pix2pix

July 26, 2024

0.1 Introdução

O objetivo deste notebook é treinar um modelo pix2pix para tradução de imagens.

Queremos gerar imagens de desenho animado de pessoas a partir de uma foto real.

[ ]:
```
import matplotlib.pyplot as plt
import pandas as pd
import numpy as np
import cv2
import os
```

[ ]:
```
from keras.layers import Conv2D, Conv2DTranspose, Input,Dropout,␣
↪ReLU,BatchNormalization,Concatenate,LeakyReLU,Identity
from keras.models import Model
from tensorflow.keras.utils import plot_model
import tensorflow as tf
```

[ ]:
```
!wget -nc https://github.com/Sxela/face2comics/releases/download/v2.0.0/
↪face2comics_v2.0.0_by_Sxela_faces.tar
!tar --skip-old-files -xf face2comics_v2.0.0_by_Sxela_faces.tar
```

[ ]:
```
!wget -nc https://github.com/Sxela/face2comics/releases/download/v2.0.0/
↪face2comics_v2.0.0_by_Sxela_comics.tar
!tar --skip-old-files -xf face2comics_v2.0.0_by_Sxela_comics.tar
```

Apos rodar as linhas acima, devem aparecer 2 diretorios novos:

* comics/
* faces/

[ ]:
```
y_folder = "comics"
x_folder = "faces"
```

Todas as imagens de rostos reais em `faces/` possuem um equivalente em `comics/`.

Os pares de treinamento todos possuem o mesmo nome de arquivo.

[ ]:
```
#Precisamos gerar os caminhos para as imagens, tanto para faces/ quanto para␣
↪comics/
```

```
x_files = sorted([os.path.join(x_folder, fname) for fname in os.
 ↪listdir(x_folder) if fname.endswith(".jpg")])
y_files = sorted([os.path.join(y_folder, fname) for fname in os.
 ↪listdir(y_folder) if fname.endswith(".jpg")])
#Teste de sanidade para garantir que temos o mesmo número de instâncias
assert len(x_files) == len(y_files), "Number of files in each folder must be␣
 ↪the same"
```

Como as imagens são relativamente grandes e a GPU é relativamente fraca, redimensionaremos as imagens para um tamanho gerenciável.

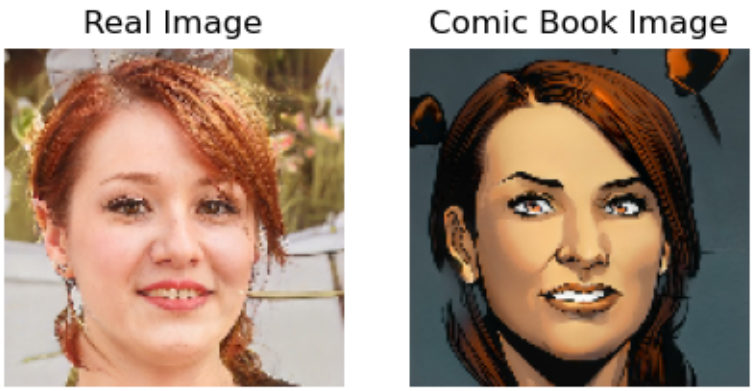
[ ]:
```
img_size = 128 # Variavel usada para reescalar as imagens, alem a entrada dos␣
 ↪definir os modelos
```

[ ]:
```
# Funcao para carregar e pre-processar as imagens
def load_image(file_path):
    image = tf.io.read_file(file_path)
    #Todas as imagens sao RGB
    image = tf.image.decode_jpeg(image, channels=3)
    #Resize para manter o tamanho constante
    image = tf.image.resize(image, [img_size, img_size])
    #Como no paper original, o generador constroi imagens no intervalo [-1...1]
    #Assim, para manter as imagens comparaveis, precisamos transformar o␣
 ↪intervalo [0...255] -> [-1...1]
    image = tf.cast(image, tf.float32)
    # [0...255]  - 127.5 = [-127,5 .... 127,5]
    # [-127,5 .... 127,5] / 127.5  -> [-1...1]
    image = (image - 127.5) / 127.5
    return image

# Function to load and preprocess paired images
def load_pair(x_path, y_path):
    x_image = load_image(x_path)
    y_image = load_image(y_path)
    return x_image, y_image
```

Com os dados carregados, podemos ver um exemplo de par a ser aprendido.

[ ]:
```
plt.figure(figsize=(5,5))
plt.subplot(1,2,1)
plt.imshow((load_image(x_files[0]) +1)/2)
plt.title("Real Image")
plt.axis('off')
plt.subplot(1,2,2)
plt.imshow((load_image(y_files[0]) +1)/2)
plt.title("Comic Book Image")
plt.axis('off')
```

```
plt.show()
```



0.2 Separacao em Treino e Teste

Nesse momento, a separacao tem o objetivo de atestar a capacidade de generalizacao do modelo

[ ]:
```
from sklearn.model_selection import train_test_split
```

[ ]:
```
X_train, X_test, Y_train, Y_test = train_test_split(x_files, y_files,␣
 ↪test_size=0.2, random_state=42)
X_train, X_val, Y_train, Y_val = train_test_split(X_train, Y_train, test_size=0.
 ↪125, random_state=42)

len(X_train),len(X_val),len(X_test)
```

[ ]:
```
(7000, 1000, 2000)
```

[ ]:
```
def create_dataset(x_files, y_files,batch_size=8,is_train=False):
    # Com base nos arquivos
    dataset = tf.data.Dataset.from_tensor_slices((x_files, y_files))

    # Carregue os dados com a funcao load_pair(x,y)
    # O map aqui eh usado para aplicar a funcao sobre todos os dados,
    # tf.py_function faz a execucao ser mais eficiente
    dataset = dataset.map(lambda x, y: tf.py_function(load_pair, [x, y], [tf.
 ↪float32, tf.float32]))

    # Para o dataset de treino, queremos que os dados sejam aleatorizados a␣
 ↪cada passada
    # A prob de um elemento qualquer ser escolhido ao caso eh de 1/1000
    # O ideal seria 1/len(X)
```

```
    # Entretanto, para escolher as amostras aleatoriamente, eh preciso␣
↪preencher um buffer de tamanho len(X)
    # Isso faz que o treinamento seja extremamente lento, pois o programa leva␣
↪varias iteracoes para preencher o buffer de tamanho len(x)
    # A escolha do buffer_size = 1000 suaviza isso, sem prejudicar a premissa␣
↪da aleatoriedade.
    if is_train: dataset = dataset.shuffle(1000)

    # Batch e prefetch sao APIs para otimizar o uso do dataset
    dataset = dataset.batch(batch_size).prefetch(buffer_size=tf.data.
↪experimental.AUTOTUNE)
    return dataset

train_dataset = create_dataset(X_train, Y_train,is_train=True)
test_dataset = create_dataset(X_test, Y_test)
val_dataset = create_dataset(X_val, Y_val)
```

0.3 Definicao dos Modelos

Aqui, instanciamos a arquitetura dos modelos e as funcoes de perda

O RMSE (Raiz do MSE) e o PSNR sao funcoes usadas para medir o desempenho da reconstrucao feita pelo gerador

Quando **menor** o RMSE melhor.

Quanto **maior** o PNSR melhor.

[ ]:
```
def rmse(y_true, y_pred):
    return tf.sqrt(tf.reduce_mean(tf.square(y_pred - y_true)))

def psnr(y_true, y_pred):
    max_pixel = 1.0
    return tf.image.psnr(y_true, y_pred, max_val=max_pixel)
```

Foram usadas as mesmas abstracoes que o paper original

CK: sao camadas sequenciais `Convolution-BatchNorm-ReLu`

CDK:sao camadas sequenciais `Convolution-BatchNormDropout-ReLU`

Todas com filtro 4x4 e stride 2. Ambas camadas podem ser downsample ou upsample, a depende do parametro.

Em caso de upsampling, trocamos `Conv2D -> Conv2DTranspose`.

Algumas camadas podem ser ReLU ou LeakyReLU, isso tambem eh passado como parametro.

Por fim, nem toda camada aplica `BatchNormalization`.

```
[ ]: #Camada Convolution-BatchNorm-ReLu
def CK(filters, kernel_size=(4, 4), strides=(2, 2), padding='same',␣
 ↪use_batch_norm=True, downsample=True):
    '''
        filters: quantidade de filtros
        kernel_size 4x4 | strides 2x2 | padding same | sao constantes durante o␣
 ↪codigo
        use_batch_norm ->   indica quando devemos usar BatchNormalization, em␣
 ↪caso de negativo, a camada se torna a Identidade
        downsample ->       indica se a dimensao deve aumentar ou diminuir
    '''

    # Esse chavemento usando  if ternario serve para selecionar as camadas com␣
 ↪base nos atributos
    conv = Conv2D               if downsample       else Conv2DTranspose
    norm = BatchNormalization   if use_batch_norm   else Identity
    actf = LeakyReLU(0.2)       if downsample       else ReLU()
    # alpha de 0.2 na LeakyReLU foi definido no paper original

    # Com o chaveamento pronto, a camada pode ser montada sequencialmente
    def layer(x):
        x = conv(filters, kernel_size, strides=strides, padding=padding)(x)
        x = norm()(x)
        x = actf(x)
        return x
    return layer

def CDK(filters, kernel_size=(4, 4), strides=(2, 2), padding='same',␣
 ↪use_batch_norm=True, downsample=True,dropout_rate=0.5):
    '''
        filters: quantidade de filtros
        kernel_size 4x4 | strides 2x2 | padding same | dropout_rate 0.5 | sao␣
 ↪constantes durante o codigo
        use_batch_norm ->   indica quando devemos usar BatchNormalization, em␣
 ↪caso de negativo, a camada se torna a Identidade
        downsample ->       indica se a dimensao deve aumentar ou diminuir
    '''
    # Esse chavemento usando  if ternario serve para selecionar as camadas com␣
 ↪base nos atributos
    conv = Conv2D               if downsample       else Conv2DTranspose
    norm = BatchNormalization   if use_batch_norm   else Identity
    actf = ReLU()
    # alpha de 0.2 na LeakyReLU foi definido no paper original

    # Com o chaveamento pronto, a camada pode ser montada sequencialmente
    def layer(x):
```

```
        x = conv(filters, kernel_size, strides=strides, padding=padding)(x)
        x = norm()(x)
        x = Dropout(dropout_rate)(x) # Unica diferenca entre CK e CDK
        x = actf(x)
        return x
    return layer
```

[ ]:
```
def generator(input_nc, output_nc, ngf, num_blocks=1, num_downsample=3):
    # Aqui, definimos o modelo gerador

    # Ele deve receber uma imagem (img_size,img_size,input_nc)
    inputs = Input(shape=(img_size, img_size, input_nc))

    # --------------- START ENCODER -------------------------

    x = inputs

    # Uma convolucao eh aplicada inicialmente sem o batch_norm
    x = CK(ngf,use_batch_norm=False)(x)
    # img_shape = img_size/2,img_size/2,ngf

    # Aqui implementamos o caminho onde a dimensao da imagem vai diminuindo
    #Armazenamos as skip connections
    skips = []
    for i in range(num_downsample + num_blocks - 1):
        # Como o numero de filtros vai aumentando exponencialmente, existe um momento em que o crescimento eh cessado e a qtd se torna constante
        # Este e o momento em que i+1 >= num_downsample
        # A partir dai, o numero de filtros nao diminui
        expo = min(i+1,num_downsample)
        # Aplicamos convolucao com o numero de filtros escolhido
        x = CK(ngf*(2**(expo)))(x)
        # Guardamos a coneccao
        skips.append(x)

    # --------------- FIM   ENCODER -------------------------
    '''
    Aqui, a imagem esta no formato:
    img_shape = img_size/(num_downsample + num_blocks),img_size/(num_downsample + num_blocks),ngf*(2**(expo))

    '''
    # --------------- START DECODER -------------------------

    # As conexoes sao processadas de tras pra frente, ja que a ultima skip gerada vai se ligar com a primeira camada do decoder
    skips = list(reversed(skips))
```

```
    # No paper original, as num_blocks - 1 conexoes que mantem o numero de␣
↪filtros constantes devem se ligar em camadas com dropout
    for skip in skips[:num_blocks-1]:
        # Primeiro juntamos as conexoes,
        # aqui a ordem importa, se fizermos a convolucao primeiro, as imagens␣
↪terao resolucao diferente.
        # Isso pode ser resolvido colocando mais uma convolucao entre o encoder␣
↪e o decoder
        x = Concatenate()([x, skip])
        x = CDK(ngf*(2**(num_downsample)),downsample=False)(x)
        # Atencao no downsample = False, fazendo a camada aumentar a resolucao␣
↪da imagem

    # Para as skips que sobraram, devemos conecta-las a camadas sem dropout
    for skip in skips[num_blocks-1:]:
        x = Concatenate()([x, skip])
        x = CK(ngf * (2 ** i),downsample=False)(x)

    #    img_shape = img_size/(2),img_size/(2),ngf*(2**(expo))
    # --------------- FIM   DECODER --------------------------

    # Por fim, uma ultima convolucao com TanH para gerar o resultado final
    # Numero de canais = output_nc  = 3 = RGB
    output = Conv2DTranspose(output_nc, (4, 4),␣
↪activation='tanh',padding="same",strides=(2, 2))(x)
    return Model(inputs=inputs, outputs=output)
```

[ ]:
```
def discriminator(input_nc,output_nc, ngf, num_blocks=1, num_downsample=3):

    # O discriminador por sua vez, recebe a entrada e a saida do modelo,␣
↪tentando assim decidir se aquilo 'e real ou nao
    inp = Input(shape=[img_size, img_size, input_nc], name='input_image')
    tar = Input(shape=[img_size, img_size, output_nc], name='target_image')

    # Concatenamos as duas imagens para fazer uma unica previsao
    x = Concatenate()([inp, tar])

    # Initial convolutional layers # SEM BATCH NORM !
    x = CK(ngf,use_batch_norm=False)(x)

    # Contracting path
    for i in range(num_downsample):
        x = CK(ngf*(2**(i+1)))(x)
```

```
    # Por fim, a patchGan gera uma classificao binaria por patch, o tamanho do patch eh definido pelo num_downsample. Quanto maior, menor a area de recepcao
    # Por exemplo num_downsample = 4 faz com que o discriminador classifique blocos de 16x16
    output = Conv2D(1, (4, 4), activation='sigmoid',padding="same",strides=(2,2))(x)
    return Model(inputs=[inp, tar], outputs=output)
```

0.4 Funcoes de perda

[ ]:
```
from tensorflow.keras.losses import BinaryCrossentropy
from tensorflow.keras.optimizers import Adam
```

Nesse codigo, as equacoes sao da seguinte forma ### Loss do discriminador

$$\text{discriminator\_loss} = \text{real\_loss} + \text{fake\_loss}$$

onde

$$\text{real\_loss} = \text{CrossEntropy}(\mathbf{1}, \text{real\_output})$$
$$\text{fake\_loss} = \text{CrossEntropy}(\mathbf{0}, \text{fake\_output})$$

$$\text{generator\_loss} = \text{CrossEntropy}(\mathbf{1}, \text{fake\_output}) + \lambda \text{L1\_loss}$$

onde:

$$\text{L1\_loss} = \text{Mean}(|\text{real\_image} - \text{generated\_image}|)$$

λ eh o peso que a L1 loss tem na reconstrucao da imagem.

[ ]:
```
# Essas funcoes espelham o que foi escrito acima
def discriminator_loss(real_output, fake_output):
    cross_entropy = BinaryCrossentropy(from_logits=False)
    real_loss = cross_entropy(tf.ones_like(real_output), real_output)
    fake_loss = cross_entropy(tf.zeros_like(fake_output), fake_output)
    total_loss = real_loss + fake_loss
    return total_loss

def generator_loss(fake_output):
    cross_entropy = BinaryCrossentropy(from_logits=False)
    return cross_entropy(tf.ones_like(fake_output), fake_output)

def l1_loss(real_image, generated_image):
    return tf.reduce_mean(tf.abs(real_image - generated_image))
```

[ ]:
```
generator_optimizer = Adam(2e-4, beta_1=0.5,beta_2=0.999)
discriminator_optimizer = Adam(2e-4, beta_1=0.5,beta_2=0.999)
LAMBDA = 100
# O treinamento foi feito com Adam, usando os mesmos lr | b1 | b2 do paper␣
 ↪orignal

# tf.function para tratar os gradientes separadamente
@tf.function
def train_step(input_image, target_image, generator, discriminator):
    '''
    Aqui eh definido um passo de treinamento
    '''

    with tf.GradientTape() as gen_tape, tf.GradientTape() as disc_tape:
        # Geramos a imagem fake
        generated_image = generator(input_image, training=True)
        # Fazemos o discriminador classificar tanto a imagem fake, quanto a␣
 ↪imagem real
        real_output = discriminator([input_image, target_image], training=True)
        fake_output = discriminator([input_image, generated_image],␣
 ↪training=True)
        # A partir disso, podemos calcula a loss do gerador, como escrita acima
        # LAMBDA = 100 igual o paper original
        gen_loss = generator_loss(fake_output) + LAMBDA*l1_loss(target_image,␣
 ↪generated_image)
        # E a loss do discriminador
        disc_loss = discriminator_loss(real_output, fake_output)

    # Calculamos os gradientes para os dois modelos
    gradients_of_generator = gen_tape.gradient(gen_loss, generator.
 ↪trainable_variables)
    gradients_of_discriminator = disc_tape.gradient(disc_loss, discriminator.
 ↪trainable_variables)
    # Um passo de gradiente descendente
    # Nota-se que quem executa a operacao sao os *optimizers*
    generator_optimizer.apply_gradients(zip(gradients_of_generator, generator.
 ↪trainable_variables))
    discriminator_optimizer.apply_gradients(zip(gradients_of_discriminator,␣
 ↪discriminator.trainable_variables))
    return gen_loss, disc_loss
```

[ ]:
```
# Funcao para calcular a loss e o rmse do gerador em cada passo
def evaluate_model(validation_dataset, generator_model, discriminator_model):
    # Initialize accumulators for metrics
    val_gen_loss_total = 0
    val_rmse_total = 0
```

```
    num_batches = 0

    # Iterate over the validation dataset
    for batch in validation_dataset:
        input_image, target_image = batch

        # Generate images using the generator model
        generated_image = generator_model(input_image, training=False)

        # Compute losses
        val_gen_loss = generator_loss(discriminator_model([input_image,␣
 ↪target_image], training=False)) + l1_loss(target_image, generated_image)
        val_rmse = rmse(target_image, generated_image)

        # Accumulate metrics
        val_gen_loss_total += val_gen_loss
        val_rmse_total += val_rmse
        num_batches += 1

    # Compute average metrics
    avg_val_gen_loss = val_gen_loss_total / num_batches
    avg_val_rmse = val_rmse_total / num_batches

    return avg_val_gen_loss, avg_val_rmse
```

[ ]:
```
# Uso
input_nc = 3  # Number of input channels (RGB)
output_nc = 3  # Number of output channels (RGB)
ngf = 64  # Number of generator filters in first conv layer
# Parametro ngf eh importante para regular o tamanho do modelo, como os pesos␣
 ↪crescem exponencialemente, um alto ngf tras dificuldades na computacao

# Todos com 3 blocos e 4 downsamples
generator_model     = generator(input_nc, output_nc, ngf, num_blocks=3,␣
 ↪num_downsample=4)
discriminator_model = discriminator(input_nc,output_nc, ngf, num_blocks=3,␣
 ↪num_downsample=4)

# Instanciamos a loss de cada um
generator_model.compile(optimizer=generator_optimizer, loss=generator_loss)
discriminator_model.compile(optimizer=discriminator_optimizer,␣
 ↪loss=discriminator_loss)
```

[ ]:
```
generator_model.summary()
```

```
Model: "model"
_________________________________________________________________________________
```

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

 conv2d (Conv2D)             (None, 64, 64, 64)        3136
['input_1[0][0]']

 identity (Identity)         (None, 64, 64, 64)        0
['conv2d[0][0]']

 leaky_re_lu (LeakyReLU)     (None, 64, 64, 64)        0
['identity[0][0]']

 conv2d_1 (Conv2D)           (None, 32, 32, 128)       131200
['leaky_re_lu[0][0]']

 batch_normalization (Batch  (None, 32, 32, 128)       512
['conv2d_1[0][0]']
 Normalization)

 leaky_re_lu_1 (LeakyReLU)   (None, 32, 32, 128)       0
['batch_normalization[0][0]']

 conv2d_2 (Conv2D)           (None, 16, 16, 256)       524544
['leaky_re_lu_1[0][0]']

 batch_normalization_1 (Bat  (None, 16, 16, 256)       1024
['conv2d_2[0][0]']
 chNormalization)

 leaky_re_lu_2 (LeakyReLU)   (None, 16, 16, 256)       0
['batch_normalization_1[0][0]'
                                                                  ]

 conv2d_3 (Conv2D)           (None, 8, 8, 512)         2097664
['leaky_re_lu_2[0][0]']

 batch_normalization_2 (Bat  (None, 8, 8, 512)         2048
['conv2d_3[0][0]']
 chNormalization)

 leaky_re_lu_3 (LeakyReLU)   (None, 8, 8, 512)         0
['batch_normalization_2[0][0]'
                                                                  ]

 conv2d_4 (Conv2D)           (None, 4, 4, 1024)        8389632
```

```
['leaky_re_lu_3[0][0]']

 batch_normalization_3 (Bat  (None, 4, 4, 1024)          4096
['conv2d_4[0][0]']
 chNormalization)

 leaky_re_lu_4 (LeakyReLU)   (None, 4, 4, 1024)          0
['batch_normalization_3[0][0]'
                                                                 ]

 conv2d_5 (Conv2D)           (None, 2, 2, 1024)          1677824
['leaky_re_lu_4[0][0]']
                                                         0

 batch_normalization_4 (Bat  (None, 2, 2, 1024)          4096
['conv2d_5[0][0]']
 chNormalization)

 leaky_re_lu_5 (LeakyReLU)   (None, 2, 2, 1024)          0
['batch_normalization_4[0][0]'
                                                                 ]

 conv2d_6 (Conv2D)           (None, 1, 1, 1024)          1677824
['leaky_re_lu_5[0][0]']
                                                         0

 batch_normalization_5 (Bat  (None, 1, 1, 1024)          4096
['conv2d_6[0][0]']
 chNormalization)

 leaky_re_lu_6 (LeakyReLU)   (None, 1, 1, 1024)          0
['batch_normalization_5[0][0]'
                                                                 ]

 concatenate (Concatenate)   (None, 1, 1, 2048)          0
['leaky_re_lu_6[0][0]',
'leaky_re_lu_6[0][0]']

 conv2d_transpose (Conv2DTr  (None, 2, 2, 1024)          3355545
['concatenate[0][0]']
 anspose)                                                6

 batch_normalization_6 (Bat  (None, 2, 2, 1024)          4096
['conv2d_transpose[0][0]']
 chNormalization)

 dropout (Dropout)           (None, 2, 2, 1024)          0
['batch_normalization_6[0][0]'
```

```
                                                                  ]

 re_lu (ReLU)                (None, 2, 2, 1024)           0
['dropout[0][0]']

 concatenate_1 (Concatenate  (None, 2, 2, 2048)           0
['re_lu[0][0]',
 )
'leaky_re_lu_5[0][0]']

 conv2d_transpose_1 (Conv2D  (None, 4, 4, 1024)           3355545
['concatenate_1[0][0]']
 Transpose)                                               6

 batch_normalization_7 (Bat  (None, 4, 4, 1024)           4096
['conv2d_transpose_1[0][0]']
 chNormalization)

 dropout_1 (Dropout)         (None, 4, 4, 1024)           0
['batch_normalization_7[0][0]'
                                                                  ]

 re_lu_1 (ReLU)              (None, 4, 4, 1024)           0
['dropout_1[0][0]']

 concatenate_2 (Concatenate  (None, 4, 4, 2048)           0
['re_lu_1[0][0]',
 )
'leaky_re_lu_4[0][0]']

 conv2d_transpose_2 (Conv2D  (None, 8, 8, 2048)           6711091
['concatenate_2[0][0]']
 Transpose)                                               2

 batch_normalization_8 (Bat  (None, 8, 8, 2048)           8192
['conv2d_transpose_2[0][0]']
 chNormalization)

 re_lu_2 (ReLU)              (None, 8, 8, 2048)           0
['batch_normalization_8[0][0]'
                                                                  ]

 concatenate_3 (Concatenate  (None, 8, 8, 2560)           0
['re_lu_2[0][0]',
 )
'leaky_re_lu_3[0][0]']

 conv2d_transpose_3 (Conv2D  (None, 16, 16, 2048)         8388812
```

```
['concatenate_3[0][0]']
 Transpose)                                          8

 batch_normalization_9 (Bat  (None, 16, 16, 2048)         8192
['conv2d_transpose_3[0][0]']
 chNormalization)

 re_lu_3 (ReLU)              (None, 16, 16, 2048)         0
['batch_normalization_9[0][0]'
                                                                  ]

 concatenate_4 (Concatenate  (None, 16, 16, 2304)         0
['re_lu_3[0][0]',
 )
'leaky_re_lu_2[0][0]']

 conv2d_transpose_4 (Conv2D  (None, 32, 32, 2048)         7549952
['concatenate_4[0][0]']
 Transpose)                                          0

 batch_normalization_10 (Ba  (None, 32, 32, 2048)         8192
['conv2d_transpose_4[0][0]']
 tchNormalization)

 re_lu_4 (ReLU)              (None, 32, 32, 2048)         0
['batch_normalization_10[0][0]
                                                                  ']

 concatenate_5 (Concatenate  (None, 32, 32, 2176)         0
['re_lu_4[0][0]',
 )
'leaky_re_lu_1[0][0]']

 conv2d_transpose_5 (Conv2D  (None, 64, 64, 2048)         7130521
['concatenate_5[0][0]']
 Transpose)                                          6

 batch_normalization_11 (Ba  (None, 64, 64, 2048)         8192
['conv2d_transpose_5[0][0]']
 tchNormalization)

 re_lu_5 (ReLU)              (None, 64, 64, 2048)         0
['batch_normalization_11[0][0]
                                                                  ']

 conv2d_transpose_6 (Conv2D  (None, 128, 128, 3)          98307
['re_lu_5[0][0]']
 Transpose)
```

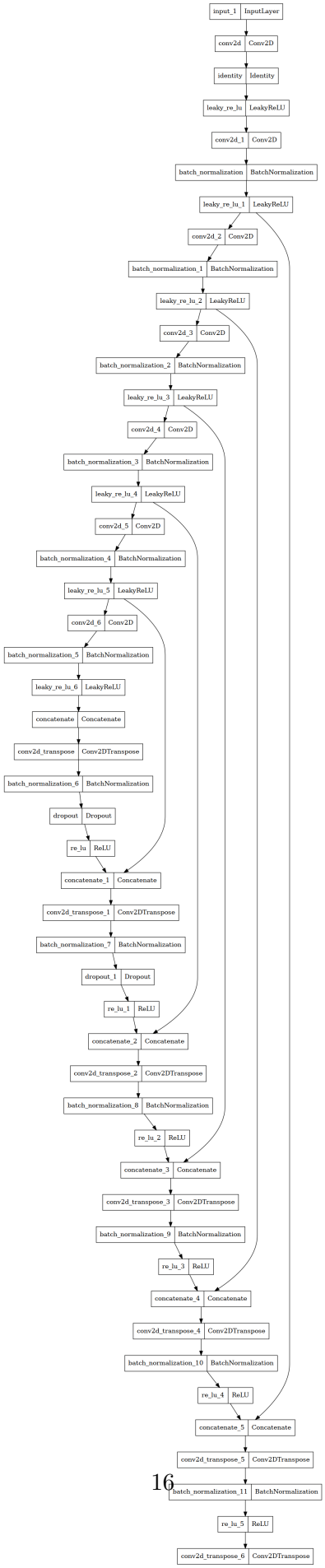
```
=================================================================================
==================
Total params: 409772483 (1.53 GB)
Trainable params: 409744067 (1.53 GB)
Non-trainable params: 28416 (111.00 KB)
---------------------------------------------------------------------------------
------------------
```

O gerador ficou com bastante parametros 409_744_067. Talvez nao rode no colab

Podemos ver sua arquitetura visualmente:

[ ]:
```
plot_model(generator_model)
```

[ ]:


input_1 InputLayer
conv2d Conv2D
identity Identity
leaky_re_lu LeakyReLU
conv2d_1 Conv2D
batch_normalization BatchNormalization
leaky_re_lu_1 LeakyReLU
conv2d_2 Conv2D
batch_normalization_1 BatchNormalization
leaky_re_lu_2 LeakyReLU
conv2d_3 Conv2D
batch_normalization_2 BatchNormalization
leaky_re_lu_3 LeakyReLU
conv2d_4 Conv2D
batch_normalization_3 BatchNormalization
leaky_re_lu_4 LeakyReLU
conv2d_5 Conv2D
batch_normalization_4 BatchNormalization
leaky_re_lu_5 LeakyReLU
conv2d_6 Conv2D
batch_normalization_5 BatchNormalization
leaky_re_lu_6 LeakyReLU
concatenate Concatenate
conv2d_transpose Conv2DTranspose
batch_normalization_6 BatchNormalization
dropout Dropout
re_lu ReLU
concatenate_1 Concatenate
conv2d_transpose_1 Conv2DTranspose
batch_normalization_7 BatchNormalization
dropout_1 Dropout
re_lu_1 ReLU
concatenate_2 Concatenate
conv2d_transpose_2 Conv2DTranspose
batch_normalization_8 BatchNormalization
re_lu_2 ReLU
concatenate_3 Concatenate
conv2d_transpose_3 Conv2DTranspose
batch_normalization_9 BatchNormalization
re_lu_3 ReLU
concatenate_4 Concatenate
conv2d_transpose_4 Conv2DTranspose
batch_normalization_10 BatchNormalization
re_lu_4 ReLU
concatenate_5 Concatenate
conv2d_transpose_5 Conv2DTranspose
batch_normalization_11 BatchNormalization
re_lu_5 ReLU
conv2d_transpose_6 Conv2DTranspose

```
[ ]: discriminator_model.summary()
```

```
Model: "model_1"
__________________________________________________________________________________________
 Layer (type)                Output Shape              Param #   Connected to
==========================================================================================
 input_image (InputLayer)    [(None, 128, 128, 3)]     0         []

 target_image (InputLayer)   [(None, 128, 128, 3)]     0         []

 concatenate_6 (Concatenate  (None, 128, 128, 6)       0
['input_image[0][0]',
 )
'target_image[0][0]']

 conv2d_7 (Conv2D)           (None, 64, 64, 64)        6208
['concatenate_6[0][0]']

 identity_1 (Identity)       (None, 64, 64, 64)        0
['conv2d_7[0][0]']

 leaky_re_lu_7 (LeakyReLU)   (None, 64, 64, 64)        0
['identity_1[0][0]']

 conv2d_8 (Conv2D)           (None, 32, 32, 128)       131200
['leaky_re_lu_7[0][0]']

 batch_normalization_12 (Ba  (None, 32, 32, 128)       512
['conv2d_8[0][0]']
 tchNormalization)

 leaky_re_lu_8 (LeakyReLU)   (None, 32, 32, 128)       0
['batch_normalization_12[0][0]
                                                                  ']

 conv2d_9 (Conv2D)           (None, 16, 16, 256)       524544
['leaky_re_lu_8[0][0]']

 batch_normalization_13 (Ba  (None, 16, 16, 256)       1024
['conv2d_9[0][0]']
 tchNormalization)

 leaky_re_lu_9 (LeakyReLU)   (None, 16, 16, 256)       0
```

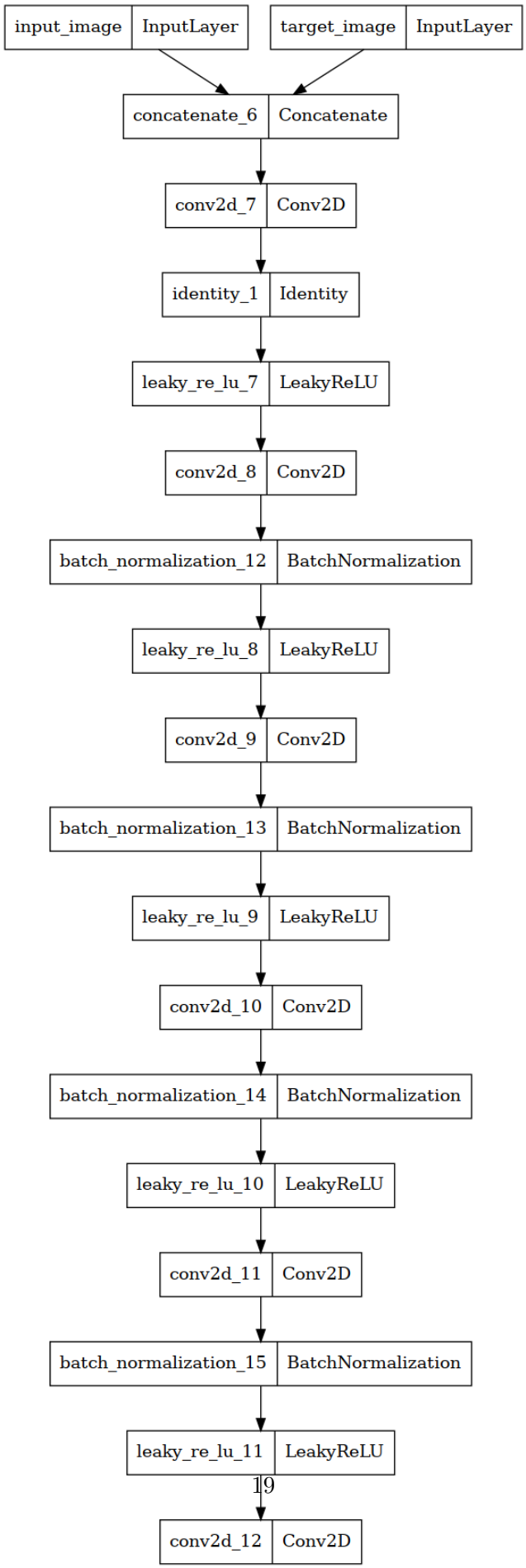
```
['batch_normalization_13[0][0]
                                                                  ']

 conv2d_10 (Conv2D)          (None, 8, 8, 512)            2097664
['leaky_re_lu_9[0][0]']

 batch_normalization_14 (Ba  (None, 8, 8, 512)            2048
['conv2d_10[0][0]']
 tchNormalization)

 leaky_re_lu_10 (LeakyReLU)  (None, 8, 8, 512)            0
['batch_normalization_14[0][0]
                                                                  ']

 conv2d_11 (Conv2D)          (None, 4, 4, 1024)           8389632
['leaky_re_lu_10[0][0]']

 batch_normalization_15 (Ba  (None, 4, 4, 1024)           4096
['conv2d_11[0][0]']
 tchNormalization)

 leaky_re_lu_11 (LeakyReLU)  (None, 4, 4, 1024)           0
['batch_normalization_15[0][0]
                                                                  ']

 conv2d_12 (Conv2D)          (None, 2, 2, 1)              16385
['leaky_re_lu_11[0][0]']

==================================================================================
==================
Total params: 11173313 (42.62 MB)
Trainable params: 11169473 (42.61 MB)
Non-trainable params: 3840 (15.00 KB)
----------------------------------------------------------------------------------
------------------
```

O discriminator ficou com bastante parametros 11_173_313. Talvez nao rode no colab

Podemos ver sua arquitetura visualmente:

[ ]:
```
plot_model(discriminator_model)
```

[ ]:


input_image InputLayer
target_image InputLayer
concatenate_6 Concatenate
conv2d_7 Conv2D
identity_1 Identity
leaky_re_lu_7 LeakyReLU
conv2d_8 Conv2D
batch_normalization_12 BatchNormalization
leaky_re_lu_8 LeakyReLU
conv2d_9 Conv2D
batch_normalization_13 BatchNormalization
leaky_re_lu_9 LeakyReLU
conv2d_10 Conv2D
batch_normalization_14 BatchNormalization
leaky_re_lu_10 LeakyReLU
conv2d_11 Conv2D
batch_normalization_15 BatchNormalization
leaky_re_lu_11 LeakyReLU
conv2d_12 Conv2D

0.5 Treinamento

[ ]:
```
# Lists to store metrics
epochs_list = []
gen_losses = []
disc_losses = []
val_gen_losses = []
val_rmses = []
val_psnrs = []
```

[ ]:
```
# Training loop
epochs = 200
for epoch in range(epochs):
    #profilling
    gen_loss_total = 0
    disc_loss_total = 0
    num_batches = 0

    # Aplica-se um passo do treinamento em cada batch
    for batch in train_dataset:
        input_image, target_image = batch
        gen_loss, disc_loss = train_step(input_image, target_image,␣
 ↪generator_model, discriminator_model)

        # Accumulate training losses
        gen_loss_total += gen_loss.numpy().item()
        disc_loss_total += disc_loss.numpy().item()
        num_batches += 1

    # Rodamos a avalia'cao no conjunto de validacao
    val_gen_loss, val_rmse = evaluate_model(val_dataset, generator_model,␣
 ↪discriminator_model)

    # Compute average training losses
    gen_loss = gen_loss_total / num_batches
    disc_loss = disc_loss_total / num_batches

    # Collect stats
    epochs_list.append(epoch + 1)
    gen_losses.append(gen_loss)
    disc_losses.append(disc_loss)
    val_gen_losses.append(val_gen_loss.numpy().item())
    val_rmses.append(val_rmse.numpy().item())
```

```
    # Profile
    print(f"Epoch {epoch+1}/{epochs} - Gen Loss: {gen_loss:.4f}, D Loss:␣
↪{disc_loss:.4f}")
    print(f"Val Gen Loss: {val_gen_loss.numpy().item():.4f}, RMSE: {val_rmse.
↪numpy().item():.4f}")
    print()
```

```
2024-07-25 12:00:59.113873: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 808 of 1000
2024-07-25 12:01:01.608247: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.
2024-07-25 12:01:05.186466: E
tensorflow/core/grappler/optimizers/meta_optimizer.cc:954] layout failed:
INVALID_ARGUMENT: Size of values 0 does not match size of permutation 4 @ fanin
shape inmodel/dropout/dropout/SelectV2-2-TransposeNHWCToNCHW-LayoutOptimizer
2024-07-25 12:01:05.764448: I
tensorflow/compiler/xla/stream_executor/cuda/cuda_dnn.cc:432] Loaded cuDNN
version 8907
2024-07-25 12:01:10.462046: I tensorflow/compiler/xla/service/service.cc:168]
XLA service 0x77fc2835e270 initialized for platform CUDA (this does not
guarantee that XLA will be used). Devices:
2024-07-25 12:01:10.462085: I tensorflow/compiler/xla/service/service.cc:176]
StreamExecutor device (0): NVIDIA GeForce RTX 4060 Ti, Compute Capability 8.9
2024-07-25 12:01:10.466516: I
tensorflow/compiler/mlir/tensorflow/utils/dump_mlir_util.cc:255] disabling MLIR
crash reproducer, set env var `MLIR_CRASH_REPRODUCER_DIRECTORY` to enable.
2024-07-25 12:01:10.574708: I ./tensorflow/compiler/jit/device_compiler.h:186]
Compiled cluster using XLA!  This line is logged at most once for the lifetime
of the process.

Epoch 1/200 - Gen Loss: 30.3387, D Loss: 0.4464
Val Gen Loss: 2.9092, RMSE: 0.5241


2024-07-25 12:09:59.652226: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 799 of 1000
2024-07-25 12:10:02.153232: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 2/200 - Gen Loss: 31.3714, D Loss: 0.1939
Val Gen Loss: 3.5382, RMSE: 0.4620


2024-07-25 12:18:26.914573: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 668 of 1000
```

```
2024-07-25 12:18:31.851166: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 3/200 - Gen Loss: 27.4595, D Loss: 0.7618
Val Gen Loss: 1.5845, RMSE: 0.3577


2024-07-25 12:27:03.839419: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 817 of 1000
2024-07-25 12:27:06.129212: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 4/200 - Gen Loss: 25.5461, D Loss: 0.8709
Val Gen Loss: 1.0510, RMSE: 0.3602


2024-07-25 12:35:31.355436: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 773 of 1000
2024-07-25 12:35:34.213987: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 5/200 - Gen Loss: 24.8349, D Loss: 0.8949
Val Gen Loss: 1.0934, RMSE: 0.3709


2024-07-25 12:44:09.949525: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 811 of 1000
2024-07-25 12:44:12.345131: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 6/200 - Gen Loss: 24.1846, D Loss: 0.8755
Val Gen Loss: 0.4919, RMSE: 0.3648


2024-07-25 12:52:51.909683: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 803 of 1000
2024-07-25 12:52:54.512427: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 7/200 - Gen Loss: 23.5256, D Loss: 0.8491
Val Gen Loss: 0.8769, RMSE: 0.3482


2024-07-25 13:01:11.764818: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 849 of 1000
2024-07-25 13:01:13.611651: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.
```

```
Epoch 8/200 - Gen Loss: 22.9028, D Loss: 0.8476
Val Gen Loss: 0.6091, RMSE: 0.3512


2024-07-25 13:09:33.822625: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 853 of 1000
2024-07-25 13:09:35.520010: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 9/200 - Gen Loss: 22.3523, D Loss: 0.8157
Val Gen Loss: 1.3345, RMSE: 0.3512


2024-07-25 13:17:54.649117: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 854 of 1000
2024-07-25 13:17:56.401155: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 10/200 - Gen Loss: 22.0379, D Loss: 0.7834
Val Gen Loss: 0.9118, RMSE: 0.3338


2024-07-25 13:26:21.206150: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 846 of 1000
2024-07-25 13:26:23.029083: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 11/200 - Gen Loss: 21.7345, D Loss: 0.7449
Val Gen Loss: 0.7318, RMSE: 0.3290


2024-07-25 13:34:49.070812: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 871 of 1000
2024-07-25 13:34:50.547892: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 12/200 - Gen Loss: 21.4026, D Loss: 0.7006
Val Gen Loss: 0.5819, RMSE: 0.3316


2024-07-25 13:43:15.796593: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 878 of 1000
2024-07-25 13:43:17.224165: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 13/200 - Gen Loss: 21.1119, D Loss: 0.6882
Val Gen Loss: 0.5074, RMSE: 0.3236
```

```
2024-07-25 13:51:43.011333: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 883 of 1000
2024-07-25 13:51:44.441918: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 14/200 - Gen Loss: 20.9408, D Loss: 0.6542
Val Gen Loss: 1.5725, RMSE: 0.3414


2024-07-25 14:00:09.852909: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 866 of 1000
2024-07-25 14:00:11.447283: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 15/200 - Gen Loss: 20.6837, D Loss: 0.6441
Val Gen Loss: 1.0198, RMSE: 0.3236


2024-07-25 14:08:36.609411: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 895 of 1000
2024-07-25 14:08:37.788507: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 16/200 - Gen Loss: 20.4214, D Loss: 0.6227
Val Gen Loss: 0.7050, RMSE: 0.3234


2024-07-25 14:17:00.607114: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 846 of 1000
2024-07-25 14:17:02.575230: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 17/200 - Gen Loss: 20.3252, D Loss: 0.6018
Val Gen Loss: 1.2695, RMSE: 0.3275


2024-07-25 14:25:29.219574: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 859 of 1000
2024-07-25 14:25:30.901606: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 18/200 - Gen Loss: 20.1877, D Loss: 0.5894
Val Gen Loss: 0.8752, RMSE: 0.3241


2024-07-25 14:33:54.356837: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 875 of 1000
```

```
2024-07-25 14:33:55.884576: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 19/200 - Gen Loss: 19.9536, D Loss: 0.5875
Val Gen Loss: 1.1506, RMSE: 0.3189


2024-07-25 14:42:20.807845: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 742 of 1000
2024-07-25 14:42:24.111436: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 20/200 - Gen Loss: 19.8338, D Loss: 0.5501
Val Gen Loss: 1.0020, RMSE: 0.3192


2024-07-25 14:50:47.249301: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 871 of 1000
2024-07-25 14:50:48.801395: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 21/200 - Gen Loss: 19.7644, D Loss: 0.5456
Val Gen Loss: 1.0189, RMSE: 0.3249


2024-07-25 14:59:12.656217: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 845 of 1000
2024-07-25 14:59:14.490649: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 22/200 - Gen Loss: 19.6581, D Loss: 0.5505
Val Gen Loss: 0.9328, RMSE: 0.3215


2024-07-25 15:07:42.305984: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 856 of 1000
2024-07-25 15:07:44.195746: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 23/200 - Gen Loss: 19.6388, D Loss: 0.5045
Val Gen Loss: 0.8440, RMSE: 0.3250


2024-07-25 15:16:09.126200: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 862 of 1000
2024-07-25 15:16:10.747788: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.
```

```
Epoch 24/200 - Gen Loss: 19.6055, D Loss: 0.4763
Val Gen Loss: 1.5337, RMSE: 0.3239


2024-07-25 15:24:32.404909: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 878 of 1000
2024-07-25 15:24:33.829192: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 25/200 - Gen Loss: 19.6858, D Loss: 0.4858
Val Gen Loss: 1.5525, RMSE: 0.3240


2024-07-25 15:32:57.735307: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 876 of 1000
2024-07-25 15:32:59.070854: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 26/200 - Gen Loss: 19.4173, D Loss: 0.5077
Val Gen Loss: 1.0424, RMSE: 0.3178


2024-07-25 15:41:22.486787: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 898 of 1000
2024-07-25 15:41:23.661065: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 27/200 - Gen Loss: 20.2644, D Loss: 0.4145
Val Gen Loss: 0.7659, RMSE: 0.3239


2024-07-25 15:49:47.609470: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 854 of 1000
2024-07-25 15:49:49.674484: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 28/200 - Gen Loss: 19.5833, D Loss: 0.4835
Val Gen Loss: 0.9597, RMSE: 0.3175


2024-07-25 15:58:13.102558: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 879 of 1000
2024-07-25 15:58:14.553481: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 29/200 - Gen Loss: 19.3140, D Loss: 0.4423
Val Gen Loss: 1.4872, RMSE: 0.3149
```

```
2024-07-25 16:06:38.086235: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 878 of 1000
2024-07-25 16:06:39.493428: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 30/200 - Gen Loss: 19.1337, D Loss: 0.4685
Val Gen Loss: 1.3345, RMSE: 0.3166


2024-07-25 16:15:05.031708: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 893 of 1000
2024-07-25 16:15:06.244997: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 31/200 - Gen Loss: 19.1871, D Loss: 0.4494
Val Gen Loss: 1.1104, RMSE: 0.3182


2024-07-25 16:23:32.876533: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 877 of 1000
2024-07-25 16:23:34.368122: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 32/200 - Gen Loss: 19.3022, D Loss: 0.3919
Val Gen Loss: 1.0389, RMSE: 0.3169


2024-07-25 16:31:58.366423: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 863 of 1000
2024-07-25 16:32:00.004426: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 33/200 - Gen Loss: 19.4001, D Loss: 0.4053
Val Gen Loss: 1.3047, RMSE: 0.3148


2024-07-25 16:40:26.568654: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 872 of 1000
2024-07-25 16:40:28.115576: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 34/200 - Gen Loss: 19.2607, D Loss: 0.4280
Val Gen Loss: 0.9282, RMSE: 0.3155


2024-07-25 16:48:51.924207: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 903 of 1000
```

```
2024-07-25 16:48:52.987294: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 35/200 - Gen Loss: 19.1221, D Loss: 0.4308
Val Gen Loss: 1.0269, RMSE: 0.3107


2024-07-25 16:57:15.760614: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 851 of 1000
2024-07-25 16:57:17.636735: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 36/200 - Gen Loss: 19.1009, D Loss: 0.3843
Val Gen Loss: 1.2046, RMSE: 0.3137


2024-07-25 17:05:43.355433: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 865 of 1000
2024-07-25 17:05:45.031865: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 37/200 - Gen Loss: 18.9556, D Loss: 0.4159
Val Gen Loss: 1.0924, RMSE: 0.3184


2024-07-25 17:14:10.811274: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 885 of 1000
2024-07-25 17:14:12.223172: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 38/200 - Gen Loss: 18.9238, D Loss: 0.4186
Val Gen Loss: 1.7603, RMSE: 0.3088


2024-07-25 17:22:37.660042: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 895 of 1000
2024-07-25 17:22:38.838057: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 39/200 - Gen Loss: 18.9742, D Loss: 0.3613
Val Gen Loss: 1.6305, RMSE: 0.3149


2024-07-25 17:31:02.519943: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 904 of 1000
2024-07-25 17:31:03.688822: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.
```

```
Epoch 40/200 - Gen Loss: 18.9471, D Loss: 0.3812
Val Gen Loss: 1.4987, RMSE: 0.3140


2024-07-25 17:39:29.562667: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 761 of 1000
2024-07-25 17:39:33.345940: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 41/200 - Gen Loss: 18.8787, D Loss: 0.3816
Val Gen Loss: 1.2548, RMSE: 0.3120


2024-07-25 17:47:56.766150: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 884 of 1000
2024-07-25 17:47:58.126200: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 42/200 - Gen Loss: 18.9033, D Loss: 0.3680
Val Gen Loss: 0.9442, RMSE: 0.3108


2024-07-25 17:56:23.686276: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 845 of 1000
2024-07-25 17:56:26.137558: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 43/200 - Gen Loss: 18.7373, D Loss: 0.4050
Val Gen Loss: 2.0078, RMSE: 0.3082


2024-07-25 18:04:49.318790: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 913 of 1000
2024-07-25 18:04:50.330712: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 44/200 - Gen Loss: 18.6143, D Loss: 0.3537
Val Gen Loss: 1.3219, RMSE: 0.3103


2024-07-25 18:13:13.779126: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 889 of 1000
2024-07-25 18:13:15.069738: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 45/200 - Gen Loss: 18.5347, D Loss: 0.3885
Val Gen Loss: 1.1961, RMSE: 0.3105
```

```
2024-07-25 18:21:38.882493: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 876 of 1000
2024-07-25 18:21:40.348953: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 46/200 - Gen Loss: 18.5691, D Loss: 0.3648
Val Gen Loss: 1.5190, RMSE: 0.3076


2024-07-25 18:30:02.030220: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 871 of 1000
2024-07-25 18:30:03.518809: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 47/200 - Gen Loss: 18.4824, D Loss: 0.3624
Val Gen Loss: 1.7935, RMSE: 0.3104


2024-07-25 18:38:26.739635: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 882 of 1000
2024-07-25 18:38:28.088944: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 48/200 - Gen Loss: 18.7242, D Loss: 0.3292
Val Gen Loss: 1.6526, RMSE: 0.3106


2024-07-25 18:46:51.860908: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 869 of 1000
2024-07-25 18:46:53.382684: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 49/200 - Gen Loss: 18.3169, D Loss: 0.3796
Val Gen Loss: 2.2002, RMSE: 0.3114


2024-07-25 18:55:18.779377: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 858 of 1000
2024-07-25 18:55:20.480363: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 50/200 - Gen Loss: 18.4650, D Loss: 0.3494
Val Gen Loss: 2.2905, RMSE: 0.3065


2024-07-25 19:03:43.554662: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 854 of 1000
```

```
2024-07-25 19:03:45.347748: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 51/200 - Gen Loss: 18.2981, D Loss: 0.3736
Val Gen Loss: 2.0077, RMSE: 0.3074


2024-07-25 19:12:10.037863: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 792 of 1000
2024-07-25 19:12:13.588037: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 52/200 - Gen Loss: 18.3342, D Loss: 0.3279
Val Gen Loss: 1.7825, RMSE: 0.3092


2024-07-25 19:20:35.494830: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 878 of 1000
2024-07-25 19:20:36.900707: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 53/200 - Gen Loss: 18.2279, D Loss: 0.3598
Val Gen Loss: 2.3852, RMSE: 0.3074


2024-07-25 19:29:02.267277: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 884 of 1000
2024-07-25 19:29:03.663056: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 54/200 - Gen Loss: 18.0666, D Loss: 0.3577
Val Gen Loss: 1.5724, RMSE: 0.3050


2024-07-25 19:37:27.571802: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 874 of 1000
2024-07-25 19:37:28.956723: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 55/200 - Gen Loss: 18.2155, D Loss: 0.3239
Val Gen Loss: 1.8401, RMSE: 0.3083


2024-07-25 19:45:53.030674: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 859 of 1000
2024-07-25 19:45:54.773577: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.
```

```
Epoch 56/200 - Gen Loss: 18.7865, D Loss: 0.2969
Val Gen Loss: 1.5121, RMSE: 0.3097


2024-07-25 19:54:18.701778: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 870 of 1000
2024-07-25 19:54:20.169450: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 57/200 - Gen Loss: 18.2270, D Loss: 0.3337
Val Gen Loss: 1.7756, RMSE: 0.3101


2024-07-25 20:02:44.304897: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 931 of 1000
2024-07-25 20:02:45.055863: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 58/200 - Gen Loss: 17.9091, D Loss: 0.3644
Val Gen Loss: 2.1275, RMSE: 0.3038


2024-07-25 20:11:08.305020: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 860 of 1000
2024-07-25 20:11:09.953852: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 59/200 - Gen Loss: 17.8622, D Loss: 0.3281
Val Gen Loss: 2.4388, RMSE: 0.3053


2024-07-25 20:19:35.119974: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 865 of 1000
2024-07-25 20:19:36.869547: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 60/200 - Gen Loss: 18.0245, D Loss: 0.3233
Val Gen Loss: 1.3453, RMSE: 0.3067


2024-07-25 20:28:01.293283: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 878 of 1000
2024-07-25 20:28:02.746563: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.

Epoch 61/200 - Gen Loss: 18.0412, D Loss: 0.3389
Val Gen Loss: 2.6644, RMSE: 0.3046
```

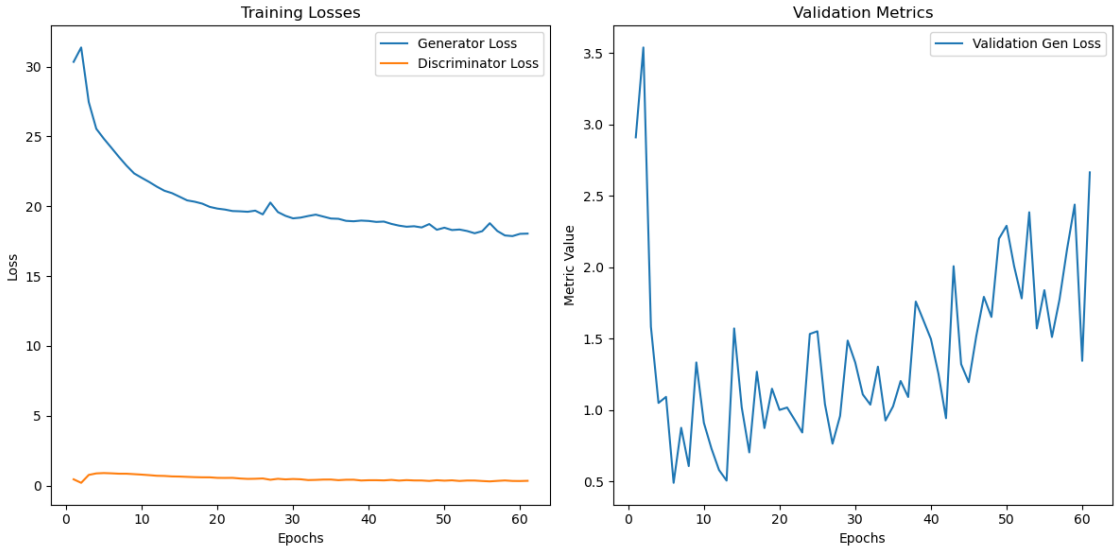
```
2024-07-25 20:36:26.410138: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 787 of 1000
2024-07-25 20:36:29.847051: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.
```

```
---------------------------------------------------------------------------
KeyboardInterrupt                         Traceback (most recent call last)
Cell In[27], line 13
     10 gen_loss, disc_loss = train_step(input_image, target_image,␣
 ↪generator_model, discriminator_model)
     12 # Accumulate training losses
---> 13 gen_loss_total += gen_loss.numpy().item()
     14 disc_loss_total += disc_loss.numpy().item()
     15 num_batches += 1

File ~/.local/lib/python3.9/site-packages/tensorflow/python/framework/ops.py:
 ↪1141, in _EagerTensorBase.numpy(self)
   1118 """Copy of the contents of this Tensor into a NumPy array or scalar.
   1119
   1120 Unlike NumPy arrays, Tensors are immutable, so this method has to copy
   (…)
   1138     NumPy dtype.
   1139 """
   1140 # TODO(slebedev): Consider avoiding a copy for non-CPU or remote tensor.
-> 1141 maybe_arr = self._numpy()  # pylint: disable=protected-access
   1142 return maybe_arr.copy() if isinstance(maybe_arr, np.ndarray) else␣
 ↪maybe_arr

File ~/.local/lib/python3.9/site-packages/tensorflow/python/framework/ops.py:
 ↪1107, in _EagerTensorBase._numpy(self)
   1105 def _numpy(self):
   1106   try:
-> 1107     return self._numpy_internal()
   1108   except core._NotOkStatusException as e:  # pylint:␣
 ↪disable=protected-access
   1109     raise core._status_to_exception(e) from None

KeyboardInterrupt:
```

0.6 Resultados

[ ]:
```
# Plot metrics
plt.figure(figsize=(12, 6))

# Plot Generator and Discriminator Loss
```

```
plt.subplot(1, 2, 1)
plt.plot(epochs_list, gen_losses, label='Generator Loss')
plt.plot(epochs_list, disc_losses, label='Discriminator Loss')
plt.xlabel('Epochs')
plt.ylabel('Loss')
plt.title('Training Losses')
plt.legend()

# Plot Validation Metrics
plt.subplot(1, 2, 2)
plt.plot(epochs_list, val_gen_losses, label='Validation Gen Loss')
plt.xlabel('Epochs')
plt.ylabel('Metric Value')
plt.title('Validation Metrics')
plt.legend()

plt.tight_layout()
plt.show()
```



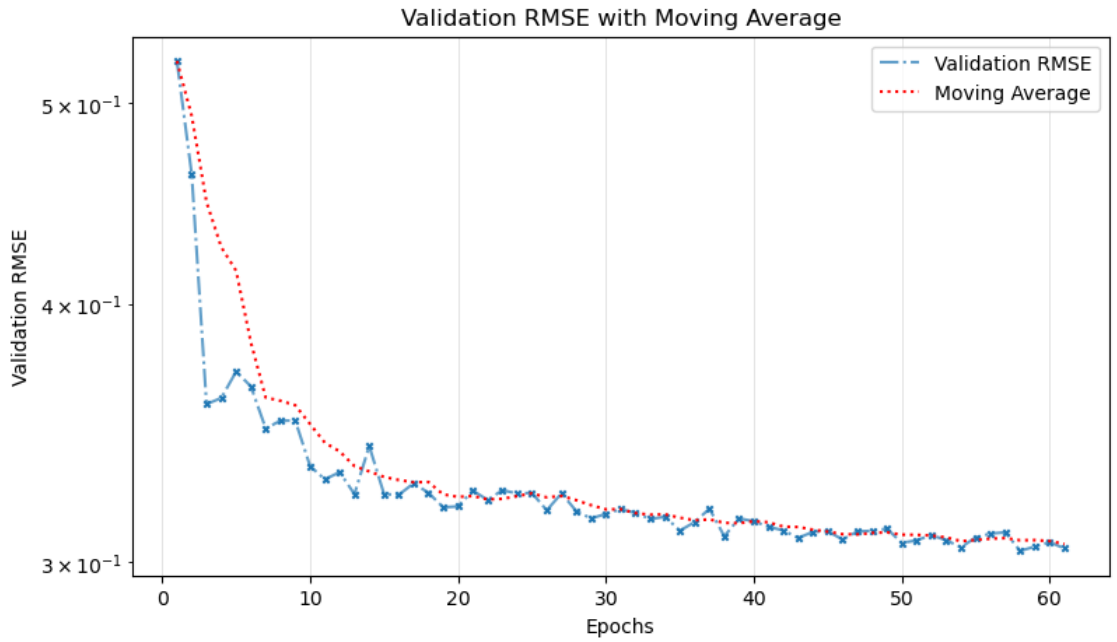
[ ]:
```
epochs_list = np.array(epochs_list)
```

Podemos ver que o rmse continua caindo. Mais treinamento pode gerar resultados melhores

[ ]:
```
# Calculate moving average using pandas
window_size = 5
val_rmses_series = pd.Series(val_rmses)
moving_avg = val_rmses_series.rolling(window=window_size, min_periods=1).mean()
plt.figure(figsize=(9, 5))
```

```
# Plot validation RMSE values
plt.plot(epochs_list, val_rmses, label='Validation RMSE', alpha=0.7,␣
 ↪linestyle='dashdot')
plt.scatter(epochs_list, val_rmses, s=10, marker='x')

# Plot the moving average
plt.plot(epochs_list, moving_avg, color='red', linestyle=':', label='Moving␣
 ↪Average')

# Set y-axis to logarithmic scale
plt.yscale('log')

# Add grid
plt.grid(color='gray', linestyle='-', linewidth=0.5, alpha=0.3)

# Add labels and legend
plt.xlabel('Epochs')
plt.ylabel('Validation RMSE')
plt.title('Validation RMSE with Moving Average')
plt.legend()
```

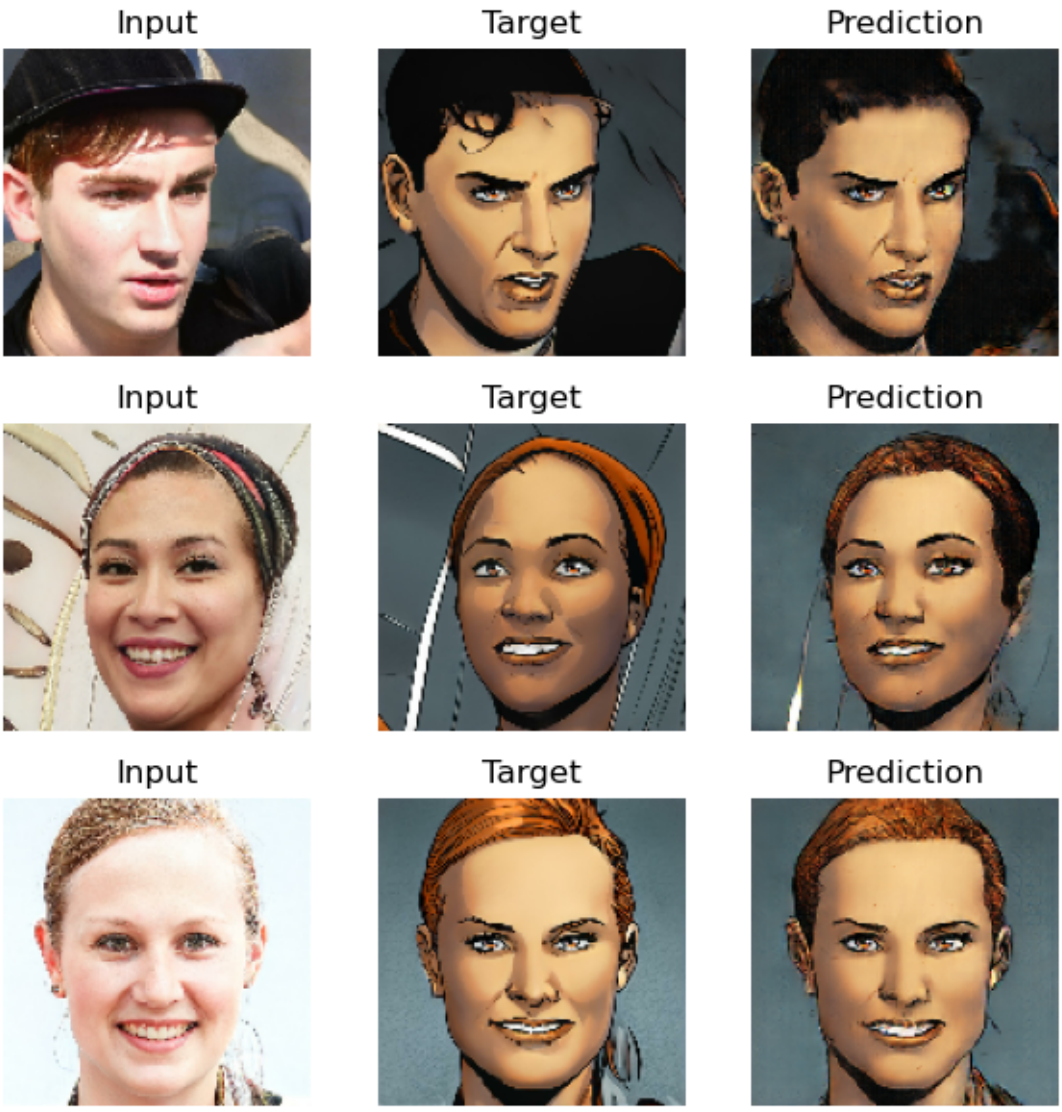
[ ]: <matplotlib.legend.Legend at 0x77fcdbbc4f70>



[ ]:
```
def display_random_images(val_dataset, generator_model, num_samples=3):
    # Get a random batch from the validation dataset
    val_dataset = val_dataset.shuffle(buffer_size=len(val_dataset))
```

```
    iterator = iter(val_dataset)

    # Collect a few random samples
    input_images = []
    target_images = []
    predicted_images = []

    for _ in range(num_samples):
        batch = next(iterator)
        input_image, target_image = batch
        input_images.append(input_image.numpy()[0])
        target_images.append(target_image.numpy()[0])
        predicted_image = generator_model(input_image, training=False)
        predicted_images.append(predicted_image.numpy()[0])

    # Plot the images
    fig, axes = plt.subplots(num_samples, 3, figsize=(num_samples*2,␣
 ↪num_samples*2))

    for i in range(num_samples):
        # Input image
        axes[i, 0].imshow((input_images[i] + 1) / 2)  # Normalize for display
        axes[i, 0].set_title("Input")
        axes[i, 0].axis('off')

        # Target image
        axes[i, 1].imshow((target_images[i] + 1) / 2)  # Normalize for display
        axes[i, 1].set_title("Target")
        axes[i, 1].axis('off')

        # Predicted image
        axes[i, 2].imshow((predicted_images[i] + 1) / 2)  # Normalize for␣
 ↪display
        axes[i, 2].set_title("Prediction")
        axes[i, 2].axis('off')

    plt.tight_layout()
    plt.show()

# Example usage
display_random_images(val_dataset, generator_model, num_samples=3)
```

```
2024-07-25 20:46:39.665788: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:422] Filling up shuffle
buffer (this may take a while): 112 of 125
2024-07-25 20:46:40.803551: I
tensorflow/core/kernels/data/shuffle_dataset_op.cc:450] Shuffle buffer filled.
```



[ ]:
```
generator_model.save("models/generator.tf")
```

```
INFO:tensorflow:Assets written to: models/generator.tf/assets
INFO:tensorflow:Assets written to: models/generator.tf/assets
```

[ ]:
```
discriminator_model.save("models/discriminator.tf")
```

```
INFO:tensorflow:Assets written to: models/discriminator.tf/assets
INFO:tensorflow:Assets written to: models/discriminator.tf/assets
```

[ ]:
```
import pickle
# List of metrics to save
```

```
metrics = {
    'epochs': epochs_list,
    'gen_losses': gen_losses,
    'disc_losses': disc_losses,
    'val_gen_losses': val_gen_losses,
    'val_rmses': val_rmses,
    'val_psnrs': val_psnrs
}

# Save metrics to a file
with open('training_history.pkl', 'wb') as f:
    pickle.dump(metrics, f)

print("Metrics saved successfully!")
```

```
Metrics saved successfully!
```