assignment_4_notebook

September 2, 2024

1 Assignment 4 - TinyML HelloWorld - Section 1

Based on the **hello_world** example from TensorFlow Lite for MicroControllers.

1.1 Introduction

In this section you will train a Tensorflow model to a set of sinusoidal data. First you will synthesize the data to mimic a sine wave. Then you can build your own tensorflow model and fit the model to the generated data. Start by importing the relevant modules.

1.2 Import modules

[1]:
```
# Import Tensorflow and NumPy
# Set random seed to get reproducible results
import numpy as np
np.random.seed(1)

import tensorflow as tf
tf.random.set_seed(1)
```

[2]:
```
import os
from tensorflow import keras
import matplotlib.pyplot as plt
import math
```

1.3 Create the Dataset

You can use NumPy to generate a sinewave data and add some gaussian noise to make the data more realistic. The dataset will consist of 1000 datapoints (x-values) and relevant y-values. The following code creates a sine wave dataset.

[3]:
```
# Number of sample datapoints
SAMPLES = 1000

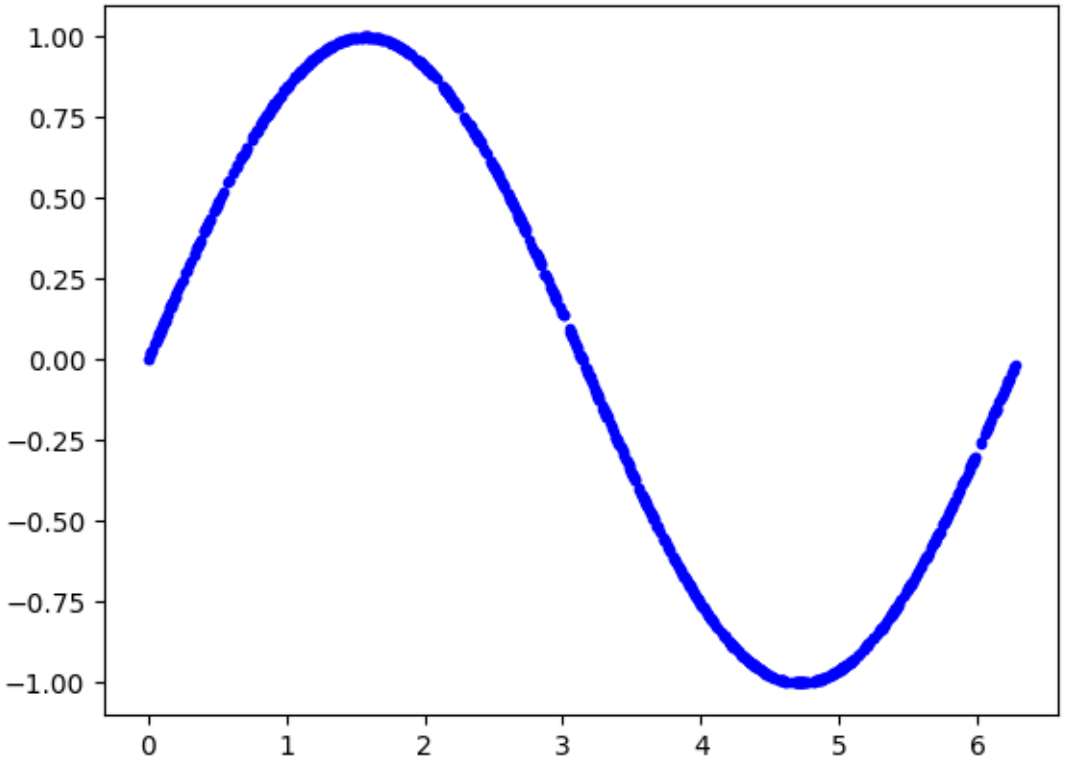
# Generate a uniformly distributed set of random numbers in the range from
# 0 to 2 , which covers a complete sine wave oscillation
x_values = np.random.uniform(
```

```
    low=0, high=2*math.pi, size=SAMPLES).astype(np.float32)

# Shuffle the values to guarantee they're not in order
np.random.shuffle(x_values)

# Calculate the corresponding sine values
y_values = np.sin(x_values).astype(np.float32)

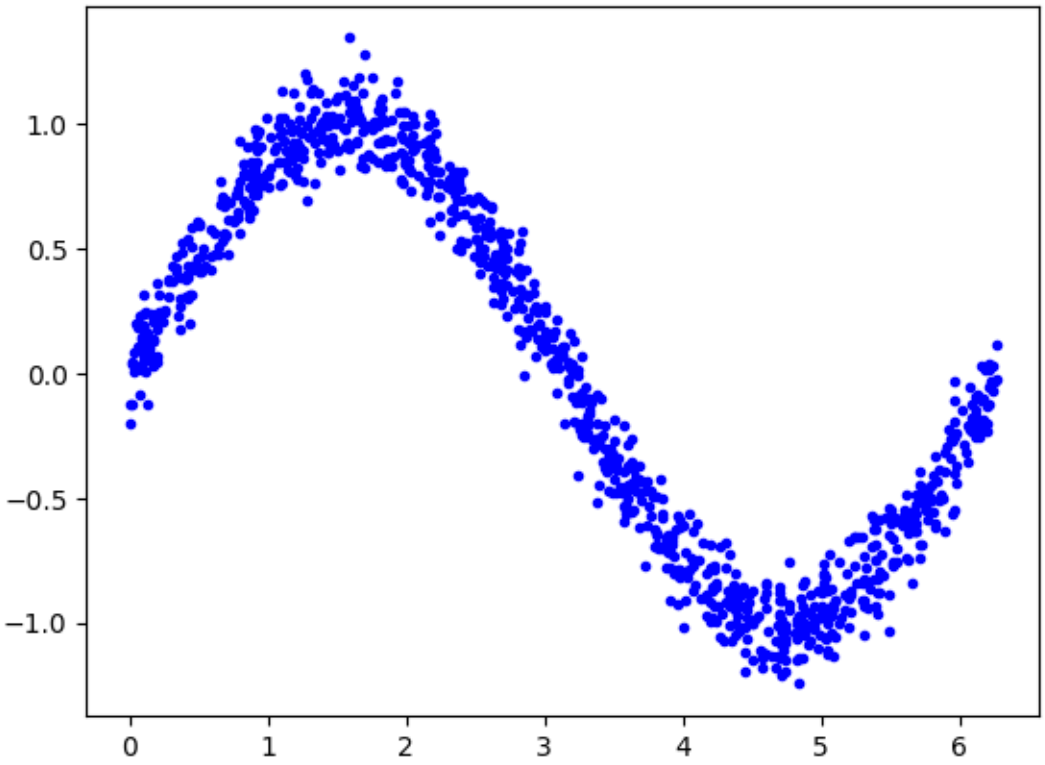
# Plot the data. The 'b.' argument tells the library to print blue dots.
plt.plot(x_values, y_values, 'b.')
plt.show()
```



Next add noise to the data to make the data more realistic. (In real-life the data we obtain usually get contaminated by different kinds of noise.)

[4]:
```
# Add a small random number to each y value
y_values += 0.1 * np.random.randn(*y_values.shape)

# Plot our data
plt.plot(x_values, y_values, 'b.')
plt.show()
```



1.4 Pre-process data (Graded)

The dataset has been given, now you will have to split this dataset into train, validation and test subsets. The following table shows the split ratio you should be using.

Split	Percentage
Train	60%
Validation	20%
Test	20%

You may use the `np.split()` function for obtaining 3 splits of data from one line of code. You have to provide the indiced of points which the dataset is divided. The second argument to `np.split()` is an array of indices where the data will be split. We provide two indices, so the data will be divided into three chunks. For more clarification look into the documentation of np.split().

1.4.1 Exercise 1

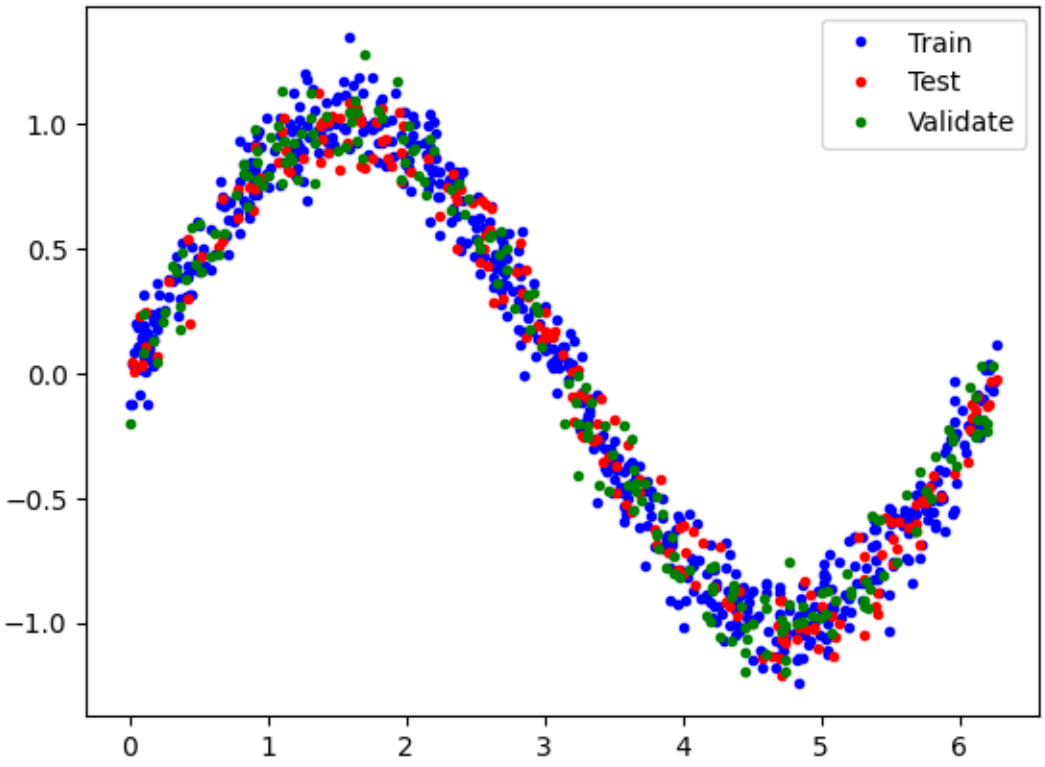
Complete the code below to split the data accordingly and plot all three splits in the same plot.

[5]:
```
# Define the indices where the dataset will get chopped (TODO)
TRAIN_SPLIT = int(0.6 * SAMPLES)
TEST_SPLIT = int(0.2 * SAMPLES + TRAIN_SPLIT)
```

```
# Use np.split to chop the data into three parts (TODO)
x_train, x_test, x_validate = np.split(x_values, [TRAIN_SPLIT, TEST_SPLIT])
y_train, y_test, y_validate = np.split(y_values, [TRAIN_SPLIT, TEST_SPLIT])

# Double check that our splits add up correctly
assert (x_train.size + x_validate.size + x_test.size) ==  SAMPLES

# Plot the data in each partition in different colors
plt.plot(x_train, y_train, 'b.', label="Train")
plt.plot(x_test, y_test, 'r.', label="Test")
plt.plot(x_validate, y_validate, 'g.', label="Validate")
plt.legend()
plt.show()
```



1.5 Build the Model (Graded)

You have successfully pre-processed the dataset. Next you will have to define build the Tensorflow model using Keras. You may use the Tensorflow Keras Sequential API. Please refer to the official Keras documentation for further information. Use the below architecture to design your the model.

- Input layer
- 2 Dense layers each consisting of 16 hidden units and ReLU activation - keras.layers.Dense()

- Output layer with 1 unit

1.5.1 Exercise 2

Design the sequential model according to the specifications above.

[24]:
```
# Define the model using the Keras API (TODO)

model = tf.keras.Sequential()
model.add(keras.layers.Dense(16, activation='relu', input_shape=(1,)))
model.add(keras.layers.Dense(16, activation='relu'))
model.add(keras.layers.Dense(1))
```

Now that you have created the model, specify the optimizer, loss function and acuracy metrics. Use the below,

- Optimizer: Adam
- Loss function: Mean Squared Error (MSE)
- Metric: Mean Absolute Error (MAE)

You may use `model.compile()` and read the tf.keras.Sequential documentation for this.

1.5.2 Exercise 3

Set the optimizer and loss function details as specified as above.

[25]:
```
# Compile the model using a standard optimizer and loss function for regression
model.compile(optimizer='adam', loss='mse', metrics=['mae'])
```

[27]:
```
# Get model summary
model.summary()
```

```
Model: "sequential_2"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_6 (Dense)              (None, 16)                32
_________________________________________________________________
dense_7 (Dense)              (None, 16)                272
_________________________________________________________________
dense_8 (Dense)              (None, 1)                 17
```

```
Total params: 321 (1.25 KB)

Trainable params: 321 (1.25 KB)

Non-trainable params: 0 (0.00 B)
```

1.6 Train the Model (Graded)

Fit the model to the data using `model.fit()`. Train for 500 epochs with a batch size of 64. Use only the train and validation sets during training.

1.6.1 Exercise 4

Fit the model to the data. Keep track of the losses and metrics using `history` object.

[28]:
```
# Fit the model to the data and keep track of losses (TODO)
history = model.fit(x_train, y_train, epochs=500, batch_size=64,
                    validation_data=(x_validate, y_validate))
```

```
Epoch 1/500
10/10             1s 22ms/step -
loss: 2.6868 - mae: 1.3060 - val_loss: 1.9640 - val_mae: 1.1728
Epoch 2/500
10/10             0s 7ms/step - loss:
1.7174 - mae: 1.0856 - val_loss: 1.2485 - val_mae: 0.9806
Epoch 3/500
10/10             0s 5ms/step - loss:
1.0916 - mae: 0.9078 - val_loss: 0.8336 - val_mae: 0.8330
Epoch 4/500
10/10             0s 5ms/step - loss:
0.7436 - mae: 0.7752 - val_loss: 0.6301 - val_mae: 0.7250
Epoch 5/500
10/10             0s 5ms/step - loss:
0.5817 - mae: 0.6860 - val_loss: 0.5460 - val_mae: 0.6541
Epoch 6/500
10/10             0s 6ms/step - loss:
0.5184 - mae: 0.6355 - val_loss: 0.5141 - val_mae: 0.6208
Epoch 7/500
10/10             0s 6ms/step - loss:
0.4960 - mae: 0.6100 - val_loss: 0.5016 - val_mae: 0.6101
Epoch 8/500
10/10             0s 5ms/step - loss:
0.4855 - mae: 0.5990 - val_loss: 0.4908 - val_mae: 0.6032
Epoch 9/500
10/10             0s 7ms/step - loss:
0.4752 - mae: 0.5917 - val_loss: 0.4799 - val_mae: 0.5970
Epoch 10/500
```

```
10/10            0s 7ms/step - loss:
0.4643 - mae: 0.5855 - val_loss: 0.4686 - val_mae: 0.5906
Epoch 11/500
10/10            0s 7ms/step - loss:
0.4524 - mae: 0.5787 - val_loss: 0.4516 - val_mae: 0.5808
Epoch 12/500
10/10            0s 5ms/step - loss:
0.4345 - mae: 0.5683 - val_loss: 0.4374 - val_mae: 0.5736
Epoch 13/500
10/10            0s 7ms/step - loss:
0.4212 - mae: 0.5609 - val_loss: 0.4230 - val_mae: 0.5637
Epoch 14/500
10/10            0s 6ms/step - loss:
0.4071 - mae: 0.5493 - val_loss: 0.4079 - val_mae: 0.5523
Epoch 15/500
10/10            0s 5ms/step - loss:
0.3936 - mae: 0.5379 - val_loss: 0.3949 - val_mae: 0.5442
Epoch 16/500
10/10            0s 5ms/step - loss:
0.3809 - mae: 0.5291 - val_loss: 0.3821 - val_mae: 0.5357
Epoch 17/500
10/10            0s 6ms/step - loss:
0.3685 - mae: 0.5202 - val_loss: 0.3697 - val_mae: 0.5276
Epoch 18/500
10/10            0s 7ms/step - loss:
0.3564 - mae: 0.5116 - val_loss: 0.3576 - val_mae: 0.5194
Epoch 19/500
10/10            0s 8ms/step - loss:
0.3446 - mae: 0.5028 - val_loss: 0.3458 - val_mae: 0.5112
Epoch 20/500
10/10            0s 7ms/step - loss:
0.3332 - mae: 0.4942 - val_loss: 0.3343 - val_mae: 0.5031
Epoch 21/500
10/10            0s 5ms/step - loss:
0.3222 - mae: 0.4857 - val_loss: 0.3232 - val_mae: 0.4952
Epoch 22/500
10/10            0s 5ms/step - loss:
0.3114 - mae: 0.4774 - val_loss: 0.3124 - val_mae: 0.4875
Epoch 23/500
10/10            0s 7ms/step - loss:
0.3009 - mae: 0.4693 - val_loss: 0.3020 - val_mae: 0.4800
Epoch 24/500
10/10            0s 7ms/step - loss:
0.2908 - mae: 0.4616 - val_loss: 0.2919 - val_mae: 0.4726
Epoch 25/500
10/10            0s 6ms/step - loss:
0.2811 - mae: 0.4540 - val_loss: 0.2821 - val_mae: 0.4654
Epoch 26/500
```

```
10/10            0s 10ms/step -
loss: 0.2717 - mae: 0.4464 - val_loss: 0.2728 - val_mae: 0.4582
Epoch 27/500
10/10            0s 8ms/step - loss:
0.2626 - mae: 0.4389 - val_loss: 0.2639 - val_mae: 0.4511
Epoch 28/500
10/10            0s 12ms/step -
loss: 0.2539 - mae: 0.4316 - val_loss: 0.2553 - val_mae: 0.4441
Epoch 29/500
10/10            0s 8ms/step - loss:
0.2455 - mae: 0.4243 - val_loss: 0.2470 - val_mae: 0.4369
Epoch 30/500
10/10            0s 8ms/step - loss:
0.2374 - mae: 0.4171 - val_loss: 0.2390 - val_mae: 0.4298
Epoch 31/500
10/10            0s 9ms/step - loss:
0.2295 - mae: 0.4099 - val_loss: 0.2314 - val_mae: 0.4229
Epoch 32/500
10/10            0s 8ms/step - loss:
0.2219 - mae: 0.4029 - val_loss: 0.2240 - val_mae: 0.4158
Epoch 33/500
10/10            0s 7ms/step - loss:
0.2144 - mae: 0.3954 - val_loss: 0.2167 - val_mae: 0.4084
Epoch 34/500
10/10            0s 8ms/step - loss:
0.2072 - mae: 0.3878 - val_loss: 0.2100 - val_mae: 0.4018
Epoch 35/500
10/10            0s 8ms/step - loss:
0.2003 - mae: 0.3809 - val_loss: 0.2035 - val_mae: 0.3952
Epoch 36/500
10/10            0s 8ms/step - loss:
0.1938 - mae: 0.3741 - val_loss: 0.1972 - val_mae: 0.3889
Epoch 37/500
10/10            0s 7ms/step - loss:
0.1876 - mae: 0.3676 - val_loss: 0.1914 - val_mae: 0.3827
Epoch 38/500
10/10            0s 12ms/step -
loss: 0.1817 - mae: 0.3614 - val_loss: 0.1858 - val_mae: 0.3769
Epoch 39/500
10/10            0s 10ms/step -
loss: 0.1761 - mae: 0.3554 - val_loss: 0.1806 - val_mae: 0.3712
Epoch 40/500
10/10            0s 10ms/step -
loss: 0.1709 - mae: 0.3495 - val_loss: 0.1757 - val_mae: 0.3656
Epoch 41/500
10/10            0s 9ms/step - loss:
0.1660 - mae: 0.3438 - val_loss: 0.1710 - val_mae: 0.3599
Epoch 42/500
```

```
10/10            0s 8ms/step - loss:
0.1613 - mae: 0.3383 - val_loss: 0.1663 - val_mae: 0.3539
Epoch 43/500
10/10            0s 8ms/step - loss:
0.1569 - mae: 0.3330 - val_loss: 0.1621 - val_mae: 0.3484
Epoch 44/500
10/10            0s 8ms/step - loss:
0.1527 - mae: 0.3280 - val_loss: 0.1584 - val_mae: 0.3433
Epoch 45/500
10/10            0s 7ms/step - loss:
0.1489 - mae: 0.3233 - val_loss: 0.1549 - val_mae: 0.3383
Epoch 46/500
10/10            0s 5ms/step - loss:
0.1454 - mae: 0.3188 - val_loss: 0.1516 - val_mae: 0.3335
Epoch 47/500
10/10            0s 6ms/step - loss:
0.1421 - mae: 0.3144 - val_loss: 0.1487 - val_mae: 0.3289
Epoch 48/500
10/10            0s 5ms/step - loss:
0.1390 - mae: 0.3103 - val_loss: 0.1459 - val_mae: 0.3244
Epoch 49/500
10/10            0s 5ms/step - loss:
0.1361 - mae: 0.3063 - val_loss: 0.1434 - val_mae: 0.3201
Epoch 50/500
10/10            0s 5ms/step - loss:
0.1335 - mae: 0.3025 - val_loss: 0.1410 - val_mae: 0.3162
Epoch 51/500
10/10            0s 7ms/step - loss:
0.1310 - mae: 0.2989 - val_loss: 0.1388 - val_mae: 0.3124
Epoch 52/500
10/10            0s 5ms/step - loss:
0.1286 - mae: 0.2956 - val_loss: 0.1367 - val_mae: 0.3090
Epoch 53/500
10/10            0s 7ms/step - loss:
0.1265 - mae: 0.2925 - val_loss: 0.1349 - val_mae: 0.3058
Epoch 54/500
10/10            0s 7ms/step - loss:
0.1245 - mae: 0.2893 - val_loss: 0.1333 - val_mae: 0.3028
Epoch 55/500
10/10            0s 7ms/step - loss:
0.1226 - mae: 0.2862 - val_loss: 0.1316 - val_mae: 0.2998
Epoch 56/500
10/10            0s 5ms/step - loss:
0.1208 - mae: 0.2835 - val_loss: 0.1302 - val_mae: 0.2971
Epoch 57/500
10/10            0s 7ms/step - loss:
0.1193 - mae: 0.2809 - val_loss: 0.1289 - val_mae: 0.2946
Epoch 58/500
```

```
10/10            0s 5ms/step - loss:
0.1177 - mae: 0.2783 - val_loss: 0.1276 - val_mae: 0.2921
Epoch 59/500
10/10            0s 7ms/step - loss:
0.1163 - mae: 0.2759 - val_loss: 0.1265 - val_mae: 0.2899
Epoch 60/500
10/10            0s 5ms/step - loss:
0.1150 - mae: 0.2736 - val_loss: 0.1254 - val_mae: 0.2880
Epoch 61/500
10/10            0s 5ms/step - loss:
0.1138 - mae: 0.2714 - val_loss: 0.1244 - val_mae: 0.2861
Epoch 62/500
10/10            0s 6ms/step - loss:
0.1126 - mae: 0.2692 - val_loss: 0.1234 - val_mae: 0.2843
Epoch 63/500
10/10            0s 6ms/step - loss:
0.1115 - mae: 0.2671 - val_loss: 0.1225 - val_mae: 0.2826
Epoch 64/500
10/10            0s 7ms/step - loss:
0.1104 - mae: 0.2651 - val_loss: 0.1217 - val_mae: 0.2808
Epoch 65/500
10/10            0s 6ms/step - loss:
0.1094 - mae: 0.2632 - val_loss: 0.1209 - val_mae: 0.2791
Epoch 66/500
10/10            0s 5ms/step - loss:
0.1085 - mae: 0.2614 - val_loss: 0.1201 - val_mae: 0.2775
Epoch 67/500
10/10            0s 7ms/step - loss:
0.1076 - mae: 0.2598 - val_loss: 0.1194 - val_mae: 0.2759
Epoch 68/500
10/10            0s 7ms/step - loss:
0.1068 - mae: 0.2581 - val_loss: 0.1187 - val_mae: 0.2743
Epoch 69/500
10/10            0s 7ms/step - loss:
0.1060 - mae: 0.2565 - val_loss: 0.1180 - val_mae: 0.2727
Epoch 70/500
10/10            0s 5ms/step - loss:
0.1052 - mae: 0.2550 - val_loss: 0.1173 - val_mae: 0.2712
Epoch 71/500
10/10            0s 6ms/step - loss:
0.1045 - mae: 0.2536 - val_loss: 0.1167 - val_mae: 0.2697
Epoch 72/500
10/10            0s 5ms/step - loss:
0.1039 - mae: 0.2522 - val_loss: 0.1161 - val_mae: 0.2685
Epoch 73/500
10/10            0s 7ms/step - loss:
0.1032 - mae: 0.2508 - val_loss: 0.1155 - val_mae: 0.2671
Epoch 74/500
```

```
10/10            0s 6ms/step - loss:
0.1025 - mae: 0.2494 - val_loss: 0.1149 - val_mae: 0.2658
Epoch 75/500
10/10            0s 6ms/step - loss:
0.1019 - mae: 0.2481 - val_loss: 0.1144 - val_mae: 0.2647
Epoch 76/500
10/10            0s 7ms/step - loss:
0.1014 - mae: 0.2470 - val_loss: 0.1139 - val_mae: 0.2637
Epoch 77/500
10/10            0s 6ms/step - loss:
0.1008 - mae: 0.2458 - val_loss: 0.1134 - val_mae: 0.2626
Epoch 78/500
10/10            0s 8ms/step - loss:
0.1002 - mae: 0.2446 - val_loss: 0.1129 - val_mae: 0.2614
Epoch 79/500
10/10            0s 7ms/step - loss:
0.0997 - mae: 0.2435 - val_loss: 0.1124 - val_mae: 0.2603
Epoch 80/500
10/10            0s 5ms/step - loss:
0.0992 - mae: 0.2425 - val_loss: 0.1119 - val_mae: 0.2593
Epoch 81/500
10/10            0s 7ms/step - loss:
0.0987 - mae: 0.2415 - val_loss: 0.1114 - val_mae: 0.2582
Epoch 82/500
10/10            0s 5ms/step - loss:
0.0982 - mae: 0.2406 - val_loss: 0.1109 - val_mae: 0.2572
Epoch 83/500
10/10            0s 5ms/step - loss:
0.0977 - mae: 0.2396 - val_loss: 0.1105 - val_mae: 0.2564
Epoch 84/500
10/10            0s 6ms/step - loss:
0.0973 - mae: 0.2387 - val_loss: 0.1100 - val_mae: 0.2554
Epoch 85/500
10/10            0s 5ms/step - loss:
0.0968 - mae: 0.2378 - val_loss: 0.1096 - val_mae: 0.2546
Epoch 86/500
10/10            0s 5ms/step - loss:
0.0963 - mae: 0.2369 - val_loss: 0.1091 - val_mae: 0.2536
Epoch 87/500
10/10            0s 8ms/step - loss:
0.0959 - mae: 0.2360 - val_loss: 0.1086 - val_mae: 0.2527
Epoch 88/500
10/10            0s 5ms/step - loss:
0.0954 - mae: 0.2351 - val_loss: 0.1082 - val_mae: 0.2518
Epoch 89/500
10/10            0s 5ms/step - loss:
0.0950 - mae: 0.2343 - val_loss: 0.1077 - val_mae: 0.2510
Epoch 90/500
```

```
10/10            0s 5ms/step - loss:
0.0946 - mae: 0.2335 - val_loss: 0.1073 - val_mae: 0.2501
Epoch 91/500
10/10            0s 5ms/step - loss:
0.0941 - mae: 0.2328 - val_loss: 0.1069 - val_mae: 0.2493
Epoch 92/500
10/10            0s 7ms/step - loss:
0.0937 - mae: 0.2320 - val_loss: 0.1064 - val_mae: 0.2484
Epoch 93/500
10/10            0s 7ms/step - loss:
0.0933 - mae: 0.2312 - val_loss: 0.1060 - val_mae: 0.2476
Epoch 94/500
10/10            0s 8ms/step - loss:
0.0928 - mae: 0.2303 - val_loss: 0.1055 - val_mae: 0.2467
Epoch 95/500
10/10            0s 6ms/step - loss:
0.0924 - mae: 0.2296 - val_loss: 0.1051 - val_mae: 0.2459
Epoch 96/500
10/10            0s 7ms/step - loss:
0.0920 - mae: 0.2288 - val_loss: 0.1046 - val_mae: 0.2451
Epoch 97/500
10/10            0s 7ms/step - loss:
0.0916 - mae: 0.2281 - val_loss: 0.1042 - val_mae: 0.2444
Epoch 98/500
10/10            0s 5ms/step - loss:
0.0912 - mae: 0.2274 - val_loss: 0.1037 - val_mae: 0.2436
Epoch 99/500
10/10            0s 5ms/step - loss:
0.0908 - mae: 0.2267 - val_loss: 0.1033 - val_mae: 0.2428
Epoch 100/500
10/10            0s 6ms/step - loss:
0.0903 - mae: 0.2260 - val_loss: 0.1029 - val_mae: 0.2420
Epoch 101/500
10/10            0s 7ms/step - loss:
0.0899 - mae: 0.2252 - val_loss: 0.1025 - val_mae: 0.2412
Epoch 102/500
10/10            0s 7ms/step - loss:
0.0895 - mae: 0.2245 - val_loss: 0.1020 - val_mae: 0.2405
Epoch 103/500
10/10            0s 7ms/step - loss:
0.0891 - mae: 0.2238 - val_loss: 0.1016 - val_mae: 0.2397
Epoch 104/500
10/10            0s 8ms/step - loss:
0.0887 - mae: 0.2231 - val_loss: 0.1012 - val_mae: 0.2389
Epoch 105/500
10/10            0s 7ms/step - loss:
0.0883 - mae: 0.2224 - val_loss: 0.1007 - val_mae: 0.2382
Epoch 106/500
```

```
10/10            0s 7ms/step - loss:
0.0879 - mae: 0.2217 - val_loss: 0.1003 - val_mae: 0.2376
Epoch 107/500
10/10            0s 7ms/step - loss:
0.0875 - mae: 0.2211 - val_loss: 0.0999 - val_mae: 0.2368
Epoch 108/500
10/10            0s 7ms/step - loss:
0.0871 - mae: 0.2204 - val_loss: 0.0995 - val_mae: 0.2362
Epoch 109/500
10/10            0s 6ms/step - loss:
0.0868 - mae: 0.2198 - val_loss: 0.0991 - val_mae: 0.2355
Epoch 110/500
10/10            0s 7ms/step - loss:
0.0864 - mae: 0.2191 - val_loss: 0.0986 - val_mae: 0.2349
Epoch 111/500
10/10            0s 7ms/step - loss:
0.0860 - mae: 0.2185 - val_loss: 0.0982 - val_mae: 0.2342
Epoch 112/500
10/10            0s 5ms/step - loss:
0.0856 - mae: 0.2179 - val_loss: 0.0978 - val_mae: 0.2336
Epoch 113/500
10/10            0s 5ms/step - loss:
0.0852 - mae: 0.2172 - val_loss: 0.0974 - val_mae: 0.2330
Epoch 114/500
10/10            0s 5ms/step - loss:
0.0848 - mae: 0.2166 - val_loss: 0.0970 - val_mae: 0.2323
Epoch 115/500
10/10            0s 5ms/step - loss:
0.0844 - mae: 0.2159 - val_loss: 0.0965 - val_mae: 0.2317
Epoch 116/500
10/10            0s 5ms/step - loss:
0.0840 - mae: 0.2153 - val_loss: 0.0961 - val_mae: 0.2311
Epoch 117/500
10/10            0s 7ms/step - loss:
0.0837 - mae: 0.2147 - val_loss: 0.0957 - val_mae: 0.2304
Epoch 118/500
10/10            0s 6ms/step - loss:
0.0833 - mae: 0.2140 - val_loss: 0.0953 - val_mae: 0.2298
Epoch 119/500
10/10            0s 7ms/step - loss:
0.0829 - mae: 0.2134 - val_loss: 0.0949 - val_mae: 0.2292
Epoch 120/500
10/10            0s 7ms/step - loss:
0.0825 - mae: 0.2128 - val_loss: 0.0944 - val_mae: 0.2285
Epoch 121/500
10/10            0s 6ms/step - loss:
0.0821 - mae: 0.2122 - val_loss: 0.0940 - val_mae: 0.2279
Epoch 122/500
```

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10/10            0s 8ms/step - loss:
0.0818 - mae: 0.2116 - val_loss: 0.0936 - val_mae: 0.2273
Epoch 123/500
10/10            0s 8ms/step - loss:
0.0814 - mae: 0.2110 - val_loss: 0.0932 - val_mae: 0.2267
Epoch 124/500
10/10            0s 9ms/step - loss:
0.0810 - mae: 0.2105 - val_loss: 0.0928 - val_mae: 0.2260
Epoch 125/500
10/10            0s 9ms/step - loss:
0.0806 - mae: 0.2099 - val_loss: 0.0924 - val_mae: 0.2254
Epoch 126/500
10/10            0s 13ms/step -
loss: 0.0803 - mae: 0.2093 - val_loss: 0.0919 - val_mae: 0.2248
Epoch 127/500
10/10            0s 7ms/step - loss:
0.0799 - mae: 0.2087 - val_loss: 0.0915 - val_mae: 0.2242
Epoch 128/500
10/10            0s 9ms/step - loss:
0.0795 - mae: 0.2081 - val_loss: 0.0911 - val_mae: 0.2236
Epoch 129/500
10/10            0s 7ms/step - loss:
0.0791 - mae: 0.2076 - val_loss: 0.0907 - val_mae: 0.2230
Epoch 130/500
10/10            0s 8ms/step - loss:
0.0788 - mae: 0.2070 - val_loss: 0.0903 - val_mae: 0.2223
Epoch 131/500
10/10            0s 9ms/step - loss:
0.0784 - mae: 0.2064 - val_loss: 0.0899 - val_mae: 0.2218
Epoch 132/500
10/10            0s 9ms/step - loss:
0.0780 - mae: 0.2059 - val_loss: 0.0894 - val_mae: 0.2211
Epoch 133/500
10/10            0s 9ms/step - loss:
0.0776 - mae: 0.2053 - val_loss: 0.0890 - val_mae: 0.2206
Epoch 134/500
10/10            0s 11ms/step -
loss: 0.0773 - mae: 0.2047 - val_loss: 0.0886 - val_mae: 0.2200
Epoch 135/500
10/10            0s 9ms/step - loss:
0.0769 - mae: 0.2042 - val_loss: 0.0882 - val_mae: 0.2194
Epoch 136/500
10/10            0s 9ms/step - loss:
0.0765 - mae: 0.2036 - val_loss: 0.0878 - val_mae: 0.2188
Epoch 137/500
10/10            0s 9ms/step - loss:
0.0762 - mae: 0.2031 - val_loss: 0.0874 - val_mae: 0.2182
Epoch 138/500
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10/10            0s 9ms/step - loss:
0.0758 - mae: 0.2025 - val_loss: 0.0870 - val_mae: 0.2176
Epoch 139/500
10/10            0s 10ms/step -
loss: 0.0754 - mae: 0.2020 - val_loss: 0.0865 - val_mae: 0.2170
Epoch 140/500
10/10            0s 9ms/step - loss:
0.0751 - mae: 0.2014 - val_loss: 0.0861 - val_mae: 0.2164
Epoch 141/500
10/10            0s 10ms/step -
loss: 0.0747 - mae: 0.2009 - val_loss: 0.0857 - val_mae: 0.2158
Epoch 142/500
10/10            0s 9ms/step - loss:
0.0744 - mae: 0.2003 - val_loss: 0.0853 - val_mae: 0.2152
Epoch 143/500
10/10            0s 8ms/step - loss:
0.0740 - mae: 0.1998 - val_loss: 0.0849 - val_mae: 0.2146
Epoch 144/500
10/10            0s 7ms/step - loss:
0.0736 - mae: 0.1993 - val_loss: 0.0845 - val_mae: 0.2140
Epoch 145/500
10/10            0s 5ms/step - loss:
0.0733 - mae: 0.1987 - val_loss: 0.0841 - val_mae: 0.2134
Epoch 146/500
10/10            0s 7ms/step - loss:
0.0729 - mae: 0.1982 - val_loss: 0.0836 - val_mae: 0.2128
Epoch 147/500
10/10            0s 7ms/step - loss:
0.0726 - mae: 0.1977 - val_loss: 0.0832 - val_mae: 0.2122
Epoch 148/500
10/10            0s 7ms/step - loss:
0.0722 - mae: 0.1971 - val_loss: 0.0828 - val_mae: 0.2116
Epoch 149/500
10/10            0s 9ms/step - loss:
0.0718 - mae: 0.1966 - val_loss: 0.0824 - val_mae: 0.2111
Epoch 150/500
10/10            0s 5ms/step - loss:
0.0715 - mae: 0.1960 - val_loss: 0.0820 - val_mae: 0.2104
Epoch 151/500
10/10            0s 5ms/step - loss:
0.0711 - mae: 0.1954 - val_loss: 0.0816 - val_mae: 0.2099
Epoch 152/500
10/10            0s 5ms/step - loss:
0.0708 - mae: 0.1949 - val_loss: 0.0812 - val_mae: 0.2093
Epoch 153/500
10/10            0s 5ms/step - loss:
0.0704 - mae: 0.1944 - val_loss: 0.0807 - val_mae: 0.2087
Epoch 154/500
```

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10/10            0s 5ms/step - loss:
0.0700 - mae: 0.1938 - val_loss: 0.0803 - val_mae: 0.2080
Epoch 155/500
10/10            0s 6ms/step - loss:
0.0697 - mae: 0.1932 - val_loss: 0.0799 - val_mae: 0.2074
Epoch 156/500
10/10            0s 5ms/step - loss:
0.0693 - mae: 0.1927 - val_loss: 0.0795 - val_mae: 0.2068
Epoch 157/500
10/10            0s 6ms/step - loss:
0.0690 - mae: 0.1920 - val_loss: 0.0791 - val_mae: 0.2063
Epoch 158/500
10/10            0s 10ms/step -
loss: 0.0686 - mae: 0.1915 - val_loss: 0.0787 - val_mae: 0.2057
Epoch 159/500
10/10            0s 5ms/step - loss:
0.0683 - mae: 0.1909 - val_loss: 0.0783 - val_mae: 0.2051
Epoch 160/500
10/10            0s 5ms/step - loss:
0.0679 - mae: 0.1904 - val_loss: 0.0779 - val_mae: 0.2045
Epoch 161/500
10/10            0s 7ms/step - loss:
0.0676 - mae: 0.1899 - val_loss: 0.0775 - val_mae: 0.2039
Epoch 162/500
10/10            0s 7ms/step - loss:
0.0672 - mae: 0.1893 - val_loss: 0.0771 - val_mae: 0.2033
Epoch 163/500
10/10            0s 5ms/step - loss:
0.0668 - mae: 0.1887 - val_loss: 0.0767 - val_mae: 0.2028
Epoch 164/500
10/10            0s 7ms/step - loss:
0.0665 - mae: 0.1881 - val_loss: 0.0763 - val_mae: 0.2022
Epoch 165/500
10/10            0s 5ms/step - loss:
0.0661 - mae: 0.1875 - val_loss: 0.0759 - val_mae: 0.2017
Epoch 166/500
10/10            0s 6ms/step - loss:
0.0658 - mae: 0.1869 - val_loss: 0.0755 - val_mae: 0.2012
Epoch 167/500
10/10            0s 5ms/step - loss:
0.0654 - mae: 0.1864 - val_loss: 0.0751 - val_mae: 0.2006
Epoch 168/500
10/10            0s 5ms/step - loss:
0.0651 - mae: 0.1859 - val_loss: 0.0746 - val_mae: 0.2001
Epoch 169/500
10/10            0s 7ms/step - loss:
0.0647 - mae: 0.1853 - val_loss: 0.0742 - val_mae: 0.1995
Epoch 170/500
```

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10/10            0s 5ms/step - loss:
0.0644 - mae: 0.1847 - val_loss: 0.0738 - val_mae: 0.1989
Epoch 171/500
10/10            0s 7ms/step - loss:
0.0640 - mae: 0.1842 - val_loss: 0.0734 - val_mae: 0.1984
Epoch 172/500
10/10            0s 7ms/step - loss:
0.0637 - mae: 0.1837 - val_loss: 0.0730 - val_mae: 0.1978
Epoch 173/500
10/10            0s 5ms/step - loss:
0.0633 - mae: 0.1831 - val_loss: 0.0726 - val_mae: 0.1972
Epoch 174/500
10/10            0s 7ms/step - loss:
0.0630 - mae: 0.1826 - val_loss: 0.0722 - val_mae: 0.1966
Epoch 175/500
10/10            0s 8ms/step - loss:
0.0626 - mae: 0.1820 - val_loss: 0.0718 - val_mae: 0.1961
Epoch 176/500
10/10            0s 5ms/step - loss:
0.0623 - mae: 0.1815 - val_loss: 0.0714 - val_mae: 0.1955
Epoch 177/500
10/10            0s 5ms/step - loss:
0.0619 - mae: 0.1809 - val_loss: 0.0710 - val_mae: 0.1950
Epoch 178/500
10/10            0s 5ms/step - loss:
0.0616 - mae: 0.1804 - val_loss: 0.0706 - val_mae: 0.1944
Epoch 179/500
10/10            0s 5ms/step - loss:
0.0612 - mae: 0.1798 - val_loss: 0.0702 - val_mae: 0.1938
Epoch 180/500
10/10            0s 7ms/step - loss:
0.0609 - mae: 0.1793 - val_loss: 0.0698 - val_mae: 0.1933
Epoch 181/500
10/10            0s 7ms/step - loss:
0.0605 - mae: 0.1788 - val_loss: 0.0694 - val_mae: 0.1928
Epoch 182/500
10/10            0s 7ms/step - loss:
0.0602 - mae: 0.1783 - val_loss: 0.0690 - val_mae: 0.1923
Epoch 183/500
10/10            0s 6ms/step - loss:
0.0598 - mae: 0.1776 - val_loss: 0.0687 - val_mae: 0.1918
Epoch 184/500
10/10            0s 7ms/step - loss:
0.0595 - mae: 0.1771 - val_loss: 0.0683 - val_mae: 0.1913
Epoch 185/500
10/10            0s 5ms/step - loss:
0.0592 - mae: 0.1766 - val_loss: 0.0679 - val_mae: 0.1907
Epoch 186/500
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10/10            0s 7ms/step - loss:
0.0588 - mae: 0.1761 - val_loss: 0.0675 - val_mae: 0.1902
Epoch 187/500
10/10            0s 6ms/step - loss:
0.0585 - mae: 0.1755 - val_loss: 0.0671 - val_mae: 0.1897
Epoch 188/500
10/10            0s 7ms/step - loss:
0.0581 - mae: 0.1750 - val_loss: 0.0667 - val_mae: 0.1891
Epoch 189/500
10/10            0s 5ms/step - loss:
0.0578 - mae: 0.1745 - val_loss: 0.0663 - val_mae: 0.1886
Epoch 190/500
10/10            0s 7ms/step - loss:
0.0575 - mae: 0.1739 - val_loss: 0.0659 - val_mae: 0.1880
Epoch 191/500
10/10            0s 5ms/step - loss:
0.0571 - mae: 0.1733 - val_loss: 0.0655 - val_mae: 0.1874
Epoch 192/500
10/10            0s 6ms/step - loss:
0.0568 - mae: 0.1728 - val_loss: 0.0651 - val_mae: 0.1868
Epoch 193/500
10/10            0s 6ms/step - loss:
0.0564 - mae: 0.1722 - val_loss: 0.0647 - val_mae: 0.1863
Epoch 194/500
10/10            0s 5ms/step - loss:
0.0561 - mae: 0.1717 - val_loss: 0.0643 - val_mae: 0.1857
Epoch 195/500
10/10            0s 7ms/step - loss:
0.0558 - mae: 0.1711 - val_loss: 0.0639 - val_mae: 0.1851
Epoch 196/500
10/10            0s 5ms/step - loss:
0.0554 - mae: 0.1706 - val_loss: 0.0635 - val_mae: 0.1846
Epoch 197/500
10/10            0s 6ms/step - loss:
0.0551 - mae: 0.1701 - val_loss: 0.0631 - val_mae: 0.1840
Epoch 198/500
10/10            0s 7ms/step - loss:
0.0548 - mae: 0.1695 - val_loss: 0.0627 - val_mae: 0.1835
Epoch 199/500
10/10            0s 7ms/step - loss:
0.0544 - mae: 0.1690 - val_loss: 0.0623 - val_mae: 0.1828
Epoch 200/500
10/10            0s 7ms/step - loss:
0.0541 - mae: 0.1684 - val_loss: 0.0619 - val_mae: 0.1823
Epoch 201/500
10/10            0s 8ms/step - loss:
0.0538 - mae: 0.1679 - val_loss: 0.0615 - val_mae: 0.1817
Epoch 202/500
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10/10            0s 5ms/step - loss:
0.0534 - mae: 0.1674 - val_loss: 0.0612 - val_mae: 0.1812
Epoch 203/500
10/10            0s 5ms/step - loss:
0.0531 - mae: 0.1668 - val_loss: 0.0608 - val_mae: 0.1807
Epoch 204/500
10/10            0s 5ms/step - loss:
0.0527 - mae: 0.1663 - val_loss: 0.0604 - val_mae: 0.1801
Epoch 205/500
10/10            0s 6ms/step - loss:
0.0524 - mae: 0.1657 - val_loss: 0.0600 - val_mae: 0.1796
Epoch 206/500
10/10            0s 6ms/step - loss:
0.0521 - mae: 0.1652 - val_loss: 0.0596 - val_mae: 0.1791
Epoch 207/500
10/10            0s 7ms/step - loss:
0.0518 - mae: 0.1646 - val_loss: 0.0592 - val_mae: 0.1786
Epoch 208/500
10/10            0s 5ms/step - loss:
0.0514 - mae: 0.1641 - val_loss: 0.0588 - val_mae: 0.1780
Epoch 209/500
10/10            0s 6ms/step - loss:
0.0511 - mae: 0.1635 - val_loss: 0.0584 - val_mae: 0.1774
Epoch 210/500
10/10            0s 7ms/step - loss:
0.0508 - mae: 0.1629 - val_loss: 0.0580 - val_mae: 0.1768
Epoch 211/500
10/10            0s 8ms/step - loss:
0.0505 - mae: 0.1624 - val_loss: 0.0577 - val_mae: 0.1762
Epoch 212/500
10/10            0s 5ms/step - loss:
0.0501 - mae: 0.1619 - val_loss: 0.0573 - val_mae: 0.1757
Epoch 213/500
10/10            0s 7ms/step - loss:
0.0498 - mae: 0.1613 - val_loss: 0.0569 - val_mae: 0.1751
Epoch 214/500
10/10            0s 7ms/step - loss:
0.0495 - mae: 0.1608 - val_loss: 0.0565 - val_mae: 0.1745
Epoch 215/500
10/10            0s 7ms/step - loss:
0.0492 - mae: 0.1603 - val_loss: 0.0561 - val_mae: 0.1740
Epoch 216/500
10/10            0s 5ms/step - loss:
0.0488 - mae: 0.1598 - val_loss: 0.0557 - val_mae: 0.1734
Epoch 217/500
10/10            0s 7ms/step - loss:
0.0485 - mae: 0.1593 - val_loss: 0.0553 - val_mae: 0.1728
Epoch 218/500
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10/10            0s 7ms/step - loss:
0.0482 - mae: 0.1587 - val_loss: 0.0549 - val_mae: 0.1722
Epoch 219/500
10/10            0s 7ms/step - loss:
0.0479 - mae: 0.1582 - val_loss: 0.0545 - val_mae: 0.1717
Epoch 220/500
10/10            0s 5ms/step - loss:
0.0476 - mae: 0.1577 - val_loss: 0.0542 - val_mae: 0.1711
Epoch 221/500
10/10            0s 6ms/step - loss:
0.0472 - mae: 0.1572 - val_loss: 0.0538 - val_mae: 0.1705
Epoch 222/500
10/10            0s 5ms/step - loss:
0.0469 - mae: 0.1566 - val_loss: 0.0534 - val_mae: 0.1700
Epoch 223/500
10/10            0s 5ms/step - loss:
0.0466 - mae: 0.1561 - val_loss: 0.0530 - val_mae: 0.1694
Epoch 224/500
10/10            0s 5ms/step - loss:
0.0463 - mae: 0.1555 - val_loss: 0.0526 - val_mae: 0.1688
Epoch 225/500
10/10            0s 7ms/step - loss:
0.0460 - mae: 0.1549 - val_loss: 0.0522 - val_mae: 0.1683
Epoch 226/500
10/10            0s 7ms/step - loss:
0.0456 - mae: 0.1544 - val_loss: 0.0519 - val_mae: 0.1677
Epoch 227/500
10/10            0s 6ms/step - loss:
0.0453 - mae: 0.1538 - val_loss: 0.0515 - val_mae: 0.1672
Epoch 228/500
10/10            0s 7ms/step - loss:
0.0450 - mae: 0.1533 - val_loss: 0.0511 - val_mae: 0.1667
Epoch 229/500
10/10            0s 5ms/step - loss:
0.0447 - mae: 0.1529 - val_loss: 0.0508 - val_mae: 0.1661
Epoch 230/500
10/10            0s 8ms/step - loss:
0.0444 - mae: 0.1524 - val_loss: 0.0504 - val_mae: 0.1656
Epoch 231/500
10/10            0s 8ms/step - loss:
0.0441 - mae: 0.1519 - val_loss: 0.0500 - val_mae: 0.1650
Epoch 232/500
10/10            0s 8ms/step - loss:
0.0438 - mae: 0.1514 - val_loss: 0.0497 - val_mae: 0.1644
Epoch 233/500
10/10            0s 9ms/step - loss:
0.0435 - mae: 0.1509 - val_loss: 0.0493 - val_mae: 0.1639
Epoch 234/500
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10/10            0s 9ms/step - loss:
0.0432 - mae: 0.1504 - val_loss: 0.0489 - val_mae: 0.1634
Epoch 235/500
10/10            0s 12ms/step -
loss: 0.0429 - mae: 0.1499 - val_loss: 0.0486 - val_mae: 0.1628
Epoch 236/500
10/10            0s 8ms/step - loss:
0.0426 - mae: 0.1494 - val_loss: 0.0482 - val_mae: 0.1623
Epoch 237/500
10/10            0s 7ms/step - loss:
0.0423 - mae: 0.1489 - val_loss: 0.0478 - val_mae: 0.1617
Epoch 238/500
10/10            0s 8ms/step - loss:
0.0420 - mae: 0.1484 - val_loss: 0.0475 - val_mae: 0.1611
Epoch 239/500
10/10            0s 9ms/step - loss:
0.0418 - mae: 0.1480 - val_loss: 0.0471 - val_mae: 0.1606
Epoch 240/500
10/10            0s 10ms/step -
loss: 0.0415 - mae: 0.1475 - val_loss: 0.0468 - val_mae: 0.1600
Epoch 241/500
10/10            0s 10ms/step -
loss: 0.0412 - mae: 0.1470 - val_loss: 0.0464 - val_mae: 0.1594
Epoch 242/500
10/10            0s 10ms/step -
loss: 0.0409 - mae: 0.1465 - val_loss: 0.0461 - val_mae: 0.1588
Epoch 243/500
10/10            0s 9ms/step - loss:
0.0406 - mae: 0.1461 - val_loss: 0.0457 - val_mae: 0.1583
Epoch 244/500
10/10            0s 9ms/step - loss:
0.0403 - mae: 0.1456 - val_loss: 0.0453 - val_mae: 0.1577
Epoch 245/500
10/10            0s 9ms/step - loss:
0.0401 - mae: 0.1451 - val_loss: 0.0450 - val_mae: 0.1571
Epoch 246/500
10/10            0s 11ms/step -
loss: 0.0398 - mae: 0.1447 - val_loss: 0.0446 - val_mae: 0.1565
Epoch 247/500
10/10            0s 6ms/step - loss:
0.0395 - mae: 0.1442 - val_loss: 0.0443 - val_mae: 0.1560
Epoch 248/500
10/10            0s 7ms/step - loss:
0.0392 - mae: 0.1438 - val_loss: 0.0440 - val_mae: 0.1554
Epoch 249/500
10/10            0s 5ms/step - loss:
0.0389 - mae: 0.1433 - val_loss: 0.0436 - val_mae: 0.1548
Epoch 250/500
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10/10            0s 6ms/step - loss:
0.0387 - mae: 0.1427 - val_loss: 0.0433 - val_mae: 0.1542
Epoch 251/500
10/10            0s 5ms/step - loss:
0.0384 - mae: 0.1423 - val_loss: 0.0429 - val_mae: 0.1537
Epoch 252/500
10/10            0s 5ms/step - loss:
0.0381 - mae: 0.1418 - val_loss: 0.0426 - val_mae: 0.1531
Epoch 253/500
10/10            0s 8ms/step - loss:
0.0378 - mae: 0.1413 - val_loss: 0.0422 - val_mae: 0.1525
Epoch 254/500
10/10            0s 5ms/step - loss:
0.0376 - mae: 0.1408 - val_loss: 0.0419 - val_mae: 0.1519
Epoch 255/500
10/10            0s 7ms/step - loss:
0.0373 - mae: 0.1404 - val_loss: 0.0415 - val_mae: 0.1513
Epoch 256/500
10/10            0s 5ms/step - loss:
0.0370 - mae: 0.1398 - val_loss: 0.0412 - val_mae: 0.1508
Epoch 257/500
10/10            0s 7ms/step - loss:
0.0367 - mae: 0.1392 - val_loss: 0.0409 - val_mae: 0.1503
Epoch 258/500
10/10            0s 7ms/step - loss:
0.0365 - mae: 0.1387 - val_loss: 0.0405 - val_mae: 0.1497
Epoch 259/500
10/10            0s 5ms/step - loss:
0.0362 - mae: 0.1381 - val_loss: 0.0402 - val_mae: 0.1490
Epoch 260/500
10/10            0s 9ms/step - loss:
0.0359 - mae: 0.1377 - val_loss: 0.0399 - val_mae: 0.1485
Epoch 261/500
10/10            0s 7ms/step - loss:
0.0357 - mae: 0.1372 - val_loss: 0.0395 - val_mae: 0.1479
Epoch 262/500
10/10            0s 7ms/step - loss:
0.0354 - mae: 0.1367 - val_loss: 0.0392 - val_mae: 0.1472
Epoch 263/500
10/10            0s 7ms/step - loss:
0.0351 - mae: 0.1362 - val_loss: 0.0388 - val_mae: 0.1466
Epoch 264/500
10/10            0s 5ms/step - loss:
0.0349 - mae: 0.1357 - val_loss: 0.0385 - val_mae: 0.1460
Epoch 265/500
10/10            0s 5ms/step - loss:
0.0346 - mae: 0.1352 - val_loss: 0.0382 - val_mae: 0.1454
Epoch 266/500
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10/10            0s 7ms/step - loss:
0.0343 - mae: 0.1348 - val_loss: 0.0378 - val_mae: 0.1448
Epoch 267/500
10/10            0s 6ms/step - loss:
0.0341 - mae: 0.1343 - val_loss: 0.0375 - val_mae: 0.1441
Epoch 268/500
10/10            0s 6ms/step - loss:
0.0338 - mae: 0.1338 - val_loss: 0.0372 - val_mae: 0.1435
Epoch 269/500
10/10            0s 8ms/step - loss:
0.0336 - mae: 0.1334 - val_loss: 0.0368 - val_mae: 0.1429
Epoch 270/500
10/10            0s 7ms/step - loss:
0.0333 - mae: 0.1329 - val_loss: 0.0365 - val_mae: 0.1423
Epoch 271/500
10/10            0s 6ms/step - loss:
0.0331 - mae: 0.1325 - val_loss: 0.0362 - val_mae: 0.1417
Epoch 272/500
10/10            0s 7ms/step - loss:
0.0328 - mae: 0.1320 - val_loss: 0.0359 - val_mae: 0.1412
Epoch 273/500
10/10            0s 5ms/step - loss:
0.0326 - mae: 0.1316 - val_loss: 0.0355 - val_mae: 0.1406
Epoch 274/500
10/10            0s 6ms/step - loss:
0.0323 - mae: 0.1311 - val_loss: 0.0352 - val_mae: 0.1401
Epoch 275/500
10/10            0s 7ms/step - loss:
0.0321 - mae: 0.1307 - val_loss: 0.0349 - val_mae: 0.1395
Epoch 276/500
10/10            0s 8ms/step - loss:
0.0318 - mae: 0.1302 - val_loss: 0.0346 - val_mae: 0.1390
Epoch 277/500
10/10            0s 5ms/step - loss:
0.0316 - mae: 0.1298 - val_loss: 0.0343 - val_mae: 0.1384
Epoch 278/500
10/10            0s 7ms/step - loss:
0.0313 - mae: 0.1293 - val_loss: 0.0340 - val_mae: 0.1379
Epoch 279/500
10/10            0s 5ms/step - loss:
0.0311 - mae: 0.1289 - val_loss: 0.0337 - val_mae: 0.1374
Epoch 280/500
10/10            0s 5ms/step - loss:
0.0309 - mae: 0.1285 - val_loss: 0.0334 - val_mae: 0.1369
Epoch 281/500
10/10            0s 6ms/step - loss:
0.0306 - mae: 0.1280 - val_loss: 0.0331 - val_mae: 0.1363
Epoch 282/500
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10/10            0s 6ms/step - loss:
0.0304 - mae: 0.1276 - val_loss: 0.0328 - val_mae: 0.1358
Epoch 283/500
10/10            0s 6ms/step - loss:
0.0302 - mae: 0.1272 - val_loss: 0.0325 - val_mae: 0.1353
Epoch 284/500
10/10            0s 5ms/step - loss:
0.0299 - mae: 0.1268 - val_loss: 0.0322 - val_mae: 0.1348
Epoch 285/500
10/10            0s 7ms/step - loss:
0.0297 - mae: 0.1264 - val_loss: 0.0319 - val_mae: 0.1342
Epoch 286/500
10/10            0s 6ms/step - loss:
0.0295 - mae: 0.1260 - val_loss: 0.0316 - val_mae: 0.1338
Epoch 287/500
10/10            0s 6ms/step - loss:
0.0293 - mae: 0.1256 - val_loss: 0.0313 - val_mae: 0.1333
Epoch 288/500
10/10            0s 7ms/step - loss:
0.0291 - mae: 0.1252 - val_loss: 0.0311 - val_mae: 0.1328
Epoch 289/500
10/10            0s 6ms/step - loss:
0.0289 - mae: 0.1248 - val_loss: 0.0308 - val_mae: 0.1323
Epoch 290/500
10/10            0s 5ms/step - loss:
0.0286 - mae: 0.1244 - val_loss: 0.0305 - val_mae: 0.1318
Epoch 291/500
10/10            0s 6ms/step - loss:
0.0284 - mae: 0.1240 - val_loss: 0.0302 - val_mae: 0.1313
Epoch 292/500
10/10            0s 7ms/step - loss:
0.0282 - mae: 0.1236 - val_loss: 0.0300 - val_mae: 0.1308
Epoch 293/500
10/10            0s 5ms/step - loss:
0.0280 - mae: 0.1232 - val_loss: 0.0297 - val_mae: 0.1303
Epoch 294/500
10/10            0s 6ms/step - loss:
0.0278 - mae: 0.1228 - val_loss: 0.0294 - val_mae: 0.1298
Epoch 295/500
10/10            0s 7ms/step - loss:
0.0276 - mae: 0.1224 - val_loss: 0.0292 - val_mae: 0.1293
Epoch 296/500
10/10            0s 6ms/step - loss:
0.0274 - mae: 0.1220 - val_loss: 0.0289 - val_mae: 0.1288
Epoch 297/500
10/10            0s 5ms/step - loss:
0.0272 - mae: 0.1217 - val_loss: 0.0287 - val_mae: 0.1284
Epoch 298/500
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10/10            0s 6ms/step - loss:
0.0270 - mae: 0.1213 - val_loss: 0.0284 - val_mae: 0.1279
Epoch 299/500
10/10            0s 7ms/step - loss:
0.0268 - mae: 0.1209 - val_loss: 0.0281 - val_mae: 0.1273
Epoch 300/500
10/10            0s 7ms/step - loss:
0.0266 - mae: 0.1206 - val_loss: 0.0279 - val_mae: 0.1269
Epoch 301/500
10/10            0s 7ms/step - loss:
0.0264 - mae: 0.1202 - val_loss: 0.0276 - val_mae: 0.1264
Epoch 302/500
10/10            0s 6ms/step - loss:
0.0262 - mae: 0.1199 - val_loss: 0.0274 - val_mae: 0.1260
Epoch 303/500
10/10            0s 7ms/step - loss:
0.0260 - mae: 0.1195 - val_loss: 0.0272 - val_mae: 0.1255
Epoch 304/500
10/10            0s 5ms/step - loss:
0.0258 - mae: 0.1191 - val_loss: 0.0269 - val_mae: 0.1251
Epoch 305/500
10/10            0s 7ms/step - loss:
0.0257 - mae: 0.1188 - val_loss: 0.0267 - val_mae: 0.1247
Epoch 306/500
10/10            0s 6ms/step - loss:
0.0255 - mae: 0.1183 - val_loss: 0.0264 - val_mae: 0.1243
Epoch 307/500
10/10            0s 8ms/step - loss:
0.0253 - mae: 0.1179 - val_loss: 0.0262 - val_mae: 0.1239
Epoch 308/500
10/10            0s 5ms/step - loss:
0.0251 - mae: 0.1176 - val_loss: 0.0260 - val_mae: 0.1234
Epoch 309/500
10/10            0s 8ms/step - loss:
0.0249 - mae: 0.1172 - val_loss: 0.0257 - val_mae: 0.1230
Epoch 310/500
10/10            0s 5ms/step - loss:
0.0247 - mae: 0.1169 - val_loss: 0.0255 - val_mae: 0.1226
Epoch 311/500
10/10            0s 8ms/step - loss:
0.0245 - mae: 0.1166 - val_loss: 0.0253 - val_mae: 0.1222
Epoch 312/500
10/10            0s 8ms/step - loss:
0.0244 - mae: 0.1162 - val_loss: 0.0251 - val_mae: 0.1218
Epoch 313/500
10/10            0s 8ms/step - loss:
0.0242 - mae: 0.1159 - val_loss: 0.0248 - val_mae: 0.1214
Epoch 314/500
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10/10            0s 5ms/step - loss:
0.0240 - mae: 0.1156 - val_loss: 0.0246 - val_mae: 0.1210
Epoch 315/500
10/10            0s 6ms/step - loss:
0.0239 - mae: 0.1153 - val_loss: 0.0244 - val_mae: 0.1206
Epoch 316/500
10/10            0s 7ms/step - loss:
0.0237 - mae: 0.1150 - val_loss: 0.0242 - val_mae: 0.1202
Epoch 317/500
10/10            0s 6ms/step - loss:
0.0235 - mae: 0.1146 - val_loss: 0.0240 - val_mae: 0.1198
Epoch 318/500
10/10            0s 6ms/step - loss:
0.0234 - mae: 0.1143 - val_loss: 0.0238 - val_mae: 0.1194
Epoch 319/500
10/10            0s 5ms/step - loss:
0.0232 - mae: 0.1140 - val_loss: 0.0236 - val_mae: 0.1189
Epoch 320/500
10/10            0s 8ms/step - loss:
0.0230 - mae: 0.1137 - val_loss: 0.0234 - val_mae: 0.1185
Epoch 321/500
10/10            0s 6ms/step - loss:
0.0229 - mae: 0.1134 - val_loss: 0.0232 - val_mae: 0.1181
Epoch 322/500
10/10            0s 7ms/step - loss:
0.0227 - mae: 0.1131 - val_loss: 0.0230 - val_mae: 0.1177
Epoch 323/500
10/10            0s 8ms/step - loss:
0.0226 - mae: 0.1128 - val_loss: 0.0228 - val_mae: 0.1174
Epoch 324/500
10/10            0s 7ms/step - loss:
0.0224 - mae: 0.1125 - val_loss: 0.0226 - val_mae: 0.1170
Epoch 325/500
10/10            0s 5ms/step - loss:
0.0223 - mae: 0.1122 - val_loss: 0.0224 - val_mae: 0.1166
Epoch 326/500
10/10            0s 6ms/step - loss:
0.0221 - mae: 0.1119 - val_loss: 0.0222 - val_mae: 0.1162
Epoch 327/500
10/10            0s 7ms/step - loss:
0.0220 - mae: 0.1116 - val_loss: 0.0220 - val_mae: 0.1159
Epoch 328/500
10/10            0s 9ms/step - loss:
0.0218 - mae: 0.1113 - val_loss: 0.0219 - val_mae: 0.1156
Epoch 329/500
10/10            0s 7ms/step - loss:
0.0217 - mae: 0.1110 - val_loss: 0.0217 - val_mae: 0.1152
Epoch 330/500
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10/10            0s 9ms/step - loss:
0.0215 - mae: 0.1107 - val_loss: 0.0215 - val_mae: 0.1148
Epoch 331/500
10/10            0s 10ms/step -
loss: 0.0214 - mae: 0.1104 - val_loss: 0.0214 - val_mae: 0.1145
Epoch 332/500
10/10            0s 9ms/step - loss:
0.0212 - mae: 0.1102 - val_loss: 0.0212 - val_mae: 0.1141
Epoch 333/500
10/10            0s 9ms/step - loss:
0.0211 - mae: 0.1099 - val_loss: 0.0211 - val_mae: 0.1139
Epoch 334/500
10/10            0s 10ms/step -
loss: 0.0210 - mae: 0.1096 - val_loss: 0.0209 - val_mae: 0.1136
Epoch 335/500
10/10            0s 9ms/step - loss:
0.0208 - mae: 0.1094 - val_loss: 0.0207 - val_mae: 0.1132
Epoch 336/500
10/10            0s 8ms/step - loss:
0.0207 - mae: 0.1091 - val_loss: 0.0206 - val_mae: 0.1129
Epoch 337/500
10/10            0s 9ms/step - loss:
0.0206 - mae: 0.1088 - val_loss: 0.0204 - val_mae: 0.1126
Epoch 338/500
10/10            0s 9ms/step - loss:
0.0204 - mae: 0.1085 - val_loss: 0.0203 - val_mae: 0.1123
Epoch 339/500
10/10            0s 9ms/step - loss:
0.0203 - mae: 0.1083 - val_loss: 0.0201 - val_mae: 0.1120
Epoch 340/500
10/10            0s 10ms/step -
loss: 0.0202 - mae: 0.1080 - val_loss: 0.0200 - val_mae: 0.1116
Epoch 341/500
10/10            0s 8ms/step - loss:
0.0201 - mae: 0.1077 - val_loss: 0.0198 - val_mae: 0.1113
Epoch 342/500
10/10            0s 9ms/step - loss:
0.0199 - mae: 0.1075 - val_loss: 0.0197 - val_mae: 0.1111
Epoch 343/500
10/10            0s 11ms/step -
loss: 0.0198 - mae: 0.1073 - val_loss: 0.0196 - val_mae: 0.1109
Epoch 344/500
10/10            0s 9ms/step - loss:
0.0197 - mae: 0.1071 - val_loss: 0.0194 - val_mae: 0.1106
Epoch 345/500
10/10            0s 9ms/step - loss:
0.0196 - mae: 0.1069 - val_loss: 0.0193 - val_mae: 0.1102
Epoch 346/500
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10/10            0s 8ms/step - loss:
0.0195 - mae: 0.1067 - val_loss: 0.0192 - val_mae: 0.1099
Epoch 347/500
10/10            0s 10ms/step -
loss: 0.0194 - mae: 0.1065 - val_loss: 0.0190 - val_mae: 0.1095
Epoch 348/500
10/10            0s 10ms/step -
loss: 0.0192 - mae: 0.1063 - val_loss: 0.0189 - val_mae: 0.1092
Epoch 349/500
10/10            0s 7ms/step - loss:
0.0191 - mae: 0.1061 - val_loss: 0.0187 - val_mae: 0.1089
Epoch 350/500
10/10            0s 5ms/step - loss:
0.0190 - mae: 0.1059 - val_loss: 0.0186 - val_mae: 0.1085
Epoch 351/500
10/10            0s 7ms/step - loss:
0.0189 - mae: 0.1057 - val_loss: 0.0185 - val_mae: 0.1082
Epoch 352/500
10/10            0s 5ms/step - loss:
0.0188 - mae: 0.1055 - val_loss: 0.0184 - val_mae: 0.1079
Epoch 353/500
10/10            0s 6ms/step - loss:
0.0187 - mae: 0.1053 - val_loss: 0.0182 - val_mae: 0.1076
Epoch 354/500
10/10            0s 8ms/step - loss:
0.0186 - mae: 0.1051 - val_loss: 0.0181 - val_mae: 0.1073
Epoch 355/500
10/10            0s 7ms/step - loss:
0.0185 - mae: 0.1049 - val_loss: 0.0180 - val_mae: 0.1070
Epoch 356/500
10/10            0s 6ms/step - loss:
0.0184 - mae: 0.1047 - val_loss: 0.0179 - val_mae: 0.1067
Epoch 357/500
10/10            0s 6ms/step - loss:
0.0183 - mae: 0.1045 - val_loss: 0.0178 - val_mae: 0.1064
Epoch 358/500
10/10            0s 6ms/step - loss:
0.0182 - mae: 0.1043 - val_loss: 0.0177 - val_mae: 0.1062
Epoch 359/500
10/10            0s 7ms/step - loss:
0.0181 - mae: 0.1041 - val_loss: 0.0176 - val_mae: 0.1059
Epoch 360/500
10/10            0s 7ms/step - loss:
0.0180 - mae: 0.1039 - val_loss: 0.0175 - val_mae: 0.1056
Epoch 361/500
10/10            0s 9ms/step - loss:
0.0179 - mae: 0.1037 - val_loss: 0.0173 - val_mae: 0.1053
Epoch 362/500
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10/10            0s 5ms/step - loss:
0.0178 - mae: 0.1035 - val_loss: 0.0172 - val_mae: 0.1051
Epoch 363/500
10/10            0s 5ms/step - loss:
0.0178 - mae: 0.1033 - val_loss: 0.0171 - val_mae: 0.1048
Epoch 364/500
10/10            0s 5ms/step - loss:
0.0177 - mae: 0.1031 - val_loss: 0.0170 - val_mae: 0.1046
Epoch 365/500
10/10            0s 6ms/step - loss:
0.0176 - mae: 0.1029 - val_loss: 0.0169 - val_mae: 0.1043
Epoch 366/500
10/10            0s 7ms/step - loss:
0.0175 - mae: 0.1027 - val_loss: 0.0169 - val_mae: 0.1040
Epoch 367/500
10/10            0s 7ms/step - loss:
0.0174 - mae: 0.1025 - val_loss: 0.0168 - val_mae: 0.1038
Epoch 368/500
10/10            0s 5ms/step - loss:
0.0173 - mae: 0.1024 - val_loss: 0.0167 - val_mae: 0.1035
Epoch 369/500
10/10            0s 7ms/step - loss:
0.0172 - mae: 0.1022 - val_loss: 0.0166 - val_mae: 0.1032
Epoch 370/500
10/10            0s 7ms/step - loss:
0.0172 - mae: 0.1020 - val_loss: 0.0165 - val_mae: 0.1030
Epoch 371/500
10/10            0s 6ms/step - loss:
0.0171 - mae: 0.1019 - val_loss: 0.0164 - val_mae: 0.1027
Epoch 372/500
10/10            0s 7ms/step - loss:
0.0170 - mae: 0.1017 - val_loss: 0.0163 - val_mae: 0.1025
Epoch 373/500
10/10            0s 7ms/step - loss:
0.0169 - mae: 0.1015 - val_loss: 0.0162 - val_mae: 0.1022
Epoch 374/500
10/10            0s 7ms/step - loss:
0.0169 - mae: 0.1013 - val_loss: 0.0161 - val_mae: 0.1019
Epoch 375/500
10/10            0s 6ms/step - loss:
0.0168 - mae: 0.1012 - val_loss: 0.0160 - val_mae: 0.1018
Epoch 376/500
10/10            0s 8ms/step - loss:
0.0167 - mae: 0.1010 - val_loss: 0.0159 - val_mae: 0.1015
Epoch 377/500
10/10            0s 5ms/step - loss:
0.0166 - mae: 0.1008 - val_loss: 0.0159 - val_mae: 0.1012
Epoch 378/500
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10/10            0s 5ms/step - loss:
0.0165 - mae: 0.1006 - val_loss: 0.0158 - val_mae: 0.1010
Epoch 379/500
10/10            0s 5ms/step - loss:
0.0165 - mae: 0.1005 - val_loss: 0.0157 - val_mae: 0.1008
Epoch 380/500
10/10            0s 8ms/step - loss:
0.0164 - mae: 0.1003 - val_loss: 0.0156 - val_mae: 0.1005
Epoch 381/500
10/10            0s 5ms/step - loss:
0.0163 - mae: 0.1001 - val_loss: 0.0155 - val_mae: 0.1003
Epoch 382/500
10/10            0s 7ms/step - loss:
0.0163 - mae: 0.1000 - val_loss: 0.0155 - val_mae: 0.1001
Epoch 383/500
10/10            0s 9ms/step - loss:
0.0162 - mae: 0.0998 - val_loss: 0.0154 - val_mae: 0.0999
Epoch 384/500
10/10            0s 8ms/step - loss:
0.0162 - mae: 0.0997 - val_loss: 0.0153 - val_mae: 0.0997
Epoch 385/500
10/10            0s 5ms/step - loss:
0.0161 - mae: 0.0996 - val_loss: 0.0152 - val_mae: 0.0995
Epoch 386/500
10/10            0s 5ms/step - loss:
0.0160 - mae: 0.0994 - val_loss: 0.0151 - val_mae: 0.0992
Epoch 387/500
10/10            0s 8ms/step - loss:
0.0160 - mae: 0.0993 - val_loss: 0.0151 - val_mae: 0.0990
Epoch 388/500
10/10            0s 7ms/step - loss:
0.0159 - mae: 0.0992 - val_loss: 0.0150 - val_mae: 0.0988
Epoch 389/500
10/10            0s 5ms/step - loss:
0.0159 - mae: 0.0991 - val_loss: 0.0149 - val_mae: 0.0986
Epoch 390/500
10/10            0s 5ms/step - loss:
0.0158 - mae: 0.0990 - val_loss: 0.0148 - val_mae: 0.0984
Epoch 391/500
10/10            0s 7ms/step - loss:
0.0158 - mae: 0.0989 - val_loss: 0.0148 - val_mae: 0.0981
Epoch 392/500
10/10            0s 8ms/step - loss:
0.0157 - mae: 0.0987 - val_loss: 0.0147 - val_mae: 0.0979
Epoch 393/500
10/10            0s 5ms/step - loss:
0.0156 - mae: 0.0986 - val_loss: 0.0146 - val_mae: 0.0977
Epoch 394/500
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10/10            0s 5ms/step - loss:
0.0156 - mae: 0.0985 - val_loss: 0.0146 - val_mae: 0.0975
Epoch 395/500
10/10            0s 5ms/step - loss:
0.0155 - mae: 0.0984 - val_loss: 0.0145 - val_mae: 0.0974
Epoch 396/500
10/10            0s 7ms/step - loss:
0.0155 - mae: 0.0983 - val_loss: 0.0145 - val_mae: 0.0972
Epoch 397/500
10/10            0s 7ms/step - loss:
0.0154 - mae: 0.0982 - val_loss: 0.0144 - val_mae: 0.0971
Epoch 398/500
10/10            0s 6ms/step - loss:
0.0154 - mae: 0.0981 - val_loss: 0.0144 - val_mae: 0.0969
Epoch 399/500
10/10            0s 7ms/step - loss:
0.0153 - mae: 0.0980 - val_loss: 0.0143 - val_mae: 0.0967
Epoch 400/500
10/10            0s 7ms/step - loss:
0.0153 - mae: 0.0978 - val_loss: 0.0142 - val_mae: 0.0965
Epoch 401/500
10/10            0s 7ms/step - loss:
0.0152 - mae: 0.0978 - val_loss: 0.0142 - val_mae: 0.0963
Epoch 402/500
10/10            0s 7ms/step - loss:
0.0152 - mae: 0.0977 - val_loss: 0.0141 - val_mae: 0.0961
Epoch 403/500
10/10            0s 6ms/step - loss:
0.0151 - mae: 0.0976 - val_loss: 0.0141 - val_mae: 0.0958
Epoch 404/500
10/10            0s 6ms/step - loss:
0.0151 - mae: 0.0974 - val_loss: 0.0140 - val_mae: 0.0957
Epoch 405/500
10/10            0s 7ms/step - loss:
0.0150 - mae: 0.0973 - val_loss: 0.0140 - val_mae: 0.0955
Epoch 406/500
10/10            0s 6ms/step - loss:
0.0150 - mae: 0.0973 - val_loss: 0.0139 - val_mae: 0.0953
Epoch 407/500
10/10            0s 9ms/step - loss:
0.0150 - mae: 0.0971 - val_loss: 0.0139 - val_mae: 0.0951
Epoch 408/500
10/10            0s 7ms/step - loss:
0.0149 - mae: 0.0970 - val_loss: 0.0138 - val_mae: 0.0949
Epoch 409/500
10/10            0s 7ms/step - loss:
0.0149 - mae: 0.0969 - val_loss: 0.0138 - val_mae: 0.0948
Epoch 410/500
```

```
10/10            0s 7ms/step - loss:
0.0148 - mae: 0.0969 - val_loss: 0.0137 - val_mae: 0.0946
Epoch 411/500
10/10            0s 8ms/step - loss:
0.0148 - mae: 0.0967 - val_loss: 0.0137 - val_mae: 0.0945
Epoch 412/500
10/10            0s 6ms/step - loss:
0.0148 - mae: 0.0967 - val_loss: 0.0136 - val_mae: 0.0943
Epoch 413/500
10/10            0s 5ms/step - loss:
0.0147 - mae: 0.0966 - val_loss: 0.0136 - val_mae: 0.0941
Epoch 414/500
10/10            0s 6ms/step - loss:
0.0147 - mae: 0.0965 - val_loss: 0.0135 - val_mae: 0.0940
Epoch 415/500
10/10            0s 6ms/step - loss:
0.0146 - mae: 0.0964 - val_loss: 0.0135 - val_mae: 0.0938
Epoch 416/500
10/10            0s 7ms/step - loss:
0.0146 - mae: 0.0963 - val_loss: 0.0135 - val_mae: 0.0937
Epoch 417/500
10/10            0s 7ms/step - loss:
0.0146 - mae: 0.0962 - val_loss: 0.0134 - val_mae: 0.0935
Epoch 418/500
10/10            0s 6ms/step - loss:
0.0145 - mae: 0.0961 - val_loss: 0.0134 - val_mae: 0.0933
Epoch 419/500
10/10            0s 6ms/step - loss:
0.0145 - mae: 0.0960 - val_loss: 0.0133 - val_mae: 0.0932
Epoch 420/500
10/10            0s 7ms/step - loss:
0.0145 - mae: 0.0960 - val_loss: 0.0133 - val_mae: 0.0930
Epoch 421/500
10/10            0s 5ms/step - loss:
0.0144 - mae: 0.0958 - val_loss: 0.0132 - val_mae: 0.0928
Epoch 422/500
10/10            0s 6ms/step - loss:
0.0144 - mae: 0.0958 - val_loss: 0.0132 - val_mae: 0.0926
Epoch 423/500
10/10            0s 6ms/step - loss:
0.0143 - mae: 0.0957 - val_loss: 0.0131 - val_mae: 0.0924
Epoch 424/500
10/10            0s 6ms/step - loss:
0.0143 - mae: 0.0957 - val_loss: 0.0131 - val_mae: 0.0923
Epoch 425/500
10/10            0s 6ms/step - loss:
0.0143 - mae: 0.0956 - val_loss: 0.0131 - val_mae: 0.0921
Epoch 426/500
```

```
10/10            0s 7ms/step - loss:
0.0143 - mae: 0.0956 - val_loss: 0.0130 - val_mae: 0.0919
Epoch 427/500
10/10            0s 5ms/step - loss:
0.0142 - mae: 0.0954 - val_loss: 0.0130 - val_mae: 0.0918
Epoch 428/500
10/10            0s 8ms/step - loss:
0.0142 - mae: 0.0954 - val_loss: 0.0129 - val_mae: 0.0916
Epoch 429/500
10/10            0s 9ms/step - loss:
0.0142 - mae: 0.0953 - val_loss: 0.0129 - val_mae: 0.0915
Epoch 430/500
10/10            0s 9ms/step - loss:
0.0141 - mae: 0.0952 - val_loss: 0.0129 - val_mae: 0.0913
Epoch 431/500
10/10            0s 8ms/step - loss:
0.0141 - mae: 0.0951 - val_loss: 0.0128 - val_mae: 0.0913
Epoch 432/500
10/10            0s 7ms/step - loss:
0.0141 - mae: 0.0951 - val_loss: 0.0128 - val_mae: 0.0911
Epoch 433/500
10/10            0s 9ms/step - loss:
0.0141 - mae: 0.0950 - val_loss: 0.0128 - val_mae: 0.0910
Epoch 434/500
10/10            0s 9ms/step - loss:
0.0140 - mae: 0.0950 - val_loss: 0.0127 - val_mae: 0.0909
Epoch 435/500
10/10            0s 8ms/step - loss:
0.0140 - mae: 0.0949 - val_loss: 0.0127 - val_mae: 0.0908
Epoch 436/500
10/10            0s 9ms/step - loss:
0.0140 - mae: 0.0949 - val_loss: 0.0127 - val_mae: 0.0906
Epoch 437/500
10/10            0s 8ms/step - loss:
0.0140 - mae: 0.0948 - val_loss: 0.0126 - val_mae: 0.0906
Epoch 438/500
10/10            0s 9ms/step - loss:
0.0140 - mae: 0.0947 - val_loss: 0.0126 - val_mae: 0.0905
Epoch 439/500
10/10            0s 11ms/step -
loss: 0.0139 - mae: 0.0947 - val_loss: 0.0126 - val_mae: 0.0903
Epoch 440/500
10/10            0s 9ms/step - loss:
0.0139 - mae: 0.0946 - val_loss: 0.0126 - val_mae: 0.0903
Epoch 441/500
10/10            0s 9ms/step - loss:
0.0139 - mae: 0.0946 - val_loss: 0.0125 - val_mae: 0.0902
Epoch 442/500
```

```
10/10            0s 8ms/step - loss:
0.0139 - mae: 0.0945 - val_loss: 0.0125 - val_mae: 0.0900
Epoch 443/500
10/10            0s 10ms/step -
loss: 0.0139 - mae: 0.0944 - val_loss: 0.0125 - val_mae: 0.0900
Epoch 444/500
10/10            0s 10ms/step -
loss: 0.0138 - mae: 0.0944 - val_loss: 0.0125 - val_mae: 0.0898
Epoch 445/500
10/10            0s 11ms/step -
loss: 0.0138 - mae: 0.0944 - val_loss: 0.0124 - val_mae: 0.0897
Epoch 446/500
10/10            0s 7ms/step - loss:
0.0138 - mae: 0.0943 - val_loss: 0.0124 - val_mae: 0.0896
Epoch 447/500
10/10            0s 7ms/step - loss:
0.0138 - mae: 0.0942 - val_loss: 0.0124 - val_mae: 0.0895
Epoch 448/500
10/10            0s 5ms/step - loss:
0.0138 - mae: 0.0942 - val_loss: 0.0124 - val_mae: 0.0894
Epoch 449/500
10/10            0s 6ms/step - loss:
0.0137 - mae: 0.0942 - val_loss: 0.0123 - val_mae: 0.0893
Epoch 450/500
10/10            0s 6ms/step - loss:
0.0137 - mae: 0.0941 - val_loss: 0.0123 - val_mae: 0.0892
Epoch 451/500
10/10            0s 8ms/step - loss:
0.0137 - mae: 0.0941 - val_loss: 0.0123 - val_mae: 0.0892
Epoch 452/500
10/10            0s 9ms/step - loss:
0.0137 - mae: 0.0940 - val_loss: 0.0123 - val_mae: 0.0890
Epoch 453/500
10/10            0s 6ms/step - loss:
0.0137 - mae: 0.0939 - val_loss: 0.0122 - val_mae: 0.0890
Epoch 454/500
10/10            0s 7ms/step - loss:
0.0137 - mae: 0.0939 - val_loss: 0.0122 - val_mae: 0.0889
Epoch 455/500
10/10            0s 6ms/step - loss:
0.0136 - mae: 0.0939 - val_loss: 0.0122 - val_mae: 0.0888
Epoch 456/500
10/10            0s 6ms/step - loss:
0.0136 - mae: 0.0938 - val_loss: 0.0122 - val_mae: 0.0887
Epoch 457/500
10/10            0s 6ms/step - loss:
0.0136 - mae: 0.0938 - val_loss: 0.0122 - val_mae: 0.0886
Epoch 458/500
```

```
10/10            0s 5ms/step - loss:
0.0136 - mae: 0.0938 - val_loss: 0.0121 - val_mae: 0.0886
Epoch 459/500
10/10            0s 7ms/step - loss:
0.0136 - mae: 0.0937 - val_loss: 0.0121 - val_mae: 0.0885
Epoch 460/500
10/10            0s 7ms/step - loss:
0.0136 - mae: 0.0937 - val_loss: 0.0121 - val_mae: 0.0884
Epoch 461/500
10/10            0s 8ms/step - loss:
0.0136 - mae: 0.0936 - val_loss: 0.0121 - val_mae: 0.0883
Epoch 462/500
10/10            0s 6ms/step - loss:
0.0135 - mae: 0.0936 - val_loss: 0.0121 - val_mae: 0.0883
Epoch 463/500
10/10            0s 8ms/step - loss:
0.0135 - mae: 0.0936 - val_loss: 0.0120 - val_mae: 0.0882
Epoch 464/500
10/10            0s 6ms/step - loss:
0.0135 - mae: 0.0935 - val_loss: 0.0120 - val_mae: 0.0881
Epoch 465/500
10/10            0s 6ms/step - loss:
0.0135 - mae: 0.0935 - val_loss: 0.0120 - val_mae: 0.0881
Epoch 466/500
10/10            0s 7ms/step - loss:
0.0135 - mae: 0.0934 - val_loss: 0.0120 - val_mae: 0.0880
Epoch 467/500
10/10            0s 5ms/step - loss:
0.0135 - mae: 0.0934 - val_loss: 0.0120 - val_mae: 0.0880
Epoch 468/500
10/10            0s 6ms/step - loss:
0.0135 - mae: 0.0934 - val_loss: 0.0120 - val_mae: 0.0879
Epoch 469/500
10/10            0s 7ms/step - loss:
0.0135 - mae: 0.0934 - val_loss: 0.0119 - val_mae: 0.0878
Epoch 470/500
10/10            0s 6ms/step - loss:
0.0135 - mae: 0.0933 - val_loss: 0.0119 - val_mae: 0.0877
Epoch 471/500
10/10            0s 6ms/step - loss:
0.0134 - mae: 0.0933 - val_loss: 0.0119 - val_mae: 0.0877
Epoch 472/500
10/10            0s 7ms/step - loss:
0.0134 - mae: 0.0933 - val_loss: 0.0119 - val_mae: 0.0876
Epoch 473/500
10/10            0s 6ms/step - loss:
0.0134 - mae: 0.0933 - val_loss: 0.0119 - val_mae: 0.0875
Epoch 474/500
```

```
10/10            0s 8ms/step - loss:
0.0134 - mae: 0.0932 - val_loss: 0.0119 - val_mae: 0.0875
Epoch 475/500
10/10            0s 6ms/step - loss:
0.0134 - mae: 0.0932 - val_loss: 0.0118 - val_mae: 0.0875
Epoch 476/500
10/10            0s 7ms/step - loss:
0.0134 - mae: 0.0931 - val_loss: 0.0118 - val_mae: 0.0874
Epoch 477/500
10/10            0s 7ms/step - loss:
0.0134 - mae: 0.0931 - val_loss: 0.0118 - val_mae: 0.0873
Epoch 478/500
10/10            0s 6ms/step - loss:
0.0134 - mae: 0.0931 - val_loss: 0.0118 - val_mae: 0.0873
Epoch 479/500
10/10            0s 6ms/step - loss:
0.0133 - mae: 0.0931 - val_loss: 0.0118 - val_mae: 0.0873
Epoch 480/500
10/10            0s 17ms/step -
loss: 0.0133 - mae: 0.0930 - val_loss: 0.0118 - val_mae: 0.0871
Epoch 481/500
10/10            0s 20ms/step -
loss: 0.0133 - mae: 0.0930 - val_loss: 0.0117 - val_mae: 0.0871
Epoch 482/500
10/10            0s 7ms/step - loss:
0.0133 - mae: 0.0930 - val_loss: 0.0117 - val_mae: 0.0871
Epoch 483/500
10/10            0s 7ms/step - loss:
0.0133 - mae: 0.0929 - val_loss: 0.0117 - val_mae: 0.0870
Epoch 484/500
10/10            0s 7ms/step - loss:
0.0133 - mae: 0.0929 - val_loss: 0.0117 - val_mae: 0.0870
Epoch 485/500
10/10            0s 19ms/step -
loss: 0.0133 - mae: 0.0929 - val_loss: 0.0117 - val_mae: 0.0870
Epoch 486/500
10/10            0s 19ms/step -
loss: 0.0133 - mae: 0.0929 - val_loss: 0.0117 - val_mae: 0.0869
Epoch 487/500
10/10            0s 7ms/step - loss:
0.0133 - mae: 0.0929 - val_loss: 0.0117 - val_mae: 0.0869
Epoch 488/500
10/10            0s 5ms/step - loss:
0.0133 - mae: 0.0928 - val_loss: 0.0117 - val_mae: 0.0868
Epoch 489/500
10/10            0s 9ms/step - loss:
0.0132 - mae: 0.0928 - val_loss: 0.0116 - val_mae: 0.0868
Epoch 490/500
```

```
10/10             0s 6ms/step - loss:
0.0132 - mae: 0.0928 - val_loss: 0.0116 - val_mae: 0.0868
Epoch 491/500
10/10             0s 6ms/step - loss:
0.0132 - mae: 0.0927 - val_loss: 0.0116 - val_mae: 0.0867
Epoch 492/500
10/10             0s 7ms/step - loss:
0.0132 - mae: 0.0927 - val_loss: 0.0116 - val_mae: 0.0867
Epoch 493/500
10/10             0s 6ms/step - loss:
0.0132 - mae: 0.0927 - val_loss: 0.0116 - val_mae: 0.0866
Epoch 494/500
10/10             0s 7ms/step - loss:
0.0132 - mae: 0.0926 - val_loss: 0.0116 - val_mae: 0.0866
Epoch 495/500
10/10             0s 7ms/step - loss:
0.0132 - mae: 0.0927 - val_loss: 0.0116 - val_mae: 0.0866
Epoch 496/500
10/10             0s 7ms/step - loss:
0.0132 - mae: 0.0927 - val_loss: 0.0116 - val_mae: 0.0865
Epoch 497/500
10/10             0s 8ms/step - loss:
0.0132 - mae: 0.0926 - val_loss: 0.0116 - val_mae: 0.0864
Epoch 498/500
10/10             0s 6ms/step - loss:
0.0132 - mae: 0.0926 - val_loss: 0.0115 - val_mae: 0.0864
Epoch 499/500
10/10             0s 7ms/step - loss:
0.0132 - mae: 0.0926 - val_loss: 0.0115 - val_mae: 0.0864
Epoch 500/500
10/10             0s 6ms/step - loss:
0.0132 - mae: 0.0925 - val_loss: 0.0115 - val_mae: 0.0863
```

1.7 Plotting Loss Curves

The following code plots the loss curves (Training loss and validation loss) with each epoch. The loss curve can be used to check whether your model converged correctly.

Run the below cell and make sure your loss curves appear to be as the ones on the right of the below image. For more reading, refer to this.

[29]:
```
# Draw a graph of the loss, which is the distance between
# the predicted and actual values during training and validation.
loss = history.history['loss']
val_loss = history.history['val_loss']

epochs = range(1, len(loss) + 1)
```

```
plt.plot(epochs, loss, 'g.', label='Training loss')
plt.plot(epochs, val_loss, 'b', label='Validation loss')
plt.title('Training and validation loss')
plt.xlabel('Epochs')
plt.ylabel('Loss')
plt.legend()
plt.show()

# Exclude the first few epochs so the graph is easier to read
SKIP = 100

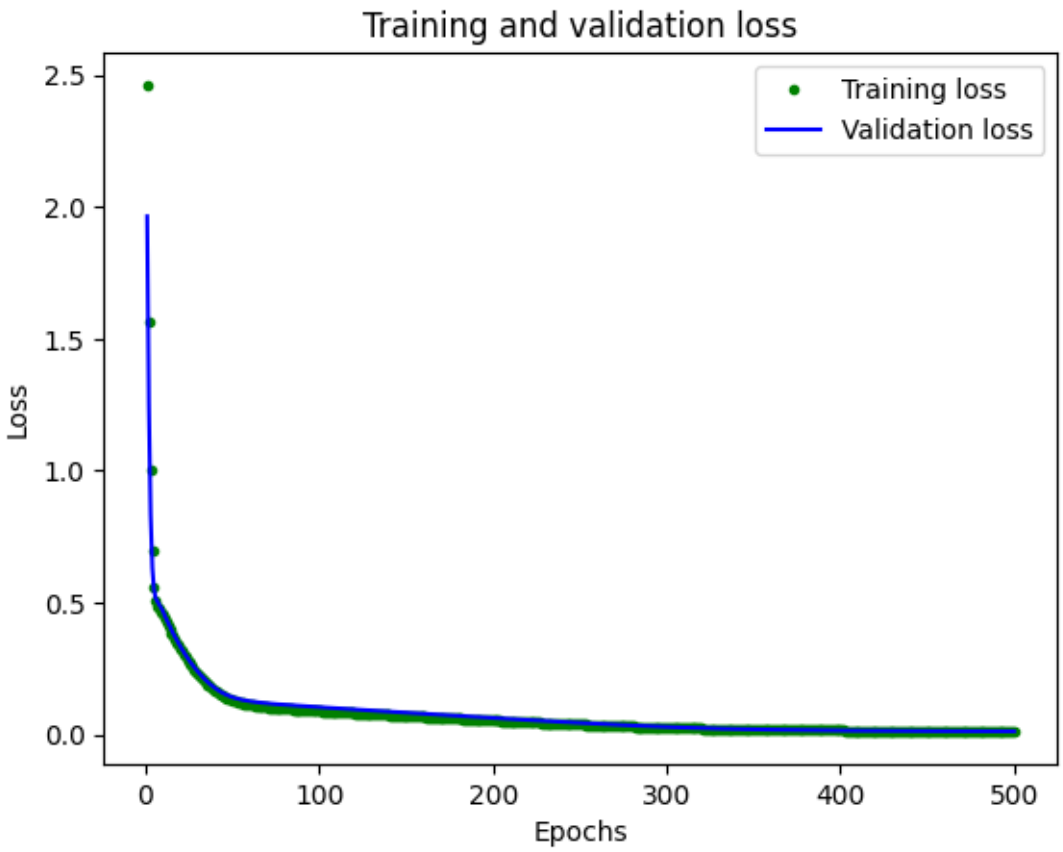
plt.clf()

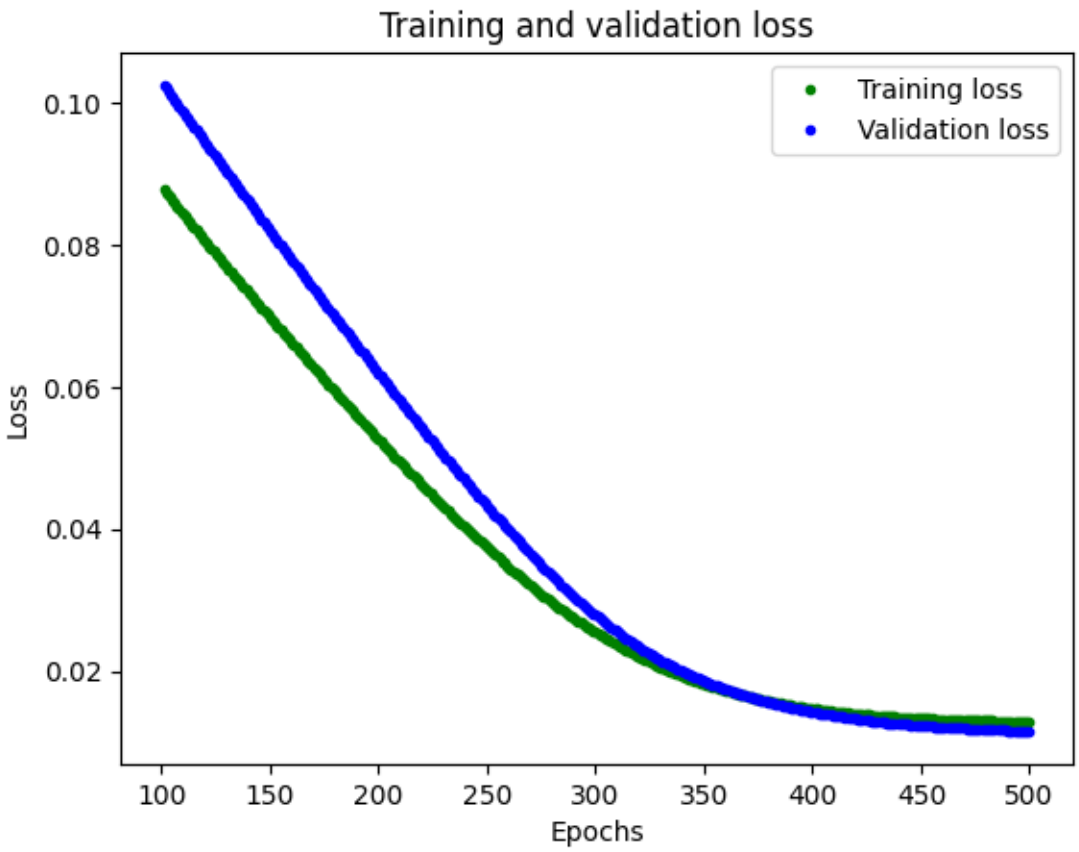
plt.plot(epochs[SKIP:], loss[SKIP:], 'g.', label='Training loss')
plt.plot(epochs[SKIP:], val_loss[SKIP:], 'b.', label='Validation loss')
plt.title('Training and validation loss')
plt.xlabel('Epochs')
plt.ylabel('Loss')
plt.legend()
plt.show()

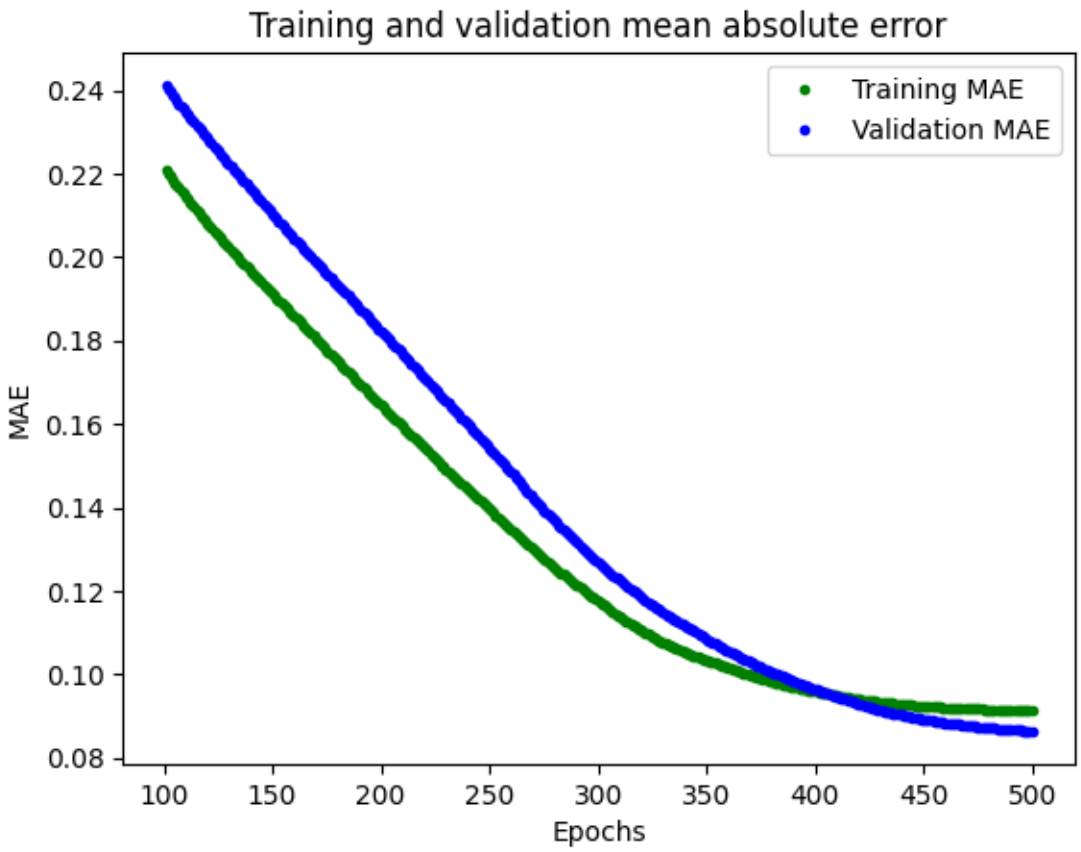
plt.clf()

# Draw a graph of mean absolute error, which is another way of
# measuring the amount of error in the prediction.
mae = history.history['mae']
val_mae = history.history['val_mae']

plt.plot(epochs[SKIP:], mae[SKIP:], 'g.', label='Training MAE')
plt.plot(epochs[SKIP:], val_mae[SKIP:], 'b.', label='Validation MAE')
plt.title('Training and validation mean absolute error')
plt.xlabel('Epochs')
plt.ylabel('MAE')
plt.legend()
plt.show()
```


Training and validation loss
Training loss
Validation loss
Loss
Epochs
2.5
2.0
1.5
1.0
0.5
0.0
0
100
200
300
400
500


Training and validation loss
Training loss
Validation loss
Loss
0.10
0.08
0.06
0.04
0.02
100
150
200
250
300
350
400
450
500
Epochs



1.8 Predict using model (Graded)

Use `model.predict()` to predict values for all data in test set and plot it against true values. You may refer to this documentation for more information.

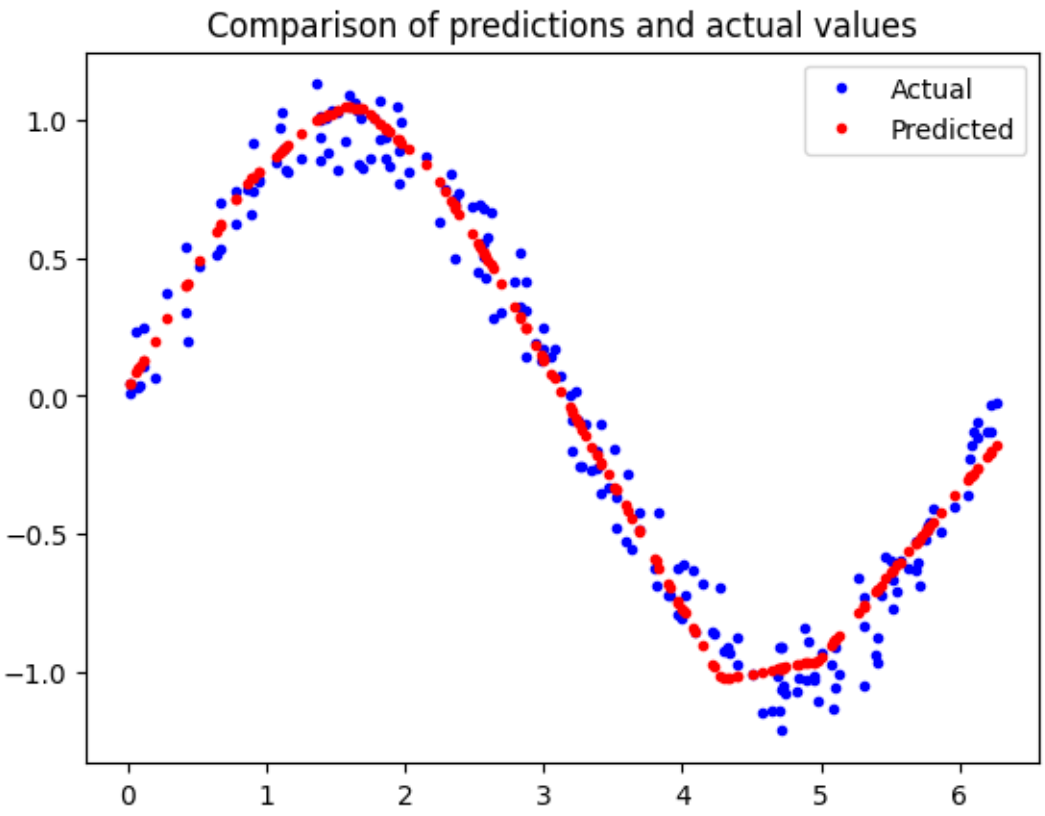
1.8.1 Exercise 5

Predict y values for test data and plot it with true values.

[30]:
```
# Make predictions based on our test dataset (TODO)
predictions = model.predict(x_test)

# Graph the predictions against the actual values
plt.clf()
plt.title('Comparison of predictions and actual values')
plt.plot(x_test, y_test, 'b.', label='Actual')
plt.plot(x_test, predictions, 'r.', label='Predicted')
plt.legend()
plt.show()
```

```
7/7             0s 7ms/step
```



1.8.2 Exercise 6

The predicted graph is not nearly as smooth enough to be a sine. Rather it may look like a piecewise combination of linear functions. Briefly explain how you can make this more smoother and identical to an actual sine wave.

1.9 Get weights

Now you will extract the weight matrices from the model. This step is in order to convert these weight matrices to C++ files that will be embedded in the Microcontroller.

[31]:
```
# Extract weights and biases as Numpy arrays
W1, b1 = model.layers[0].get_weights()
W2, b2 = model.layers[1].get_weights()
W3, b3 = model.layers[2].get_weights()
```

[32]:
```
print(W1.shape, b1.shape)
print(W2.shape, b2.shape)
print(W3.shape, b3.shape)
```

```
(1, 16) (16,)
(16, 16) (16,)
```

```
(16, 1) (1,)
```

The following code performs the forward propagation of the model manually using NumPy matrix multiplication. Run the following code to make sure the model's prediction and manual prediction is same.

[34]:
```
xs = x_test
```

[35]:
```
# This is what the TF model does internally:
ys = []
for x in xs:
    x = np.array([x])       # x should be array
    h1 = x @ W1 + b1        # dense layer
    h1 = np.maximum(0, h1)  # ReLU
    h2 = h1 @ W2 + b2       # dense layer
    h2 = np.maximum(0, h2)  # ReLU
    h3 = h2 @ W3 + b3       # dense layer
    ys.append(h3)

ys = np.stack(ys)
```

[36]:
```
# Are our predictions the same as TF's predictions?
# This should print 0 if the results are close enough.
np.sum(np.abs(ys - predictions) > 1e-6)
```

[36]:
```
0
```

1.10 Export the weights for C++

The following code compresses the weights and biases into a C++ format which will be stored in the Microcontroller's FLASH memory. Copy the generated output and paste in file named `model_data.cpp`.

[37]:
```
# Note that we transpose W2. This makes the inner loop for the
# matrix multiplication a little simpler.

names = ["W1_data", "b1_data", "W2_data", "b2_data", "W3_data", "b3_data"]
arrays = [W1, b1, W2.T, b2, W3, b3]
```

[38]:
```
# Copy this into model_data.cpp:

for name, array in zip(names, arrays):
    print("const float %s[] PROGMEM = {" % name)
    print("    ", ", ".join([str(x) + "f" for x in array.flatten()]))
    print("};\n")
```

```
const float W1_data[] PROGMEM = {
    -0.13218746f, 0.59996355f, 0.412222f, 0.44855297f, -0.014016151f,
-0.45300373f, -0.51863825f, -0.5602349f, 0.113381766f, -0.18971908f, 0.5485602f,
```

```
0.45640317f, -0.23779255f, -0.50725836f, -0.20097929f, 0.30370054f
};

const float b1_data[] PROGMEM = {
    0.0f, -0.81330454f, -0.1956339f, 0.44369745f, 0.0f, 0.0f, 0.0f, 0.0f,
0.8302129f, 0.0f, -0.9388026f, 0.0002821723f, 0.0f, 0.0f, 0.0f, -0.41189936f
};

const float W2_data[] PROGMEM = {
    -0.0814293f, 0.31467018f, 0.09936015f, -0.46658295f, -0.34383413f,
-0.39724156f, -0.25829348f, 0.1859639f, 0.19191241f, 0.06506437f, 0.40153182f,
0.07302374f, 0.30591205f, -0.032506227f, -0.38932526f, 0.25660425f,
-0.033857405f, -0.120869875f, -0.18025494f, -0.37479421f, 0.17500809f,
0.18167922f, 0.16650286f, -0.19364475f, 0.4856144f, -0.21229133f, -0.6973603f,
0.122914925f, 0.23566893f, -0.42979547f, 0.27463695f, 0.10863667f, -0.34888372f,
-0.032540414f, -0.1495519f, 0.26439288f, 0.17552933f, -0.20527093f, 0.08973119f,
-0.35302833f, -0.03105605f, -0.26136172f, 0.3712269f, 0.23217261f, -0.12800276f,
0.28553095f, -0.3864955f, -0.3971526f, -0.42178833f, -0.2558291f, -0.2751876f,
0.17860591f, 0.15573856f, 0.37497225f, -0.18131232f, -0.3122084f, -0.3303416f,
0.40992168f, 0.2489902f, 0.27736095f, 0.2790039f, 0.2978296f, 0.07483229f,
-0.3000354f, 0.10606822f, 0.27006644f, 0.17834553f, -0.062551424f, 0.077923924f,
0.39407387f, -0.41227284f, -0.3997555f, 0.38307783f, -0.150624f, 0.11818202f,
0.2724562f, -0.0010328889f, -0.20342636f, 0.12878498f, 0.25789696f,
-0.37737823f, 0.04650709f, -0.23476383f, -0.0064300895f, 0.009438962f,
-0.17276317f, 0.1770871f, -0.2942045f, -0.2939648f, -0.14115676f, -0.20031302f,
-0.26640862f, -0.34374058f, -0.11711681f, 0.42918542f, 0.30132946f, 0.31533715f,
0.37559023f, -0.3363221f, -0.14321345f, 0.028212756f, -0.23840773f, 0.2901462f,
-0.23004326f, -0.4918976f, 0.029613793f, 0.39278078f, 0.17345148f, -0.37158304f,
-0.4167127f, 0.23276243f, 0.50909185f, -0.16300395f, 0.22188875f, -0.17577326f,
-0.06409836f, 0.24066308f, -0.41605404f, -0.05830744f, 0.06943628f,
-0.23657782f, -0.39258468f, -0.28929356f, 0.27772304f, -0.31356528f,
0.08302173f, 0.3011599f, -0.3152363f, 0.04852292f, -0.18195951f, -0.38723668f,
-0.43213466f, -0.0039304793f, -0.32469746f, -0.09341133f, -0.38154057f,
0.62532693f, 0.012787193f, -0.30684993f, -0.46911365f, -0.32160342f,
0.028526813f, 0.19625679f, 0.4309139f, -0.18663476f, 0.15984657f, -0.24097888f,
-0.39041162f, 0.025295854f, 0.3438085f, 0.035538644f, -0.3561422f, -0.40275306f,
0.31373057f, 0.1547235f, -0.28422385f, 0.37870196f, -0.33039054f, 0.11264387f,
-0.21608287f, -0.2661497f, 0.39809114f, 0.0032252274f, 0.3927152f, -0.270778f,
-0.2618453f, -0.06384936f, 0.115965396f, 0.44110468f, 0.28747997f, 0.1185662f,
-0.25367102f, -0.41467315f, -0.3812446f, -0.21392126f, -0.38798395f,
0.32055423f, -0.02881561f, 0.21749838f, 0.06924525f, -0.29682034f, -0.10467854f,
0.3548034f, 0.17538002f, 0.4928956f, 0.13384905f, -0.28138766f, 0.28184882f,
-0.40137532f, -0.15023842f, 0.2451823f, -0.105327986f, -0.38548097f,
-0.3041309f, -0.4969511f, 0.27674192f, 0.30203655f, -0.09718862f, 0.06804165f,
-0.21185845f, 0.55313873f, 0.068104655f, -0.8145125f, 0.12946333f, -0.2371954f,
-0.42606413f, 0.21764919f, -0.25359985f, 0.33025417f, -0.2764726f, -0.39123198f,
-0.107339114f, 0.25436255f, 0.20355615f, -0.06755251f, 0.2885171f, 0.2453095f,
-0.380735f, -0.29453266f, -0.02897845f, 0.41348f, 0.105828136f, -0.26892847f,
```

```
0.24928987f, 0.044234306f, 0.20880799f, 0.08368413f, -0.89205414f, 0.11311641f,
0.3124821f, -0.0525333f, -0.23345208f, 0.64566666f, -0.1533204f, -0.16913737f,
-0.70203006f, -0.26658723f, -0.35603505f, 0.18518344f, -0.28958362f,
-0.052967936f, 0.30959436f, 0.35122523f, 0.03056526f, -0.22363f, 0.39768973f,
-0.28136444f, -0.02795425f, 0.10691896f, 0.3512484f, 0.4291724f, 0.013770978f,
0.25968453f, -0.42399958f, 0.20219925f, 0.026950946f
};

const float b2_data[] PROGMEM = {
    -0.17459181f, 0.4678906f, 0.18095414f, -0.0362184f, 0.095704f, 0.0f,
-0.7803509f, 0.0f, 0.3809197f, 0.0f, 0.1577547f, 0.16245067f, 1.0524595f,
0.34766844f, 0.39542902f, -0.18656933f
};

const float W3_data[] PROGMEM = {
    0.6084634f, -0.58747125f, -0.5033548f, -0.17378953f, -0.07683507f,
0.45434606f, 1.2287146f, 0.49423707f, -0.6484613f, 0.5158857f, -0.43554372f,
-0.20404805f, 1.4981053f, -0.7975156f, -0.70974165f, 0.28028616f
};

const float b3_data[] PROGMEM = {
    -0.1731168f
};
```

1.11 End of Section 1

These code lines are to save Colab notebook as pdf

[56]:
```
from google.colab import drive
drive.mount('/content/drive')
```

```
Drive already mounted at /content/drive; to attempt to forcibly remount, call
drive.mount("/content/drive", force_remount=True).
```

[57]:
```
!jupyter nbconvert --to pdf "/content/drive/MyDrive/Colab Notebooks/
 ↪assignment_4_notebook.ipynb"
```

```
[NbConvertApp] Converting notebook /content/drive/MyDrive/Colab
Notebooks/assignment_4_notebook.ipynb to pdf
[NbConvertApp] Support files will be in assignment_4_notebook_files/
[NbConvertApp] Making directory ./assignment_4_notebook_files
[NbConvertApp] Making directory ./assignment_4_notebook_files
[NbConvertApp] Making directory ./assignment_4_notebook_files
[NbConvertApp] Making directory ./assignment_4_notebook_files
[NbConvertApp] Making directory ./assignment_4_notebook_files
[NbConvertApp] Making directory ./assignment_4_notebook_files
[NbConvertApp] Making directory ./assignment_4_notebook_files
```

```
[NbConvertApp] Writing 140024 bytes to notebook.tex
[NbConvertApp] Building PDF
[NbConvertApp] Running xelatex 3 times: ['xelatex', 'notebook.tex', '-quiet']
[NbConvertApp] Running bibtex 1 time: ['bibtex', 'notebook']
[NbConvertApp] WARNING | bibtex had problems, most likely because there were no
citations
[NbConvertApp] PDF successfully created
[NbConvertApp] Writing 285570 bytes to /content/drive/MyDrive/Colab
Notebooks/assignment_4_notebook.pdf
```