Monocular Depth Estimation

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Contributions

Vaibhav Valecha (vvalecha@uwaterloo.ca):

- Got GPU training working
- wrote abstract, and little bit of the remaining sections
- Created various transformation including saturation, brightness and crop and recenter
- Wrote bilinear sampler method
- created primitive nn architecture (starting point)
- trained models, displayed various sanity_test dataset disparity image
- Added validation

Huck Kim (h363kim@uwaterloo.ca):

- contributed to implementing bilinear sampler method
- improved nn architecture (starting point)
- wrote the data processing pipeline with `Dataset` and `Dataloader`
- researched and implemented the different loss metrics referenced in the paper
- designed and implemented the final `MonodepthModel` in pytorch used for final depth estimation

Abstract

The problem we will be trying to solve is monocular depth estimation. Determining depth is a task that humans perform easily through stereo vision, which involves capturing two images using each eye and determining the offset of the two images to calculate depth. Of course this is done subconsciously.

Similarly when working with computers, when we have 2 stereo images we have techniques to get an estimated depth map (such as the algorithms implemented in A4). To date there are several techniques that allow us to determine depth maps, including depth from focus, vanishing point detection, and others. For example, when looking at a picture of a road, the road appears wider near the camera but converges to a single point in the horizon. This allows us to infer that the part of the road converging to the vanishing point is further away than the part where the road appears wider.

However, is it also possible to determine depth using only a single image? When humans covers one of their eyes, their depth perception goes down but we can still estimate depth with good accuracy. We can ask in a similar vein can computers also recover depth information from a single image?

Machine Learning

For our project we are using machine learning in hopes of training a model that can create a depth map given a single scene image. We are using the KITTI dataset, which contains over 10,000 datapoints with stereo images captured by a vehicle driving around the city of Karlsruhe with a binocular pair of cameras. Out model is inspired after the model described in the paper Unsupervised Monocular Depth Estimation with Left-Right Consistency.

Model Paradigm

The pivotal idea from the paper is to reframe depth estimation as a image reconstruction problem. Classically depth estimation using machine learning has generally followed the design

$$\text{Model}(\text{Img}) \rightarrow \text{Depth Map}_{\text{Model}}, \quad \text{minimize}\,(Loss(\text{Depth Map}_{\text{Model}}, \text{Depth Map}_{\text{G}}$$

As to say people would train a model generate a model to directly produce depth maps using ground truth values. This is similar to the semantic segmentation assignment where we had the ground truth masks properly categorized.

However this would require a (large) database of image and ground truth pairs which would require a substantial amount of expensive and technical hardware such as lasers scanners or LIDAR. Instead we can treat this task as an image reconstruction problem and design the model as follows

$$\text{Model}(\text{ImgL}) \rightarrow \text{Pixel Map}, \quad \text{minimize}\,(Loss(Map(\text{Pixel Map}, \text{ImgL}), \text{ImgR}))$$

Here instead of recreating a depth map, we are trying to find, for each pixel the proper x-axis offset by providing a value between -1.0 and 1.0. Now when training we only require the left and right binocular images of a scene. This is relatively easy to obtain as you can simply take a video of scenes with a binocular set of cameras.

Model Architecture

Our model consists of 2 main sections, the convolution stage and the upsampling stage. For the convolution stage we model our architecture after popular image networks such as ResNET and VGG (in our case VGG) and use it to convolve our image down multiple stages.

We then upsample this back to a tensor of dimensions of $(H, W, 2)$, where H is the height of the image and W is the width of the image and the values in the last dimensions are between -1.0 and 1.0. After we have this tensor we can apply a bilinear sampling algorithm to reconstruct the right image from the left image. When the difference between the reconstructed right image and the real right image are small we have succeeded in creating a depth map.

Note

Note that we create an image with a final 2 channels. This is because another key aspect of the model described in the paper is to train both left image to right image, but also right image to left image. They describe this as LR consistency and requires the extra channel to store an extra disparity map.

Loss functions

On the more technical side we have chosen to try implementing the Left Right Disparity consistency loss. Our network predicts both left and right image disparities using only left view as input, and enforces coherence with an L1 left-right disparity consistency penalty to make the left-view disparity map equal to the projected right-view disparity map. The following is the loss function.

$$\frac{1}{N}\sum_{i,j}|d^l_{ij} - d^r_{ij+d^r_{ij}}|$$

Our neural network takes an image as input and encodes it, then uses skip connections and decoder to create the disparity map of the image and the corresponding right image even if it does not exist. When testing the neural network, the disparity map corresponding to the input image is returned. During training, we also supply the right image to calculate the loss. We apply the linear bilinear sampler function to both the left and right images with their corresponding disparity maps to obtain the opposite stereo image. Finally, we calculate the loss by taking the L1 difference between the generated images and the actual image.

Report structure

The code portion of our notebook is organized into various sections:

1. Data retrieval- obtain and load the KITTI dataset into `sanity_dataloader`, `train_dataloader`, and `test_dataloader` and apply various image transformation ie, saturation, brightness, resize and cropping
2. Neural Network Architecture- Develop the core components for the neural network, it's loss functions, and the bilinear sampler.
3. Training Model- train various models on different loss functions and the different datasets.
4. Results- display plots on the various models

In [ ]:
```
#Libraries

# Python Libraries
import random
import math
import numbers
import platform
import copy
import zipfile
import glob
import os
from skimage import io

#data libs
import numpy as np
import matplotlib.pyplot as plt
import urllib.request

#pytorch
import torch
import torch.nn.functional as F
from torch import nn
from torch.utils.data import DataLoader, Dataset, Subset
import torchvision.transforms as transforms
import torchvision.transforms.functional as tF

# separate library for the SSIM metric
!pip install piqa
import piqa
```

```
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e-packages (1.3.0)
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ib/python3.10/site-packages (from torchvision>=0.13.0->piqa) (9.5.0)
Requirement already satisfied: requests in /usr/lib/python3/dist-packages (
from torchvision>=0.13.0->piqa) (2.25.1)
Requirement already satisfied: mpmath>=0.19 in /home/hkim/.local/lib/python
3.10/site-packages (from sympy->torch>=1.12.0->piqa) (1.3.0)
```

In [ ]:
```
#establish hardware

%matplotlib inline
USE_GPU = True
GPU_AVAIL = torch.cuda.is_available()
device = torch.device("cuda" if GPU_AVAIL else "cpu")
print("cuda" if GPU_AVAIL and USE_GPU else "cpu")
```

```
cuda
```

1. Data Retrieval

As noted before we are getting left right binocular images from the KITTI database which is free to use.

In [ ]:
```
def retrieve_data(name):
    if not os.path.isfile(f'kitti_{name}_archives.txt'):
        urllib.request.urlretrieve(f'https://raw.githubusercontent.com/huckk

    if not os.path.isfile(f'kitti_{name}_folders.txt'):
        urllib.request.urlretrieve(f'https://raw.githubusercontent.com/huckk

    if not os.path.isdir(f'kitti_{name}_zip/'):
        try:
          os.mkdir(f'kitti_{name}_zip/')
        except OSError as error:
          pass
        with open(f'kitti_{name}_archives.txt', 'r') as f:
            urls = f.readlines()
        urls = [url for url in urls if url.strip() != '']
        for url in urls:
            filename = url.split('/')[-1].strip()
            print(url, filename)
            urllib.request.urlretrieve(url, os.path.join(f'kitti_{name}_zip/

    if not os.path.isdir(f'kitti_{name}_data/'):
      for base in glob.glob(f'kitti_{name}_zip/*.zip'):
        with zipfile.ZipFile(base, 'r') as zip_ref:
          zip_ref.extractall(f'kitti_{name}_data/')
```

Rational about transformations:

To improve generalization, we will apply various data modification techniques to the training dataset. We will randomly adjust the brightness of the image within a range of 0.6-1.5, and the saturation within a range of 0.4-2, where 1 is the original image. This adjustment will allow the model to generalize to various cameras and lighting conditions. Additionally, we will randomly resize the image between 0.8 and 1.5 times its original size and then crop it. This technique makes it possible for the road, which is present in most images in the Kitti dataset, to be less central in the image, thus improving generalization to settings without roads.

In [ ]:
```
#arbitrary values that worked well
imgHeight = 260
imgWidth = 920
import random as rnd

class RandomResizeCrop(object):
    def __init__(self, size = 600, minScale=0.8, maxScale =1.3):
        self.size = size
        self.minScale = minScale
        self.maxScale = maxScale

    def __call__(self, imgL, imgR):
        scale = self.minScale + rnd.random()*(self.maxScale - self.minScale)
        rescaled_imgL = tF.resize(imgL, (int(imgL.size()[1]*scale), int(imgL
        rescaled_imgR = tF.resize(imgR, (int(imgR.size()[1]*scale), int(imgR

        top = int((rescaled_imgL.size()[1]-imgHeight) * rnd.random())
        left = int((rescaled_imgL.size()[2]-imgWidth) * rnd.random())

        return tF.crop(rescaled_imgL, top,left, imgHeight, imgWidth), tF.cro

class RandomSaturation(object):
    def __init__(self):
        self.min = 0.4
        self.max = 2
    def __call__(self, imgL, imgR):
        scale = self.min + (rnd.random() * self.max)
        sat_imgL = tF.adjust_saturation(imgL, scale)
        sat_imgR = tF.adjust_saturation(imgR, scale)
        return sat_imgL, sat_imgR


class RandomBrightness(object):
    def __init__(self):
        self.min = 0.6
        self.max = 1.5
    def __call__(self, imgL, imgR):
        scale = rnd.random() + self.min
        bright_imgL = tF.adjust_brightness(imgL, scale)
        bright_imgR = tF.adjust_brightness(imgR, scale)
        return bright_imgL, bright_imgR
```

Since we are using PyTorch we have created a custom `Dataset` class to streamline the training process. After we download the KITTI archives, they are stored in separate timestamped folders with 4 image subdirectories. The first 2 images directores (`image0` and `image1`) correspond to the stero left right image pairs in black and white, while the second 2 (`image2` and `image3`) correspond to the left and right pairs in RGB. The second two drives are the ones we will be getting our data from. We split our avilable data into $\%80$ train set, and $\%20$ test set. `Dataloader` is used to take advantage of the batching mechanism in PyTorch models.

In [ ]:
```
class SteroPairDataset(Dataset):
  def __init__(self, data, datapath):
    self.data=data
    self.datapath=datapath
    self.resizeCropTransform = RandomResizeCrop()
    self.brightTransform = RandomBrightness()
    self.satTransform = RandomSaturation()

    self.imageWidth = 32*16
    self.imageHeight = 10*16
  def __len__(self):
    return len(self.data)
  def __getitem__(self, idx):
    img_path_L = os.path.join(f'./{self.datapath}/{self.data[idx][1]}/image_
    img_path_R = os.path.join(f'./{self.datapath}/{self.data[idx][1]}/image_
    img_L = io.imread(img_path_L)
    img_R = io.imread(img_path_R)

    #transform = transforms.Compose([
    #    transforms.ToTensor(),
    #    transforms.Resize(size=(10*16, 32*16))
    #    #transforms.Normalize((0.5,0.5,0.5), (0.5,0.5,0.5))
    #])
    #return transform(img_L), transform(img_R)
    tensorify = transforms.ToTensor()
    resizer = transforms.Resize(size=(10*16, 32*16))
    transLeft, transRight = self.satTransform(*self.brightTransform(*self.re
        tensorify(img_L), tensorify(img_R))))
    return resizer(transLeft), resizer(transRight)

def load_data(base, type='sanity'):
  #unzip_data(base)
  retrieve_data(base)

  datapath = f'kitti_{base}_data/2011_09_26'

  img_paths = open(f'kitti_{base}_folders.txt').readlines()
  for i, path in enumerate(img_paths):
```

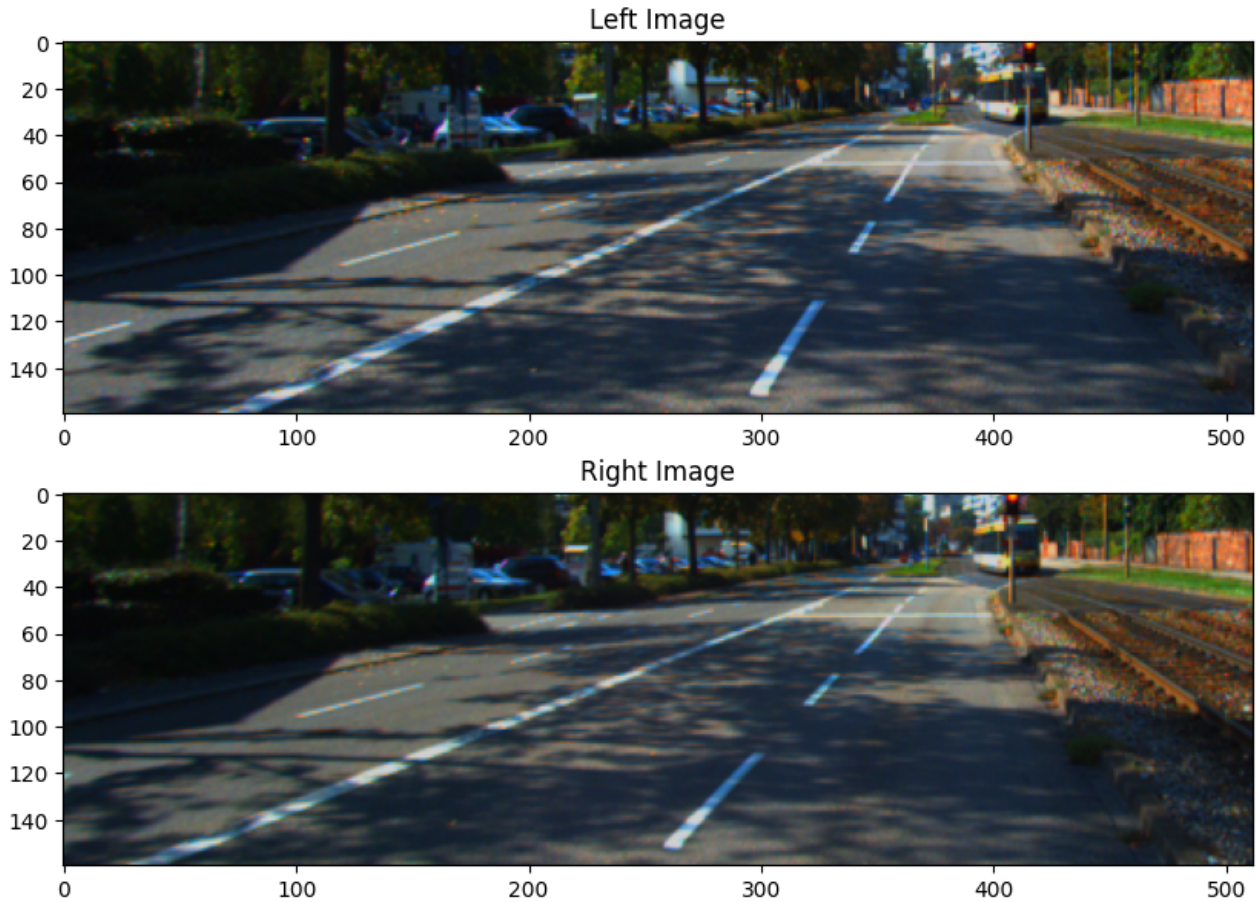
```
    img_paths[i] = img_paths[i].strip()

  data = []
  for p in img_paths:
    for name in glob.glob(f'{datapath}/{p}/image_02/data/*.png'):
      filename = name.split('/')[-1]
      data.append((filename, p))

  if type == 'real':
    return SteroPairDataset(data[0:int(0.8*len(data))], datapath), SteroPair
  elif type == 'sanity':
    return SteroPairDataset(data[0:1], datapath), SteroPairDataset(data[1:2]
```

In [ ]:

```
# Load training dataset
train_dev_dataset, test_dev_dataset = load_data('dev', 'real')
print(len(train_dev_dataset),len(test_dev_dataset) )

stereo_train_dataloader = DataLoader(train_dev_dataset, shuffle=True, batch_
stereo_test_dataloader = DataLoader(test_dev_dataset, shuffle=False, batch_s

print(f"small test set has {len(stereo_train_dataloader.dataset)} train imag

imgL, imgR = stereo_train_dataloader.dataset[0]
plt.figure(figsize=(10,7))
plt.subplot(211)
plt.title("Left Image")
plt.imshow(imgL.squeeze().permute(1,2,0))
plt.subplot(212)
plt.title("Right Image")
plt.imshow(imgR.squeeze().permute(1,2,0))
plt.show()
```

```
271 68
small test set has 271 train images, 68 test images
```

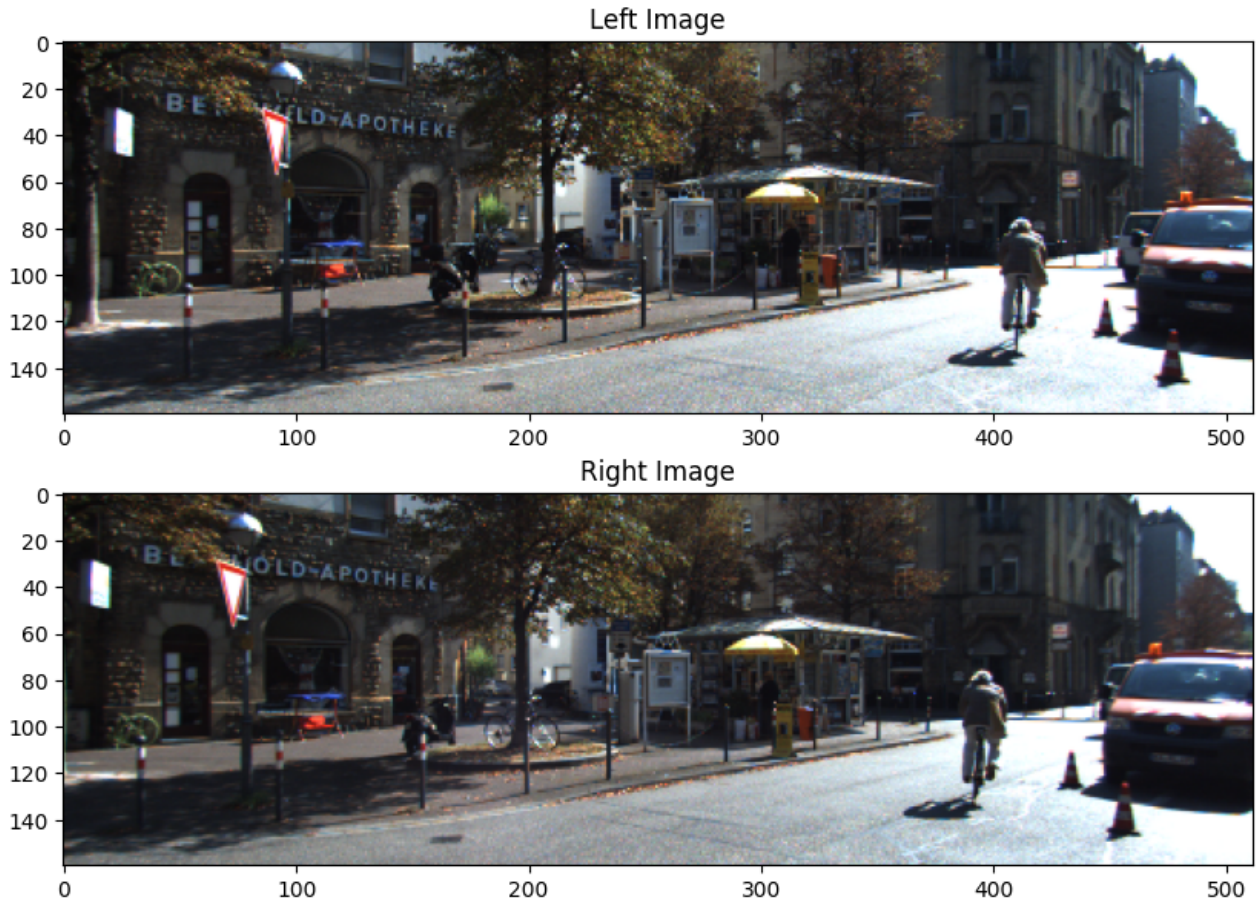
```
/home/hkim/.local/lib/python3.10/site-packages/torchvision/transforms/funct
ional.py:1603: UserWarning: The default value of the antialias parameter of
all the resizing transforms (Resize(), RandomResizedCrop(), etc.) will chan
ge from None to True in v0.17, in order to be consistent across the PIL and
Tensor backends. To suppress this warning, directly pass antialias=True (re
commended, future default), antialias=None (current default, which means Fa
lse for Tensors and True for PIL), or antialias=False (only works on Tensor
s - PIL will still use antialiasing). This also applies if you are using th
e inference transforms from the models weights: update the call to weights.
transforms(antialias=True).
  warnings.warn(
```



The following are the stereo images containing the transformations applied.

In [ ]:
```
# Load training dataset
train_dev_dataset, test_dev_dataset = load_data('dev', type='sanity')

sanity_train_dataloader = DataLoader(train_dev_dataset, shuffle=True, batch_
sanity_test_dataloader = DataLoader(test_dev_dataset, shuffle=True, batch_si

print(f"sanity test set has {len(sanity_train_dataloader.dataset)} train ima

imgL, imgR = sanity_train_dataloader.dataset[0]
plt.figure(figsize=(10,7))
plt.subplot(211)
plt.title("Left Image")
plt.imshow(imgL.squeeze().permute(1,2,0))
plt.subplot(212)
plt.title("Right Image")
plt.imshow(imgR.squeeze().permute(1,2,0))
plt.show()
```

```
sanity test set has 1 train images, 1 test images
```



2. Net Architecture

The purpose of the bilinear sampler in our case is to create the second image in the stereo pair given the first image and the disparity map. Our bilinear sampler offsets the pixels in the x-direction for the first stereo image by the disparity map. If the offset location does not result in the exact center of a pixel, it takes a weighted average of the surrounding pixels. By obtaining the reconstructed second image, we can determine how well our model creates a disparity map by evaluating the similarity between the reconstructed image and the actual second image in the stereo pair.

In [ ]:
```
def bilinear_sampler(src, disp):
  batch = src.shape[0]
  height = src.shape[2]
  width = src.shape[3]

  affine_matrices = torch.zeros((batch, 2, 3))
  affine_matrices[:, 0, 0] = 1.0
  affine_matrices[:, 1, 1] = 1.0


  grid = torch.nn.functional.affine_grid(affine_matrices, src.size()).to(dev
  grid_x = grid[:,:, :, 0]
  disp = disp.squeeze(1)
  grid_x = torch.add(grid_x, disp)
  grid_x = grid_x.unsqueeze(-1)
  grid_y  = (grid[:,:, :, 1]).unsqueeze(-1)
  res = torch.cat([grid_x, grid_y], 3)
  retval = F.grid_sample(src, res)
  return retval
  # disp are array of values 0..1 representing how far to go to the right (+
```

In [ ]:
```
from piqa import SSIM

#develop neural net architecture
class SSIM_Loss(SSIM):
  def forward(self, x, y):
    return 1. - super().forward(x, y)

class MyNet(nn.Module):
    def __init__(self, l1_alpha, lr_alpha, dsp_alpha, criterion=None, withou
        super(MyNet, self).__init__()

        # This the architecture of the image model we choose to use
        # in this case VGG
        # If you look at the conv_block function each layer has stride 2
        # this halves the dimensions of the image each layer

        #                                          resulting dims
        self.vgg_conv1 = self.conv_block(3, 8, 7) # 8 ch, HxW / 2
        self.vgg_conv2 = self.conv_block(8, 16, 5) # 16 ch, HxW / 4
        self.vgg_conv3 = self.conv_block(16, 32, 3) # 32 ch, HxW / 8
        self.vgg_conv4 = self.conv_block(32, 64, 3) # 64 ch, HxW / 16
        self.vgg_conv5 = self.conv_block(64, 128, 3) # 128 ch, HxW / 32

        # next we upsample on the way back to the original dimension of the
        self.upconv5 = self.upconv_block(128, 64, 3, 2)
        self.upconv4 = self.upconv_block(64, 32, 3, 2)
        self.upconv3 = self.upconv_block(32, 16, 3, 2)
        self.upconv2 = self.upconv_block(16, 8, 3, 2)
```

```
        self.upconv1 = self.upconv_block(8, 4, 3, 2)

        self.conv5 = nn.Conv2d(128,64,kernel_size=3,stride=1, padding='same'
        self.conv4 = nn.Conv2d(64,32,kernel_size=3,stride=1, padding='same')
        self.conv3 = nn.Conv2d(32+2,16,kernel_size=3,stride=1, padding='same
        self.conv2 = nn.Conv2d(16+2,8,kernel_size=3,stride=1, padding='same'
        self.conv1 = nn.Conv2d(4+2,4,kernel_size=3,stride=1, padding='same')

        # these convolutions are responsible for creating the disparities ma
        # used to reconstruct the right image

        # note that we generate 4 of them.
        self.disp_conv4 = self.disp_block(32) #
        self.udisp4 = nn.Upsample(scale_factor=2, mode='nearest')

        self.disp_conv3 = self.disp_block(16)
        self.udisp3 = nn.Upsample(scale_factor=2, mode='nearest')

        self.disp_conv2 = self.disp_block(8)
        self.udisp2 = nn.Upsample(scale_factor=2, mode='nearest')

        self.disp_conv1 = self.disp_block(4)
        self.l1_alpha = l1_alpha
        self.lr_alpha = lr_alpha
        self.dsp_alpha = dsp_alpha
        self.without = without

        self.alpha = 0.5
        self.SSIM = SSIM_Loss()

    def disp_block(self, num_in_layers):
      return nn.Sequential(
          nn.Conv2d(num_in_layers, 2, kernel_size=3,stride=1,padding='same')
          nn.Tanh() # to ensure values between -1.0 and 1.0
      )

    # Convolution block used for VGG
    # due to memory constraints only using a single layer, but usually there
    def conv_block(self, num_in_layers, num_out_layers, kernel_size):
      return nn.Sequential(
        nn.Conv2d(num_in_layers, num_out_layers,padding=(kernel_size-1)//2,k
        nn.ReLU()
        # TODO: get more GPU memory
        #nn.Conv2d(num_out_layers, num_out_layers, kernel_size=kernel_size,s
        #nn.ReLU()
      )

    # Up convolution block used to construct the disparities.
    def upconv_block(self, num_in_layers, num_out_layers, kernel_size, scale
      return nn.Sequential(
```

```
        nn.Upsample(scale_factor=scale, mode='nearest'),
        nn.Conv2d(num_in_layers, num_out_layers, kernel_size, stride=1, pa
    )

  # This is used so we can compare the disparity at each dimension with sc
  # target right image. Explained in the loss we take the loss calculatior
  # of the pipeline to get a robust loss
  def get_scaled_imgs(self, imgL):
    h, w = imgL.shape[2], imgL.shape[3]
    return [imgL, transforms.Resize(size=(h//2, w//2))(imgL), transforms.R

  # Here we split the data and make the first element the left to right di
  # and the second the right to left disp. This is the convention chosen a
  def get_lr_disp(self, disps):
    return disps[:,0,:,:].unsqueeze(1), disps[:,1,:,:].unsqueeze(1)

  # reconstruct the right image from imgL and lr_disp
  def gen_img_r(self, imgL, lr_disp):
    return bilinear_sampler(imgL, lr_disp)

  # reconstruct the left image from imgR and rl_disp, note the negative si
  # since we shift backwards instead of forwards now
  def gen_img_l(self, imgR, disp):
    return bilinear_sampler(imgR, -disp)

  def get_disp_smoothness(self, disps, imgs):
    # shift disparities
    x_shift_disps, y_shift_disps = [], []
    for i in range(4):
      x_shift_disps += [self.gradient_x(disps[i])]
      y_shift_disps += [self.gradient_y(disps[i])]

    x_weights, y_weights = [], []
    for i in range(4):
      x_weights += [torch.exp(torch.mean(torch.abs(self.gradient_x(imgs[i]
      y_weights += [torch.exp(torch.mean(torch.abs(self.gradient_y(imgs[i]

    x_smooth, y_smooth = [], []
    for i in range(4):
      x_smooth += [x_shift_disps[i]*x_weights[i]]
      y_smooth += [y_shift_disps[i]*y_weights[i]]

    return x_smooth + y_smooth

  def gradient_x(self, disp):
    return torch.roll(disp, -1, 3) - disp
  def gradient_y(self, disp):
    return torch.roll(disp, -1, 2) - disp

  #forward pass of our model
```

```
    def forward(self, imgL, imgR=None, criterion=None):
      skip1 = self.vgg_conv1(imgL) # skip1 = 8ch HW/2
      skip2 = self.vgg_conv2(skip1) # skip2 = 16ch HW/4
      skip3 = self.vgg_conv3(skip2) # skip3 = 32ch HW/8
      skip4 = self.vgg_conv4(skip3) # skip4 = 64ch HW/16
      h = self.vgg_conv5(skip4) # h = 128ch HW/32

      upconv5 = self.upconv5(h) # upconv5 = 64ch, HW/16
      concat5 = torch.cat([upconv5, skip4], 1) # concat = 128ch, HW/16
      iconv5 = self.conv5(concat5)

      upconv4 = self.upconv4(iconv5)
      concat4 = torch.cat([upconv4, skip3], 1)
      iconv4 = self.conv4(concat4)
      disp4 = 0.3*self.disp_conv4(iconv4)
      udisp = self.udisp4(disp4)

      upconv3 = self.upconv3(iconv4)
      concat3 = torch.cat([upconv3, skip2, udisp], 1)
      iconv3 = self.conv3(concat3)
      disp3 = 0.3*self.disp_conv3(iconv3)
      udisp = self.udisp3(disp3)

      upconv2 = self.upconv2(iconv3)
      concat2 = torch.cat([upconv2, skip1, udisp], 1)
      iconv2 = self.conv2(concat2)
      disp2 = 0.3*self.disp_conv2(iconv2)
      udisp = self.udisp2(disp2)

      upconv1 = self.upconv1(iconv2)
      concat1 = torch.cat([upconv1,udisp], 1)
      iconv1 = self.conv1(concat1)
      disp1 = 0.3*self.disp_conv1(iconv1)

      disps = [disp1, disp2, disp3, disp4]

      if imgR == None:
        return disp1


      # ASSUME imgR no None and train = true or validation

      # LOSS CALCULATION TIME
      scaled_imgs_l = self.get_scaled_imgs(imgL)
      scaled_imgs_r = self.get_scaled_imgs(imgR)

      lr_disps, rl_disps = [], []

      # get Left and Right Disparities
      for i in range(4):
```

```
        ld, rd = self.get_lr_disp(disps[i])
        lr_disps += [ld]
        rl_disps += [rd]

    ##### Intermediate maps needed for loss
    ## Generate estimate reconstructed images from disparities
    recon_r_imgs = [self.gen_img_r(scaled_imgs_l[i], lr_disps[i]) for i in
    recon_l_imgs = [self.gen_img_l(scaled_imgs_r[i], rl_disps[i]) for i in

    ## Generate maps used for LR consistency loss calculation
    r_to_l_disp = [self.gen_img_l(lr_disps[i], rl_disps[i]) for i in range
    l_to_r_disp = [self.gen_img_r(rl_disps[i], lr_disps[i]) for i in range

    ## Generate disparity smoothness values
    disp_smooth_l = self.get_disp_smoothness(r_to_l_disp, scaled_imgs_l)
    disp_smooth_r = self.get_disp_smoothness(l_to_r_disp, scaled_imgs_r)

    ## calculate loss

    # L1 Loss
    l1_loss = 0.0
    image_loss = 0.0
    ssim_loss = 0.0
    for i in range(4):
        image_loss += criterion(recon_r_imgs[i], scaled_imgs_r[i])
        image_loss += criterion(recon_l_imgs[i], scaled_imgs_l[i])
        ssim_loss += self.SSIM(recon_l_imgs[i], scaled_imgs_l[i])
        ssim_loss += self.SSIM(recon_r_imgs[i], scaled_imgs_r[i])

        #validation mode
    if self.training == False:
            return image_loss

    l1_loss = self.alpha*ssim_loss + (1-self.alpha)*image_loss

    # LR consistency
    lr_consistency_loss = 0.0
    for i in range(4):
        lr_consistency_loss += criterion(r_to_l_disp[i], rl_disps[i])
        lr_consistency_loss += criterion(l_to_r_disp[i], lr_disps[i])

    ## Disparity smoothness
    disp_smooth_loss = 0.0
    for i in range(4):
        disp_smooth_loss += torch.mean(torch.abs(disp_smooth_l[i]))/2**i
        disp_smooth_loss += torch.mean(torch.abs(disp_smooth_r[i]))/2**i

    if self.without == 'lr_alpha':
        loss = self.l1_alpha * l1_loss + self.dsp_alpha * disp_smooth_loss
    elif self.without == 'disp_smooth':
```

```
        loss = self.l1_alpha * l1_loss + self.lr_alpha * lr_consistency_loss
      elif self.without == 'both':
        loss = self.l1_alpha * l1_loss
      else:
        loss = self.l1_alpha * l1_loss + self.lr_alpha * lr_consistency_loss
      return loss
```

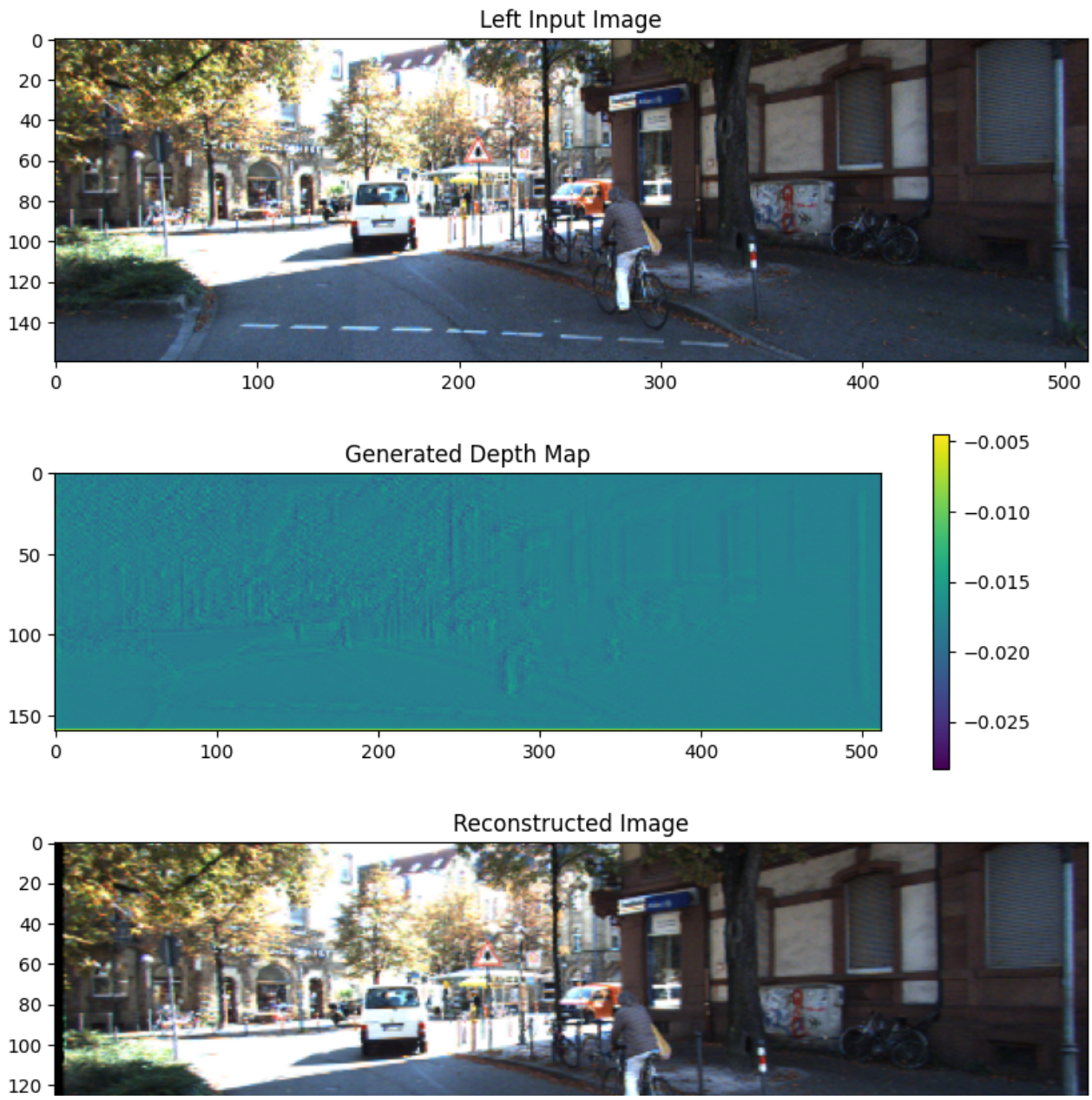
In [ ]:
```
#initalize various models
sanity_criterion = nn.L1Loss().to(device)
sanity_model = MyNet(1.0, 1.0, 0.8).to(device)
sanity_model.eval()
sanity_optimzer = torch.optim.Adam(sanity_model.parameters())

# currently using Adam but was experimenting with SGD
#my_optimzer = torch.optim.SGD(my_model.parameters(), lr=0.0005, momentum=0.
```

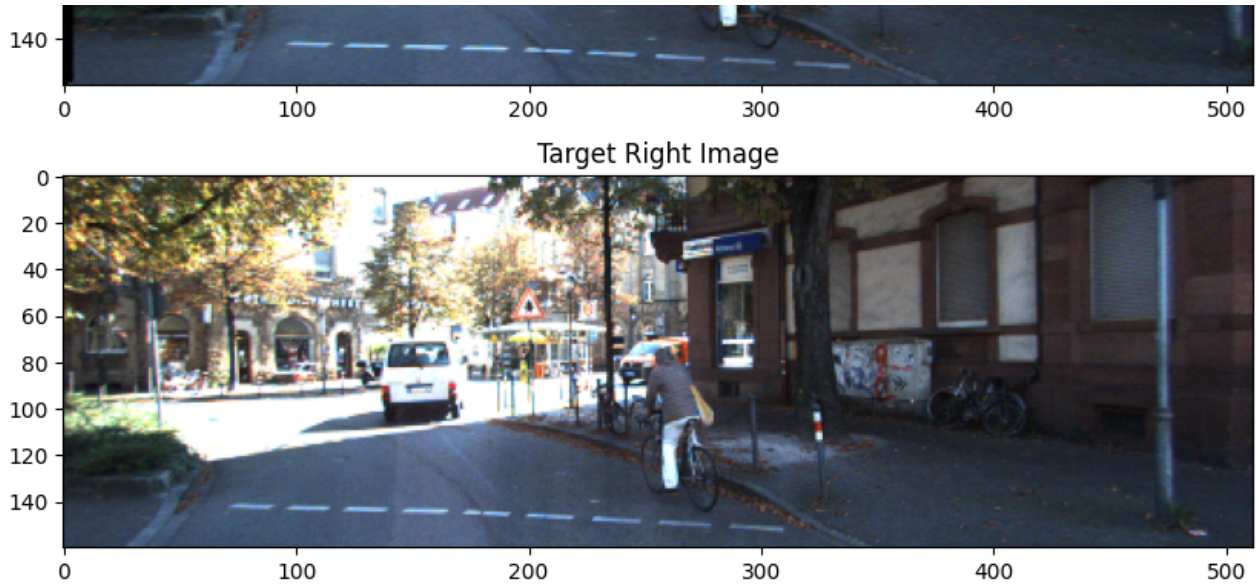
In [ ]:
```
#display one stereo pair image in dataloader, the disparity map and the
#the reconstructed right image
def sanity_test(model, dataloader):
  model.eval()
  for imgL, imgR in dataloader:
    imgL = imgL.to(device)
    res = model(imgL)
  disp = (res[:,0,:,:].unsqueeze(1))
  disp = disp.to(device)
  recon_r = bilinear_sampler(imgL, disp).cpu()
  imgL = imgL.cpu()
  disp = disp.cpu()

  plt.figure(figsize=(10,15))
  plt.subplot(411)
  plt.title("Left Input Image")
  plt.imshow(imgL[0].squeeze().permute(1,2,0))
  plt.subplot(412)
  plt.title("Generated Depth Map")
  plt.imshow(disp[0].squeeze().detach().numpy())
  plt.colorbar()
  plt.subplot(413)
  plt.title("Reconstructed Image")
  plt.imshow(recon_r[0].detach().permute(1,2,0))
  plt.subplot(414)
  plt.title("Target Right Image")
  plt.imshow(imgR[0].squeeze().permute(1,2,0))
```

Sanity Check

We train the model on the `sanity_train_dataloader` that consists of a single test image. This is a form of sanity check to determine if the model is working as expected. We can see without any training there is little to no information about the depth but it resembles some parts of the original image. Also note that the values of the untrained model are very low seen in the colour bar, this results in very little shift applied to the left image.

In [ ]:
```
#non trained nn sanity test
sanity_test(sanity_model, sanity_test_dataloader)
```





3. Training

The following the generic training code used. We see that when training we feed in both the left and right image to the model to allow it to learn the transformations. When two images are passed it returns the loss. However when evaluating our model can also accept only the right image and in this case the disparity map is returned.

In [ ]:
```
!mkdir -p model_checkpoints

#log_interval = 50

def train(dataloader, epoch, model, optimizer, criterion, isTrain=True):
    if(isTrain):
        model.train() # set to training mode
    else:
        model.eval()
    train_loss = 0
    for batch_idx, (imgL, imgR) in enumerate(dataloader):
        imgL, imgR = imgL.to(device), imgR.to(device)
        if(isTrain):
            optimizer.zero_grad()
        loss = model(imgL, imgR, criterion)
        if(isTrain):
            loss.backward()
        train_loss += loss.item()
        if(isTrain):
            optimizer.step()

        #if batch_idx % log_interval == 0:
        #    print(f"Epoch: {epoch}({batch_idx * len(imgL)}/{len(dataloader)

    average_train_loss = train_loss / len(dataloader.dataset)
    return average_train_loss
```

In [ ]:
```
epochs = 2000
average_train_loss = []
best_train_loss = 1
for epoch in range(1, epochs+1):
    loss = train(sanity_train_dataloader, epoch, sanity_model, sanity_optimz
    print(f"Epoch: {epoch}, Average Train Loss: {loss}")
    average_train_loss += [loss]
    if best_train_loss > loss:
        torch.save(sanity_model, 'model_checkpoints/sanity_model.pt')
```

```
Epoch: 1, Average Train Loss: 3.139474868774414
Epoch: 2, Average Train Loss: 3.0037307739257812
Epoch: 3, Average Train Loss: 2.833242893218994
Epoch: 4, Average Train Loss: 2.796372413635254
Epoch: 5, Average Train Loss: 2.6284921169281006
Epoch: 6, Average Train Loss: 2.5858867168426514
Epoch: 7, Average Train Loss: 2.568730592727661
Epoch: 8, Average Train Loss: 2.480226993560791
Epoch: 9, Average Train Loss: 2.4027459621429443
Epoch: 10, Average Train Loss: 2.4011785984039307
Epoch: 11, Average Train Loss: 2.3620424270629883
Epoch: 12, Average Train Loss: 2.2728772163391113
```

```
Epoch: 13, Average Train Loss: 2.179932117462158
Epoch: 14, Average Train Loss: 2.1121666431427
Epoch: 15, Average Train Loss: 2.1609127521514893
Epoch: 16, Average Train Loss: 2.1894359588623047
Epoch: 17, Average Train Loss: 2.1737680435180664
Epoch: 18, Average Train Loss: 2.1392316818237305
Epoch: 19, Average Train Loss: 2.104261636734009
Epoch: 20, Average Train Loss: 2.098536968231201
Epoch: 21, Average Train Loss: 2.0761098861694336
Epoch: 22, Average Train Loss: 2.051149368286133
Epoch: 23, Average Train Loss: 2.0577504634857178
Epoch: 24, Average Train Loss: 2.062242031097412
Epoch: 25, Average Train Loss: 2.047168016433716
Epoch: 26, Average Train Loss: 2.0248210430145264
Epoch: 27, Average Train Loss: 2.010932445526123
Epoch: 28, Average Train Loss: 2.0063111782073975
Epoch: 29, Average Train Loss: 2.001042604446411
Epoch: 30, Average Train Loss: 1.9977799654006958
Epoch: 31, Average Train Loss: 1.9934632778167725
Epoch: 32, Average Train Loss: 1.9802122116088867
Epoch: 33, Average Train Loss: 1.9681497812271118
Epoch: 34, Average Train Loss: 1.9615137577056885
Epoch: 35, Average Train Loss: 1.959472894668579
Epoch: 36, Average Train Loss: 1.951123833656311
Epoch: 37, Average Train Loss: 1.9409106969833374
Epoch: 38, Average Train Loss: 1.932106614112854
Epoch: 39, Average Train Loss: 1.9495655298233032
Epoch: 40, Average Train Loss: 2.0517215728759766
Epoch: 41, Average Train Loss: 1.9283555746078491
Epoch: 42, Average Train Loss: 2.002347946166992
Epoch: 43, Average Train Loss: 1.9223241806030273
Epoch: 44, Average Train Loss: 1.9333875179290771
Epoch: 45, Average Train Loss: 1.9326564073562622
Epoch: 46, Average Train Loss: 1.9025912284851074
Epoch: 47, Average Train Loss: 1.9233465194702148
Epoch: 48, Average Train Loss: 1.876143217086792
Epoch: 49, Average Train Loss: 1.8845181465148926
Epoch: 50, Average Train Loss: 1.8568592071533203
Epoch: 51, Average Train Loss: 1.8688390254974365
Epoch: 52, Average Train Loss: 1.8245621919631958
Epoch: 53, Average Train Loss: 1.825271725654602
Epoch: 54, Average Train Loss: 1.8837250471115112
Epoch: 55, Average Train Loss: 1.81086003780365
Epoch: 56, Average Train Loss: 1.7917906045913696
Epoch: 57, Average Train Loss: 1.8002394437789917
Epoch: 58, Average Train Loss: 1.768723726272583
Epoch: 59, Average Train Loss: 1.7885242700576782
Epoch: 60, Average Train Loss: 1.7389618158340454
Epoch: 61, Average Train Loss: 1.756515383720398
Epoch: 62, Average Train Loss: 1.7589802742004395
```

```
Epoch: 63, Average Train Loss: 1.7140620946884155
Epoch: 64, Average Train Loss: 1.7166993618011475
Epoch: 65, Average Train Loss: 1.7196905612945557
Epoch: 66, Average Train Loss: 1.6880637407302856
Epoch: 67, Average Train Loss: 1.6855075359344482
Epoch: 68, Average Train Loss: 1.6792943477630615
Epoch: 69, Average Train Loss: 1.6629164218902588
Epoch: 70, Average Train Loss: 1.6759111881256104
Epoch: 71, Average Train Loss: 1.66837739944458
Epoch: 72, Average Train Loss: 1.65255606174469
Epoch: 73, Average Train Loss: 1.635556697845459
Epoch: 74, Average Train Loss: 1.63469398021698
Epoch: 75, Average Train Loss: 1.6346794366836548
Epoch: 76, Average Train Loss: 1.6163209676742554
Epoch: 77, Average Train Loss: 1.5896917581558228
Epoch: 78, Average Train Loss: 1.5738816261291504
Epoch: 79, Average Train Loss: 1.6124024391174316
Epoch: 80, Average Train Loss: 1.5954910516738892
Epoch: 81, Average Train Loss: 1.561558723449707
Epoch: 82, Average Train Loss: 1.558866024017334
Epoch: 83, Average Train Loss: 1.5592014789581299
Epoch: 84, Average Train Loss: 1.5631005764007568
Epoch: 85, Average Train Loss: 1.5232924222946167
Epoch: 86, Average Train Loss: 1.5029232501983643
Epoch: 87, Average Train Loss: 1.5000081062316895
Epoch: 88, Average Train Loss: 1.480804443359375
Epoch: 89, Average Train Loss: 1.4628229141235352
Epoch: 90, Average Train Loss: 1.4300483465194702
Epoch: 91, Average Train Loss: 1.4207215309143066
Epoch: 92, Average Train Loss: 1.3971095085144043
Epoch: 93, Average Train Loss: 1.3847286701202393
Epoch: 94, Average Train Loss: 1.4189597368240356
Epoch: 95, Average Train Loss: 1.4130420684814453
Epoch: 96, Average Train Loss: 1.301416277885437
Epoch: 97, Average Train Loss: 1.4053692817687988
Epoch: 98, Average Train Loss: 1.243079423904419
Epoch: 99, Average Train Loss: 1.29115891456604
Epoch: 100, Average Train Loss: 1.309011697769165
Epoch: 101, Average Train Loss: 1.262125849723816
Epoch: 102, Average Train Loss: 1.2965490818023682
Epoch: 103, Average Train Loss: 1.2155460119247437
Epoch: 104, Average Train Loss: 1.2794580459594727
Epoch: 105, Average Train Loss: 1.2117280960083008
Epoch: 106, Average Train Loss: 1.1867799758911133
Epoch: 107, Average Train Loss: 1.2410773038864136
Epoch: 108, Average Train Loss: 1.187240719795227
Epoch: 109, Average Train Loss: 1.1944658756256104
Epoch: 110, Average Train Loss: 1.1897544860839844
Epoch: 111, Average Train Loss: 1.1690309047698975
Epoch: 112, Average Train Loss: 1.1617958545684814
```

```
Epoch: 113, Average Train Loss: 1.1416350603103638
Epoch: 114, Average Train Loss: 1.1309261322021484
Epoch: 115, Average Train Loss: 1.1396434307098389
Epoch: 116, Average Train Loss: 1.1178061962127686
Epoch: 117, Average Train Loss: 1.1139506101608276
Epoch: 118, Average Train Loss: 1.1017261743545532
Epoch: 119, Average Train Loss: 1.0987865924835205
Epoch: 120, Average Train Loss: 1.0985976457595825
Epoch: 121, Average Train Loss: 1.0939465761184692
Epoch: 122, Average Train Loss: 1.0877934694290161
Epoch: 123, Average Train Loss: 1.0759340524673462
Epoch: 124, Average Train Loss: 1.0641690492630005
Epoch: 125, Average Train Loss: 1.0620924234390259
Epoch: 126, Average Train Loss: 1.0812166929244995
Epoch: 127, Average Train Loss: 1.0811090469360352
Epoch: 128, Average Train Loss: 1.1090202331542969
Epoch: 129, Average Train Loss: 1.1117446422576904
Epoch: 130, Average Train Loss: 1.075469732284546
Epoch: 131, Average Train Loss: 1.0389418601989746
Epoch: 132, Average Train Loss: 1.0698118209838867
Epoch: 133, Average Train Loss: 1.1357871294021606
Epoch: 134, Average Train Loss: 1.0418810844421387
Epoch: 135, Average Train Loss: 1.1603596210479736
Epoch: 136, Average Train Loss: 1.107297658920288
Epoch: 137, Average Train Loss: 1.086254358291626
Epoch: 138, Average Train Loss: 1.1232839822769165
Epoch: 139, Average Train Loss: 1.1274679899215698
Epoch: 140, Average Train Loss: 1.02454674243927
Epoch: 141, Average Train Loss: 1.119853138923645
Epoch: 142, Average Train Loss: 1.0126824378967285
Epoch: 143, Average Train Loss: 1.10036039352417
Epoch: 144, Average Train Loss: 1.0527069568634033
Epoch: 145, Average Train Loss: 1.0504138469696045
Epoch: 146, Average Train Loss: 1.0319401025772095
Epoch: 147, Average Train Loss: 1.0526437759399414
Epoch: 148, Average Train Loss: 1.0198462009429932
Epoch: 149, Average Train Loss: 1.0284019708633423
Epoch: 150, Average Train Loss: 1.0077991485595703
Epoch: 151, Average Train Loss: 1.0316370725631714
Epoch: 152, Average Train Loss: 1.0104206800460815
Epoch: 153, Average Train Loss: 1.0170882940292358
Epoch: 154, Average Train Loss: 0.9981086850166321
Epoch: 155, Average Train Loss: 1.012529969215393
Epoch: 156, Average Train Loss: 0.9973089694976807
Epoch: 157, Average Train Loss: 1.001656174659729
Epoch: 158, Average Train Loss: 0.978147029876709
Epoch: 159, Average Train Loss: 1.0004792213439941
Epoch: 160, Average Train Loss: 0.9956006407737732
Epoch: 161, Average Train Loss: 1.0492277145385742
Epoch: 162, Average Train Loss: 0.997270405292511
```

```
Epoch: 163, Average Train Loss: 1.0400677919387817
Epoch: 164, Average Train Loss: 1.1317204236984253
Epoch: 165, Average Train Loss: 0.9725050330162048
Epoch: 166, Average Train Loss: 1.1039783954620361
Epoch: 167, Average Train Loss: 1.06325101852417
Epoch: 168, Average Train Loss: 1.0170948505401611
Epoch: 169, Average Train Loss: 1.1548055410385132
Epoch: 170, Average Train Loss: 0.9862576127052307
Epoch: 171, Average Train Loss: 1.1471446752548218
Epoch: 172, Average Train Loss: 1.0280351638793945
Epoch: 173, Average Train Loss: 1.123370885848999
Epoch: 174, Average Train Loss: 0.9892467856407166
Epoch: 175, Average Train Loss: 1.0861371755599976
Epoch: 176, Average Train Loss: 1.0172326564788818
Epoch: 177, Average Train Loss: 1.0598015785217285
Epoch: 178, Average Train Loss: 0.9647969603538513
Epoch: 179, Average Train Loss: 1.0458431243896484
Epoch: 180, Average Train Loss: 0.9851401448249817
Epoch: 181, Average Train Loss: 0.9988743662834167
Epoch: 182, Average Train Loss: 0.9597765803337097
Epoch: 183, Average Train Loss: 0.9955922961235046
Epoch: 184, Average Train Loss: 0.9566457867622375
Epoch: 185, Average Train Loss: 0.9681559205055237
Epoch: 186, Average Train Loss: 0.9632646441459656
Epoch: 187, Average Train Loss: 0.9472293853759766
Epoch: 188, Average Train Loss: 0.9728126525878906
Epoch: 189, Average Train Loss: 0.9371864199638367
Epoch: 190, Average Train Loss: 0.9692949652671814
Epoch: 191, Average Train Loss: 0.9329243302345276
Epoch: 192, Average Train Loss: 0.9516163468360901
Epoch: 193, Average Train Loss: 0.9375128746032715
Epoch: 194, Average Train Loss: 0.9335366487503052
Epoch: 195, Average Train Loss: 0.9373447895050049
Epoch: 196, Average Train Loss: 0.9282417297363281
Epoch: 197, Average Train Loss: 0.9217679500579834
Epoch: 198, Average Train Loss: 0.9307017922401428
Epoch: 199, Average Train Loss: 0.9176831841468811
Epoch: 200, Average Train Loss: 0.9140666127204895
Epoch: 201, Average Train Loss: 0.9171852469444275
Epoch: 202, Average Train Loss: 0.9136660099029541
Epoch: 203, Average Train Loss: 0.9038652181625366
Epoch: 204, Average Train Loss: 0.908647894859314
Epoch: 205, Average Train Loss: 0.9054335355758667
Epoch: 206, Average Train Loss: 0.9064942598342896
Epoch: 207, Average Train Loss: 0.896739661693573
Epoch: 208, Average Train Loss: 0.8967754244804382
Epoch: 209, Average Train Loss: 0.9004184603691101
Epoch: 210, Average Train Loss: 0.8960712552070618
Epoch: 211, Average Train Loss: 0.8950209021568298
Epoch: 212, Average Train Loss: 0.8878952860832214
```

```
Epoch: 213, Average Train Loss: 0.8885926604270935
Epoch: 214, Average Train Loss: 0.8915754556655884
Epoch: 215, Average Train Loss: 0.8894583582878113
Epoch: 216, Average Train Loss: 0.8906325697898865
Epoch: 217, Average Train Loss: 0.8848255276679993
Epoch: 218, Average Train Loss: 0.8825684785842896
Epoch: 219, Average Train Loss: 0.8846484422683716
Epoch: 220, Average Train Loss: 0.8808315992355347
Epoch: 221, Average Train Loss: 0.8830747604370117
Epoch: 222, Average Train Loss: 0.8870974779129028
Epoch: 223, Average Train Loss: 0.8896937966346741
Epoch: 224, Average Train Loss: 0.8819593191146851
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Epoch: 1799, Average Train Loss: 0.6197617650032043
Epoch: 1800, Average Train Loss: 0.6232136487960815
Epoch: 1801, Average Train Loss: 0.6242578625679016
Epoch: 1802, Average Train Loss: 0.627479076385498
Epoch: 1803, Average Train Loss: 0.6216537952423096
Epoch: 1804, Average Train Loss: 0.6195259690284729
Epoch: 1805, Average Train Loss: 0.62388014793396
Epoch: 1806, Average Train Loss: 0.6242848038673401
Epoch: 1807, Average Train Loss: 0.6182441711425781
Epoch: 1808, Average Train Loss: 0.6189029216766357
Epoch: 1809, Average Train Loss: 0.6214690804481506
Epoch: 1810, Average Train Loss: 0.6260385513305664
Epoch: 1811, Average Train Loss: 0.6204577684402466
Epoch: 1812, Average Train Loss: 0.6189827919006348
```

```
Epoch: 1813, Average Train Loss: 0.6218013763427734
Epoch: 1814, Average Train Loss: 0.6249521374702454
Epoch: 1815, Average Train Loss: 0.6196991205215454
Epoch: 1816, Average Train Loss: 0.6232677102088928
Epoch: 1817, Average Train Loss: 0.623620867729187
Epoch: 1818, Average Train Loss: 0.6251479983329773
Epoch: 1819, Average Train Loss: 0.6205218434333801
Epoch: 1820, Average Train Loss: 0.6233398914337158
Epoch: 1821, Average Train Loss: 0.6234143972396851
Epoch: 1822, Average Train Loss: 0.6238959431648254
Epoch: 1823, Average Train Loss: 0.6247606873512268
Epoch: 1824, Average Train Loss: 0.6279162168502808
Epoch: 1825, Average Train Loss: 0.6296166181564331
Epoch: 1826, Average Train Loss: 0.6247687935829163
Epoch: 1827, Average Train Loss: 0.6235024333000183
Epoch: 1828, Average Train Loss: 0.6222668290138245
Epoch: 1829, Average Train Loss: 0.6165742874145508
Epoch: 1830, Average Train Loss: 0.6176024675369263
Epoch: 1831, Average Train Loss: 0.6165243983268738
Epoch: 1832, Average Train Loss: 0.6190731525421143
Epoch: 1833, Average Train Loss: 0.6169617176055908
Epoch: 1834, Average Train Loss: 0.6191698908805847
Epoch: 1835, Average Train Loss: 0.6243883371353149
Epoch: 1836, Average Train Loss: 0.6252265572547913
Epoch: 1837, Average Train Loss: 0.6261940598487854
Epoch: 1838, Average Train Loss: 0.628086507320404
Epoch: 1839, Average Train Loss: 0.6287675499916077
Epoch: 1840, Average Train Loss: 0.6210583448410034
Epoch: 1841, Average Train Loss: 0.6258609890937805
Epoch: 1842, Average Train Loss: 0.6218869090080261
Epoch: 1843, Average Train Loss: 0.6171364188194275
Epoch: 1844, Average Train Loss: 0.6179457902908325
Epoch: 1845, Average Train Loss: 0.6210739612579346
Epoch: 1846, Average Train Loss: 0.6261897087097168
Epoch: 1847, Average Train Loss: 0.6256154179573059
Epoch: 1848, Average Train Loss: 0.6292903423309326
Epoch: 1849, Average Train Loss: 0.6300760507583618
Epoch: 1850, Average Train Loss: 0.6223059296607971
Epoch: 1851, Average Train Loss: 0.6205713748931885
Epoch: 1852, Average Train Loss: 0.6209062933921814
Epoch: 1853, Average Train Loss: 0.6257479190826416
Epoch: 1854, Average Train Loss: 0.631628692150116
Epoch: 1855, Average Train Loss: 0.6333200931549072
Epoch: 1856, Average Train Loss: 0.6288342475891113
Epoch: 1857, Average Train Loss: 0.6260820031166077
Epoch: 1858, Average Train Loss: 0.6251770257949829
Epoch: 1859, Average Train Loss: 0.6236689686775208
Epoch: 1860, Average Train Loss: 0.6213929653167725
Epoch: 1861, Average Train Loss: 0.6216434240341187
Epoch: 1862, Average Train Loss: 0.6230174899101257
```

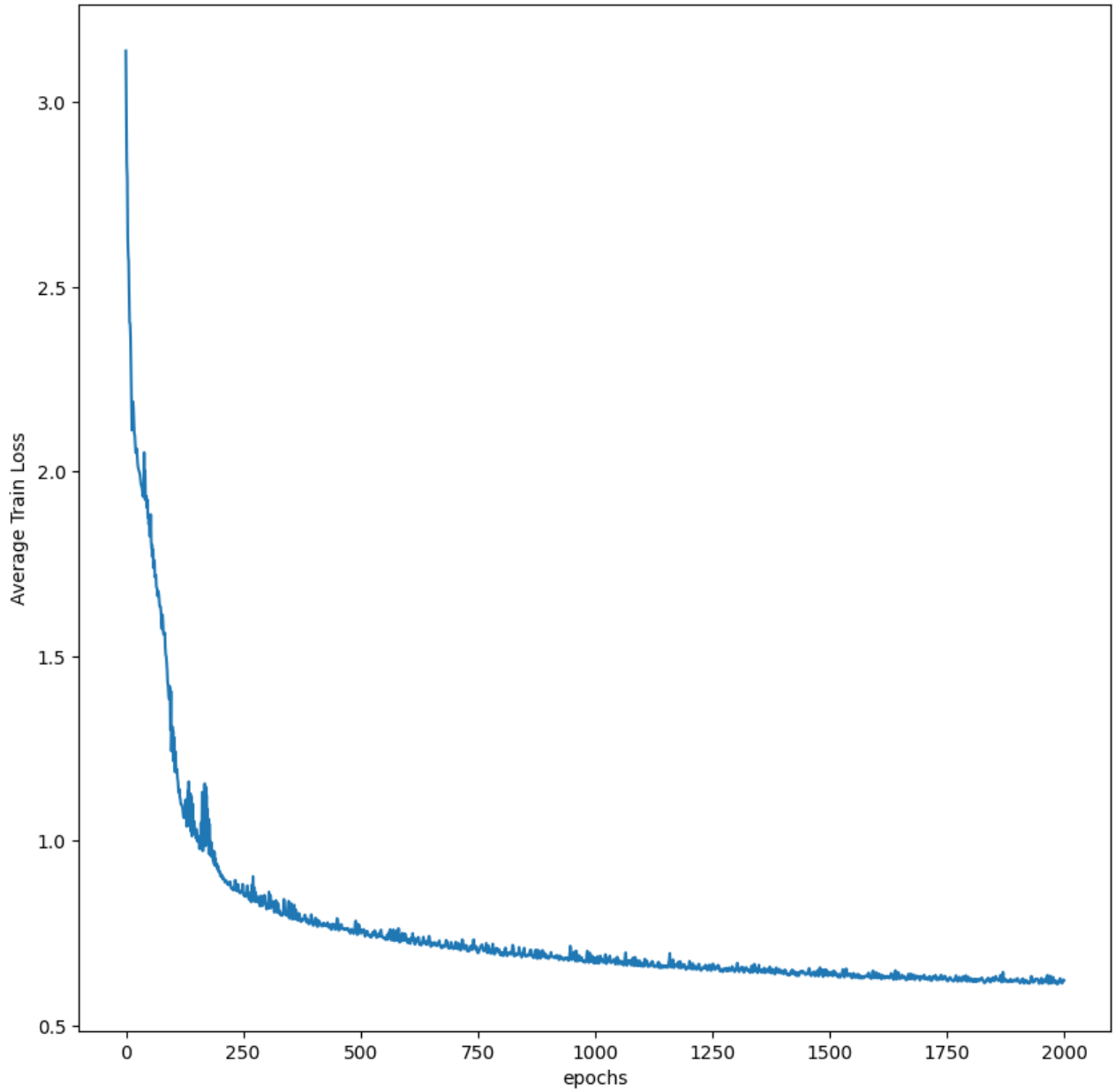
```
Epoch: 1863, Average Train Loss: 0.6278669834136963
Epoch: 1864, Average Train Loss: 0.6329171657562256
Epoch: 1865, Average Train Loss: 0.6366711854934692
Epoch: 1866, Average Train Loss: 0.6229620575904846
Epoch: 1867, Average Train Loss: 0.6170984506607056
Epoch: 1868, Average Train Loss: 0.6190432906150818
Epoch: 1869, Average Train Loss: 0.6299979090690613
Epoch: 1870, Average Train Loss: 0.6445092558860779
Epoch: 1871, Average Train Loss: 0.6337974667549133
Epoch: 1872, Average Train Loss: 0.620053768157959
Epoch: 1873, Average Train Loss: 0.6195899248123169
Epoch: 1874, Average Train Loss: 0.6211684346199036
Epoch: 1875, Average Train Loss: 0.626103937625885
Epoch: 1876, Average Train Loss: 0.6214824318885803
Epoch: 1877, Average Train Loss: 0.620999813079834
Epoch: 1878, Average Train Loss: 0.6219773888587952
Epoch: 1879, Average Train Loss: 0.6196436285972595
Epoch: 1880, Average Train Loss: 0.6176539659500122
Epoch: 1881, Average Train Loss: 0.6181089282035828
Epoch: 1882, Average Train Loss: 0.6218575835227966
Epoch: 1883, Average Train Loss: 0.6187707781791687
Epoch: 1884, Average Train Loss: 0.6189448833465576
Epoch: 1885, Average Train Loss: 0.6224390268325806
Epoch: 1886, Average Train Loss: 0.6257866024971008
Epoch: 1887, Average Train Loss: 0.6219932436943054
Epoch: 1888, Average Train Loss: 0.619873046875
Epoch: 1889, Average Train Loss: 0.6208471655845642
Epoch: 1890, Average Train Loss: 0.6188883781433105
Epoch: 1891, Average Train Loss: 0.6182367205619812
Epoch: 1892, Average Train Loss: 0.6198590397834778
Epoch: 1893, Average Train Loss: 0.6224148273468018
Epoch: 1894, Average Train Loss: 0.6240203380584717
Epoch: 1895, Average Train Loss: 0.6239668130874634
Epoch: 1896, Average Train Loss: 0.6236118674278259
Epoch: 1897, Average Train Loss: 0.621185302734375
Epoch: 1898, Average Train Loss: 0.6195748448371887
Epoch: 1899, Average Train Loss: 0.6203336715698242
Epoch: 1900, Average Train Loss: 0.6251897215843201
Epoch: 1901, Average Train Loss: 0.6277518272399902
Epoch: 1902, Average Train Loss: 0.6245924830436707
Epoch: 1903, Average Train Loss: 0.6212021708488464
Epoch: 1904, Average Train Loss: 0.6198617815971375
Epoch: 1905, Average Train Loss: 0.6165605187416077
Epoch: 1906, Average Train Loss: 0.6154096126556396
Epoch: 1907, Average Train Loss: 0.6148220896720886
Epoch: 1908, Average Train Loss: 0.6168719530105591
Epoch: 1909, Average Train Loss: 0.6180926561355591
Epoch: 1910, Average Train Loss: 0.624956488609314
Epoch: 1911, Average Train Loss: 0.6250963807106018
Epoch: 1912, Average Train Loss: 0.6261560916900635
```

```
Epoch: 1913, Average Train Loss: 0.6268088221549988
Epoch: 1914, Average Train Loss: 0.617766261100769
Epoch: 1915, Average Train Loss: 0.6139459013938904
Epoch: 1916, Average Train Loss: 0.6195634007453918
Epoch: 1917, Average Train Loss: 0.6221983432769775
Epoch: 1918, Average Train Loss: 0.618188202381134
Epoch: 1919, Average Train Loss: 0.6177936792373657
Epoch: 1920, Average Train Loss: 0.6227489709854126
Epoch: 1921, Average Train Loss: 0.620379626750946
Epoch: 1922, Average Train Loss: 0.6157866716384888
Epoch: 1923, Average Train Loss: 0.6172894835472107
Epoch: 1924, Average Train Loss: 0.6156712174415588
Epoch: 1925, Average Train Loss: 0.6143419146537781
Epoch: 1926, Average Train Loss: 0.6141319870948792
Epoch: 1927, Average Train Loss: 0.6146665215492249
Epoch: 1928, Average Train Loss: 0.6176862716674805
Epoch: 1929, Average Train Loss: 0.6219615936279297
Epoch: 1930, Average Train Loss: 0.6330510973930359
Epoch: 1931, Average Train Loss: 0.6329169273376465
Epoch: 1932, Average Train Loss: 0.6266031861305237
Epoch: 1933, Average Train Loss: 0.6209143400192261
Epoch: 1934, Average Train Loss: 0.6175922751426697
Epoch: 1935, Average Train Loss: 0.61650550365448
Epoch: 1936, Average Train Loss: 0.6203025579452515
Epoch: 1937, Average Train Loss: 0.61929851770401
Epoch: 1938, Average Train Loss: 0.624022364616394
Epoch: 1939, Average Train Loss: 0.6256759166717529
Epoch: 1940, Average Train Loss: 0.623928427696228
Epoch: 1941, Average Train Loss: 0.6248782873153687
Epoch: 1942, Average Train Loss: 0.6266927123069763
Epoch: 1943, Average Train Loss: 0.6258951425552368
Epoch: 1944, Average Train Loss: 0.62446129322052
Epoch: 1945, Average Train Loss: 0.624253511428833
Epoch: 1946, Average Train Loss: 0.6167252063751221
Epoch: 1947, Average Train Loss: 0.613426685333252
Epoch: 1948, Average Train Loss: 0.6144357919692993
Epoch: 1949, Average Train Loss: 0.6200463771820068
Epoch: 1950, Average Train Loss: 0.6224079728126526
Epoch: 1951, Average Train Loss: 0.6244184374809265
Epoch: 1952, Average Train Loss: 0.6284081339836121
Epoch: 1953, Average Train Loss: 0.6201408505439758
Epoch: 1954, Average Train Loss: 0.6140414476394653
Epoch: 1955, Average Train Loss: 0.6152125597000122
Epoch: 1956, Average Train Loss: 0.6198247075080872
Epoch: 1957, Average Train Loss: 0.6226935386657715
Epoch: 1958, Average Train Loss: 0.6235823035240173
Epoch: 1959, Average Train Loss: 0.625177800655365
Epoch: 1960, Average Train Loss: 0.618602991104126
Epoch: 1961, Average Train Loss: 0.6168906092643738
Epoch: 1962, Average Train Loss: 0.6201004385948181
```

```
Epoch: 1963, Average Train Loss: 0.6267582774162292
Epoch: 1964, Average Train Loss: 0.6337681412696838
Epoch: 1965, Average Train Loss: 0.6363446712493896
Epoch: 1966, Average Train Loss: 0.6231866478919983
Epoch: 1967, Average Train Loss: 0.6135718822479248
Epoch: 1968, Average Train Loss: 0.6134189367294312
Epoch: 1969, Average Train Loss: 0.6199548840522766
Epoch: 1970, Average Train Loss: 0.6318203210830688
Epoch: 1971, Average Train Loss: 0.6342254877090454
Epoch: 1972, Average Train Loss: 0.6286609768867493
Epoch: 1973, Average Train Loss: 0.6159497499465942
Epoch: 1974, Average Train Loss: 0.6143549084663391
Epoch: 1975, Average Train Loss: 0.6195588707923889
Epoch: 1976, Average Train Loss: 0.6257524490356445
Epoch: 1977, Average Train Loss: 0.6308963298797607
Epoch: 1978, Average Train Loss: 0.6233684420585632
Epoch: 1979, Average Train Loss: 0.6189610958099365
Epoch: 1980, Average Train Loss: 0.6158325672149658
Epoch: 1981, Average Train Loss: 0.617156445980072
Epoch: 1982, Average Train Loss: 0.6220606565475464
Epoch: 1983, Average Train Loss: 0.6185299158096313
Epoch: 1984, Average Train Loss: 0.6143658757209778
Epoch: 1985, Average Train Loss: 0.6122984290122986
Epoch: 1986, Average Train Loss: 0.613308310508728
Epoch: 1987, Average Train Loss: 0.6126679182052612
Epoch: 1988, Average Train Loss: 0.617192804813385
Epoch: 1989, Average Train Loss: 0.6174640655517578
Epoch: 1990, Average Train Loss: 0.6235281229019165
Epoch: 1991, Average Train Loss: 0.6243191361427307
Epoch: 1992, Average Train Loss: 0.6274202466011047
Epoch: 1993, Average Train Loss: 0.6220376491546631
Epoch: 1994, Average Train Loss: 0.6172114610671997
Epoch: 1995, Average Train Loss: 0.6151384711265564
Epoch: 1996, Average Train Loss: 0.6142107248306274
Epoch: 1997, Average Train Loss: 0.6165711879730225
Epoch: 1998, Average Train Loss: 0.6196998953819275
Epoch: 1999, Average Train Loss: 0.6240101456642151
Epoch: 2000, Average Train Loss: 0.622465193271637
```

In [ ]:

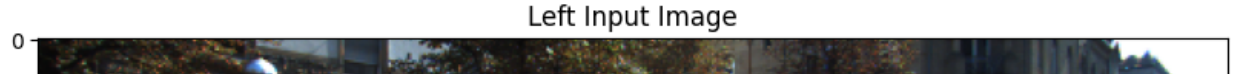
```
plt.figure(figsize=(10,10))
plt.plot(average_train_loss)
plt.xlabel("epochs")
plt.ylabel("Average Train Loss")
plt.show()
```

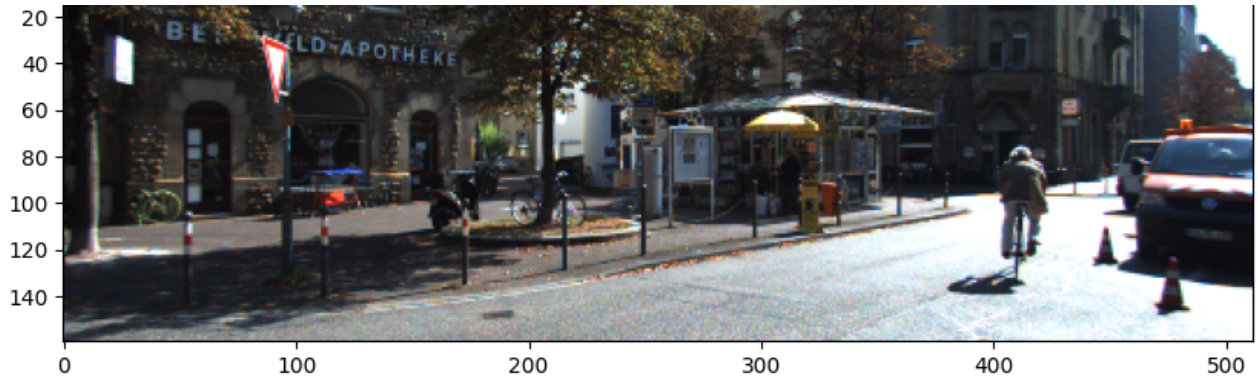


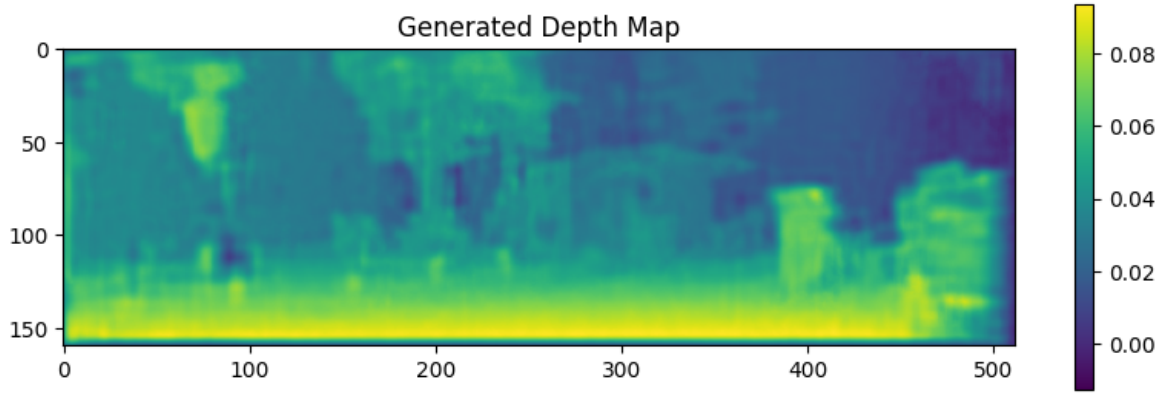
Sanity Train Set

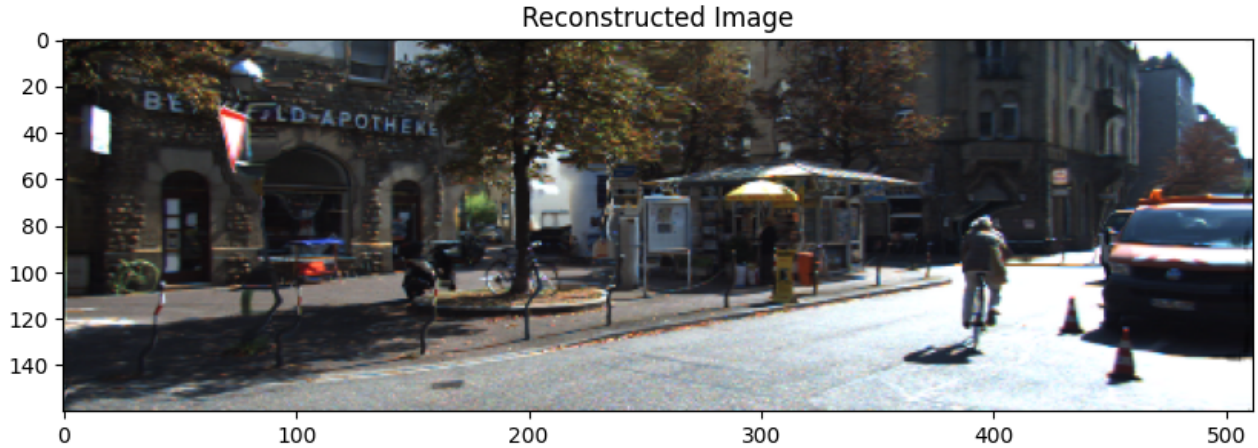
Now after training on the sanity set we see a much nicer disparity map generated from this model. It is more coherent and consistent with basic features of the image. This includes the gradient between the ground and the sky as well as some features such as walls, cars, and people.

In [ ]:
```
sanity_model = torch.load('model_checkpoints/sanity_model.pt')
sanity_test(sanity_model, sanity_train_dataloader)
```




20
40
60
80
100
120
140
0
100
200
300
400
500

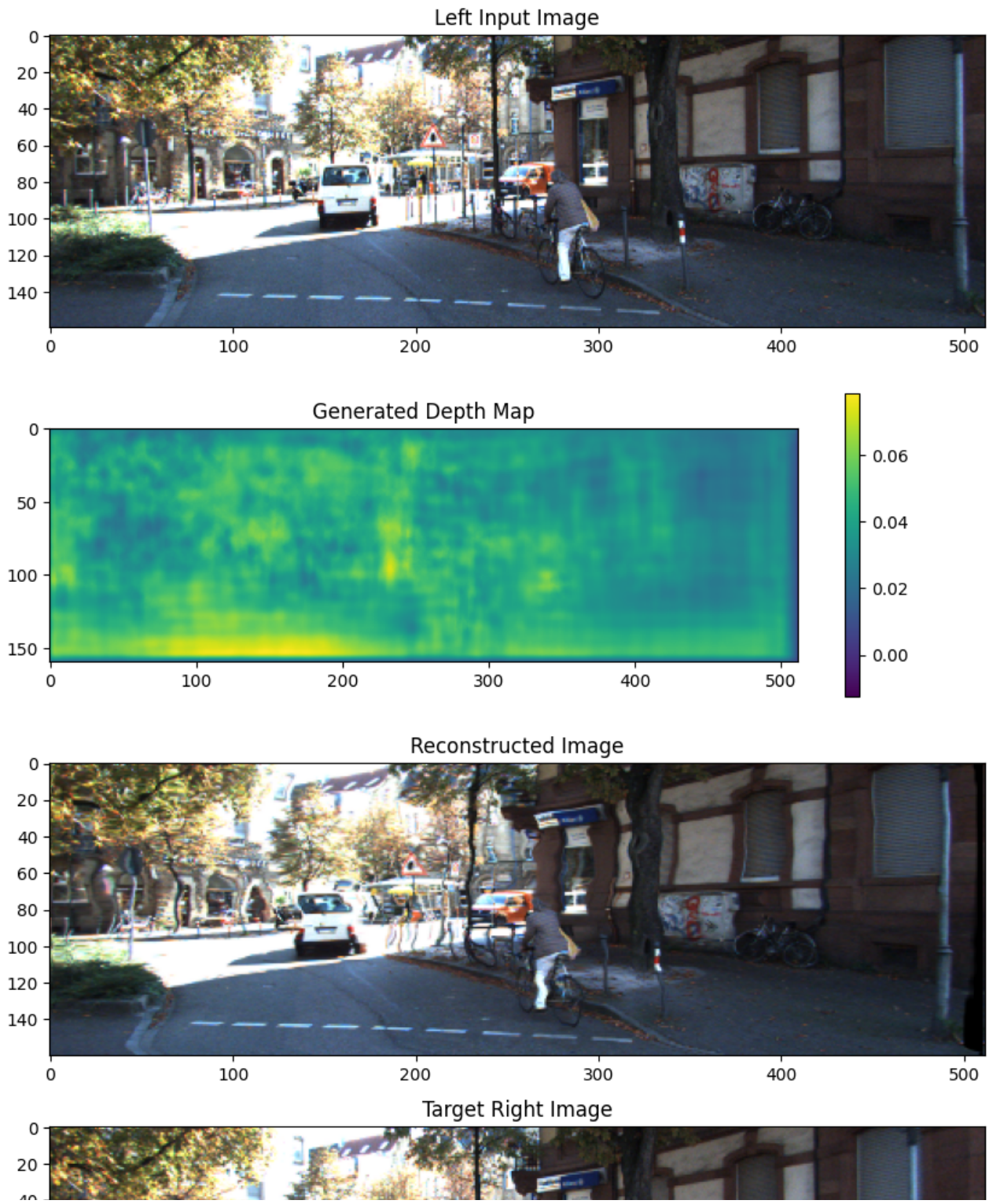

Generated Depth Map
0
50
100
150
0
100
200
300
400
500
0.08
0.06
0.04
0.02
0.00


Reconstructed Image
0
20
40
60
80
100
120
140
0
100
200
300
400
500

Target Right Image
0
20
40
60
80
100
120
140
0
100
200
300
400
500

However now when we try to predict with an image it has never seen before we run into problems. This is expected however since the training set was so limited. Knowing we're are getting relatively reasonable answers we can start training with larger models.

In [ ]:
```
#test on another image and on sampleImgRight
sanity_test(sanity_model, sanity_test_dataloader)
```



Small dataset

We upgrade our model by training on a dataset with more images this will lead to longer training times, but hopefully a more general model.

Loss functions

We can also demonstrate the importance of different parts of the loss function by seeing how the model performs wihtout them.

In [ ]:
```
def trainModel(epochs, modelName, model, optimizer, criterion):
    average_train_loss = []
    for epoch in range(1, epochs+1):
        loss = train(stereo_train_dataloader, epoch, model, optimizer, crite
        print(f"Epoch: {epoch}, Average Train Loss: {loss}")
        average_train_loss += [loss]
    torch.save(sanity_model, 'model_checkpoints/' + modelName + ".pt")
```

In [ ]:
```
# Wihout either special loss and only L1 loss
my_criterion = nn.L1Loss().to(device)
l1_model = MyNet(1.0, 1.0, 0.8, without='both').to(device)
l1_model.train()
my_optimzer = torch.optim.Adam(l1_model.parameters())

trainModel(75, 'l1loss', l1_model, my_optimzer, my_criterion)
```

```
Epoch: 1, Average Train Loss: 0.01927310107378942
Epoch: 2, Average Train Loss: 0.018290679393219333
Epoch: 3, Average Train Loss: 0.017422220363828088
Epoch: 4, Average Train Loss: 0.016464904225620396
Epoch: 5, Average Train Loss: 0.01502821778679246
Epoch: 6, Average Train Loss: 0.014637392000518602
Epoch: 7, Average Train Loss: 0.01395094312205086
Epoch: 8, Average Train Loss: 0.013700407479521974
Epoch: 9, Average Train Loss: 0.01349893041862333
Epoch: 10, Average Train Loss: 0.013146609672761052
```

```
Epoch: 11, Average Train Loss: 0.013110644647995924
Epoch: 12, Average Train Loss: 0.012930445510522906
Epoch: 13, Average Train Loss: 0.012838856100596185
Epoch: 14, Average Train Loss: 0.01316919895335757
Epoch: 15, Average Train Loss: 0.012594579550612897
Epoch: 16, Average Train Loss: 0.012473985442816112
Epoch: 17, Average Train Loss: 0.012404690149525435
Epoch: 18, Average Train Loss: 0.012486542997764926
Epoch: 19, Average Train Loss: 0.01239677323406473
Epoch: 20, Average Train Loss: 0.01229121280332333
Epoch: 21, Average Train Loss: 0.012191852630284439
Epoch: 22, Average Train Loss: 0.011944159810393498
Epoch: 23, Average Train Loss: 0.011870414623475163
Epoch: 24, Average Train Loss: 0.011855061148805373
Epoch: 25, Average Train Loss: 0.011824332040174421
Epoch: 26, Average Train Loss: 0.011643306795521415
Epoch: 27, Average Train Loss: 0.011709044835224362
Epoch: 28, Average Train Loss: 0.011973742189442539
Epoch: 29, Average Train Loss: 0.011679274789521615
Epoch: 30, Average Train Loss: 0.011627674432698212
Epoch: 31, Average Train Loss: 0.011615518879186623
Epoch: 32, Average Train Loss: 0.011385136424835319
Epoch: 33, Average Train Loss: 0.011339919813444694
Epoch: 34, Average Train Loss: 0.011420940945949061
Epoch: 35, Average Train Loss: 0.011242546773484713
Epoch: 36, Average Train Loss: 0.011286813449595687
Epoch: 37, Average Train Loss: 0.01136254796902632
Epoch: 38, Average Train Loss: 0.011225424569471296
Epoch: 39, Average Train Loss: 0.011079682250304417
Epoch: 40, Average Train Loss: 0.011105010815212207
Epoch: 41, Average Train Loss: 0.011297889686158663
Epoch: 42, Average Train Loss: 0.011211824758026432
Epoch: 43, Average Train Loss: 0.011039823623600922
Epoch: 44, Average Train Loss: 0.01098275767481195
Epoch: 45, Average Train Loss: 0.011111940734940701
Epoch: 46, Average Train Loss: 0.010993940418936669
Epoch: 47, Average Train Loss: 0.01103301186843112
Epoch: 48, Average Train Loss: 0.01105276761899575
Epoch: 49, Average Train Loss: 0.010907206808069095
Epoch: 50, Average Train Loss: 0.010794466656952327
Epoch: 51, Average Train Loss: 0.010772930190132113
Epoch: 52, Average Train Loss: 0.010779248612393313
Epoch: 53, Average Train Loss: 0.010792348162714406
Epoch: 54, Average Train Loss: 0.01072648893423186
Epoch: 55, Average Train Loss: 0.01078587803453537
Epoch: 56, Average Train Loss: 0.010842256000561028
Epoch: 57, Average Train Loss: 0.010957214225262293
Epoch: 58, Average Train Loss: 0.010750001481978216
Epoch: 59, Average Train Loss: 0.01069776312451521
Epoch: 60, Average Train Loss: 0.01063952806690962
```

```
Epoch: 61, Average Train Loss: 0.010667865566661877
Epoch: 62, Average Train Loss: 0.010584722695755343
Epoch: 63, Average Train Loss: 0.010568377606543227
Epoch: 64, Average Train Loss: 0.010588605300526778
Epoch: 65, Average Train Loss: 0.010614734294229768
Epoch: 66, Average Train Loss: 0.010616047960805716
Epoch: 67, Average Train Loss: 0.010717038188913211
Epoch: 68, Average Train Loss: 0.011280712661268087
Epoch: 69, Average Train Loss: 0.010767321470038917
Epoch: 70, Average Train Loss: 0.010555071639398807
Epoch: 71, Average Train Loss: 0.010549229449451629
Epoch: 72, Average Train Loss: 0.010455885716469965
Epoch: 73, Average Train Loss: 0.010454811128303133
Epoch: 74, Average Train Loss: 0.010412547036290609
Epoch: 75, Average Train Loss: 0.010636327396459686
```

In [ ]:

```
# Only with L1 loss and lr_alpha
my_criterion = nn.L1Loss().to(device)
l1_lralpha_model = MyNet(1.0, 1.0, 0.8, without='lr_alpha').to(device)
l1_lralpha_model.train()
my_optimzer = torch.optim.Adam(l1_lralpha_model.parameters())

trainModel(75, 'l1_lralpha', l1_lralpha_model, my_optimzer, my_criterion)
```

```
Epoch: 1, Average Train Loss: 0.01977749669243929
Epoch: 2, Average Train Loss: 0.018696666753600006
Epoch: 3, Average Train Loss: 0.01843260124160795
Epoch: 4, Average Train Loss: 0.017534672334185385
Epoch: 5, Average Train Loss: 0.016762707726102034
Epoch: 6, Average Train Loss: 0.015918005986407233
Epoch: 7, Average Train Loss: 0.015198080907008745
Epoch: 8, Average Train Loss: 0.01493532284819332
Epoch: 9, Average Train Loss: 0.014694368212425401
Epoch: 10, Average Train Loss: 0.014540799924368348
Epoch: 11, Average Train Loss: 0.014623058897982663
Epoch: 12, Average Train Loss: 0.014170869085181684
Epoch: 13, Average Train Loss: 0.013789056466954221
Epoch: 14, Average Train Loss: 0.013546148129494867
Epoch: 15, Average Train Loss: 0.013608798219708939
Epoch: 16, Average Train Loss: 0.013439160651386443
Epoch: 17, Average Train Loss: 0.013453467030806736
Epoch: 18, Average Train Loss: 0.01323467905451011
Epoch: 19, Average Train Loss: 0.013192023848255623
Epoch: 20, Average Train Loss: 0.013369540501784575
Epoch: 21, Average Train Loss: 0.012909531813266092
Epoch: 22, Average Train Loss: 0.012730404514668173
Epoch: 23, Average Train Loss: 0.012805517859124609
Epoch: 24, Average Train Loss: 0.012789602649167895
Epoch: 25, Average Train Loss: 0.012827268220841665
Epoch: 26, Average Train Loss: 0.012588142139005484
```

```
Epoch: 27, Average Train Loss: 0.012586210651591255
Epoch: 28, Average Train Loss: 0.012644698314121289
Epoch: 29, Average Train Loss: 0.01249353081757732
Epoch: 30, Average Train Loss: 0.012337997610718562
Epoch: 31, Average Train Loss: 0.012378621090382227
Epoch: 32, Average Train Loss: 0.012215317175397134
Epoch: 33, Average Train Loss: 0.01241104035359907
Epoch: 34, Average Train Loss: 0.012157079038584805
Epoch: 35, Average Train Loss: 0.012085153662850496
Epoch: 36, Average Train Loss: 0.012094037614185432
Epoch: 37, Average Train Loss: 0.012341485692126284
Epoch: 38, Average Train Loss: 0.012051585855519199
Epoch: 39, Average Train Loss: 0.01183537248095903
Epoch: 40, Average Train Loss: 0.011764121396515202
Epoch: 41, Average Train Loss: 0.01173300991639
Epoch: 42, Average Train Loss: 0.011719945557003092
Epoch: 43, Average Train Loss: 0.011722686490889405
Epoch: 44, Average Train Loss: 0.011650623155695925
Epoch: 45, Average Train Loss: 0.01164858796499752
Epoch: 46, Average Train Loss: 0.01199824294260947
Epoch: 47, Average Train Loss: 0.011789724065808792
Epoch: 48, Average Train Loss: 0.011686652898788452
Epoch: 49, Average Train Loss: 0.011681323286792009
Epoch: 50, Average Train Loss: 0.01154573267236407
Epoch: 51, Average Train Loss: 0.011420444533833719
Epoch: 52, Average Train Loss: 0.011544698443799881
Epoch: 53, Average Train Loss: 0.011427778489475321
Epoch: 54, Average Train Loss: 0.011380300640619989
Epoch: 55, Average Train Loss: 0.011386696098035552
Epoch: 56, Average Train Loss: 0.011407151598332114
Epoch: 57, Average Train Loss: 0.011502197032924948
Epoch: 58, Average Train Loss: 0.011391132960020397
Epoch: 59, Average Train Loss: 0.011352275955281134
Epoch: 60, Average Train Loss: 0.011203150907565747
Epoch: 61, Average Train Loss: 0.011208026776454546
Epoch: 62, Average Train Loss: 0.011206080662808295
Epoch: 63, Average Train Loss: 0.011154696730230127
Epoch: 64, Average Train Loss: 0.011205170922173786
Epoch: 65, Average Train Loss: 0.011155428316760327
Epoch: 66, Average Train Loss: 0.011223070955804354
Epoch: 67, Average Train Loss: 0.011192704863653851
Epoch: 68, Average Train Loss: 0.011391721583380471
Epoch: 69, Average Train Loss: 0.011278167806868184
Epoch: 70, Average Train Loss: 0.011108340867331108
Epoch: 71, Average Train Loss: 0.011071332211424064
Epoch: 72, Average Train Loss: 0.011057769570403433
Epoch: 73, Average Train Loss: 0.01125950676928587
Epoch: 74, Average Train Loss: 0.011181934128388268
Epoch: 75, Average Train Loss: 0.011058897439844053
```

In [ ]:
```
# Only with L1 loss and disp_smooth
my_criterion = nn.L1Loss().to(device)
l1_dispSmooth_model = MyNet(1.0, 1.0, 0.8, without='disp_smooth').to(device)
l1_dispSmooth_model.train()
my_optimzer = torch.optim.Adam(l1_dispSmooth_model.parameters())

trainModel(75, 'l1_dispSmooth', l1_dispSmooth_model, my_optimzer, my_criteri
```

```
Epoch: 1, Average Train Loss: 0.02934720573390102
Epoch: 2, Average Train Loss: 0.020375353053926983
Epoch: 3, Average Train Loss: 0.019371492726336547
Epoch: 4, Average Train Loss: 0.019102887033976314
Epoch: 5, Average Train Loss: 0.01906196316669788
Epoch: 6, Average Train Loss: 0.018931433833393223
Epoch: 7, Average Train Loss: 0.01869789205793965
Epoch: 8, Average Train Loss: 0.018188735545781265
Epoch: 9, Average Train Loss: 0.018037189306808133
Epoch: 10, Average Train Loss: 0.017839699983596802
Epoch: 11, Average Train Loss: 0.017803208634422273
Epoch: 12, Average Train Loss: 0.017557997985079718
Epoch: 13, Average Train Loss: 0.017190153638375203
Epoch: 14, Average Train Loss: 0.017425005781254645
Epoch: 15, Average Train Loss: 0.01686020591382171
Epoch: 16, Average Train Loss: 0.01638252730739073
Epoch: 17, Average Train Loss: 0.015674259609841774
Epoch: 18, Average Train Loss: 0.015521033553619666
Epoch: 19, Average Train Loss: 0.015113360107604867
Epoch: 20, Average Train Loss: 0.01508242623172563
Epoch: 21, Average Train Loss: 0.014824601611967896
Epoch: 22, Average Train Loss: 0.014786959574231363
Epoch: 23, Average Train Loss: 0.014944735323371042
Epoch: 24, Average Train Loss: 0.014852004132587531
Epoch: 25, Average Train Loss: 0.014871513601598704
Epoch: 26, Average Train Loss: 0.014575136598625747
Epoch: 27, Average Train Loss: 0.014448193441457854
Epoch: 28, Average Train Loss: 0.014328898593948336
Epoch: 29, Average Train Loss: 0.014349762748968117
Epoch: 30, Average Train Loss: 0.014270941654694476
Epoch: 31, Average Train Loss: 0.014386782896914606
Epoch: 32, Average Train Loss: 0.014242292000358835
Epoch: 33, Average Train Loss: 0.014099758929432098
Epoch: 34, Average Train Loss: 0.0140274206650653
Epoch: 35, Average Train Loss: 0.013950647518203707
Epoch: 36, Average Train Loss: 0.013919619341618021
Epoch: 37, Average Train Loss: 0.013901085211342111
Epoch: 38, Average Train Loss: 0.01378755991749218
Epoch: 39, Average Train Loss: 0.013701283733783173
Epoch: 40, Average Train Loss: 0.01367728665086176
Epoch: 41, Average Train Loss: 0.013521927474169713
Epoch: 42, Average Train Loss: 0.013470023485567298
```

```
Epoch: 43, Average Train Loss: 0.013396789721897168
Epoch: 44, Average Train Loss: 0.013410629381552833
Epoch: 45, Average Train Loss: 0.013723624588378681
Epoch: 46, Average Train Loss: 0.01349215770339614
Epoch: 47, Average Train Loss: 0.01329546814914999
Epoch: 48, Average Train Loss: 0.013476897264758599
Epoch: 49, Average Train Loss: 0.013248012074685185
Epoch: 50, Average Train Loss: 0.013122567611426885
Epoch: 51, Average Train Loss: 0.01329867640764511
Epoch: 52, Average Train Loss: 0.01313166094882022
Epoch: 53, Average Train Loss: 0.013096758965196645
Epoch: 54, Average Train Loss: 0.013019503042706704
Epoch: 55, Average Train Loss: 0.01304412718408662
Epoch: 56, Average Train Loss: 0.012940022778247115
Epoch: 57, Average Train Loss: 0.012946699598178653
Epoch: 58, Average Train Loss: 0.012997734095777532
Epoch: 59, Average Train Loss: 0.012897704195272438
Epoch: 60, Average Train Loss: 0.012877920841818807
Epoch: 61, Average Train Loss: 0.012875703812965168
Epoch: 62, Average Train Loss: 0.012863696666221338
Epoch: 63, Average Train Loss: 0.013036078082679382
Epoch: 64, Average Train Loss: 0.012938291109356053
Epoch: 65, Average Train Loss: 0.012691814796071212
Epoch: 66, Average Train Loss: 0.012654280365613113
Epoch: 67, Average Train Loss: 0.0126711491949004
Epoch: 68, Average Train Loss: 0.012587967064107915
Epoch: 69, Average Train Loss: 0.012812882386890285
Epoch: 70, Average Train Loss: 0.012743679854702686
Epoch: 71, Average Train Loss: 0.012729897105385897
Epoch: 72, Average Train Loss: 0.012493101213251093
Epoch: 73, Average Train Loss: 0.012380455802727449
Epoch: 74, Average Train Loss: 0.012429511909995132
Epoch: 75, Average Train Loss: 0.012551929128126025
```

In [ ]:

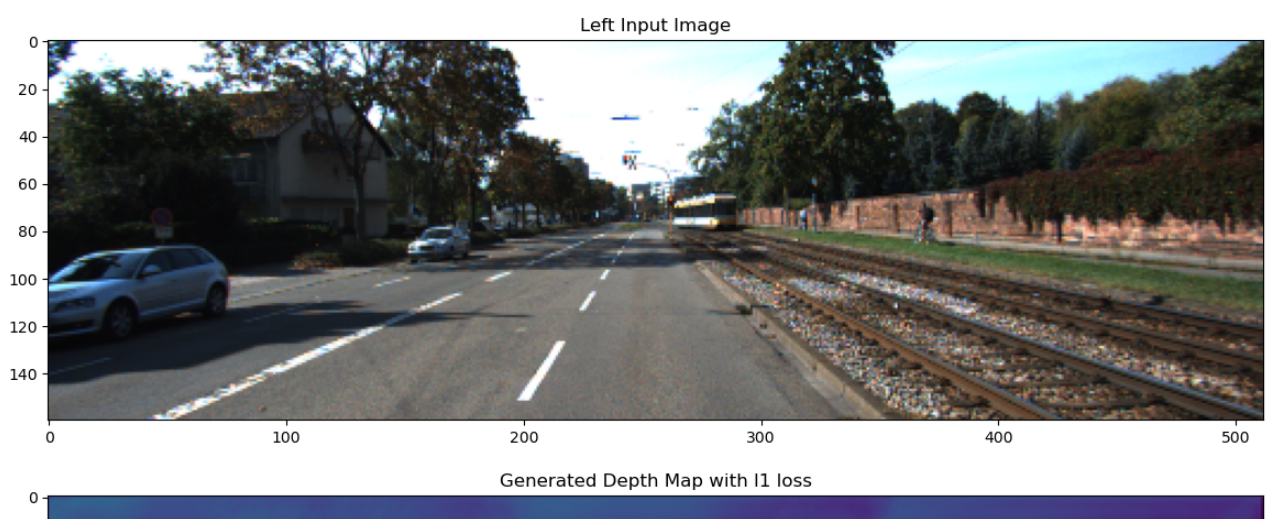
```
# With both special loss and only L1 loss
my_criterion = nn.L1Loss().to(device)
complete_model = MyNet(1.0, 1.0, 0.8).to(device)
complete_model.train()
my_optimzer = torch.optim.Adam(complete_model.parameters())
trainModel(75, 'complete', complete_model, my_optimzer, my_criterion)
```

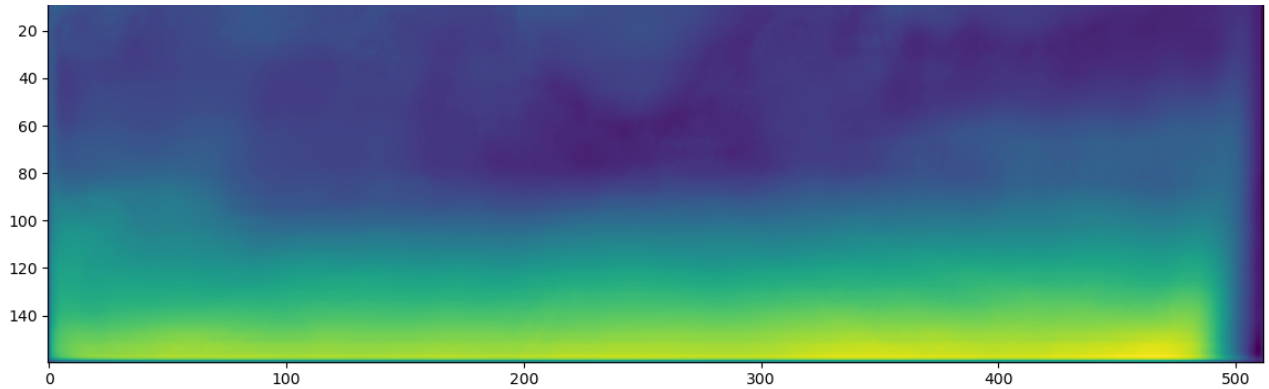
```
Epoch: 1, Average Train Loss: 0.02497336543354161
Epoch: 2, Average Train Loss: 0.021928698044421487
Epoch: 3, Average Train Loss: 0.02140279097750618
Epoch: 4, Average Train Loss: 0.020895107755801775
Epoch: 5, Average Train Loss: 0.01959264927244714
Epoch: 6, Average Train Loss: 0.01922327697936899
Epoch: 7, Average Train Loss: 0.01900488875009037
Epoch: 8, Average Train Loss: 0.01895810691193021
Epoch: 9, Average Train Loss: 0.018689158547848354
```

```
Epoch: 10, Average Train Loss: 0.018478733147202383
Epoch: 11, Average Train Loss: 0.018275845534687113
Epoch: 12, Average Train Loss: 0.017771122420405988
Epoch: 13, Average Train Loss: 0.017322523402551884
Epoch: 14, Average Train Loss: 0.01710883299802942
Epoch: 15, Average Train Loss: 0.016823257797318632
Epoch: 16, Average Train Loss: 0.01677113892407435
Epoch: 17, Average Train Loss: 0.01726558001718838
Epoch: 18, Average Train Loss: 0.016617605661993978
Epoch: 19, Average Train Loss: 0.015918894887410405
Epoch: 20, Average Train Loss: 0.015634588209905306
Epoch: 21, Average Train Loss: 0.015439882269644649
Epoch: 22, Average Train Loss: 0.015246737212272588
Epoch: 23, Average Train Loss: 0.015051764150827132
Epoch: 24, Average Train Loss: 0.01494639232149863
Epoch: 25, Average Train Loss: 0.014866857566076891
Epoch: 26, Average Train Loss: 0.014537248774208266
Epoch: 27, Average Train Loss: 0.014651402336205063
Epoch: 28, Average Train Loss: 0.01458015152669041
Epoch: 29, Average Train Loss: 0.014514688636104119
Epoch: 30, Average Train Loss: 0.014510630406576769
Epoch: 31, Average Train Loss: 0.014446458418430877
Epoch: 32, Average Train Loss: 0.014421913456652877
Epoch: 33, Average Train Loss: 0.014199117672839288
Epoch: 34, Average Train Loss: 0.014114941508127754
Epoch: 35, Average Train Loss: 0.014041075572316496
Epoch: 36, Average Train Loss: 0.013921058760797845
Epoch: 37, Average Train Loss: 0.013879553583275347
Epoch: 38, Average Train Loss: 0.014098929193187023
Epoch: 39, Average Train Loss: 0.014081594248979293
Epoch: 40, Average Train Loss: 0.014135172666218887
Epoch: 41, Average Train Loss: 0.013806130448390637
Epoch: 42, Average Train Loss: 0.013869699021986929
Epoch: 43, Average Train Loss: 0.013886512095637868
Epoch: 44, Average Train Loss: 0.013768816071242864
Epoch: 45, Average Train Loss: 0.01370973252722258
Epoch: 46, Average Train Loss: 0.013652233729943139
Epoch: 47, Average Train Loss: 0.013610181553337406
Epoch: 48, Average Train Loss: 0.013561105266268404
Epoch: 49, Average Train Loss: 0.013677336687971305
Epoch: 50, Average Train Loss: 0.0135165260506732
Epoch: 51, Average Train Loss: 0.013595759043834307
Epoch: 52, Average Train Loss: 0.01331765977219022
Epoch: 53, Average Train Loss: 0.013343494041819413
Epoch: 54, Average Train Loss: 0.01336242170571401
Epoch: 55, Average Train Loss: 0.013256652163843387
Epoch: 56, Average Train Loss: 0.013242261876039399
Epoch: 57, Average Train Loss: 0.013147088379437634
Epoch: 58, Average Train Loss: 0.013380458269172049
Epoch: 59, Average Train Loss: 0.013353669115538086
```

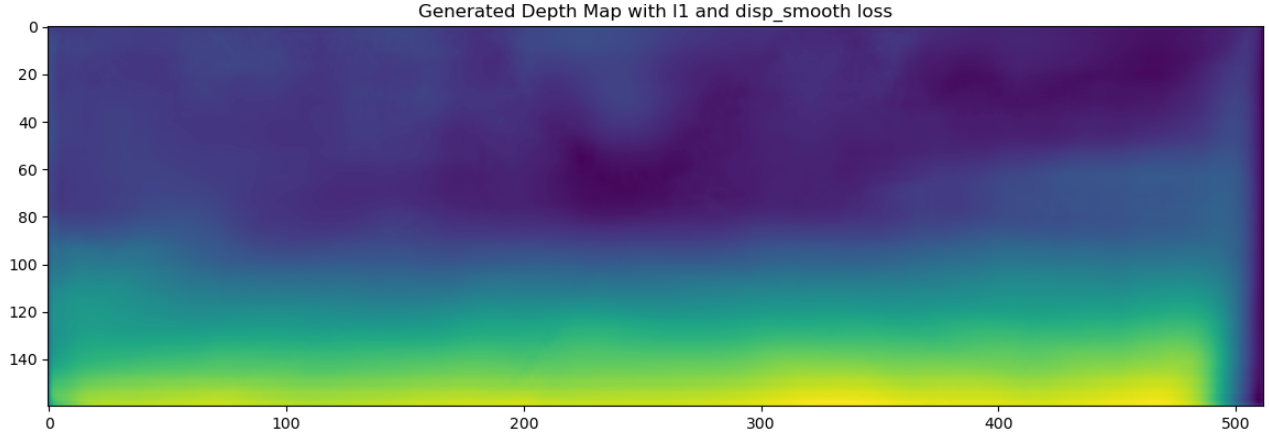
```
Epoch: 60, Average Train Loss: 0.01325052135325006
Epoch: 61, Average Train Loss: 0.013316918343195617
Epoch: 62, Average Train Loss: 0.01315805475430295
Epoch: 63, Average Train Loss: 0.01301231254510774
Epoch: 64, Average Train Loss: 0.012988109320292174
Epoch: 65, Average Train Loss: 0.013088299394533643
Epoch: 66, Average Train Loss: 0.013208773248310018
Epoch: 67, Average Train Loss: 0.013106304781023427
Epoch: 68, Average Train Loss: 0.013278779508442896
Epoch: 69, Average Train Loss: 0.013115948141720901
Epoch: 70, Average Train Loss: 0.013087468833501049
Epoch: 71, Average Train Loss: 0.013107781645556657
Epoch: 72, Average Train Loss: 0.01292420802741033
Epoch: 73, Average Train Loss: 0.01294021561356928
Epoch: 74, Average Train Loss: 0.012776522453860604
Epoch: 75, Average Train Loss: 0.012842551368628921
```

In [ ]:
```
#display image and corresponding diparity map
recon_images = []
disps = []
models_name = [[l1_model, "l1 loss"],
               [l1_lralpha_model, "l1 and disp_smooth loss"],
               [l1_dispSmooth_model, "l1 and lr_alpha loss"],
               [complete_model, "l1 and lr_alpha and disp_smooth loss"]]

fig, axs = plt.subplots(nrows=5, ncols=1, figsize=(25, 26))

for imgL, imgR in sanity_test_dataloader:
    axs[0].imshow(imgL[0].squeeze().permute(1,2,0))
    #axs[0, 1].imshow(imgR[0].squeeze().permute(1,2,0))
    axs[0].set_title('Left Input Image')
    #axs[0, 1].set_title('Target Right Image')

for i in range(len(models_name)):
    model = models_name[i][0]
    name = models_name[i][1]
    for imgL, imgR in sanity_test_dataloader:
        imgL = imgL.to(device)
        res = model(imgL)
        disp = (res[:,0,:,:].unsqueeze(1))
        disp = disp.to(device)
        recon_r = bilinear_sampler(imgL, disp).cpu()
        imgL = imgL.cpu()
        disp = disp.cpu()
        axs[i+1].imshow(disp[0].squeeze().detach().numpy())
        #axs[i+1, 1].imshow(recon_r[0].detach().permute(1,2,0))
        axs[i+1].set_title('Generated Depth Map with '+ name)
        #axs[i+1, 1].set_title('Reconstructed Image with '+ name)


# Show the figure
plt.show()
```

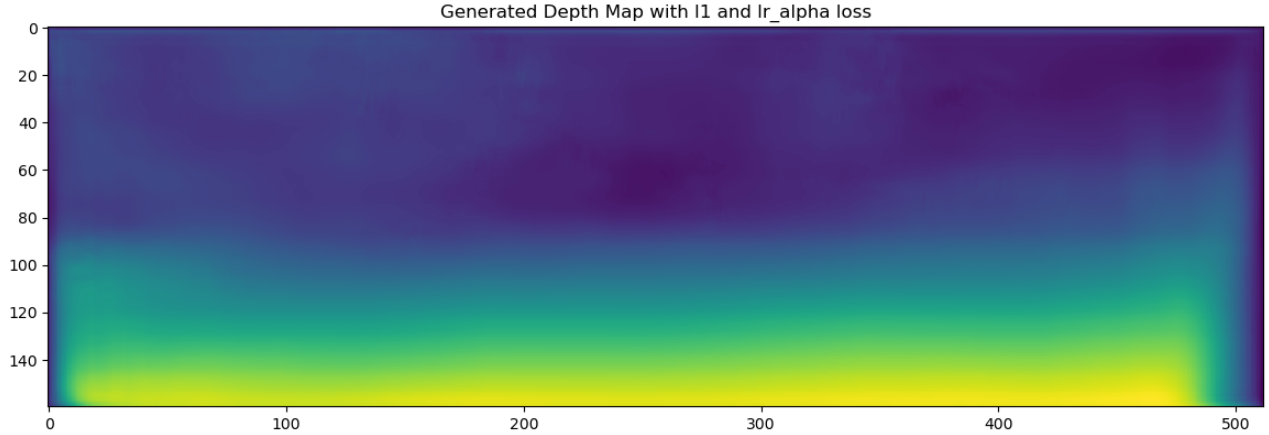




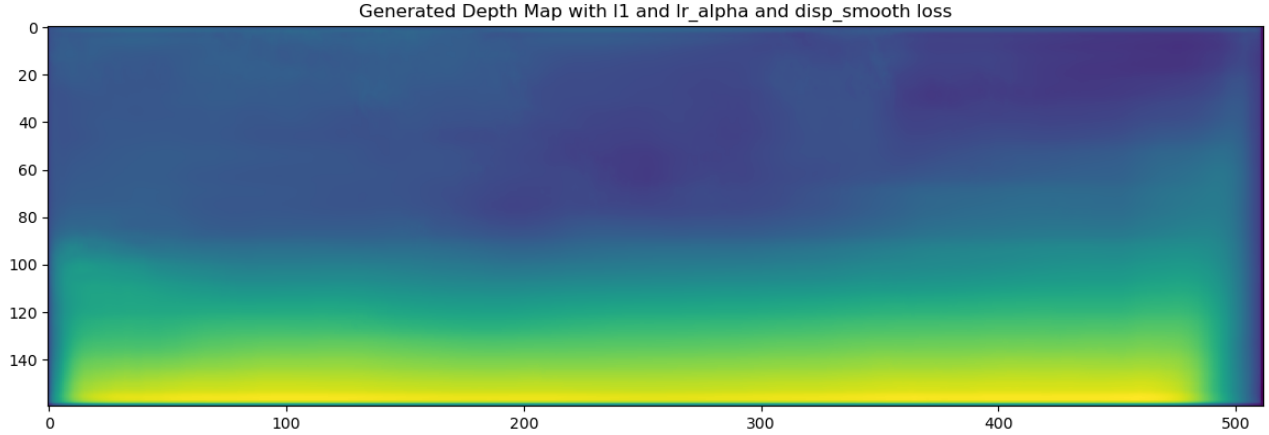
Generated Depth Map with l1 and disp_smooth loss



Generated Depth Map with l1 and lr_alpha loss



Generated Depth Map with l1 and lr_alpha and disp_smooth loss



Calculate the reconstructed loss on validation set and determine which loss function provided the best results

In [ ]:
```
models_name = [[l1_model, "l1 loss function"],
               [l1_lralpha_model, "l1 and disp_smooth loss function"],
               [l1_dispSmooth_model, "l1 and lr_alpha loss function"],
               [complete_model, "l1 and lr_alpha and disp_smooth loss functic

for i in range(len(models_name)):
    model = models_name[i][0]
    model.eval()
    name = models_name[i][1]
    my_criterion = nn.L1Loss().to(device)
    loss = train(stereo_test_dataloader, 1, model, None, my_criterion, False
    print(f"Average Train Loss with {name}: {loss}")
```

```
Average Train Loss with l1 loss function: 0.03149507282411351
Average Train Loss with l1 and disp_smooth loss function: 0.031644657254219
055
Average Train Loss with l1 and lr_alpha loss function: 0.03330018371343613
Average Train Loss with l1 and lr_alpha and disp_smooth loss function: 0.03
307314085609773
```

In [ ]:
```
#save for future use
torch.save(l1_model, 'model_checkpoints/l1loss.pt')
torch.save(l1_lralpha_model, 'model_checkpoints/l1_lralpha.pt')
torch.save(l1_dispSmooth_model, 'model_checkpoints/l1_dispSmooth.pt')
torch.save(complete_model, 'model_checkpoints/complete.pt')
```

After running testing various model with different loss functions on the validation set and obtaining the image loss (ie how close the image resembles original) we can see that the loss function containing only l1 yield in the smallest loss function. The higher loss combining all 3 loss function together may result due to over smoothing thus resulting in a greater loss.

4. Extensions

Some other experiment that could have been performed to improve determine the weighing for each loss function, however, due to limitation of hardware we were unable to train more models with varying levels of weights per loss component. Performing this test may have changed our result on the most effective loss function.

There are many practical real-world scenarios where depth estimation is required, such as in self-driving cars. Traditionally, expensive equipment and sensors such as LIDAR and stereo cameras have been used to determine depth, but using monocular depth estimation can be used as an alternative. By using a single camera, it is possible to determine the depth of surrounding objects in a cost-effective way. Using multiple cameras to determine the depth of objects can be impractical due to the real-time nature of the problem. This is because multiple cameras require sophisticated synchronization and calibration, which can be challenging to achieve in real-world applications. Therefore, monocular depth estimation has become an attractive alternative for real-time applications such as self-driving cars.

Moreover, monocular depth estimation has the advantage of being able to estimate depth in a wide range of lighting conditions and environments. It can work well even in low-light or adverse weather conditions, which can be a major limitation for other depth sensing technologies. Additionally, monocular depth estimation can provide accurate depth estimation for both static and dynamic scenes, making it a versatile technology for a range of applications.

In [ ]:

```
```