Capstone Project

Neural translation model

Instructions

In this notebook, you will create a neural network that translates from English to German. You will use concepts from throughout this course, including building more flexible model architectures, freezing layers, data processing pipeline and sequence modelling.

This project is peer-assessed. Within this notebook you will find instructions in each section for how to complete the project. Pay close attention to the instructions as the peer review will be carried out according to a grading rubric that checks key parts of the project instructions. Feel free to add extra cells into the notebook as required.

How to submit

When you have completed the Capstone project notebook, you will submit a pdf of the notebook for peer review. First ensure that the notebook has been fully executed from beginning to end, and all of the cell outputs are visible. This is important, as the grading rubric depends on the reviewer being able to view the outputs of your notebook. Save the notebook as a pdf (you could download the notebook with File -> Download .ipynb, open the notebook locally, and then File -> Download as -> PDF via LaTeX), and then submit this pdf for review.

Let's get started!

We'll start by running some imports, and loading the dataset. For this project you are free to make further imports throughout the notebook as you wish.

In [2]:

```
import tensorflow as tf
import tensorflow_hub as hub
import unicodedata
import re
from IPython.display import Image
```

For the capstone project, you will use a language dataset from http://www.manythings.org/anki/ to build a neural translation model. This dataset consists of over 200,000 pairs of sentences in English and German. In order to make the training quicker, we will restrict to our dataset to 20,000 pairs. Feel free to change this if you wish - the size of the dataset used is not part of the grading rubric.

Your goal is to develop a neural translation model from English to German, making use of a pre-trained English word embedding module.

Import the data

The dataset is available for download as a zip file at the following link:

https://drive.google.com/open?id=1KczOciG7sYY7SB9UlBeRP1T9659b121Q

You should store the unzipped folder in Drive for use in this Colab notebook.

In [3]:

```
# Run this cell to connect to your Drive folder

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

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

import os
path = '/content/drive/My Drive/INSAID/TensorFlow/Customizing your models with Tensorflow 2/Week5'
os.chdir(path)
```

```
os.listdir()
```

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

Out[3]:

```
['deu.txt',
 'english-german.pkl',
 'encoder.h5',
 'decoder.h5',
 'Capstone_Project.ipynb',
 'nmt_with_attention.ipynb',
 'machine_translation_tensorflow_orig.ipynb',
 'neural_translation_model.png']
```

In [4]:

```python
# Run this cell to load the dataset

NUM_EXAMPLES = 20000
data_examples = []
with open(os.path.join(path,'deu.txt'), 'r', encoding='utf8') as f:
    for line in f.readlines():
        if len(data_examples) < NUM_EXAMPLES:
            data_examples.append(line)
        else:
            break
```

In [5]:

```python
# These functions preprocess English and German sentences

def unicode_to_ascii(s):
    return ''.join(c for c in unicodedata.normalize('NFD', s) if unicodedata.category(c) != 'Mn')

def preprocess_sentence(sentence):
    sentence = sentence.lower().strip()
    sentence = re.sub(r"ü", 'ue', sentence)
    sentence = re.sub(r"ä", 'ae', sentence)
    sentence = re.sub(r"ö", 'oe', sentence)
    sentence = re.sub(r'ß', 'ss', sentence)

    sentence = unicode_to_ascii(sentence)
    sentence = re.sub(r"([?.!,])", r" \1 ", sentence)
    sentence = re.sub(r"[^a-z?.!,']+", " ", sentence)
    sentence = re.sub(r'[" "]+', " ", sentence)

    return sentence.strip()
```

The custom translation model

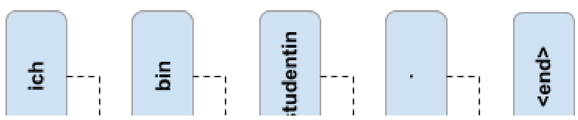
The following is a schematic of the custom translation model architecture you will develop in this project.

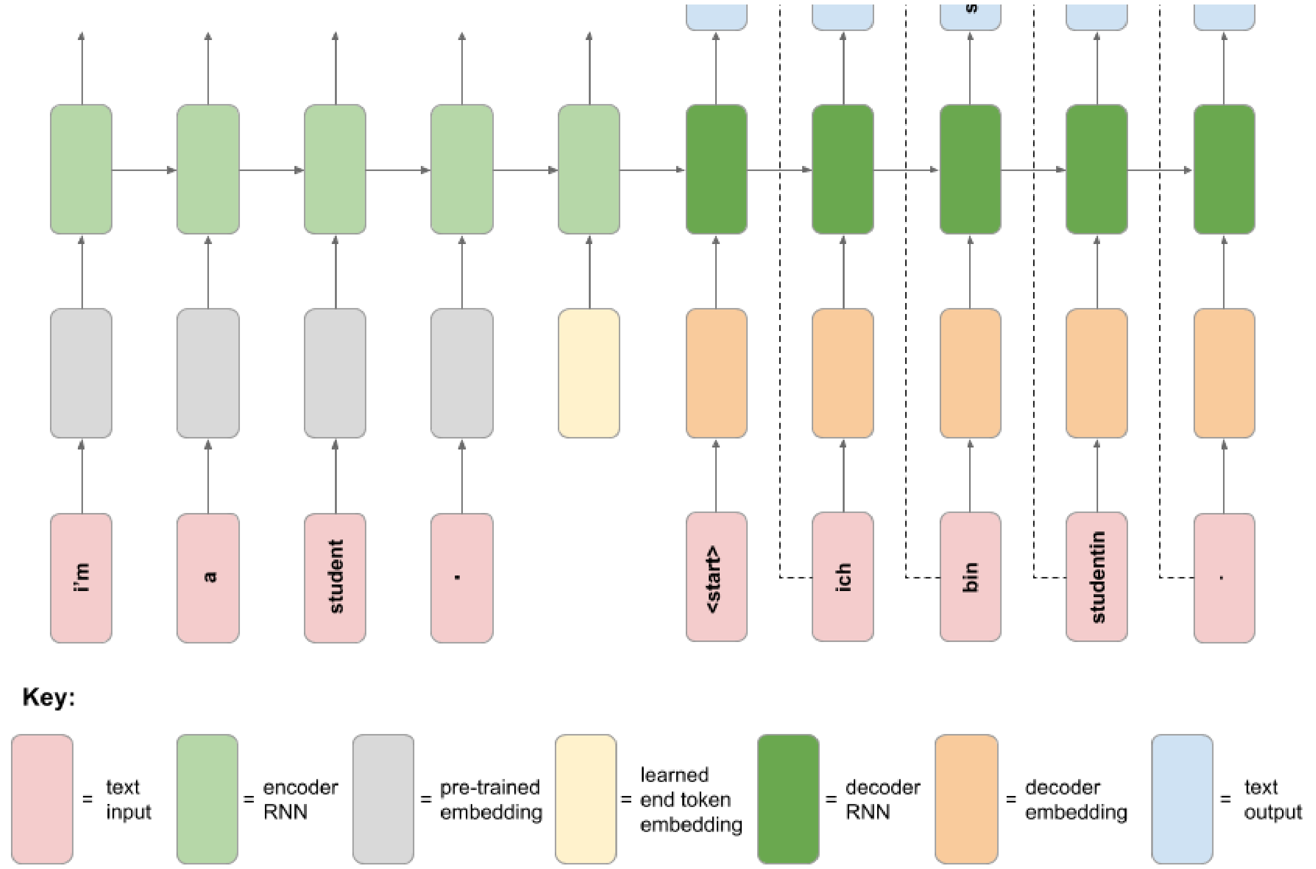
In [6]:

```python
# Run this cell to download and view a schematic diagram for the neural translation model

!wget -q -O neural_translation_model.png --no-check-certificate "https://docs.google.com/uc?export=down
load&id=1XsS1VlXoaEo-RbYNilJ9jcscNZvsSPmd"
Image("neural_translation_model.png")
```

Out[6]:





The custom model consists of an encoder RNN and a decoder RNN. The encoder takes words of an English sentence as input, and uses a pre-trained word embedding to embed the words into a 128-dimensional space. To indicate the end of the input sentence, a special end token (in the same 128-dimensional space) is passed in as an input. This token is a TensorFlow Variable that is learned in the training phase (unlike the pre-trained word embedding, which is frozen).

The decoder RNN takes the internal state of the encoder network as its initial state. A start token is passed in as the first input, which is embedded using a learned German word embedding. The decoder RNN then makes a prediction for the next German word, which during inference is then passed in as the following input, and this process is repeated until the special `<end>` token is emitted from the decoder.

1. Text preprocessing

- Create separate lists of English and German sentences, and preprocess them using the `preprocess_sentence` function provided for you above.
- Add a special `"<start>"` and `"<end>"` token to the beginning and end of every German sentence.
- Use the Tokenizer class from the `tf.keras.preprocessing.text` module to tokenize the German sentences, ensuring that no character filters are applied. *Hint: use the Tokenizer's "filter" keyword argument.*
- Print out at least 5 randomly chosen examples of (preprocessed) English and German sentence pairs. For the German sentence, print out the text (with start and end tokens) as well as the tokenized sequence.
- Pad the end of the tokenized German sequences with zeros, and batch the complete set of sequences into one numpy array.

In [7]:

```
# Inspect the first few data examples
data_examples[:5]
```

Out[7]:

```
['Hi.\tHallo!\tCC-BY 2.0 (France) Attribution: tatoeba.org #538123 (CM) & #380701 (cburgmer)\n',
 'Hi.\tGrüß Gott!\tCC-BY 2.0 (France) Attribution: tatoeba.org #538123 (CM) & #659813 (Esperantostern)\
n',
 'Run!\tLauf!\tCC-BY 2.0 (France) Attribution: tatoeba.org #906328 (papabear) & #941078 (Fingerhut)\n',
 'Wow!\tPotzdonner!\tCC-BY 2.0 (France) Attribution: tatoeba.org #52027 (Zifre) & #2122382 (Pfirsichbae
umchen)\n',
 'Wow!\tDonnerwetter!\tCC-BY 2.0 (France) Attribution: tatoeba.org #52027 (Zifre) & #2122391 (Pfirsichb
aeumchen)\n']
```

In [8]:

```
# Extract the English and the German sentences
english = [l.split("\t")[0] for l in data_examples]
german = [l.split("\t")[1] for l in data_examples]
```

In [9]:

```
# Preprocess the language datasets
import numpy as np

english = np.array([preprocess_sentence(s) for s in english])
german = np.array([preprocess_sentence(s) for s in german])
```

In [10]:

```
# Add start and end tokens
german = np.array(["<start> {} <end>".format(s) for s in german])
```

In [11]:

```
# Tokenize the German sequences
from tensorflow.keras.preprocessing.text import Tokenizer

german_tokenizer = Tokenizer(filters='')
german_tokenizer.fit_on_texts(german)
```

In [12]:

```
# Convert the German sentences to token sequences
tokenized_german_sequences = german_tokenizer.texts_to_sequences(german)
```

In [13]:

```
# Inspect a few examples of each
inx = np.random.choice(len(english), 5, replace=False)

for eng, ger in zip(english[inx], german[inx]):
    print(eng)
    print(ger)
    print(german_tokenizer.texts_to_sequences(ger.split()))
    print('')
```

```
i am out of work .
<start> ich bin arbeitslos . <end>
[[1], [4], [15], [2051], [3], [2]]

make it stop .
<start> mach , dass es aufhoert ! <end>
[[1], [79], [25], [132], [10], [2482], [9], [2]]

we miss you , too .
<start> wir vermissen dich auch . <end>
[[1], [17], [473], [28], [112], [3], [2]]

she helps us .
<start> sie hilft uns . <end>
[[1], [8], [545], [31], [3], [2]]

use your fist .
<start> nutze deine faust ! <end>
[[1], [1930], [117], [2557], [9], [2]]
```

In [14]:

```
# Pad the tokenized sequences with zeros
from tensorflow.keras.preprocessing.sequence import pad_sequences

padded_german_seq = pad_sequences(tokenized_german_sequences, padding="post")
```

In [15]:

```
# Get the number of tokens
num_german_tokens = max(german_tokenizer.index_word.keys()) + 1
print(num_german_tokens)
```

```
5744
```

2. Prepare the data

Load the embedding layer

As part of the dataset preproceessing for this project, you will use a pre-trained English word embedding module from TensorFlow Hub. The URL for the module is https://tfhub.dev/google/tf2-preview/nnlm-en-dim128-with-normalization/1.

This embedding takes a batch of text tokens in a 1-D tensor of strings as input. It then embeds the separate tokens into a 128-dimensional space.

The code to load and test the embedding layer is provided for you below.

NB: this model can also be used as a sentence embedding module. The module will process each token by removing punctuation and splitting on spaces. It then averages the word embeddings over a sentence to give a single embedding vector. However, we will use it only as a word embedding module, and will pass each word in the input sentence as a separate token.

In [16]:

```
# Load embedding module from Tensorflow Hub
embedding_layer = hub.KerasLayer("https://tfhub.dev/google/tf2-preview/nnlm-en-dim128/1",
                                 output_shape=[128], input_shape=[], dtype=tf.string)
```

In [17]:

```
# Test the layer
embedding_layer(tf.constant(["these", "aren't", "the", "droids", "you're", "looking", "for"])).shape
```

Out[17]:

```
TensorShape([7, 128])
```

You should now prepare the training and validation Datasets.

- Create a random training and validation set split of the data, reserving e.g. 20% of the data for validation (NB: each English dataset example is a single sentence string, and each German dataset example is a sequence of padded integer tokens).
- Load the training and validation sets into a tf.data.Dataset object, passing in a tuple of English and German data for both training and validation sets.
- Create a function to map over the datasets that splits each English sentence at spaces. Apply this function to both Dataset objects using the map method. *Hint: look at the tf.strings.split function.*
- Create a function to map over the datasets that embeds each sequence of English words using the loaded embedding layer/model. Apply this function to both Dataset objects using the map method.
- Create a function to filter out dataset examples where the English sentence is greater than or equal to than 13 (embedded) tokens in length. Apply this function to both Dataset objects using the filter method.
- Create a function to map over the datasets that pads each English sequence of embeddings with some distinct padding value before the sequence, so that each sequence is length 13. Apply this function to both Dataset objects using the map method. *Hint: look at the tf.pad function. You can extract a Tensor shape using tf.shape; you might also find the tf.math.maximum function useful.*

function useful.

- Batch both training and validation Datasets with a batch size of 16.
- Print the `element_spec` property for the training and validation Datasets.
- Using the Dataset `.take(1)` method, print the shape of the English data example from the training Dataset.
- Using the Dataset `.take(1)` method, print the German data example Tensor from the validation Dataset.

In [18]:

```
# Create training, test and validation splits
from random import shuffle
from sklearn.model_selection import train_test_split

english_train, english_valid, german_train, german_valid = train_test_split(english,
                                                                            padded_german_seq,
                                                                            test_size=0.2)
```

In [19]:

```
# Create a translation Dataset
eng_ger_train = tf.data.Dataset.from_tensor_slices((english_train, german_train))
eng_ger_valid = tf.data.Dataset.from_tensor_slices((english_valid, german_valid))
eng_ger_train.element_spec
```

Out[19]:

```
(TensorSpec(shape=(), dtype=tf.string, name=None),
 TensorSpec(shape=(14,), dtype=tf.int32, name=None))
```

In [20]:

```
# Split the English sentences at spaces
def split_at_spaces(eng, ger):
    return tf.strings.split(eng), ger

eng_ger_train = eng_ger_train.map(split_at_spaces)
eng_ger_valid = eng_ger_valid.map(split_at_spaces)
eng_ger_train.element_spec
```

Out[20]:

```
(TensorSpec(shape=(None,), dtype=tf.string, name=None),
 TensorSpec(shape=(14,), dtype=tf.int32, name=None))
```

In [21]:

```
# Get the embeddings for the English sentences
def get_embedding(eng, ger):
    return embedding_layer(eng), ger

eng_ger_train = eng_ger_train.map(get_embedding)
eng_ger_valid = eng_ger_valid.map(get_embedding)
eng_ger_train.element_spec
```

Out[21]:

```
(TensorSpec(shape=(None, 128), dtype=tf.float32, name=None),
 TensorSpec(shape=(14,), dtype=tf.int32, name=None))
```

In [22]:

```
# Filter out examples where the English sentence is longer than 13 tokens
max_english_sentence_len = 13

def filter_long_sentences(eng, ger):
    return tf.shape(eng)[0] <= max_english_sentence_len

eng_ger_train = eng_ger_train.filter(filter_long_sentences)
```

```
eng_ger_train = eng_ger_train.filter(filter_long_sentences)
eng_ger_valid = eng_ger_valid.filter(filter_long_sentences)
eng_ger_train.element_spec
```

Out[22]:

```
(TensorSpec(shape=(None, 128), dtype=tf.float32, name=None),
 TensorSpec(shape=(14,), dtype=tf.int32, name=None))
```

In [23]:

```
# Pad the English sentences
def pad_embedding_sequences(eng, ger):
    length_emb = tf.shape(eng)[0]
    padding = [[tf.math.maximum(0, max_english_sentence_len - length_emb), 0], [0, 0]]
    return tf.pad(eng, padding, 'CONSTANT', constant_values=-1000), ger

eng_ger_train = eng_ger_train.map(pad_embedding_sequences)
eng_ger_valid = eng_ger_valid.map(pad_embedding_sequences)
eng_ger_train.element_spec
```

Out[23]:

```
(TensorSpec(shape=(None, 128), dtype=tf.float32, name=None),
 TensorSpec(shape=(14,), dtype=tf.int32, name=None))
```

In [24]:

```
# Batch the Datasets
eng_ger_train = eng_ger_train.batch(16)
eng_ger_valid = eng_ger_valid.batch(16)
```

In [25]:

```
# Print the final training Dataset element_spec
eng_ger_train.element_spec
```

Out[25]:

```
(TensorSpec(shape=(None, None, 128), dtype=tf.float32, name=None),
 TensorSpec(shape=(None, 14), dtype=tf.int32, name=None))
```

In [26]:

```
# Print the shape of a batch of English data examples
for eng, ger in eng_ger_train.take(1):
    print(eng.shape)
```

```
(16, 13, 128)
```

In [27]:

```
# Print a batch of German data examples
for eng, ger in eng_ger_valid.take(1):
    print(ger)
```

```
tf.Tensor(
[[   1  763   17  381    7    2    0    0    0    0    0    0    0    0]
 [   1    5 4038   22   12    3    2    0    0    0    0    0    0    0]
 [   1    4 3434    3    2    0    0    0    0    0    0    0    0    0]
 [   1   10    6  625  401    3    2    0    0    0    0    0    0    0]
 [   1   11  152    6  611    3    2    0    0    0    0    0    0    0]
 [   1    4  918   10  141    3    2    0    0    0    0    0    0    0]
 [   1  406   53 1165    9    2    0    0    0    0    0    0    0    0]
```

```
 [   1  202 2485 1329   34    3    2    0    0    0    0    0    0    0]
 [   1    4   18   27   37 1368 4835    3    2    0    0    0    0    0]
 [   1    5  165 1735   20   54    3    2    0    0    0    0    0    0]
 [   1    5   16 2694    3    2    0    0    0    0    0    0    0    0]
 [   1    4   39   10  124  220    3    2    0    0    0    0    0    0]
 [   1    4   61  119    3    2    0    0    0    0    0    0    0    0]
 [   1    4   18   40 1593    3    2    0    0    0    0    0    0    0]
 [   1   14 5568  125    3    2    0    0    0    0    0    0    0    0]
 [   1   13  246  342   92    3    2    0    0    0    0    0    0    0]], shape=(16, 14), dtype=int32)
```

3. Create the custom layer

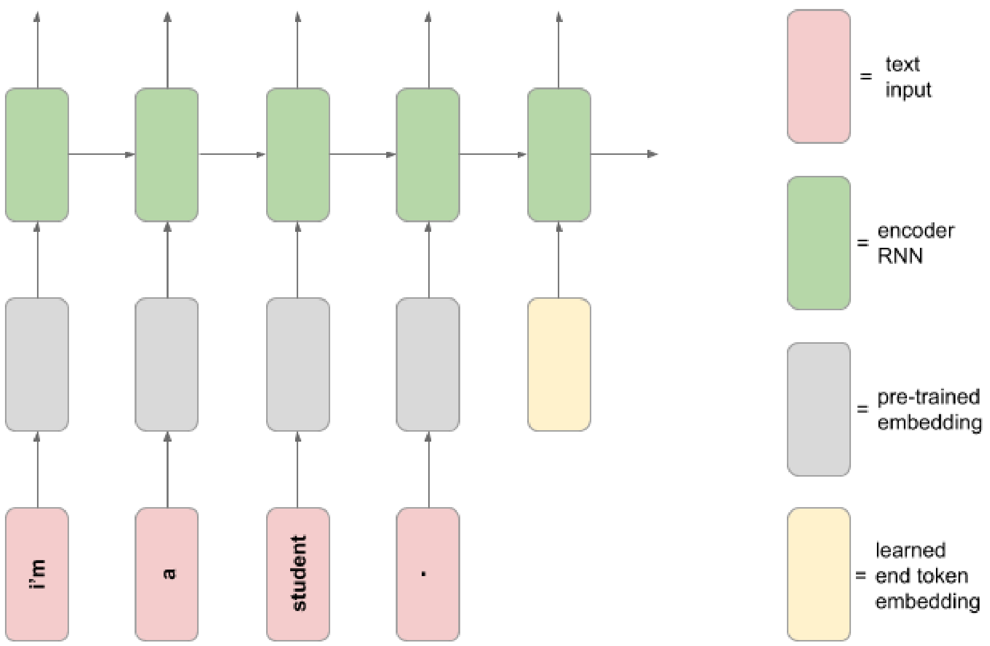
You will now create a custom layer to add the learned end token embedding to the encoder model:

In [28]:

```
# Run this cell to download and view a schematic diagram for the encoder model

!wget -q -O neural_translation_model.png --no-check-certificate "https://docs.google.com/uc?export=down
load&id=1JrtNOzUJDaOWrK4C-xv-4wUuZaI12sQI"
Image("neural_translation_model.png")
```

Out[28]:



You should now build the custom layer.

- Using layer subclassing, create a custom layer that takes a batch of English data examples from one of the Datasets, and adds a learned embedded 'end' token to the end of each sequence.
- This layer should create a TensorFlow Variable (that will be learned during training) that is 128-dimensional (the size of the embedding space). *Hint: you may find it helpful in the call method to use the tf.tile function to replicate the end token embedding across every element in the batch.*
- Using the Dataset `.take(1)` method, extract a batch of English data examples from the training Dataset and print the shape. Test the custom layer by calling the layer on the English data batch Tensor and print the resulting Tensor shape (the layer should increase the sequence length by one).

In [29]:

```
# Create the custom layer to add an end token embedding
class AddEndToken(tf.keras.layers.Layer):
    def __init__(self, **kwargs):
        super(AddEndToken, self).__init__(**kwargs)

    def build(self, input_shape):
        embedding_size = input_shape[-1]
```

```
        self.end_token = self.add_weight(shape=(1, embedding_size),
                                         initializer='random_normal',
                                         name='english_end_token')

    def call(self, inputs):
        batch_size = tf.shape(inputs)[0]
        token = tf.tile(tf.expand_dims(self.end_token, 0), [batch_size, 1, 1])
        return tf.concat([inputs, token], 1)
```

In [30]:

```
# Test the layer
add_end_token = AddEndToken()

for eng, ger in eng_ger_train.take(1):
    print(eng.shape)
    print(add_end_token(eng).shape)
```

```
(16, 13, 128)
(16, 14, 128)
```

In [30]:

```

```

4. Build the encoder network

The encoder network follows the schematic diagram above. You should now build the RNN encoder model.

- Using the functional API, build the encoder network according to the following spec:
  - The model will take a batch of sequences of embedded English words as input, as given by the Dataset objects.
  - The next layer in the encoder will be the custom layer you created previously, to add a learned end token embedding to the end of the English sequence.
  - This is followed by a Masking layer, with the `mask_value` set to the distinct padding value you used when you padded the English sequences with the Dataset preprocessing above.
  - The final layer is an LSTM layer with 512 units, which also returns the hidden and cell states.
  - The encoder is a multi-output model. There should be two output Tensors of this model: the hidden state and cell states of the LSTM layer. The output of the LSTM layer is unused.
- Using the Dataset `.take(1)` method, extract a batch of English data examples from the training Dataset and test the encoder model by calling it on the English data Tensor, and print the shape of the resulting Tensor outputs.
- Print the model summary for the encoder network.

In [31]:

```
# Build the encoder
from tensorflow.keras.models import Model
from tensorflow.keras.layers import Input, LSTM, Masking

def get_encoder():
    encoder_input = Input(shape=(None, 128))
    h = AddEndToken()(encoder_input)
    h = Masking(mask_value=-1000)(h)
    enc_output, enc_hidden, enc_cell = LSTM(512, return_state=True)(h)

    return Model(inputs=encoder_input, outputs=[enc_hidden, enc_cell])

encoder = get_encoder()
```

In [32]:

```
# Test the encoder
for eng, ger in eng_ger_train.take(1):
    print([t.shape for t in encoder(eng)])
```

```
[TensorShape([16, 512]), TensorShape([16, 512])]
```

In [33]:

```
# Print the encoder summary
encoder.summary()
```

```
Model: "functional_1"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
input_1 (InputLayer)         [(None, None, 128)]       0
_________________________________________________________________
add_end_token_1 (AddEndToken (None, None, 128)         128
_________________________________________________________________
masking (Masking)            (None, None, 128)         0
_________________________________________________________________
lstm (LSTM)                  [(None, 512), (None, 512) 1312768
=================================================================
Total params: 1,312,896
Trainable params: 1,312,896
Non-trainable params: 0
_________________________________________________________________
```

5. Build the decoder network

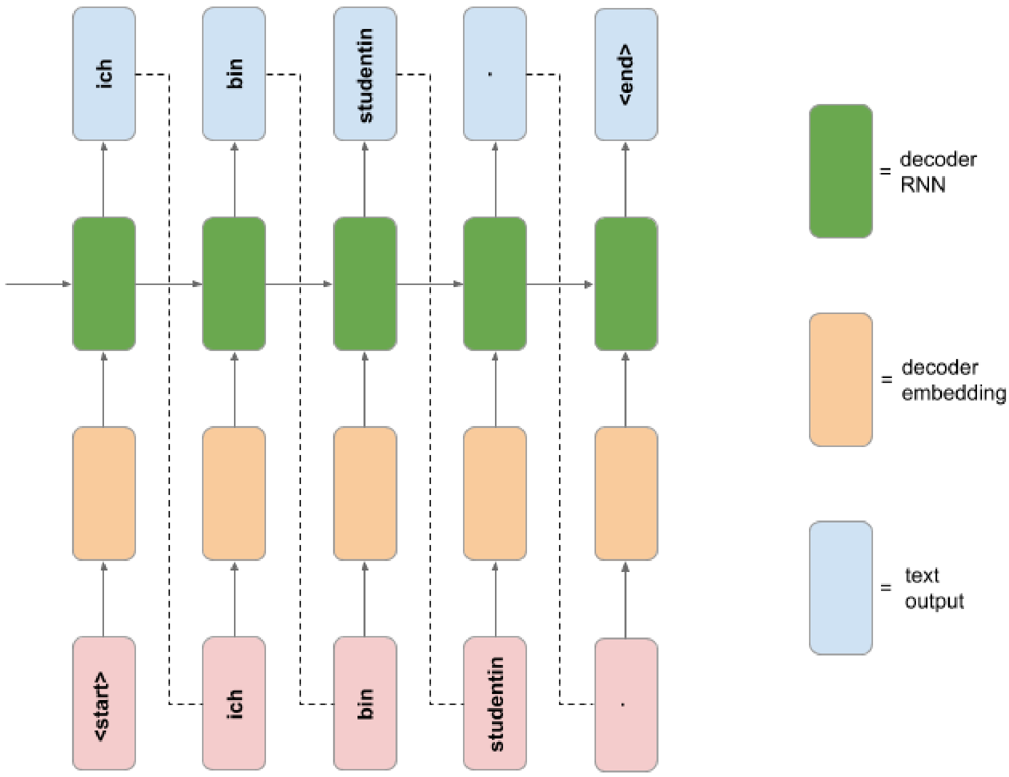
The decoder network follows the schematic diagram below.

In [34]:

```
# Run this cell to download and view a schematic diagram for the decoder model

!wget -q -O neural_translation_model.png --no-check-certificate "https://docs.google.com/uc?export=down
load&id=1DTeaXD8tA8RjkpVrB2mr9csSBOY4LQiW"
Image("neural_translation_model.png")
```

Out[34]:



You should now build the RNN decoder model.

- Using Model subclassing, build the decoder network according to the following spec:
  - The initializer should create the following layers:
    - An Embedding layer with vocabulary size set to the number of unique German tokens, embedding dimension 128, and set to mask zero values in the input.
    - An LSTM layer with 512 units, that returns its hidden and cell states, and also returns sequences.
    - A Dense layer with number of units equal to the number of unique German tokens, and no activation function.
  - The call method should include the usual `inputs` argument, as well as the additional keyword arguments `hidden_state` and `cell_state`. The default value for these keyword arguments should be `None`.
  - The call method should pass the inputs through the Embedding layer, and then through the LSTM layer. If the `hidden_state` and `cell_state` arguments are provided, these should be used for the initial state of the LSTM layer. *Hint: use the* `initial_state` *keyword argument when calling the LSTM layer on its input.*
  - The call method should pass the LSTM output sequence through the Dense layer, and return the resulting Tensor, along with the hidden and cell states of the LSTM layer.
- Using the Dataset `.take(1)` method, extract a batch of English and German data examples from the training Dataset. Test the decoder model by first calling the encoder model on the English data Tensor to get the hidden and cell states, and then call the decoder model on the German data Tensor and hidden and cell states, and print the shape of the resulting decoder Tensor outputs.
- Print the model summary for the decoder network.

In [35]:

```
# Build the decoder
from tensorflow.keras.layers import Dense, Embedding

class Decoder(Model):
    def __init__(self, **kwargs):
        super(Decoder, self).__init__(**kwargs)
        self.embedding = Embedding(num_german_tokens, 128, mask_zero=True)
        self.lstm = LSTM(512, return_state=True, return_sequences=True)
        self.dense = Dense(num_german_tokens)

    def call(self, inputs, hidden_state=None, cell_state=None, training=True):
        if hidden_state is None:
            assert cell_state is None
            h = self.embedding(inputs)
            o, h, c = self.lstm(h)
        else:
            h = self.embedding(inputs)
            o, h, c = self.lstm(h, initial_state=[hidden_state, cell_state])
        return self.dense(o), h, c

decoder = Decoder()
```

In [36]:

```
# Test the decoder
for eng, ger in eng_ger_train.take(1):
    hidden, cell = encoder(eng)
    print([t.shape for t in decoder(ger, hidden_state=hidden, cell_state=cell)])
```

```
[TensorShape([16, 14, 5744]), TensorShape([16, 512]), TensorShape([16, 512])]
```

In [37]:

```
# Print the decoder summary
decoder.summary()
```

```
Model: "decoder"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
embedding (Embedding)        multiple                  735232
_________________________________________________________________
lstm_1 (LSTM)                multiple                  1312768
```

```
dense (Dense)                multiple                  2946672
=================================================================
Total params: 4,994,672
Trainable params: 4,994,672
Non-trainable params: 0
_________________________________________________________________
```

6. Make a custom training loop

You should now write a custom training loop to train your custom neural translation model.

- Define a function that takes a Tensor batch of German data (as extracted from the training Dataset), and returns a tuple containing German inputs and outputs for the decoder model (refer to schematic diagram above).
- Define a function that computes the forward and backward pass for your translation model. This function should take an English input, German input and German output as arguments, and should do the following:
  - Pass the English input into the encoder, to get the hidden and cell states of the encoder LSTM.
  - These hidden and cell states are then passed into the decoder, along with the German inputs, which returns a sequence of outputs (the hidden and cell state outputs of the decoder LSTM are unused in this function).
  - The loss should then be computed between the decoder outputs and the German output function argument.
  - The function returns the loss and gradients with respect to the encoder and decoder's trainable variables.
  - Decorate the function with `@tf.function`
- Define and run a custom training loop for a number of epochs (for you to choose) that does the following:
  - Iterates through the training dataset, and creates decoder inputs and outputs from the German sequences.
  - Updates the parameters of the translation model using the gradients of the function above and an optimizer object.
  - Every epoch, compute the validation loss on a number of batches from the validation and save the epoch training and validation losses.
- Plot the learning curves for loss vs epoch for both training and validation sets.

Hint: This model is computationally demanding to train. The quality of the model or length of training is not a factor in the grading rubric. However, to obtain a better model we recommend using the GPU accelerator hardware on Colab.

In [38]:

```
# Define the loss function and optimizer
loss_fn = tf.keras.losses.SparseCategoricalCrossentropy(from_logits=True)
optimizer = tf.keras.optimizers.Adam()
```

In [39]:

```
# Function to create German tokens inputs and outputs
def get_german_inputs_outputs(ger_in):
    return ger_in[:, :-1], ger_in[:, 1:]
```

In [40]:

```
# Define the forward and backward pass
@tf.function
def get_loss_and_grads(eng_in, ger_in, ger_out):
    with tf.GradientTape() as tape:
        h, c = encoder(eng_in)
        outputs, _1, _2 = decoder(ger_in, hidden_state=h, cell_state=c)
        current_loss = loss_fn(ger_out, outputs)
        grads = tape.gradient(current_loss,
                              encoder.trainable_variables + decoder.trainable_variables)
    return current_loss, grads
```

In [41]:

```
# For evaluation
@tf.function
def get_loss(eng_in, ger_in, ger_out):
    h, c = encoder(eng_in)
    outputs, _1, _2 = decoder(ger_in, hidden_state=h, cell_state=c)
    return loss_fn(ger_out, outputs)
```

In [42]:

```
# Run the custom training loop
num_epochs = 8
num_valid_steps = 100

epoch_history = {
    'epoch': [],
    'loss': [],
    'val_loss': []
}
batch_history = {
    'iteration': [],
    'loss': []
}

for epoch in range(num_epochs):
    epoch_loss = tf.keras.metrics.Mean()

    for iteration, (eng, ger) in enumerate(eng_ger_train):
        ger_inputs, ger_outputs = get_german_inputs_outputs(ger)
        loss, grads = get_loss_and_grads(eng, ger_inputs, ger_outputs)
        epoch_loss(loss)
        print("Iteration {}, loss: {}".format(iteration, loss))
        if iteration % 10 == 0:
            batch_history['iteration'].append(iteration)
            batch_history['loss'].append(loss)
        optimizer.apply_gradients(zip(grads, encoder.trainable_variables + decoder.trainable_variables)
)
    print("End of epoch {}, loss: {}".format(epoch, epoch_loss.result() + 1))

    # Validation
    for (eng, ger) in eng_ger_valid.take(num_valid_steps):
        valid_loss = tf.keras.metrics.Mean()
        ger_inputs, ger_outputs = get_german_inputs_outputs(ger)
        valid_loss(get_loss(eng, ger_inputs, ger_outputs))
    print("Validation loss: {}".format(valid_loss.result()))

    epoch_history['epoch'].append(epoch)
    epoch_history['loss'].append(epoch_loss.result())
    epoch_history['val_loss'].append(valid_loss.result())
```

```
Iteration 146, loss: 2.8058855533599854
Iteration 147, loss: 2.7952470779418945
Iteration 148, loss: 2.9884378910064697
Iteration 149, loss: 2.950084686279297
Iteration 150, loss: 2.741946220397949
Iteration 151, loss: 2.887845754623413
Iteration 152, loss: 2.7155299186706543
Iteration 153, loss: 2.885842800140381
Iteration 154, loss: 2.812913656234741
Iteration 155, loss: 2.878556251525879
Iteration 156, loss: 2.9246485233306885
Iteration 157, loss: 2.775843620300293
Iteration 158, loss: 2.751404047012329
Iteration 159, loss: 2.5388360023498535
Iteration 160, loss: 2.8655099868774414
Iteration 161, loss: 2.964594841003418
Iteration 162, loss: 2.7003533840179443
Iteration 163, loss: 2.8629777431488037
Iteration 164, loss: 2.6988489627838135
Iteration 165, loss: 2.719658851623535
Iteration 166, loss: 2.761998414993286
Iteration 167, loss: 2.8764612674713135
Iteration 168, loss: 2.8896565437316895
Iteration 169, loss: 2.9137344360351562
Iteration 170, loss: 2.7605552673339844
Iteration 171, loss: 3.0624351501464844
Iteration 172, loss: 2.89264178276062
Iteration 173, loss: 2.909329652786255
Iteration 174, loss: 2.7756612300872803
Iteration 175, loss: 2.8397061824798584
Iteration 176, loss: 2.738278865814209
Iteration 177, loss: 2.8613011837005615
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Iteration 178, loss: 2.8184030055999756
Iteration 179, loss: 2.764652729034424
Iteration 180, loss: 2.7360410690307617
Iteration 181, loss: 2.9279191493988037
Iteration 182, loss: 2.662417411804199
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Iteration 184, loss: 2.823753833770752
Iteration 185, loss: 2.8803470134735107
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Iteration 188, loss: 2.770155668258667
Iteration 189, loss: 2.831960439682007
Iteration 190, loss: 2.7174527645111084
Iteration 191, loss: 2.7775731086730957
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Iteration 193, loss: 2.9516406059265137
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Iteration 200, loss: 2.8782551288604736
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Iteration 204, loss: 2.7651727199554443
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Iteration 254, loss: 2.7382092475891113
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Iteration 562, loss: 2.6070942878723145
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Iteration 639, loss: 2.4798777103424072
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Iteration 947, loss: 2.204312324523926
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End of epoch 3, loss: 3.567085027694702
Validation loss: 2.443629264831543
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Iteration 3, loss: 2.181905746459961
Iteration 4, loss: 2.156905174255371
Iteration 5, loss: 2.189368724822998
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Iteration 7, loss: 2.1189980506896973
Iteration 8, loss: 2.167840003967285
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Iteration 15, loss: 2.219418525695801
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Iteration 18, loss: 2.2959864139556885
Iteration 19, loss: 2.2147140502929688
Iteration 20, loss: 2.2737345695495605
Iteration 21, loss: 2.2330756187438965
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Iteration 22, loss: 2.2220215797424316
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Iteration 24, loss: 2.0518171787261963
Iteration 25, loss: 2.241594076156616
Iteration 26, loss: 2.292088508605957
Iteration 27, loss: 2.2811620235443115
Iteration 28, loss: 2.1809675693511963
Iteration 29, loss: 2.1543099880218506
Iteration 30, loss: 2.224841594696045
Iteration 31, loss: 2.083775043487549
Iteration 32, loss: 2.071556329727173
Iteration 33, loss: 2.3499794006347656
Iteration 34, loss: 2.2095377445220947
Iteration 35, loss: 2.120694637298584
Iteration 36, loss: 2.1846139430999756
Iteration 37, loss: 2.085258722305298
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Iteration 39, loss: 2.2094554901123047
Iteration 40, loss: 2.163623332977295
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Iteration 42, loss: 2.040458917617798
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Iteration 61, loss: 2.229891300201416
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Iteration 97, loss: 2.0717194080352783
Iteration 98, loss: 2.0973660945892334
Iteration 99, loss: 2.128282070159912
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Iteration 101, loss: 2.132812976837158
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Iteration 970, loss: 1.5829453468322754
Iteration 971, loss: 1.5106950998306274
Iteration 972, loss: 1.4775352478027344
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Iteration 975, loss: 1.4938172101974487
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Iteration 977, loss: 1.552668809890747
Iteration 978, loss: 1.4663116931915283
Iteration 979, loss: 1.4829108715057373
Iteration 980, loss: 1.4177342653274536
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Iteration 984, loss: 1.476143479347229
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Iteration 988, loss: 1.5015016794204712
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Iteration 991, loss: 1.5317720174789429
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Iteration 995, loss: 1.472898244857788
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Iteration 998, loss: 1.4540975093841553
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End of epoch 4, loss: 2.8222713470458984
Validation loss: 1.8756128549575806
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Iteration 1, loss: 1.4363118410110474
Iteration 2, loss: 1.4087754487991333
Iteration 3, loss: 1.4420262575149536
Iteration 4, loss: 1.482550859451294
Iteration 5, loss: 1.5007649660110474
Iteration 6, loss: 1.5038306713104248
Iteration 7, loss: 1.4295140504837036
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Iteration 9, loss: 1.4236963987350464
Iteration 10, loss: 1.4848933219909668
Iteration 11, loss: 1.512355089187622
Iteration 12, loss: 1.5288249254226685
Iteration 13, loss: 1.4739562273025513
Iteration 14, loss: 1.5672872066497803
Iteration 15, loss: 1.5133156776428223
Iteration 16, loss: 1.5366578102111816
Iteration 17, loss: 1.5183762311935425
Iteration 18, loss: 1.599089503288269
Iteration 19, loss: 1.5120564699172974
Iteration 20, loss: 1.548127293586731
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Iteration 23, loss: 1.3945943117141724
Iteration 24, loss: 1.3805819749832153
Iteration 25, loss: 1.537406086921692
Iteration 26, loss: 1.5544918775558472
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Iteration 97, loss: 1.3792216777801514
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Iteration 918, loss: 0.9814977049827576
Iteration 919, loss: 1.006693720817566
Iteration 920, loss: 0.9485213160514832
Iteration 921, loss: 0.9991140961647034
Iteration 922, loss: 0.973479688167572
Iteration 923, loss: 0.9836858510971069
Iteration 924, loss: 0.9822402596473694
Iteration 925, loss: 1.0495641231536865
Iteration 926, loss: 0.9680442810058594
Iteration 927, loss: 0.9582633972167969
Iteration 928, loss: 1.007190465927124
Iteration 929, loss: 0.83547043800354
Iteration 930, loss: 1.0606186389923096
Iteration 931, loss: 0.9660081267356873
Iteration 932, loss: 0.925424337387085
Iteration 933, loss: 0.9820288419723511
Iteration 934, loss: 1.0433297157287598
Iteration 935, loss: 0.9466943144798279
Iteration 936, loss: 0.9892946481704712
Iteration 937, loss: 0.9938830137252808
Iteration 938, loss: 0.9421875476837158
Iteration 939, loss: 1.0117024183273315
Iteration 940, loss: 0.9662874937057495
Iteration 941, loss: 0.9688053727149963
Iteration 942, loss: 0.9305317401885986
Iteration 943, loss: 1.0092110633850098
```

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Iteration 944, loss: 1.0608879327774048
Iteration 945, loss: 1.0059542655944824
Iteration 946, loss: 0.9651960730552673
Iteration 947, loss: 0.9539811015129089
Iteration 948, loss: 0.9463104605674744
Iteration 949, loss: 0.8627492189407349
Iteration 950, loss: 0.9553599953651428
Iteration 951, loss: 0.9486192464828491
Iteration 952, loss: 0.9403049945831299
Iteration 953, loss: 0.9425152540206909
Iteration 954, loss: 0.9703810214996338
Iteration 955, loss: 0.9836364388465881
Iteration 956, loss: 0.9511006474494934
Iteration 957, loss: 0.9630511999130249
Iteration 958, loss: 0.8860827088356018
Iteration 959, loss: 0.9539110660552979
Iteration 960, loss: 0.9940687417984009
Iteration 961, loss: 0.8565061092376709
Iteration 962, loss: 0.9694800972938538
Iteration 963, loss: 1.0459938049316406
Iteration 964, loss: 0.9500558376312256
Iteration 965, loss: 0.9824050068855286
Iteration 966, loss: 1.007138967514038
Iteration 967, loss: 0.9338066577911377
Iteration 968, loss: 0.9045533537864685
Iteration 969, loss: 0.9914922118186951
Iteration 970, loss: 1.0180631875991821
Iteration 971, loss: 0.9367100596427917
Iteration 972, loss: 0.9499215483665466
Iteration 973, loss: 0.9956591129302979
Iteration 974, loss: 0.9441712498664856
Iteration 975, loss: 0.9560216069221497
Iteration 976, loss: 0.9894440770149231
Iteration 977, loss: 0.9818942546844482
Iteration 978, loss: 0.9236741662025452
Iteration 979, loss: 0.9459839463233948
Iteration 980, loss: 0.864730715751648
Iteration 981, loss: 0.9284086227416992
Iteration 982, loss: 0.8822657465934753
Iteration 983, loss: 0.8922047019004822
Iteration 984, loss: 0.9243815541267395
Iteration 985, loss: 0.9781865477561951
Iteration 986, loss: 0.9680315256118774
Iteration 987, loss: 0.9671944975852966
Iteration 988, loss: 0.9228289723396301
Iteration 989, loss: 0.9196102619171143
Iteration 990, loss: 0.9619083404541016
Iteration 991, loss: 1.0114213228225708
Iteration 992, loss: 0.9738110303878784
Iteration 993, loss: 0.9120689630508423
Iteration 994, loss: 0.90351402759552
Iteration 995, loss: 0.9014826416969299
Iteration 996, loss: 0.9408146142959595
Iteration 997, loss: 1.1411586999893188
Iteration 998, loss: 0.9159939289093018
Iteration 999, loss: 0.8669404983520508
End of epoch 5, loss: 2.1984479427337646
Validation loss: 1.4300923347473145
Iteration 0, loss: 1.0218559503555298
Iteration 1, loss: 0.9072954654693604
Iteration 2, loss: 0.889885663986206
Iteration 3, loss: 0.8973697423934937
Iteration 4, loss: 0.962757408618927
Iteration 5, loss: 1.003585696220398
Iteration 6, loss: 0.9648170471191406
Iteration 7, loss: 0.8942257761955261
Iteration 8, loss: 0.9265689253807068
Iteration 9, loss: 0.8994598388671875
Iteration 10, loss: 0.9685699939727783
Iteration 11, loss: 0.9619287848472595
Iteration 12, loss: 1.0070717334747314
Iteration 13, loss: 0.9200350046157837
Iteration 14, loss: 1.0055615901947021
Iteration 15, loss: 0.9440730810165405
Iteration 16, loss: 0.9829254746437073
Iteration 17, loss: 0.9933240413665771
Iteration 18, loss: 1.0272390842437744
```

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Iteration 19, loss: 0.9790473580360413
Iteration 20, loss: 1.024342656135559
Iteration 21, loss: 1.0100280046463013
Iteration 22, loss: 0.9830559492111206
Iteration 23, loss: 0.8786798119544983
Iteration 24, loss: 0.8832809925079346
Iteration 25, loss: 1.0188575983047485
Iteration 26, loss: 1.024062156677246
Iteration 27, loss: 1.0134778022766113
Iteration 28, loss: 0.9288766384124756
Iteration 29, loss: 0.9520953297615051
Iteration 30, loss: 0.9542974829673767
Iteration 31, loss: 0.9148282408714294
Iteration 32, loss: 0.9214850068092346
Iteration 33, loss: 1.0167758464813232
Iteration 34, loss: 0.9834414124488831
Iteration 35, loss: 0.9154990315437317
Iteration 36, loss: 0.897251546382904
Iteration 37, loss: 0.8554385900497437
Iteration 38, loss: 0.9193137288093567
Iteration 39, loss: 0.9528558254241943
Iteration 40, loss: 0.9410148859024048
Iteration 41, loss: 1.0019587278366089
Iteration 42, loss: 0.8760501146316528
Iteration 43, loss: 0.9111246466636658
Iteration 44, loss: 0.8843404054641724
Iteration 45, loss: 1.0232337713241577
Iteration 46, loss: 0.9777405261993408
Iteration 47, loss: 0.9098526239395142
Iteration 48, loss: 0.9357474446296692
Iteration 49, loss: 0.9551281332969666
Iteration 50, loss: 0.9651819467544556
Iteration 51, loss: 0.9292752146720886
Iteration 52, loss: 0.921195924282074
Iteration 53, loss: 0.9435252547264099
Iteration 54, loss: 0.8728234767913818
Iteration 55, loss: 1.0499809980392456
Iteration 56, loss: 0.8203508853912354
Iteration 57, loss: 0.9703998565673828
Iteration 58, loss: 1.0189473628997803
Iteration 59, loss: 0.8647748231887817
Iteration 60, loss: 0.8718922138214111
Iteration 61, loss: 1.0282715559005737
Iteration 62, loss: 0.9866800904273987
Iteration 63, loss: 0.9342921376228333
Iteration 64, loss: 0.8812845945358276
Iteration 65, loss: 0.959103524684906
Iteration 66, loss: 0.8857120275497437
Iteration 67, loss: 0.9995700120925903
Iteration 68, loss: 0.9256178140640259
Iteration 69, loss: 0.9898574352264404
Iteration 70, loss: 0.8806710839271545
Iteration 71, loss: 0.9817469716072083
Iteration 72, loss: 0.9009026885032654
Iteration 73, loss: 0.8771053552627563
Iteration 74, loss: 1.0495879650115967
Iteration 75, loss: 0.910538375377655
Iteration 76, loss: 0.9076036214828491
Iteration 77, loss: 0.9393948316574097
Iteration 78, loss: 0.9744197130203247
Iteration 79, loss: 0.8230503797531128
Iteration 80, loss: 0.9033164978027344
Iteration 81, loss: 0.8981243371963501
Iteration 82, loss: 0.8834357857704163
Iteration 83, loss: 0.9389496445655823
Iteration 84, loss: 0.9297940135002136
Iteration 85, loss: 0.866331160068512
Iteration 86, loss: 0.9052814245223999
Iteration 87, loss: 0.9253038763999939
Iteration 88, loss: 0.9552360773086548
Iteration 89, loss: 0.8957363367080688
Iteration 90, loss: 0.9213762283325195
Iteration 91, loss: 0.964959979057312
Iteration 92, loss: 0.8412952423095703
Iteration 93, loss: 0.9718412160873413
Iteration 94, loss: 0.8923993706703186
Iteration 95, loss: 0.9320775270462036
```

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Iteration 96, loss: 0.8754532933235168
Iteration 97, loss: 0.8459824919700623
Iteration 98, loss: 0.9491638541221619
Iteration 99, loss: 0.9000946879386902
Iteration 100, loss: 0.8542159199714661
Iteration 101, loss: 0.8915119767189026
Iteration 102, loss: 0.8864759802818298
Iteration 103, loss: 0.8143819570541382
Iteration 104, loss: 1.002389669418335
Iteration 105, loss: 0.916386604309082
Iteration 106, loss: 0.9435262084007263
Iteration 107, loss: 0.8353556394577026
Iteration 108, loss: 0.8851874470710754
Iteration 109, loss: 1.022578477859497
Iteration 110, loss: 0.9594384431838989
Iteration 111, loss: 0.9755893349647522
Iteration 112, loss: 0.849632203578949
Iteration 113, loss: 0.9841350317001343
Iteration 114, loss: 0.8745803236961365
Iteration 115, loss: 0.9198826551437378
Iteration 116, loss: 1.0227468013763428
Iteration 117, loss: 0.9579765796661377
Iteration 118, loss: 0.927623987197876
Iteration 119, loss: 0.9014514088630676
Iteration 120, loss: 0.8557427525520325
Iteration 121, loss: 0.8305995464324951
Iteration 122, loss: 0.8607120513916016
Iteration 123, loss: 0.9177263975143433
Iteration 124, loss: 0.8770326375961304
Iteration 125, loss: 0.8800392746925354
Iteration 126, loss: 0.879586935043335
Iteration 127, loss: 0.842131495475769
Iteration 128, loss: 0.8657596111297607
Iteration 129, loss: 0.9327220320701599
Iteration 130, loss: 0.8382186889648438
Iteration 131, loss: 0.8800725340843201
Iteration 132, loss: 0.9313675165176392
Iteration 133, loss: 0.8372120261192322
Iteration 134, loss: 0.8849490284919739
Iteration 135, loss: 0.8319264650344849
Iteration 136, loss: 0.8309022188186646
Iteration 137, loss: 0.8278471231460571
Iteration 138, loss: 0.9034378528594971
Iteration 139, loss: 0.8830604553222656
Iteration 140, loss: 0.8267036080360413
Iteration 141, loss: 0.8912827372550964
Iteration 142, loss: 0.9639756679534912
Iteration 143, loss: 0.8459849953651428
Iteration 144, loss: 0.8278381824493408
Iteration 145, loss: 0.9027568101882935
Iteration 146, loss: 0.8138877153396606
Iteration 147, loss: 0.8994622826576233
Iteration 148, loss: 0.9521878957748413
Iteration 149, loss: 0.948165774345398
Iteration 150, loss: 0.825919508934021
Iteration 151, loss: 0.9141203761100769
Iteration 152, loss: 0.8403248190879822
Iteration 153, loss: 0.92961186170578
Iteration 154, loss: 0.9220077991485596
Iteration 155, loss: 0.9256978631019592
Iteration 156, loss: 0.9097658395767212
Iteration 157, loss: 0.8269466161727905
Iteration 158, loss: 0.7852127552032471
Iteration 159, loss: 0.7351556420326233
Iteration 160, loss: 0.9373709559440613
Iteration 161, loss: 0.8829022645950317
Iteration 162, loss: 0.8888434767723083
Iteration 163, loss: 0.882045328617096
Iteration 164, loss: 0.8350791335105896
Iteration 165, loss: 0.8553070425987244
Iteration 166, loss: 0.8679037094116211
Iteration 167, loss: 0.9166418313980103
Iteration 168, loss: 0.8434067368507385
Iteration 169, loss: 0.9282661080360413
Iteration 170, loss: 0.8502291440963745
Iteration 171, loss: 1.030239224433899
Iteration 172, loss: 0.9046831130981445
```

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Iteration 173, loss: 0.8558511734008789
Iteration 174, loss: 0.8481331467628479
Iteration 175, loss: 0.8635778427124023
Iteration 176, loss: 0.7575655579566956
Iteration 177, loss: 0.8058710098266602
Iteration 178, loss: 0.869042158126831
Iteration 179, loss: 0.7842137217521667
Iteration 180, loss: 0.8932709097862244
Iteration 181, loss: 0.9253327250480652
Iteration 182, loss: 0.8097310662269592
Iteration 183, loss: 0.8983021974563599
Iteration 184, loss: 0.8021138310432434
Iteration 185, loss: 0.8705583214759827
Iteration 186, loss: 0.8030154705047607
Iteration 187, loss: 0.9188892841339111
Iteration 188, loss: 0.8471412658691406
Iteration 189, loss: 0.9097527861595154
Iteration 190, loss: 0.8510033488273621
Iteration 191, loss: 0.8496848344802856
Iteration 192, loss: 0.8838393688201904
Iteration 193, loss: 0.9197355508804321
Iteration 194, loss: 0.8301395773887634
Iteration 195, loss: 0.8423118591308594
Iteration 196, loss: 0.9319328665733337
Iteration 197, loss: 0.8284026384353638
Iteration 198, loss: 0.8733347654342651
Iteration 199, loss: 0.7938292622566223
Iteration 200, loss: 0.8384371995925903
Iteration 201, loss: 0.8697353601455688
Iteration 202, loss: 0.8786749243736267
Iteration 203, loss: 0.8004320859909058
Iteration 204, loss: 0.8430666327476501
Iteration 205, loss: 0.9304803013801575
Iteration 206, loss: 0.9124780297279358
Iteration 207, loss: 0.8797286748886108
Iteration 208, loss: 0.8669863343238831
Iteration 209, loss: 0.7972903847694397
Iteration 210, loss: 0.8533755540847778
Iteration 211, loss: 0.9193031787872314
Iteration 212, loss: 0.9119314551353455
Iteration 213, loss: 0.8383331894874573
Iteration 214, loss: 0.9057743549346924
Iteration 215, loss: 0.799924910068512
Iteration 216, loss: 0.8311851024627686
Iteration 217, loss: 0.9053977131843567
Iteration 218, loss: 0.8461582660675049
Iteration 219, loss: 0.8327049016952515
Iteration 220, loss: 0.8389177918434143
Iteration 221, loss: 0.8519670963287354
Iteration 222, loss: 0.7870400547981262
Iteration 223, loss: 0.819198489189148
Iteration 224, loss: 0.9158393144607544
Iteration 225, loss: 0.982645571231842
Iteration 226, loss: 0.7698707580566406
Iteration 227, loss: 0.9211000204086304
Iteration 228, loss: 0.8516718149185181
Iteration 229, loss: 0.8753018975257874
Iteration 230, loss: 0.8160852193832397
Iteration 231, loss: 0.7740980386734009
Iteration 232, loss: 0.8211933970451355
Iteration 233, loss: 0.9024377465248108
Iteration 234, loss: 0.8059256076812744
Iteration 235, loss: 0.8345785737037659
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Iteration 237, loss: 0.8043502569198608
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Iteration 239, loss: 0.8186228275299072
Iteration 240, loss: 0.8060745000839233
Iteration 241, loss: 0.787233293056488
Iteration 242, loss: 0.9303598403930664
Iteration 243, loss: 0.8451740741729736
Iteration 244, loss: 0.7623157501220703
Iteration 245, loss: 0.720420777797699
Iteration 246, loss: 0.7508468627929688
Iteration 247, loss: 0.8174037933349609
Iteration 248, loss: 0.8054824471473694
Iteration 249, loss: 0.7605491876602173
```

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Iteration 250, loss: 0.8778208494186401
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Iteration 254, loss: 0.8474769592285156
Iteration 255, loss: 0.809559166431427
Iteration 256, loss: 0.9137589931488037
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Iteration 258, loss: 0.8727610111236572
Iteration 259, loss: 0.8257952332496643
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Iteration 261, loss: 0.841705322265625
Iteration 262, loss: 0.7750676274299622
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Iteration 265, loss: 0.8624306321144104
Iteration 266, loss: 0.8899823427200317
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Iteration 271, loss: 0.7898350954055786
Iteration 272, loss: 0.8895102739334106
Iteration 273, loss: 0.8389474153518677
Iteration 274, loss: 0.7612175345420837
Iteration 275, loss: 0.8445191979408264
Iteration 276, loss: 0.9233758449554443
Iteration 277, loss: 0.7417351603507996
Iteration 278, loss: 0.7735482454299927
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Iteration 286, loss: 0.95307856798172
Iteration 287, loss: 0.7950757741928101
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Iteration 292, loss: 0.8572565913200378
Iteration 293, loss: 0.7615233063697815
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Iteration 305, loss: 0.7208656072616577
Iteration 306, loss: 0.8698428273200989
Iteration 307, loss: 0.7811132669448853
Iteration 308, loss: 0.829380452632904
Iteration 309, loss: 0.8314145803451538
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Iteration 321, loss: 0.7442213892936707
Iteration 322, loss: 0.8028680086135864
Iteration 323, loss: 0.7452332973480225
Iteration 324, loss: 0.919165849685669
Iteration 325, loss: 0.780604362487793
Iteration 326, loss: 0.7862886190414429
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Iteration 326, loss: 0.7[illegible]
Iteration 327, loss: 0.7037765979766846
Iteration 328, loss: 0.7629006505012512
Iteration 329, loss: 0.8739849328994751
Iteration 330, loss: 0.8015835285186768
Iteration 331, loss: 0.818517804145813
Iteration 332, loss: 0.7004196643829346
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Iteration 334, loss: 0.7806278467178345
Iteration 335, loss: 0.8060370087623596
Iteration 336, loss: 0.8116986155509949
Iteration 337, loss: 0.8363903760910034
Iteration 338, loss: 0.8230047821998596
Iteration 339, loss: 0.8685699701309204
Iteration 340, loss: 0.7926853895187378
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Iteration 347, loss: 0.8310299515724182
Iteration 348, loss: 0.7820034027099609
Iteration 349, loss: 0.7644932866096497
Iteration 350, loss: 0.7136849164962769
Iteration 351, loss: 0.7896157503128052
Iteration 352, loss: 0.89383864402771
Iteration 353, loss: 0.8264636993408203
Iteration 354, loss: 0.8411709070205688
Iteration 355, loss: 0.7507946491241455
Iteration 356, loss: 0.822133481502533
Iteration 357, loss: 0.8634814023971558
Iteration 358, loss: 0.7303842902183533
Iteration 359, loss: 0.8222361207008362
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Iteration 361, loss: 0.7994983196258545
Iteration 362, loss: 0.8351473212242126
Iteration 363, loss: 0.696782112121582
Iteration 364, loss: 0.7027661204338074
Iteration 365, loss: 0.8460829257965088
Iteration 366, loss: 0.8240472078323364
Iteration 367, loss: 0.7513972520828247
Iteration 368, loss: 0.8548148274421692
Iteration 369, loss: 0.7602236270904541
Iteration 370, loss: 0.7484174966812134
Iteration 371, loss: 0.7359906435012817
Iteration 372, loss: 0.7702592015266418
Iteration 373, loss: 0.669430673122406
Iteration 374, loss: 0.7529183626174927
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Iteration 376, loss: 0.7562160491943359
Iteration 377, loss: 0.7294586896896362
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Iteration 380, loss: 0.8391824960708618
Iteration 381, loss: 0.7955535054206848
Iteration 382, loss: 0.8178874254226685
Iteration 383, loss: 0.7696306705474854
Iteration 384, loss: 0.7320446372032166
Iteration 385, loss: 0.8937121033668518
Iteration 386, loss: 0.8273982405662537
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Iteration 856, loss: 0.6255158185958862
Iteration 857, loss: 0.7361761927604675
Iteration 858, loss: 0.701903223991394
Iteration 859, loss: 0.6347763538360596
Iteration 860, loss: 0.6859128475189209
Iteration 861, loss: 0.6604819893836975
Iteration 862, loss: 0.6440842747688293
Iteration 863, loss: 0.675784170627594
Iteration 864, loss: 0.6253531575202942
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Iteration 865, loss: 0.6790532469749451
Iteration 866, loss: 0.6416808366775513
Iteration 867, loss: 0.6449558734893799
Iteration 868, loss: 0.6430408954620361
Iteration 869, loss: 0.5700759887695312
Iteration 870, loss: 0.6220682859420776
Iteration 871, loss: 0.6491774320602417
Iteration 872, loss: 0.6462789177894592
Iteration 873, loss: 0.6562796235084534
Iteration 874, loss: 0.6651768088340759
Iteration 875, loss: 0.6118944883346558
Iteration 876, loss: 0.5898662209510803
Iteration 877, loss: 0.5816580057144165
Iteration 878, loss: 0.7585504055023193
Iteration 879, loss: 0.6145409941673279
Iteration 880, loss: 0.6046310663223267
Iteration 881, loss: 0.6427987217903137
Iteration 882, loss: 0.5953057408332825
Iteration 883, loss: 0.6020224094390869
Iteration 884, loss: 0.6382684707641602
Iteration 885, loss: 0.6528434157371521
Iteration 886, loss: 0.6656027436256409
Iteration 887, loss: 0.6259041428565979
Iteration 888, loss: 0.5931633114814758
Iteration 889, loss: 0.6199208498001099
Iteration 890, loss: 0.6520683765411377
Iteration 891, loss: 0.6644653081893921
Iteration 892, loss: 0.6152803897857666
Iteration 893, loss: 0.6250174641609192
Iteration 894, loss: 0.6879395842552185
Iteration 895, loss: 0.6113541722297668
Iteration 896, loss: 0.6033629775047302
Iteration 897, loss: 0.6183633208274841
Iteration 898, loss: 0.6465592980384827
Iteration 899, loss: 0.5855289101600647
Iteration 900, loss: 0.6604378819465637
Iteration 901, loss: 0.6159229278564453
Iteration 902, loss: 0.5990491509437561
Iteration 903, loss: 0.5478845834732056
Iteration 904, loss: 0.6429821848869324
Iteration 905, loss: 0.6718733906745911
Iteration 906, loss: 0.6284554600715637
Iteration 907, loss: 0.6557324528694153
Iteration 908, loss: 0.6515026092529297
Iteration 909, loss: 0.6339667439460754
Iteration 910, loss: 0.6709883809089661
Iteration 911, loss: 0.6233908534049988
Iteration 912, loss: 0.6170549392700195
Iteration 913, loss: 0.5756374597549438
Iteration 914, loss: 0.5608857274055481
Iteration 915, loss: 0.6212491989135742
Iteration 916, loss: 0.636346161365509
Iteration 917, loss: 0.5154281854629517
Iteration 918, loss: 0.6286675333976746
Iteration 919, loss: 0.6040599346160889
Iteration 920, loss: 0.5958192348480225
Iteration 921, loss: 0.6139214038848877
Iteration 922, loss: 0.6521099805831909
Iteration 923, loss: 0.6542444825172424
Iteration 924, loss: 0.5998026132583618
Iteration 925, loss: 0.6956421732902527
Iteration 926, loss: 0.6055550575256348
Iteration 927, loss: 0.5932872295379639
Iteration 928, loss: 0.6646223068237305
Iteration 929, loss: 0.5304097533226013
Iteration 930, loss: 0.7000669240951538
Iteration 931, loss: 0.6222591996192932
Iteration 932, loss: 0.5618321299552917
Iteration 933, loss: 0.6338673830032349
Iteration 934, loss: 0.6910197734832764
Iteration 935, loss: 0.6088632941246033
Iteration 936, loss: 0.6512609124183655
Iteration 937, loss: 0.6557268500328064
Iteration 938, loss: 0.5881652235984802
Iteration 939, loss: 0.6593648195266724
Iteration 940, loss: 0.5938503742218018
Iteration 941, loss: 0.6506609320640564
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Iteration 942, loss: 0.5733956098556519
Iteration 943, loss: 0.6429315805435181
Iteration 944, loss: 0.7025004029273987
Iteration 945, loss: 0.7072393894195557
Iteration 946, loss: 0.621221661567688
Iteration 947, loss: 0.6195839643478394
Iteration 948, loss: 0.5950924158096313
Iteration 949, loss: 0.535594642162323
Iteration 950, loss: 0.613554835319519
Iteration 951, loss: 0.6030067801475525
Iteration 952, loss: 0.5800262689590454
Iteration 953, loss: 0.5938462615013123
Iteration 954, loss: 0.5888075232505798
Iteration 955, loss: 0.6332883834838867
Iteration 956, loss: 0.5757916569709778
Iteration 957, loss: 0.6163014769554138
Iteration 958, loss: 0.5706685781478882
Iteration 959, loss: 0.6005257964134216
Iteration 960, loss: 0.6424334645271301
Iteration 961, loss: 0.5215511918067932
Iteration 962, loss: 0.6007929444313049
Iteration 963, loss: 0.6532762050628662
Iteration 964, loss: 0.6027713418006897
Iteration 965, loss: 0.6460216045379639
Iteration 966, loss: 0.6875719428062439
Iteration 967, loss: 0.5549365282058716
Iteration 968, loss: 0.5580839514732361
Iteration 969, loss: 0.638715386390686
Iteration 970, loss: 0.657795786857605
Iteration 971, loss: 0.585892915725708
Iteration 972, loss: 0.5989444255828857
Iteration 973, loss: 0.6235386729240417
Iteration 974, loss: 0.580352246761322
Iteration 975, loss: 0.625419020652771
Iteration 976, loss: 0.6665743589401245
Iteration 977, loss: 0.6254605650901794
Iteration 978, loss: 0.5843326449394226
Iteration 979, loss: 0.6281428933143616
Iteration 980, loss: 0.5385528206825256
Iteration 981, loss: 0.5817055106163025
Iteration 982, loss: 0.5806183815002441
Iteration 983, loss: 0.572575032711029
Iteration 984, loss: 0.5999234914779663
Iteration 985, loss: 0.6061955690383911
Iteration 986, loss: 0.6107160449028015
Iteration 987, loss: 0.6107631325721741
Iteration 988, loss: 0.5403700470924377
Iteration 989, loss: 0.6098780632019043
Iteration 990, loss: 0.5992317795753479
Iteration 991, loss: 0.6532313823699951
Iteration 992, loss: 0.6107380986213684
Iteration 993, loss: 0.583556592464447
Iteration 994, loss: 0.5398576259613037
Iteration 995, loss: 0.5699387788772583
Iteration 996, loss: 0.6399946212768555
Iteration 997, loss: 0.7611187696456909
Iteration 998, loss: 0.5926269888877869
Iteration 999, loss: 0.5379374027252197
End of epoch 6, loss: 1.7589681148529053
Validation loss: 1.1912322044372559
Iteration 0, loss: 0.6665000915527344
Iteration 1, loss: 0.5462044477462769
Iteration 2, loss: 0.5681434273719788
Iteration 3, loss: 0.5382514595985413
Iteration 4, loss: 0.6469284892082214
Iteration 5, loss: 0.6145490407943726
Iteration 6, loss: 0.5895761251449585
Iteration 7, loss: 0.5469764471054077
Iteration 8, loss: 0.5905635356903076
Iteration 9, loss: 0.565906822681427
Iteration 10, loss: 0.632039487361908
Iteration 11, loss: 0.6332642436027527
Iteration 12, loss: 0.669865071773529
Iteration 13, loss: 0.5474310517311096
Iteration 14, loss: 0.6287732720375061
Iteration 15, loss: 0.6013845801353455
Iteration 16, loss: 0.6191433668136597
```

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Iteration 17, loss: 0.6411393880844116
Iteration 18, loss: 0.6649078726768494
Iteration 19, loss: 0.6173925995826721
Iteration 20, loss: 0.6467505097389221
Iteration 21, loss: 0.6631468534469604
Iteration 22, loss: 0.6291888952255249
Iteration 23, loss: 0.5497475862503052
Iteration 24, loss: 0.5927566289901733
Iteration 25, loss: 0.6493628025054932
Iteration 26, loss: 0.7061859965324402
Iteration 27, loss: 0.6799107193946838
Iteration 28, loss: 0.6068140268325806
Iteration 29, loss: 0.6181630492210388
Iteration 30, loss: 0.6145358681678772
Iteration 31, loss: 0.5703355073928833
Iteration 32, loss: 0.6114943027496338
Iteration 33, loss: 0.6379684209823608
Iteration 34, loss: 0.6692882776260376
Iteration 35, loss: 0.5864897966384888
Iteration 36, loss: 0.5897533893585205
Iteration 37, loss: 0.5257866382598877
Iteration 38, loss: 0.6136492490768433
Iteration 39, loss: 0.5911397337913513
Iteration 40, loss: 0.5905194282531738
Iteration 41, loss: 0.6472712159156799
Iteration 42, loss: 0.5430986881256104
Iteration 43, loss: 0.5616767406463623
Iteration 44, loss: 0.5867823362350464
Iteration 45, loss: 0.6741635799407959
Iteration 46, loss: 0.6364250183105469
Iteration 47, loss: 0.5873063802719116
Iteration 48, loss: 0.6330575942993164
Iteration 49, loss: 0.6577568650245667
Iteration 50, loss: 0.5959106683731079
Iteration 51, loss: 0.5896448493003845
Iteration 52, loss: 0.5892296433448792
Iteration 53, loss: 0.5686604380607605
Iteration 54, loss: 0.5675601959228516
Iteration 55, loss: 0.6781317591667175
Iteration 56, loss: 0.49863559007644653
Iteration 57, loss: 0.6366126537322998
Iteration 58, loss: 0.6902245879173279
Iteration 59, loss: 0.5382639765739441
Iteration 60, loss: 0.5660065412521362
Iteration 61, loss: 0.7081008553504944
Iteration 62, loss: 0.6707220673561096
Iteration 63, loss: 0.5987451076507568
Iteration 64, loss: 0.5644603967666626
Iteration 65, loss: 0.6303953528404236
Iteration 66, loss: 0.5499672293663025
Iteration 67, loss: 0.6474276185035706
Iteration 68, loss: 0.6033510565757751
Iteration 69, loss: 0.6534325480461121
Iteration 70, loss: 0.5596904158592224
Iteration 71, loss: 0.6506742238998413
Iteration 72, loss: 0.5627849102020264
Iteration 73, loss: 0.5620670914649963
Iteration 74, loss: 0.7031892538070679
Iteration 75, loss: 0.5946177244186401
Iteration 76, loss: 0.5539941191673279
Iteration 77, loss: 0.6164015531539917
Iteration 78, loss: 0.6183942556381226
Iteration 79, loss: 0.5214621424674988
Iteration 80, loss: 0.5846730470657349
Iteration 81, loss: 0.5897908210754395
Iteration 82, loss: 0.56578129529953
Iteration 83, loss: 0.6225101947784424
Iteration 84, loss: 0.6169043779373169
Iteration 85, loss: 0.5550137758255005
Iteration 86, loss: 0.5857762694358826
Iteration 87, loss: 0.5999957919120789
Iteration 88, loss: 0.6529505848884583
Iteration 89, loss: 0.6071507930755615
Iteration 90, loss: 0.5430310368537903
Iteration 91, loss: 0.6255862712860107
Iteration 92, loss: 0.522678792476654
Iteration 93, loss: 0.637019693851471
```

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Iteration 94, loss: 0.5519654750823975
Iteration 95, loss: 0.57383131980896
Iteration 96, loss: 0.5432835817337036
Iteration 97, loss: 0.5362409353256226
Iteration 98, loss: 0.6347137689590454
Iteration 99, loss: 0.5778191685676575
Iteration 100, loss: 0.5075140595436096
Iteration 101, loss: 0.5632899403572083
Iteration 102, loss: 0.5535290241241455
Iteration 103, loss: 0.4942598044872284
Iteration 104, loss: 0.6977672576904297
Iteration 105, loss: 0.6209660172462463
Iteration 106, loss: 0.6033396124839783
Iteration 107, loss: 0.5138502717018127
Iteration 108, loss: 0.5753366947174072
Iteration 109, loss: 0.6587884426116943
Iteration 110, loss: 0.6365460157394409
Iteration 111, loss: 0.6780939102172852
Iteration 112, loss: 0.5492252707481384
Iteration 113, loss: 0.6767125725746155
Iteration 114, loss: 0.5959800481796265
Iteration 115, loss: 0.5974347591400146
Iteration 116, loss: 0.7157501578330994
Iteration 117, loss: 0.6689746379852295
Iteration 118, loss: 0.6050633192062378
Iteration 119, loss: 0.6031100153923035
Iteration 120, loss: 0.5334571599960327
Iteration 121, loss: 0.4840131998062134
Iteration 122, loss: 0.556280791759491
Iteration 123, loss: 0.57906574010849
Iteration 124, loss: 0.5547638535499573
Iteration 125, loss: 0.558188796043396
Iteration 126, loss: 0.5511943697929382
Iteration 127, loss: 0.5151695609092712
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Iteration 131, loss: 0.5953906178474426
Iteration 132, loss: 0.6060569882392883
Iteration 133, loss: 0.5269914865493774
Iteration 134, loss: 0.5803970694541931
Iteration 135, loss: 0.5325458645820618
Iteration 136, loss: 0.5142765641212463
Iteration 137, loss: 0.5253081917762756
Iteration 138, loss: 0.5866838693618774
Iteration 139, loss: 0.5514191389083862
Iteration 140, loss: 0.5181262493133545
Iteration 141, loss: 0.5625912547111511
Iteration 142, loss: 0.618439257144928
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Iteration 144, loss: 0.5023159384727478
Iteration 145, loss: 0.5679849982261658
Iteration 146, loss: 0.490822970867157
Iteration 147, loss: 0.5992709398269653
Iteration 148, loss: 0.6185916066169739
Iteration 149, loss: 0.6408127546310425
Iteration 150, loss: 0.5394671559333801
Iteration 151, loss: 0.6063522100448608
Iteration 152, loss: 0.5617595314979553
Iteration 153, loss: 0.6184964776039124
Iteration 154, loss: 0.6257454752922058
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Iteration 156, loss: 0.5826345086097717
Iteration 157, loss: 0.517297625541687
Iteration 158, loss: 0.5070986151695251
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Iteration 160, loss: 0.6057040095329285
Iteration 161, loss: 0.5416584014892578
Iteration 162, loss: 0.5757129192352295
Iteration 163, loss: 0.5612152218818665
Iteration 164, loss: 0.5229899883270264
Iteration 165, loss: 0.5405610203742981
Iteration 166, loss: 0.5859717726707458
Iteration 167, loss: 0.6102120280265808
Iteration 168, loss: 0.5451760292053223
Iteration 169, loss: 0.6179670095443726
Iteration 170, loss: 0.5598944425582886
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Iteration 171, loss: 0.6515529155731201
Iteration 172, loss: 0.6032933592796326
Iteration 173, loss: 0.5051769614219666
Iteration 174, loss: 0.538699209690094
Iteration 175, loss: 0.5710490942001343
Iteration 176, loss: 0.4715490937232971
Iteration 177, loss: 0.4770118296146393
Iteration 178, loss: 0.5543356537818909
Iteration 179, loss: 0.5139683485031128
Iteration 180, loss: 0.6010326147079468
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Iteration 245, loss: 0.4481247365474701
Iteration 246, loss: 0.4617133140563965
Iteration 247, loss: 0.5138390064239502
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Iteration 248, loss: 0.5299096703529358
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Iteration 250, loss: 0.5629012584686279
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Iteration 284, loss: 0.5250194072723389
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Iteration 287, loss: 0.5092136859893799
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Iteration 289, loss: 0.5174272060394287
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Iteration 292, loss: 0.5676199197769165
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Iteration 304, loss: 0.5151989459991455
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Iteration 307, loss: 0.4837879538536072
Iteration 308, loss: 0.5481751561164856
Iteration 309, loss: 0.5550399422645569
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Iteration 318, loss: 0.4432271420955658
Iteration 319, loss: 0.5024064779281616
Iteration 320, loss: 0.5372991561889648
Iteration 321, loss: 0.5044656991958618
Iteration 322, loss: 0.4982423186302185
Iteration 323, loss: 0.45612651109695435
Iteration 324, loss: 0.5766839385032654
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Iteration 325, loss: 0.47564947605133057
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Iteration 796, loss: 0.5114054083824158
Iteration 797, loss: 0.4222618639469147
Iteration 798, loss: 0.42353785037994385
Iteration 799, loss: 0.45665809512138367
Iteration 800, loss: 0.4165031611919403
Iteration 801, loss: 0.45036283135414124
Iteration 802, loss: 0.46866485476493835
Iteration 803, loss: 0.396745890378952
Iteration 804, loss: 0.4737938344478607
Iteration 805, loss: 0.45122987031936646
Iteration 806, loss: 0.44000786542892456
Iteration 807, loss: 0.4005368649959564
Iteration 808, loss: 0.47155624628067017
Iteration 809, loss: 0.4855249524116516
Iteration 810, loss: 0.4888263940811157
Iteration 811, loss: 0.3931560218334198
Iteration 812, loss: 0.4505190849304199
Iteration 813, loss: 0.39020779728889465
Iteration 814, loss: 0.47439196705818176
Iteration 815, loss: 0.46601879596710205
Iteration 816, loss: 0.3863501250743866
Iteration 817, loss: 0.47030550241470337
Iteration 818, loss: 0.4793294370174408
Iteration 819, loss: 0.5095840692520142
Iteration 820, loss: 0.44736334681510925
Iteration 821, loss: 0.5421078205108643
Iteration 822, loss: 0.4511737823486328
Iteration 823, loss: 0.40640416741371155
Iteration 824, loss: 0.4815562069416046
Iteration 825, loss: 0.4113156497478485
Iteration 826, loss: 0.4633575677871704
Iteration 827, loss: 0.4563363790512085
Iteration 828, loss: 0.4073048233985901
Iteration 829, loss: 0.466789186000824
Iteration 830, loss: 0.4389910399913788
Iteration 831, loss: 0.5536973476409912
Iteration 832, loss: 0.38051557540893555
Iteration 833, loss: 0.4290030896663666
Iteration 834, loss: 0.4181872010231018
Iteration 835, loss: 0.5440652966499329
Iteration 836, loss: 0.4409351646900177
Iteration 837, loss: 0.42292946577072144
Iteration 838, loss: 0.42648208141326904
Iteration 839, loss: 0.41455304622650146
Iteration 840, loss: 0.42466339468955994
Iteration 841, loss: 0.4537380337715149
Iteration 842, loss: 0.4269311726093292
Iteration 843, loss: 0.4259868860244751
Iteration 844, loss: 0.38573864102363586
Iteration 845, loss: 0.4343963861465454
Iteration 846, loss: 0.44829124212265015
Iteration 847, loss: 0.44861161708831787
Iteration 848, loss: 0.5421838164329529
Iteration 849, loss: 0.5207926034927368
Iteration 850, loss: 0.35398194193840027
Iteration 851, loss: 0.43467971682548523
Iteration 852, loss: 0.4251871407032013
Iteration 853, loss: 0.4490538239479065
Iteration 854, loss: 0.38761234283447266
Iteration 855, loss: 0.3826557397842407
Iteration 856, loss: 0.43512514233558917
Iteration 857, loss: 0.4911326766014099
Iteration 858, loss: 0.4911806285381317
Iteration 859, loss: 0.43983447551727295
Iteration 860, loss: 0.44404715299606323
Iteration 861, loss: 0.43993741273880005
Iteration 862, loss: 0.4700457453727722
Iteration 863, loss: 0.4710559844970703
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Iteration 863, loss: 0.4710559844970703
Iteration 864, loss: 0.4528883695602417
Iteration 865, loss: 0.4473179578781128
Iteration 866, loss: 0.4387912452220917
Iteration 867, loss: 0.41039082407951355
Iteration 868, loss: 0.43675845861434937
Iteration 869, loss: 0.37202173471450806
Iteration 870, loss: 0.40200966596603394
Iteration 871, loss: 0.4330611526966095
Iteration 872, loss: 0.43553730845451355
Iteration 873, loss: 0.42006462812423706
Iteration 874, loss: 0.4500080943107605
Iteration 875, loss: 0.41395267844200134
Iteration 876, loss: 0.39581865072250366
Iteration 877, loss: 0.39973127841949463
Iteration 878, loss: 0.5434184670448303
Iteration 879, loss: 0.42232653498649597
Iteration 880, loss: 0.4159753918647766
Iteration 881, loss: 0.4046385884284973
Iteration 882, loss: 0.3958177864551544
Iteration 883, loss: 0.376852810382843
Iteration 884, loss: 0.40905603766441345
Iteration 885, loss: 0.4410563111305237
Iteration 886, loss: 0.42614108324050903
Iteration 887, loss: 0.4080106317996979
Iteration 888, loss: 0.3860209584236145
Iteration 889, loss: 0.41548824310302734
Iteration 890, loss: 0.4247642159461975
Iteration 891, loss: 0.4393032193183899
Iteration 892, loss: 0.4083010256290436
Iteration 893, loss: 0.4181317090988159
Iteration 894, loss: 0.48688599467277527
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Iteration 896, loss: 0.39997848868370056
Iteration 897, loss: 0.41435083746910095
Iteration 898, loss: 0.4585551619529724
Iteration 899, loss: 0.36391326785087585
Iteration 900, loss: 0.4346119165420532
Iteration 901, loss: 0.40695542097091675
Iteration 902, loss: 0.38561245799064636
Iteration 903, loss: 0.34395188093185425
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Iteration 905, loss: 0.45933279395103455
Iteration 906, loss: 0.4167375862598419
Iteration 907, loss: 0.41299107670783997
Iteration 908, loss: 0.4685550332069397
Iteration 909, loss: 0.4083004593849182
Iteration 910, loss: 0.4446195065975189
Iteration 911, loss: 0.41355615854263306
Iteration 912, loss: 0.41116729378700256
Iteration 913, loss: 0.3663681745529175
Iteration 914, loss: 0.3874569237232208
Iteration 915, loss: 0.42584228515625
Iteration 916, loss: 0.397993266582489
Iteration 917, loss: 0.33673346042633057
Iteration 918, loss: 0.4415537714958191
Iteration 919, loss: 0.40949827432632446
Iteration 920, loss: 0.3825960159301758
Iteration 921, loss: 0.4064168334007263
Iteration 922, loss: 0.45628249645233154
Iteration 923, loss: 0.45038461685180664
Iteration 924, loss: 0.43037131428718567
Iteration 925, loss: 0.45520246028900146
Iteration 926, loss: 0.4065370559692383
Iteration 927, loss: 0.38350769877433777
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Iteration 929, loss: 0.3453662693500519
Iteration 930, loss: 0.4525356590747833
Iteration 931, loss: 0.4402886927127838
Iteration 932, loss: 0.3562065660953522
Iteration 933, loss: 0.43700382113456726
Iteration 934, loss: 0.49446916580200195
Iteration 935, loss: 0.4238187372684479
Iteration 936, loss: 0.4591507613658905
Iteration 937, loss: 0.4521297216415405
Iteration 938, loss: 0.4089770019054413
Iteration 939, loss: 0.46351078152656555
Iteration 940, loss: 0.3873854875564575
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Iteration 940, loss: 0.3873854875564575
Iteration 941, loss: 0.4694371819496155
Iteration 942, loss: 0.3744162917137146
Iteration 943, loss: 0.45482203364372253
Iteration 944, loss: 0.5299216508865356
Iteration 945, loss: 0.5228284001350403
Iteration 946, loss: 0.44800570607185364
Iteration 947, loss: 0.4100286662578583
Iteration 948, loss: 0.41317880153656006
Iteration 949, loss: 0.3549821972846985
Iteration 950, loss: 0.4222787022590637
Iteration 951, loss: 0.41734907031059265
Iteration 952, loss: 0.40172815322875977
Iteration 953, loss: 0.37745407223701477
Iteration 954, loss: 0.41142672300338745
Iteration 955, loss: 0.42366883158683777
Iteration 956, loss: 0.373458594083786
Iteration 957, loss: 0.4426725208759308
Iteration 958, loss: 0.38154375553131104
Iteration 959, loss: 0.4017448127269745
Iteration 960, loss: 0.4293513298034668
Iteration 961, loss: 0.34749382734298706
Iteration 962, loss: 0.3842560350894928
Iteration 963, loss: 0.43093040585517883
Iteration 964, loss: 0.44513261318206787
Iteration 965, loss: 0.47686073184013367
Iteration 966, loss: 0.4921889305114746
Iteration 967, loss: 0.34905657172203064
Iteration 968, loss: 0.3661159873008728
Iteration 969, loss: 0.43498244881629944
Iteration 970, loss: 0.44794410467147827
Iteration 971, loss: 0.3830909729003906
Iteration 972, loss: 0.3997810184955597
Iteration 973, loss: 0.41291528940200806
Iteration 974, loss: 0.3983769714832306
Iteration 975, loss: 0.4112418591976166
Iteration 976, loss: 0.44491884112358093
Iteration 977, loss: 0.4187615215778351
Iteration 978, loss: 0.37693876028060913
Iteration 979, loss: 0.4267154037952423
Iteration 980, loss: 0.36929208040237427
Iteration 981, loss: 0.38091257214546204
Iteration 982, loss: 0.43088021874427795
Iteration 983, loss: 0.39700719714164734
Iteration 984, loss: 0.41779422760009766
Iteration 985, loss: 0.4202190041542053
Iteration 986, loss: 0.4089076817035675
Iteration 987, loss: 0.4145519435405731
Iteration 988, loss: 0.31634217500686646
Iteration 989, loss: 0.398227721452713
Iteration 990, loss: 0.37161943316459656
Iteration 991, loss: 0.3986757695674896
Iteration 992, loss: 0.40357935428619385
Iteration 993, loss: 0.3743937909603119
Iteration 994, loss: 0.3253327012062073
Iteration 995, loss: 0.37630051374435425
Iteration 996, loss: 0.4159518778324127
Iteration 997, loss: 0.55936598777771
Iteration 998, loss: 0.35163599252700806
Iteration 999, loss: 0.35530751943588257
End of epoch 7, loss: 1.4969019889831543
Validation loss: 1.0703672170639038
```

In [43]:

```python
# Save the complete models

decoder.save('models/decoder')
encoder.save('models/encoder')

# decoder = tf.keras.models.load_model('models/decoder')
# encoder = tf.keras.models.load_model('models/encoder')
```

```
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/tensorflow/python/training/tracking/trac
king.py:111: Model.state_updates (from tensorflow.python.keras.engine.training) is deprecated and will
```

```
king.py:111: Model.state_updates (from tensorflow.python.keras.engine.training) is deprecated and will
be removed in a future version.
Instructions for updating:
This property should not be used in TensorFlow 2.0, as updates are applied automatically.
```


```
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/tensorflow/python/training/tracking/trac
king.py:111: Model.state_updates (from tensorflow.python.keras.engine.training) is deprecated and will
be removed in a future version.
Instructions for updating:
This property should not be used in TensorFlow 2.0, as updates are applied automatically.
```


```
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/tensorflow/python/training/tracking/trac
king.py:111: Layer.updates (from tensorflow.python.keras.engine.base_layer) is deprecated and will be r
emoved in a future version.
Instructions for updating:
This property should not be used in TensorFlow 2.0, as updates are applied automatically.
```


```
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/tensorflow/python/training/tracking/trac
king.py:111: Layer.updates (from tensorflow.python.keras.engine.base_layer) is deprecated and will be r
emoved in a future version.
Instructions for updating:
This property should not be used in TensorFlow 2.0, as updates are applied automatically.
```


```
INFO:tensorflow:Assets written to: models/decoder/assets
```


```
INFO:tensorflow:Assets written to: models/decoder/assets
```


```
INFO:tensorflow:Assets written to: models/encoder/assets
```

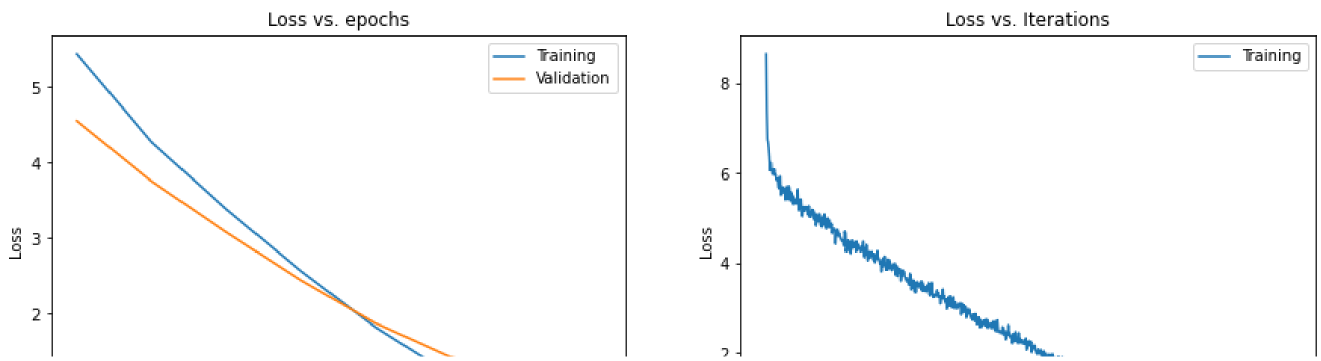

```
INFO:tensorflow:Assets written to: models/encoder/assets
```

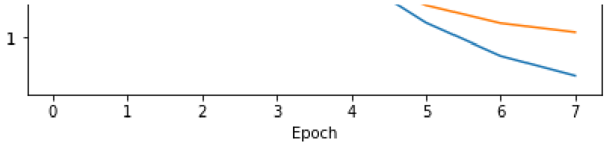

In [44]:

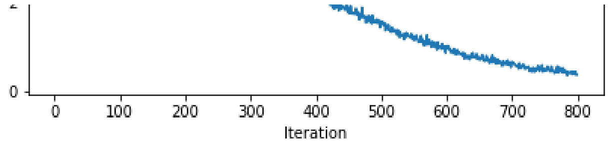
```python
# Plot the learning curves
import matplotlib.pyplot as plt
plt.figure(figsize=(15,5))

plt.subplot(121)
plt.plot(epoch_history['loss'])
plt.plot(epoch_history['val_loss'])
plt.title('Loss vs. epochs')
plt.ylabel('Loss')
plt.xlabel('Epoch')
plt.legend(['Training', 'Validation'], loc='upper right')

plt.subplot(122)
plt.plot(batch_history['loss'])
plt.title('Loss vs. Iterations')
plt.ylabel('Loss')
plt.xlabel('Iteration')
plt.legend(['Training'], loc='upper right')
plt.show()
```







7. Use the model to translate

Now it's time to put your model into practice! You should run your translation for five randomly sampled English sentences from the dataset. For each sentence, the process is as follows:

- Preprocess and embed the English sentence according to the model requirements.
- Pass the embedded sentence through the encoder to get the encoder hidden and cell states.
- Starting with the special `"<start>"` token, use this token and the final encoder hidden and cell states to get the one-step prediction from the decoder, as well as the decoder's updated hidden and cell states.
- Create a loop to get the next step prediction and updated hidden and cell states from the decoder, using the most recent hidden and cell states. Terminate the loop when the `"<end>"` token is emitted, or when the sentence has reached a maximum length.
- Decode the output token sequence into German text and print the English text and the model's German translation.

In [45]:

```
# Sample a random English sentence to translate

for _ in range(5):
    english_sentence = english[np.random.choice(len(english))]
    print("English input: \t\t", re.sub(r" ([?.!,])", r"\1 ", english_sentence))

    max_translation_length = 10

    german_translation = ["<start>"]
    ger_token = german_tokenizer.texts_to_sequences(german_translation)
    ger_token = np.array(ger_token)

    embedded_sentence = embedding_layer(tf.constant(english_sentence.split(' ')))

    hidden, cell = encoder(embedded_sentence[np.newaxis, ...])

    while True:
        decoder_output, hidden, cell = decoder(ger_token, hidden_state=hidden, cell_state=cell)
        ger_token = np.argmax(np.squeeze(decoder_output))
        if ger_token == 0:
            break
        ger_word = german_tokenizer.index_word[ger_token]
        ger_token = ger_token[np.newaxis, np.newaxis, ...]
        if ger_word == "<end>":
            break
        german_translation.append(ger_word)
        if len(german_translation) >= max_translation_length:
            break

    sentence = ' '.join(german_translation[1:])
    print("Model translation:\t", re.sub(r" ([?.!,])", r"\1 ", sentence))
    print('')
```

```
English input:     tom can't sing.
Model translation:  tom kann nicht zaehlen.

English input:     how perceptive!
Model translation:  wie aufregend!

English input:     could i ask why?
Model translation:  darf ich fragen,  warum?

English input:     what's it worth?
Model translation:  was ist das nun?

English input:     i'll be glad to.
Model translation:  ich werde brav sein.
```

In [ ]:

```

```

In [ ]:

```

```