



*AYDIN*

*ADNAN MENDERES UNIVERSITY  
FACULTY OF ENGINEERING*

*Department of Electrical and Electronics Engineering*

**EE454 – Digital Image Processing**

**2022-2023, Fall**

**Presentation 6**

**Dr. Adem Ükte**

# Sharpening (High Pass) Spatial Filters



- Sharpening highlights transitions in intensity.
- Uses of image sharpening range from electronic printing and medical imaging to industrial inspection and autonomous guidance in military systems.
- In previous sections, we saw that image blurring could be accomplished in the spatial domain by pixel averaging (smoothing) in a neighborhood.
- Because averaging is analogous to integration, it is logical to conclude that sharpening can be accomplished by spatial differentiation.
- In fact, this is the case, and the following discussion deals with various ways of defining and implementing operators for sharpening by digital differentiation.
- As noted in previous sections, smoothing is often referred to as low-pass filtering, a term borrowed from frequency domain processing. In a similar manner, sharpening is often referred to as high-pass filtering.
- In this case, high frequencies (which are responsible for fine details) are passed, while low frequencies are attenuated or rejected.
- High-frequency components in the image are sudden intensity (gray level) changes at the edges that follow the details.
- Accordingly, sudden changes in the image can be easily detected as a result of high-pass filtering.
- As the low-frequency components are reduced as a result of the filtering and the high-frequency components are superior in the image, the background noise effect begins to be felt in the filtered image. Because the background noise of the image typically has high frequency components.

# Sharpening (High Pass) Spatial Filters



- Since the logic in high-pass filtering is to highlight the gray level of the pixel of interest and attenuate the gray level values in other neighboring pixels, the impulse response of the spatial filter that will perform this operation is determined in such a way that the center value is positive and the neighboring values are negative, and the sum of the values of these coefficients is zero.
- Accordingly, if the gray level values of the part of the image remaining inside the filter window show a constant or slow change (low frequency components), then the output of the filter window for the relevant pixel will be zero or very small. This is an expected result.
- The figure below shows a conventional 3×3 high-pass (sharpening) filter window built around this logic.

$$\left(\frac{1}{9}\right) \times \begin{array}{|c|c|c|} \hline -1 & -1 & -1 \\ \hline -1 & 8 & -1 \\ \hline -1 & -1 & -1 \\ \hline \end{array}$$

# Sharpening (High Pass) Spatial Filters



- **Example 12:** High pass filtering removes the DC component in the image. As a result, the average gray level value in the image approaches zero, leading to a drastic reduction in the overall contrast of the image. This example shows the result obtained by applying the filter window as given on the previous page, on a sample image.

Original image



Output image obtained with HPF



```
clc;clear;close all;
I=imread('cameraman.tif');
%3x3 sized HPF window
h_HPF=-1/9*ones(3); h_HPF(2,2)=8/9;
%Obtaining HPF'ed version of original image
O=func_spat_filt(I,h_HPF);
%Viewing the result
figure,subplot(1,2,1),imshow(I)
title('Original image')
subplot(1,2,2), imshow(uint8(O))
title('Output image obtained with HPF')
```

# Highboost Filtering



- The high-pass filtered image can also be calculated by taking the difference between the original image and the low-pass filtered version of this image. This situation can be expressed as follows.

$$I_{HPF} = I - I_{LPF} \quad (5)$$

- Here,  $I$  is the original image,  $I_{LPF}$  is the low-pass filtered version of the original image, and  $I_{HPF}$  is the high-pass filtered version of the original image.
- The original image  $I$  and its low-pass filtered form  $I_{LPF}$  are multiplied by two real coefficients  $a$  and  $b$ , respectively, to obtain a highboost filtered image, which is defined as a filter that amplifies high-frequency components.

$$\hat{I}_{HPF} = aI - bI_{LPF} \quad (6)$$

- Here,  $a > b > 0$ , and if  $I_{LPF}$  is taken from eq. (5) and replaced in eq. (6), the following result is obtained.

$$\hat{I}_{HPF} = (a - b)I + bI_{HPF} \quad (7)$$

- Equation (7) expresses the standard high-pass filtered image for  $a = b = 1$ .
- When  $a > 1$ , part of the original image is added to the high-pass filtered part. This process partially repairs low-frequency components lost as a result of high-pass filtering.
- Thus, the highboost filtered image becomes quite similar to the original image, with a relative level of edge enhancement dependent on the value of  $a$  and  $b$ .

# Highboost Filtering



- If equations (5) and (7) are reinterpreted considering the filter impulse responses and the convolution definition, using equation (5), which is  $I_{HPF} = I - I_{LPF}$ , the impulse response of the HPF is obtained as follows:

$$\begin{aligned} I * h_{HPF} &= I * \delta - I * h_{LPF} \quad \rightarrow \quad I * h_{HPF} = I * (\delta - h_{LPF}) \\ h_{HPF} &= \delta - h_{LPF} \end{aligned} \quad (8)$$

- Using the equation (7), which is  $\hat{I}_{HPF} = (a - b)I + bI_{HPF}$ , and equation (8), the impulse response of the high boost filter is obtained as follows:

$$\begin{aligned} I * \hat{h}_{HPF} &= I * [(a - b)\delta] + I * (bh_{HPF}) \\ \rightarrow \quad I * \hat{h}_{HPF} &= I * [(a - b)\delta + bh_{HPF}] \\ \rightarrow \quad I * \hat{h}_{HPF} &= I * [(a - b)\delta + b(\delta - h_{LPF})] \\ \hat{h}_{HPF} &= a\delta - bh_{LPF} \end{aligned} \quad (9)$$

- Here;

$h_{LPF}$	→	Impulse response of low-pass filter
$h_{HPF}$	→	Impulse response of high-pass filter
$\hat{h}_{HPF}$	→	Impulse response of high boost filter
$\delta$	→	2d impulse function with equal size with $h_{LPF}$ , $h_{HPF}$ and $\hat{h}_{HPF}$

# Highboost Filtering



- When the equations (8) and (9) are compared, as stated before,  $\hat{h}_{HPF} = h_{HPF}$  is obtained for  $a = b = 1$ .
- Accordingly, using the 3×3 LPF1 filter window, the general form of the highboost filter window is given as follows.

$$\hat{h}_{HPF} = \left(\frac{1}{9}\right) \times \begin{array}{|c|c|c|} \hline -b & -b & -b \\ \hline -b & w & -b \\ \hline -b & -b & -b \\ \hline \end{array}$$

- Here,  $w = 9a - b$  for  $a \geq 1$ .
- $a$  and  $b$  are the values that characterize the filter.

# Highboost Filtering



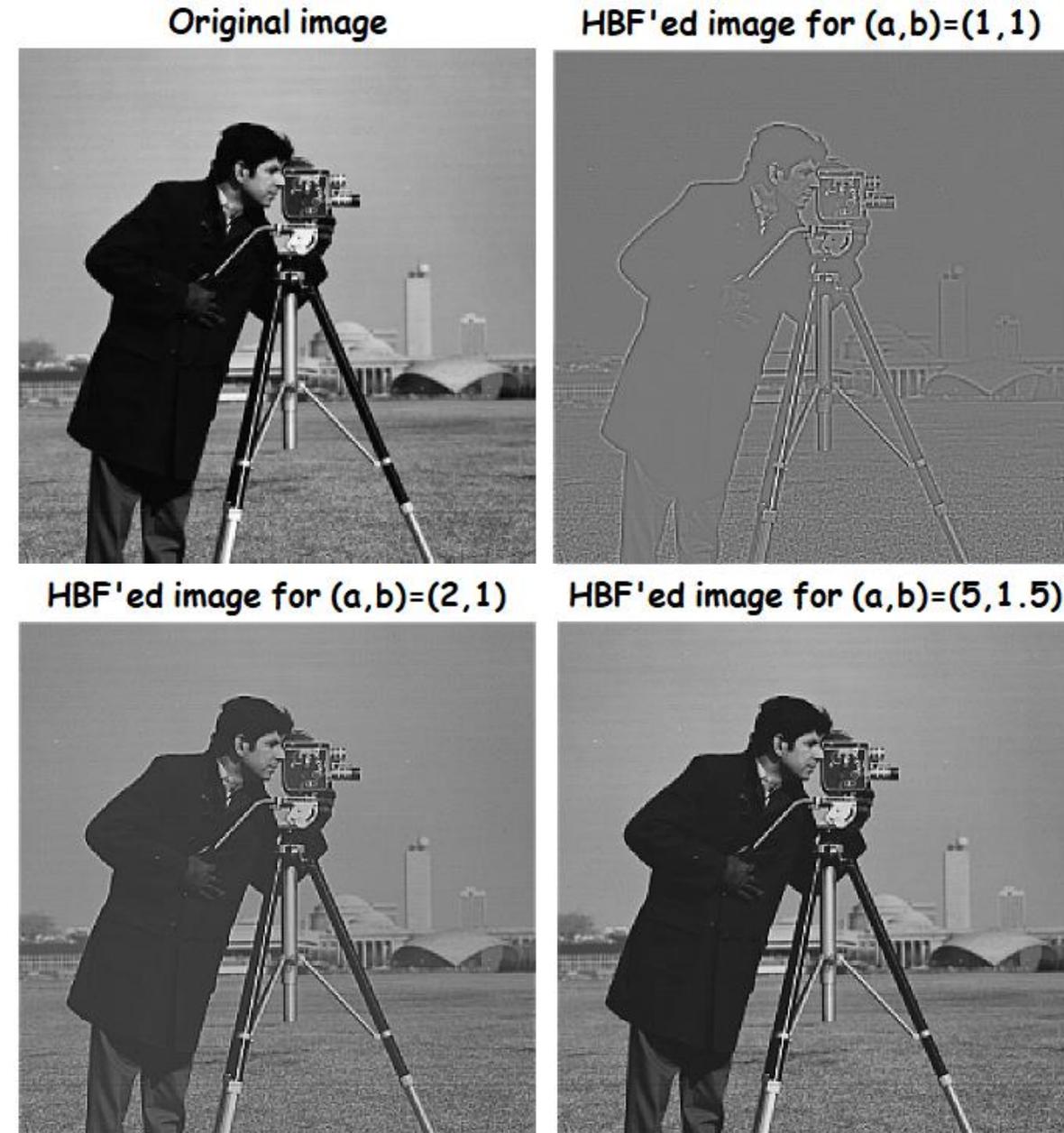
- With regard to high-pass filtering, the following conclusions can be drawn:
- With conventional high-pass filtering, background information about the image is almost completely lost. This is a result of the sum of the coefficients for the conventional high-pass filter given in the previous pages being zero.
- Background information of the image is preserved with highboost filtering. This is a result of the non-zero sum of the coefficients for the highboost filter defined for  $a > b$ .
- Gray level values in the processed image obtained as a result of high-pass filtering can usually have values outside the range of 0-255 (assuming working with 8-bit grayscale images). For this reason, the results obtained must be scaled to the dynamic range 0-255 for an accurate display (contrast stretching).
- Background noise associated with the image contains a significant amount of high-frequency components. Since high-pass filtering highlights high-frequency components, it not only increases the regional contrast of the image and the sharpness of the view, but also causes background noise to become active. Emphasizing background noise is the most important factor limiting the algorithm designed to sharpen the visual appearance of an image and increase regional contrast.

- **Example 13:** In the following figure, the results obtained with the highboost filter window for  $(a,b) = (1,1)$ ,  $(2,1)$ , and  $(5,1.5)$  are given. When the results are compared, better images are obtained for  $b \geq 1$  and  $a > 1$  than conventional high-pass filtering. Besides the edges, the background of the image is also preserved.

```

clc;clear;close all;
I=imread('cameraman.tif');
% 3x3 sized LPF1 window
h_LPF1=1/9*ones(3);
% 3x3 sized 2d impulse function
delta=zeros(3,3); delta(2,2)=1;
% Highboost filter windows for different (a,b) couples
h_HBF1=delta-h_LPF1; % (a,b)=(1,1)
h_HBF2=2*delta-h_LPF1; % (a,b)=(2,1)
h_HBF3=5*delta-1.5*h_LPF1; % (a,b)=(5,1.5)
% Obtaining HBF'ed versions of original image
O1=func_spat_filt(I,h_HBF1);
O2=func_spat_filt(I,h_HBF2);
O3=func_spat_filt(I,h_HBF3);
% Stretching the contrasts of HBF'ed images to [0-255]
O1=func_cont_strch(O1,0,255);
O2=func_cont_strch(O2,0,255);
O3=func_cont_strch(O3,0,255);
%Viewing the results
figure,subplot(2,2,1),imshow(I),title('Original image')
subplot(2,2,2),imshow(uint8(O1))
title('HBF'ed image for (a,b)=(1,1)')
subplot(2,2,3),imshow(uint8(O2))
title('HBF'ed image for (a,b)=(2,1)')
subplot(2,2,4),imshow(uint8(O3))
title('HBF'ed image for (a,b)=(5,1.5)')

```



# Homomorphic Filtering in Spatial Domain



- Homomorphic filtering is a filtering technique used to enhance images exposed to variable illumination.
- For example, when trying to record an image with a large dynamic range, such as a natural landscape on a sunny day, on media with a small dynamic range, such as film or paper, the contrast of the image will decrease drastically, especially in dark and bright areas.
- Before saving such an image in medium with a small dynamic range, reducing the dynamic range of this image and increasing its regional contrast can be given as an approach to image enhancement.
- The illumination-reflectance model introduced in previous sections can be used to develop a homomorphic procedure for improving the appearance of an image by simultaneous intensity range compression (reducing the dynamic range) and contrast enhancement (increasing its regional contrast).
- As stated earlier, typically an image is created by recording the light reflected from an object illuminated by any light source.
- By using this discussion, an image  $f(x, y)$  can be expressed as the product of its illumination,  $i(x, y)$ , and reflectance,  $r(x, y)$ , components:

$$f(x, y) = i(x, y)r(x, y)$$

- In a homomorphic system design for image enhancement, the illumination component,  $i(x, y)$ , is assumed to be a slowly changing component that contributes to the dynamic range of the image and therefore corresponds to the low-frequency components.
- On the other hand, the reflection component,  $r(x, y)$ , is assumed to be a rapidly changing component that contributes to the regional contrast of the image. In this sense, the reflection component represents the details of the image and therefore corresponds to the high-frequency components.

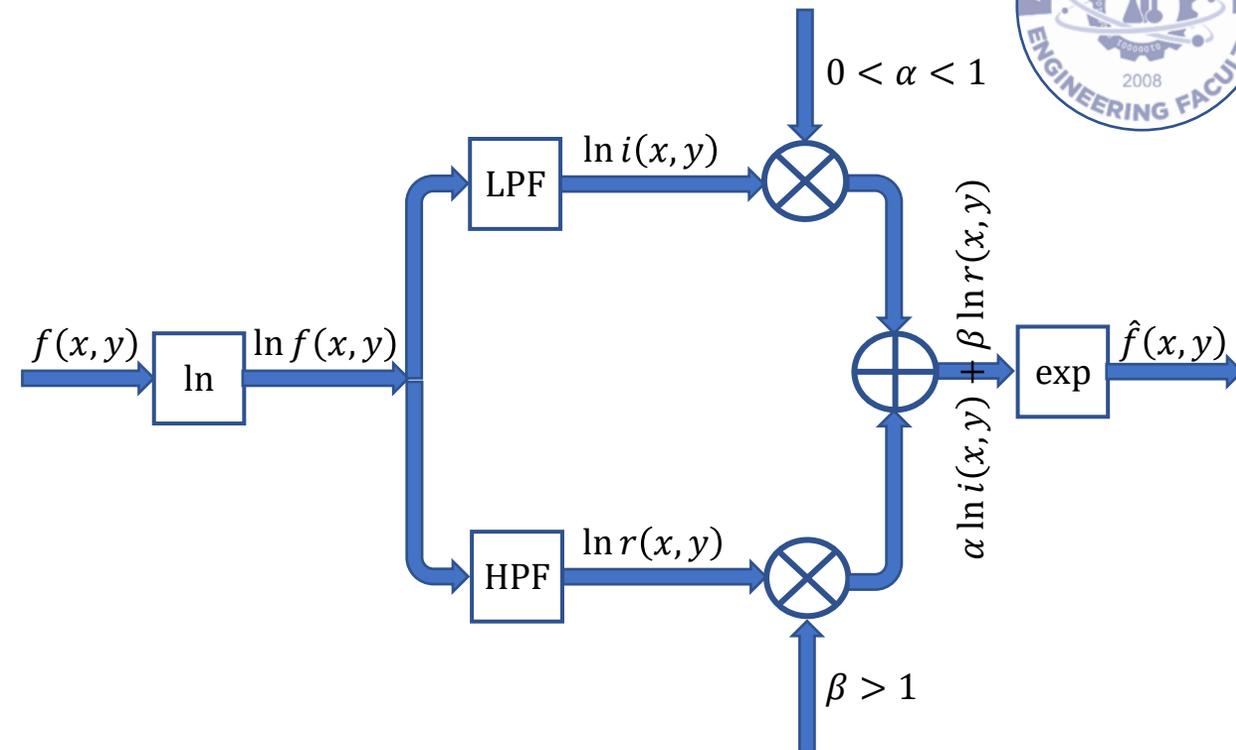
# Homomorphic Filtering in Spatial Domain



- To decrease dynamic range and increase regional contrast, it is necessary to decrease  $i(x, y)$  and increase  $r(x, y)$ .
- For this, first, the components  $i(x, y)$  and  $r(x, y)$  must be separated from each other. To separate the two components in product form, the natural logarithm operation is applied, and the following expression is obtained.

$$\ln f(x, y) = \ln i(x, y) + \ln r(x, y)$$

- Thus, it will be easier to process the additive components separately rather than the multiplicative components.
- Considering that  $\ln i(x, y)$  changes slowly and  $\ln r(x, y)$  changes rapidly, low pass filtering of  $\ln f(x, y)$  will result in  $\ln i(x, y)$ .
- Similarly, high pass filtering of  $\ln f(x, y)$  will result in  $\ln r(x, y)$ .
- Accordingly, to reduce the dynamic range,  $\ln i(x, y)$  is multiplied by a constant coefficient such as  $0 < \alpha < 1$ .
- On the other hand, to increase the regional contrast,  $\ln r(x, y)$  is multiplied by a constant coefficient such as  $\beta > 1$ .
- Then the two multiplication results are added together.
- To pass from the logarithmic domain back to the image intensity domain, the exponent of the sum is taken and thus the homomorphic filtered image is obtained.
- All these processes are shown in the block diagram in the next figure.



- While the high-frequency components are boosted with the homomorphic filter, the effect of the low-frequency components is reduced.
- Thus, the appearance of edges and details in the image is sharpened, while the effect of variability in lighting is reduced.
- If  $f(x, y)$  has any zero values, a 1 must be added to the image to avoid having to deal with  $\ln(0)$ . The 1 is then subtracted from the final result.

# Homomorphic Filtering in Spatial Domain



```
function f_hat=func_spat_hom_filt(f,h_LP,h_HP,alpha,beta)
%FUNC_SPAT_HOM_FILT performs spatial homomorphic filtering on the image
% F_HAT=FUNC_SPAT_HOM_FILT(F,H_LP,H_HP,ALPHA,BETA)
% f_hat: double type Output image
% f: uint8 or double type input image
% h_LP: Window (impulse response) function of LPF
% h_HP: Window (impulse response) function of HPF
% alpha: Multiplication coefficient to reduce the dynamic range, 0<alpha<1
% beta: Multiplication coefficient to increase the regional contrast, beta>1
f=double(f); %Converting double for mathematical calculations
f_hat=exp(alpha*func_spat_filt(log(f+1),h_LP)+...
    beta*func_spat_filt(log(f+1),h_HP));
f_hat=f_hat-1;
% 1 is added and then subtracted to avoid log(0)=inf
```

$$\hat{f}(x, y) = e^{\alpha \ln i(x, y) + \beta \ln r(x, y)}$$

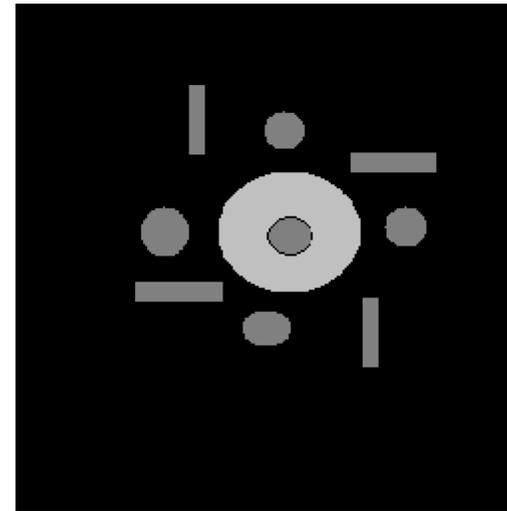
- **Example 14:** The following figure shows the homomorphic filtering results obtained for various  $\alpha$  and  $\beta$  values using the LP and HP filter windows given below.

$$h_{LPF} = \left(\frac{1}{9}\right) \times \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

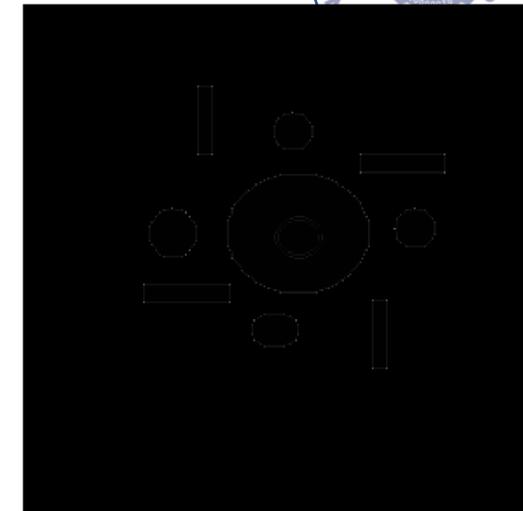
$$h_{HPF} = \left(\frac{1}{9}\right) \times \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

- When the images are examined, it is seen that the edges become more prominent especially as the  $\beta$  value increases. This result is quite common, as edges and details are high-frequency components.
- Since the value of  $\alpha$  is related to the illumination function, an increase in  $\alpha$  causes an increase in the change in illumination.
- For example, in images where  $\alpha$  is 0.1 and 0.3, the entire background appears black, while in image where  $\alpha$  is 0.5, gray tones in the background also stand out.

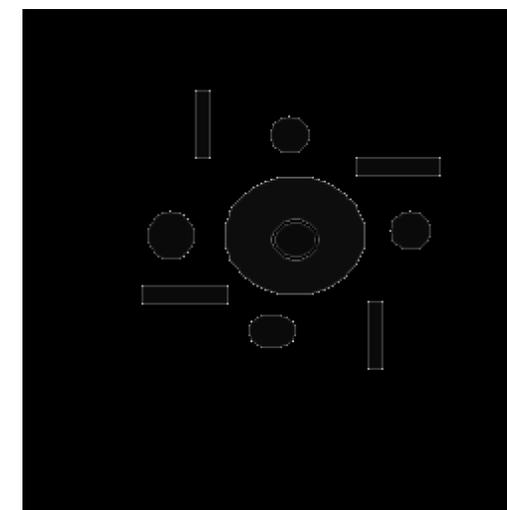
Original image



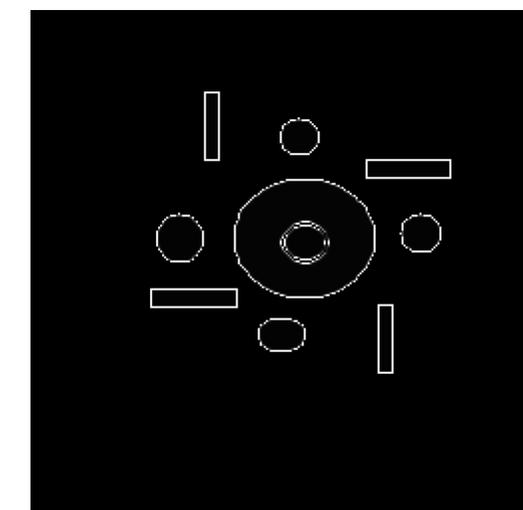
Homomorphic filtered image for  $\alpha=0.1$  and  $\beta=1.5$



Homomorphic filtered image for  $\alpha=0.5$  and  $\beta=1.5$



Homomorphic filtered image for  $\alpha=0.3$  and  $\beta=3$



- Example 14 (Cont.):

```

clc;clear;close all;
f=imread('shapes.bmp');
% LPF and HPF impulse responses
h_LP=1/9*ones(3);
h_HP=-1/9*ones(3); h_HP(2,2)=8/9;
% alpha and beta coefficients
alpha1=0.1; beta1=1.5;
alpha2=0.5; beta2=1.5;
alpha3=0.3; beta3=3;
% Homomorphic filtered images
f_hat1=func_spat_hom_filt(f,h_LP,h_HP,alpha1,beta1);
f_hat2=func_spat_hom_filt(f,h_LP,h_HP,alpha2,beta2);
f_hat3=func_spat_hom_filt(f,h_LP,h_HP,alpha3,beta3);
%Viewing the results
figure,subplot(2,2,1),imshow(f),...
    title('Original image','FontSize',14,'FontName','Comic Sans MS')
subplot(2,2,2),imshow(uint8(f_hat1)),...
    title(['Homomorphic filtered image for \alpha=',num2str(alpha1),...
        ' and \beta=',num2str(beta1)],'FontSize',14,'FontName','Comic Sans MS')
subplot(2,2,3),imshow(uint8(f_hat2)),...
    title(['Homomorphic filtered image for \alpha=',num2str(alpha2),...
        ' and \beta=',num2str(beta2)],'FontSize',14,'FontName','Comic Sans MS')
subplot(2,2,4),imshow(uint8(f_hat3)),...
    title(['Homomorphic filtered image for \alpha=',num2str(alpha3),...
        ' and \beta=',num2str(beta3)],'FontSize',14,'FontName','Comic Sans MS')

```

# END OF PRESENTATION 6

## References:

- ✓ Gonzalez, Woods, and Eddins, Digital Image Processing Using MATLAB 2nd Ed., 2009.
- ✓ Gonzalez and Woods, Digital Image Processing 4th Ed., 2018.
- ✓ Kizilkaya A., Görüntü İşleme Teknikleri ve Uygulamaları Ders Notları, PAÜ, 2008.