# Q2_CNN_Autoencoder

March 24, 2022

## 1 Allowing Import from Parent Directory

[19]:
```
import os
import sys
import inspect

currentdir = os.path.dirname(os.path.abspath(inspect.getfile(inspect.
 ↪currentframe())))
parentdir = os.path.dirname(currentdir)
sys.path.insert(0, parentdir)
```

## 2 Importing Packages

[1]:
```
import glob
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import time
import tools.loaddata as loaddata
import tools.dataassimilation as da
import tools.visualisation as visual

import sklearn
assert sklearn.__version__ >= "0.20"
from sklearn.metrics import mean_squared_error
from sklearn.decomposition import PCA

# TensorFlow  2.0 is required
import tensorflow as tf
from tensorflow import keras
assert tf.__version__ >= "2.0"
```

## 3 Loading and reshaping data

```
[ ]: path_train = "../data/train/"
     path_test = "../data/test/"
     path_back = "../data/background/"
     path_obs = "../data/satellite/"
```

```
[3]: train_full, test, model_data, satellite_data = loaddata.
      ↪load_all_data(path_train, path_test, path_back, path_obs)
```

```
[18]: # reducing the dataset due to RAM issues
```

```
[4]: train = train_full[0:300]
```

```
[5]: print(f"Train data before reshaping: {np.shape(train)}")
     print(f"Test data before reshaping: {np.shape(test)}")
     print(f"background data before reshaping: {np.shape(model_data)}")
     print(f"observational data before reshaping: {np.shape(satellite_data)}")
```

```
Train data before reshaping: (300, 871, 913)
Test data before reshaping: (300, 871, 913)
background data before reshaping: (5, 871, 913)
observational data before reshaping: (5, 871, 913)
```

```
[6]: train_1D, test_1D, model_data_1D, satellite_data_1D = loaddata.
      ↪reshape_all_datasets(train, test, model_data, satellite_data)
```

```
[7]: print(f"Train data after reshaping: {train_1D.shape}")
     print(f"Test data after reshaping: {test_1D.shape}")
     print(f"Model data after reshaping: {model_data_1D.shape}")
     print(f"Observational data after reshaping: {satellite_data_1D.shape}")
```

```
Train data after reshaping: (300, 795223)
Test data after reshaping: (300, 795223)
Model data after reshaping: (5, 795223)
Observational data after reshaping: (5, 795223)
```

## 4 CNN Autoencoder

```
[8]: np.random.seed(42)
     tf.random.set_seed(42)

     encoder = keras.models.Sequential([keras.Input(shape=(795223,)),
                                        keras.layers.Reshape((871,913,1)),
                                        keras.layers.
    ↪Convolution2D(4,(10,10),activation='relu',padding='same'),
                                        keras.layers.
    ↪MaxPooling2D((5,5),padding='same'),
                                        keras.layers.
    ↪Convolution2D(8,(2,2),activation='relu',padding='same'),
                                        keras.layers.
    ↪MaxPooling2D((3,3),padding='same'),
                                        keras.layers.
    ↪Convolution2D(16,(3,3),activation='relu',padding='same'),
                                        keras.layers.
    ↪MaxPooling2D((3,3),padding='same'),
                                        keras.layers.
    ↪Convolution2D(32,(3,3),activation='relu',padding='same'),
                                        keras.layers.
    ↪MaxPooling2D((2,2),padding='same'),
                                        keras.layers.Flatten(),
                                        keras.layers.Dense(30)])

     decoder = keras.models.Sequential([keras.Input(shape=(30,)),
                                        keras.layers.Dense(110),
                                        keras.layers.Reshape((10,11,1)),
                                        keras.layers.
     ↪Convolution2D(32,(2,2),activation='relu',padding='same'),
                                        keras.layers.UpSampling2D((2,2)),
                                        keras.layers.
     ↪Convolution2D(16,(3,3),activation='relu',padding='same'),
                                        keras.layers.UpSampling2D((3,3)),
                                        keras.layers.
     ↪Convolution2D(8,(3,3),activation='relu',padding='same'),
                                        keras.layers.UpSampling2D((3,3)),
                                        keras.layers.
     ↪Convolution2D(4,(10,10),activation='relu',padding='same'),
                                        keras.layers.UpSampling2D((5,5)),
                                        keras.layers.
     ↪Cropping2D(cropping=((29,0),(77,0)),data_format=None),
                                        keras.layers.
     ↪Convolution2D(1,(10,10),activation='sigmoid',padding='same'),
                                        keras.layers.Flatten()])


     autoencoder=keras.models.Sequential([encoder, decoder])
     autoencoder.build(input_shape=(1,795223))
     autoencoder.compile(loss='binary_crossentropy',
                         optimizer=keras.optimizers.Adam(),
                         metrics=['mse'])
```

```
print('Encoder:')
encoder.summary()
print('\nDencoder:')
decoder.summary()
print('\nAutoencoder:')
autoencoder.summary()
```

```
Encoder:
Model: "sequential"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 reshape (Reshape)           (None, 871, 913, 1)       0

 conv2d (Conv2D)             (None, 871, 913, 4)       404

 max_pooling2d (MaxPooling2D  (None, 175, 183, 4)      0
 )

 conv2d_1 (Conv2D)           (None, 175, 183, 8)       136

 max_pooling2d_1 (MaxPooling  (None, 59, 61, 8)        0
 2D)

 conv2d_2 (Conv2D)           (None, 59, 61, 16)        1168

 max_pooling2d_2 (MaxPooling  (None, 20, 21, 16)       0
 2D)

 conv2d_3 (Conv2D)           (None, 20, 21, 32)        4640

 max_pooling2d_3 (MaxPooling  (None, 10, 11, 32)       0
 2D)

 flatten (Flatten)           (None, 3520)              0

 dense (Dense)               (None, 30)                105630

=================================================================
Total params: 111,978
Trainable params: 111,978
Non-trainable params: 0
_________________________________________________________________

Dencoder:
Model: "sequential_1"
_________________________________________________________________
```

```
 Layer (type)                Output Shape              Param #
=================================================================
 dense_1 (Dense)             (None, 110)               3410

 reshape_1 (Reshape)         (None, 10, 11, 1)         0

 conv2d_4 (Conv2D)           (None, 10, 11, 32)        160

 up_sampling2d (UpSampling2D  (None, 20, 22, 32)       0
 )

 conv2d_5 (Conv2D)           (None, 20, 22, 16)        4624

 up_sampling2d_1 (UpSampling  (None, 60, 66, 16)       0
 2D)

 conv2d_6 (Conv2D)           (None, 60, 66, 8)         1160

 up_sampling2d_2 (UpSampling  (None, 180, 198, 8)      0
 2D)

 conv2d_7 (Conv2D)           (None, 180, 198, 4)       3204

 up_sampling2d_3 (UpSampling  (None, 900, 990, 4)      0
 2D)

 cropping2d (Cropping2D)     (None, 871, 913, 4)       0

 conv2d_8 (Conv2D)           (None, 871, 913, 1)       401

 flatten_1 (Flatten)         (None, 795223)            0

=================================================================
Total params: 12,959
Trainable params: 12,959
Non-trainable params: 0
_________________________________________________________________

Autoencoder:
Model: "sequential_2"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 sequential (Sequential)     (None, 30)                111978

 sequential_1 (Sequential)   (None, 795223)            12959

=================================================================
Total params: 124,937
Trainable params: 124,937
Non-trainable params: 0
_________________________________________________________________
```

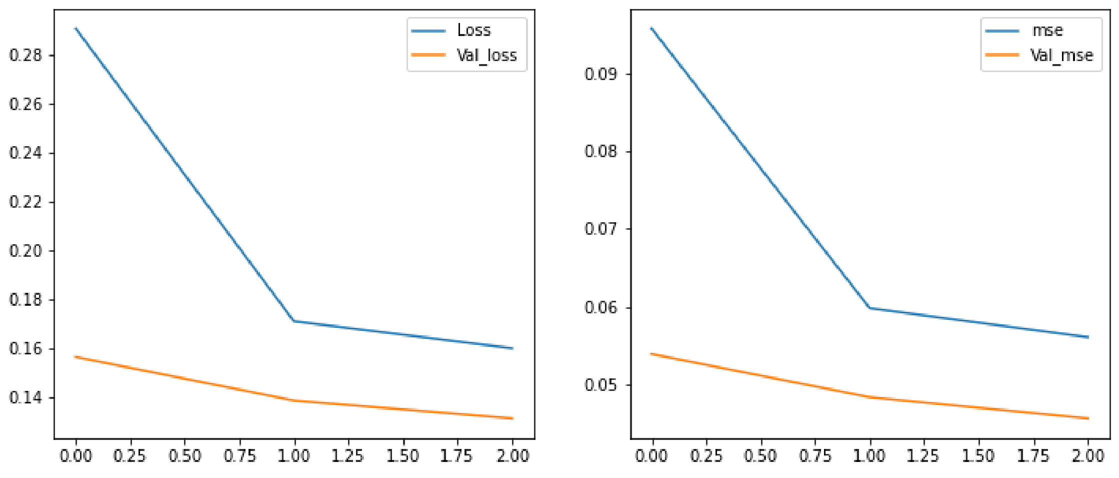
[9]:
```
from keras import callbacks
earlystopping = callbacks.EarlyStopping(monitor ="val_loss",
                                        mode ="min", patience = 5,
                                        restore_best_weights = True)
```

[10]:
```
start = time.time()
history = autoencoder.fit(train_1D,
                          train_1D,
                          epochs=3,
                          batch_size=8,
                          verbose=2,
                          validation_data = (test_1D, test_1D),
                          shuffle = True, callbacks = [earlystopping])
time_ae = time.time() - start
print('Execution time: ', time_ae)
```

```
Epoch 1/3
38/38 - 259s - loss: 0.2909 - mse: 0.0957 - val_loss: 0.1564 - val_mse: 0.0539 -
259s/epoch - 7s/step
Epoch 2/3
38/38 - 253s - loss: 0.1710 - mse: 0.0598 - val_loss: 0.1385 - val_mse: 0.0483 -
253s/epoch - 7s/step
Epoch 3/3
38/38 - 255s - loss: 0.1599 - mse: 0.0561 - val_loss: 0.1312 - val_mse: 0.0456 -
255s/epoch - 7s/step
Execution time:  766.8620219230652
```

[11]:
```
fig, axes = plt.subplots(1,2, figsize=(12,5))
axes[0].plot(history.history['loss'])
axes[0].plot(history.history['val_loss'])
axes[0].legend(['Loss', 'Val_loss'])
axes[1].plot(history.history['mse'])
axes[1].plot(history.history['val_mse'])
axes[1].legend(['mse', 'Val_mse'])
```

[11]:
```
<matplotlib.legend.Legend at 0x7fa08ee11b50>
```



[12]:
```
test_recovered = autoencoder.predict(test_1D)
mse_test = da.mse(test_1D, test_recovered)
print('mse: ', mse_test)
```

```
mse:  0.04562492107644386
```

## 5 Data Assimilation - Kalman Filter (BLUE)

[13]:
```
model_data_compr = encoder.predict(model_data_1D)
satellite_data_compr = encoder.predict(satellite_data_1D)

latent_space = satellite_data_compr.shape[1]
nNodes = latent_space  # latent_space is the size of the compressed variables␣
↪or number of principal components used
I = np.identity(nNodes)
R = np.cov(satellite_data_compr.T)
H = I
B = 0.001 * I
```

[14]:
```
## Performing data assimilation
updated_data_array = da.assimilate(B, H, R, model_data_compr,␣
↪satellite_data_compr)

## Printing MSE in latent space
mse_before_DA = da.mse(satellite_data_compr, model_data_compr)
mse_after_DA = da.mse(satellite_data_compr, updated_data_array)
print('MSE before assimilation in latent space: ', mse_before_DA )
print('MSE after assimilation in latent space: ', mse_after_DA)
```

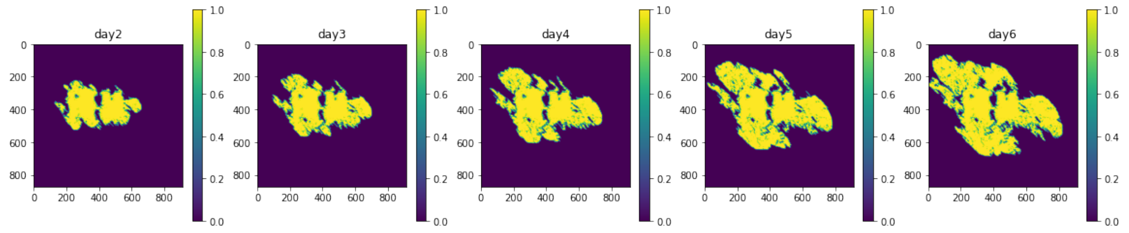
```python
## Printing MSE in Physical space space
updated_data_recon = decoder.predict(updated_data_array)
mse_before_DA_physical = da.mse(satellite_data_1D, model_data_1D)
mse_after_DA_physical = da.mse(satellite_data_1D, updated_data_recon)

print('MSE before assimilation in physical space: ', mse_before_DA_physical)
print('MSE after assimilation in physical space: ', mse_after_DA_physical)
```

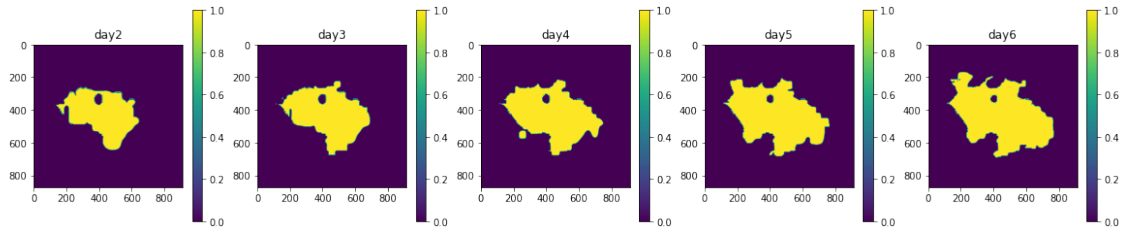
```
MSE before assimilation in latent space:  2.2674706
MSE after assimilation in latent space:  1.8236891496834948
MSE before assimilation in physical space:  0.1191695914227833
MSE after assimilation in physical space:  0.09038456877522648
```

## 6 Visualising Results

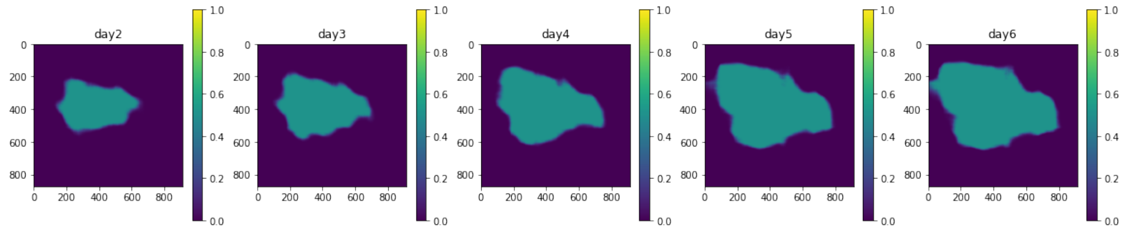
[15]:
```python
# Plot model data
visual.plot_data(model_data)
```



[16]:
```python
# Plot satellite data
visual.plot_data(satellite_data)
```



[17]:
```python
# Plot reconstructed model
updated_data_recon = np.reshape(updated_data_recon, (5, 871, 913))
visual.plot_data(updated_data_recon)
```



```
[ ]: !wget -nc https://raw.githubusercontent.com/brpy/colab-pdf/master/colab_pdf.py
     from colab_pdf import colab_pdf
     colab_pdf('Q2_CNN_Autoencoder.ipynb')
```

```
File ‘colab_pdf.py’ already there; not retrieving.

Mounted at /content/drive/

WARNING: apt does not have a stable CLI interface. Use with caution in scripts.


WARNING: apt does not have a stable CLI interface. Use with caution in scripts.

Extracting templates from packages: 100%
```