Homework 5: Sequence2Sequence Machine Translation

Course : Real-Time Machine Learning 5106

Name : Tarun Reddy Challa

Student ID : 801318301

Github Link : https://github.com/tarunreddy03/RTML

```
!pip install setuptools==66
!pip install d2l==1.0.0-beta0

import cv2
import numpy as np
import pandas as pd
from tqdm import tqdm
from datetime import datetime
from matplotlib import pyplot as plt

import torch
from torch import nn
from d2l import torch as d2l
from torch.nn import functional as F

!pip install ptflops
import ptflops
from ptflops import get_model_complexity_info
import math
import collections
```

```
      exit code: 1
      └─> See above for output.

      note: This error originates from a subprocess, and is likely not a problem with pi
      Building wheel for gym (setup.py) ... error
      ERROR: Failed building wheel for gym
      Running setup.py clean for gym
    Failed to build gym
    Installing collected packages: qtpy, jedi, gym, qtconsole, jupyter, linear-operator,
      Attempting uninstall: gym
        Found existing installation: gym 0.25.2
        Uninstalling gym-0.25.2:
          Successfully uninstalled gym-0.25.2
      Running setup.py install for gym ... done
      DEPRECATION: gym was installed using the legacy 'setup.py install' method, because
    Successfully installed d2l-1.0.0b0 gpytorch-1.10 gym-0.21.0 jedi-0.18.2 jupyter-1.0.
    Looking in indexes: https://pypi.org/simple, https://us-python.pkg.dev/colab-wheels/
    Collecting ptflops
      Downloading ptflops-0.7.tar.gz (13 kB)
      Preparing metadata (setup.py) ... done
    Requirement already satisfied: torch in /usr/local/lib/python3.9/dist-packages (from
    Requirement already satisfied: jinja2 in /usr/local/lib/python3.9/dist-packages (fro
    Requirement already satisfied: triton==2.0.0 in /usr/local/lib/python3.9/dist-packag
    Requirement already satisfied: typing-extensions in /usr/local/lib/python3.9/dist-pa
    Requirement already satisfied: networkx in /usr/local/lib/python3.9/dist-packages (f
    Requirement already satisfied: filelock in /usr/local/lib/python3.9/dist-packages (f
    Requirement already satisfied: sympy in /usr/local/lib/python3.9/dist-packages (from
    Requirement already satisfied: lit in /usr/local/lib/python3.9/dist-packages (from t
    Requirement already satisfied: cmake in /usr/local/lib/python3.9/dist-packages (from
    Requirement already satisfied: MarkupSafe>=2.0 in /usr/local/lib/python3.9/dist-pack
    Requirement already satisfied: mpmath>=0.19 in /usr/local/lib/python3.9/dist-package
    Building wheels for collected packages: ptflops
      Building wheel for ptflops (setup.py) ... done
      Created wheel for ptflops: filename=ptflops-0.7-py3-none-any.whl size=11093 sha256
      Stored in directory: /root/.cache/pip/wheels/2d/c7/b1/6eefc63fedc8e43f313b1af1e153
    Successfully built ptflops
    Installing collected packages: ptflops
    Successfully installed ptflops-0.7
```

PROBLEM 1)

```
class MTFraEng(d2l.DataModule):
    def _download(self):
        d2l.extract(d2l.download(
            d2l.DATA_URL+'fra-eng.zip', self.root,
            '94646ad1522d915e7b0f9296181140edcf86a4f5'))
        with open(self.root + '/fra-eng/fra.txt', encoding='utf-8') as f:
            return f.read()

data = MTFraEng()
raw_text = data._download()
print(raw_text[:75])
```

```
Downloading ../data/fra-eng.zip from http://d2l-data.s3-accelerate.amazonaws.com/fra-eng
Go.	Va !
Hi.	Salut !
Run!	Cours !
Run!	Courez !
Who?	Qui ?
Wow!	Ça alors !
```

```
@d2l.add_to_class(MTFraEng)
def _preprocess(self, text):
    text = text.replace('\u202f', ' ').replace('\xa0', ' ')
    no_space = lambda char, prev_char: char in ',.!?' and prev_char != ' '
    out = [' ' + char if i > 0 and no_space(char, text[i - 1]) else char
           for i, char in enumerate(text.lower())]
    return ''.join(out)

text = data._preprocess(raw_text)
print(text[:80])
```

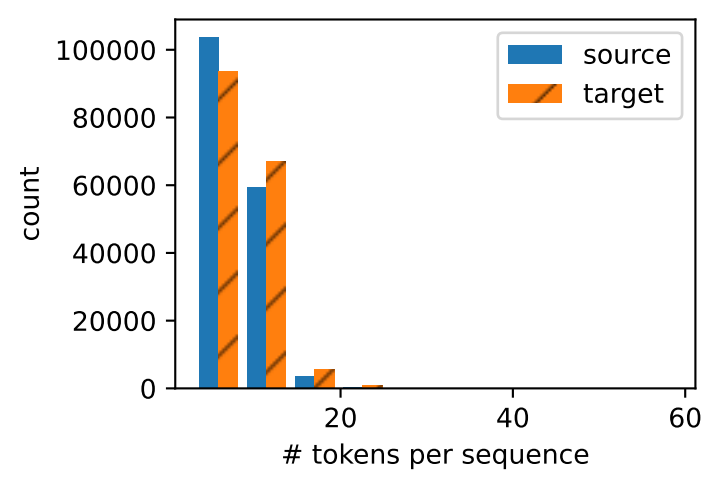
```
go .	va !
hi .	salut !
run !	cours !
run !	courez !
who ?	qui ?
wow !	ça alors !
```

```
@d2l.add_to_class(MTFraEng)
def _tokenize(self, text, max_examples=None):
    src, tgt = [], []
    for i, line in enumerate(text.split('\n')):
        if max_examples and i > max_examples: break
        parts = line.split('\t')
        if len(parts) == 2:
            src.append([t for t in f'{parts[0]} <eos>'.split(' ') if t])
            tgt.append([t for t in f'{parts[1]} <eos>'.split(' ') if t])
    return src, tgt

src, tgt = data._tokenize(text)
src[:6], tgt[:6]
```

```
([['go', '.', '<eos>'],
  ['hi', '.', '<eos>'],
  ['run', '!', '<eos>'],
  ['run', '!', '<eos>'],
  ['who', '?', '<eos>'],
  ['wow', '!', '<eos>']],
 [['va', '!', '<eos>'],
  ['salut', '!', '<eos>'],
  ['cours', '!', '<eos>'],
```

```
        ['courez', '!', '<eos>'],
        ['qui', '?', '<eos>'],
        ['ça', 'alors', '!', '<eos>']])
```

```
def show_list_len_pair_hist(legend, xlabel, ylabel, xlist, ylist):
    d2l.set_figsize()
    _, _, patches = d2l.plt.hist(
        [[len(l) for l in xlist], [len(l) for l in ylist]])
    d2l.plt.xlabel(xlabel)
    d2l.plt.ylabel(ylabel)
    for patch in patches[1].patches:
        patch.set_hatch('/')
    d2l.plt.legend(legend)

show_list_len_pair_hist(['source', 'target'], '# tokens per sequence',
                        'count', src, tgt);
```




```
@d2l.add_to_class(MTFraEng)
def __init__(self, batch_size, num_steps=9, num_train=512, num_val=128):
    super(MTFraEng, self).__init__()
    self.save_hyperparameters()
    self.arrays, self.src_vocab, self.tgt_vocab = self._build_arrays(
        self._download())

@d2l.add_to_class(MTFraEng)
def _build_arrays(self, raw_text, src_vocab=None, tgt_vocab=None):
    def _build_array(sentences, vocab, is_tgt=False):
        pad_or_trim = lambda seq, t: (
            seq[:t] if len(seq) > t else seq + ['<pad>'] * (t - len(seq)))
        sentences = [pad_or_trim(s, self.num_steps) for s in sentences]
        if is_tgt:
            sentences = [['<bos>'] + s for s in sentences]
        if vocab is None:
            vocab = d2l.Vocab(sentences, min_freq=2)
        array = torch.tensor([vocab[s] for s in sentences])
```

```
        valid_len = (array != vocab['<pad>']).type(torch.int32).sum(1)
        return array, vocab, valid_len
    src, tgt = self._tokenize(self._preprocess(raw_text),
                              self.num_train + self.num_val)
    src_array, src_vocab, src_valid_len = _build_array(src, src_vocab)
    tgt_array, tgt_vocab, _ = _build_array(tgt, tgt_vocab, True)
    return ((src_array, tgt_array[:,:-1], src_valid_len, tgt_array[:,1:]),
            src_vocab, tgt_vocab)
```

```
@d2l.add_to_class(MTFraEng)
def get_dataloader(self, train):
    idx = slice(0, self.num_train) if train else slice(self.num_train, None)
    return self.get_tensorloader(self.arrays, train, idx)
```

```
data = MTFraEng(batch_size=3)
src, tgt, src_valid_len, label = next(iter(data.train_dataloader()))
print('source:', src.type(torch.int32))
print('decoder input:', tgt.type(torch.int32))
print('source len excluding pad:', src_valid_len.type(torch.int32))
print('label:', label.type(torch.int32))
```

```
source: tensor([[86, 88,  2,  3,  4,  4,  4,  4,  4],
        [92, 73,  2,  3,  4,  4,  4,  4,  4],
        [16, 42,  2,  3,  4,  4,  4,  4,  4]], dtype=torch.int32)
decoder input: tensor([[  3, 108, 183, 126,   2,   4,   5,   5,   5],
        [  3,  37, 113,   6,   2,   4,   5,   5,   5],
        [  3, 182, 110,   0,   4,   5,   5,   5,   5]], dtype=torch.int32)
source len excluding pad: tensor([4, 4, 4], dtype=torch.int32)
label: tensor([[108, 183, 126,   2,   4,   5,   5,   5,   5],
        [ 37, 113,   6,   2,   4,   5,   5,   5,   5],
        [182, 110,   0,   4,   5,   5,   5,   5,   5]], dtype=torch.int32)
```

```
@d2l.add_to_class(MTFraEng)
def build(self, src_sentences, tgt_sentences):
    raw_text = '\n'.join([src + '\t' + tgt for src, tgt in zip(
        src_sentences, tgt_sentences)])
    arrays, _, _ = self._build_arrays(
        raw_text, self.src_vocab, self.tgt_vocab)
    return arrays

src, tgt, _,  _ = data.build(['hi .'], ['salut .'])
print('source:', data.src_vocab.to_tokens(src[0].type(torch.int32)))
print('target:', data.tgt_vocab.to_tokens(tgt[0].type(torch.int32)))
```

```
source: ['hi', '.', '<eos>', '<pad>', '<pad>', '<pad>', '<pad>', '<pad>', '<pad>']
target: ['<bos>', 'salut', '.', '<eos>', '<pad>', '<pad>', '<pad>', '<pad>', '<pad>']
```

```
class Encoder(nn.Module):
    def __init__(self):
```

```
        super().__init__()

    def forward(self, X, *args):
        raise NotImplementedError
```

```
class Decoder(nn.Module):
    def __init__(self):
        super().__init__()

    def init_state(self, enc_all_outputs, *args):
        raise NotImplementedError

    def forward(self, X, state):
        raise NotImplementedError
```

```
class EncoderDecoder(d2l.Classifier):
    def __init__(self, encoder, decoder):
        super().__init__()
        self.encoder = encoder
        self.decoder = decoder

    def forward(self, enc_X, dec_X, *args):
        enc_all_outputs = self.encoder(enc_X, *args)
        dec_state = self.decoder.init_state(enc_all_outputs, *args)
        return self.decoder(dec_X, dec_state)[0]
```

```
def init_Sequence2Sequence(module):
    if type(module) == nn.Linear:
         nn.init.xavier_uniform_(module.weight)
    if type(module) == nn.GRU:
        for param in module._flat_weights_names:
            if "weight" in param:
                nn.init.xavier_uniform_(module._parameters[param])

class Sequence2SequenceEncoder(d2l.Encoder):
    def __init__(self, vocab_size, embed_size, num_hiddens, num_layers,
                 dropout=0):
        super().__init__()
        self.embedding = nn.Embedding(vocab_size, embed_size)
        self.rnn = d2l.GRU(embed_size, num_hiddens, num_layers, dropout)
        self.apply(init_Sequence2Sequence)

    def forward(self, X, *args):
        embs = self.embedding(X.t().type(torch.int64))
        outputs, state = self.rnn(embs)
        return outputs, state
```

```
vocab_size, embed_size, num_hiddens, num_layers = 10, 8, 16, 2
batch_size, num_steps = 4, 9
encoder = Sequence2SequenceEncoder(vocab_size, embed_size, num_hiddens, num_layers)
X = torch.zeros((batch_size, num_steps))
enc_outputs, enc_state = encoder(X)
d2l.check_shape(enc_outputs, (num_steps, batch_size, num_hiddens))
```

```
d2l.check_shape(enc_state, (num_layers, batch_size, num_hiddens))
```

```
class Sequence2SequenceDecoder(d2l.Decoder):
    def __init__(self, vocab_size, embed_size, num_hiddens, num_layers,
                 dropout=0):
        super().__init__()
        self.embedding = nn.Embedding(vocab_size, embed_size)
        self.rnn = d2l.GRU(embed_size+num_hiddens, num_hiddens,
                           num_layers, dropout)
        self.dense = nn.LazyLinear(vocab_size)
        self.apply(init_Sequence2Sequence)

    def init_state(self, enc_all_outputs, *args):
        return enc_all_outputs

    def forward(self, X, state):
        embs = self.embedding(X.t().type(torch.int32))
        enc_output, hidden_state = state
        context = enc_output[-1]
        context = context.repeat(embs.shape[0], 1, 1)
        embs_and_context = torch.cat((embs, context), -1)
        outputs, hidden_state = self.rnn(embs_and_context, hidden_state)
        outputs = self.dense(outputs).swapaxes(0, 1)
        return outputs, [enc_output, hidden_state]
```

```
decoder = Sequence2SequenceDecoder(vocab_size, embed_size, num_hiddens, num_layers)
state = decoder.init_state(encoder(X))
dec_outputs, state = decoder(X, state)
d2l.check_shape(dec_outputs, (batch_size, num_steps, vocab_size))
d2l.check_shape(state[1], (num_layers, batch_size, num_hiddens))
```

```
/usr/local/lib/python3.9/dist-packages/torch/nn/modules/lazy.py:180: UserWarning: Lazy m
  warnings.warn('Lazy modules are a new feature under heavy development '
```

```
class Sequence2Sequence(d2l.EncoderDecoder):
    def __init__(self, encoder, decoder, tgt_pad, lr):
        super().__init__(encoder, decoder)
        self.save_hyperparameters()
        self.train_loss = []
        self.val_loss = []
```

```
    def validation_step(self, batch):
        Y_hat = self(*batch[:-1])
        self.plot('loss', self.loss(Y_hat, batch[-1]), train=False)
        self.val_loss.append(self.loss(Y_hat, batch[-1]))

    def configure_optimizers(self):

        return torch.optim.Adam(self.parameters(), lr=self.lr)
```

```
@d2l.add_to_class(Sequence2Sequence)
def loss(self, Y_hat, Y):
    l = super(Sequence2Sequence, self).loss(Y_hat, Y, averaged=False)
    mask = (Y.reshape(-1) != self.tgt_pad).type(torch.float32)
    return (l * mask).sum() / mask.sum()
```

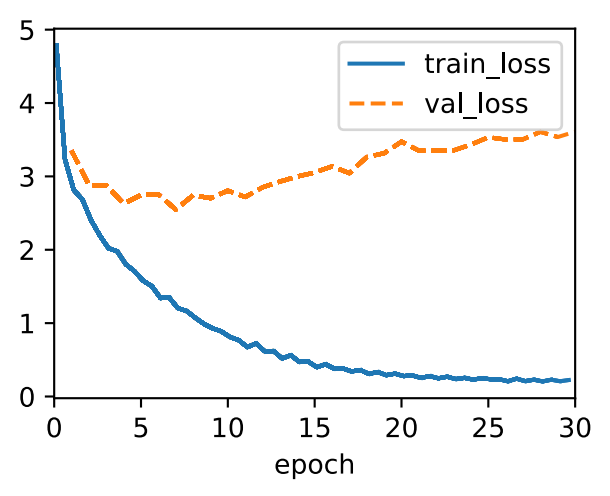
```
data = d2l.MTFraEng(batch_size=128)
```

```
@d2l.add_to_class(d2l.EncoderDecoder)
def predict_step(self, batch, device, num_steps,
                 save_attention_weights=False):
    batch = [a.to(device) for a in batch]
    src, tgt, src_valid_len, _ = batch
    enc_all_outputs = self.encoder(src, src_valid_len)
    dec_state = self.decoder.init_state(enc_all_outputs, src_valid_len)
    outputs, attention_weights = [tgt[:, 0].unsqueeze(1), ], []
    for _ in range(num_steps):
        Y, dec_state = self.decoder(outputs[-1], dec_state)
        outputs.append(Y.argmax(2))
        if save_attention_weights:
            attention_weights.append(self.decoder.attention_weights)
    return torch.cat(outputs[1:], 1), attention_weights
```

```
def bleu(pred_seq, label_seq, k):
    pred_tokens, label_tokens = pred_seq.split(' '), label_seq.split(' ')
    len_pred, len_label = len(pred_tokens), len(label_tokens)
    score = math.exp(min(0, 1 - len_label / len_pred))
    for n in range(1, min(k, len_pred) + 1):
        num_matches, label_subs = 0, collections.defaultdict(int)
        for i in range(len_label - n + 1):
            label_subs[' '.join(label_tokens[i: i + n])] += 1
        for i in range(len_pred - n + 1):
            if label_subs[' '.join(pred_tokens[i: i + n])] > 0:
                num_matches += 1
                label_subs[' '.join(pred_tokens[i: i + n])] -= 1
        score *= math.pow(num_matches / (len_pred - n + 1), math.pow(0.5, n))
    return score
```

Baseline GRU Model

```
embed_size, num_hiddens, num_layers, dropout = 256, 256, 2, 0.2
encoder = Sequence2SequenceEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Sequence2SequenceDecoder(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = Sequence2Sequence(encoder, decoder, tgt_pad=data.tgt_vocab['<pad>'],
                lr=0.005)
trainer = d2l.Trainer(max_epochs=30, gradient_clip_val=1, num_gpus=1)
trainer.fit(model, data)
```




```
model.val_loss[-1]
```

```
tensor(3.2136, device='cuda:0')
```

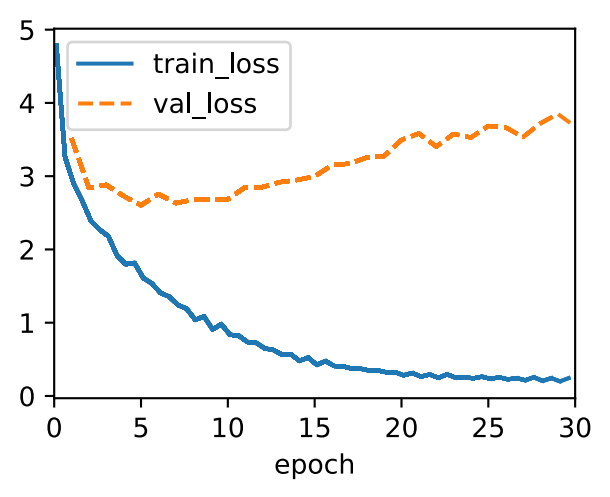
```
engs = ['go .', 'i lost .', 'he\'s calm .', 'i\'m home .']
fras = ['va !', 'j\'ai perdu .', 'il est calme .', 'je suis chez moi .']
preds, _ = model.predict_step(
    data.build(engs, fras), d2l.try_gpu(), data.num_steps)
for en, fr, p in zip(engs, fras, preds):
    translation = []
    for token in data.tgt_vocab.to_tokens(p):
        if token == '<eos>':
            break
        translation.append(token)
    print(f'{en} => {translation}, bleu,'
          f'{bleu(" ".join(translation), fr, k=2):.3f}')
```

```
go . => ['va', '!'], bleu,1.000
i lost . => ["j'ai", 'perdu', '.'], bleu,1.000
he's calm . => ['il', 'court', '.'], bleu,0.000
i'm home . => ['je', 'suis', 'chez', 'moi', '.'], bleu,1.000
```

Part a) Hyperparameter Tuning : Adjust Embed Size, Number of Hidden States,Number of Layers and Dropout

Model 1:) Embed Size = 256 ; Number of Hidden States = 256 ; Dropout = 0.2 ; Number of Layers = 2

```
embed_size, num_hiddens, num_layers, dropout = 256, 256, 2, 0.2
encoder = Sequence2SequenceEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Sequence2SequenceDecoder(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = Sequence2Sequence(encoder, decoder, tgt_pad=data.tgt_vocab['<pad>'],
                lr=0.005)
trainer = d2l.Trainer(max_epochs=30, gradient_clip_val=1, num_gpus=1)
trainer.fit(model, data)
```




```
model.val_loss[-1]
```

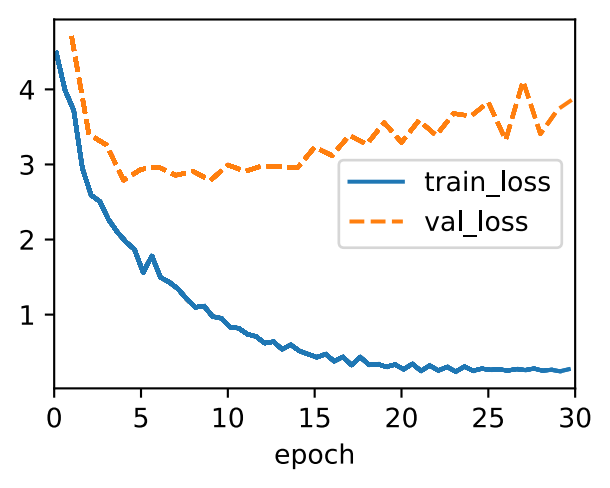
```
tensor(2.7372, device='cuda:0')
```

```
engs = ['go .', 'i lost .', 'he\'s calm .', 'i\'m home .']
fras = ['va !', 'j\'ai perdu .', 'il est calme .', 'je suis chez moi .']
preds, _ = model.predict_step(
    data.build(engs, fras), d2l.try_gpu(), data.num_steps)
for en, fr, p in zip(engs, fras, preds):
    translation = []
    for token in data.tgt_vocab.to_tokens(p):
        if token == '<eos>':
            break
        translation.append(token)
    print(f'{en} => {translation}, bleu,'
          f'{bleu(" ".join(translation), fr, k=2):.3f}')
```

```
go . => ['<unk>', '!'], bleu,0.000
i lost . => ["j'ai", 'perdu', '.'], bleu,1.000
he's calm . => ['il', 'est', 'mouillé', '.'], bleu,0.658
i'm home . => ['je', 'suis', 'chez', 'moi', '.'], bleu,1.000
```

Model 2:) Embed Size = 256 ; Number of Hidden States = 512 ; Dropout = 0.3 ; Number of Layers = 2

```
embed_size, num_hiddens, num_layers, dropout = 256, 512, 2, 0.3
encoder = Sequence2SequenceEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Sequence2SequenceDecoder(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = Sequence2Sequence(encoder, decoder, tgt_pad=data.tgt_vocab['<pad>'],
                lr=0.005)
trainer = d2l.Trainer(max_epochs=30, gradient_clip_val=1, num_gpus=1)
trainer.fit(model, data)
```




```
model.val_loss[-1]
```

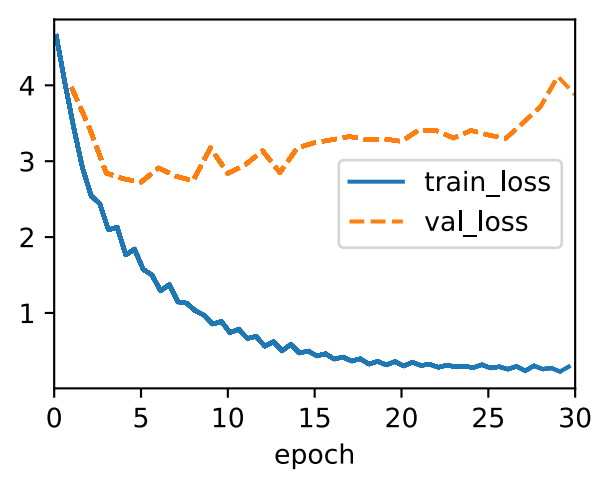
```
tensor(3.2917, device='cuda:0')
```

```
engs = ['go .', 'i lost .', 'he\'s calm .', 'i\'m home .']
fras = ['va !', 'j\'ai perdu .', 'il est calme .', 'je suis chez moi .']
preds, _ = model.predict_step(
    data.build(engs, fras), d2l.try_gpu(), data.num_steps)
for en, fr, p in zip(engs, fras, preds):
    translation = []
    for token in data.tgt_vocab.to_tokens(p):
        if token == '<eos>':
            break
        translation.append(token)
    print(f'{en} => {translation}, bleu,'
          f'{bleu(" ".join(translation), fr, k=2):.3f}')
```

```
go . => ['va', '!'], bleu,1.000
i lost . => ["j'ai", 'perdu', '.'], bleu,1.000
he's calm . => ['il', 'est', 'mouillé', '.'], bleu,0.658
i'm home . => ['je', 'suis', 'chez', 'moi', '.'], bleu,1.000
```

Model 3:) Embed Size = 382 ; Number of Hidden States = 512 ; Dropout = 0.5 ; Number of Layers = 2

```
embed_size, num_hiddens, num_layers, dropout = 382, 512, 2, 0.5
encoder = Sequence2SequenceEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Sequence2SequenceDecoder(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = Sequence2Sequence(encoder, decoder, tgt_pad=data.tgt_vocab['<pad>'],
                lr=0.005)
trainer = d2l.Trainer(max_epochs=30, gradient_clip_val=1, num_gpus=1)
trainer.fit(model, data)
```




```
model.val_loss[-1]
```

```
tensor(2.1235, device='cuda:0')
```

```
engs = ['go .', 'i lost .', 'he\'s calm .', 'i\'m home .']
fras = ['va !', 'j\'ai perdu .', 'il est calme .', 'je suis chez moi .']
preds, _ = model.predict_step(
    data.build(engs, fras), d2l.try_gpu(), data.num_steps)
for en, fr, p in zip(engs, fras, preds):
    translation = []
    for token in data.tgt_vocab.to_tokens(p):
        if token == '<eos>':
            break
        translation.append(token)
    print(f'{en} => {translation}, bleu,'
          f'{bleu(" ".join(translation), fr, k=2):.3f}')
```

```
go . => ['va', '!'], bleu,1.000
i lost . => ["j'ai", 'perdu', '.'], bleu,1.000
he's calm . => ['soyez', 'calmes', '!'], bleu,0.000
i'm home . => ['je', 'suis', 'chez', 'moi', '.'], bleu,1.000
```

Results

We can see that Experiment Models 2 and 3 outperformed the Baseline Model in terms of validation and train loss.

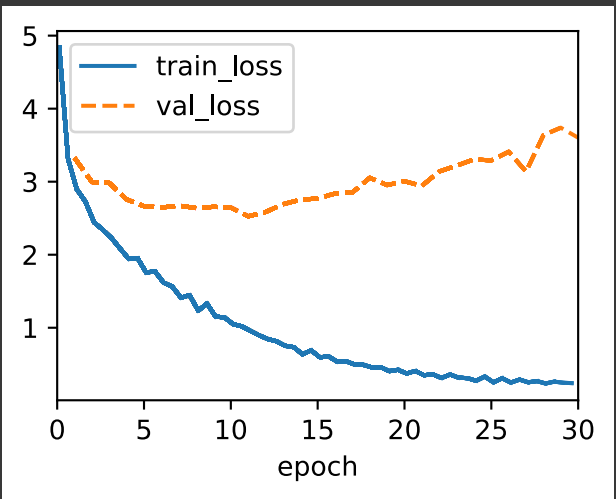
Part b) Please run an experiment for it with 3 layers for encoder and 2 layers for decoder.

```
class Sequence2SequenceEncoder_partb(d2l.Encoder):
    def __init__(self, vocab_size, embed_size, num_hiddens, num_layers,
                 dropout=0):
        super().__init__()
        self.embedding = nn.Embedding(vocab_size, embed_size)
        self.rnn = d2l.GRU(embed_size, num_hiddens, num_layers, dropout)
        self.apply(init_Sequence2Sequence)

    def forward(self, X, *args):
        embs = self.embedding(X.t().type(torch.int64))
        outputs, state = self.rnn(embs)
        return outputs, state

class Sequence2SequenceDecoder_partb(d2l.Decoder):
    def __init__(self, vocab_size, embed_size, num_hiddens, num_layers, dropout=0):
        super().__init__()
        self.embedding = nn.Embedding(vocab_size, embed_size)
        self.rnn = d2l.GRU(embed_size+num_hiddens, num_hiddens, num_layers, dropout)
        self.dense = nn.LazyLinear(vocab_size)
        self.apply(init_Sequence2Sequence)

    def init_state(self, enc_outputs, *args):
        enc_output, hidden_state = enc_outputs
        hidden_state = hidden_state.mean(dim=0, keepdim=True)
        hidden_state = hidden_state.repeat(self.rnn.num_layers, 1, 1)
        return enc_output, hidden_state

    def forward(self, X, state):
        embs = self.embedding(X.t().type(torch.int32))
        enc_output, hidden_state = state
        context = enc_output[-1]
        context = context.repeat(embs.shape[0], 1, 1)
        embs_and_context = torch.cat((embs, context), -1)
        outputs, hidden_state = self.rnn(embs_and_context, hidden_state)
        outputs = self.dense(outputs).swapaxes(0, 1)
        return outputs, [enc_output, hidden_state]
```

```
vocab_size, embed_size, num_hiddens, num_layers = 10, 8, 16, 2
batch_size, num_steps = 4, 9
encoder = Sequence2SequenceEncoder_partb(vocab_size, embed_size, num_hiddens, num_layers)
X = torch.zeros((batch_size, num_steps))
enc_outputs, enc_state = encoder(X)
d2l.check_shape(enc_outputs, (num_steps, batch_size, num_hiddens))
```

```
decoder = Sequence2SequenceDecoder_partb(vocab_size, embed_size, num_hiddens, num_layers)
state = decoder.init_state(encoder(X))
dec_outputs, state = decoder(X, state)
d2l.check_shape(dec_outputs, (batch_size, num_steps, vocab_size))
d2l.check_shape(state[1], (num_layers, batch_size, num_hiddens))
```

```
embed_size, num_hiddens, num_layers, dropout = 256, 256, 2, 0.2
encoder = Sequence2SequenceEncoder_partb(
    len(data.src_vocab), embed_size, num_hiddens, 3, dropout)
decoder = Sequence2SequenceDecoder_partb(
    len(data.tgt_vocab), embed_size, num_hiddens, 2, dropout)
model = Sequence2Sequence(encoder, decoder, tgt_pad=data.tgt_vocab['<pad>'],
                lr=0.005)
trainer = d2l.Trainer(max_epochs=30, gradient_clip_val=1, num_gpus=1)
trainer.fit(model, data)
```




```
model.val_loss[-1]
```

```
tensor(3.9133, device='cuda:0')
```

```
engs = ['go .', 'i lost .', 'he\'s calm .', 'i\'m home .']
fras = ['va !', 'j\'ai perdu .', 'il est calme .', 'je suis chez moi .']
preds, _ = model.predict_step(
    data.build(engs, fras), d2l.try_gpu(), data.num_steps)
for en, fr, p in zip(engs, fras, preds):
    translation = []
```

```
    for token in data.tgt_vocab.to_tokens(p):
        if token == '<eos>':
            break
        translation.append(token)
    print(f'{en} => {translation}, bleu,'
          f'{bleu(" ".join(translation), fr, k=2):.3f}')
```

```
 go . => ['va', '!'], bleu,1.000
 i lost . => ["j'ai", 'perdu', '.'], bleu,1.000
 he's calm . => ['viens', 'ici', '.'], bleu,0.000
 i'm home . => ['je', 'suis', 'chez', 'moi', '.'], bleu,1.000
```

Results

The model with two layers of encoder and two layers of decoder performed poorly as compared to the baseline model, indicating an increase in validation loss of about 0.5.

Part c) Train model by replacing GRU with LSTM

```
class LSTM(d2l.RNN):
    def __init__(self, num_inputs, num_hiddens,num_layers=1,dropout=0):
        d2l.Module.__init__(self)
        self.save_hyperparameters()
        self.rnn = nn.LSTM(num_inputs, num_hiddens,num_layers,dropout=dropout)

    def forward(self, inputs, H_C=None):
        return self.rnn(inputs, H_C)
```

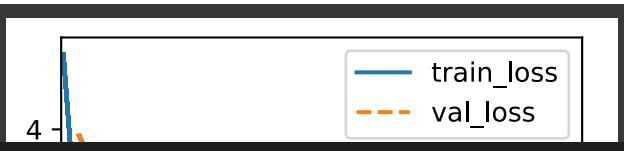
```
class Sequence2SequenceDecoder_LSTM(d2l.Decoder):
    def __init__(self, vocab_size, embed_size, num_hiddens, num_layers,
                 dropout=0):
        super().__init__()
        self.embedding = nn.Embedding(vocab_size, embed_size)
        self.rnn = LSTM(embed_size+num_hiddens, num_hiddens,
                        num_layers, dropout)
        self.dense = nn.LazyLinear(vocab_size)
        self.apply(init_Sequence2Sequence)

    def init_state(self, enc_all_outputs, *args):
        return enc_all_outputs

    def forward(self, X, state):
        embs = self.embedding(X.t().type(torch.int32))
        enc_output, hidden_state = state
        context = enc_output[-1]
        context = context.repeat(embs.shape[0], 1, 1)
        embs_and_context = torch.cat((embs, context), -1)
        outputs, hidden_state = self.rnn(embs_and_context, hidden_state)
```

```
        outputs = self.dense(outputs).swapaxes(0, 1)
        return outputs, [enc_output, hidden_state]

class Sequence2SequenceEncoder_LSTM(d2l.Encoder):
    def __init__(self, vocab_size, embed_size, num_hiddens, num_layers,
                 dropout=0):
        super().__init__()
        self.embedding = nn.Embedding(vocab_size, embed_size)
        self.rnn = LSTM(embed_size, num_hiddens, num_layers, dropout)
        self.apply(init_Sequence2Sequence)

    def forward(self, X, *args):
        embs = self.embedding(X.t().type(torch.int64))
        outputs, state = self.rnn(embs)
        return outputs, state
```

```
vocab_size, embed_size, num_hiddens, num_layers = 10, 8, 16, 2
batch_size, num_steps = 4, 9
encoder = Sequence2SequenceEncoder_LSTM(vocab_size, embed_size, num_hiddens, num_layers)
X = torch.zeros((batch_size, num_steps))
enc_outputs, enc_state = encoder(X)
d2l.check_shape(enc_outputs, (num_steps, batch_size, num_hiddens))
```

```
decoder = Sequence2SequenceDecoder_LSTM(vocab_size, embed_size, num_hiddens, num_layers)
state = decoder.init_state(encoder(X))
dec_outputs, state = decoder(X, state)
d2l.check_shape(dec_outputs, (batch_size, num_steps, vocab_size))
```

```
embed_size, num_hiddens, num_layers, dropout = 384, 512, 3, 0.3
encoder = Sequence2SequenceEncoder_LSTM(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Sequence2SequenceDecoder_LSTM(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = Sequence2Sequence(encoder, decoder, tgt_pad=data.tgt_vocab['<pad>'],
                lr=0.005)
trainer = d2l.Trainer(max_epochs=30, gradient_clip_val=1, num_gpus=1)
trainer.fit(model, data)
```




```
model.val_loss[-1]
```

```
tensor(2.7101, device='cuda:0')
```

```
engs = ['go .', 'i lost .', 'he\'s calm .', 'i\'m home .']
fras = ['va !', 'j\'ai perdu .', 'il est calme .', 'je suis chez moi .']
preds, _ = model.predict_step(
    data.build(engs, fras), d2l.try_gpu(), data.num_steps)
for en, fr, p in zip(engs, fras, preds):
    translation = []
    for token in data.tgt_vocab.to_tokens(p):
        if token == '<eos>':
            break
        translation.append(token)
    print(f'{en} => {translation}, bleu,'
          f'{bleu(" ".join(translation), fr, k=2):.3f}')
```

```
go . => ['<unk>', '!'], bleu,0.000
i lost . => ['je', 'suis', '<unk>', '.'], bleu,0.000
he's calm . => ['<unk>', '<unk>', '.'], bleu,0.000
i'm home . => ['je', 'suis', '<unk>', '.'], bleu,0.512
```

Results

The Baseline GRU model gave a better perfomance than the LSTM model with a minimal difference in the validation and training loss values.

Problem 2) Bahdanau Attention Mechanism

Part a) Explores Layers with 1,2,3,4

```
class AttentionDecoder(d2l.Decoder):
    def __init__(self):
        super().__init__()

    @property
    def attention_weights(self):
        raise NotImplementedError
```

```
class Sequence2SequenceAttentionDecoder(AttentionDecoder):
    def __init__(self, vocab_size, embed_size, num_hiddens, num_layers,
                 dropout=0):
```

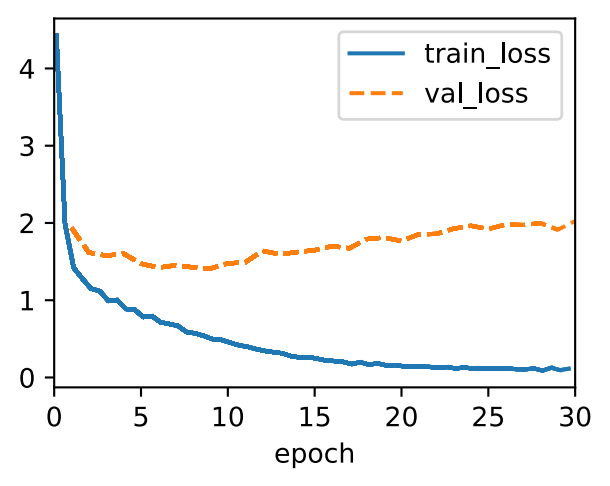
```
        super().__init__()
        self.attention = d2l.AdditiveAttention(num_hiddens, dropout)
        self.embedding = nn.Embedding(vocab_size, embed_size)
        self.rnn = nn.GRU(
            embed_size + num_hiddens, num_hiddens, num_layers,
            dropout=dropout)
        self.dense = nn.LazyLinear(vocab_size)
        self.apply(d2l.init_Sequence2Sequence)

    def init_state(self, enc_outputs, enc_valid_lens):
        outputs, hidden_state = enc_outputs
        return (outputs.permute(1, 0, 2), hidden_state, enc_valid_lens)

    def forward(self, X, state):
        enc_outputs, hidden_state, enc_valid_lens = state
        X = self.embedding(X).permute(1, 0, 2)
        outputs, self._attention_weights = [], []
        for x in X:
            query = torch.unsqueeze(hidden_state[-1], dim=1)
            context = self.attention(
                query, enc_outputs, enc_outputs, enc_valid_lens)
            x = torch.cat((context, torch.unsqueeze(x, dim=1)), dim=-1)
            out, hidden_state = self.rnn(x.permute(1, 0, 2), hidden_state)
            outputs.append(out)
            self._attention_weights.append(self.attention.attention_weights)
        outputs = self.dense(torch.cat(outputs, dim=0))
        return outputs.permute(1, 0, 2), [enc_outputs, hidden_state,
                                          enc_valid_lens]

    @property
    def attention_weights(self):
        return self._attention_weights
```

```
vocab_size, embed_size, num_hiddens, num_layers = 10, 8, 16, 2
batch_size, num_steps = 4, 7
encoder = d2l.Sequence2SequenceEncoder(vocab_size, embed_size, num_hiddens, num_layers)
decoder = Sequence2SequenceAttentionDecoder(vocab_size, embed_size, num_hiddens,
                                  num_layers)
X = torch.zeros((batch_size, num_steps), dtype=torch.long)
state = decoder.init_state(encoder(X), None)
output, state = decoder(X, state)
d2l.check_shape(output, (batch_size, num_steps, vocab_size))
d2l.check_shape(state[0], (batch_size, num_steps, num_hiddens))
d2l.check_shape(state[1][0], (batch_size, num_hiddens))
```

Baseline Model : 2 Layers

```
data = d2l.MTFraEng(batch_size=128)
embed_size, num_hiddens, num_layers, dropout = 256, 256, 2, 0.2
```

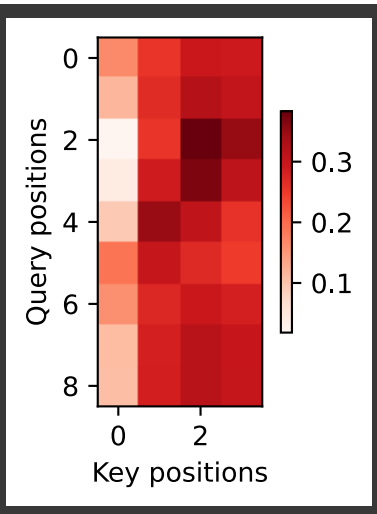
```
encoder = d2l.Sequence2SequenceEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Sequence2SequenceAttentionDecoder(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = d2l.Sequence2Sequence(encoder, decoder, tgt_pad=data.tgt_vocab['<pad>'],
                      lr=0.005)
trainer = d2l.Trainer(max_epochs=30, gradient_clip_val=1, num_gpus=1)
trainer.fit(model, data)
```




```
engs = ['go .', 'i lost .', 'he\'s calm .', 'i\'m home .']
fras = ['va !', 'j\'ai perdu .', 'il est calme .', 'je suis chez moi .']
preds, _ = model.predict_step(
    data.build(engs, fras), d2l.try_gpu(), data.num_steps)
for en, fr, p in zip(engs, fras, preds):
    translation = []
    for token in data.tgt_vocab.to_tokens(p):
        if token == '<eos>':
            break
        translation.append(token)
    print(f'{en} => {translation}, bleu,'
          f'{d2l.bleu(" ".join(translation), fr, k=2):.3f}')
```

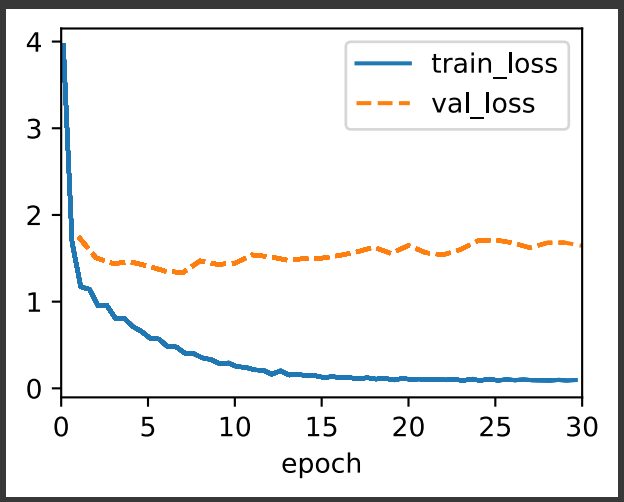
```
go . => ['va', '!'], bleu,1.000
i lost . => ["j'ai", 'perdu', '.'], bleu,1.000
he's calm . => ['je', 'suis', 'calme', '.'], bleu,0.537
i'm home . => ['je', 'suis', 'chez', 'moi', '.'], bleu,1.000
```

```
_, dec_attention_weights = model.predict_step(
    data.build([engs[-1]], [fras[-1]]), d2l.try_gpu(), data.num_steps, True)
attention_weights = torch.cat(
    [step[0][0][0] for step in dec_attention_weights], 0)
attention_weights = attention_weights.reshape((1, 1, -1, data.num_steps))

d2l.show_heatmaps(
    attention_weights[:, :, :, :len(engs[-1].split()) + 1].cpu(),
    xlabel='Key positions', ylabel='Query positions')
```



Sample Model : 1 Layer

```
data = d2l.MTFraEng(batch_size=128)
embed_size, num_hiddens, num_layers, dropout = 256, 256, 1, 0.2
encoder = d2l.Sequence2SequenceEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Sequence2SequenceAttentionDecoder(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = d2l.Sequence2Sequence(encoder, decoder, tgt_pad=data.tgt_vocab['<pad>'],
                      lr=0.005)
trainer = d2l.Trainer(max_epochs=30, gradient_clip_val=1, num_gpus=1)
trainer.fit(model, data)
```

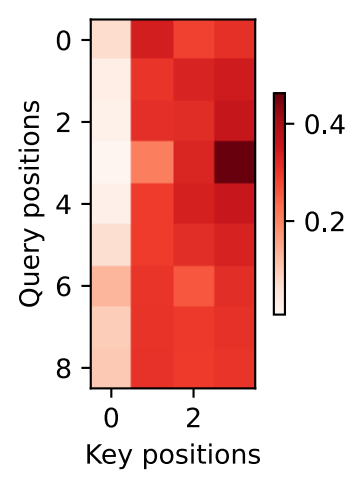



```
engs = ['go .', 'i lost .', 'he\'s calm .', 'i\'m home .']
fras = ['va !', 'j\'ai perdu .', 'il est calme .', 'je suis chez moi .']
preds, _ = model.predict_step(
    data.build(engs, fras), d2l.try_gpu(), data.num_steps)
for en, fr, p in zip(engs, fras, preds):
    translation = []
    for token in data.tgt_vocab.to_tokens(p):
        if token == '<eos>':
```

```
            break
        translation.append(token)
    print(f'{en} => {translation}, bleu,'
          f'{d2l.bleu(" ".join(translation), fr, k=2):.3f}')
```

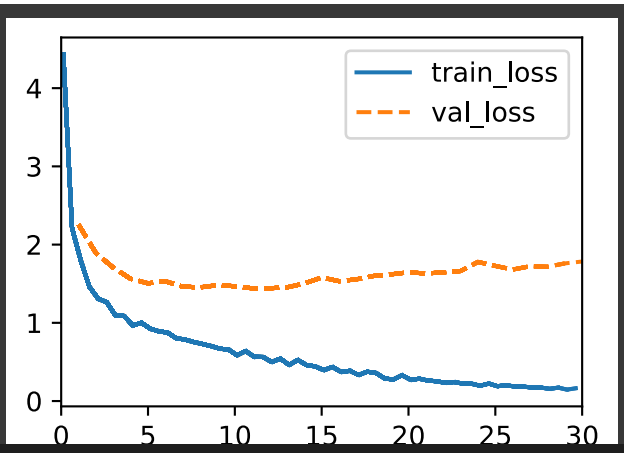
```
go . => ['va', '!'], bleu,1.000
i lost . => ["j'ai", 'perdu', '.'], bleu,1.000
he's calm . => ['<unk>', '.'], bleu,0.000
i'm home . => ['je', 'suis', 'chez', 'moi', '.'], bleu,1.000
```

```
_, dec_attention_weights = model.predict_step(
    data.build([engs[-1]], [fras[-1]]), d2l.try_gpu(), data.num_steps, True)
attention_weights = torch.cat(
    [step[0][0][0] for step in dec_attention_weights], 0)
attention_weights = attention_weights.reshape((1, 1, -1, data.num_steps))

d2l.show_heatmaps(
    attention_weights[:, :, :, :len(engs[-1].split()) + 1].cpu(),
    xlabel='Key positions', ylabel='Query positions')
```



Sample Model : 3 Layers

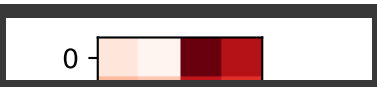
```
data = d2l.MTFraEng(batch_size=128)
embed_size, num_hiddens, num_layers, dropout = 256, 256, 3, 0.2
encoder = d2l.Sequence2SequenceEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Sequence2SequenceAttentionDecoder(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = d2l.Sequence2Sequence(encoder, decoder, tgt_pad=data.tgt_vocab['<pad>'],
                      lr=0.005)
trainer = d2l.Trainer(max_epochs=30, gradient_clip_val=1, num_gpus=1)
trainer.fit(model, data)
```




```
engs = ['go .', 'i lost .', 'he\'s calm .', 'i\'m home .']
fras = ['va !', 'j\'ai perdu .', 'il est calme .', 'je suis chez moi .']
preds, _ = model.predict_step(
    data.build(engs, fras), d2l.try_gpu(), data.num_steps)
for en, fr, p in zip(engs, fras, preds):
    translation = []
    for token in data.tgt_vocab.to_tokens(p):
        if token == '<eos>':
            break
        translation.append(token)
    print(f'{en} => {translation}, bleu,'
          f'{d2l.bleu(" ".join(translation), fr, k=2):.3f}')
```

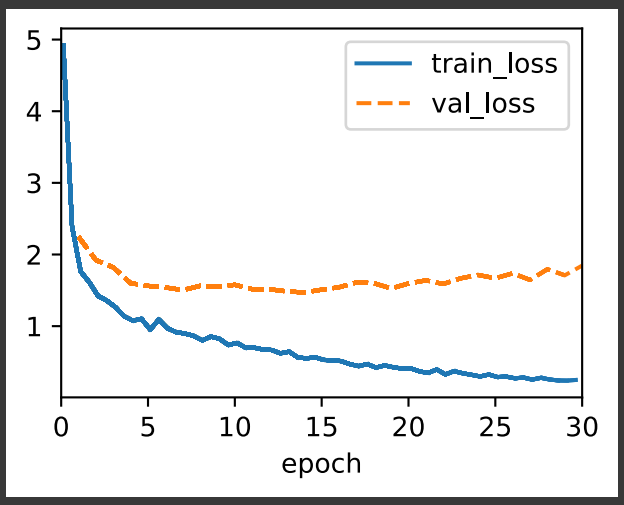
```
go . => ['poursuis', '.'], bleu,0.000
i lost . => ["j'ai", 'perdu', '.'], bleu,1.000
he's calm . => ['il', 'est', 'mouillé', '.'], bleu,0.658
i'm home . => ['je', 'suis', 'malade', '.'], bleu,0.512
```

```
_, dec_attention_weights = model.predict_step(
    data.build([engs[-1]], [fras[-1]]), d2l.try_gpu(), data.num_steps, True)
attention_weights = torch.cat(
    [step[0][0][0] for step in dec_attention_weights], 0)
attention_weights = attention_weights.reshape((1, 1, -1, data.num_steps))
d2l.show_heatmaps(
    attention_weights[:, :, :, :len(engs[-1].split()) + 1].cpu(),
    xlabel='Key positions', ylabel='Query positions')
```



Sample Model : 4 Layers


```
data = d2l.MTFraEng(batch_size=128)
embed_size, num_hiddens, num_layers, dropout = 256, 256, 4, 0.2
encoder = d2l.Sequence2SequenceEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Sequence2SequenceAttentionDecoder(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = d2l.Sequence2Sequence(encoder, decoder, tgt_pad=data.tgt_vocab['<pad>'],
                      lr=0.005)
trainer = d2l.Trainer(max_epochs=30, gradient_clip_val=1, num_gpus=1)
trainer.fit(model, data)
```

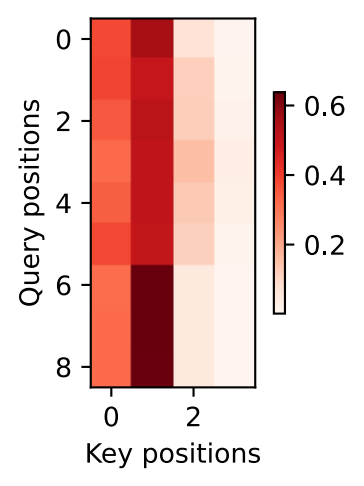



```
engs = ['go .', 'i lost .', 'he\'s calm .', 'i\'m home .']
fras = ['va !', 'j\'ai perdu .', 'il est calme .', 'je suis chez moi .']
preds, _ = model.predict_step(
    data.build(engs, fras), d2l.try_gpu(), data.num_steps)
for en, fr, p in zip(engs, fras, preds):
    translation = []
    for token in data.tgt_vocab.to_tokens(p):
        if token == '<eos>':
            break
        translation.append(token)
    print(f'{en} => {translation}, bleu,'
          f'{d2l.bleu(" ".join(translation), fr, k=2):.3f}')
```

```
go . => ['va', '!'], bleu,1.000
i lost . => ['je', 'suis', 'tombé', '.'], bleu,0.000
he's calm . => ['je', '<unk>', '.'], bleu,0.000
i'm home . => ['je', 'vais', 'bien', '.'], bleu,0.000
```

```
_, dec_attention_weights = model.predict_step(
    data.build([engs[-1]], [fras[-1]]), d2l.try_gpu(), data.num_steps, True)
```

```
attention_weights = torch.cat(
    [step[0][0][0] for step in dec_attention_weights], 0)
attention_weights = attention_weights.reshape((1, 1, -1, data.num_steps))
d2l.show_heatmaps(
    attention_weights[:, :, :, :len(engs[-1].split()) + 1].cpu(),
    xlabel='Key positions', ylabel='Query positions')
```



Results

Since both the validation loss and training loss increased as the number of layers increased from 1 to 4, the performance was pretty bad.Despite the fact that there are differences in correlations with a change in the number of layers in the attention weights matrices.

Part b) Train model by replacing GRU with LSTM

```
class Sequence2SequenceAttentionDecoder_LSTM(AttentionDecoder):
    def __init__(self, vocab_size, embed_size, num_hiddens, num_layers,
                 dropout=0):
        super().__init__()
        self.attention = d2l.AdditiveAttention(num_hiddens, dropout)
        self.embedding = nn.Embedding(vocab_size, embed_size)
        self.rnn = nn.LSTM(
            embed_size + num_hiddens, num_hiddens, num_layers,
            dropout=dropout)
        self.dense = nn.LazyLinear(vocab_size)
        self.apply(d2l.init_Sequence2Sequence)

    def init_state(self, enc_outputs, enc_valid_lens):
        outputs, hidden_state = enc_outputs
        cell_state = hidden_state.new_zeros(hidden_state.shape)
        return (outputs.permute(1, 0, 2), (hidden_state, cell_state), enc_valid_lens)
    def forward(self, X, state):
        enc_outputs, hidden_and_cell_state, enc_valid_lens = state
```

```
        X = self.embedding(X).permute(1, 0, 2)
        outputs, self._attention_weights = [], []
        for x in X:
            query = torch.unsqueeze(hidden_and_cell_state[0][-1], dim=1)
            context = self.attention(
                query, enc_outputs, enc_outputs, enc_valid_lens)
            x = torch.cat((context, torch.unsqueeze(x, dim=1)), dim=-1)
            out, hidden_and_cell_state = self.rnn(x.permute(1, 0, 2), hidden_and_cell_state)
            outputs.append(out)
            self._attention_weights.append(self.attention.attention_weights)
        outputs = self.dense(torch.cat(outputs, dim=0))
        return outputs.permute(1, 0, 2), [enc_outputs, hidden_and_cell_state,
                                          enc_valid_lens]

    @property
    def attention_weights(self):
        return self._attention_weights
```

```
vocab_size, embed_size, num_hiddens, num_layers = 10, 8, 16, 2
batch_size, num_steps = 4, 7
encoder = d2l.Sequence2SequenceEncoder(vocab_size, embed_size, num_hiddens, num_layers)
decoder = Sequence2SequenceAttentionDecoder_LSTM(vocab_size, embed_size, num_hiddens,
                                    num_layers)
X = torch.zeros((batch_size, num_steps), dtype=torch.long)
state = decoder.init_state(encoder(X), None)
output, state = decoder(X, state)
d2l.check_shape(output, (batch_size, num_steps, vocab_size))
d2l.check_shape(state[0], (batch_size, num_steps, num_hiddens))
```

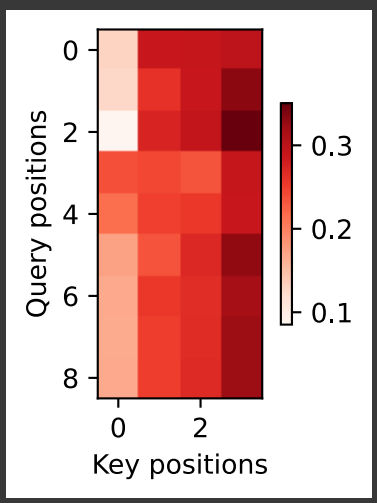
Baseline Model : 2 Layers

```
data = d2l.MTFraEng(batch_size=128)
embed_size, num_hiddens, num_layers, dropout = 256, 256, 2, 0.2
encoder = d2l.Sequence2SequenceEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Sequence2SequenceAttentionDecoder_LSTM(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = d2l.Sequence2Sequence(encoder, decoder, tgt_pad=data.tgt_vocab['<pad>'],
                    lr=0.005)
trainer = d2l.Trainer(max_epochs=30, gradient_clip_val=1, num_gpus=1)
trainer.fit(model, data)
```


```
engs = ['go .', 'i lost .', 'he\'s calm .', 'i\'m home .']
fras = ['va !', 'j\'ai perdu .', 'il est calme .', 'je suis chez moi .']
preds, _ = model.predict_step(
    data.build(engs, fras), d2l.try_gpu(), data.num_steps)
for en, fr, p in zip(engs, fras, preds):
    translation = []
    for token in data.tgt_vocab.to_tokens(p):
        if token == '<eos>':
            break
        translation.append(token)
    print(f'{en} => {translation}, bleu,'
          f'{d2l.bleu(" ".join(translation), fr, k=2):.3f}')
```

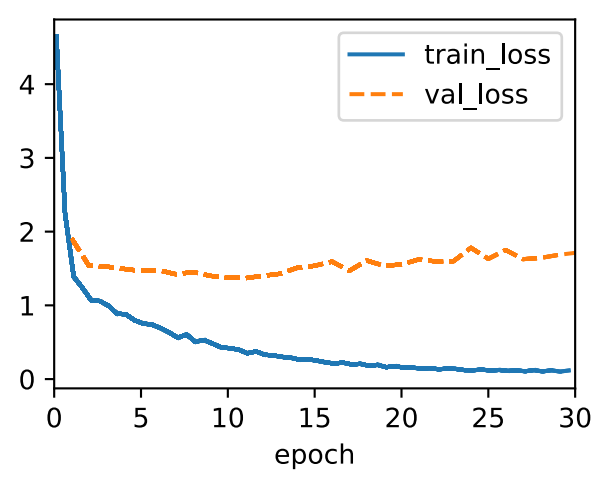
```
go . => ['va', '!'], bleu,1.000
i lost . => ["j'ai", 'perdu', '.'], bleu,1.000
he's calm . => ['elle', 'est', 'mouillé', '.'], bleu,0.000
i'm home . => ['je', 'suis', 'juste', '.'], bleu,0.512
```

```
_, dec_attention_weights = model.predict_step(
    data.build([engs[-1]], [fras[-1]]), d2l.try_gpu(), data.num_steps, True)
attention_weights = torch.cat(
    [step[0][0][0] for step in dec_attention_weights], 0)
attention_weights = attention_weights.reshape((1, 1, -1, data.num_steps))
d2l.show_heatmaps(
    attention_weights[:, :, :, :len(engs[-1].split()) + 1].cpu(),
    xlabel='Key positions', ylabel='Query positions')
```



Experiment Model : 1 Layers

```
data = d2l.MTFraEng(batch_size=128)
embed_size, num_hiddens, num_layers, dropout = 256, 256, 1, 0.2
encoder = d2l.Sequence2SequenceEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Sequence2SequenceAttentionDecoder_LSTM(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = d2l.Sequence2Sequence(encoder, decoder, tgt_pad=data.tgt_vocab['<pad>'],
                    lr=0.005)
trainer = d2l.Trainer(max_epochs=30, gradient_clip_val=1, num_gpus=1)
trainer.fit(model, data)
```

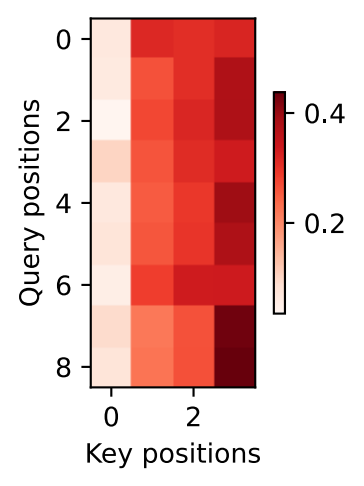



```
engs = ['go .', 'i lost .', 'he\'s calm .', 'i\'m home .']
fras = ['va !', 'j\'ai perdu .', 'il est calme .', 'je suis chez moi .']
preds, _ = model.predict_step(
    data.build(engs, fras), d2l.try_gpu(), data.num_steps)
for en, fr, p in zip(engs, fras, preds):
    translation = []
    for token in data.tgt_vocab.to_tokens(p):
        if token == '<eos>':
            break
        translation.append(token)
    print(f'{en} => {translation}, bleu,'
          f'{d2l.bleu(" ".join(translation), fr, k=2):.3f}')
```

```
go . => ['va', '!'], bleu,1.000
i lost . => ["j'ai", 'perdu', '.'], bleu,1.000
he's calm . => ['<unk>', '.'], bleu,0.000
i'm home . => ['je', 'suis', 'chez', 'moi', '.'], bleu,1.000
```

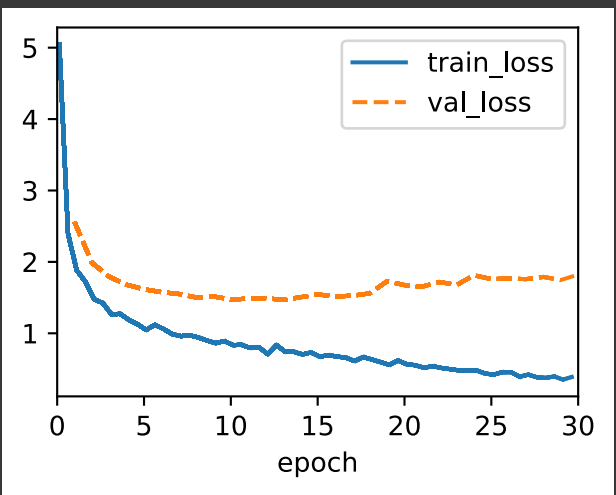
```
_, dec_attention_weights = model.predict_step(
    data.build([engs[-1]], [fras[-1]]), d2l.try_gpu(), data.num_steps, True)
attention_weights = torch.cat(
    [step[0][0][0] for step in dec_attention_weights], 0)
attention_weights = attention_weights.reshape((1, 1, -1, data.num_steps))
d2l.show_heatmaps(
```

```
    attention_weights[:, :, :, :len(engs[-1].split()) + 1].cpu(),
    xlabel='Key positions', ylabel='Query positions')
```



Experiment Model : 3 Layers

```
data = d2l.MTFraEng(batch_size=128)
embed_size, num_hiddens, num_layers, dropout = 256, 256, 3, 0.2
encoder = d2l.Sequence2SequenceEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Sequence2SequenceAttentionDecoder_LSTM(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = d2l.Sequence2Sequence(encoder, decoder, tgt_pad=data.tgt_vocab['<pad>'],
                      lr=0.005)
trainer = d2l.Trainer(max_epochs=30, gradient_clip_val=1, num_gpus=1)
trainer.fit(model, data)
```

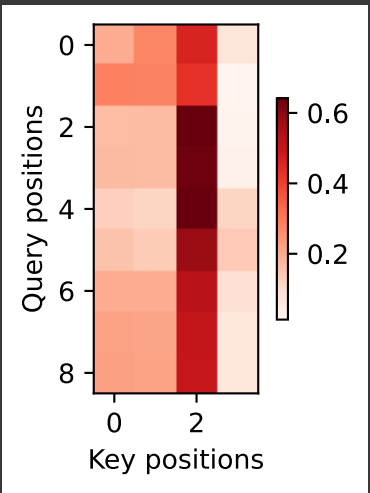



```
engs = ['go .', 'i lost .', 'he\'s calm .', 'i\'m home .']
fras = ['va !', 'j\'ai perdu .', 'il est calme .', 'je suis chez moi .']
preds, _ = model.predict_step(
    data.build(engs, fras), d2l.try_gpu(), data.num_steps)
for en, fr, p in zip(engs, fras, preds):
```

```
    translation = []
    for token in data.tgt_vocab.to_tokens(p):
        if token == '<eos>':
            break
        translation.append(token)
    print(f'{en} => {translation}, bleu,'
          f'{d2l.bleu(" ".join(translation), fr, k=2):.3f}')
```

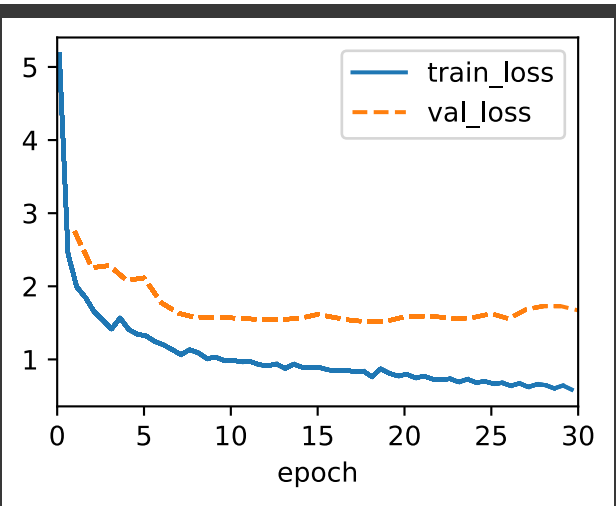
```
 go . => ['<unk>', 'à', 'la', 'maison', '.'], bleu,0.000
 i lost . => ["j'ai", '<unk>', '.'], bleu,0.000
 he's calm . => ['il', 'est', '<unk>', '.'], bleu,0.658
 i'm home . => ['je', 'suis', '<unk>', '.'], bleu,0.512
```

```
_, dec_attention_weights = model.predict_step(
    data.build([engs[-1]], [fras[-1]]), d2l.try_gpu(), data.num_steps, True)
attention_weights = torch.cat(
    [step[0][0][0] for step in dec_attention_weights], 0)
attention_weights = attention_weights.reshape((1, 1, -1, data.num_steps))
d2l.show_heatmaps(
    attention_weights[:, :, :, :len(engs[-1].split()) + 1].cpu(),
    xlabel='Key positions', ylabel='Query positions')
```



Experiment Model : 4 Layers

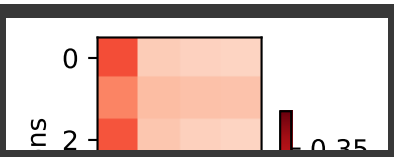
```
data = d2l.MTFraEng(batch_size=128)
embed_size, num_hiddens, num_layers, dropout = 256, 256, 4, 0.2
encoder = d2l.Sequence2SequenceEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Sequence2SequenceAttentionDecoder_LSTM(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = d2l.Sequence2Sequence(encoder, decoder, tgt_pad=data.tgt_vocab['<pad>'],
                    lr=0.005)
trainer = d2l.Trainer(max_epochs=30, gradient_clip_val=1, num_gpus=1)
trainer.fit(model, data)
```




```
engs = ['go .', 'i lost .', 'he\'s calm .', 'i\'m home .']
fras = ['va !', 'j\'ai perdu .', 'il est calme .', 'je suis chez moi .']
preds, _ = model.predict_step(
    data.build(engs, fras), d2l.try_gpu(), data.num_steps)
for en, fr, p in zip(engs, fras, preds):
    translation = []
    for token in data.tgt_vocab.to_tokens(p):
        if token == '<eos>':
            break
        translation.append(token)
    print(f'{en} => {translation}, bleu,'
          f'{d2l.bleu(" ".join(translation), fr, k=2):.3f}')
```

```
go . => ['<unk>', '!'], bleu,0.000
i lost . => ['je', 'suis', '<unk>', '.'], bleu,0.000
he's calm . => ['<unk>', '.'], bleu,0.000
i'm home . => ['je', 'suis', '<unk>', '.'], bleu,0.512
```

```
_, dec_attention_weights = model.predict_step(
    data.build([engs[-1]], [fras[-1]]), d2l.try_gpu(), data.num_steps, True)
attention_weights = torch.cat(
    [step[0][0][0] for step in dec_attention_weights], 0)
attention_weights = attention_weights.reshape((1, 1, -1, data.num_steps))
d2l.show_heatmaps(
    attention_weights[:, :, :, :len(engs[-1].split()) + 1].cpu(),
    xlabel='Key positions', ylabel='Query positions')
```



Results

The LSTM model performed similarly to the GRU model when its number of layers was increased from 1 to 4. Despite the fact that the attention weights matrices reveal different associations with a change in layer count.

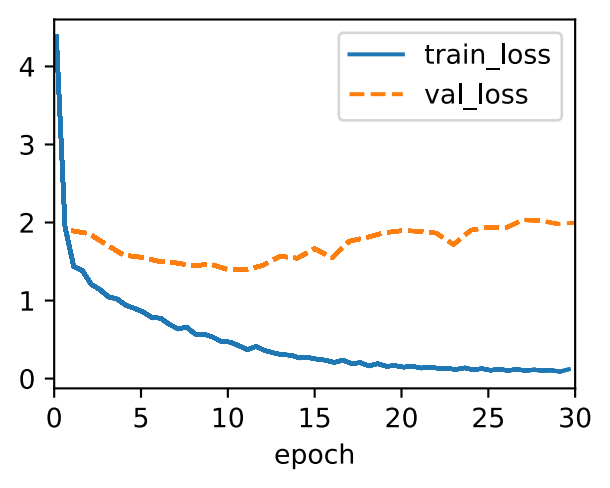
Problem 3) Replace Bahdanau Attention with Luong Attention [BONUS Question]

```
class Sequence2SequenceAttentionDecoder(AttentionDecoder):
    def __init__(self, vocab_size, embed_size, num_hiddens, num_layers,
                 dropout=0):
        super().__init__()
        self.attention = d2l.DotProductAttention(dropout)
        self.embedding = nn.Embedding(vocab_size, embed_size)
        self.rnn = nn.GRU(
            embed_size + num_hiddens, num_hiddens, num_layers,
            dropout=dropout)
        self.dense = nn.LazyLinear(vocab_size)
        self.apply(d2l.init_Sequence2Sequence)

    def init_state(self, enc_outputs, enc_valid_lens):
        outputs, hidden_state = enc_outputs
        return (outputs.permute(1, 0, 2), hidden_state, enc_valid_lens)

    def forward(self, X, state):
        enc_outputs, hidden_state, enc_valid_lens = state
        X = self.embedding(X).permute(1, 0, 2)
        outputs, self._attention_weights = [], []
        for x in X:
            query = torch.unsqueeze(hidden_state[-1], dim=1)
            context = self.attention(
                query, enc_outputs, enc_outputs, enc_valid_lens)
            x = torch.cat((context, torch.unsqueeze(x, dim=1)), dim=-1)
            out, hidden_state = self.rnn(x.permute(1, 0, 2), hidden_state)
            outputs.append(out)
            self._attention_weights.append(self.attention.attention_weights)
        outputs = self.dense(torch.cat(outputs, dim=0))
        return outputs.permute(1, 0, 2), [enc_outputs, hidden_state,
                                          enc_valid_lens]

    @property
    def attention_weights(self):
        return self._attention_weights
```

```
vocab_size, embed_size, num_hiddens, num_layers = 10, 8, 16, 2
batch_size, num_steps = 4, 7
encoder = d2l.Sequence2SequenceEncoder(vocab_size, embed_size, num_hiddens, num_layers)
decoder = Sequence2SequenceAttentionDecoder(vocab_size, embed_size, num_hiddens,
                                  num_layers)
X = torch.zeros((batch_size, num_steps), dtype=torch.long)
state = decoder.init_state(encoder(X), None)
output, state = decoder(X, state)
d2l.check_shape(output, (batch_size, num_steps, vocab_size))
d2l.check_shape(state[0], (batch_size, num_steps, num_hiddens))
d2l.check_shape(state[1][0], (batch_size, num_hiddens))
```

Baseline Model : 2 Layers

```
data = d2l.MTFraEng(batch_size=128)
embed_size, num_hiddens, num_layers, dropout = 256, 256, 2, 0.2
encoder = d2l.Sequence2SequenceEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Sequence2SequenceAttentionDecoder(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = d2l.Sequence2Sequence(encoder, decoder, tgt_pad=data.tgt_vocab['<pad>'],
                    lr=0.005)
trainer = d2l.Trainer(max_epochs=30, gradient_clip_val=1, num_gpus=1)
trainer.fit(model, data)
```

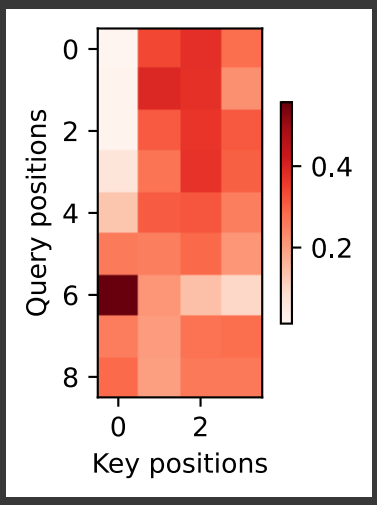



```
engs = ['go .', 'i lost .', 'he\'s calm .', 'i\'m home .']
fras = ['va !', 'j\'ai perdu .', 'il est calme .', 'je suis chez moi .']
preds, _ = model.predict_step(
    data.build(engs, fras), d2l.try_gpu(), data.num_steps)
for en, fr, p in zip(engs, fras, preds):
    translation = []
    for token in data.tgt_vocab.to_tokens(p):
        if token == '<eos>':
            break
```

```
        translation.append(token)
    print(f'{en} => {translation}, bleu,'
          f'{d2l.bleu(" ".join(translation), fr, k=2):.3f}')
```

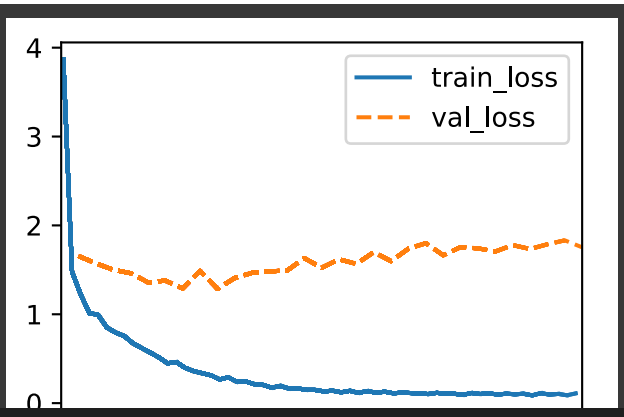
```
go . => ['va', '!'], bleu,1.000
i lost . => ["j'ai", 'perdu', '.'], bleu,1.000
he's calm . => ['il', 'est', 'mouillé', '.'], bleu,0.658
i'm home . => ['je', 'suis', 'chez', 'moi', '.'], bleu,1.000
```

```
_, dec_attention_weights = model.predict_step(
    data.build([engs[-1]], [fras[-1]]), d2l.try_gpu(), data.num_steps, True)
attention_weights = torch.cat(
    [step[0][0][0] for step in dec_attention_weights], 0)
attention_weights = attention_weights.reshape((1, 1, -1, data.num_steps))

d2l.show_heatmaps(
    attention_weights[:, :, :, :len(engs[-1].split()) + 1].cpu(),
    xlabel='Key positions', ylabel='Query positions')
```



Experiment Model : 1 Layers

```
data = d2l.MTFraEng(batch_size=128)
embed_size, num_hiddens, num_layers, dropout = 256, 256, 1, 0.2
encoder = d2l.Sequence2SequenceEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Sequence2SequenceAttentionDecoder(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = d2l.Sequence2Sequence(encoder, decoder, tgt_pad=data.tgt_vocab['<pad>'],
                      lr=0.005)
trainer = d2l.Trainer(max_epochs=30, gradient_clip_val=1, num_gpus=1)
trainer.fit(model, data)
```



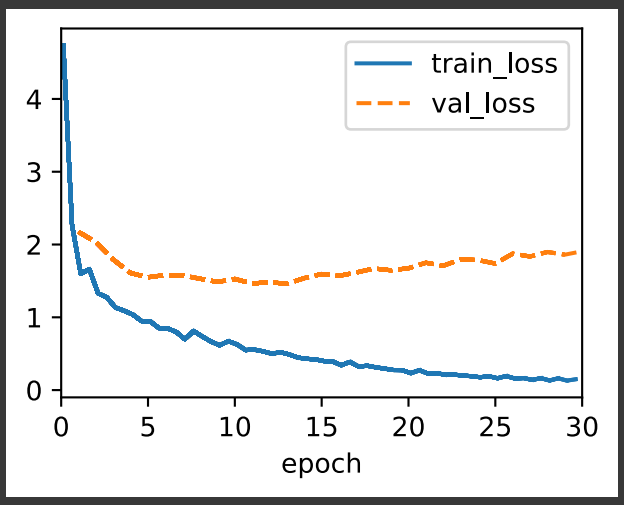

```
engs = ['go .', 'i lost .', 'he\'s calm .', 'i\'m home .']
fras = ['va !', 'j\'ai perdu .', 'il est calme .', 'je suis chez moi .']
preds, _ = model.predict_step(
    data.build(engs, fras), d2l.try_gpu(), data.num_steps)
for en, fr, p in zip(engs, fras, preds):
    translation = []
    for token in data.tgt_vocab.to_tokens(p):
        if token == '<eos>':
            break
        translation.append(token)
    print(f'{en} => {translation}, bleu,'
          f'{d2l.bleu(" ".join(translation), fr, k=2):.3f}')
```

```
go . => ['va', '!'], bleu,1.000
i lost . => ["j'ai", 'perdu', '.'], bleu,1.000
he's calm . => ['je', 'suis', 'calme', '.'], bleu,0.537
i'm home . => ['je', 'suis', 'chez', 'moi', '.'], bleu,1.000
```

```
_, dec_attention_weights = model.predict_step(
    data.build([engs[-1]], [fras[-1]]), d2l.try_gpu(), data.num_steps, True)
attention_weights = torch.cat(
    [step[0][0][0] for step in dec_attention_weights], 0)
attention_weights = attention_weights.reshape((1, 1, -1, data.num_steps))

d2l.show_heatmaps(
    attention_weights[:, :, :, :len(engs[-1].split()) + 1].cpu(),
    xlabel='Key positions', ylabel='Query positions')
```

Experiment Model : 3 Layers

```
data = d2l.MTFraEng(batch_size=128)
embed_size, num_hiddens, num_layers, dropout = 256, 256, 3, 0.2
encoder = d2l.Sequence2SequenceEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Sequence2SequenceAttentionDecoder(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = d2l.Sequence2Sequence(encoder, decoder, tgt_pad=data.tgt_vocab['<pad>'],
                      lr=0.005)
trainer = d2l.Trainer(max_epochs=30, gradient_clip_val=1, num_gpus=1)
trainer.fit(model, data)
```

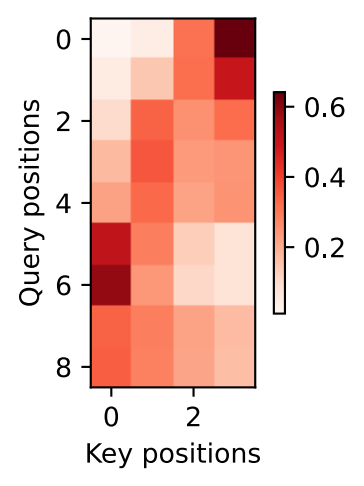



```
engs = ['go .', 'i lost .', 'he\'s calm .', 'i\'m home .']
fras = ['va !', 'j\'ai perdu .', 'il est calme .', 'je suis chez moi .']
preds, _ = model.predict_step(
    data.build(engs, fras), d2l.try_gpu(), data.num_steps)
for en, fr, p in zip(engs, fras, preds):
    translation = []
    for token in data.tgt_vocab.to_tokens(p):
        if token == '<eos>':
            break
        translation.append(token)
    print(f'{en} => {translation}, bleu,'
          f'{d2l.bleu(" ".join(translation), fr, k=2):.3f}')
```

```
go . => ['poursuis', '!'], bleu,0.000
i lost . => ["j'ai", 'perdu', '.'], bleu,1.000
he's calm . => ['il', 'est', 'mouillé', '.'], bleu,0.658
i'm home . => ['je', 'suis', 'chez', 'moi', '.'], bleu,1.000
```

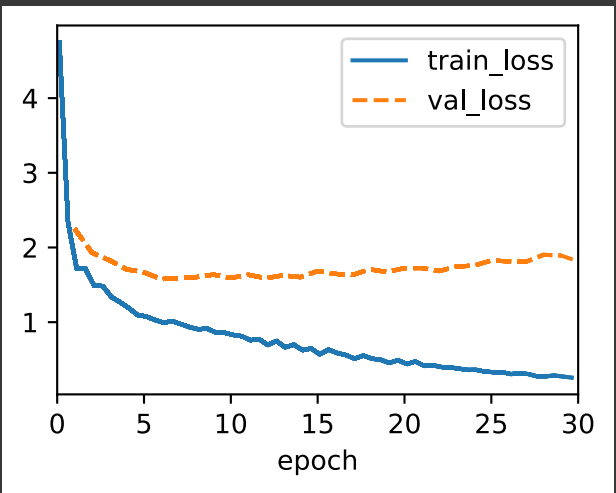
```
_, dec_attention_weights = model.predict_step(
    data.build([engs[-1]], [fras[-1]]), d2l.try_gpu(), data.num_steps, True)
```

```
attention_weights = torch.cat(
    [step[0][0][0] for step in dec_attention_weights], 0)
attention_weights = attention_weights.reshape((1, 1, -1, data.num_steps))
d2l.show_heatmaps(
    attention_weights[:, :, :, :len(engs[-1].split()) + 1].cpu(),
    xlabel='Key positions', ylabel='Query positions')
```



Experiment Model : 4 Layers

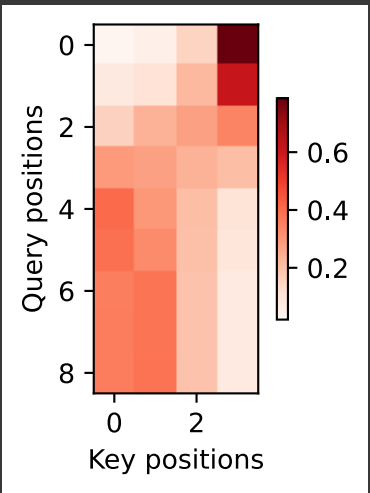
```
data = d2l.MTFraEng(batch_size=128)
embed_size, num_hiddens, num_layers, dropout = 256, 256, 4, 0.2
encoder = d2l.Sequence2SequenceEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Sequence2SequenceAttentionDecoder(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = d2l.Sequence2Sequence(encoder, decoder, tgt_pad=data.tgt_vocab['<pad>'],
                      lr=0.005)
trainer = d2l.Trainer(max_epochs=30, gradient_clip_val=1, num_gpus=1)
trainer.fit(model, data)
```



```
engs = ['go .', 'i lost .', 'he\'s calm .', 'i\'m home .']
fras = ['va !', 'j\'ai perdu .', 'il est calme .', 'je suis chez moi .']
preds, _ = model.predict_step(
    data.build(engs, fras), d2l.try_gpu(), data.num_steps)
for en, fr, p in zip(engs, fras, preds):
    translation = []
    for token in data.tgt_vocab.to_tokens(p):
        if token == '<eos>':
            break
        translation.append(token)
    print(f'{en} => {translation}, bleu,'
          f'{d2l.bleu(" ".join(translation), fr, k=2):.3f}')
```

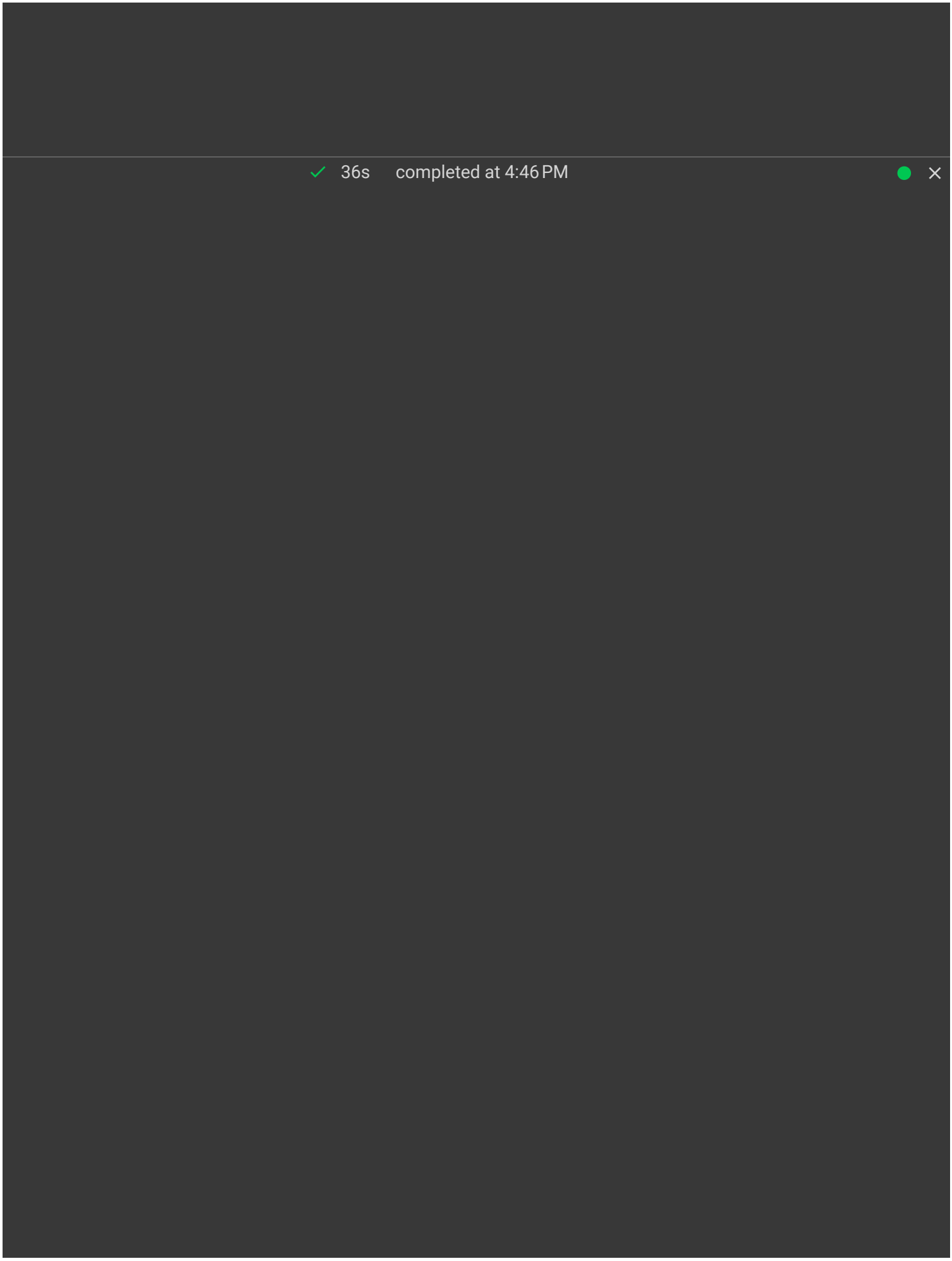
```
go . => ['va', '!'], bleu,1.000
i lost . => ["j'ai", '<unk>', '.'], bleu,0.000
he's calm . => ['elle', 'est', '<unk>', '.'], bleu,0.000
i'm home . => ['je', 'suis', '<unk>', '.'], bleu,0.512
```

```
_, dec_attention_weights = model.predict_step(
    data.build([engs[-1]], [fras[-1]]), d2l.try_gpu(), data.num_steps, True)
attention_weights = torch.cat(
    [step[0][0][0] for step in dec_attention_weights], 0)
attention_weights = attention_weights.reshape((1, 1, -1, data.num_steps))
d2l.show_heatmaps(
    attention_weights[:, :, :, :len(engs[-1].split()) + 1].cpu(),
    xlabel='Key positions', ylabel='Query positions')
```



Results

When Bahdanau attention is substituted with a Luong attention mechanism, we find that Bahdanau attention functioned better when the number of layers was 3 or 4, and Luong attention performed better when the number of layers was 1 or 2.


36s completed at 4:46 PM