ECE228 Project

May 26, 2021

[1]:
```python
from tensorflow.keras.layers import Conv2D, BatchNormalization, Activation
import numpy as np
import cv2
import os


def dataset_setup(data_dir='', n_ims=2975, offset_bias=0, img_dim=256):
    """
    Method to import the training data from CityScape and divide into␣
 ↪image-label pairs

    Inputs
    --
    data_dir: string
        Location for the data that is being imported
    n_ims: int
        Number of images contained in the folder chosen
    offset_bias: int
        Optionally, skip some images by starting at a position further than 0
    img_dim: int
        Expected image dimension (assuming square images)

    Outputs
    --
    X: list
        Images
    y: list
        Image labels per pixel
    """

    flist = os.listdir(data_dir)
    img0 = cv2.imread(data_dir+flist[0])

    y_dim,x_dim,_ = np.shape(img0)
    X = np.zeros((n_ims,y_dim,int(x_dim/2),3))
    y = np.zeros((n_ims,y_dim,int(x_dim/2),3))
```

```
    k = 0
    for f in flist[offset_bias:offset_bias+n_ims]:
        X[k] = cv2.imread(data_dir+f)[:,:img_dim]/img_dim
        y[k] = cv2.imread(data_dir+f)[:,img_dim:]/img_dim
        k = k+1

    return X, y
```

[2]:
```
import matplotlib.pyplot as plt
from sklearn.model_selection import train_test_split

# Directories containing the train and val data
train_files = "./ECE228_project/data/train/"
test_files = "./ECE228_project/data/val/"

# Setup image-label pairs
x, y = dataset_setup(data_dir=train_files, n_ims=2975, offset_bias=0,␣
↪img_dim=256)
x_train, x_val, y_train, y_val = train_test_split(x, y, test_size=0.1,␣
↪random_state=42)
x_test, y_test = dataset_setup(data_dir=test_files, n_ims=500, offset_bias=0,␣
↪img_dim=256)
```

[3]:
```
from tensorflow.keras.layers import MaxPooling2D, Dropout, Conv2DTranspose,␣
↪Conv2D, concatenate
from tensorflow.keras.layers import Conv2D, BatchNormalization, Activation
from tensorflow.keras.backend import binary_crossentropy, square
from tensorflow.keras.backend import sum as ksum
from tensorflow.keras import Model, Input
import tensorflow as tf


def reconstruction_loss(y_true, y_pred):
    """
    Using binary crossentropy from Keras for reconstruction loss
    """

    return ksum(binary_crossentropy(y_true, y_pred), axis=-1)


def conv2d_block(input_tensor, n_filters=16, filter_size=3, activation='relu',␣
↪pad='same', batch_norm=True):
    """
    Custom block method to perform consecutive convolutions with optional batch␣
↪normalization
```

```
    Inputs
    --
    input_tensor: tensor
        Input image tensor data structure defined within Keras
    n_filters: int
        Depth for the convolution layer outputs
    filter_size: int
        Dimensions of the filter convolved with the tensor inputs
    activation: string
        Activation function for the intermediate layers between convolutions
    pad: string
        Determination of if input shape is maintained in convolution
    batch_norm: bool
        Flag if batch normalization is used

    Outputs
    --
    x: tensor
        Twice convolved input with optional batch normalization and activation␣
↪non-linearities
    """

    x = Conv2D(filters=n_filters, kernel_size=(filter_size, filter_size),
               kernel_initializer='he_normal', padding=pad)(input_tensor)
    if batch_norm:
        x = BatchNormalization()(x)
    x = Activation(activation)(x)

    x = Conv2D(filters=n_filters, kernel_size=(filter_size, filter_size),
               kernel_initializer='he_normal', padding=pad)(x)
    if batch_norm:
        x = BatchNormalization()(x)
    x = Activation('relu')(x)

    return x


def UNET(input_shape=(256,256,3), conv_block=conv2d_block, n_filters=32,␣
↪dropout=0.5, padding='same', batch_norm=True):
    """
    UNET architecture as originally outlined in https://arxiv.org/pdf/1505.
↪04597.pdf with modifications
    to fit different input dimensions.

    Inputs
    --
    input_shape: tuple(int)
```

```
        Tuple in 3D corresponding to the dimensions of the input images
    conv_block: func
        Custom block method to perform consecutive convolutions with optional␣
↪batch normalization
    n_filters: int
        Number of filters corresponding to depth of input for next layer
    dropout: float
        Dropout percentage hyperparameter to tune overfitting
    padding: string
        Descriptor determining if padding maintain size during convolutions
    batch_norm: bool
        Determines if batch normalization is used

    Outputs
    --
    model: Model
        Returns model architecture without compile
    """

    tensor = Input(shape=input_shape)

    print('Contracting Path')
    c1 = conv_block(tensor, n_filters * 1, filter_size=3, activation='relu',␣
↪pad=padding, batch_norm=batch_norm)
    p1 = MaxPooling2D((2, 2))(c1)
    p1 = Dropout(dropout)(p1)

    c2 = conv_block(p1, n_filters * 2, filter_size=3, activation='relu',␣
↪pad=padding, batch_norm=batch_norm)
    p2 = MaxPooling2D((2, 2))(c2)
    p2 = Dropout(dropout)(p2)

    c3 = conv_block(p2, n_filters * 4,  filter_size=3, activation='relu',␣
↪pad=padding, batch_norm=batch_norm)
    p3 = MaxPooling2D((2, 2))(c3)
    p3 = Dropout(dropout)(p3)

    c4 = conv_block(p3, n_filters * 8,  filter_size=3, activation='relu',␣
↪pad=padding, batch_norm=batch_norm)
    p4 = MaxPooling2D((2, 2))(c4)
    p4 = Dropout(dropout)(p4)

    c5 = conv_block(p4, n_filters * 16, filter_size=3, activation='relu',␣
↪pad=padding, batch_norm=batch_norm)

    print('Expanding Path')
```

```
    u6 = Conv2DTranspose(n_filters * 8, (3, 3), strides=(2, 2),␣
 ↪padding=padding)(c5)
    u6 = concatenate([u6, c4])
    u6 = Dropout(dropout)(u6)
    c6 = conv_block(u6, n_filters * 8,  filter_size=3, activation='relu',␣
 ↪pad=padding, batch_norm=batch_norm)

    u7 = Conv2DTranspose(n_filters * 4, (3, 3), strides=(2, 2),␣
 ↪padding=padding)(c6)
    u7 = concatenate([u7, c3])
    u7 = Dropout(dropout)(u7)
    c7 = conv_block(u7, n_filters * 4,  filter_size=3, activation='relu',␣
 ↪pad=padding, batch_norm=batch_norm)

    u8 = Conv2DTranspose(n_filters * 2, (3, 3), strides=(2, 2),␣
 ↪padding=padding)(c7)
    u8 = concatenate([u8, c2])
    u8 = Dropout(dropout)(u8)
    c8 = conv_block(u8, n_filters * 2,  filter_size=3, activation='relu',␣
 ↪pad=padding, batch_norm=batch_norm)

    u9 = Conv2DTranspose(n_filters * 1, (3, 3), strides=(2, 2),␣
 ↪padding=padding)(c8)
    u9 = concatenate([u9, c1])
    u9 = Dropout(dropout)(u9)
    c9 = conv_block(u9, n_filters * 1,  filter_size=3, activation='relu',␣
 ↪pad=padding, batch_norm=batch_norm)

    outputs = Conv2D(3, (1, 1), activation='sigmoid')(c9)
    model = Model(inputs=[tensor], outputs=[outputs])

    # Return model architecture
    return model


def UNET_plusplus(input_shape=(256,256,3), conv_block=conv2d_block,␣
 ↪n_filters=32, dropout=0.5, padding='same', batch_norm=True):
    """
    UNET++ architecture as originally outlined in https://arxiv.org/pdf/1807.
 ↪10165.pdf with modifications
    to fit different input dimensions.

    Inputs
    --
    input_shape: tuple(int)
        Tuple in 3D corresponding to the dimensions of the input images
```

```
    conv_block: func
        Custom block method to perform consecutive convolutions with optional␣
↪batch normalization
    n_filters: int
        Number of filters corresponding to depth of input for next layer
    dropout: float
        Dropout percentage hyperparameter to tune overfitting
    padding: string
        Descriptor determining if padding maintain size during convolutions
    batch_norm: bool
        Determines if batch normalization is used

    Outputs
    --
    model: Model
        Returns model architecture without compile
    """

    tensor = Input(shape=input_shape)

    print('Backbone')

    c00 = conv_block(tensor, n_filters * 1, filter_size=3, activation='relu',␣
↪pad=padding, batch_norm=batch_norm)
    p00 = MaxPooling2D((2, 2))(c00)
    p00 = Dropout(dropout)(p00)

    c10 = conv_block(p00, n_filters * 2, filter_size=3, activation='relu',␣
↪pad=padding, batch_norm=batch_norm)
    p10 = MaxPooling2D((2, 2))(c10)
    p10 = Dropout(dropout)(p10)

    c20 = conv_block(p10, n_filters * 4,  filter_size=3, activation='relu',␣
↪pad=padding, batch_norm=batch_norm)
    p20 = MaxPooling2D((2, 2))(c20)
    p20 = Dropout(dropout)(p20)

    c30 = conv_block(p20, n_filters * 8,  filter_size=3, activation='relu',␣
↪pad=padding, batch_norm=batch_norm)
    p30 = MaxPooling2D((2, 2))(c30)
    p30 = Dropout(dropout)(p30)

    c40 = conv_block(p30, n_filters * 16, filter_size=3, activation='relu',␣
↪pad=padding, batch_norm=batch_norm)

    print('First Up Path')
```

```python
    u01 = Conv2DTranspose(n_filters * 1, (3, 3), strides=(2, 2),␣
↪padding=padding)(c10)
    u01 = concatenate([u01, c00])
    u01 = Dropout(dropout)(u01)
    c01 = conv_block(u01, n_filters * 1,  filter_size=3, activation='relu',␣
↪pad=padding, batch_norm=batch_norm)

    print('Second Up Path')

    u11 = Conv2DTranspose(n_filters * 2, (3, 3), strides=(2, 2),␣
↪padding=padding)(c20)
    u11 = concatenate([u11, c10])
    u11 = Dropout(dropout)(u11)
    c11 = conv_block(u11, n_filters * 2,  filter_size=3, activation='relu',␣
↪pad=padding, batch_norm=batch_norm)

    u02 = Conv2DTranspose(n_filters * 1, (3, 3), strides=(2, 2),␣
↪padding=padding)(c11)
    u02 = concatenate([u02, c01, c00])
    u02 = Dropout(dropout)(u02)
    c02 = conv_block(u02, n_filters * 1,  filter_size=3, activation='relu',␣
↪pad=padding, batch_norm=batch_norm)

    print('Third Up Path')

    u21 = Conv2DTranspose(n_filters * 4, (3, 3), strides=(2, 2),␣
↪padding=padding)(c30)
    u21 = concatenate([u21, c20])
    u21 = Dropout(dropout)(u21)
    c21 = conv_block(u21, n_filters * 4,  filter_size=3, activation='relu',␣
↪pad=padding, batch_norm=batch_norm)

    u12 = Conv2DTranspose(n_filters * 2, (3, 3), strides=(2, 2),␣
↪padding=padding)(c21)
    u12 = concatenate([u12, c11, c10])
    u12 = Dropout(dropout)(u12)
    c12 = conv_block(u12, n_filters * 2,  filter_size=3, activation='relu',␣
↪pad=padding, batch_norm=batch_norm)

    u03 = Conv2DTranspose(n_filters * 1, (3, 3), strides=(2, 2),␣
↪padding=padding)(c12)
    u03 = concatenate([u03, c02, c01, c00])
    u03 = Dropout(dropout)(u03)
    c03 = conv_block(u03, n_filters * 1,  filter_size=3, activation='relu',␣
↪pad=padding, batch_norm=batch_norm)
```

```
    print('Final Up Path')

    u31 = Conv2DTranspose(n_filters * 8, (3, 3), strides=(2, 2),␣
 ↪padding=padding)(c40)
    u31 = concatenate([u31, c30])
    u31 = Dropout(dropout)(u31)
    c31 = conv_block(u31, n_filters * 8,  filter_size=3, activation='relu',␣
 ↪pad=padding, batch_norm=batch_norm)

    u22 = Conv2DTranspose(n_filters * 4, (3, 3), strides=(2, 2),␣
 ↪padding=padding)(c31)
    u22 = concatenate([u22, c21, c20])
    u22 = Dropout(dropout)(u22)
    c22 = conv_block(u22, n_filters * 4,  filter_size=3, activation='relu',␣
 ↪pad=padding, batch_norm=batch_norm)

    u13 = Conv2DTranspose(n_filters * 2, (3, 3), strides=(2, 2),␣
 ↪padding=padding)(c22)
    u13 = concatenate([u13, c12, c11, c10])
    u13 = Dropout(dropout)(u13)
    c13 = conv_block(u13, n_filters * 2,  filter_size=3, activation='relu',␣
 ↪pad=padding, batch_norm=batch_norm)

    u04 = Conv2DTranspose(n_filters * 1, (3, 3), strides=(2, 2),␣
 ↪padding=padding)(c13)
    u04 = concatenate([u04, c03, c02, c01, c00])
    u04 = Dropout(dropout)(u04)
    c04 = conv_block(u04, n_filters * 1,  filter_size=3, activation='relu',␣
 ↪pad=padding, batch_norm=batch_norm)

    #Outputs
    outputs = Conv2D(3, (1, 1), activation='sigmoid')(c04)
    model = Model(inputs=[tensor], outputs=[outputs])

    # Return model architecture
    return model
```

[4]:
```
# Initialize UNET
model = UNET_plusplus(input_shape=(256,256,3), conv_block=conv2d_block,␣
 ↪n_filters=8, dropout=0.5, padding='same', batch_norm=True)
print(model.summary())
```

```
Backbone
First Up Path
Second Up Path
Third Up Path
```

Final Up Path

```
Model: "model"
__________________________________________________________________________________________________
Layer (type)                    Output Shape         Param #     Connected to
==================================================================================================
input_1 (InputLayer)            [(None, 256, 256, 3) 0
__________________________________________________________________________________________________
conv2d (Conv2D)                 (None, 256, 256, 8)  224         input_1[0][0]
__________________________________________________________________________________________________
batch_normalization (BatchNorma (None, 256, 256, 8)  32          conv2d[0][0]
__________________________________________________________________________________________________
activation (Activation)         (None, 256, 256, 8)  0
batch_normalization[0][0]
__________________________________________________________________________________________________
conv2d_1 (Conv2D)               (None, 256, 256, 8)  584
activation[0][0]
__________________________________________________________________________________________________
batch_normalization_1 (BatchNor (None, 256, 256, 8)  32          conv2d_1[0][0]
__________________________________________________________________________________________________
activation_1 (Activation)       (None, 256, 256, 8)  0
batch_normalization_1[0][0]
__________________________________________________________________________________________________
max_pooling2d (MaxPooling2D)    (None, 128, 128, 8)  0
activation_1[0][0]
__________________________________________________________________________________________________
dropout (Dropout)               (None, 128, 128, 8)  0
max_pooling2d[0][0]
__________________________________________________________________________________________________
conv2d_2 (Conv2D)               (None, 128, 128, 16) 1168        dropout[0][0]
__________________________________________________________________________________________________
batch_normalization_2 (BatchNor (None, 128, 128, 16) 64          conv2d_2[0][0]
__________________________________________________________________________________________________
activation_2 (Activation)       (None, 128, 128, 16) 0
batch_normalization_2[0][0]
__________________________________________________________________________________________________
```

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__________________
conv2d_3 (Conv2D)               (None, 128, 128, 16) 2320
activation_2[0][0]
________________________________________________________________________________
__________________
batch_normalization_3 (BatchNor (None, 128, 128, 16) 64          conv2d_3[0][0]
________________________________________________________________________________
__________________
activation_3 (Activation)       (None, 128, 128, 16) 0
batch_normalization_3[0][0]
________________________________________________________________________________
__________________
max_pooling2d_1 (MaxPooling2D)  (None, 64, 64, 16)   0
activation_3[0][0]
________________________________________________________________________________
__________________
dropout_1 (Dropout)             (None, 64, 64, 16)   0
max_pooling2d_1[0][0]
________________________________________________________________________________
__________________
conv2d_4 (Conv2D)               (None, 64, 64, 32)   4640        dropout_1[0][0]
________________________________________________________________________________
__________________
batch_normalization_4 (BatchNor (None, 64, 64, 32)   128         conv2d_4[0][0]
________________________________________________________________________________
__________________
activation_4 (Activation)       (None, 64, 64, 32)   0
batch_normalization_4[0][0]
________________________________________________________________________________
__________________
conv2d_5 (Conv2D)               (None, 64, 64, 32)   9248
activation_4[0][0]
________________________________________________________________________________
__________________
batch_normalization_5 (BatchNor (None, 64, 64, 32)   128         conv2d_5[0][0]
________________________________________________________________________________
__________________
activation_5 (Activation)       (None, 64, 64, 32)   0
batch_normalization_5[0][0]
________________________________________________________________________________
__________________
max_pooling2d_2 (MaxPooling2D)  (None, 32, 32, 32)   0
activation_5[0][0]
________________________________________________________________________________
__________________
dropout_2 (Dropout)             (None, 32, 32, 32)   0
max_pooling2d_2[0][0]
________________________________________________________________________________
```

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__________________
conv2d_6 (Conv2D)               (None, 32, 32, 64)   18496       dropout_2[0][0]
________________________________________________________________________________
__________________
batch_normalization_6 (BatchNor (None, 32, 32, 64)   256         conv2d_6[0][0]
________________________________________________________________________________
__________________
activation_6 (Activation)       (None, 32, 32, 64)   0
batch_normalization_6[0][0]
________________________________________________________________________________
__________________
conv2d_7 (Conv2D)               (None, 32, 32, 64)   36928
activation_6[0][0]
________________________________________________________________________________
__________________
batch_normalization_7 (BatchNor (None, 32, 32, 64)   256         conv2d_7[0][0]
________________________________________________________________________________
__________________
activation_7 (Activation)       (None, 32, 32, 64)   0
batch_normalization_7[0][0]
________________________________________________________________________________
__________________
max_pooling2d_3 (MaxPooling2D)  (None, 16, 16, 64)   0
activation_7[0][0]
________________________________________________________________________________
__________________
dropout_3 (Dropout)             (None, 16, 16, 64)   0
max_pooling2d_3[0][0]
________________________________________________________________________________
__________________
conv2d_8 (Conv2D)               (None, 16, 16, 128)  73856       dropout_3[0][0]
________________________________________________________________________________
__________________
batch_normalization_8 (BatchNor (None, 16, 16, 128)  512         conv2d_8[0][0]
________________________________________________________________________________
__________________
activation_8 (Activation)       (None, 16, 16, 128)  0
batch_normalization_8[0][0]
________________________________________________________________________________
__________________
conv2d_9 (Conv2D)               (None, 16, 16, 128)  147584
activation_8[0][0]
________________________________________________________________________________
__________________
batch_normalization_9 (BatchNor (None, 16, 16, 128)  512         conv2d_9[0][0]
________________________________________________________________________________
__________________
activation_9 (Activation)       (None, 16, 16, 128)  0
```

```
batch_normalization_9[0][0]
__________________________________________________________________________________________________
conv2d_transpose_6 (Conv2DTrans (None, 32, 32, 64)   73792
activation_9[0][0]
__________________________________________________________________________________________________
concatenate_6 (Concatenate)     (None, 32, 32, 128)  0
conv2d_transpose_6[0][0]
activation_7[0][0]
__________________________________________________________________________________________________
conv2d_transpose_3 (Conv2DTrans (None, 64, 64, 32)   18464
activation_7[0][0]
__________________________________________________________________________________________________
dropout_10 (Dropout)            (None, 32, 32, 128)  0
concatenate_6[0][0]
__________________________________________________________________________________________________
concatenate_3 (Concatenate)     (None, 64, 64, 64)   0
conv2d_transpose_3[0][0]
activation_5[0][0]
__________________________________________________________________________________________________
conv2d_transpose_1 (Conv2DTrans (None, 128, 128, 16) 4624
activation_5[0][0]
__________________________________________________________________________________________________
conv2d_22 (Conv2D)              (None, 32, 32, 64)   73792
dropout_10[0][0]
__________________________________________________________________________________________________
dropout_7 (Dropout)             (None, 64, 64, 64)   0
concatenate_3[0][0]
__________________________________________________________________________________________________
concatenate_1 (Concatenate)     (None, 128, 128, 32) 0
conv2d_transpose_1[0][0]
activation_3[0][0]
__________________________________________________________________________________________________
conv2d_transpose (Conv2DTranspo (None, 256, 256, 8)  1160
activation_3[0][0]
__________________________________________________________________________________________________
batch_normalization_22 (BatchNo (None, 32, 32, 64)   256         conv2d_22[0][0]
__________________________________________________________________________________________________
```

```
__________________
conv2d_16 (Conv2D)              (None, 64, 64, 32)   18464       dropout_7[0][0]
________________________________________________________________________________
__________________
dropout_5 (Dropout)             (None, 128, 128, 32) 0
concatenate_1[0][0]
________________________________________________________________________________
__________________
concatenate (Concatenate)       (None, 256, 256, 16) 0
conv2d_transpose[0][0]
activation_1[0][0]
________________________________________________________________________________
__________________
activation_22 (Activation)      (None, 32, 32, 64)   0
batch_normalization_22[0][0]
________________________________________________________________________________
__________________
batch_normalization_16 (BatchNo (None, 64, 64, 32)   128         conv2d_16[0][0]
________________________________________________________________________________
__________________
conv2d_12 (Conv2D)              (None, 128, 128, 16) 4624        dropout_5[0][0]
________________________________________________________________________________
__________________
dropout_4 (Dropout)             (None, 256, 256, 16) 0
concatenate[0][0]
________________________________________________________________________________
__________________
conv2d_23 (Conv2D)              (None, 32, 32, 64)   36928
activation_22[0][0]
________________________________________________________________________________
__________________
activation_16 (Activation)      (None, 64, 64, 32)   0
batch_normalization_16[0][0]
________________________________________________________________________________
__________________
batch_normalization_12 (BatchNo (None, 128, 128, 16) 64          conv2d_12[0][0]
________________________________________________________________________________
__________________
conv2d_10 (Conv2D)              (None, 256, 256, 8)  1160        dropout_4[0][0]
________________________________________________________________________________
__________________
batch_normalization_23 (BatchNo (None, 32, 32, 64)   256         conv2d_23[0][0]
________________________________________________________________________________
__________________
conv2d_17 (Conv2D)              (None, 64, 64, 32)   9248
activation_16[0][0]
________________________________________________________________________________
__________________
```

```
activation_12 (Activation)      (None, 128, 128, 16) 0
batch_normalization_12[0][0]
________________________________________________________________________________
__________________
batch_normalization_10 (BatchNo (None, 256, 256, 8)  32          conv2d_10[0][0]
________________________________________________________________________________
__________________
activation_23 (Activation)      (None, 32, 32, 64)   0
batch_normalization_23[0][0]
________________________________________________________________________________
__________________
batch_normalization_17 (BatchNo (None, 64, 64, 32)   128         conv2d_17[0][0]
________________________________________________________________________________
__________________
conv2d_13 (Conv2D)              (None, 128, 128, 16) 2320
activation_12[0][0]
________________________________________________________________________________
__________________
activation_10 (Activation)      (None, 256, 256, 8)  0
batch_normalization_10[0][0]
________________________________________________________________________________
__________________
conv2d_transpose_7 (Conv2DTrans (None, 64, 64, 32)   18464
activation_23[0][0]
________________________________________________________________________________
__________________
activation_17 (Activation)      (None, 64, 64, 32)   0
batch_normalization_17[0][0]
________________________________________________________________________________
__________________
batch_normalization_13 (BatchNo (None, 128, 128, 16) 64          conv2d_13[0][0]
________________________________________________________________________________
__________________
conv2d_11 (Conv2D)              (None, 256, 256, 8)  584
activation_10[0][0]
________________________________________________________________________________
__________________
concatenate_7 (Concatenate)     (None, 64, 64, 96)   0
conv2d_transpose_7[0][0]
activation_17[0][0]
activation_5[0][0]
________________________________________________________________________________
__________________
conv2d_transpose_4 (Conv2DTrans (None, 128, 128, 16) 4624
activation_17[0][0]
________________________________________________________________________________
__________________
activation_13 (Activation)      (None, 128, 128, 16) 0
```

```
batch_normalization_13[0][0]
__________________________________________________________________________________________________
batch_normalization_11 (BatchNo (None, 256, 256, 8)  32          conv2d_11[0][0]
__________________________________________________________________________________________________
dropout_11 (Dropout)            (None, 64, 64, 96)   0
concatenate_7[0][0]
__________________________________________________________________________________________________
concatenate_4 (Concatenate)     (None, 128, 128, 48) 0
conv2d_transpose_4[0][0]
activation_13[0][0]
activation_3[0][0]
__________________________________________________________________________________________________
conv2d_transpose_2 (Conv2DTrans (None, 256, 256, 8)  1160
activation_13[0][0]
__________________________________________________________________________________________________
activation_11 (Activation)      (None, 256, 256, 8)  0
batch_normalization_11[0][0]
__________________________________________________________________________________________________
conv2d_24 (Conv2D)              (None, 64, 64, 32)   27680
dropout_11[0][0]
__________________________________________________________________________________________________
dropout_8 (Dropout)             (None, 128, 128, 48) 0
concatenate_4[0][0]
__________________________________________________________________________________________________
concatenate_2 (Concatenate)     (None, 256, 256, 24) 0
conv2d_transpose_2[0][0]
activation_11[0][0]
activation_1[0][0]
__________________________________________________________________________________________________
batch_normalization_24 (BatchNo (None, 64, 64, 32)   128         conv2d_24[0][0]
__________________________________________________________________________________________________
conv2d_18 (Conv2D)              (None, 128, 128, 16) 6928        dropout_8[0][0]
__________________________________________________________________________________________________
dropout_6 (Dropout)             (None, 256, 256, 24) 0
concatenate_2[0][0]
__________________________________________________________________________________________________
```

```
activation_24 (Activation)      (None, 64, 64, 32)   0
batch_normalization_24[0][0]
--------------------------------------------------------------------------------
------------------
batch_normalization_18 (BatchNo (None, 128, 128, 16) 64          conv2d_18[0][0]
--------------------------------------------------------------------------------
------------------
conv2d_14 (Conv2D)              (None, 256, 256, 8)  1736        dropout_6[0][0]
--------------------------------------------------------------------------------
------------------
conv2d_25 (Conv2D)              (None, 64, 64, 32)   9248
activation_24[0][0]
--------------------------------------------------------------------------------
------------------
activation_18 (Activation)      (None, 128, 128, 16) 0
batch_normalization_18[0][0]
--------------------------------------------------------------------------------
------------------
batch_normalization_14 (BatchNo (None, 256, 256, 8)  32          conv2d_14[0][0]
--------------------------------------------------------------------------------
------------------
batch_normalization_25 (BatchNo (None, 64, 64, 32)   128         conv2d_25[0][0]
--------------------------------------------------------------------------------
------------------
conv2d_19 (Conv2D)              (None, 128, 128, 16) 2320
activation_18[0][0]
--------------------------------------------------------------------------------
------------------
activation_14 (Activation)      (None, 256, 256, 8)  0
batch_normalization_14[0][0]
--------------------------------------------------------------------------------
------------------
activation_25 (Activation)      (None, 64, 64, 32)   0
batch_normalization_25[0][0]
--------------------------------------------------------------------------------
------------------
batch_normalization_19 (BatchNo (None, 128, 128, 16) 64          conv2d_19[0][0]
--------------------------------------------------------------------------------
------------------
conv2d_15 (Conv2D)              (None, 256, 256, 8)  584
activation_14[0][0]
--------------------------------------------------------------------------------
------------------
conv2d_transpose_8 (Conv2DTrans (None, 128, 128, 16) 4624
activation_25[0][0]
--------------------------------------------------------------------------------
------------------
activation_19 (Activation)      (None, 128, 128, 16) 0
```

```
batch_normalization_19[0][0]
__________________________________________________________________________________________________
batch_normalization_15 (BatchNo (None, 256, 256, 8)  32          conv2d_15[0][0]
__________________________________________________________________________________________________
concatenate_8 (Concatenate)     (None, 128, 128, 64) 0
conv2d_transpose_8[0][0]
activation_19[0][0]
activation_13[0][0]
activation_3[0][0]
__________________________________________________________________________________________________
conv2d_transpose_5 (Conv2DTrans (None, 256, 256, 8)  1160
activation_19[0][0]
__________________________________________________________________________________________________
activation_15 (Activation)      (None, 256, 256, 8)  0
batch_normalization_15[0][0]
__________________________________________________________________________________________________
dropout_12 (Dropout)            (None, 128, 128, 64) 0
concatenate_8[0][0]
__________________________________________________________________________________________________
concatenate_5 (Concatenate)     (None, 256, 256, 32) 0
conv2d_transpose_5[0][0]
activation_15[0][0]
activation_11[0][0]
activation_1[0][0]
__________________________________________________________________________________________________
conv2d_26 (Conv2D)              (None, 128, 128, 16) 9232
dropout_12[0][0]
__________________________________________________________________________________________________
dropout_9 (Dropout)             (None, 256, 256, 32) 0
concatenate_5[0][0]
__________________________________________________________________________________________________
batch_normalization_26 (BatchNo (None, 128, 128, 16) 64          conv2d_26[0][0]
__________________________________________________________________________________________________
conv2d_20 (Conv2D)              (None, 256, 256, 8)  2312        dropout_9[0][0]
__________________________________________________________________________________________________
activation_26 (Activation)      (None, 128, 128, 16) 0
batch_normalization_26[0][0]
```

```
________________________________________________________________________________
__________________
batch_normalization_20 (BatchNo (None, 256, 256, 8)  32          conv2d_20[0][0]
________________________________________________________________________________
__________________
conv2d_27 (Conv2D)              (None, 128, 128, 16) 2320
activation_26[0][0]
________________________________________________________________________________
__________________
activation_20 (Activation)      (None, 256, 256, 8)  0
batch_normalization_20[0][0]
________________________________________________________________________________
__________________
batch_normalization_27 (BatchNo (None, 128, 128, 16) 64          conv2d_27[0][0]
________________________________________________________________________________
__________________
conv2d_21 (Conv2D)              (None, 256, 256, 8)  584
activation_20[0][0]
________________________________________________________________________________
__________________
activation_27 (Activation)      (None, 128, 128, 16) 0
batch_normalization_27[0][0]
________________________________________________________________________________
__________________
batch_normalization_21 (BatchNo (None, 256, 256, 8)  32          conv2d_21[0][0]
________________________________________________________________________________
__________________
conv2d_transpose_9 (Conv2DTrans (None, 256, 256, 8)  1160
activation_27[0][0]
________________________________________________________________________________
__________________
activation_21 (Activation)      (None, 256, 256, 8)  0
batch_normalization_21[0][0]
________________________________________________________________________________
__________________
concatenate_9 (Concatenate)     (None, 256, 256, 40) 0
conv2d_transpose_9[0][0]
activation_21[0][0]
activation_15[0][0]
activation_11[0][0]
activation_1[0][0]
________________________________________________________________________________
__________________
dropout_13 (Dropout)            (None, 256, 256, 40) 0
concatenate_9[0][0]
________________________________________________________________________________
__________________
conv2d_28 (Conv2D)              (None, 256, 256, 8)  2888
```

```
dropout_13[0][0]
________________________________________________________________________________
__________________
batch_normalization_28 (BatchNo (None, 256, 256, 8)  32          conv2d_28[0][0]
________________________________________________________________________________
__________________
activation_28 (Activation)      (None, 256, 256, 8)  0
batch_normalization_28[0][0]
________________________________________________________________________________
__________________
conv2d_29 (Conv2D)              (None, 256, 256, 8)  584
activation_28[0][0]
________________________________________________________________________________
__________________
batch_normalization_29 (BatchNo (None, 256, 256, 8)  32          conv2d_29[0][0]
________________________________________________________________________________
__________________
activation_29 (Activation)      (None, 256, 256, 8)  0
batch_normalization_29[0][0]
________________________________________________________________________________
__________________
conv2d_30 (Conv2D)              (None, 256, 256, 3)  27
activation_29[0][0]
================================================================================
==================
Total params: 641,491
Trainable params: 639,667
Non-trainable params: 1,824
________________________________________________________________________________
__________________
None
```

[5]:

```
# Compile model with specified optimizer and loss
optimizer = tf.keras.optimizers.Adam(learning_rate=0.01)
metrics = ['accuracy']
model.compile(optimizer=optimizer, loss='mse', metrics = metrics)
```

[6]:

```
datagen1 = tf.keras.preprocessing.image.ImageDataGenerator()

datagen1.fit(x_train)

datagen2 = tf.keras.preprocessing.image.ImageDataGenerator(
#     rotation_range=20,
#     width_shift_range=0.2,
#     height_shift_range=0.2,
    horizontal_flip=True
)
```

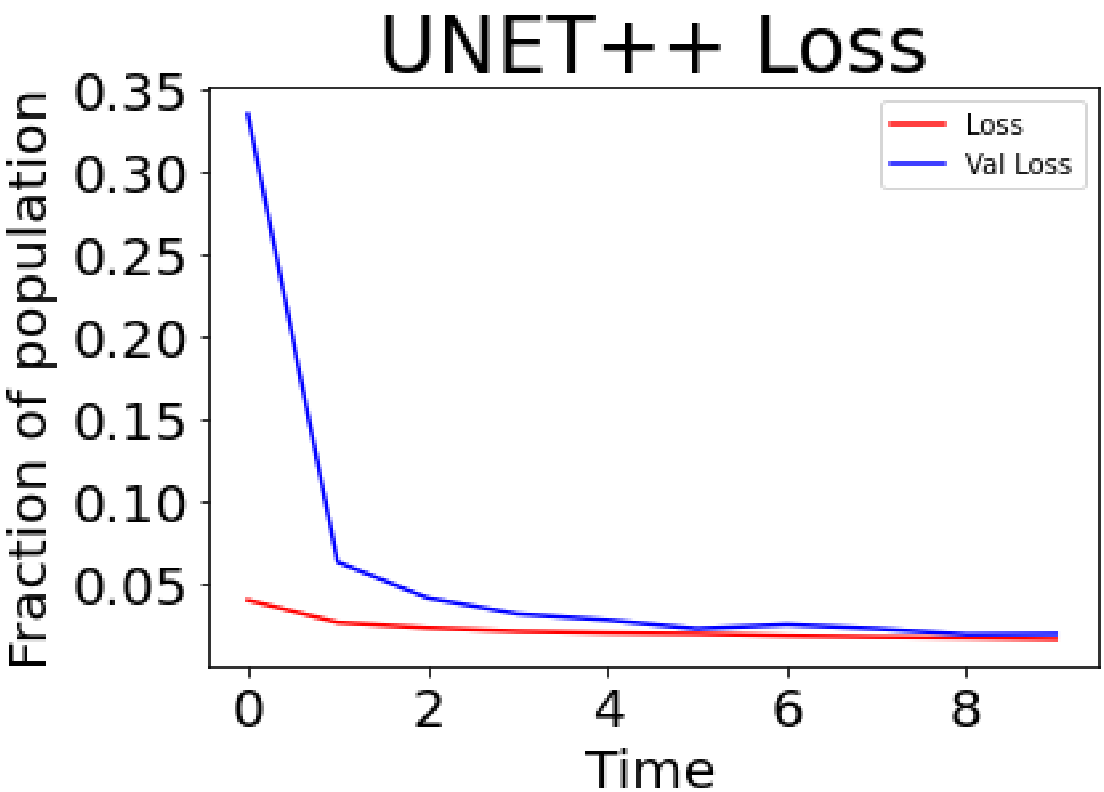
```
datagen2.fit(x_train)

# Track model history as it trains
h_11 = model.fit(datagen1.flow(x_train, y_train, batch_size=32), \
         steps_per_epoch=len(x_train) // 32, epochs=10, \
              validation_data=datagen1.flow(x_val, y_val, batch_size=32))
h_12 = model.fit(datagen2.flow(x_train, y_train, batch_size=32), \
         steps_per_epoch=len(x_train) // 32, epochs=5, \
              validation_data=datagen2.flow(x_val, y_val, batch_size=32))

# Save the weights
model.save_weights('./checkpoints/UNET++')
```

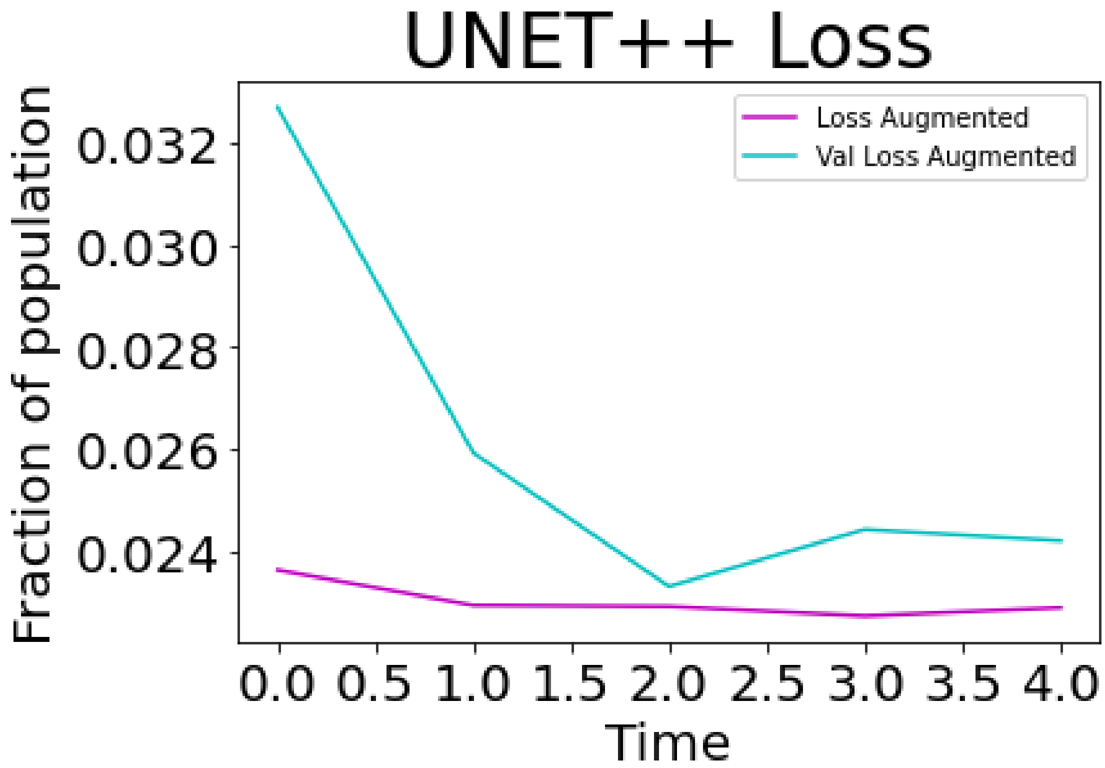
```
WARNING:tensorflow:sample_weight modes were coerced from
  …
    to
  ['…']
WARNING:tensorflow:sample_weight modes were coerced from
  …
    to
  ['…']
Train for 83 steps, validate for 10 steps
Epoch 1/10
83/83 [==============================] - 40s 481ms/step - loss: 0.0399 -
accuracy: 0.4225 - val_loss: 0.3345 - val_accuracy: 0.3696
Epoch 2/10
83/83 [==============================] - 26s 309ms/step - loss: 0.0262 -
accuracy: 0.6078 - val_loss: 0.0629 - val_accuracy: 0.4163
Epoch 3/10
83/83 [==============================] - 25s 303ms/step - loss: 0.0229 -
accuracy: 0.6062 - val_loss: 0.0412 - val_accuracy: 0.5231
Epoch 4/10
83/83 [==============================] - 26s 310ms/step - loss: 0.0209 -
accuracy: 0.6067 - val_loss: 0.0314 - val_accuracy: 0.5633
Epoch 5/10
83/83 [==============================] - 25s 304ms/step - loss: 0.0199 -
accuracy: 0.6185 - val_loss: 0.0276 - val_accuracy: 0.3961
Epoch 6/10
83/83 [==============================] - 25s 300ms/step - loss: 0.0193 -
accuracy: 0.5944 - val_loss: 0.0223 - val_accuracy: 0.4178
Epoch 7/10
83/83 [==============================] - 25s 302ms/step - loss: 0.0181 -
accuracy: 0.5843 - val_loss: 0.0249 - val_accuracy: 0.3544
Epoch 8/10
83/83 [==============================] - 25s 295ms/step - loss: 0.0174 -
accuracy: 0.5887 - val_loss: 0.0224 - val_accuracy: 0.4425
```

```
Epoch 9/10
83/83 [==============================] - 25s 300ms/step - loss: 0.0168 -
accuracy: 0.5908 - val_loss: 0.0189 - val_accuracy: 0.4738
Epoch 10/10
83/83 [==============================] - 25s 300ms/step - loss: 0.0161 -
accuracy: 0.6073 - val_loss: 0.0193 - val_accuracy: 0.6206
WARNING:tensorflow:sample_weight modes were coerced from
  …
    to
  ['…']
WARNING:tensorflow:sample_weight modes were coerced from
  …
    to
  ['…']
Train for 83 steps, validate for 10 steps
Epoch 1/5
83/83 [==============================] - 25s 299ms/step - loss: 0.0237 -
accuracy: 0.5029 - val_loss: 0.0327 - val_accuracy: 0.3545
Epoch 2/5
83/83 [==============================] - 24s 288ms/step - loss: 0.0230 -
accuracy: 0.5144 - val_loss: 0.0259 - val_accuracy: 0.4163
Epoch 3/5
83/83 [==============================] - 24s 293ms/step - loss: 0.0229 -
accuracy: 0.5171 - val_loss: 0.0233 - val_accuracy: 0.3898
Epoch 4/5
83/83 [==============================] - 24s 291ms/step - loss: 0.0228 -
accuracy: 0.5335 - val_loss: 0.0244 - val_accuracy: 0.3869
Epoch 5/5
83/83 [==============================] - 24s 291ms/step - loss: 0.0229 -
accuracy: 0.5030 - val_loss: 0.0242 - val_accuracy: 0.5918
```

[11]:
```
# Print results for training MSE and validation MSE
plt.plot(h_11.history['loss'], 'r', label='Loss')
plt.plot(h_11.history['val_loss'], 'b', label='Val Loss')
plt.title('UNET++ Loss', fontsize=30)
plt.xlabel("Time", fontsize=20)
plt.xticks(fontsize=20)
plt.ylabel("Fraction of population", fontsize=20)
plt.yticks(fontsize=20)
plt.legend(loc='best')
plt.show()
plt.plot(h_12.history['loss'], 'm', label='Loss Augmented')
plt.plot(h_12.history['val_loss'], 'c', label='Val Loss Augmented')
plt.title('UNET++ Loss', fontsize=30)
plt.xlabel("Time", fontsize=20)
plt.xticks(fontsize=20)
plt.ylabel("Fraction of population", fontsize=20)
```

```
plt.yticks(fontsize=20)
plt.legend(loc='best')
plt.show()
```

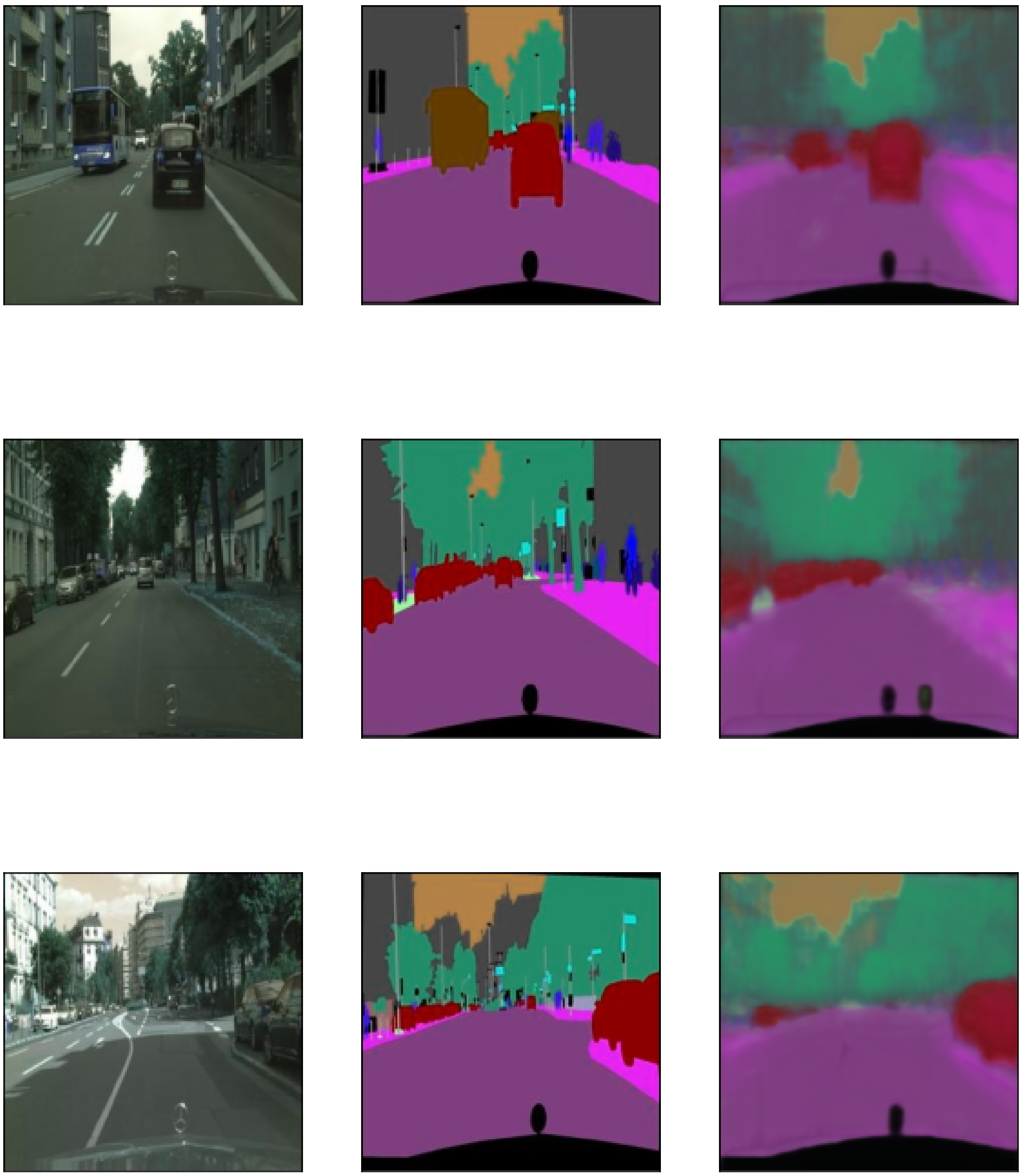


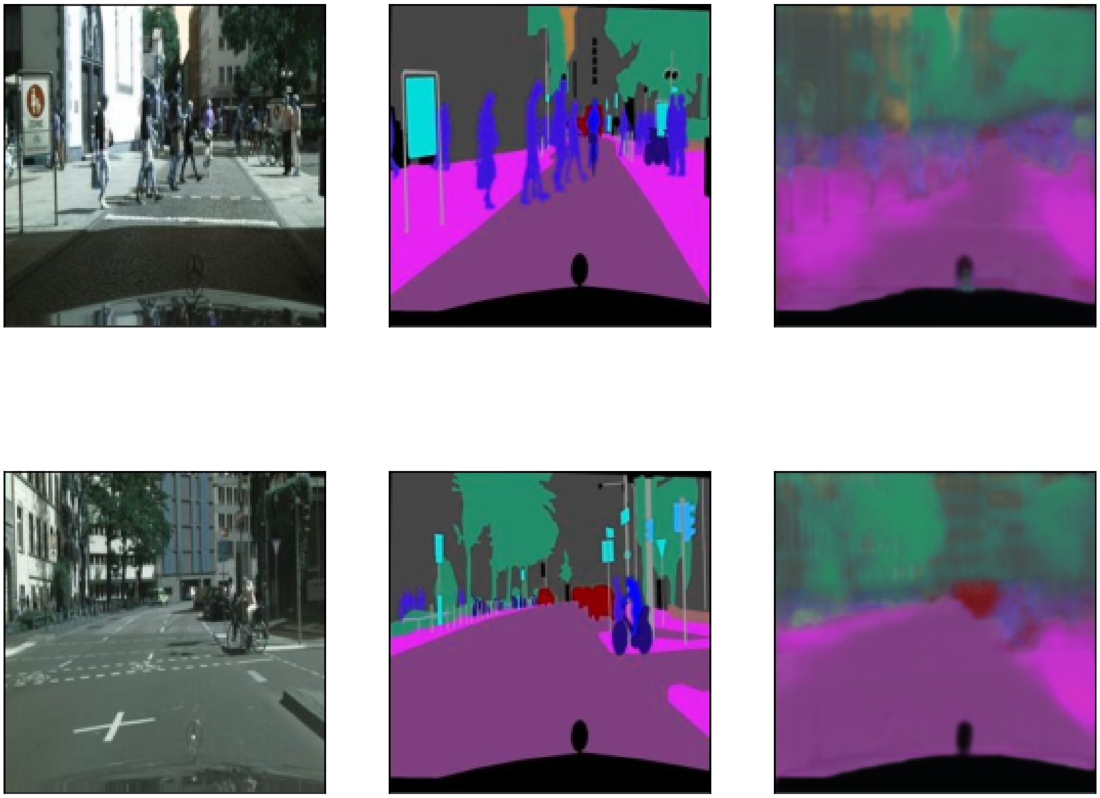


[8]:

```
#show the result
pp = model.predict(x_test[:5,:,:,:], batch_size=1)

ni = 5
for k in range(ni):
    plt.figure(figsize=(10,30))
    plt.subplot(ni,3,1+k*3)
    plt.imshow(x_test[k])
    figure = plt.gca()
    x_axis = figure.axes.get_xaxis()
    x_axis.set_visible(False)
    y_axis = figure.axes.get_yaxis()
    y_axis.set_visible(False)
    plt.subplot(ni,3,2+k*3)
    plt.imshow(y_test[k])
    figure = plt.gca()
    x_axis = figure.axes.get_xaxis()
    x_axis.set_visible(False)
    y_axis = figure.axes.get_yaxis()
    y_axis.set_visible(False)
    plt.subplot(ni,3,3+k*3)
    plt.imshow(pp[k])
```

```
    figure = plt.gca()
    x_axis = figure.axes.get_xaxis()
    x_axis.set_visible(False)
    y_axis = figure.axes.get_yaxis()
    y_axis.set_visible(False)
```





[9]:
```
intersection = np.logical_and(y_test[1,:,:,:], pp)
union = np.logical_or(y_test[1,:,:,:], pp)
iou_score = np.sum(intersection) / np.sum(union)
print(iou_score)
```

```
0.9607899983723959
```

[10]:
```
diff = y_test[1] - pp[1]
m_norm = np.sum(abs(diff))
print(m_norm)
print(m_norm/(256*256))
```

```
11151.228615228087
0.17015424522747935
```

[4]:
```
# Initialize UNET
model2 = UNET(input_shape=(256,256,3), conv_block=conv2d_block, n_filters=8, dropout=0.5, padding='same', batch_norm=True)
print(model2.summary())
```

```
Contracting Path
Expanding Path
```

```
Model: "model"
__________________________________________________________________________________________________
Layer (type)                    Output Shape         Param #     Connected to
==================================================================================================
input_1 (InputLayer)            [(None, 256, 256, 3) 0
__________________________________________________________________________________________________
conv2d (Conv2D)                 (None, 256, 256, 8)  224         input_1[0][0]
__________________________________________________________________________________________________
batch_normalization (BatchNorma (None, 256, 256, 8)  32          conv2d[0][0]
__________________________________________________________________________________________________
activation (Activation)         (None, 256, 256, 8)  0
batch_normalization[0][0]
__________________________________________________________________________________________________
conv2d_1 (Conv2D)               (None, 256, 256, 8)  584
activation[0][0]
__________________________________________________________________________________________________
batch_normalization_1 (BatchNor (None, 256, 256, 8)  32          conv2d_1[0][0]
__________________________________________________________________________________________________
activation_1 (Activation)       (None, 256, 256, 8)  0
batch_normalization_1[0][0]
__________________________________________________________________________________________________
max_pooling2d (MaxPooling2D)    (None, 128, 128, 8)  0
activation_1[0][0]
__________________________________________________________________________________________________
dropout (Dropout)               (None, 128, 128, 8)  0
max_pooling2d[0][0]
__________________________________________________________________________________________________
conv2d_2 (Conv2D)               (None, 128, 128, 16) 1168        dropout[0][0]
__________________________________________________________________________________________________
batch_normalization_2 (BatchNor (None, 128, 128, 16) 64          conv2d_2[0][0]
__________________________________________________________________________________________________
activation_2 (Activation)       (None, 128, 128, 16) 0
batch_normalization_2[0][0]
__________________________________________________________________________________________________
```

```
conv2d_3 (Conv2D)              (None, 128, 128, 16) 2320
activation_2[0][0]
________________________________________________________________________________
__________________
batch_normalization_3 (BatchNor (None, 128, 128, 16) 64          conv2d_3[0][0]
________________________________________________________________________________
__________________
activation_3 (Activation)      (None, 128, 128, 16) 0
batch_normalization_3[0][0]
________________________________________________________________________________
__________________
max_pooling2d_1 (MaxPooling2D)  (None, 64, 64, 16)   0
activation_3[0][0]
________________________________________________________________________________
__________________
dropout_1 (Dropout)            (None, 64, 64, 16)   0
max_pooling2d_1[0][0]
________________________________________________________________________________
__________________
conv2d_4 (Conv2D)              (None, 64, 64, 32)   4640        dropout_1[0][0]
________________________________________________________________________________
__________________
batch_normalization_4 (BatchNor (None, 64, 64, 32)   128         conv2d_4[0][0]
________________________________________________________________________________
__________________
activation_4 (Activation)      (None, 64, 64, 32)   0
batch_normalization_4[0][0]
________________________________________________________________________________
__________________
conv2d_5 (Conv2D)              (None, 64, 64, 32)   9248
activation_4[0][0]
________________________________________________________________________________
__________________
batch_normalization_5 (BatchNor (None, 64, 64, 32)   128         conv2d_5[0][0]
________________________________________________________________________________
__________________
activation_5 (Activation)      (None, 64, 64, 32)   0
batch_normalization_5[0][0]
________________________________________________________________________________
__________________
max_pooling2d_2 (MaxPooling2D)  (None, 32, 32, 32)   0
activation_5[0][0]
________________________________________________________________________________
__________________
dropout_2 (Dropout)            (None, 32, 32, 32)   0
max_pooling2d_2[0][0]
________________________________________________________________________________
__________________
```

```
conv2d_6 (Conv2D)               (None, 32, 32, 64)   18496       dropout_2[0][0]
________________________________________________________________________________
__________________
batch_normalization_6 (BatchNor (None, 32, 32, 64)   256         conv2d_6[0][0]
________________________________________________________________________________
__________________
activation_6 (Activation)       (None, 32, 32, 64)   0
batch_normalization_6[0][0]
________________________________________________________________________________
__________________
conv2d_7 (Conv2D)               (None, 32, 32, 64)   36928
activation_6[0][0]
________________________________________________________________________________
__________________
batch_normalization_7 (BatchNor (None, 32, 32, 64)   256         conv2d_7[0][0]
________________________________________________________________________________
__________________
activation_7 (Activation)       (None, 32, 32, 64)   0
batch_normalization_7[0][0]
________________________________________________________________________________
__________________
max_pooling2d_3 (MaxPooling2D)  (None, 16, 16, 64)   0
activation_7[0][0]
________________________________________________________________________________
__________________
dropout_3 (Dropout)             (None, 16, 16, 64)   0
max_pooling2d_3[0][0]
________________________________________________________________________________
__________________
conv2d_8 (Conv2D)               (None, 16, 16, 128)  73856       dropout_3[0][0]
________________________________________________________________________________
__________________
batch_normalization_8 (BatchNor (None, 16, 16, 128)  512         conv2d_8[0][0]
________________________________________________________________________________
__________________
activation_8 (Activation)       (None, 16, 16, 128)  0
batch_normalization_8[0][0]
________________________________________________________________________________
__________________
conv2d_9 (Conv2D)               (None, 16, 16, 128)  147584
activation_8[0][0]
________________________________________________________________________________
__________________
batch_normalization_9 (BatchNor (None, 16, 16, 128)  512         conv2d_9[0][0]
________________________________________________________________________________
__________________
activation_9 (Activation)       (None, 16, 16, 128)  0
batch_normalization_9[0][0]
```

```
________________________________________________________________________________
__________________
conv2d_transpose (Conv2DTranspo (None, 32, 32, 64)   73792
activation_9[0][0]
________________________________________________________________________________
__________________
concatenate (Concatenate)       (None, 32, 32, 128)  0
conv2d_transpose[0][0]
activation_7[0][0]
________________________________________________________________________________
__________________
dropout_4 (Dropout)             (None, 32, 32, 128)  0
concatenate[0][0]
________________________________________________________________________________
__________________
conv2d_10 (Conv2D)              (None, 32, 32, 64)   73792       dropout_4[0][0]
________________________________________________________________________________
__________________
batch_normalization_10 (BatchNo (None, 32, 32, 64)   256         conv2d_10[0][0]
________________________________________________________________________________
__________________
activation_10 (Activation)      (None, 32, 32, 64)   0
batch_normalization_10[0][0]
________________________________________________________________________________
__________________
conv2d_11 (Conv2D)              (None, 32, 32, 64)   36928
activation_10[0][0]
________________________________________________________________________________
__________________
batch_normalization_11 (BatchNo (None, 32, 32, 64)   256         conv2d_11[0][0]
________________________________________________________________________________
__________________
activation_11 (Activation)      (None, 32, 32, 64)   0
batch_normalization_11[0][0]
________________________________________________________________________________
__________________
conv2d_transpose_1 (Conv2DTrans (None, 64, 64, 32)   18464
activation_11[0][0]
________________________________________________________________________________
__________________
concatenate_1 (Concatenate)     (None, 64, 64, 64)   0
conv2d_transpose_1[0][0]
activation_5[0][0]
________________________________________________________________________________
__________________
dropout_5 (Dropout)             (None, 64, 64, 64)   0
concatenate_1[0][0]
________________________________________________________________________________
```

```
------------------
conv2d_12 (Conv2D)              (None, 64, 64, 32)   18464       dropout_5[0][0]
________________________________________________________________________________
------------------
batch_normalization_12 (BatchNo (None, 64, 64, 32)   128         conv2d_12[0][0]
________________________________________________________________________________
------------------
activation_12 (Activation)      (None, 64, 64, 32)   0
batch_normalization_12[0][0]
________________________________________________________________________________
------------------
conv2d_13 (Conv2D)              (None, 64, 64, 32)   9248
activation_12[0][0]
________________________________________________________________________________
------------------
batch_normalization_13 (BatchNo (None, 64, 64, 32)   128         conv2d_13[0][0]
________________________________________________________________________________
------------------
activation_13 (Activation)      (None, 64, 64, 32)   0
batch_normalization_13[0][0]
________________________________________________________________________________
------------------
conv2d_transpose_2 (Conv2DTrans (None, 128, 128, 16) 4624
activation_13[0][0]
________________________________________________________________________________
------------------
concatenate_2 (Concatenate)     (None, 128, 128, 32) 0
conv2d_transpose_2[0][0]
activation_3[0][0]
________________________________________________________________________________
------------------
dropout_6 (Dropout)             (None, 128, 128, 32) 0
concatenate_2[0][0]
________________________________________________________________________________
------------------
conv2d_14 (Conv2D)              (None, 128, 128, 16) 4624        dropout_6[0][0]
________________________________________________________________________________
------------------
batch_normalization_14 (BatchNo (None, 128, 128, 16) 64          conv2d_14[0][0]
________________________________________________________________________________
------------------
activation_14 (Activation)      (None, 128, 128, 16) 0
batch_normalization_14[0][0]
________________________________________________________________________________
------------------
conv2d_15 (Conv2D)              (None, 128, 128, 16) 2320
activation_14[0][0]
________________________________________________________________________________
```

```
__________________
batch_normalization_15 (BatchNo (None, 128, 128, 16) 64          conv2d_15[0][0]
________________________________________________________________________________
__________________
activation_15 (Activation)      (None, 128, 128, 16) 0
batch_normalization_15[0][0]
________________________________________________________________________________
__________________
conv2d_transpose_3 (Conv2DTrans (None, 256, 256, 8)  1160
activation_15[0][0]
________________________________________________________________________________
__________________
concatenate_3 (Concatenate)     (None, 256, 256, 16) 0
conv2d_transpose_3[0][0]
activation_1[0][0]
________________________________________________________________________________
__________________
dropout_7 (Dropout)             (None, 256, 256, 16) 0
concatenate_3[0][0]
________________________________________________________________________________
__________________
conv2d_16 (Conv2D)              (None, 256, 256, 8)  1160        dropout_7[0][0]
________________________________________________________________________________
__________________
batch_normalization_16 (BatchNo (None, 256, 256, 8)  32          conv2d_16[0][0]
________________________________________________________________________________
__________________
activation_16 (Activation)      (None, 256, 256, 8)  0
batch_normalization_16[0][0]
________________________________________________________________________________
__________________
conv2d_17 (Conv2D)              (None, 256, 256, 8)  584
activation_16[0][0]
________________________________________________________________________________
__________________
batch_normalization_17 (BatchNo (None, 256, 256, 8)  32          conv2d_17[0][0]
________________________________________________________________________________
__________________
activation_17 (Activation)      (None, 256, 256, 8)  0
batch_normalization_17[0][0]
________________________________________________________________________________
__________________
conv2d_18 (Conv2D)              (None, 256, 256, 3)  27
activation_17[0][0]
================================================================================
==================
Total params: 543,179
Trainable params: 541,707
```

```
Non-trainable params: 1,472
________________________________________________________________________________
__________________
None
```

[5]:

```
# Compile model with specified optimizer and loss
optimizer2 = tf.keras.optimizers.Adam(learning_rate=0.01)
metrics2 = ['accuracy']
model2.compile(optimizer=optimizer2, loss='mse', metrics = metrics2)
```

[6]:

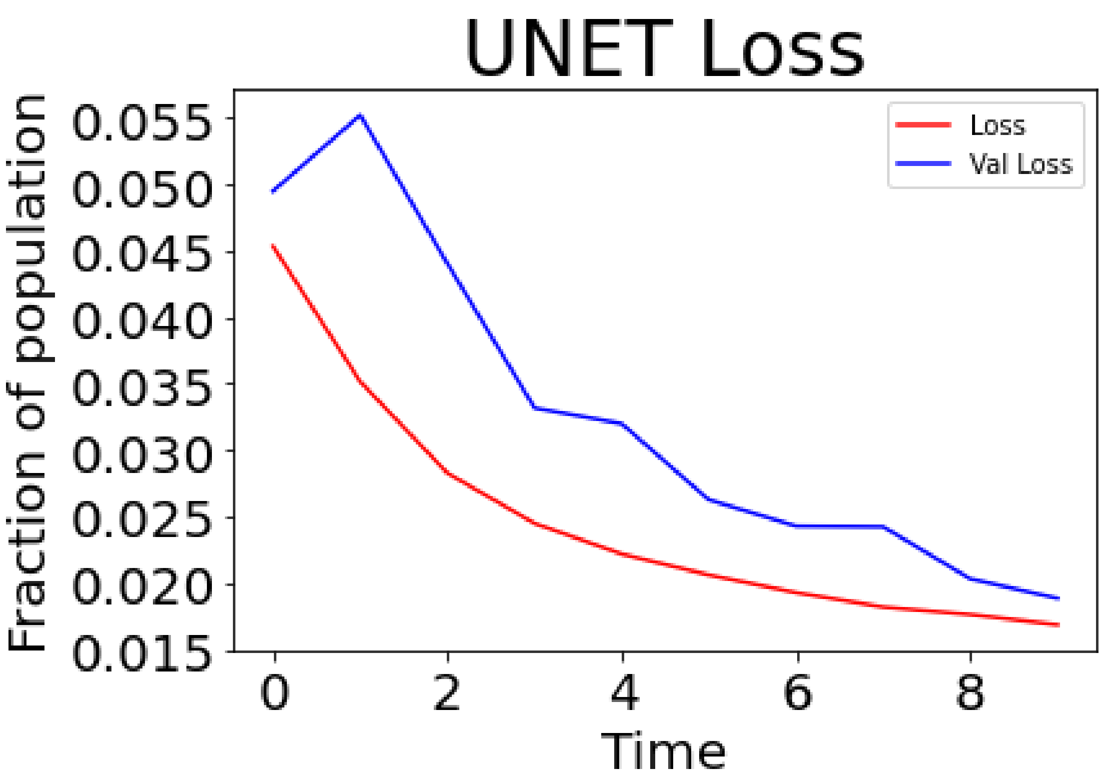
```
datagen3 = tf.keras.preprocessing.image.ImageDataGenerator()

datagen3.fit(x_train)

datagen4 = tf.keras.preprocessing.image.ImageDataGenerator(
#     rotation_range=20,
#     width_shift_range=0.2,
#     height_shift_range=0.2,
    horizontal_flip=True
)

datagen4.fit(x_train)

# Track model history as it trains
h_21 = model2.fit(datagen3.flow(x_train, y_train, batch_size=32), \
         steps_per_epoch=len(x_train) // 32, epochs=10, \
              validation_data=datagen3.flow(x_val, y_val, batch_size=32))
h_22 = model2.fit(datagen4.flow(x_train, y_train, batch_size=32), \
         steps_per_epoch=len(x_train) // 32, epochs=5, \
              validation_data=datagen4.flow(x_val, y_val, batch_size=32))

# Save the weights
model2.save_weights('./checkpoints/UNET')
```

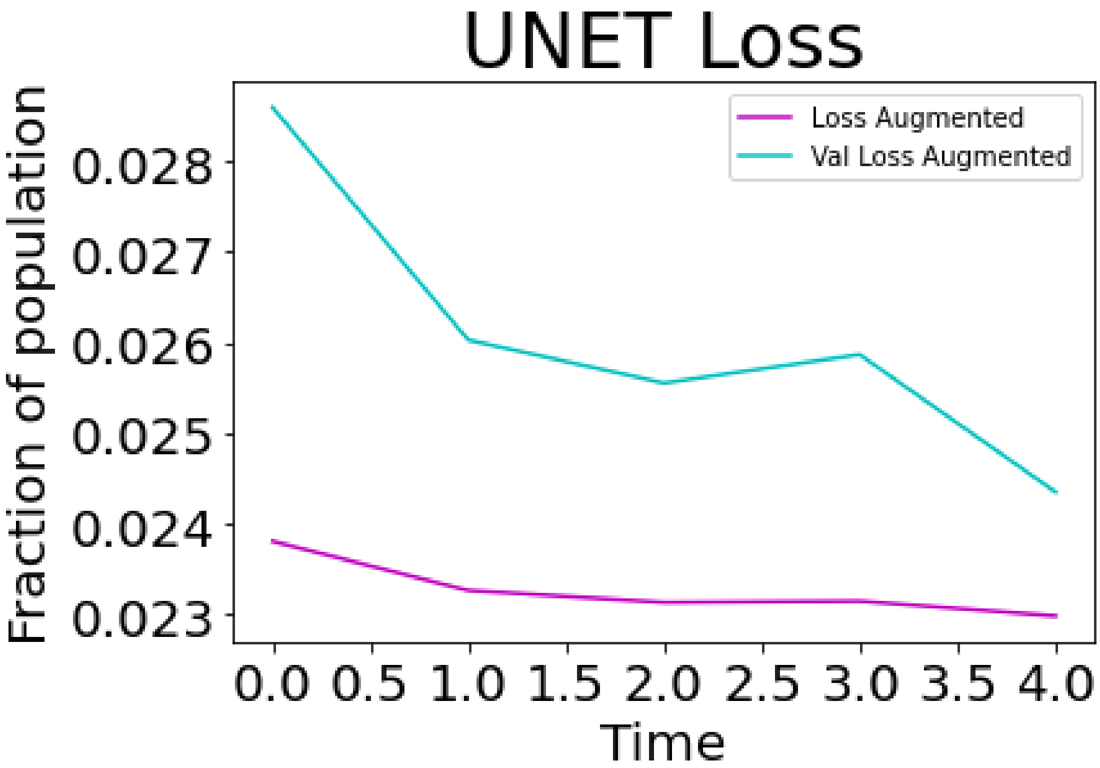
```
WARNING:tensorflow:sample_weight modes were coerced from
  …
    to
  ['…']
WARNING:tensorflow:sample_weight modes were coerced from
  …
    to
  ['…']
Train for 83 steps, validate for 10 steps
Epoch 1/10
83/83 [==============================] - 23s 280ms/step - loss: 0.0453 -
accuracy: 0.4655 - val_loss: 0.0495 - val_accuracy: 0.4701
Epoch 2/10
83/83 [==============================] - 12s 147ms/step - loss: 0.0351 -
```

```
accuracy: 0.3889 - val_loss: 0.0552 - val_accuracy: 0.2923
Epoch 3/10
83/83 [==============================] - 12s 141ms/step - loss: 0.0283 -
accuracy: 0.5394 - val_loss: 0.0441 - val_accuracy: 0.3601
Epoch 4/10
83/83 [==============================] - 12s 144ms/step - loss: 0.0245 -
accuracy: 0.5435 - val_loss: 0.0332 - val_accuracy: 0.6604
Epoch 5/10
83/83 [==============================] - 12s 146ms/step - loss: 0.0222 -
accuracy: 0.5278 - val_loss: 0.0320 - val_accuracy: 0.5822
Epoch 6/10
83/83 [==============================] - 12s 141ms/step - loss: 0.0206 -
accuracy: 0.5165 - val_loss: 0.0263 - val_accuracy: 0.4682
Epoch 7/10
83/83 [==============================] - 12s 139ms/step - loss: 0.0193 -
accuracy: 0.5423 - val_loss: 0.0243 - val_accuracy: 0.4365
Epoch 8/10
83/83 [==============================] - 11s 129ms/step - loss: 0.0182 -
accuracy: 0.5578 - val_loss: 0.0242 - val_accuracy: 0.3964
Epoch 9/10
83/83 [==============================] - 11s 131ms/step - loss: 0.0176 -
accuracy: 0.5650 - val_loss: 0.0203 - val_accuracy: 0.4563
Epoch 10/10
83/83 [==============================] - 11s 132ms/step - loss: 0.0169 -
accuracy: 0.5712 - val_loss: 0.0188 - val_accuracy: 0.4536
WARNING:tensorflow:sample_weight modes were coerced from
  …
    to
  ['…']
WARNING:tensorflow:sample_weight modes were coerced from
  …
    to
  ['…']
Train for 83 steps, validate for 10 steps
Epoch 1/5
83/83 [==============================] - 13s 154ms/step - loss: 0.0238 -
accuracy: 0.5083 - val_loss: 0.0286 - val_accuracy: 0.3957
Epoch 2/5
83/83 [==============================] - 12s 140ms/step - loss: 0.0233 -
accuracy: 0.5094 - val_loss: 0.0260 - val_accuracy: 0.4152
Epoch 3/5
83/83 [==============================] - 13s 155ms/step - loss: 0.0231 -
accuracy: 0.5348 - val_loss: 0.0256 - val_accuracy: 0.3987
Epoch 4/5
83/83 [==============================] - 12s 147ms/step - loss: 0.0232 -
accuracy: 0.5203 - val_loss: 0.0259 - val_accuracy: 0.3868
Epoch 5/5
83/83 [==============================] - 12s 146ms/step - loss: 0.0230 -
```

accuracy: 0.5362 - val_loss: 0.0244 - val_accuracy: 0.3913

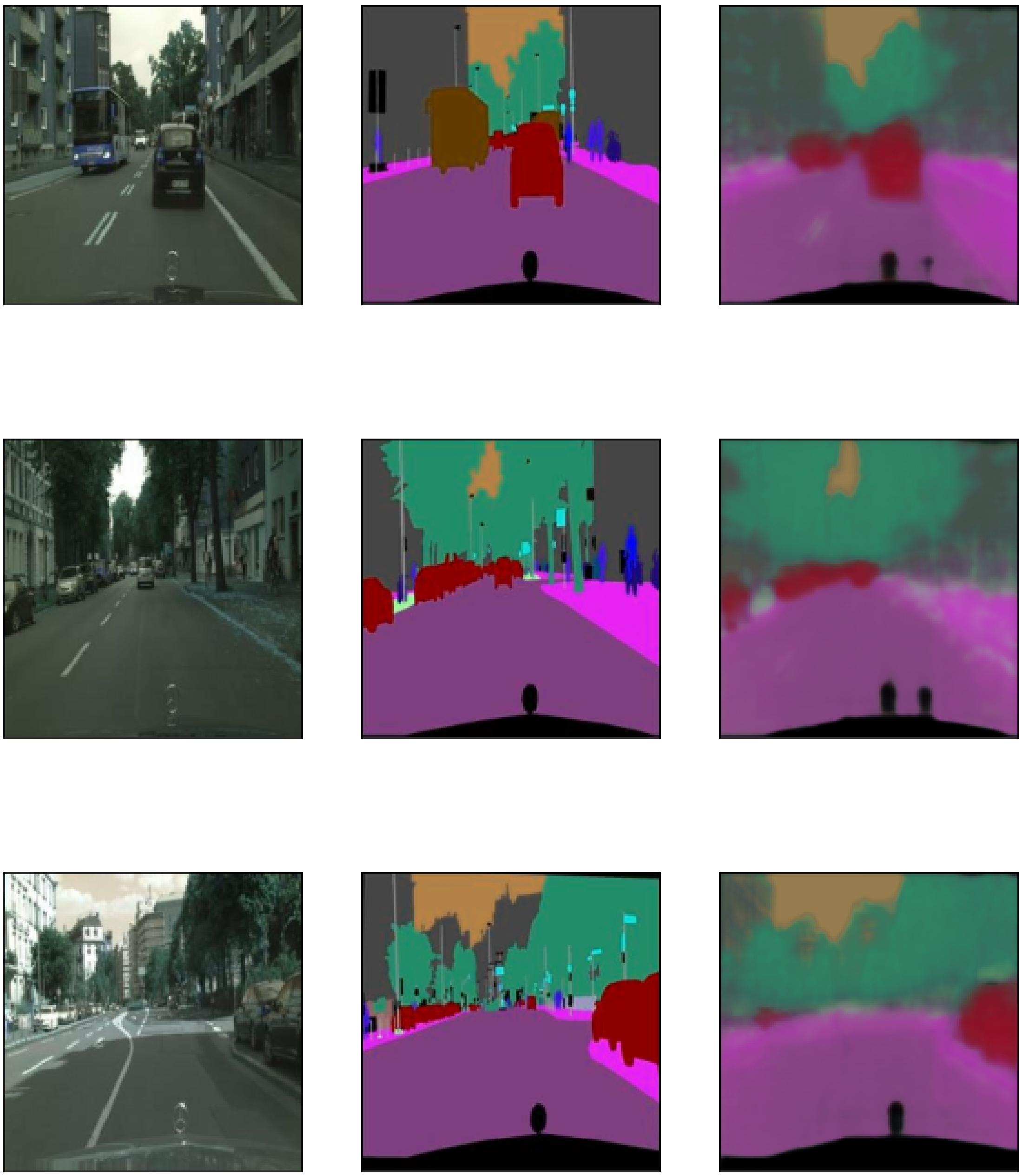
[7]:
```
# Print results for training MSE and validation MSE
plt.plot(h_21.history['loss'], 'r', label='Loss')
plt.plot(h_21.history['val_loss'], 'b', label='Val Loss')
plt.title('UNET Loss', fontsize=30)
plt.xlabel("Time", fontsize=20)
plt.xticks(fontsize=20)
plt.ylabel("Fraction of population", fontsize=20)
plt.yticks(fontsize=20)
plt.legend(loc='best')
plt.show()
plt.plot(h_22.history['loss'], 'm', label='Loss Augmented')
plt.plot(h_22.history['val_loss'], 'c', label='Val Loss Augmented')
plt.title('UNET Loss', fontsize=30)
plt.xlabel("Time", fontsize=20)
plt.xticks(fontsize=20)
plt.ylabel("Fraction of population", fontsize=20)
plt.yticks(fontsize=20)
plt.legend(loc='best')
plt.show()
```

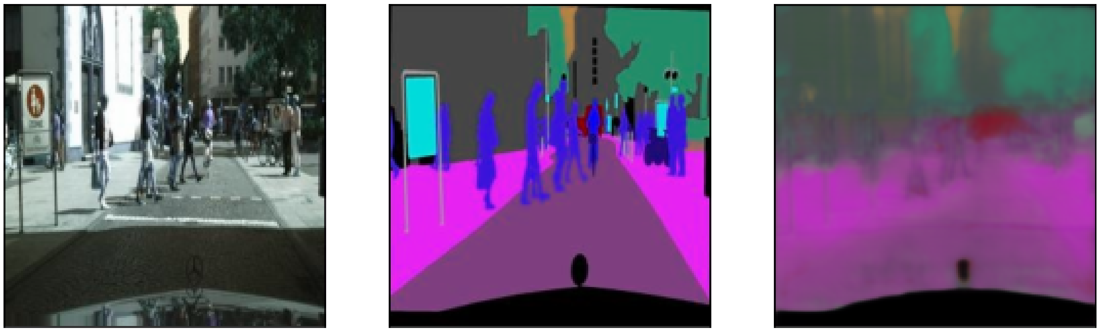


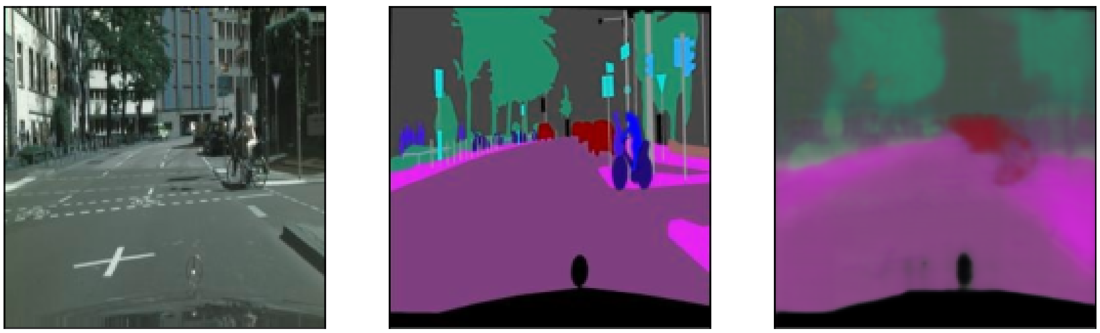


[8]:
```
#show the result
pp2 = model2.predict(x_test[:5,:,:,:], batch_size=1)

ni = 5
for k in range(ni):
    plt.figure(figsize=(10,30))
    plt.subplot(ni,3,1+k*3)
    plt.imshow(x_test[k])
    figure = plt.gca()
    x_axis = figure.axes.get_xaxis()
    x_axis.set_visible(False)
    y_axis = figure.axes.get_yaxis()
    y_axis.set_visible(False)
    plt.subplot(ni,3,2+k*3)
    plt.imshow(y_test[k])
    figure = plt.gca()
    x_axis = figure.axes.get_xaxis()
    x_axis.set_visible(False)
    y_axis = figure.axes.get_yaxis()
    y_axis.set_visible(False)
    plt.subplot(ni,3,3+k*3)
    plt.imshow(pp2[k])
```

```
    figure = plt.gca()
    x_axis = figure.axes.get_xaxis()
    x_axis.set_visible(False)
    y_axis = figure.axes.get_yaxis()
    y_axis.set_visible(False)
```







[9]:
```
intersection = np.logical_and(y_test[1,:,:,:], pp2)
union = np.logical_or(y_test[1,:,:,:], pp2)
iou_score = np.sum(intersection) / np.sum(union)
print(iou_score)
```

```
0.9607899983723959
```

[10]:
```
diff2 = y_test[1] - pp2[1]
m_norm2 = np.sum(abs(diff2))
print(m_norm2)
print(m_norm2/(256*256))
```

```
13774.887988135903
0.21018811017053074
```