Digital Signal Processing

Lecture 11 – digital image processing 1

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Digital Image Definition

An image is a two-dimensional function **f(x,y)**, where x and y are the **sp atial** (plane) coordinates, and the amplitude of **f** at any pair of coordinat es (x,y) is called the intensity of the image at that level.

If **x,y** and the **amplitude** values of **f** are **finite** and **discrete quantitie s**, we call the image a **digital image**. A digital image is composed of a fi nite number of elements called **pixels**, each of which has a particular lo cation and value.

Digital Image Representation

Pixel intensity value

$\underbrace{f(1,1)}_{\text{Pixel location}} = 103$

Consider the following image (2724x2336 pixels) to be 2D function or a **matrix** with **r ows** and **columns**

$f(2724,2336) = 88$

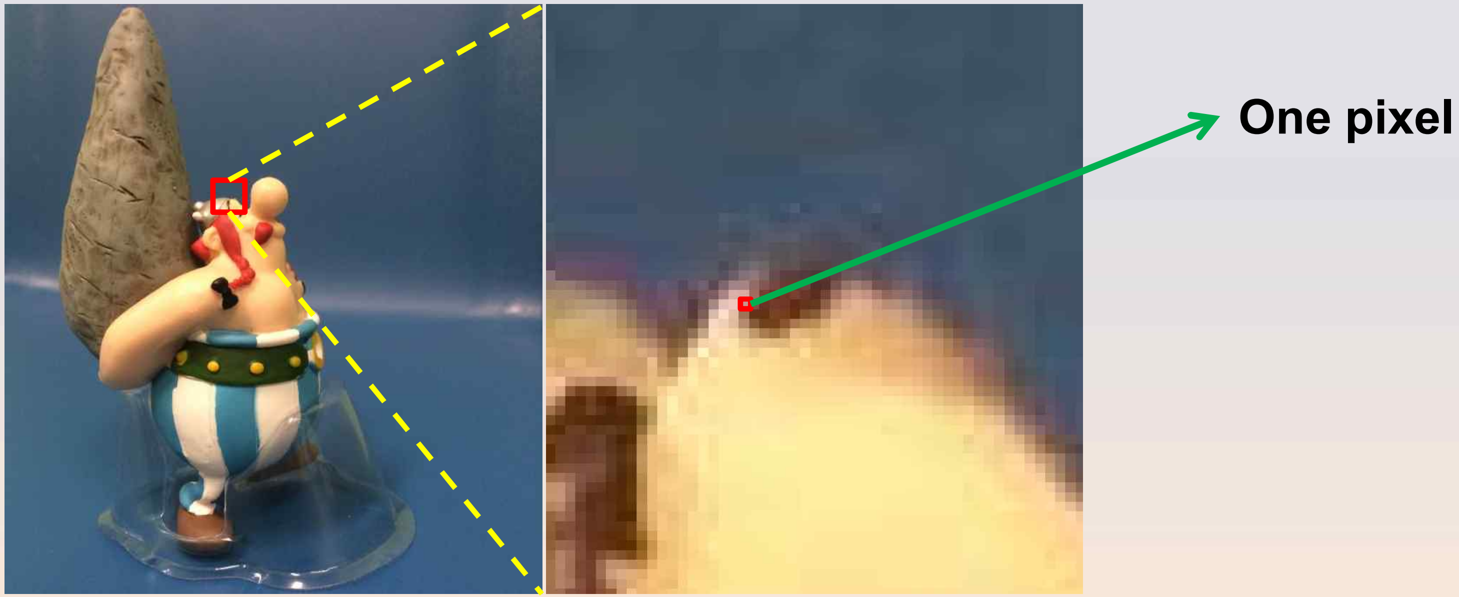
In 8-bit representation
Pixel intensity values change between 0 (Black) and 255 (White)

$f(\underbrace{645:650}_{\text{rows}},\underbrace{1323:1328}_{\text{columns}}) =$

$$\begin{matrix} 83 & 82 & 82 & 82 & 82 & 82 \\ 82 & 82 & 82 & 81 & 81 & 81 \\ 82 & 82 & 81 & 81 & 80 & 80 \\ 82 & 82 & 81 & 80 & 80 & 79 \\ 80 & 79 & 78 & 77 & 77 & 77 \\ 80 & 79 & 78 & 78 & 77 & 77 \end{matrix}$$

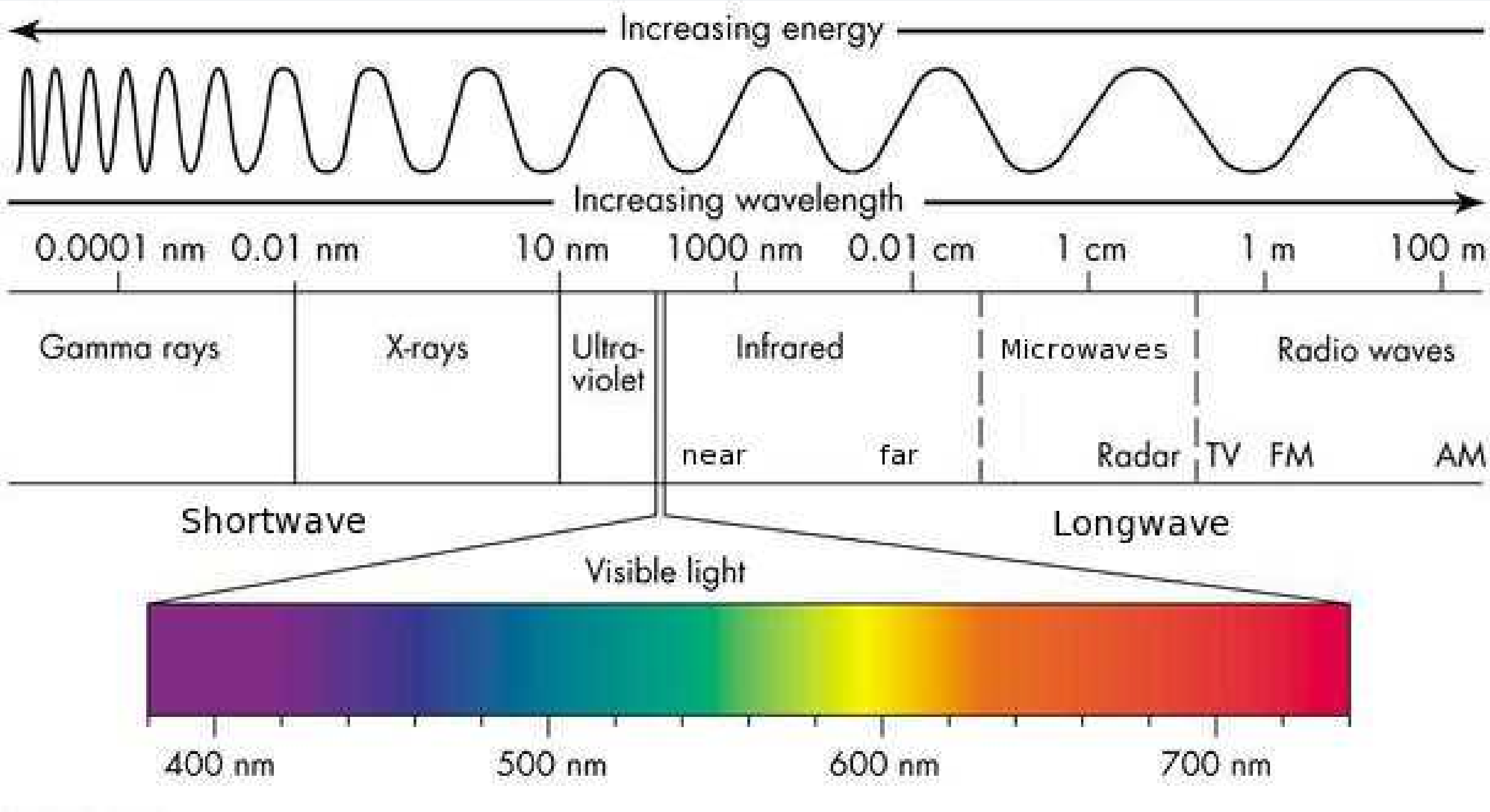
Digitization

Remember *digitization* implies that a digital image is an *approximation* of a real scene



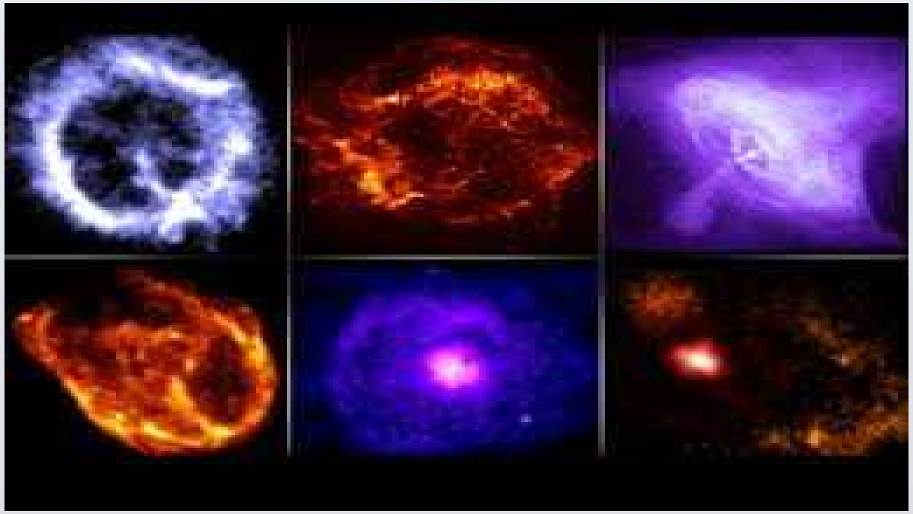
Sources of Digital Images

The principal source for the images is the electromagnetic (EM) energy s pectrum.

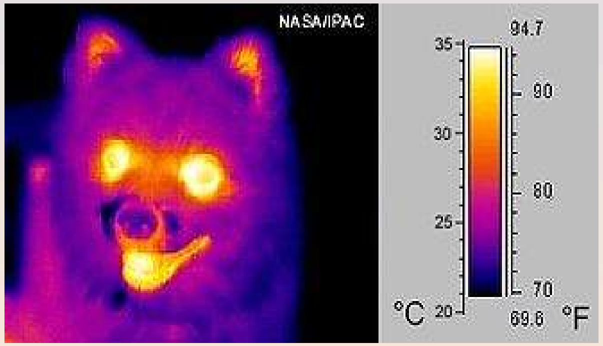


Examples

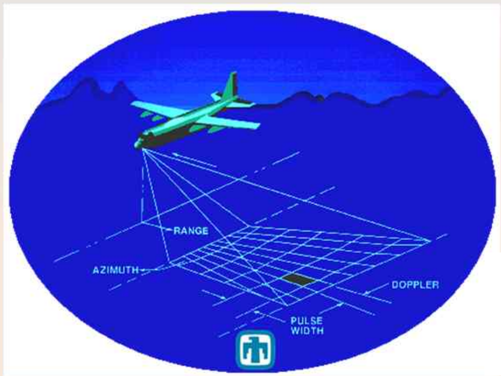
Gamma-Ray imaging of
A starburst galaxy about 12
million light-years away



X-ray images from the space
The Chandra X-Ray Observatory



Infrared thermal image



Synthetic Aperture Radar
System

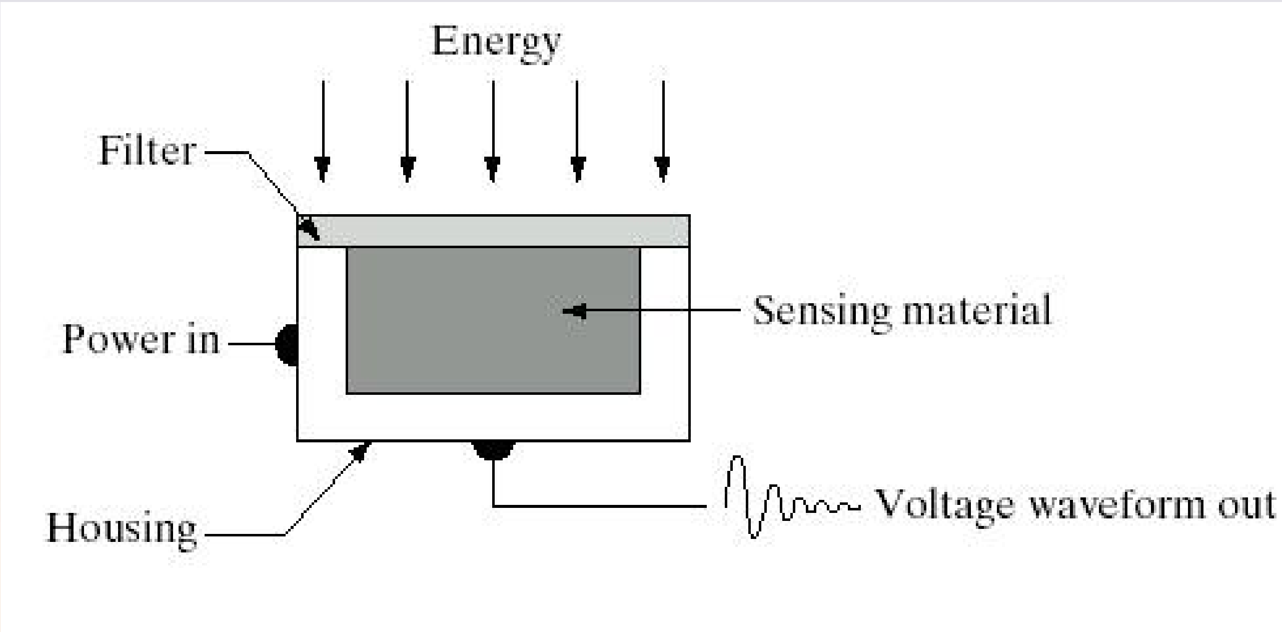
Digital Image Processing Level

Low Level Process	Mid Level Process	High Level Process
Input: Image	Input: Image	Input: Attributes
Output: Image	Output: Attributes	Output: Understanding
Examples: Noise removal, image sharpening	Examples: Object recognition, segmentation	Examples: Scene understanding, autonomous navigation

Acquisition of Images

The images are generated by the combination of an *illumination source* and th e reflection or absorption of energy from that source by the elements of the *scene* being imaged.

Imaging sensors are used to transform the *illumination energy* into digital images.



Types of Image Sensors

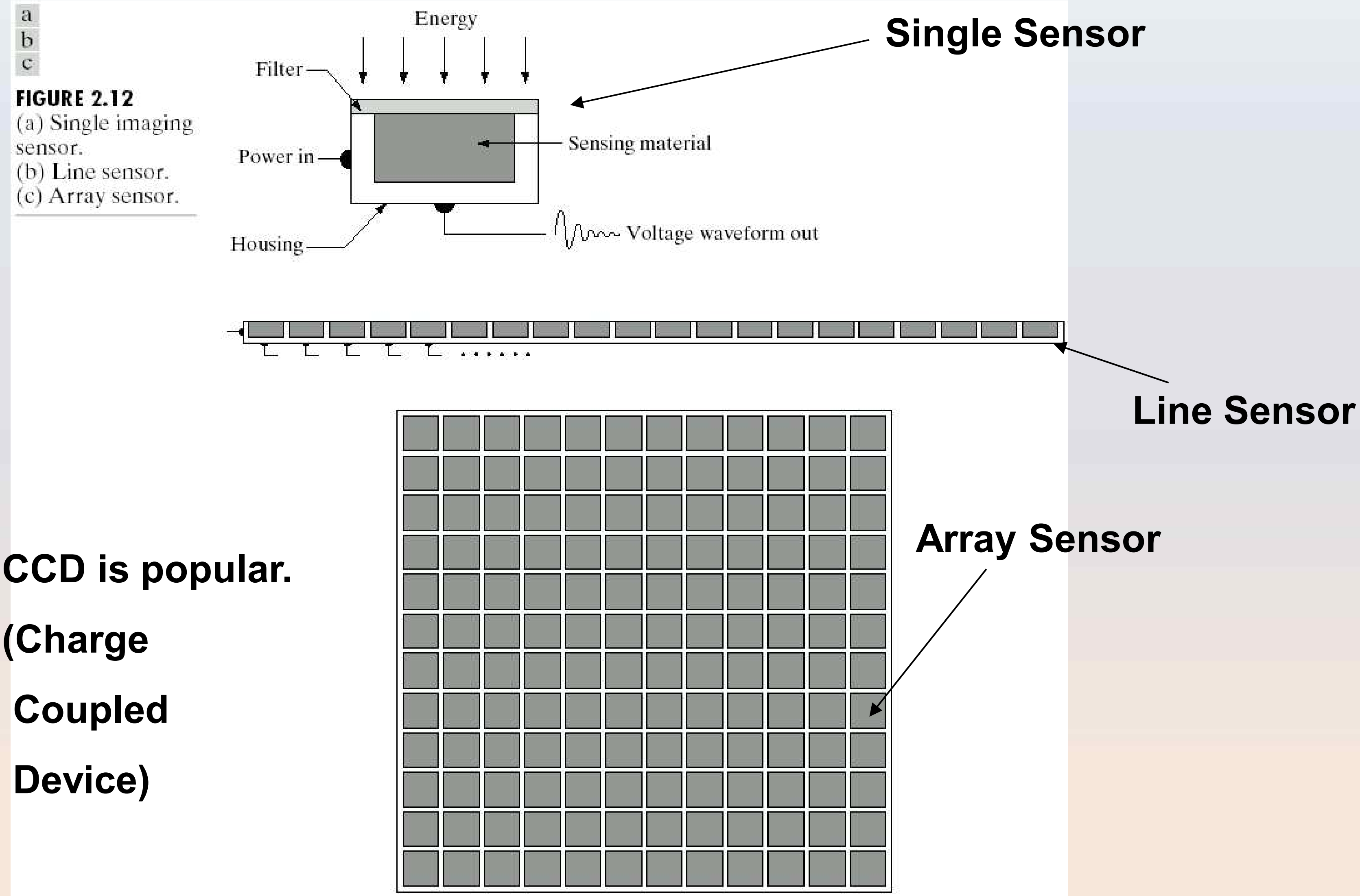
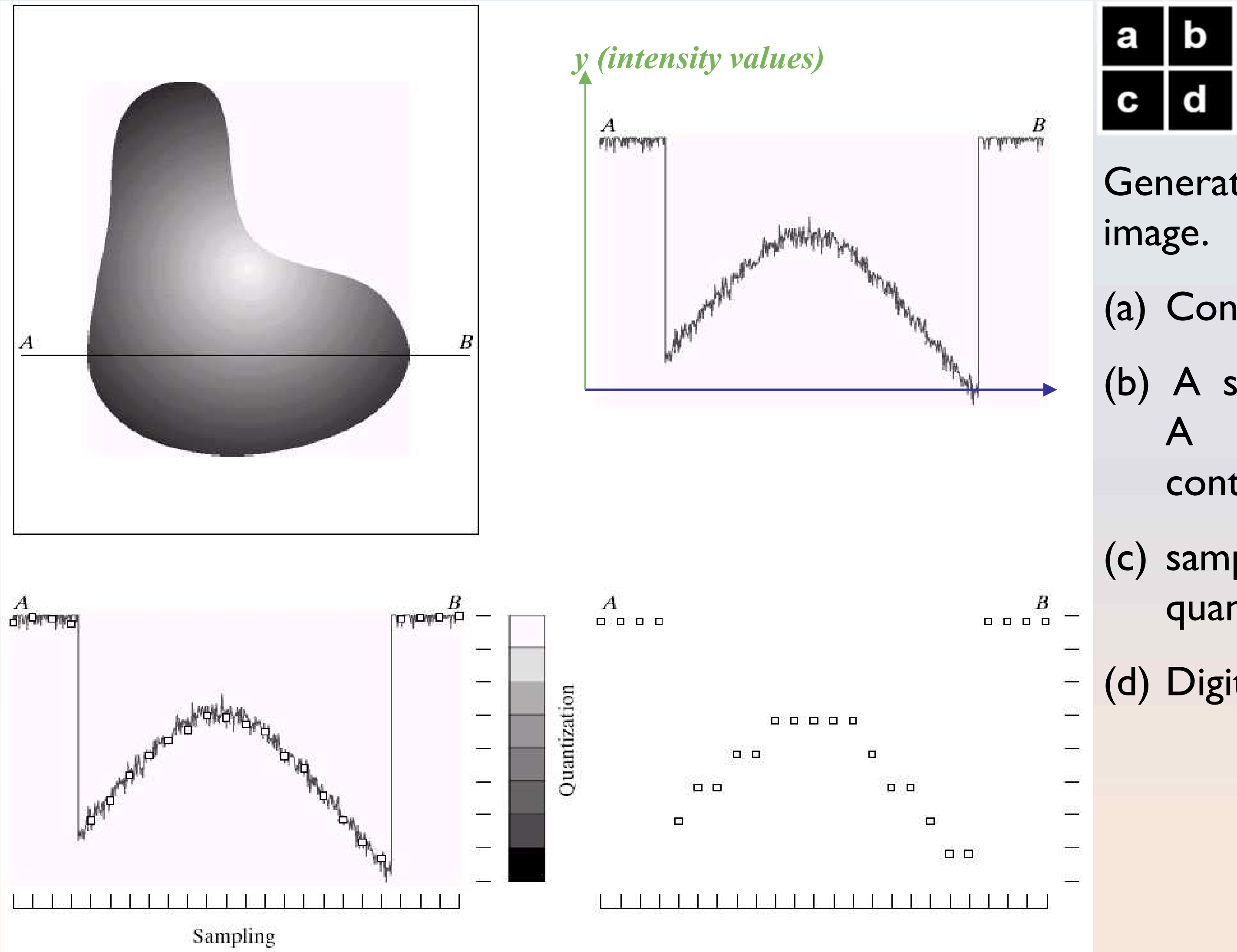


FIGURE 2.12 (a) Single imaging sensor. (b) Line sensor. (c) Array sensor.

CCD is popular.

(Charge Coupled Device)

Sampling & Quantization



Generating a digital image.

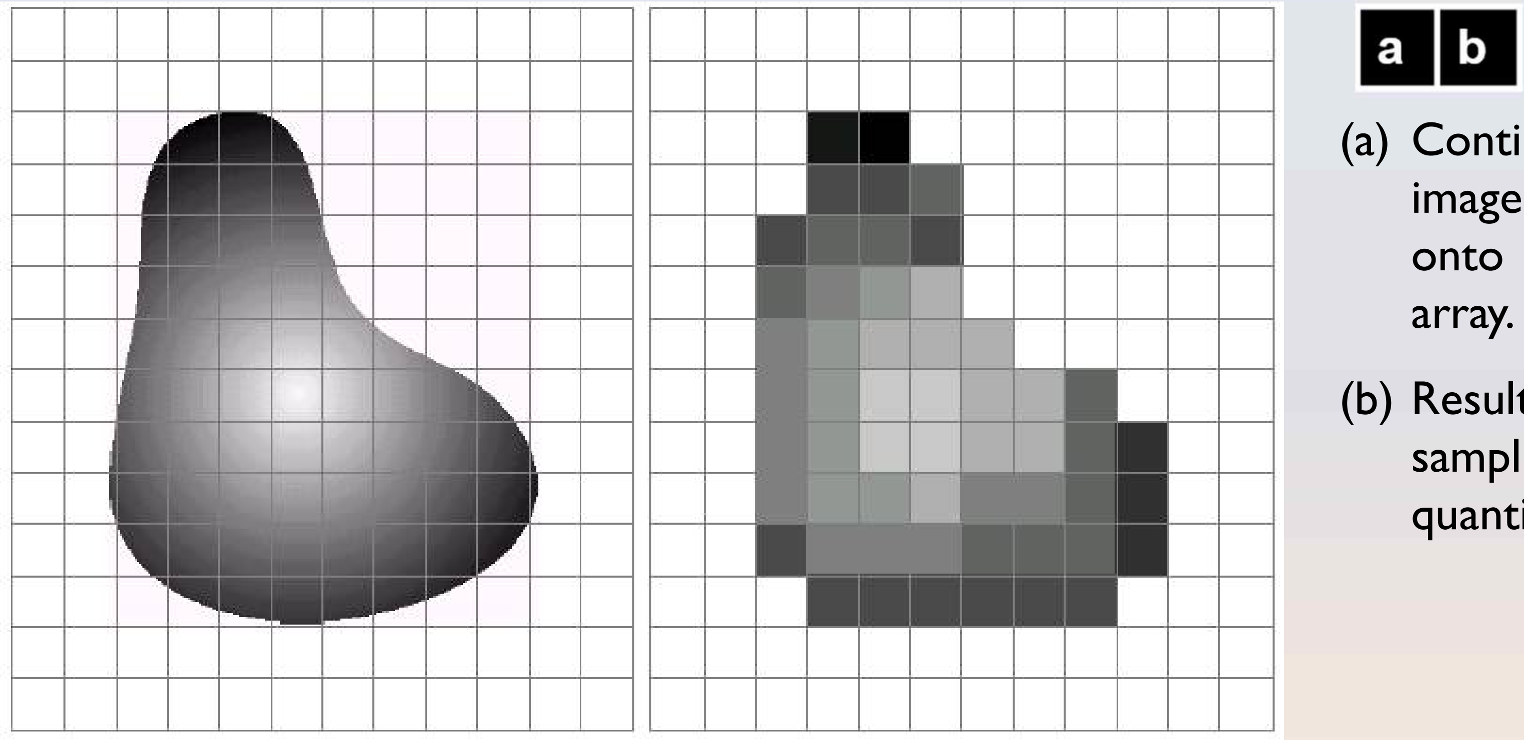
(a) Continuous image.

(b) A scaling line from A to B in the continuous image.

(c) sampling and quantization.

(d) Digital scan line.

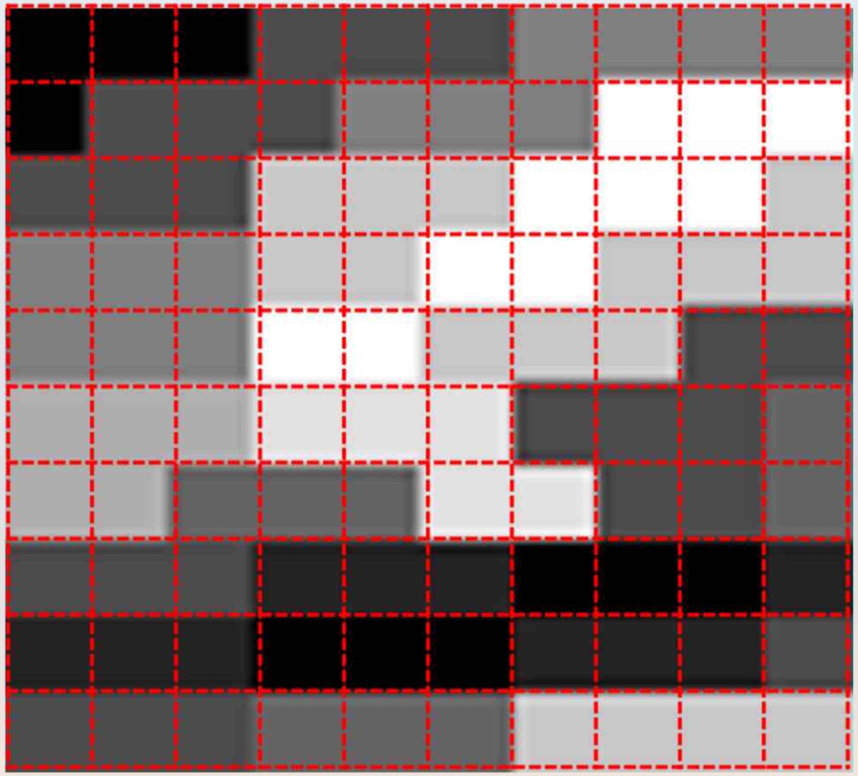
Sampling & Quantization



(a) Continuous image projected onto a sensor array.

(b) Result of image sampling and quantization.

Image as a Signal



0	0	0	75	75	75	128	128	128	128
0	75	75	75	128	128	128	255	255	255
75	75	75	200	200	200	255	255	255	200
128	128	128	200	200	255	255	200	200	200
128	128	128	255	255	200	200	200	75	75
175	175	175	225	225	225	75	75	75	100
175	175	100	100	100	225	225	75	75	100
75	75	75	35	35	35	0	0	0	35
35	35	35	0	0	0	35	35	35	75
75	75	75	100	100	100	200	200	200	200

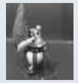
Sampling Rates – The same pixel size

1024

512

256

128



Sampling Rates – The same picture size

1024

512

256

128

64

32

Quantization Precision

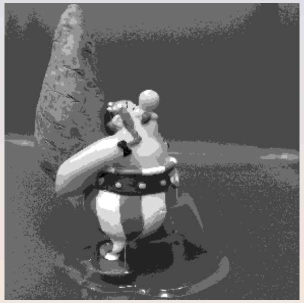
8-bit

7-bit

6-bit

5-bit

4-bit



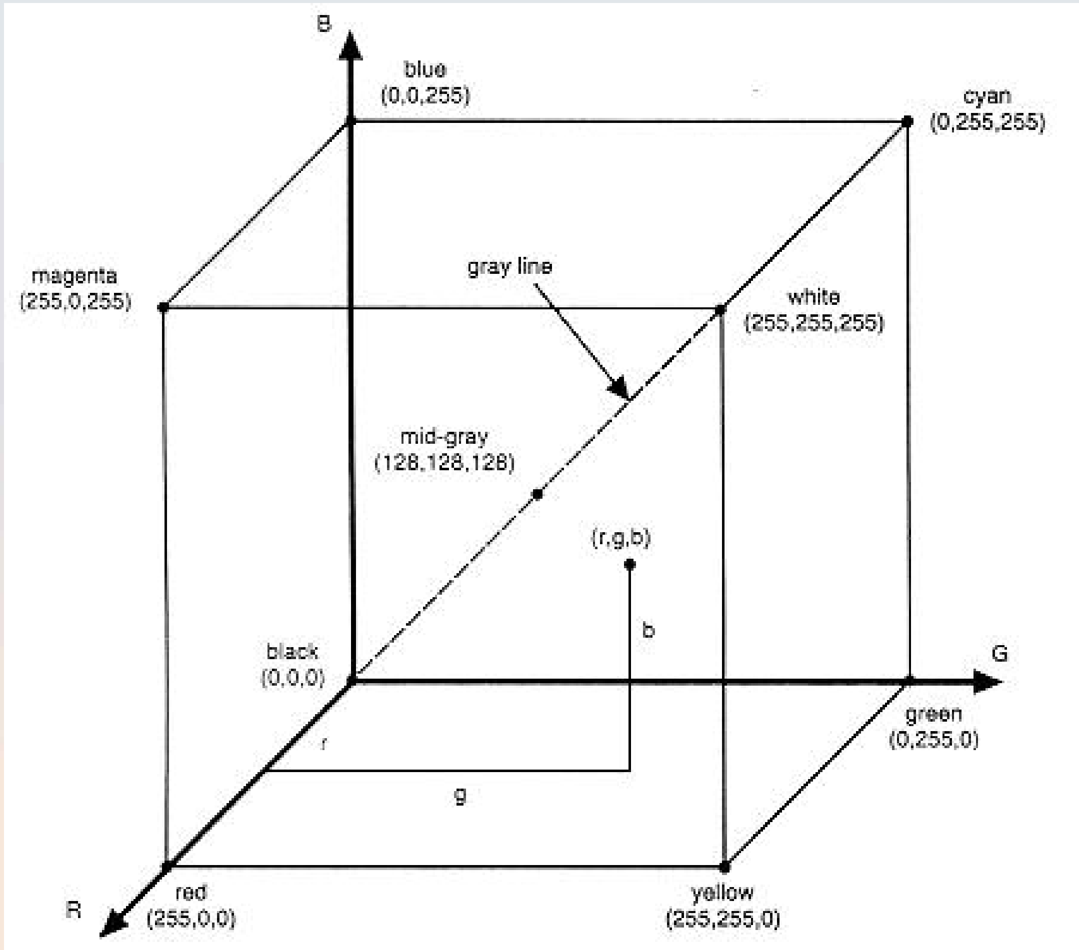
3-bit

2-bit

1-bit

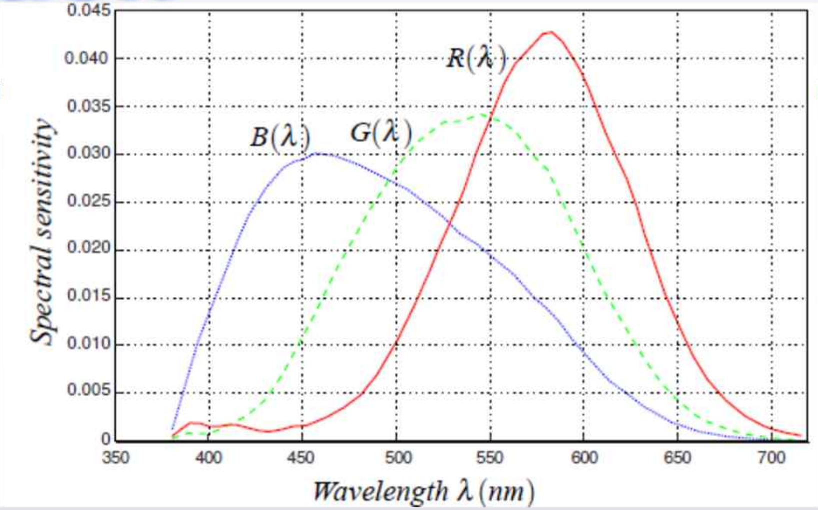
Color Image Representation

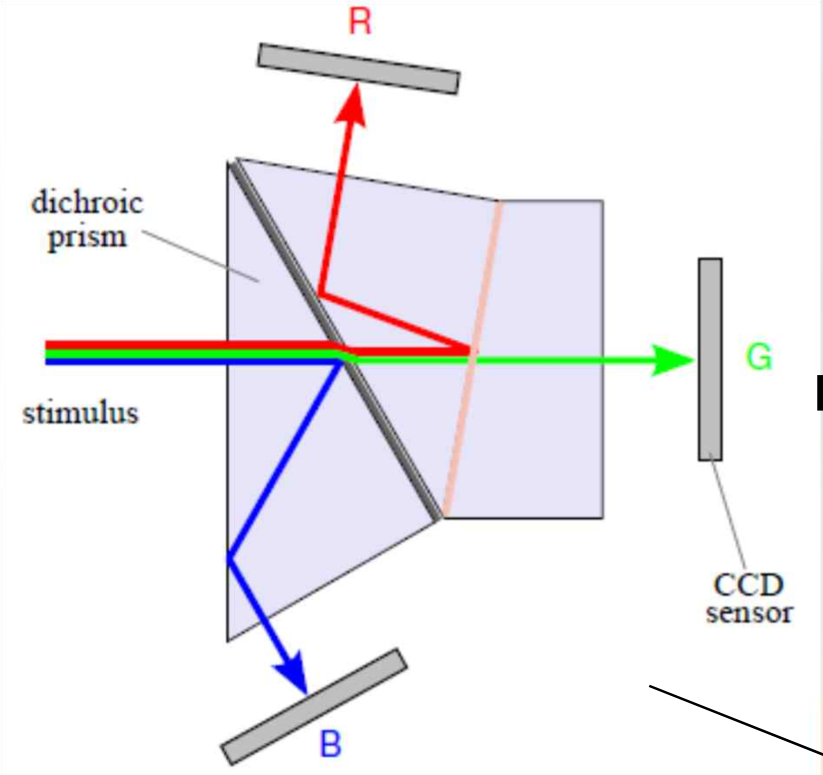
- Hardware generally delivers or displays c olor via RGB model (red, green, and blue).
- Gray has the same amount of r, g, b components.



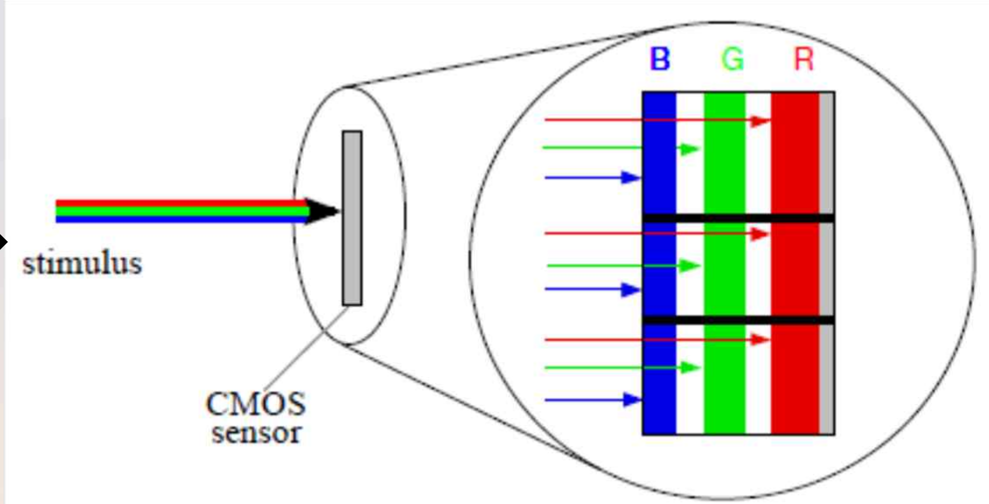
Color Image Acquisition

- Three-CCD sensor
  - High manufacturing cost





(a) Beam splitting by a trichroic prism assembly.

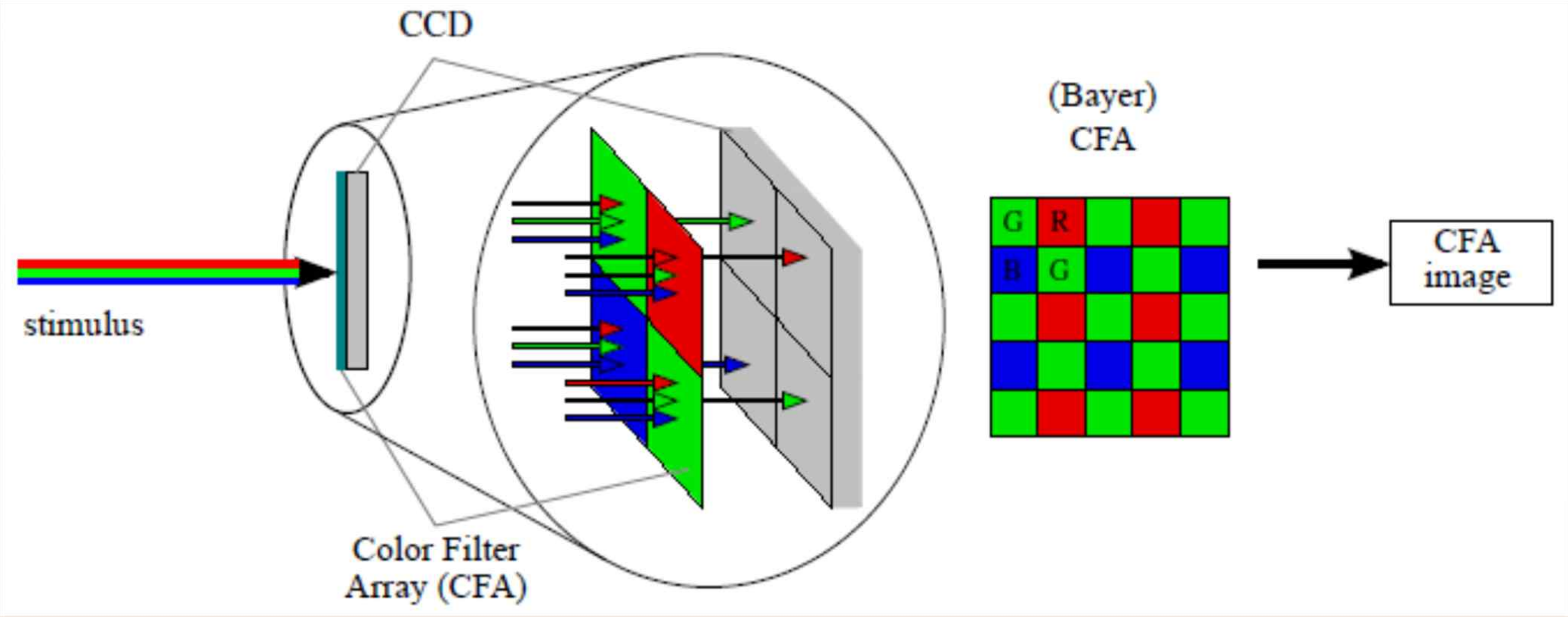


(a) Wavelength absorption within the Foveon X3 sensor.

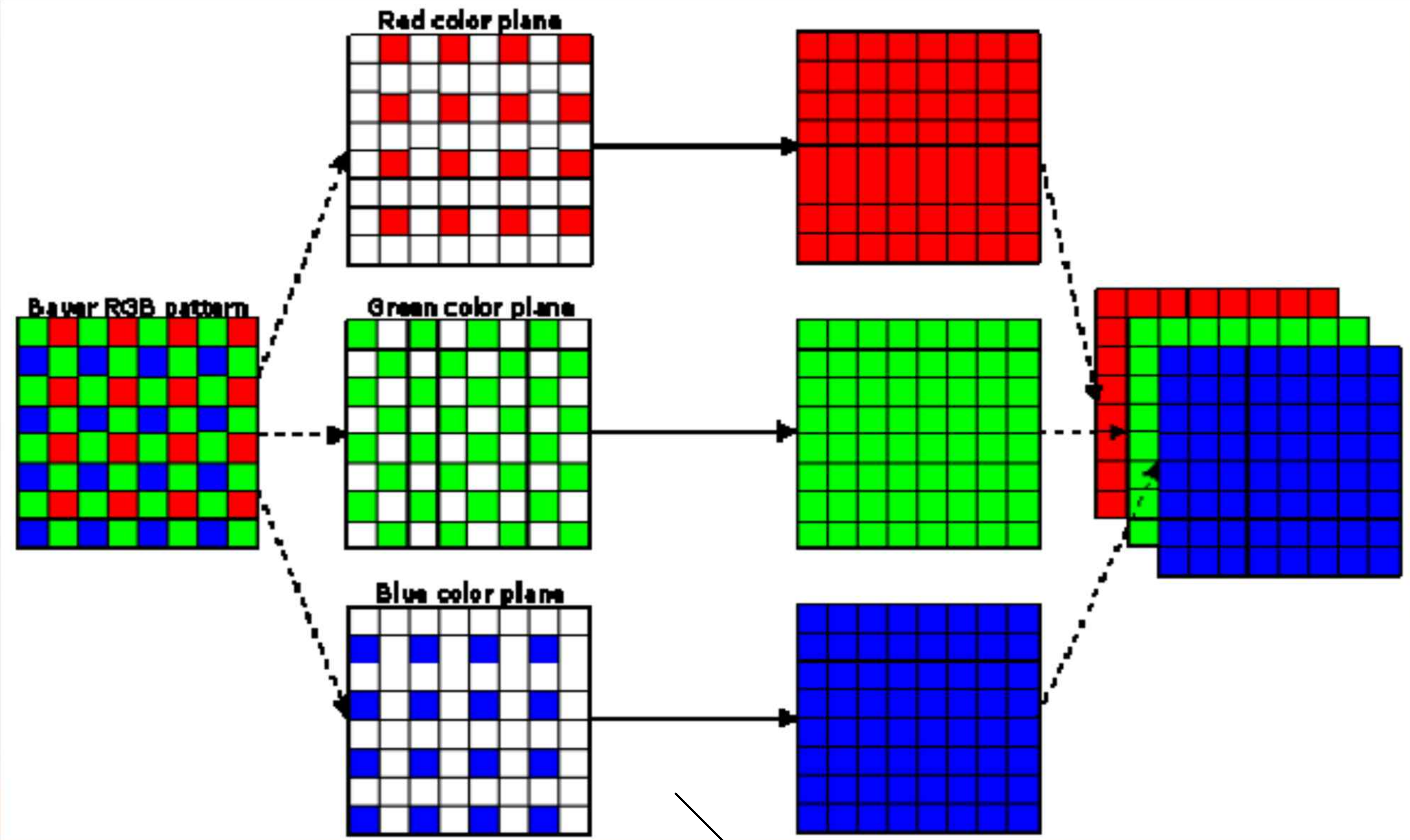
The spectral sensitivity differs from human's one.

Color Image Acquisition

- One CCD sensor
  - Color filter array (CFA) is a mosaic of spectrally selective color filters.
  - There are many CFA patterns, Bayer's CFA is most widespread.
  - Bayer's observation : The human eye has a greater resolving power for green light.

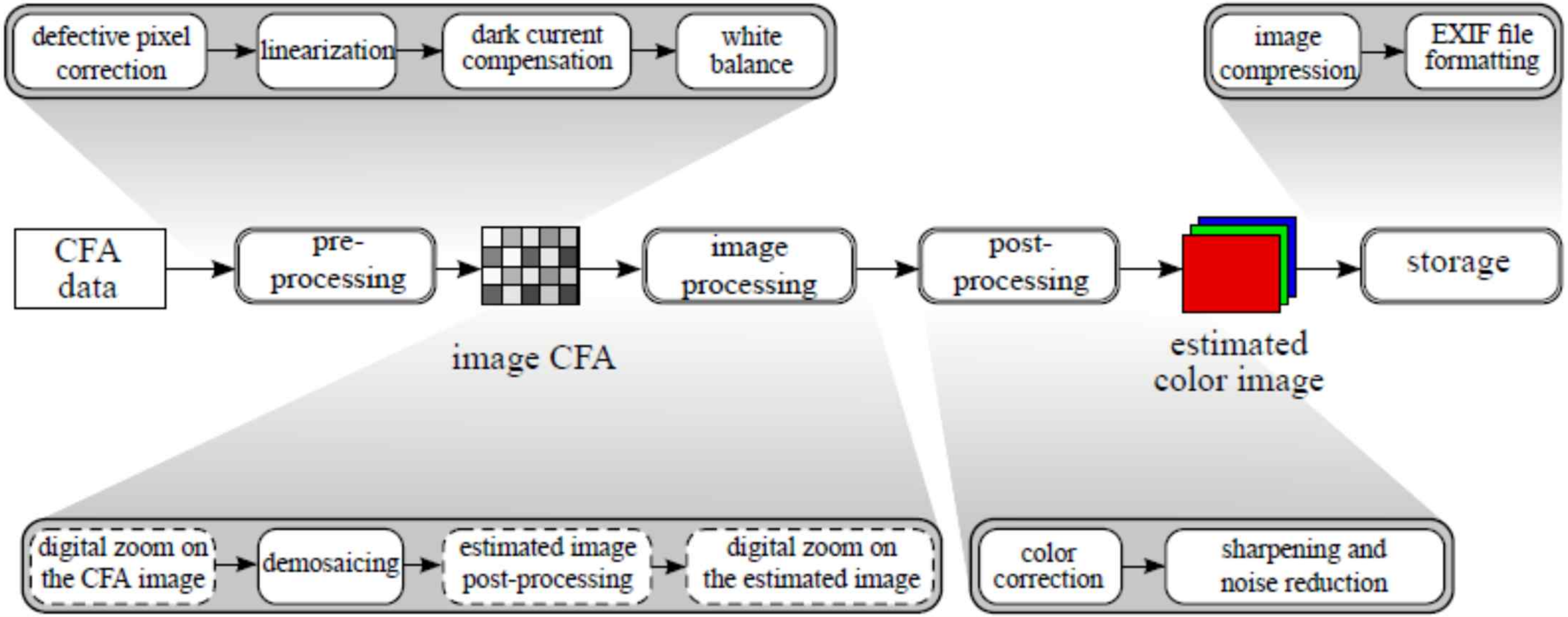


Demosaicing



Demosaicing (Interpolation)

Image Acquisition - Pipeline



Lab

- Image read & write
- Image color manipulation
- Image display

IMAGE FILTERING

Mask (Kernel)

w(-1,-1)	w(-1,0)	w(-1,1)
w(0,-1)	w(0,0)	w(0,1)
w(1,-1)	w(1,0)	w(1,1)

Mask coefficients showing coordinate arrangement

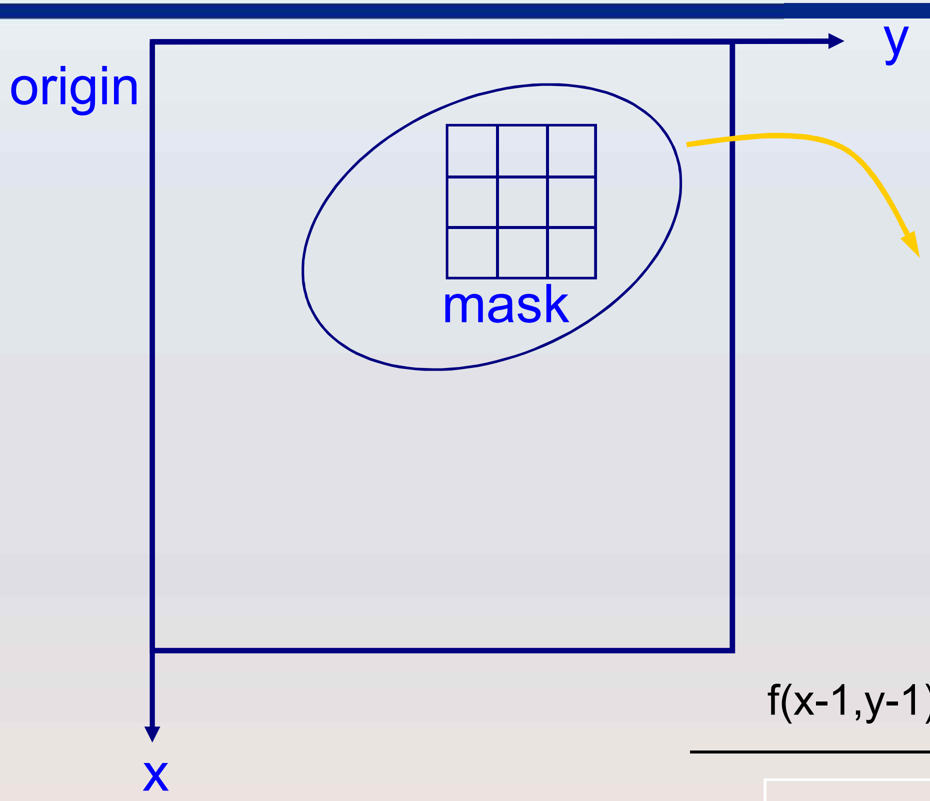
Spatial Filtering

Convolution

$$g(x,y)=\sum_{s=-a}^{a}\sum_{t=-b}^{b}\omega(s,t)f(x-s,y-t)$$

$$g=\omega * f$$

Spatial Filtering



W(-1,-1)	W(-1,0)	W(-1,1)
W(0,-1)	W(0,0)	W(0,1)
W(1,-1)	W(1,0)	W(1,1)

Mask coefficients

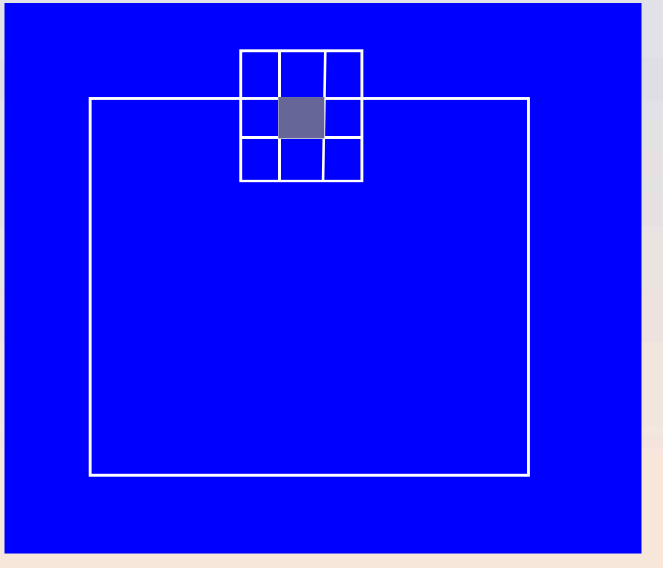
f(x-1,y-1)	f(x-1,y)	f(x-1,y+1)
f(x,y-1)	f(x,y)	f(x,y+1)
f(x+1,y-1)	f(x+1,y)	f(x+1,y+1)

Image section under mask

$$g(x,y) = \sum_{s=-a}^{a} \sum_{t=-b}^{b} w(s,t) f(x+s, y+t)$$

What happens at the borders?

- The mask falls outside the edge.
- Solutions?
  - Ignore the edges
    - The resultant image is smaller than the original
    - With 3x3 kernel, the size is reduced by 2, both horizontally and vertically.
  - Pad with zeros
    - Introducing unwanted artifacts



Values Outside the Range

- Linear filtering might bring the intensity outside the display range.
- Solutions?
  - Clip values

$$y = \begin{cases} 0 & \text{if } x < 0 \\ x & \text{if } 0 \le x \le 255 \\ 255 & \text{if } x > 255 \end{cases}$$

  - Scaling transformation

New min

$$y = 255 \frac{x - g_L}{g_H - g_L}$$

New max

Transform values in $[g_L,g_H]$ to $[0,255]$

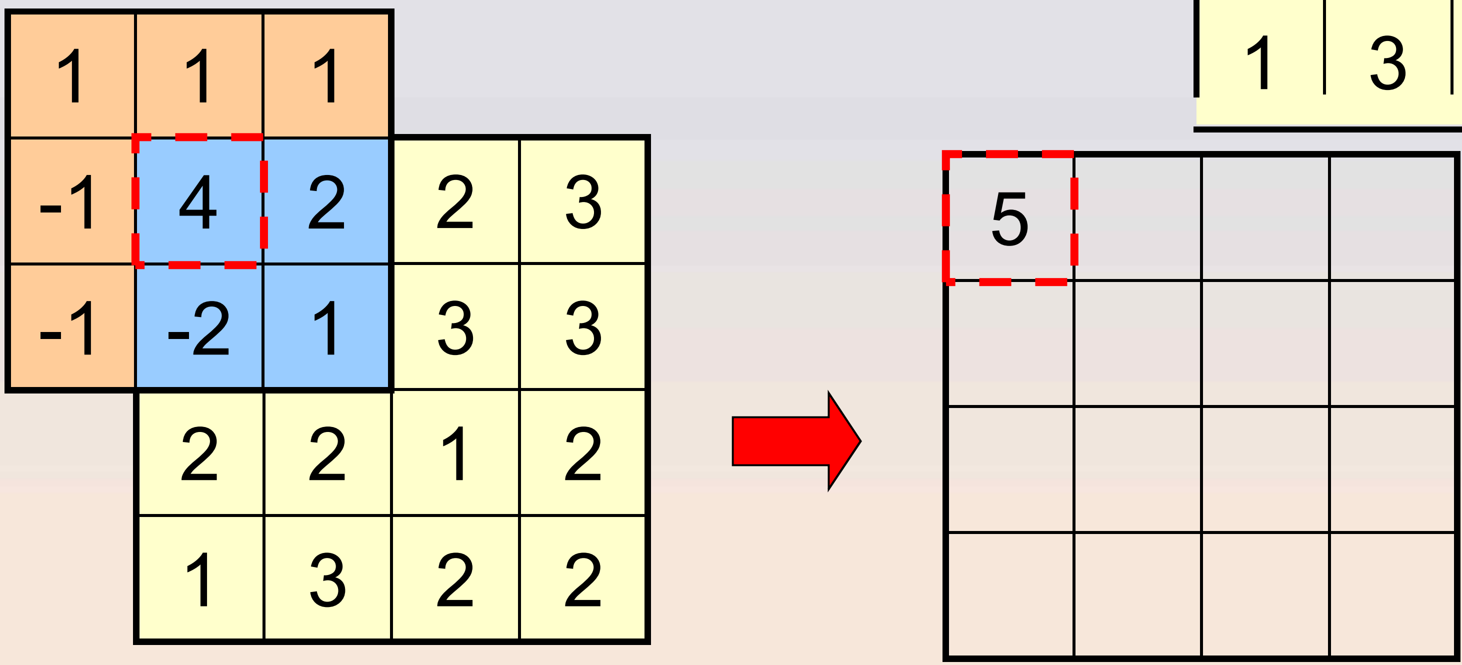
Spatial Filtering – step by step

Convolution kernel, ω

1	1	1
-1	2	1
-1	-1	1

Input Image, f

2	2	2	3
2	1	3	3
2	2	1	2
1	3	2	2



Output Image, g

Spatial Filtering – step by step

1	1	1
-1	2	1
-1	-1	1

2	2	2	3
2	1	3	3
2	2	1	2
1	3	2	2

1	1	1	
-2	4	2	3
-2	-1	3	3
2	2	1	2
1	3	2	2

→

5	4		

Output I mage, g

Spatial Filtering – step by step

1	1	1
-1	2	1
-1	-1	1

2	2	2	3
2	1	3	3
2	2	1	2
1	3	2	2

1	1	1	
-2	4	2	3
-2	-1	3	3
2	2	1	2
1	3	2	2

→

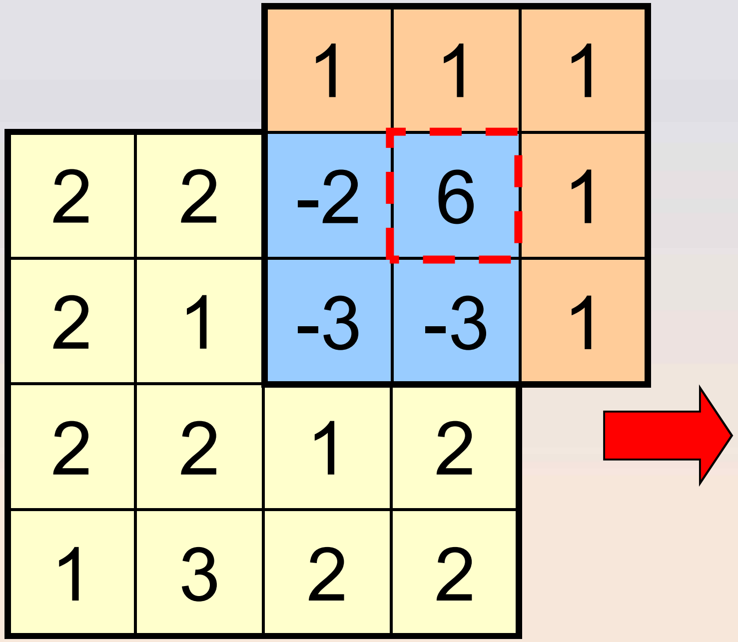
5	4		

Output I mage, g

Spatial Filtering – step by step

1	1	1
-1	2	1
-1	-1	1

2	2	2	3
2	1	3	3
2	2	1	2
1	3	2	2



5	4	4	-2

Output Image, g

Spatial Filtering – step by step

1	2	2	2	3
-1	4	1	3	3
-1	-2	2	1	2
	1	3	2	2

5	4	4	-2
9			

2	2	2	3
-2	2	3	3
-2	-2	1	2
1	3	2	2

5	4	4	-2
9	6		

Spatial Filtering – step by step

5	4	4	-2
9	6	14	5
11	7	6	5
9	12	8	5

Final output Image, g

Low Pass Filter - Averaging

- One simple example is smoothing using a 3x3 mask.

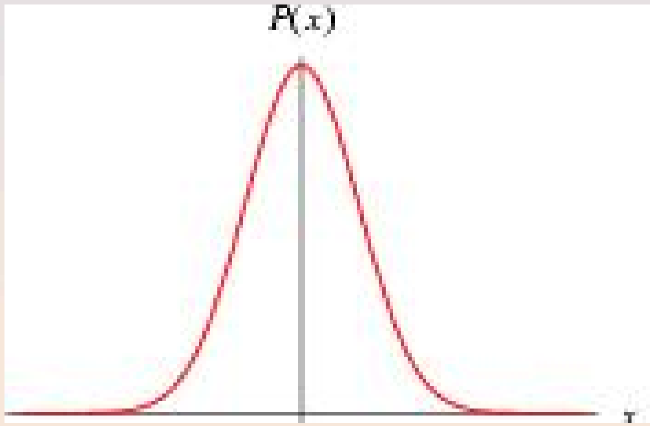
$$\frac{1}{9} \times \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \qquad \frac{1}{16} \times \begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix}$$

Box filter — Weighted average filter

Low Pass Filter - Gaussian

- Mostly for noise reduction/removal and smoothing
  - 3x3 averaging filter to blur edges
  - Gaussian filter,
    - based on Gaussian probability distribution function
    - a popular filter for smoothing
    - more later when we discuss image restoration

In 1D: $P(x) = e^{-x^2/2\sigma^2}$



LPF – Different Kernel Size

Original

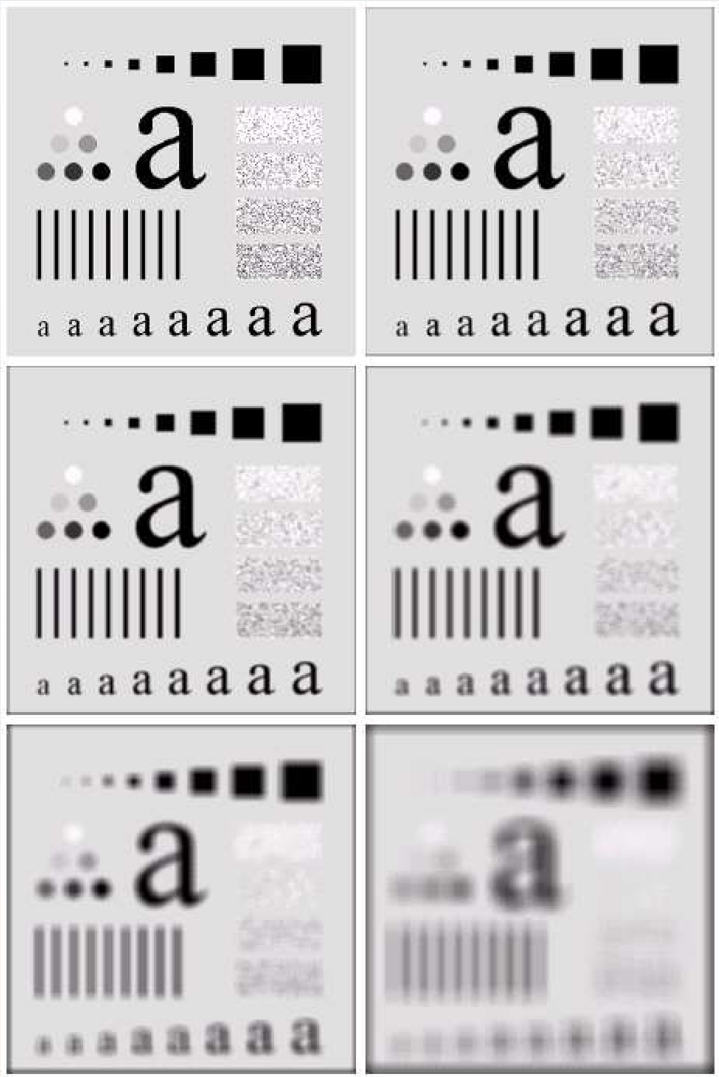
3x3

5x5

9x9

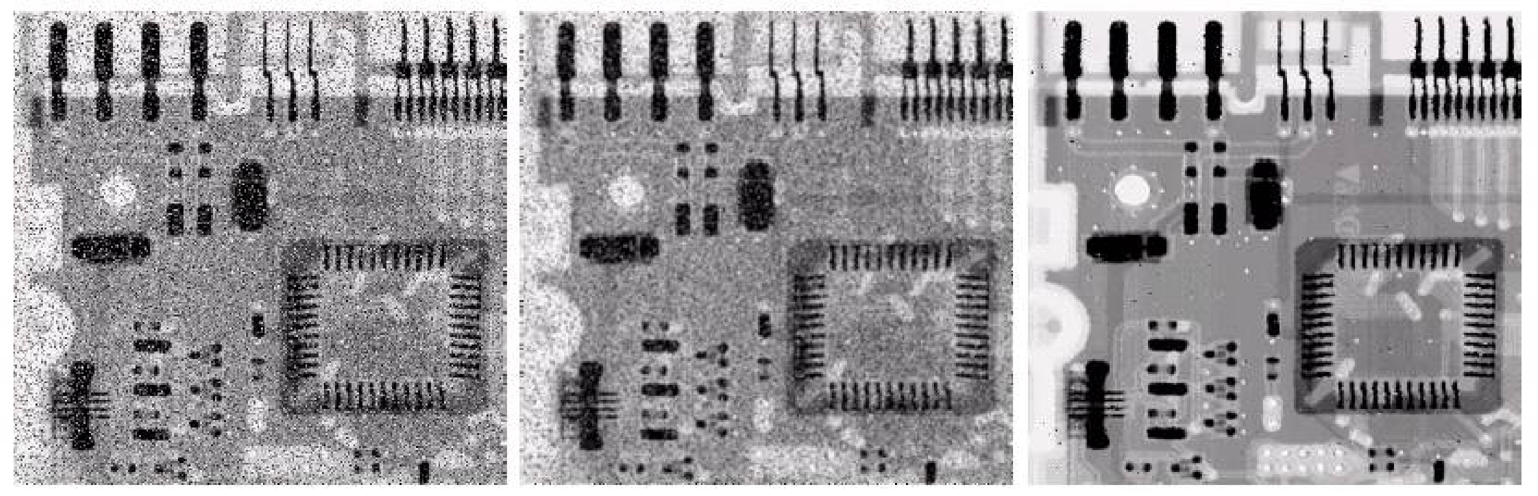
15x15

35x35



Median Filter

$a_1 < a_2 < \ldots < a_n$ then median is $a_{(1+n)/2}$



Corrupted by salt and pepper noise

Averaging filter

Median filter

Laplacian Filter - I

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

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

$$= f(x+1) + f(x-1) - 2f(x)$$

Laplacian Filter - 2

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

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

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

The 2D Laplacian

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

Laplacian Filter - 3

The 2D Laplacian

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

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

Laplacian Filter - 4

Sobel Filter - I

The Gradient

$$\nabla \mathbf{f} = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \dfrac{\partial f}{\partial x} \\ \dfrac{\partial f}{\partial y} \end{bmatrix}$$

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

Sobel Filter - 2

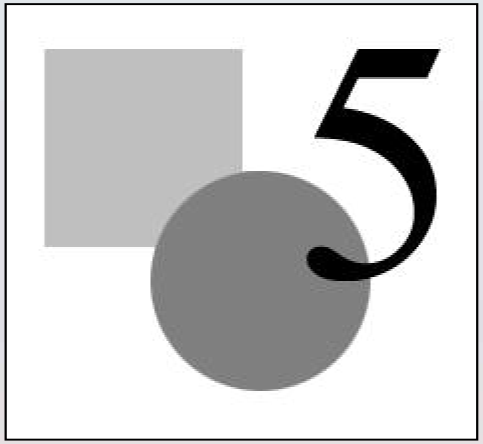
$$\nabla f \approx |G_x| + |G_y|$$

$$\nabla f \approx |G_x| + |G_y| = |(z_7 + 2z_8 + z_9) - (z_1 + 2z_2 + z_3)|$$
$$+ |(z_3 + 2z_6 + z_9) - (z_1 + 2z_4 + z_7)|$$

−1	−2	−1
0	0	0
1	2	1

−1	0	1
−2	0	2
−1	0	1

Sobel Filter - 3



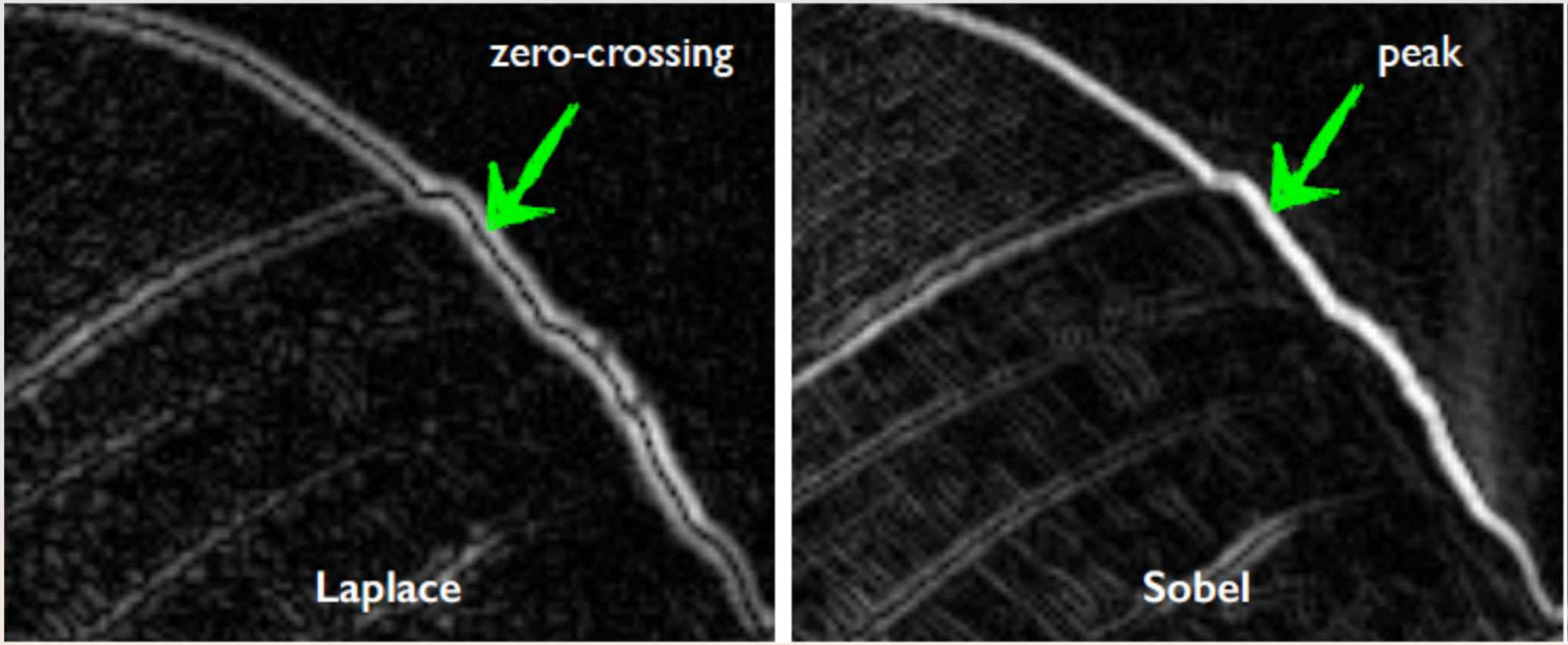
Horizontal Vertical

Comparison (Laplacian, Gradient)

- Gradient
  - The value is proportional to the degree of value change.
- Laplacian
  -

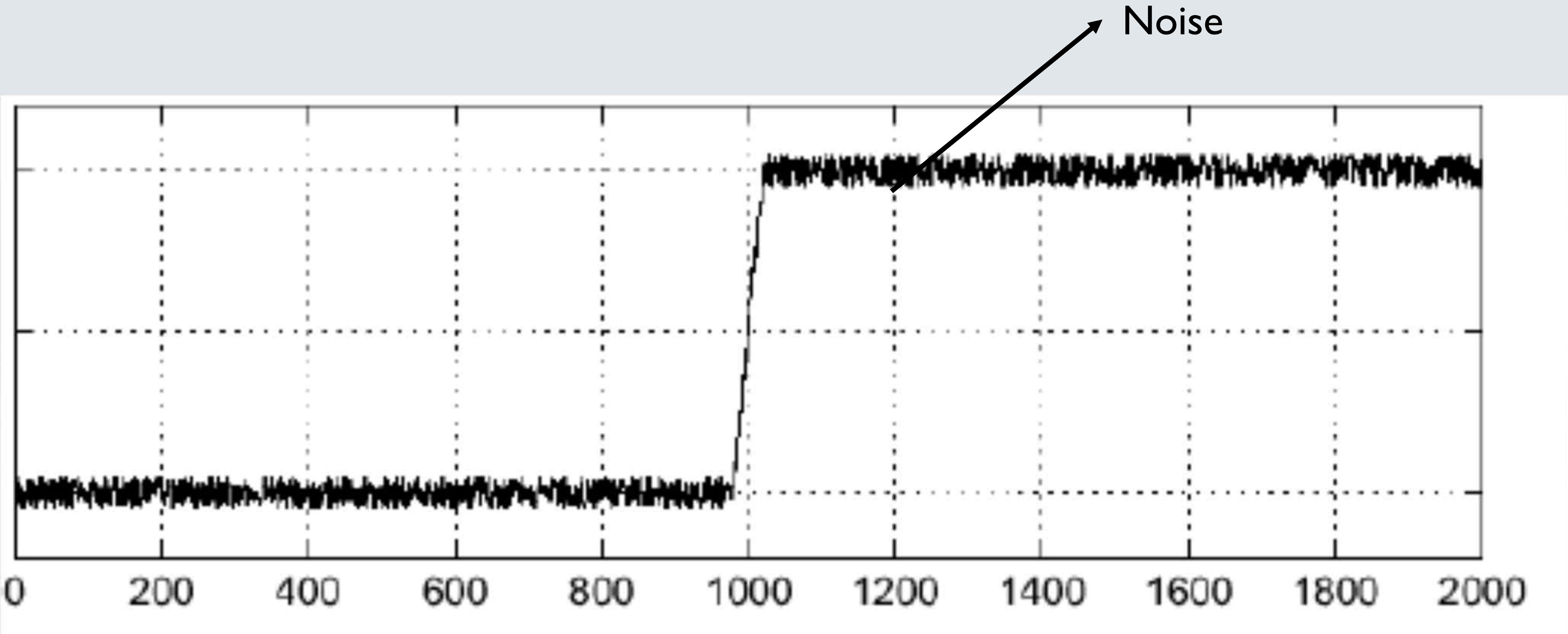
Comparison (Laplacian, Gradient)

Comparison (Laplacian, Gradient)



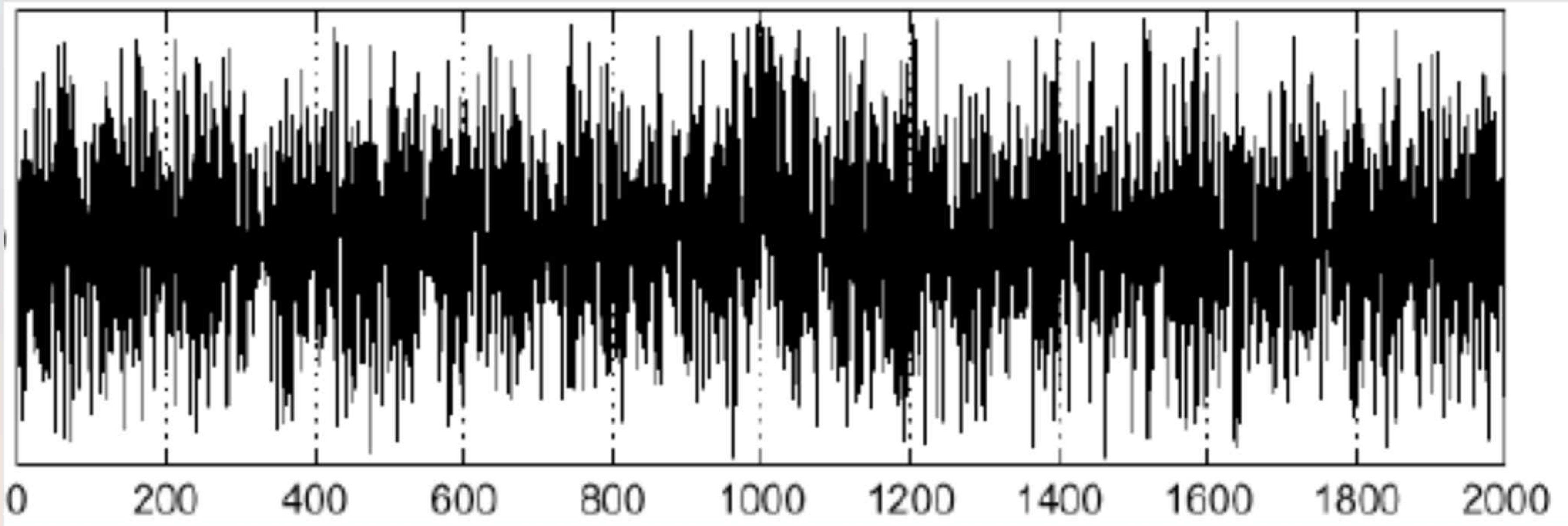
Noise & Filtering

- How do you find the edge from this signal?



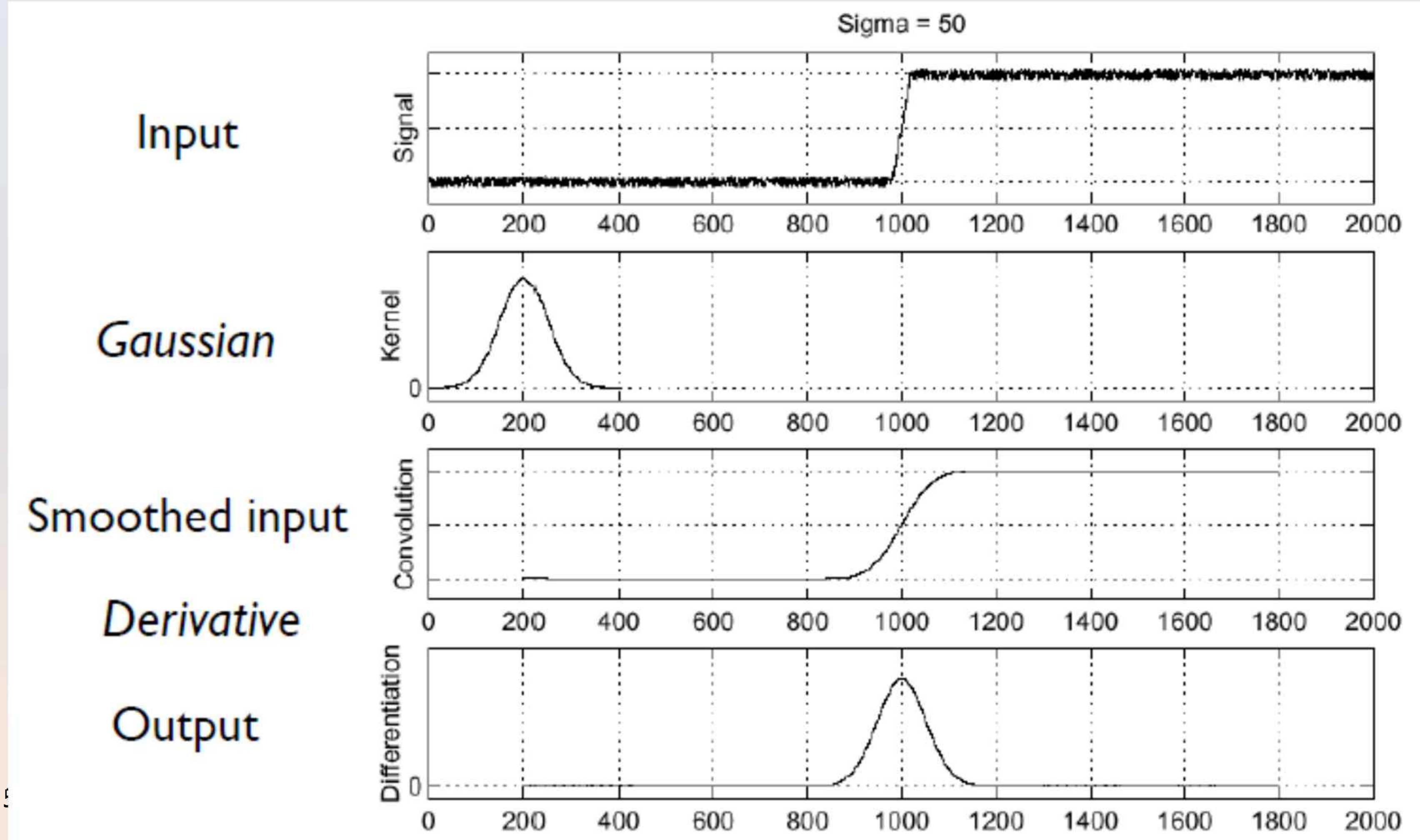
Noise & Filtering

- Use a derivative filter
  - Sensitive to noise

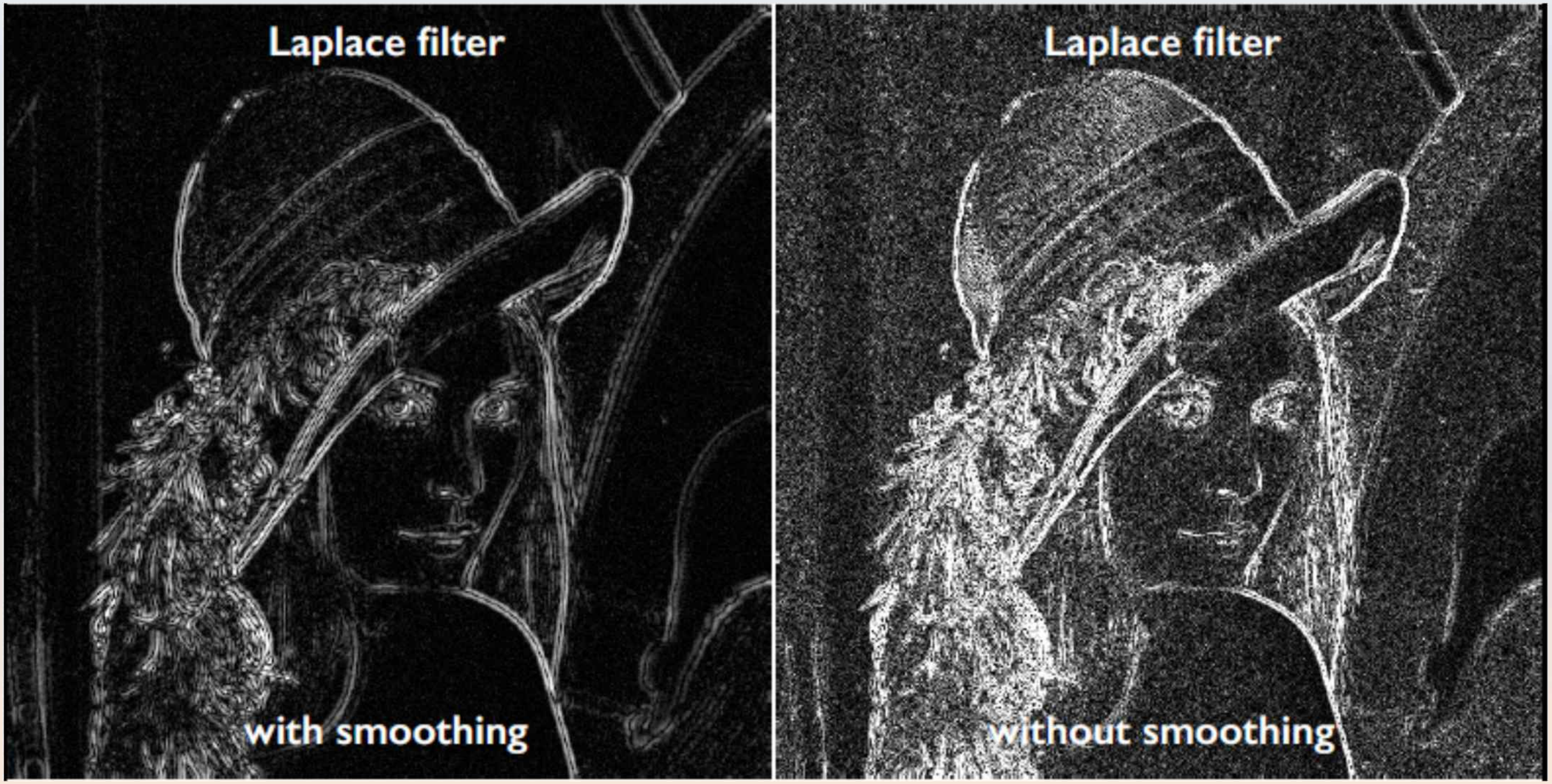


Noise & Filtering

- Don’t forget to smooth before running derivative filters



Noise & Filtering



LAB

- Smoothing filter (low pass filter)
  - Box
  - Gaussian
- Edge detection filter (high pass filter)
  - Sobel
  - Laplacian
- More filters