ECE 57000 Assignment 6 Exercise

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Objective: Build an RNN model to predict the next character in a sequence of text data from Shakespeare's plays.

Exercise 1: Data Preprocessing (30 points)

In this part, you will implement some preprocessing functions. Run the following code to load the text data from the given file "shakespeare.txt". Do not change the random seed.

In [1]:

```
import numpy as np
! pip install unidecode
import unidecode
import string
import time
import torch
import pdb

import torch.nn as nn
from torch.autograd import Variable

all_characters = string.printable
print(all_characters)
```

```
Collecting unidecode
  Downloading Unidecode-1.3.8-py3-none-any.whl (235 kB)
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Installing collected packages: unidecode
Successfully installed unidecode-1.3.8
0123456789abcdefghijklmnopqrstuvwxyzABCDEFGHIJKLMNOPQRSTUVWXYZ!"#$%&'()*+,-./:;<=>?@
[\]^_`{|}~
⍰
```

Follow the step on the instructions and mount your google drive on Colab which allows to access the .txt file uploaded on your drive that was included with this assignment.

In [2]:

```
from google.colab import drive
drive.mount('/content/drive')
```

```
Mounted at /content/drive
```

In [3]:

```
def read_file(filename):
    file = unidecode.unidecode(open(filename).read())
    return file

dir_root = '/content/drive/MyDrive/ECE 473/Assignment-6/Assignment-6'     # Your assig
file_path = dir_root + '/shakespeare.txt'
file = read_file(file_path)
file_len = len(file)
```

```
print(f"file length: {file_len}")
print(file[:100])
```

```
file length: 1115394
First Citizen:
Before we proceed any further, hear me speak.

All:
Speak, speak.

First Citizen:
You
```

Task 1: Implement function to get a random chunk of Shakespeare text (15 points)

The `get_random_chunk` function is a helper function that generates a random chunk of **input text data** and **output text data** (which is one character shifted from the input) from the Shakespeare dataset. Specifically, the `chunk_len` argument specifies the size of the input and output sequences. For example, if `chunk_len=4`, then a valid return value would be the two chunks: `('Befo','efor')` or `('proc','roce')`. This function is useful in generating diverse sets of input data for training the RNN model in the assignment.

Hints:

- Start from a random index of the file (but note that the max index must be small enough so that a full chunk can be extracted).
- Based on this random start index, extract `chunk_len` characters for the input sequence and `chunk_len` characters for the output sequence (shifted one character to the right).

In [5]:

```
def get_random_chunk(file, rng, chunk_len = 100):
    ######### Your Code Here ###########
    max = len(file) - chunk_len - 1
    start = rng.randint(0, max)

    first = file[start:start + chunk_len]
    sec = file[start + 1:start + chunk_len + 1]

    return first, sec
    ######### End of your code #########

rng = np.random.RandomState(123) # use this if you need to generate a random sample
curr_chunk, next_chunk = get_random_chunk(file='Hello world!', rng=rng, chunk_len=10)
print(f"curr_chunk =>{curr_chunk}\n next_chunk=> {next_chunk}")

print(f"Is curr_chunk and next_chunk same length: {len(curr_chunk) == len(next_chunk)}
print(f"Is next chunk shifted by one: {curr_chunk[1:] == next_chunk[:-1]}")
```

```
curr_chunk =>Hello worl
 next_chunk=> ello world
Is curr_chunk and next_chunk same length: True
Is next chunk shifted by one: True
```

Task 2: Implement function to convert to tensors (15 points)

Define a function `to_tensor(string)` that takes a string of characters as input and return torch tensor as output, similar to in the demo in class. Specifically,

1. Create an empty tensor of shape `(len(string), 1, len(all_characters))` using the PyTorch `torch.zeros` function, where `len(string)` is the length of the input string, 1 is the batch size, and `len(all_characters)` is the total number of unique characters in the text data.
2. Loop through each character in the input string and convert it to a one-hot encoded vector.

In [6]:

```
def to_tensor(string):
######### Your Code Here ###########
  new = torch.zeros(len(string), 1, len(all_characters))
  for i in range(len(string)):
    new[i][0][all_characters.find(string[i])] = 1
  return new
######### End of your code #########

def get_one_hot_tensors(input, output):
    return to_tensor(input), to_tensor(output)

rng = np.random.RandomState(123) # use this if you need to generate a random sample
input, output = get_random_chunk(file, rng,  50)
print(input.replace('\n', ' '))
print(output.replace('\n', ' '))
input_tensor, output_tensor = get_one_hot_tensors(input, output)
print(f"input shape: {input_tensor.shape}")
print(f"output shape: {output_tensor.shape}")
```

```
g's, which Florizel I now name to you; and with sp
's, which Florizel I now name to you; and with spe
input shape: torch.Size([50, 1, 100])
output shape: torch.Size([50, 1, 100])
```

Exercise 2: Build the RNN model (30 points)

In this part, you will build the RNN model using PyTorch.

- nn.GRU is used to implement the GRU algorithm for processing sequential input data.
    - https://pytorch.org/docs/stable/generated/torch.nn.GRU.html
- The decoder layer is a fully connected neural network layer that maps the output of the GRU layer to the desired output size.
- As we are only implementing a single layer RNN, the model is not powerful enough to learn long-term dependencies in the text data. So don't be surprised if the output sentences are not very meaningful. We are providing you loss plots (`gru_loss_ex2.png`) to help you check if your code is working correctly.

In [10]:

```
import torch
import torch.nn as nn
from torch.autograd import Variable

class RNN(nn.Module):
    def __init__(self, input_size, hidden_size, output_size, n_layers=1):
        super(RNN, self).__init__()

        self.input_size = input_size
        self.hidden_size = hidden_size
        self.output_size = output_size
        self.n_layers = n_layers

        # Define modules of RNN
        ######### Your Code Here ###########
        # Set `self.rnn_cell` to a nn.GRU
        self.rnn_cell = nn.GRU(input_size, hidden_size, n_layers)
        # Define a linear decoder layer that maps from the hidden size to the output s
        linear = nn.Linear(hidden_size, output_size)
        self.decoder = nn.Sequential(linear)
        ######### End of your code #########

    def forward(self, input, hidden):
        ######### Your Code Here ###########
        # 1. Reshape the input to (1, 1, -1) and pass it to the GRU layer
        # 2. Reshape the rnn_cell output to (1, -1) and pass it to the decoder layer
        output, hidden = self.rnn_cell(input.view(1, 1, -1), hidden)
        output = self.decoder(output.view(1, -1))


        ######### End of your code #########
        return output, hidden

    def init_hidden(self):
        return Variable(torch.zeros(self.n_layers, 1, self.hidden_size))
```

In [8]:

```
def train(inp, target, decoder):
    hidden = decoder.init_hidden()
    decoder.zero_grad()
    loss = 0

    input_tensor, target_tensor = get_one_hot_tensors(inp, target)
    for c in range(len(inp)):
        output, hidden = decoder(input_tensor[c], hidden)
        loss += criterion(output, torch.argmax(target_tensor[c]).unsqueeze(0))

    loss.backward()
    decoder_optimizer.step()
    return loss.item() / max_length
```

In [12]:

```
def evaluate(decoder, prime_str='A', predict_len=100, temperature=0.8):
    hidden = decoder.init_hidden()
    prime_input = to_tensor(prime_str)
    predicted = prime_str

    # Use priming string to "build up" hidden state
    for p in range(len(prime_str) - 1):
        out, hidden = decoder(prime_input[p], hidden)
    inp = prime_input[-1]
    for p in range(predict_len):
        output, hidden = decoder(inp, hidden)

        # Sample from the network as a multinomial distribution
        output_dist = output.data.view(-1).div(temperature).exp()
        top_i = torch.multinomial(output_dist, 1)[0]
        # Add predicted character to string and use as next input
        predicted_char = all_characters[top_i]
        predicted += predicted_char
        inp = to_tensor(predicted_char)

    return predicted
```

In [13]:

```
n_epochs = 2000
print_every = 100
plot_every = 10
hidden_size = 100
n_layers = 1
lr = 0.005
max_length = len(all_characters)

decoder = RNN(max_length, hidden_size, max_length)
decoder_optimizer = torch.optim.Adam(decoder.parameters(), lr=lr)
criterion = nn.CrossEntropyLoss()

start = time.time()
all_losses = []
loss_avg = 0
rng = np.random.RandomState(123) # use this if you need to generate a random sample

for epoch in range(1, n_epochs + 1):
    loss = train(*get_random_chunk(file, rng), decoder)
    loss_avg += loss

    if epoch % print_every == 0:
        print(f"[({epoch} {epoch / n_epochs * 100}%) {loss}]")
        print(evaluate(decoder, 'Wh', 100), '\n')

    if epoch % plot_every == 0:
        all_losses.append(loss_avg / plot_every)
        loss_avg = 0

print(f"______________________________________________________________")
print(evaluate(decoder, 'Th', 200, temperature=0.2))

import matplotlib.pyplot as plt
plt.plot(all_losses)
plt.title("GRU Loss: Loss vs Epoch")
plt.xlabel("Epoch")
plt.ylabel("Loss")
plt.show()
```

```
[(100 5.0%) 2.7766888427734373]
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e sarand ane hoov

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[(800 40.0%) 1.9939183044433593]
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GOLZOLIOS:
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GLOUCESTER:
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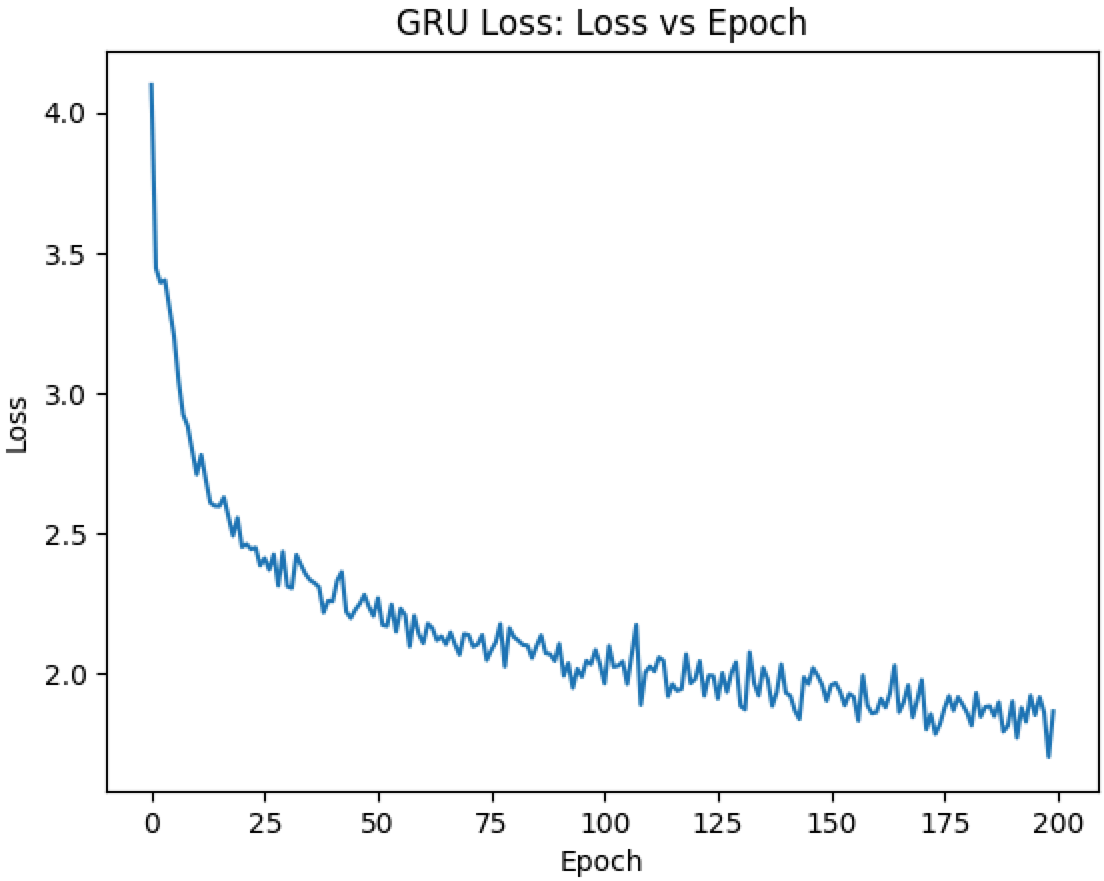

Exercise 3: Implement an LSTM model (30 points)

Using the equations from the slides in class, write your own LSTM cell module. The code below will use this instead of the GRU cell module and train the model.

Notes:

- Note that for LSTM the hidden state is really both the h_t and C_t so we just unpack the passed hidden state into these two variables at the beginning, and pack them into a tuple for returning.
- We apply a single linear layer to compute all the linear parts of the model that operate on h'_{t-1} and then unpack these using `chunk(4)` into the four separate parts. This is equivalent to having 4 separate linear layers.
- As we are only implementing a single layer RNN, the model is not powerful enough to learn long-term dependencies in the text data. So don't be surprised if the output sentences are not very meaningful. We are providing you loss plots (`lstm_loss_ex3.png`) to help you check if your code is working correctly.

In [15]:
```
class LSTMCell(nn.Module):
    def __init__(self, input_size, hidden_size, bias=True):
        super(LSTMCell, self).__init__()
        self.input_size = input_size
        self.hidden_size = hidden_size
        self.bias = bias

        self.xh = nn.Linear(input_size, hidden_size * 4, bias=bias)
        self.hh = nn.Linear(hidden_size, hidden_size * 4, bias=bias)
        self.reset_parameters()

    def reset_parameters(self):
        std = 1.0 / np.sqrt(self.hidden_size)
        for w in self.parameters():
            w.data.uniform_(-std, std)

    def forward(self, input, hidden=None):
        # Unpack hidden state and cell state
        hx, cx = hidden

        # Apply linear layers to input and hidden state
        linear = self.xh(input) + self.hh(hx)

        # Get outputs of applying a linear transform for each part of the LSTM
        input_linear, forget_linear, cell_linear, output_linear = linear.reshape(-1).c

        ######### Your Code Here ###########
        # 1. Apply activation functions to get gates and new cell state information
        # 2. Calculate the new cell state (c_new)
        # 3. Calculate the new hidden state (h_new)

        input = torch.sigmoid(input_linear)
        forget = torch.sigmoid(forget_linear)
        cell = torch.sigmoid(cell_linear)
        output = torch.sigmoid(output_linear)

        c_new = forget * cx + input * cell
        h_new = output * torch.tanh(c_new)
        ######### End of your code #########

        # Pack cell state $C_t$ and hidden state $h_t$ into a single hidden state tupl
        output = h_new # For LSTM the output is just the hidden state
        hidden = (h_new, c_new) # Packed h and C
        return output, hidden
```

In [17]:

```
lr = 0.001
class LSTM_RNN(RNN):
    def __init__(self, *args, **kwargs):
        super().__init__(*args, **kwargs)
        # Replace the gru cell with LSTM cell
        self.rnn_cell = LSTMCell(max_length, hidden_size, max_length)

    def init_hidden(self):
        # LSTM cells need two hidden variables in a tuple of (h_t,C_t)
        return (Variable(torch.zeros(1, 1, self.hidden_size)), Variable(torch.zeros(1,

decoder = LSTM_RNN(max_length, hidden_size, max_length)
decoder_optimizer = torch.optim.Adam(decoder.parameters(), lr=lr)

all_losses = []
loss_avg = 0
rng = np.random.RandomState(123) # use this if you need to generate a random sample
```

```
for epoch in range(1, n_epochs + 1):
    loss = train(*get_random_chunk(file, rng),decoder)
    loss_avg += loss

    if epoch % print_every == 0:
        print(f"[({epoch} {epoch / n_epochs * 100}%) {loss}]")
        print(evaluate(decoder, 'Wh', 100), '\n')

    if epoch % plot_every == 0:
        all_losses.append(loss_avg / plot_every)
        loss_avg = 0

print(f"______________________________________________________________")
print(evaluate(decoder, 'Th', 200, temperature=0.2))

plt.plot(all_losses)
plt.title("LSTM Loss: Loss vs Epoch")
plt.xlabel("Epoch")
plt.ylabel("Loss")
plt.show()
```

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[(1200 60.0%) 2.5171849060058595]
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[(1300 65.0%) 2.554895477294922]
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[(1400 70.0%) 2.563016662597656]
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[(1600 80.0%) 2.7027182006835937]
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[(1700 85.0%) 2.516194305419922]
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[(1900 95.0%) 2.382176513671875]
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[(2000 100.0%) 2.2701629638671874]
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______________________________________________________________
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```
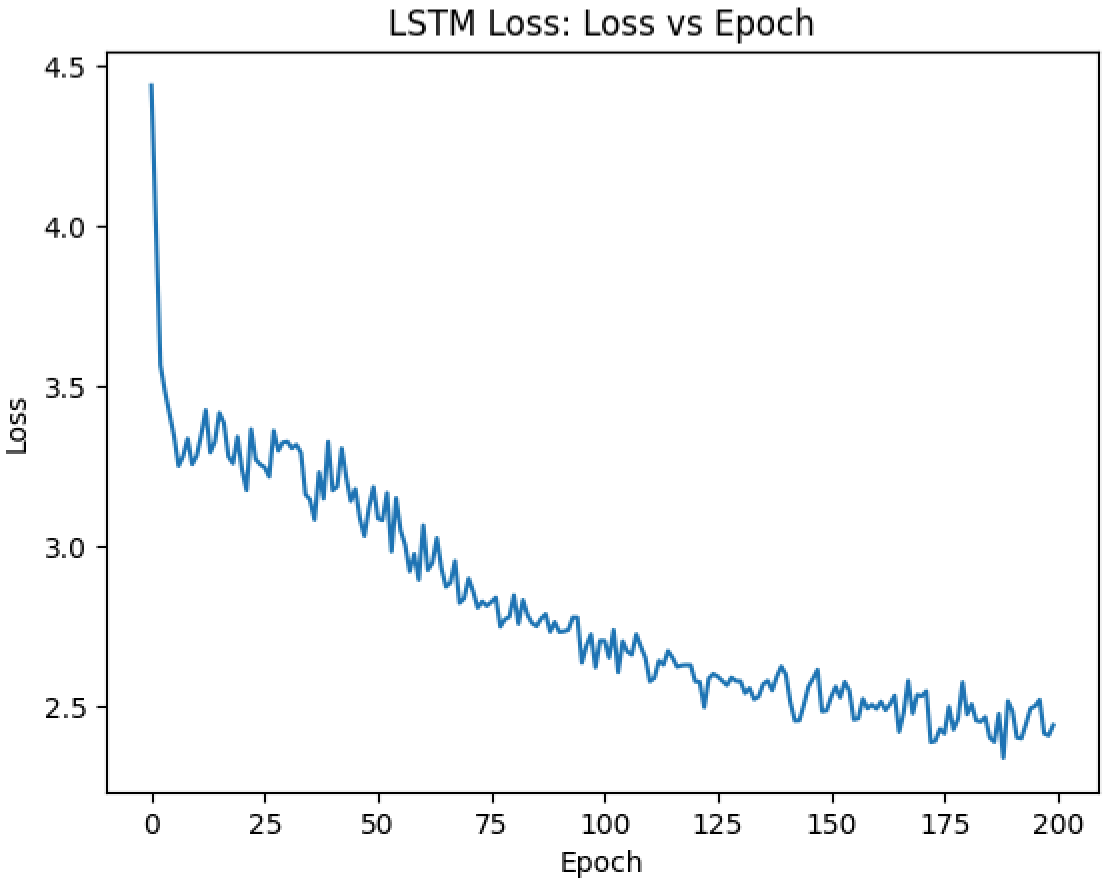



Exercise 4: Implement your own GRU (10 points)

Same as above but implement a GRU instead of an LSTM module. An exmaple of GRU architecture can be found from the lecture slide: https://www.davidinouye.com/course/ece57000-fall-2023/lectures/recurrent-neural-networks.pdf

You output loss plot should be similar in Exercise 2.

In [18]:
```
class GRUCell(nn.Module):
    def __init__(self, input_size, hidden_size, bias=True):
        super(GRUCell, self).__init__()
        self.input_size = input_size
        self.hidden_size = hidden_size
        self.bias = bias

        self.h2z = nn.Linear(input_size + hidden_size, hidden_size)
        self.h2r = nn.Linear(input_size + hidden_size, hidden_size)
        self.h2h = nn.Linear(input_size + hidden_size, hidden_size)
        self.reset_parameters()


    def reset_parameters(self):
        std = 1.0 / np.sqrt(self.hidden_size)
        for w in self.parameters():
            w.data.uniform_(-std, std)

    def forward(self, input, hx=None):
        # Inputs:
        #       input: of shape (batch_size, input_size)
        #       hx: of shape (batch_size, hidden_size)
        # Output:
        #       h_t, h_t: h_t is of shape (batch_size, hidden_size)

        if hx is None:
            hx = Variable(input.new_zeros(input.size(0), self.hidden_size))

        ######### Your Code Here ###########

        # Concatenate hidden and input to get h_prime (see torch.cat)
        combined = torch.cat((hx, input), 2)
        # Use self.h2z to calculate z_t
        z_t = torch.sigmoid(self.h2z(combined))
        # Use self.h2r to calculate r_t
        r_t = torch.sigmoid(self.h2r(combined))

        # Use Hadamard product of r_t and hx and concatenate with input
        # Then use h2h to calculate new hidden information h_tbar
        r_hx = r_t * hx
        combined_prime = torch.cat((r_hx, input), 2)
        h_t_bar = torch.tanh(self.h2h(combined_prime))
        # Update h_t with z_t, hx, and h_tbar
        h_t = (1 - z_t) * h_t_bar + z_t * hx

        ######### End of your code #########

        # Reshape h_t match input size
        h_t = h_t.reshape(1, 1, -1)

        return h_t, h_t   # Output and hidden are both h_t
```

In [19]:

```
n_epochs = 2000
print_every = 100
plot_every = 10
hidden_size = 100
n_layers = 1
lr = 0.005
max_length = len(all_characters)

# Replace the RNN module with your implemented GRUcell
class GRU_RNN(RNN):
    def __init__(self, *args, **kwargs):
        super().__init__(*args, **kwargs)
        # Replace wtih your gru cell
        self.rnn_cell = GRUCell(max_length, hidden_size, max_length)

decoder = GRU_RNN(max_length, hidden_size, max_length)
```

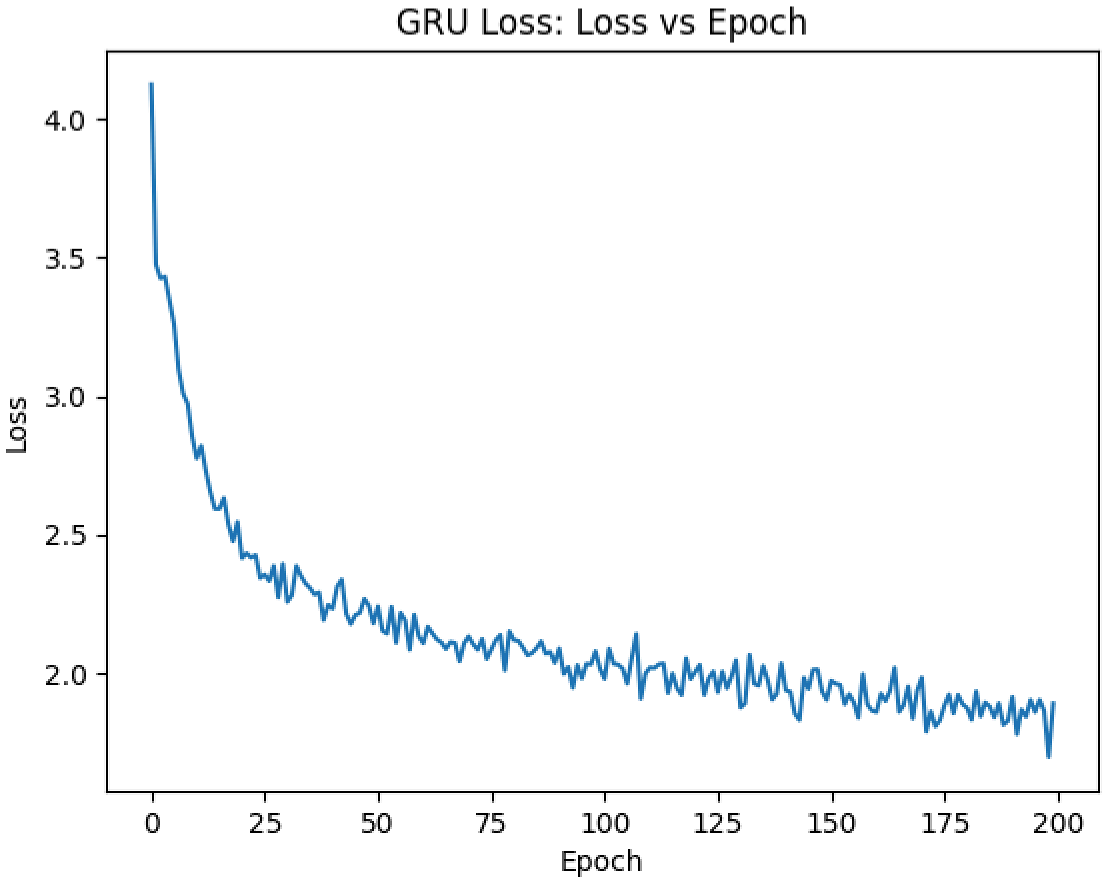
```
decoder_optimizer = torch.optim.Adam(decoder.parameters(), lr=lr)

all_losses = []
loss_avg = 0
rng = np.random.RandomState(123) # use this if you need to generate a random sample

for epoch in range(1, n_epochs + 1):
    loss = train(*get_random_chunk(file, rng),decoder)
    loss_avg += loss

    if epoch % print_every == 0:
        print(f"[({epoch} {epoch / n_epochs * 100}%) {loss}]")
        print(evaluate(decoder, 'Wh', 100), '\n')

    if epoch % plot_every == 0:
        all_losses.append(loss_avg / plot_every)
        loss_avg = 0

print(f"______________________________________________________________")
print(evaluate(decoder, 'Th', 200, temperature=0.2))

plt.plot(all_losses)
plt.title("GRU Loss: Loss vs Epoch")
plt.xlabel("Epoch")
plt.ylabel("Loss")
plt.show()
```

```
[(100 5.0%) 2.8400006103515625]
Whcciro sserd io ne, see cerdecsen rise esead msd ut re taet elsi yeut no b s jato ts
to toe dentneS,


[(200 10.0%) 2.4432923889160154]
Whit' sarl brefur mis polI to ree the by ard,
I yetsoe careace tind sour for war andeas foun Wove lbul

[(300 15.0%) 2.678175964355469]
Whee btiscy thilt taif hiul ao.

Wham and sinechrey whit thoud so blery thit bureofseringers shard ind

[(400 20.0%) 2.389241943359375]
Wh enpy air ohs sindirs
I telll waso mare thas.
Youcat co dear ant mene.

PLLO:
I ENELE:
ANUD:
Il RF J

[(500 25.0%) 2.155301055908203]
Whe der,
Shal thete cofmarter.

TAThARD IENO:
Shat hre't my our wis dowhers not we mo thy Emusg and at

[(600 30.0%) 2.112471923828125]
Whall
Be that ant dut us spate the to for me nerive by ding the laing I mive; the sord in a
nd vase the

[(700 35.0%) 2.149075622558594]
What: the morem for for os mestea lut so the sonost't hos our groon.

SSCAUELO:
Hed, bat of in top the

[(800 40.0%) 2.009592742919922]
Whry mlay ald beaken me extofer: in bove at thy ioo my marine;
Thare the heach matry for me tore an at

[(900 45.0%) 2.0608779907226564]
Why cald.
Why, wath what hos ward nty son stee cuven,
I me with in he land your of sseer Cinssnost
I m

[(1000 50.0%) 2.1425775146484374]
Wh on whow, wo thou senkenits wo al bead.

Clowd in wisred
Well wath dey sir that on
And apes be and '

[(1100 55.00000000000001%) 2.1849714660644532]
```

```
Whears this no dard,
To bey sorg a prown afowiog bued ancurg.
Our a, by that
I Pary yours santer, and

[(1200 60.0%) 1.9081629943847656]
Whone withse I shoust searchord?

KINl so lave fors to he weathery monisht of your fall;
The house her

[(1300 65.0%) 2.1849012756347657]
Whiss his an his our late are, fir:
To hour's live stall
Hor he will that sir lade
Ads ane you love hi

[(1400 70.0%) 1.9304212951660156]
Wharen to to now you sid.

MARIIO:
You gout if afesty ixtred but will fails.

KING LICKI:
Gof for a go

[(1500 75.0%) 1.9460189819335938]
Whop to the path is harg?

BENVISA:
And me the weltone how the seath she make ward
Hase with a mise wi

[(1600 80.0%) 2.0056607055664064]
When the pranione such thy sing and poong;
How, my brownots, and world Lace!

LLOED SCENRY OF
BROWES:


[(1700 85.0%) 1.8857994079589844]
Whith the pritous,
Whuss to my it trespeless.

Clerstand
Sempowing all but in came to the er; thou par

[(1800 90.0%) 2.135401306152344]
Wher me be the gradiom.

Lord:
For a so hong: me lend that not meents that your for that
The shourred.

[(1900 95.0%) 1.7817237854003907]
What hath be your farth;
To sir, Wime you masty for to moof him dishore
In comemed nike, le muse the s
```

```
[(2000 100.0%) 1.6379400634765624]
Whessed is our may the mare to a thank:
Amage, no my lay as as calence's lay?

First So to my lant
Ave
```

```
The son the shall the son the son and the lay so the son and the son and the son the
lard.

SICINIUS:
What shall the san and son the can and marries the dear the son and son and sent cent
er:
And the san
```


GRU Loss: Loss vs Epoch
Loss
Epoch