CSE185
Introduction to Computer Vision
Lab 03: Spatial Filters

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Sobel Filter

- Sobel filter is a simple edge detector
- $H_y = \begin{pmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{pmatrix}$ or $H_x = \begin{pmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{pmatrix}$

Input image

Sobel filter output

2D filter

- Submatrix Indexing:

- Code for H_x :

```
I1 = im2double(imread('lena.jpg'));

function sobel(I1)
       Hx = [-1 0 1; -2 0 2; -1 0 1]
       [rows, cols] = size(I1):
       I2 = zeros(rows+2, cols+2);
       img2(1+1:rows+1,1+1:cols+1) = I1;

       for i=1:rows
              for j=1:cols
                S1(i,j) = sum(sum(Hx.*A(i:i+2,j:j+2)))
              end for
       end
end function
```

Sobel Filter

- `sobel_filter.m`

```
function output = sobel_filter(img, kernel)
    % YOUR CODE HERE
end
```

- In `lab03.m`:

```
img = im2double(imread('lena.jpg'));

%% Sobel filter
H = [1, 2, 1; 0, 0, 0; -1, -2, -1]; % horizontal edge
%H = [1, 0, -1; 2, 0, -2; 1, 0, -1]; % vertical edge

img_sobel = sobel_filter(img, H);
figure, imshow(img_sobel);
imwrite(img_sobel, 'sobel_h.jpg');
```

- Compare your result with `I = imfilter(img, H);`

2D filter to 1D filter

- $H_x = \begin{pmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{pmatrix} \Rightarrow H_x = \begin{pmatrix} 1 \\ 2 \\ 1 \end{pmatrix} * \begin{pmatrix} 1 & 0 & -1 \end{pmatrix}$

- $H_y = \begin{pmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{pmatrix} \Rightarrow H_y = \begin{pmatrix} 1 \\ 0 \\ -1 \end{pmatrix} * \begin{pmatrix} 1 & 2 & 1 \end{pmatrix}$

- Pseudo code for H_x : convolve 1D filter column wise filter first, and then convolve 1D filter row wise.

```
function sobel(I1)
        HX1 = [1 1  1;2 2  2;1 1  1]; HX2 = [1 0 -1];
        tic
       [rows,cols] = size(I1);
        I2 = zeros(rows+2, cols+2);
        I2(1+1:rows+1,1+1:cols+1) = I1;
        ouput = zeros(rows+2, cols+2);
        output2 = zeros(rows, cols);
        for i = 1:rows
           for j = 1:cols
                output(i,j:j+2) = sum(HX1.*I2(i:i+2,j:j+2), 1);
                output2(i,j) = sum(HX2.*output(i,j:j+2));
       end
        toc
end function
```

2D filter to 1D filter

- $H_x = \begin{pmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{pmatrix} \rightarrow H_x = \begin{pmatrix} 1 \\ 2 \\ 1 \end{pmatrix} * (1 \quad 0 \quad -1)$

- $H_y = \begin{pmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{pmatrix} \rightarrow H_y = \begin{pmatrix} 1 \\ 0 \\ -1 \end{pmatrix} * (1 \quad 2 \quad 1)$

- Pseudo code for H_x : convolve 1D filter row wise filter first, and then convolve 1D filter column wise.

```
function sobel(I1)
        HX1 = [1 0 -1; 1 0 -1; 1 0 -1]; HX2 = [1 2 1];
        tic
        [rows,cols] = size(I1);
        I2 = zeros(rows+2, cols+2);
        I2(1+1:rows+1,1+1:cols+1) = I1;
        ouput = zeros(rows+2, cols+2);
        output2 = zeros(rows, cols);
        for i = 1:rows
           for j = 1:cols
                output(i:i+2,j) = sum(HX1.*I2(i:i+2,j:j+2), 2);
                output2(i,j) = sum(HX2'.*output(i:i+2,j));
       end
       toc
end function
```

- Compare results and elapsed time with 2D filter and column-wise first row-wise last

Gaussian Filter

- Gaussian filter is a low-pass/smoothing filter

$$g(\Delta x, \Delta y) = \frac{1}{Z} \exp\left(-\frac{\Delta x^2 + \Delta y^2}{2\sigma^2}\right)$$

Input image

Gaussian filter output

Gaussian Filter

- Gaussian filter is a low-pass/smoothing filter

$$g(\Delta x, \Delta y) = \frac{1}{Z} \exp\left(-\frac{\Delta x^2 + \Delta y^2}{2\sigma^2}\right)$$

- $\Delta x, \Delta y$ are offsets from the kernel center, and Z is the normalized term to make the sum of all weights equal to 1
- In MATLAB:

0.0113	0.0149	0.0176	0.0186	0.0176	0.0149	0.0113
0.0149	0.0197	0.0233	0.0246	0.0233	0.0197	0.0149
0.0176	0.0233	0.0275	0.029	0.0275	0.0233	0.0176
0.0186	0.0246	0.029	0.0307	0.029	0.0246	0.0186
0.0176	0.0233	0.0275	0.029	0.0275	0.0233	0.0176
0.0149	0.0197	0.0233	0.0246	0.0233	0.0197	0.0149
0.0113	0.0149	0.0176	0.0186	0.0176	0.0149	0.0113

Gaussian Filter

- Gaussian filter is a low-pass/smoothing filter

$$g(\Delta x, \Delta y) = \frac{1}{Z} \exp\left(-\frac{\Delta x^2 + \Delta y^2}{2\sigma^2}\right)$$

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0.0149	0.0197	0.0233	0.0246	0.0233	0.0197	0.0149
0.0176	0.0233	0.0275	0.029	0.0275	0.0233	0.0176
0.0186	0.0246	0.029	0.0307	0.029	0.0246	0.0186
0.0176	0.0233	0.0275	0.029	0.0275	0.0233	0.0176
0.0149	0.0197	0.0233	0.0246	0.0233	0.0197	0.0149
0.0113	0.0149	0.0176	0.0186	0.0176	0.0149	0.0113

Δy

Δx

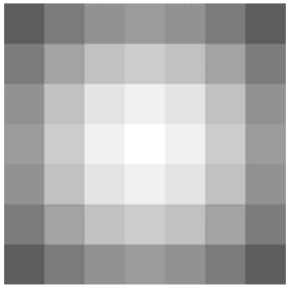
Gaussian Filter

- You don't need to implement Gaussian kernel by yourself (this is bonus).
- Use `fspecial`:

```
H = fspecial('gaussian', hsize, sigma);
```

`hsize` is the size of the kernel, `sigma` = σ

- Visualization of a Gaussian kernel:



Gaussian Filter

- `gaussian_filter.m`

```
function output = gaussian_filter(img, hsize, sigma)
    H = fspecial('gaussian', hsize, sigma);
    % YOUR CODE HERE
end
```

- In `lab03.m`:

```
%% Gaussian filter
hsize = 5; sigma = 2;
% hsize = 9; sigma = 4;

img_gaussian = gaussian_filter(img, hsize, sigma);
figure, imshow(img_gaussian);
imwrite(img_gaussian, 'gaussian_5.jpg');
```

- Compare your result with `I = imfilter(img, H);`

Lab assignment 03

1. Implement sobel_filter.m, use H_y filter and save the image as sobel_y.jpg
2. Use H_x filter and save the image as sobel_x.jpg
3. Break 2D filter (H_y) to 1D filter, use column-wise filter first and then row-wise filter, save the image as sobel_cr.jpg
4. Use row-wise filter first and then column-wise filter, save the image as sobel_rc.jpg
5. Implement gaussian_filter.m, use hsize = 5, sigma = 2, and save the image as gaussian_5.jpg
6. Use hsize = 9, sigma = 4, and save the image as gaussian_9.jpg
7. Upload your output images and lab03.m, sobel_filter.m, median_filter.m, and gaussian_filter.m

* All questions should utilize the 'lena.jpg'

Bonus

- Implement boundary padding
  - zero padding (pixels outside the image are zero)
  - replicated/repeated padding (pixels outside the image are the same as pixels on the boundaries)
- You can try built-in function `padarray` or `wextend`, but you need to implement by yourself to get bonus points

- Implement Gaussian kernel
  - compute a matrix based on $g(\Delta x, \Delta y) = \exp\left(-\frac{\Delta x^2+\Delta y^2}{2\sigma^2}\right)$
  - normalize the matrix to have sum equal to 1

To get the bus, please implement the codes in lab03_bonus.m, boundary_padding_bonus.m, gaussian_kernel_bonus.m

Reference

- Spatial Filtering
- Linear Algebra and MATLAB Tutorial
- Awesome Computer Vision