IMAGE PROCESSING

whoami

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Outline

- What is Image Processing ?
- Recap DSP
- Intensity Transformation
- Filtering in Spatial/Frequency Domain
- Color Model
- Image Segmentation

1.
What is Image Processing ?

“Processing digital image by means of a digital computer. We can also say that it is a use of computer algorithms, in order to get enhanced image either to extract some useful information.

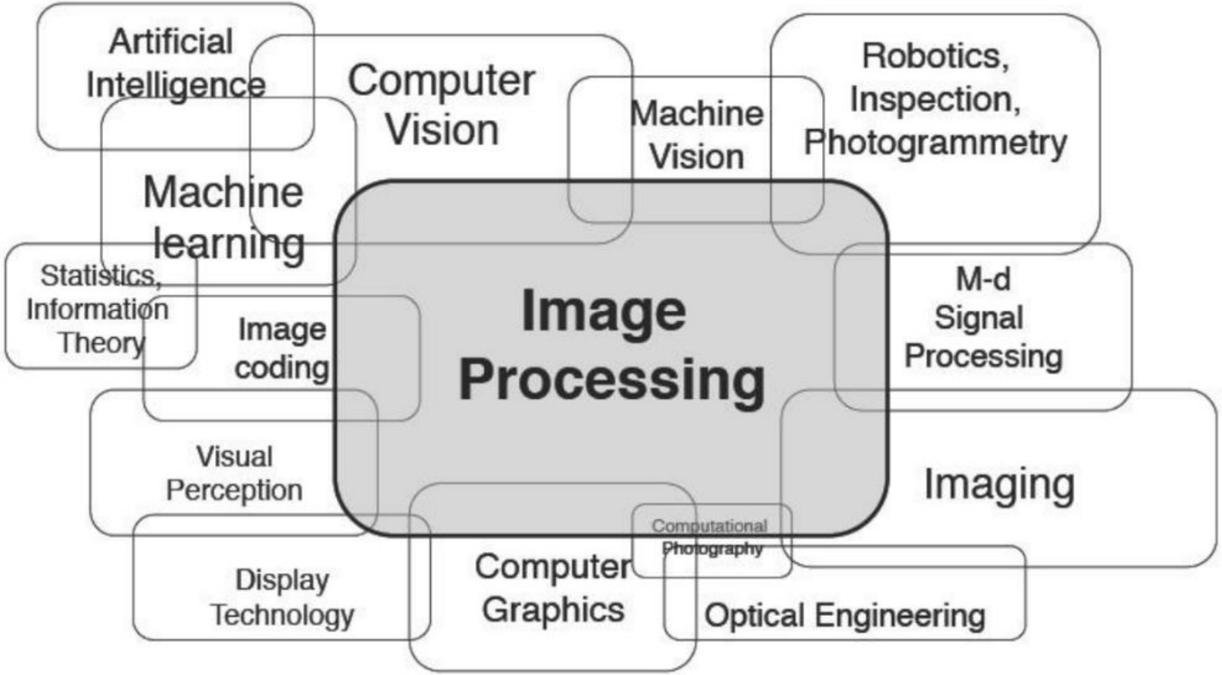
Why does this subject very interesting ?

- Solution to problems in the field of digital image processing generally require extensive experimental work involving software simulation and testing with large sets of sample images.
- VR (Virtual Reality) and AR (Augmented Reality) are around us. Image Processing and Computer Vision are the keys
- To see the world in the unlimited spectrum beyond our capability of human being's visual sense.

DIP focuses on two major tasks

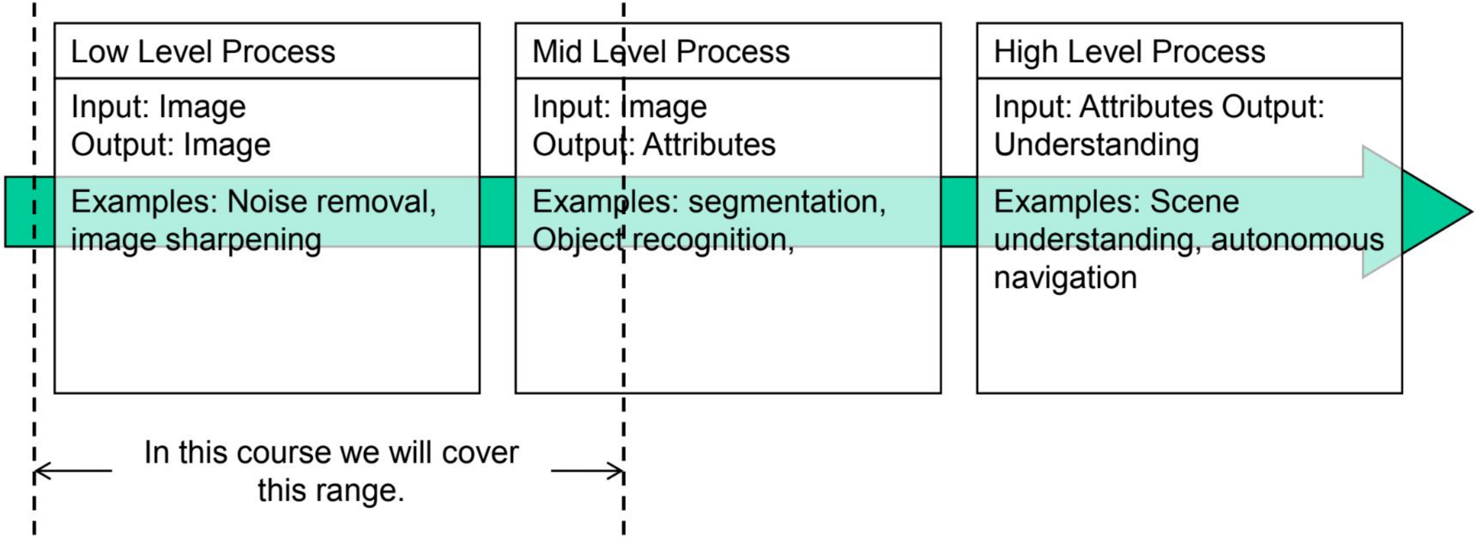
- Improvement of pictorial information for human interpretation.
- Processing of image data for storage, transmission and representation for autonomous machine perception.

Image Processing and Related Fields

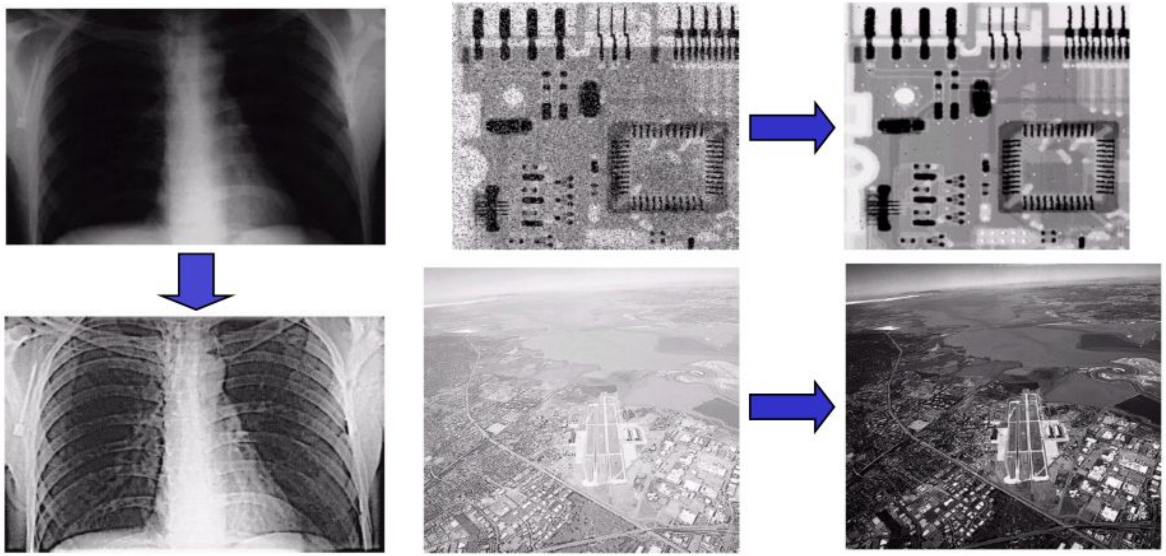


Some argument about where image processing ends and fields such as image analysis and computer vision start.

The continuum from image processing to computer vision can be broken up into low-, mid- and high-level processes.



DIP Example



DIP Example

(a) initial image (b) processed image

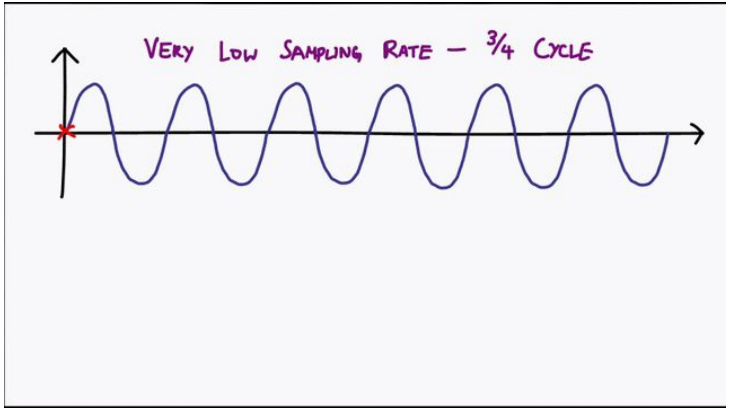
2.

Recap DSP 🌈

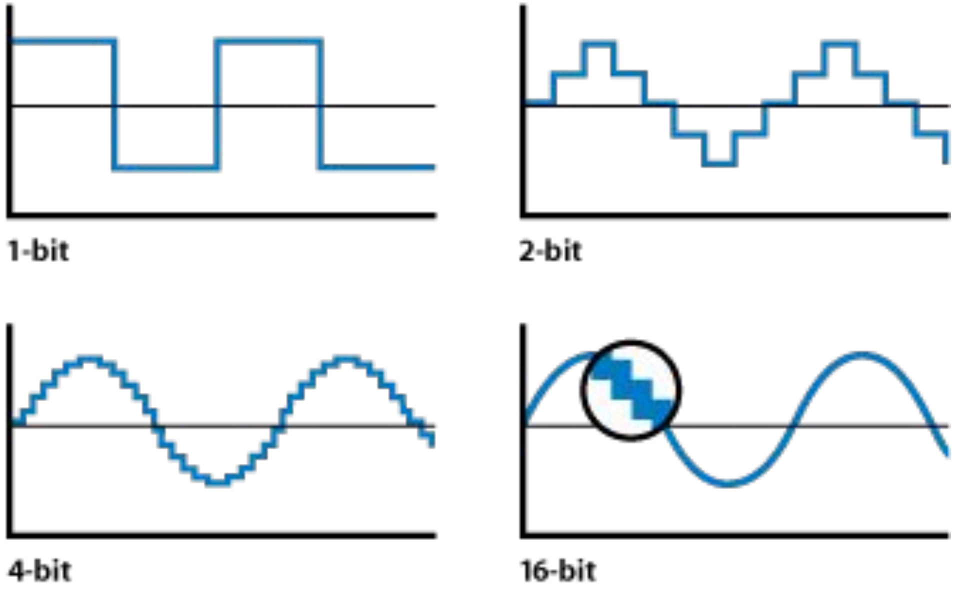
Sampling & Aliasing

- Nyquist-Shannon Sampling Theorem

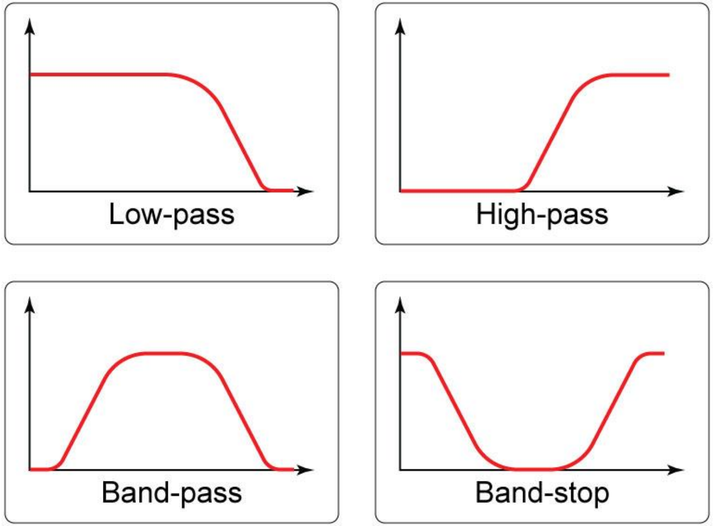
$$f_{sampling} \geq 2f_{max}$$



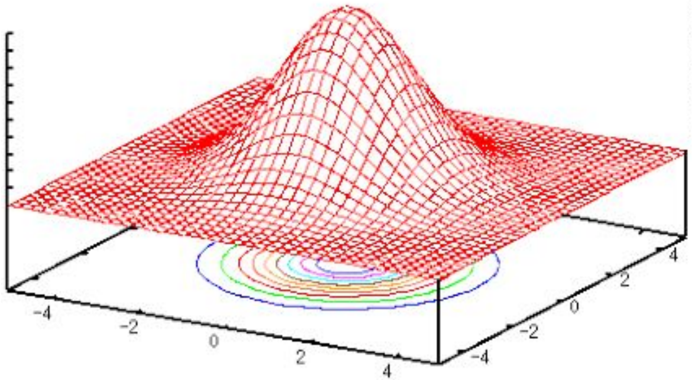
Quantization



Filter

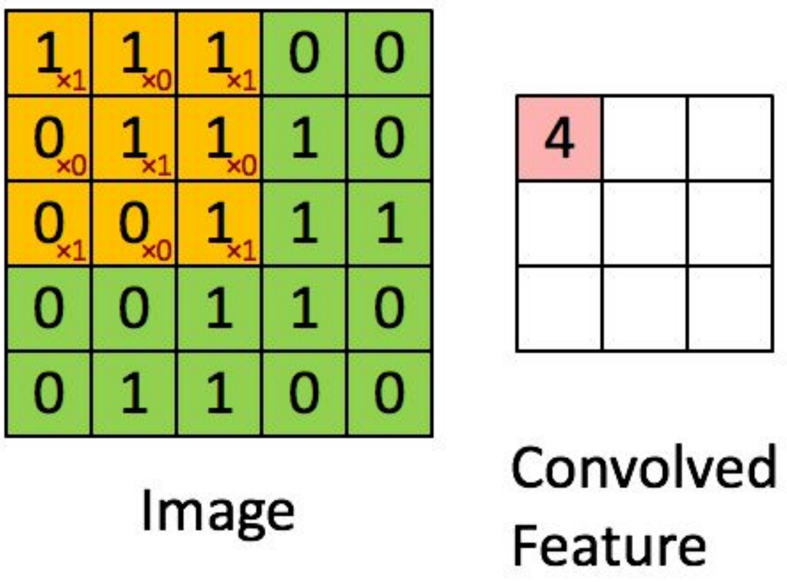


1D Filter

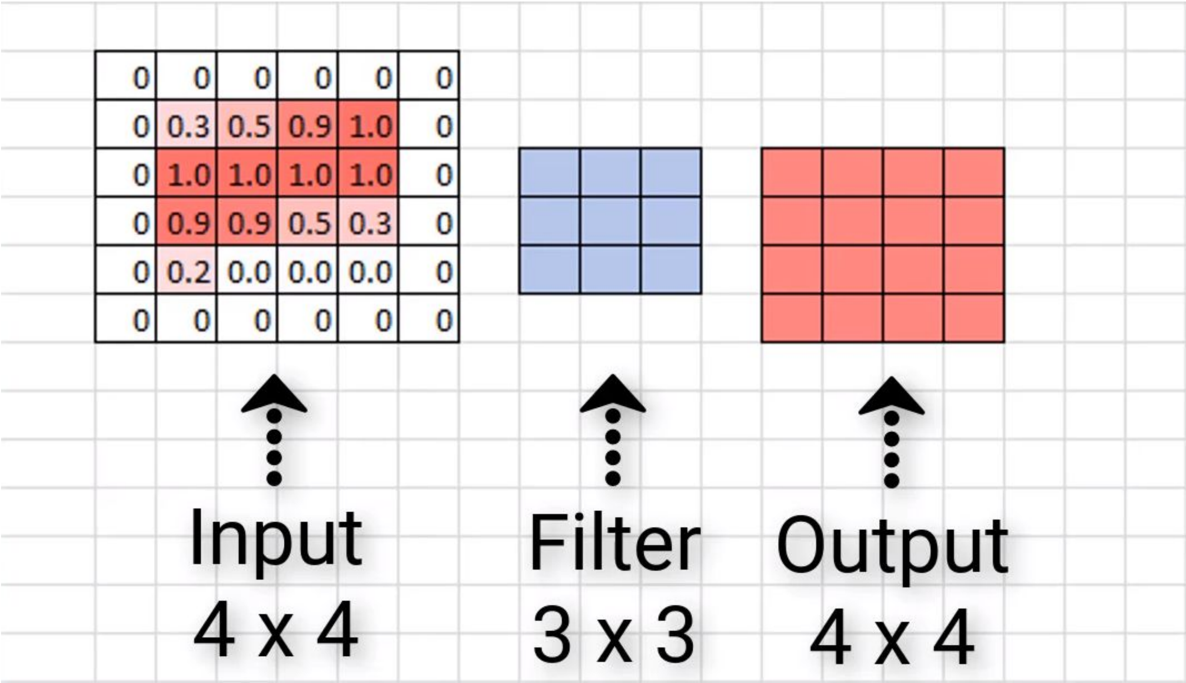


2D Filter

Convolution

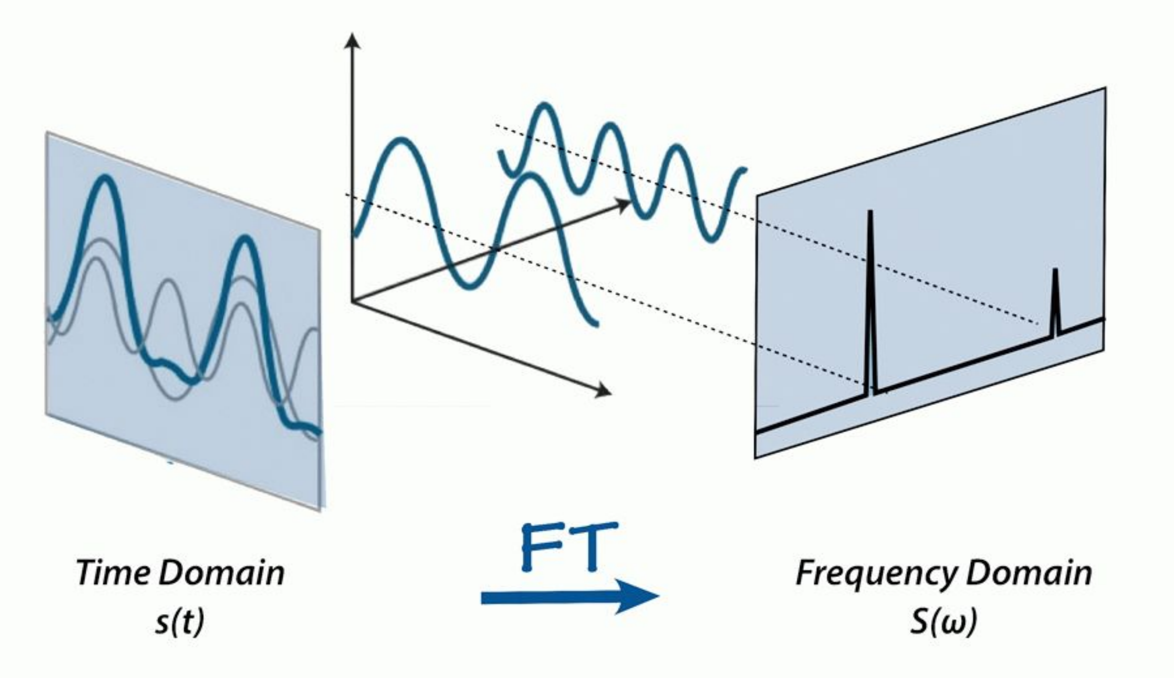


Padding



0 0 0 0 0 0
0 0.3 0.5 0.9 1.0 0
0 1.0 1.0 1.0 1.0 0
0 0.9 0.9 0.5 0.3 0
0 0.2 0.0 0.0 0.0 0
0 0 0 0 0 0
Input
4 x 4
Filter
3 x 3
Output
4 x 4

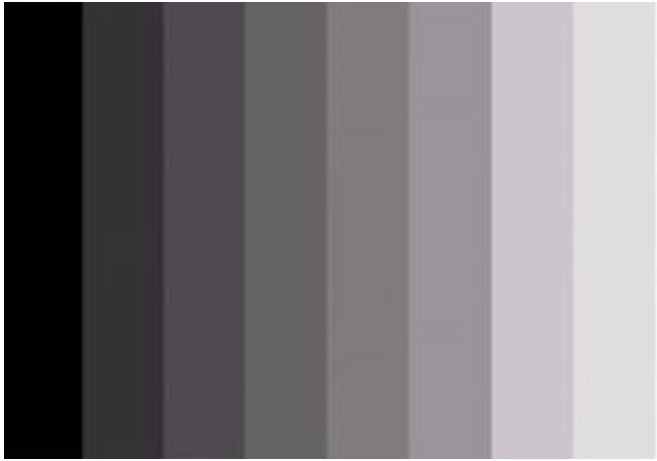
Fourier Transform

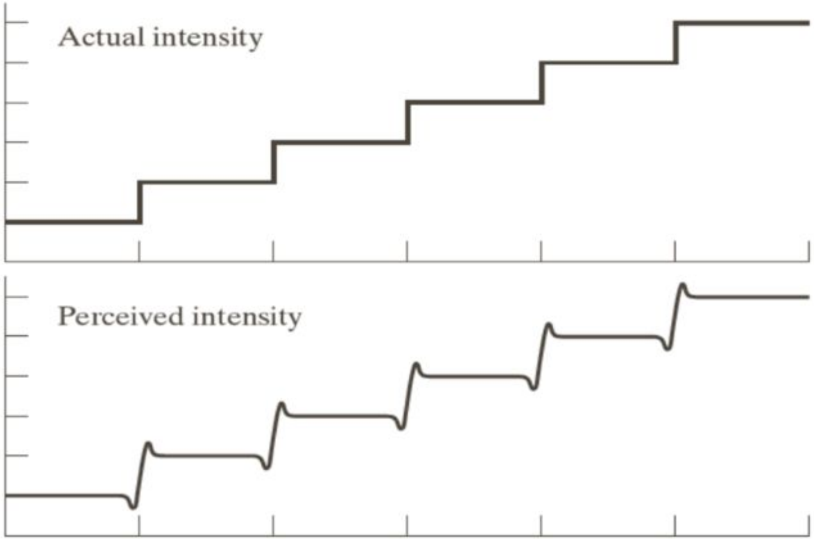


3.
Image Processing in Everyday Life

Lenna (1972)

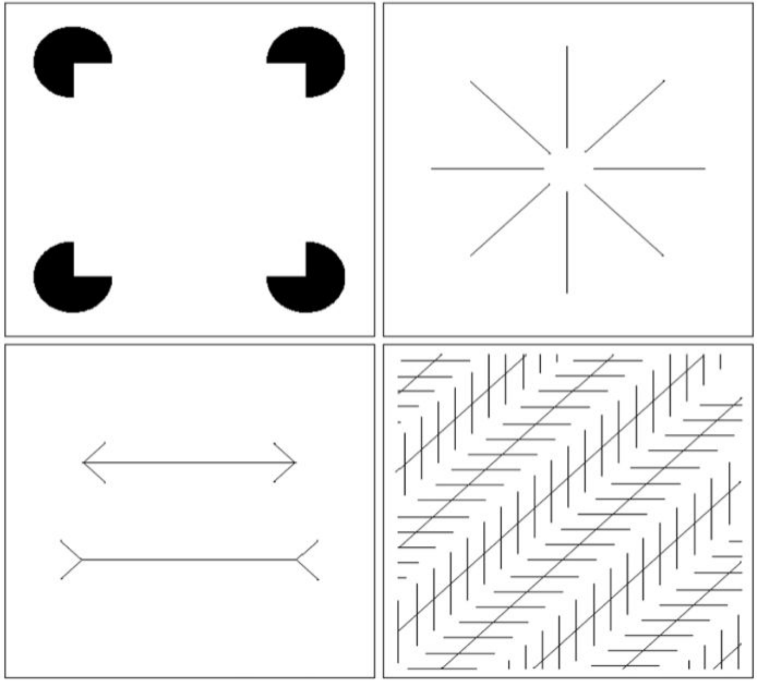
Band Mach Effect





Moire Effect

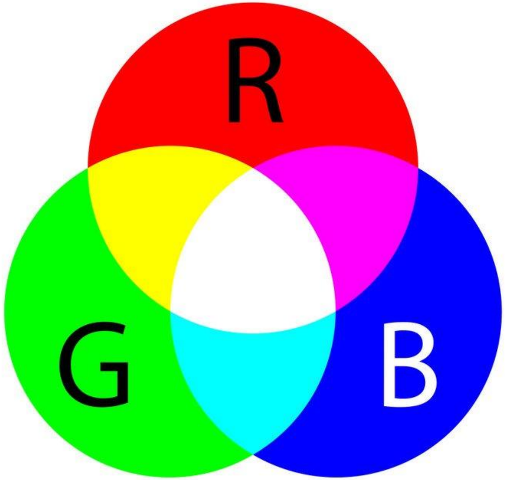
Human Visual Perception



4.

Intensity Transformation

Introduction



Introduction

Original

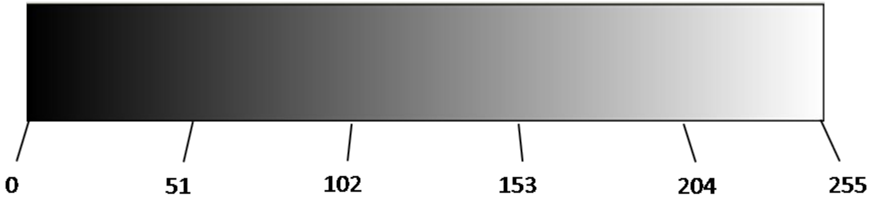
Red

Green

Blue

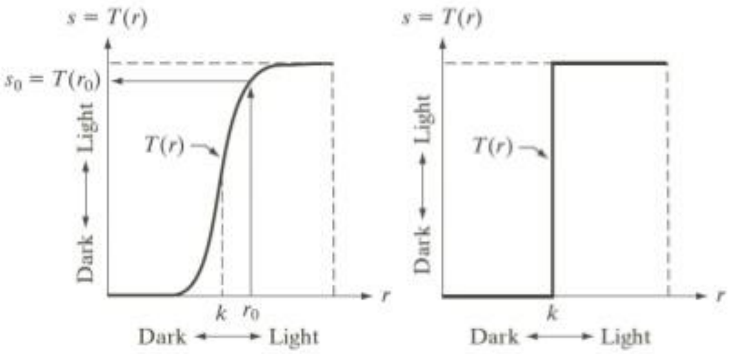
Introduction

8Bits



Intensity Transformation Functions

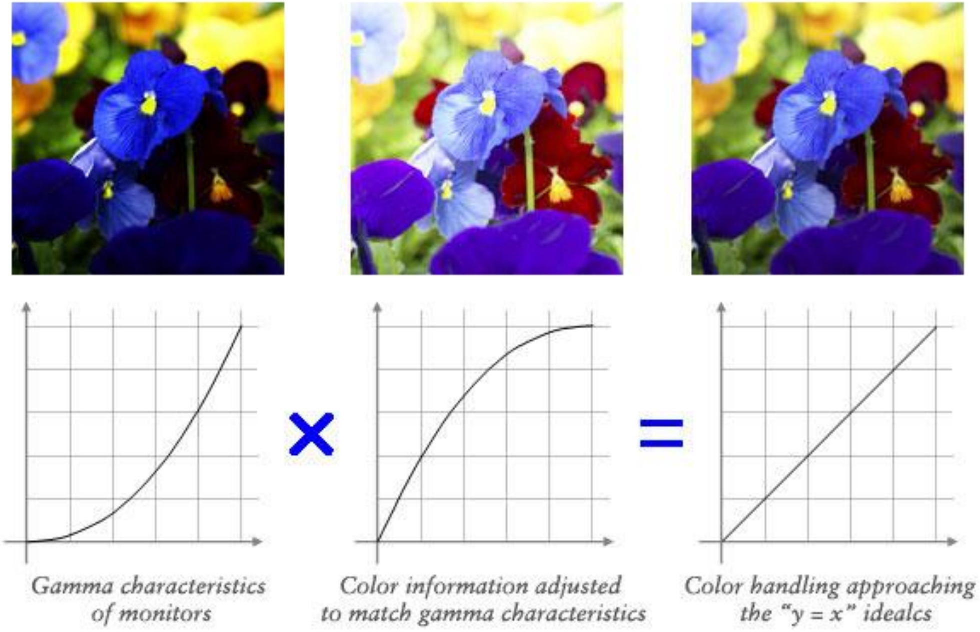
$$s = T(r)$$



a b

FIGURE 3.2 Intensity transformation functions. (a) Contrast-stretching function. (b) Thresholding function.

Gamma Adjustment

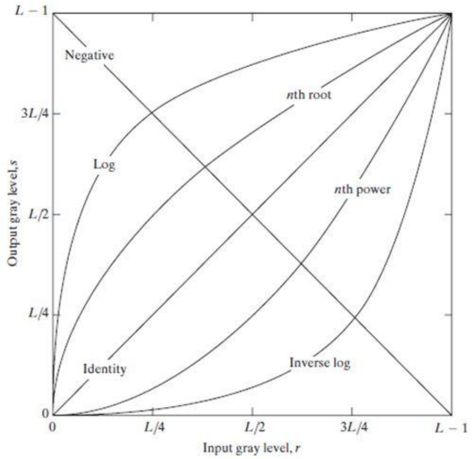


Gamma > 1 | Gamma < 1 | Gamma = 1

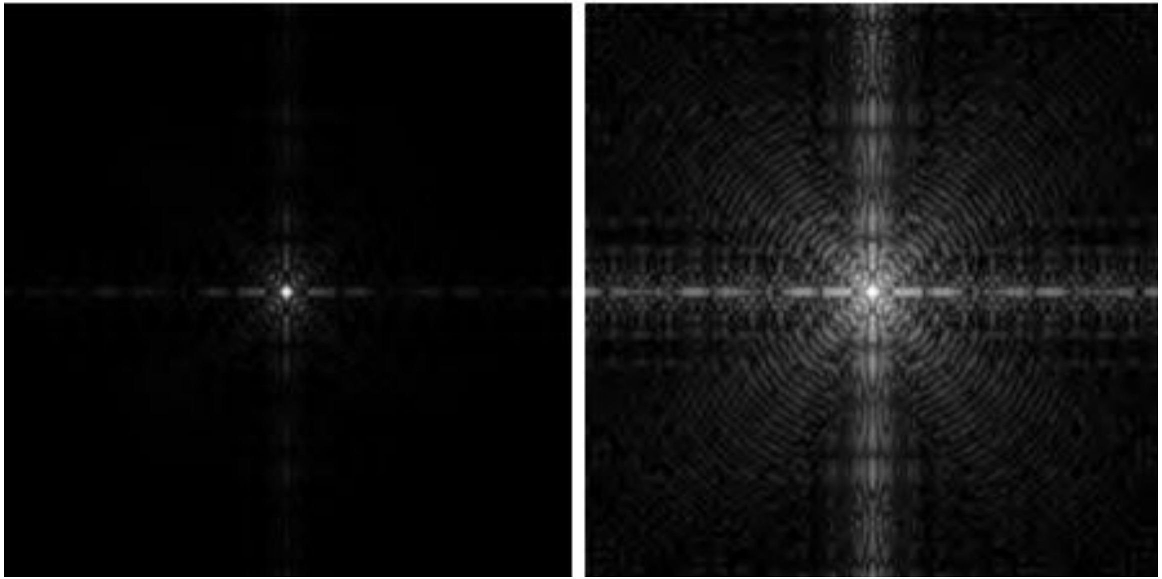
Intensity Transformation Functions

Some Intensity Transformation Functions

FIGURE 3.3 Some basic gray-level transformation functions used for image enhancement.

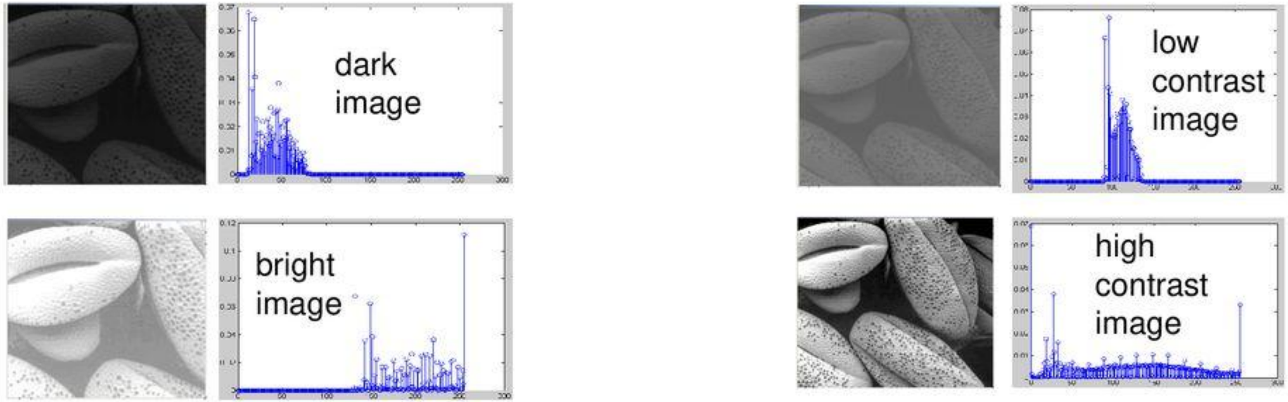


Logarithmic Intensity Transformation



Histogram

- Probability Density Function of occurrence of gray level intensity

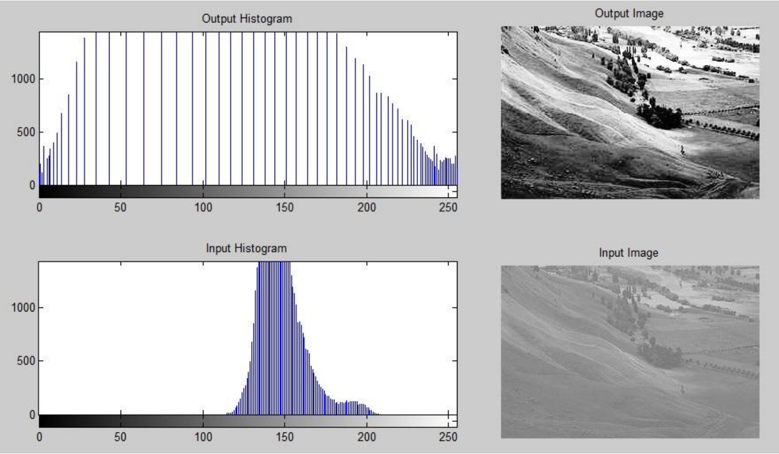


Histogram Processing

- Histogram Equalization
- Histogram Matching

Histogram Equalization

- The idea is to fill an image with the available grayscale range, Uniformly distributed over this range



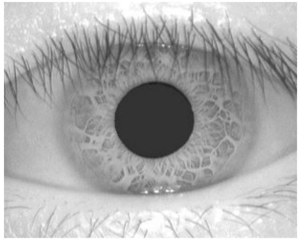
Histogram Equalization

Intensity (r)	No. of Pixels (n_j)	Acc Sum of P_r	Output value	Quantized Output (s)
0	20	0.2	0.2x7 = 1.4	1
1	5	0.25	0.25*7 = 1.75	2
2	25	0.5	0.5*7 = 3.5	3
3	10	0.6	0.6*7 = 4.2	4
4	15	0.75	0.75*7 = 5.25	5
5	5	0.8	0.8*7 = 5.6	6
6	10	0.9	0.9*7 = 6.3	6
7	10	1.0	1.0x7 = 7	7
Total	100			

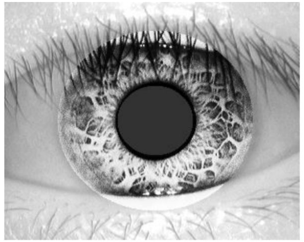
Local Histogram Equalization

- The previous histogram processing methods are global. Although this global approach is suitable for overall enhancement, there are cases in which it is necessary to enhance details over small areas in an image.

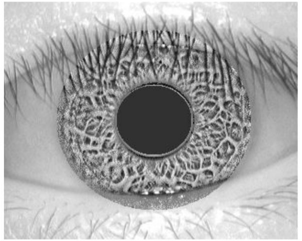
Sliding window approach: different histogram (and mapping) for every pixel



Original



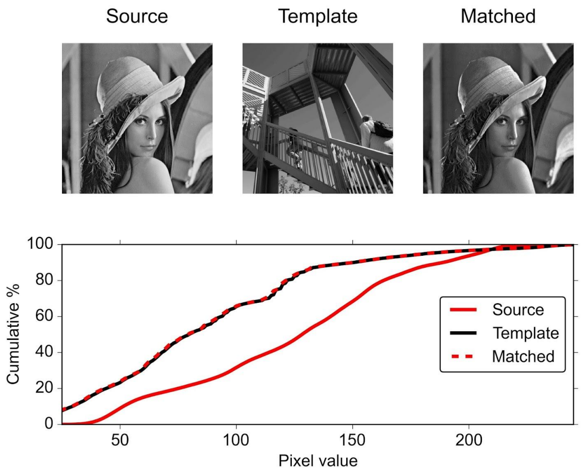
Histogram Equalization



Local Histogram Equalization

Histogram Matching

- A process where an image is modified such that its histogram matches that of another reference dataset



Histogram Matching

- Given input and reference images. Compute their histograms.

Intensity (s)	# pixels
0	20
1	5
2	25
3	10
4	15
5	5
6	10
7	10
Total	100

input

Intensity (z)	# pixels
0	5
1	10
2	15
3	20
4	20
5	15
6	10
7	5
Total	100

reference

Histogram Matching

- Equalize both of them.

r	(n_j)	ΣP_r	s
0	20	0.2	1
1	5	0.25	2
2	25	0.5	3
3	10	0.6	4
4	15	0.75	5
5	5	0.8	6
6	10	0.9	6
7	10	1.0	7

input

z	(n_j)	ΣP_z	v
0	5	0.05	0
1	10	0.15	1
2	15	0.3	2
3	20	0.5	4
4	20	0.7	5
5	15	0.85	6
6	10	0.95	7
7	5	1.0	7

reference

Histogram Matching

- Map

r → s

r	s
0	1
1	2
2	3
3	4
4	5
5	6
6	6
7	7

s → v

v → z

v	z
0	0
1	1
2	2
4	3
5	4
6	5
7	6
7	7

r	z
0	1
1	2
2	2
3	3
4	4
5	5
6	5
7	6

5. Filtering in Spatial/Frequency Domain

Spatial Linear Filtering

- Replacing the value of every pixel in an image by the average of the gray levels in the neighborhood defined by the filter mask.
  - Smoothing Linear Filters
  - Sharpening Linear Filters

Smoothing Linear Filters

- Used for blurring, noise reduction
- Blurring is used in preprocessing steps to removal of small details from an image prior to object extraction and bridging of small gaps in lines or curves
- Noise reduction can be accomplished by blurring

Smoothing Linear Filters

- Used for blurring, noise reduction
- Low pass filter
- Blurring is used in preprocessing steps to removal of small details from an image prior to object extraction and bridging of small gaps in lines or curves
- Noise reduction can be accomplished by blurring

Smoothing Linear Filters

- Averaging Filter
- Weighted Averaging Filter

Averaging Filter

- A major use of averaging filters is in the reduction of irrelevant detail in image.

$$\frac{1}{9} \times \begin{array}{|c|c|c|} \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline \end{array}$$

Weighted Averaging Filter

- Giving more weight to some pixel at the expanses of others.
- The center pixel is multiplied by a higher value than any other, thus giving the pixel more importance in the calculation of average.

$$\frac{1}{16} \times \begin{array}{|c|c|c|} \hline 1 & 2 & 1 \\ \hline 2 & 4 & 2 \\ \hline 1 & 2 & 1 \\ \hline \end{array}$$

Sharpening Linear Filters

- Sharpening, which can help emphasize details and enhance the edges of object in image
- High pass filter

1st & 2nd Order Derivative

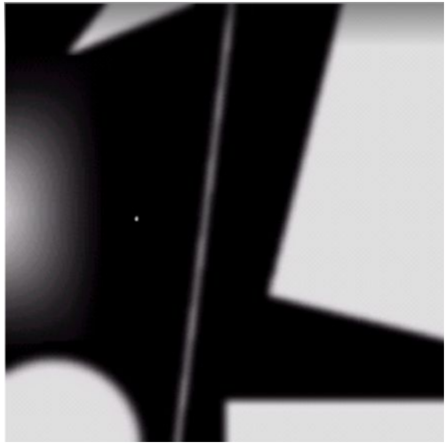
- First order derivative

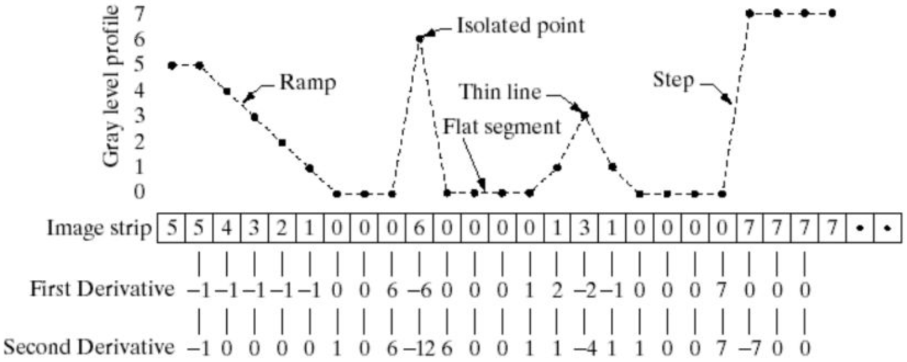
$$\frac{\partial f}{\partial x} = f(x+1) - f(x) \qquad (1)$$

- Second order derivative

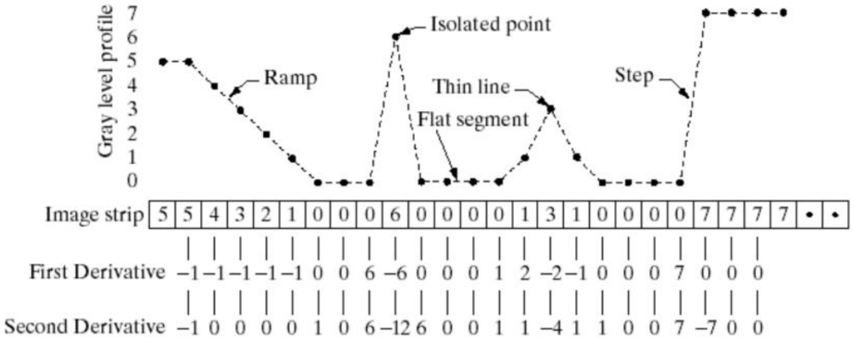
$$\frac{\partial^2 f}{\partial x^2} = f(x+1) + f(x-1) - 2f(x) \qquad (2)$$

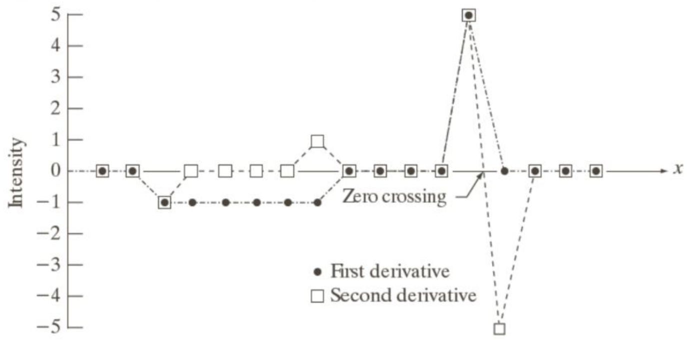
1st & 2nd Order Derivative





1st & 2nd Order Derivative





Laplacian Filter

Laplacian : $$\nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$$

x direction : $$\frac{\partial^2 f}{\partial x^2} = f(x+1, y) + f(x-1, y) - 2f(x, y)$$

y direction : $$\frac{\partial^2 f}{\partial y^2} = f(x, y+1) + f(x, y-1) - 2f(x, y)$$

$$\therefore \nabla^2 f = [f(x+1, y) + f(x-1, y) + f(x, y+1) + f(x, y-1)] - 4f(x, y)$$

Laplacian Filter

0	1	0
1	−4	1
0	1	0

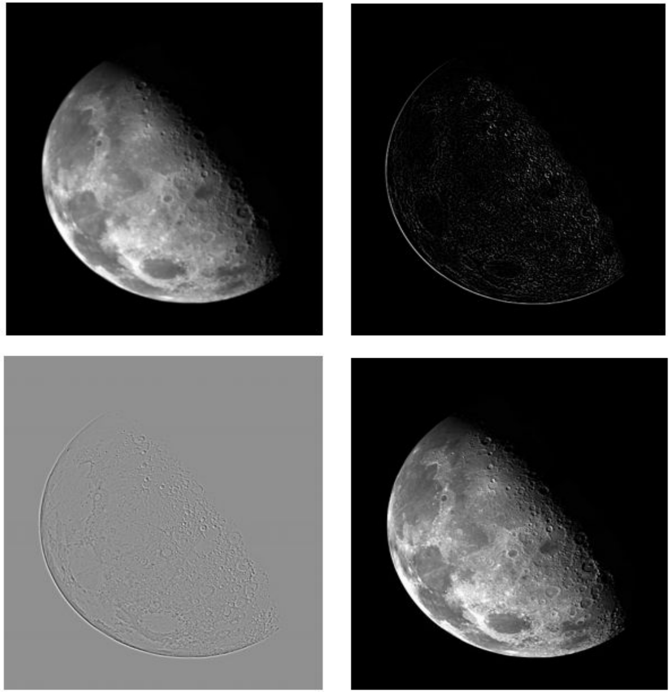
1	1	1
1	−8	1
1	1	1

0	−1	0
−1	4	−1
0	−1	0

−1	−1	−1
−1	8	−1
−1	−1	−1

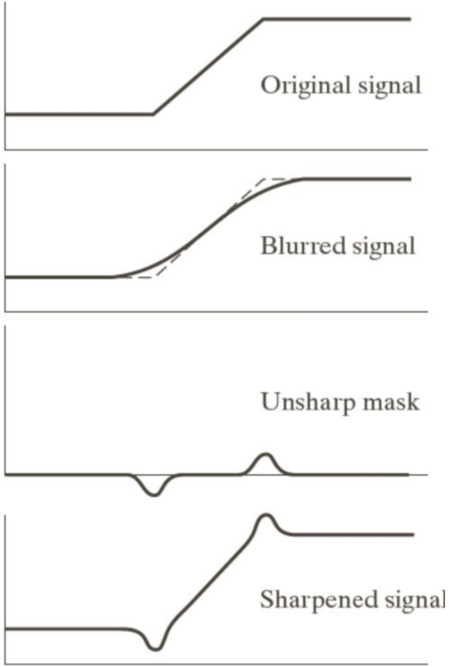
$$g(x,y) = f(x,y) + c\left[\nabla^2 f(x,y)\right]$$

Image Sharpening with Laplacian Filter



1.original image
2.laplacian without scaling
3.laplacian with scaling
4.sharpened image (1 - 3)

Image Sharpening with Unsharp Masking



Gradient Mask

Prewitt Operator

h_1

1	1	1
0	0	0
–1	–1	–1

h_2

0	1	1
–1	0	1
–1	–1	0

h_3

–1	0	1
–1	0	1
–1	0	1

Sobel Operator

h_1

1	2	1
0	0	0
–1	–2	–1

h_2

0	1	2
–1	0	1
–2	–1	0

h_3

–1	0	1
–2	0	2
–1	0	1

Robinson Operator

h_1

1	1	1
1	–2	1
–1	–1	–1

h_2

1	1	1
–1	–2	1
–1	–1	1

h_3

–1	1	1
–1	–2	1
–1	1	1

Spatial Nonlinear Filtering

- Linear Filtering is based on computing the convolution/correlation sum which is a linear operation.

- Nonlinear Filtering is based on nonlinear operations involving the pixels of a neighborhood

Spatial Nonlinear Filtering

- Nonlinear Smoothing Filtering
  - Aim to make image clean and smooth
- Nonlinear Sharpening Filtering
  - Aim to find edges and discontinuities

Salt & Pepper Noise

Nonlinear Smoothing Filter

- Minimum Filter
- Maximum Filter
- Median Filter

Minimum Filter

- Selects the smallest value in the window and replace the center by the smallest value
- Reduce salt noise.

Maximum Filter

- Selects the largest value in the window and replace the center by the largest value
- Reduce pepper noise.

Median Filter

- Sort the neighboring pixels into order based upon their intensities.

- Replace the original value of the pixel with the median value from the list.

Median Filter

- Sort the neighboring pixels into order based upon their intensities.

- Replace the original value of the pixel with the median value from the list.

Nonlinear Smoothing Filtering

TABLE 5.2 Spatial filters. The variables m and n denote respectively the number of rows and columns of the filter neighborhood.

Filter Name	Equation	Comments
Arithmetic mean	$\hat{f}(x,y) = \frac{1}{mn} \sum_{(s,t)\in S_{xy}} g(s,t)$	Implemented using IPT functions `w = fspecial('average', [m, n])` and `f = imfilter(g, w)`.
Geometric mean	$\hat{f}(x,y) = \left[\prod_{(s,t)\in S_{xy}} g(s,t) \right]^{\frac{1}{mn}}$	This nonlinear filter is implemented using function `gmean` (see custom function `spfilt` in this section).
Harmonic mean	$\hat{f}(x,y) = \dfrac{mn}{\sum_{(s,t)\in S_{xy}} \frac{1}{g(s,t)}}$	This nonlinear filter is implemented using function `harmean` (see custom function `spfilt` in this section).
Contraharmonic mean	$\hat{f}(x,y) = \dfrac{\sum_{(s,t)\in S_{xy}} g(s,t)^{Q+1}}{\sum_{(s,t)\in S_{xy}} g(s,t)^{Q}}$	This nonlinear filter is implemented using function `charmean` (see custom function `spfilt` in this section).
Median	$\hat{f}(x,y) = \underset{(s,t)\in S_{xy}}{\text{median}} \{g(s,t)\}$	Implemented using IPT function `medfilt2`: `f = medfilt2(g, [m n])`.
Max	$\hat{f}(x,y) = \max_{(s,t)\in S_{xy}} \{g(s,t)\}$	Implemented using IPT function `ordfilt2`: `f = ordfilt2(g, m*n, ones(m, n))`.
Min	$\hat{f}(x,y) = \min_{(s,t)\in S_{xy}} \{g(s,t)\}$	Implemented using IPT function `ordfilt2`: `f = ordfilt2(g, 1, ones(m, n))`.
Midpoint	$\hat{f}(x,y) = \frac{1}{2}\left[\max_{(s,t)\in S_{xy}} \{g(s,t)\} + \min_{(s,t)\in S_{xy}} \{g(s,t)\} \right]$	Implemented as 0.5 times the sum of the max and min filtering operations.
Alpha-trimmed mean	$\hat{f}(x,y) = \frac{1}{mn-d} \sum_{(s,t)\in S_{xy}} g_r(s,t)$	The $d/2$ lowest and $d/2$ highest intensity levels of $g(s,t)$ in S_{xy} are deleted, $g_r(s,t)$ denotes the remaining $mn - d$ pixels in the neighborhood. Implemented using function `alphatrim` (see custom function `spfilt` in this section).

Nonlinear Sharpening Filter

- Using first-order derivatives for image sharpening , "Gradient"

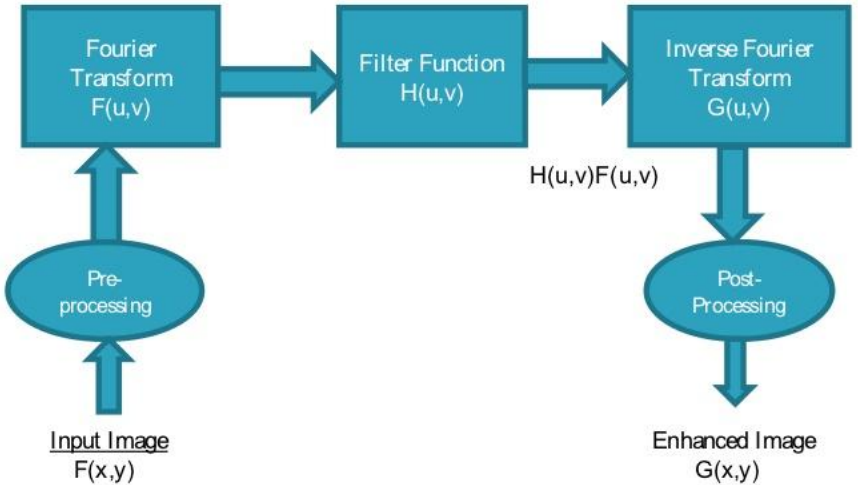
$$\nabla \mathbf{f} \equiv \operatorname{grad}(f(x,y)) \equiv \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \dfrac{\partial f(x,y)}{\partial x} \\ \dfrac{\partial f(x,y)}{\partial y} \end{bmatrix}$$

value at (x,y) of the rate change in the direction of the gradient vector, "Gradient Image"

$$\nabla f(x,y) = \operatorname{mag}[\nabla \mathbf{f}] = \sqrt{G_x^2 + G_y^2} = \left[\left(\frac{\partial f(x,y)}{\partial x} \right)^2 + \left(\frac{\partial f(x,y)}{\partial y} \right)^2 \right]^{\frac{1}{2}}$$

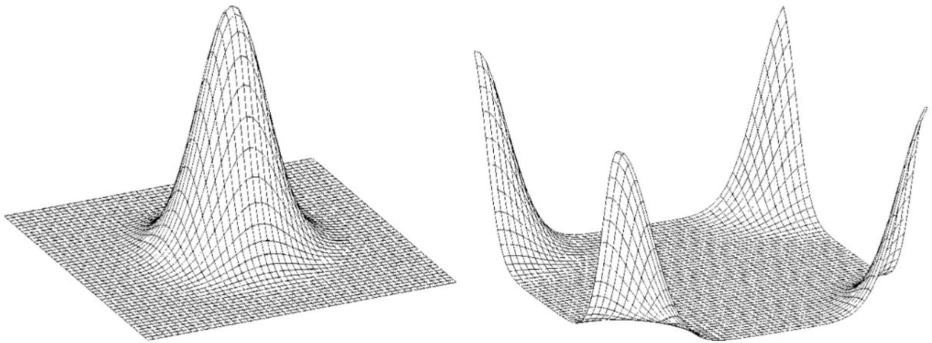
Frequency Domain Filtering

- Used for smoothing and sharpening of image by removal of high or low frequency components

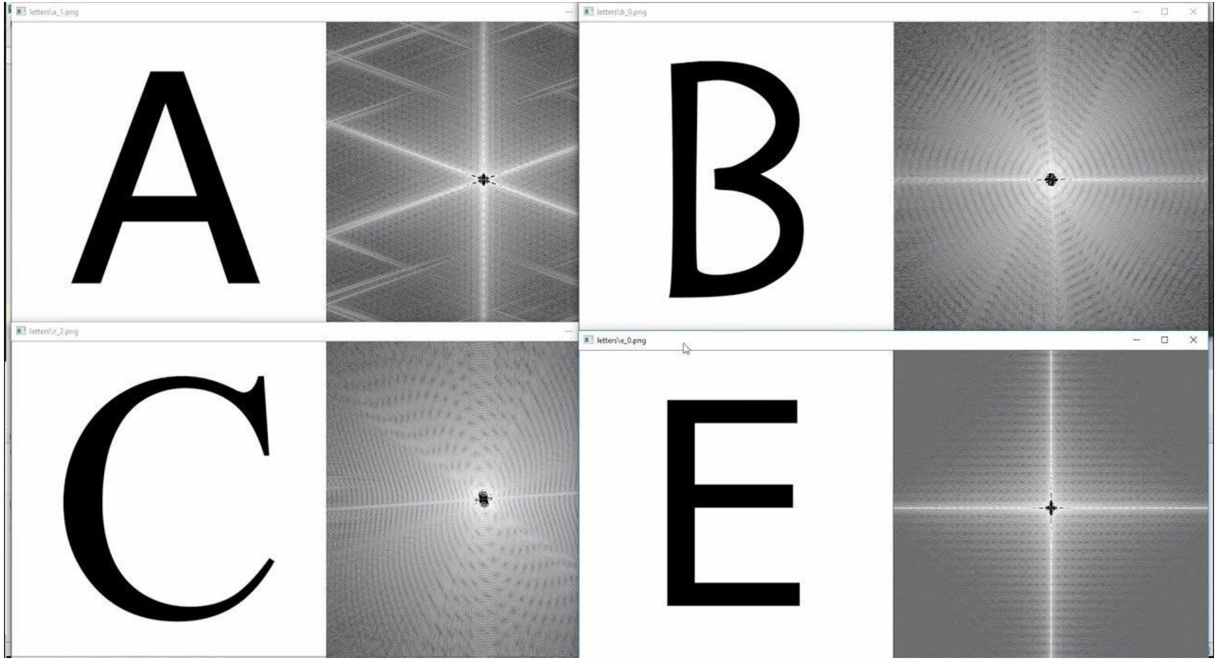


Frequency Domain Filtering

- rearranges the outputs of fft by moving the zero-frequency component to the center of the array



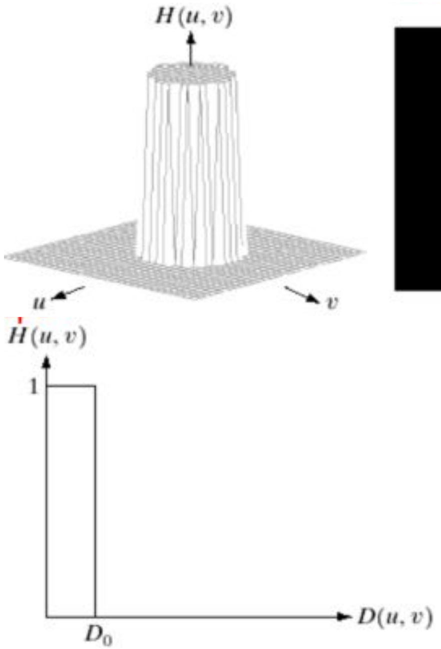
Frequency Domain Filtering

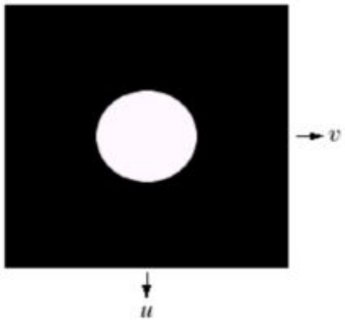


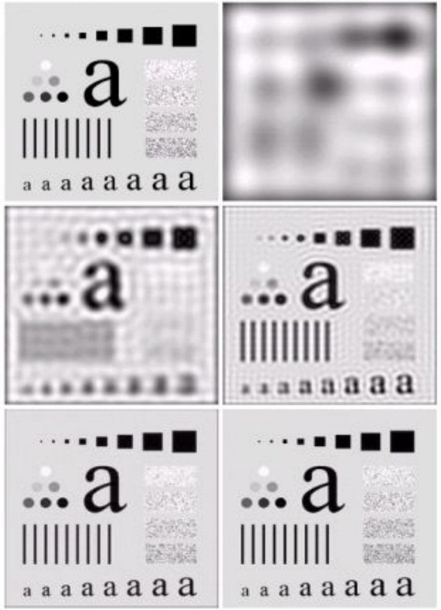
Frequency Domain Filtering

- Ideal Filter
- Butterworth Filter
- Gaussian Filter

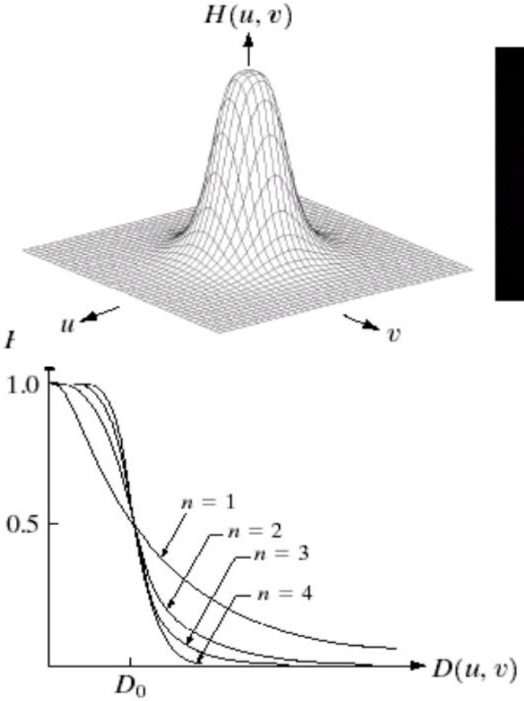
Lowpass Ideal Filter

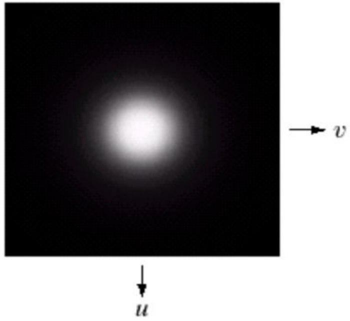


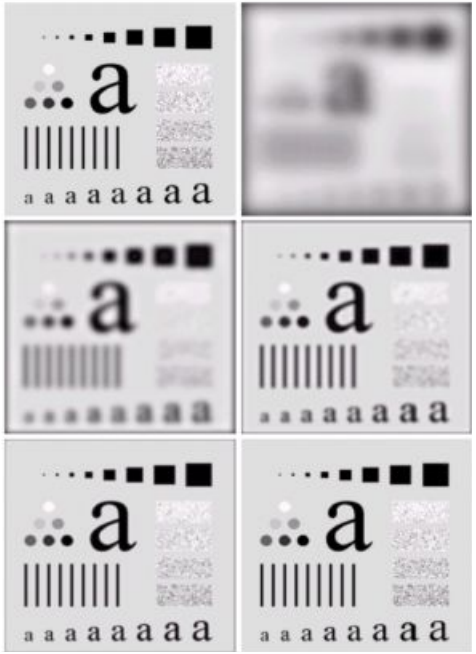




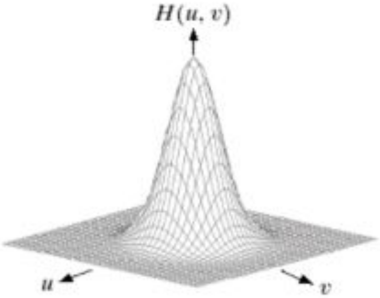
Lowpass Butterworth Filter

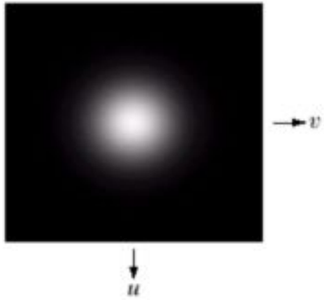


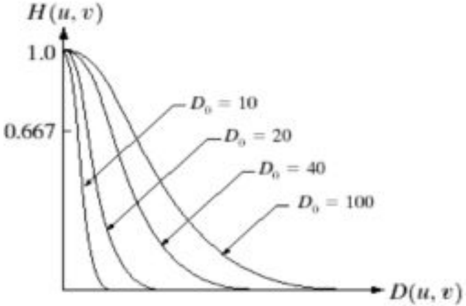


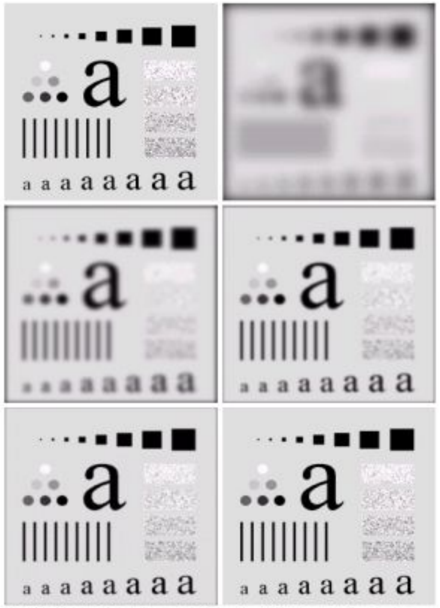


Lowpass Gaussian Filter

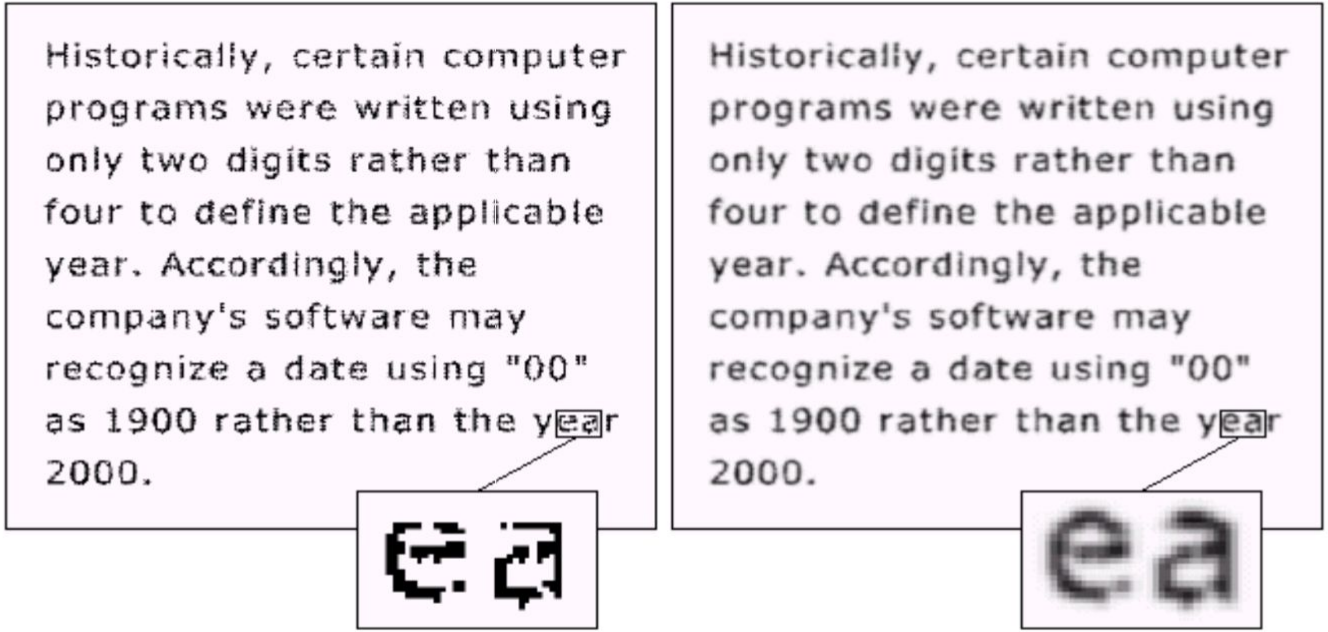




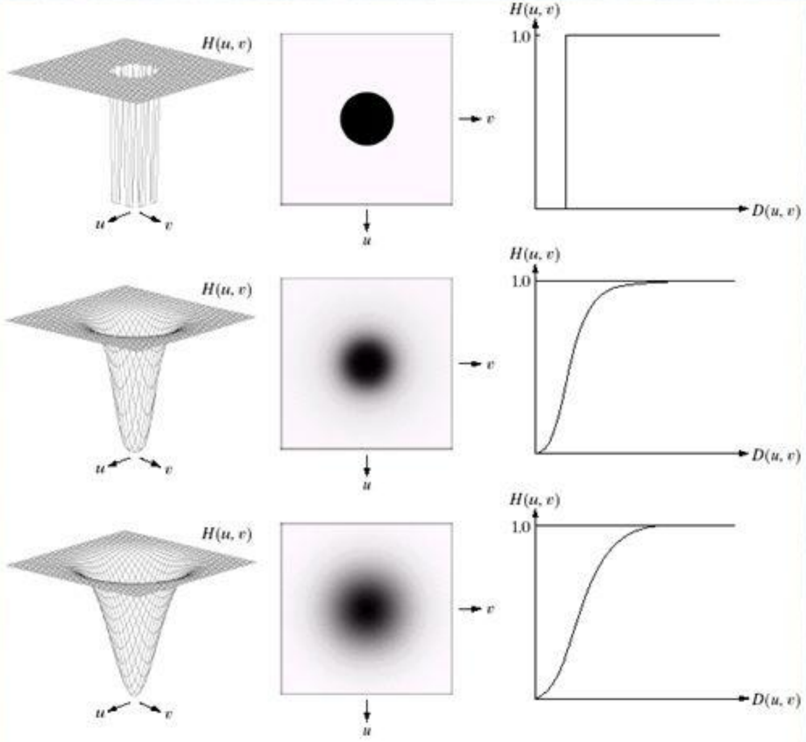




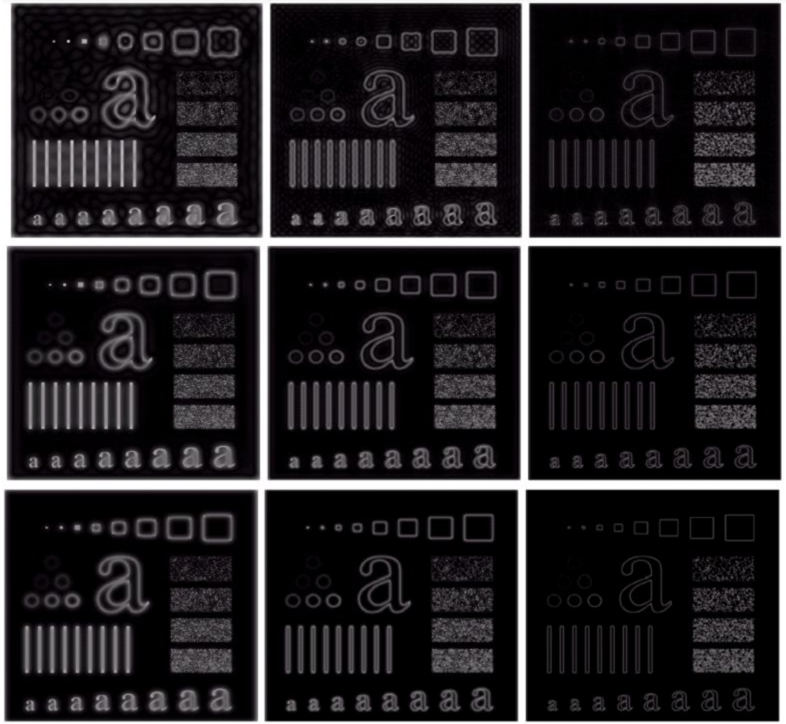
Application of Lowpass Filtering



Highpass Filter



Highpass Filter



Ideal Highpass Filtering

Butterworth Highpass Filtering

Gaussian Highpass Filtering

Application of Highpass Filtering

Image Restoration by Filtering in Frequency Domain

- Bandstop Filter

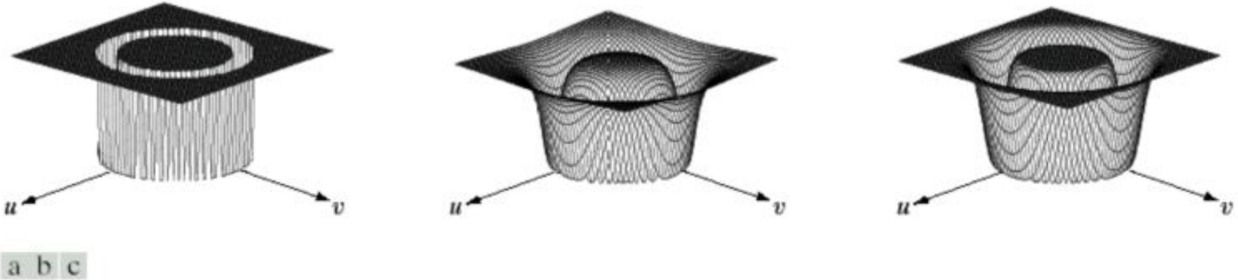


FIGURE 5.15 From left to right, perspective plots of ideal, Butterworth (of order 1), and Gaussian bandreject filters.

Image Restoration by Filtering in Frequency Domain

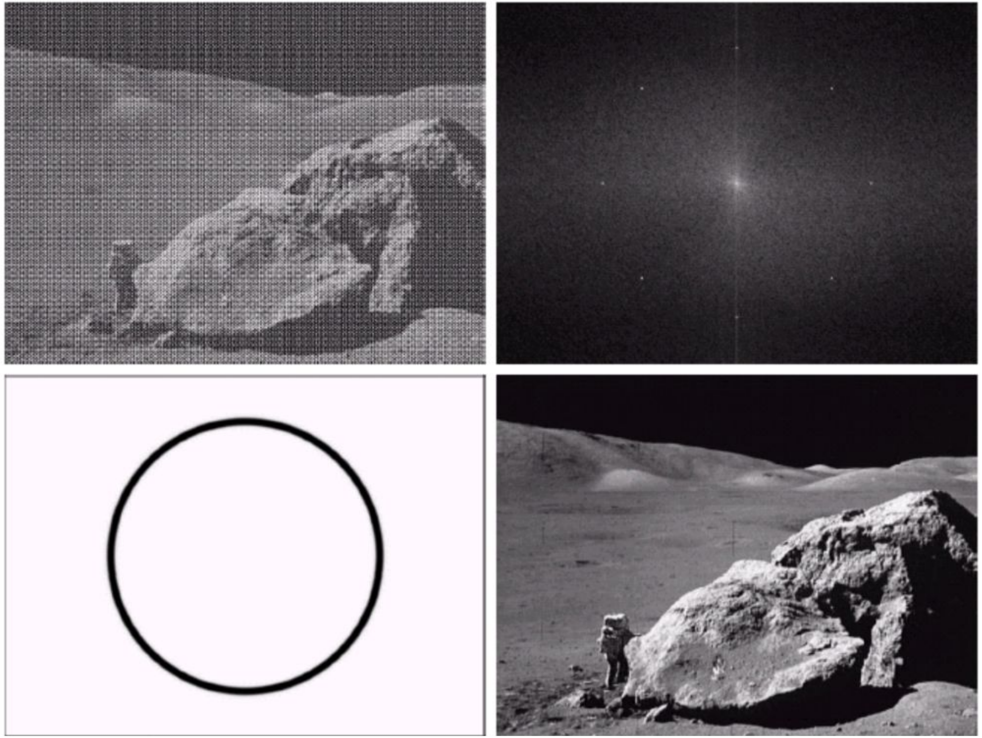


Image Restoration by Filtering in Frequency Domain

- Bandpass Filter
  - The band-pass filter has been applied for sinusoidal image enhancement such as fingerprint and some texture pattern images.

Image Restoration by Filtering in Frequency Domain

- Notch Filter

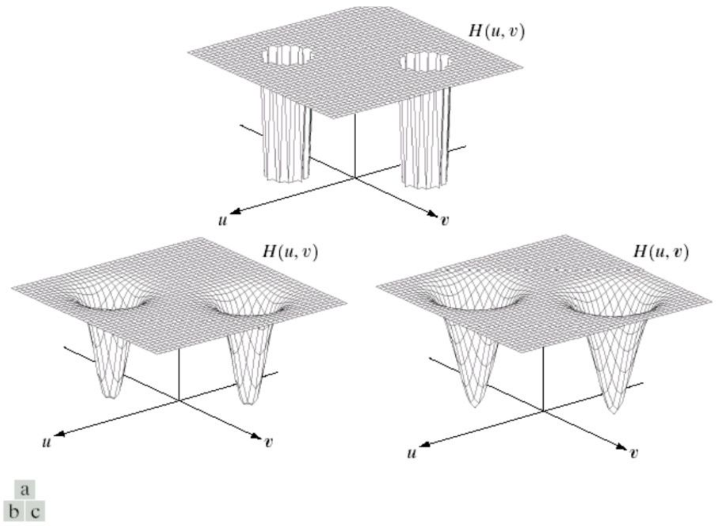
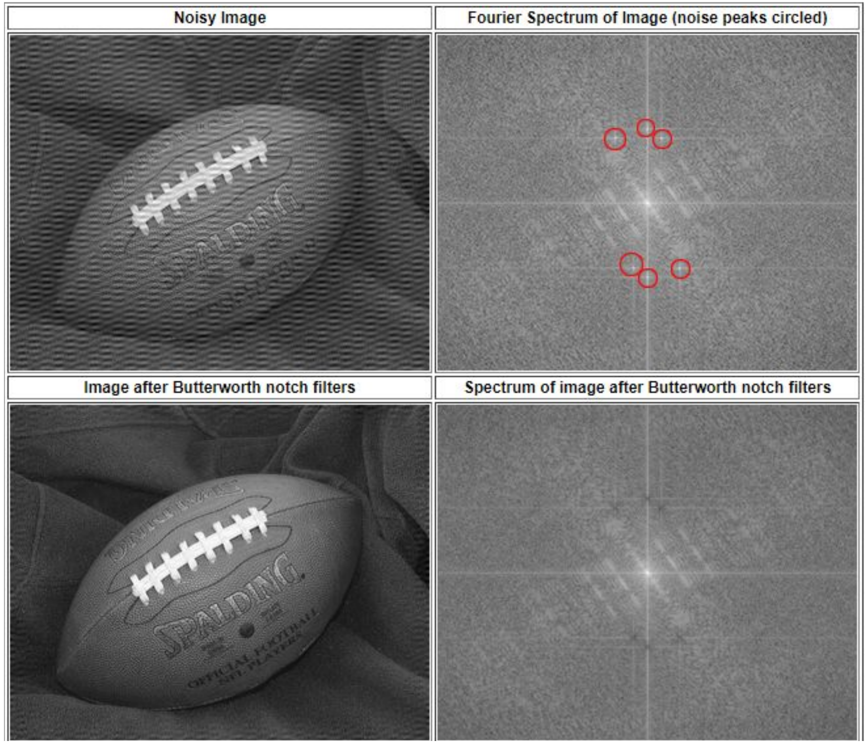


FIGURE 5.18 Perspective plots of (a) ideal, (b) Butterworth (of order 2), and (c) Gaussian notch (reject) filters.

Image Restoration by Filtering in Frequency Domain



6.

Color Model

Color Models

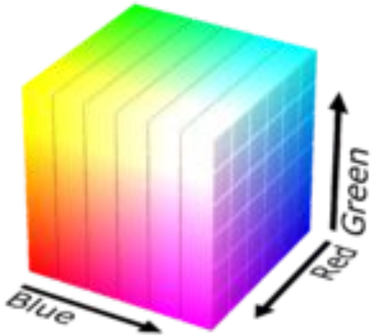
Different types of color models are used in multiple fields like in hardware, in multiple applications of creating animation, etc.

- In Digital Image Processing, the hardware-oriented models that are commonly used are the RGB model for color monitors.
- CMY(cyan, magenta, yellow) and CMYK(cyan, magenta, yellow, black) models are used for color printing.
- HSI(hue, saturation, intensity) deals with colors as humans interpret.

RGB

In the RGB model, each color appears in its primary components of red, green and blue. This model is based on a Cartesian coordinate system

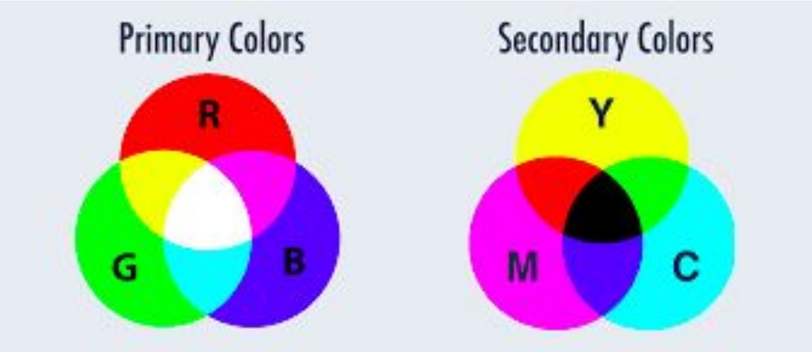
- widely used in the representation and display of images in electronic systems like computers and televisions.
- Image scanner which scans images and converts it to a digital image mostly supports RGB color
- It is used in web graphics.



CMY, CMYK

This model contains the secondary colors. In this model, any secondary color when passed through white light will not reflect the color from which a combination of colors is made.

- It is used in color printing as it uses colored inks.
- It is used in most commercial printing like magazines, books, etc.

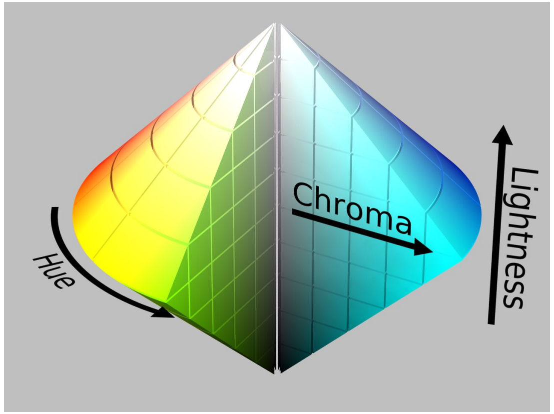


$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

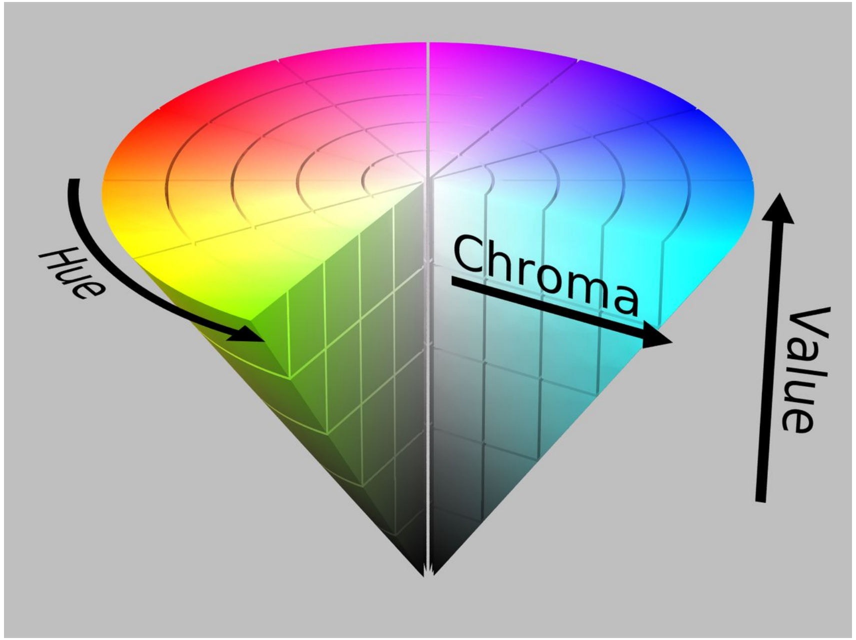
HSI

When humans view a color object, we tend to describe it by its hue, saturation, and brightness.

- Hue is an attribute that describes a pure color (e.g., pure yellow, orange, or red).
- Saturation gives a measure of the degree to which a pure color is diluted by white light.
- Brightness is a subjective descriptor that is practically impossible to measure. It embodies the achromatic notion of intensity and is a key factor in describing color sensation.



HSV

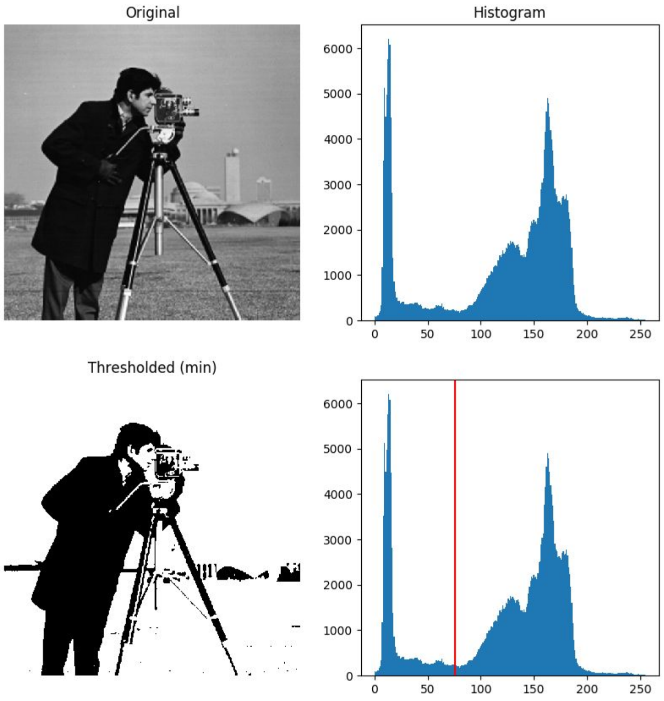


7.
Image Segmentation

Thresholding

The simplest method of image segmentation is called the thresholding method. This method is based on a clip-level (or a threshold value) to turn a gray-scale image into a binary image.

Thresholding

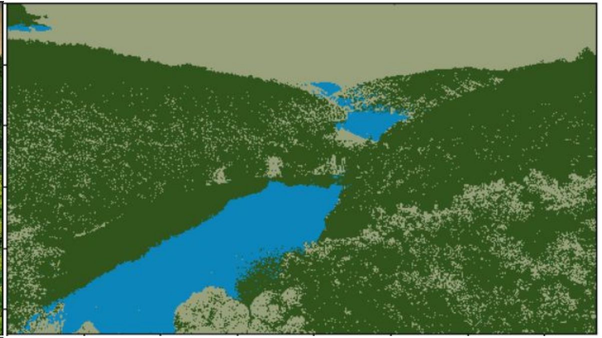


K-mean Clustering

K-Means clustering is unsupervised machine learning algorithm that aims to partition N observations into K clusters in which each observation belongs to the cluster with the nearest mean. A cluster refers to a collection of data points aggregated together because of certain similarities.

K-mean Clustering

K-mean Clustering



Motion & Interactive Segmentation

- look at the differences between a pair of images. Assuming the object of interest is moving, the difference will be exactly that object.

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THANKS!

Any questions?