



T81-558: Applications of Deep Neural Networks

Module 10: Time Series in Keras

Part 10.1: Time Series Data Encoding for Deep Learning

- Instructor: [Jeff Heaton](#), McKelvey School of Engineering, [Washington University in St. Louis](#)
- For more information visit the [class website](#).

Module 10 Material

- **Part 10.1: Time Series Data Encoding for Deep Learning** [\[Video\]](#) [\[Notebook\]](#)
- Part 10.2: Programming LSTM with Keras and TensorFlow [\[Video\]](#) [\[Notebook\]](#)
- Part 10.3: Text Generation with Keras and TensorFlow [\[Video\]](#) [\[Notebook\]](#)
- Part 10.4: Introduction to Transformers [\[Video\]](#) [\[Notebook\]](#)
- Part 10.5: Transformers for Timeseries [\[Video\]](#) [\[Notebook\]](#)

Google CoLab Instructions

The following code ensures that Google CoLab is running the correct version of TensorFlow.

```
In [1]: try:
        %tensorflow_version 2.x
        COLAB = True
        print("Note: using Google CoLab")
    except:
        print("Note: not using Google CoLab")
        COLAB = False
```

Note: not using Google CoLab

Part 10.1: Time Series Data Encoding

There are many different methods to encode data over time to a neural network. In this chapter, we will examine time series encoding and recurrent networks, two topics that are logical to put together because they are both methods for dealing with data

that spans over time. Time series encoding deals with representing events that occur over time to a neural network. This encoding is necessary because a feedforward neural network will always produce the same output vector for a given input vector. Recurrent neural networks do not require encoding time series data because they can automatically handle data that occur over time.

The variation in temperature during the week is an example of time-series data. For instance, if we know that today's temperature is 25 degrees Fahrenheit and tomorrow's temperature is 27 degrees, the recurrent neural networks and time series encoding provide another option to predict the correct temperature for the week. Conversely, a traditional feedforward neural network will always respond with the same output for a given input. If we train a feedforward neural network to predict tomorrow's temperature, it should return a value of 27 for 25. It will always output 27 when given 25 might hinder its predictions. Surely the temperature of 27 will not always follow 25. It would be better for the neural network to consider the temperatures for days before the prediction. Perhaps the temperature over the last week might allow us to predict tomorrow's temperature. Therefore, recurrent neural networks and time series encoding represent two different approaches to representing data over time to a neural network.

Previously we trained neural networks with input (x) and expected output (y). X was a matrix, the rows were training examples, and the columns were values to be predicted. The x value will now contain sequences of data. The definition of the y value will stay the same.

Dimensions of the training set (x):

- Axis 1: Training set elements (sequences) (must be of the same size as y size)
- Axis 2: Members of sequence
- Axis 3: Features in data (like input neurons)

Previously, we might take as input a single stock price to predict if we should buy (1), sell (-1), or hold (0). The following code illustrates this encoding.

```
In [2]: x = [  
    [32],  
    [41],  
    [39],  
    [20],  
    [15]  
]  
  
y = [  
    1,  
    -1,  
    0,  
    -1,  
    1
```

```
]
print(x)
print(y)
```

```
[[32], [41], [39], [20], [15]]
[1, -1, 0, -1, 1]
```

The following code builds a CSV file from scratch. To see it as a data frame, use the following:

```
In [3]: from IPython.display import display, HTML
import pandas as pd
import numpy as np

x = np.array(x)
print(x[:,0])

df = pd.DataFrame({'x':x[:,0], 'y':y})
display(df)
```

```
[32 41 39 20 15]
```

/tmp/ipykernel_5068/2644240216.py:2: DeprecationWarning:
Pyarrow will become a required dependency of pandas in the next major release of pandas (pandas 3.0),
(to allow more performant data types, such as the Arrow string type, and better interoperability with other libraries)
but was not found to be installed on your system.
If this would cause problems for you,
please provide us feedback at <https://github.com/pandas-dev/pandas/issues/54466>

```
import pandas as pd
```

	x	y
0	32	1
1	41	-1
2	39	0
3	20	-1
4	15	1

You might want to put volume in with the stock price. The following code shows how to add a dimension to handle the volume.

```
In [4]: x = [
[32,1383],
[41,2928],
[39,8823],
[20,1252],
```

```

    [15,1532]
]

y = [
    1,
    -1,
    0,
    -1,
    1
]

print(x)
print(y)

```

```

[[32, 1383], [41, 2928], [39, 8823], [20, 1252], [15, 1532]]
[1, -1, 0, -1, 1]

```

Again, very similar to what we did before. The following shows this as a data frame.

```

In [5]: from IPython.display import display, HTML
import pandas as pd
import numpy as np

x = np.array(x)
print(x[:,0])

df = pd.DataFrame({'price':x[:,0], 'volume':x[:,1], 'y':y})
display(df)

```

```

[32 41 39 20 15]

```

	price	volume	y
0	32	1383	1
1	41	2928	-1
2	39	8823	0
3	20	1252	-1
4	15	1532	1

Now we get to sequence format. We want to predict something over a sequence, so the data format needs to add a dimension. You must specify a maximum sequence length. The individual sequences can be of any size.

```

In [6]: x = [
    [[32,1383],[41,2928],[39,8823],[20,1252],[15,1532]],
    [[35,8272],[32,1383],[41,2928],[39,8823],[20,1252]],
    [[37,2738],[35,8272],[32,1383],[41,2928],[39,8823]],
    [[34,2845],[37,2738],[35,8272],[32,1383],[41,2928]],
    [[32,2345],[34,2845],[37,2738],[35,8272],[32,1383]]
]

```

```

y = [
    1,
    -1,
    0,
    -1,
    1
]

print(x)
print(y)

```

```

[[[32, 1383], [41, 2928], [39, 8823], [20, 1252], [15, 1532]], [[35, 8272],
[32, 1383], [41, 2928], [39, 8823], [20, 1252]], [[37, 2738], [35, 8272], [3
2, 1383], [41, 2928], [39, 8823]], [[34, 2845], [37, 2738], [35, 8272], [32,
1383], [41, 2928]], [[32, 2345], [34, 2845], [37, 2738], [35, 8272], [32, 13
83]]]
[1, -1, 0, -1, 1]

```

Even if there is only one feature (price), you must use 3 dimensions.

```

In [7]: x = [
    [[32],[41],[39],[20],[15]],
    [[35],[32],[41],[39],[20]],
    [[37],[35],[32],[41],[39]],
    [[34],[37],[35],[32],[41]],
    [[32],[34],[37],[35],[32]],
    ]

y = [
    1,
    -1,
    0,
    -1,
    1
]

print(x)
print(y)

```

```

[[[32], [41], [39], [20], [15]], [[35], [32], [41], [39], [20]], [[37], [3
5], [32], [41], [39]], [[34], [37], [35], [32], [41]], [[32], [34], [37], [3
5], [32]]]
[1, -1, 0, -1, 1]

```

Module 10 Assignment

You can find the first assignment here: [assignment 10](#)

In []:



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- Part 10.5: Transformers for Timeseries [\[Video\]](#) [\[Notebook\]](#)

Google CoLab Instructions

The following code ensures that Google CoLab is running the correct version of TensorFlow. Running the following code will map your GDrive to `/content/drive`.

```
In [1]: try:
        from google.colab import drive
        drive.mount('/content/drive', force_remount=True)
        COLAB = True
        print("Note: using Google CoLab")
        %tensorflow_version 2.x
    except:
        print("Note: not using Google CoLab")
        COLAB = False
```

Mounted at /content/drive

Note: using Google CoLab

Part 10.2: Programming LSTM with Keras and TensorFlow

So far, the neural networks that we've examined have always had forward connections. Neural networks of this type always begin with an input layer connected to the first hidden layer. Each hidden layer always connects to the next hidden layer. The final hidden layer always connects to the output layer. This manner of connection is why these networks are called "feedforward." Recurrent neural networks are not as rigid, as backward linkages are also allowed. A recurrent connection links a neuron in a layer to either a previous layer or the neuron itself. Most recurrent neural network architectures maintain the state in the recurrent connections. Feedforward neural networks don't keep any state.

Understanding LSTM

Long Short Term Memory (LSTM) layers are a type of recurrent unit that you often use with deep neural networks.[\[Cite:hochreiter1997long\]](#) For TensorFlow, you can think of LSTM as a layer type that you can combine with other layer types, such as dense. LSTM makes use of two transfer function types internally.

The first type of transfer function is the sigmoid. This transfer function type is used form gates inside of the unit. The sigmoid transfer function is given by the following equation:

$$S(t) = \frac{1}{1+e^{-t}}$$

The second type of transfer function is the hyperbolic tangent (tanh) function, which allows you to scale the output of the LSTM. This functionality is similar to how we have used other transfer functions in this course.

We provide the graphs for these functions here:

```
In [2]: %matplotlib inline

import matplotlib
import numpy as np
import matplotlib.pyplot as plt
import math

def sigmoid(x):
    a = []
    for item in x:
        a.append(1/(1+math.exp(-item)))
    return a

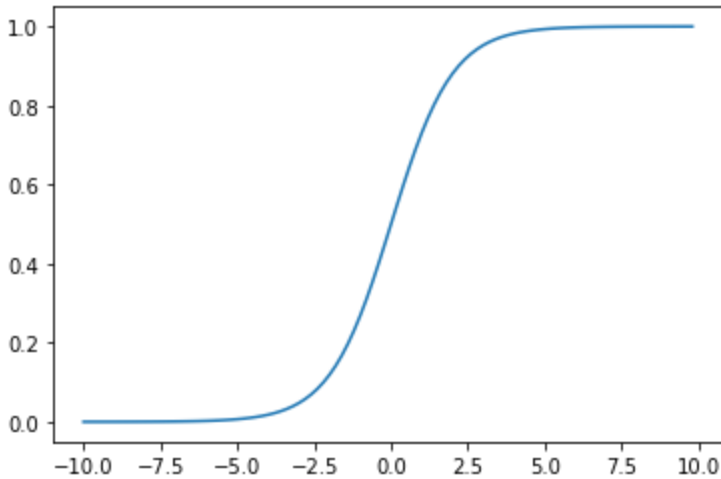
def f2(x):
    a = []
    for item in x:
        a.append(math.tanh(item))
    return a
```

```
x = np.arange(-10., 10., 0.2)
y1 = sigmoid(x)
y2 = f2(x)

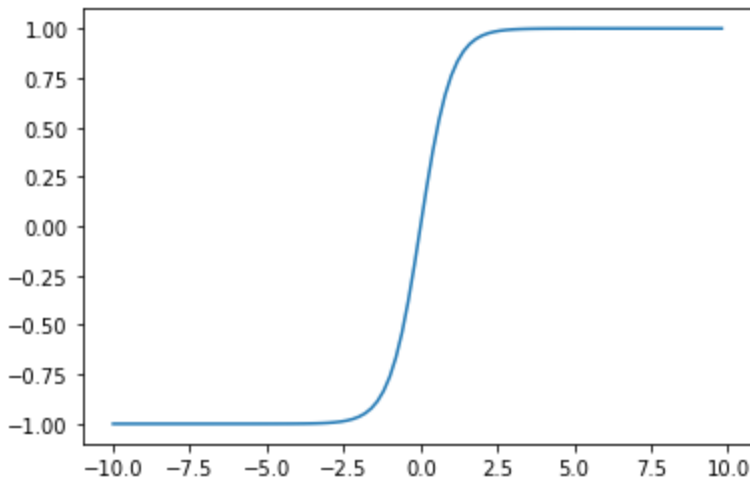
print("Sigmoid")
plt.plot(x,y1)
plt.show()

print("Hyperbolic Tangent(tanh)")
plt.plot(x,y2)
plt.show()
```

Sigmoid

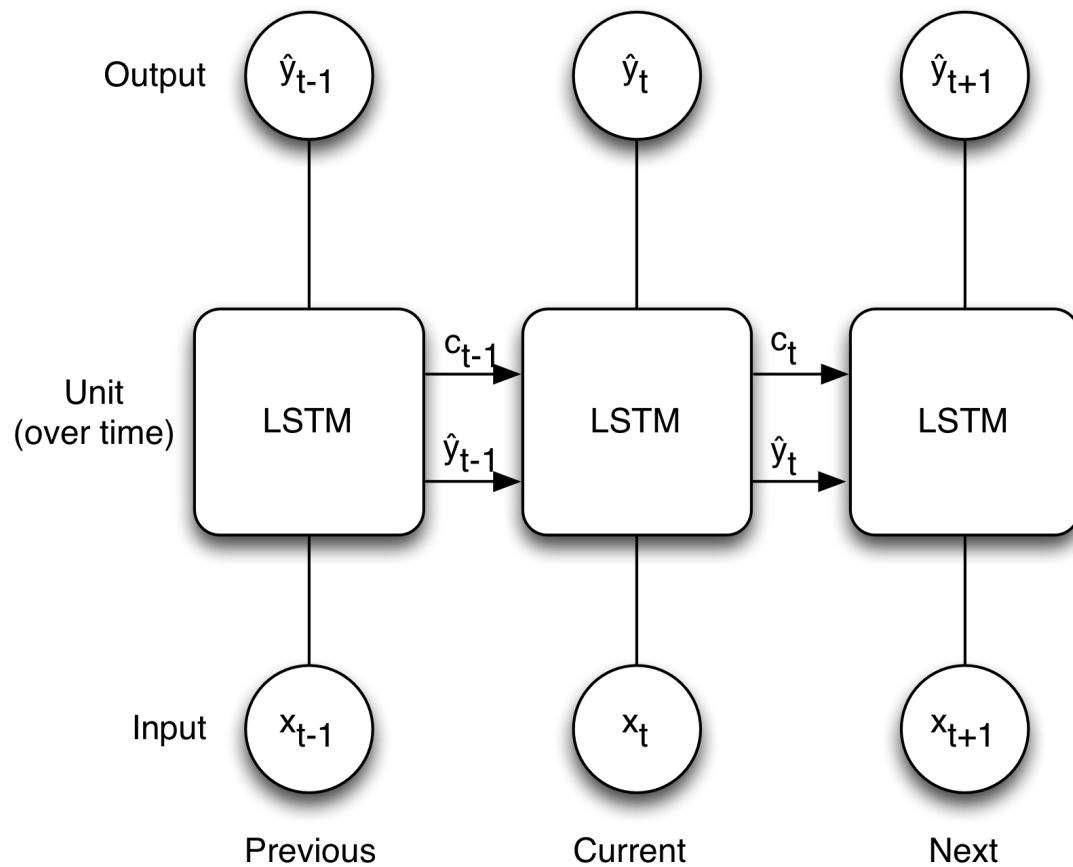


Hyperbolic Tangent(tanh)

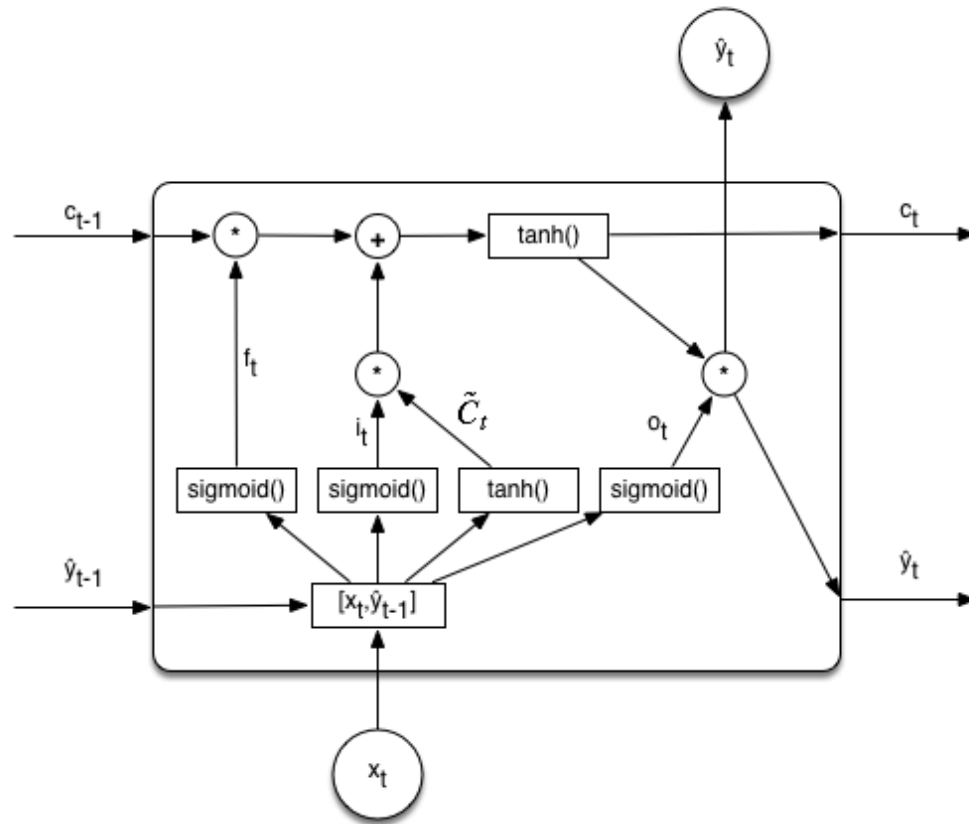


Both of these two functions compress their output to a specific range. For the sigmoid function, this range is 0 to 1. For the hyperbolic tangent function, this range is -1 to 1.

LSTM maintains an internal state and produces an output. The following diagram shows an LSTM unit over three timeslices: the current time slice (t), as well as the previous (t-1) and next (t+1) slice, as demonstrated by Figure 10.LSTM.

Figure 10.LSTM: LSTM Layers

The values \hat{y} are the output from the unit; the values (x) are the input to the unit, and the values c are the context values. The output and context values always feed their output to the next time slice. The context values allow the network to maintain the state between calls. Figure 10.ILSTM shows the internals of a LSTM layer.

Figure 10.ILSTM: Inside a LSTM Layer

A LSTM unit consists of three gates:

- Forget Gate (f_t) - Controls if/when the context is forgotten. (MC)
- Input Gate (i_t) - Controls if/when the context should remember a value. (M+/MS)
- Output Gate (o_t) - Controls if/when the remembered value is allowed to pass from the unit. (RM)

Simple Keras LSTM Example

The following code creates the LSTM network, an example of an RNN for classification. The following code trains on a data set (x) with a max sequence size of 6 (columns) and six training elements (rows)

```
In [3]: from tensorflow.keras.preprocessing import sequence
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense, Embedding
from tensorflow.keras.layers import LSTM
import numpy as np

max_features = 4 # 0,1,2,3 (total of 4)
x = [
    [[0],[1],[1],[0],[0],[0]],
    [[0],[0],[0],[2],[2],[0]],
    [[0],[0],[0],[0],[3],[3]],
    [[0],[2],[2],[0],[0],[0]],
    [[0],[0],[3],[3],[0],[0]],
    [[0],[0],[0],[0],[1],[1]]
]
x = np.array(x,dtype=np.float32)
y = np.array([1,2,3,2,3,1],dtype=np.int32)

# Convert y2 to dummy variables
y2 = np.zeros((y.shape[0], max_features),dtype=np.float32)
y2[np.arange(y.shape[0]), y] = 1.0
print(y2)

print('Build model...')
model = Sequential()
model.add(LSTM(128, dropout=0.2, recurrent_dropout=0.2, \
               input_shape=(None, 1)))
model.add(Dense(4, activation='sigmoid'))

# try using different optimizers and different optimizer configs
model.compile(loss='binary_crossentropy',
              optimizer='adam',
              metrics=['accuracy'])

print('Train...')
model.fit(x,y2,epochs=200)
pred = model.predict(x)
predict_classes = np.argmax(pred,axis=1)
print("Predicted classes: {}".format(predict_classes))
print("Expected classes: {}".format(y))
```

```
[[0. 1. 0. 0.]  
 [0. 0. 1. 0.]  
 [0. 0. 0. 1.]  
 [0. 0. 1. 0.]  
 [0. 0. 0. 1.]  
 [0. 1. 0. 0.]]
```

Build model...

Train...

Epoch 1/200

1/1 [=====] - 6s 6s/step - loss: 0.6885 - accuracy: 0.3333

Epoch 2/200

1/1 [=====] - 0s 45ms/step - loss: 0.6807 - accuracy: 0.3333

Epoch 3/200

1/1 [=====] - 0s 38ms/step - loss: 0.6773 - accuracy: 0.3333

Epoch 4/200

1/1 [=====] - 0s 37ms/step - loss: 0.6684 - accuracy: 0.3333

Epoch 5/200

1/1 [=====] - 0s 33ms/step - loss: 0.6556 - accuracy: 0.3333

Epoch 6/200

1/1 [=====] - 0s 37ms/step - loss: 0.6555 - accuracy: 0.3333

Epoch 7/200

1/1 [=====] - 0s 31ms/step - loss: 0.6397 - accuracy: 0.1667

Epoch 8/200

1/1 [=====] - 0s 40ms/step - loss: 0.6376 - accuracy: 0.3333

Epoch 9/200

1/1 [=====] - 0s 39ms/step - loss: 0.6302 - accuracy: 0.3333

Epoch 10/200

1/1 [=====] - 0s 39ms/step - loss: 0.6217 - accuracy: 0.5000

Epoch 11/200

1/1 [=====] - 0s 52ms/step - loss: 0.6196 - accuracy: 0.6667

Epoch 12/200

1/1 [=====] - 0s 41ms/step - loss: 0.6009 - accuracy: 0.5000

Epoch 13/200

1/1 [=====] - 0s 34ms/step - loss: 0.6049 - accuracy: 0.3333

Epoch 14/200

1/1 [=====] - 0s 42ms/step - loss: 0.5894 - accuracy: 0.3333

Epoch 15/200

1/1 [=====] - 0s 23ms/step - loss: 0.5853 - accuracy: 0.3333

Epoch 16/200

1/1 [=====] - 0s 31ms/step - loss: 0.5648 - accuracy: 0.3333

```
Epoch 17/200
1/1 [=====] - 0s 51ms/step - loss: 0.5497 - accurac
y: 0.3333
Epoch 18/200
1/1 [=====] - 0s 39ms/step - loss: 0.5413 - accurac
y: 0.3333
Epoch 19/200
1/1 [=====] - 0s 70ms/step - loss: 0.5429 - accurac
y: 0.3333
Epoch 20/200
1/1 [=====] - 0s 32ms/step - loss: 0.5217 - accurac
y: 0.3333
Epoch 21/200
1/1 [=====] - 0s 53ms/step - loss: 0.5304 - accurac
y: 0.3333
Epoch 22/200
1/1 [=====] - 0s 58ms/step - loss: 0.5332 - accurac
y: 0.3333
Epoch 23/200
1/1 [=====] - 0s 52ms/step - loss: 0.5090 - accurac
y: 0.3333
Epoch 24/200
1/1 [=====] - 0s 55ms/step - loss: 0.5055 - accurac
y: 0.3333
Epoch 25/200
1/1 [=====] - 0s 47ms/step - loss: 0.5020 - accurac
y: 0.3333
Epoch 26/200
1/1 [=====] - 0s 47ms/step - loss: 0.5224 - accurac
y: 0.1667
Epoch 27/200
1/1 [=====] - 0s 32ms/step - loss: 0.5060 - accurac
y: 0.1667
Epoch 28/200
1/1 [=====] - 0s 50ms/step - loss: 0.5123 - accurac
y: 0.1667
Epoch 29/200
1/1 [=====] - 0s 42ms/step - loss: 0.4740 - accurac
y: 0.5000
Epoch 30/200
1/1 [=====] - 0s 40ms/step - loss: 0.5018 - accurac
y: 0.3333
Epoch 31/200
1/1 [=====] - 0s 32ms/step - loss: 0.4982 - accurac
y: 0.3333
Epoch 32/200
1/1 [=====] - 0s 42ms/step - loss: 0.4640 - accurac
y: 0.3333
Epoch 33/200
1/1 [=====] - 0s 47ms/step - loss: 0.4748 - accurac
y: 0.5000
Epoch 34/200
1/1 [=====] - 0s 50ms/step - loss: 0.4593 - accurac
y: 0.5000
Epoch 35/200
1/1 [=====] - 0s 47ms/step - loss: 0.4712 - accurac
```

```
y: 0.3333
Epoch 36/200
1/1 [=====] - 0s 47ms/step - loss: 0.4444 - accurac
y: 0.5000
Epoch 37/200
1/1 [=====] - 0s 46ms/step - loss: 0.4651 - accurac
y: 0.5000
Epoch 38/200
1/1 [=====] - 0s 41ms/step - loss: 0.4582 - accurac
y: 0.5000
Epoch 39/200
1/1 [=====] - 0s 39ms/step - loss: 0.4191 - accurac
y: 0.5000
Epoch 40/200
1/1 [=====] - 0s 45ms/step - loss: 0.4470 - accurac
y: 0.5000
Epoch 41/200
1/1 [=====] - 0s 79ms/step - loss: 0.4258 - accurac
y: 0.5000
Epoch 42/200
1/1 [=====] - 0s 35ms/step - loss: 0.4161 - accurac
y: 0.6667
Epoch 43/200
1/1 [=====] - 0s 43ms/step - loss: 0.4094 - accurac
y: 0.6667
Epoch 44/200
1/1 [=====] - 0s 25ms/step - loss: 0.4246 - accurac
y: 0.6667
Epoch 45/200
1/1 [=====] - 0s 33ms/step - loss: 0.4377 - accurac
y: 0.3333
Epoch 46/200
1/1 [=====] - 0s 37ms/step - loss: 0.4404 - accurac
y: 0.3333
Epoch 47/200
1/1 [=====] - 0s 35ms/step - loss: 0.4526 - accurac
y: 0.3333
Epoch 48/200
1/1 [=====] - 0s 34ms/step - loss: 0.4009 - accurac
y: 0.8333
Epoch 49/200
1/1 [=====] - 0s 30ms/step - loss: 0.4128 - accurac
y: 0.5000
Epoch 50/200
1/1 [=====] - 0s 39ms/step - loss: 0.3961 - accurac
y: 0.6667
Epoch 51/200
1/1 [=====] - 0s 36ms/step - loss: 0.4152 - accurac
y: 0.6667
Epoch 52/200
1/1 [=====] - 0s 31ms/step - loss: 0.3690 - accurac
y: 0.8333
Epoch 53/200
1/1 [=====] - 0s 30ms/step - loss: 0.4025 - accurac
y: 0.6667
Epoch 54/200
```

```
1/1 [=====] - 0s 40ms/step - loss: 0.3933 - accurac
y: 0.6667
Epoch 55/200
1/1 [=====] - 0s 34ms/step - loss: 0.4072 - accurac
y: 0.8333
Epoch 56/200
1/1 [=====] - 0s 34ms/step - loss: 0.4008 - accurac
y: 0.6667
Epoch 57/200
1/1 [=====] - 0s 30ms/step - loss: 0.3789 - accurac
y: 0.6667
Epoch 58/200
1/1 [=====] - 0s 51ms/step - loss: 0.3937 - accurac
y: 0.6667
Epoch 59/200
1/1 [=====] - 0s 36ms/step - loss: 0.3516 - accurac
y: 0.6667
Epoch 60/200
1/1 [=====] - 0s 32ms/step - loss: 0.3525 - accurac
y: 0.8333
Epoch 61/200
1/1 [=====] - 0s 31ms/step - loss: 0.3484 - accurac
y: 1.0000
Epoch 62/200
1/1 [=====] - 0s 53ms/step - loss: 0.3067 - accurac
y: 0.8333
Epoch 63/200
1/1 [=====] - 0s 40ms/step - loss: 0.3600 - accurac
y: 0.5000
Epoch 64/200
1/1 [=====] - 0s 37ms/step - loss: 0.4628 - accurac
y: 0.1667
Epoch 65/200
1/1 [=====] - 0s 62ms/step - loss: 0.4443 - accurac
y: 0.5000
Epoch 66/200
1/1 [=====] - 0s 33ms/step - loss: 0.3164 - accurac
y: 0.8333
Epoch 67/200
1/1 [=====] - 0s 42ms/step - loss: 0.3303 - accurac
y: 0.8333
Epoch 68/200
1/1 [=====] - 0s 35ms/step - loss: 0.3264 - accurac
y: 0.8333
Epoch 69/200
1/1 [=====] - 0s 29ms/step - loss: 0.3518 - accurac
y: 0.5000
Epoch 70/200
1/1 [=====] - 0s 27ms/step - loss: 0.2797 - accurac
y: 0.8333
Epoch 71/200
1/1 [=====] - 0s 29ms/step - loss: 0.3595 - accurac
y: 0.5000
Epoch 72/200
1/1 [=====] - 0s 29ms/step - loss: 0.3141 - accurac
y: 0.6667
```

```
Epoch 73/200
1/1 [=====] - 0s 35ms/step - loss: 0.2957 - accuracy: 0.8333
Epoch 74/200
1/1 [=====] - 0s 33ms/step - loss: 0.3181 - accuracy: 0.8333
Epoch 75/200
1/1 [=====] - 0s 39ms/step - loss: 0.3049 - accuracy: 0.6667
Epoch 76/200
1/1 [=====] - 0s 32ms/step - loss: 0.3390 - accuracy: 0.6667
Epoch 77/200
1/1 [=====] - 0s 31ms/step - loss: 0.3328 - accuracy: 0.6667
Epoch 78/200
1/1 [=====] - 0s 41ms/step - loss: 0.3262 - accuracy: 0.6667
Epoch 79/200
1/1 [=====] - 0s 34ms/step - loss: 0.2353 - accuracy: 0.8333
Epoch 80/200
1/1 [=====] - 0s 34ms/step - loss: 0.3484 - accuracy: 0.6667
Epoch 81/200
1/1 [=====] - 0s 26ms/step - loss: 0.4174 - accuracy: 0.6667
Epoch 82/200
1/1 [=====] - 0s 32ms/step - loss: 0.2780 - accuracy: 0.8333
Epoch 83/200
1/1 [=====] - 0s 30ms/step - loss: 0.3406 - accuracy: 0.5000
Epoch 84/200
1/1 [=====] - 0s 42ms/step - loss: 0.2736 - accuracy: 0.6667
Epoch 85/200
1/1 [=====] - 0s 35ms/step - loss: 0.3383 - accuracy: 0.6667
Epoch 86/200
1/1 [=====] - 0s 51ms/step - loss: 0.3119 - accuracy: 0.6667
Epoch 87/200
1/1 [=====] - 0s 21ms/step - loss: 0.5429 - accuracy: 0.3333
Epoch 88/200
1/1 [=====] - 0s 33ms/step - loss: 0.2317 - accuracy: 0.8333
Epoch 89/200
1/1 [=====] - 0s 30ms/step - loss: 0.4463 - accuracy: 0.5000
Epoch 90/200
1/1 [=====] - 0s 39ms/step - loss: 0.3199 - accuracy: 0.6667
Epoch 91/200
1/1 [=====] - 0s 39ms/step - loss: 0.2997 - accuracy:
```



```
y: 0.8333
Epoch 92/200
1/1 [=====] - 0s 53ms/step - loss: 0.3121 - accurac
y: 0.8333
Epoch 93/200
1/1 [=====] - 0s 24ms/step - loss: 0.3872 - accurac
y: 0.5000
Epoch 94/200
1/1 [=====] - 0s 30ms/step - loss: 0.3367 - accurac
y: 0.5000
Epoch 95/200
1/1 [=====] - 0s 33ms/step - loss: 0.3248 - accurac
y: 0.6667
Epoch 96/200
1/1 [=====] - 0s 34ms/step - loss: 0.3325 - accurac
y: 0.6667
Epoch 97/200
1/1 [=====] - 0s 32ms/step - loss: 0.3257 - accurac
y: 0.6667
Epoch 98/200
1/1 [=====] - 0s 33ms/step - loss: 0.3003 - accurac
y: 0.6667
Epoch 99/200
1/1 [=====] - 0s 34ms/step - loss: 0.3220 - accurac
y: 0.6667
Epoch 100/200
1/1 [=====] - 0s 33ms/step - loss: 0.2347 - accurac
y: 0.8333
Epoch 101/200
1/1 [=====] - 0s 35ms/step - loss: 0.3386 - accurac
y: 0.6667
Epoch 102/200
1/1 [=====] - 0s 30ms/step - loss: 0.3677 - accurac
y: 0.5000
Epoch 103/200
1/1 [=====] - 0s 43ms/step - loss: 0.2826 - accurac
y: 0.6667
Epoch 104/200
1/1 [=====] - 0s 42ms/step - loss: 0.3603 - accurac
y: 0.6667
Epoch 105/200
1/1 [=====] - 0s 35ms/step - loss: 0.2047 - accurac
y: 0.8333
Epoch 106/200
1/1 [=====] - 0s 36ms/step - loss: 0.2239 - accurac
y: 0.8333
Epoch 107/200
1/1 [=====] - 0s 62ms/step - loss: 0.2280 - accurac
y: 0.8333
Epoch 108/200
1/1 [=====] - 0s 34ms/step - loss: 0.2398 - accurac
y: 0.8333
Epoch 109/200
1/1 [=====] - 0s 32ms/step - loss: 0.2423 - accurac
y: 0.8333
Epoch 110/200
```

```
1/1 [=====] - 0s 25ms/step - loss: 0.2059 - accurac
y: 0.8333
Epoch 111/200
1/1 [=====] - 0s 28ms/step - loss: 0.3120 - accurac
y: 0.6667
Epoch 112/200
1/1 [=====] - 0s 29ms/step - loss: 0.5211 - accurac
y: 0.5000
Epoch 113/200
1/1 [=====] - 0s 30ms/step - loss: 0.2082 - accurac
y: 0.8333
Epoch 114/200
1/1 [=====] - 0s 47ms/step - loss: 0.2927 - accurac
y: 0.6667
Epoch 115/200
1/1 [=====] - 0s 48ms/step - loss: 0.2020 - accurac
y: 0.8333
Epoch 116/200
1/1 [=====] - 0s 43ms/step - loss: 0.3345 - accurac
y: 0.6667
Epoch 117/200
1/1 [=====] - 0s 38ms/step - loss: 0.1803 - accurac
y: 0.8333
Epoch 118/200
1/1 [=====] - 0s 43ms/step - loss: 0.1741 - accurac
y: 0.8333
Epoch 119/200
1/1 [=====] - 0s 43ms/step - loss: 0.3439 - accurac
y: 0.5000
Epoch 120/200
1/1 [=====] - 0s 48ms/step - loss: 0.3067 - accurac
y: 0.5000
Epoch 121/200
1/1 [=====] - 0s 54ms/step - loss: 0.2623 - accurac
y: 0.6667
Epoch 122/200
1/1 [=====] - 0s 38ms/step - loss: 0.2178 - accurac
y: 0.6667
Epoch 123/200
1/1 [=====] - 0s 30ms/step - loss: 0.2032 - accurac
y: 0.8333
Epoch 124/200
1/1 [=====] - 0s 49ms/step - loss: 0.2357 - accurac
y: 0.6667
Epoch 125/200
1/1 [=====] - 0s 28ms/step - loss: 0.2624 - accurac
y: 0.8333
Epoch 126/200
1/1 [=====] - 0s 41ms/step - loss: 0.2712 - accurac
y: 0.6667
Epoch 127/200
1/1 [=====] - 0s 39ms/step - loss: 0.2747 - accurac
y: 0.6667
Epoch 128/200
1/1 [=====] - 0s 43ms/step - loss: 0.2485 - accurac
y: 0.6667
```

Epoch 129/200
1/1 [=====] - 0s 23ms/step - loss: 0.2423 - accuracy: 0.6667
Epoch 130/200
1/1 [=====] - 0s 36ms/step - loss: 0.2219 - accuracy: 0.6667
Epoch 131/200
1/1 [=====] - 0s 59ms/step - loss: 0.4338 - accuracy: 0.6667
Epoch 132/200
1/1 [=====] - 0s 48ms/step - loss: 0.1960 - accuracy: 0.6667
Epoch 133/200
1/1 [=====] - 0s 35ms/step - loss: 0.4131 - accuracy: 0.8333
Epoch 134/200
1/1 [=====] - 0s 37ms/step - loss: 0.2598 - accuracy: 0.8333
Epoch 135/200
1/1 [=====] - 0s 31ms/step - loss: 0.3850 - accuracy: 0.6667
Epoch 136/200
1/1 [=====] - 0s 41ms/step - loss: 0.5136 - accuracy: 0.5000
Epoch 137/200
1/1 [=====] - 0s 35ms/step - loss: 0.1772 - accuracy: 0.8333
Epoch 138/200
1/1 [=====] - 0s 30ms/step - loss: 0.3608 - accuracy: 0.5000
Epoch 139/200
1/1 [=====] - 0s 36ms/step - loss: 0.4406 - accuracy: 0.6667
Epoch 140/200
1/1 [=====] - 0s 30ms/step - loss: 0.1779 - accuracy: 0.8333
Epoch 141/200
1/1 [=====] - 0s 50ms/step - loss: 0.2793 - accuracy: 0.6667
Epoch 142/200
1/1 [=====] - 0s 35ms/step - loss: 0.4084 - accuracy: 0.6667
Epoch 143/200
1/1 [=====] - 0s 44ms/step - loss: 0.2198 - accuracy: 0.8333
Epoch 144/200
1/1 [=====] - 0s 66ms/step - loss: 0.2510 - accuracy: 0.6667
Epoch 145/200
1/1 [=====] - 0s 60ms/step - loss: 0.2303 - accuracy: 0.8333
Epoch 146/200
1/1 [=====] - 0s 46ms/step - loss: 0.1859 - accuracy: 0.8333
Epoch 147/200
1/1 [=====] - 0s 46ms/step - loss: 0.2167 - accuracy:

```
y: 1.0000
Epoch 148/200
1/1 [=====] - 0s 40ms/step - loss: 0.2193 - accurac
y: 0.6667
Epoch 149/200
1/1 [=====] - 0s 32ms/step - loss: 0.3893 - accurac
y: 0.5000
Epoch 150/200
1/1 [=====] - 0s 43ms/step - loss: 0.1955 - accurac
y: 0.8333
Epoch 151/200
1/1 [=====] - 0s 33ms/step - loss: 0.2113 - accurac
y: 1.0000
Epoch 152/200
1/1 [=====] - 0s 35ms/step - loss: 0.1952 - accurac
y: 0.8333
Epoch 153/200
1/1 [=====] - 0s 31ms/step - loss: 0.2329 - accurac
y: 0.6667
Epoch 154/200
1/1 [=====] - 0s 41ms/step - loss: 0.2074 - accurac
y: 0.8333
Epoch 155/200
1/1 [=====] - 0s 36ms/step - loss: 0.2839 - accurac
y: 0.6667
Epoch 156/200
1/1 [=====] - 0s 40ms/step - loss: 0.2847 - accurac
y: 0.6667
Epoch 157/200
1/1 [=====] - 0s 37ms/step - loss: 0.1876 - accurac
y: 0.8333
Epoch 158/200
1/1 [=====] - 0s 51ms/step - loss: 0.3081 - accurac
y: 0.6667
Epoch 159/200
1/1 [=====] - 0s 46ms/step - loss: 0.2110 - accurac
y: 0.8333
Epoch 160/200
1/1 [=====] - 0s 51ms/step - loss: 0.1817 - accurac
y: 1.0000
Epoch 161/200
1/1 [=====] - 0s 45ms/step - loss: 0.2173 - accurac
y: 0.8333
Epoch 162/200
1/1 [=====] - 0s 51ms/step - loss: 0.1674 - accurac
y: 0.8333
Epoch 163/200
1/1 [=====] - 0s 48ms/step - loss: 0.2233 - accurac
y: 0.6667
Epoch 164/200
1/1 [=====] - 0s 52ms/step - loss: 0.2647 - accurac
y: 0.6667
Epoch 165/200
1/1 [=====] - 0s 50ms/step - loss: 0.2601 - accurac
y: 0.8333
Epoch 166/200
```

```
1/1 [=====] - 0s 43ms/step - loss: 0.2574 - accurac
y: 0.6667
Epoch 167/200
1/1 [=====] - 0s 54ms/step - loss: 0.1954 - accurac
y: 1.0000
Epoch 168/200
1/1 [=====] - 0s 42ms/step - loss: 0.1537 - accurac
y: 1.0000
Epoch 169/200
1/1 [=====] - 0s 45ms/step - loss: 0.1472 - accurac
y: 1.0000
Epoch 170/200
1/1 [=====] - 0s 52ms/step - loss: 0.2924 - accurac
y: 0.8333
Epoch 171/200
1/1 [=====] - 0s 47ms/step - loss: 0.2536 - accurac
y: 0.8333
Epoch 172/200
1/1 [=====] - 0s 58ms/step - loss: 0.3378 - accurac
y: 0.6667
Epoch 173/200
1/1 [=====] - 0s 57ms/step - loss: 0.2863 - accurac
y: 0.6667
Epoch 174/200
1/1 [=====] - 0s 49ms/step - loss: 0.2654 - accurac
y: 0.6667
Epoch 175/200
1/1 [=====] - 0s 50ms/step - loss: 0.3798 - accurac
y: 0.6667
Epoch 176/200
1/1 [=====] - 0s 52ms/step - loss: 0.2439 - accurac
y: 0.8333
Epoch 177/200
1/1 [=====] - 0s 52ms/step - loss: 0.2164 - accurac
y: 0.8333
Epoch 178/200
1/1 [=====] - 0s 42ms/step - loss: 0.2440 - accurac
y: 0.8333
Epoch 179/200
1/1 [=====] - 0s 33ms/step - loss: 0.2581 - accurac
y: 0.6667
Epoch 180/200
1/1 [=====] - 0s 42ms/step - loss: 0.2226 - accurac
y: 0.8333
Epoch 181/200
1/1 [=====] - 0s 38ms/step - loss: 0.2108 - accurac
y: 0.8333
Epoch 182/200
1/1 [=====] - 0s 51ms/step - loss: 0.1613 - accurac
y: 0.8333
Epoch 183/200
1/1 [=====] - 0s 42ms/step - loss: 0.1548 - accurac
y: 0.8333
Epoch 184/200
1/1 [=====] - 0s 58ms/step - loss: 0.4014 - accurac
y: 0.6667
```

```

Epoch 185/200
1/1 [=====] - 0s 41ms/step - loss: 0.1978 - accuracy: 1.0000
Epoch 186/200
1/1 [=====] - 0s 63ms/step - loss: 0.3166 - accuracy: 0.8333
Epoch 187/200
1/1 [=====] - 0s 42ms/step - loss: 0.1714 - accuracy: 1.0000
Epoch 188/200
1/1 [=====] - 0s 38ms/step - loss: 0.1819 - accuracy: 0.8333
Epoch 189/200
1/1 [=====] - 0s 33ms/step - loss: 0.3144 - accuracy: 0.6667
Epoch 190/200
1/1 [=====] - 0s 35ms/step - loss: 0.2543 - accuracy: 0.8333
Epoch 191/200
1/1 [=====] - 0s 58ms/step - loss: 0.3698 - accuracy: 0.6667
Epoch 192/200
1/1 [=====] - 0s 29ms/step - loss: 0.2331 - accuracy: 0.6667
Epoch 193/200
1/1 [=====] - 0s 37ms/step - loss: 0.3119 - accuracy: 0.8333
Epoch 194/200
1/1 [=====] - 0s 43ms/step - loss: 0.2397 - accuracy: 0.8333
Epoch 195/200
1/1 [=====] - 0s 54ms/step - loss: 0.4169 - accuracy: 0.6667
Epoch 196/200
1/1 [=====] - 0s 36ms/step - loss: 0.2346 - accuracy: 0.8333
Epoch 197/200
1/1 [=====] - 0s 81ms/step - loss: 0.1831 - accuracy: 0.8333
Epoch 198/200
1/1 [=====] - 0s 45ms/step - loss: 0.2516 - accuracy: 0.8333
Epoch 199/200
1/1 [=====] - 0s 66ms/step - loss: 0.2622 - accuracy: 0.6667
Epoch 200/200
1/1 [=====] - 0s 39ms/step - loss: 0.2329 - accuracy: 0.6667
Predicted classes: {} [1 2 3 2 3 1]
Expected classes: {} [1 2 3 2 3 1]

```

We can now present a sequence directly to the model for classification.

```

In [4]: def runit(model, inp):
        inp = np.array(inp, dtype=np.float32)
        pred = model.predict(inp)

```

```

    return np.argmax(pred[0])

print( runit( model, [[[0],[0],[0],[0],[0],[1]]] ))

```

1

Sun Spots Example

This section shows an example of RNN regression to predict sunspots. You can find the data files needed for this example at the following location.

- [Sunspot Data Files](#)
- [Download Daily Sunspots](#) - 1/1/1818 to now.

The following code loads the sunspot file:

```

In [5]: import pandas as pd
import os

names = ['year', 'month', 'day', 'dec_year', 'sn_value' ,
         'sn_error', 'obs_num', 'unused1']
df = pd.read_csv(
    "https://data.heatonresearch.com/data/t81-558/SN_d_tot_V2.0.csv",
    sep=';', header=None, names=names,
    na_values=['-1'], index_col=False)

print("Starting file:")
print(df[0:10])

print("Ending file:")
print(df[-10:])

```

Starting file:

	year	month	day	dec_year	sn_value	sn_error	obs_num	unused1
0	1818	1	1	1818.001	-1	NaN	0	1
1	1818	1	2	1818.004	-1	NaN	0	1
2	1818	1	3	1818.007	-1	NaN	0	1
3	1818	1	4	1818.010	-1	NaN	0	1
4	1818	1	5	1818.012	-1	NaN	0	1
5	1818	1	6	1818.015	-1	NaN	0	1
6	1818	1	7	1818.018	-1	NaN	0	1
7	1818	1	8	1818.021	65	10.2	1	1
8	1818	1	9	1818.023	-1	NaN	0	1
9	1818	1	10	1818.026	-1	NaN	0	1

Ending file:

	year	month	day	dec_year	sn_value	sn_error	obs_num	unused1
72855	2017	6	21	2017.470	35	1.0	41	0
72856	2017	6	22	2017.473	24	0.8	39	0
72857	2017	6	23	2017.475	23	0.9	40	0
72858	2017	6	24	2017.478	26	2.3	15	0
72859	2017	6	25	2017.481	17	1.0	18	0
72860	2017	6	26	2017.484	21	1.1	25	0
72861	2017	6	27	2017.486	19	1.2	36	0
72862	2017	6	28	2017.489	17	1.1	22	0
72863	2017	6	29	2017.492	12	0.5	25	0
72864	2017	6	30	2017.495	11	0.5	30	0

As you can see, there is quite a bit of missing data near the end of the file. We want to find the starting index where the missing data no longer occurs. This technique is somewhat sloppy; it would be better to find a use for the data between missing values. However, the point of this example is to show how to use LSTM with a somewhat simple time-series.

```
In [6]: start_id = max(df[df['obs_num'] == 0].index.tolist()+1) # Find the last zero
print(start_id)
df = df[start_id:] # Trim the rows that have missing observations
```

11314

```
In [7]: df['sn_value'] = df['sn_value'].astype(float)
df_train = df[df['year'] < 2000]
df_test = df[df['year'] >= 2000]

spots_train = df_train['sn_value'].tolist()
spots_test = df_test['sn_value'].tolist()

print("Training set has {} observations.".format(len(spots_train)))
print("Test set has {} observations.".format(len(spots_test)))
```

Training set has 55160 observations.

Test set has 6391 observations.

To create an algorithm that will predict future values, we need to consider how to encode this data to be presented to the algorithm. The data must be submitted as sequences, using a sliding window algorithm to encode the data. We must define how large the window will be. Consider an n -sized window. Each sequence's x values will be

a n data points sequence. The y 's will be the next value, after the sequence, that we are trying to predict. You can use the following function to take a series of values, such as sunspots, and generate sequences (x) and predicted values (y).

```
In [8]: import numpy as np

def to_sequences(seq_size, obs):
    x = []
    y = []

    for i in range(len(obs)-SEQUENCE_SIZE):
        #print(i)
        window = obs[i:(i+SEQUENCE_SIZE)]
        after_window = obs[i+SEQUENCE_SIZE]
        window = [[x] for x in window]
        #print("{} - {}".format(window, after_window))
        x.append(window)
        y.append(after_window)

    return np.array(x), np.array(y)

SEQUENCE_SIZE = 10
x_train, y_train = to_sequences(SEQUENCE_SIZE, spots_train)
x_test, y_test = to_sequences(SEQUENCE_SIZE, spots_test)

print("Shape of training set: {}".format(x_train.shape))
print("Shape of test set: {}".format(x_test.shape))
```

Shape of training set: (55150, 10, 1)

Shape of test set: (6381, 10, 1)

We can see the internal structure of the training data. The first dimension is the number of training elements, the second indicates a sequence size of 10, and finally, we have one data point per timeslice in the window.

```
In [9]: x_train.shape
```

```
Out[9]: (55150, 10, 1)
```

We are now ready to build and train the model.

```
In [ ]: from tensorflow.keras.preprocessing import sequence
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense, Embedding
from tensorflow.keras.layers import LSTM
from tensorflow.keras.datasets import imdb
from tensorflow.keras.callbacks import EarlyStopping
import numpy as np

print('Build model...')
model = Sequential()
model.add(LSTM(64, dropout=0.0, recurrent_dropout=0.0, \
              input_shape=(None, 1)))
```

```

model.add(Dense(32))
model.add(Dense(1))
model.compile(loss='mean_squared_error', optimizer='adam')
monitor = EarlyStopping(monitor='val_loss', min_delta=1e-3, patience=5,
                        verbose=1, mode='auto', restore_best_weights=True)
print('Train...')

model.fit(x_train,y_train,validation_data=(x_test,y_test),
        callbacks=[monitor],verbose=2,epochs=1000)

```

Build model...

Train...

Epoch 1/1000

1724/1724 - 12s - loss: 1392.9260 - val_loss: 212.4303 - 12s/epoch - 7ms/step

Epoch 2/1000

1724/1724 - 10s - loss: 516.7653 - val_loss: 239.7139 - 10s/epoch - 6ms/step

Epoch 3/1000

1724/1724 - 10s - loss: 509.0716 - val_loss: 227.2393 - 10s/epoch - 6ms/step

Epoch 4/1000

1724/1724 - 10s - loss: 503.2472 - val_loss: 257.9693 - 10s/epoch - 6ms/step

Epoch 5/1000

1724/1724 - 10s - loss: 498.1863 - val_loss: 226.4870 - 10s/epoch - 6ms/step

Epoch 6/1000

1724/1724 - 10s - loss: 499.1180 - val_loss: 208.2820 - 10s/epoch - 6ms/step

Epoch 7/1000

1724/1724 - 10s - loss: 498.4828 - val_loss: 224.2135 - 10s/epoch - 6ms/step

Epoch 8/1000

1724/1724 - 10s - loss: 497.6813 - val_loss: 253.0776 - 10s/epoch - 6ms/step

Epoch 9/1000

1724/1724 - 10s - loss: 496.7933 - val_loss: 211.7351 - 10s/epoch - 6ms/step

Epoch 10/1000

1724/1724 - 10s - loss: 497.0393 - val_loss: 215.1721 - 10s/epoch - 6ms/step

Epoch 11/1000

Restoring model weights from the end of the best epoch: 6.

1724/1724 - 10s - loss: 495.1920 - val_loss: 220.1826 - 10s/epoch - 6ms/step

Epoch 11: early stopping

Finally, we evaluate the model with RMSE.

In []: `from sklearn import metrics`

```

pred = model.predict(x_test)
score = np.sqrt(metrics.mean_squared_error(pred,y_test))
print("Score (RMSE): {}".format(score))

```



T81-558: Applications of Deep Neural Networks

Module 10: Time Series in Keras

- Instructor: [Jeff Heaton](#), McKelvey School of Engineering, [Washington University in St. Louis](#)
- For more information visit the [class website](#).

Module 10 Material

- Part 10.1: Time Series Data Encoding for Deep Learning [\[Video\]](#) [\[Notebook\]](#)
- Part 10.2: Programming LSTM with Keras and TensorFlow [\[Video\]](#) [\[Notebook\]](#)
- **Part 10.3: Text Generation with Keras and TensorFlow** [\[Video\]](#) [\[Notebook\]](#)
- Part 10.4: Introduction to Transformers [\[Video\]](#) [\[Notebook\]](#)
- Part 10.5: Transformers for Timeseries [\[Video\]](#) [\[Notebook\]](#)

Google CoLab Instructions

The following code ensures that Google CoLab is running the correct version of TensorFlow.

```
In [1]: try:
        %tensorflow_version 2.x
        COLAB = True
        print("Note: using Google CoLab")
    except:
        print("Note: not using Google CoLab")
        COLAB = False
```

Note: using Google CoLab

Part 10.3: Text Generation with LSTM

Recurrent neural networks are also known for their ability to generate text. As a result, the neural network's output can be free-form text. This section will demonstrate how to train an LSTM on a textual document, such as classic literature, and learn to output new text that appears to be of the same form as the training material. If you train your

LSTM on [Shakespeare](#), it will learn to crank out new prose similar to what Shakespeare had written.

Don't get your hopes up. You will not teach your deep neural network to write the next [Pulitzer Prize for Fiction](#). The prose generated by your neural network will be nonsensical. However, the output text will usually be nearly grammatically correct and similar to the source training documents.

A neural network generating nonsensical text based on literature may not seem helpful. However, this technology gets so much interest because it forms the foundation for many more advanced technologies. The LSTM will typically learn human grammar from the source document opens a wide range of possibilities. You can use similar technology to complete sentences when entering text. The ability to output free-form text has become the foundation of many other technologies. In the next part, we will use this technique to create a neural network that can write captions for images to describe what is going on in the picture.

Additional Information

The following are some articles that I found helpful in putting this section together.

- [The Unreasonable Effectiveness of Recurrent Neural Networks](#)
- [Keras LSTM Generation Example](#)

Character-Level Text Generation

There are several different approaches to teaching a neural network to output free-form text. The most basic question is if you wish the neural network to learn at the word or character level. Learning at the character level is the more interesting of the two. The LSTM is learning to construct its own words without even being shown what a word is. We will begin with character-level text generation. In the next module, we will see how we can use nearly the same technique to operate at the word level. We will implement word-level automatic captioning in the next module.

We import the needed Python packages and define the sequence length, named **maxlen**. Time-series neural networks always accept their input as a fixed-length array. Because you might not use all of the sequence elements, filling extra pieces with zeros is common. You will divide the text into sequences of this length, and the neural network will train to predict what comes after this sequence.

```
In [2]: from tensorflow.keras.callbacks import LambdaCallback
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense
from tensorflow.keras.layers import LSTM
from tensorflow.keras.optimizers import RMSprop
```

```
from tensorflow.keras.utils import get_file
import numpy as np
import random
import sys
import io
import requests
import re
```

We will train the neural network on the classic children's book [Treasure Island](#). We begin by loading this text into a Python string and displaying the first 1,000 characters.

```
In [3]: r = requests.get("https://data.heatonresearch.com/data/t81-558/text/"\
                        "treasure_island.txt")
raw_text = r.text
print(raw_text[0:1000])
```

ï»¿The Project Gutenberg EBook of Treasure Island, by Robert Louis Stevenson

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Author: Robert Louis Stevenson

Illustrator: Milo Winter

Release Date: January 12, 2009 [EBook #27780]

Language: English

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Treasure Island

Robert Louis Stevenson

Illustrated by
Milo Winter

[Illustration]

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NEW YORK

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We will extract all unique characters from the text and sort them. This technique allows us to assign a unique ID to each character. Because we sorted the characters, these IDs should remain the same. The IDs will change if we add new characters to the original text. We build two dictionaries. The first **char2idx** is used to convert a character into its ID. The second **idx2char** converts an ID back into its character.

```
In [4]: processed_text = raw_text.lower()
processed_text = re.sub(r'^[\x00-\x7f]', r'', processed_text)

print('corpus length:', len(processed_text))

chars = sorted(list(set(processed_text)))
print('total chars:', len(chars))
char_indices = dict((c, i) for i, c in enumerate(chars))
indices_char = dict((i, c) for i, c in enumerate(chars))
```

```
corpus length: 397400
total chars: 60
```

We are now ready to build the actual sequences. Like previous neural networks, there will be an x and y . However, for the LSTM, x and y will be sequences. The x input will specify the sequences where y is the expected output. The following code generates all possible sequences.

```
In [5]: # cut the text in semi-redundant sequences of maxlen characters
maxlen = 40
step = 3
sentences = []
next_chars = []
for i in range(0, len(processed_text) - maxlen, step):
    sentences.append(processed_text[i: i + maxlen])
    next_chars.append(processed_text[i + maxlen])
print('nb sequences:', len(sentences))
```

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nb sequences: 132454
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In [6]: sentences
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[illegible]

We can now convert the text into vectors.

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```

for t, char in enumerate(sentence):
    x[i, t, char_indices[char]] = 1
    y[i, char_indices[next_chars[i]]] = 1

```

Vectorization...

/usr/local/lib/python3.7/dist-packages/ipykernel_launcher.py:2: DeprecationWarning: `np.bool` is a deprecated alias for the builtin `bool`. To silence this warning, use `bool` by itself. Doing this will not modify any behavior and is safe. If you specifically wanted the numpy scalar type, use `np.bool_` here.

Deprecated in NumPy 1.20; for more details and guidance: <https://numpy.org/devdocs/release/1.20.0-notes.html#deprecations>

/usr/local/lib/python3.7/dist-packages/ipykernel_launcher.py:3: DeprecationWarning: `np.bool` is a deprecated alias for the builtin `bool`. To silence this warning, use `bool` by itself. Doing this will not modify any behavior and is safe. If you specifically wanted the numpy scalar type, use `np.bool_` here.

Deprecated in NumPy 1.20; for more details and guidance: <https://numpy.org/devdocs/release/1.20.0-notes.html#deprecations>

This is separate from the ipykernel package so we can avoid doing imports until

Next, we create the neural network. This neural network's primary feature is the LSTM layer, which allows the sequences to be processed.

```

In [8]: # build the model: a single LSTM
print('Build model...')
model = Sequential()
model.add(LSTM(128, input_shape=(maxlen, len(chars))))
model.add(Dense(len(chars), activation='softmax'))

optimizer = RMSprop(lr=0.01)
model.compile(loss='categorical_crossentropy', optimizer=optimizer)

```

Build model...

/usr/local/lib/python3.7/dist-packages/keras/optimizer_v2/rmsprop.py:130: UserWarning: The `lr` argument is deprecated, use `learning_rate` instead.

super(RMSprop, self).__init__(name, **kwargs)

```

In [9]: model.summary()

```

Model: "sequential"

Layer (type)	Output Shape	Param #
=====		
lstm (LSTM)	(None, 128)	96768
dense (Dense)	(None, 60)	7740
=====		
Total params: 104,508		
Trainable params: 104,508		
Non-trainable params: 0		
=====		

The LSTM will produce new text character by character. We will need to sample the correct letter from the LSTM predictions each time. The **sample** function accepts the following two parameters:

- **preds** - The output neurons.
- **temperature** - 1.0 is the most conservative, 0.0 is the most confident (willing to make spelling and other errors).

The sample function below essentially performs a softmax on the neural network predictions. This process causes each output neuron to become a probability of its particular letter.

```
In [10]: def sample(preds, temperature=1.0):
# helper function to sample an index from a probability array
preds = np.asarray(preds).astype('float64')
preds = np.log(preds) / temperature
exp_preds = np.exp(preds)
preds = exp_preds / np.sum(exp_preds)
probas = np.random.multinomial(1, probs, 1)
return np.argmax(probas)
```

Keras calls the following function at the end of each training Epoch. The code generates sample text generations that visually demonstrate the neural network better at text generation. As the neural network trains, the generations should look more realistic.

```
In [11]: def on_epoch_end(epoch, _):
# Function invoked at end of each epoch. Prints generated text.
print("*****")
print('----- Generating text after Epoch: %d' % epoch)

start_index = random.randint(0, len(processed_text) - maxlen - 1)
for temperature in [0.2, 0.5, 1.0, 1.2]:
    print('----- temperature:', temperature)

    generated = ''
    sentence = processed_text[start_index: start_index + maxlen]
    generated += sentence
    print('----- Generating with seed: "' + sentence + '"')
    sys.stdout.write(generated)

    for i in range(400):
        x_pred = np.zeros((1, maxlen, len(chars)))
        for t, char in enumerate(sentence):
            x_pred[0, t, char_indices[char]] = 1.

        preds = model.predict(x_pred, verbose=0)[0]
        next_index = sample(preds, temperature)
        next_char = indices_char[next_index]

        generated += next_char
```

```
sentence = sentence[1:] + next_char

sys.stdout.write(next_char)
sys.stdout.flush()
print()
```

We are now ready to train. Depending on how fast your computer is, it can take up to an hour to train this network. If you have a GPU available, please make sure to use it.

```
In [12]: # Ignore useless W0819 warnings generated by TensorFlow 2.0. Hopefully can
# See https://github.com/tensorflow/tensorflow/issues/31308
import logging, os
logging.disable(logging.WARNING)
os.environ["TF_CPP_MIN_LOG_LEVEL"] = "3"

# Fit the model
print_callback = LambdaCallback(on_epoch_end=on_epoch_end)

model.fit(x, y,
          batch_size=128,
          epochs=60,
          callbacks=[print_callback])
```

Epoch 1/60

1035/1035 [=====] - ETA: 0s - loss: 2.0244*****

----- Generating text after Epoch: 0

----- temperature: 0.2

----- Generating with seed: ". as for sounds, there was
the steady d"

. as for sounds, there was

the steady down the captain. "you was the captain on the comating the captai
n and the captain silver was the sea and there sand was the sea the stood an
d the stood and the rear stound on the cound his man and there was the stood
and there were was were had there were the cound there were was a seet of th
e stould see the searand see the comaning the store and there was stound han
ds and the counting the sea and

----- temperature: 0.5

----- Generating with seed: ". as for sounds, there was
the steady d"

. as for sounds, there was

the steady down and there seen the hight man light in the book where i had c
ourd i was i were the thoor a swork be rean man one, in the captain, but the
captain. "seread a dillow and there stouldong as a found the captain and her
e there was the book on the was the gead was of have insteres, and a decros
of i have and there sonet the stolling allow, and that i captain said of i s
hould silver, and the hire the

----- temperature: 1.0

----- Generating with seed: ". as for sounds, there was
the steady d"

. as for sounds, there was

porered steintsuces amoy prelow serow sword for mained. the ruven'ugh, ont,
and beexpice onchers of the forsars

----- temperature: 1.2

----- Generating with seed: ". as for sounds, there was
the steady d"

. as for sounds, there was

1035/1035 [=====] - 79s 70ms/step - loss: 2.0244

Epoch 2/60

1035/1035 [=====] - ETA: 0s - loss: 1.6519*****

----- Generating text after Epoch: 1

----- temperature: 0.2

----- Generating with seed: ".

"ay, ay, sir," cried the cook, in t"

.

"ay, ay, sir," cried the cook, in the said and the stood was a spirate and t
he said of the said and the captain spread and the sea and the bottor and the
shore. i had before the said and the said and the captain silver, and the sa
id the said and the said of the sand of the said of the sand on the sand of
the captain and the sort that the sand and the said and the sand of the sand
of the captain and the captain and the said of the ca

----- temperature: 0.5

----- Generating with seed: ".

"ay, ay, sir," cried the cook, in t"

.

of and a crite in the slain. in the beard to the cappain and his look had an
d the captain, and the wire of the sore on the sound st contor companions of
the silly said his plast and the crissing in a project gutenbergm t

----- temperature: 1.0

----- Generating with seed: ".

"ay, ay, sir," cried the cook, in t"

.

here. well, ever a fine; what that not captation. whold were epen stampativni
gglest have the not, d

----- temperature: 1.2

----- Generating with seed: ".

"ay, ay, sir," cried the cook, in t"

.

```

treasipams, m
1035/1035 [=====] - 73s 71ms/step - loss: 1.6519
Epoch 3/60
1031/1035 [=====>.] - ETA: 0s - loss: 1.5398*****
*****

```

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----- Generating text after Epoch: 2
----- temperature: 0.2
----- Generating with seed: "ptain, "i learn we are going after treas"

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----- temperature: 0.5
----- Generating with seed: "ptain, "i learn we are going after treas"

```

```

the blockhouse, but i had part and so a look as a sive and the didder and th
e man bask as been to little and the and the dire's pirang about the most my
blood head to say and head and s
----- temperature: 1.0
----- Generating with seed: "ptain, "i learn we are going after treas"

```

```

talked here never, and the
----- temperature: 1.2
----- Generating with seed: "ptain, "i learn we are going after treas"

```

icved theure in him shivid bense, mown fook ababoving, we ad! we was nocomed
der mevers peinis. the

1035/1035 [=====] - 74s 71ms/step - loss: 1.5399

Epoch 4/60

1031/1035 [=====>.] - ETA: 0s - loss: 1.4793*****

----- Generating text after Epoch: 3

----- temperature: 0.2

----- Generating with seed: "t in another
world are very small.

t"

t in another
world are very small.

the stare of the stockade. i was a sunder of the stood and silver was a shot
and should and better the stockade of the stood and pressed the stockade of
the stockade, and the shore was a shot of the shoulders, and the stood and s
hore of the storess to the storig was of the stockade. the stare of the star
e. and a singed the shoulders, and the stood and see the stockade, and the s
toress of the stores

----- temperature: 0.5

----- Generating with seed: "t in another
world are very small.

t"

t in another
world are very small.

the same hand and the captain and pipe. the man and that were the little man
which i close hand should have tay and now the first that down the more that
came as the captain was distretting the fire, and a ladge and the sure great
think was a great porsh

----- temperature: 1.0

----- Generating with seed: "t in another
world are very small.

t"

t in another
world are very small.

we should us, of you look and another. i

----- temperature: 1.2

----- Generating with seed: "t in another

world are very small.

t"
t in another
world are very small.

conhind though.

1035/1035 [=====] - 74s 71ms/step - loss: 1.4794

Epoch 5/60

1033/1035 [=====>.] - ETA: 0s - loss: 1.4381*****

----- Generating text after Epoch: 4

----- temperature: 0.2

----- Generating with seed: "e raisins before them, and the doctor sm"

e raisins before them, and the doctor smoked to the ship was a shot to the s
hout of the shout of the shoulder on the shoulder and the shout of the sure
of the shoulder and the shout of the so the so in the storiger to the soundr
eas of the shout of the work on the sailor was the shout with the shout of t
he shout was the sure of the shout and the sure of the shout of the worst, a
nd the sure was a shot with the shout of the so nearess, and

----- temperature: 0.5

----- Generating with seed: "e raisins before them, and the doctor sm"

t

----- temperature: 1.0

----- Generating with seed: "e raisins before them, and the doctor sm"

----- temperature: 1.2

----- Generating with seed: "e raisins before them, and the doctor sm"

```

log
1035/1035 [=====] - 74s 71ms/step - loss: 1.4382
Epoch 6/60
1034/1035 [=====>.] - ETA: 0s - loss: 1.4062*****
*****
----- Generating text after Epoch: 5
----- temperature: 0.2
----- Generating with seed: "awing near us in the woods along the sho"
awing near us in the woods along the shoulder of the captain stare, and the
captain some of course, and the stockade and the tall the captain stare, and
the captain stare to the stockade, and the stood over the captain stare on t
he stockade of the captain state and the stockade and state on the corner of
the captain stare, and the captain stard on the chose, and the captain stare
the color the captain stand the barross the color hand of
----- temperature: 0.5
----- Generating with seed: "awing near us in the woods along the sho"

had feet my little from the color he was an to recap were so add the words w
ell, on it the blind back on and beside a stound out in the black with the s
tack
----- temperature: 1.0
----- Generating with seed: "awing near us in the woods along the sho"

                                     is rau
----- temperature: 1.2
----- Generating with seed: "awing near us in the woods along the sho"

```

```

lin was bit more, and, '
1035/1035 [=====] - 74s 71ms/step - loss: 1.4062
Epoch 7/60

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```

1035/1035 [=====] - ETA: 0s - loss: 1.3809*****
*****
----- Generating text after Epoch: 6
----- temperature: 0.2
----- Generating with seed: "me of the men who
had been to field-wor"
me of the men who
had been to field-work the tallers, and the stander of the standers of the s
torigh of the stores of the stores of the start of the station of the statio
n of the start and the station and the start of the station and the same was
of the standers of the stack of the station of the start of the stores of th
e stores of the stores of the stack of the stores of the standers, and all t
he sun the tames and the storigh and the
----- temperature: 0.5
----- Generating with seed: "me of the men who
had been to field-wor"
me of the men who

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```

the captain stouts of the steets. we for the parroarse of the curree was wit
h the tack, and of the ching the southess in the branger of the southess sto
rts, and i clut who had a sharp a tell you say
----- temperature: 1.0
----- Generating with seed: "me of the men who
had been to field-wor"
me of the men who

```

```

"now, bent," sost in the piraal noop and part of the boat side, that was of
sails comp
----- temperature: 1.2
----- Generating with seed: "me of the men who
had been to field-wor"
me of the men who

```

```

1035/1035 [=====] - 74s 71ms/step - loss: 1.3809
Epoch 8/60
1032/1035 [=====>.] - ETA: 0s - loss: 1.3628*****
*****
----- Generating text after Epoch: 7
----- temperature: 0.2
----- Generating with seed: ", it seemed impossible to fancy that the"
, it seemed impossible to fancy that the black clept of the bottom shoulder

```

and the stockade, and the captain smollett and the black clepped the captain. and i was a boat shoulder and the corner of the captain. i was not a sign and the black clept of the bottom the poor sailor and the storess on the first had been and a lighter in the storest to see now and the captain. and the black good before the captain. in the storest with a sound

----- temperature: 0.5

----- Generating with seed: ", it seemed impossible to fancy that the"

"i did in a man was so the black

----- temperature: 1.0

----- Generating with seed: ", it seemed impossible to fancy that the"

----- temperature: 1.2

----- Generating with seed: ", it seemed impossible to fancy that the"

from the crass, as sempeld, now to leg, on owfied xa way full beond, and by an. at fort is us, handwalc

1035/1035 [=====] - 73s 71ms/step - loss: 1.3627

Epoch 9/60

1031/1035 [=====>.] - ETA: 0s - loss: 1.3466*****

----- Generating text after Epoch: 8

----- temperature: 0.2

----- Generating with seed: "d ahead?"

"i have, sir," said silver."

d ahead?"

"i have, sir," said silver. "then the captain, "the store of the stores, "if it's a strains of the story who had starked to the stores. the same was a sure, sitting the pare. i had starked to the strangers, and the store of the strangers of the strangers, and the store of the part, and the stern with the start, and the story the same distriets, and the same was a surprise the ship were a surprise of the straight. the capta

----- temperature: 0.5

----- Generating with seed: "d ahead?"

"i have, sir," said silver."
d ahead?"

"i have, sir," said silver. "you was companions and did of the speaked in th
e man where the sprete the one of the cook. and the story shipped of the sho
re, where one as if it in the blockhousagaying of the thing presenter and th
e story of the work over his hands, and we never on the southern the shore,
and the little of nothing of the ships of the stores. in one the blockhousan
e. the hore the fore in the captain. i was a st

----- temperature: 1.0

----- Generating with seed: "d ahead?"

"i have, sir," said silver."
d ahead?"

ascrew the belorst in spite stumps, and cructed you call he was,

----- temperature: 1.2

----- Generating with seed: "d ahead?"

"i have, sir," said silver."
d ahead?"

the other meant ki

1035/1035 [=====] - 73s 71ms/step - loss: 1.3470

Epoch 10/60

1032/1035 [=====>.] - ETA: 0s - loss: 1.3323*****

----- Generating text after Epoch: 9

----- temperature: 0.2

----- Generating with seed: " of speaking. i laid by nine
hundred sa"

of speaking. i laid by nine

hundred saility to the cook and the cook and found the cook of the cook of t
he cook the cook and the cook and the cook and the colores, and the color of
the shoulder and the boats and the cook and the cook and the cook and the co
rner of the fire of the shoulder and the corner of the cook and side of the
shoulder. the sun had sundle of the rest in the cooked of the shoulder. i wa
s the storing was the corner

----- temperature: 0.5

----- Generating with seed: " of speaking. i laid by nine

hundred sa"
of speaking. i laid by nine

noot of the book shoulder ship the anchor of the satule should of the crosse
s had a conting, that was the sun on the hands in the feeling, and the cold
with the gain in the captain and the word and the usele. i thundered over th
e cove. the pire, stood made me dare the captain as the seat the turning, an
d the cover i was our order,

----- temperature: 1.0

----- Generating with seed: " of speaking. i laid by nine

hundred sa"

of speaking. i laid by nine

and the sure, and a not it lay at that than. there's long

----- temperature: 1.2

----- Generating with seed: " of speaking. i laid by nine

hundred sa"

of speaking. i laid by nine

intur it? h

1035/1035 [=====] - 74s 71ms/step - loss: 1.3324

Epoch 11/60

1033/1035 [=====>.] - ETA: 0s - loss: 1.3206*****

----- Generating text after Epoch: 10

----- temperature: 0.2

----- Generating with seed: "

in the direction of the stockade upon t"

in the direction of the stockade upon the captain out and the stockade, and
the story the stockade, and the story and the story, and the story, and i wa
s a state by the stockade, and the same the stockade, and a sudden with the
stockade, and the story and the story of the story, and the stockade of the
story, and the story and still brought the story, and the stockade is a soun
d the story, and the story, and the same the stockade, and

----- temperature: 0.5

----- Generating with seed: "

in the direction of the stockade upon t"

in the direction of the stockade upon the other side in a ship and the time,
and the same the captain light had seen the porture, and the semrice and see

n the ship had seen the captain shoulded a ship was so mander was sound of t
 he sign of the stockade, and the strong the captain san seally about my mind
 for a sound of the note of the stockade, and the stare the talling was made
 and resened the first and shoulder dead in, and the seal
 ----- temperature: 1.0
 ----- Generating with seed: "
 in the direction of the stockade upon t"

the clopered, speak, a
 ----- temperature: 1.2
 ----- Generating with seed: "
 in the direction of the stockade upon t"

ma
 1035/1035 [=====] - 74s 71ms/step - loss: 1.3207
 Epoch 12/60
 1034/1035 [=====>.] - ETA: 0s - loss: 1.3100*****

 ----- Generating text after Epoch: 11
 ----- temperature: 0.2
 ----- Generating with seed: "ooner nor later. "you can calculate for "
 ooner nor later. "you can calculate for the stockane and seemed and the sur
 e, and the stockane of the captain. and there we had looked and stoping and
 beside the sign of the stockanes of the storigh of the storigh of the sidely
 and the shoulder and particularly any grath and sea that he had seen a spot
 side and the stockane of the shoulder of the storigh of the same the way of
 the shoulder and the same the storigh and the storigh of the
 ----- temperature: 0.5
 ----- Generating with seed: "ooner nor later. "you can calculate for "

 story, and i had started as a sundy speaking with a spit.
 ----- temperature: 1.0
 ----- Generating with seed: "ooner nor later. "you can calculate for "

any rayt of wown, no mate sillests, a may a whid right and ground; he "alone
 the house--ampart like some hidden still upon that he to captain smollidtge u
 p, i swe-pose upon buchesness, and there
 ----- temperature: 1.2
 ----- Generating with seed: "ooner nor later. "you can calculate for "

that n
 1035/1035 [=====] - 74s 71ms/step - loss: 1.3102
 Epoch 13/60
 1035/1035 [=====] - ETA: 0s - loss: 1.2997*****

 ----- Generating text after Epoch: 12
 ----- temperature: 0.2
 ----- Generating with seed: "at i had heard of cannibals. i was withi"

i was a s
 ----- temperature: 0.5
 ----- Generating with seed: "at i had heard of cannibals. i was withi"

the slicks of the ship and he was ben gunn of the marsce it was a fear the n
 ober. silver was we began to the last as a companions had been
 ----- temperature: 1.0

----- Generating with seed: "at i had heard of cannibals. i was withi"

saw cimbured the wind cleanly he crieding ill and hoarse of long gave me a
h, sapen the moan and wad and captain smem

----- temperature: 1.2

----- Generating with seed: "at i had heard of cannibals. i was withi"

of a thince all himself had behind the captain; and, a losi, lo?" ared with
1035/1035 [=====] - 74s 71ms/step - loss: 1.2997
Epoch 14/60

1028/1035 [=====>.] - ETA: 0s - loss: 1.2906*****

----- Generating text after Epoch: 13

----- temperature: 0.2

----- Generating with seed: " "you'll find i do my
duty."

and wit"

"you'll find i do my
duty."

and with a still story on the story. silver was a story and the story, and w
e were before you see the captain silver to the story, and a still given the
story, and i was a still below it was a storing and so much as the story, an
d the captain lay no more of the story, and the story, and the story, and th
e story, and the corner of the story. now, i could you can the story, and th
e story, and the sound is

----- temperature: 0.5

----- Generating with seed: " "you'll find i do my
duty."

and wit"

"you'll find i do my
duty."

spot by the side, and as the story. "leaving his boat," he and the door, all
the captain complinions to work to the starul followed out of the other to s
tores, that i say with the first i found bear on in the saper, and the sapen
and i place still black, in the door of the condres

----- temperature: 1.0

----- Generating with seed: " "you'll find i do my
duty."

```
and wit"
  "you'll find i do my
duty."
```

```
prodites, and dead. why harrle abo'ill plamed at
----- temperature: 1.2
----- Generating with seed: " "you'll find i do my
duty."
```

```
and wit"
  "you'll find i do my
duty."
```

```
"you have a
1035/1035 [=====] - 74s 71ms/step - loss: 1.2906
Epoch 15/60
1031/1035 [=====>.] - ETA: 0s - loss: 1.2857*****
*****
----- Generating text after Epoch: 14
----- temperature: 0.2
----- Generating with seed: " me, incomprehensible, it
filled the sq"
  me, incomprehensible, it
```

```
the captain smollettridery was a strong that was a good man and the stockad
e, and the storately and the stockade, and th
----- temperature: 0.5
----- Generating with seed: " me, incomprehensible, it
filled the sq"
  me, incomprehensible, it
```

```
and the corner of thought the crignty and so instand and the shore of the ca
ptain; of seament and the sure, and the sure and the surf was a head and wit
h black we and the ship was a shot only the treasure island so look and seem
ed to the stock do to and flithually for the captain and the stict bewwhole
out and between to the captain. and a little bee
----- temperature: 1.0
----- Generating with seed: " me, incomprehensible, it
```

```
filled the sq"
me, incomprehensible, it
```

```
stro
----- temperature: 1.2
----- Generating with seed: " me, incomprehensible, it
filled the sq"
me, incomprehensible, it
```

```
hand in i
1035/1035 [=====] - 74s 71ms/step - loss: 1.2859
Epoch 16/60
1032/1035 [=====>.] - ETA: 0s - loss: 1.2769*****
*****
----- Generating text after Epoch: 15
----- temperature: 0.2
----- Generating with seed: "d on the summit of the spy-glass, and so"
d on the summit of the spy-glass, and so thing the sails of the shoulder in
a man they was a stiffing and the captain and the stock, and the story and t
he ship's ship's shoulder and the ship's companion and side and between the
ship's shoulder and seamen, shipments, and beside the stock, and the ship's
companion and still beside and the surf and the ship's companion and the sur
f was a still with the ship's some offort and the ship's sho
----- temperature: 0.5
----- Generating with seed: "d on the summit of the spy-glass, and so"
```

```
"i
----- temperature: 1.0
----- Generating with seed: "d on the summit of the spy-glass, and so"
```

for of the wayness, whom on, a men demepeds for a go add tills grew the emem
ecutmander upon the way, we would dim

----- temperature: 1.2

----- Generating with seed: "d on the summit of the spy-glass, and so"

sliequite thought doctosc; found it again, it mumtn' mut, i've done, if a gr
eataji'l bi's unshertirns to the numbers of this', the mitch and mening nifo
l swotl. jumring foremed

1035/1035 [=====] - 73s 71ms/step - loss: 1.2771

Epoch 17/60

1027/1035 [=====>.] - ETA: 0s - loss: 1.2735*****

----- Generating text after Epoch: 16

----- temperature: 0.2

----- Generating with seed: "el could move about; he was
now armed, "

el could move about; he was

"well, i'll cound me to the ship's done, and then he had

----- temperature: 0.5

----- Generating with seed: "el could move about; he was
now armed, "

el could move about; he was

at the other and the most color him apprest her cheet. and they were all the
wood, and i had a crutbles of some to see the mainse and the stockade, and t
he eas of the might he was found as i was a little parror, and the ship engl
ing and here and since and the coracle would have the captain the spy-glass-

-i saw the wo

----- temperature: 1.0

----- Generating with seed: "el could move about; he was
now armed, "

el could move about; he was

no a fearing-trees,s bearong with our electronic works was accepledesse

----- temperature: 1.2

----- Generating with seed: "el could move about; he was
now armed, "

el could move about; he was

might his cooupperforh, sight for cave creepen, thankfully her floords upon
e
1035/1035 [=====] - 73s 70ms/step - loss: 1.2733
Epoch 18/60
1035/1035 [=====] - ETA: 0s - loss: 1.2664*****

----- Generating text after Epoch: 17
----- temperature: 0.2
----- Generating with seed: "ore boats full of
negroes and mexican i"
ore boats full of

"well, i'll say and here," said the captain. "there's a surted the captain.
"but i had a started the coracle that was a surprise, and i saw the story, a
nd there was a surprise, and the same seared the cheer. i had a still for th
e captain land and silver was a
----- temperature: 0.5
----- Generating with seed: "ore boats full of
negroes and mexican i"
ore boats full of

i could see a run you and the sun had been to
----- temperature: 1.0
----- Generating with seed: "ore boats full of
negroes and mexican i"
ore boats full of

the
----- temperature: 1.2
----- Generating with seed: "ore boats full of
negroes and mexican i"
ore boats full of

two link more thaving tannay his awryfice with moremantaat you'll swack acr
omise, what gives been e
1035/1035 [=====] - 72s 70ms/step - loss: 1.2664
Epoch 19/60
1034/1035 [=====>.] - ETA: 0s - loss: 1.2615*****

----- Generating text after Epoch: 18
----- temperature: 0.2
----- Generating with seed: "ee to indemnify and hold the foundation,"

capped that i was so that we were all the shoulder of the stockade, and the
spoin of the sand that i was so for the same man and be the shoulder was soo

n the shores, and the sails was the spoiner, and the sailed the shoulder of the shoulder were a ship and the sho

----- temperature: 0.5

----- Generating with seed: "ee to indemnify and hold the foundation,"

ee to indemnify and hold the foundation, the restood the captain. and the sa il of a silven was round of still piece of the sand was gbod had come a comp anion, i would seen the first with provided from my hone, and the ship. i ha d been the trees, and, we began to help and down the parror, and as so man t he corner of strange of the hold of the same was might hand we were not the spord, and the captain line of the shoared; and the sun had

----- temperature: 1.0

----- Generating with seed: "ee to indemnify and hold the foundation,"

t

----- temperature: 1.2

----- Generating with seed: "ee to indemnify and hold the foundation,"

a stare come alteese the m

1035/1035 [=====] - 72s 70ms/step - loss: 1.2614

Epoch 20/60

1035/1035 [=====] - ETA: 0s - loss: 1.2555*****

----- Generating text after Epoch: 19

----- temperature: 0.2

----- Generating with seed: "an

english man-of-war, fell in talk wit"

an

english man-of-war, fell in talk with the story, and the stockade and the st ockade, which i had been the man and the stockade, and the spoke and see the sea hilderers, and the sporning and the captain and the stockade of the stoc kade. i had been the sound, and the captain straight on the boat, and the co racle were at the stockade, and the spot, and the spot, and the stockade and the story, and the spot, and the stockade of the stock

----- temperature: 0.5

----- Generating with seed: "an

english man-of-war, fell in talk wit"

an

english man-of-war, fell in talk with his head into the party on the worst t

hree buriese and the blow on the boat, and i looked the first the way on the
 breathern shoulder and the doctor and however are all the thick hands were m
 y hands of the mring way and with one of the party of the worst, and the fir
 st the time strong through the pills, while i would have seen so much before
 i were all the well spread one of the side, and the sp
 ----- temperature: 1.0
 ----- Generating with seed: "an
 english man-of-war, fell in talk wit"
 an

know guirsclor! by-never here your part, as the captain straight the wix
 be insidence. one was perform, hall, which yet, if becavels, "geonad, my min
 ds, a
 ----- temperature: 1.2
 ----- Generating with seed: "an
 english man-of-war, fell in talk wit"
 an

"thinking, h
 1035/1035 [=====] - 73s 71ms/step - loss: 1.2555
 Epoch 21/60
 1031/1035 [=====>.] - ETA: 0s - loss: 1.2489*****

 ----- Generating text after Epoch: 20
 ----- temperature: 0.2
 ----- Generating with seed: "
 bidden on the sand, "you'll have to gi"

"well seemed the stockade, "you see, i did besk the stockade, "you see the s
 tockade, and i'll can the captain smollett, the sure. sitting the stockade.
 it was a stiff the boat stood of the stockade. i was a stiff the thing the m
 ainsail, and the stoc
 ----- temperature: 0.5
 ----- Generating with seed: "
 bidden on the sand, "you'll have to gi"

```
"well, i'll take the boy, wit
----- temperature: 1.0
----- Generating with seed: "
bidden on the sand, "you'll have to gi"
```

```
piper of the lookes. there either about voling of me i order tow monget at l
ast, and that coraked from the blade of the stranger and we were
----- temperature: 1.2
----- Generating with seed: "
bidden on the sand, "you'll have to gi"
```

```
"well with us plast fresh run nownway ; to oy face. whysept you can been bet
aps unny forth neck," cried me he know!
1035/1035 [=====] - 74s 71ms/step - loss: 1.2491
Epoch 22/60
1033/1035 [=====>.] - ETA: 0s - loss: 1.2447*****
*****
----- Generating text after Epoch: 21
----- temperature: 0.2
----- Generating with seed: "t place, where the darkness was thickest"
t place, where the darkness was thickest of the stranger of the boats and th
e captain, where he had a project gutenbergm the captain. and i was the wo
rd in a still water and the ship was a still water and the stockade of the b
oats of the boats and the stockane of the stranger of the boats and the bloc
khorages. the county and the stockade, and the counced man of the blockhous
e, and the stockade of the captain, where he was so that was
----- temperature: 0.5
----- Generating with seed: "t place, where the darkness was thickest"
```

```
had along the doctor. ir the anchorage or any hung itself of his barist; but
had the plateag to the
----- temperature: 1.0
----- Generating with seed: "t place, where the darkness was thickest"
```


b

and then i asked

----- temperature: 1.2

----- Generating with seed: "t place, where the darkness was thickest"

"you'll must risk of trelch. ; and then, spray, you--a greesin, mar! arsail
in? is draw myself. stratge'll silver, an

1035/1035 [=====] - 74s 71ms/step - loss: 1.2446

Epoch 23/60

1032/1035 [=====>.] - ETA: 0s - loss: 1.2403*****

----- Generating text after Epoch: 22

----- temperature: 0.2

----- Generating with seed: "eak up."

i did as i was bid, and, as "
eak up."

i did as i was bid, and, as you are a pigly the stockade, and the spy-glasse
rvely cap'n silence of the boat, and i was fit about the stockade, and the s
tory, and the doctor in the captain, and the captain soon and so and the cap
tain sitn and the stockade, and the captain situ's money in the captain. and
then i was a pipe, and the sailes of the stockade, and the boatswaid of the
captain. and i was flint's creasible, and then

----- temperature: 0.5

----- Generating with seed: "eak up."

i did as i was bid, and, as "
eak up."

----- temperature: 1.0

----- Generating with seed: "eak up."

i did as i was bid, and, as "
eak up."

```

not lipers
----- temperature: 1.2
----- Generating with seed: "eak up."

i did as i was bid, and, as "
eak up."

```

```

grakan, syover being-gnow, mr. ewreing then through the pirace, but it walk
so a old hands i carset havy w
1035/1035 [=====] - 73s 71ms/step - loss: 1.2402
Epoch 24/60
1027/1035 [=====>.] - ETA: 0s - loss: 1.2344*****
*****
----- Generating text after Epoch: 23
----- temperature: 0.2
----- Generating with seed: "and my conscience, which had
smitten me"
and my conscience, which had
smitten me the man of the house, and the captain spoke a surpers, and the sp
oke his portions and the captain disclable and since and the captain lit to
the spoke over the story and sea as a sure, and the sure is a stick of the s
poke of the crig to the spit, and the captain spoke a piteuenty and the riss
e of the work and the spoke over the cright and the spoke of the word, and t
he spoke over the spand of the
----- temperature: 0.5
----- Generating with seed: "and my conscience, which had
smitten me"
and my conscience, which had
smitten me, there was the susk he was some timbed to provide to the brought
on the rest and the safe time the widence of the burying, and then, so the pa
rtions and the blind raged, and the sun of which of the way with ming that b
en gunn's shortle of the fore or compagion of the surf.cearing together with
his crutch, and i looked of the man of the rum the captain. "i'll can the do
ctor's saff you the long john
----- temperature: 1.0
----- Generating with seed: "and my conscience, which had
smitten me"
and my conscience, which had

```

```

at; the other was where the volunestain knife cages and with rep
----- temperature: 1.2

```

----- Generating with seed: "and my conscience, which had
smitten me"
and my conscience, which had

settle of each, and jau
1035/1035 [=====] - 73s 70ms/step - loss: 1.2349
Epoch 25/60
1027/1035 [=====>.] - ETA: 0s - loss: 1.2298*****

----- Generating text after Epoch: 24
----- temperature: 0.2
----- Generating with seed: "he bosom of his jacket, trundled back
a"
he bosom of his jacket, trundled back
again, and the sure i lay in the captain's sorage from the captain's so be t
hat the captain's so be that that ben gunn of the shoulder, and the same mor
e was almost to the saise was a stiffing of the shoulders of the stockade. i
had so this the boats and the sure i was not a good was the captain's so tha
t i had so this a confity the sure i looked out of the stockade and the capt
ain's some thoughts
----- temperature: 0.5
----- Generating with seed: "he bosom of his jacket, trundled back
a"
he bosom of his jacket, trundled back

i was not a great and the first--that was a state shot his own consrassed an
d the shoulders of my thinds of fretward, and the bore looked before he co
uld meant about the barrel of the sound was a coracle ready in the b
----- temperature: 1.0
----- Generating with seed: "he bosom of his jacket, trundled back
a"
he bosom of his jacket, trundled back

such a whole at lase been amo
----- temperature: 1.2
----- Generating with seed: "he bosom of his jacket, trundled back
a"
he bosom of his jacket, trundled back

```

silver curred dus they desirtly me that doucu was oa
1035/1035 [=====] - 73s 71ms/step - loss: 1.2297
Epoch 26/60
1035/1035 [=====] - ETA: 0s - loss: 1.2271*****
*****

```

```

----- Generating text after Epoch: 25
----- temperature: 0.2
----- Generating with seed: "i was thus turning the business over in "
i was thus turning the business over in the stockade, and the same time and
the same time and were the boats and the stockade, and the spoke of the stoc
kade, and the southeanch the spreath and the stockade, and the spoke of the s
ound of the man who had been the story and the captain and the continued to
the stockade, and the stockade on the stockade, and the same said, and the s
ure of the same time and the ship, and the same time on the
----- temperature: 0.5
----- Generating with seed: "i was thus turning the business over in "

```

```

at la
----- temperature: 1.0
----- Generating with seed: "i was thus turning the business over in "

```

```

"but you may lay to the pick up
----- temperature: 1.2
----- Generating with seed: "i was thus turning the business over in "

```

```

"bors anothe belidy!" said sirn's pioes, mooky strigst to pl
1035/1035 [=====] - 74s 72ms/step - loss: 1.2271
Epoch 27/60
1032/1035 [=====>.] - ETA: 0s - loss: 1.2229*****
*****
----- Generating text after Epoch: 26
----- temperature: 0.2
----- Generating with seed: "ropose we should have
up the cold pie, "
ropose we should have
up the cold pie, and the shoulder the most hand of the thing to the first to
the stockade, and the stockade at the ship's company, and a steating to the
shoulder reaster and the shoulder and the captain and the house and black to
the third and the color of the shoulder was a project gutenbergm were at t
he stockade, and the stockade at the stockade, and the shoulder and seemed t
o the stockade, and the first the s
----- temperature: 0.5
----- Generating with seed: "ropose we should have
up the cold pie, "
ropose we should have

"now, you have a man and sure, you can s
----- temperature: 1.0
----- Generating with seed: "ropose we should have
up the cold pie, "
ropose we should have

side of the fancy, and they
----- temperature: 1.2
----- Generating with seed: "ropose we should have
up the cold pie, "
ropose we should have

```

```

this thick, when we gavuat's likery wor, m. h
1035/1035 [=====] - 74s 72ms/step - loss: 1.2230
Epoch 28/60
1030/1035 [=====>.] - ETA: 0s - loss: 1.2201*****
*****
----- Generating text after Epoch: 27
----- temperature: 0.2
----- Generating with seed: "the
north.

i was greatly elated with"
the
north.

i was greatly elated with a sure of the shore sandy had started a surpermess
of the shore of the stare in the same thing the worse of the same thing the
captain singing and the ship of the same time a sure in the strength of the
shore sandy had started a sure and since and the story of the shore. i was a
thin a man was still of the same man was the same time a sure in the shore o
f the same man was a states and the story o
----- temperature: 0.5
----- Generating with seed: "the
north.

i was greatly elated with"
the
north.

dectance had be
----- temperature: 1.0
----- Generating with seed: "the
north.

i was greatly elated with"
the
north.

copy i youn take ob
----- temperature: 1.2
----- Generating with seed: "the
north.

```

i was greatly elated with"
the
north.

pillanide again year, so fear theh--o'_ c
1035/1035 [=====] - 74s 71ms/step - loss: 1.2200
Epoch 29/60
1034/1035 [=====>.] - ETA: 0s - loss: 1.2180*****

----- Generating text after Epoch: 28
----- temperature: 0.2
----- Generating with seed: "n a steady whisper that was
no more tha"
n a steady whisper that was
no more that the stockade, and the stockaded to sea-chart--the stockaded the
stockade, and the south and the stockade, and the stockaded the stockade, an
d the stockaded the sure, and the stockaded and the stockade, and the treasu
re island, and the stern was a breat bering the stores, and the corner of th
e treasure island, and the stern which, the stern was the treasure-huire. it
was the stockade, and the sur
----- temperature: 0.5
----- Generating with seed: "n a steady whisper that was
no more tha"
n a steady whisper that was

a little man ben gunn's short, and he was
----- temperature: 1.0
----- Generating with seed: "n a steady whisper that was
no more tha"
n a steady whisper that was

from the mairsl shar.""nel whole preking over

```

----- temperature: 1.2
----- Generating with seed: "n a steady whisper that was
no more tha"
n a steady whisper that was

```

```

it lones, ale, not bidled make me herefure of them, dumblar., fully ob
1035/1035 [=====] - 74s 72ms/step - loss: 1.2179
Epoch 30/60
1033/1035 [=====>.] - ETA: 0s - loss: 1.2115*****
*****

```

```

----- Generating text after Epoch: 29
----- temperature: 0.2
----- Generating with seed: "shot was fired, and the last boarder
ma"
shot was fired, and the last boarder

```

```

i had the stern was companions as we had started the stockade, and the sun h
ad been two had to hav
----- temperature: 0.5
----- Generating with seed: "shot was fired, and the last boarder
ma"
shot was fired, and the last boarder

```

```

"make the squire, "you are a ship a main," answered the captain. "i'll get t
he stockade, and so named i little three and surprise to sauled. i looked a
council. but you get the stern wer
----- temperature: 1.0
----- Generating with seed: "shot was fired, and the last boarder
ma"
shot was fired, and the last boarder

```

```

wair, while i had heard of clease no
----- temperature: 1.2
----- Generating with seed: "shot was fired, and the last boarder
ma"
shot was fired, and the last boarder

```



```
, ma
1035/1035 [=====] - 74s 72ms/step - loss: 1.2114
Epoch 31/60
1029/1035 [=====>.] - ETA: 0s - loss: 1.2094*****
*****
----- Generating text after Epoch: 30
----- temperature: 0.2
----- Generating with seed: "e pious woman. but it were providence
t"
e pious woman. but it were providence
the stockade, and the stockade was the chance of the stockade, and the stock
ade start all the captain. and then we were all and the stockade, and when i
was still black spit the stockade, and the stockade had been the captain sil
ver and the stockade, and the captain smollett and the stockade, and the sam
e the chance was the stockade, and the captain smollett and the stockade, an
d the surfical the p
----- temperature: 0.5
----- Generating with seed: "e pious woman. but it were providence
t"
e pious woman. but it were providence
the woods, and when i stopped the sboct and the same cheer at the southbod;
the innly, and the sha-pinestalled and ship of little with the honest and wh
ich went from the creatine of the south and the project gutenbergm words y
our pare man of a companions to companions and the treatern, shot all the ch
art. there was my lighted for the parror, the sviecing with the barrow and r
edruth to brisk, and
----- temperature: 1.0
----- Generating with seed: "e pious woman. but it were providence
t"
e pious woman. but it were providence

my parron, spretting together had pin you show. no, jim--of a reaping and su
ch what i werth and ban as you, of states saulo-wander of. i've fit a" gorey,
drdwutl
----- temperature: 1.2
----- Generating with seed: "e pious woman. but it were providence
t"
e pious woman. but it were providence
```

```

    mishough, feld first up upon --cleaking for a fice 'pen. awayrly, and ben
by gaven won
1035/1035 [=====] - 74s 72ms/step - loss: 1.2096
Epoch 32/60
1030/1035 [=====>.] - ETA: 0s - loss: 1.2065*****
*****

```

```

----- Generating text after Epoch: 31
----- temperature: 0.2
----- Generating with seed: "ohn's ship."

```

```

"well, i tell you now," "
ohn's ship."

```

```

"well, i'll all still was below the s
----- temperature: 0.5
----- Generating with seed: "ohn's ship."

```

```

"well, i tell you now," "
ohn's ship."

```

```

"here's a country, and a please by man or this complined charting and a se
a. the sailed, who h
----- temperature: 1.0
----- Generating with seed: "ohn's ship."

```

```

"well, i tell you now," "
ohn's ship."

```

```

dogmore treasures iundry
----- temperature: 1.2
----- Generating with seed: "ohn's ship."

```

```

"well, i tell you now," "
ohn's ship."

```

```

war, pulled, step'd with pase, not
1035/1035 [=====] - 75s 72ms/step - loss: 1.2066
Epoch 33/60
1031/1035 [=====>.] - ETA: 0s - loss: 1.2052*****
*****

```

```

----- Generating text after Epoch: 32
----- temperature: 0.2
----- Generating with seed: " the squire after him.

```

```

"ay, ay, sir,"
the squire after him.

```

```

"well, i'll say it's the worst, and then i say, and then we were all and the
captain sill the stern was still to the spines, and the captain sill the sid
e of the worsh of a spoilical the shoulder of the sea through the blood, and
----- temperature: 0.5
----- Generating with seed: " the squire after him.

```

```

"ay, ay, sir,"
the squire after him.

```

```

the sillet's cressures i had thing out as i was beside hims, and then we wer
e all the gun, and the last the words, and all the captain spoke in my hous
e, and i suppose in the blood. it was bearing to that certain to the in
----- temperature: 1.0
----- Generating with seed: " the squire after him.

```

```

"ay, ay, sir,"
the squire after him.

```

```

beginning with the her nooding, sharked the door a litesroquid of my pare af
ay mutiny shungs and about, hiffways short. the seas to lead, the hore, me,
in you, and then you supptic
----- temperature: 1.2
----- Generating with seed: " the squire after him.

```

"ay, ay, sir,"
the squire after him.

han
1035/1035 [=====] - 74s 71ms/step - loss: 1.2051
Epoch 34/60
1034/1035 [=====>.] - ETA: 0s - loss: 1.2002*****

----- Generating text after Epoch: 33
----- temperature: 0.2
----- Generating with seed: " at least, the end
of that; and before "
at least, the end
of that; and before the captain smollett before the sign of the shoulder of
the shoulder. i was the shoulder had to that before my heart to the stockade
e, and the same sendered to the stockade, and then i was to the stockade, an
d the same sendient with a course, they were all and they were all was the s
ame time he was so that were my mother and the stockade, and the same sendre
ttion was a good stores, and the same sea
----- temperature: 0.5
----- Generating with seed: " at least, the end
of that; and before "
at least, the end

licking to the ship, and then he had let her he had all hands and still befo
re the boat, and i was on the stockade, and i was the stockade, and then he
was the trine
----- temperature: 1.0
----- Generating with seed: " at least, the end
of that; and before "
at least, the end

man temping men boyks. with he had thatate barbecus--
----- temperature: 1.2

```
----- Generating with seed: " at least, the end  
of that; and before "  
at least, the end
```

```
ran. no distle of
```

```
/usr/local/lib/python3.7/dist-packages/ipykernel_launcher.py:4: RuntimeWarni  
ng: divide by zero encountered in log  
after removing the cwd from sys.path.
```

```

"held well, i smell take swiftle, but iffaisp
1035/1035 [=====] - 74s 72ms/step - loss: 1.2002
Epoch 35/60
1032/1035 [=====>.] - ETA: 0s - loss: 1.1953*****
*****
----- Generating text after Epoch: 34
----- temperature: 0.2
----- Generating with seed: "se
shaking with "yo-ho-ho and a bottle "
se
shaking with "yo-ho-ho and a bottle be straight to the stockade, and the sur
f the same was the chart were along the stockade, and the stern was a state
with the stockade of the black spot the worst, and the thing was a surprise
that was a state and the stockade, and the stockade had start of the stockad
e, and the shore seaman and the stockade on the stockade, and the thing was
a state for the stockade, and the captain since as i sto
----- temperature: 0.5
----- Generating with seed: "se
shaking with "yo-ho-ho and a bottle "
se

you and a stiff of the doctor, since i had that the color than as you have s
trange of his stockade, and the worst of the man, and with a sparr of the we
nt of the sign and the captain sleeping to the fellow with the parror of the
thought as a place and distributing the chance and the chart of the worst, a
nd the every for the house, and the blockhoused my jightling a
----- temperature: 1.0
----- Generating with seed: "se
shaking with "yo-ho-ho and a bottle "
se

morust. when i opene
----- temperature: 1.2
----- Generating with seed: "se
shaking with "yo-ho-ho and a bottle "
se

```

"bucca

```

1035/1035 [=====] - 74s 72ms/step - loss: 1.1957
Epoch 36/60
1031/1035 [=====>.] - ETA: 0s - loss: 1.1931*****
*****
----- Generating text after Epoch: 35
----- temperature: 0.2
"

```

```

"all and seem the squire sail hands, the stockaded and the stockades. i was
a statue to the south and the stockaded the stockain and the stockades, and
the south and since and the same man who had started the treasure is deceare
d to the boat, and the same seaman was but we can see the first was beside t
he stockade, and the stockaded
----- temperature: 0.5
"

```

```

"i have cap'n-
cook of the start, man's short and four i was a seaman was bones, and and th
e stortsnelly at the same time what his to the severage, but we were had been
sin as he began to sea a pillance to see the face, he was in the stern hands
was not
----- temperature: 1.0
"

```

```

and pessessed, it was gone baving hund, and the two back and m
----- temperature: 1.2
"

```

```

siyey more frog outab nearers, yet, fr
1035/1035 [=====] - 74s 71ms/step - loss: 1.1934
Epoch 37/60
1029/1035 [=====>.] - ETA: 0s - loss: 1.1897*****
*****
----- Generating text after Epoch: 36
----- temperature: 0.2
----- Generating with seed: "cline, the thick tree-stumps, and the so"
cline, the thick tree-stumps, and the southeant to the same company the side
s, and a seaman to the pork of the stockade, and the same sailed the side we
re and the stockade of the shoulder of the stockade, and the sun had started
to the rest, and the sailed the sign pines, and the surpente of the stockad
e, and the same sailed the sides, and the ship's soul shore a seaman was sil
ver, and the same company to the stockade, and the same seam
----- temperature: 0.5

```

----- Generating with seed: "cline, the thick tree-stumps, and the so"

"seamst

----- temperature: 1.0

----- Generating with seed: "cline, the thick tree-stumps, and the so"

and i'--i'rroam the sea a refoot. well, i am we saw good together for the man

----- temperature: 1.2

----- Generating with seed: "cline, the thick tree-stumps, and the so"

jumsedpe know was two of the unnies provided of afut informaiuspy. i down this

1035/1035 [=====] - 74s 71ms/step - loss: 1.1896

Epoch 38/60

1035/1035 [=====] - ETA: 0s - loss: 1.1871*****

----- Generating text after Epoch: 37

----- temperature: 0.2

----- Generating with seed: "ol, and,
from first to last, not one of"

ol, and,

the same time the sprands and the stockade, and the shoulder had been the shore. i was still the captain silver had stark a sound of the shore, and the sto

----- temperature: 0.5

----- Generating with seed: "ol, and,
from first to last, not one of"

ol, and,

short, and the first like silver and the sound, and a speaking him at the shore. i reckon beside with him comless of the sound and the first should it, and the great wast under the captain so fear him his something, and short and dead, by the most hand had not me a pracitay hand with a sta

----- temperature: 1.0

----- Generating with seed: "ol, and,
from first to last, not one of"

ol, and,


```

and dead mische
----- temperature: 1.2
----- Generating with seed: "ol, and,
from first to last, not one of"
ol, and,

```

```

ancress whe
1035/1035 [=====] - 74s 72ms/step - loss: 1.1871
Epoch 39/60
1029/1035 [=====>.] - ETA: 0s - loss: 1.1847*****
*****

```

```

----- Generating text after Epoch: 38
----- temperature: 0.2
----- Generating with seed: "ho held the
loose end of the rope, now "
ho held the
loose end of the rope, now and we were behind the captain healt from the wor
ds and the same time as i was believe a lay from the sea and the same time a
t the sea and the doctor the block interripbe and the same time he was belie
ve my eyes and the captain to the party and seemed and the sand had strang w
as the captain so be a stat, and the same time at the same time i was ben gu
nn, and the same time at the same time he was b
----- temperature: 0.5
----- Generating with seed: "ho held the
loose end of the rope, now "
ho held the

```

```

the doctor on the stockade, and the whole distred and seemed at, and the sap
er, and all the consparis the coast was the windor of the sholls an each, an
d the last consing the
----- temperature: 1.0
----- Generating with seed: "ho held the
loose end of the rope, now "
ho held the

```

```

it was hamrow anywaher of ein to any nerm, as "pew! dexame't afraid in when
i had out upon hi
----- temperature: 1.2
----- Generating with seed: "ho held the
loose end of the rope, now "
ho held the
loose end of the rope, now las in silet's! of haffs; lafted in slok

```

```

"verid
1035/1035 [=====] - 74s 72ms/step - loss: 1.1849
Epoch 40/60
1029/1035 [=====>.] - ETA: 0s - loss: 1.1853*****
*****
----- Generating text after Epoch: 39
----- temperature: 0.2
----- Generating with seed: "istance. that was, at least, the end
of"
istance. that was, at least, the end

```

```

"that's a bette
----- temperature: 0.5
----- Generating with seed: "istance. that was, at least, the end
of"
istance. that was, at least, the end

```

```

feet the way of the time he had eestrighted the captain of seamen took the c
olor had that when they want he had a little way we should be a pa
----- temperature: 1.0
----- Generating with seed: "istance. that was, at least, the end
of"
istance. that was, at least, the end

```

```

airge was the breaths and the white began. i was on the nose i such
----- temperature: 1.2
----- Generating with seed: "istance. that was, at least, the end
of"
istance. that was, at least, the end

```

```

stiffle-svaaid on hard
1035/1035 [=====] - 74s 71ms/step - loss: 1.1852
Epoch 41/60
1031/1035 [=====>.] - ETA: 0s - loss: 1.1774*****
*****
----- Generating text after Epoch: 40
----- temperature: 0.2
----- Generating with seed: " with
the saber cut, first took up his "
with

surprist, and the stockade, and the sun hung and the stockade, and the sun h
ad been the state of the thing the
----- temperature: 0.5
----- Generating with seed: " with
the saber cut, first took up his "
with

```

```

seach around his armmsin--getting the side of the woods of the might like a
hug of the gigs. the sun had
----- temperature: 1.0
----- Generating with seed: " with
the saber cut, first took up his "
with

```

"little," said silver; "gun

----- temperature: 1.2
 ----- Generating with seed: " with
 the saber cut, first took up his "
 with

at otil, i did cam
 1035/1035 [=====] - 73s 71ms/step - loss: 1.1779
 Epoch 42/60
 1032/1035 [=====>.] - ETA: 0s - loss: 1.1745*****

 ----- Generating text after Epoch: 41
 ----- temperature: 0.2
 ----- Generating with seed: "e poor souls that manned her--coral
 lon"
 e poor souls that manned her--coral

"tha
 ----- temperature: 0.5
 ----- Generating with seed: "e poor souls that manned her--coral
 lon"
 e poor souls that manned her--coral
 long and the corner of the sound, and the first was pines, and the pork. the
 word races and the stick toot up the same timber that i was not a good very
 shot should with a suddenly the redruedred the tall the silver's complite wi
 th a which that the night the treasure island, and the flat ben gunn's silve
 r was so that the followed, and the little had put the brought buskly contin
 uenty to the bally out
 ----- temperature: 1.0
 ----- Generating with seed: "e poor souls that manned her--coral
 lon"
 e poor souls that manned her--coral

```
"this second consing scut, mate, do you recars with the sid look one tillt w
his. to be cangoned a
----- temperature: 1.2
----- Generating with seed: "e poor souls that manned her--coral
lon"
e poor souls that manned her--coral
```

```
chapped if on have in this ship, melas
1035/1035 [=====] - 74s 72ms/step - loss: 1.1746
Epoch 43/60
1031/1035 [=====>.] - ETA: 0s - loss: 1.1743*****
*****
----- Generating text after Epoch: 42
----- temperature: 0.2
----- Generating with seed: "estward
until i had laid her head due e"
estward
until i had laid her head due each was a proming-tost the stockade and the b
ottom of the buccaneers. the shoulder was the blockhout the buccaneers. the
blockhouse was the blockhout the blockhouted and the back shoulder and the b
right and the blockhouted the broughts or for to be state the cordish was bo
th the blockhouted to the buccaneers. the water was the blockhout the blockh
ouse, and the blockhouse before me a powder, and th
----- temperature: 0.5
----- Generating with seed: "estward
until i had laid her head due e"
estward
```

```
the man with a hand with the foremast had been on the sea, and seemed to his
head by ben gunn's surprise of t
----- temperature: 1.0
----- Generating with seed: "estward
until i had laid her head due e"
estward
```

possed himself was sittich, which on the indivives were upon our move; and p
leeming was, now, at least, "he snalled gigh!" says mo; and illus? we came h
e hasn yourve
----- temperature: 1.2
----- Generating with seed: "estward
until i had laid her head due e"
estward

sitty among the ro
1035/1035 [=====] - 74s 71ms/step - loss: 1.1745
Epoch 44/60
1032/1035 [=====>.] - ETA: 0s - loss: 1.1713*****

----- Generating text after Epoch: 43
----- temperature: 0.2
----- Generating with seed: "e chest out
alow and aloft."

"is it "
e chest out
alow and aloft."

"who had sits i'm a sure," said the captain. "the captain sit done to
----- temperature: 0.5
----- Generating with seed: "e chest out
alow and aloft."

"is it "
e chest out
alow and aloft."

"down, i'll and the sound man. not the same bright to his spite and the righ
t was the sight of the cord and sand had alreese at me, and i was a sound of
any of the followerel, and of the ship's don't like the captain. "they was t
he same more than the captain should have straight and
----- temperature: 1.0
----- Generating with seed: "e chest out
alow and aloft."

"is it "
e chest out
alow and aloft."

hamy to oarr. malleriing. we've be more san aobour searajion, as s
 ----- temperature: 1.2
 ----- Generating with seed: "e chest out
 alow and aloft."

"is it "
 e chest out
 alow and aloft."

all, hardy bray of itt, the's thite's ec
 1035/1035 [=====] - 74s 71ms/step - loss: 1.1712
 Epoch 45/60
 1033/1035 [=====>.] - ETA: 0s - loss: 1.1684*****

 ----- Generating text after Epoch: 44
 ----- temperature: 0.2
 ----- Generating with seed: "l of admiration, "he was the flower of t"

"that's the chor, some of the chor, and the sail had
 ----- temperature: 0.5
 ----- Generating with seed: "l of admiration, "he was the flower of t"

the captain silver he stortal been fluy the signer were a little spiver of t
 he same storis; and the sure the luffull. i had a steed, th
 ----- temperature: 1.0
 ----- Generating with seed: "l of admiration, "he was the flower of t"

heavy taken his great came, and dead of the fancy, on his slutbers, when i w
 as wit
 ----- temperature: 1.2
 ----- Generating with seed: "l of admiration, "he was the flower of t"

```
nwickne. i was flintworll doat, sior step unus
1035/1035 [=====] - 74s 71ms/step - loss: 1.1685
Epoch 46/60
1032/1035 [=====>.] - ETA: 0s - loss: 1.1645*****
*****
```

```
----- Generating text after Epoch: 45
----- temperature: 0.2
----- Generating with seed: ", and his bright, black eyes and
pleasa"
, and his bright, black eyes and
```

```
"ay, bee, "i'll she besides of the captain smollett the stock in the shore,
and i was a sure the captain should have the captain seemed to a sound of th
e stranger was the captain should have t
----- temperature: 0.5
----- Generating with seed: ", and his bright, black eyes and
pleasa"
, and his bright, black eyes and
```

```
a man who the purite of a suddenly came on the schooner and the ships of the
captain should are a spray and side hands of a side of the shoressuistance o
f the ship's step and done of it, and the same who, in the stranger and the
color and one afray the short, and the flack for the captain chest him on th
e cabin went on into his long she
----- temperature: 1.0
----- Generating with seed: ", and his bright, black eyes and
pleasa"
, and his bright, black eyes and
```

```
scr
----- temperature: 1.2
----- Generating with seed: ", and his bright, black eyes and
pleasa"
, and his bright, black eyes and
```



```

spiting ris far
1035/1035 [=====] - 74s 72ms/step - loss: 1.1647
Epoch 47/60
1032/1035 [=====>.] - ETA: 0s - loss: 1.1632*****
*****
----- Generating text after Epoch: 46
----- temperature: 0.2
----- Generating with seed: " across the
widest spaces--long john's "
        across the

```

```

the sure the south of the sound of the story of the story of the story of th
e story of the sand, and the so
----- temperature: 0.5
----- Generating with seed: " across the
widest spaces--long john's "
        across the

```

```

with be come to than we were to find the
----- temperature: 1.0
----- Generating with seed: " across the
widest spaces--long john's "
        across the

```

```

at the
----- temperature: 1.2
----- Generating with seed: " across the
widest spaces--long john's "
        across the

```

helk hold. yown so good formate, bring all's siles you'p all wal. moston, th

```

ere began is squire, but he was burned almost. the bla
1035/1035 [=====] - 74s 72ms/step - loss: 1.1633
Epoch 48/60
1034/1035 [=====>.] - ETA: 0s - loss: 1.1619*****
*****
----- Generating text after Epoch: 47
----- temperature: 0.2
----- Generating with seed: " flint's old ship, as i've seen a-muck
"
    flint's old ship, as i've seen a-muck
was on the state was a sudden head and stepped the captain. "i don't don't c
ome and distrey on the state, silver, and the cold ried the captain, and the
cold ried had started the crew when the sun had stand out of the shoulder of
the companions the chion of the shoulder of the word of the cold the courag
e. there was a little that the sing blow on the boat, and the captain someth
ing the captain. "y
----- temperature: 0.5
----- Generating with seed: " flint's old ship, as i've seen a-muck
"
    flint's old ship, as i've seen a-muck

over as for itself in the parly and the captain like showner and the th
----- temperature: 1.0
----- Generating with seed: " flint's old ship, as i've seen a-muck
"
    flint's old ship, as i've seen a-muck

we should hand loyal of the
----- temperature: 1.2
----- Generating with seed: " flint's old ship, as i've seen a-muck
"
    flint's old ship, as i've seen a-muck

```

```

as underward ats
1035/1035 [=====] - 74s 71ms/step - loss: 1.1618
Epoch 49/60
1030/1035 [=====>.] - ETA: 0s - loss: 1.1591*****
*****
----- Generating text after Epoch: 48
----- temperature: 0.2
----- Generating with seed: "dden his
boat--a thing quite worth doin"
dden his
boat--a thing quite worth doing the stockade, and the same man with him they
were the blockhouse, and the same man with a stortsparriccurite the black win
e, and the captain said the stockade, and the corner of the stockade, and th
e stockade the captain stand of the stockade, and the coracle was a bottle o
f the botts in the captain shoulder a sudder, and the stockade the captain s
ilence, and the stockade the captain shoulder the
----- temperature: 0.5
----- Generating with seed: "dden his
boat--a thing quite worth doin"
dden his

```

```

mutineers, and her doublibles. what i along the companime and compass shout
and dead again of the cutment distrigitation of the work was the party was b
elieved to the barce doggly over had already born of the part, with the
----- temperature: 1.0
----- Generating with seed: "dden his
boat--a thing quite worth doin"
dden his

```

```

out of the round was, tilt, comply and like a bottle to that very the brough
t me with all the color throum in great from the stood nood. unds when he we
re a piece of mecupter by hear. but had this the round to jough, "who has th
e muces
----- temperature: 1.2
----- Generating with seed: "dden his
boat--a thing quite worth doin"
dden his

```

```

nog holding the took my
1035/1035 [=====] - 74s 71ms/step - loss: 1.1587
Epoch 50/60
1031/1035 [=====>.] - ETA: 0s - loss: 1.1550*****
*****
----- Generating text after Epoch: 49
----- temperature: 0.2
----- Generating with seed: "des of the ship.

```

in i got bodily into"
des of the ship.

"ah, and then, you say, "you have the stockade, and the captain said had been the thing the captain. "it's to have a man of the stockade, and the sure
----- temperature: 0.5
----- Generating with seed: "des of the ship.

in i got bodily into"
des of the ship.

far and it
----- temperature: 1.0
----- Generating with seed: "des of the ship.

in i got bodily into"
des of the ship.

the air tromactibland ships, saw paces to have to pavid." cair your far the
captain. on your lipe, aiving posseskent big your accoped chape
----- temperature: 1.2
----- Generating with seed: "des of the ship.

in i got bodily into"
des of the ship.

```
sea s
1035/1035 [=====] - 75s 72ms/step - loss: 1.1550
Epoch 51/60
1033/1035 [=====>.] - ETA: 0s - loss: 1.1528*****
*****
```

```
----- Generating text after Epoch: 50
----- temperature: 0.2
----- Generating with seed: "s to you i am speaking."
```

```
still no rep"
s to you i am speaking."
```

```
i had the consigning and the captain. and, while i was a sudden the stockadd
le of the shoulder and the stockadds and the man with the deck, and the stoc
kad the stockaded the stockadds and the cabin went of the stockadds and the
first island had to the boat, and the stockad the thing was boat and the cab
in went of the was on th
----- temperature: 0.5
----- Generating with seed: "s to you i am speaking."
```

```
still no rep"
s to you i am speaking."
```

```
below it on
----- temperature: 1.0
----- Generating with seed: "s to you i am speaking."
```

```
still no rep"
s to you i am speaking."
```

```
long would near of the spring--refore might huddled;
----- temperature: 1.2
----- Generating with seed: "s to you i am speaking."
```

```
still no rep"
s to you i am speaking."
```

where coiving set my cea
 1035/1035 [=====] - 74s 72ms/step - loss: 1.1531
 Epoch 52/60
 1032/1035 [=====>.] - ETA: 0s - loss: 1.1513*****

----- Generating text after Epoch: 51
 ----- temperature: 0.2
 ----- Generating with seed: "n on
 deck.

"down, dog!" cried the ca"
 n on
 deck.

"ay, bet as i "us a sound me silver, you see," said the captain. "you have b
 een silver, i don't contrulbers, and then, hands, as so that i was a steet b
 efore the schept, and the more was the way was a stot; and the man with him,
 and the man with him and the stockade, and the captain should had a state to
 the parater of the corner of the words and the southeat and the captain and
 the capt
 ----- temperature: 0.5
 ----- Generating with seed: "n on
 deck.

"down, dog!" cried the ca"
 n on
 deck.

in the house; and i was not a man of fortune and the condivel for it was a b
 oyant saw the chart, which he was a
 ----- temperature: 1.0
 ----- Generating with seed: "n on
 deck.

"down, dog!" cried the ca"
 n on
 deck.

"over," said i. "it, you are, i feet here bering bally all whom had clast

----- temperature: 1.2
 ----- Generating with seed: "n on
 deck.

"down, dog!" cried the ca"
 n on
 deck.

blind man piped, a po
 1035/1035 [=====] - 74s 72ms/step - loss: 1.1512
 Epoch 53/60
 1032/1035 [=====>.] - ETA: 0s - loss: 1.1493*****

 ----- Generating text after Epoch: 52
 ----- temperature: 0.2
 ----- Generating with seed: "s stern to
 that much dollars for a booz"
 s stern to

"and then," said the doctor, "that's we were all the captain sit on the wors
 e, and i was desirity at the worst of the boats we were all han
 ----- temperature: 0.5
 ----- Generating with seed: "s stern to
 that much dollars for a booz"
 s stern to

```
"that's severy," said the captain, "i've the sound i could you she was d
----- temperature: 1.0
----- Generating with seed: "s stern to
that much dollars for a booz"
s stern to
```

```
tiller likeng about the most eyes under
----- temperature: 1.2
----- Generating with seed: "s stern to
that much dollars for a booz"
s stern to
```

```
up an
1035/1035 [=====] - 75s 72ms/step - loss: 1.1494
Epoch 54/60
1033/1035 [=====>.] - ETA: 0s - loss: 1.1460*****
*****
----- Generating text after Epoch: 53
----- temperature: 0.2
----- Generating with seed: "or tale of the island. it was plainly a "
```

```
"ay, by hank," said he, "i did you don't compliat you are a sea at the stock
ade, and the sure was a stiffle, and the sure that we were along the sure to
t
----- temperature: 0.5
----- Generating with seed: "or tale of the island. it was plainly a "
```

```
"the shipmast hands," said the capta
----- temperature: 1.0
----- Generating with seed: "or tale of the island. it was plainly a "
```


sand. after that we were running at a done; futiencely at the new a blud cal
led to a punting s

----- temperature: 1.2

----- Generating with seed: "or tale of the island. it was plainly a "

lowd asayalcreasing to p

1035/1035 [=====] - 75s 72ms/step - loss: 1.1459

Epoch 55/60

1031/1035 [=====>.] - ETA: 0s - loss: 1.1454*****

----- Generating text after Epoch: 54

----- temperature: 0.2

----- Generating with seed: "med to cool silver down. he had been
gr"

med to cool silver down. he had been

groanded the southers, and the blockhough began to see the blow on the corn
with the cabin six shore and the first the captain smollett. the captain sil
ver with the cabin and speaking, and the south and speaking, and the coracle
had been the blow out of the corn like a sudder of the boats were all the ca
ptain of the pork of the barraly the spines, and and the brought of the cora
cle and would be a st

----- temperature: 0.5

----- Generating with seed: "med to cool silver down. he had been
gr"

med to cool silver down. he had been

and the blein see so the portue course, and so much every man was breaking o
f the coracle of the gun bewwhere the pork and a little histers of the botto
m of the dead by a seaman, the first was a own barrow and consay of the cabi
n and repents, and good

----- temperature: 1.0

----- Generating with seed: "med to cool silver down. he had been
gr"

med to cool silver down. he had been

men the color as a remapigh of viin's-lrout blow, ginn's. you trisk you

----- temperature: 1.2

----- Generating with seed: "med to cool silver down. he had been

gr"
med to cool silver down. he had been

sometimes she comping his skicks aviled cerhalt burying, and he quickeded. hi
s has a hurrer--this etember what it lromoned. ning on how plushed earta
1035/1035 [=====] - 74s 72ms/step - loss: 1.1458
Epoch 56/60
1035/1035 [=====] - ETA: 0s - loss: 1.1423*****

----- Generating text after Epoch: 55
----- temperature: 0.2
----- Generating with seed: " ear.

when i came again to myself the"
ear.

when i came again to myself the stockade, and the blockholded man, and the s
ure is dead, and the stern was still the worst of the stockade, and the bloc
kholding of the blockhouse, and the stern was still the captain shout added
the same was the same beside the stockade of the same thing the spreadis and
the stern had been all the stockade and the stern we were all the sure of th
e same time, and the same had started the captain.
----- temperature: 0.5
----- Generating with seed: " ear.

when i came again to myself the"
ear.

"o, all to that!" i sawen so much ben gunn. now, it was the same who had set
my life, and the
----- temperature: 1.0
----- Generating with seed: " ear.

when i came again to myself the"
ear.

```

still father but he
----- temperature: 1.2
----- Generating with seed: " ear.

```

```

when i came again to myself the"
ear.

```

```

irons, i would spea
1035/1035 [=====] - 74s 71ms/step - loss: 1.1423
Epoch 57/60
1030/1035 [=====>.] - ETA: 0s - loss: 1.1395*****
*****

```

```

----- Generating text after Epoch: 56
----- temperature: 0.2
----- Generating with seed: " six men
was as though he had been stru"

```

```

    six men
was as though he had been struck the stockade and the stockade, and the supe
r, the stern was pulbers of the rock, and the same story and the stern was b
rought on the stockade, and we were alreading to the steep was a seamance an
d the stranger of the rest--not only the stockade, and the bladd of the stoc
kade and the stockade, and all the stern was brisk of the stockade, and the
same story and the captain should take the stockad

```

```

----- temperature: 0.5
----- Generating with seed: " six men
was as though he had been stru"
    six men

```

```

i do two blame in the other sid
----- temperature: 1.0
----- Generating with seed: " six men
was as though he had been stru"
    six men

```

```

did imagined, with you cumpang many. but pirated banger, so that thin
----- temperature: 1.2
----- Generating with seed: " six men
was as though he had been stru"
    six men

```

```
well's
1035/1035 [=====] - 74s 71ms/step - loss: 1.1398
Epoch 58/60
1028/1035 [=====>.] - ETA: 0s - loss: 1.1389*****
*****
```

```
----- Generating text after Epoch: 57
----- temperature: 0.2
----- Generating with seed: "able
humbug, i declare i think his cond"
able
```

```
"and i say. i say, you see," he said, "you see the captain, "i don't lay,
i'll get a thickol, and i say, you all thought i was star
----- temperature: 0.5
----- Generating with seed: "able
humbug, i declare i think his cond"
able
```

```
"and i should you say, been sich!" he rep
----- temperature: 1.0
----- Generating with seed: "able
humbug, i declare i think his cond"
able
```

a boupp

```
every man a reabsick, spangest, ever gentleman up to be liked, fity
----- temperature: 1.2
----- Generating with seed: "able
humbug, i declare i think his cond"
able
```

```
1035/1035 [=====] - 75s 72ms/step - loss: 1.1391
Epoch 59/60
1031/1035 [=====>.] - ETA: 0s - loss: 1.1362*****
*****
----- Generating text after Epoch: 58
----- temperature: 0.2
----- Generating with seed: "d the captain.

"well," said he, "my m"
d the captain.
```

```
"the was ben gunni
----- temperature: 0.5
----- Generating with seed: "d the captain.

"well," said he, "my m"
d the captain.
```

```
"the cook here, but there was not on the partiou, and we had b
----- temperature: 1.0
----- Generating with seed: "d the captain.

"well," said he, "my m"
d the captain.
```

```
"well," said he, "my mear water speaking, and the, you he had you!" come
```

```
"ho geor as carable for this," he crieded, "that were go to cut. he rose
----- temperature: 1.2
----- Generating with seed: "d the captain.

"well," said he, "my m"
d the captain.
```

```
"well," said he, "my matthuse and !"xpeum to suored, you-
```

```
speaking to carrious,  
1035/1035 [=====] - 74s 71ms/step - loss: 1.1361  
Epoch 60/60  
1029/1035 [=====>.] - ETA: 0s - loss: 1.1339*****  
*****  
----- Generating text after Epoch: 59  
----- temperature: 0.2  
----- Generating with seed: "  
tail of it on his unruly followers. th"
```

```
"it's a don't be men belief in my till be captain silver had been the blows  
and the stockade, and a man of the boats was place and the captain. he was a  
pairs and seemed to the barrows and the part, and i saw he was a state befor  
e the pirates of his s  
----- temperature: 0.5  
----- Generating with seed: "  
tail of it on his unruly followers. th"
```

```
----- temperature: 1.0  
----- Generating with seed: "  
tail of it on his unruly followers. th"
```

```
pl
----- temperature: 1.2
----- Generating with seed: "
tail of it on his unruly followers. th"
```

```
levor, as i could now shee ehe me so come kint and so so
1035/1035 [=====] - 74s 72ms/step - loss: 1.1339
```

Out[12]: <keras.callbacks.History at 0x7f79b2792a50>

In [12]:



T81-558: Applications of Deep Neural Networks

Module 10: Time Series in Keras

- Instructor: [Jeff Heaton](#), McKelvey School of Engineering, [Washington University in St. Louis](#)
- For more information visit the [class website](#).

Module 10 Material

- Part 10.1: Time Series Data Encoding for Deep Learning [\[Video\]](#) [\[Notebook\]](#)
- Part 10.2: Programming LSTM with Keras and TensorFlow [\[Video\]](#) [\[Notebook\]](#)
- Part 10.3: Text Generation with Keras and TensorFlow [\[Video\]](#) [\[Notebook\]](#)
- **Part 10.4: Introduction to Transformers** [\[Video\]](#) [\[Notebook\]](#)
- Part 10.5: Transformers for Timeseries [\[Video\]](#) [\[Notebook\]](#)

Google CoLab Instructions

The following code ensures that Google CoLab is running the correct version of TensorFlow. Running the following code will map your GDrive to `/content/drive`.

```
In [ ]: try:
        %tensorflow_version 2.x
        COLAB = True
        print("Note: using Google CoLab")
    except:
        print("Note: not using Google CoLab")
        COLAB = False
```

Note: not using Google CoLab

Part 10.4: Introduction to Transformers

Transformers are neural networks that provide state-of-the-art solutions for many of the problems previously assigned to recurrent neural networks.

[\[Cite:vaswani2017attention\]](#) Sequences can form both the input and the output of a neural network, examples of such configurations include::

- Vector to Sequence - Image captioning
- Sequence to Vector - Sentiment analysis
- Sequence to Sequence - Language translation

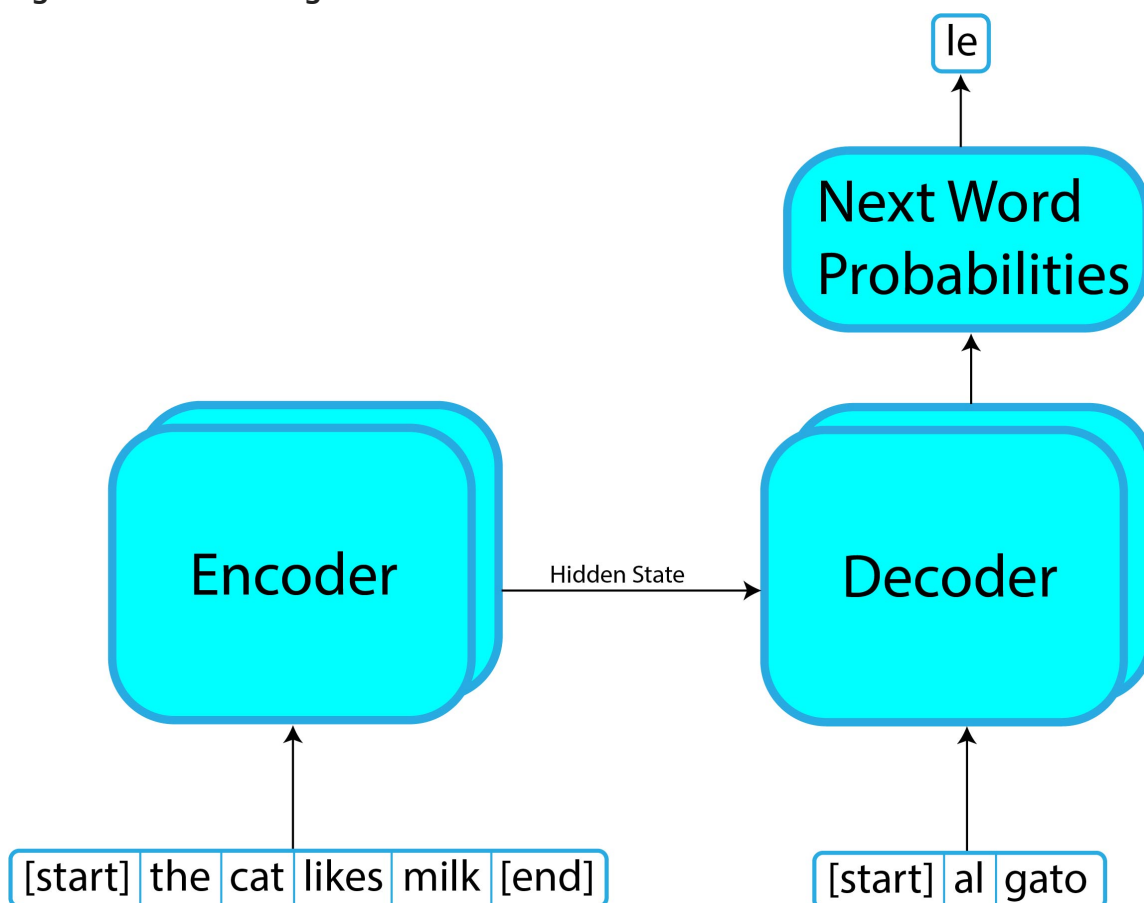
Sequence-to-sequence allows an input sequence to produce an output sequence based on an input sequence. Transformers focus primarily on this sequence-to-sequence configuration.

High-Level Overview of Transformers

This course focuses primarily on the application of deep neural networks. The focus will be on presenting data to a transformer and a transformer's major components. As a result, we will not focus on implementing a transformer at the lowest level. The following section provides an overview of critical internal parts of a transformer, such as residual connections and attention. In the next chapter, we will use transformers from [Hugging Face](#) to perform natural language processing with transformers. If you are interested in implementing a transformer from scratch, Keras provides a comprehensive [example](#).

Figure 10.TRANS-1 presents a high-level view of a transformer for language translation.

Figure 10.TRANS-1: High Level View of a Translation Transformer



We use a transformer that translates between English and Spanish for this example. We present the English sentence "the cat likes milk" and receive a Spanish translation of "al gato le gusta la leche."

We begin by placing the English source sentence between the beginning and ending tokens. This input can be of any length, and we presented it to the neural network as a ragged Tensor. Because the Tensor is ragged, no padding is necessary. Such input is acceptable for the attention layer that will receive the source sentence. The encoder transforms this ragged input into a hidden state containing a series of key-value pairs representing the knowledge in the source sentence. The encoder understands to read English and convert to a hidden state. The decoder understands how to output Spanish from this hidden state.

We initially present the decoder with the hidden state and the starting token. The decoder will predict the probabilities of all words in its vocabulary. The word with the highest probability is the first word of the sentence.

The highest probability word is attached concatenated to the translated sentence, initially containing only the beginning token. This process continues, growing the translated sentence in each iteration until the decoder predicts the ending token.

Transformer Hyperparameters

Before we describe how these layers fit together, we must consider the following transformer hyperparameters, along with default settings from the Keras transformer example:

- `num_layers` = 4
- `d_model` = 128
- `dff` = 512
- `num_heads` = 8
- `dropout_rate` = 0.1

Multiple encoder and decoder layers can be present. The **num_layers** hyperparameter specifies how many encoder and decoder layers there are. The expected tensor shape for the input to the encoder layer is the same as the output produced; as a result, you can easily stack these layers.

We will see embedding layers in the next chapter. However, you can think of an embedding layer as a dictionary for now. Each entry in the embedding corresponds to each word in a fixed-size vocabulary. Similar words should have similar vectors. The **d_model** hyperparameter specifies the size of the embedding vector. Though you will sometimes preload embeddings from a project such as [Word2vec](#) or [GloVe](#), the optimizer can train these embeddings with the rest of the transformer. Training your

embeddings allows the **d_model** hyperparameter to set to any desired value. If you transfer the embeddings, you must set the **d_model** hyperparameter to the same value as the transferred embeddings.

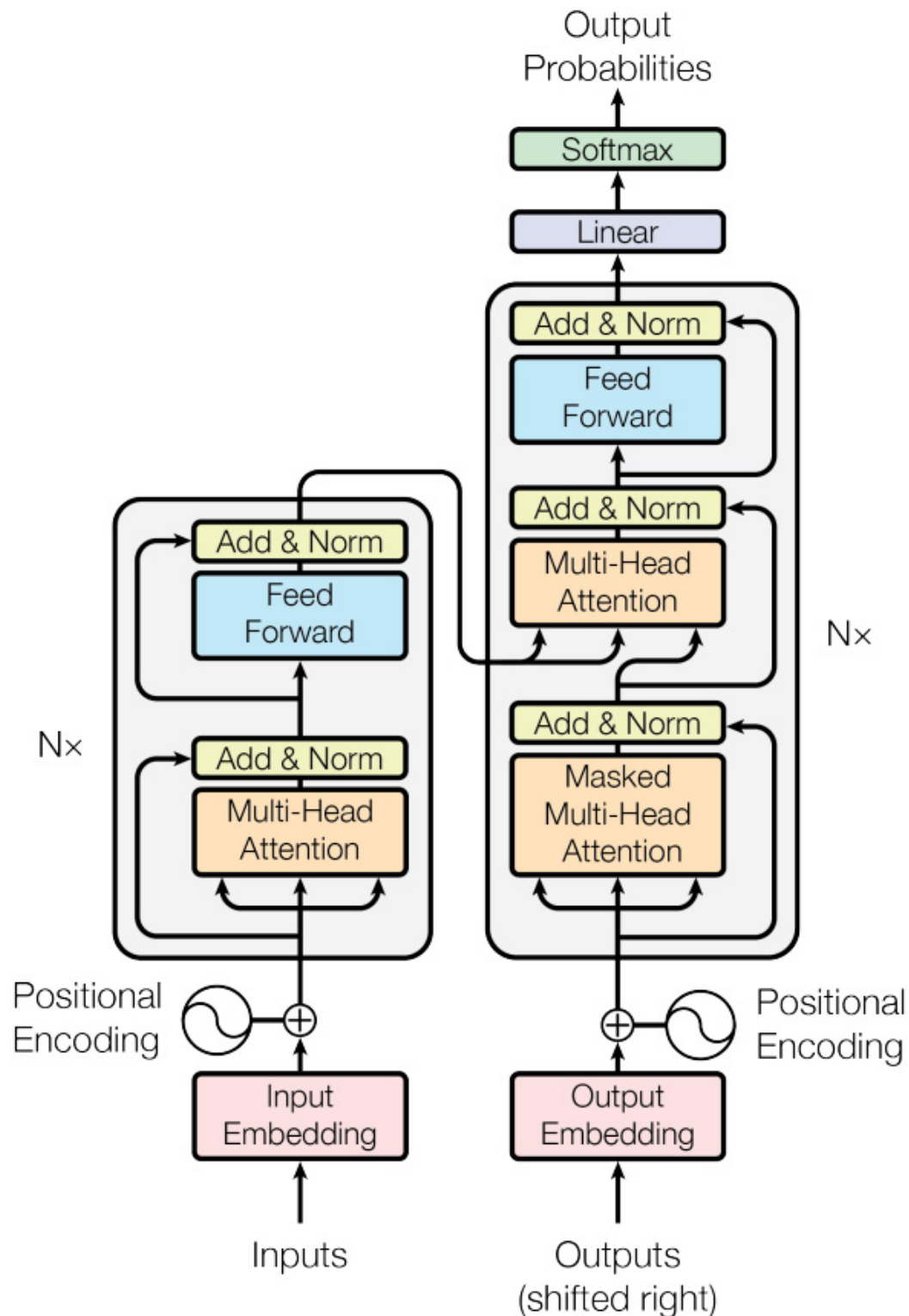
The **dff** hyperparameter specifies the size of the dense feedforward layers. The **num_heads** hyperparameter sets the number of attention layers heads. Finally, the **dropout_rate** specifies a dropout percentage to combat overfitting. We discussed dropout previously in this book.

Inside a Transformer

In this section, we will examine the internals of a transformer so that you become familiar with essential concepts such as:

- Embeddings
- Positional Encoding
- Attention and Self-Attention
- Residual Connection

You can see a lower-level diagram of a transformer in Figure 10.TRANS-2.

Figure 10.TRANS-2: Architectural Diagram from the Paper

While the original transformer paper is titled "Attention is All you Need," attention isn't the only layer type you need. The transformer also contains dense layers. However, the title "Attention and Dense Layers are All You Need" isn't as catchy.

The transformer begins by tokenizing the input English sentence. Tokens may or may not be words. Generally, familiar parts of words are tokenized and become building

blocks of longer words. This tokenization allows common suffixes and prefixes to be understood independently of their stem word. Each token becomes a numeric index that the transformer uses to look up the vector. There are several special tokens:

- Index 0 = Pad
- Index 1 = Unknow
- Index 2 = Start token
- Index 3 = End token

The transformer uses index 0 when we must pad unused space at the end of a tensor. Index 1 is for unknown words. The starting and ending tokens are provided by indexes 2 and 3.

The token vectors are simply the inputs to the attention layers; there is no implied order or position. The transformer adds the slopes of a sine and cosine wave to the token vectors to encode position.

Attention layers have three inputs: key (k), value(v), and query (q). This layer is self-attention if the query, key, and value are the same. The key and value pairs specify the information that the query operates upon. The attention layer learns what positions of data to focus upon.

The transformer presents the position encoded embedding vectors to the first self-attention segment in the encoder layer. The output from the attention is normalized and ultimately becomes the hidden state after all encoder layers are processed.

The hidden state is only calculated once per query. Once the input Spanish sentence becomes a hidden state, this value is presented repeatedly to the decoder until the decoder forms the final Spanish sentence.

This section presented a high-level introduction to transformers. In the next part, we will implement the encoder and apply it to time series. In the following chapter, we will use [Hugging Face](#) transformers to perform natural language processing.

In []:



T81-558: Applications of Deep Neural Networks

Module 10: Time Series in Keras

- Instructor: [Jeff Heaton](#), McKelvey School of Engineering, [Washington University in St. Louis](#)
- For more information visit the [class website](#).

Module 10 Material

- Part 10.1: Time Series Data Encoding for Deep Learning [\[Video\]](#) [\[Notebook\]](#)
- Part 10.2: Programming LSTM with Keras and TensorFlow [\[Video\]](#) [\[Notebook\]](#)
- Part 10.3: Text Generation with Keras and TensorFlow [\[Video\]](#) [\[Notebook\]](#)
- Part 10.4: Introduction to Transformers [\[Video\]](#) [\[Notebook\]](#)
- **Part 10.5: Transformers for Timeseries** [\[Video\]](#) [\[Notebook\]](#)

Google CoLab Instructions

The following code ensures that Google CoLab is running the correct version of TensorFlow. Running the following code will map your GDrive to `/content/drive`.

```
In [1]: try:
        from google.colab import drive
        drive.mount('/content/drive', force_remount=True)
        COLAB = True
        print("Note: using Google CoLab")
        %tensorflow_version 2.x
    except:
        print("Note: not using Google CoLab")
        COLAB = False
```

Mounted at /content/drive

Note: using Google CoLab

Part 10.5: Programming Transformers with Keras

This section shows an example of a transformer encoder to predict sunspots. You can find the data files needed for this example at the following location.

- [Sunspot Data Files](#)
- [Download Daily Sunspots](#) - 1/1/1818 to now.

The following code loads the sunspot file:

```
In [2]: import pandas as pd
import os

names = ['year', 'month', 'day', 'dec_year', 'sn_value',
         'sn_error', 'obs_num', 'extra']
df = pd.read_csv(
    "https://data.heatonresearch.com/data/t81-558/SN_d_tot_V2.0.csv",
    sep=';', header=None, names=names,
    na_values=['-1'], index_col=False)

print("Starting file:")
print(df[0:10])

print("Ending file:")
print(df[-10:])
```

Starting file:

	year	month	day	dec_year	sn_value	sn_error	obs_num	extra
0	1818	1	1	1818.001	-1	NaN	0	1
1	1818	1	2	1818.004	-1	NaN	0	1
2	1818	1	3	1818.007	-1	NaN	0	1
3	1818	1	4	1818.010	-1	NaN	0	1
4	1818	1	5	1818.012	-1	NaN	0	1
5	1818	1	6	1818.015	-1	NaN	0	1
6	1818	1	7	1818.018	-1	NaN	0	1
7	1818	1	8	1818.021	65	10.2	1	1
8	1818	1	9	1818.023	-1	NaN	0	1
9	1818	1	10	1818.026	-1	NaN	0	1

Ending file:

	year	month	day	dec_year	sn_value	sn_error	obs_num	extra
72855	2017	6	21	2017.470	35	1.0	41	0
72856	2017	6	22	2017.473	24	0.8	39	0
72857	2017	6	23	2017.475	23	0.9	40	0
72858	2017	6	24	2017.478	26	2.3	15	0
72859	2017	6	25	2017.481	17	1.0	18	0
72860	2017	6	26	2017.484	21	1.1	25	0
72861	2017	6	27	2017.486	19	1.2	36	0
72862	2017	6	28	2017.489	17	1.1	22	0
72863	2017	6	29	2017.492	12	0.5	25	0
72864	2017	6	30	2017.495	11	0.5	30	0

As you can see, there is quite a bit of missing data near the end of the file. We want to find the starting index where the missing data no longer occurs. This technique is somewhat sloppy; it would be better to find a use for the data between missing values.

However, the point of this example is to show how to use a transformer encoder with a somewhat simple time series.

```
In [3]: # Find the last zero and move one beyond
start_id = max(df[df['obs_num'] == 0].index.tolist())+1
print(start_id)
df = df[start_id:] # Trim the rows that have missing observations
```

11314

Divide into training and test/validation sets.

```
In [4]: df['sn_value'] = df['sn_value'].astype(float)
df_train = df[df['year'] < 2000]
df_test = df[df['year'] >= 2000]

spots_train = df_train['sn_value'].tolist()
spots_test = df_test['sn_value'].tolist()

print("Training set has {} observations.".format(len(spots_train)))
print("Test set has {} observations.".format(len(spots_test)))
```

Training set has 55160 observations.

Test set has 6391 observations.

The **to_sequences** function takes linear time series data into an **x** and **y** where **x** is all possible sequences of seq_size. After each **x** sequence, this function places the next value into the **y** variable. These **x** and **y** data can train a time-series neural network.

```
In [5]: import numpy as np

def to_sequences(seq_size, obs):
    x = []
    y = []

    for i in range(len(obs)-SEQUENCE_SIZE):
        #print(i)
        window = obs[i:(i+SEQUENCE_SIZE)]
        after_window = obs[i+SEQUENCE_SIZE]
        window = [[x] for x in window]
        #print("{} - {}".format(window, after_window))
        x.append(window)
        y.append(after_window)

    return np.array(x), np.array(y)

SEQUENCE_SIZE = 10
x_train, y_train = to_sequences(SEQUENCE_SIZE, spots_train)
x_test, y_test = to_sequences(SEQUENCE_SIZE, spots_test)

print("Shape of training set: {}".format(x_train.shape))
print("Shape of test set: {}".format(x_test.shape))
```


Shape of training set: (55150, 10, 1)

Shape of test set: (6381, 10, 1)

We can view the results of the **to_sequences** encoding of the sunspot data.

```
In [6]: print(x_train.shape)
```

```
(55150, 10, 1)
```

Next, we create the transformer_encoder; I obtained this function from a [Keras example](#). This layer includes residual connections, layer normalization, and dropout. This resulting layer can be stacked multiple times. We implement the projection layers with the Keras Conv1D.

```
In [7]: from tensorflow import keras
        from tensorflow.keras import layers

        def transformer_encoder(inputs, head_size, num_heads, ff_dim, dropout=0):
            # Normalization and Attention
            x = layers.LayerNormalization(epsilon=1e-6)(inputs)
            x = layers.MultiHeadAttention(
                key_dim=head_size, num_heads=num_heads, dropout=dropout
            )(x, x)
            x = layers.Dropout(dropout)(x)
            res = x + inputs

            # Feed Forward Part
            x = layers.LayerNormalization(epsilon=1e-6)(res)
            x = layers.Conv1D(filters=ff_dim, kernel_size=1, activation="relu")(x)
            x = layers.Dropout(dropout)(x)
            x = layers.Conv1D(filters=inputs.shape[-1], kernel_size=1)(x)
            return x + res
```

The following function is provided to build the model, including the attention layer.

```
In [8]: def build_model(
        input_shape,
        head_size,
        num_heads,
        ff_dim,
        num_transformer_blocks,
        mlp_units,
        dropout=0,
        mlp_dropout=0,
    ):
        inputs = keras.Input(shape=input_shape)
        x = inputs
        for _ in range(num_transformer_blocks):
            x = transformer_encoder(x, head_size, num_heads, ff_dim, dropout)

        x = layers.GlobalAveragePooling1D(data_format="channels_first")(x)
        for dim in mlp_units:
            x = layers.Dense(dim, activation="relu")(x)
            x = layers.Dropout(mlp_dropout)(x)
```

```
outputs = layers.Dense(1)(x)
return keras.Model(inputs, outputs)
```

We are now ready to build and train the model.

```
In [9]: input_shape = x_train.shape[1:]

model = build_model(
    input_shape,
    head_size=256,
    num_heads=4,
    ff_dim=4,
    num_transformer_blocks=4,
    mlp_units=[128],
    mlp_dropout=0.4,
    dropout=0.25,
)

model.compile(
    loss="mean_squared_error",
    optimizer=keras.optimizers.Adam(learning_rate=1e-4)
)
#model.summary()

callbacks = [keras.callbacks.EarlyStopping(patience=10, \
    restore_best_weights=True)]

model.fit(
    x_train,
    y_train,
    validation_split=0.2,
    epochs=200,
    batch_size=64,
    callbacks=callbacks,
)

model.evaluate(x_test, y_test, verbose=1)
```

```
Epoch 1/200
690/690 [=====] - 25s 16ms/step - loss: 1919.4844 -
val_loss: 463.2157
Epoch 2/200
690/690 [=====] - 11s 16ms/step - loss: 1113.0945 -
val_loss: 365.1375
Epoch 3/200
690/690 [=====] - 11s 16ms/step - loss: 873.6814 -
val_loss: 345.2026
Epoch 4/200
690/690 [=====] - 11s 16ms/step - loss: 789.0035 -
val_loss: 329.4594
Epoch 5/200
690/690 [=====] - 11s 15ms/step - loss: 762.3812 -
val_loss: 324.1521
Epoch 6/200
690/690 [=====] - 11s 15ms/step - loss: 750.8315 -
val_loss: 323.2135
Epoch 7/200
690/690 [=====] - 11s 15ms/step - loss: 744.6664 -
val_loss: 326.0743
Epoch 8/200
690/690 [=====] - 11s 15ms/step - loss: 737.4108 -
val_loss: 312.2708
Epoch 9/200
690/690 [=====] - 11s 15ms/step - loss: 719.6789 -
val_loss: 307.9902
Epoch 10/200
690/690 [=====] - 11s 16ms/step - loss: 715.9462 -
val_loss: 296.0132
Epoch 11/200
690/690 [=====] - 11s 15ms/step - loss: 712.4185 -
val_loss: 299.6908
Epoch 12/200
690/690 [=====] - 11s 15ms/step - loss: 709.5587 -
val_loss: 297.3573
Epoch 13/200
690/690 [=====] - 11s 16ms/step - loss: 703.4562 -
val_loss: 293.3137
Epoch 14/200
690/690 [=====] - 11s 15ms/step - loss: 714.5865 -
val_loss: 310.3690
Epoch 15/200
690/690 [=====] - 11s 15ms/step - loss: 706.6390 -
val_loss: 304.2530
Epoch 16/200
690/690 [=====] - 11s 15ms/step - loss: 701.1292 -
val_loss: 297.4577
Epoch 17/200
690/690 [=====] - 10s 15ms/step - loss: 705.1274 -
val_loss: 326.7051
Epoch 18/200
690/690 [=====] - 11s 15ms/step - loss: 696.4119 -
val_loss: 290.4462
Epoch 19/200
690/690 [=====] - 10s 15ms/step - loss: 701.0396 -
```

```
val_loss: 324.6311
Epoch 20/200
690/690 [=====] - 11s 17ms/step - loss: 694.8000 -
val_loss: 304.3717
Epoch 21/200
690/690 [=====] - 11s 16ms/step - loss: 697.7822 -
val_loss: 314.0597
Epoch 22/200
690/690 [=====] - 11s 15ms/step - loss: 696.5428 -
val_loss: 296.1778
Epoch 23/200
690/690 [=====] - 11s 16ms/step - loss: 688.9620 -
val_loss: 291.3384
Epoch 24/200
690/690 [=====] - 11s 15ms/step - loss: 692.5215 -
val_loss: 294.7356
Epoch 25/200
690/690 [=====] - 10s 15ms/step - loss: 695.5998 -
val_loss: 309.7605
Epoch 26/200
690/690 [=====] - 11s 16ms/step - loss: 688.1234 -
val_loss: 289.6525
Epoch 27/200
690/690 [=====] - 11s 16ms/step - loss: 680.7135 -
val_loss: 287.5633
Epoch 28/200
690/690 [=====] - 11s 15ms/step - loss: 689.2556 -
val_loss: 306.3144
Epoch 29/200
690/690 [=====] - 11s 15ms/step - loss: 686.9375 -
val_loss: 294.5692
Epoch 30/200
690/690 [=====] - 10s 15ms/step - loss: 689.2764 -
val_loss: 295.0640
Epoch 31/200
690/690 [=====] - 11s 15ms/step - loss: 683.3184 -
val_loss: 306.8054
Epoch 32/200
690/690 [=====] - 11s 16ms/step - loss: 679.1677 -
val_loss: 311.3470
Epoch 33/200
690/690 [=====] - 11s 15ms/step - loss: 683.5298 -
val_loss: 292.4295
Epoch 34/200
690/690 [=====] - 11s 15ms/step - loss: 689.2239 -
val_loss: 298.1823
Epoch 35/200
690/690 [=====] - 11s 15ms/step - loss: 682.8902 -
val_loss: 297.4239
Epoch 36/200
690/690 [=====] - 11s 15ms/step - loss: 679.1320 -
val_loss: 289.7046
Epoch 37/200
690/690 [=====] - 11s 16ms/step - loss: 673.3400 -
val_loss: 297.0687
200/200 [=====] - 1s 5ms/step - loss: 214.5603
```

Out[9]: 214.56031799316406

Finally, we evaluate the model with RMSE.

```
In [10]: from sklearn import metrics

pred = model.predict(x_test)
score = np.sqrt(metrics.mean_squared_error(pred,y_test))
print("Score (RMSE): {}".format(score))
```

Score (RMSE): 14.647875946283007