08.01.2025

INTERNATIONAL INSTITUTE OF INFORMATION TECHNOLOGY
HYDERABAD

Digital Image Processing - Recap

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Administrivia

- Tutorial slot : Wed, 11.40am – 12.40pm, H-105

Additionally …

- PGSSP/MS/PhD
  - Take some time understanding the Moodle portal and other IIIT e-services
  - Consider forming e-study / discussion groups
- Reach out to TAs, us in case you have difficulty with material.
- Feedback need not wait until end of course.

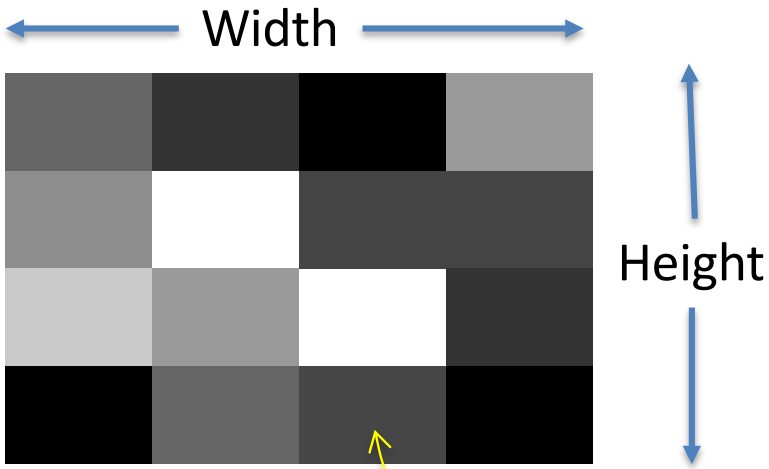
Taking Notes

- Take notes actively !
  - Improves ability to summarize key ideas (core career skill !)
  - Do well in exams
  - Antidote to sleepiness ☺
  - Tip: Note slide headings – useful for revision/recap

What is a **digital** image ?

- An **array** of numbers representing color intensities

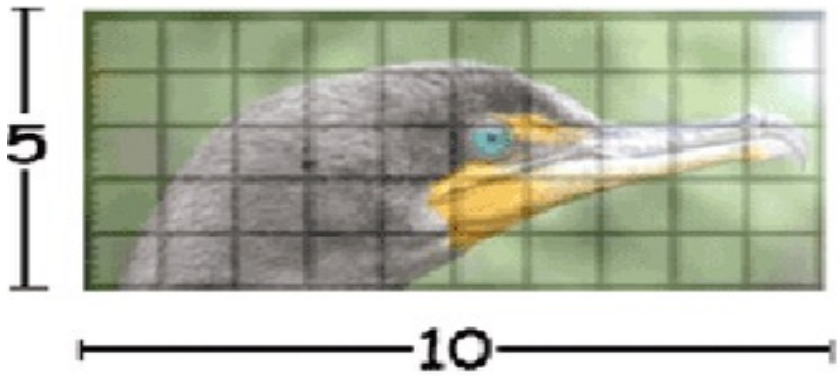
100	50	0	150
90	255	70	70
200	150	255	50
0	100	80	0

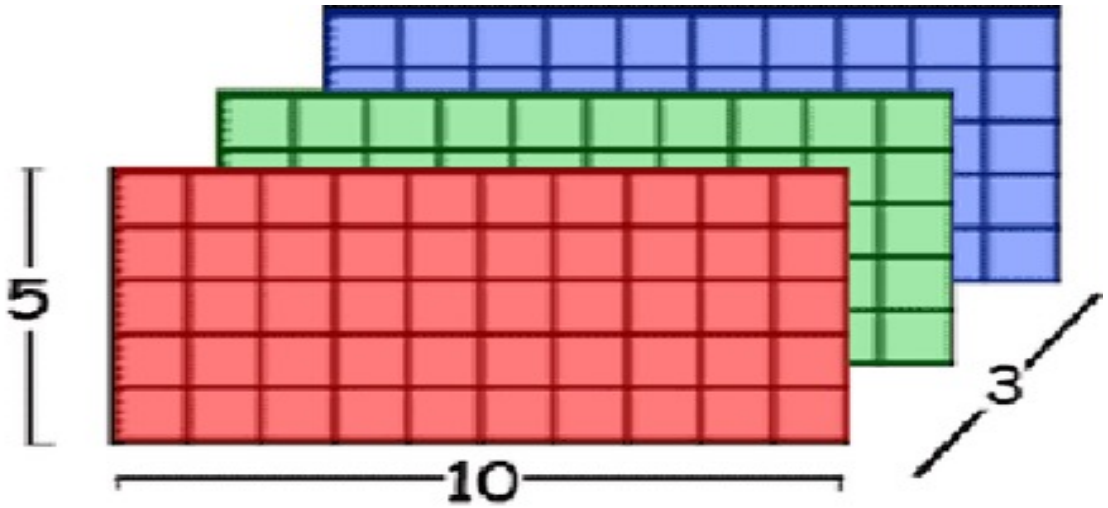


1 2-D channel
8 bits/pixel

pixel

Image Representation (RGB)



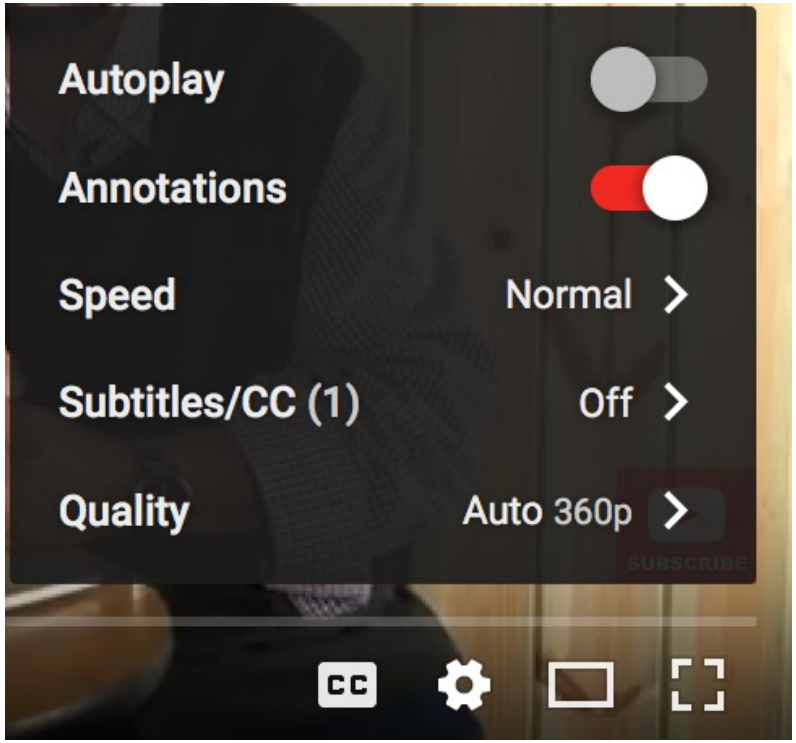


3 2-D channels
24 bits per pixel

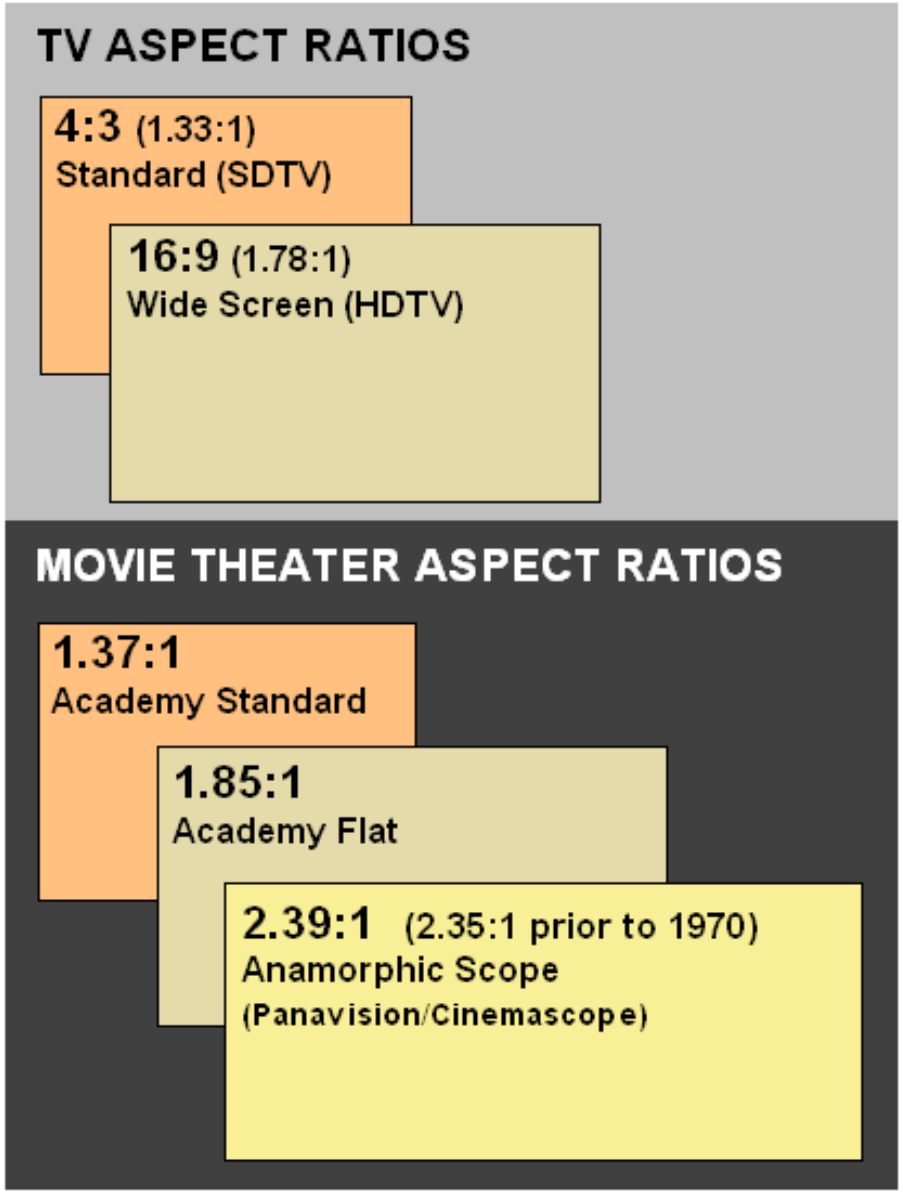
https://www.researchgate.net/profile/Bhupendra_Pratap_Singh/publication/282798184/figure/fig15/AS:283989639221249@1444719814399/Color-image-representation-and-RGB-matrix.png

Full HD
1920 x 1080
4K
3840 x 2160
5K
5120 x 2160
8K
7680 x 4320

- Video resolution example
  - Settings in YouTube



Aspect Ratios



Key Terms

Standard Video Qualities: Standard combinations of aspect ratio and video resolution

Video Quality	4:3 Aspect Ratio Resolution	16:9 Aspect Ratio Resolution
360p	480 x 360	640 x 360
480p	640 x 480	854 x 480
720p	Not generally used	1280 x 720
1080p	Not generally used	1920 x 1280

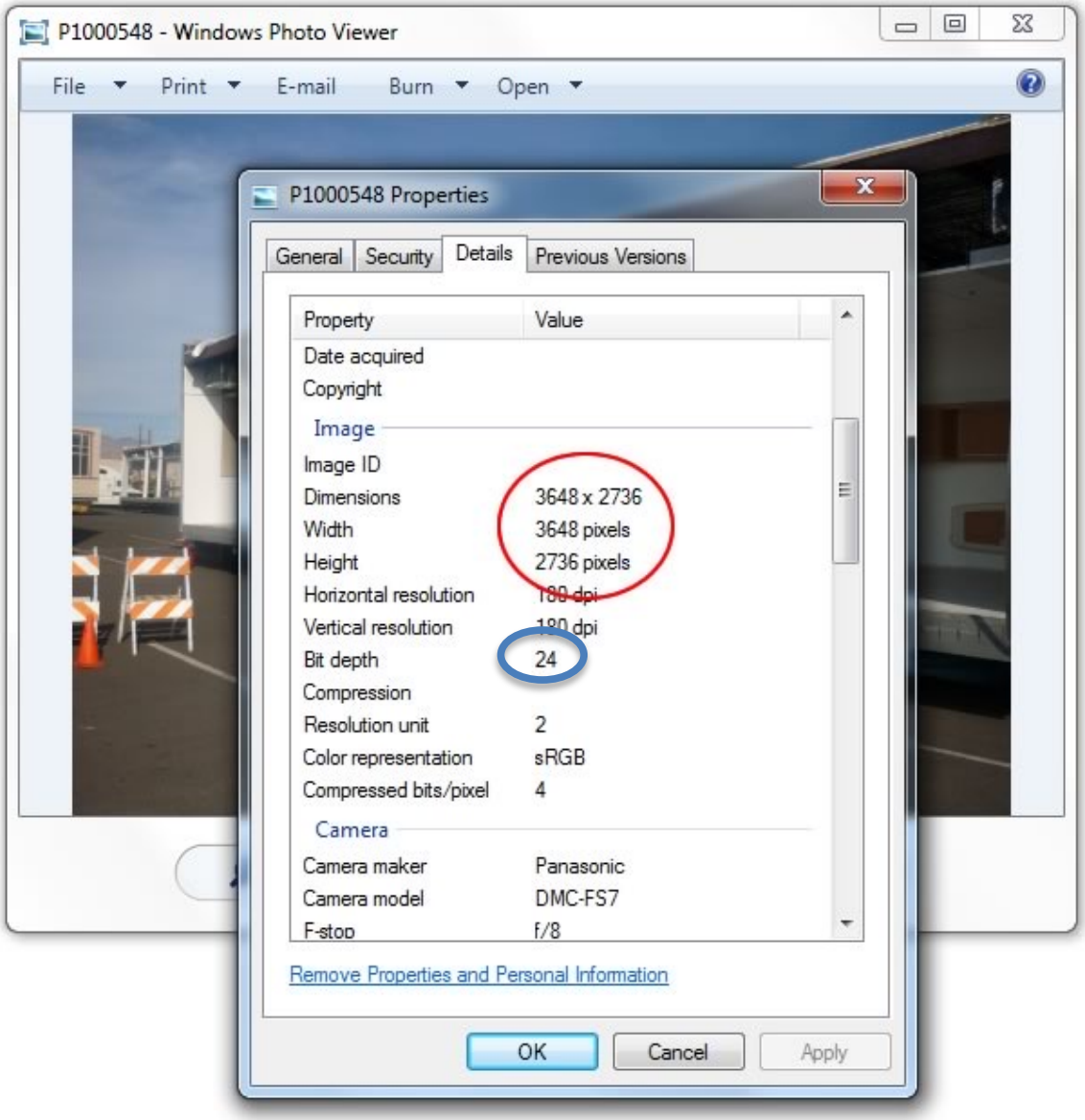
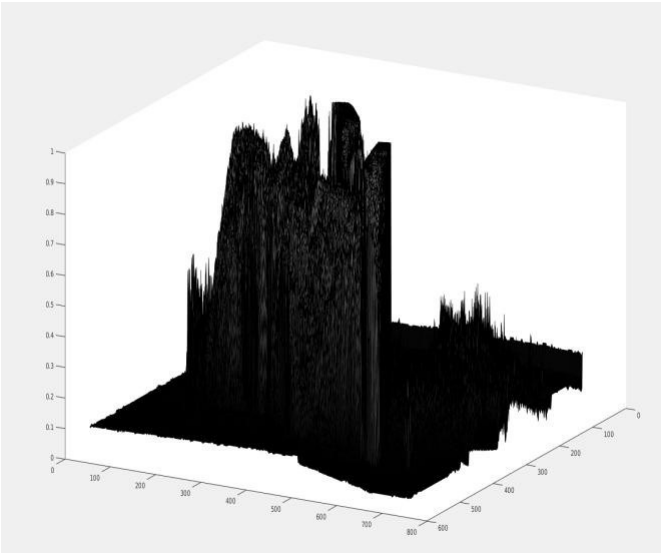

P1000548 - Windows Photo Viewer
File
Print
E-mail
Burn
Open
P1000548 Properties
General
Security
Details
Previous Versions
Property
Value
Date acquired
Copyright
Image
Image ID
Dimensions
3648 x 2736
Width
3648 pixels
Height
2736 pixels
Horizontal resolution
180 dpi
Vertical resolution
180 dpi
Bit depth
24
Compression
Resolution unit
2
Color representation
sRGB
Compressed bits/pixel
4
Camera
Camera maker
Panasonic
Camera model
DMC-FS7
F-stop
f/8
Remove Properties and Personal Information
OK
Cancel
Apply

Image as a function / 3D surface

- $f(x,y) = z$
- Domain : (x,y)
- Range = Intensity

x

y



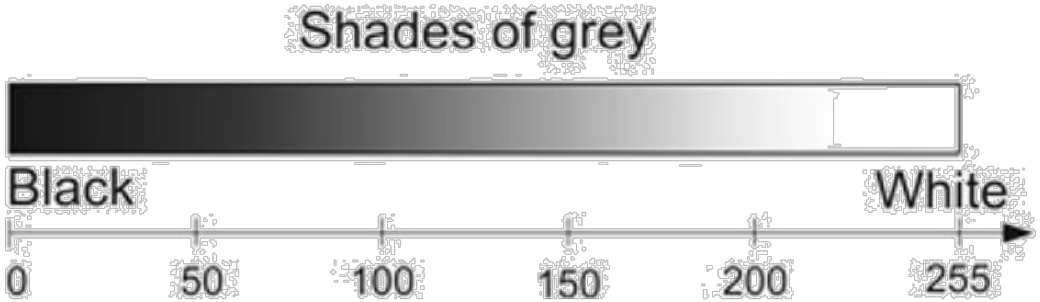


Image acquisition process

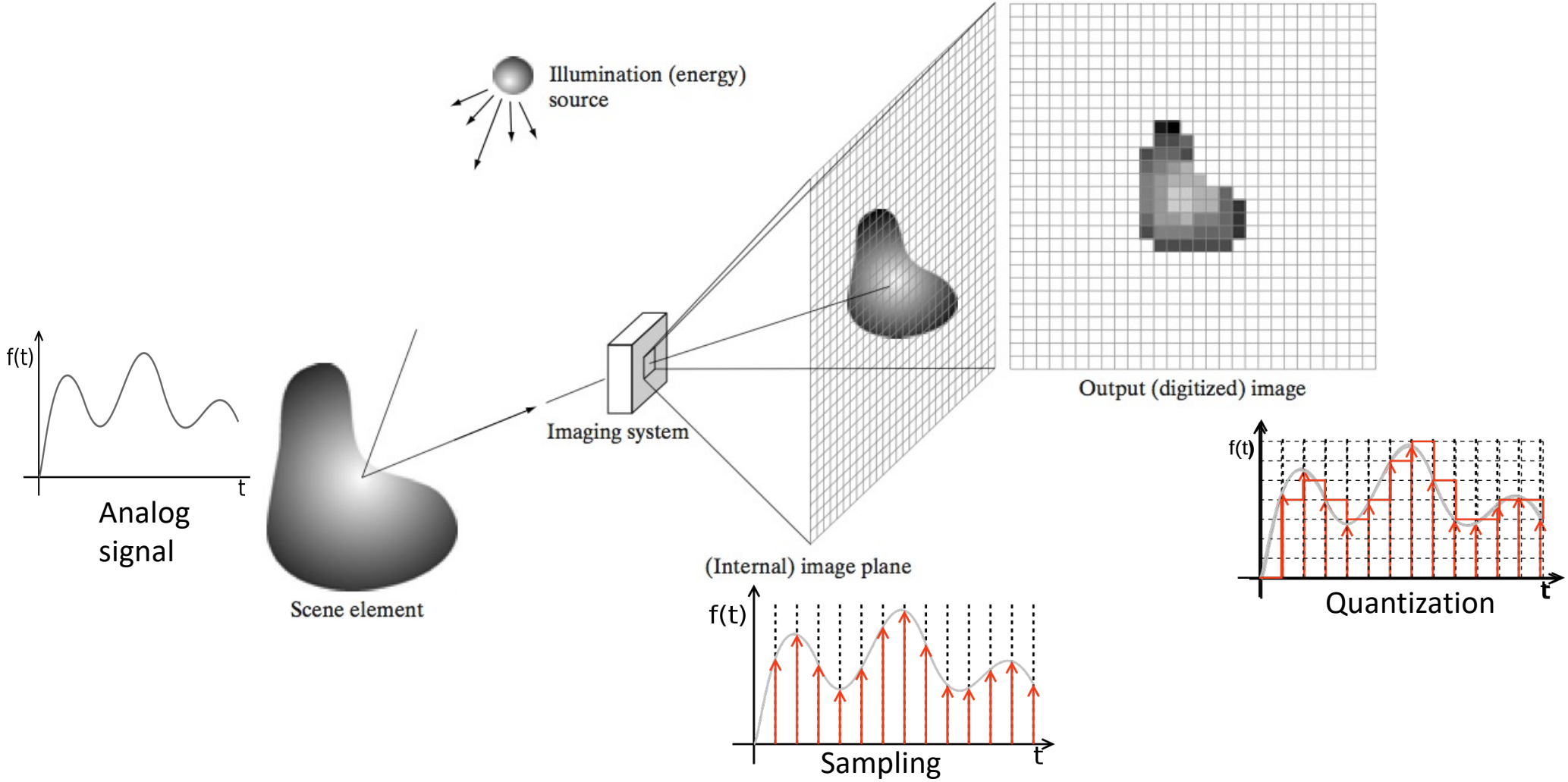
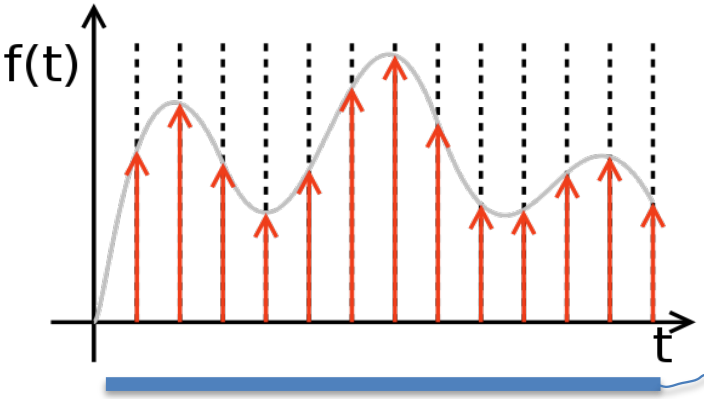
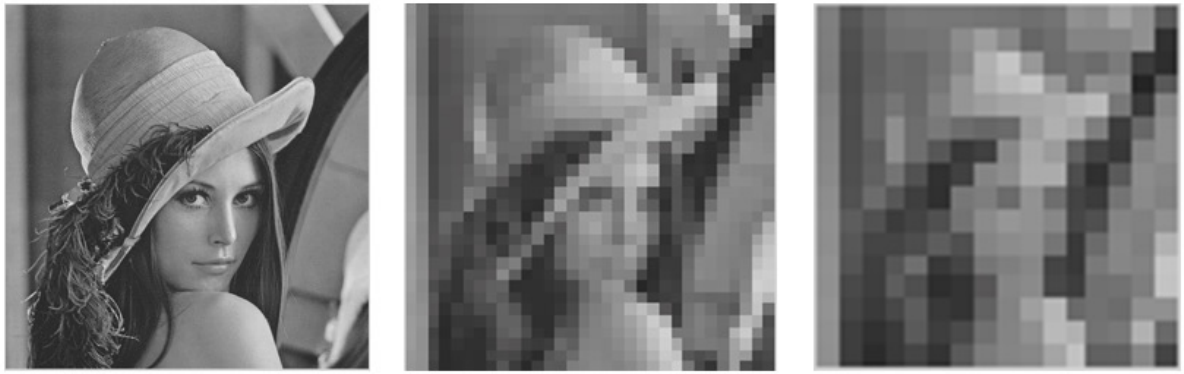


Image courtesy: Gonzalez and Woods

Summary

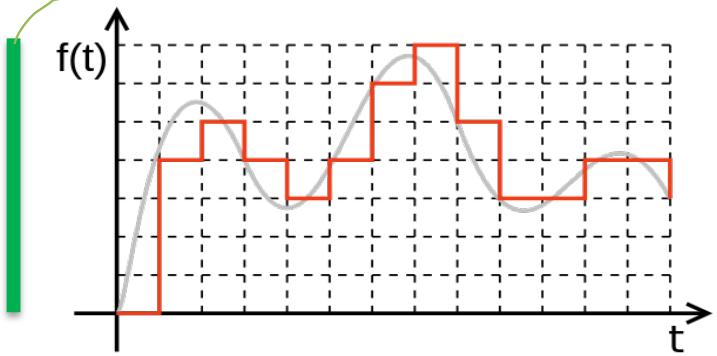


Sampling



256 × 256 32 × 32 16 × 16

Quantization

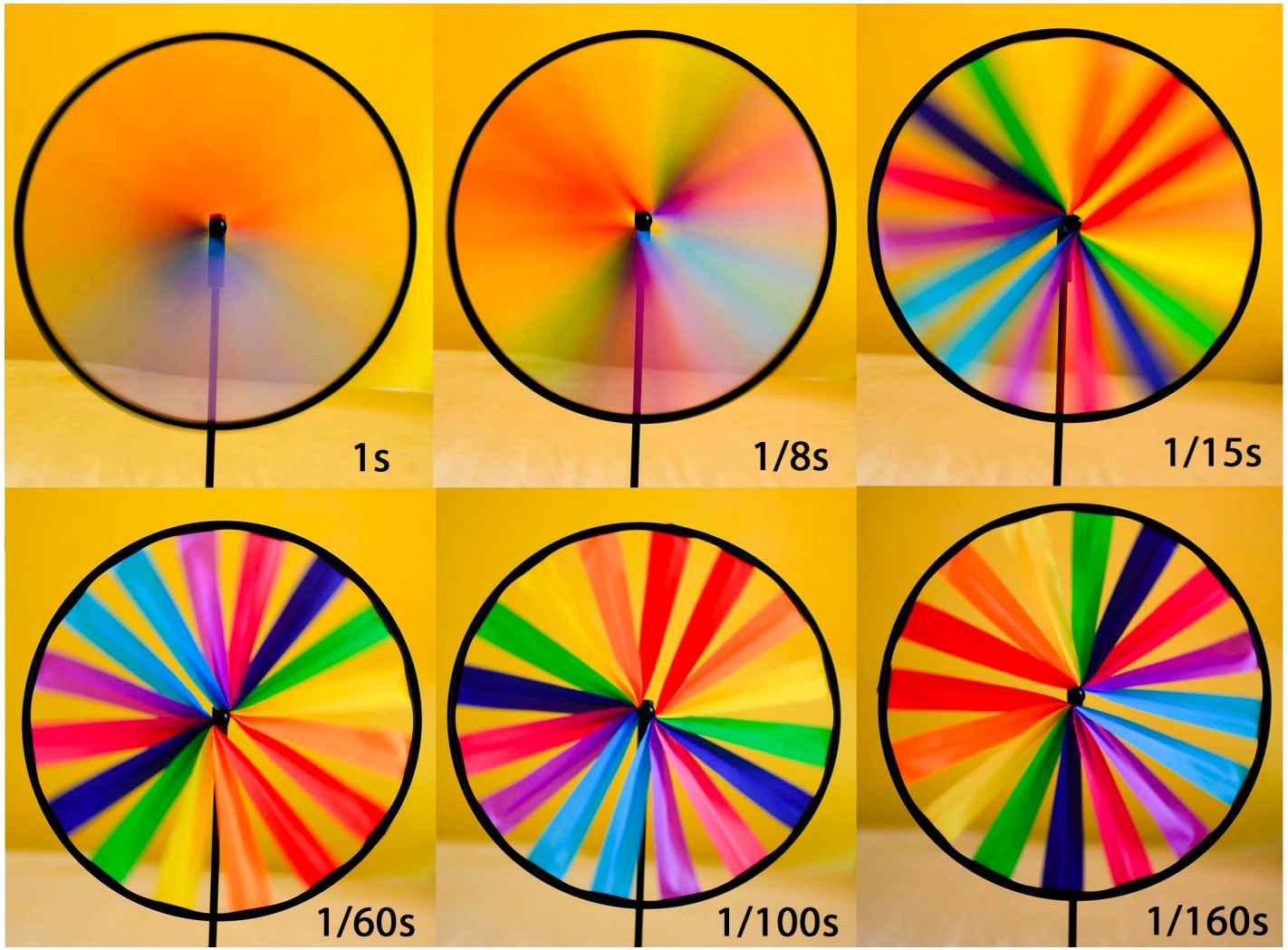


8 bits per pixel 4 bits per pixel 2 bits per pixel 1 bit per pixel

Temporal Sampling

Aperture
small aperture
F32
F22
F16
F11
F8
F5,6
F4
F2,8
F2
F1,4
large aperture
Shutter
fast shutter speed
1/1000
1/500
1/250
1/125
1/60
1/30
1/15
1/8
1/4
1/2
slow shutter speed
ISO
low sensitivity
ISO 50
ISO 100
ISO 200
ISO 400
ISO 800
ISO 1600
ISO 3200
ISO 6400
ISO 12800
ISO 25600
high sensitivity

Temporal Sampling



Temporal Sampling

Image Processing – Two Paradigms

- Directly manipulating pixels in spatial domain
- Manipulating in transform domain

Spatial Domain Processing

- Manipulating Pixels Directly in Spatial Domain
- 3 approaches
- 1. Point to Point

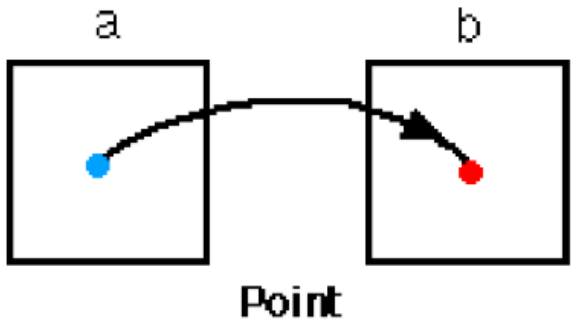
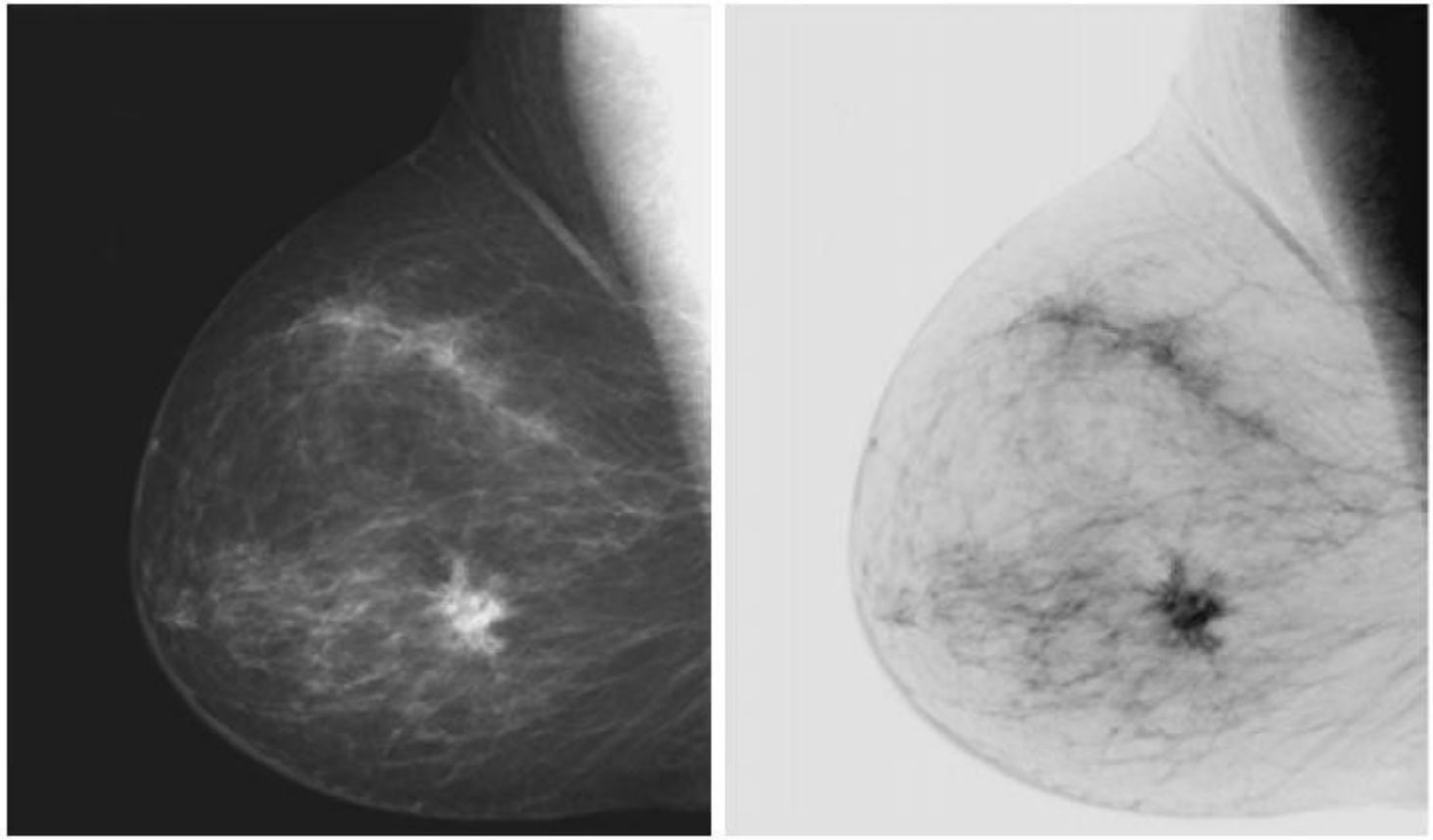


Image Negatives

Intensity levels r: [0, L-1] s = T(r) =

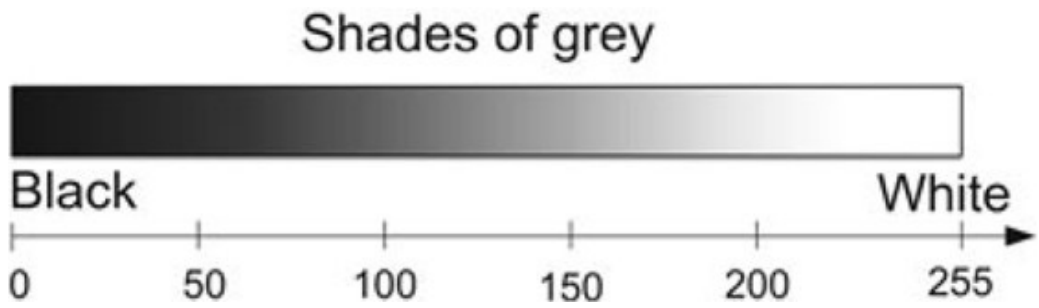


a b

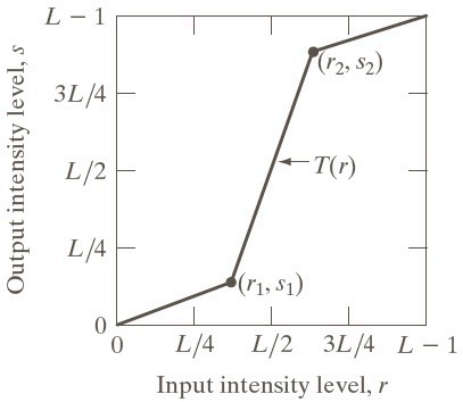
FIGURE 3.4 (a) Original digital mammogram. (b) Negative image obtained using the negative transformation in Eq. (3.2-1). (Courtesy of G.E. Medical Systems.)

Linear Intensity Transforms

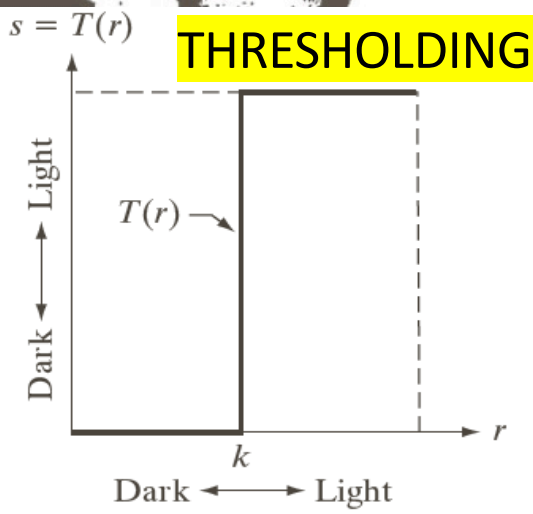
- $T(z) = z + K$
- $T(z) = z - K$
- $T(z) = Kz$
- $T(z) = K_1 z + K_2$



Piecewise-Linear Transformations



THRESHOLDING

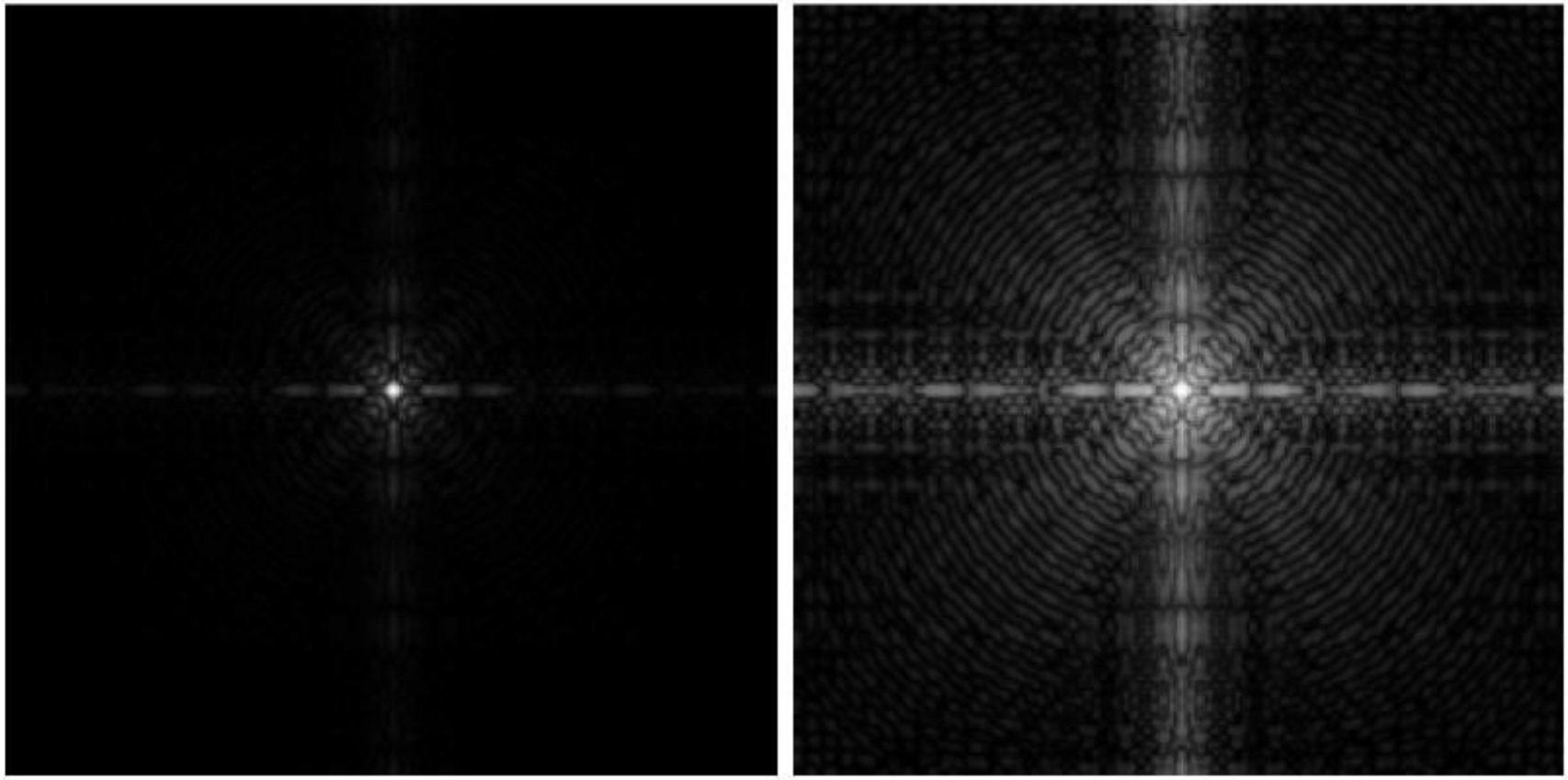


(r1,s1) = ?
(r2,s2) = ?

Log Transformations

a b

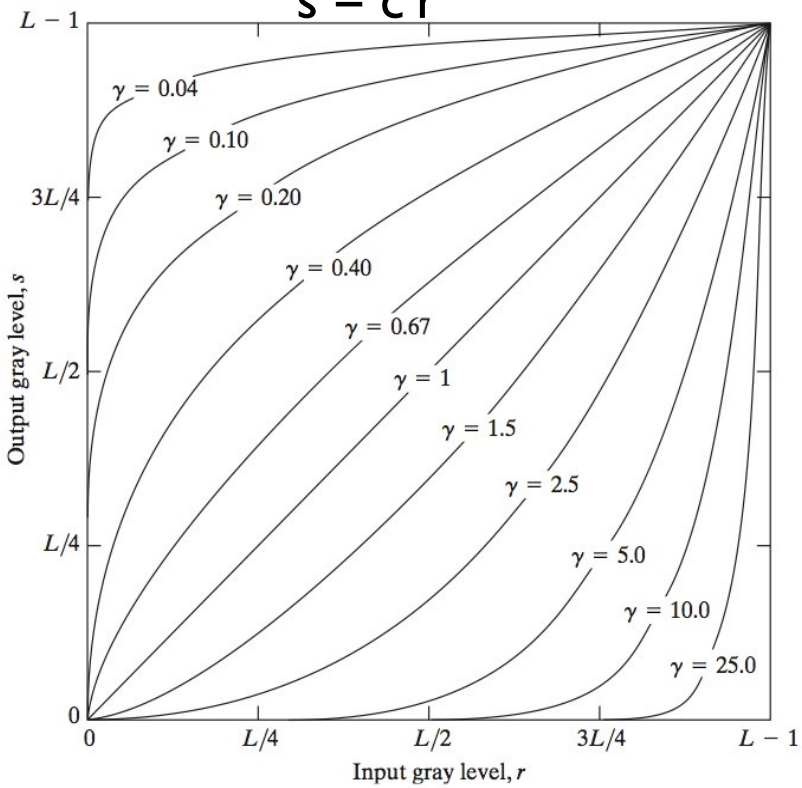
FIGURE 3.5 (a) Fourier spectrum. (b) Result of applying the log transformation given in Eq. (3.2-2) with $c = 1$.

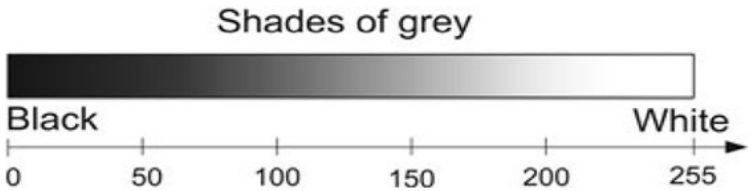


$$s = T(r) = c\ log(1 + r)$$

Power-Law Transformations

$s = c\,r^{\gamma}$





a b
c d

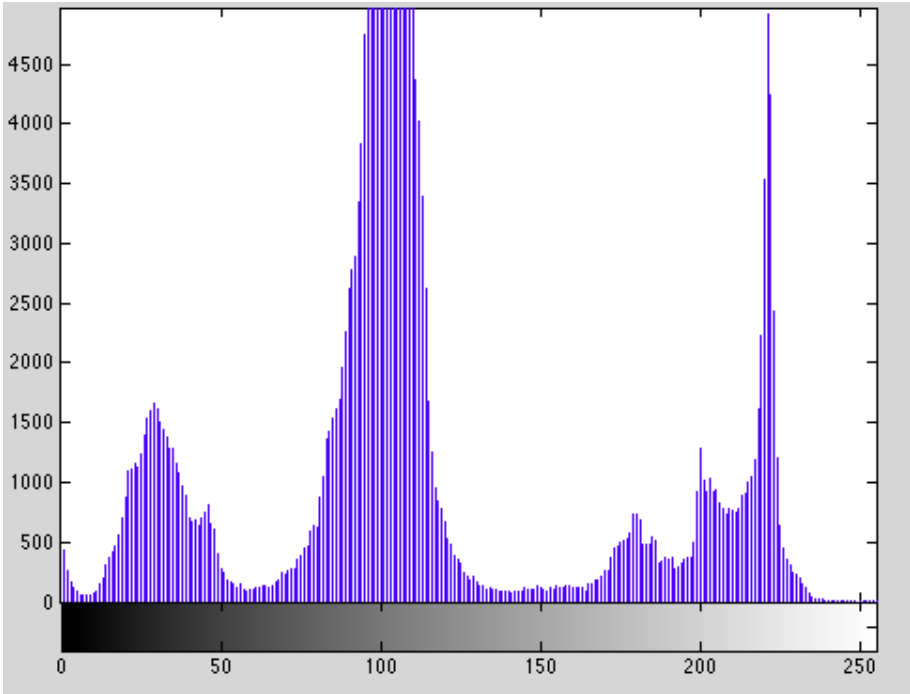
FIGURE 3.9 (a) Aerial image. (b)–(d) Results of applying the transformation in Eq. (3.2-3) with $c = 1$ and $\gamma = 3.0, 4.0$, and 5.0, respectively. (Original image for this example courtesy of NASA.)

Histogram

$$h_r(i) = n_i$$

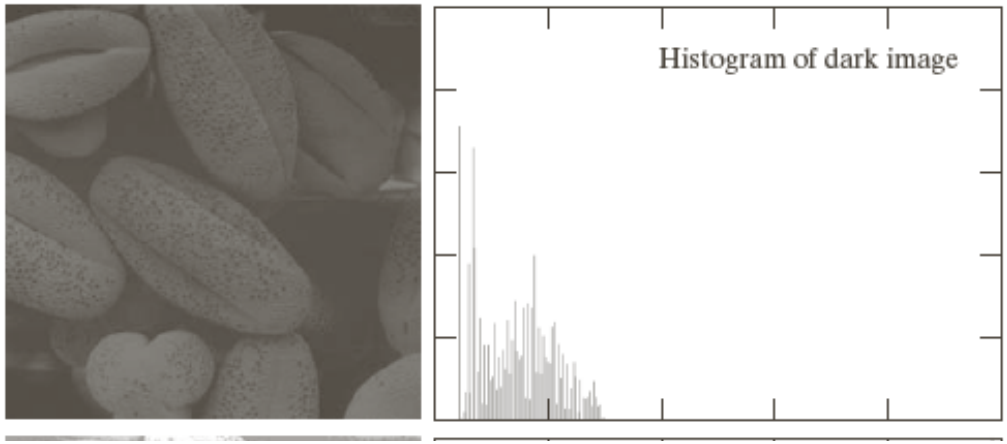
i → intensity value, range [0,L-1]

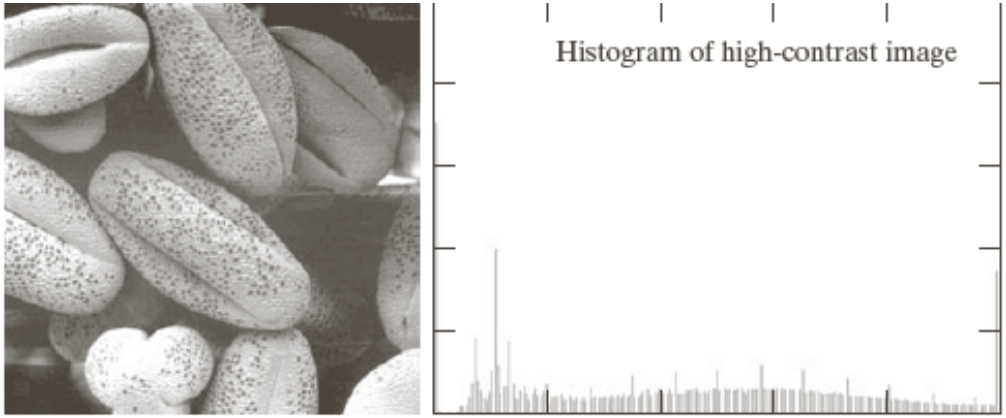
n_i → number of pixels with intensity i

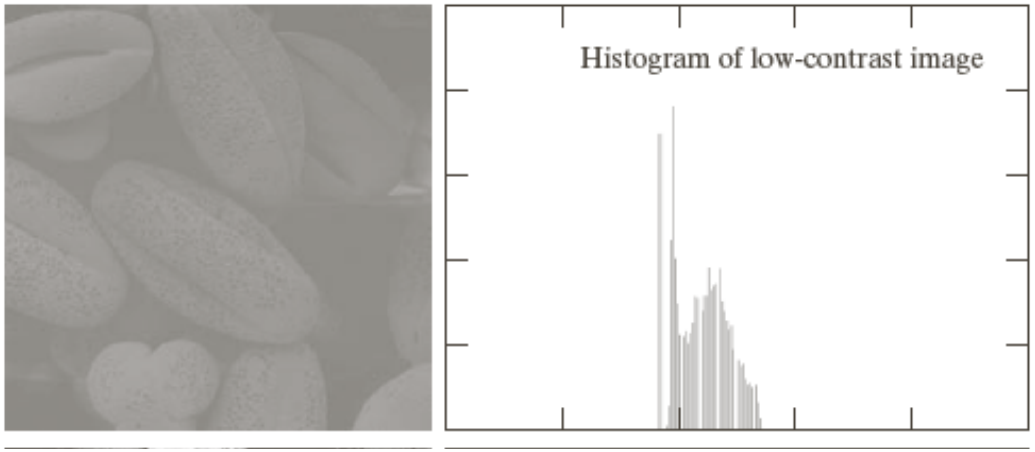


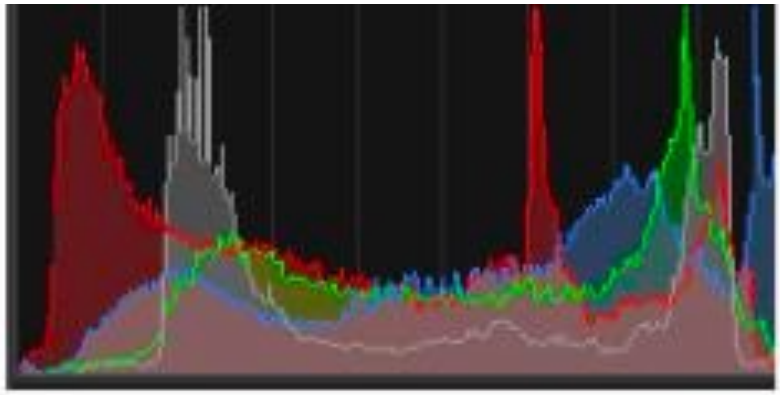
Histograms and Contrast

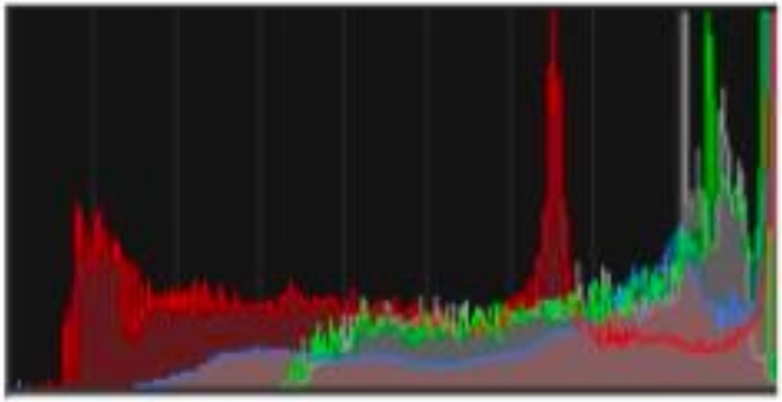
$$\frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

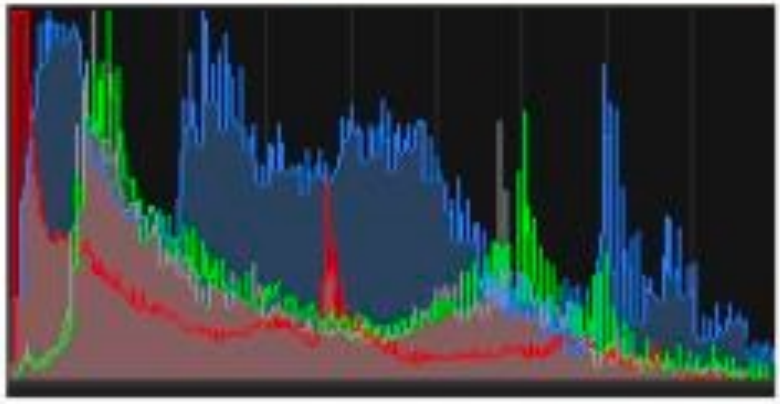






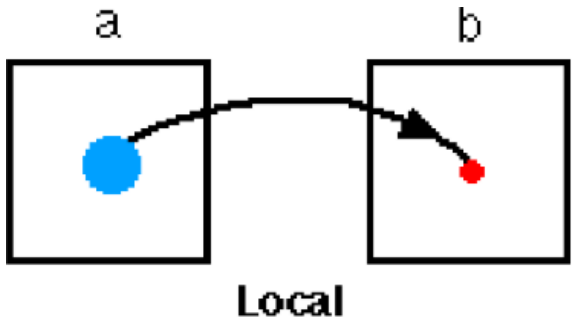






Spatial Domain Processing

- Manipulating Pixels Directly in Spatial Domain
- 3 approaches



- 2. Neighborhood to Point

48	219	168	145	244	188	120	58
49	218	87	94	133	35	17	148
174	151	74	179	224	3	252	194
77	127	87	139	44	228	149	135
138	229	136	113	250	51	108	163
38	210	185	177	69	76	131	53
178	164	79	158	64	169	85	97
96	209	214	203	223	73	110	200

Current pixel

3×5 neighbourhood

Mean/Average Filter (Smoothing)

```
M = 3
For each valid location [x,y] in S
        a ← Average of intensities in a M x M neighborhood centered on [x,y]
        D[x,y] = round(a)
```

120	190	140	150	200
17	21	30	8	27
89	123	150	73	56
10	178	140	150	18
190	14	76	69	87

x

1/9	1/9	1/9
1/9	1/9	1/9
1/9	1/9	1/9

=

	98			

http://199.116.233.101/index.php?title=File:Animated-kernels.gif

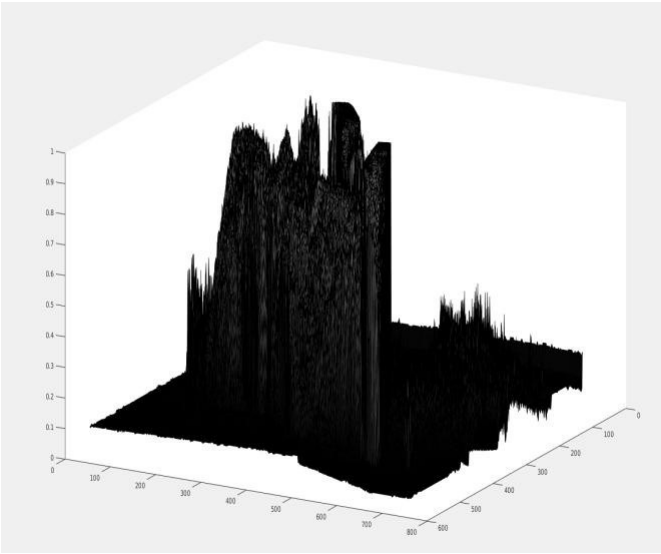
$$1/9 * \begin{matrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{matrix}$$

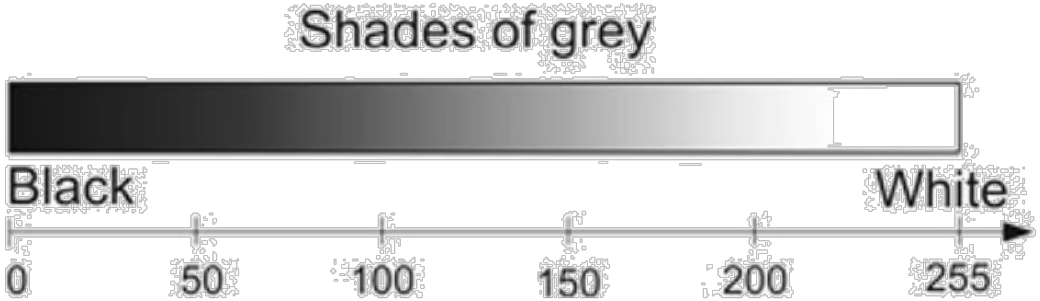
Recall: Image as a function

- $f(x,y) = z$
- Domain : (x,y)
- Range = Intensity

x

y

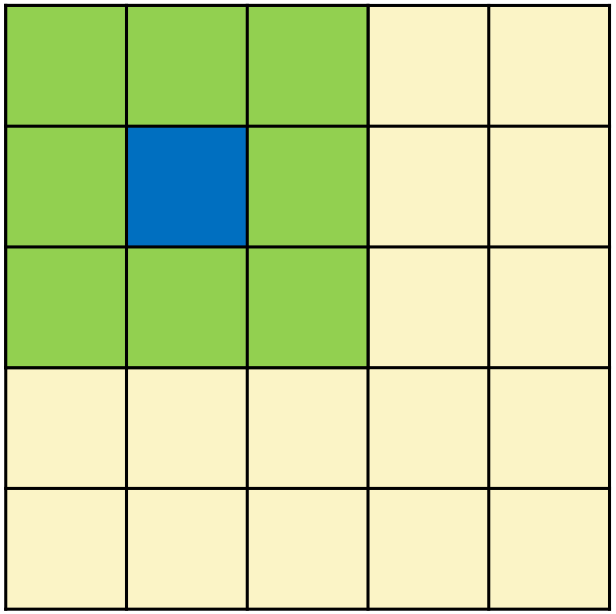




Mean/Average Filter

Note: Coefficients sum to 1

I



H

1/9	1/9	1/9
1/9	1/9	1/9
1/9	1/9	1/9

3 x 3 Weight Mask / Kernel / Filter

$$I'(u,v) \leftarrow \frac{1}{9} \cdot \sum_{j=-1}^{1} \sum_{i=-1}^{1} I(u+i, v+j)$$

$$I'(u,v) \leftarrow \sum_{j=-1}^{1} \sum_{i=-1}^{1} I(u+i, v+j) \boxed{\bullet\ H(i,j)}$$

Effect of Mask Size

Original Image

[3x3]

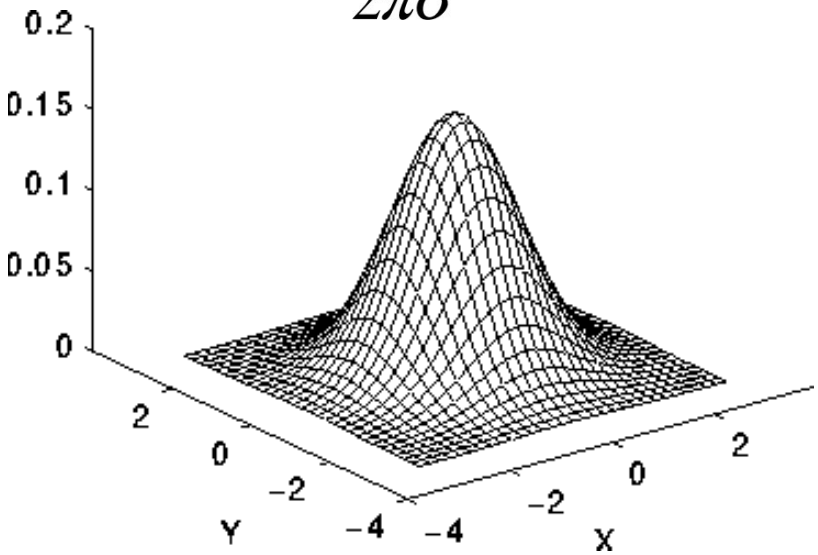
[5x5]

[7x7]

Gaussian Smoothing

- Mask weights are samples of a zero-mean 2-D Gaussian

$$G(x, y) = \frac{1}{2\pi\sigma^2} \exp\{-(x^2 + y^2)/2\sigma^2\}$$



$\frac{1}{265}$

1	4	6	4	1
4	16	26	16	4
6	26	43	26	6
4	16	26	16	4
1	4	6	4	1

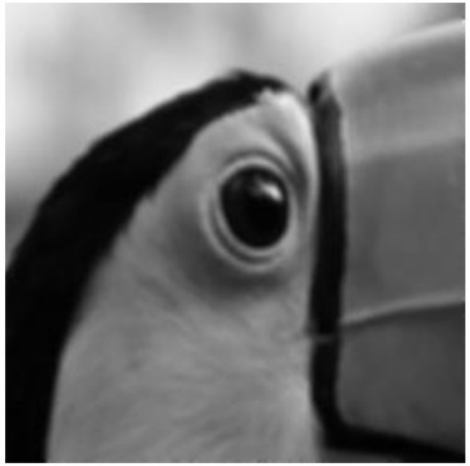
5×5 Gaussian filter, $\sigma=1$

Gaussian Smoothing – Effect of sigma

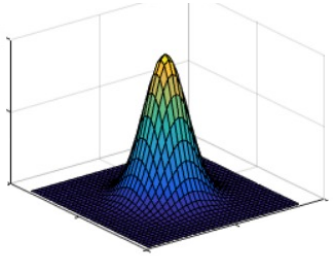
$$G(x, y) = \frac{1}{2\pi\sigma^2} \exp\{-(x^2 + y^2)/2\sigma^2\}$$

Original Image
(Sigma 0)

Gaussian Blur
(Sigma 0.7)



Gaussian Blur
(Sigma 2.8)



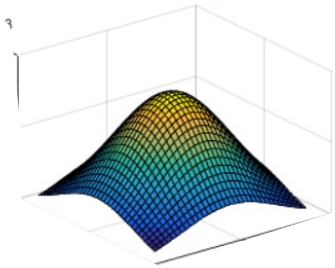


Image Gradient and Edges

$$\frac{f(x+h,y)-f(x-h,y)}{2h} \Rightarrow \begin{array}{|c|c|c|}\hline -1 & 0 & 1 \\ \hline \end{array}$$

x-derivative

$$\frac{f(x,y+h)-f(x,y-h)}{2h} \Rightarrow \begin{array}{|c|}\hline -1 \\ \hline 0 \\ \hline 1 \\ \hline \end{array}$$

y-derivative

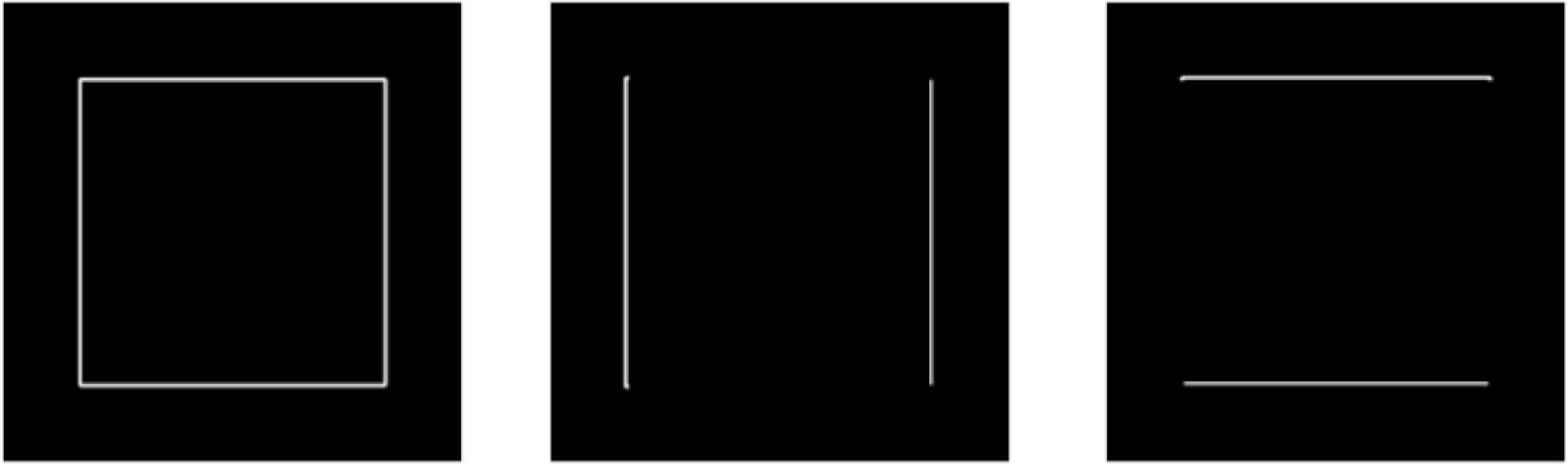


Image | Gradient in x | Gradient in y

https://i1.wp.com/theailearner.com/wp-content/uploads/2019/05/gradxy.png?resize=768%2C280&ssl=1

Edge ‘Image’

https://i0.wp.com/theailearner.com/wp-content/uploads/2019/05/Sobel64.png?w=731&ssl=1

Image gradient

The gradient of an image:

$$\nabla f = \left[\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}\right]$$

The gradient points in the direction of most rapid change in intensity

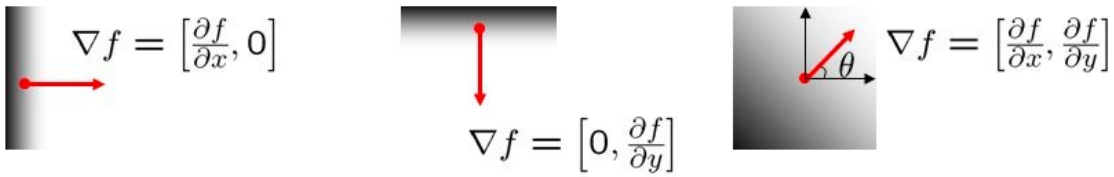
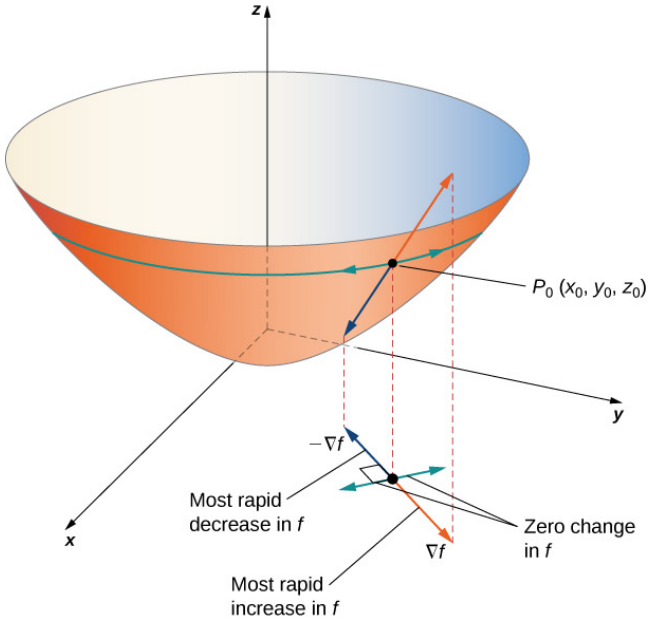
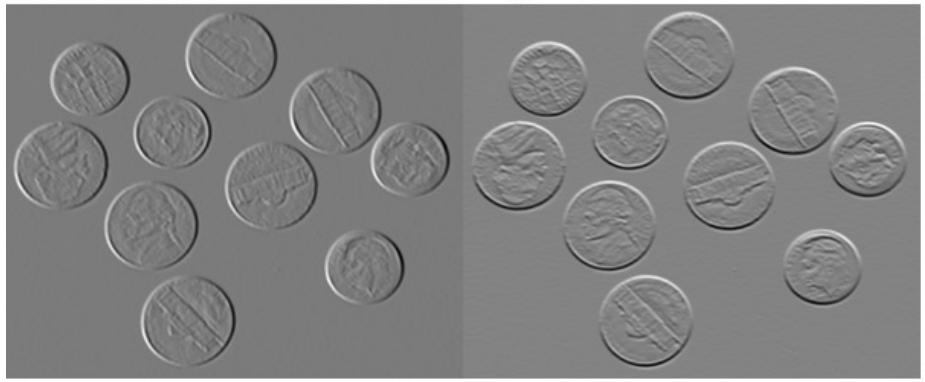
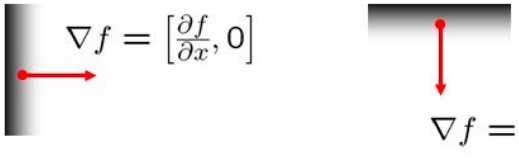


Image **Gradient in x** **Gradient in y**



Edge is perpendicular to gradient





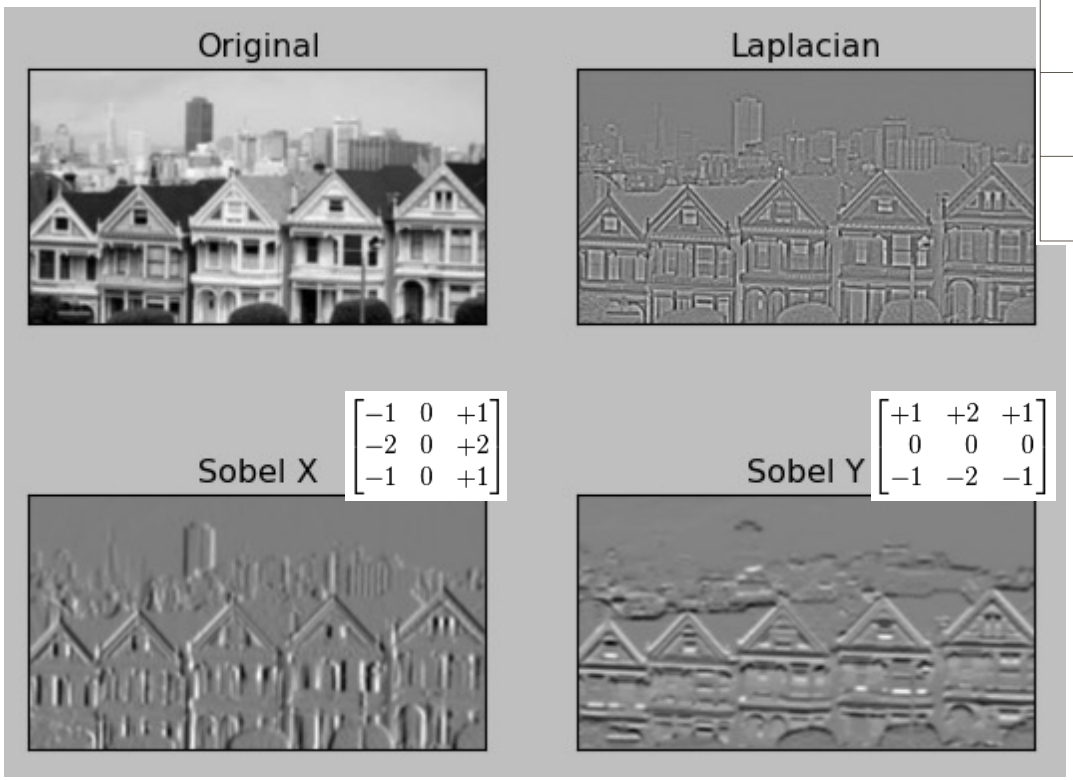
-1	0	+1
-1	0	+1
-1	0	+1

G_x

+1	+1	+1
0	0	0
-1	-1	-1

G_y

Edge Masks – Sobel , Laplacian

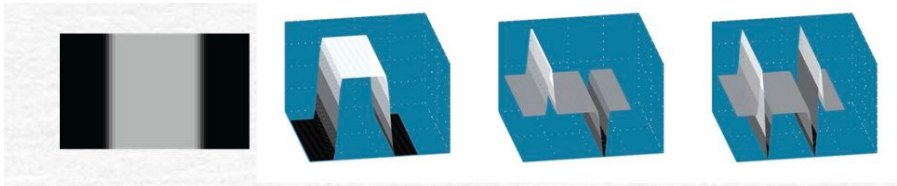


$$\begin{bmatrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{bmatrix}$$

$$\begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

0	−1	0
−1	4	−1
0	−1	0

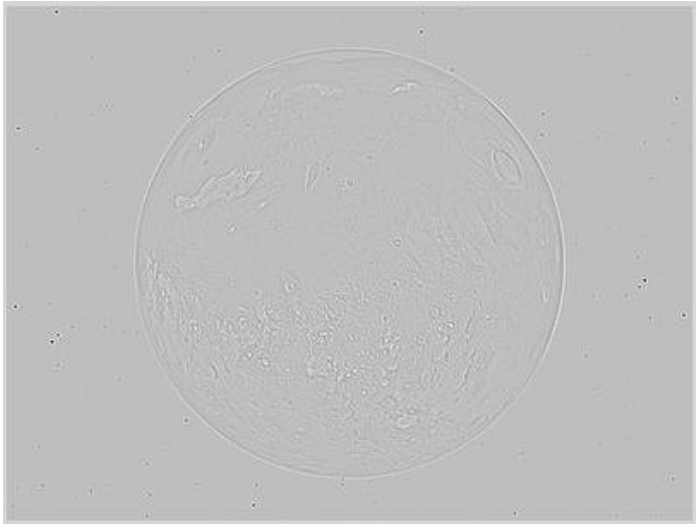
Note: Coefficients sum to 0



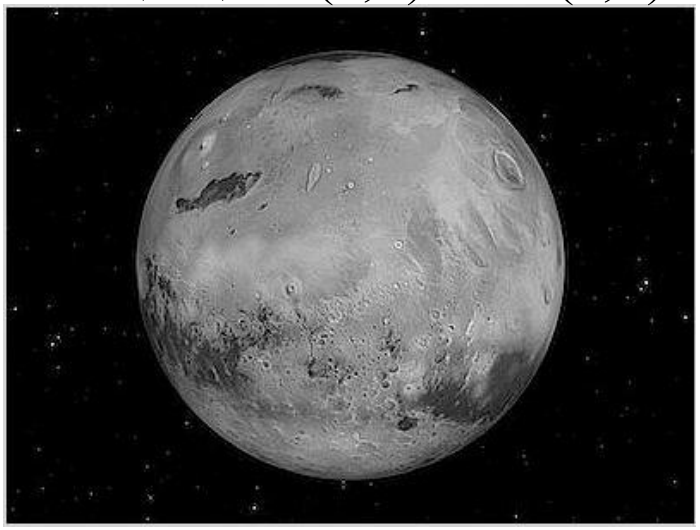
Sharpening (Unsharp Masking)

$I(u,v)$

$\nabla\ I(u,v)$



$I'(u,v) = I(u,v) + \nabla^2 I(u,v)$



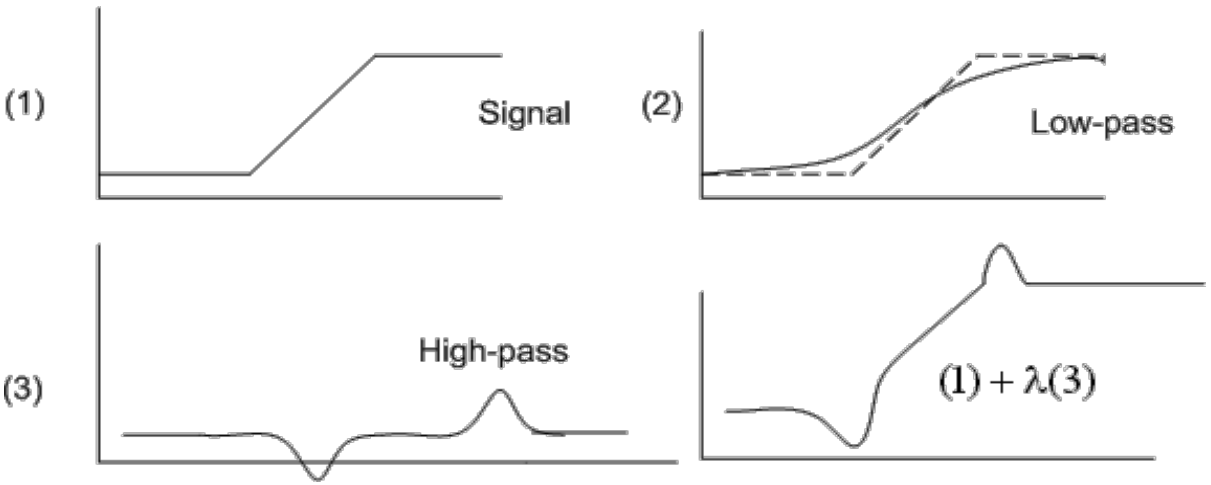
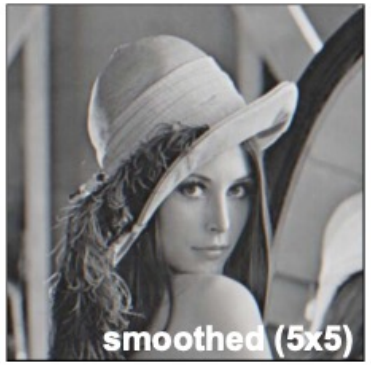


Image Courtesy: NASA

Highboost Filtering

- What does blurring take away?

–



=

- Let's add it back:

+ a

=

Unsharp Masking vs Highboost Filtering

Unsharp Masking / Highboost Filtering as Spatial Filters

A=1

w = 9A-1

-1	-1	-1
-1	w	-1
-1	-1	-1

A=2

w = 17

-1	-1	-1
-1	17	-1
-1	-1	-1

- If **A=1**, we get unsharp masking. $I'(u,v) = I(u,v) + \nabla^2 I(u,v)$
- If **A>1**, original image is added back to detail image (highboost filtering).

Corner cases, Padding

```
M = 3
For each valid location [x,y] in S
        a ← Average of intensities in a M x M neighborhood centered on [x,y]
        D[x,y] = round(a)
```

120	190	140	150	200
17	21	30	8	27
89	123	150	73	56
10	178	140	150	18
190	14	76	69	87

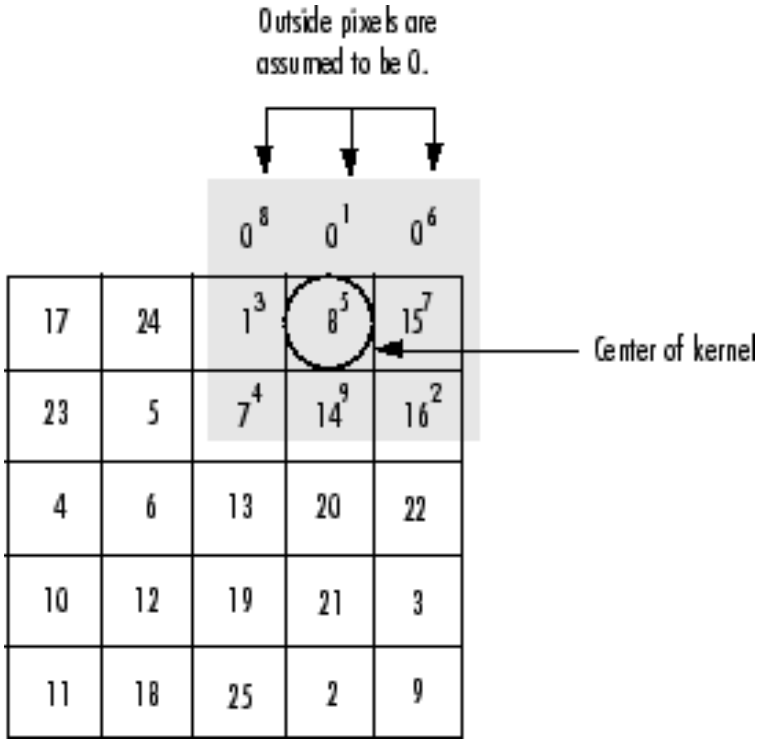
x

1/9	1/9	1/9
1/9	1/9	1/9
1/9	1/9	1/9

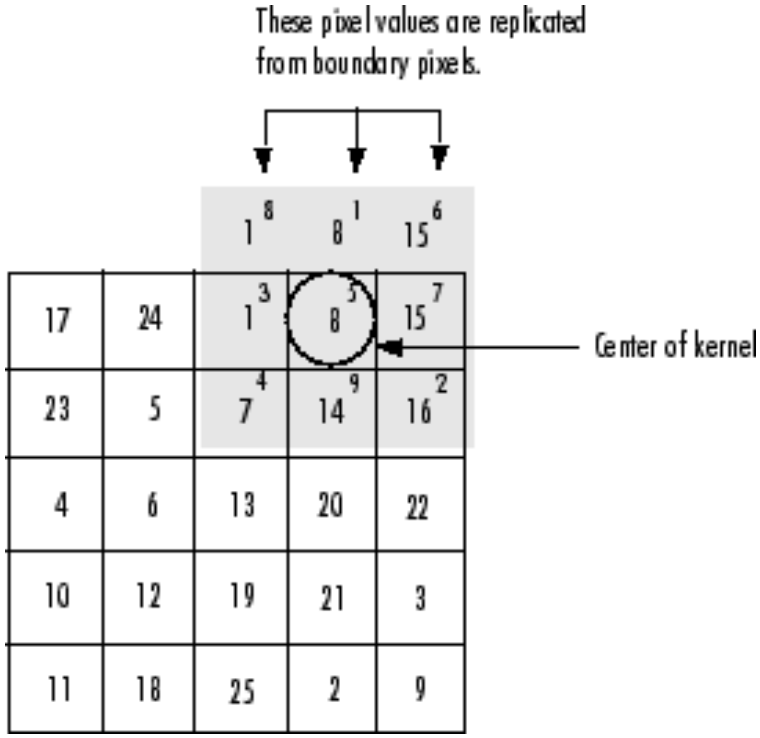
=

	98			

Image Padding



zero



replicate

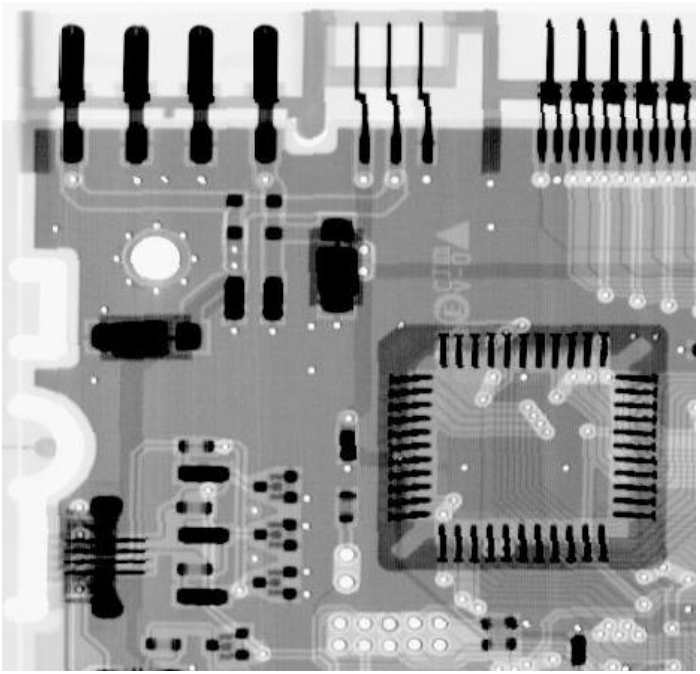
Spatial Domain Filtering - Approaches

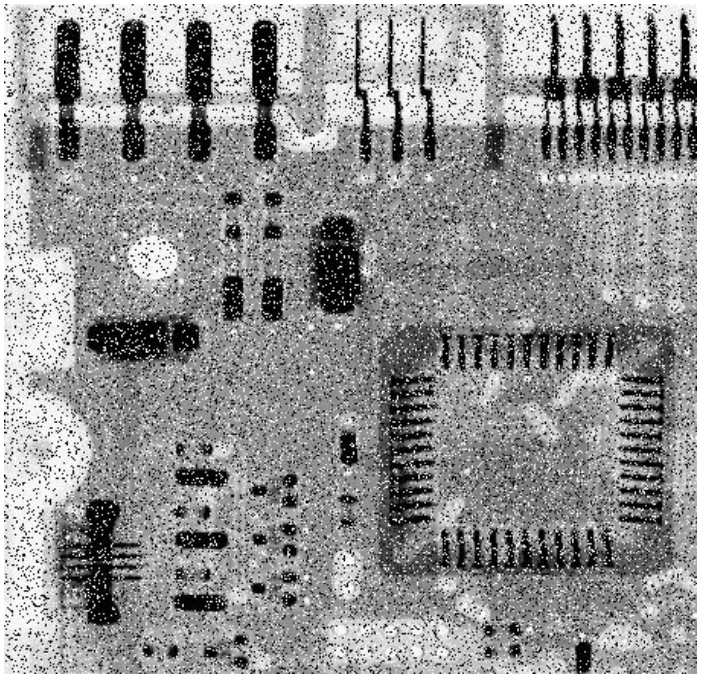
- Linear (Average, Gaussian, Prewitt, Sobel, Laplacian)
- Non-linear

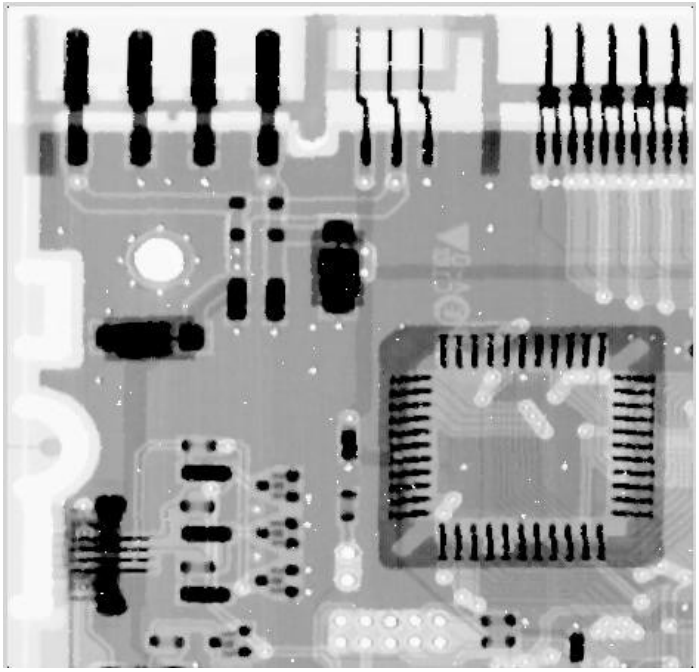
Non-linear Spatial Filters (median)

salt & pepper noise

After applying median filter







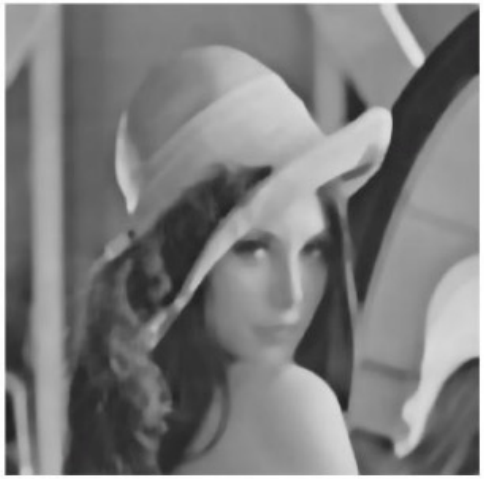
max, min, median → also known as rank / order statistic filters

- Mean: blurs image, removes simple noise, no details are preserved
- Gaussian: blurs image, preserves details only for small σ.
- Median: preserves some details, good at removing strong noise

original

3x3 mean

3x3 gaussian



3x3 median

Edge Detection-Biometrics

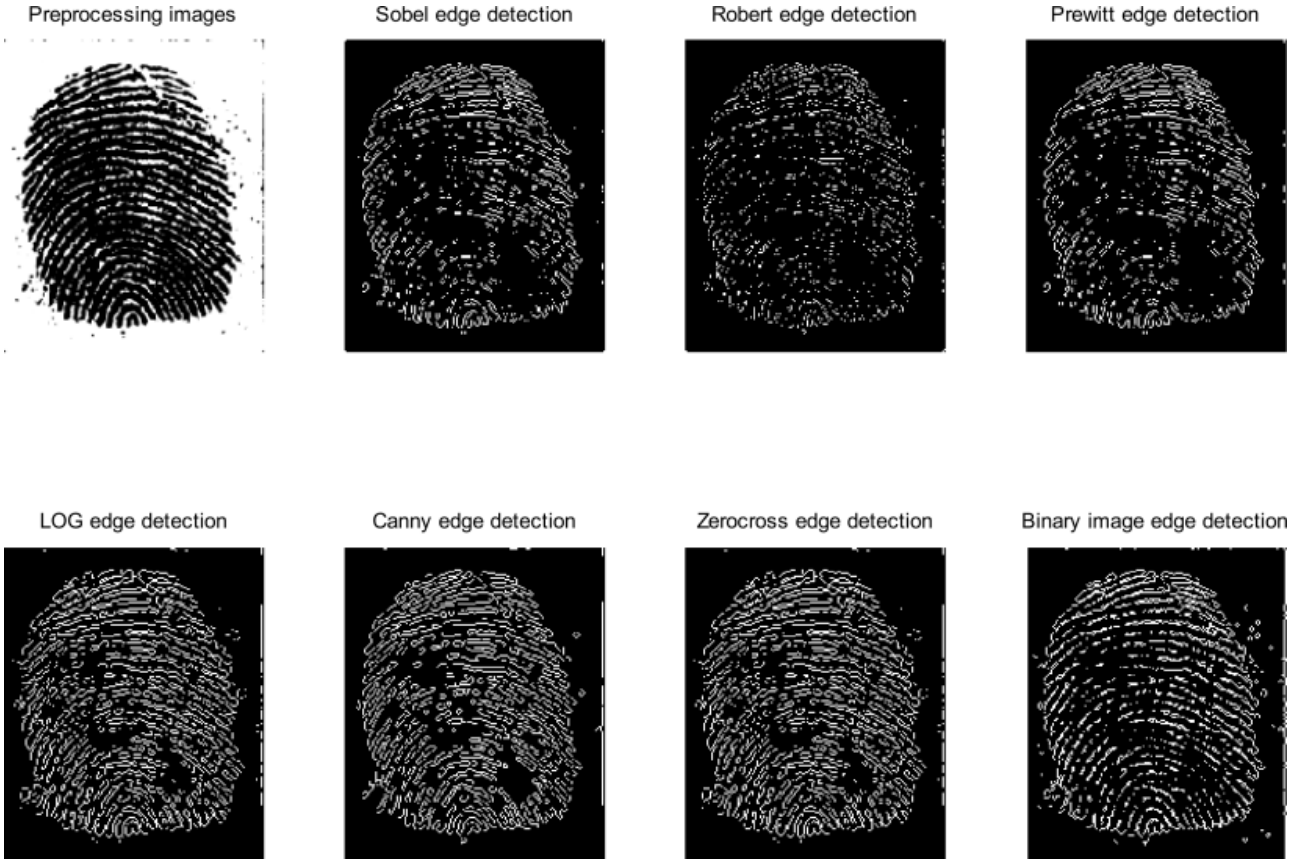


Image Courtesy: Cui et al., “The research of edge detection algorithm for fingerprint images,” World Automation Congress, 2008

Edge Detection-Biometrics

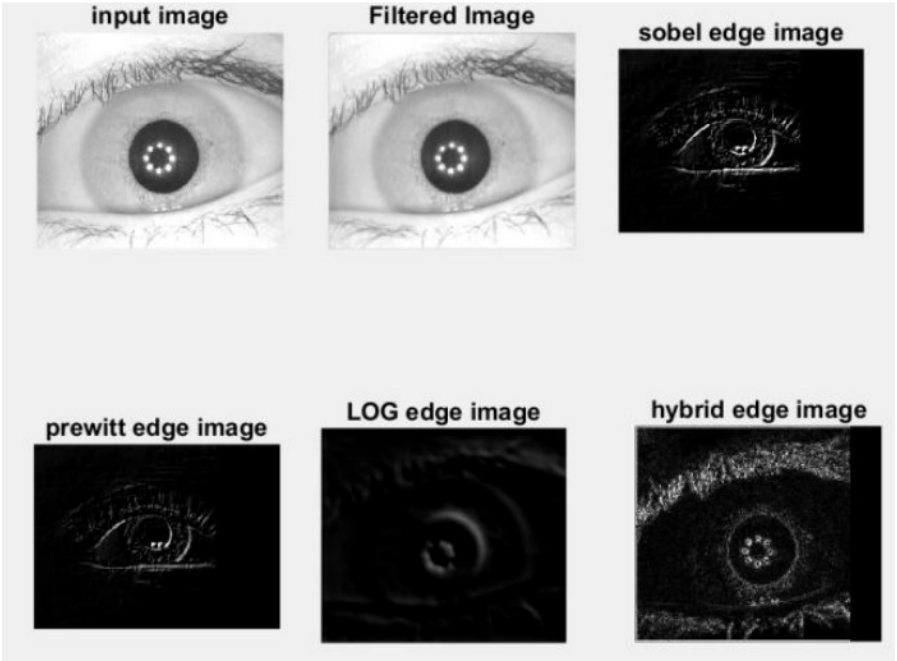
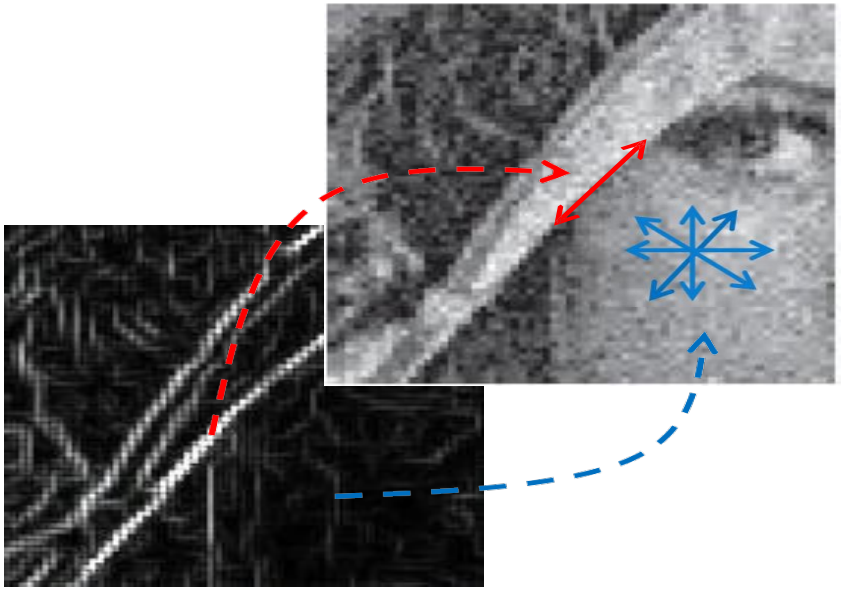


Image Courtesy: Kaur et al., “Comparison of edge detection techniques for iris recognition,” Intl. Journal of Computer Applications, 2016

Edge Preserving Filtering

- Edges ⇒ smooth only along edges
- "Smooth" regions ⇒ smooth isotropically

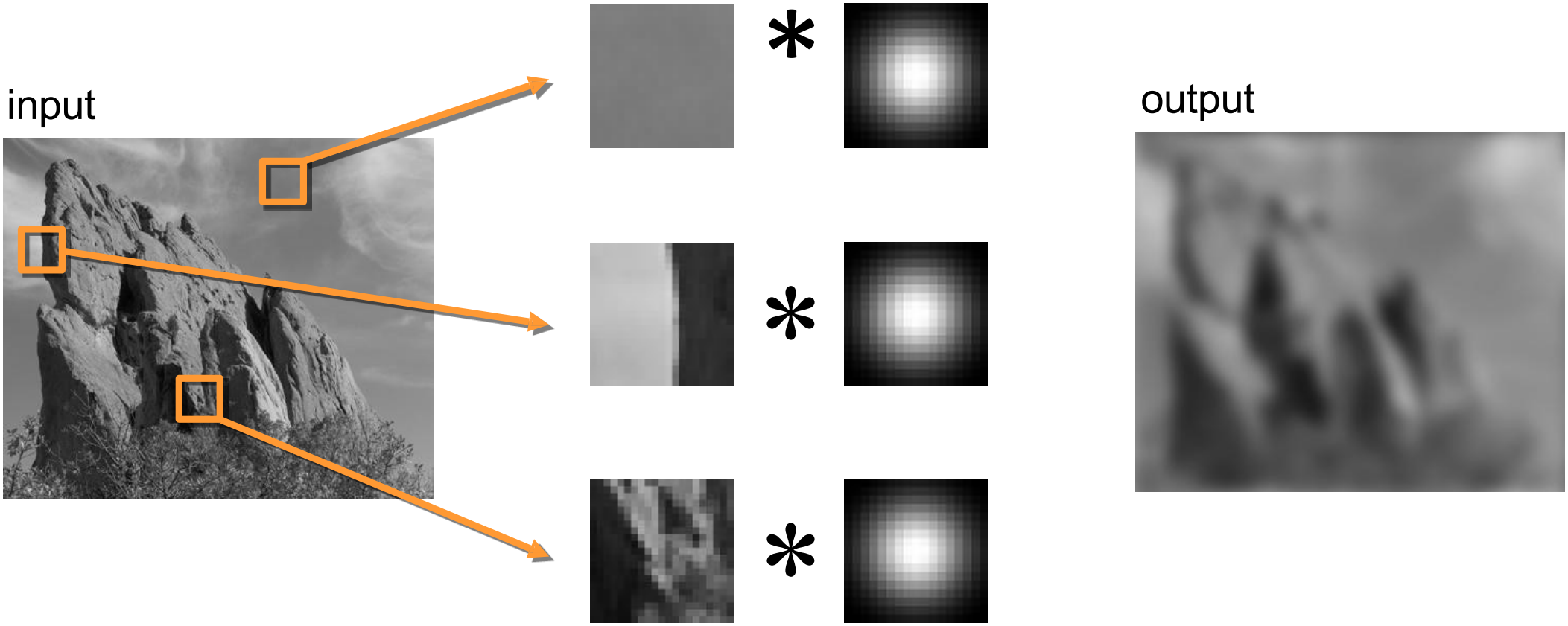


gradient

Bilateral Filtering (Edge preserving smoothing)

Original image taken from cs.cityu.edu.hk

Usual Gaussian Filtering



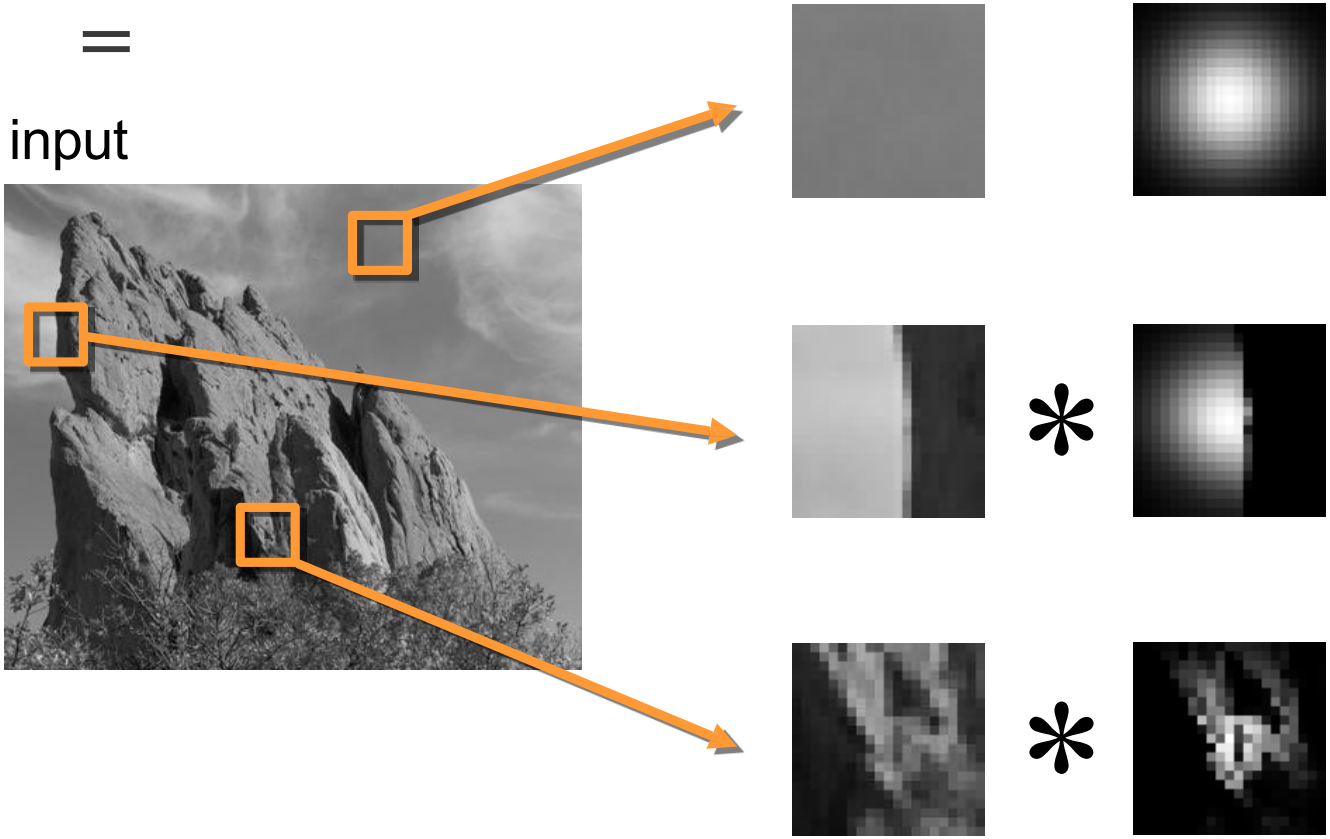
Same Gaussian kernel everywhere.

Source: Sylvain Paris

Bilateral Filtering

=

input



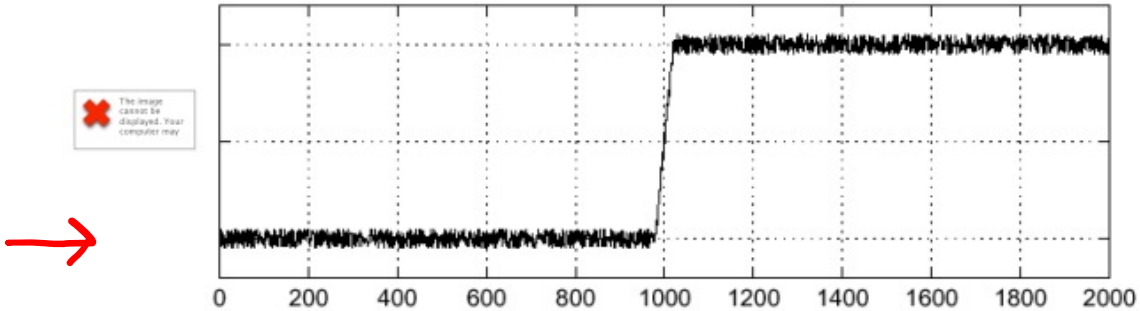
output

The kernel shape depends on the image content.

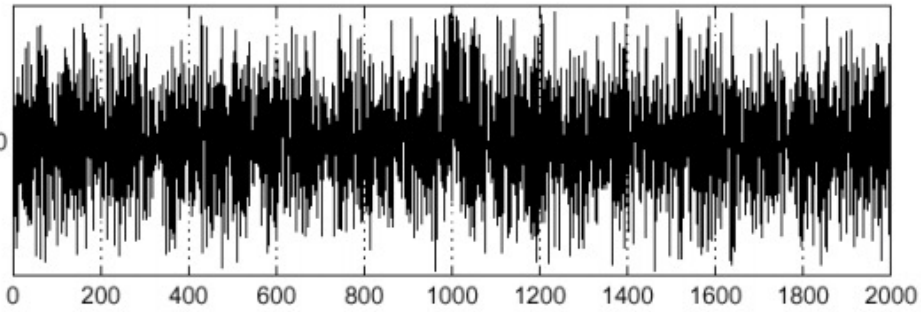
Source: Sylvain Paris

Effects of noise

Consider a single row or column of the image



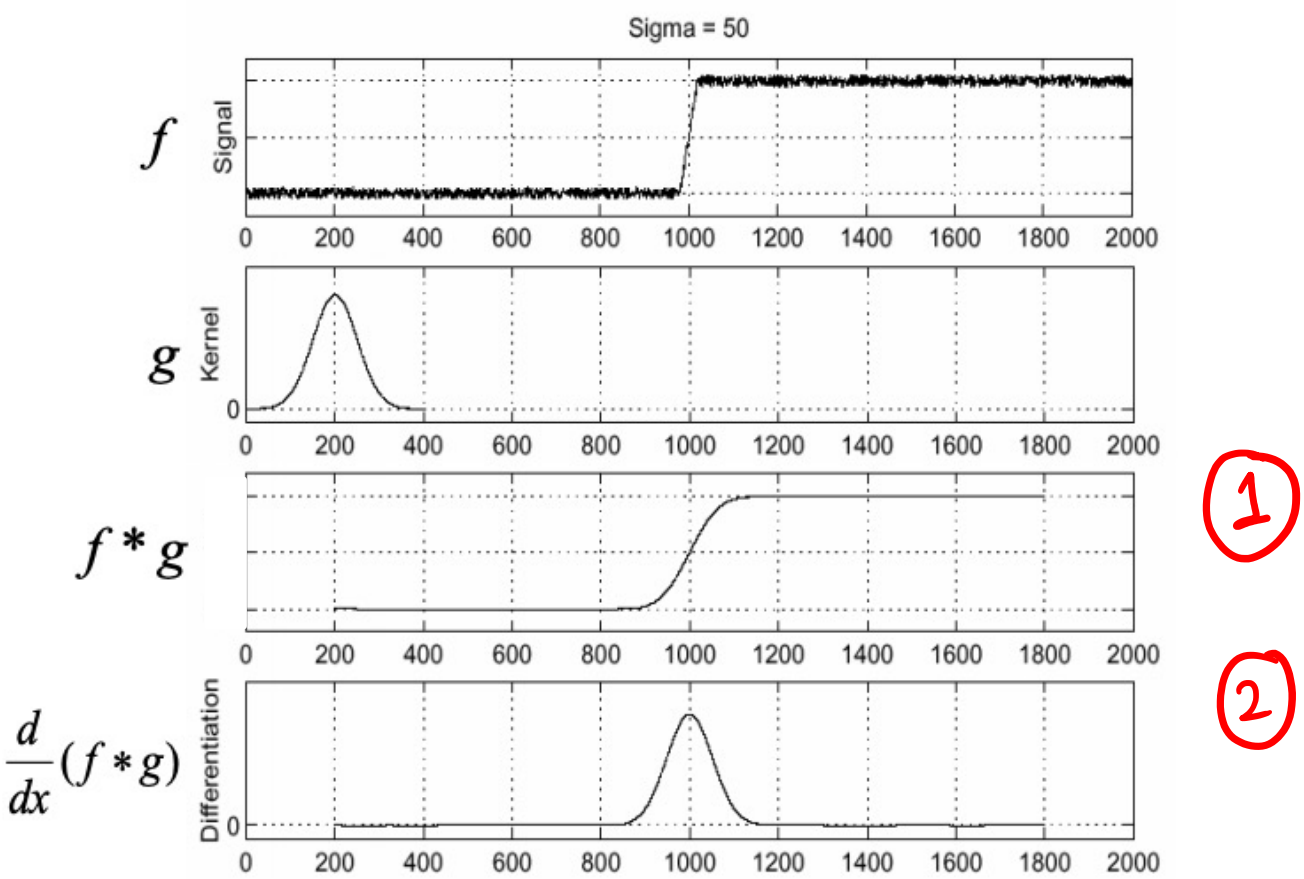
$\frac{d}{dx}f(x)$



Where is the edge?

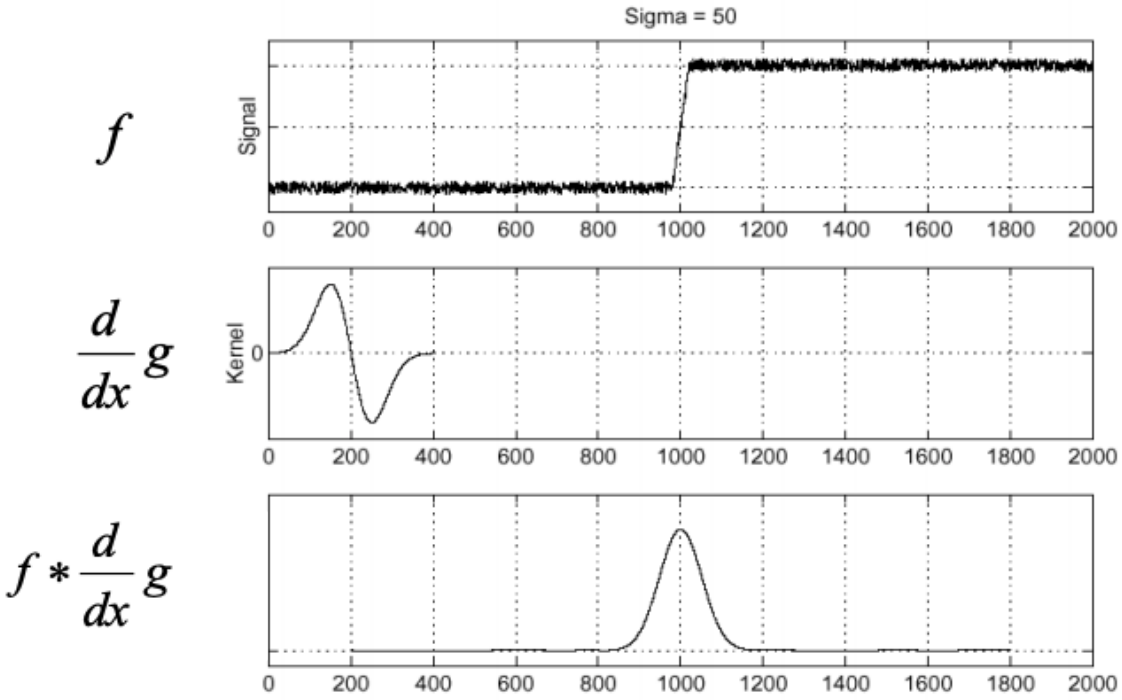
Source: S. Seitz

Solution: smooth first



$$\frac{d}{dx}(f * g) = f * \frac{d}{dx} g$$

- This saves us one operation:



Source: S. Seitz

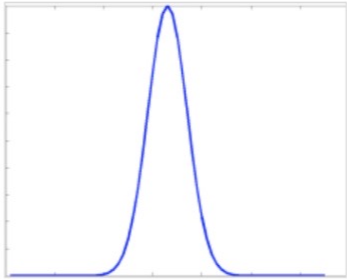
Other Important Filters

- Laplacian of Gaussian
  - Noise Suppression

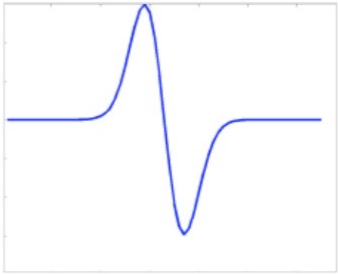
Robert Collins
CSE486

1D Gaussian and Derivatives

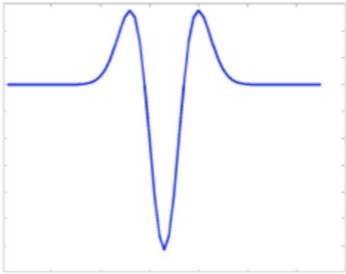
$$g(x) = e^{-\frac{x^2}{2\sigma^2}}$$



$$g'(x) = -\frac{1}{2\sigma^2} 2xe^{-\frac{x^2}{2\sigma^2}} = -\frac{x}{\sigma^2} e^{-\frac{x^2}{2\sigma^2}}$$

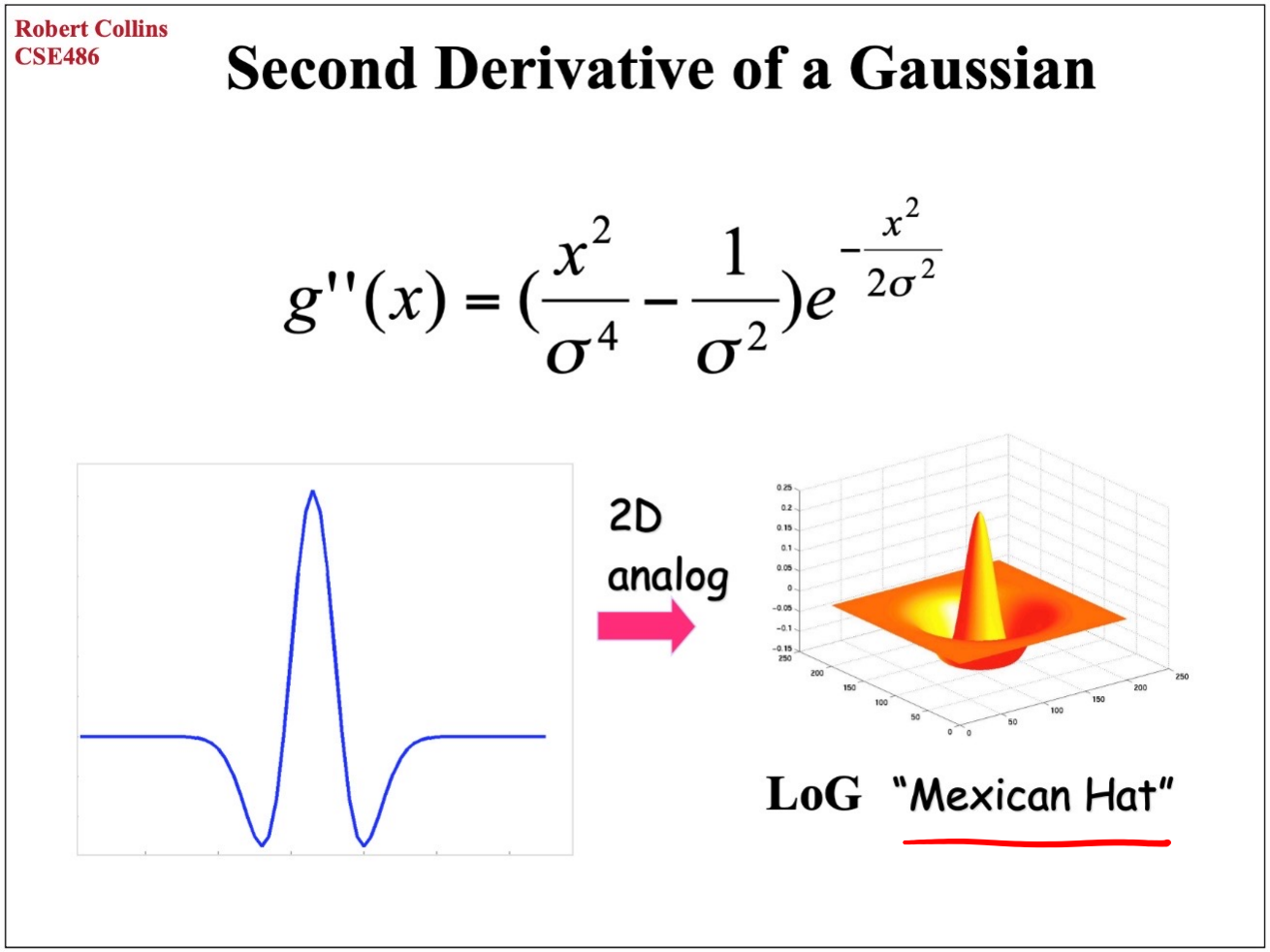


$$g''(x) = \left(\frac{x^2}{\sigma^4} - \frac{1}{\sigma^2}\right) e^{-\frac{x^2}{2\sigma^2}}$$



Other Important Filters

- Laplacian of Gaussian
  - Noise Suppression



Convolution / Linear Filters

$I * f = I'$

correlation

- Smoothing (Average, Gaussian)
- Edge Filters (Prewitt, Sobel, Laplacian)

$$I'(u,v) \leftarrow \sum_{j=-1}^{1} \sum_{i=-1}^{1} I(u+i, v+j) \cdot H(i,j)$$

i \ j	-1	0	1
-1	a	b	c
0	d	e	f
1	g	h	i

averaging

$T[x[n]] = y[n]$

120	190	140	150	200
17	21	30	8	27
89	123	150	73	56
10	178	140	150	18
190	14	76	69	87

x

1/9	1/9	1/9
1/9	1/9	1/9
1/9	1/9	1/9

=

	98			

$x[n]$

convolution

Resources

- Image Processing Libraries (look at tutorials)
  - **opencv-python**
  - scikit-image
  - Kornia
  - PIL