Homework 3

November 19, 2021

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ECE 253 - Fundamentals of Digital Image Processing

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Assignment3_Problem1

November 21, 2021

Import Libraries

[1]:
```
import cv2
import numpy as np
from matplotlib import pyplot as plt
```

Function performs Non-maximum supression

[2]:
```
def nms(I_grad_mag, I_grad_edge):
    #  Non-maximum supression
    I_grad_mag_nms = np.copy(I_grad_mag)
    a_temp = [];
    for i in range(1, I_grad_mag.shape[0]-1):
        for j in range (1, I_grad_mag.shape[1]-1):

            ang_val = np.rint(np.abs(I_grad_edge[i,j])/(np.pi/4))
            if (ang_val not in a_temp):
                a_temp.append(ang_val)

            if(ang_val == 0 or ang_val == 4):
                candidate = np.array([I_grad_mag[i,j+1], I_grad_mag[i,j-1]])
            elif (ang_val == 1):
                candidate = np.array([I_grad_mag[i-1,j+1], I_grad_mag[i+1,j-1]])
            elif (ang_val == 2):
                candidate = np.array([I_grad_mag[i+1,j], I_grad_mag[i-1,j]])
            elif (ang_val == 3):
                candidate = np.array([I_grad_mag[i+1,j+1], I_grad_mag[i-1,j-1]])

            if(np.all(I_grad_mag[i][j]>candidate)):
                I_grad_mag_nms[i,j] = I_grad_mag[i,j]
            else:
                I_grad_mag_nms[i,j] = 0

    #print(a_temp)
    return I_grad_mag_nms
```

[ ]:
```
```

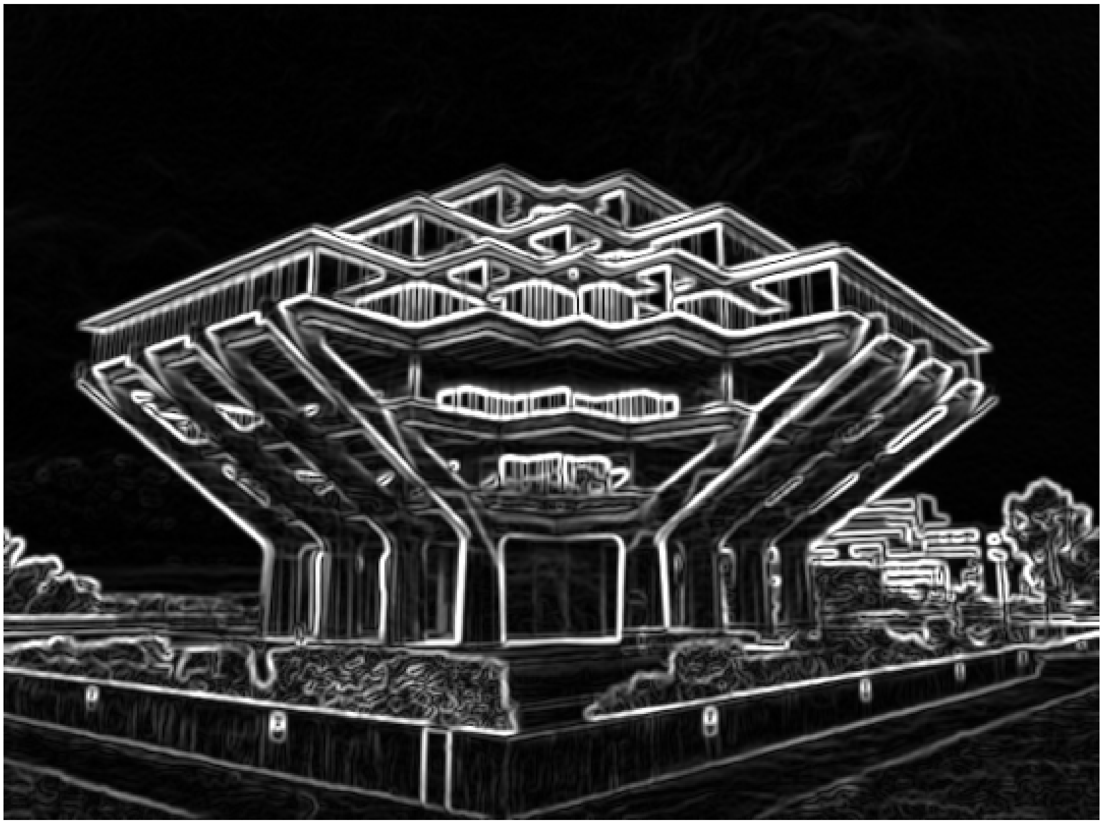
Main Canny Edge Detector

[3]:
```python
def cannyEdgeDetection(I, T):
    # Gaussian smoothing

    assert(np.shape(I.shape)[0] == 2)

    filter = np.array([[2, 4, 5, 4, 2],[4, 9, 12, 9, 4],[5, 12, 15, 12, 5],
                       [4, 9, 12, 9, 4],[2, 4, 5, 4, 2]])/159
    I_smooth = cv2.filter2D(I, -1,filter)


    # Apply Sobel operator
    filter = np.array([[-1,0,1],[-2,0,2],[-1,0,1]])
    I_edge_x = cv2.filter2D(I_smooth, -1, filter)

    filter = np.array([[-1,-2,-1],[0,0,0],[1,2,1]])
    I_edge_y = cv2.filter2D(I_smooth, -1, filter)

    # Compute gradient images
    I_edge_mag = np.sqrt(np.square(I_edge_x) + np.square(I_edge_y))
    I_edge_dir = np.arctan2(I_edge_y,I_edge_x)
    I_edge_mag[I_edge_mag>=1] = 1.0

    # Apply NMS
    I_edge_NMS = nms(I_edge_mag, I_edge_dir)

    # Prevent clipping
    I_edge = np.copy(I_edge_NMS)

    # Threshold
    I_edge[I_edge<=T] = 0
    I_edge[I_edge>T] = 1.0

    return I_edge_mag , I_edge_NMS, I_edge
```

Read image and perform Canny edge detection

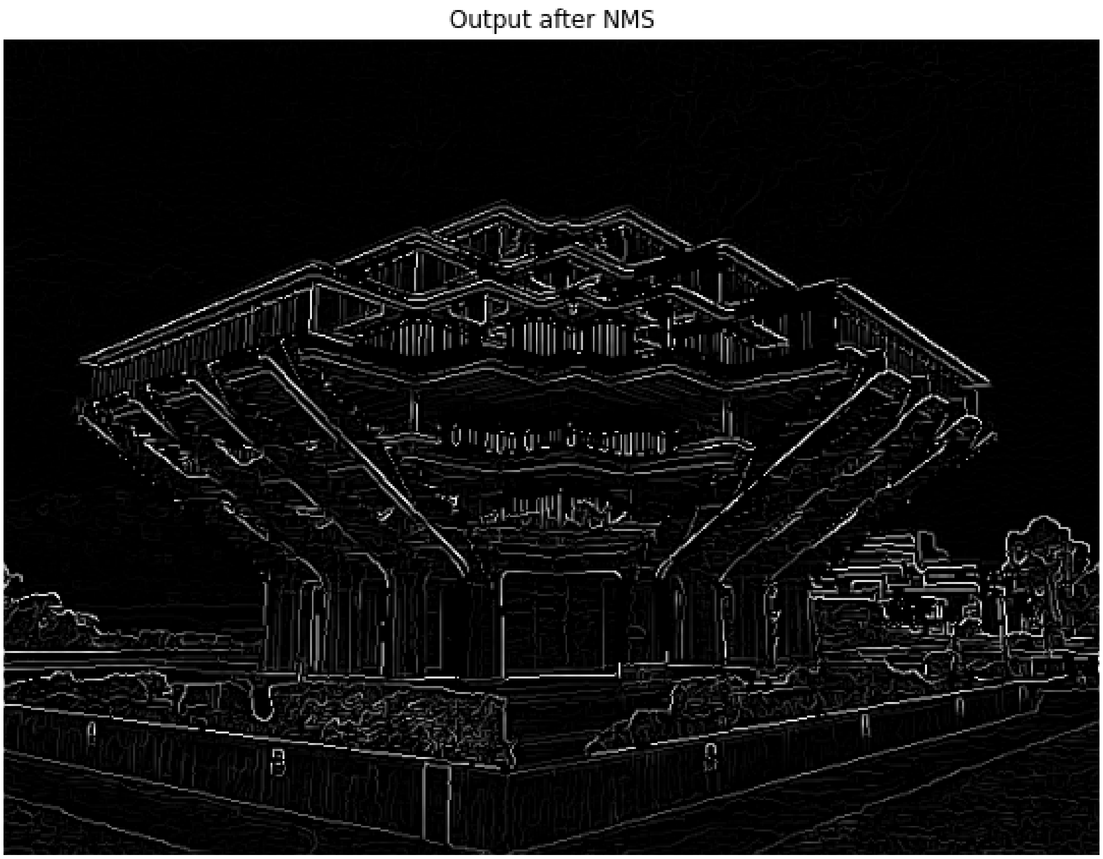
[4]:
```python
I = cv2.imread('/home/parth/work/UCSD/Fall 2021/ECE 253 Image Processing/
 ↪Assignment 3/HW3_geisel.jpg',0)
#I = cv2.resize(I, (0,0), fx=0.25, fy=0.25)
I = I/255

plt.figure(figsize=(10,10))
plt.imshow(I, cmap='gray')
plt.title('Original Image')
plt.axis('off')
plt.show()
```

Gradient magnitude image



[7]:

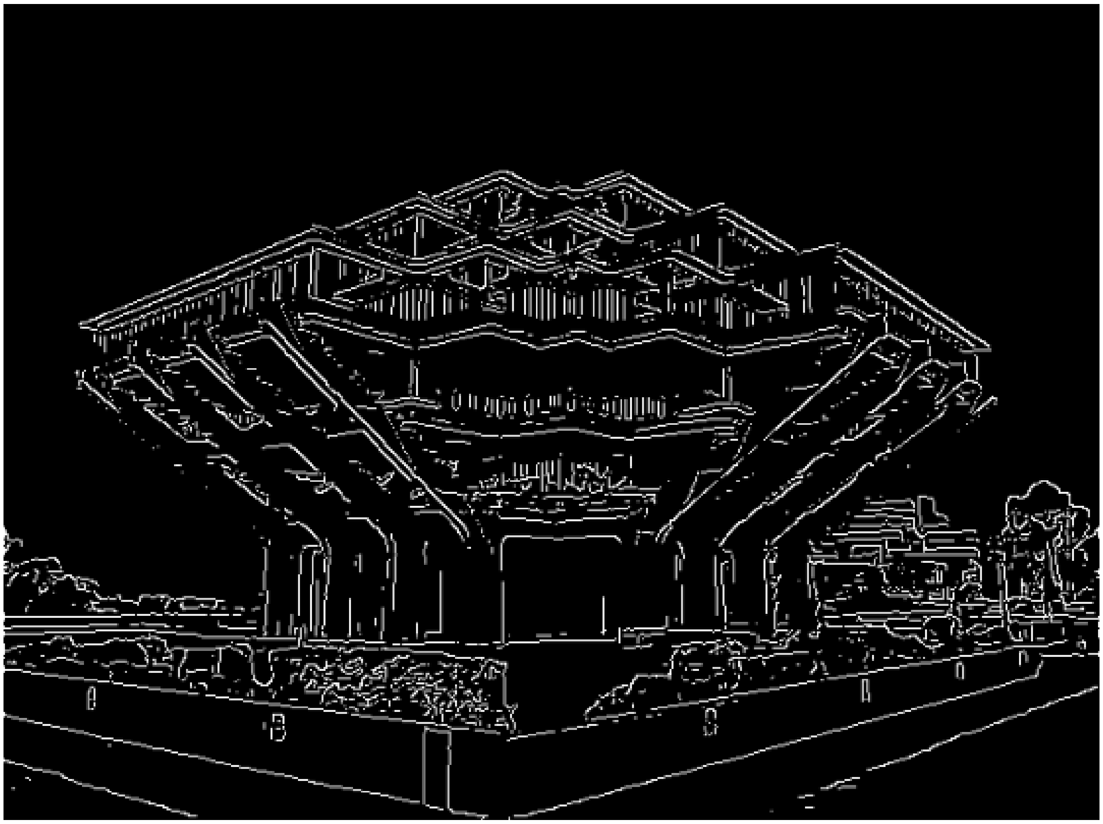
```
plt.figure(figsize=(10,10))
plt.imshow(I_edge_NMS ,cmap='gray')
plt.title('Output after NMS')
plt.axis('off')
plt.show()
```



Output of canny edge detector with a threshold 0.25

[8]:
```
plt.figure(figsize=(10,10))
plt.imshow(I_edge, cmap='gray')
plt.title('Output of canny edge detector')
plt.axis('off')
plt.show()
```

Output of canny edge detector



```
[ ]:
```

Assignment3_Problem2

November 18, 2021

[354]:
```
import numpy as np
import cv2
from matplotlib import pyplot as plt
```

Reading the original image

[355]:
```
I = cv2.imread('Car.tif', 0)
plt.imshow(I, cmap='gray')
plt.title('Original car.tif')
plt.axis('off')
plt.show()
```

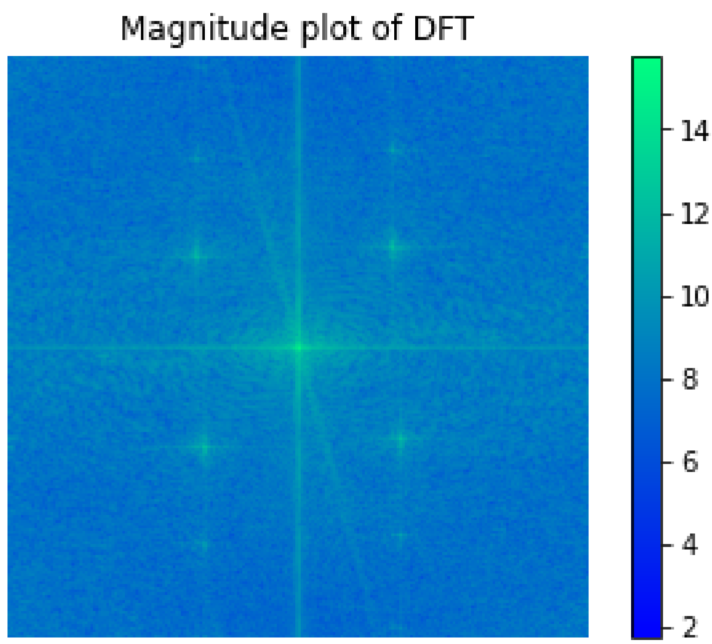
Padding the image uniformly to make it of size (512,512)

[356]:
```
pad_x = int((512-I.shape[0])/2)
pad_y = int((512-I.shape[1])/2)
I_pad = np.pad(I, ((pad_x, pad_x),(pad_y, pad_y)), constant_values = (0))
```

DFT of original image with the dc term shifted to the center

[357]:
```
I_DFT = np.fft.fftshift(np.fft.fft2(I_pad))
I_DFT_mag = np.abs(I_DFT)
```

[358]:
```
im = plt.imshow(np.log(I_DFT_mag), cmap='winter')
plt.title('Magnitude plot of DFT')
plt.colorbar(im)
plt.axis('off')
plt.show()
```



Notch reject filter with n = 4 and D_0 = 20. The four impulses are taken to be at (85,170), (85, 85), (85, -85) and (85, -170)

[359]:
```
# Notch Reject Butterworth filter
x_axis = np.linspace(-256,255,512)
y_axis = np.linspace(-256,255,512)
[u,v] = np.meshgrid(x_axis,y_axis)

H_NRBF = np.ones_like(u)

n = 4
D_0 = 20

U = np.array([1,1,1,1])*85
V = np.array([170,85,-85,-170])
```

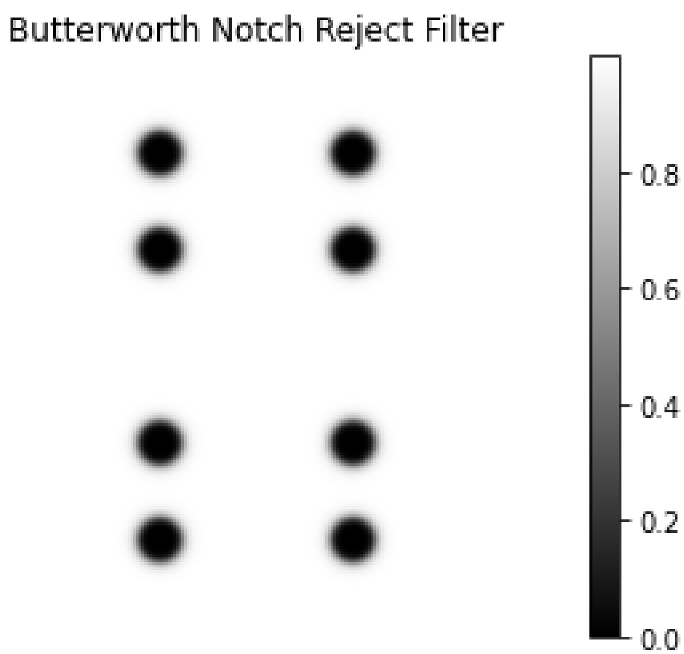
```
impulse_loc = np.stack((U,V))
```

Creating the BNRF.

[360]:
```
for i in range(H_NRBF.shape[0]):
    for j in range(H_NRBF.shape[1]):
        p = np.array([[u[i,j]],[v[i,j]]])
        d1 = np.linalg.norm(impulse_loc-p, axis=0) + 1e-9
        d2 = np.linalg.norm(impulse_loc+p, axis=0) + 1e-9
        f1 = 1/(1+pow(D_0/d1,2*n))
        f2 = 1/(1+pow(D_0/d2,2*n))
        H_NRBF[i][j] = np.prod(f1*f2)
```

BNRF in the frequency domain

[361]:
```
im  = plt.imshow(H_NRBF, cmap='gray')
plt.colorbar(im)
plt.title('Butterworth Notch Reject Filter')
plt.axis('off')
plt.show()
```



Filtering the given image with the constructed filter in the frequency domain

[362]:
```
I_filered = I_DFT* H_NRBF
I_filered_mag = np.abs(I_filered)
```

Obtaining the filter image by taking the inverse fourirer transform

[363]:
```
I_final = np.abs(np.fft.ifft2(I_filered))
I_final_crop = I_final[pad_x+1:pad_x+246, pad_y+1:pad_y+168]
plt.imshow(I_final_crop, cmap='gray')
plt.title('Filtered Image')
plt.axis('off')
plt.show()
```

Filtered Image

Readin the original image Street.png

[364]:
```
I = cv2.imread('Street.png',0)

plt.imshow(I, cmap='gray')
plt.title('Original Image street.png')
plt.axis('off')
plt.show()
```

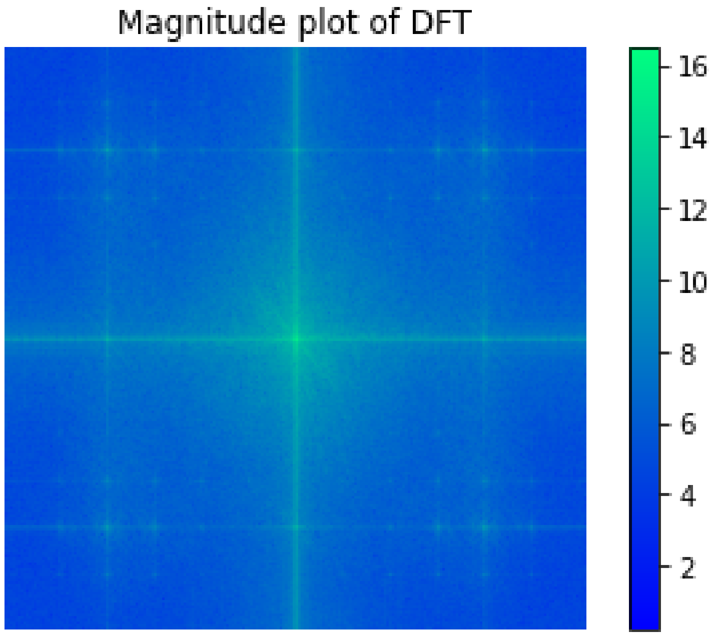
Padding the image

[365]:
```
pad_x = int((512-I.shape[0])/2)
pad_y = int((512-I.shape[1])/2)
I_pad = np.pad(I, ((pad_x, pad_x),(pad_y, pad_y+1)), constant_values = (0))
```

Magnitude plot of the DFT of the image shifted to the center

[366]:
```
I_DFT = np.fft.fftshift(np.fft.fft2(I_pad))
I_DFT_mag = np.abs(I_DFT)
```

[367]:
```
im = plt.imshow(np.log(I_DFT_mag), cmap='winter')
plt.colorbar(im)
plt.axis('off')
plt.title('Magnitude plot of DFT')
plt.show()
```



Notch reject filter with n = 5 and $D_0 = 10$. The four impulses are taken to be at (0,200) and (170,0)

[368]:
```
# Notch Reject Butterworth filter
x_axis = np.linspace(-256,255,512)
y_axis = np.linspace(-256,255,512)
[u,v] = np.meshgrid(x_axis,y_axis)

H_NRBF = np.ones_like(u)

n = 5
D_0 = 10

U = np.array([0,1])*170
V = np.array([1,0])*200
impulse_loc = np.stack((U,V))
```

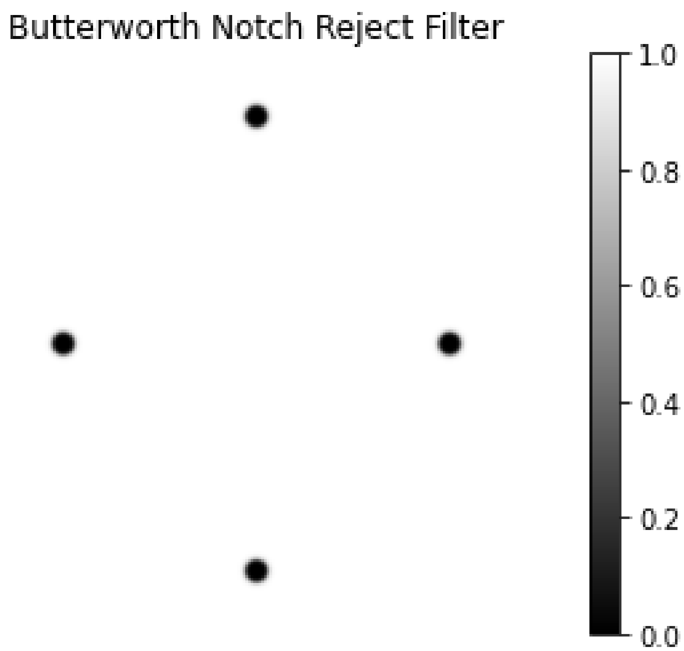
Constructing the Butterworth notch reject filter in the frequency domain

[369]:
```
for i in range(H_NRBF.shape[0]):
    for j in range(H_NRBF.shape[1]):
        p = np.array([[u[i,j]],[v[i,j]]])
        d1 = np.linalg.norm(impulse_loc-p, axis=0) + 1e-9
        d2 = np.linalg.norm(impulse_loc+p, axis=0) + 1e-9
        f1 = 1/(1+pow(D_0/d1,2*n))
        f2 = 1/(1+pow(D_0/d2,2*n))
```

```
        H_NRBF[i][j] = np.prod(f1*f2)
```

Filter plotted in the frequency domain

[370]:
```
im  = plt.imshow(H_NRBF, cmap='gray')
plt.colorbar(im)
plt.axis('off')
plt.title('Butterworth Notch Reject Filter')
plt.show()
```



Filtering the given image with the constructed filter in the frequency domain

[371]:
```
I_filered = I_DFT* H_NRBF
I_filered_mag = np.abs(I_filered)
```

Obtaining the filter image by taking the inverse fourirer transform

[372]:
```
I_final = np.abs(np.fft.ifft2(I_filered))
I_final_crop = I_final[pad_x+1:pad_x+I.shape[0], pad_y+1:pad_y+I.shape[1]]
plt.imshow(I_final_crop, cmap='gray')
plt.title('Filtered Image')
plt.axis('off')
plt.show()
```

Filtered Image

Assignment3_Problem3

November 19, 2021

[27]:
```
import torch
import torchvision
import torchvision.transforms as transforms
```

[28]:
```
transform = transforms.Compose(
    [transforms.ToTensor(),
     transforms.Normalize((0.5, 0.5, 0.5), (0.5, 0.5, 0.5))])

batch_size = 4

trainset = torchvision.datasets.CIFAR10(root='./data', train=True,
                                        download=True, transform=transform)
trainloader = torch.utils.data.DataLoader(trainset, batch_size=batch_size,
                                          shuffle=True, num_workers=2)

testset = torchvision.datasets.CIFAR10(root='./data', train=False,
                                       download=True, transform=transform)

testloader = torch.utils.data.DataLoader(testset, batch_size=batch_size,
                                         shuffle=False, num_workers=2)

classes = ('plane', 'car', 'bird', 'cat',
           'deer', 'dog', 'frog', 'horse', 'ship', 'truck')
```

```
Files already downloaded and verified
Files already downloaded and verified
```

(i)
The batch size is 4 and the number of images used for training is 50,000.

(ii) Yes, we do normalize the images in this example.

[29]:
```
import matplotlib.pyplot as plt
import numpy as np

# functions to show an image


def imshow(img):
```

```
    img = img / 2 + 0.5      # unnormalize
    npimg = img.numpy()
    plt.figure(figsize=(12,7))
    plt.axis('off')
    plt.imshow(np.transpose(npimg, (1, 2, 0)))
    plt.show()


# get some random training images
dataiter = iter(trainloader)
images, labels = dataiter.next()

# show images
imshow(torchvision.utils.make_grid(images))
# print labels
print(' '.join('%5s' % classes[labels[j]] for j in range(batch_size)))
```

```
  cat truck horse  bird
```

[30]:
```
import torch.nn as nn
import torch.nn.functional as F


class Net(nn.Module):
    def __init__(self):
        super().__init__()
        self.conv1 = nn.Conv2d(3, 6, 5)
        self.pool = nn.MaxPool2d(2, 2)
        self.conv2 = nn.Conv2d(6, 16, 5)
        self.fc1 = nn.Linear(16 * 5 * 5, 120)
        self.fc2 = nn.Linear(120, 84)
        self.fc3 = nn.Linear(84, 10)

    def forward(self, x):
        x = self.pool(F.relu(self.conv1(x)))
```

```
        x = self.pool(F.relu(self.conv2(x)))
        x = torch.flatten(x, 1) # flatten all dimensions except batch
        x = F.relu(self.fc1(x))
        x = F.relu(self.fc2(x))
        x = self.fc3(x)
        return x

    def visualizeFirstLayer(self, x):
        return self.pool(F.relu(self.conv1(x)))

net = Net()
```

[31]:
```
device = torch.device("cuda:0" if torch.cuda.is_available() else "cpu")

# Assuming that we are on a CUDA machine, this should print a CUDA device:

print(device)
net.to(device)
```

```
cuda:0
```

[31]:
```
Net(
  (conv1): Conv2d(3, 6, kernel_size=(5, 5), stride=(1, 1))
  (pool): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1,
ceil_mode=False)
  (conv2): Conv2d(6, 16, kernel_size=(5, 5), stride=(1, 1))
  (fc1): Linear(in_features=400, out_features=120, bias=True)
  (fc2): Linear(in_features=120, out_features=84, bias=True)
  (fc3): Linear(in_features=84, out_features=10, bias=True)
)
```

[32]:
```
import torch.optim as optim

criterion = nn.CrossEntropyLoss()
optimizer = optim.SGD(net.parameters(), lr=0.001, momentum=0.9)
```

[33]:
```
loss_list = []
for epoch in range(2):  # loop over the dataset multiple times

    running_loss = 0.0
    for i, data in enumerate(trainloader, 0):
        # get the inputs; data is a list of [inputs, labels]
        inputs, labels = data[0].to(device), data[1].to(device)

        # zero the parameter gradients
        optimizer.zero_grad()
```

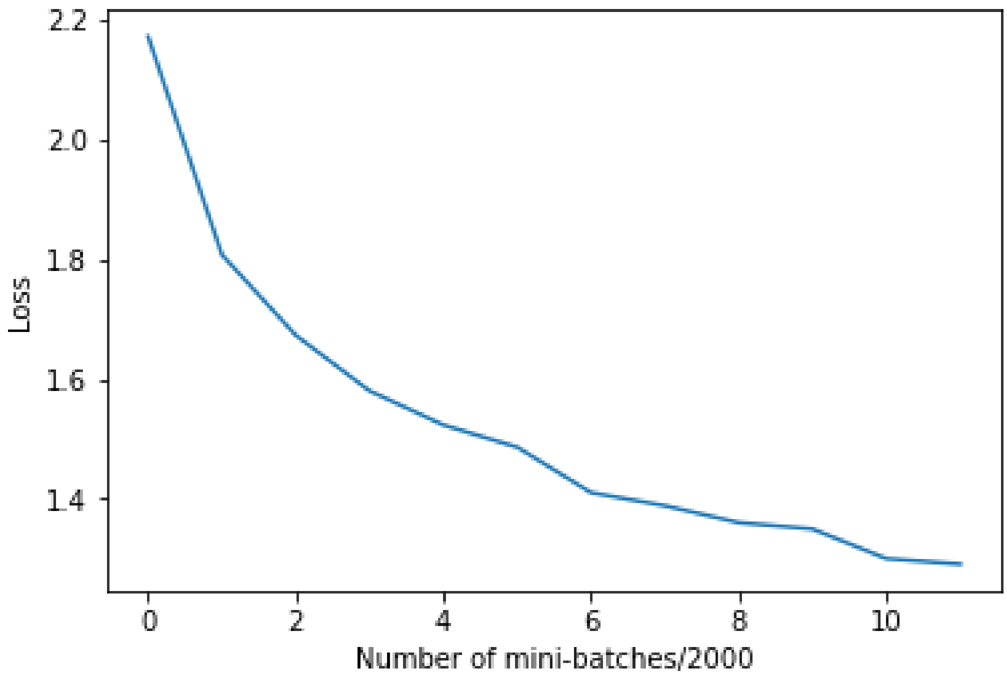
```
        # forward + backward + optimize
        outputs = net(inputs)
        loss = criterion(outputs, labels)
        loss.backward()
        optimizer.step()

        # print statistics
        running_loss += loss.item()
        if i % 2000 == 1999:    # print every 2000 mini-batches
            print('[%d, %5d] loss: %.3f' %
                  (epoch + 1, i + 1, running_loss / 2000))
            loss_list.append(running_loss/2000)
            running_loss = 0.0
print('Finished Training')
```

```
[1,  2000] loss: 2.172
[1,  4000] loss: 1.808
[1,  6000] loss: 1.673
[1,  8000] loss: 1.580
[1, 10000] loss: 1.523
[1, 12000] loss: 1.486
[2,  2000] loss: 1.410
[2,  4000] loss: 1.388
[2,  6000] loss: 1.360
[2,  8000] loss: 1.350
[2, 10000] loss: 1.300
[2, 12000] loss: 1.291
Finished Training
```

Plot of loss function with each 2000 mini-batch across the 2 epochs

[47]:
```
plt.plot(loss_list)
plt.ylabel('Loss')
plt.xlabel('Number of mini-batches/2000')
```

[47]:
```
Text(0.5, 0, 'Number of mini-batches/2000')
```



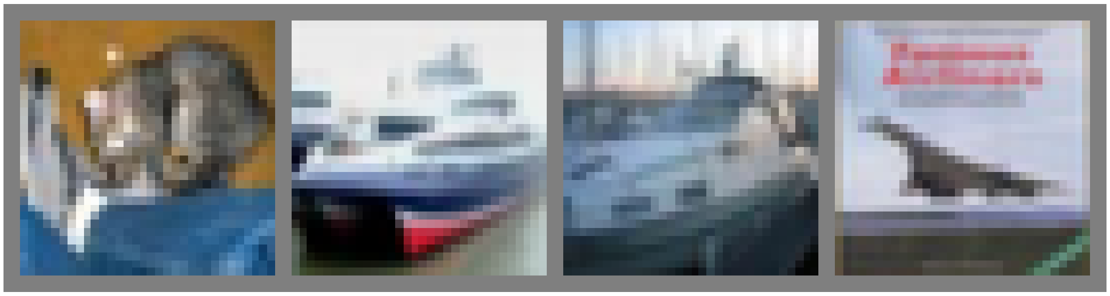
[35]:
```
PATH = './cifar_net.pth'
torch.save(net.state_dict(), PATH)
```

[37]:
```
net = Net()
net.load_state_dict(torch.load(PATH))
```

[37]: <All keys matched successfully>

[40]:
```
dataiter = iter(testloader)
images, labels = dataiter.next()

outputs = net(images)
```

[41]:
```
_, predicted = torch.max(outputs, 1)

# print images
imshow(torchvision.utils.make_grid(images))

print('GroundTruth: ', ' '.join('%5s' % classes[labels[j]] for j in range(4)))
print('Predicted: ', ' '.join('%5s' % classes[predicted[j]]
                              for j in range(4)))
```



```
GroundTruth:    cat  ship  ship plane
Predicted:    cat  ship  ship  ship
```

[43]:
```
correct = 0
total = 0
# since we're not training, we don't need to calculate the gradients for our␣
↪outputs
with torch.no_grad():
    for data in testloader:
        images, labels = data #data[0].to(device), data[1].to(device)
        # calculate outputs by running images through the network
        outputs = net(images)
        # the class with the highest energy is what we choose as prediction
        _, predicted = torch.max(outputs.data, 1)
        total += labels.size(0)
        correct += (predicted == labels).sum().item()

print('Accuracy of the network on the 10000 test images: %d %%' % (
    100 * correct / total))
```

```
Accuracy of the network on the 10000 test images: 55 %
```

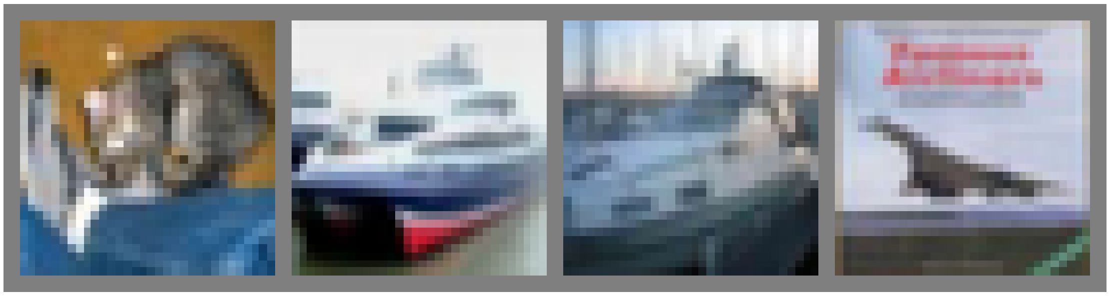
[44]:
```
# prepare to count predictions for each class
correct_pred = {classname: 0 for classname in classes}
total_pred = {classname: 0 for classname in classes}

# again no gradients needed
with torch.no_grad():
    for data in testloader:
        images, labels = data
        outputs = net(images)
        _, predictions = torch.max(outputs, 1)
        # collect the correct predictions for each class
        for label, prediction in zip(labels, predictions):
            if label == prediction:
                correct_pred[classes[label]] += 1
```

```
            total_pred[classes[label]] += 1


# print accuracy for each class
for classname, correct_count in correct_pred.items():
    accuracy = 100 * float(correct_count) / total_pred[classname]
    print("Accuracy for class {:5s} is: {:.1f} %".format(classname,
                                                       accuracy))
```

```
Accuracy for class plane is: 61.0 %
Accuracy for class car   is: 76.1 %
Accuracy for class bird  is: 20.0 %
Accuracy for class cat   is: 43.8 %
Accuracy for class deer  is: 65.2 %
Accuracy for class dog   is: 41.8 %
Accuracy for class frog  is: 62.0 %
Accuracy for class horse is: 51.8 %
Accuracy for class ship  is: 73.3 %
Accuracy for class truck is: 57.1 %
```

(v) Predicting the class labels of 4 sample images.

[45]:
```
dataiter = iter(testloader)
images, labels = dataiter.next()
layer = net.visualizeFirstLayer(images)
imshow(torchvision.utils.make_grid(images))

outputs = net(images)
_, predicted = torch.max(outputs, 1)
print('GroundTruth: ', ' '.join('%5s' % classes[labels[j]] for j in range(4)))
print('Predicted: ', ' '.join('%5s' % classes[predicted[j]]
                              for j in range(4)))
```



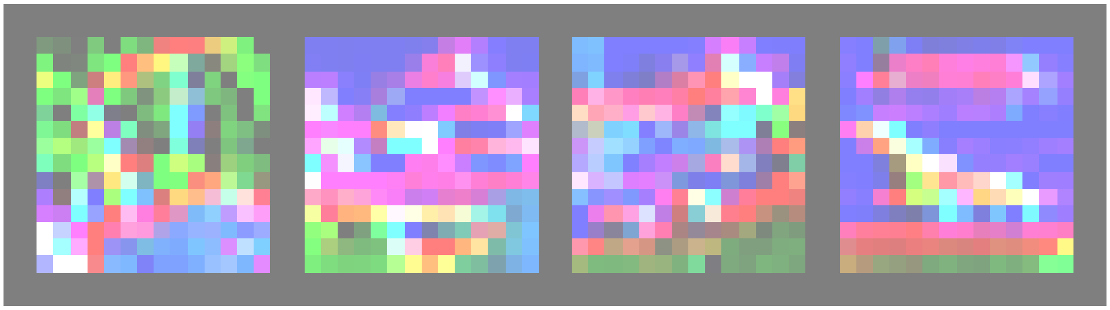
```
GroundTruth:    cat  ship  ship plane
Predicted:    cat  ship  ship  ship
```

(vi)

Visualization of the output of the first layer of the network

[46]:
```
imshow(torchvision.utils.make_grid(layer[:,0:3,:,:]))
imshow(torchvision.utils.make_grid(layer[:,3:6,:,:]))
```

```
Clipping input data to the valid range for imshow with RGB data ([0..1] for
floats or [0..255] for integers).
```



```
Clipping input data to the valid range for imshow with RGB data ([0..1] for
floats or [0..255] for integers).
```