```
! pip install setuptools==66
```

```
! pip install d2l==1.0.0b0
```

```
import time
import os
import torch
import torchvision
from torch import nn
from torchvision import transforms
from d2l import torch as d2l
```

D2L Stuff

```
class HyperParameters:
    def save_hyperparameters(self, ignore=[]):
        raise NotImplemented
```

```
def add_to_class(Class):
    def wrapper(obj):
        setattr(Class, obj.__name__, obj)
    return wrapper
```

```
class ProgressBoard(d2l.HyperParameters):
    def __init__(self, xlabel=None, ylabel=None, xlim=None,
                 ylim=None, xscale='linear', yscale='linear',
                 ls=['-', '--', '-.', ':'], colors=['C0', 'C1', 'C2', 'C3'],
                 fig=None, axes=None, figsize=(3.5, 2.5), display=True):
        self.save_hyperparameters()

    def draw(self, x, y, label, every_n=1):
        raise NotImplemented
```

```
class Module(nn.Module, d2l.HyperParameters):
    def __init__(self, plot_train_per_epoch=2, plot_valid_per_epoch=1):
        super().__init__()
        self.save_hyperparameters()
        self.board = ProgressBoard()
    def loss(self, y_hat, y):
        raise NotImplementedError

    def forward(self, X):
        assert hasattr(self, 'net'), 'Neural network is defined'
        return self.net(X)

    def plot(self, key, value, train):
        """Plot a point in animation."""
        assert hasattr(self, 'trainer'), 'Trainer is not inited'
        self.board.xlabel = 'epoch'
        if train:
            x = self.trainer.train_batch_idx / \
                self.trainer.num_train_batches
            n = self.trainer.num_train_batches / \
                self.plot_train_per_epoch
        else:
            x = self.trainer.epoch + 1
            n = self.trainer.num_val_batches / \
                self.plot_valid_per_epoch
        self.board.draw(x, value.to(d2l.cpu()).detach().numpy(),
                        ('train_' if train else 'val_') + key,
                        every_n=int(n))
    def training_step(self, batch):
        l = self.loss(self(*batch[:-1]), batch[-1])
        self.plot('loss', l, train=True)
        return l

    def validation_step(self, batch):
        l = self.loss(self(*batch[:-1]), batch[-1])
        self.plot('loss', l, train=False)
        return l

    def configure_optimizers(self):
        raise NotImplementedError


class Trainer(d2l.HyperParameters):
    def __init__(self, max_epochs, num_gpus=0, gradient_clip_val=0):
        self.save_hyperparameters()
        assert num_gpus == 0, 'No GPU support yet'

    def prepare_data(self, data):
        self.train_dataloader = data.train_dataloader()
        self.val_dataloader = data.val_dataloader()
        self.num_train_batches = len(self.train_dataloader)
        self.num_val_batches = (len(self.val_dataloader)
                                if self.val_dataloader is not None else 0)

    def prepare_model(self, model):
        model.trainer = self
        model.board.xlim = [0, self.max_epochs]
        self.model = model

    def fit(self, model, data):
        self.prepare_data(data)
        self.prepare_model(model)
        self.optim = model.configure_optimizers()
        self.epoch = 0
        self.train_batch_idx = 0
        self.val_batch_idx = 0
        for self.epoch in range(self.max_epochs):
            self.fit_epoch()

    def fit_epoch(self):
        raise NotImplementedError


@d2l.add_to_class(d2l.Trainer)
def prepare_batch(self, batch):
    return batch

@d2l.add_to_class(d2l.Trainer)
def fit_epoch(self):
    self.model.train()

    for batch in self.train_dataloader:
        loss = self.model.training_step(self.prepare_batch(batch))
        self.optim.zero_grad()
        with torch.no_grad():
            loss.backward()
            if self.gradient_clip_val > 0:  # To be discussed later
                self.clip_gradients(self.gradient_clip_val, self.model)
            self.optim.step()
        self.train_batch_idx += 1


    if self.val_dataloader is None:
        return
    self.model.eval()
    for batch in self.val_dataloader:
        with torch.no_grad():
            self.model.validation_step(self.prepare_batch(batch))
        self.val_batch_idx += 1


class DataModule(d2l.HyperParameters):
    def __init__(self, root='../data', num_workers=4):
        self.save_hyperparameters()

    def get_dataloader(self, train):
        raise NotImplementedError

    def train_dataloader(self):
        return self.get_dataloader(train=True)

    def val_dataloader(self):
        return self.get_dataloader(train=False)
```

French Dataset

```
class MTFraEng(d2l.DataModule):
    """The English-French dataset."""
    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.zip...
Go.     Va !
Hi.     Salut !
Run!    Cours !
Run!    Courez !
Who?    Qui ?
Wow!    Ça alors !
```

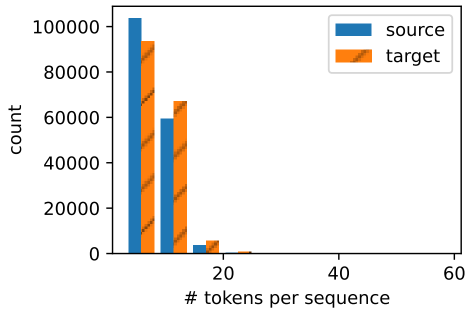
```
@d2l.add_to_class(MTFraEng)
def _preprocess(self, text):
    # Replace non-breaking space with space
    text = text.replace('\u202f', ' ').replace('\xa0', ' ')
    # Insert space between words and punctuation marks
    no_space = lambda char, prev_char: char in ',.!?' and prev_char != ' '
    out = [' ' + 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:
            # Skip empty tokens
            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):
    """Plot the histogram for list length pairs."""
    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([[169,  99,   2,   3,   4,   4,   4,   4,   4],
        [ 91, 191,   2,   3,   4,   4,   4,   4,   4],
        [ 28, 122,   2,   3,   4,   4,   4,   4,   4]], dtype=torch.int32)
decoder input: tensor([[  3,   6, 187,   2,   4,   5,   5,   5,   5],
        [  3,  69,   6,   2,   4,   5,   5,   5,   5],
        [  3,  15,   0,   4,   5,   5,   5,   5,   5]], dtype=torch.int32)
source len excluding pad: tensor([4, 4, 4], dtype=torch.int32)
label: tensor([[  6, 187,   2,   4,   5,   5,   5,   5,   5],
        [ 69,   6,   2,   4,   5,   5,   5,   5,   5],
        [ 15,   0,   4,   5,   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>']
```

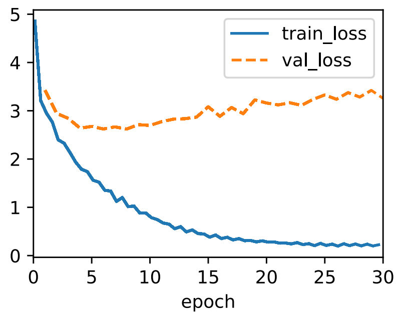
1a) Baseline EncoderDecoder

```
import collections
import math
import torch
from torch import nn
from torch.nn import functional as F
from d2l import torch as d2l


### Building the Encoder ###

def init_seq2seq(module):
    """Initialize weights for Seq2Seq."""
    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 Seq2SeqEncoder(d2l.Encoder):
    """The RNN encoder for sequence to sequence learning."""
    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_seq2seq)

    def forward(self, X, *args):
        # X shape: (batch_size, num_steps)
        embs = self.embedding(X.t().type(torch.int64))
        # embs shape: (num_steps, batch_size, embed_size)
        outputs, state = self.rnn(embs)
        # outputs shape: (num_steps, batch_size, num_hiddens)
        # state shape: (num_layers, batch_size, num_hiddens)
        return outputs, state


### Building the Decoder ###

class Seq2SeqDecoder(d2l.Decoder):
    """The RNN decoder for sequence to sequence learning."""
    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_seq2seq)

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

    def forward(self, X, state):
        # X shape: (batch_size, num_steps)
        # embs shape: (num_steps, batch_size, embed_size)
        embs = self.embedding(X.t().type(torch.int32))
        enc_output, hidden_state = state
        # context shape: (batch_size, num_hiddens)
        context = enc_output[-1]
        # Broadcast context to (num_steps, batch_size, num_hiddens)
        context = context.repeat(embs.shape[0], 1, 1)
        # Concat at the feature dimension
        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)
        # outputs shape: (batch_size, num_steps, vocab_size)
        # hidden_state shape: (num_layers, batch_size, num_hiddens)
        return outputs, [enc_output, hidden_state]
```

```
### Assembling the EncoderDecoder ###

class Seq2Seq(d2l.EncoderDecoder):
    """The RNN encoder-decoder for sequence to sequence learning."""
    def __init__(self, encoder, decoder, tgt_pad, lr):
        super().__init__(encoder, decoder)
        self.save_hyperparameters()

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

    def configure_optimizers(self):
        # Adam optimizer is used here
        return torch.optim.Adam(self.parameters(), lr=self.lr)
```

```
### Loss w/ Special Token Padding ###

@d2l.add_to_class(Seq2Seq)
def loss(self, Y_hat, Y):
    l = super(Seq2Seq, self).loss(Y_hat, Y, averaged=False)
    mask = (Y.reshape(-1) != self.tgt_pad).type(torch.float32)
    return (l * mask).sum() / mask.sum()
```

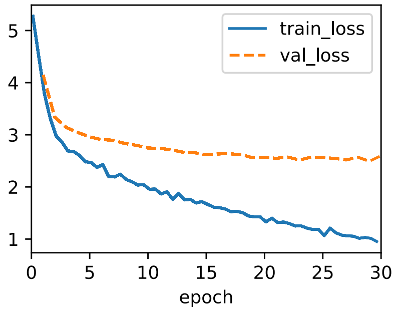
```
# Baseline Model

data = d2l.MTFraEng(batch_size=128)
embed_size, num_hiddens, num_layers, dropout = 256, 256, 2, 0.2
encoder = Seq2SeqEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Seq2SeqDecoder(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = Seq2Seq(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)
```



Improving Baseline Performance

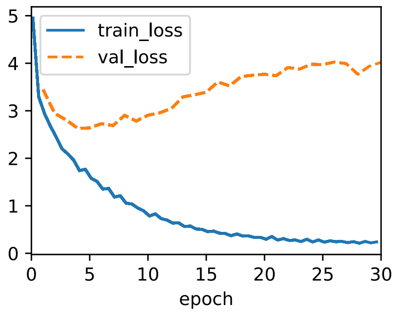
```
# Improved baseline model

data = d2l.MTFraEng(batch_size=128)
embed_size, num_hiddens, num_layers, dropout = 256, 64, 2, 0.2
```

```
encoder = Seq2SeqEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Seq2SeqDecoder(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = Seq2Seq(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)
```



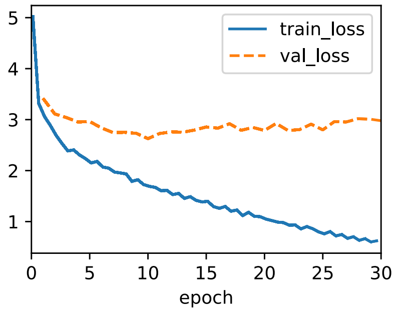
1b) Adjusting Coder Layers

```
### Building the Encoder ###

def init_seq2seq(module):
    """Initialize weights for Seq2Seq."""
    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 Seq2SeqEncoder(d2l.Encoder):
    """The RNN encoder for sequence to sequence learning."""
    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_seq2seq)

    def forward(self, X, *args):
        # X shape: (batch_size, num_steps)
        embs = self.embedding(X.t().type(torch.int64))
        # embs shape: (num_steps, batch_size, embed_size)
        outputs, fullState = self.rnn(embs)
        state = fullState[-2:][:][:]
        # outputs shape: (num_steps, batch_size, num_hiddens)
        # state shape: (num_layers, batch_size, num_hiddens)
        return outputs, state


### Building the Decoder ###

class Seq2SeqDecoder(d2l.Decoder):
    """The RNN decoder for sequence to sequence learning."""
    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_seq2seq)

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

    def forward(self, X, state):
        # X shape: (batch_size, num_steps)
        # embs shape: (num_steps, batch_size, embed_size)
        embs = self.embedding(X.t().type(torch.int32))
        enc_output, hidden_state = state
        # context shape: (batch_size, num_hiddens)
        context = enc_output[-1]
        # Broadcast context to (num_steps, batch_size, num_hiddens)
        context = context.repeat(embs.shape[0], 1, 1)
        # Concat at the feature dimension
        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)
        # outputs shape: (batch_size, num_steps, vocab_size)
        # hidden_state shape: (num_layers, batch_size, num_hiddens)
        return outputs, [enc_output, hidden_state]


### Assembling the EncoderDecoder ###

class Seq2Seq(d2l.EncoderDecoder):
    """The RNN encoder-decoder for sequence to sequence learning."""
    def __init__(self, encoder, decoder, tgt_pad, lr):
        super().__init__(encoder, decoder)
        self.save_hyperparameters()

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

    def configure_optimizers(self):
        # Adam optimizer is used here
        return torch.optim.Adam(self.parameters(), lr=self.lr)


### Loss w/ Special Token Padding ###

@d2l.add_to_class(Seq2Seq)
def loss(self, Y_hat, Y):
    l = super(Seq2Seq, self).loss(Y_hat, Y, averaged=False)
    mask = (Y.reshape(-1) != self.tgt_pad).type(torch.float32)
    return (l * mask).sum() / mask.sum()


# 3 layers for Encoder
# 2 layers for Decoder

data = d2l.MTFraEng(batch_size=128)
embed_size, num_hiddens, dropout = 256, 256, 0.2
encoder_layers, decoder_layers = 3, 2

encoder = Seq2SeqEncoder(
    len(data.src_vocab), embed_size, num_hiddens, encoder_layers, dropout)
decoder = Seq2SeqDecoder(
    len(data.tgt_vocab), embed_size, num_hiddens, decoder_layers, dropout)
model = Seq2Seq(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)
```



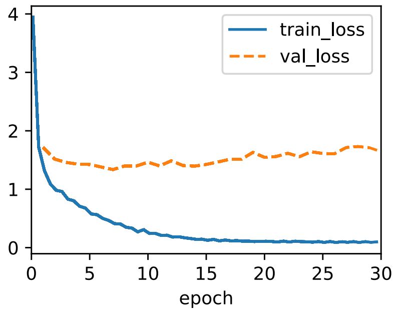
1c) LSTM Version

```
class LSTM(d2l.RNN):
    """The multi-layer LSTM model.

    Defined in :numref:`sec_deep_rnn`"""
    def __init__(self, num_inputs, num_hiddens, num_layers, dropout=0):
        d2l.Module.__init__(self)
        self.save_hyperparameters()
        self.rnn = nn.LSTM(num_inputs, num_hiddens, num_layers,
                          dropout=dropout)


### Building the LSTM Encoder ###

def init_seq2seq(module):
    """Initialize weights for Seq2Seq."""
    if type(module) == nn.Linear:
         nn.init.xavier_uniform_(module.weight)
    if type(module) == nn.LSTM:
        for param in module._flat_weights_names:
            if "weight" in param:
                nn.init.xavier_uniform_(module._parameters[param])

class Seq2SeqEncoder(d2l.Encoder):
    """The RNN encoder for sequence to sequence learning."""
    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_seq2seq)

    def forward(self, X, *args):
        # X shape: (batch_size, num_steps)
        embs = self.embedding(X.t().type(torch.int64))
        # embs shape: (num_steps, batch_size, embed_size)
        outputs, state = self.rnn(embs)
        # outputs shape: (num_steps, batch_size, num_hiddens)
        # state shape: (num_layers, batch_size, num_hiddens)
        return outputs, state


### Building the LSTM Decoder ###

class Seq2SeqDecoder(d2l.Decoder):
    """The RNN decoder for sequence to sequence learning."""
    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_seq2seq)

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

    def forward(self, X, state):
        # X shape: (batch_size, num_steps)
        # embs shape: (num_steps, batch_size, embed_size)
        embs = self.embedding(X.t().type(torch.int32))
        enc_output, hidden_state = state
        # context shape: (batch_size, num_hiddens)
        context = enc_output[-1]
        # Broadcast context to (num_steps, batch_size, num_hiddens)
        context = context.repeat(embs.shape[0], 1, 1)
        # Concat at the feature dimension
        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)
        # outputs shape: (batch_size, num_steps, vocab_size)
        # hidden_state shape: (num_layers, batch_size, num_hiddens)
        return outputs, [enc_output, hidden_state]


### Assembling the EncoderDecoder ###

class Seq2Seq(d2l.EncoderDecoder):
    """The RNN encoder-decoder for sequence to sequence learning."""
    def __init__(self, encoder, decoder, tgt_pad, lr):
        super().__init__(encoder, decoder)
        self.save_hyperparameters()

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

    def configure_optimizers(self):
        # Adam optimizer is used here
        return torch.optim.Adam(self.parameters(), lr=self.lr)


### Loss w/ Special Token Padding ###

@d2l.add_to_class(Seq2Seq)
def loss(self, Y_hat, Y):
    l = super(Seq2Seq, self).loss(Y_hat, Y, averaged=False)
    mask = (Y.reshape(-1) != self.tgt_pad).type(torch.float32)
    return (l * mask).sum() / mask.sum()


# LSTM Version of Baseline Model

data = d2l.MTFraEng(batch_size=128)
embed_size, num_hiddens, num_layers, dropout = 256, 256, 2, 0.2
encoder = Seq2SeqEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Seq2SeqDecoder(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = Seq2Seq(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)
```



2a) Hidden Layer Adjustments

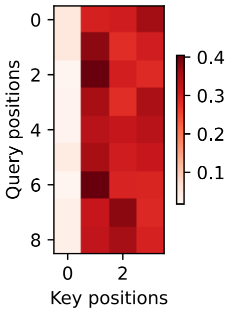
```
class AttentionDecoder(d2l.Decoder):
    """The base attention-based decoder interface."""
    def __init__(self):
        super().__init__()

    @property
    def attention_weights(self):
        raise NotImplementedError


class Seq2SeqAttentionDecoder(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_seq2seq)

    def init_state(self, enc_outputs, enc_valid_lens):
        # Shape of outputs: (num_steps, batch_size, num_hiddens).
        # Shape of hidden_state: (num_layers, batch_size, num_hiddens)
        outputs, hidden_state = enc_outputs
        return (outputs.permute(1, 0, 2), hidden_state, enc_valid_lens)

    def forward(self, X, state):
        # Shape of enc_outputs: (batch_size, num_steps, num_hiddens).
        # Shape of hidden_state: (num_layers, batch_size, num_hiddens)
        enc_outputs, hidden_state, enc_valid_lens = state
        # Shape of the output X: (num_steps, batch_size, embed_size)
        X = self.embedding(X).permute(1, 0, 2)
        outputs, self._attention_weights = [], []
        for x in X:
            # Shape of query: (batch_size, 1, num_hiddens)
            query = torch.unsqueeze(hidden_state[-1], dim=1)
            # Shape of context: (batch_size, 1, num_hiddens)
            context = self.attention(
                query, enc_outputs, enc_outputs, enc_valid_lens)
            # Concatenate on the feature dimension
            x = torch.cat((context, torch.unsqueeze(x, dim=1)), dim=-1)
            # Reshape x as (1, batch_size, embed_size + num_hiddens)
            out, hidden_state = self.rnn(x.permute(1, 0, 2), hidden_state)
            outputs.append(out)
            self._attention_weights.append(self.attention.attention_weights)
        # After fully connected layer transformation, shape of outputs:
        # (num_steps, batch_size, vocab_size)
        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


@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))
        # Save attention weights (to be covered later)
        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):
    """Compute the BLEU."""
    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


### 1 Hidden Layer ###

data = d2l.MTFraEng(batch_size=128)
embed_size, num_hiddens, num_layers, dropout = 256, 256, 1, 0.2
encoder = d2l.Seq2SeqEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Seq2SeqAttentionDecoder(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = d2l.Seq2Seq(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)
```



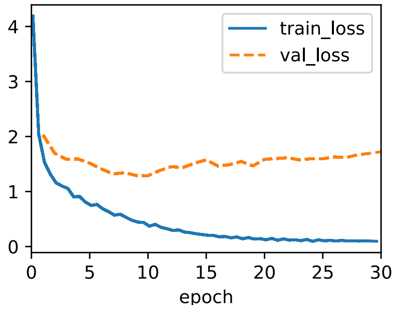
```
engs = ['go .', 'i lost .', 'he\'s calm .', 'i\'m home .']
fras = ['va !', 'j\'ai perdu .', 'il est calme .', 'je suis chez moi .']
preds, _ = model.predict_step(
    data.build(engs, fras), d2l.try_gpu(), data.num_steps)
for en, fr, p in zip(engs, fras, preds):
    translation = []
    for token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

# Plus one to include the end-of-sequence token
d2l.show_heatmaps(
    attention_weights[:, :, :, :len(engs[-1].split()) + 1].cpu(),
    xlabel='Key positions', ylabel='Query positions')
```



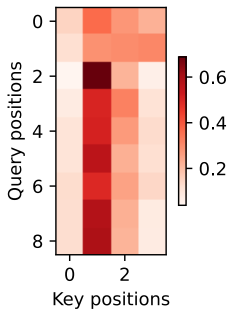
```
### 2 Hidden Layers ###

data = d2l.MTFraEng(batch_size=128)
embed_size, num_hiddens, num_layers, dropout = 256, 256, 2, 0.2
encoder = d2l.Seq2SeqEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Seq2SeqAttentionDecoder(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = d2l.Seq2Seq(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 . => ['sois', 'calme', '!'], 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))

# Plus one to include the end-of-sequence token
d2l.show_heatmaps(
    attention_weights[:, :, :, :len(engs[-1].split()) + 1].cpu(),
    xlabel='Key positions', ylabel='Query positions')
```



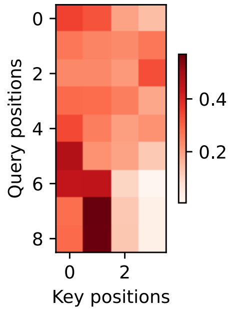
```
### 3 Hidden Layers ###

data = d2l.MTFraEng(batch_size=128)
embed_size, num_hiddens, num_layers, dropout = 256, 256, 3, 0.2
encoder = d2l.Seq2SeqEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Seq2SeqAttentionDecoder(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = d2l.Seq2Seq(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)
```

train_loss
val_loss
4
3
2

```
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', 'détendu', '.'], 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))

# Plus one to include the end-of-sequence token
d2l.show_heatmaps(
    attention_weights[:, :, :, :len(engs[-1].split()) + 1].cpu(),
    xlabel='Key positions', ylabel='Query positions')
```

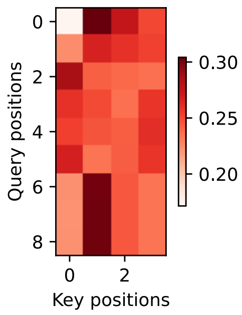


```
### 4 Hidden Layers ###

data = d2l.MTFraEng(batch_size=128)
embed_size, num_hiddens, num_layers, dropout = 256, 256, 4, 0.2
encoder = d2l.Seq2SeqEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Seq2SeqAttentionDecoder(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = d2l.Seq2Seq(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', '<unk>', '!'], bleu,0.000
i lost . => ["j'ai", 'gagné', '.'], 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))

# Plus one to include the end-of-sequence token
d2l.show_heatmaps(
    attention_weights[:, :, :, :len(engs[-1].split()) + 1].cpu(),
    xlabel='Key positions', ylabel='Query positions')
```



2b) LSTM Version

```
class LSTM(d2l.RNN):
    """The multi-layer LSTM model.

    Defined in :numref:`sec_deep_rnn`"""
    def __init__(self, num_inputs, num_hiddens, num_layers, dropout=0):
        d2l.Module.__init__(self)
        self.save_hyperparameters()
        self.rnn = nn.LSTM(num_inputs, num_hiddens, num_layers,
                           dropout=dropout)


### Building the LSTM Encoder ###

def init_seq2seq(module):
    """Initialize weights for Seq2Seq."""
    if type(module) == nn.Linear:
         nn.init.xavier_uniform_(module.weight)
    if type(module) == nn.LSTM:
        for param in module._flat_weights_names:
            if "weight" in param:
                nn.init.xavier_uniform_(module._parameters[param])

class Seq2SeqEncoder(d2l.Encoder):
    """The RNN encoder for sequence to sequence learning."""
    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_seq2seq)

    def forward(self, X, *args):
        # X shape: (batch_size, num_steps)
        embs = self.embedding(X.t().type(torch.int64))
        # embs shape: (num_steps, batch_size, embed_size)
        outputs, state = self.rnn(embs)
        # outputs shape: (num_steps, batch_size, num_hiddens)
        # state shape: (num_layers, batch_size, num_hiddens)
        return outputs, state


class AttentionDecoder(d2l.Decoder):
    """The base attention-based decoder interface."""
    def __init__(self):
        super().__init__()

    @property
    def attention_weights(self):
        raise NotImplementedError


class Seq2SeqAttentionDecoder(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 = LSTM(
            embed_size + num_hiddens, num_hiddens, num_layers,
            dropout=dropout)
        self.dense = nn.LazyLinear(vocab_size)
        self.apply(d2l.init_seq2seq)

    def init_state(self, enc_outputs, enc_valid_lens):
        # Shape of outputs: (num_steps, batch_size, num_hiddens).
        # Shape of hidden_state: (num_layers, batch_size, num_hiddens)
        outputs, hidden_state = enc_outputs
        return (outputs.permute(1, 0, 2), hidden_state, enc_valid_lens)

    def forward(self, X, state):
        # Shape of enc_outputs: (batch_size, num_steps, num_hiddens).
        # Shape of hidden_state: (num_layers, batch_size, num_hiddens)
        enc_outputs, hidden_state, enc_valid_lens = state
        # Shape of the output X: (num_steps, batch_size, embed_size)
        X = self.embedding(X).permute(1, 0, 2)
        outputs, self._attention_weights = [], []
        for x in X:
            # Shape of query: (batch_size, 1, num_hiddens)
            query = torch.unsqueeze(hidden_state[-1], dim=1)
            # Shape of context: (batch_size, 1, num_hiddens)
            context = self.attention(
                query, enc_outputs, enc_outputs, enc_valid_lens)
            # Concatenate on the feature dimension
            x = torch.cat((context, torch.unsqueeze(x, dim=1)), dim=-1)
            # Reshape x as (1, batch_size, embed_size + num_hiddens)
            out, hidden_state = self.rnn(x.permute(1, 0, 2), hidden_state)
            outputs.append(out)
            self._attention_weights.append(self.attention.attention_weights)
        # After fully connected layer transformation, shape of outputs:
        # (num_steps, batch_size, vocab_size)
        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


### Assembling the EncoderDecoder ###

class Seq2Seq(d2l.EncoderDecoder):
    """The RNN encoder-decoder for sequence to sequence learning."""
    def __init__(self, encoder, decoder, tgt_pad, lr):
        super().__init__(encoder, decoder)
        self.save_hyperparameters()

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

    def configure_optimizers(self):
        # Adam optimizer is used here
        return torch.optim.Adam(self.parameters(), lr=self.lr)


@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))
        # Save attention weights (to be covered later)
        if save_attention_weights:
            attention_weights.append(self.decoder.attention_weights)
    return torch.cat(outputs[1:], 1), attention_weights


### 2 Layer LSTM Version ###

data = d2l.MTFraEng(batch_size=128)
embed_size, num_hiddens, num_layers, dropout = 256, 256, 2, 0.2
encoder = d2l.Seq2SeqEncoder(
    len(data.src_vocab), embed_size, num_hiddens, num_layers, dropout)
decoder = Seq2SeqAttentionDecoder(
    len(data.tgt_vocab), embed_size, num_hiddens, num_layers, dropout)
model = d2l.Seq2Seq(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)
```

```
---------------------------------------------------------------------------
RuntimeError                              Traceback (most recent call last)
<ipython-input-190-8f0863972714> in <cell line: 12>()
     10                     lr=0.005)
     11 trainer = d2l.Trainer(max_epochs=30, gradient_clip_val=1, num_gpus=1)
---> 12 trainer.fit(model, data)

                          10 frames

/usr/local/lib/python3.9/dist-packages/torch/nn/modules/rnn.py in forward(self, input, hx)
    796                         msg = ("For batched 3-D input, hx and cx should "
    797                                f"also be 3-D but got ({hx[0].dim()}-D, {hx[1].dim()}-D) tensors")
--> 798                         raise RuntimeError(msg)
    799                 else:
    800                     if hx[0].dim() != 2 or hx[1].dim() != 2:

RuntimeError: For batched 3-D input, hx and cx should also be 3-D but got (2-D, 2-D) tensors
```

SEARCH STACK OVERFLOW

```
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}')


_, 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))

# Plus one to include the end-of-sequence token
d2l.show_heatmaps(
    attention_weights[:, :, :, :len(engs[-1].split()) + 1].cpu(),
    xlabel='Key positions', ylabel='Query positions')
```

✓ 1m 32s completed at 8:29 PM