Assignment_3_2

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1 Assignment 3, Question 2

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Reading material * [1] *Oriol Vinyals, Alexander Toshev, Samy Bengio, Dumitru Erhan, "Show and Tell: A Neural Image Caption Generator"*, CVPR, 2015. https://arxiv.org/abs/1411.4555

Task: Implement and test the image caption generator proposed in [1], see further instructions below. Please insert your code between two consecutive occurrences of # …

NOTE When submitting your notebook, please make sure that the training history of your model is visible in the output. This means that you should **NOT** clean your output cells of the notebook. Make sure that your notebook runs without errors in linear order.

[1]:
```
%matplotlib inline

import numpy as np
import matplotlib.pyplot as plt
import os
import shutil
import pickle
import time
import nltk

import keras.backend as K
from tensorflow.keras import Model
from tensorflow.keras.models import load_model
from tensorflow.keras.layers import Input, Embedding, Dense, LSTM, Dropout,␣
 ↪concatenate
from tensorflow.keras import losses, optimizers
from tensorflow.keras.applications import MobileNetV2
from tensorflow.keras.callbacks import EarlyStopping

from google.colab import drive

# training parameters
embedding_dim = 512
lstm_dim = 500
lstm_dropout = 0.5
```

```
batch_size = 100
```

```
Using TensorFlow backend.
```

2 Mount Google Drive

We will save the data and our model there, in the folder deeplearning2020_ass3_task1. **This requires about 600 MB**.

[2]:
```
if not os.path.isdir('drive'):
  drive.mount('drive')
else:
  print('drive already mounted')

base_path = os.path.join('drive', 'My Drive', 'Università', 'Deep Learning',␣
 ↪'Assignment 3', 'deeplearning2020_ass3_task1')
if not os.path.isdir(base_path):
  os.makedirs(base_path)
```

```
Go to this URL in a browser: https://accounts.google.com/o/oauth2/auth?client_id
=947318989803-6bn6qk8qdgf4n4g3pfee6491hc0brc4i.apps.googleusercontent.com&redire
ct_uri=urn%3aietf%3awg%3aoauth%3a2.0%3aoob&response_type=code&scope=email%20http
s%3a%2f%2fwww.googleapis.com%2fauth%2fdocs.test%20https%3a%2f%2fwww.googleapis.c
om%2fauth%2fdrive%20https%3a%2f%2fwww.googleapis.com%2fauth%2fdrive.photos.reado
nly%20https%3a%2f%2fwww.googleapis.com%2fauth%2fpeopleapi.readonly

Enter your authorization code:
··········
Mounted at drive
```

3 Download Data - Flickr8k

Please don't distribute the dataset

This is a preprocessed version of the Flickr8k dataset, with punctuation and special tokens removed. Furthermore, any word which occurs less than 5 times in the whole corpus has been removed. The images have been rescaled to 128x128 RGB.

images: numpy array (8091,128,128,3), uint8, holding 8091 RGB images.

captions: collection of 5 human-annotated captions for each image. Stored as a python list of length 8091. * *captions[i]* is a list of length 5, for i=0..8090, holding the 5 annotations for the i'th image. * *captions[i][j]* is a caption, represented as a list of strings, for i=0..8090, j=0..4. * For example: *captions[42][3] = ['a', 'young', 'boy', 'wearing', 'a', 'red', 'coat', 'is', 'playing', 'in', 'a', 'long', 'tunnel']*. * Thus, there are in total 8091 * 5 = 40455 captions.

Please don't distribute the dataset

[3]:
```
if not os.path.isdir('drive'):
  raise AssertionError('Google drive seems to be unmounted -- please run cell␣
↪above.')

flickr_file = os.path.join(base_path, 'Flickr8k_processed.pkl')

if not os.path.isfile(flickr_file):
  start_time = time.time()
  if not os.path.isfile(flickr_file):
    ! wget https://surfdrive.surf.nl/files/index.php/s/kOIDM5tQPzv6IID/download␣
↪-O Flickr8k_processed.pkl
    shutil.move('Flickr8k_processed.pkl', flickr_file)
  print("Elapsed time: {} seconds.".format(time.time()-start_time))
else:
  print('Found file {}'.format(flickr_file))

images, captions = pickle.load(open(flickr_file, 'rb'))

print('Data loaded.')
print('images: {} {} {}'.format(images.shape, type(images), images.dtype))
print('captions: {} {}'.format(len(captions), type(captions)))
```

```
Found file drive/My Drive/Università/Deep Learning/Assignment
3/deeplearning2020_ass3_task1/Flickr8k_processed.pkl
Data loaded.
images: (8091, 128, 128, 3) <class 'numpy.ndarray'> uint8
captions: 8091 <class 'list'>
```

4 Extract Image Representation

- Use the 'Conv_1' layer from *MobileNetV2* to generate neural codes for each image in the array *images*.
- Please generate a (8091,20480) numpy array in single precision (dtype=np.float32) holding the neural codes, where each row holds the code for the corresponding row in *images*.
- Call the resulting array *image_codes*.
- **Hint:** Process the images in batches (of e.g. 200), as the GPU won't be able to process all 8091 images in parallel.
- **Hint:** MobileNetV2 requires images in floating point as inputs, with pixels rescaled to range [-1,1]. In order to save some RAM (and reduce troubles with Colab running out of resources), convert only the batches into single precision, and keep the *images* in their original format (uint8).

[4]:
```
def get_image_codes(images):
  convnet = MobileNetV2(input_shape=(128,128,3),
                        include_top=False,
                        weights='imagenet')
  convnet.summary()
```

```python
  # ...
  # rescale images
  preprocessed_images = (images / 255) * 2 - 1

  # retrieve model and compute codes
  input_layer = convnet.inputs
  output_layer = convnet.get_layer('Conv_1').output
  model = Model(inputs=input_layer, outputs=output_layer)
  print('Computing neural codes...')
  image_codes = model.predict(preprocessed_images, batch_size=100, verbose=1)

  # reshape codes
  shape = (len(image_codes), -1)
  image_codes = image_codes.reshape(shape)
  # ...

  return image_codes

image_codes = get_image_codes(images)
print(image_codes.shape, image_codes.dtype)
```

```
Downloading data from https://storage.googleapis.com/tensorflow/keras-applicatio
ns/mobilenet_v2/mobilenet_v2_weights_tf_dim_ordering_tf_kernels_1.0_128_no_top.h
5
9412608/9406464 [==============================] - 0s 0us/step
Model: "mobilenetv2_1.00_128"

--------------------------------------------------------------------------------
------------------
Layer (type)                    Output Shape         Param #     Connected to
================================================================================
==================
input_1 (InputLayer)            [(None, 128, 128, 3) 0

--------------------------------------------------------------------------------
------------------
Conv1_pad (ZeroPadding2D)       (None, 129, 129, 3)  0           input_1[0][0]

--------------------------------------------------------------------------------
------------------
Conv1 (Conv2D)                  (None, 64, 64, 32)   864         Conv1_pad[0][0]

--------------------------------------------------------------------------------
------------------
bn_Conv1 (BatchNormalization)   (None, 64, 64, 32)   128         Conv1[0][0]

--------------------------------------------------------------------------------
------------------
Conv1_relu (ReLU)               (None, 64, 64, 32)   0           bn_Conv1[0][0]

--------------------------------------------------------------------------------
------------------
```

```
expanded_conv_depthwise (Depthw (None, 64, 64, 32)   288
Conv1_relu[0][0]
--------------------------------------------------------------------------------
------------------
expanded_conv_depthwise_BN (Bat (None, 64, 64, 32)   128
expanded_conv_depthwise[0][0]
--------------------------------------------------------------------------------
------------------
expanded_conv_depthwise_relu (R (None, 64, 64, 32)   0
expanded_conv_depthwise_BN[0][0]
--------------------------------------------------------------------------------
------------------
expanded_conv_project (Conv2D)  (None, 64, 64, 16)   512
expanded_conv_depthwise_relu[0][0
--------------------------------------------------------------------------------
------------------
expanded_conv_project_BN (Batch (None, 64, 64, 16)   64
expanded_conv_project[0][0]
--------------------------------------------------------------------------------
------------------
block_1_expand (Conv2D)         (None, 64, 64, 96)   1536
expanded_conv_project_BN[0][0]
--------------------------------------------------------------------------------
------------------
block_1_expand_BN (BatchNormali (None, 64, 64, 96)   384
block_1_expand[0][0]
--------------------------------------------------------------------------------
------------------
block_1_expand_relu (ReLU)      (None, 64, 64, 96)   0
block_1_expand_BN[0][0]
--------------------------------------------------------------------------------
------------------
block_1_pad (ZeroPadding2D)     (None, 65, 65, 96)   0
block_1_expand_relu[0][0]
--------------------------------------------------------------------------------
------------------
block_1_depthwise (DepthwiseCon (None, 32, 32, 96)   864
block_1_pad[0][0]
--------------------------------------------------------------------------------
------------------
block_1_depthwise_BN (BatchNorm (None, 32, 32, 96)   384
block_1_depthwise[0][0]
--------------------------------------------------------------------------------
------------------
block_1_depthwise_relu (ReLU)   (None, 32, 32, 96)   0
block_1_depthwise_BN[0][0]
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------------------
```

```
block_1_project (Conv2D)        (None, 32, 32, 24)   2304
block_1_depthwise_relu[0][0]

--------------------------------------------------------------------------------
------------------
block_1_project_BN (BatchNormal (None, 32, 32, 24)   96
block_1_project[0][0]

--------------------------------------------------------------------------------
------------------
block_2_expand (Conv2D)         (None, 32, 32, 144)  3456
block_1_project_BN[0][0]

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------------------
block_2_expand_BN (BatchNormali (None, 32, 32, 144)  576
block_2_expand[0][0]

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------------------
block_2_expand_relu (ReLU)      (None, 32, 32, 144)  0
block_2_expand_BN[0][0]

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------------------
block_2_depthwise (DepthwiseCon (None, 32, 32, 144)  1296
block_2_expand_relu[0][0]

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block_2_depthwise_BN (BatchNorm (None, 32, 32, 144)  576
block_2_depthwise[0][0]

--------------------------------------------------------------------------------
------------------
block_2_depthwise_relu (ReLU)   (None, 32, 32, 144)  0
block_2_depthwise_BN[0][0]

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------------------
block_2_project (Conv2D)        (None, 32, 32, 24)   3456
block_2_depthwise_relu[0][0]

--------------------------------------------------------------------------------
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block_2_project_BN (BatchNormal (None, 32, 32, 24)   96
block_2_project[0][0]

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------------------
block_2_add (Add)               (None, 32, 32, 24)   0
block_1_project_BN[0][0]
block_2_project_BN[0][0]

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------------------
block_3_expand (Conv2D)         (None, 32, 32, 144)  3456
block_2_add[0][0]

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block_3_expand_BN (BatchNormali (None, 32, 32, 144)  576
block_3_expand[0][0]
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__________________
block_3_expand_relu (ReLU)      (None, 32, 32, 144)  0
block_3_expand_BN[0][0]
________________________________________________________________________________
__________________
block_3_pad (ZeroPadding2D)     (None, 33, 33, 144)  0
block_3_expand_relu[0][0]
________________________________________________________________________________
__________________
block_3_depthwise (DepthwiseCon (None, 16, 16, 144)  1296
block_3_pad[0][0]
________________________________________________________________________________
__________________
block_3_depthwise_BN (BatchNorm (None, 16, 16, 144)  576
block_3_depthwise[0][0]
________________________________________________________________________________
__________________
block_3_depthwise_relu (ReLU)   (None, 16, 16, 144)  0
block_3_depthwise_BN[0][0]
________________________________________________________________________________
__________________
block_3_project (Conv2D)        (None, 16, 16, 32)   4608
block_3_depthwise_relu[0][0]
________________________________________________________________________________
__________________
block_3_project_BN (BatchNormal (None, 16, 16, 32)   128
block_3_project[0][0]
________________________________________________________________________________
__________________
block_4_expand (Conv2D)         (None, 16, 16, 192)  6144
block_3_project_BN[0][0]
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__________________
block_4_expand_BN (BatchNormali (None, 16, 16, 192)  768
block_4_expand[0][0]
________________________________________________________________________________
__________________
block_4_expand_relu (ReLU)      (None, 16, 16, 192)  0
block_4_expand_BN[0][0]
________________________________________________________________________________
__________________
block_4_depthwise (DepthwiseCon (None, 16, 16, 192)  1728
block_4_expand_relu[0][0]
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block_4_depthwise_BN (BatchNorm (None, 16, 16, 192)  768
block_4_depthwise[0][0]

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------------------
block_4_depthwise_relu (ReLU)   (None, 16, 16, 192)  0
block_4_depthwise_BN[0][0]

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------------------
block_4_project (Conv2D)        (None, 16, 16, 32)   6144
block_4_depthwise_relu[0][0]

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block_4_project_BN (BatchNormal (None, 16, 16, 32)   128
block_4_project[0][0]

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------------------
block_4_add (Add)               (None, 16, 16, 32)   0
block_3_project_BN[0][0]
block_4_project_BN[0][0]

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block_5_expand (Conv2D)         (None, 16, 16, 192)  6144
block_4_add[0][0]

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------------------
block_5_expand_BN (BatchNormali (None, 16, 16, 192)  768
block_5_expand[0][0]

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------------------
block_5_expand_relu (ReLU)      (None, 16, 16, 192)  0
block_5_expand_BN[0][0]

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------------------
block_5_depthwise (DepthwiseCon (None, 16, 16, 192)  1728
block_5_expand_relu[0][0]

________________________________________________________________________________
------------------
block_5_depthwise_BN (BatchNorm (None, 16, 16, 192)  768
block_5_depthwise[0][0]

________________________________________________________________________________
------------------
block_5_depthwise_relu (ReLU)   (None, 16, 16, 192)  0
block_5_depthwise_BN[0][0]

________________________________________________________________________________
------------------
block_5_project (Conv2D)        (None, 16, 16, 32)   6144
block_5_depthwise_relu[0][0]
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__________________________________________________________________________________
__________________
block_5_project_BN (BatchNormal (None, 16, 16, 32)   128
block_5_project[0][0]
__________________________________________________________________________________
__________________
block_5_add (Add)               (None, 16, 16, 32)   0
block_4_add[0][0]
block_5_project_BN[0][0]
__________________________________________________________________________________
__________________
block_6_expand (Conv2D)         (None, 16, 16, 192)  6144
block_5_add[0][0]
__________________________________________________________________________________
__________________
block_6_expand_BN (BatchNormali (None, 16, 16, 192)  768
block_6_expand[0][0]
__________________________________________________________________________________
__________________
block_6_expand_relu (ReLU)      (None, 16, 16, 192)  0
block_6_expand_BN[0][0]
__________________________________________________________________________________
__________________
block_6_pad (ZeroPadding2D)     (None, 17, 17, 192)  0
block_6_expand_relu[0][0]
__________________________________________________________________________________
__________________
block_6_depthwise (DepthwiseCon (None, 8, 8, 192)    1728
block_6_pad[0][0]
__________________________________________________________________________________
__________________
block_6_depthwise_BN (BatchNorm (None, 8, 8, 192)    768
block_6_depthwise[0][0]
__________________________________________________________________________________
__________________
block_6_depthwise_relu (ReLU)   (None, 8, 8, 192)    0
block_6_depthwise_BN[0][0]
__________________________________________________________________________________
__________________
block_6_project (Conv2D)        (None, 8, 8, 64)     12288
block_6_depthwise_relu[0][0]
__________________________________________________________________________________
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block_6_project_BN (BatchNormal (None, 8, 8, 64)     256
block_6_project[0][0]
__________________________________________________________________________________
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block_7_expand (Conv2D)         (None, 8, 8, 384)    24576
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block_6_project_BN[0][0]
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block_7_expand_BN (BatchNormali (None, 8, 8, 384)    1536
block_7_expand[0][0]
--------------------------------------------------------------------------------
------------------
block_7_expand_relu (ReLU)      (None, 8, 8, 384)    0
block_7_expand_BN[0][0]
--------------------------------------------------------------------------------
------------------
block_7_depthwise (DepthwiseCon (None, 8, 8, 384)    3456
block_7_expand_relu[0][0]
--------------------------------------------------------------------------------
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block_7_depthwise_BN (BatchNorm (None, 8, 8, 384)    1536
block_7_depthwise[0][0]
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------------------
block_7_depthwise_relu (ReLU)   (None, 8, 8, 384)    0
block_7_depthwise_BN[0][0]
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------------------
block_7_project (Conv2D)        (None, 8, 8, 64)     24576
block_7_depthwise_relu[0][0]
--------------------------------------------------------------------------------
------------------
block_7_project_BN (BatchNormal (None, 8, 8, 64)     256
block_7_project[0][0]
--------------------------------------------------------------------------------
------------------
block_7_add (Add)               (None, 8, 8, 64)     0
block_6_project_BN[0][0]
block_7_project_BN[0][0]
--------------------------------------------------------------------------------
------------------
block_8_expand (Conv2D)         (None, 8, 8, 384)    24576
block_7_add[0][0]
--------------------------------------------------------------------------------
------------------
block_8_expand_BN (BatchNormali (None, 8, 8, 384)    1536
block_8_expand[0][0]
--------------------------------------------------------------------------------
------------------
block_8_expand_relu (ReLU)      (None, 8, 8, 384)    0
block_8_expand_BN[0][0]
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block_8_depthwise (DepthwiseCon (None, 8, 8, 384)    3456
block_8_expand_relu[0][0]
________________________________________________________________________________
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block_8_depthwise_BN (BatchNorm (None, 8, 8, 384)    1536
block_8_depthwise[0][0]
________________________________________________________________________________
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block_8_depthwise_relu (ReLU)   (None, 8, 8, 384)    0
block_8_depthwise_BN[0][0]
________________________________________________________________________________
__________________
block_8_project (Conv2D)        (None, 8, 8, 64)     24576
block_8_depthwise_relu[0][0]
________________________________________________________________________________
__________________
block_8_project_BN (BatchNormal (None, 8, 8, 64)     256
block_8_project[0][0]
________________________________________________________________________________
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block_8_add (Add)               (None, 8, 8, 64)     0
block_7_add[0][0]
block_8_project_BN[0][0]
________________________________________________________________________________
__________________
block_9_expand (Conv2D)         (None, 8, 8, 384)    24576
block_8_add[0][0]
________________________________________________________________________________
__________________
block_9_expand_BN (BatchNormali (None, 8, 8, 384)    1536
block_9_expand[0][0]
________________________________________________________________________________
__________________
block_9_expand_relu (ReLU)      (None, 8, 8, 384)    0
block_9_expand_BN[0][0]
________________________________________________________________________________
__________________
block_9_depthwise (DepthwiseCon (None, 8, 8, 384)    3456
block_9_expand_relu[0][0]
________________________________________________________________________________
__________________
block_9_depthwise_BN (BatchNorm (None, 8, 8, 384)    1536
block_9_depthwise[0][0]
________________________________________________________________________________
__________________
block_9_depthwise_relu (ReLU)   (None, 8, 8, 384)    0
block_9_depthwise_BN[0][0]
________________________________________________________________________________
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------------------
block_9_project (Conv2D)        (None, 8, 8, 64)     24576
block_9_depthwise_relu[0][0]
________________________________________________________________________________
------------------
block_9_project_BN (BatchNormal (None, 8, 8, 64)     256
block_9_project[0][0]
________________________________________________________________________________
------------------
block_9_add (Add)               (None, 8, 8, 64)     0
block_8_add[0][0]
block_9_project_BN[0][0]
________________________________________________________________________________
------------------
block_10_expand (Conv2D)        (None, 8, 8, 384)    24576
block_9_add[0][0]
________________________________________________________________________________
------------------
block_10_expand_BN (BatchNormal (None, 8, 8, 384)    1536
block_10_expand[0][0]
________________________________________________________________________________
------------------
block_10_expand_relu (ReLU)     (None, 8, 8, 384)    0
block_10_expand_BN[0][0]
________________________________________________________________________________
------------------
block_10_depthwise (DepthwiseCo (None, 8, 8, 384)    3456
block_10_expand_relu[0][0]
________________________________________________________________________________
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block_10_depthwise_BN (BatchNor (None, 8, 8, 384)    1536
block_10_depthwise[0][0]
________________________________________________________________________________
------------------
block_10_depthwise_relu (ReLU)  (None, 8, 8, 384)    0
block_10_depthwise_BN[0][0]
________________________________________________________________________________
------------------
block_10_project (Conv2D)       (None, 8, 8, 96)     36864
block_10_depthwise_relu[0][0]
________________________________________________________________________________
------------------
block_10_project_BN (BatchNorma (None, 8, 8, 96)     384
block_10_project[0][0]
________________________________________________________________________________
------------------
block_11_expand (Conv2D)        (None, 8, 8, 576)    55296
block_10_project_BN[0][0]
```

```
________________________________________________________________________________
__________________
block_11_expand_BN (BatchNormal (None, 8, 8, 576)    2304
block_11_expand[0][0]
________________________________________________________________________________
__________________
block_11_expand_relu (ReLU)     (None, 8, 8, 576)    0
block_11_expand_BN[0][0]
________________________________________________________________________________
__________________
block_11_depthwise (DepthwiseCo (None, 8, 8, 576)    5184
block_11_expand_relu[0][0]
________________________________________________________________________________
__________________
block_11_depthwise_BN (BatchNor (None, 8, 8, 576)    2304
block_11_depthwise[0][0]
________________________________________________________________________________
__________________
block_11_depthwise_relu (ReLU)  (None, 8, 8, 576)    0
block_11_depthwise_BN[0][0]
________________________________________________________________________________
__________________
block_11_project (Conv2D)       (None, 8, 8, 96)     55296
block_11_depthwise_relu[0][0]
________________________________________________________________________________
__________________
block_11_project_BN (BatchNorma (None, 8, 8, 96)     384
block_11_project[0][0]
________________________________________________________________________________
__________________
block_11_add (Add)              (None, 8, 8, 96)     0
block_10_project_BN[0][0]
block_11_project_BN[0][0]
________________________________________________________________________________
__________________
block_12_expand (Conv2D)        (None, 8, 8, 576)    55296
block_11_add[0][0]
________________________________________________________________________________
__________________
block_12_expand_BN (BatchNormal (None, 8, 8, 576)    2304
block_12_expand[0][0]
________________________________________________________________________________
__________________
block_12_expand_relu (ReLU)     (None, 8, 8, 576)    0
block_12_expand_BN[0][0]
________________________________________________________________________________
__________________
block_12_depthwise (DepthwiseCo (None, 8, 8, 576)    5184
```

```
block_12_expand_relu[0][0]
__________________________________________________________________________________________________
block_12_depthwise_BN (BatchNor (None, 8, 8, 576)    2304
block_12_depthwise[0][0]
__________________________________________________________________________________________________
block_12_depthwise_relu (ReLU)  (None, 8, 8, 576)    0
block_12_depthwise_BN[0][0]
__________________________________________________________________________________________________
block_12_project (Conv2D)       (None, 8, 8, 96)     55296
block_12_depthwise_relu[0][0]
__________________________________________________________________________________________________
block_12_project_BN (BatchNorma (None, 8, 8, 96)     384
block_12_project[0][0]
__________________________________________________________________________________________________
block_12_add (Add)              (None, 8, 8, 96)     0
block_11_add[0][0]
block_12_project_BN[0][0]
__________________________________________________________________________________________________
block_13_expand (Conv2D)        (None, 8, 8, 576)    55296
block_12_add[0][0]
__________________________________________________________________________________________________
block_13_expand_BN (BatchNormal (None, 8, 8, 576)    2304
block_13_expand[0][0]
__________________________________________________________________________________________________
block_13_expand_relu (ReLU)     (None, 8, 8, 576)    0
block_13_expand_BN[0][0]
__________________________________________________________________________________________________
block_13_pad (ZeroPadding2D)    (None, 9, 9, 576)    0
block_13_expand_relu[0][0]
__________________________________________________________________________________________________
block_13_depthwise (DepthwiseCo (None, 4, 4, 576)    5184
block_13_pad[0][0]
__________________________________________________________________________________________________
block_13_depthwise_BN (BatchNor (None, 4, 4, 576)    2304
block_13_depthwise[0][0]
__________________________________________________________________________________________________
```

```
block_13_depthwise_relu (ReLU)  (None, 4, 4, 576)    0
block_13_depthwise_BN[0][0]

--------------------------------------------------------------------------------
------------------
block_13_project (Conv2D)       (None, 4, 4, 160)    92160
block_13_depthwise_relu[0][0]

--------------------------------------------------------------------------------
------------------
block_13_project_BN (BatchNorma (None, 4, 4, 160)    640
block_13_project[0][0]

--------------------------------------------------------------------------------
------------------
block_14_expand (Conv2D)        (None, 4, 4, 960)    153600
block_13_project_BN[0][0]

--------------------------------------------------------------------------------
------------------
block_14_expand_BN (BatchNormal (None, 4, 4, 960)    3840
block_14_expand[0][0]

--------------------------------------------------------------------------------
------------------
block_14_expand_relu (ReLU)     (None, 4, 4, 960)    0
block_14_expand_BN[0][0]

--------------------------------------------------------------------------------
------------------
block_14_depthwise (DepthwiseCo (None, 4, 4, 960)    8640
block_14_expand_relu[0][0]

--------------------------------------------------------------------------------
------------------
block_14_depthwise_BN (BatchNor (None, 4, 4, 960)    3840
block_14_depthwise[0][0]

--------------------------------------------------------------------------------
------------------
block_14_depthwise_relu (ReLU)  (None, 4, 4, 960)    0
block_14_depthwise_BN[0][0]

--------------------------------------------------------------------------------
------------------
block_14_project (Conv2D)       (None, 4, 4, 160)    153600
block_14_depthwise_relu[0][0]

--------------------------------------------------------------------------------
------------------
block_14_project_BN (BatchNorma (None, 4, 4, 160)    640
block_14_project[0][0]

--------------------------------------------------------------------------------
------------------
block_14_add (Add)              (None, 4, 4, 160)    0
block_13_project_BN[0][0]
block_14_project_BN[0][0]

--------------------------------------------------------------------------------
```

```
------------------
block_15_expand (Conv2D)        (None, 4, 4, 960)    153600
block_14_add[0][0]
__________________________________________________________________________________
------------------
block_15_expand_BN (BatchNormal (None, 4, 4, 960)    3840
block_15_expand[0][0]
__________________________________________________________________________________
------------------
block_15_expand_relu (ReLU)     (None, 4, 4, 960)    0
block_15_expand_BN[0][0]
__________________________________________________________________________________
------------------
block_15_depthwise (DepthwiseCo (None, 4, 4, 960)    8640
block_15_expand_relu[0][0]
__________________________________________________________________________________
------------------
block_15_depthwise_BN (BatchNor (None, 4, 4, 960)    3840
block_15_depthwise[0][0]
__________________________________________________________________________________
------------------
block_15_depthwise_relu (ReLU)  (None, 4, 4, 960)    0
block_15_depthwise_BN[0][0]
__________________________________________________________________________________
------------------
block_15_project (Conv2D)       (None, 4, 4, 160)    153600
block_15_depthwise_relu[0][0]
__________________________________________________________________________________
------------------
block_15_project_BN (BatchNorma (None, 4, 4, 160)    640
block_15_project[0][0]
__________________________________________________________________________________
------------------
block_15_add (Add)              (None, 4, 4, 160)    0
block_14_add[0][0]
block_15_project_BN[0][0]
__________________________________________________________________________________
------------------
block_16_expand (Conv2D)        (None, 4, 4, 960)    153600
block_15_add[0][0]
__________________________________________________________________________________
------------------
block_16_expand_BN (BatchNormal (None, 4, 4, 960)    3840
block_16_expand[0][0]
__________________________________________________________________________________
------------------
block_16_expand_relu (ReLU)     (None, 4, 4, 960)    0
block_16_expand_BN[0][0]
```

```
------------------------------------------------------------------------------------------------------
block_16_depthwise (DepthwiseCo (None, 4, 4, 960)    8640
block_16_expand_relu[0][0]

------------------------------------------------------------------------------------------------------
block_16_depthwise_BN (BatchNor (None, 4, 4, 960)    3840
block_16_depthwise[0][0]

------------------------------------------------------------------------------------------------------
block_16_depthwise_relu (ReLU)  (None, 4, 4, 960)    0
block_16_depthwise_BN[0][0]

------------------------------------------------------------------------------------------------------
block_16_project (Conv2D)       (None, 4, 4, 320)    307200
block_16_depthwise_relu[0][0]

------------------------------------------------------------------------------------------------------
block_16_project_BN (BatchNorma (None, 4, 4, 320)    1280
block_16_project[0][0]

------------------------------------------------------------------------------------------------------
Conv_1 (Conv2D)                 (None, 4, 4, 1280)   409600
block_16_project_BN[0][0]

------------------------------------------------------------------------------------------------------
Conv_1_bn (BatchNormalization)  (None, 4, 4, 1280)   5120        Conv_1[0][0]

------------------------------------------------------------------------------------------------------
out_relu (ReLU)                 (None, 4, 4, 1280)   0           Conv_1_bn[0][0]
======================================================================================================
Total params: 2,257,984
Trainable params: 2,223,872
Non-trainable params: 34,112

------------------------------------------------------------------------------------------------------
Computing neural codes…
81/81 [==============================] - 3s 39ms/step
(8091, 20480) float32
```

5 Analyze Captions

- Find the maximal caption length in the *captions* and store it in a variable *max_caption_length*.
- Construct a collection of all words (i.e. strings) occurring in the captions, and count their occurrences. Include the special word '_' (the *stop word*, signaling the end of the captions)

in this collection.

- Construct a dictionary *word_to_idx* which maps words to integers as follows:
  - '_' -> 0
  - most frequent word -> 1
  - second most frequent word -> 2
  - ...
- Construct a dictionary *idx_to_word* which inverts the mapping *word_to_idx*.
- Store the number of unique words, including '_', in a variable *num_words*.

[0]:
```
# ...
captions = np.array(captions)

# max length of captions
max_caption_length = max(map(len, captions.reshape(-1)))

# count words
word_dict = {}
for caption in captions:
  for line in caption:
    for word in line:
      if word in word_dict.keys():
        word_dict[word] += 1
      else:
        word_dict[word] = 1

# sort dictionaries by frequency
word_dict = {k:v for k,v in sorted(word_dict.items(), key=lambda item :␣
↪item[1], reverse=True)}
word_to_idx = {'_': 0}
idx_to_word = {0: '_'}
for i,key in enumerate(word_dict.keys()):
  word_to_idx[key] = i+1
  idx_to_word[i+1] = key

# unique words
num_words = len(word_to_idx)

# ...
```

Report the 10 most frequent words. Do you note a bias in the dataset?

The 10 most frequent words are: `{'a', 'in', 'the', 'on', 'is', 'and', 'dog', 'with', 'man', 'of'}`. These words do not highlight a clear bias in our opinion. A part from `dog`, `man` and `is`, all the words are either conjunctions or nouns. Furthermore, `man` and `is` are really common words in English, so it is not surprising that they are among the most frequent. The only word that seems out of place is `dog`. Even though this word is also common in English, it could suggest that in the dataset there are big quantities of dog pictures, which could alter the prediction accuracy of the model.

How many unique words are there in the corpus, including '_'?

The number of unique words is 2992, including `'_'`

6 Train/Validation/Test Split

[0]:
```
val_images = images[0:1000, ...]
val_codes = image_codes[0:1000, ...]
val_captions = [captions[k] for k in range(1000)]

test_images = images[1000:2000, ...]
test_codes = image_codes[1000:2000, ...]
test_captions = [captions[k] for k in range(1000, 2000)]

train_images = images[2000:, ...]
train_codes = image_codes[2000:, ...]
train_captions = [captions[k] for k in range(2000, images.shape[0])]
```

7 Convert Train and Validation Data into Matrix Format

This encodes the captions to integer matrices using the mapping *word_to_idx*. It also duplicates the corresponding image codes. The result is two matrices {train, val}_codes and {train, val}_y, which hold image codes and integer encoded captions, whose rows correspond to each other.

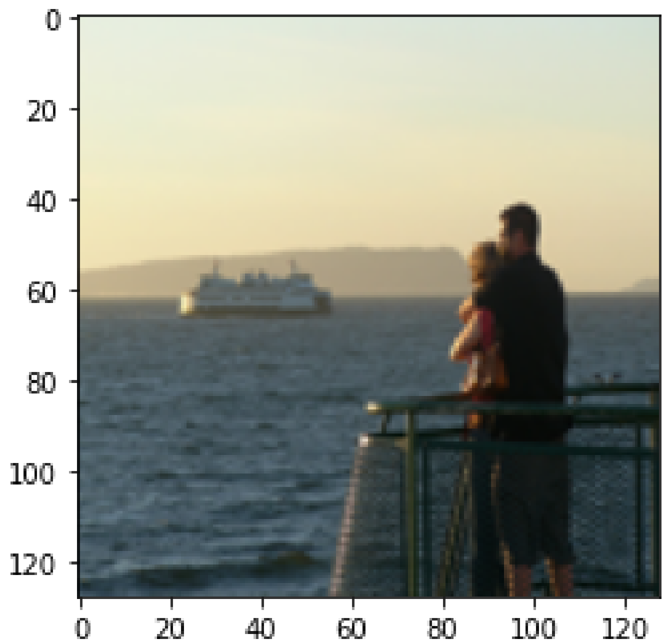
[7]:
```
def convert_data(codes, captions, max_caption_length, word_to_idx):
  if codes.shape[0] != len(captions):
    raise AssertionError("Different number of codes and captions.")

  N = codes.shape[0]
  duplicate_codes = None
  labels = None
  for k in range(5):
    cur_labels = np.zeros((N, max_caption_length), dtype=np.uint32)
    for l in range(N):
      for count, w in enumerate(captions[l][k]):
        cur_labels[l, count] = word_to_idx[w]

    if duplicate_codes is None:
      duplicate_codes = codes
      labels = cur_labels
    else:
      duplicate_codes = np.concatenate((duplicate_codes, codes), 0)
      labels = np.concatenate((labels, cur_labels), 0)

  return duplicate_codes, labels
```

```
train_codes, train_y = convert_data(train_codes, train_captions,␣
 ↪max_caption_length, word_to_idx)
val_codes, val_y = convert_data(val_codes, val_captions, max_caption_length,␣
 ↪word_to_idx)

print(train_codes.shape)
print(train_y.shape)
print(val_codes.shape)
print(val_y.shape)
```

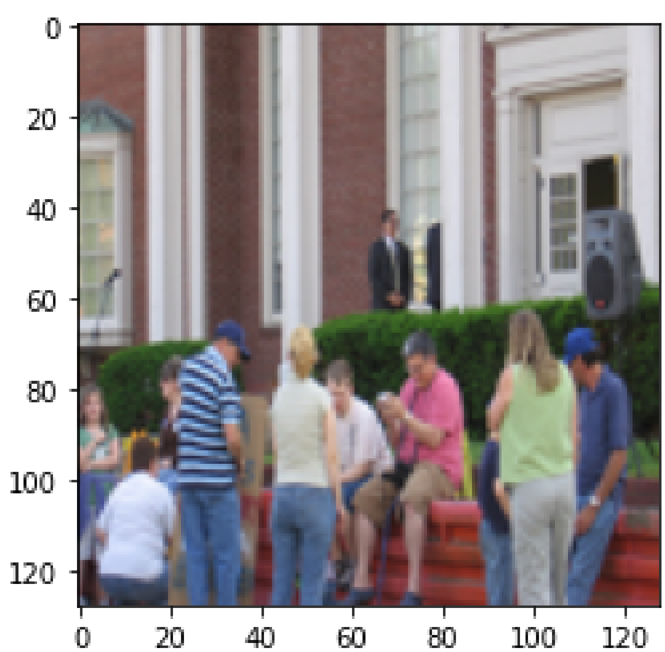
```
(30455, 20480)
(30455, 35)
(5000, 20480)
(5000, 35)
```

8 Show Random Images from Train and Validation Sets

[0]:
```
def show_random_image_and_captions(images, labels, idx_to_word):
  n = images.shape[0]
  idx = np.random.randint(0, n)

  plt.imshow(images[idx % images.shape[0], ...])
  plt.show()

  encoded_caption = labels[idx, ...]
  encoded_caption = [k for k in encoded_caption if k >= 0]
  caption = [idx_to_word[i] for i in encoded_caption]
  print(caption)
  print('\n\n')

show_random_image_and_captions(train_images, train_y, idx_to_word)
show_random_image_and_captions(val_images, val_y, idx_to_word)
```




```
['a', 'couple', 'hold', 'each', 'other', 'standing', 'on', 'a', 'ferry',
'looking', 'out', 'at', 'a', 'ferry', '_', '_', '_', '_', '_', '_', '_', '_',
'_', '_', '_', '_', '_', '_', '_', '_', '_', '_', '_', '_', '_']
```



```
['a', 'group', 'of', 'people', 'are', 'outside', 'a', 'brick', 'building',
'taking', 'pictures', '_', '_', '_', '_', '_', '_', '_', '_', '_', '_', '_',
'_', '_', '_', '_', '_', '_', '_', '_', '_', '_', '_', '_', '_']
```

9 Make Model

The model takes two inputs:

- *image_input*: placeholder for image codes.
- *caption_inputs*: placeholder for integer-encoded captions.

You need to insert the following structure:

- Image embedding: *Dense* layer, mapping image codes to embeddings of length *embedding_dim*.
- Caption embedding: *Embedding* layer, mapping integers to embeddings of length *embedding_dim*.
- Concatenate Image embedding and Caption embeddings along the time axis. The image embedding should be at time t=0.
- LSTM with *lstm_dim* units, taking the concatenated embedding as input.
- Apply Dropout with rate 0.5 to the LSTM.
- Output layer: *Dense* layer, mapping the output of the LSTM to a categorical distribution (via *softmax*) of length *num_words*.

Hint: The function K.expand_dims() might be useful here.

[0]:
```
from keras.utils import plot_model

def make_model(code_length, max_caption_length, embedding_dim, num_words,␣
 ↪lstm_dim, lstm_dropout):

  # inputs
  image_input = Input(shape=(code_length,), name='img_input')
  caption_input = Input(shape=(max_caption_length - 1,), name='caption_input')

  # ...
  # embeddings
  emb_img = Dense(embedding_dim, name='emb_img')(image_input)
  emb_words = Embedding(num_words, embedding_dim,␣
 ↪name='emb_words')(caption_input)

  # expand dimensions of img embedding to match words embeddings
  expand_emb_img = K.expand_dims(emb_img, axis=1)
```

```
  # concatenate img and words (img must be first input of the sequence)
  concatenation = concatenate([expand_emb_img, emb_words], axis=1,␣
 ↪name='concatenation')

  # LSTM layer
  LSTM_layer = LSTM(lstm_dim, dropout=lstm_dropout, return_sequences=True,␣
 ↪name='LSTM')(concatenation)

  # output softmax to predict words
  output = Dense(num_words, activation='softmax', name='output')(LSTM_layer)
  # ...

  return Model([image_input, caption_input], output)

model = make_model(code_length=train_codes.shape[1],
                   max_caption_length=max_caption_length,
                   embedding_dim=embedding_dim,
                   num_words=num_words,
                   lstm_dim=lstm_dim,
                   lstm_dropout=lstm_dropout)
model.summary()
```

```
Model: "model_1"
________________________________________________________________________________
__________________
Layer (type)                    Output Shape         Param #     Connected to
================================================================================
==================
img_input (InputLayer)          [(None, 20480)]      0
________________________________________________________________________________
__________________
emb_img (Dense)                 (None, 512)          10486272    img_input[0][0]
________________________________________________________________________________
__________________
caption_input (InputLayer)      [(None, 34)]         0
________________________________________________________________________________
__________________
tf_op_layer_ExpandDims (TensorF [(None, 1, 512)]     0           emb_img[0][0]
________________________________________________________________________________
__________________
emb_words (Embedding)           (None, 34, 512)      1531904
caption_input[0][0]
________________________________________________________________________________
__________________
concatenation (Concatenate)     (None, 35, 512)      0
tf_op_layer_ExpandDims[0][0]
```

```
                                                                 emb_words[0][0]
__________________________________________________________________________________
__________________
LSTM (LSTM)                     (None, 35, 500)      2026000
concatenation[0][0]
__________________________________________________________________________________
__________________
output (Dense)                  (None, 35, 2992)     1498992     LSTM[0][0]
==================================================================================
==================
Total params: 15,543,168
Trainable params: 15,543,168
Non-trainable params: 0
__________________________________________________________________________________
__________________
```

10 Train Model

- Use Adam with learning rate 0.001 and early stopping with patience 1. Provide the separate validation set for early stopping.
- Use a batch size of 100.
- Use a maximal number of epochs of 100 (early stopping will likely stop training much earlier).
- Use crossentropy as loss function.
- Report which data serves as input and which serves as output, and why.
- **Hint:** Use the sparse version of crossentropy, in order to avoid memory issues.

[0]:
```
early_stopping_callback = EarlyStopping(monitor='val_loss',
                                        min_delta=0,
                                        patience=1,
                                        verbose=1,
                                        mode='auto')


# ...
model.compile(optimizers.Adam(),
              loss = 'sparse_categorical_crossentropy')
model.fit(x = [train_codes, train_y[:, :-1]], # model output at each step =␣
 ↪p(S_t | img, S_0, S_1, ..., S_t-1)
          y = train_y,
          epochs = 100,
          batch_size = 100,
          callbacks = early_stopping_callback,
          validation_data = ([val_codes, val_y[:, :-1]], val_y))
# ...

model.save(os.path.join(base_path, 'model.h5'))
```

```
Epoch 1/100
```

```
305/305 [==============================] - 19s 62ms/step - loss: 1.6384 -
val_loss: 1.3243
Epoch 2/100
305/305 [==============================] - 18s 61ms/step - loss: 1.2352 -
val_loss: 1.1807
Epoch 3/100
305/305 [==============================] - 19s 61ms/step - loss: 1.1256 -
val_loss: 1.1063
Epoch 4/100
305/305 [==============================] - 19s 61ms/step - loss: 1.0555 -
val_loss: 1.0581
Epoch 5/100
305/305 [==============================] - 19s 61ms/step - loss: 1.0053 -
val_loss: 1.0268
Epoch 6/100
305/305 [==============================] - 19s 61ms/step - loss: 0.9679 -
val_loss: 1.0060
Epoch 7/100
305/305 [==============================] - 19s 61ms/step - loss: 0.9381 -
val_loss: 0.9894
Epoch 8/100
305/305 [==============================] - 19s 61ms/step - loss: 0.9121 -
val_loss: 0.9809
Epoch 9/100
305/305 [==============================] - 19s 61ms/step - loss: 0.8909 -
val_loss: 0.9720
Epoch 10/100
305/305 [==============================] - 18s 60ms/step - loss: 0.8709 -
val_loss: 0.9655
Epoch 11/100
305/305 [==============================] - 18s 58ms/step - loss: 0.8510 -
val_loss: 0.9616
Epoch 12/100
305/305 [==============================] - 18s 59ms/step - loss: 0.8341 -
val_loss: 0.9603
Epoch 13/100
305/305 [==============================] - 18s 58ms/step - loss: 0.8187 -
val_loss: 0.9572
Epoch 14/100
305/305 [==============================] - 18s 59ms/step - loss: 0.8032 -
val_loss: 0.9589
Epoch 00014: early stopping
```

How does the input and output need to be organized?

> The input needs to be 'flattened' before giving it to the model. Originally the dataset is shaped as: * `images_codes.shape = (8091,5, caption_max_len)`, which means that we have a matrix containing an image code for each row. * `captions.shape = (8091,5)`, which means that we have a matrix containing 5 captions for each image of

the previous matrix.

Flattening the input means that we create two matrices with `8091*5 = 40455` rows. The same row index refers to an image code in the first matrix and one of its related captions in the second one. We therefore duplicate each image 5 times, to take into consideration each related caption.

Eventually, we give to the model batches of rows of these matrices, dividing, for each row, the caption from the image. Before submitting the caption we also remove its last term, due to the fact that the input sequence of the LSTM layer must be `max_caption_length` long and, in the model, we assign to the first time-step the image code.

The output labels are composed by batches of rows of the caption matrix only. At each training step we compare one predicted caption with the caption assigned in the above-described matrices.

For how many time steps `T` should the LSTM be unrolled?

It should be unrolled for `max_caption_length` time steps. Therefore, 35 in our case

For each time step, `t = 0, ... , T-1`, which embedding should be input to the LSTM and what should be the target?

- `t = 0`. The input should be an image code embedded into the dimension of the embedding space. The target should be the first word of the ground truth caption.
- For each `t in {1, ... , T-1}`, the input should be the word in position `t - 1` of the ground-truth sequence composed of the image code at `t = 0` and the ground truth caption with the last term removed. The target should be the word in position t of the ground truth caption.

11 Evaluate Model

- Evaluate and report the final train and validation loss.

[8]:
```
model = load_model(os.path.join(base_path, 'model.h5'))
model.summary()

# ...
# Evaluating
print('Evaluating training set...')
train_loss = model.evaluate(x = [train_codes, train_y[:, :-1]],
                            y = train_y)
print('Evaluating validation set...')
val_loss = model.evaluate(x = [val_codes, val_y[:, :-1]],
                          y = val_y)

# Printing results
print(f'\nTrain loss = {train_loss}')
print(f'Valid loss = {val_loss}')
# ...
```

```
Model: "model_1"
________________________________________________________________________________
__________________
Layer (type)                    Output Shape         Param #     Connected to
================================================================================
==================
img_input (InputLayer)          [(None, 20480)]      0

________________________________________________________________________________
__________________
emb_img (Dense)                 (None, 512)          10486272    img_input[0][0]

________________________________________________________________________________
__________________
caption_input (InputLayer)      [(None, 34)]         0

________________________________________________________________________________
__________________
tf_op_layer_ExpandDims (TensorF (None, 1, 512)       0           emb_img[0][0]

________________________________________________________________________________
__________________
emb_words (Embedding)           (None, 34, 512)      1531904
caption_input[0][0]

________________________________________________________________________________
__________________
concatenation (Concatenate)     (None, 35, 512)      0
tf_op_layer_ExpandDims[0][0]
                                                                 emb_words[0][0]

________________________________________________________________________________
__________________
LSTM (LSTM)                     (None, 35, 500)      2026000
concatenation[0][0]

________________________________________________________________________________
__________________
output (Dense)                  (None, 35, 2992)     1498992     LSTM[0][0]
================================================================================
==================
Total params: 15,543,168
Trainable params: 15,543,168
Non-trainable params: 0

________________________________________________________________________________
__________________
Evaluating training set…
952/952 [==============================] - 7s 8ms/step - loss: 0.7594
Evaluating validation set…
157/157 [==============================] - 1s 7ms/step - loss: 0.9589

Train loss = 0.7594326734542847
Valid loss = 0.9588773250579834
```

12 Make Decoder

- Make a greedy decoder model, which iteratively predicts the most likely word at each time step. The decoder is akin to the trained model above, but with a crucial difference: at time step t (t > 0), the LSTM takes the embedding of the word *predicted at time step t-1* as input. At time t=0, the LSTM takes the image embedding as input.
- The decoder should return the predicted captions, encoded as integer matrix of shape (batch_size, max_caption_length).
- Equip the decoder with the weights of the trained model.
- **Hint:** You will need to pass on the internal state of the LSTM from time step to time step. To this end, use the argument *return_state=True* when creating the LSTM, and the *initial_state* argument when calling the LSTM.
- **Hint:** Use the argument *weights* to pass the parameters of the trained model. This should contain the weights for image embedding, word embedding, LSTM, and output layer. Use the methods *get_weights()* and *set_weights()* to this end.
- **Hint:** The functions *K.expand_dims()*, *K.argmax()*, and *K.stack()* might be useful here.

[0]:
```
def make_decoder(code_length, max_caption_length, embedding_dim, num_words,␣
↪lstm_dim, lstm_dropout, weights):

  # input
  image_input = Input(shape=(code_length,))

  # ...
  # parameters
  predicted_caption = []

  # layers definition
  img_to_emb = Dense(embedding_dim, name='emb_img')
  LSTM_iterator = LSTM(lstm_dim, dropout=lstm_dropout, return_state=True,␣
↪name='LSTM')
  embedder = Embedding(num_words, embedding_dim, name='emb_words')
  softmaxer = Dense(num_words, activation='softmax', name='softmaxer')

  # embedding image
  emb_img = img_to_emb(image_input)
  expanded_emb = K.expand_dims(emb_img, axis = 1)

  # first iteration LSTM
  LSTM_output, state_h, state_c = LSTM_iterator(expanded_emb)
  previous_state = [state_h, state_c]
  softmax_output = softmaxer(LSTM_output)
  predicted_word = K.argmax(softmax_output, axis=1)
  predicted_caption.append(predicted_word)

  # LSTM cicle
  for i in range(max_caption_length - 1):
```

```
    # embed word
    emb_word = embedder(predicted_word)
    expanded_emb = K.expand_dims(emb_word, axis = 1)

    # LSTM iteration
    LSTM_output, state_h, state_c = LSTM_iterator(expanded_emb,␣
↪initial_state=previous_state)
    previous_state = [state_h, state_c]
    softmax_output = softmaxer(LSTM_output)
    predicted_word = K.argmax(softmax_output, axis=1)
    predicted_caption.append(predicted_word)

  # stuck all outputs and complete network
  output = K.stack(predicted_caption, axis = 1)

  # finally, define model
  model = Model(inputs = image_input, outputs = output)

  # set layer weights
  model.get_layer('emb_img').set_weights(weights['emb_img'])
  model.get_layer('emb_words').set_weights(weights['emb_words'])
  model.get_layer('LSTM').set_weights(weights['LSTM'])
  model.get_layer('softmaxer').set_weights(weights['output'])
  # ...

  return model

# Get the weights from trained model, and put them in a list 'weights'.
# ...
layers = ['emb_img', 'emb_words', 'LSTM', 'output']
weights = {name : model.get_layer(name).get_weights() for name in layers}
# ...

decoder = make_decoder(code_length=train_codes.shape[1],
                       max_caption_length=max_caption_length,
                       embedding_dim=embedding_dim,
                       num_words=num_words,
                       lstm_dim=lstm_dim,
                       lstm_dropout=lstm_dropout,
                       weights=weights)
```

13 Predict Test Captions

- Use the decoder to predict the test captions.
- Decode them to text using the mapping *idx_to_word*.
- Show 10 random test images and their predicted captions. Categorize them like in Figure 5

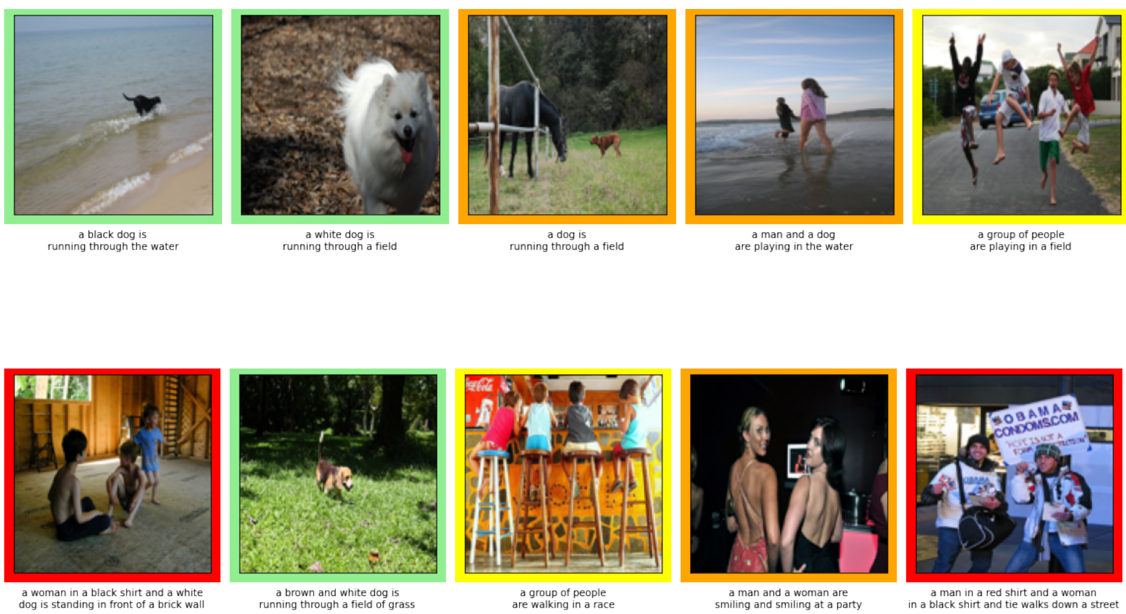
in the paper.

- Report the 1-gram, 2-gram, 3-gram, and 4-gram BLEU scores of the test predictions. **Hint:** You can use the *nltk* package for this.

[20]:
```
# ...
import matplotlib.pyplot as plt
from mpl_toolkits.axes_grid1 import ImageGrid
from typing import List

def show_row_of_imgs(
    imgs_idxs: np.ndarray,
    pred_captions: np.ndarray,
    edges: List
):
  # canvas initialization
  fig = plt.figure(figsize=(20., 80.))
  grid = ImageGrid(fig, 111, nrows_ncols=(1, 5), axes_pad=0.4)

  # fitting images into grid
  for enum_i, (ax, i) in enumerate(zip(grid, imgs_idxs)):
      ax.imshow(test_images[i])
      ax.set_xticks([]), ax.set_yticks([])

      # elaborating caption
      caption = np.delete(pred_captions[i], np.where(pred_captions[i] == '_'))
      first_half, second_half = caption[:len(caption)//2], caption[len(caption)/
↪/2:]
      first_half, second_half = ' '.join(first_half), ' '.join(second_half)
      final_caption = first_half + '\n' + second_half
      final_caption = final_caption.split('_')[0]
      ax.set_xlabel('\n' + final_caption)

      # set frame
      ax.patch.set_edgecolor(edges[enum_i])
      ax.patch.set_linewidth('20')

  plt.show()

# generate predictions
print('Predicting...')
predictions = decoder.predict(test_codes, verbose=1, batch_size=100)

# transform indexes in words
captionize = lambda x: idx_to_word[x]
pred_captions = np.vectorize(captionize)(predictions)

# take 10 random images
```

```
np.random.seed(456)
random_idxs = np.random.randint(0, 1000, size = (10))

# visualize results
print('')
edges_first_half = ['lightgreen', 'lightgreen', 'orange', 'orange', 'yellow']
edges_second_half = ['red', 'lightgreen', 'yellow', 'orange', 'red']
show_row_of_imgs(random_idxs[:5], pred_captions, edges_first_half)
show_row_of_imgs(random_idxs[5:], pred_captions, edges_second_half)
# ...
```

```
Predicting…
10/10 [==============================] - 0s 39ms/step
```



Colors to images are given according to the following schema: * green = the image is described without errors * orange = the image is described with minor errors * yellow = the caption is somehow related to the image * red = the caption is unrelated to the image

[22]:
```
# ...
import warnings
warnings.filterwarnings('ignore')

# n-grams BLUE score
gram1, gram2, gram3, gram4 = 0.0, 0.0, 0.0, 0.0
weights1, weights2, weights3 = tuple([1.0]), (0.5, 0.5), (0.33, 0.33, 0.33)
pred_captions = [np.delete(caption, np.where(caption == '_')) for caption in␣
↪pred_captions]
```

```python
gram1 += nltk.translate.bleu_score.corpus_bleu(test_captions, pred_captions,␣
    ↪weights=weights1)
gram2 += nltk.translate.bleu_score.corpus_bleu(test_captions, pred_captions,␣
    ↪weights=weights2)
gram3 += nltk.translate.bleu_score.corpus_bleu(test_captions, pred_captions,␣
    ↪weights=weights3)
gram4 += nltk.translate.bleu_score.corpus_bleu(test_captions, pred_captions)

# showing scores
print(f'1-gram BLEU score on test set: {gram1}')
print(f'2-gram BLEU score on test set: {gram2}')
print(f'3-gram BLEU score on test set: {gram3}')
print(f'4-gram BLEU score on test set: {gram4}')
# ...
```

```
1-gram BLEU score on test set: 0.4792822185970636
2-gram BLEU score on test set: 0.3061506039593639
3-gram BLEU score on test set: 0.1952958067392502
4-gram BLEU score on test set: 0.12142915943523283
```