Digital Image Processing ECE 6258

Lecture 3:

Image Enhancement in Spatial Domain

Camera technologies and basics of digital image

Pixel Operations and Histogram Processing

Digital Camera Technologies

- CCD (Charge Coupled Device)
  - *Capacitive device*
  - *Proper mechanism for charge transfer*
- CMOS (Complementary magnetic oxide)
  - *Fabricated in standard semiconductor production line*
  - *A CCD system typically requires 2–5 watts (digital output), compared to 20–50 milliwatts for the same pixel throughput using an active-pixel system*

Digital Camera Technologies

CCD Array Cameras

Consists of sensor elements/ photo detectors (active devices) and charge storage devices also called charge buckets

Every element in the array is linked (charge coupled) to other element.

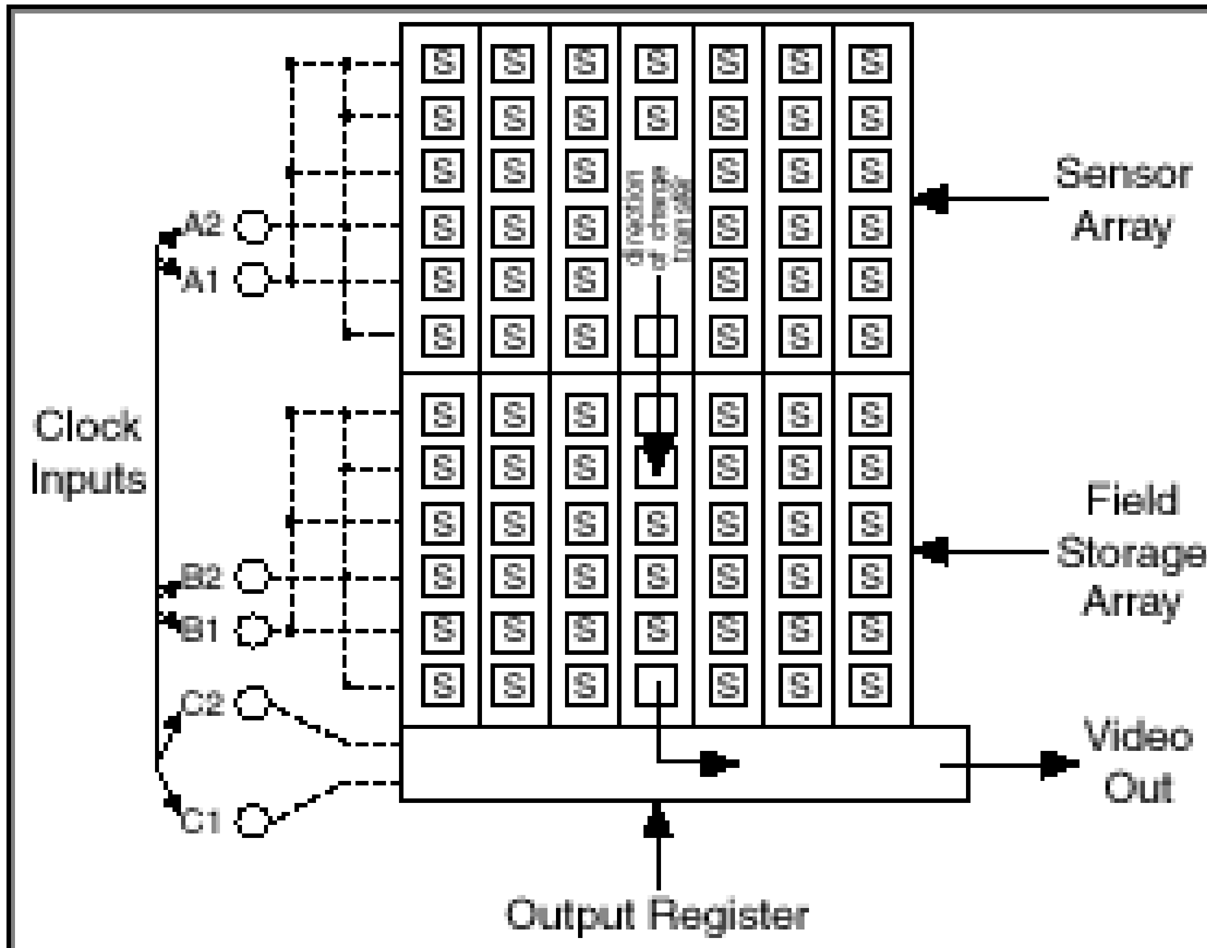
Charges are transferred serially out of the array through shifting charges from one element to the other.

Digital Camera Technologies

CCD Array Cameras

Frame Transfer

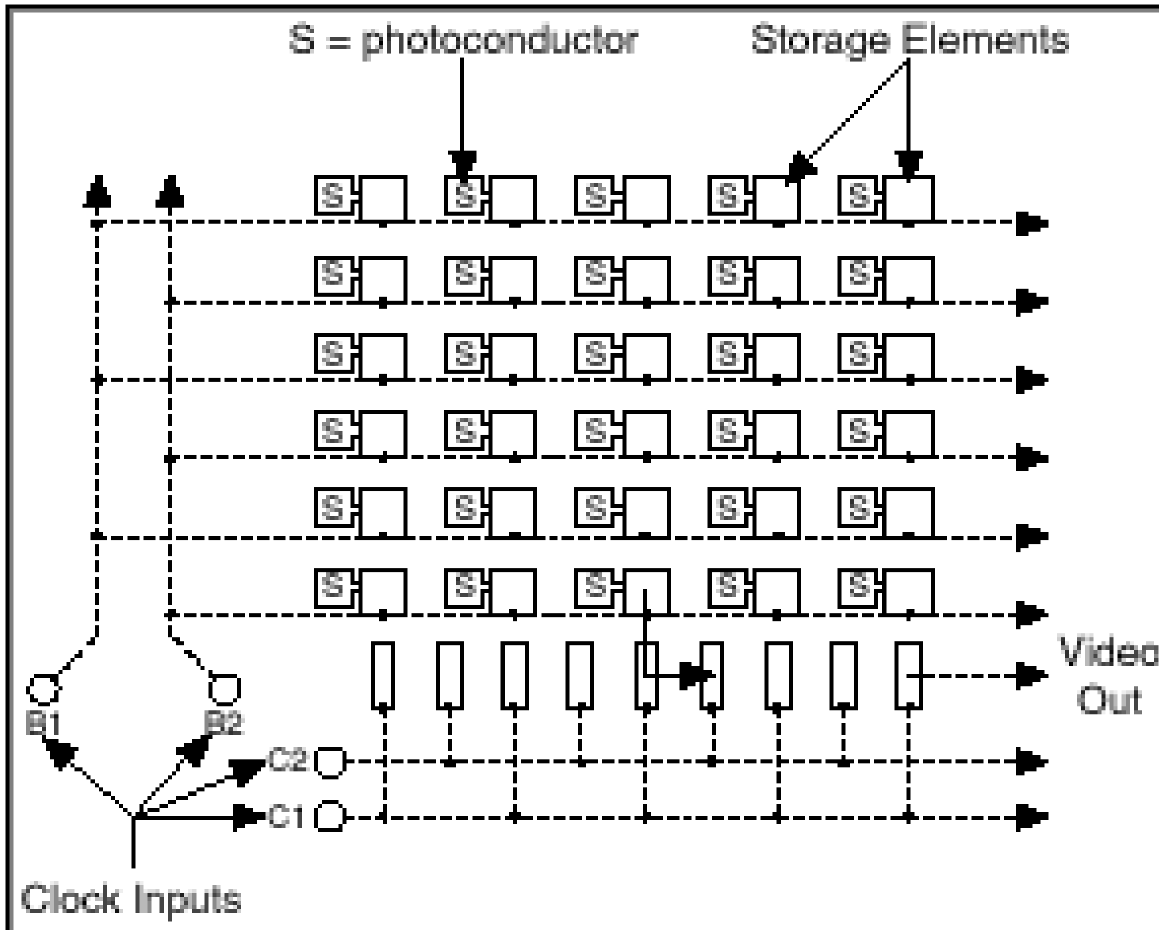
Architecture



Digital Camera Technologies

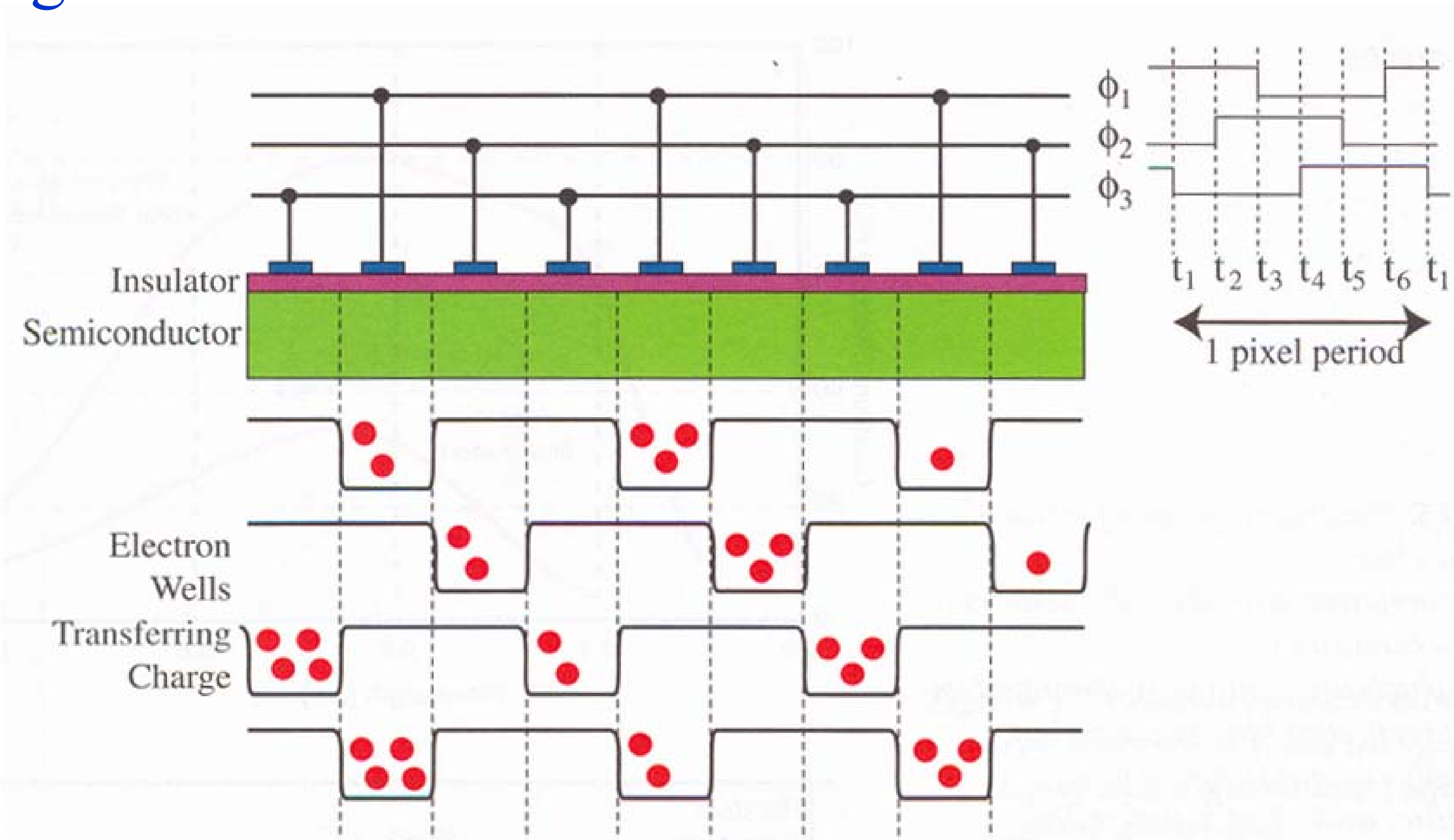
CCD Array Cameras

Interline Transfer Architecture



Digital Camera Technologies

Charge transfer in CCD Cameras



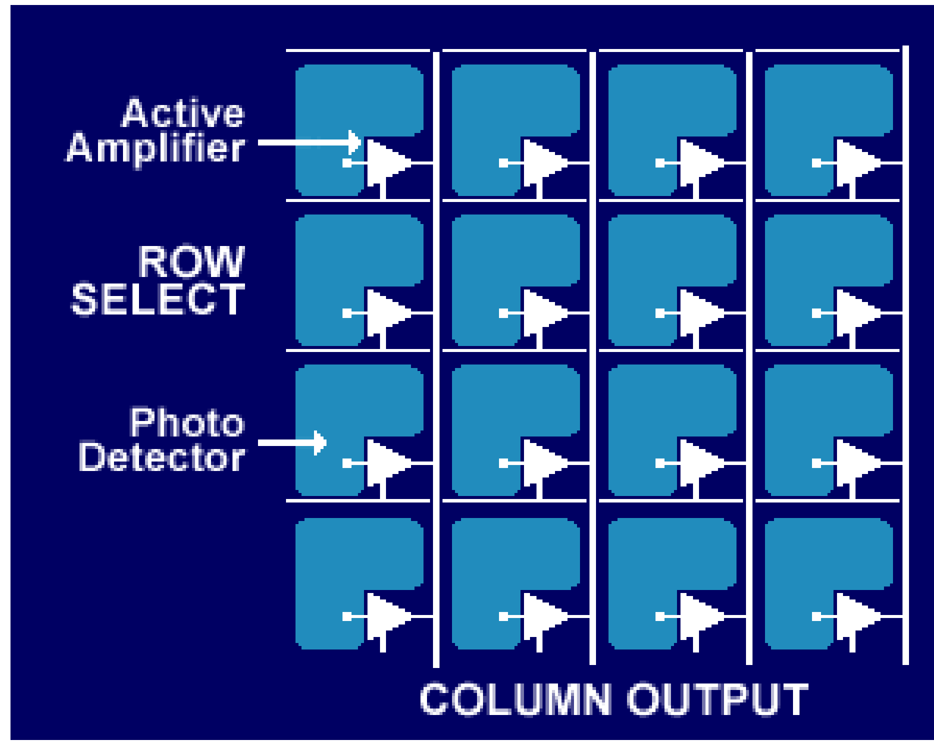
Varying voltages on a set of three electrodes shift electrons from one pixel to another

Digital Camera Technologies

CMOS Array Cameras

Standard semiconductor production line

Active pixel architecture
Photo-detector and amplifier are both fabricated inside each pixel.



Digital camera technologies comparison

CCD (Charge Coupled Device)

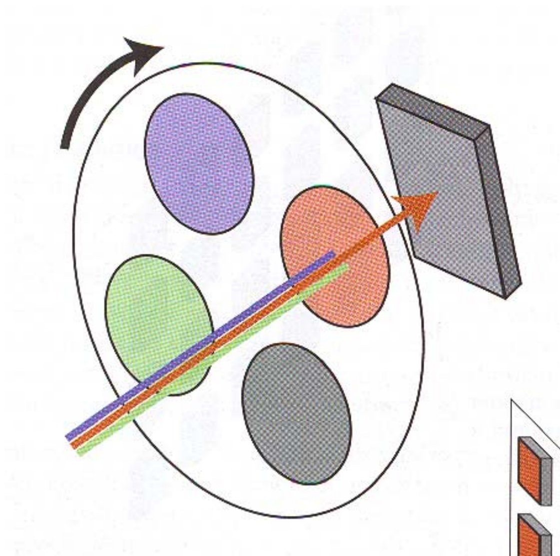
- *Specialized fabrication techniques are used so expensive technology*
- *Larger size*
- *Higher power consumption because of the capacitive architecture*
- *Always have to read out the whole image*
- *Resolution is limited by sensor elements size*
- *Less on-chip circuitry so lesser dark currents and noise*

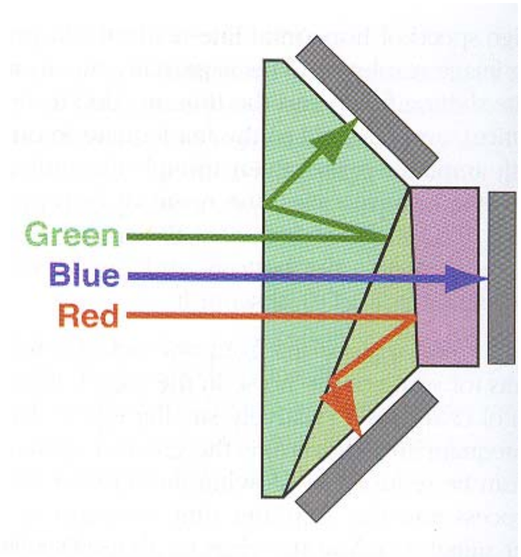
CMOS (Complementary Metal Oxide Semiconductor)

- *Cheaper technology*
- *Smaller size*
- *Low power consumption*
- *Readout for selective area of an image is possible*
- *Amplifier and additional circuitry can be fabricated inside each pixel.*
- *Higher resolution possible*
- *Stronger noise due to higher dark currents because of more on-chip circuitry*

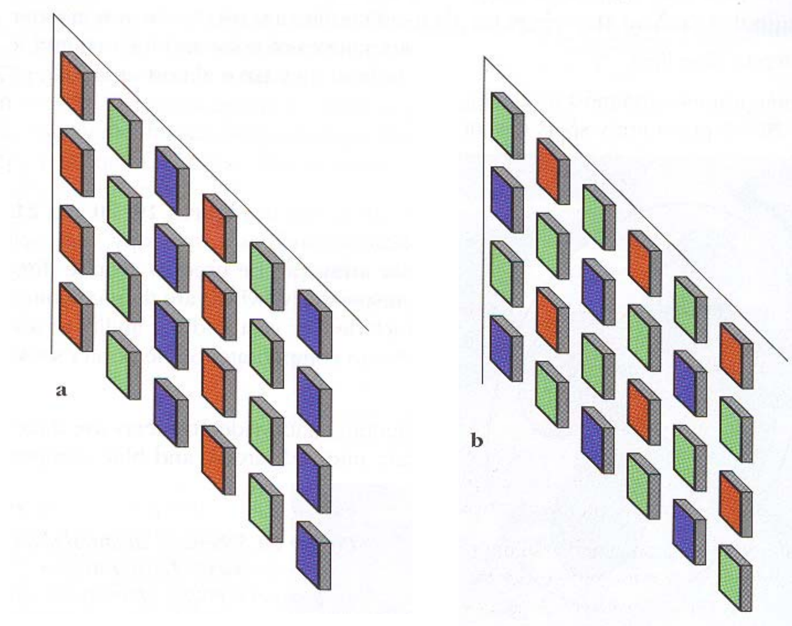
Acquisition of color images

Single sensor assembly
For still scenes





Three sensors
with prisms



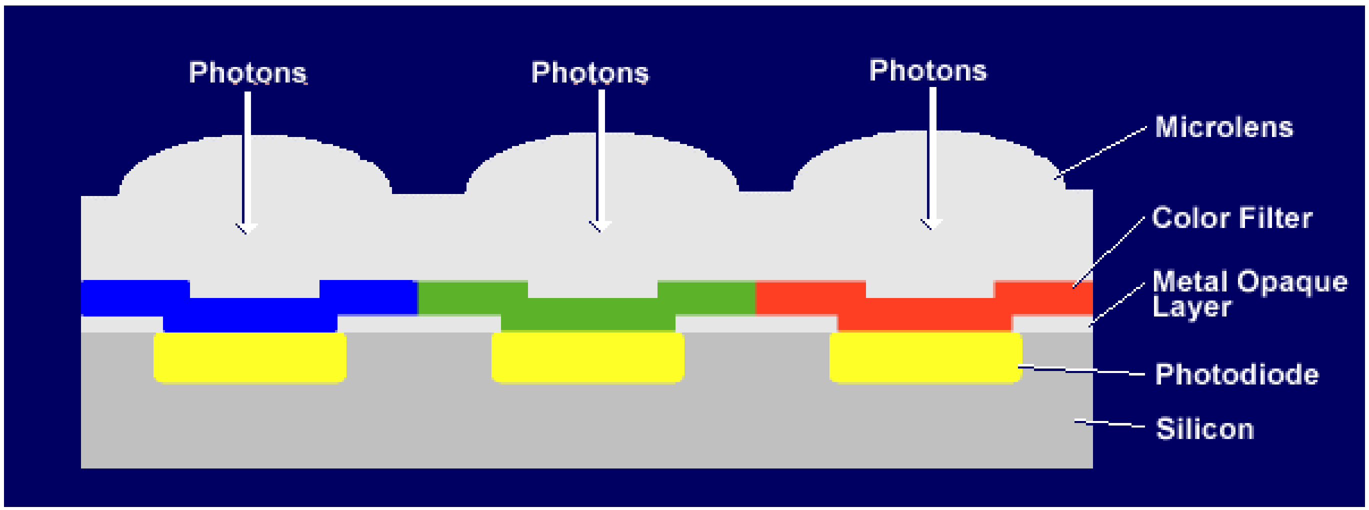
Sensor arrays

a. Stripe filter pattern

b. Bayers filter pattern

Acquisition of color images

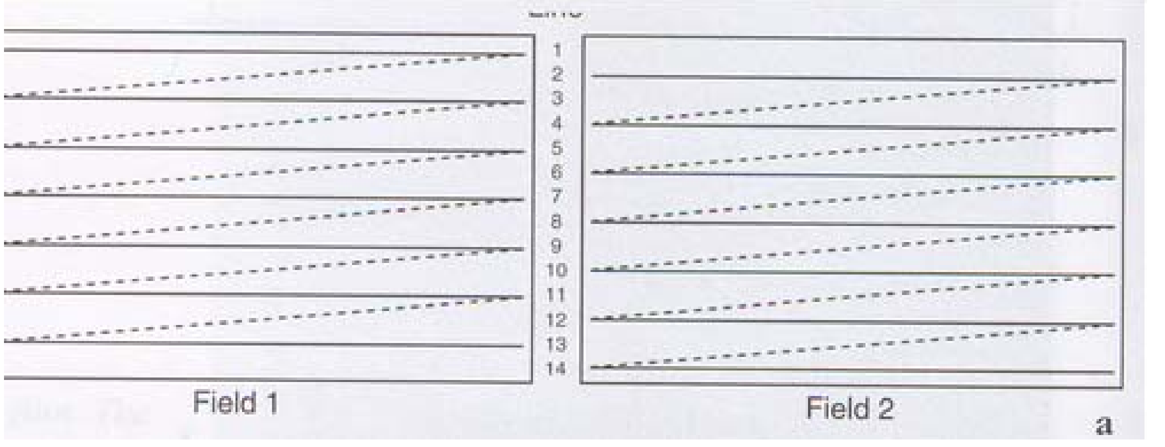
- Fabrication of CMOS colored sensors



Scanning Schemes

Interlaced scanning (used in TV)

- Read/display all even-numbered lines (even field, half-size)
- Restart
- Read/display all odd-numbered lines (odd field, half-size)
- Stitch the even and odd fields together and form a single, full-size frame
- Output the full-size frame



A typical Interlaced Scanning scheme

Interlaced scanning

When motion is present the interlaced scanning produces blurring in the image

Scanning Schemes

Progressive Scanning

- Immediately transfer an entire frame at once from the image sensor without performing any line-interlacing.
- Suitable for fast motion detection applications
- Incompatible with standard television systems.
- Popular in digital cameras (computer applications)

Basic relationships between pixels

Arrangement of pixels:

0	1	1
0	1	0
0	0	1

4 neighbours $N_4(p)$:

	1	
0	1	0
	0	

Diagonal neighbours $N_D(p)$:

0		1
	1	
0		1

8 neighbours $N_8(p) = N_D(p) \cup N_4(p)$:

0	1	1
0	1	0
0	0	1

Basic relationships between Pixels

- Connectivity between pixels:

  An important concept used in establishing boundaries of objects and components of regions

  Two pixels p and q are connected if

  – They are adjacent in some sense

  – If their gray levels satisfy a specified criterion of similarity

V: Set of gray level values used to define the criterion of similarity

4-connectivity: If gray-level p , q $\in V$, and q $\in$ N4(p)

8-connectivity: If gray-level p , q $\in V$, and q $\in$ N8(p)

m-connectivity (mixed connectivity):

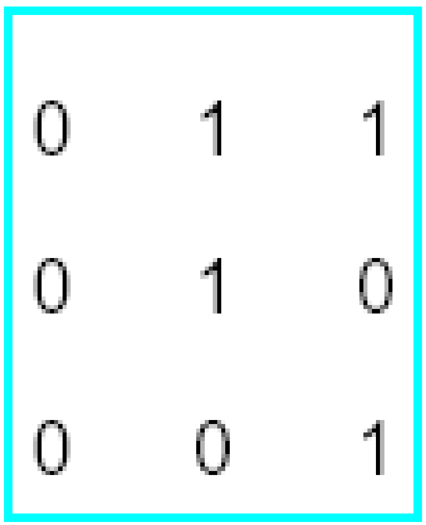
Gray-level p , q $\in V$, and q satisfies one of the following:

1) q $\in$ N4(p), 2) q $\in N_D(p)$ **and** $N_4(p) \cap N_4(q)$ has no values from V

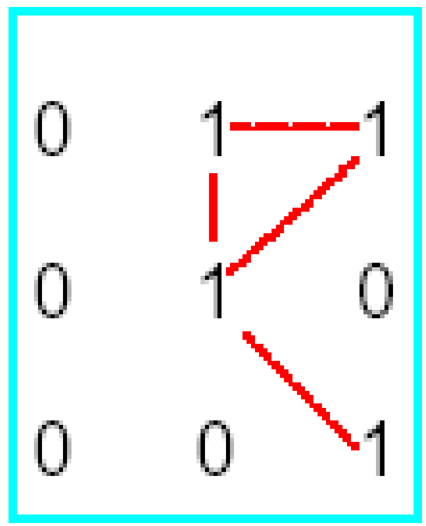
Basic relationships between pixels

Mixed Connectivity:

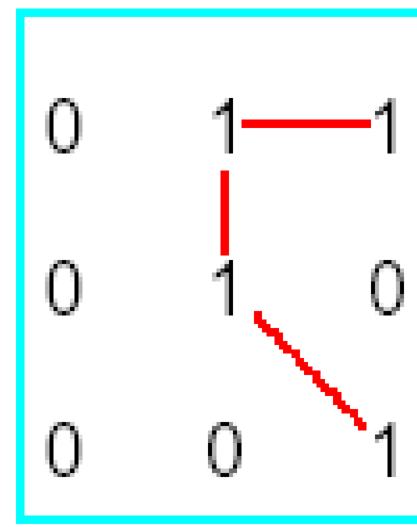
Note: Mixed connectivity can eliminate the multiple path connections that often occurs in 8-connectivity



Pixel arrangement



8-adjacent to the center pixel



m-adjacency

Basic relationships between pixels

Path

Let coordinates of pixel p: (x, y), and of pixel q: (s, t)

A *path* from p to q is a sequence of distinct pixels with coordinates: $(x_0, y_0), (x_1, y_1), \ldots\ldots, (x_n, y_n)$ where

$(x_0, y_0) = (x, y)$ & $(x_n, y_n) = (s, t)$,

and (x_i, y_i) is adjacent to (x_{i-1}, y_{i-1}) $1 \leq i \leq n$

Regions

A set of pixels in an image where all component pixels are connected

Boundary of a region

A set of pixels of a region R that have one of more neighbors that are not in R

Distance Measures

Given coordinates of pixels p, q, and z: (x,y), (s,t), and (u,v)

Euclidean distance between p and q:

$$D_e(p,q) = \sqrt{(x-s)^2 + (y-t)^2}$$

- *The pixels with D_e distance $\le r$ from (x,y) define a disk of radius* r *centered at* (x,y)

City-block distance between p and q:

$$D_4(p,q) = |x-s| + |y-t|$$

- *The pixels with D_4 distance $\le r$ from (x,y) form a diamond centered at* (x,y)
- *the pixels with D_4=1 are the 4-neighbors of (x,y)*

- Chessboard distance between p and q:

$$D_8(p,q) = \max(|x-s|, |y-t|)$$

- *The pixels with D_8 distance $\le r$ from (x,y) form a square centered at* (x,y)
- *The pixels with D_8=1 are the 8-neighbors of (x,y)*

Reading Assignment

- Chapters 1 and 2 of "*Digital Image Processing*" by Gonzalez.
- Chapter 2 of "*Digital Image Processing using MATLAB*" by Gonzalez.

Image Enhancement

Process an image to make the result more suitable than the original image for a specific application

- *Image enhancement is subjective (problem/application oriented)*

Image enhancement methods

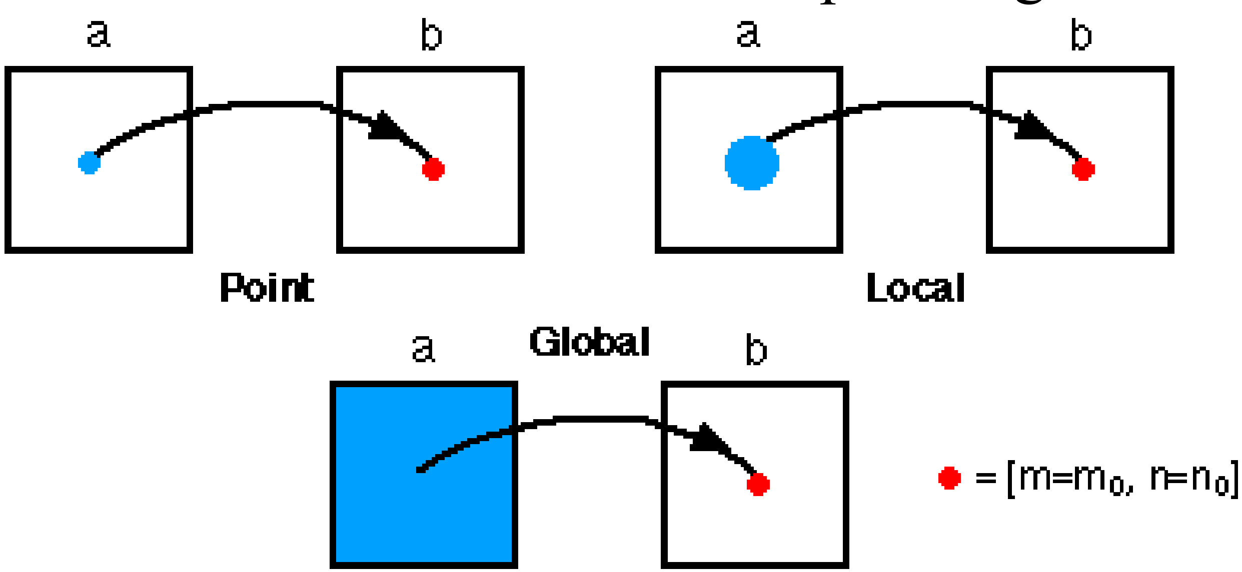
Spatial domain:	Direct manipulation of pixel in an image(on the image plane)
Frequency domain:	Processing the image based on modifying the Fourier transform of an image

Many techniques are based on various combinations of methods from these two categories

Image Enhancement

Types of image enhancement operations

Point/pixel operations	Output value at specific coordinates (x,y) is dependent only on the input value at (x,y)
Local operations	The output value at (x,y) is dependent on the input values in the *neighborhood* of (x,y)
Global operations	The output value at (x,y) is dependent on all the values in the input image



Basic concepts

Spatial domain enhancement methods can be generalized as

$$g(x,y)=T[f(x,y)]$$

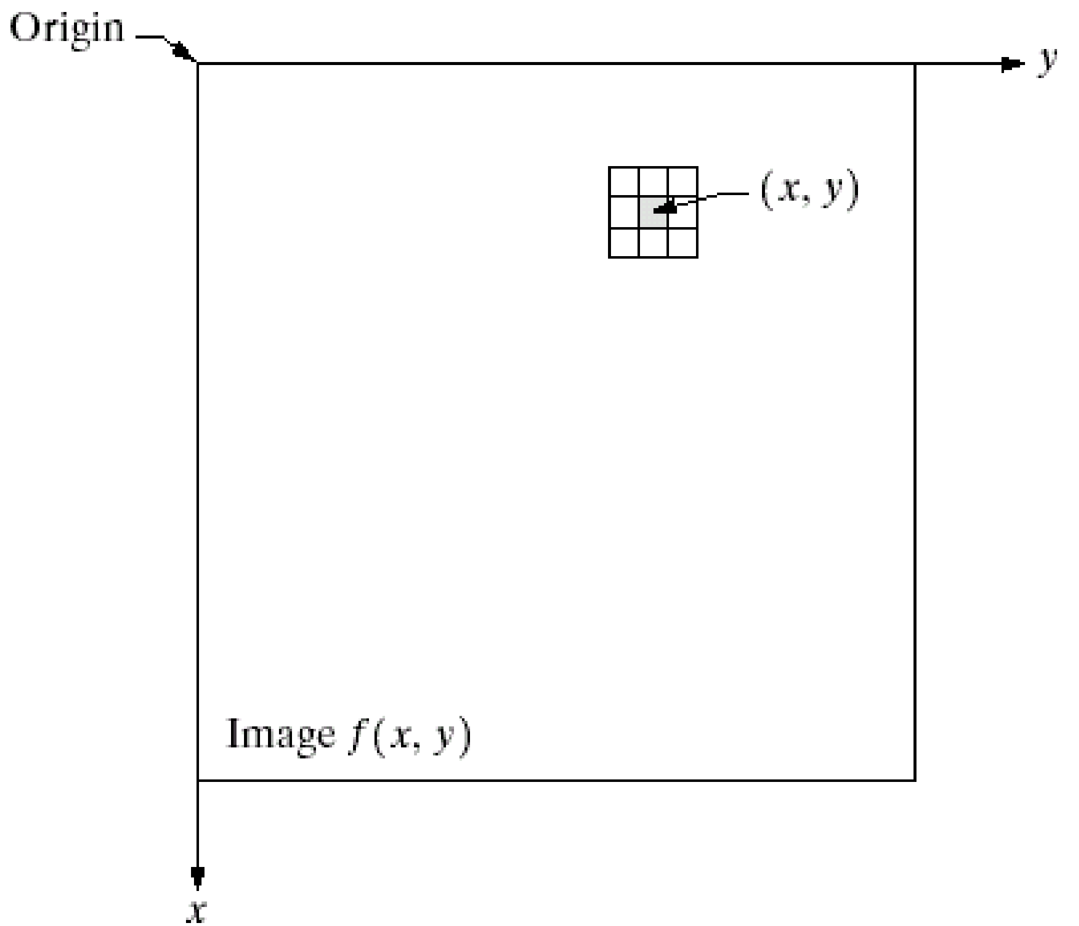
$f(x,y)$: input image

$g(x,y)$: processed (output) image

$T[*]$: an operator on f (or a set of input images), defined over neighborhood of (x,y)

Neighborhood about (x,y): a square or rectangular sub-image area centered at (x,y)

Basic Concepts



3x3 neighborhood about (x,y)

Basic concepts

$$g(x,y) = T\,[f(x,y)]$$

Pixel/point operation:

Neighborhood of size 1x1: g depends only on f at (x,y)

T: a gray-level/intensity transformation/mapping function

Let $r = f(x,y)$ $s = g(x,y)$

r and s represent gray levels of f and g at (x,y)

Then $s = T(r)$

Local operations:

g depends on the predefined number of neighbors of f at (x,y)

Implemented by using mask processing or filtering

Masks (filters, windows, kernels, templates) :

a small (e.g. 3×3) 2-D array, in which the values of the coefficients determine the nature of the process

Common pixel operations

- Image negatives
- Log transformations
- Power-law transformations

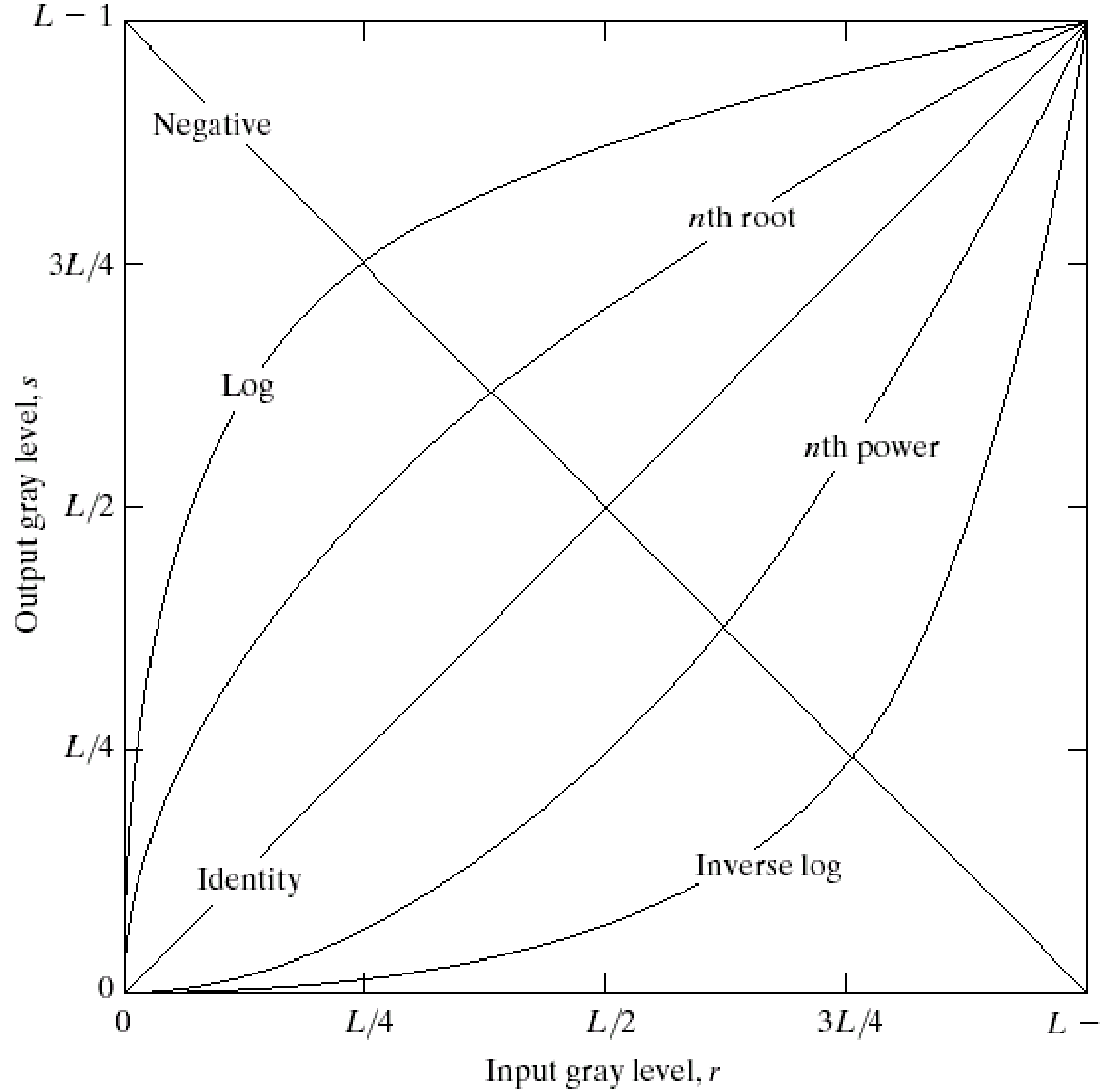


Image negatives

- Reverses the gray level order
- For L gray levels the transformation function is

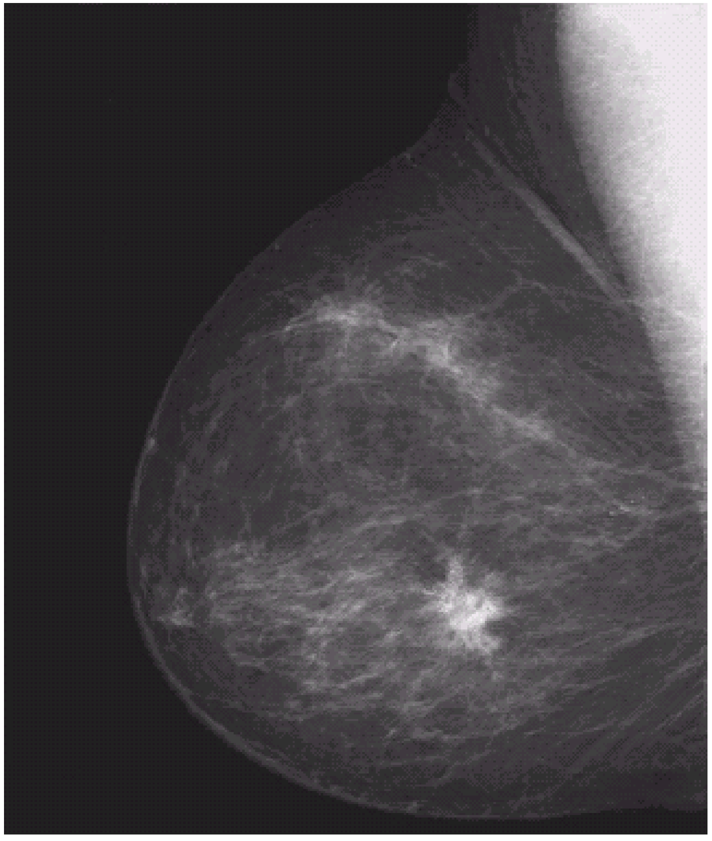
$$s = T(r) = (L-1)-r$$

Input image (X-ray image)

Output image (negative)

Image negatives

Application: To enhance the visibility for images with more dark portion



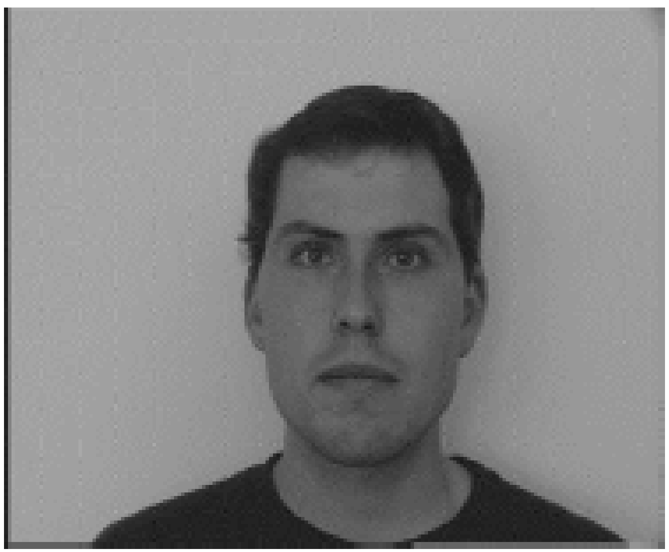
Original digital mammogram

Output image

Image scaling

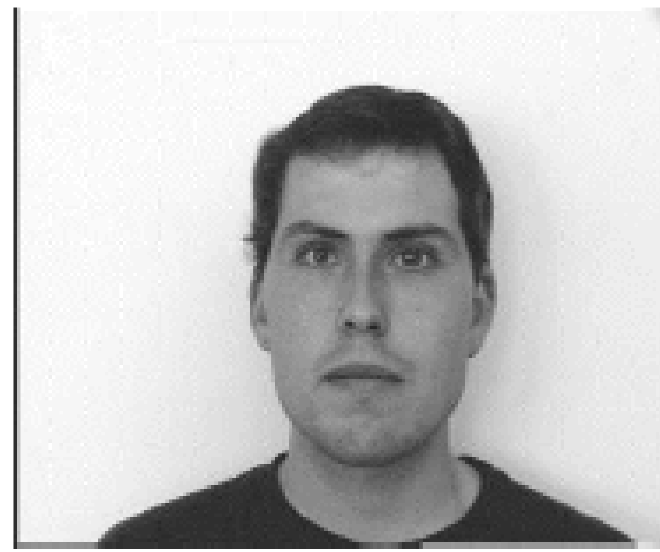
$s = T(r) = a.r$ (a is a constant)

Original image



$f(x,y)$

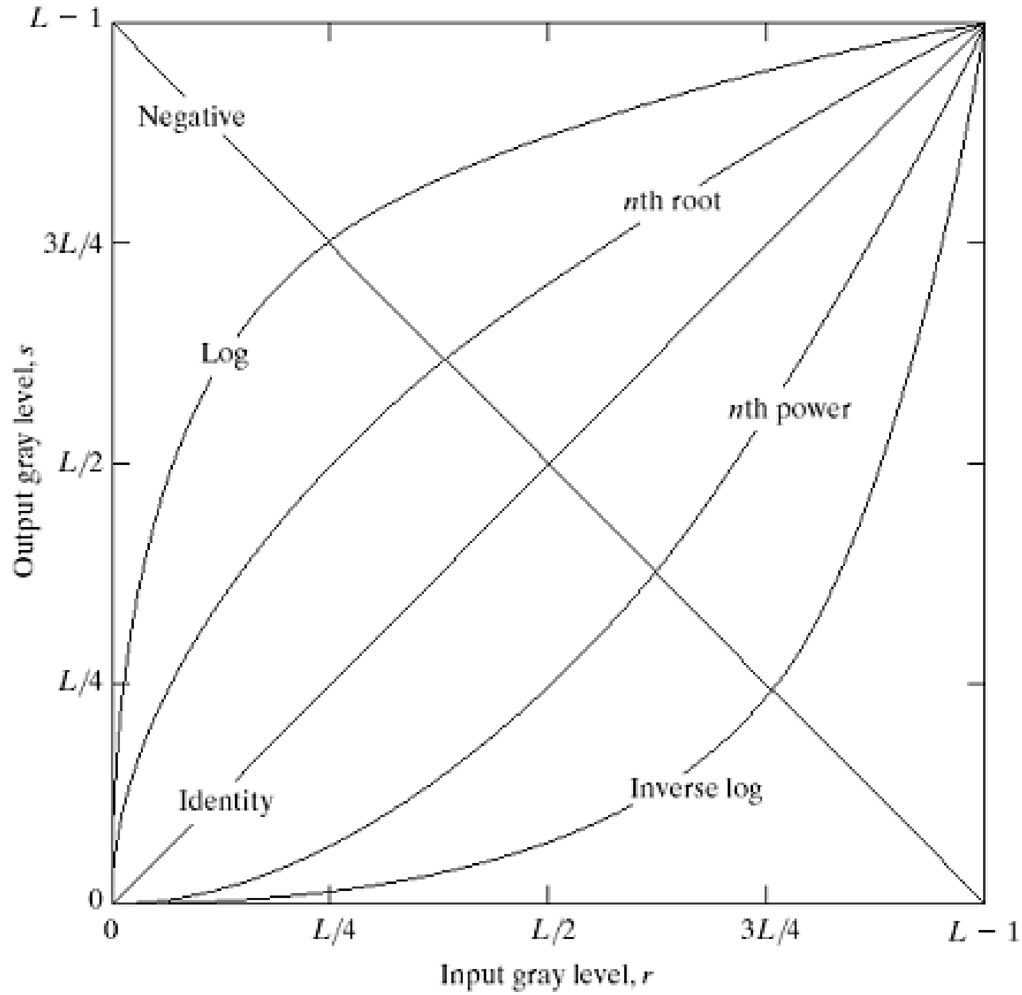
Scaled image



$a \cdot f(x,y)$

Log transformations

Function of $s = c\ \mathrm{Log}(1+r)$



Log transformations

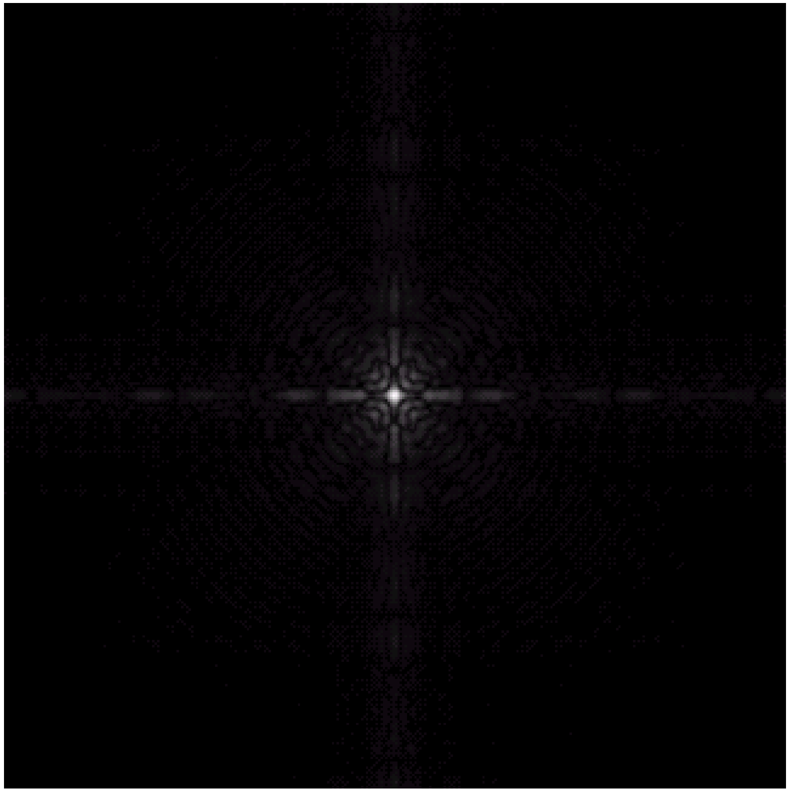
Properties of log transformations

- *For lower amplitudes of input image the range of gray levels is expanded*
- *For higher amplitudes of input image the range of gray levels is compressed*

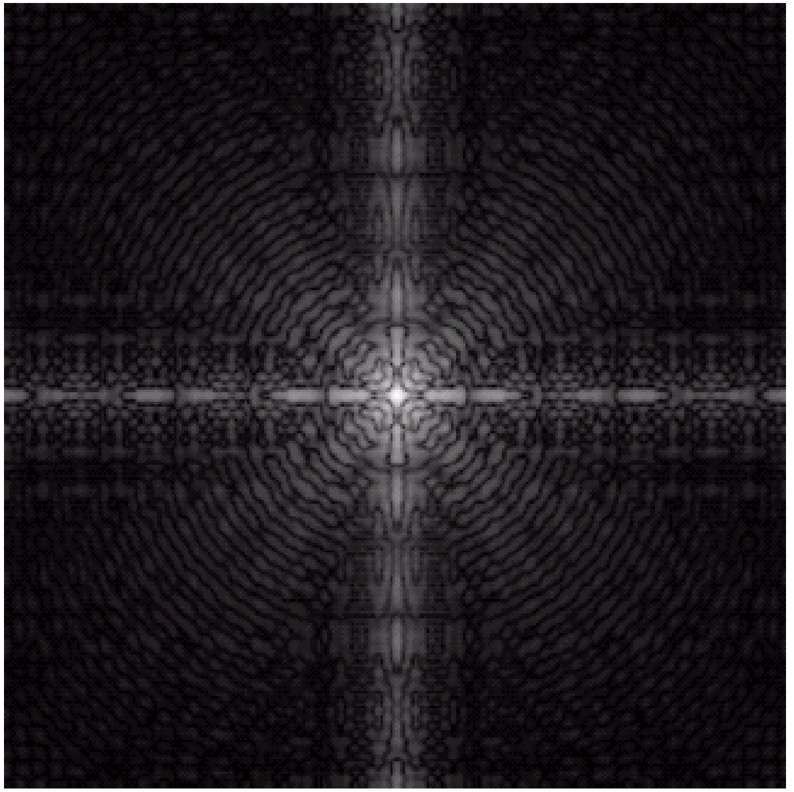
Application:

- *This transformation is suitable for the case when the dynamic range of a processed image far exceeds the capability of the display device (e.g. display of the Fourier spectrum of an image)*
- *Also called "dynamic-range compression / expansion"*

Log transformations



Fourier spectrum with values of range 0 to 1.5×10^6 scaled linearly



The result applying log transformation, $c = 1$

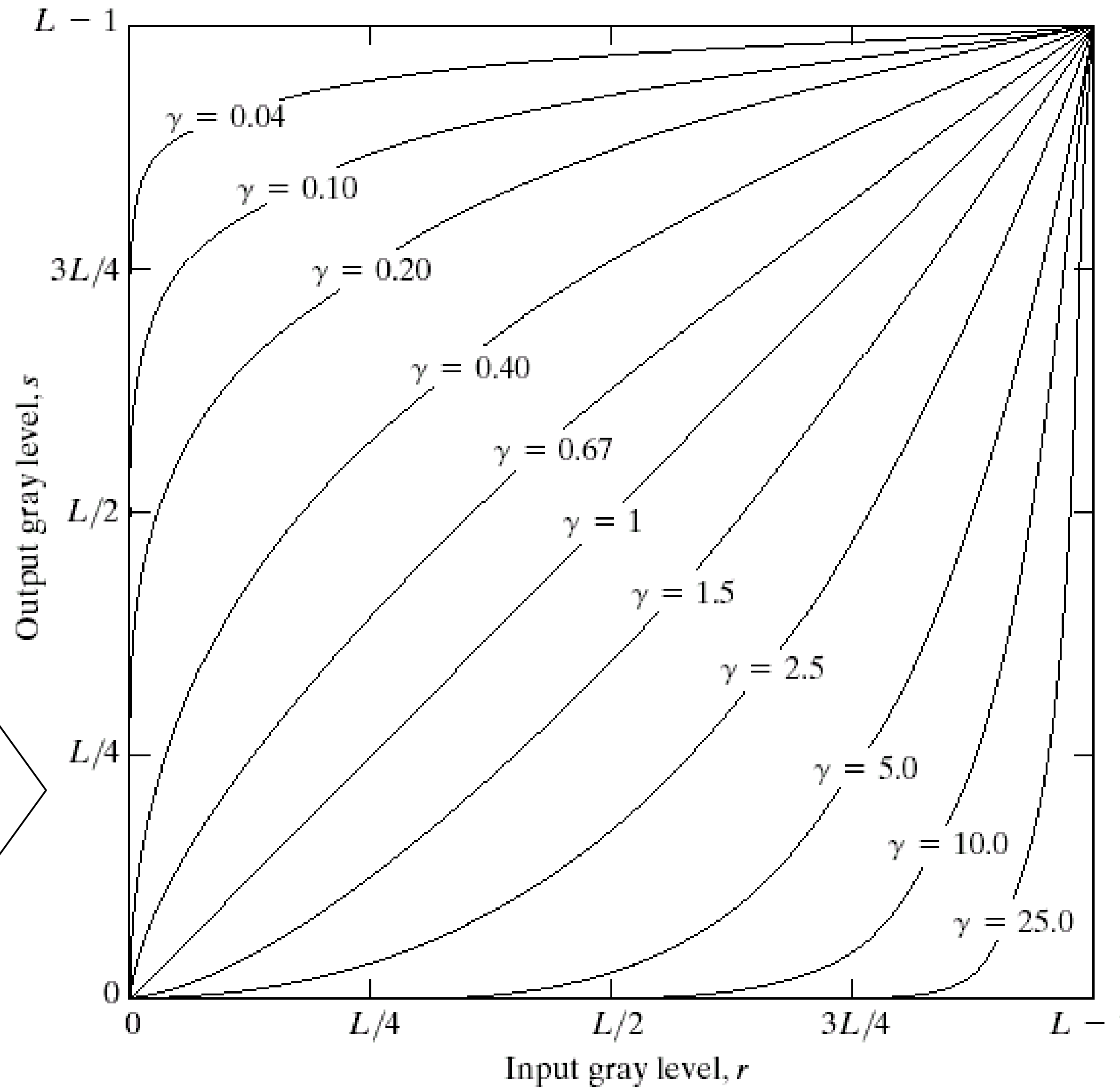
Power-law Transformation

Basic form:

$$s = cr^{\gamma} \; ,$$

where c & γ are positive

Plots of equation
$s = cr^{\gamma}$,
For various values of γ
(c = 1)



Power-law Transformation

For $\gamma < 1$: Expands values of dark pixels, compress values of brighter pixels

For $\gamma > 1$: Compresses values of dark pixels, expand values of brighter pixels

If γ=1 & c=1: Identity transformation ($s = r$)

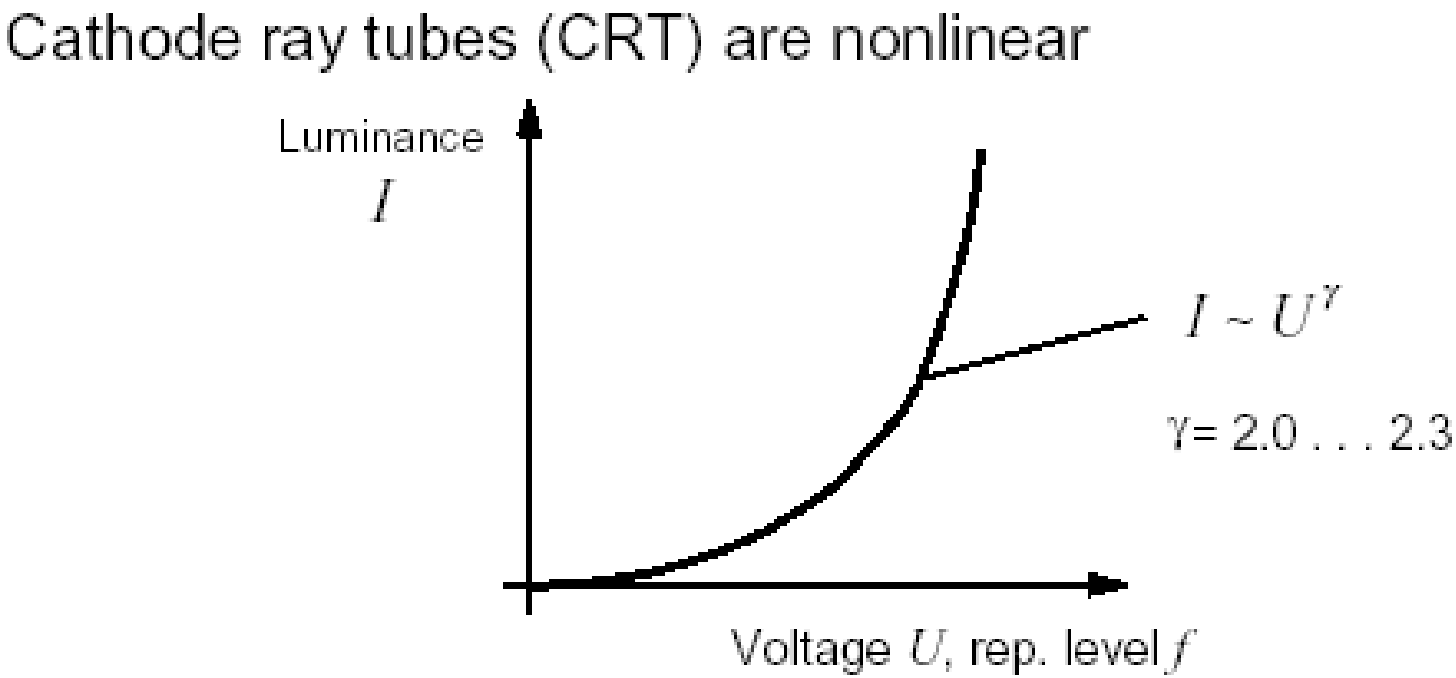
A variety of devices (image capture, printing, display) respond according to a power law and need to be corrected;

Gamma (γ) correction

The process used to correct the power-law response phenomena

Power-law Transformation

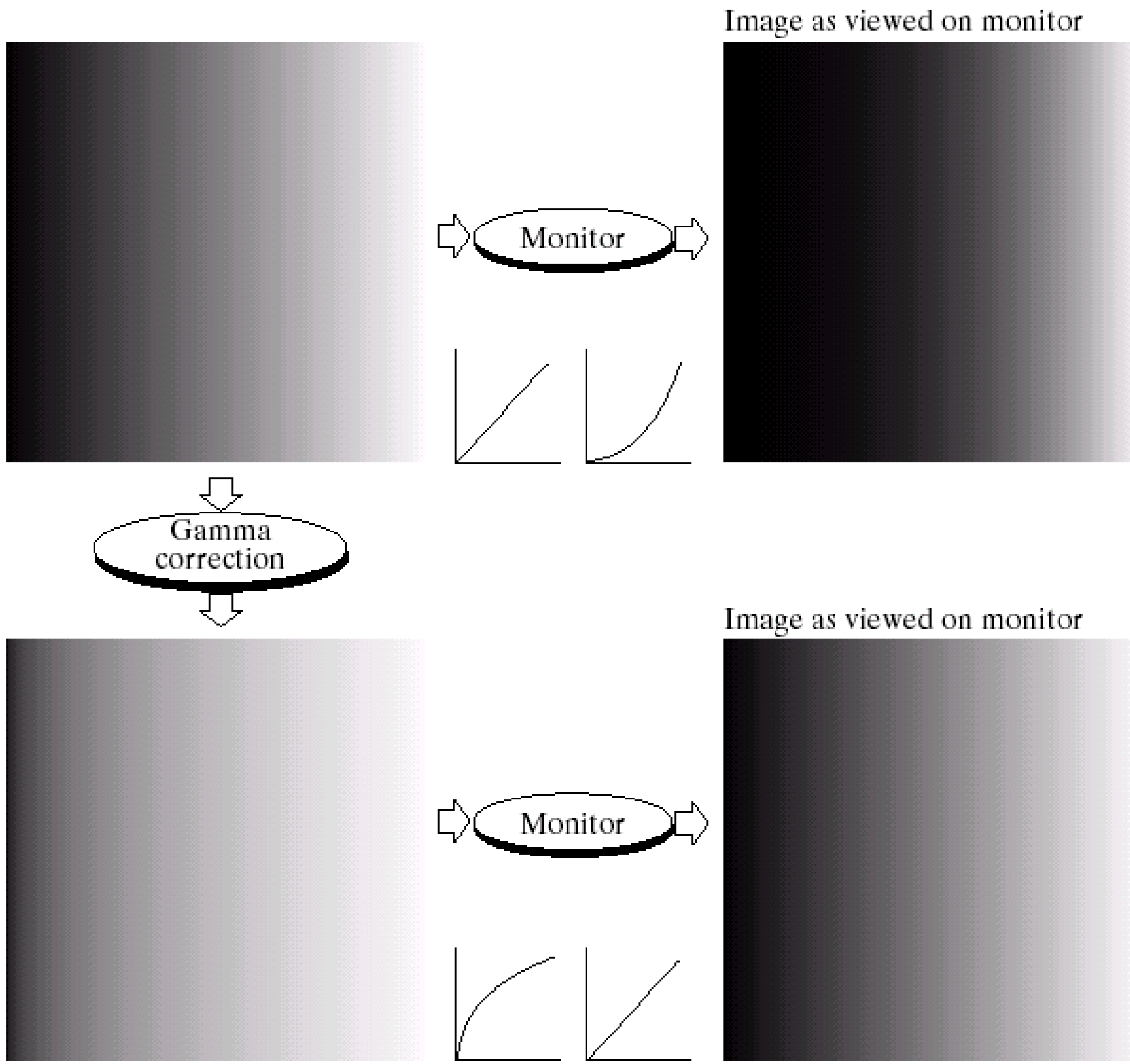
- Example of gamma correction



- To linearize the CRT response a pre-distortion circuit is needed $s = cr^{1/\gamma}$

Gamma correction

Linear wedge gray scale image



Response of CRT to Linear wedge

Gamma corrected wedge

Output of monitor

Power-law Transformation: Example

MRI image of fractured human spine

Result of applying power-law transformation

$c = 1, \gamma = 0.6$

Result of applying power-law transformation

$c = 1, \gamma = 0.4$

Result of applying power-law transformation

$c = 1, \gamma = 0.3$

Power-law Transformation: Example

Original satellite image

Result of applying power-law transformation

c = 1, $\gamma = 3.0$

Result of applying power-law transformation

c = 1, $\gamma = 4.0$

Result of applying power-law transformation

c = 1, $\gamma = 5.0$

Piecewise-linear transformation

Contrast stretching

Goal:

Increase the dynamic range of the gray levels for low contrast images

Low-contrast images can result from

- *poor illumination*
- *lack of dynamic range in the imaging sensor*
- *wrong setting of a lens aperture during image acquisition*

Piecewise-linear transformation: contrast stretching

Method

$$s = T(r) = \begin{cases} a_1 r, \ 0 \le r < r_1 & s_1 = T(r_1) \\ a_2(r - r_1) + s_1, \ r_1 \le r < r_2 & s_2 = T(r_2) \\ a_3(r - r_2) + s_2, \ r_2 \le r \le (L-1) & \end{cases}$$

where a_1, a_2, and a_3 control the result of contrast stretching

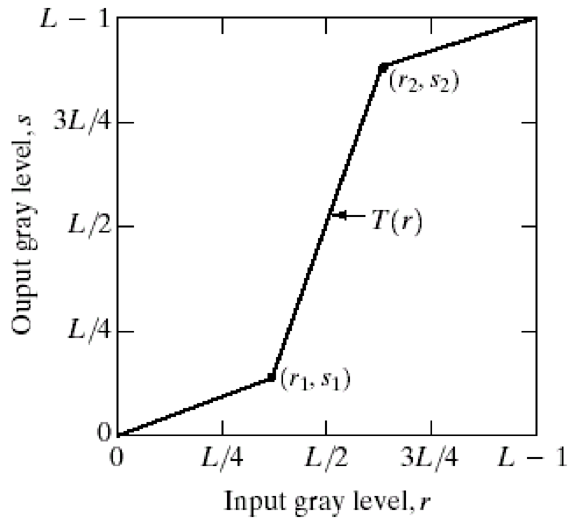
if $a_1 = a_2 = a_3 = 1$ no change in gray levels

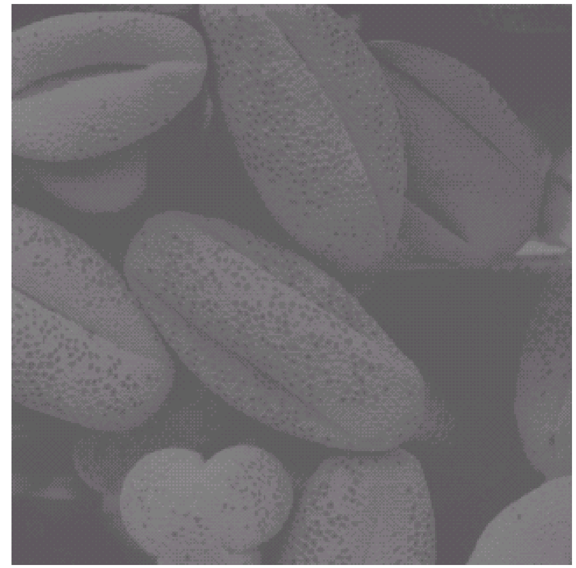
if $a_1 = a_3 = 0$ and $r_1 = r_2$, $T(*)$ is a thresholding function,

the result is a binary image

Contrast Stretching Example

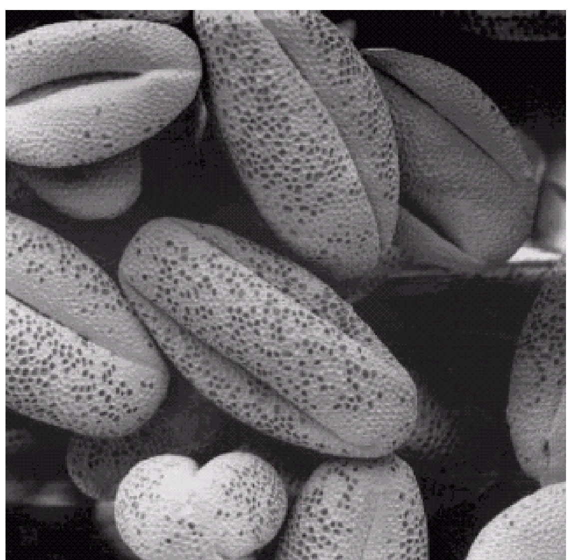
Form of Transformation function





Original low-contrast image

Result of contrast stretching



Result of thresholding