 47.7820 - val_mae: 5.250
2
Epoch 132/200
7/7 [==============================] - 0s 15ms/step - loss: 0.2602 - mae: 0.3832 - val_loss: 44.4101 - val_mae: 4.947
1
```

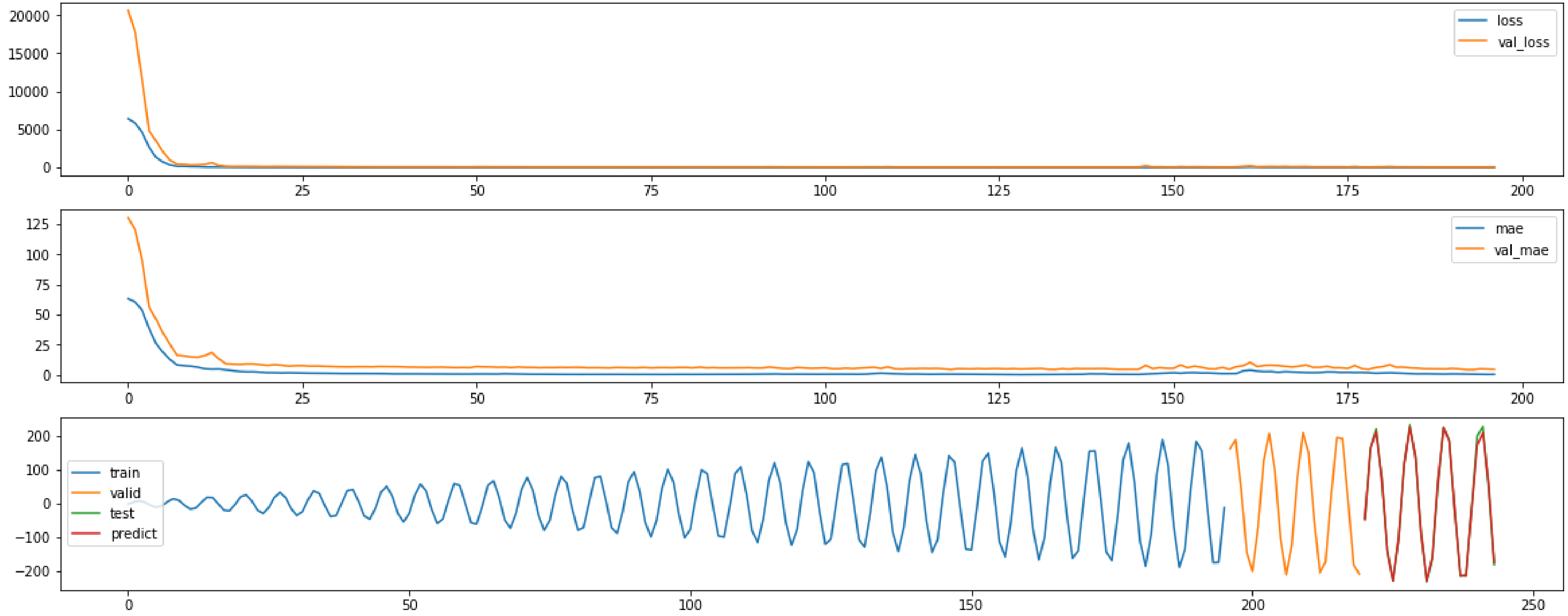
```
Epoch 133/200
7/7 [==============================] - 0s 13ms/step - loss: 0.3329 - mae: 0.4113 - val_loss: 46.9559 - val_mae: 5.098
7
Epoch 134/200
7/7 [==============================] - 0s 13ms/step - loss: 0.3454 - mae: 0.4440 - val_loss: 48.0085 - val_mae: 5.227
4
Epoch 135/200
7/7 [==============================] - 0s 14ms/step - loss: 0.5234 - mae: 0.4700 - val_loss: 52.8697 - val_mae: 5.389
0
Epoch 136/200
7/7 [==============================] - 0s 14ms/step - loss: 0.5489 - mae: 0.5001 - val_loss: 38.9874 - val_mae: 4.705
4
Epoch 137/200
7/7 [==============================] - 0s 13ms/step - loss: 0.5227 - mae: 0.5093 - val_loss: 38.8782 - val_mae: 4.601
5
Epoch 138/200
7/7 [==============================] - 0s 14ms/step - loss: 0.4167 - mae: 0.4535 - val_loss: 45.0925 - val_mae: 5.183
0
Epoch 139/200
7/7 [==============================] - 0s 13ms/step - loss: 0.6429 - mae: 0.5269 - val_loss: 54.0056 - val_mae: 4.837
6
Epoch 140/200
7/7 [==============================] - 0s 14ms/step - loss: 0.9808 - mae: 0.6236 - val_loss: 50.1576 - val_mae: 5.337
0
Epoch 141/200
7/7 [==============================] - 0s 14ms/step - loss: 1.1597 - mae: 0.6692 - val_loss: 43.6099 - val_mae: 5.162
0
Epoch 142/200
7/7 [==============================] - 0s 14ms/step - loss: 2.8918 - mae: 1.0705 - val_loss: 44.9266 - val_mae: 5.208
0
Epoch 143/200
7/7 [==============================] - 0s 13ms/step - loss: 1.5036 - mae: 0.9501 - val_loss: 47.4221 - val_mae: 5.223
8
Epoch 144/200
7/7 [==============================] - 0s 13ms/step - loss: 1.8257 - mae: 0.9934 - val_loss: 45.4317 - val_mae: 5.287
4
Epoch 145/200
7/7 [==============================] - 0s 13ms/step - loss: 0.7647 - mae: 0.6616 - val_loss: 44.7751 - val_mae: 5.044
5
Epoch 146/200
7/7 [==============================] - 0s 14ms/step - loss: 0.7721 - mae: 0.6105 - val_loss: 34.7528 - val_mae: 4.708
3
Epoch 147/200
7/7 [==============================] - 0s 13ms/step - loss: 0.8203 - mae: 0.6758 - val_loss: 41.0391 - val_mae: 4.704
```

```
1
Epoch 148/200
7/7 [==============================] - 0s 13ms/step - loss: 0.7728 - mae: 0.6229 - val_loss: 36.3252 - val_mae: 4.636
8
Epoch 149/200
7/7 [==============================] - 0s 13ms/step - loss: 0.6731 - mae: 0.5739 - val_loss: 41.3200 - val_mae: 4.747
6
Epoch 150/200
7/7 [==============================] - 0s 13ms/step - loss: 1.8556 - mae: 0.8684 - val_loss: 208.4961 - val_mae: 8.08
77
Epoch 151/200
7/7 [==============================] - 0s 14ms/step - loss: 6.0247 - mae: 1.2457 - val_loss: 60.3927 - val_mae: 5.279
5
Epoch 152/200
7/7 [==============================] - 0s 13ms/step - loss: 5.8258 - mae: 1.3790 - val_loss: 74.3302 - val_mae: 6.125
0
Epoch 153/200
7/7 [==============================] - 0s 14ms/step - loss: 7.9472 - mae: 1.6340 - val_loss: 49.6811 - val_mae: 5.512
8
Epoch 154/200
7/7 [==============================] - 0s 13ms/step - loss: 6.7512 - mae: 1.9502 - val_loss: 46.0629 - val_mae: 5.544
1
Epoch 155/200
7/7 [==============================] - 0s 14ms/step - loss: 5.2483 - mae: 1.5535 - val_loss: 90.3306 - val_mae: 8.343
7
Epoch 156/200
7/7 [==============================] - 0s 13ms/step - loss: 7.9064 - mae: 1.9924 - val_loss: 60.2314 - val_mae: 6.077
7
Epoch 157/200
7/7 [==============================] - 0s 13ms/step - loss: 8.3541 - mae: 2.0386 - val_loss: 80.0915 - val_mae: 7.386
3
Epoch 158/200
7/7 [==============================] - 0s 14ms/step - loss: 6.1442 - mae: 1.7520 - val_loss: 64.4263 - val_mae: 6.466
5
Epoch 159/200
7/7 [==============================] - 0s 13ms/step - loss: 5.7365 - mae: 1.7638 - val_loss: 42.8556 - val_mae: 5.136
8
Epoch 160/200
7/7 [==============================] - 0s 13ms/step - loss: 5.5318 - mae: 1.5235 - val_loss: 40.9622 - val_mae: 5.008
2
Epoch 161/200
7/7 [==============================] - 0s 13ms/step - loss: 2.9153 - mae: 1.2220 - val_loss: 55.9273 - val_mae: 6.296
6
Epoch 162/200
```

```
7/7 [==============================] - 0s 14ms/step - loss: 2.5272 - mae: 1.2282 - val_loss: 39.7319 - val_mae: 4.766
4
Epoch 163/200
7/7 [==============================] - 0s 14ms/step - loss: 4.4642 - mae: 1.2800 - val_loss: 67.3115 - val_mae: 6.900
1
Epoch 164/200
7/7 [==============================] - 0s 13ms/step - loss: 32.4716 - mae: 3.4595 - val_loss: 126.5515 - val_mae: 7.8
068
Epoch 165/200
7/7 [==============================] - 0s 13ms/step - loss: 42.4664 - mae: 4.0738 - val_loss: 197.8816 - val_mae: 10.
5400
Epoch 166/200
7/7 [==============================] - 0s 13ms/step - loss: 24.4823 - mae: 3.2407 - val_loss: 79.7400 - val_mae: 7.01
88
Epoch 167/200
7/7 [==============================] - 0s 13ms/step - loss: 15.9724 - mae: 2.8399 - val_loss: 94.7745 - val_mae: 7.96
77
Epoch 168/200
7/7 [==============================] - 0s 14ms/step - loss: 13.0090 - mae: 2.9096 - val_loss: 114.0227 - val_mae: 8.1
768
Epoch 169/200
7/7 [==============================] - 0s 14ms/step - loss: 8.9340 - mae: 2.3214 - val_loss: 91.8261 - val_mae: 7.905
7
Epoch 170/200
7/7 [==============================] - 0s 13ms/step - loss: 14.0911 - mae: 2.7921 - val_loss: 120.1500 - val_mae: 7.2
456
Epoch 171/200
7/7 [==============================] - 0s 14ms/step - loss: 11.4930 - mae: 2.5640 - val_loss: 80.3887 - val_mae: 6.65
61
Epoch 172/200
7/7 [==============================] - 0s 13ms/step - loss: 9.0195 - mae: 2.2407 - val_loss: 98.7074 - val_mae: 7.364
9
Epoch 173/200
7/7 [==============================] - 0s 13ms/step - loss: 10.6511 - mae: 2.0918 - val_loss: 108.1354 - val_mae: 8.3
622
Epoch 174/200
7/7 [==============================] - 0s 13ms/step - loss: 8.1949 - mae: 2.0237 - val_loss: 64.5105 - val_mae: 6.414
0
Epoch 175/200
7/7 [==============================] - 0s 13ms/step - loss: 10.9625 - mae: 2.1467 - val_loss: 67.4486 - val_mae: 6.42
74
Epoch 176/200
7/7 [==============================] - 0s 13ms/step - loss: 12.4793 - mae: 2.6267 - val_loss: 77.5662 - val_mae: 7.28
09
```

```
Epoch 177/200
7/7 [==============================] - 0s 13ms/step - loss: 11.5167 - mae: 2.5806 - val_loss: 54.2155 - val_mae: 5.99
89
Epoch 178/200
7/7 [==============================] - 0s 13ms/step - loss: 8.1670 - mae: 2.1814 - val_loss: 70.0988 - val_mae: 5.984
2
Epoch 179/200
7/7 [==============================] - 0s 13ms/step - loss: 10.4697 - mae: 2.2851 - val_loss: 45.0759 - val_mae: 5.40
03
Epoch 180/200
7/7 [==============================] - 0s 13ms/step - loss: 8.0156 - mae: 2.1034 - val_loss: 111.2877 - val_mae: 7.92
20
Epoch 181/200
7/7 [==============================] - 0s 14ms/step - loss: 9.7837 - mae: 2.1731 - val_loss: 39.4277 - val_mae: 5.248
2
Epoch 182/200
7/7 [==============================] - 0s 13ms/step - loss: 7.3907 - mae: 1.9364 - val_loss: 34.3383 - val_mae: 4.679
3
Epoch 183/200
7/7 [==============================] - 0s 13ms/step - loss: 5.9158 - mae: 1.5411 - val_loss: 64.1531 - val_mae: 6.205
9
Epoch 184/200
7/7 [==============================] - 0s 13ms/step - loss: 7.2018 - mae: 1.7727 - val_loss: 72.5931 - val_mae: 6.999
0
Epoch 185/200
7/7 [==============================] - 0s 13ms/step - loss: 7.8677 - mae: 1.9249 - val_loss: 104.4396 - val_mae: 8.51
60
Epoch 186/200
7/7 [==============================] - 0s 13ms/step - loss: 5.9831 - mae: 1.7197 - val_loss: 63.7563 - val_mae: 6.455
9
Epoch 187/200
7/7 [==============================] - 0s 13ms/step - loss: 4.6923 - mae: 1.5166 - val_loss: 65.4187 - val_mae: 6.533
1
Epoch 188/200
7/7 [==============================] - 0s 13ms/step - loss: 2.9380 - mae: 1.2072 - val_loss: 53.1938 - val_mae: 5.911
9
Epoch 189/200
7/7 [==============================] - 0s 13ms/step - loss: 1.9180 - mae: 0.9851 - val_loss: 48.4861 - val_mae: 5.618
6
Epoch 190/200
7/7 [==============================] - 0s 14ms/step - loss: 2.0262 - mae: 1.0770 - val_loss: 43.2836 - val_mae: 5.153
5
Epoch 191/200
7/7 [==============================] - 0s 13ms/step - loss: 1.6897 - mae: 0.9389 - val_loss: 41.1952 - val_mae: 5.064
```

```
1
Epoch 192/200
7/7 [==============================] - 0s 13ms/step - loss: 1.4881 - mae: 0.9002 - val_loss: 42.4477 - val_mae: 4.948
5
Epoch 193/200
7/7 [==============================] - 0s 14ms/step - loss: 1.1837 - mae: 0.8304 - val_loss: 46.3574 - val_mae: 5.009
6
Epoch 194/200
7/7 [==============================] - 0s 13ms/step - loss: 1.8510 - mae: 0.9908 - val_loss: 51.8347 - val_mae: 5.403
9
Epoch 195/200
7/7 [==============================] - 0s 14ms/step - loss: 1.3575 - mae: 0.8836 - val_loss: 41.6845 - val_mae: 5.031
0
Epoch 196/200
7/7 [==============================] - 0s 13ms/step - loss: 1.1894 - mae: 0.8095 - val_loss: 34.4531 - val_mae: 4.456
2
Epoch 197/200
7/7 [==============================] - 0s 13ms/step - loss: 0.8672 - mae: 0.7159 - val_loss: 35.2686 - val_mae: 4.436
8
Epoch 198/200
7/7 [==============================] - 0s 13ms/step - loss: 0.5902 - mae: 0.5940 - val_loss: 44.3889 - val_mae: 5.137
4
Epoch 199/200
7/7 [==============================] - 0s 13ms/step - loss: 0.5359 - mae: 0.5510 - val_loss: 41.0645 - val_mae: 4.916
0
Epoch 200/200
7/7 [==============================] - 0s 14ms/step - loss: 0.5986 - mae: 0.5809 - val_loss: 36.4095 - val_mae: 4.728
7
```



In [ ]:
```
# demonstrate prediction
start = 12
y_true = (start+n_in)*(start+n_in)
x_input = np.array([fct(x) for x in range(start,start+n_in)])
x_input = x_input.reshape((1, n_in, n_features))
yhat = model.predict(x_input, verbose=0)
print(yhat, y_true)
```

```
[[-13.641433]] 324
```

LSTM network for multi-variate time series

Multivariate time series data means data where there is more than one observation for each time step.

There are two main models we may need with multivariate time series data. These are the multiple input series or the multiple parallel series depending on whether we want to predict one or more of the variables.

In this notebook, we focus on the first case: as input, several time series and as output (the prediction), a single time series.

Prepare the data

We reuse the same `series_to_supervise()` function in order to build a dataset with :

- n_in elements for each series
- n_out elements for each series to be predict

You have also to select one (Multiple Input Series) or many time series (Multiple Parallel Series) to predict.

In [ ]:

```
# Get the time series
fct2 = lambda x: 2*x
time_series1 = [fct(x) for x in range(SIZE)]
time_series2 = [fct2(x) for x in range(SIZE)]
out_seq = [time_series1[i]+time_series2[i] for i in range(SIZE)]
```

In [ ]:

```
# Get the dataset
dataset = pd.DataFrame(data={"f1":time_series1, "f2":time_series2, "output":out_seq}, index=range(SIZE))
n_features = dataset.shape[1] # for multivariate time series
dataset.head()
```

Out[ ]:

	f1	f2	output
0	0.000000	0	0.000000
1	0.841471	2	2.841471
2	1.818595	4	5.818595
3	0.423360	6	6.423360
4	-3.027210	8	4.972790

As with the univariate time series, we must structure these data into samples with input and output elements. An LSTM model needs sufficient context to learn a mapping from an input sequence to an output value. LSTMs can support parallel input time series as separate variables or features. Therefore, we need to split the data into samples maintaining the order of observations across the two input sequences.

If we chose six input time steps for the three features, we have to transform the dataset in the following way.

In [ ]:

```
# As previously, prepare the dataset
''' In the followig example, we select
- n_in number of time steps (6)
- n_out number of time steps of output
- and one serie to predict : output
'''
n_features = dataset.shape[1] # for multivariate time series
n_in = 6
n_out = 1
output = ["output"]

data = series_to_supervised(dataset, n_in, n_out, output=output)
data.head()
```

Out[ ]:

	f1(t-6)	f2(t-6)	output(t-6)	f1(t-5)	f2(t-5)	output(t-5)	f1(t-4)	f2(t-4)	output(t-4)	f1(t-3)	f2(t-3)	output(t-3)	f1(t-2)	f2(t-2)	output(t-2)	f1(t-
6	0.000000	0.0	0.000000	0.841471	2.0	2.841471	1.818595	4.0	5.818595	0.423360	6.0	6.423360	-3.027210	8.0	4.972790	-4.79462
7	0.841471	2.0	2.841471	1.818595	4.0	5.818595	0.423360	6.0	6.423360	-3.027210	8.0	4.972790	-4.794621	10.0	5.205379	-1.67649
8	1.818595	4.0	5.818595	0.423360	6.0	6.423360	-3.027210	8.0	4.972790	-4.794621	10.0	5.205379	-1.676493	12.0	10.323507	4.5989
9	0.423360	6.0	6.423360	-3.027210	8.0	4.972790	-4.794621	10.0	5.205379	-1.676493	12.0	10.323507	4.598906	14.0	18.598906	7.9148
10	-3.027210	8.0	4.972790	-4.794621	10.0	5.205379	-1.676493	12.0	10.323507	4.598906	14.0	18.598906	7.914866	16.0	23.914866	3.7090

In [ ]:

```
# Split dataset into TRAIN, VAL and TEST
testAndValid = 0.1

SPLIT = int(testAndValid * len(data))
idx_train = len(data) - 2 * SPLIT
idx_test = len(data) - SPLIT

print(f"TRAIN=time_series[:{idx_train}]")
print(f"VALID=time_series[{idx_train}:{idx_test}]")
print(f"TEST=time_series[{idx_test}:]")

TRAIN = data[:idx_train]
VAL = data[idx_train:idx_test]
TEST = data[idx_test:]
```

```
TRAIN=time_series[:196]
VALID=time_series[196:220]
TEST=time_series[220:]
```

TODO − Students

- build train_X, val_X, test_X and train_y, val_y and test_y as before. Then print the shapes of tensors
  - train_X is a 3D-tensor (196, 6, 3) for me
  - train_y is a 1D-tensor (196,)

In [ ]:

```
# split into input and outputs
train_X, train_y = TRAIN.values[:, :-n_out], TRAIN.values[:, -n_out]
val_X, val_y = VAL.values[:, :-n_out], VAL.values[:, -n_out]
test_X, test_y = TEST.values[:, :-n_out], TEST.values[:, -n_out]

# reshape input to be 3D [samples, timesteps, features]
train_X = train_X.reshape((-1, n_in, n_features))
val_X = val_X.reshape((-1, n_in, n_features))
test_X = test_X.reshape((-1, n_in, n_features))

train_X.shape, train_y.shape
```

Out[ ]:

```
((196, 6, 3), (196,))
```

Build a neuronal model

Any of the varieties of LSTMs in the previous section can be used, such as a Vanilla, Stacked, Bidirectional. It's also possible to use CNN or mixed CNN and LSTM.

We will use a Vanilla LSTM where the number of time steps and parallel series (features) are specified for the input layer via the input_shape argument.

In [ ]:

```
# Build model
inputs = Input(shape=(n_in, n_features))
hidden = LSTM(LSTM_SIZE, return_sequences=False, activation="relu")(inputs)
outputs = Dense(n_out, activation="linear")(hidden)
model = Model(inputs, outputs)
model.summary()
```

```
Model: "model_2"
_________________________________________________________________
 Layer (type)                Output Shape              Param #   
=================================================================
 input_3 (InputLayer)        [(None, 6, 3)]            0         
                                                                 
 lstm_4 (LSTM)               (None, 16)                1280      
                                                                 
 dense_2 (Dense)             (None, 1)                 17        
                                                                 
=================================================================
Total params: 1,297
Trainable params: 1,297
Non-trainable params: 0
_________________________________________________________________
```

In [ ]:

```
model = build_and_fit(model, train_X, train_y, val_X, val_y, test_X, test_y)
```

```
Epoch 1/200
7/7 [==============================] - 1s 33ms/step - loss: 164405.3906 - mae: 346.8030 - val_loss: 509651.7500 - val
_mae: 696.6531
Epoch 2/200
7/7 [==============================] - 0s 6ms/step - loss: 147253.8125 - mae: 327.5355 - val_loss: 463813.1562 - val_
mae: 663.4233
Epoch 3/200
7/7 [==============================] - 0s 7ms/step - loss: 134877.3125 - mae: 313.0372 - val_loss: 429108.7500 - val_
mae: 636.8749
Epoch 4/200
7/7 [==============================] - 0s 6ms/step - loss: 124715.0625 - mae: 300.2824 - val_loss: 396723.5938 - val_
mae: 609.9120
Epoch 5/200
7/7 [==============================] - 0s 7ms/step - loss: 115014.5781 - mae: 286.9630 - val_loss: 361780.3438 - val_
mae: 578.4326
Epoch 6/200
7/7 [==============================] - 0s 7ms/step - loss: 102322.6094 - mae: 268.1314 - val_loss: 311233.2500 - val_
mae: 527.9244
Epoch 7/200
7/7 [==============================] - 0s 7ms/step - loss: 88423.0547 - mae: 247.4138 - val_loss: 268227.0000 - val_m
ae: 488.8546
Epoch 8/200
7/7 [==============================] - 0s 7ms/step - loss: 71162.3125 - mae: 220.4949 - val_loss: 208321.4531 - val_m
ae: 425.9018
Epoch 9/200
7/7 [==============================] - 0s 7ms/step - loss: 58403.8516 - mae: 197.9425 - val_loss: 176819.2500 - val_m
ae: 390.1928
Epoch 10/200
7/7 [==============================] - 0s 6ms/step - loss: 49358.6562 - mae: 179.5688 - val_loss: 153113.7344 - val_m
ae: 355.1621
Epoch 11/200
7/7 [==============================] - 0s 6ms/step - loss: 41982.6328 - mae: 161.2445 - val_loss: 126637.4766 - val_m
ae: 308.0824
Epoch 12/200
7/7 [==============================] - 0s 7ms/step - loss: 34104.9570 - mae: 136.9916 - val_loss: 100389.8359 - val_m
ae: 259.8584
Epoch 13/200
7/7 [==============================] - 0s 7ms/step - loss: 26774.9980 - mae: 115.0777 - val_loss: 80077.1562 - val_ma
e: 230.0773
Epoch 14/200
7/7 [==============================] - 0s 6ms/step - loss: 20842.4102 - mae: 101.7087 - val_loss: 60354.8945 - val_ma
e: 201.5160
Epoch 15/200
7/7 [==============================] - 0s 6ms/step - loss: 16479.1875 - mae: 92.2779 - val_loss: 44030.8242 - val_ma
```

```
e: 174.3538
Epoch 16/200
7/7 [==============================] - 0s 6ms/step - loss: 12227.9131 - mae: 81.1311 - val_loss: 31374.9219 - val_ma
e: 143.5351
Epoch 17/200
7/7 [==============================] - 0s 7ms/step - loss: 8391.1094 - mae: 67.3042 - val_loss: 23024.4473 - val_mae:
127.4922
Epoch 18/200
7/7 [==============================] - 0s 7ms/step - loss: 6357.0278 - mae: 59.6456 - val_loss: 18626.1602 - val_mae:
119.8643
Epoch 19/200
7/7 [==============================] - 0s 6ms/step - loss: 4968.1768 - mae: 53.9471 - val_loss: 14390.6953 - val_mae:
102.0894
Epoch 20/200
7/7 [==============================] - 0s 6ms/step - loss: 3896.0461 - mae: 46.2442 - val_loss: 11390.6719 - val_mae:
89.4920
Epoch 21/200
7/7 [==============================] - 0s 7ms/step - loss: 2972.6592 - mae: 39.6561 - val_loss: 9049.4629 - val_mae:
78.2692
Epoch 22/200
7/7 [==============================] - 0s 7ms/step - loss: 2401.2764 - mae: 35.7665 - val_loss: 7108.3145 - val_mae:
69.0479
Epoch 23/200
7/7 [==============================] - 0s 7ms/step - loss: 1889.4231 - mae: 31.8836 - val_loss: 5539.2134 - val_mae:
63.0500
Epoch 24/200
7/7 [==============================] - 0s 7ms/step - loss: 1451.1171 - mae: 29.0872 - val_loss: 4794.6504 - val_mae:
59.7849
Epoch 25/200
7/7 [==============================] - 0s 6ms/step - loss: 1240.5251 - mae: 26.8890 - val_loss: 4326.4863 - val_mae:
57.9682
Epoch 26/200
7/7 [==============================] - 0s 7ms/step - loss: 1110.0386 - mae: 25.4206 - val_loss: 3623.1667 - val_mae:
53.5880
Epoch 27/200
7/7 [==============================] - 0s 6ms/step - loss: 977.7959 - mae: 24.0429 - val_loss: 3093.9590 - val_mae: 4
8.4082
Epoch 28/200
7/7 [==============================] - 0s 6ms/step - loss: 838.4349 - mae: 22.1961 - val_loss: 2784.4807 - val_mae: 4
5.8267
Epoch 29/200
7/7 [==============================] - 0s 7ms/step - loss: 779.8119 - mae: 21.1752 - val_loss: 2396.6174 - val_mae: 4
2.4257
Epoch 30/200
```

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7/7 [==============================] - 0s 7ms/step - loss: 726.8625 - mae: 20.1579 - val_loss: 2327.4863 - val_mae: 4
2.4464
Epoch 31/200
7/7 [==============================] - 0s 6ms/step - loss: 690.5201 - mae: 19.3572 - val_loss: 2152.2024 - val_mae: 4
0.6197
Epoch 32/200
7/7 [==============================] - 0s 7ms/step - loss: 649.2204 - mae: 18.7022 - val_loss: 2143.0256 - val_mae: 4
0.2490
Epoch 33/200
7/7 [==============================] - 0s 7ms/step - loss: 639.7946 - mae: 18.5242 - val_loss: 1943.3619 - val_mae: 3
7.6561
Epoch 34/200
7/7 [==============================] - 0s 7ms/step - loss: 560.7791 - mae: 17.6152 - val_loss: 1943.1176 - val_mae: 3
9.2536
Epoch 35/200
7/7 [==============================] - 0s 7ms/step - loss: 559.8788 - mae: 17.6580 - val_loss: 1832.1161 - val_mae: 3
8.4021
Epoch 36/200
7/7 [==============================] - 0s 7ms/step - loss: 533.8823 - mae: 17.2309 - val_loss: 1694.7780 - val_mae: 3
6.4717
Epoch 37/200
7/7 [==============================] - 0s 7ms/step - loss: 507.4057 - mae: 16.8913 - val_loss: 1514.5674 - val_mae: 3
3.1745
Epoch 38/200
7/7 [==============================] - 0s 7ms/step - loss: 491.5648 - mae: 16.4927 - val_loss: 1399.6410 - val_mae: 3
2.1756
Epoch 39/200
7/7 [==============================] - 0s 6ms/step - loss: 551.6323 - mae: 17.2264 - val_loss: 2016.0070 - val_mae: 3
6.9275
Epoch 40/200
7/7 [==============================] - 0s 6ms/step - loss: 581.3759 - mae: 17.5222 - val_loss: 1975.3715 - val_mae: 3
5.3632
Epoch 41/200
7/7 [==============================] - 0s 6ms/step - loss: 557.3950 - mae: 17.1951 - val_loss: 1767.4858 - val_mae: 3
5.1058
Epoch 42/200
7/7 [==============================] - 0s 6ms/step - loss: 507.3745 - mae: 16.4058 - val_loss: 1512.4310 - val_mae: 3
2.3610
Epoch 43/200
7/7 [==============================] - 0s 6ms/step - loss: 490.3405 - mae: 15.9599 - val_loss: 1687.5234 - val_mae: 3
3.2980
Epoch 44/200
7/7 [==============================] - 0s 6ms/step - loss: 480.6082 - mae: 15.7609 - val_loss: 1598.0890 - val_mae: 3
1.8396
```

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Epoch 45/200
7/7 [==============================] - 0s 6ms/step - loss: 457.6457 - mae: 15.3690 - val_loss: 1575.2435 - val_mae: 3
1.2955
Epoch 46/200
7/7 [==============================] - 0s 6ms/step - loss: 437.3801 - mae: 14.7007 - val_loss: 1526.6885 - val_mae: 2
9.5361
Epoch 47/200
7/7 [==============================] - 0s 7ms/step - loss: 421.8268 - mae: 14.5150 - val_loss: 1450.9331 - val_mae: 2
9.7878
Epoch 48/200
7/7 [==============================] - 0s 6ms/step - loss: 418.6131 - mae: 14.5501 - val_loss: 1558.5054 - val_mae: 2
9.8330
Epoch 49/200
7/7 [==============================] - 0s 6ms/step - loss: 419.7623 - mae: 14.1075 - val_loss: 1533.6876 - val_mae: 2
9.0601
Epoch 50/200
7/7 [==============================] - 0s 7ms/step - loss: 407.0471 - mae: 13.7465 - val_loss: 1473.5927 - val_mae: 2
8.1741
Epoch 51/200
7/7 [==============================] - 0s 6ms/step - loss: 392.4981 - mae: 13.8089 - val_loss: 1375.8242 - val_mae: 2
7.7834
Epoch 52/200
7/7 [==============================] - 0s 6ms/step - loss: 379.9480 - mae: 13.4555 - val_loss: 1313.8392 - val_mae: 2
7.0558
Epoch 53/200
7/7 [==============================] - 0s 7ms/step - loss: 364.3426 - mae: 12.8293 - val_loss: 1217.2587 - val_mae: 2
6.6753
Epoch 54/200
7/7 [==============================] - 0s 7ms/step - loss: 346.8841 - mae: 12.4506 - val_loss: 1186.9940 - val_mae: 2
6.0750
Epoch 55/200
7/7 [==============================] - 0s 6ms/step - loss: 343.1487 - mae: 12.5494 - val_loss: 1065.9429 - val_mae: 2
6.2544
Epoch 56/200
7/7 [==============================] - 0s 7ms/step - loss: 324.1685 - mae: 12.3132 - val_loss: 881.4829 - val_mae: 2
3.9693
Epoch 57/200
7/7 [==============================] - 0s 7ms/step - loss: 307.7295 - mae: 11.9208 - val_loss: 1116.8717 - val_mae: 2
6.4673
Epoch 58/200
7/7 [==============================] - 0s 7ms/step - loss: 309.0134 - mae: 11.7572 - val_loss: 807.6511 - val_mae: 2
3.1303
Epoch 59/200
7/7 [==============================] - 0s 6ms/step - loss: 294.9986 - mae: 11.3982 - val_loss: 1064.5864 - val_mae: 2
```

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4.8810
Epoch 60/200
7/7 [==============================] - 0s 7ms/step - loss: 307.3674 - mae: 11.8031 - val_loss: 1045.5447 - val_mae: 2
4.3012
Epoch 61/200
7/7 [==============================] - 0s 7ms/step - loss: 286.8123 - mae: 11.4801 - val_loss: 686.3347 - val_mae: 2
0.4045
Epoch 62/200
7/7 [==============================] - 0s 7ms/step - loss: 293.5886 - mae: 11.5783 - val_loss: 1039.3597 - val_mae: 2
4.7867
Epoch 63/200
7/7 [==============================] - 0s 6ms/step - loss: 343.8802 - mae: 12.7521 - val_loss: 1656.2701 - val_mae: 3
4.9515
Epoch 64/200
7/7 [==============================] - 0s 7ms/step - loss: 595.1235 - mae: 17.1749 - val_loss: 2125.4736 - val_mae: 3
7.6362
Epoch 65/200
7/7 [==============================] - 0s 6ms/step - loss: 628.5276 - mae: 17.4339 - val_loss: 2614.8020 - val_mae: 4
1.4327
Epoch 66/200
7/7 [==============================] - 0s 6ms/step - loss: 603.8534 - mae: 17.4017 - val_loss: 2365.9834 - val_mae: 3
9.2959
Epoch 67/200
7/7 [==============================] - 0s 7ms/step - loss: 589.8774 - mae: 17.4020 - val_loss: 2118.8657 - val_mae: 3
7.1463
Epoch 68/200
7/7 [==============================] - 0s 6ms/step - loss: 534.1434 - mae: 16.5373 - val_loss: 1629.7252 - val_mae: 3
4.5360
Epoch 69/200
7/7 [==============================] - 0s 7ms/step - loss: 466.0358 - mae: 15.4875 - val_loss: 1607.3667 - val_mae: 3
5.1490
Epoch 70/200
7/7 [==============================] - 0s 7ms/step - loss: 397.6246 - mae: 14.3059 - val_loss: 1348.8110 - val_mae: 3
1.8144
Epoch 71/200
7/7 [==============================] - 0s 6ms/step - loss: 318.6679 - mae: 13.2113 - val_loss: 1025.5934 - val_mae: 2
7.4736
Epoch 72/200
7/7 [==============================] - 0s 7ms/step - loss: 296.2066 - mae: 12.7514 - val_loss: 1186.6624 - val_mae: 2
9.3891
Epoch 73/200
7/7 [==============================] - 0s 6ms/step - loss: 268.2089 - mae: 11.8971 - val_loss: 1273.9451 - val_mae: 3
0.5494
Epoch 74/200
```

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7/7 [==============================] - 0s 7ms/step - loss: 290.8217 - mae: 12.2309 - val_loss: 1243.6671 - val_mae: 2
9.4629
Epoch 75/200
7/7 [==============================] - 0s 6ms/step - loss: 346.3158 - mae: 13.1665 - val_loss: 1286.4222 - val_mae: 2
9.6737
Epoch 76/200
7/7 [==============================] - 0s 6ms/step - loss: 283.6451 - mae: 12.1458 - val_loss: 1036.8300 - val_mae: 2
5.7442
Epoch 77/200
7/7 [==============================] - 0s 7ms/step - loss: 317.7342 - mae: 12.5287 - val_loss: 1055.5438 - val_mae: 2
6.3531
Epoch 78/200
7/7 [==============================] - 0s 6ms/step - loss: 263.6926 - mae: 11.6520 - val_loss: 1198.8096 - val_mae: 2
9.1692
Epoch 79/200
7/7 [==============================] - 0s 6ms/step - loss: 260.5964 - mae: 11.3588 - val_loss: 1176.7489 - val_mae: 2
8.7802
Epoch 80/200
7/7 [==============================] - 0s 7ms/step - loss: 239.0339 - mae: 11.1812 - val_loss: 1223.4664 - val_mae: 2
9.3884
Epoch 81/200
7/7 [==============================] - 0s 6ms/step - loss: 236.4848 - mae: 11.0778 - val_loss: 1241.4824 - val_mae: 2
9.9211
Epoch 82/200
7/7 [==============================] - 0s 6ms/step - loss: 212.1409 - mae: 10.6325 - val_loss: 730.1008 - val_mae: 2
2.4998
Epoch 83/200
7/7 [==============================] - 0s 7ms/step - loss: 199.7742 - mae: 10.5116 - val_loss: 683.3707 - val_mae: 2
2.1765
Epoch 84/200
7/7 [==============================] - 0s 7ms/step - loss: 205.4158 - mae: 10.7177 - val_loss: 696.4572 - val_mae: 2
1.8011
Epoch 85/200
7/7 [==============================] - 0s 6ms/step - loss: 190.6532 - mae: 10.2982 - val_loss: 1133.9598 - val_mae: 2
7.0053
Epoch 86/200
7/7 [==============================] - 0s 7ms/step - loss: 201.3937 - mae: 10.4538 - val_loss: 942.1794 - val_mae: 2
5.1690
Epoch 87/200
7/7 [==============================] - 0s 7ms/step - loss: 182.8247 - mae: 10.2161 - val_loss: 676.4190 - val_mae: 2
1.9538
Epoch 88/200
7/7 [==============================] - 0s 7ms/step - loss: 194.8958 - mae: 10.4941 - val_loss: 520.0002 - val_mae: 1
8.4207
```

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Epoch 89/200
7/7 [==============================] - 0s 7ms/step - loss: 178.7389 - mae: 9.9785 - val_loss: 1014.9097 - val_mae: 2
4.7021
Epoch 90/200
7/7 [==============================] - 0s 6ms/step - loss: 187.5445 - mae: 10.2146 - val_loss: 767.5543 - val_mae: 2
2.9489
Epoch 91/200
7/7 [==============================] - 0s 7ms/step - loss: 176.7797 - mae: 9.9008 - val_loss: 779.0991 - val_mae: 21.
4984
Epoch 92/200
7/7 [==============================] - 0s 7ms/step - loss: 168.5827 - mae: 9.6990 - val_loss: 806.5342 - val_mae: 20.
5409
Epoch 93/200
7/7 [==============================] - 0s 6ms/step - loss: 176.4620 - mae: 10.0428 - val_loss: 744.2365 - val_mae: 2
0.0158
Epoch 94/200
7/7 [==============================] - 0s 6ms/step - loss: 163.8174 - mae: 9.5145 - val_loss: 888.5566 - val_mae: 24.
1045
Epoch 95/200
7/7 [==============================] - 0s 7ms/step - loss: 153.3220 - mae: 9.3153 - val_loss: 886.6606 - val_mae: 23.
0305
Epoch 96/200
7/7 [==============================] - 0s 6ms/step - loss: 208.3719 - mae: 9.7210 - val_loss: 840.4622 - val_mae: 23.
1483
Epoch 97/200
7/7 [==============================] - 0s 6ms/step - loss: 165.8179 - mae: 9.5515 - val_loss: 841.6387 - val_mae: 22.
8902
Epoch 98/200
7/7 [==============================] - 0s 7ms/step - loss: 188.0052 - mae: 10.0485 - val_loss: 787.9429 - val_mae: 2
2.5584
Epoch 99/200
7/7 [==============================] - 0s 6ms/step - loss: 181.9577 - mae: 9.9393 - val_loss: 648.7883 - val_mae: 22.
0313
Epoch 100/200
7/7 [==============================] - 0s 7ms/step - loss: 168.5907 - mae: 9.3653 - val_loss: 670.6946 - val_mae: 22.
2663
Epoch 101/200
7/7 [==============================] - 0s 7ms/step - loss: 198.7273 - mae: 10.0647 - val_loss: 984.1375 - val_mae: 2
3.9586
Epoch 102/200
7/7 [==============================] - 0s 6ms/step - loss: 172.9360 - mae: 9.3033 - val_loss: 562.4014 - val_mae: 20.
0062
Epoch 103/200
7/7 [==============================] - 0s 6ms/step - loss: 212.4843 - mae: 10.0745 - val_loss: 568.9857 - val_mae: 1
```

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9.7555
Epoch 104/200
7/7 [==============================] - 0s 6ms/step - loss: 180.8204 - mae: 9.6962 - val_loss: 932.1662 - val_mae: 23.
8290
Epoch 105/200
7/7 [==============================] - 0s 6ms/step - loss: 209.5091 - mae: 10.0310 - val_loss: 476.8307 - val_mae: 1
8.0474
Epoch 106/200
7/7 [==============================] - 0s 7ms/step - loss: 236.0049 - mae: 10.3998 - val_loss: 1721.5923 - val_mae: 3
1.8281
Epoch 107/200
7/7 [==============================] - 0s 6ms/step - loss: 249.6803 - mae: 10.8182 - val_loss: 1119.9325 - val_mae: 2
6.2668
Epoch 108/200
7/7 [==============================] - 0s 7ms/step - loss: 331.5683 - mae: 11.9717 - val_loss: 608.0137 - val_mae: 1
8.8583
Epoch 109/200
7/7 [==============================] - 0s 7ms/step - loss: 206.4697 - mae: 10.3095 - val_loss: 551.8798 - val_mae: 1
8.2668
Epoch 110/200
7/7 [==============================] - 0s 7ms/step - loss: 185.2874 - mae: 9.7190 - val_loss: 649.1539 - val_mae: 20.
0921
Epoch 111/200
7/7 [==============================] - 0s 6ms/step - loss: 200.1067 - mae: 9.7200 - val_loss: 555.6648 - val_mae: 19.
8057
Epoch 112/200
7/7 [==============================] - 0s 7ms/step - loss: 175.5123 - mae: 9.0664 - val_loss: 385.0868 - val_mae: 15.
6407
Epoch 113/200
7/7 [==============================] - 0s 6ms/step - loss: 146.3047 - mae: 8.5572 - val_loss: 504.7954 - val_mae: 17.
0845
Epoch 114/200
7/7 [==============================] - 0s 7ms/step - loss: 155.2187 - mae: 8.8572 - val_loss: 492.3217 - val_mae: 17.
3074
Epoch 115/200
7/7 [==============================] - 0s 6ms/step - loss: 144.7981 - mae: 8.5748 - val_loss: 429.1494 - val_mae: 16.
8420
Epoch 116/200
7/7 [==============================] - 0s 6ms/step - loss: 142.9027 - mae: 8.1656 - val_loss: 419.4727 - val_mae: 16.
4127
Epoch 117/200
7/7 [==============================] - 0s 7ms/step - loss: 162.8160 - mae: 8.6528 - val_loss: 575.2805 - val_mae: 17.
9724
Epoch 118/200
```

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7/7 [==============================] - 0s 6ms/step - loss: 162.0282 - mae: 8.8848 - val_loss: 732.4465 - val_mae: 19.
6266
Epoch 119/200
7/7 [==============================] - 0s 6ms/step - loss: 160.7242 - mae: 8.6026 - val_loss: 564.3792 - val_mae: 16.
9909
Epoch 120/200
7/7 [==============================] - 0s 7ms/step - loss: 118.2419 - mae: 7.7095 - val_loss: 340.0781 - val_mae: 14.
0362
Epoch 121/200
7/7 [==============================] - 0s 7ms/step - loss: 104.8901 - mae: 7.4408 - val_loss: 283.8978 - val_mae: 12.
7674
Epoch 122/200
7/7 [==============================] - 0s 7ms/step - loss: 107.9041 - mae: 7.4128 - val_loss: 373.1634 - val_mae: 14.
9324
Epoch 123/200
7/7 [==============================] - 0s 7ms/step - loss: 101.6190 - mae: 7.5020 - val_loss: 375.3649 - val_mae: 15.
4826
Epoch 124/200
7/7 [==============================] - 0s 7ms/step - loss: 92.6914 - mae: 7.1930 - val_loss: 489.8348 - val_mae: 16.5
187
Epoch 125/200
7/7 [==============================] - 0s 6ms/step - loss: 95.3217 - mae: 6.9649 - val_loss: 422.0893 - val_mae: 16.1
063
Epoch 126/200
7/7 [==============================] - 0s 7ms/step - loss: 86.6900 - mae: 6.8508 - val_loss: 331.1776 - val_mae: 14.2
809
Epoch 127/200
7/7 [==============================] - 0s 7ms/step - loss: 107.6058 - mae: 7.7552 - val_loss: 501.9572 - val_mae: 16.
8643
Epoch 128/200
7/7 [==============================] - 0s 7ms/step - loss: 191.3374 - mae: 8.6395 - val_loss: 786.5998 - val_mae: 20.
2308
Epoch 129/200
7/7 [==============================] - 0s 6ms/step - loss: 146.6244 - mae: 8.5784 - val_loss: 484.9590 - val_mae: 17.
0233
Epoch 130/200
7/7 [==============================] - 0s 6ms/step - loss: 119.4183 - mae: 8.0134 - val_loss: 344.8965 - val_mae: 13.
9369
Epoch 131/200
7/7 [==============================] - 0s 6ms/step - loss: 88.6186 - mae: 6.7747 - val_loss: 348.5409 - val_mae: 15.1
427
Epoch 132/200
7/7 [==============================] - 0s 6ms/step - loss: 99.9210 - mae: 7.0718 - val_loss: 313.0453 - val_mae: 14.0
132
```

```
Epoch 133/200
7/7 [==============================] - 0s 7ms/step - loss: 87.9264 - mae: 6.6001 - val_loss: 334.7349 - val_mae: 13.4
652
Epoch 134/200
7/7 [==============================] - 0s 7ms/step - loss: 92.8923 - mae: 6.9040 - val_loss: 339.1288 - val_mae: 14.4
049
Epoch 135/200
7/7 [==============================] - 0s 6ms/step - loss: 94.2197 - mae: 6.7712 - val_loss: 333.0982 - val_mae: 14.5
792
Epoch 136/200
7/7 [==============================] - 0s 7ms/step - loss: 101.1998 - mae: 6.9077 - val_loss: 462.0781 - val_mae: 16.
5104
Epoch 137/200
7/7 [==============================] - 0s 6ms/step - loss: 105.8688 - mae: 7.4893 - val_loss: 377.0702 - val_mae: 14.
7366
Epoch 138/200
7/7 [==============================] - 0s 7ms/step - loss: 99.5288 - mae: 7.3126 - val_loss: 355.0748 - val_mae: 14.7
807
Epoch 139/200
7/7 [==============================] - 0s 6ms/step - loss: 87.4042 - mae: 6.5942 - val_loss: 302.4652 - val_mae: 13.9
836
Epoch 140/200
7/7 [==============================] - 0s 7ms/step - loss: 84.5621 - mae: 6.6494 - val_loss: 277.3119 - val_mae: 12.8
127
Epoch 141/200
7/7 [==============================] - 0s 7ms/step - loss: 86.4985 - mae: 6.7545 - val_loss: 285.8305 - val_mae: 12.9
405
Epoch 142/200
7/7 [==============================] - 0s 6ms/step - loss: 76.0025 - mae: 6.2934 - val_loss: 296.4286 - val_mae: 13.7
360
Epoch 143/200
7/7 [==============================] - 0s 7ms/step - loss: 75.8274 - mae: 6.1955 - val_loss: 251.1855 - val_mae: 12.7
256
Epoch 144/200
7/7 [==============================] - 0s 6ms/step - loss: 72.6249 - mae: 6.0639 - val_loss: 249.4112 - val_mae: 12.5
942
Epoch 145/200
7/7 [==============================] - 0s 6ms/step - loss: 70.4459 - mae: 6.0771 - val_loss: 283.5013 - val_mae: 13.0
954
Epoch 146/200
7/7 [==============================] - 0s 7ms/step - loss: 70.8272 - mae: 6.0945 - val_loss: 293.9150 - val_mae: 13.4
963
Epoch 147/200
7/7 [==============================] - 0s 7ms/step - loss: 105.6021 - mae: 6.7693 - val_loss: 258.0522 - val_mae: 12.
```

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3409
Epoch 148/200
7/7 [==============================] - 0s 7ms/step - loss: 91.4409 - mae: 6.4925 - val_loss: 220.2581 - val_mae: 12.2
450
Epoch 149/200
7/7 [==============================] - 0s 7ms/step - loss: 77.8646 - mae: 6.0793 - val_loss: 218.1478 - val_mae: 11.1
314
Epoch 150/200
7/7 [==============================] - 0s 6ms/step - loss: 76.4134 - mae: 6.2347 - val_loss: 357.9958 - val_mae: 13.9
231
Epoch 151/200
7/7 [==============================] - 0s 6ms/step - loss: 78.1180 - mae: 6.4193 - val_loss: 321.1462 - val_mae: 13.8
697
Epoch 152/200
7/7 [==============================] - 0s 6ms/step - loss: 77.5338 - mae: 6.2729 - val_loss: 229.8450 - val_mae: 11.8
732
Epoch 153/200
7/7 [==============================] - 0s 7ms/step - loss: 83.2362 - mae: 6.6844 - val_loss: 260.5413 - val_mae: 12.1
757
Epoch 154/200
7/7 [==============================] - 0s 6ms/step - loss: 86.7071 - mae: 6.9721 - val_loss: 287.2674 - val_mae: 13.6
508
Epoch 155/200
7/7 [==============================] - 0s 7ms/step - loss: 77.2206 - mae: 6.3794 - val_loss: 289.4891 - val_mae: 13.8
133
Epoch 156/200
7/7 [==============================] - 0s 6ms/step - loss: 70.7082 - mae: 6.0694 - val_loss: 279.5529 - val_mae: 13.6
285
Epoch 157/200
7/7 [==============================] - 0s 7ms/step - loss: 70.5220 - mae: 6.0553 - val_loss: 262.7519 - val_mae: 13.6
332
Epoch 158/200
7/7 [==============================] - 0s 7ms/step - loss: 68.3902 - mae: 5.8993 - val_loss: 267.2055 - val_mae: 13.5
506
Epoch 159/200
7/7 [==============================] - 0s 6ms/step - loss: 67.5582 - mae: 5.8978 - val_loss: 280.8753 - val_mae: 13.2
237
Epoch 160/200
7/7 [==============================] - 0s 7ms/step - loss: 67.8948 - mae: 5.9175 - val_loss: 243.7069 - val_mae: 12.4
481
Epoch 161/200
7/7 [==============================] - 0s 6ms/step - loss: 67.4430 - mae: 5.7965 - val_loss: 281.8943 - val_mae: 13.0
255
Epoch 162/200
```
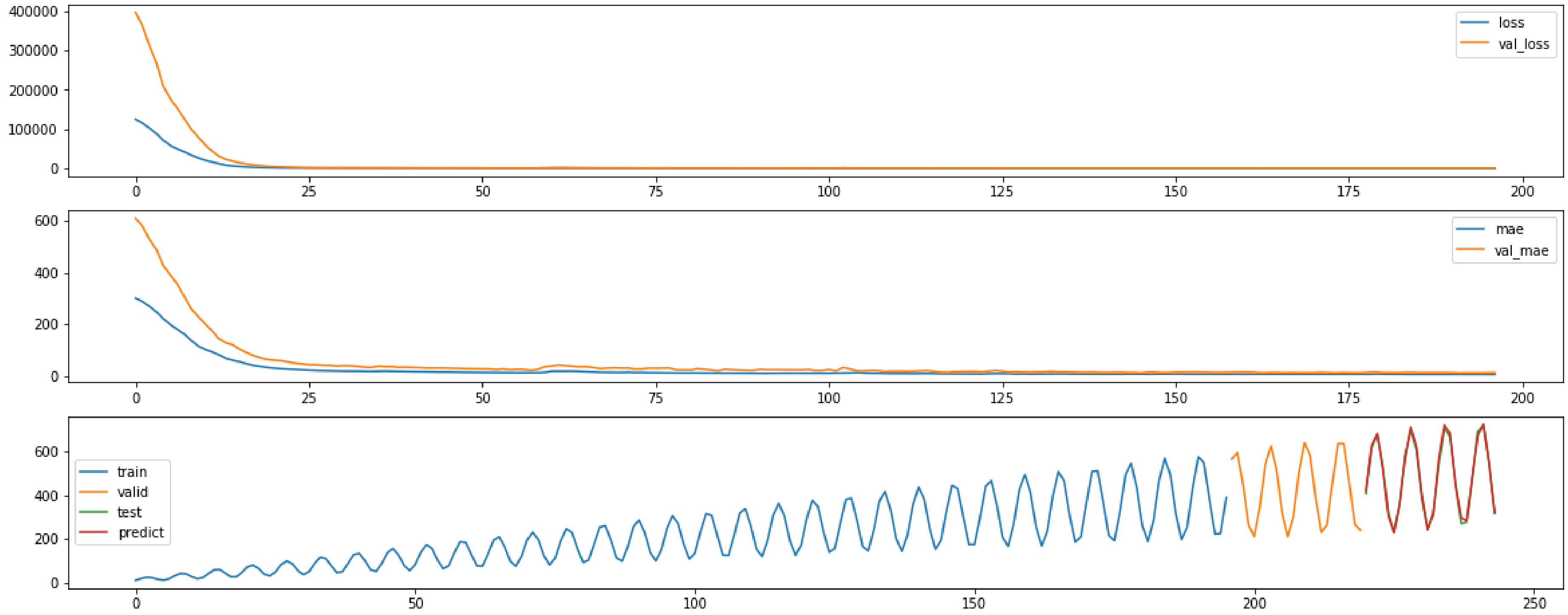

```
7/7 [==============================] - 0s 6ms/step - loss: 69.8804 - mae: 5.9396 - val_loss: 274.3936 - val_mae: 13.1
119
Epoch 163/200
7/7 [==============================] - 0s 7ms/step - loss: 68.6837 - mae: 5.9628 - val_loss: 311.4441 - val_mae: 13.8
576
Epoch 164/200
7/7 [==============================] - 0s 7ms/step - loss: 91.7501 - mae: 6.3134 - val_loss: 281.4620 - val_mae: 14.0
640
Epoch 165/200
7/7 [==============================] - 0s 6ms/step - loss: 88.9831 - mae: 6.3486 - val_loss: 282.3939 - val_mae: 13.9
456
Epoch 166/200
7/7 [==============================] - 0s 6ms/step - loss: 72.0138 - mae: 5.8973 - val_loss: 216.5609 - val_mae: 11.6
914
Epoch 167/200
7/7 [==============================] - 0s 7ms/step - loss: 73.6815 - mae: 6.0534 - val_loss: 241.9126 - val_mae: 11.5
497
Epoch 168/200
7/7 [==============================] - 0s 6ms/step - loss: 64.8598 - mae: 5.9784 - val_loss: 268.7857 - val_mae: 12.5
056
Epoch 169/200
7/7 [==============================] - 0s 7ms/step - loss: 62.1884 - mae: 5.8844 - val_loss: 224.0821 - val_mae: 11.8
705
Epoch 170/200
7/7 [==============================] - 0s 7ms/step - loss: 61.2470 - mae: 5.6820 - val_loss: 216.6689 - val_mae: 11.3
532
Epoch 171/200
7/7 [==============================] - 0s 7ms/step - loss: 58.7734 - mae: 5.5257 - val_loss: 225.7008 - val_mae: 12.0
550
Epoch 172/200
7/7 [==============================] - 0s 6ms/step - loss: 58.8762 - mae: 5.5731 - val_loss: 214.6908 - val_mae: 11.4
521
Epoch 173/200
7/7 [==============================] - 0s 6ms/step - loss: 56.6215 - mae: 5.5240 - val_loss: 229.0426 - val_mae: 11.5
575
Epoch 174/200
7/7 [==============================] - 0s 7ms/step - loss: 58.6300 - mae: 5.6500 - val_loss: 230.1971 - val_mae: 11.8
066
Epoch 175/200
7/7 [==============================] - 0s 7ms/step - loss: 59.7907 - mae: 5.5979 - val_loss: 277.7700 - val_mae: 12.7
922
Epoch 176/200
7/7 [==============================] - 0s 6ms/step - loss: 59.8210 - mae: 5.5400 - val_loss: 217.4957 - val_mae: 11.5
777
```

```
Epoch 177/200
7/7 [==============================] - 0s 7ms/step - loss: 54.9961 - mae: 5.2697 - val_loss: 202.9772 - val_mae: 10.9
278
Epoch 178/200
7/7 [==============================] - 0s 6ms/step - loss: 55.4452 - mae: 5.4441 - val_loss: 214.0706 - val_mae: 11.8
644
Epoch 179/200
7/7 [==============================] - 0s 6ms/step - loss: 53.1047 - mae: 5.3301 - val_loss: 211.4373 - val_mae: 11.4
445
Epoch 180/200
7/7 [==============================] - 0s 7ms/step - loss: 55.0370 - mae: 5.2292 - val_loss: 199.7837 - val_mae: 11.0
036
Epoch 181/200
7/7 [==============================] - 0s 6ms/step - loss: 52.0692 - mae: 5.2630 - val_loss: 228.3790 - val_mae: 11.6
686
Epoch 182/200
7/7 [==============================] - 0s 7ms/step - loss: 67.3093 - mae: 5.8754 - val_loss: 329.9140 - val_mae: 13.6
577
Epoch 183/200
7/7 [==============================] - 0s 6ms/step - loss: 79.8364 - mae: 6.3240 - val_loss: 336.9618 - val_mae: 13.8
085
Epoch 184/200
7/7 [==============================] - 0s 7ms/step - loss: 68.8451 - mae: 6.0821 - val_loss: 229.0139 - val_mae: 11.7
619
Epoch 185/200
7/7 [==============================] - 0s 7ms/step - loss: 61.1183 - mae: 5.6900 - val_loss: 216.9167 - val_mae: 11.5
276
Epoch 186/200
7/7 [==============================] - 0s 7ms/step - loss: 59.9435 - mae: 5.5530 - val_loss: 205.6172 - val_mae: 11.7
059
Epoch 187/200
7/7 [==============================] - 0s 6ms/step - loss: 54.3664 - mae: 5.2628 - val_loss: 232.4635 - val_mae: 12.3
052
Epoch 188/200
7/7 [==============================] - 0s 7ms/step - loss: 56.1097 - mae: 5.4420 - val_loss: 278.3465 - val_mae: 12.9
746
Epoch 189/200
7/7 [==============================] - 0s 6ms/step - loss: 59.9135 - mae: 5.5227 - val_loss: 211.9582 - val_mae: 11.7
329
Epoch 190/200
7/7 [==============================] - 0s 7ms/step - loss: 58.7238 - mae: 5.4492 - val_loss: 245.2475 - val_mae: 12.2
897
Epoch 191/200
7/7 [==============================] - 0s 7ms/step - loss: 62.3396 - mae: 5.5097 - val_loss: 231.9101 - val_mae: 12.0
```

```
131
Epoch 192/200
7/7 [==============================] - 0s 7ms/step - loss: 55.7794 - mae: 5.2299 - val_loss: 209.8985 - val_mae: 11.3
561
Epoch 193/200
7/7 [==============================] - 0s 6ms/step - loss: 57.1633 - mae: 5.4755 - val_loss: 239.5018 - val_mae: 12.0
244
Epoch 194/200
7/7 [==============================] - 0s 6ms/step - loss: 53.5094 - mae: 5.3310 - val_loss: 219.7712 - val_mae: 11.8
357
Epoch 195/200
7/7 [==============================] - 0s 7ms/step - loss: 55.7243 - mae: 5.2887 - val_loss: 192.8791 - val_mae: 10.7
619
Epoch 196/200
7/7 [==============================] - 0s 6ms/step - loss: 55.1635 - mae: 5.4397 - val_loss: 216.6043 - val_mae: 11.2
205
Epoch 197/200
7/7 [==============================] - 0s 6ms/step - loss: 55.4105 - mae: 5.4560 - val_loss: 195.0733 - val_mae: 11.0
912
Epoch 198/200
7/7 [==============================] - 0s 6ms/step - loss: 53.0155 - mae: 5.3075 - val_loss: 199.2735 - val_mae: 11.0
544
Epoch 199/200
7/7 [==============================] - 0s 7ms/step - loss: 56.1641 - mae: 5.5429 - val_loss: 210.3846 - val_mae: 11.6
919
Epoch 200/200
7/7 [==============================] - 0s 7ms/step - loss: 52.0826 - mae: 5.3242 - val_loss: 218.2129 - val_mae: 11.8
261
```



Lab work: Air Pollution Forecasting

This is a dataset that reports on the weather and the level of pollution each hour for five years at the US embassy in Beijing, China.

The data includes the date-time, the pollution called PM2.5 concentration, and the weather information including dew point, temperature, pressure, wind direction, wind speed and the cumulative number of hours of snow and rain. The complete feature list in the raw data is as follows:

1. No: row number
2. year: year of data in this row
3. month: month of data in this row
4. day: day of data in this row
5. hour: hour of data in this row
6. pm2.5: PM2.5 concentration
7. DEWP: Dew Point
8. TEMP: Temperature

9. PRES: Pressure
10. cbwd: Combined wind direction
11. Iws: Cumulated wind speed
12. Is: Cumulated hours of snow
13. Ir: Cumulated hours of rain

We can use this data and frame a forecasting problem where, given the weather conditions and pollution for prior hours, we forecast the pollution at the next hour.

This dataset can be used to frame other forecasting problems.

Load the data

In [ ]:

```
DATAPATH = "https://www.i3s.unice.fr/~riveill/dataset/pollution.csv"
```

In [ ]:

```
# Read the dataset
data = pd.read_csv(DATAPATH, sep=",", header=0, index_col=0)
data.head()
```

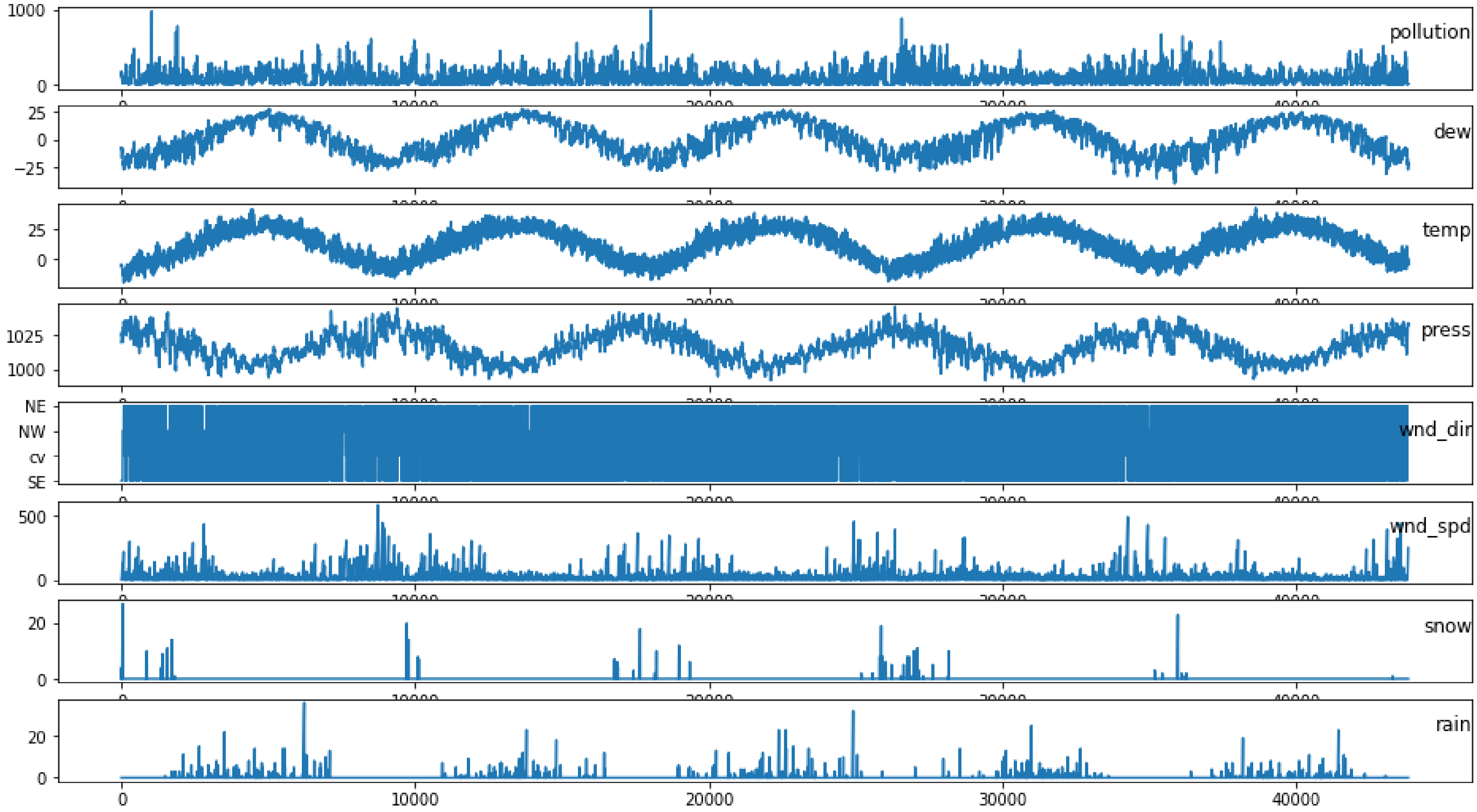
Out[ ]:

	pollution	dew	temp	press	wnd_dir	wnd_spd	snow	rain
date								
2010-01-02 00:00:00	129.0	-16	-4.0	1020.0	SE	1.79	0	0
2010-01-02 01:00:00	148.0	-15	-4.0	1020.0	SE	2.68	0	0
2010-01-02 02:00:00	159.0	-11	-5.0	1021.0	SE	3.57	0	0
2010-01-02 03:00:00	181.0	-7	-5.0	1022.0	SE	5.36	1	0
2010-01-02 04:00:00	138.0	-7	-5.0	1022.0	SE	6.25	2	0

In [ ]:

```
plt.figure(figsize=(16,9))
for i, column in enumerate(data.columns):
    plt.subplot(len(data.columns), 1, i+1)
    plt.plot(data[column].to_numpy())
```

```
    plt.title(column, y=0.5, loc='right')
plt.show()
```



Construct the dataset

The first step is to prepare the pollution dataset for the LSTM.

This involves framing the dataset as a supervised learning problem and normalizing the input variables.

We will frame the supervised learning problem as predicting the pollution at the current hour (t) given the pollution measurement and weather conditions at the prior time step.

In [ ]:

```
n_features = data.shape[1] # for multivariate time series
n_in = 6
n_out = 1
output = ["pollution"]

n_features
```

Out[ ]: 8

TODO − Students

- using `series_to_supervised` function build the dataset

In [ ]:

```
dataset = series_to_supervised(data=data, n_in=n_in, n_out=n_out, output=output)
dataset.head()
```

Out[ ]:

date	pollution(t-6)	dew(t-6)	temp(t-6)	press(t-6)	wnd_dir(t-6)	wnd_spd(t-6)	snow(t-6)	rain(t-6)	pollution(t-5)	dew(t-5)	...	rain(t-2)	pollution(t-1)	dew(t-1)	temp(t-1)	p
2010-01-02 06:00:00	129.0	-16.0	-4.0	1020.0	SE	1.79	0.0	0.0	148.0	-15.0	...	0.0	109.0	-7.0	-6.0	
2010-01-02 07:00:00	148.0	-15.0	-4.0	1020.0	SE	2.68	0.0	0.0	159.0	-11.0	...	0.0	105.0	-7.0	-6.0	
2010-01-02 08:00:00	159.0	-11.0	-5.0	1021.0	SE	3.57	0.0	0.0	181.0	-7.0	...	0.0	124.0	-7.0	-5.0	
2010-01-02 09:00:00	181.0	-7.0	-5.0	1022.0	SE	5.36	1.0	0.0	138.0	-7.0	...	0.0	120.0	-8.0	-6.0	
2010-01-02 10:00:00	138.0	-7.0	-5.0	1022.0	SE	6.25	2.0	0.0	109.0	-7.0	...	0.0	132.0	-7.0	-5.0	

5 rows × 49 columns

In [ ]:

```
dataset.dtypes
```

Out[ ]:
```
pollution(t-6)    float64
dew(t-6)          float64
temp(t-6)         float64
press(t-6)        float64
wnd_dir(t-6)       object
wnd_spd(t-6)      float64
snow(t-6)         float64
rain(t-6)         float64
pollution(t-5)    float64
dew(t-5)          float64
temp(t-5)         float64
press(t-5)        float64
wnd_dir(t-5)       object
wnd_spd(t-5)      float64
snow(t-5)         float64
rain(t-5)         float64
pollution(t-4)    float64
dew(t-4)          float64
temp(t-4)         float64
press(t-4)        float64
wnd_dir(t-4)       object
wnd_spd(t-4)      float64
snow(t-4)         float64
rain(t-4)         float64
pollution(t-3)    float64
dew(t-3)          float64
temp(t-3)         float64
press(t-3)        float64
wnd_dir(t-3)       object
wnd_spd(t-3)      float64
snow(t-3)         float64
rain(t-3)         float64
pollution(t-2)    float64
dew(t-2)          float64
temp(t-2)         float64
press(t-2)        float64
wnd_dir(t-2)       object
wnd_spd(t-2)      float64
snow(t-2)         float64
rain(t-2)         float64
pollution(t-1)    float64
dew(t-1)          float64
temp(t-1)         float64
press(t-1)        float64
```

```
wnd_dir(t-1)       object
wnd_spd(t-1)      float64
snow(t-1)         float64
rain(t-1)         float64
pollution(t)      float64
dtype: object
```

dataset.dtypes gives the following result for me

```
pollution(t-6)    float64
dew(t-6)          float64
temp(t-6)         float64
press(t-6)        float64
wnd_dir(t-6)       object
wnd_spd(t-6)      float64
snow(t-6)         float64
rain(t-6)         float64
pollution(t-5)    float64
dew(t-5)          float64
temp(t-5)         float64
press(t-5)        float64
wnd_dir(t-5)       object
wnd_spd(t-5)      float64
snow(t-5)         float64
rain(t-5)         float64
pollution(t-4)    float64
dew(t-4)          float64
temp(t-4)         float64
press(t-4)        float64
wnd_dir(t-4)       object
wnd_spd(t-4)      float64
snow(t-4)         float64
rain(t-4)         float64
pollution(t-3)    float64
dew(t-3)          float64
temp(t-3)         float64
press(t-3)        float64
wnd_dir(t-3)       object
wnd_spd(t-3)      float64
```

```
snow(t-3)          float64
rain(t-3)          float64
pollution(t-2)     float64
dew(t-2)           float64
temp(t-2)          float64
press(t-2)         float64
wnd_dir(t-2)        object
wnd_spd(t-2)       float64
snow(t-2)          float64
rain(t-2)          float64
pollution(t-1)     float64
dew(t-1)           float64
temp(t-1)          float64
press(t-1)         float64
wnd_dir(t-1)        object
wnd_spd(t-1)       float64
snow(t-1)          float64
rain(t-1)          float64
pollution(t)       float64
dtype: object
```

```
</font>
```

First, we must split the prepared dataset into train and test sets. To speed up the training of the model for this demonstration, we will only fit the model on the first year of data, then evaluate it on the remaining 4 years of data.

The example below splits the dataset into train and test sets, then splits the train and test sets into input and output variables. Finally, the inputs (X) are reshaped into the 3D format expected by LSTMs, namely [samples, timesteps, features].

In [ ]:

```
# get the values
values = dataset.values

# split into train and test sets
n_train_hours = 365 * 24
train = values[:n_train_hours, :]
```

```
val = values[n_train_hours:2*n_train_hours, :]
test = values[2*n_train_hours:, :]

# split into input and outputs
train_X, train_y = train[:, :-n_out], np.array(train[:, -n_out], dtype="float64")
val_X, val_y = val[:, :-n_out], np.array(val[:, -n_out], dtype="float64")
test_X, test_y = test[:, :-n_out], np.array(test[:, -n_out], dtype="float64")

# reshape input to be 3D [samples, timesteps, features]
train_X = train_X.reshape((train_X.shape[0], n_in, n_features))
val_X = val_X.reshape((val_X.shape[0], n_in, n_features))
test_X = test_X.reshape((test_X.shape[0], n_in, n_features))
train_X.shape, train_y.shape
```

Out[ ]:
```
((8760, 6, 8), (8760,))
```

Encode and normalize dataset

Data encoding and normalization

- The wind direction feature is label encoded (integer encoded).
- All features are normalized

And then the dataset is transformed into a supervised learning problem. The weather variables for the hour to be predicted (t) are then removed.

In [ ]:
```
numeric_features = [
    i for i, t in enumerate(dataset.dtypes[:-n_out]) if t in ["float64", "int32"]
]
numeric_transformer = Pipeline(
    steps=[("imputer", SimpleImputer(strategy="median")), ("scaler", StandardScaler())]
)

categorical_features = [
    i for i in range(len(dataset.columns) - n_out) if i not in numeric_features
]
categorical_transformer = OneHotEncoder(handle_unknown="ignore")

preprocessor = ColumnTransformer(
    transformers=[
        ("num", numeric_transformer, numeric_features),
        ("cat", categorical_transformer, categorical_features),
```

```
    ]
)

train_X_enc = preprocessor.fit_transform(train_X.reshape(len(train_X), -1)).reshape(
    len(train_X), n_in, -1
)
val_X_enc = preprocessor.fit_transform(val_X.reshape(len(val_X), -1)).reshape(
    len(val_X), n_in, -1
)
test_X_enc = preprocessor.transform(test_X.reshape(len(test_X), -1)).reshape(
    len(test_X), n_in, -1
)

n_features = train_X_enc.shape[2]  # Change with oneHotEncode
n_features
```

Out[ ]:

```
11
```

Running the code below prepare the data. Executing the next cell, prints the first 5 rows of the transformed dataset. We can see the 8 input variables (input series) and the 1 output variable (pollution level at the current hour).

Build, Compile, Fit, Predict and Evaluate a model

TODO − Students

- Build your model
  - Put the number of hidden layers you want. If possible more than one.

In [ ]:

```
LSTM_SIZE = 256

inputs = Input(shape=(n_in, n_features))
hidden = LSTM(LSTM_SIZE, return_sequences=False, activation="relu")(inputs)
outputs = Dense(n_out, activation="linear")(hidden)

model = Model(inputs=inputs, outputs=outputs)
model.summary()
```

```
Model: "model_3"
_________________________________________________________________
 Layer (type)                Output Shape              Param #   
=================================================================
 input_4 (InputLayer)        [(None, 6, 11)]           0         
                                                                 
 lstm_5 (LSTM)               (None, 256)               274432    
                                                                 
 dense_3 (Dense)             (None, 1)                 257       
                                                                 
=================================================================
Total params: 274,689
Trainable params: 274,689
Non-trainable params: 0
_________________________________________________________________
```

TODO − Students

- Compile your model

TODO − Students

- Fit your model using `EarlyStopping`

TODO − Students

- Plot learning curve

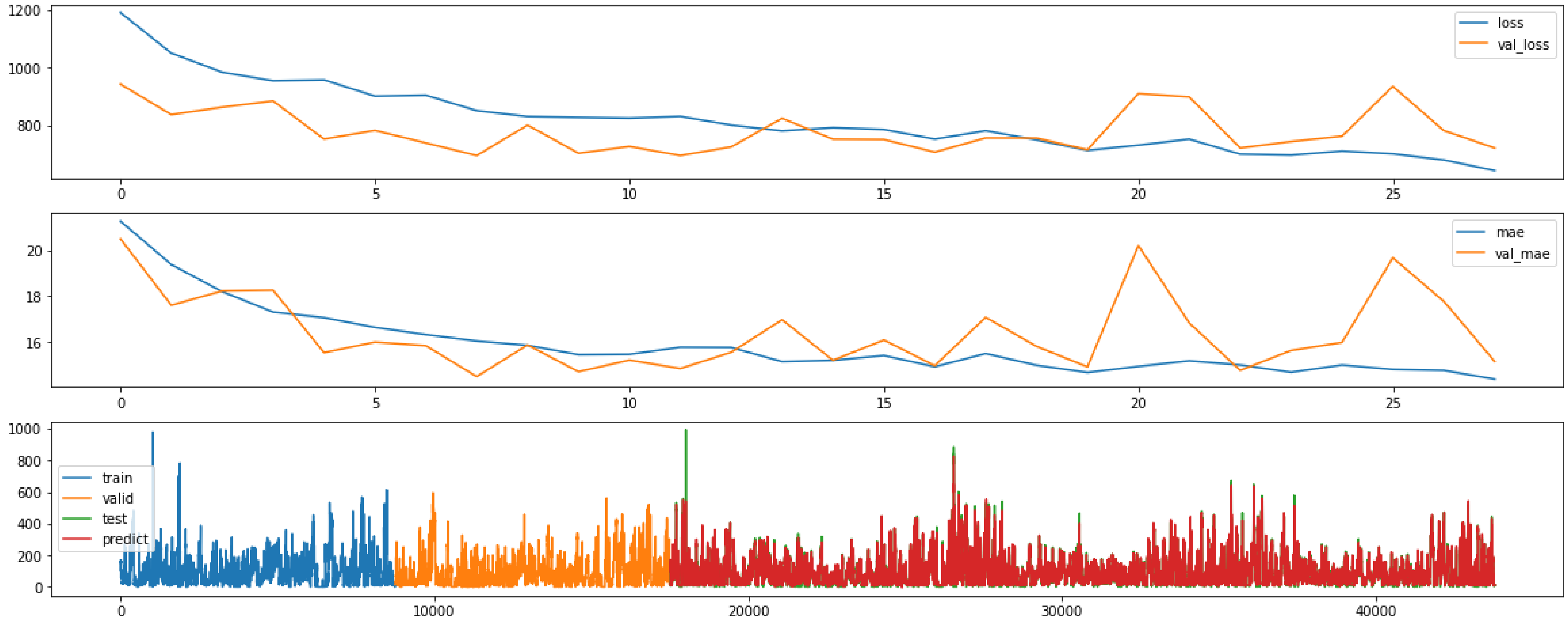
In [ ]:

```python
# compile, fit and plot
model = build_and_fit(model, train_X_enc, train_y, val_X_enc, val_y, test_X_enc, test_y, patience=20)
```

```
Epoch 1/200
274/274 [==============================] - 5s 14ms/step - loss: 5852.9771 - mae: 50.7565 - val_loss: 2075.3853 - val_
mae: 31.8709
Epoch 2/200
274/274 [==============================] - 4s 13ms/step - loss: 1835.5854 - mae: 28.7051 - val_loss: 1347.2808 - val_
mae: 25.8883
Epoch 3/200
274/274 [==============================] - 4s 13ms/step - loss: 1420.8790 - mae: 24.3021 - val_loss: 948.5038 - val_m
ae: 20.5113
Epoch 4/200
274/274 [==============================] - 5s 18ms/step - loss: 1190.9977 - mae: 21.2652 - val_loss: 942.9671 - val_m
ae: 20.4938
Epoch 5/200
274/274 [==============================] - 4s 14ms/step - loss: 1050.4246 - mae: 19.3769 - val_loss: 837.1230 - val_m
ae: 17.6048
Epoch 6/200
274/274 [==============================] - 4s 13ms/step - loss: 984.3455 - mae: 18.1973 - val_loss: 862.9943 - val_ma
e: 18.2300
Epoch 7/200
274/274 [==============================] - 4s 14ms/step - loss: 954.9193 - mae: 17.3077 - val_loss: 884.5645 - val_ma
e: 18.2607
Epoch 8/200
274/274 [==============================] - 4s 13ms/step - loss: 957.8227 - mae: 17.0630 - val_loss: 752.5789 - val_ma
e: 15.5426
Epoch 9/200
274/274 [==============================] - 4s 13ms/step - loss: 901.2725 - mae: 16.6387 - val_loss: 782.6058 - val_ma
e: 15.9985
Epoch 10/200
274/274 [==============================] - 4s 13ms/step - loss: 904.4350 - mae: 16.3248 - val_loss: 739.1362 - val_ma
e: 15.8439
Epoch 11/200
274/274 [==============================] - 4s 13ms/step - loss: 850.8406 - mae: 16.0458 - val_loss: 695.4974 - val_ma
e: 14.4974
Epoch 12/200
274/274 [==============================] - 4s 13ms/step - loss: 830.5386 - mae: 15.8581 - val_loss: 800.9019 - val_ma
e: 15.8724
Epoch 13/200
274/274 [==============================] - 4s 13ms/step - loss: 827.6859 - mae: 15.4516 - val_loss: 703.4142 - val_ma
e: 14.7106
Epoch 14/200
274/274 [==============================] - 4s 13ms/step - loss: 825.0293 - mae: 15.4678 - val_loss: 726.8975 - val_ma
e: 15.2156
Epoch 15/200
274/274 [==============================] - 4s 13ms/step - loss: 831.0204 - mae: 15.7739 - val_loss: 695.5851 - val_ma
```

```
e: 14.8492
Epoch 16/200
274/274 [==============================] - 4s 14ms/step - loss: 801.0826 - mae: 15.7639 - val_loss: 725.3162 - val_ma
e: 15.5546
Epoch 17/200
274/274 [==============================] - 4s 13ms/step - loss: 781.0113 - mae: 15.1505 - val_loss: 824.4551 - val_ma
e: 16.9702
Epoch 18/200
274/274 [==============================] - 4s 13ms/step - loss: 792.2919 - mae: 15.2062 - val_loss: 752.0257 - val_ma
e: 15.2084
Epoch 19/200
274/274 [==============================] - 4s 13ms/step - loss: 785.8606 - mae: 15.4155 - val_loss: 750.9403 - val_ma
e: 16.0889
Epoch 20/200
274/274 [==============================] - 4s 13ms/step - loss: 752.3456 - mae: 14.9268 - val_loss: 707.3210 - val_ma
e: 14.9737
Epoch 21/200
274/274 [==============================] - 4s 13ms/step - loss: 781.5649 - mae: 15.5014 - val_loss: 756.4364 - val_ma
e: 17.0761
Epoch 22/200
274/274 [==============================] - 4s 13ms/step - loss: 749.2809 - mae: 14.9908 - val_loss: 755.9730 - val_ma
e: 15.8118
Epoch 23/200
274/274 [==============================] - 4s 14ms/step - loss: 713.4810 - mae: 14.6749 - val_loss: 715.6923 - val_ma
e: 14.9230
Epoch 24/200
274/274 [==============================] - 4s 14ms/step - loss: 731.4194 - mae: 14.9425 - val_loss: 910.2025 - val_ma
e: 20.2004
Epoch 25/200
274/274 [==============================] - 4s 14ms/step - loss: 752.2016 - mae: 15.1849 - val_loss: 898.5101 - val_ma
e: 16.8313
Epoch 26/200
274/274 [==============================] - 4s 14ms/step - loss: 700.2936 - mae: 15.0043 - val_loss: 721.6417 - val_ma
e: 14.7679
Epoch 27/200
274/274 [==============================] - 4s 14ms/step - loss: 696.9597 - mae: 14.6851 - val_loss: 743.8956 - val_ma
e: 15.6340
Epoch 28/200
274/274 [==============================] - 4s 13ms/step - loss: 710.9238 - mae: 15.0031 - val_loss: 762.4767 - val_ma
e: 15.9832
Epoch 29/200
274/274 [==============================] - 4s 14ms/step - loss: 701.3711 - mae: 14.8098 - val_loss: 935.2047 - val_ma
e: 19.6713
Epoch 30/200
```

```
274/274 [==============================] - 4s 14ms/step - loss: 679.9806 - mae: 14.7658 - val_loss: 781.9975 - val_ma
e: 17.7752
Epoch 31/200
270/274 [============================>.] - ETA: 0s - loss: 648.0208 - mae: 14.4144Restoring model weights from the en
d of the best epoch: 11.
274/274 [==============================] - 4s 14ms/step - loss: 643.0889 - mae: 14.3838 - val_loss: 721.6323 - val_ma
e: 15.1601
Epoch 00031: early stopping
```



TODO − Students

- Use your model to predict test set data

In [ ]:

```
# make a prediction
y_test_pred = model.predict(test_X_enc)
y_test_pred
```

Out[ ]:
```
array([[100.44802 ],
       [103.99348 ],
       [105.48278 ],
       ...,
       [ 12.932031],
       [ 14.003244],
       [ 13.519533]], dtype=float32)
```

TODO − Students

- Evaluate your model with RMSA

In [ ]:
```
# calculate RMSE
rmse = np.sqrt(np.mean((y_test_pred.flatten() - test_y.flatten())**2))
print(f"Test RMSE: {rmse}")
```

```
Test RMSE: 26.458723208132696
```

Predict next day

Generally, what we are trying to predict is a pollution indicator for the day or per 12-hour period.

Modify the datasets to create a new column giving a pollution indicator per half day: little pollution, moderate pollution, heavy pollution.

We make a `date_id` column of shape YYYYMMDD with padding zeros on the left to make sure that:

- years have 4 characters
- months have 2 characters
- days have 2 characters

We also add a digit indicating whether the given hour is in the morning or in the afternoon.

In [ ]:
```
data.index = pd.to_datetime(data.index)
idx = data.index


def date_to_id(date):
    """converts a date to its id"""
```

```
    return (
        str(date.year).zfill(4)
        + str(date.month).zfill(2)
        + str(date.day).zfill(2)
        + str(int(date.hour >= 12))  # 0 if morning, else 1
    )


# Convert dates to date id's
day_id = pd.Series(idx).apply(date_to_id)

# Convert to list, otherwise all entries become nan when added to the df
data["day_id"] = day_id.values

# Group data by max of `day_id` instead of something like mean
# because it is common in meteorology to consider whether a certain threshold is passed,
# rather than the mean over hour.
grouped_data = data.groupby("day_id").max()
print(f"\n---> Data grouped by day id\n{grouped_data.head()}")

pollution_halfday = grouped_data.copy()["pollution"].to_dict()
print(f"\n---> Dictionary conveting day id to max pollution that halfday:\n{pollution_halfday}")

data["pollution"] = [pollution_halfday[idx] for idx in data["day_id"]]
data = data.drop(columns="day_id")
data.head(20)
```

```
---> Data grouped by day id
           pollution  dew  temp   press wnd_dir  wnd_spd  snow  rain
day_id
201001020      181.0   -7  -4.0  1026.0      SE    20.56     4     0
201001021      170.0   -7  -5.0  1028.0      SE    55.43     3     0
201001030       98.0   -7  -6.0  1027.0      SE   102.80    16     0
201001031      107.0  -10  -9.0  1023.0      cv   127.84    27     0
201001040       79.0  -14  -9.0  1031.0      NW   108.61     0     0

---> Dictionary conveting day id to max pollution that halfday:
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Out[ ]:

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2010-01-02 01:00:00	181.0	-15	-4.0	1020.0	SE	2.68	0	0
2010-01-02 02:00:00	181.0	-11	-5.0	1021.0	SE	3.57	0	0
2010-01-02 03:00:00	181.0	-7	-5.0	1022.0	SE	5.36	1	0
2010-01-02 04:00:00	181.0	-7	-5.0	1022.0	SE	6.25	2	0
2010-01-02 05:00:00	181.0	-7	-6.0	1022.0	SE	7.14	3	0
2010-01-02 06:00:00	181.0	-7	-6.0	1023.0	SE	8.93	4	0
2010-01-02 07:00:00	181.0	-7	-5.0	1024.0	SE	10.72	0	0
2010-01-02 08:00:00	181.0	-8	-6.0	1024.0	SE	12.51	0	0
2010-01-02 09:00:00	181.0	-7	-5.0	1025.0	SE	14.30	0	0
2010-01-02 10:00:00	181.0	-7	-5.0	1026.0	SE	17.43	1	0
2010-01-02 11:00:00	181.0	-8	-5.0	1026.0	SE	20.56	0	0
2010-01-02 12:00:00	170.0	-8	-5.0	1026.0	SE	23.69	0	0
2010-01-02 13:00:00	170.0	-8	-5.0	1025.0	SE	27.71	0	0
2010-01-02 14:00:00	170.0	-9	-5.0	1025.0	SE	31.73	0	0
2010-01-02 15:00:00	170.0	-9	-5.0	1025.0	SE	35.75	0	0
2010-01-02 16:00:00	170.0	-9	-5.0	1026.0	SE	37.54	0	0
2010-01-02 17:00:00	170.0	-8	-5.0	1027.0	SE	39.33	0	0
2010-01-02 18:00:00	170.0	-8	-5.0	1027.0	SE	42.46	0	0
2010-01-02 19:00:00	170.0	-8	-5.0	1028.0	SE	44.25	0	0

In [ ]:

```
train_y
```

Out[ ]:
```
array([105., 124., 120., ...,  19.,  18.,  17.])
```

In [ ]:
```
# get the values
dataset = series_to_supervised(data=data, n_in=n_in, n_out=n_out, output=output)
values = dataset.values

# split into train and test sets
n_train_hours = 365 * 24
train = values[:n_train_hours, :]
val = values[n_train_hours:2*n_train_hours, :]
test = values[2*n_train_hours:, :]

# redefine y values (X doesn't change)
train_y = np.array(train[:, -n_out], dtype="float64")
val_y = np.array(val[:, -n_out], dtype="float64")
test_y = np.array(test[:, -n_out], dtype="float64")
```

In [ ]:
```
train_y.shape
```

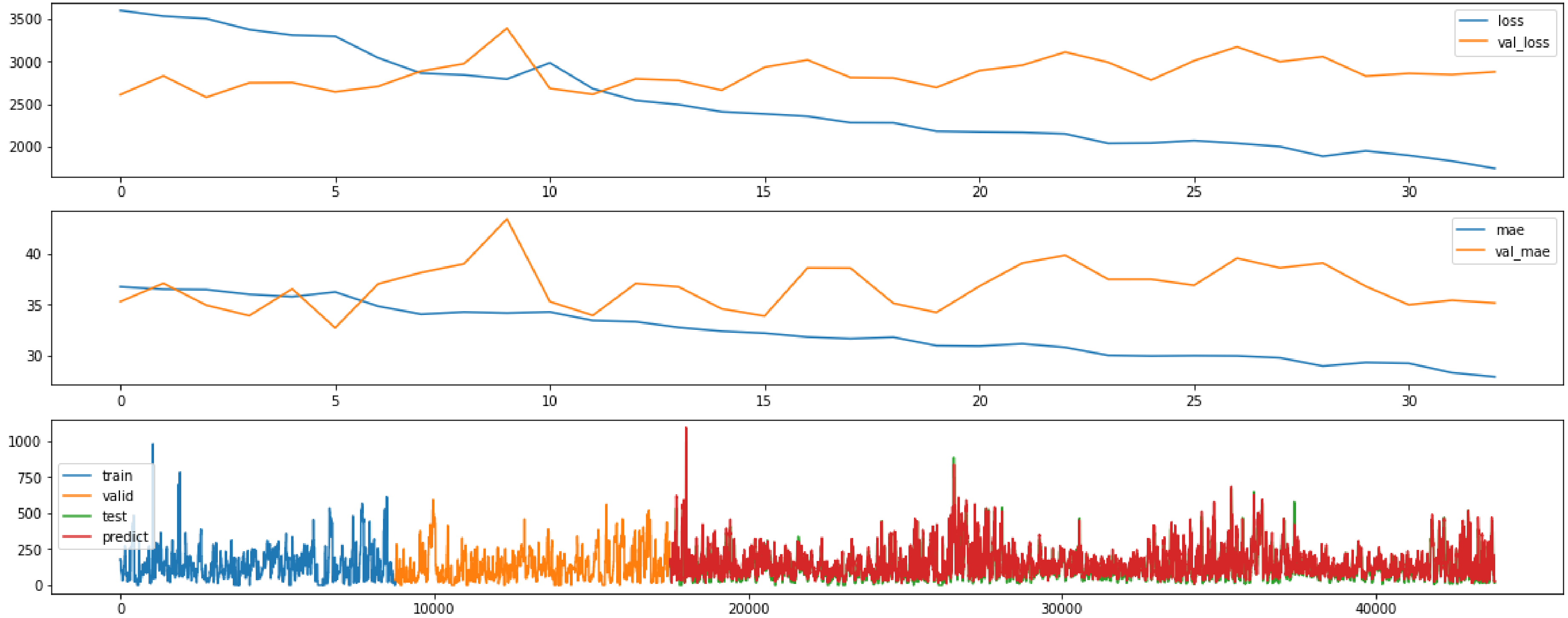
Out[ ]:
```
(8760,)
```

In [ ]:
```
history = build_and_fit(model, train_X_enc, train_y, val_X_enc, val_y, test_X_enc, test_y, patience=30)
```

```
Epoch 1/200
274/274 [==============================] - 5s 14ms/step - loss: 4341.6489 - mae: 40.6727 - val_loss: 2806.9192 - val_
mae: 36.6373
Epoch 2/200
274/274 [==============================] - 4s 14ms/step - loss: 3881.0681 - mae: 38.1534 - val_loss: 2781.7661 - val_
mae: 38.6805
Epoch 3/200
274/274 [==============================] - 4s 14ms/step - loss: 3780.3513 - mae: 37.6216 - val_loss: 2648.6038 - val_
mae: 33.4959
Epoch 4/200
274/274 [==============================] - 4s 13ms/step - loss: 3601.2224 - mae: 36.7459 - val_loss: 2613.6489 - val_
mae: 35.2939
Epoch 5/200
274/274 [==============================] - 4s 14ms/step - loss: 3534.2729 - mae: 36.5019 - val_loss: 2832.3269 - val_
mae: 37.0781
Epoch 6/200
274/274 [==============================] - 4s 14ms/step - loss: 3504.9402 - mae: 36.4668 - val_loss: 2581.7112 - val_
mae: 34.9387
Epoch 7/200
274/274 [==============================] - 4s 14ms/step - loss: 3376.7659 - mae: 36.0001 - val_loss: 2751.2869 - val_
mae: 33.9130
Epoch 8/200
274/274 [==============================] - 4s 14ms/step - loss: 3311.9011 - mae: 35.7674 - val_loss: 2754.0725 - val_
mae: 36.5352
Epoch 9/200
274/274 [==============================] - 4s 14ms/step - loss: 3297.9763 - mae: 36.2307 - val_loss: 2645.4460 - val_
mae: 32.7245
Epoch 10/200
274/274 [==============================] - 4s 14ms/step - loss: 3045.0774 - mae: 34.8405 - val_loss: 2709.6562 - val_
mae: 37.0198
Epoch 11/200
274/274 [==============================] - 4s 14ms/step - loss: 2864.2249 - mae: 34.0556 - val_loss: 2888.1404 - val_
mae: 38.1343
Epoch 12/200
274/274 [==============================] - 4s 14ms/step - loss: 2843.4382 - mae: 34.2647 - val_loss: 2976.7485 - val_
mae: 38.9867
Epoch 13/200
274/274 [==============================] - 4s 15ms/step - loss: 2794.6609 - mae: 34.1672 - val_loss: 3392.9465 - val_
mae: 43.3789
Epoch 14/200
274/274 [==============================] - 4s 14ms/step - loss: 2986.0457 - mae: 34.2734 - val_loss: 2685.6963 - val_
mae: 35.2863
Epoch 15/200
274/274 [==============================] - 4s 14ms/step - loss: 2682.6470 - mae: 33.4421 - val_loss: 2617.4180 - val_
```

```
mae: 33.9405
Epoch 16/200
274/274 [==============================] - 4s 14ms/step - loss: 2543.9031 - mae: 33.3319 - val_loss: 2798.0918 - val_
mae: 37.0641
Epoch 17/200
274/274 [==============================] - 4s 14ms/step - loss: 2495.1440 - mae: 32.7615 - val_loss: 2779.3489 - val_
mae: 36.7336
Epoch 18/200
274/274 [==============================] - 4s 14ms/step - loss: 2411.2231 - mae: 32.4010 - val_loss: 2664.0498 - val_
mae: 34.5824
Epoch 19/200
274/274 [==============================] - 4s 14ms/step - loss: 2386.3647 - mae: 32.2072 - val_loss: 2935.3103 - val_
mae: 33.8812
Epoch 20/200
274/274 [==============================] - 4s 14ms/step - loss: 2358.1919 - mae: 31.8309 - val_loss: 3019.9297 - val_
mae: 38.5889
Epoch 21/200
274/274 [==============================] - 4s 14ms/step - loss: 2283.5708 - mae: 31.6663 - val_loss: 2813.4734 - val_
mae: 38.5736
Epoch 22/200
274/274 [==============================] - 4s 14ms/step - loss: 2281.7622 - mae: 31.8098 - val_loss: 2807.8555 - val_
mae: 35.1241
Epoch 23/200
274/274 [==============================] - 4s 14ms/step - loss: 2181.7986 - mae: 30.9827 - val_loss: 2696.4172 - val_
mae: 34.2250
Epoch 24/200
274/274 [==============================] - 4s 14ms/step - loss: 2173.0881 - mae: 30.9408 - val_loss: 2894.8572 - val_
mae: 36.7958
Epoch 25/200
274/274 [==============================] - 4s 14ms/step - loss: 2167.9836 - mae: 31.1667 - val_loss: 2958.2842 - val_
mae: 39.0546
Epoch 26/200
274/274 [==============================] - 4s 14ms/step - loss: 2151.1753 - mae: 30.8124 - val_loss: 3112.9783 - val_
mae: 39.8250
Epoch 27/200
274/274 [==============================] - 4s 14ms/step - loss: 2040.1875 - mae: 30.0310 - val_loss: 2992.1992 - val_
mae: 37.4756
Epoch 28/200
274/274 [==============================] - 4s 14ms/step - loss: 2044.1036 - mae: 29.9696 - val_loss: 2783.8174 - val_
mae: 37.4765
Epoch 29/200
274/274 [==============================] - 4s 14ms/step - loss: 2071.8906 - mae: 30.0016 - val_loss: 3010.5815 - val_
mae: 36.8882
Epoch 30/200
```

```
274/274 [==============================] - 4s 14ms/step - loss: 2041.0192 - mae: 29.9798 - val_loss: 3174.0178 - val_
mae: 39.5373
Epoch 31/200
274/274 [==============================] - 4s 14ms/step - loss: 2002.2523 - mae: 29.7937 - val_loss: 2999.1714 - val_
mae: 38.5956
Epoch 32/200
274/274 [==============================] - 4s 15ms/step - loss: 1889.0518 - mae: 28.9870 - val_loss: 3059.0854 - val_
mae: 39.0660
Epoch 33/200
274/274 [==============================] - 4s 14ms/step - loss: 1952.1411 - mae: 29.3395 - val_loss: 2829.9973 - val_
mae: 36.7832
Epoch 34/200
274/274 [==============================] - 4s 14ms/step - loss: 1899.0592 - mae: 29.2621 - val_loss: 2861.8423 - val_
mae: 34.9776
Epoch 35/200
274/274 [==============================] - 4s 14ms/step - loss: 1832.2327 - mae: 28.3375 - val_loss: 2847.5229 - val_
mae: 35.4257
Epoch 36/200
271/274 [============================>.] - ETA: 0s - loss: 1745.5133 - mae: 27.9008Restoring model weights from the e
nd of the best epoch: 6.
274/274 [==============================] - 4s 14ms/step - loss: 1745.8982 - mae: 27.9298 - val_loss: 2880.3237 - val_
mae: 35.1554
Epoch 00036: early stopping
```



In [ ]:

```
# make a prediction
y_test_pred = model.predict(test_X_enc)
y_test_pred
```

Out[ ]:

```
array([[154.40854 ],
       [146.3335  ],
       [140.54207 ],
       ...,
       [ 25.413185],
       [ 25.60653 ],
       [ 24.973747]], dtype=float32)
```

In [ ]:

```
# calculate RMSE
rmse = np.sqrt(np.mean((y_test_pred.flatten() - test_y.flatten())**2))
print(f"Test RMSE: {rmse}")
```

```
Test RMSE: 51.506398635950404
```