

8_Segmentation_students-with-ERROR-message

July 13, 2019

1 Hands-On Machine Learning

1.1 Session 8: Solving segmentation tasks with Deep Learning

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1.1.1 Goals of this Session

In this session you will... * learn how to adapt the classifier architecture to solve segmentation tasks * adapt your own classifier using the knowledge above

1.1.2 PASCAL VOC Dataset

In this exercise, you will use the PASCAL VOC dataset, which you already know from your last session. It contains 20 classes, and you used it to detect the presence of classes such as “person” or “bird” in your images. Apart from the mere presence of classes, PASCAL VOC also contains information about where exactly in the image the classes are present in the form of segmentation masks. Today, you will learn how to perform segmentations using Deep Learning.

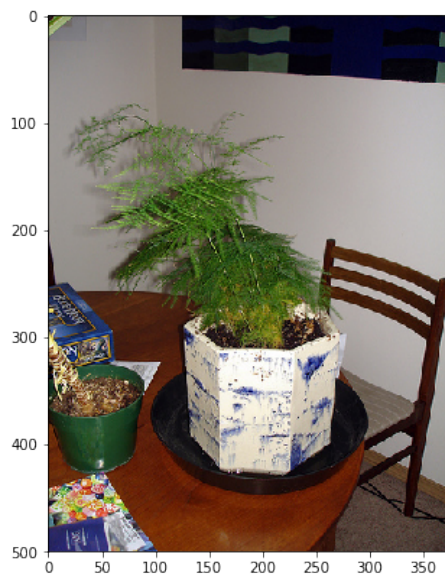
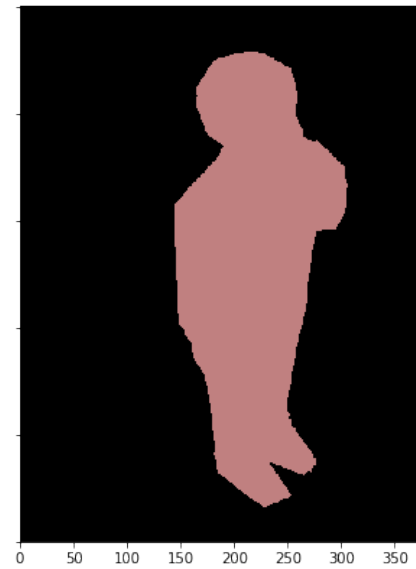
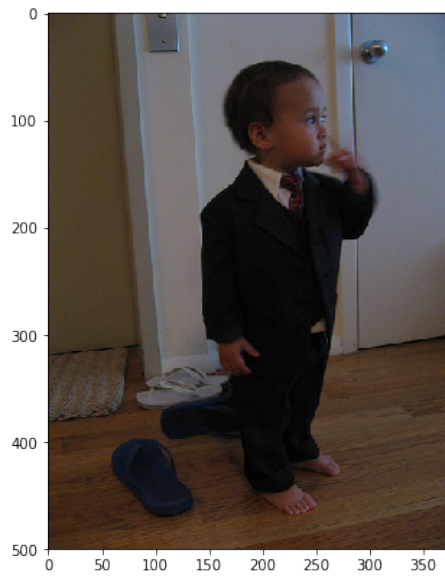
But first, let’s take a look at some images + segmentation masks from the dataset. They are loaded using the VOC class dataloader we provide you.

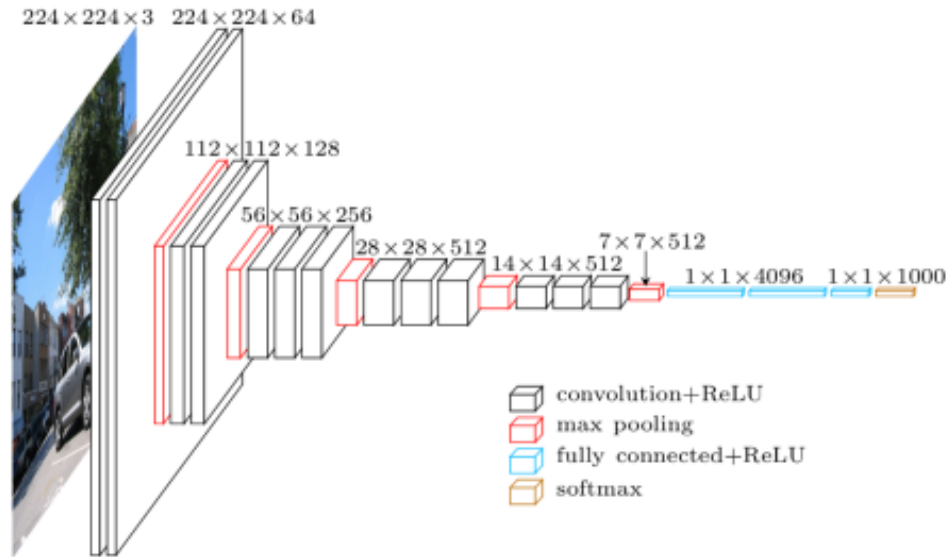
```
In [1]: %matplotlib inline
```

```
In [2]: #Import all important modules
        from voc import VOC
```

```
        from PIL import Image
        import matplotlib.pyplot as plt
        import numpy as np
        import torch
        import torch.nn as nn
        from torch.autograd import Variable
        import torchvision
        import math
        import os
        import torch.utils.model_zoo as model_zoo
        import train
        from misc import get_upsampling_weight
        os.environ['CUDA_VISIBLE_DEVICES'] = '6' # Set this parameter to your group number
```

```
In [3]: voc = VOC('train')
f, ax = plt.subplots(2, 2, sharey=True, figsize=(15,15))
for i in range(2):
    img, mask = voc.__getitem__(np.random.randint(0,8000 + 1), convert_mask = True)
    ax[i,0].imshow(img)
    ax[i,1].imshow(mask)
plt.show()
```





grafik.png

1.1.3 RECAP Deep Learning so far

As we learned in the prior sessions, Deep Learning has shown to be immensely powerful when performing object recognition tasks. Structurally, it consists of the following 3 core components:

1. Model architecture
2. Loss function
3. Optimization method.

Task: Which of the 3 components need to be adapted to change a classification model into a segmentation model? **Answer:** Model architecture and loss function

1.1.4 Changing the VGG-Net from a classifier to a segmentation model

In the following, we will change the VGG-Net from a classifier to a segmentation model. To do so, you will change the model architecture as well as the loss function accordingly.

So this is how the original VGG-Net looked like. Below, you can see a PyTorch implementation of the above representation.

```
In [4]: vgg = torchvision.models.vgg16()
        print(vgg)
```

```
VGG(
  (features): Sequential(
    (0): Conv2d(3, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (1): ReLU(inplace)
    (2): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (3): ReLU(inplace)
    (4): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
    (5): Conv2d(64, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
```

```

(6): ReLU(inplace)
(7): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
(8): ReLU(inplace)
(9): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
(10): Conv2d(128, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
(11): ReLU(inplace)
(12): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
(13): ReLU(inplace)
(14): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
(15): ReLU(inplace)
(16): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
(17): Conv2d(256, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
(18): ReLU(inplace)
(19): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
(20): ReLU(inplace)
(21): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
(22): ReLU(inplace)
(23): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
(24): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
(25): ReLU(inplace)
(26): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
(27): ReLU(inplace)
(28): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
(29): ReLU(inplace)
(30): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
)
(classifier): Sequential(
  (0): Linear(in_features=25088, out_features=4096, bias=True)
  (1): ReLU(inplace)
  (2): Dropout(p=0.5)
  (3): Linear(in_features=4096, out_features=4096, bias=True)
  (4): ReLU(inplace)
  (5): Dropout(p=0.5)
  (6): Linear(in_features=4096, out_features=1000, bias=True)
)
)

```

As you can see, the VGG model provided by torch is nicely split into the operations extracting **features** and those acting as the **classifier**. As we learned in the introductory talk, segmentation models can be thought of as classifying each pixel of the image in parallel. Therefore, it would be nice to maintain the HxW dimension in the classifying operations. **Task:** Define a new sequential model that maintains spatial HxW relations for the segmenter. Make sure that output shape = input shape! for your sequential model **Hints:** Use Convolutionary layers with appropriate Padding instead of Linear layers. A convolutionary operation with kernel-size 1x1 can serve as a per-pixel classifier.

```

In [7]: class Segmenter(nn.Module):
        def __init__(self, num_classes, pretrained=True):

```

```

super(Segmenter, self).__init__()

# extract features from VGG as shown above
vgg = torchvision.models.vgg16()
if pretrained:
    vgg.load_state_dict(model_zoo.load_url('https://download.pytorch.org/m
features = list(vgg.features.children())

self.features = nn.Sequential(*features)

self.segmenter = nn.Sequential(
    nn.Conv2d(512,4096,7, padding=3),
    nn.ReLU(),
    nn.Dropout(),
    nn.Conv2d(4096,4096,1,1),
    nn.ReLU(),
    nn.Dropout(),
    nn.Conv2d(4096, num_classes,1,1),
    nn.ReLU(),
    nn.Dropout()
)

def forward(self, x):
    #your forward call comes here
    return self.segmenter(self.features(x))

```

Let's check the model architecture!

```

In [8]: # PASCAL VOC contains 20 classes + 1 ignore label == 21 classes in total
        model = Segmenter(num_classes = 21).cuda()
        print(model)

```

```

Segmenter(
  (features): Sequential(
    (0): Conv2d(3, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (1): ReLU(inplace)
    (2): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (3): ReLU(inplace)
    (4): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
    (5): Conv2d(64, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (6): ReLU(inplace)
    (7): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (8): ReLU(inplace)
    (9): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
    (10): Conv2d(128, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (11): ReLU(inplace)
    (12): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
  )
  (segmenter): Sequential(
    (0): Conv2d(256, 4096, kernel_size=(7, 7), stride=(1, 1), padding=(3, 3))
    (1): ReLU(inplace)
    (2): Dropout2d()
    (3): Conv2d(4096, 4096, kernel_size=(1, 1), stride=(1, 1), padding=(0, 0))
    (4): ReLU(inplace)
    (5): Dropout2d()
    (6): Conv2d(4096, 21, kernel_size=(1, 1), stride=(1, 1), padding=(0, 0))
    (7): ReLU(inplace)
    (8): Dropout2d()
  )
)

```

```

(13): ReLU(inplace)
(14): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
(15): ReLU(inplace)
(16): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
(17): Conv2d(256, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
(18): ReLU(inplace)
(19): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
(20): ReLU(inplace)
(21): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
(22): ReLU(inplace)
(23): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
(24): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
(25): ReLU(inplace)
(26): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
(27): ReLU(inplace)
(28): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
(29): ReLU(inplace)
(30): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
)
(segmenter): Sequential(
  (0): Conv2d(512, 4096, kernel_size=(7, 7), stride=(1, 1), padding=(3, 3))
  (1): ReLU()
  (2): Dropout(p=0.5)
  (3): Conv2d(4096, 4096, kernel_size=(1, 1), stride=(1, 1))
  (4): ReLU()
  (5): Dropout(p=0.5)
  (6): Conv2d(4096, 21, kernel_size=(1, 1), stride=(1, 1))
  (7): ReLU()
  (8): Dropout(p=0.5)
)
)

```

Let's also check what the model output shape is.

```

In [9]: #remember, torch expects tensors of shape NxCxHxW
        shape = (1,3,180,180)
        print(model.forward(Variable(torch.Tensor(np.ones(shape=shape,dtype=np.float32))))).cuda()

torch.Size([1, 21, 5, 5])

```

Our model should now output tensors with HxW = 10 instead of the 1x1 for the classifier (if it doesn't and you fed shape of (1,3,320,320) into the model, check your model definition!). However, the shape is still far too coarse to directly compare to the input segmentation mask. **Task:** What parameters determine the output shape in HxW dimension of your model? Try changing some of your parameters, or even the input shape **Answer:** conv kernel size, conv padding, conv stride, max pool kernel size, maxpool stride, #pool-layer, #conv-layer(if padding!=(kernel size-1)/2)

If you have played around with the Input shape, you may have seen that an output is generated for any HxW shape, one major advantage of Fully Convolutional Networks (FCNs) compared to those using Fully Connected Layers! However, while your initial segmenter is capable of generating 2-D output, its output HxW dimension are way smaller than those of the image we fed into it. Therefore, we need to somehow interpolate the original input from this dense map. **Task:** How could this be done? **Answer:** bilinear interpolation, transposed convolutions, upsampling,

In Deep Learning, a neat operation exists, the Transposed Convolution. In its essence, it pads the input BEFORE performing the normal convolution operation on it. By choosing the padding in between the input(blue), kernel_size and stride accordingly, upscaling can be performed. If desired, the kernel weights are again learnable. Neat!

Task Modify your segmenter by adding Transposed Convolution (nn.ConvTranspose2d) for interpolation so that the output size matches input size for input of shape (1,3,320,320). **Hints:** 1. The output shape of the nn.ConvTranspose2d is given by Input: $(N, C_{in}, H_{in}, W_{in})$ Output: $(N, C_{out}, H_{out}, W_{out})$ where $H_{out} = (H_{in}-1)stride[0] + 2padding[0] + kernel_size[0]$ and $W_{out} = (W_{in}-1)stride[1] + 2padding[1] + kernel_size[1]$

2. Dimensionality reduction is only performed by the MaxPool layers. In total dimensionality is reduced by a factor of $2^5 = 32$. Therefore, stride of nn.ConvTranspose2d should be set to 32 so that the spatial distance between the upsampled features is kept the same.

In [32]:

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```
In [11]: class Segmenter(nn.Module):
    def __init__(self, num_classes, pretrained=True):
        super(Segmenter, self).__init__()

        # extract features from VGG as shown above
        vgg = torchvision.models.vgg16()
        if pretrained:
            vgg.load_state_dict(model_zoo.load_url('https://download.pytorch.org/'))
        features, classifier = list(vgg.features.children()), list(vgg.classifier.children())

        self.features = nn.Sequential(*features)

        #self.segmenter = nn.Sequential(
        #copy your Segmenter from above here

        #)
        self.segmenter = nn.Sequential(
            nn.Conv2d(512,4096,7, padding=3),
            nn.ReLU(),
            nn.Dropout(),
            nn.Conv2d(4096,4096,1,1),
            nn.ReLU(),
            nn.Dropout(),
            nn.Conv2d(4096, num_classes,1,1),
```

```

        nn.ReLU(),
        nn.Dropout(),
        nn.ConvTranspose2d(num_classes, num_classes, kernel_size=64, stride=32, padding=16)
    )

    self.segmenter[-1].weight.data.copy_(get_upsampling_weight(num_classes, num_classes, 64, 32))

    """
    as we are short on training time, we need to initialize our interpolator weights
    for a fast convergence.
    Do this using the get_upsampling_weight(no_input features, no_output features, kernel_size, stride)
    You can change the weights of a torch layer by calling its .weight.data.copy_()
    """

    def forward(self, x):
        #your forward call comes here
        return self.segmenter(self.features(x))

model = Segmenter(num_classes = 21)
shape = (1,3,320,320)
print(model.forward(Variable(torch.Tensor(np.ones(shape=shape,dtype=np.float32)))).size())

torch.Size([1, 21, 320, 320])

```

Our model is now able to learn interpolation from the [1, 21, 10, 10] predicted segmentation to the [1,21,320,320] sized input segmentation!. The next step is to train our model for a little bit and see what the output is. This is done by using the train module we provide you. In this train module, the model is trained with SGD using the specifications below. It does so by iterating over the contents of the VOC dataloader, optimizing the loss given by *nn.CrossEntropyLoss*. After every epoch, it uses the validation set of VOC for validation, printing averages for loss, ACCuracy, mean ACCuracy of all CLASSES, mean Intersection over Union and Frequency Weighted ACCuracy. It furthermore returns validation images that can be displayed for visualization purposes.

```

In [12]: args = {
    'epoch_num': 10,
    'lr': 1e-10,
    'weight_decay': 1e-4,
    'momentum': 0.95,
    'lr_patience': 100, # large patience denotes fixed lr
    'snapshot': '', # empty string denotes learning from scratch
    'print_freq': 20,
    'val_save_to_img_file': False,
    'val_img_sample_rate': 0.1 # randomly sample some validation results to display
}
imges = train.main(train_args=args, model=model)

{'epoch_num': 10, 'lr': 1e-10, 'weight_decay': 0.0001, 'momentum': 0.95, 'lr_patience': 100, 'snapshot': '', 'print_freq': 20, 'val_save_to_img_file': False, 'val_img_sample_rate': 0.1}

```



```
/usr/local/anaconda3/lib/python3.6/site-packages/torch/nn/functional.py:52: UserWarning: size_
warnings.warn(warning.format(ret))
```

```
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best record: [val loss 59297.94531], [acc 0.84010], [acc_cls 0.52919], [mean_iu 0.45258], [fwa
-----
```

While the model is training, you are surely asking yourself how the `nn.CrossEntropyLoss` works. It's based on the Negative-Log Likelihood Loss used for classification, which is defined as follows:

$$L_{pixel} = - \sum_{n=1}^M y_n \log(p_n)$$

Where M are the number of classes, and y_n is equal to 1 for the true class label and 0 otherwise.

Task: Modify the NLL Loss from classification to segmentation. **Hint:** Remember that segmentation can be understood as pixel-wise classification. **Answer:**

$$L = \sum_{pixel=1}^N L_{pixel}$$

After training has finished, let's look at some images from the validation set! Repeatedly execute the cell below to get several glimpses.

```
In [13]: npimg = imges.numpy()
         img_size = 405
         img_to_show = 3
         random = np.random.randint(0,65)
```



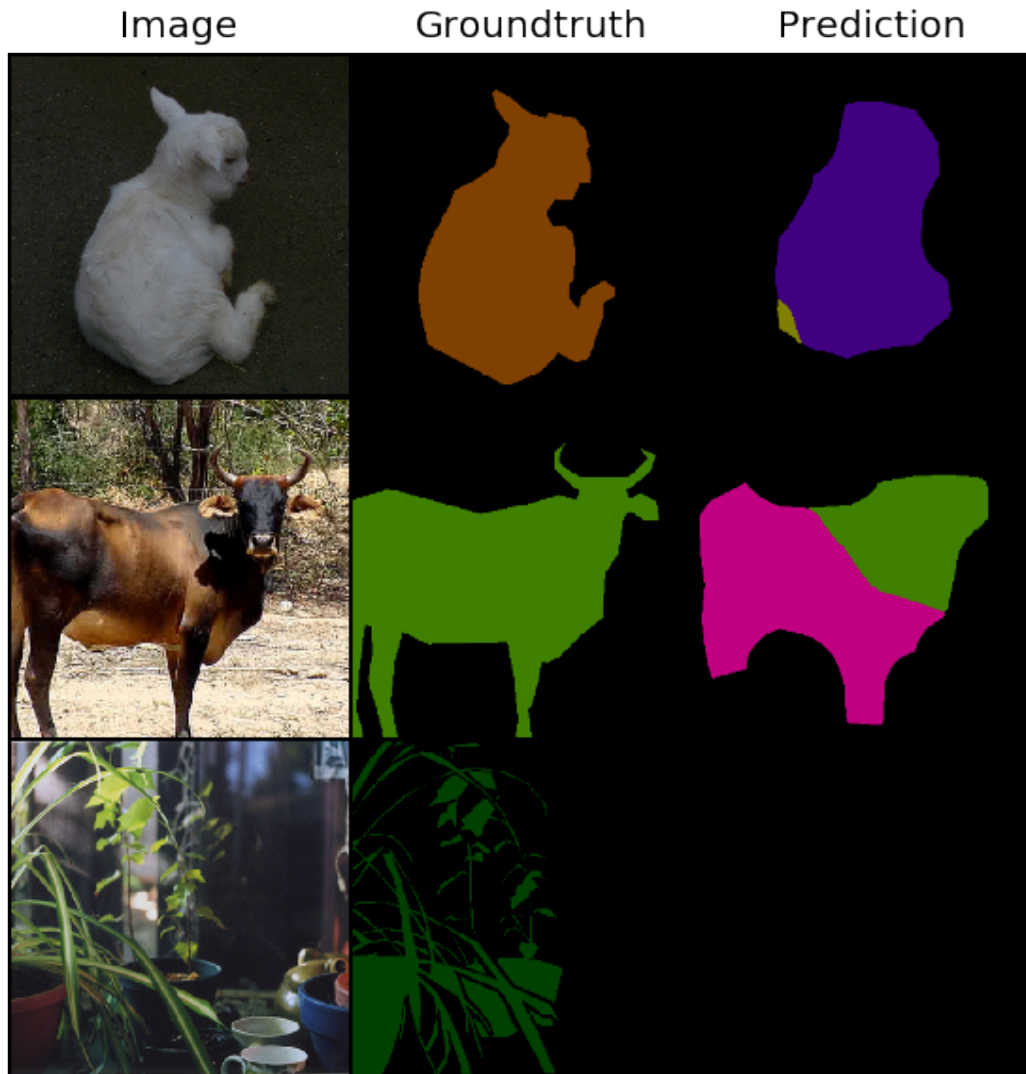
```

npimg = npimg[:,random*img_size:(random+img_to_show)*img_size, :]
plt.figure(figsize=(10,10))
plt.text(130,-20, 'Image', fontsize = 20)
plt.text(480,-20, 'Groundtruth', fontsize = 20)
plt.text(910,-20, 'Prediction', fontsize = 20)
plt.axis('off')

plt.imshow(np.transpose(npimg, (1,2,0)), interpolation='nearest')

```

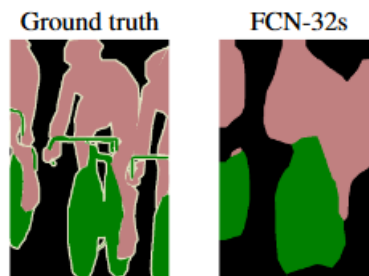
Out[13]: <matplotlib.image.AxesImage at 0x7f76042575f8>



When looking at your model predictions, keep in mind that we trained only for a very short time (10 min) compared to the hours to days it would take normally. In the best case scenario, something along the following lines can be achieved for the VGG-net that we adapted to segmentation.



grafik.png



If you can still see the checkerboard pattern of the original (1x21x10x10) predictions in your (1x21x320x320) segmentation map, your design choice regarding the `nn.ConvTranspose2d` was poor. Rethink and make sure your interpolation kernel is big enough to “see” at least 2 of the original (1x21x10x10) predictions. Redesign and retrain your model!

Even under best conditions, the model prediction is way coarser than the GT annotation. The reason for this is that the input for the transposed convolution layer simply has too little spatial resolution. If we add features with higher spatial resolution to our model architecture, we achieve a segmentation like this:

Task: Think of ways to include features with high spatial resolution into the interpolation learned by the transposed convolution? **Hint:** How about performing multiple transposed convolutions? Spatial resolution is reduced only upon every MaxPool layer. **Answer:** U-Net :)

2 Additional Tasks

Task: Using the prior knowledge of skip connections, try to implement the U-Net, a state-of-the-art Deep Learning architecture for semantic segmentation. Use the visual help for guidance! Cropping is not required since you used Padded Convolutions. Skip connections/Concatenation operations can be implemented using the `torch.cat()` function. Check for output and input shapes!

```
In [14]: class U_Net (nn.Module):
          def __init__(self, num_classes, pretrained=True):
              #your model implementation comes here
              super(U_Net, self).__init__()
```

```

self.skip1 = nn.Sequential(
    nn.Conv2d(3,64,3,padding=1),
    nn.ReLU(),
    nn.Dropout(),
    nn.Conv2d(64,64,3,padding=1),
    nn.ReLU(),
    nn.Dropout(),
)
input_features = 64
self.skip2 = nn.Sequential(
    nn.MaxPool2d(2,2),
    nn.Conv2d(input_features,2*input_features,3,padding=1),
    nn.ReLU(),
    nn.Dropout(),
    nn.Conv2d(2*input_features,2*input_features,3,padding=1),
    nn.ReLU(),
    nn.Dropout(),
)
input_features = 128
self.skip3 = nn.Sequential(
    nn.MaxPool2d(2,2),
    nn.Conv2d(input_features,2*input_features,3,padding=1),
    nn.ReLU(),
    nn.Dropout(),
    nn.Conv2d(2*input_features,2*input_features,3,padding=1),
    nn.ReLU(),
    nn.Dropout(),
)
input_features = 256
self.skip4 = nn.Sequential(
    nn.MaxPool2d(2,2),
    nn.Conv2d(input_features,2*input_features,3,padding=1),
    nn.ReLU(),
    nn.Dropout(),
    nn.Conv2d(2*input_features,2*input_features,3,padding=1),
    nn.ReLU(),
    nn.Dropout(),
)
input_features = 512
self.middle= nn.Sequential(
    nn.MaxPool2d(2,2),
    nn.Conv2d(input_features,2*input_features,3,padding=1),
    nn.ReLU(),
    nn.Dropout(),
    nn.Conv2d(2*input_features,2*input_features,3,padding=1),
    nn.ReLU(),
    nn.Dropout(),
    #upconv1

```

```

        nn.ConvTranspose2d(1024, 1024, kernel_size=2, stride=2),
        nn.Conv2d(1024,512, 1),
        nn.ReLU(),
        nn.Dropout(),
    )

    #expansive2 because includes second upconv
    self.expansive2 = nn.Sequential(
        nn.Conv2d(1024,512,3, padding=1),
        nn.ReLU(),
        nn.Dropout(),
        nn.Conv2d(512,512,3, padding=1),
        nn.ReLU(),
        nn.Dropout(),
        #upconv2
        nn.ConvTranspose2d(512, 512, kernel_size=2, stride=2),
        nn.Conv2d(512, 256, 1),
        nn.ReLU(),
        nn.Dropout(),
    )

    self.expansive3 = nn.Sequential(
        nn.Conv2d(512,256,3, padding=1),
        nn.ReLU(),
        nn.Dropout(),
        nn.Conv2d(256,256,3, padding=1),
        nn.ReLU(),
        nn.Dropout(),
        #upconv3
        nn.ConvTranspose2d(256, 256, kernel_size=2, stride=2),
        nn.Conv2d(256, 128, 1),
        nn.ReLU(),
        nn.Dropout(),
    )

    self.expansive4 = nn.Sequential(
        nn.Conv2d(256,128,3, padding=1),
        nn.ReLU(),
        nn.Dropout(),
        nn.Conv2d(128,128,3, padding=1),
        nn.ReLU(),
        nn.Dropout(),
        #upconv4
        nn.ConvTranspose2d(128, 128, kernel_size=2, stride=2),
        nn.Conv2d(128, 64, 1),
        nn.ReLU(),
        nn.Dropout(),
    )

    self.masks = nn.Sequential(
        nn.Conv2d(128,64,3, padding=1),

```

```

        nn.ReLU(),
        nn.Dropout(),
        nn.Conv2d(64,64,3, padding=1),
        nn.ReLU(),
        nn.Dropout(),
        nn.Conv2d(64, num_classes, 1,1)
    )
    # ACHTUNG!
    self.middle[-4].weight.data.copy_(get_upsampling_weight(1024,1024, kernel_size))
    self.expansive2[-4].weight.data.copy_(get_upsampling_weight(512, 512, kernel_size))
    self.expansive3[-4].weight.data.copy_(get_upsampling_weight(256, 256, kernel_size))
    self.expansive4[-4].weight.data.copy_(get_upsampling_weight(128, 128, kernel_size))

    def forward(self, x):
        #your forward call comes here
        s1 = self.skip1(x)
        s2 = self.skip2(s1)
        s3 = self.skip3(s2)
        s4 = self.skip4(s3)
        m = self.middle(s4)
        e2 = self.expansive2(torch.cat((m,s4), dim=1))
        e3 = self.expansive3(torch.cat((e2,s3), dim=1))
        e4 = self.expansive4(torch.cat((e3,s2), dim=1))
        masks = self.masks(torch.cat((e4,s1), dim=1))
        return masks

```

Task: Implement the `get_upsampling_weight(no_input features, no_output features, kernel_size)` function used to initialize the convolution kernels of the transposed convolution with a bilinear interpolation kernel.

In [15]: `def get_upsampling_weight(no_input features, no_output features, kernel_size):`

```

File "<ipython-input-15-b7c8c27c422a>", line 1
def get_upsampling_weight(no_input features, no_output features, kernel_size):
    ^
SyntaxError: invalid syntax

```

2.0.1 Feedback

Aaaaaand we're done

If you have any suggestions on how we could improve this session, please let us know in the following cell. What did you particularly like or dislike? Did you miss any contents?