This homework is intended to provide students with the opportunities to get more experience with Python and to learn the basics of constructing and using linear filters.

There are different ways to import libraries/modules into Python. Styles and practices vary. For consistency (and to make life easier for the markers) you are required to import modules for this assignment exactly as follows:

```
from PIL import Image
import numpy as np
import math
```

HINT: Review HW1 for the basics of reading/writing images, converting color to grayscale, and converting PIL images to/from Numpy arrays.

Hand in all parts of this assignment in PLATO (both the code and report PDF file as specified). To get full marks, your functions (i.e., *.py files) must not only work correctly, but also must be clearly documented with sufficient comments for others to easily use and understand the code. You will lose marks for insufficient or unclear comments. In this assignment, you also need to hand in scripts showing tests of your functions on all the cases specified as well as the images and other answers requested. The scripts and results (as screenshots or otherwise) should be pasted into a single PDF file and clearly labeled. Note that lack of submission of either the code or the PDF will also result in loss of points.

The assignment

Part 1: Gaussian Filtering

1. (10 points) We follow the convention that 2D filters always have an odd number of rows and columns (so that the center row/column of the filter is well-defined).

   As a simple warm-up exercise, write a Python function, 'boxfilter(n)', that returns a box filter of size n by n. You should check that n is odd, checking and signaling an error with an 'assert' statement. The filter should be a Numpy array. For example, your function should work as follows:

```
>>> boxfilter(5)
array([[0.04, 0.04, 0.04, 0.04, 0.04],
       [0.04, 0.04, 0.04, 0.04, 0.04],
       [0.04, 0.04, 0.04, 0.04, 0.04],
       [0.04, 0.04, 0.04, 0.04, 0.04],
       [0.04, 0.04, 0.04, 0.04, 0.04]])
>>> boxfilter(4)
Traceback (most recent call last)
    . . .
AssertionError: Dimension must be odd
```

HINT: The generation of the filter can be done as a simple one-line expression. Of course, checking that n is odd requires a bit more work.

Show the results of your boxfilter(n) function for the cases n=3, n=4, and n=7.

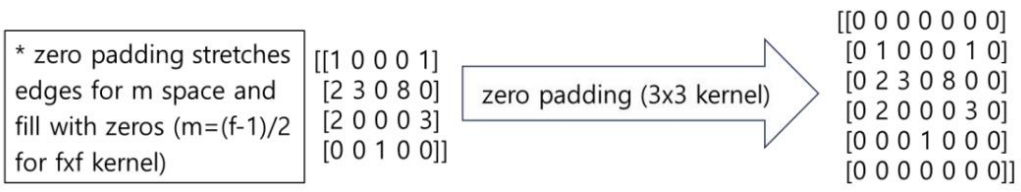
2. (10 points) Write a Python function, 'gauss1d(sigma)', that returns a 1D Gaussian filter for a given value of sigma. The filter should be a 1D Numpy array with length 6 times sigma rounded up to the next odd integer. Each value of the filter can be computed from the Gaussian function, $exp(-x\text{^}2/(2*sigma\text{^}2))$, where x is the distance of an array value from the center. This formula for the Gaussian ignores the constant factor. Therefore, you should normalize the values in the filter so that they sum to 1.

HINT: For efficiency and compactness, it is best to avoid 'for' loops in Python. One way to do this is to first generate a 1D array of values for x, and map this array through the density function. Suppose you want to generate a 1D filter from a zero-centered Gaussian with a sigma of 1.6. The filter length would be odd(1.6*6)=11. You then generate a 1D array of x values [-5,- 4,-3,-2,-1,0,1,2,3,4,5] and apply the array x to the given density function $exp(-x\text{^}2/(2*sigma\text{^}2))$. Show the filter values produced for sigma values of 0.3, 0.5, 1, and 2.

3. (10 points) Create a Python function 'gauss2d(sigma)' that returns a 2D Gaussian filter for a given value of sigma. The filter should be a 2D Numpy array. Use 'np.outer' with the 1D array from the function gauss1d(sigma). You also need to normalize the values in the filter so that they sum to 1. Show the 2D Gaussian filter for sigma values of 0.5 and 1.

4. (30 points)

(a) Write a function 'convolve2d(array, filter)' that takes in an image (stored in `array`) and a filter, and performs convolution to the image with zero paddings (thus, the image sizes of input and output are the same).



Both input variables are in type `np.float32`. Note that for this implementation you should use two for-loops to iterate through each neighborhood.

(b) Write a function 'gaussconvolve2d(array,sigma)' that applies Gaussian convolution to a 2D array for the given value of sigma. The result should be a 2D array. Do this by first generating a filter with your 'gauss2d', and then applying it to the array with 'convolve2d(array, filter)'

(c) Apply your 'gaussconvolve2d' with a sigma of 3 on the image of the dog (attached in PLATO). Load this image into Python, convert it to a greyscale, Numpy array and run your 'gaussconvolve2d' (with a sigma of 3). Note, as mentioned in class, for any image filtering or

processing operations converting image to a double array format will make your life a lot easier and avoid various artifacts. Once all processing operations are done, you will need to covert the array back to unsigned integer format for storage and display.

(d) Use PIL to show both the original and filtered images.

Part 2: Hybrid Images

Gaussian filtering produces a low-pass (blurred) filtered version of an image. Consequently, the difference between the original and the blurred results in a high-pass filtered version of the image. As defined in the original ACM Siggraph 2006 paper:

http://olivalab.mit.edu/publications/OlivaTorralb_Hybrid_Siggraph06.pdf

a hybrid image is the sum of a low-pass filtered version of the one image and a high-pass filtered version of a second image. There is a free parameter, which can be tuned for each image pair, which controls how much high frequency to remove from the first image and how much low frequency to leave in the second image. This is called the ``cutoff-frequency''. In the paper it is suggested to use two cutoff frequencies (one tuned for each image) and you are free to try that, as well. The cutoff frequency is controlled by changing the sigma of the Gaussian filter used in constructing the hybrid images.

We provide you with pairs of aligned images (attached in PLATO) which can be merged reasonably well into hybrid images. The alignment is important because it affects the perceptual grouping (read the paper for details).

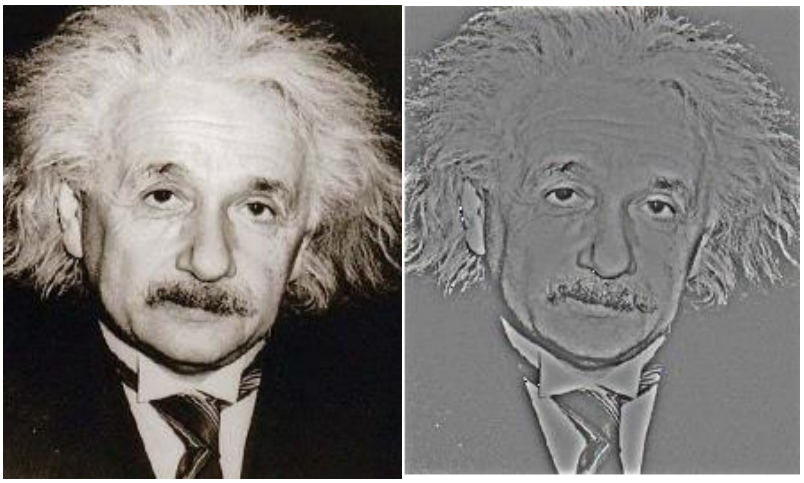
You have to use your own function 'gaussconvolve2d(array,sigma)' for the following work.

1. (12 points) Choose an appropriate sigma and create a blurred version of the one of the paired images (choose one other pair, NOT the einstein/marilyn). For this to work you will need to choose a relatively large sigma and filter each of the three color channels (RGB) separately, then compose the channels back to the color image to display. Note, you should use the same sigma for all color channels.

Original image

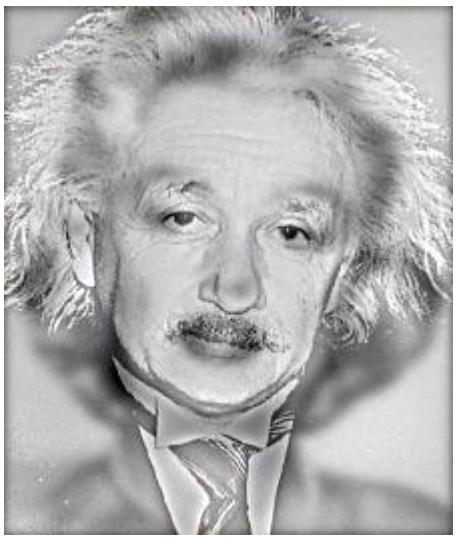
Gaussian filtered low frequency image

2. (12 points) Choose an appropriate sigma (it is suggested to use the same as above) and create a high frequency version of the second from the two the paired images. Again you will operate on each of the color channels separately and use same sigma for all channels. High frequency filtered image is obtained by first computing a low frequency Gaussian filtered image and then subtracting it from the original. The high frequency image is actually zero-mean with negative values so it is visualized by adding 128 (if you re-scaled the original image to the range between 0 and 1, then add 0.5 for visualization). In the resulting visualization illustrated below, bright values are positive and dark values are negative.



Original image **High frequency image**

3. (16 points) Now simply add the low and high frequency images (per channel). Note, the high frequency image that you add, should be the originally computed high frequency image (without adding 128; this addition is only done for visualization in the part above). You may get something like the following as a result:



Note: You may see speckle artifacts (individual pixels of bright color that do not match the image

content) in the final hybrid image produced. You should be able to get rid of most, if not all, of them by clamping the values of pixels on the high and low end to ensure they are in the valid range (between 0 and 255) for the final image. You will need to do this per color channel. However, depending on the chosen value of sigma and specific set of images a few artifacts may remain. If you are unable to completely get rid of those artifacts that's OK. You will not be penalized for them.

Deliverables

You will hand in your assignment in PLATO. You should hand in one zip file including two files, a file containing your code (i.e., *.py file). This file must have sufficient comments for others to easily use and understand the code. In addition, hand in a PDF document showing scripts (i.e., records of your interactions with the Python shell) showing the specified tests of your functions as well as the images and other answers requested. The PDF file has to be organized and easily readable / accessible.

Assignments are to be handed in before 11:59pm on their due date