assignment12_DavisAmie

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1 File information

File: Assignment12.ipynb

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Date: 2/28/2021

Course: DSC650 - Big Data

Assignment Number: 12

Purpose: Implement a variational autoencoder (VAE)

2 References:

Chollet, F. (2018). Deep learning with Python. Shelter Island, NY: Manning Publications.

https://www.tensorflow.org/datasets/catalog/celeb_a

https://www.kaggle.com/kumar1541/variational-auto-encoder-in-keras

http://airobott.blogspot.com/2020/05/how-to-generate-faces-using-vae-with.html

3 Assignment 12

Using section 8.4 in Deep Learning with Python as a guide, implement a variational autoencoder using the MNIST data set and save a grid of 15 x 15 digits to the results/vae directory. If you would rather work on a more interesting dataset, you can use the CelebFaces Attributes Dataset instead.

3.1 MNIST Dataset

[1]:

```
# VAE encoder network
# Encodes the input into a mean and variance parameter

import keras
from keras import layers
from keras import backend as K
from keras.models import Model
import numpy as np
```

```
img_shape = (28, 28, 1)
batch_size = 16

# Dimensionality of the latent space is a 2D plane
latent_dim = 2

input_img = keras.Input(shape=img_shape)

x = layers.Conv2D(32, 3,
                  padding='same', activation='relu')(input_img)
x = layers.Conv2D(64, 3,
                  padding='same', activation='relu',
                  strides=(2, 2))(x)
x = layers.Conv2D(64, 3,
                  padding='same', activation='relu')(x)
x = layers.Conv2D(64, 3,
                  padding='same', activation='relu')(x)
shape_before_flattening = K.int_shape(x)

x = layers.Flatten()(x)
x = layers.Dense(32, activation='relu')(x)


# The input image is encoded into these two parameters.
z_mean = layers.Dense(latent_dim)(x)
z_log_var = layers.Dense(latent_dim)(x)
```

```
Using TensorFlow backend.
C:\Users\amomu\Anaconda3\lib\site-
packages\tensorflow\python\framework\dtypes.py:516: FutureWarning: Passing
(type, 1) or '1type' as a synonym of type is deprecated; in a future version of
numpy, it will be understood as (type, (1,)) / '(1,)type'.
  _np_qint8 = np.dtype([("qint8", np.int8, 1)])
C:\Users\amomu\Anaconda3\lib\site-
packages\tensorflow\python\framework\dtypes.py:517: FutureWarning: Passing
(type, 1) or '1type' as a synonym of type is deprecated; in a future version of
numpy, it will be understood as (type, (1,)) / '(1,)type'.
  _np_quint8 = np.dtype([("quint8", np.uint8, 1)])
C:\Users\amomu\Anaconda3\lib\site-
packages\tensorflow\python\framework\dtypes.py:518: FutureWarning: Passing
(type, 1) or '1type' as a synonym of type is deprecated; in a future version of
numpy, it will be understood as (type, (1,)) / '(1,)type'.
  _np_qint16 = np.dtype([("qint16", np.int16, 1)])
C:\Users\amomu\Anaconda3\lib\site-
packages\tensorflow\python\framework\dtypes.py:519: FutureWarning: Passing
(type, 1) or '1type' as a synonym of type is deprecated; in a future version of
```

```
numpy, it will be understood as (type, (1,)) / '(1,)type'.
  _np_quint16 = np.dtype([("quint16", np.uint16, 1)])
C:\Users\amomu\Anaconda3\lib\site-
packages\tensorflow\python\framework\dtypes.py:520: FutureWarning: Passing
(type, 1) or '1type' as a synonym of type is deprecated; in a future version of
numpy, it will be understood as (type, (1,)) / '(1,)type'.
  _np_qint32 = np.dtype([("qint32", np.int32, 1)])
C:\Users\amomu\Anaconda3\lib\site-
packages\tensorflow\python\framework\dtypes.py:525: FutureWarning: Passing
(type, 1) or '1type' as a synonym of type is deprecated; in a future version of
numpy, it will be understood as (type, (1,)) / '(1,)type'.
  np_resource = np.dtype([("resource", np.ubyte, 1)])
C:\Users\amomu\Anaconda3\lib\site-
packages\tensorboard\compat\tensorflow_stub\dtypes.py:541: FutureWarning:
Passing (type, 1) or '1type' as a synonym of type is deprecated; in a future
version of numpy, it will be understood as (type, (1,)) / '(1,)type'.
  _np_qint8 = np.dtype([("qint8", np.int8, 1)])
C:\Users\amomu\Anaconda3\lib\site-
packages\tensorboard\compat\tensorflow_stub\dtypes.py:542: FutureWarning:
Passing (type, 1) or '1type' as a synonym of type is deprecated; in a future
version of numpy, it will be understood as (type, (1,)) / '(1,)type'.
  _np_quint8 = np.dtype([("quint8", np.uint8, 1)])
C:\Users\amomu\Anaconda3\lib\site-
packages\tensorboard\compat\tensorflow_stub\dtypes.py:543: FutureWarning:
Passing (type, 1) or '1type' as a synonym of type is deprecated; in a future
version of numpy, it will be understood as (type, (1,)) / '(1,)type'.
  _np_qint16 = np.dtype([("qint16", np.int16, 1)])
C:\Users\amomu\Anaconda3\lib\site-
packages\tensorboard\compat\tensorflow_stub\dtypes.py:544: FutureWarning:
Passing (type, 1) or '1type' as a synonym of type is deprecated; in a future
version of numpy, it will be understood as (type, (1,)) / '(1,)type'.
  _np_quint16 = np.dtype([("quint16", np.uint16, 1)])
C:\Users\amomu\Anaconda3\lib\site-
packages\tensorboard\compat\tensorflow_stub\dtypes.py:545: FutureWarning:
Passing (type, 1) or '1type' as a synonym of type is deprecated; in a future
version of numpy, it will be understood as (type, (1,)) / '(1,)type'.
  _np_qint32 = np.dtype([("qint32", np.int32, 1)])
C:\Users\amomu\Anaconda3\lib\site-
packages\tensorboard\compat\tensorflow_stub\dtypes.py:550: FutureWarning:
Passing (type, 1) or '1type' as a synonym of type is deprecated; in a future
version of numpy, it will be understood as (type, (1,)) / '(1,)type'.
  np_resource = np.dtype([("resource", np.ubyte, 1)])
```

[2]:

```python
# Latent-space-sampling function
# Draws a latent point using a small random epsilon

def sampling(args):
    z_mean, z_log_var = args
    epsilon = K.random_normal(shape=(K.shape(z_mean)[0], latent_dim),
                              mean=0., stddev=1.)
    return z_mean + K.exp(z_log_var) * epsilon

z = layers.Lambda(sampling)([z_mean, z_log_var])
```

[3]:

```
# VAE decoder network, mapping latent space points to images

# Decode z back to an image
# Input where you'll feed z
decoder_input = layers.Input(K.int_shape(z)[1:])

# Upsample the input
x = layers.Dense(np.prod(shape_before_flattening[1:]),
                 activation='relu')(decoder_input)

# Reshape z into a feature map of the same shape as the feature map
# just before the last Flatten layer in the encoder model
x = layers.Reshape(shape_before_flattening[1:])(x)
x = layers.Conv2DTranspose(32, 3,
                           padding='same',
                           activation='relu',
                           strides=(2, 2))(x)

# Use Conv2DTranspose layer and Conv2D layer to decode z into a feature map
# the same size as the original image input
x = layers.Conv2D(1, 3,
                  padding='same',
                  activation='sigmoid')(x)

# Instantiate the decoder model, which turns "decoder_input" into the decoded image
decoder = Model(decoder_input, x)

# Recover the decoded z
z_decoded = decoder(z)
```

[4]:

```
#  Custom layer used to compute the VAE loss
class CustomVariationalLayer(keras.layers.Layer):

    def vae_loss(self, x, z_decoded):
        x = K.flatten(x)
        z_decoded = K.flatten(z_decoded)
        xent_loss = keras.metrics.binary_crossentropy(x, z_decoded)
        kl_loss = -5e-4 * K.mean(
            1 + z_log_var - K.square(z_mean) - K.exp(z_log_var), axis=-1)
        return K.mean(xent_loss + kl_loss)

    # Implement custom layers by writing a call method
    def call(self, inputs):
        x = inputs[0]
        z_decoded = inputs[1]
        loss = self.vae_loss(x, z_decoded)
        self.add_loss(loss, inputs=inputs)

        # Note that x is not used
        return x

# Call the custom layer on the input and the decoded output to obtain the final␣
 ↪model output
y = CustomVariationalLayer()([input_img, z_decoded])
```

[5]:

```
# Training the VAE on the mnist dataset
from keras.datasets import mnist

vae = Model(input_img, y)
vae.compile(optimizer='rmsprop', loss=None)
vae.summary()

(x_train, _), (x_test, y_test) = mnist.load_data()

x_train = x_train.astype('float32') / 255.
x_train = x_train.reshape(x_train.shape + (1,))
x_test = x_test.astype('float32') / 255.
x_test = x_test.reshape(x_test.shape + (1,))

vae.fit(x=x_train, y=None,
        shuffle=True,
        epochs=10,
        batch_size=batch_size,
        validation_data=(x_test, None))
```

```
C:\Users\amomu\Anaconda3\lib\site-packages\keras\engine\training_utils.py:819:
UserWarning: Output custom_variational_layer_1 missing from loss dictionary. We
assume this was done on purpose. The fit and evaluate APIs will not be expecting
any data to be passed to custom_variational_layer_1.
  'be expecting any data to be passed to {0}.'.format(name))
```

```
Model: "model_2"
________________________________________________________________________________
__________________
Layer (type)                    Output Shape         Param #     Connected to
================================================================================
==================
input_1 (InputLayer)            (None, 28, 28, 1)    0
--------------------------------------------------------------------------------
------------------
conv2d_1 (Conv2D)               (None, 28, 28, 32)   320         input_1[0][0]
--------------------------------------------------------------------------------
------------------
conv2d_2 (Conv2D)               (None, 14, 14, 64)   18496       conv2d_1[0][0]
--------------------------------------------------------------------------------
------------------
conv2d_3 (Conv2D)               (None, 14, 14, 64)   36928       conv2d_2[0][0]
--------------------------------------------------------------------------------
------------------
conv2d_4 (Conv2D)               (None, 14, 14, 64)   36928       conv2d_3[0][0]
--------------------------------------------------------------------------------
------------------
flatten_1 (Flatten)             (None, 12544)        0           conv2d_4[0][0]
--------------------------------------------------------------------------------
------------------
dense_1 (Dense)                 (None, 32)           401440      flatten_1[0][0]
--------------------------------------------------------------------------------
------------------
dense_2 (Dense)                 (None, 2)            66          dense_1[0][0]
--------------------------------------------------------------------------------
------------------
dense_3 (Dense)                 (None, 2)            66          dense_1[0][0]
--------------------------------------------------------------------------------
------------------
lambda_1 (Lambda)               (None, 2)            0           dense_2[0][0]
                                                                 dense_3[0][0]
--------------------------------------------------------------------------------
------------------
model_1 (Model)                 (None, 28, 28, 1)    56385       lambda_1[0][0]
--------------------------------------------------------------------------------
------------------
custom_variational_layer_1 (Cus [(None, 28, 28, 1),  0           input_1[0][0]
                                                                 model_1[1][0]
================================================================================
==================
Total params: 550,629
Trainable params: 550,629
Non-trainable params: 0
--------------------------------------------------------------------------------
------------------
WARNING:tensorflow:From C:\Users\amomu\Anaconda3\lib\site-
packages\tensorflow\python\ops\math_grad.py:1250:
add_dispatch_support.<locals>.wrapper (from tensorflow.python.ops.array_ops) is
deprecated and will be removed in a future version.
Instructions for updating:
```

```
Use tf.where in 2.0, which has the same broadcast rule as np.where
WARNING:tensorflow:From C:\Users\amomu\Anaconda3\lib\site-
packages\keras\backend\tensorflow_backend.py:422: The name tf.global_variables
is deprecated. Please use tf.compat.v1.global_variables instead.

Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 175s 3ms/step - loss: 0.2167 -
val_loss: 0.1988
Epoch 2/10
60000/60000 [==============================] - 175s 3ms/step - loss: 0.1962 -
val_loss: 0.1915
Epoch 3/10
60000/60000 [==============================] - 175s 3ms/step - loss: 0.1902 -
val_loss: 0.1888
Epoch 4/10
60000/60000 [==============================] - 174s 3ms/step - loss: 0.1872 -
val_loss: 0.1880
Epoch 5/10
60000/60000 [==============================] - 175s 3ms/step - loss: 0.1851 -
val_loss: 0.1835
Epoch 6/10
60000/60000 [==============================] - 176s 3ms/step - loss: 0.1836 -
val_loss: 0.1839
Epoch 7/10
60000/60000 [==============================] - 176s 3ms/step - loss: 0.1823 -
val_loss: 0.1816
Epoch 8/10
60000/60000 [==============================] - 174s 3ms/step - loss: 0.1813 -
val_loss: 0.1799
Epoch 9/10
60000/60000 [==============================] - 175s 3ms/step - loss: 0.1804 -
val_loss: 0.1845
Epoch 10/10
60000/60000 [==============================] - 175s 3ms/step - loss: 0.1797 -
val_loss: 0.1792
```

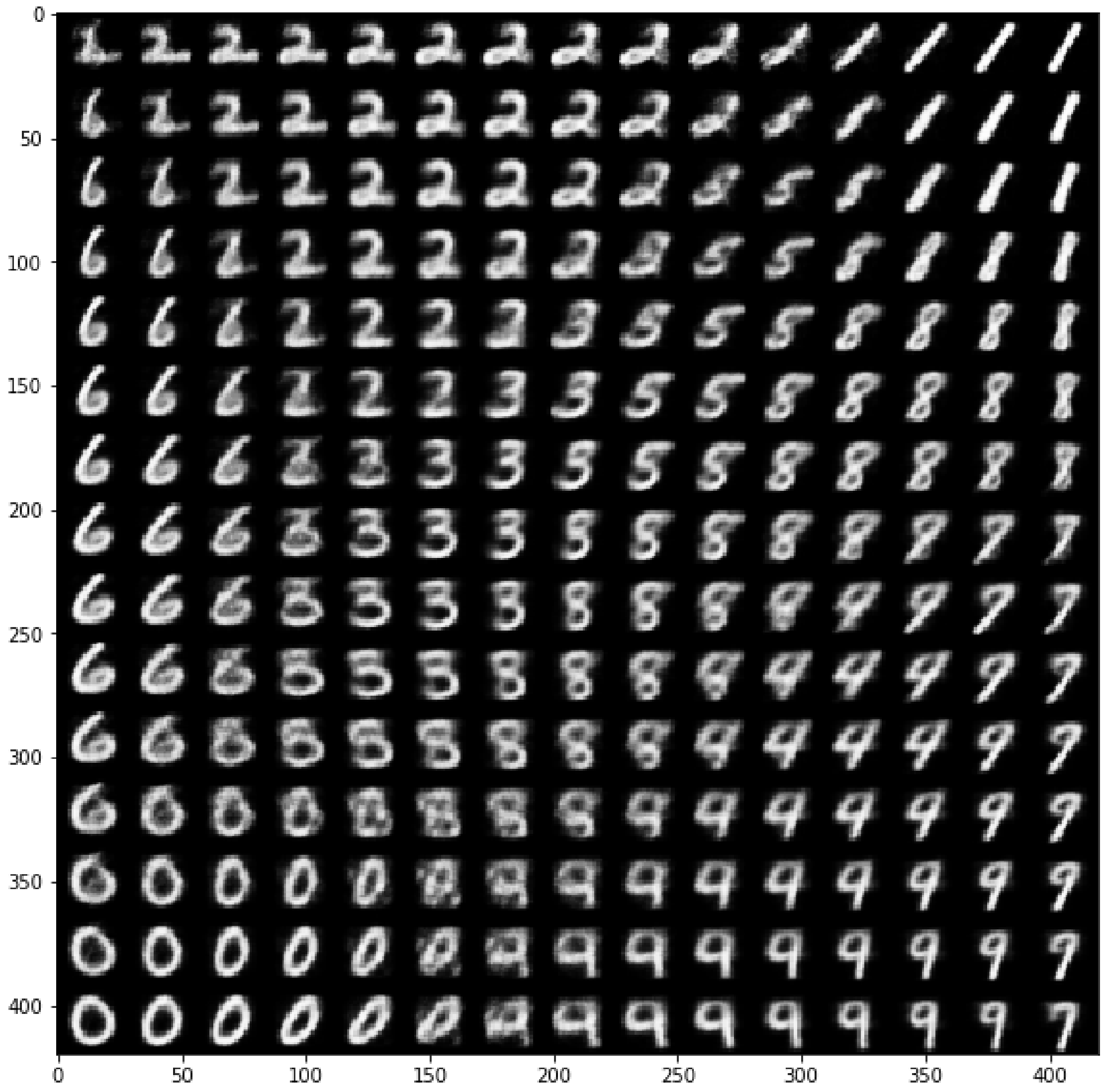
[5]:
```
<keras.callbacks.callbacks.History at 0x27b4654d188>
```

[6]:
```python
# Create results directory
import os
from pathlib import Path

current_dir=Path(os.getcwd()).absolute()

results_dir=current_dir.joinpath('results')
results_dir.mkdir(parents=True, exist_ok=True)
```

```
vae_dir=results_dir.joinpath('vae')
vae_dir.mkdir(parents=True, exist_ok=True)

mnist_out_plot=vae_dir.joinpath('mnist_vae_ouput.png')
```

[7]:

```
# Sampling a grid of points from the 2D latent space and decoding them to images
import matplotlib.pyplot as plt
from scipy.stats import norm

# Display a grid of 15 × 15 digits (255 digits total).
n = 15

digit_size = 28
figure = np.zeros((digit_size * n, digit_size * n))

# Transforms linearly spaced coordinates using the SciPy ppf function
# to produce values of the latent variable z (because the prior of the latent␣
 ↪space is Gaussian)
grid_x = norm.ppf(np.linspace(0.05, 0.95, n))
grid_y = norm.ppf(np.linspace(0.05, 0.95, n))

for i, yi in enumerate(grid_x):
    for j, xi in enumerate(grid_y):
        z_sample = np.array([[xi, yi]])

        # Repeats z multiple times to form a complete batch
        z_sample = np.tile(z_sample, batch_size).reshape(batch_size, 2)

        # Decodes the batch into digit images
        x_decoded = decoder.predict(z_sample, batch_size=batch_size)

        # Reshapes the first digit in the batch from 28 × 28 × 1 to 28 × 28
        digit = x_decoded[0].reshape(digit_size, digit_size)
        figure[i * digit_size: (i + 1) * digit_size,
               j * digit_size: (j + 1) * digit_size] = digit

plt.figure(figsize=(10, 10))
plt.imshow(figure, cmap='Greys_r')

# Save figure
plt.savefig(mnist_out_plot)
```



3.2 CelebFaces Dataset

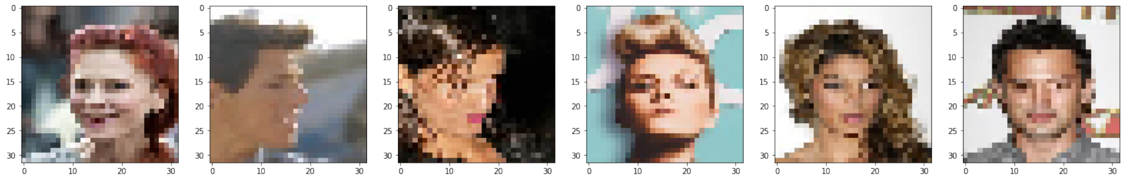
[8]:
```
# Prepare the CelebFaces Attributes Dataset (CelebA)
from keras.preprocessing.image import load_img
from keras.preprocessing.image import img_to_array

dir_data       = celeba_dir = os.path.join(current_dir,␣
 ↪'archive\img_align_celeba\img_align_celeba')

# Use 20,000 images to train & 100 to test
Ntrain         = 20000
Ntest          = 100
```

```
nm_imgs       = np.sort(os.listdir(dir_data))
## name of the jpg files for training set
nm_imgs_train = nm_imgs[:Ntrain]
## name of the jpg files for the testing data
nm_imgs_test  = nm_imgs[Ntrain:Ntrain + Ntest]
img_shape     = (32, 32, 3)

# Shrink the image size to save computation time
def get_npdata(nm_imgs_train):
    X_train = []
    for i, myid in enumerate(nm_imgs_train):
        image = load_img(dir_data + "/" + myid,
                         target_size=img_shape[:2])
        image = img_to_array(image)/255.0
        X_train.append(image)
    X_train = np.array(X_train)
    return(X_train)

X_train = get_npdata(nm_imgs_train)
print("X_train.shape = {}".format(X_train.shape))

X_test  = get_npdata(nm_imgs_test)
print("X_test.shape = {}".format(X_test.shape))
```

```
X_train.shape = (20000, 32, 32, 3)
X_test.shape = (100, 32, 32, 3)
```

[9]:

```
# Plot resized input images
fig = plt.figure(figsize=(30,10))
nplot = 7
for count in range(1,nplot):
    ax = fig.add_subplot(1,nplot,count)
    ax.imshow(X_train[count])
plt.show()
```



[10]:

```
# VAE encoder network
# Encodes the input into a mean and variance parameter

# Rebuild since image size changed to 32 x 32 x 3
```

```
img_shape = (32, 32, 3)
batch_size = 16

# AMD
latent_dim = 128

input_img = keras.Input(shape=img_shape)

x = layers.Conv2D(32, (2,2),
                  padding='same', activation='relu')(input_img)
x = layers.Conv2D(64, (2,2),
                  padding='same', activation='relu',
                  strides=(2, 2))(x)
x = layers.Conv2D(64, (2,2),
                  padding='same', activation='relu')(x)
x = layers.Conv2D(64, (2,2),
                  padding='same', activation='relu')(x)
shape_before_flattening = K.int_shape(x)

x = layers.Flatten()(x)
x = layers.Dense(256, activation='relu')(x)

# The input image is encoded into these two parameters.
z_mean = layers.Dense(latent_dim, activation='relu')(x)
z_log_var = layers.Dense(latent_dim, activation='relu')(x)
```

[11]:

```
# Latent-space-sampling function
# Draws a latent point using a small random epsilon

def sampling(args):
    z_mean, z_log_var = args
    epsilon = K.random_normal(shape=(K.shape(z_mean)[0], latent_dim),
                              mean=0., stddev=1.)
    return z_mean + K.exp(z_log_var) * epsilon

z = layers.Lambda(sampling)([z_mean, z_log_var])

encoder = Model(input_img,z,name = "VAE_Encoder")
encoder.summary()
```

```
Model: "VAE_Encoder"
________________________________________________________________________________
__________________
Layer (type)                    Output Shape         Param #     Connected to
================================================================================
==================
input_3 (InputLayer)            (None, 32, 32, 3)    0
```

```
--------------------------------------------------------------------------------
------------------
conv2d_6 (Conv2D)               (None, 32, 32, 32)   416         input_3[0][0]
--------------------------------------------------------------------------------
------------------
conv2d_7 (Conv2D)               (None, 16, 16, 64)   8256        conv2d_6[0][0]
--------------------------------------------------------------------------------
------------------
conv2d_8 (Conv2D)               (None, 16, 16, 64)   16448       conv2d_7[0][0]
--------------------------------------------------------------------------------
------------------
conv2d_9 (Conv2D)               (None, 16, 16, 64)   16448       conv2d_8[0][0]
--------------------------------------------------------------------------------
------------------
flatten_2 (Flatten)             (None, 16384)        0           conv2d_9[0][0]
--------------------------------------------------------------------------------
------------------
dense_5 (Dense)                 (None, 256)          4194560     flatten_2[0][0]
--------------------------------------------------------------------------------
------------------
dense_6 (Dense)                 (None, 128)          32896       dense_5[0][0]
--------------------------------------------------------------------------------
------------------
dense_7 (Dense)                 (None, 128)          32896       dense_5[0][0]
--------------------------------------------------------------------------------
------------------
lambda_2 (Lambda)               (None, 128)          0           dense_6[0][0]
                                                                 dense_7[0][0]
================================================================================
==================
Total params: 4,301,920
Trainable params: 4,301,920
Non-trainable params: 0
--------------------------------------------------------------------------------
------------------
```

[12]:

```
# VAE decoder network, mapping latent space points to images

# Decode z back to an image
# Input where you’ll feed z
decoder_input = layers.Input(K.int_shape(z)[1:])

# Upsample the input
x = layers.Dense(np.prod(shape_before_flattening[1:]),
                 activation='relu')(decoder_input)

# Reshape z into a feature map of the same shape as the feature map
# just before the last Flatten layer in the encoder model
x = layers.Reshape(shape_before_flattening[1:])(x)

x = layers.Conv2DTranspose(32,(3,3),
                           padding='same',
                           activation='relu',
                           strides=2)(x)

# Use Conv2DTranspose layer and Conv2D layer to decode z into a feature map
# the same size as the original image input
x = layers.Conv2D(3, (3,3),
                  padding='same',
                  activation='sigmoid')(x)

# Instantiate the decoder model, which turns "decoder_input" into the decoded image
decoder = Model(decoder_input, x)

# Recover the decoded z
z_decoded = decoder(z)
```

[13]:

```
#  Custom layer used to compute the VAE loss
class CustomVariationalLayer(keras.layers.Layer):

    def vae_loss(self, x, z_decoded):
        x = K.flatten(x)
        z_decoded = K.flatten(z_decoded)
        xent_loss = keras.metrics.binary_crossentropy(x, z_decoded)
        kl_loss = -5e-4 * K.mean(
            1 + z_log_var - K.square(z_mean) - K.exp(z_log_var), axis=-1)
        return K.mean(xent_loss + kl_loss)

    # Implement custom layers by writing a call method
    def call(self, inputs):
        x = inputs[0]
        z_decoded = inputs[1]
        loss = self.vae_loss(x, z_decoded)
        self.add_loss(loss, inputs=inputs)

        # Note that x is not used
        return x

# Call the custom layer on the input and the decoded output to obtain the final model output
y = CustomVariationalLayer()([input_img, z_decoded])

#AMD
```

```
print("y shape = {}".format(x.shape))
```

```
y shape = (?, ?, ?, 3)
```

[14]:

```
# Training the VAE on the CelebFaces Attributes Dataset (CelebA)
vae2 = Model(input_img, y)
vae2.compile(optimizer='rmsprop', loss=None)
vae2.summary()

vae2.fit(x=X_train, y=None,
        shuffle=True,
        epochs=10,
        batch_size=batch_size,
        validation_data=(X_test, None))
```

```
Model: "model_4"
--------------------------------------------------------------------------------
------------------
Layer (type)                    Output Shape         Param #     Connected to
================================================================================
==================
input_3 (InputLayer)            (None, 32, 32, 3)    0
--------------------------------------------------------------------------------
------------------
conv2d_6 (Conv2D)               (None, 32, 32, 32)   416         input_3[0][0]
--------------------------------------------------------------------------------
------------------
conv2d_7 (Conv2D)               (None, 16, 16, 64)   8256        conv2d_6[0][0]
--------------------------------------------------------------------------------
------------------
conv2d_8 (Conv2D)               (None, 16, 16, 64)   16448       conv2d_7[0][0]
--------------------------------------------------------------------------------
------------------
conv2d_9 (Conv2D)               (None, 16, 16, 64)   16448       conv2d_8[0][0]
--------------------------------------------------------------------------------
------------------
flatten_2 (Flatten)             (None, 16384)        0           conv2d_9[0][0]
--------------------------------------------------------------------------------
------------------
dense_5 (Dense)                 (None, 256)          4194560     flatten_2[0][0]
--------------------------------------------------------------------------------
------------------
dense_6 (Dense)                 (None, 128)          32896       dense_5[0][0]
--------------------------------------------------------------------------------
------------------
dense_7 (Dense)                 (None, 128)          32896       dense_5[0][0]
--------------------------------------------------------------------------------
------------------
```

```
lambda_2 (Lambda)               (None, 128)          0           dense_6[0][0]
                                                                 dense_7[0][0]
--------------------------------------------------------------------------------
------------------
model_3 (Model)                 (None, 32, 32, 3)    2132867     lambda_2[0][0]
--------------------------------------------------------------------------------
------------------
custom_variational_layer_2 (Cus [(None, 32, 32, 3),  0           input_3[0][0]
                                                                 model_3[1][0]
================================================================================
==================
Total params: 6,434,787
Trainable params: 6,434,787
Non-trainable params: 0
--------------------------------------------------------------------------------
------------------
C:\Users\amomu\Anaconda3\lib\site-packages\keras\engine\training_utils.py:819:
UserWarning: Output custom_variational_layer_2 missing from loss dictionary. We
assume this was done on purpose. The fit and evaluate APIs will not be expecting
any data to be passed to custom_variational_layer_2.
  'be expecting any data to be passed to {0}.'.format(name))

Train on 20000 samples, validate on 100 samples
Epoch 1/10
20000/20000 [==============================] - 119s 6ms/step - loss: 0.5681 -
val_loss: 0.5348
Epoch 2/10
20000/20000 [==============================] - 123s 6ms/step - loss: 0.5382 -
val_loss: 0.5326
Epoch 3/10
20000/20000 [==============================] - 120s 6ms/step - loss: 0.5316 -
val_loss: 0.5208
Epoch 4/10
20000/20000 [==============================] - 121s 6ms/step - loss: 0.5282 -
val_loss: 0.5259
Epoch 5/10
20000/20000 [==============================] - 121s 6ms/step - loss: 0.5261 -
val_loss: 0.5174
Epoch 6/10
20000/20000 [==============================] - 121s 6ms/step - loss: 0.5245 -
val_loss: 0.5162
Epoch 7/10
20000/20000 [==============================] - 121s 6ms/step - loss: 0.5231 -
val_loss: 0.5158
Epoch 8/10
20000/20000 [==============================] - 119s 6ms/step - loss: 0.5221 -
val_loss: 0.5149
Epoch 9/10
```

```
20000/20000 [==============================] - 119s 6ms/step - loss: 0.5212 -
val_loss: 0.5135
Epoch 10/10
20000/20000 [==============================] - 119s 6ms/step - loss: 0.5204 -
val_loss: 0.5142
```

[14]:
```
<keras.callbacks.callbacks.History at 0x27b4f382ac8>
```

[15]:
```python
# Sample 30 points from the latent space and decoding them to images
import numpy as np

celeb_out_plot=vae_dir.joinpath('celeb_vae_ouput.png')

# Sample 30 points from a standard normal distribution with 200 dimensions
n_to_show = 30
znew = np.random.normal(size = (n_to_show, latent_dim))

# Pass these points to the decoder.
reconst = decoder.predict(np.array(znew))

fig = plt.figure(figsize=(18, 5))
fig.subplots_adjust(hspace=0.4, wspace=0.4)
for i in range(n_to_show):
    ax = fig.add_subplot(3, 10, i+1)

    # The resulting output is a 128 × 128 × 3 image
    ax.imshow(reconst[i, :,:,:])
    ax.axis('off')

# Save figure
plt.savefig(celeb_out_plot)
```