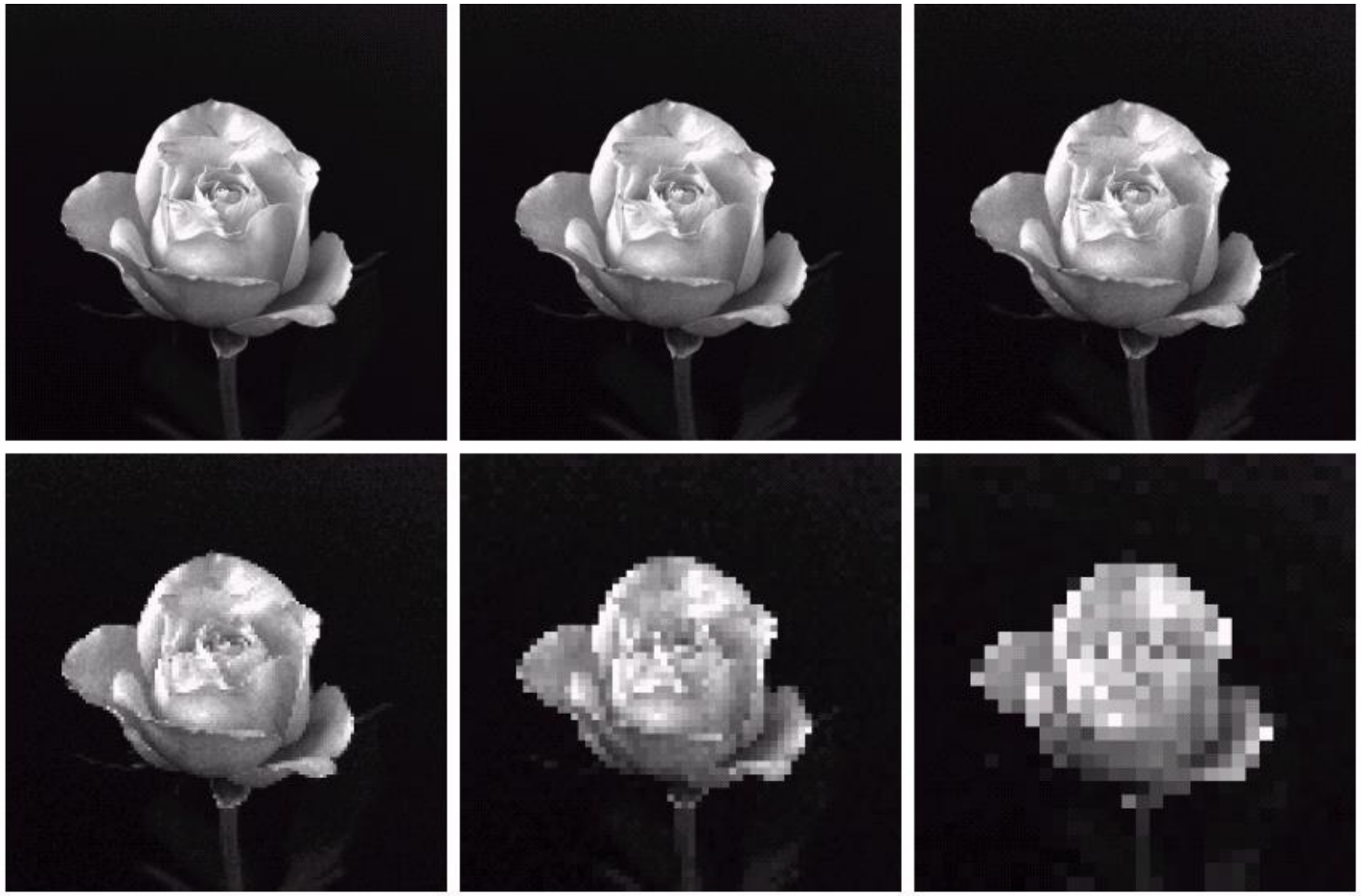
Digital Image Processing

Lecture # 2
Fundamentals & Image Enhancement

Spatial Resolution

Spatial Resolution



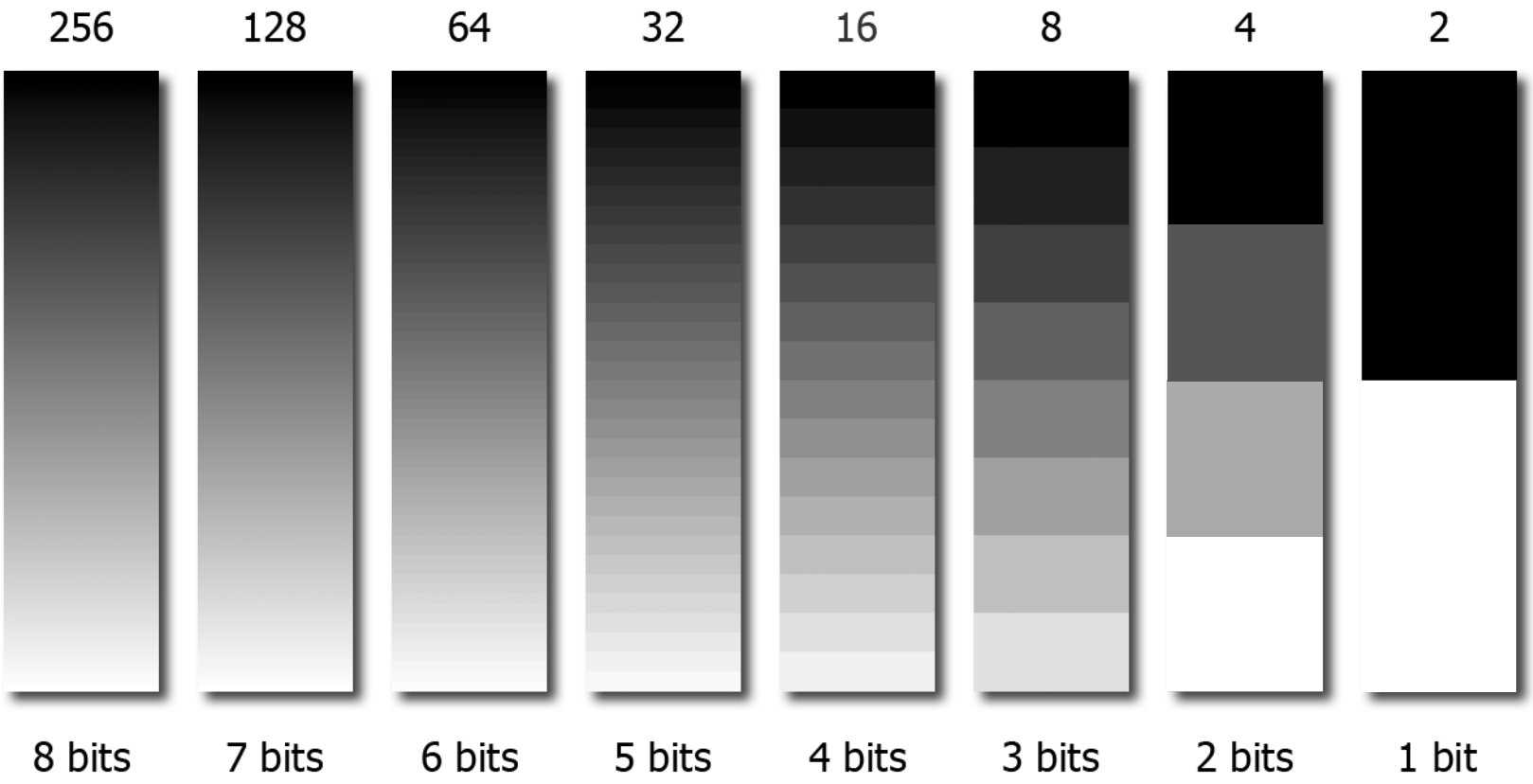
Intensity Level Resolution

- *Intensity level resolution* refers to the number of intensity levels used to represent the image
  - The more intensity levels used, the finer the level of detail in an image
  - Intensity level resolution is usually given in terms of the number of bits used to store each intensity level

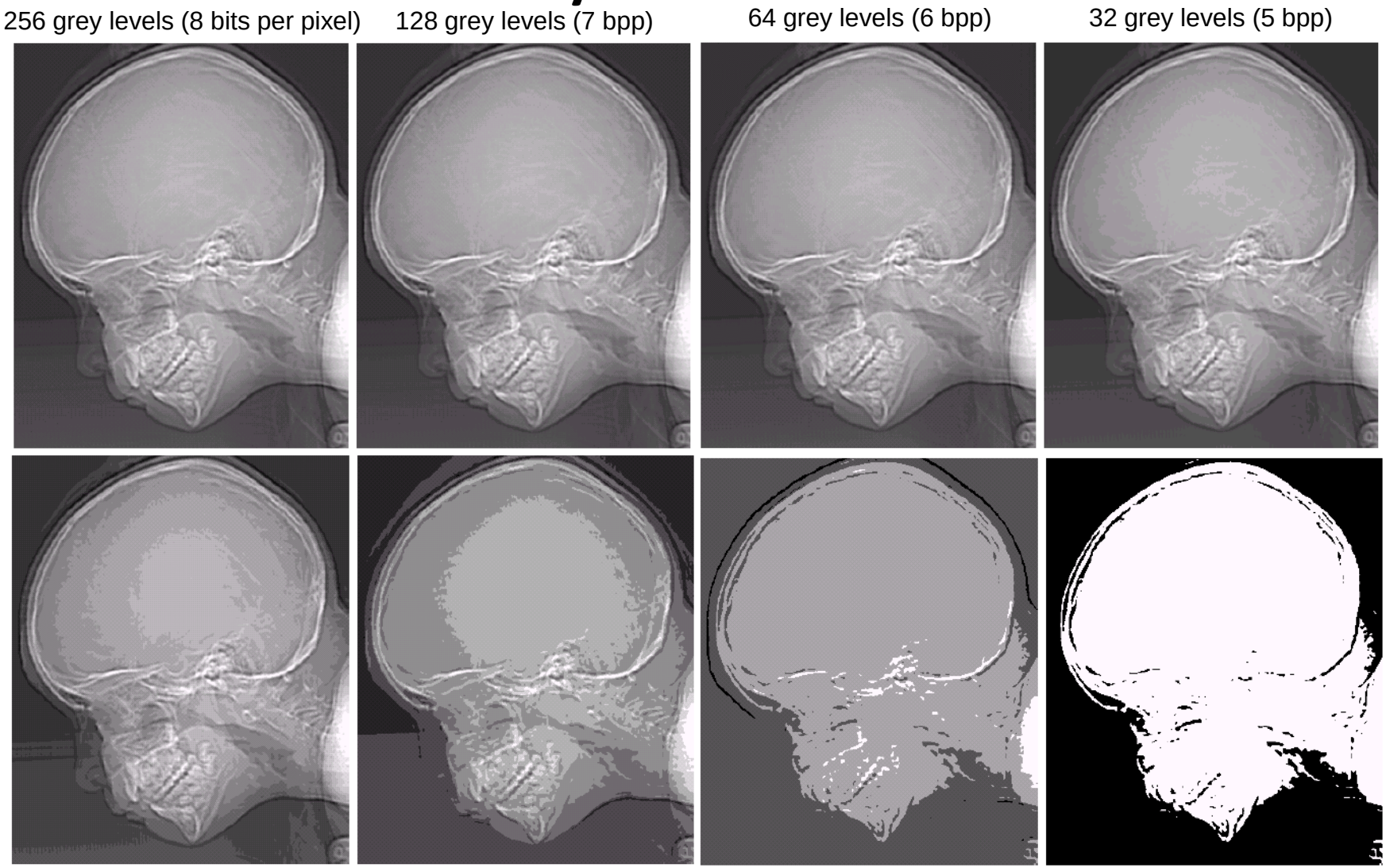
Intensity Level Resolution

Number of Bits	Number of Intensity Levels	Examples
1	2	0, 1
2	4	00, 01, 10, 11
4	16	0000, 0101, 1111
8	256	00110011, 01010101
16	65,536	1010101010101010

Intensity Level Resolution



Intensity Level Resolution



Resolution: How much is enough?

- How many samples and gray levels are required for a good approximation?
  - Quality of an image depends on number of pixels and gray-level number
  - The more these parameters are increased, the closer the digitized array approximates the original image
  - But: Storage & processing requirements increase rapidly as a function of N, M, and k

Resolution: How much is enough?

- Depends on what is in the image and what you would like to do with it

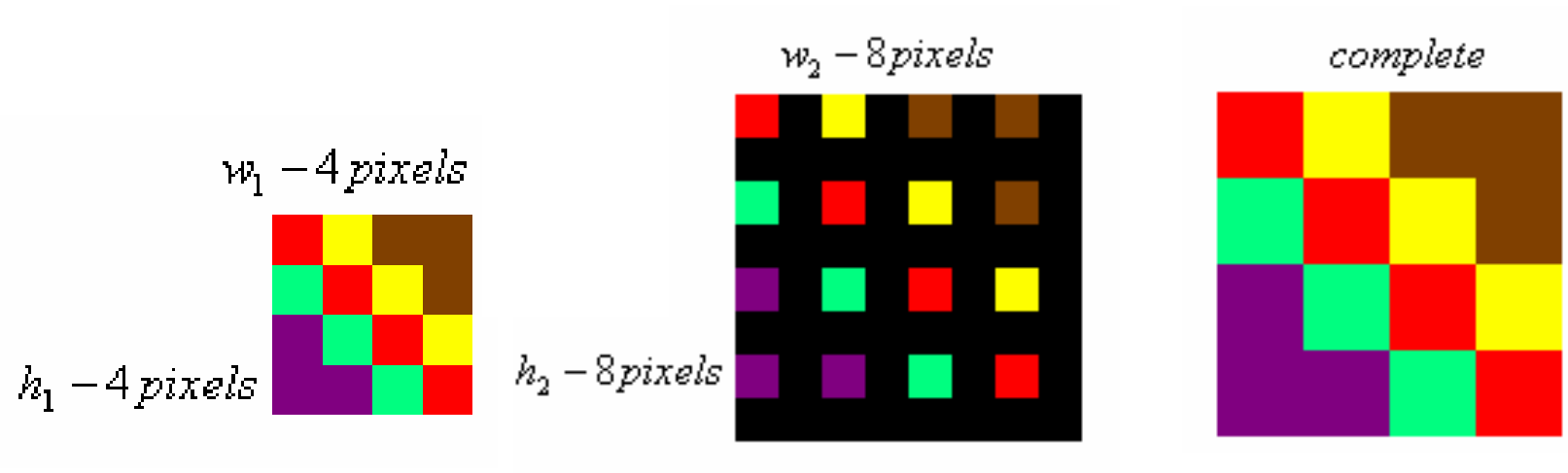
Image Resizing

- Pixel replication

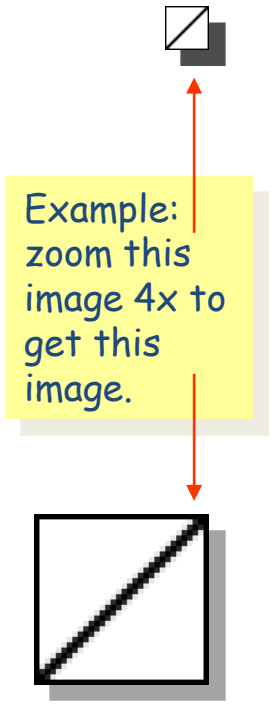
[1 2 3 4 5]

[1 1 2 2 3 3 4 4 5 5] (One step)

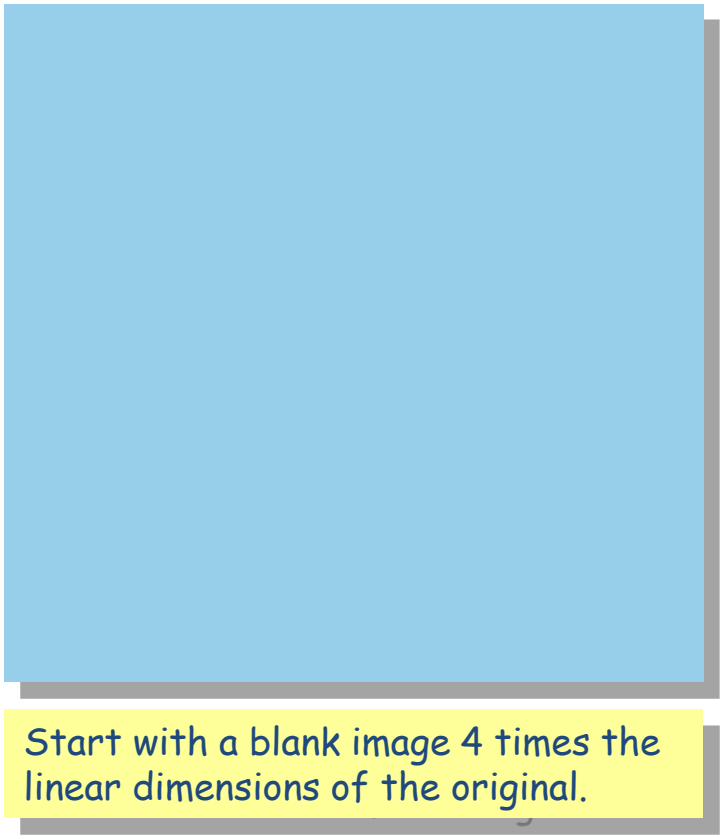
[1 1 1 2 2 2 3 3 3 4 4 4 5 5 5] (Two step)



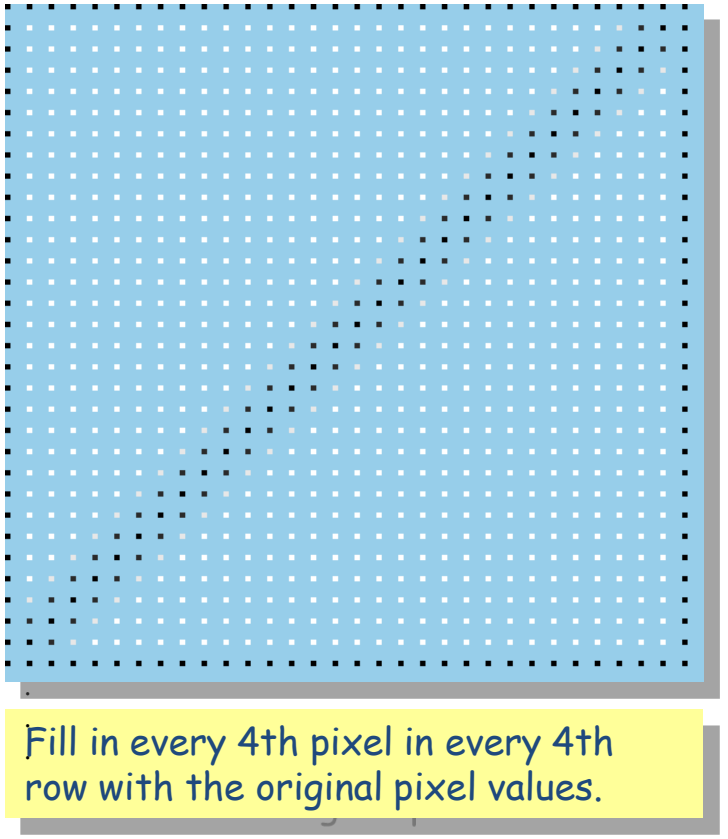
Enlarging an Image



Example: zoom this image 4x to get this image.

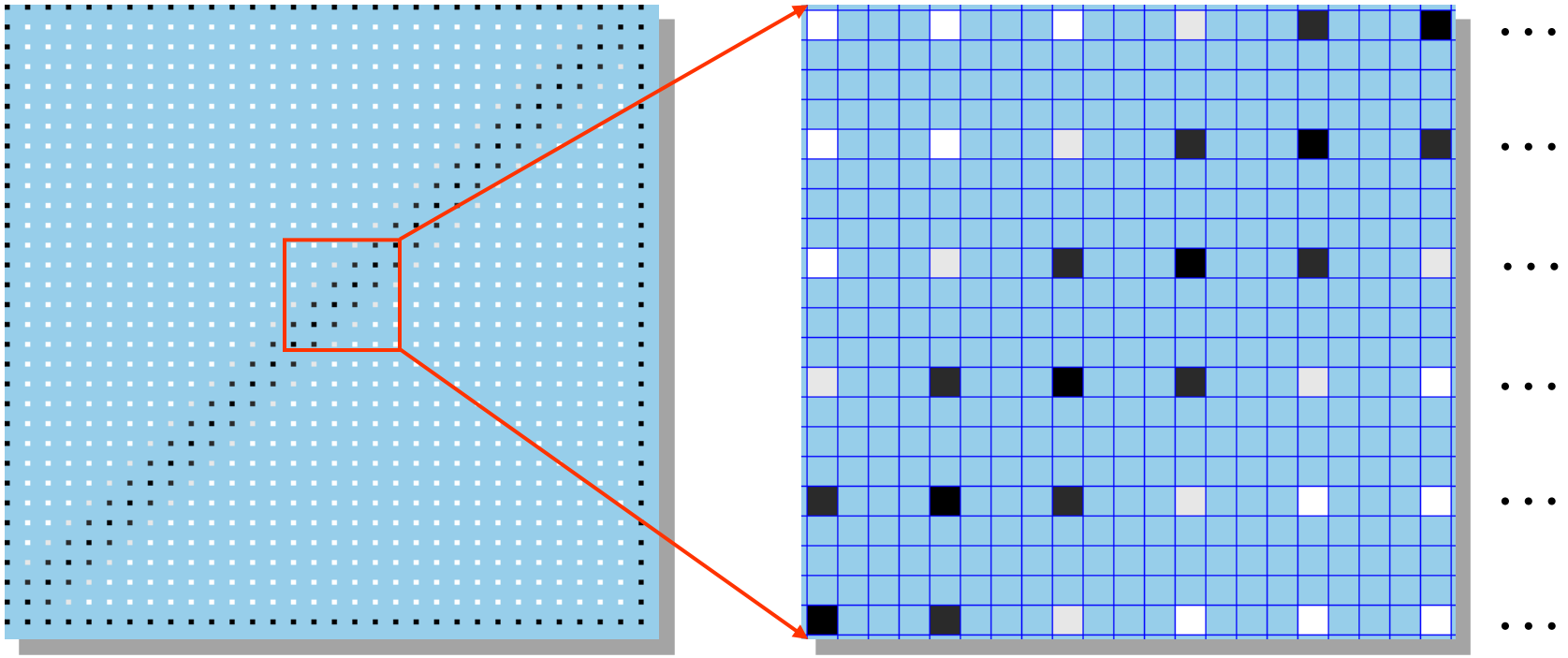


Start with a blank image 4 times the linear dimensions of the original.



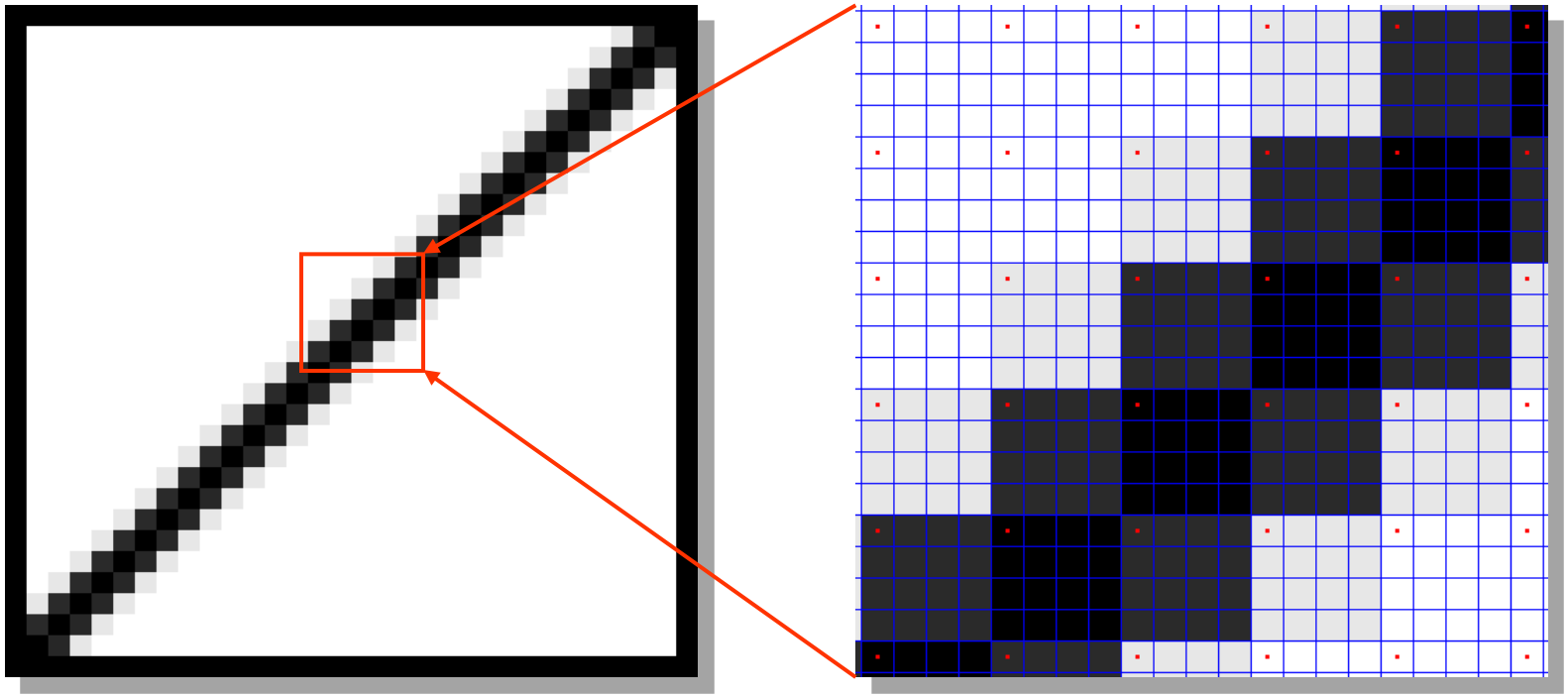
Fill in every 4th pixel in every 4th row with the original pixel values.

Enlarging an Image



Detail showing every 4th pixel in every 4th row with the original pixel values.

Enlarging an Image



Replicate the values

Image Interpolation

- Nearest neighbour interpolation
  - Simple but produces undesired artefacts
- Bilinear Interpolation
  - Contribution from 4 neighbors
- Bicubic Interpolation
  - Contribution from 16 neighbors

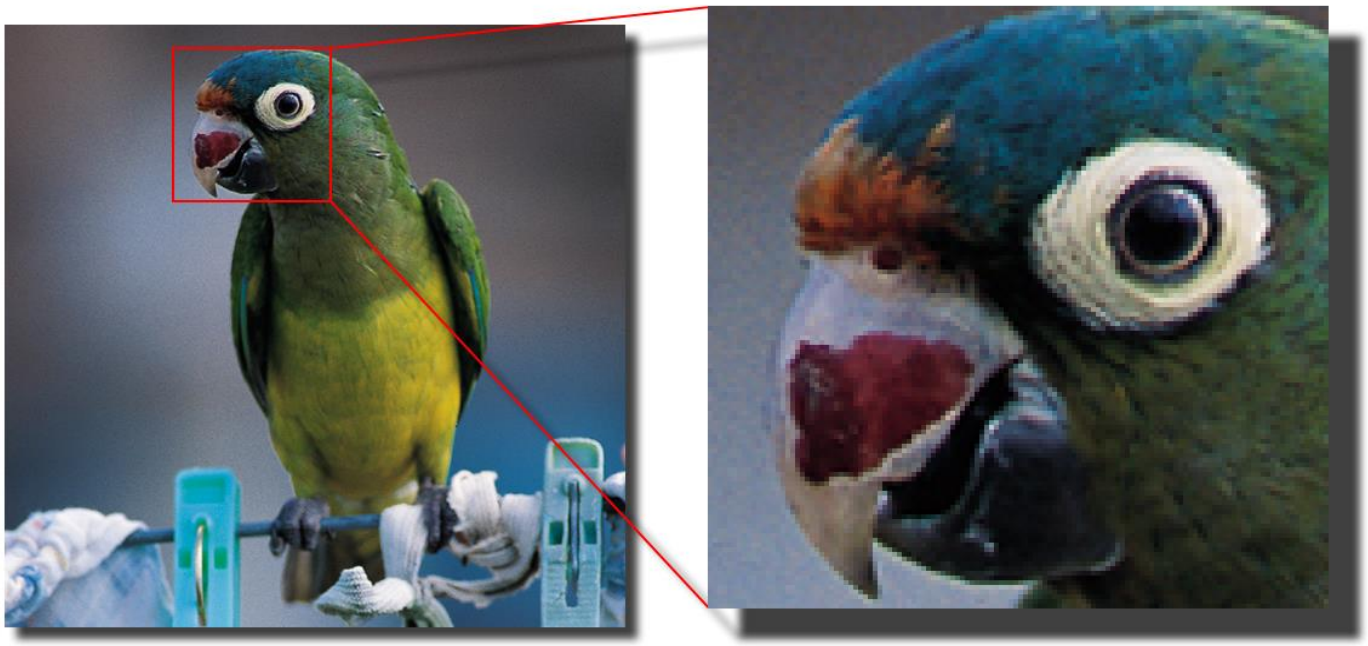
Interpolation: Comparison

We'll enlarge this image by a factor of 4 …

… via bilinear interpolation and compare it to a nearest neighbor enlargement.

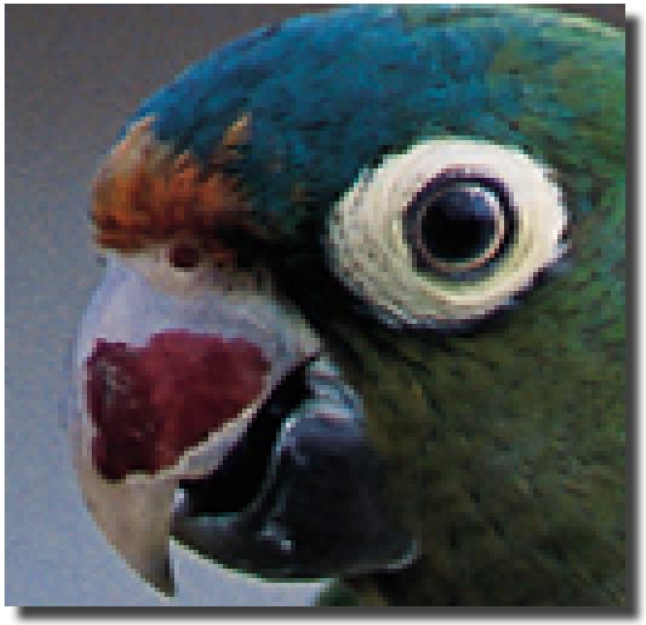
Interpolation: Comparison

Original Image



To better see what happens, we'll look at the parrot's eye.

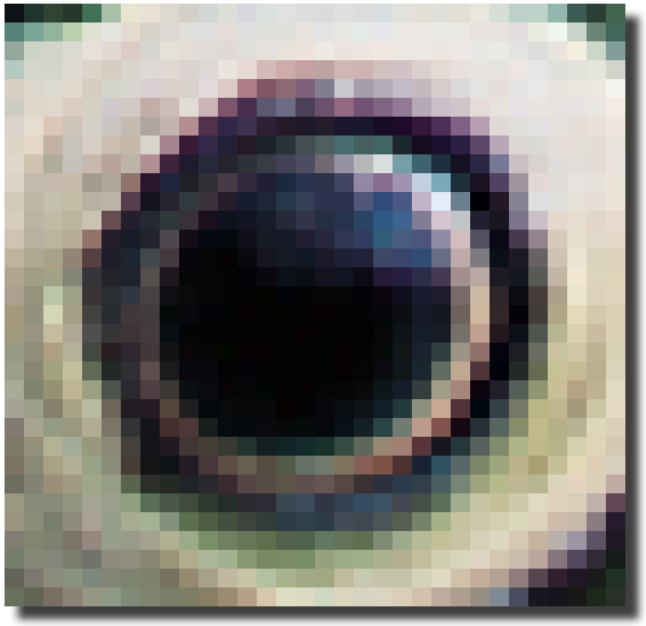
Interpolation: Comparison



Pixel replication

Bilinear interpolation

Interpolation: Comparison

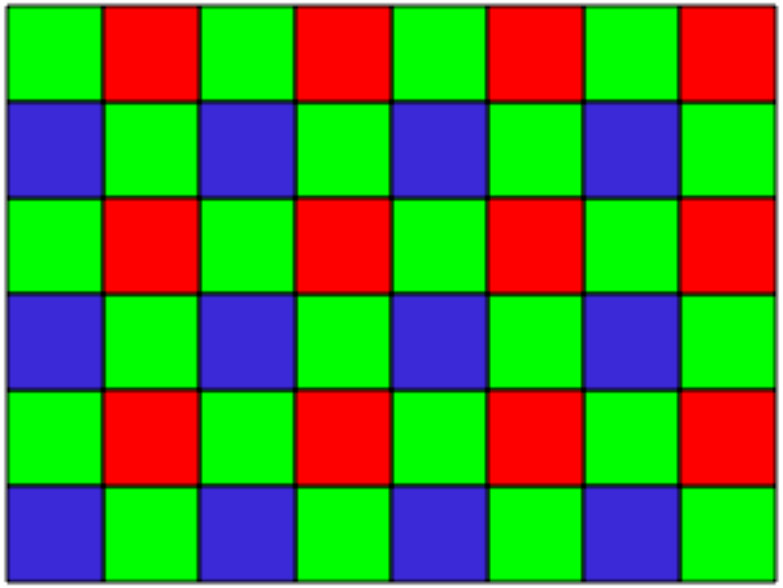


Pixel replication

Bilinear interpolation

Bayer RGB mosaic

- Each photosite has a different color filter

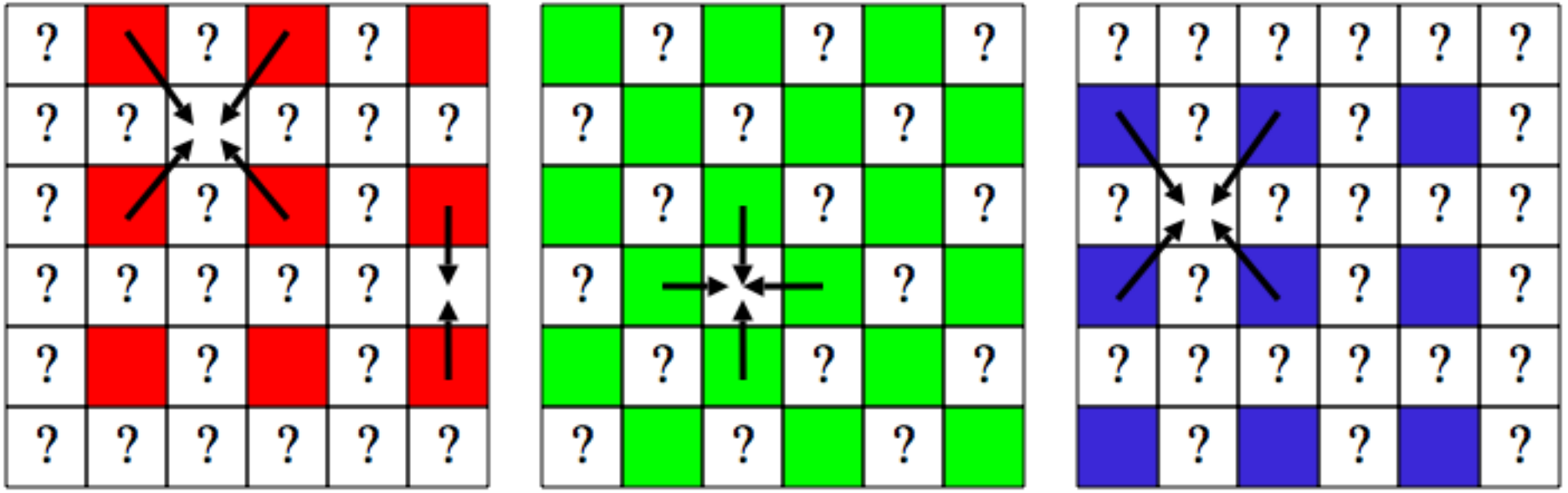


Demosaicing

- Interpolate missing values

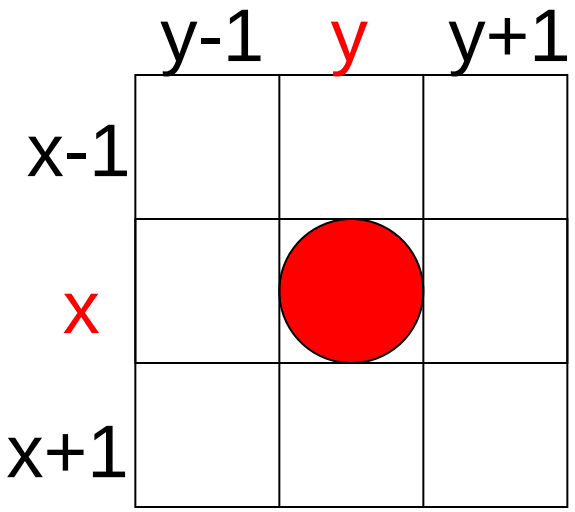
Linear interpolation

- Average of the 4 or 2 nearest neighbors
  - Linear (tent) kernel
- Smoother kernels can also be used (e.g. bicubic) but need wider support



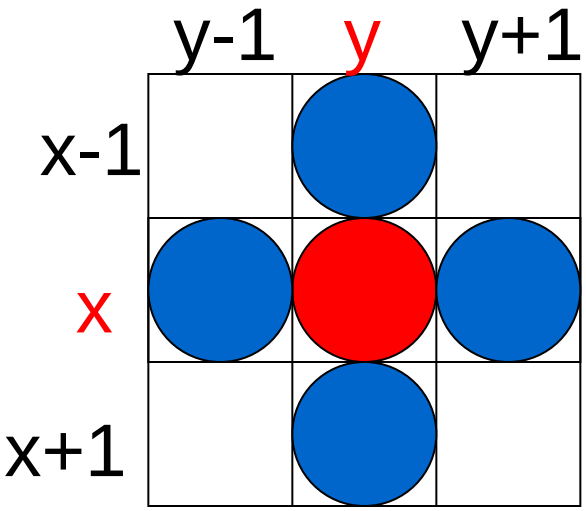
Relationships between pixels

- Neighbors of pixel are the pixels that are adjacent pixels of an identified pixel



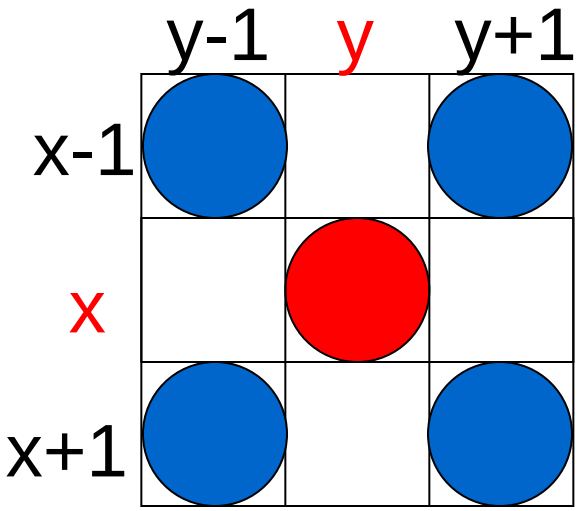
4- Neighbors of a Pixel –$N_4(p)$

What are the coordinates of each of the blue pixels



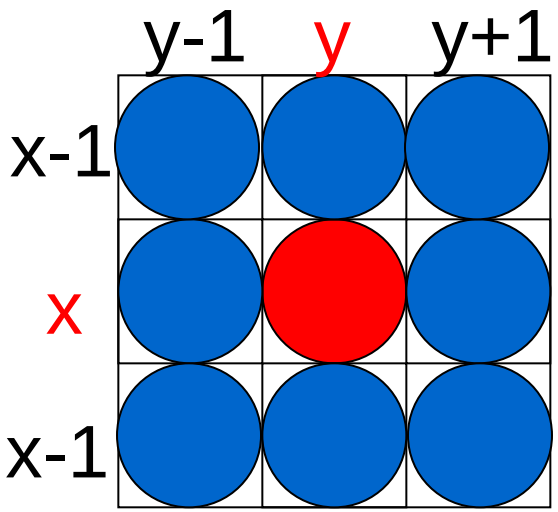
(x-1,y), (x+1,y), (x, y-1), (x, y+1)

Diagonal Neighbors of a Pixel –$N_D(p)$



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

8- Neighbors of a Pixel –$N_8(p)$

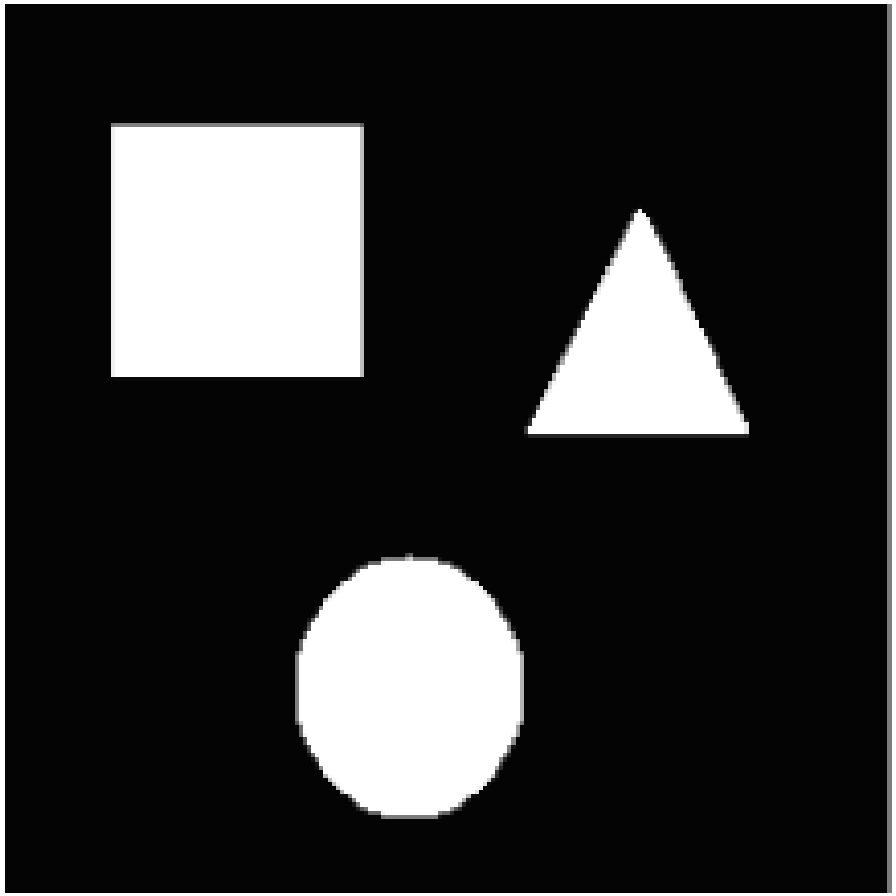


$$N_8(p) = N_4(p) \cup N_D(p)$$

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

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

Determine different regions in the image



Connectivity

- Establishing boundaries of objects and components in an image
- Group the same region by assumption that the pixels being the same color or equal intensity
- Two pixels p & q are connected if
  - *They are adjacent in some sense*
  - *If their gray levels satisfy a specified criterion of similarity*

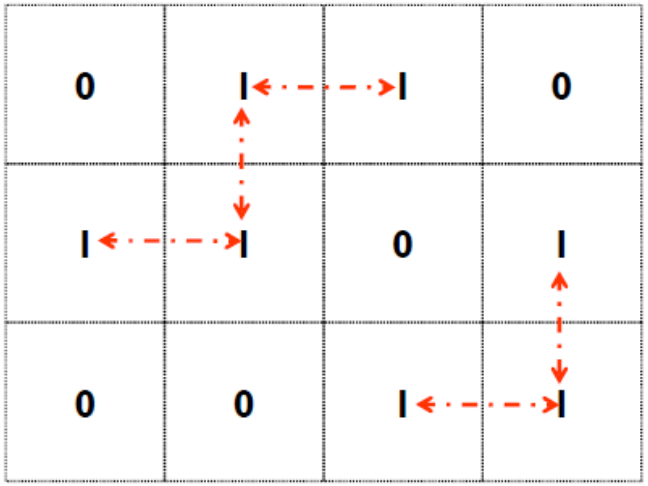
Connectivity

V: Set of gray levels used to define the criterion of similarity

4-connectivity

If gray level $(p,q) \in V, and\ q \in N_4(p)$

Set of gray levels V = {1}



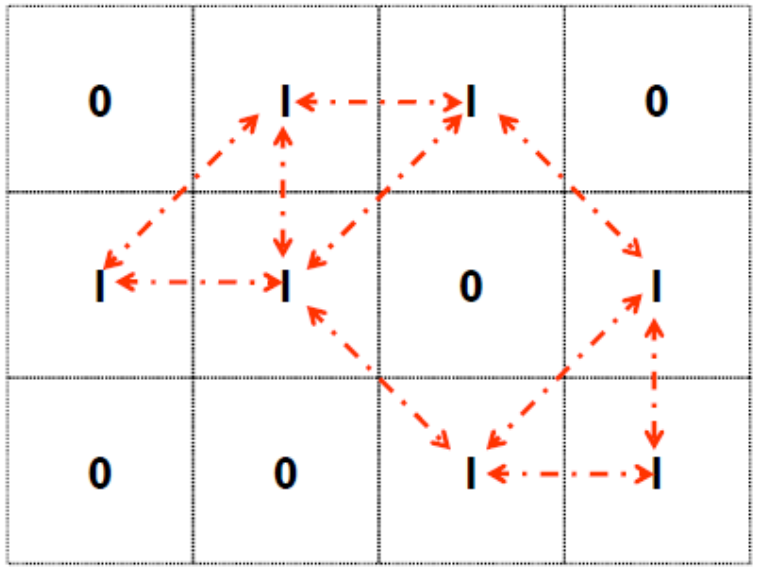
Connectivity

V: Set of gray levels used to define the criterion of similarity

8-connectivity

If gray level $(p,q) \in V, and\ q \in N_8(p)$

Set of gray levels V = {1}



Connectivity

V: Set of gray levels used to define the criterion of similarity

m-connectivity (Mixed Connectivity)

If gray level

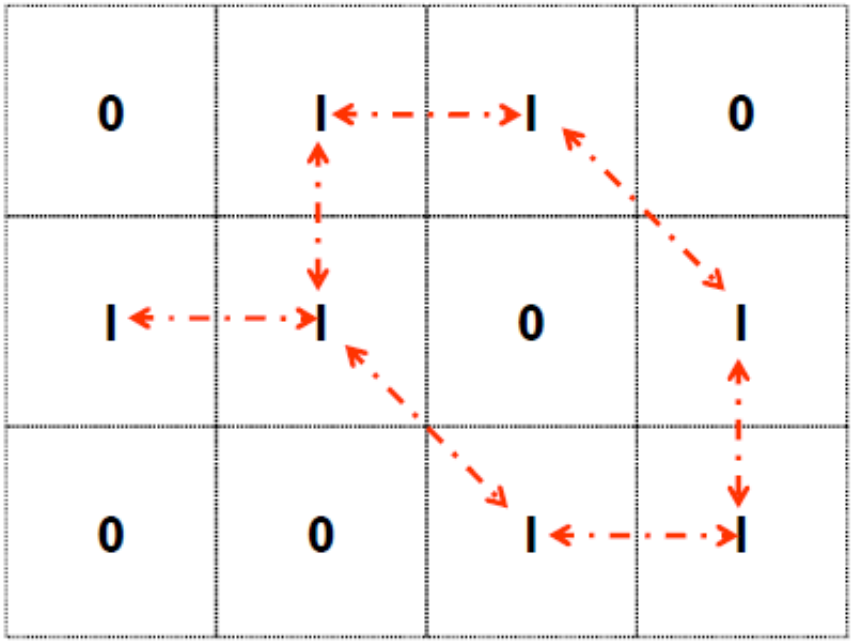
$(p,q) \in V$, *and* q satisfies one of the following:

a. $q \in N_4(p)$ *or*

b. $q \in N_D(p)$ *And* $N_4(p) \cap N_4(q)$ has no pixels whose values are from V

Example: m – Connectivity

- Set of gray levels V = {1}



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

Paths

- 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}) $1 \leq i \leq n$

Test Yourself

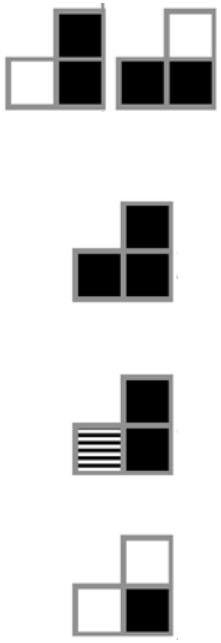
Consider the image segment shown.

(a) Let $V = \{0, 1\}$ and compute the lengths of the shortest 4-, 8-, and m-path between p and q. If a particular path does not exist between these two points, explain why.

(b) Repeat for $V = \{1, 2\}$.

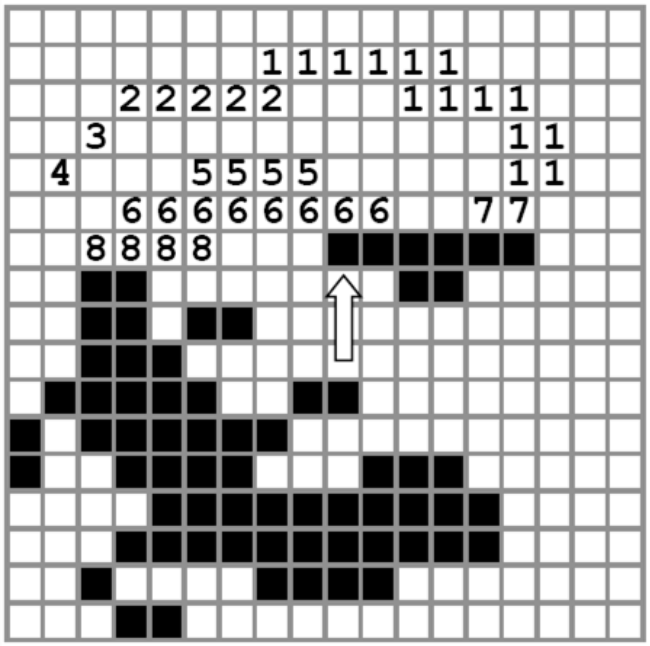
3	1	2	1 (q)
2	2	0	2
1	2	1	1
(p) 1	0	1	2

CC labeling – 4 Connectivity



- Process the image from left to right, top to bottom:
  1.) If the next pixel to process is 1
    i.) If only one of its neighbors (top or left) is 1, copy its label.
    ii.) If both are 1 and have the same label, copy it.
    iii.) If they have different labels
      – Copy the label from the left.
      – Update the equivalence table.
    iv.) Otherwise, assign a new label.

Pass 1

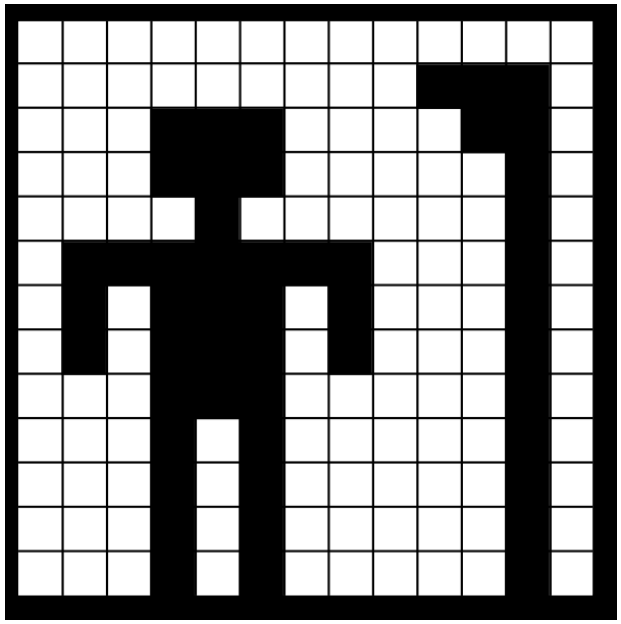


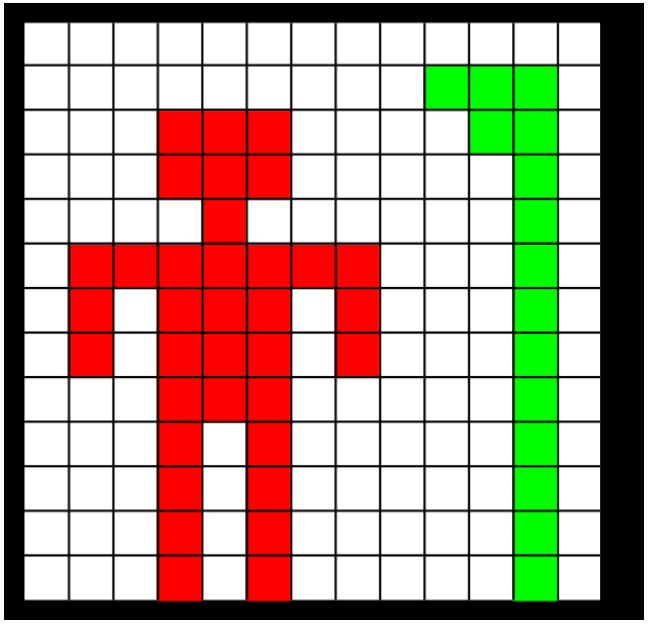
- Re-label with the smallest of equivalent labels

Pass 2

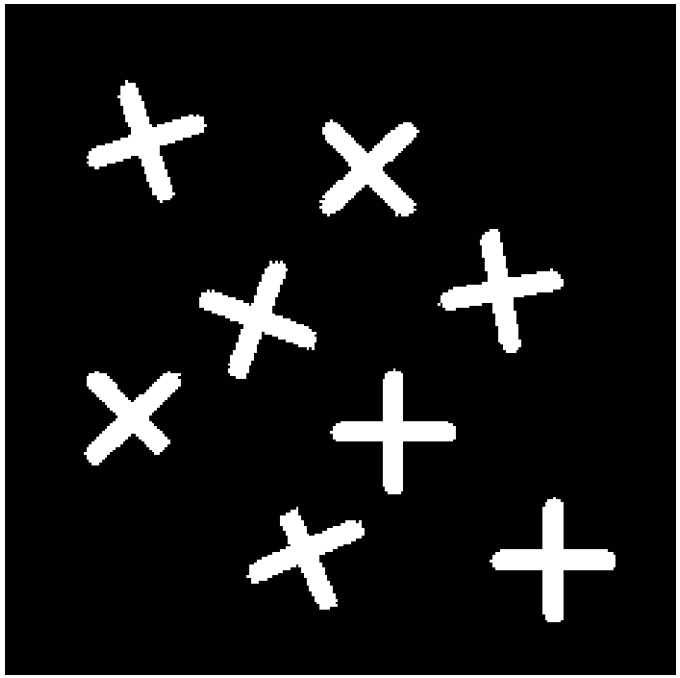
{1, 2, 7}
{3}
{4}
{5, 6, 8}

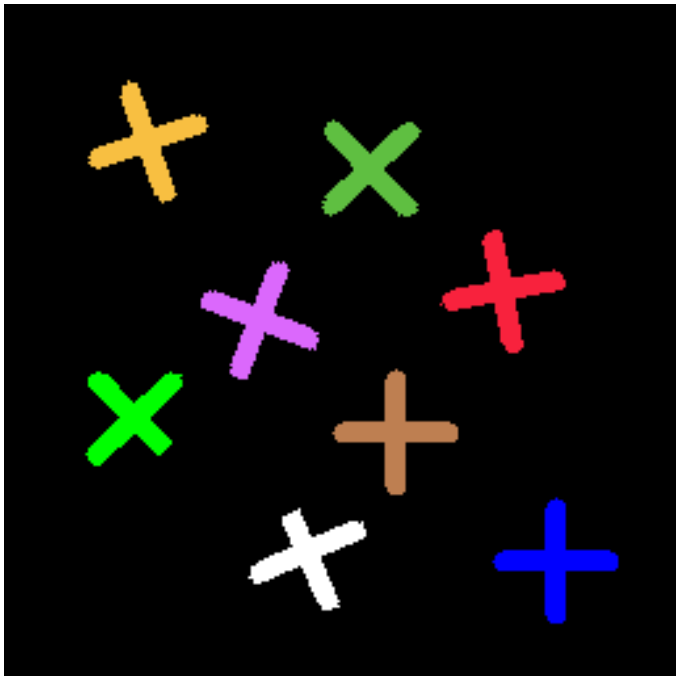
CC labeling – 4 Connectivity





CC labeling – 4 Connectivity

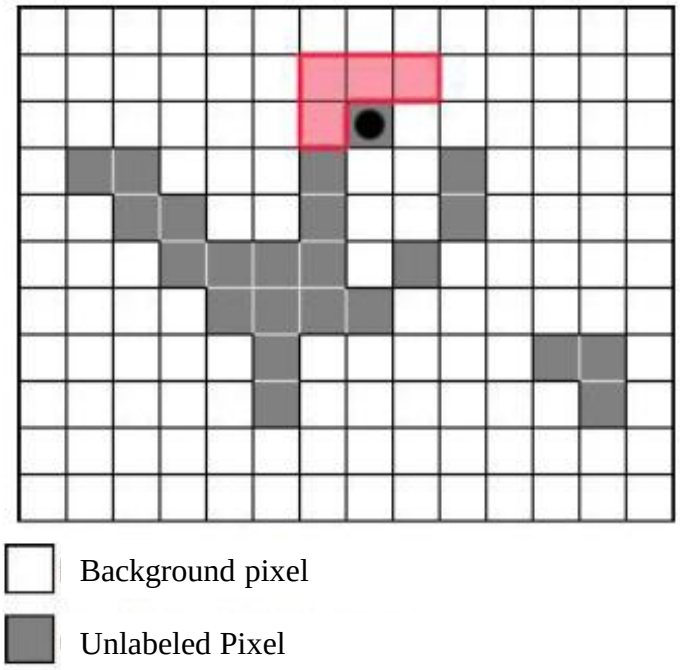


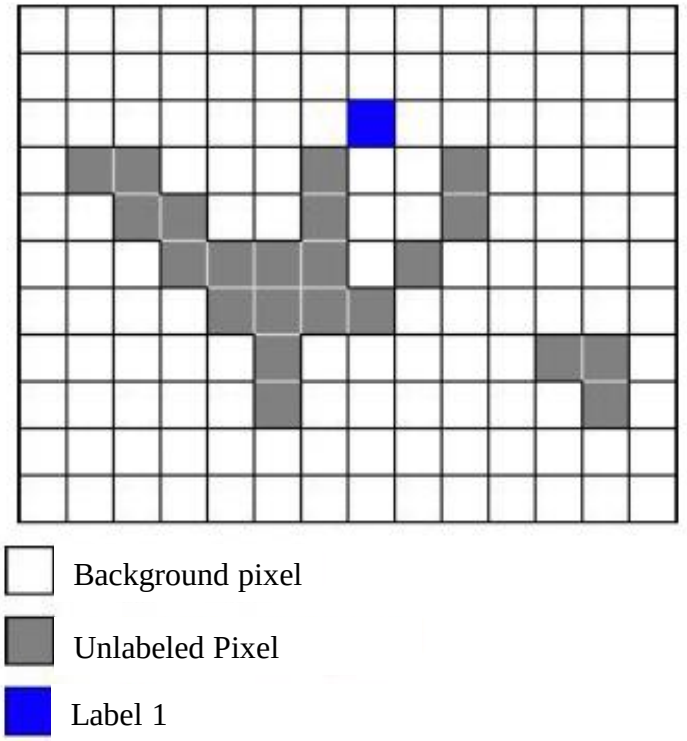


CC labeling – 8 Connectivity

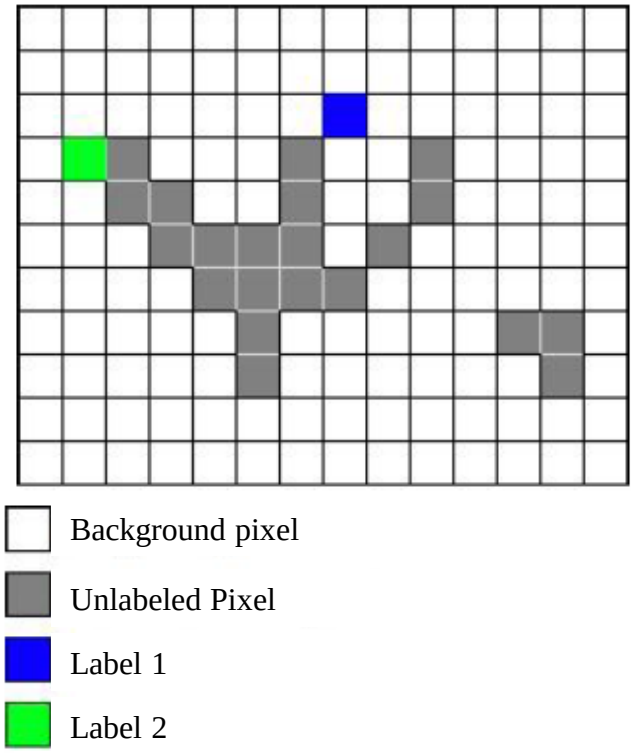
Same algorithm but examine also the upper diagonal neighbors of *p*

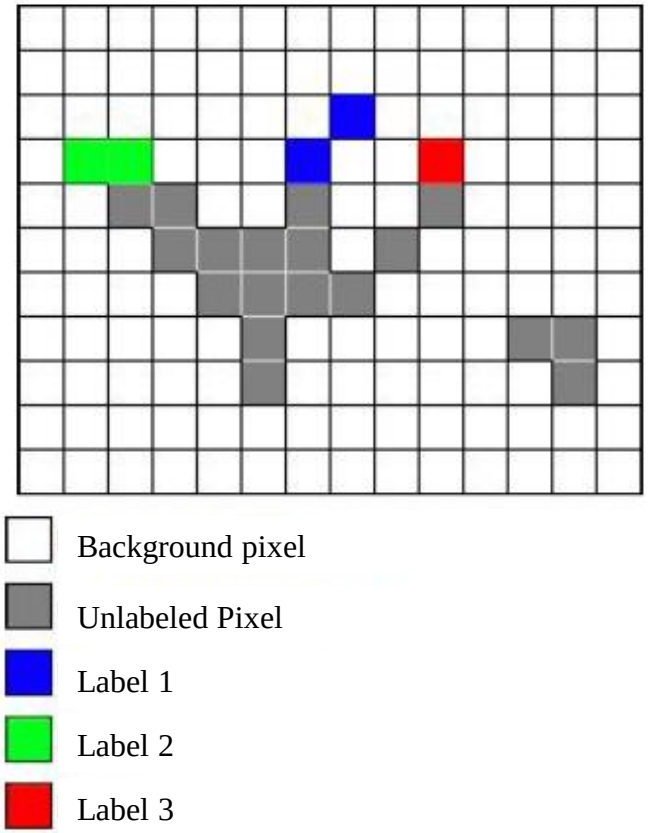
CC labeling – 8 Connectivity



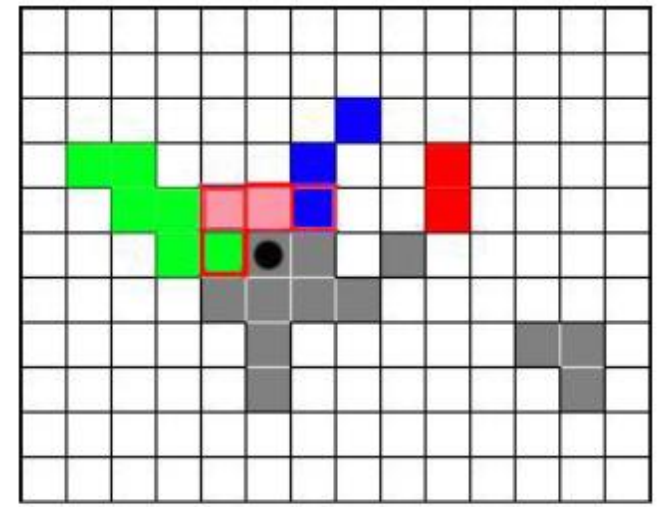


CC labeling – 8 Connectivity





CC labeling – 8 Connectivity



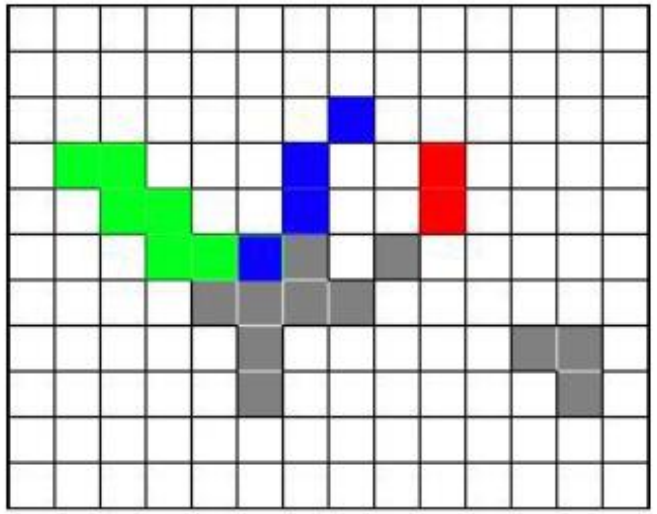
Background pixel

Unlabeled Pixel

Label 1

Label 2

Label 3



Background pixel

Unlabeled Pixel

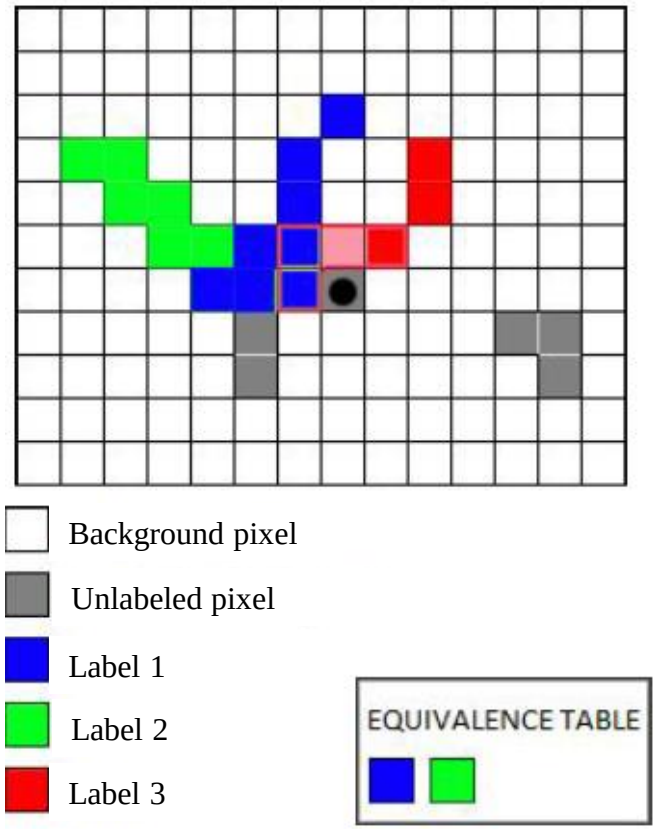
Label 1

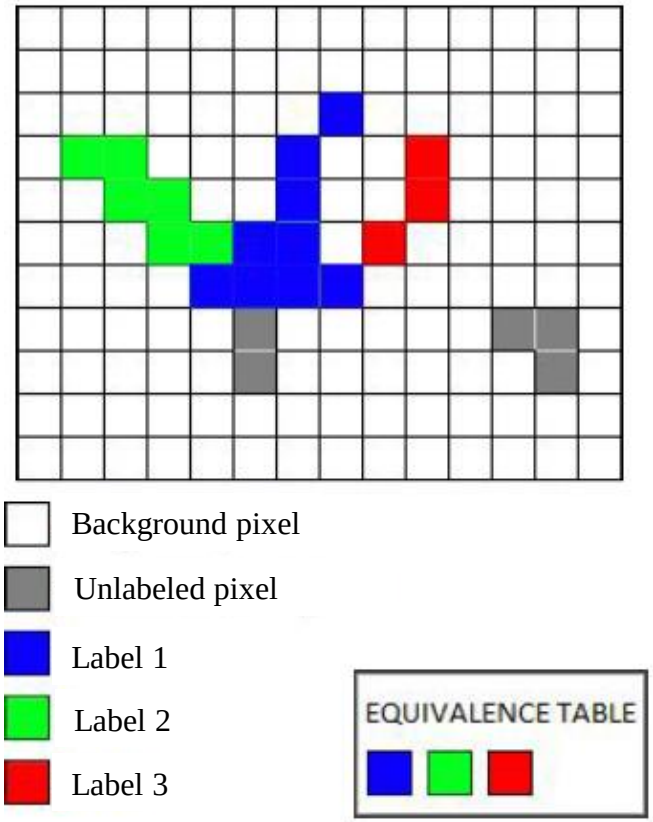
Label 2

Label 3

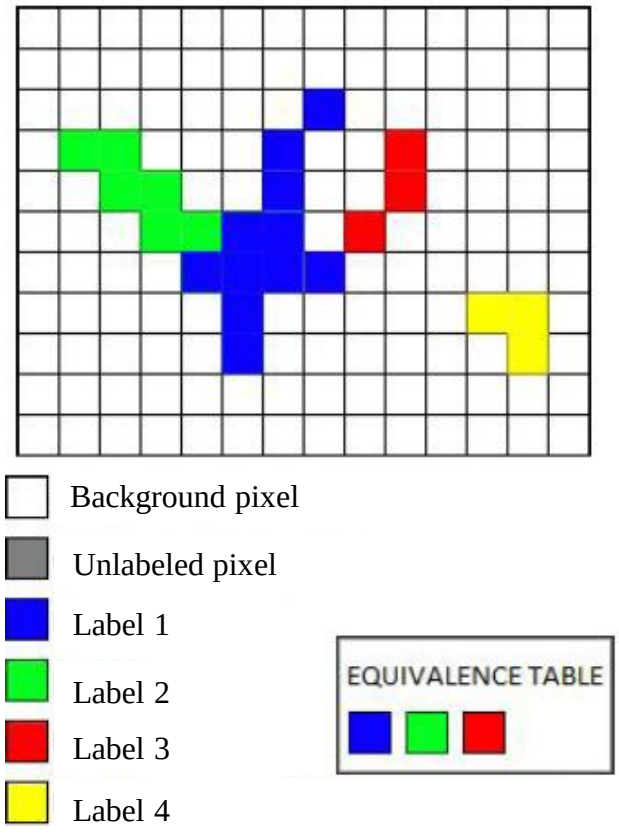
EQUIVALENCE TABLE

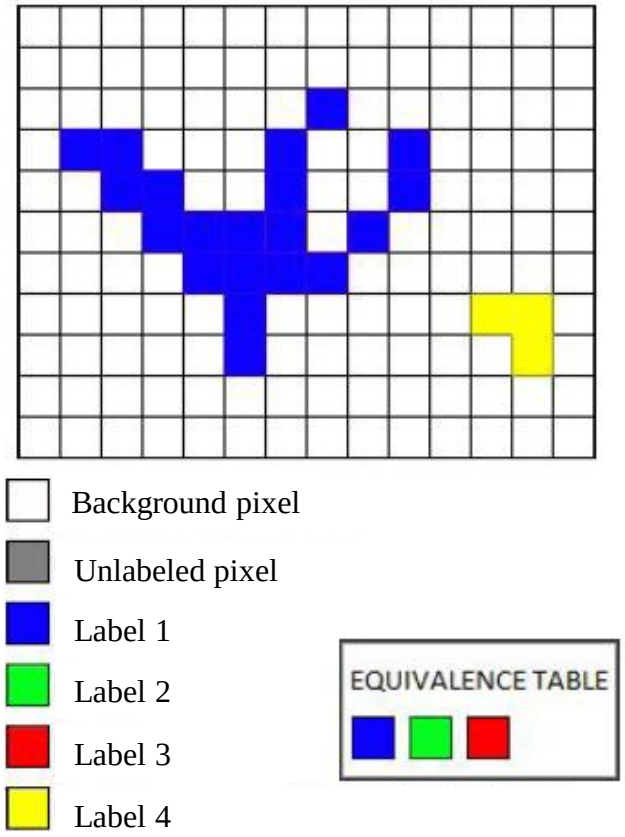
CC labeling – 8 Connectivity





CC labeling – 8 Connectivity





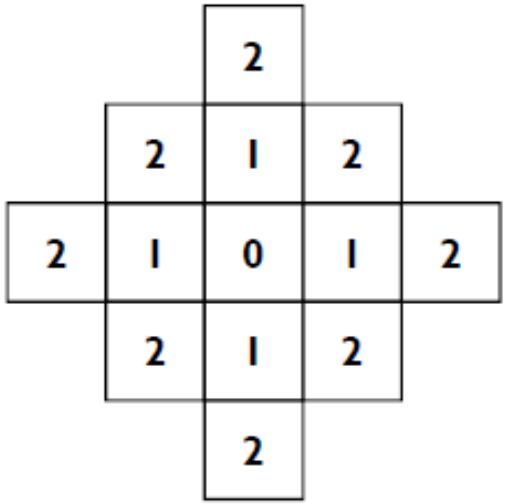
Distance Metrics

- Let pixels *p*, *q* and *z* have coordinates *(x,y)*, *(s,t)* and *(u,v)* respectively.

- D is a distance function or metric if
  - $D(p,q) \geq 0$ *and*
  - $D(p,q) = 0$ *iff* $p = q$ *and*
  - $D(p,q) = D(q,p)$ *and*
  - $D(p,z) \leq D(p,q) + D(q,z)$

City block distance (D_4 distance)

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



- Diamond with center at *(x,y)*
- D_4 = 1 are the 4 neighbors of pixel *p(x,y)*

Chessboard distance (D_8 distance)

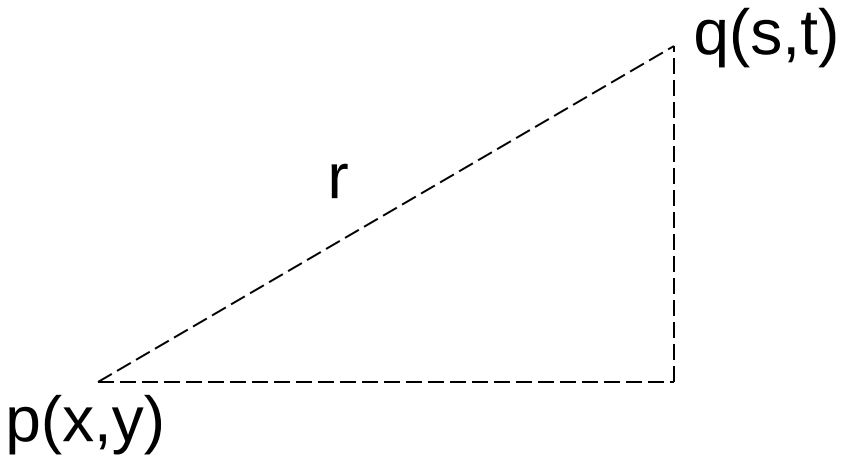
$$D_8(p,q) = \max(|x-s|, |y-t|)$$

2	2	2	2	2
2	1	1	1	2
2	1	0	1	2
2	1	1	1	2
2	2	2	2	2

- Square centered at *p(x,y)*
- D_8 = 1 are the 8 neighbors of pixel *p(x,y)*

Euclidean Distance

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



A circle with radius *r* centered at *(x,y)*

Arithmetic Operations

- Carried out between corresponding pixel pairs

$$s(x,y) = f(x,y) + g(x,y)$$

$$d(x,y) = f(x,y) - g(x,y)$$

$$p(x,y) = f(x,y) \times g(x,y)$$

$$d(x,y) = f(x,y) \div g(x,y)$$

Arithmetic Operations

- Conversion to range 0 – 255
- Difference of two 8-bit images: -255 to 255
- Sum of two 8-bit images: 0 to 510
- Solution?

Set all values < 0 to 0

Set all values > 255 to 255

Full range of arithmetic operation not captured

Arithmetic Operations

- First perform the operation

$$f_m = f - \min(f)$$

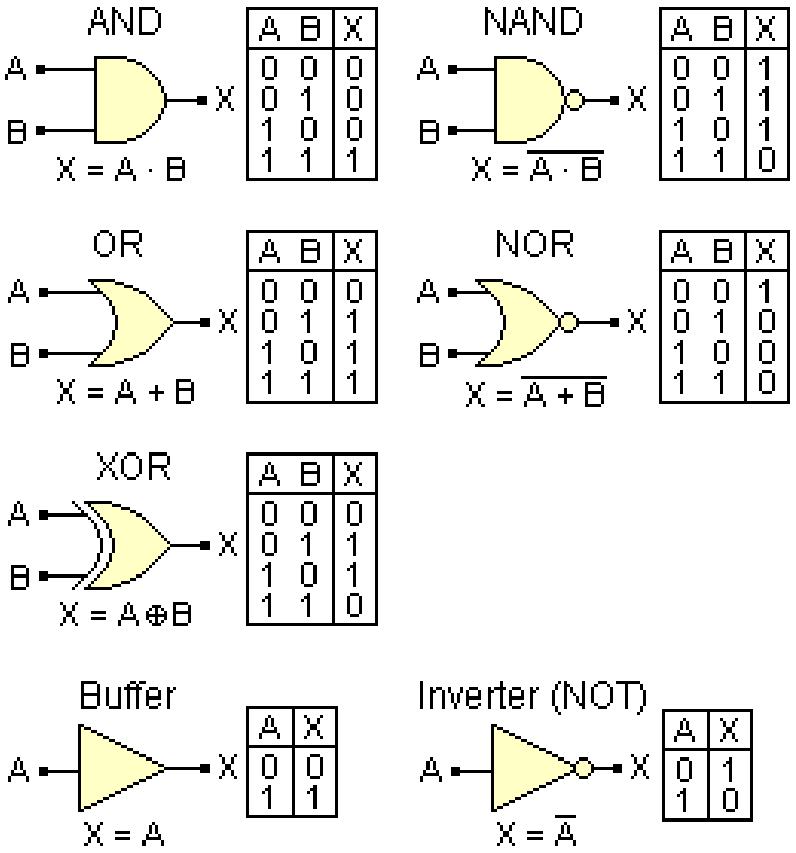
Creates an image whose minimum value is 0

- Then perform

$$f_s = K\left[f_m / \max(f_m) \right]$$

Creates a scaled image f_s with values in the range [0 K]

Logical Operations (Binary Images)



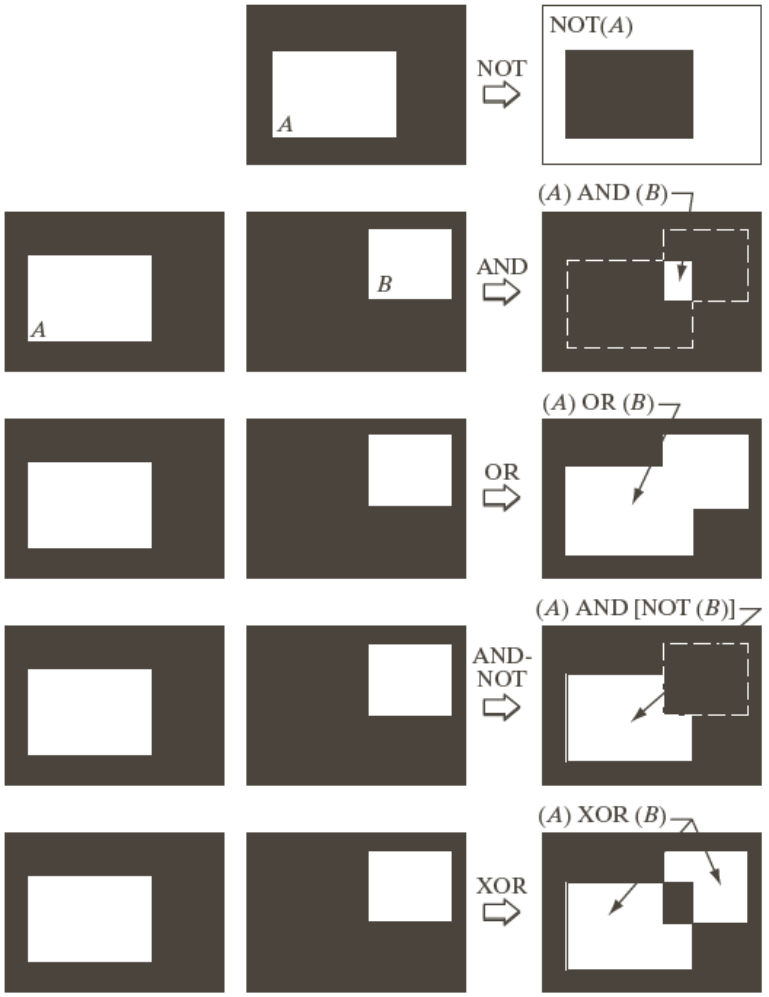
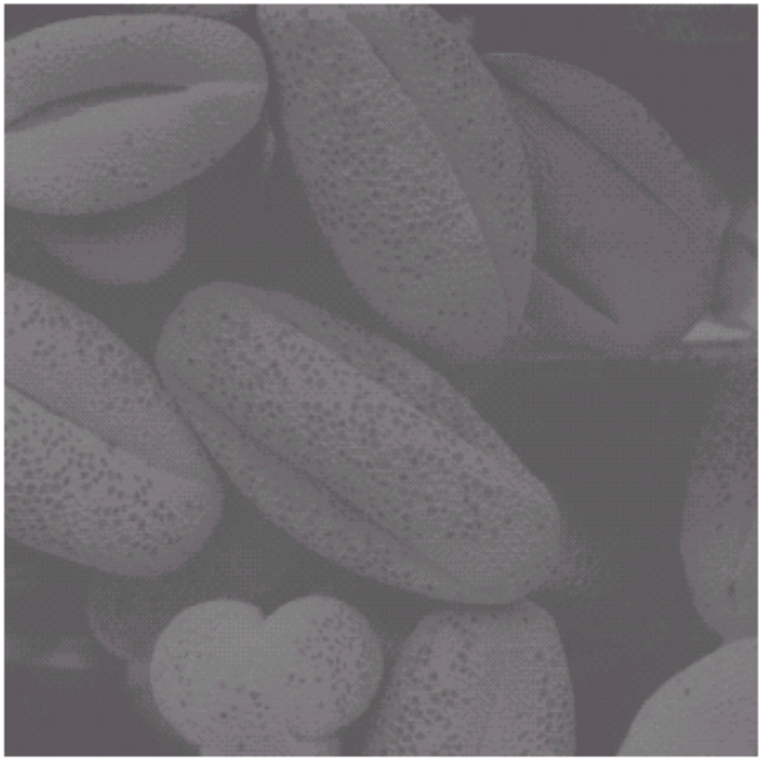


Image Enhancement

Image Enhancement



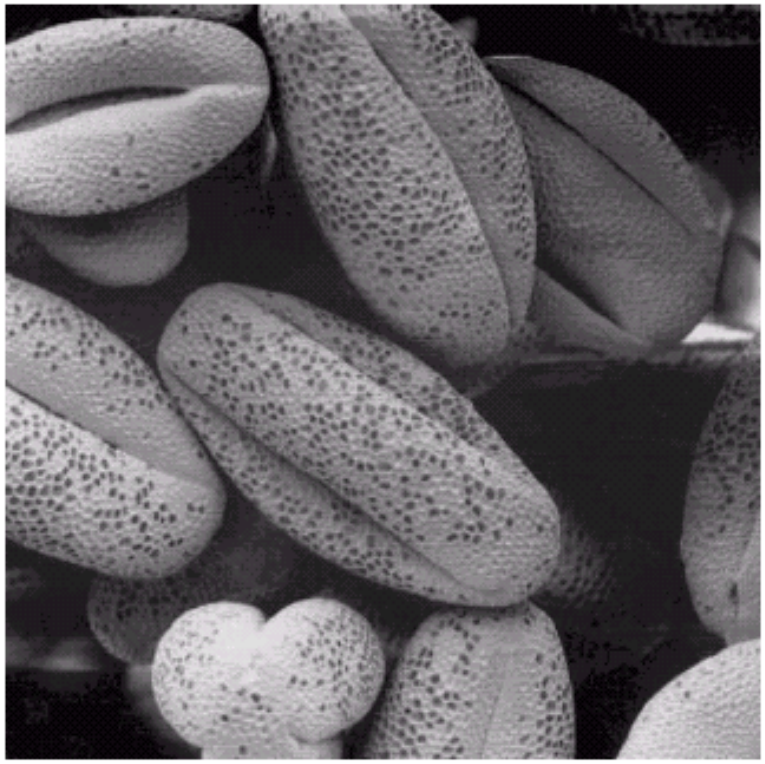


Image Enhancement

Process an image so that the result is more suitable than the original image for a specific application

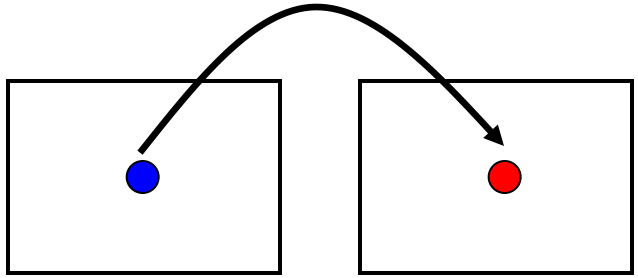
- Image Enhancement Methods
  - Spatial Domain: Direct manipulation of pixels in an image
  - Frequency Domain: Process the image by modifying the Fourier transform of an image

This Chapter – Spatial Domain

Types of image enhancement operations

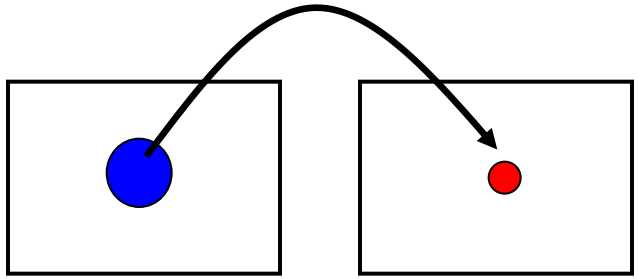
- Point/Pixel operations

  Output value at specific coordinates *(x,y)* is dependent only on the input value at *(x,y)*



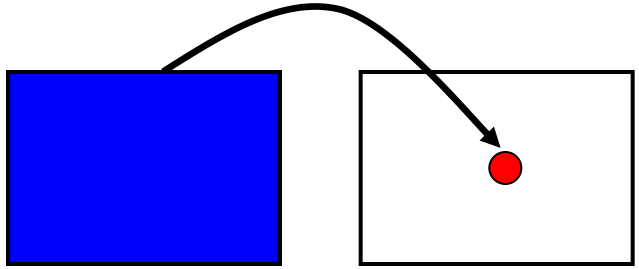
- Local operations

  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

- Most spatial domain enhancement operations can be generalized as:

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

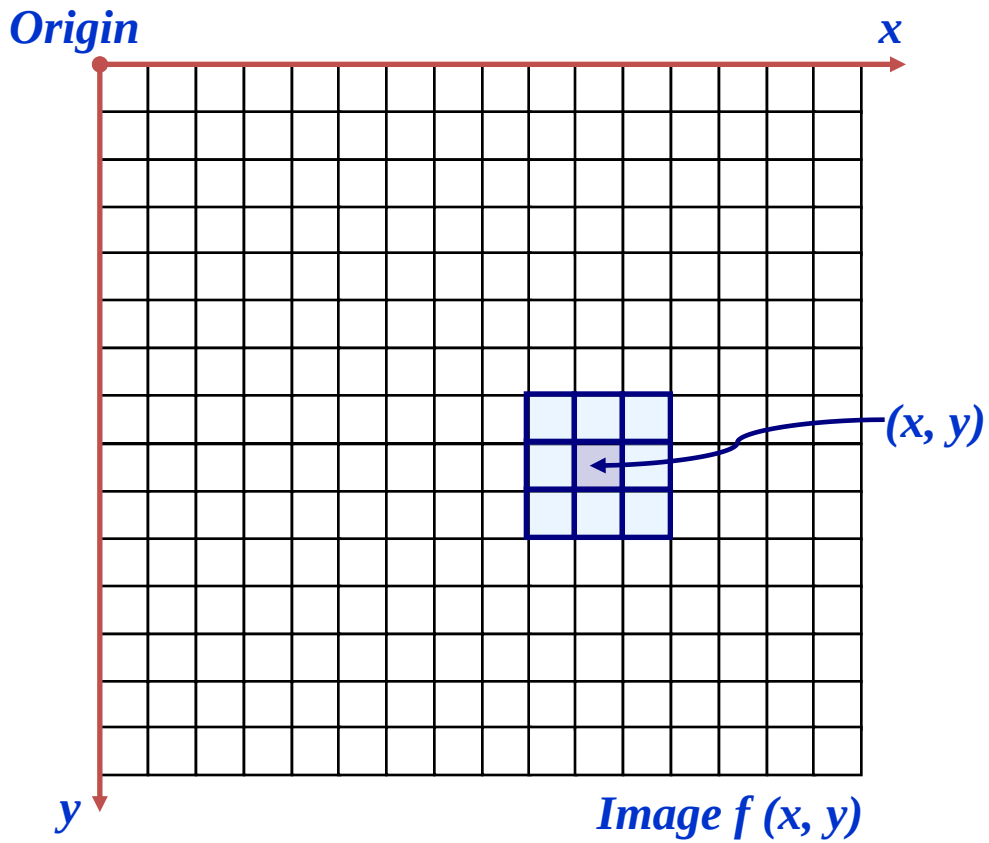
f (x, y) = the input image

g (x, y) = the processed/output image

T = some operator defined over some neighbourhood of *(x, y)*

Basic Concepts

A square or rectangular sub-image area centered at (x,y)



Point Processing

- In a digital image, point = pixel
- Point processing transforms a pixel's value as function of its value alone;
- It does not depend on the values of the pixel's neighbors.

Point Processing

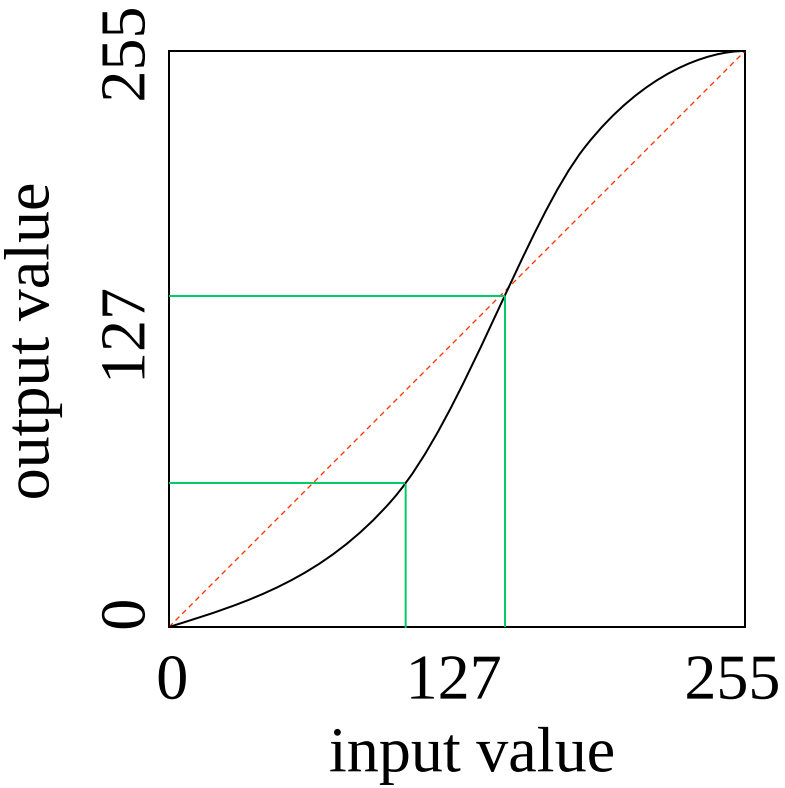
- Neighborhood of size 1x1:
- *g* depends only on *f* at *(x,y)*
- *T*: Gray-level/intensity transformation/ mapping function

$$s = T(r)$$

  - *r* = gray level of *f* at *(x,y)*
  - *s* = gray level of *g* at *(x,y)*

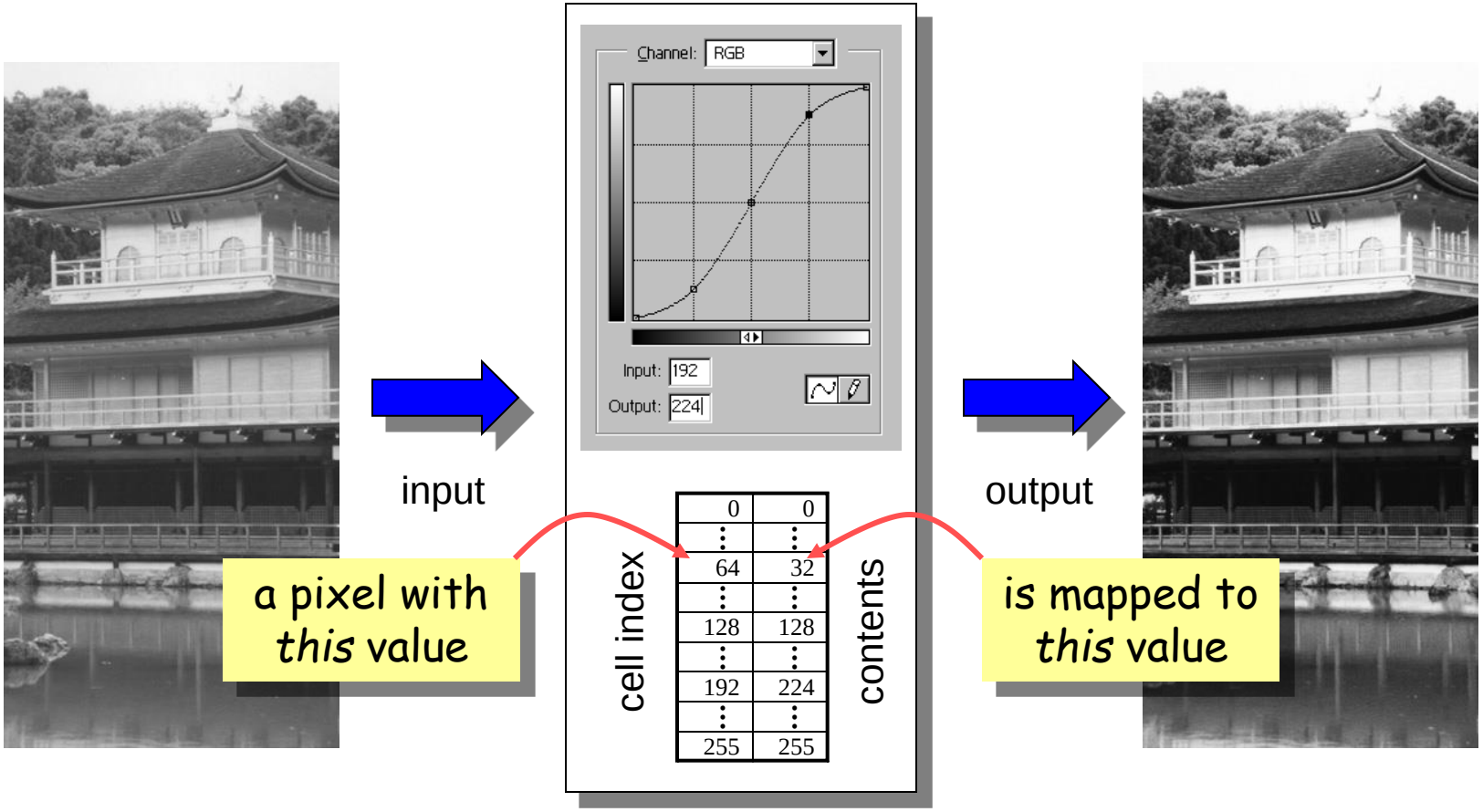
Point Processing using Look-up Tables

A look-up table (LUT) implements a functional mapping.

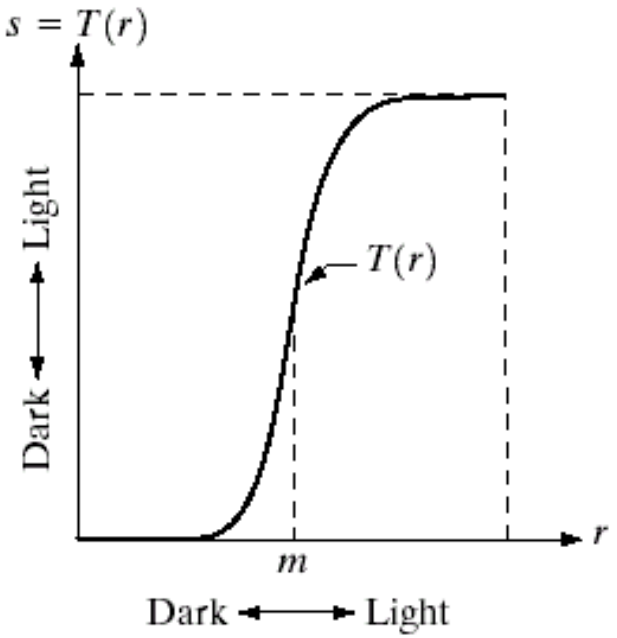


E.g.:	index	value
	...	...
	101	64
	102	68
	103	69
	104	70
	105	70
	106	71
	...	...
	input	output

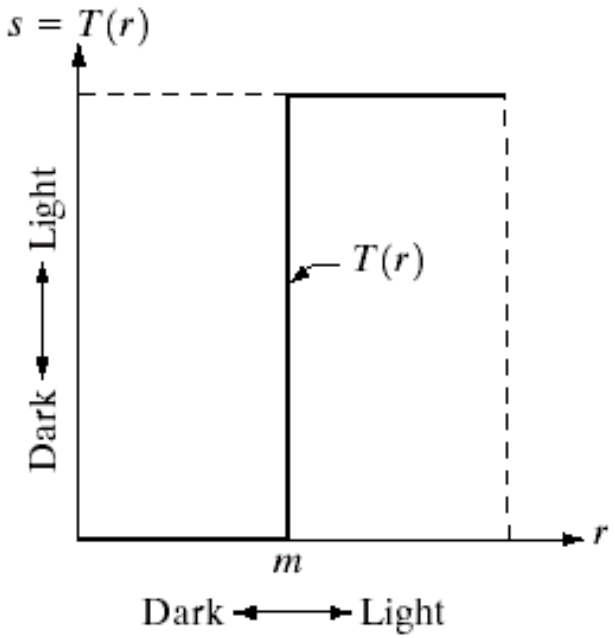
Point Processing using Look-up Tables



POINT PROCESSING



Contrast Stretching



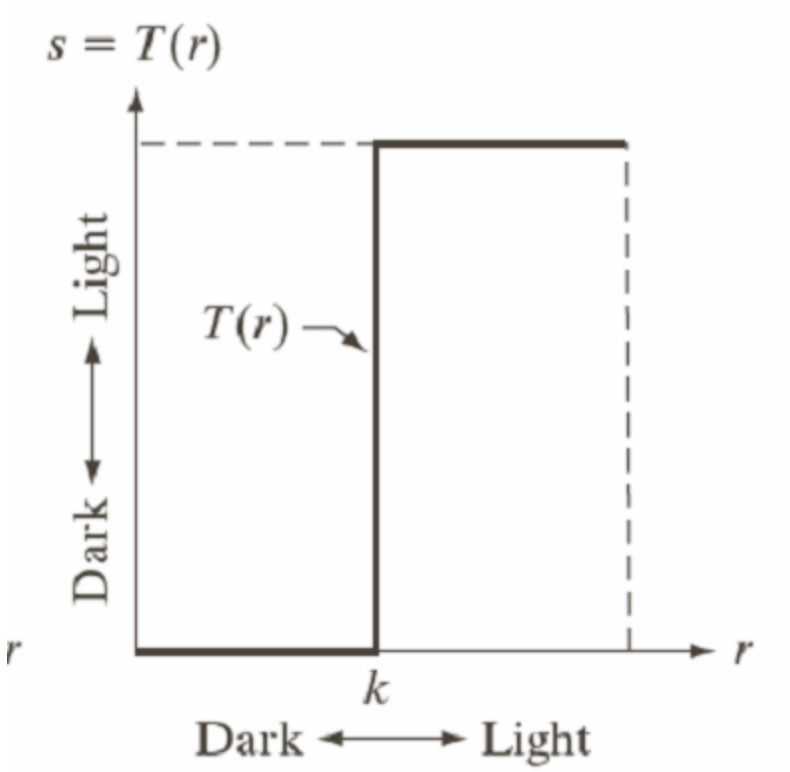
Thresholding

a b

FIGURE 3.2 Gray-level transformation functions for contrast enhancement.

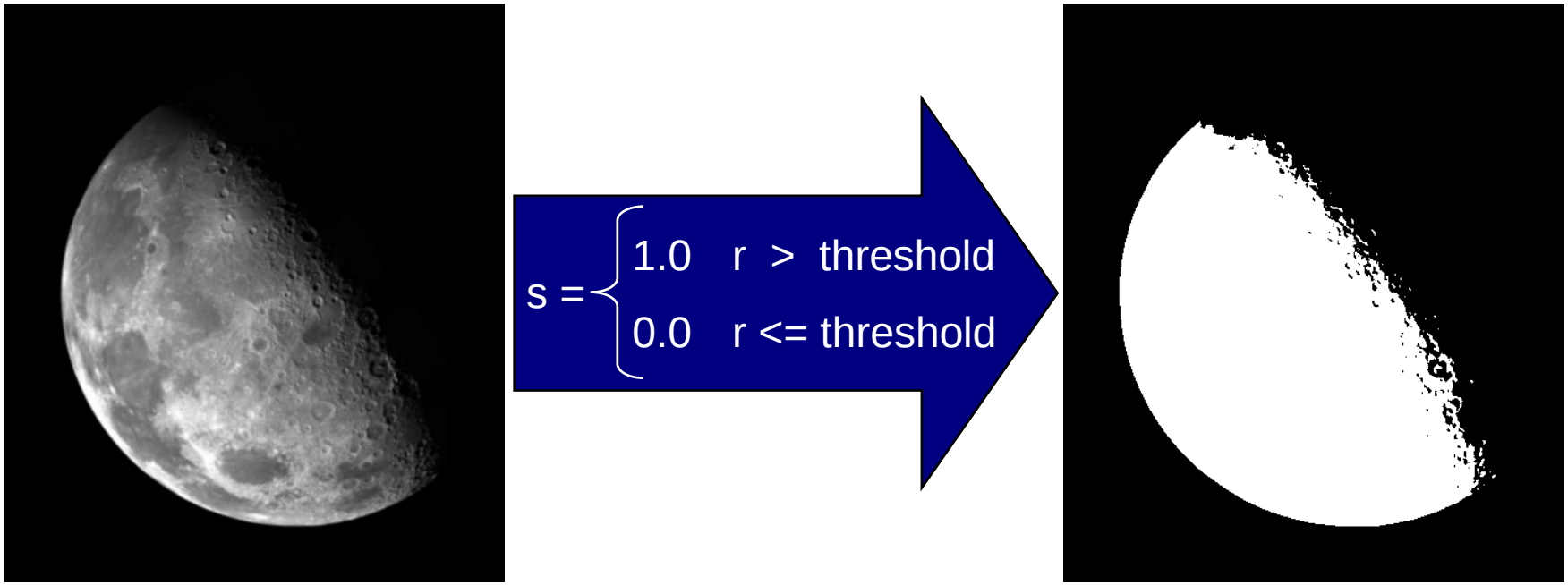
Point Processing Example: Thresholding

$$s = \begin{cases} 1.0 & r > threshold \\ 0.0 & r <= threshold \end{cases}$$



Point Processing Example: Thresholding

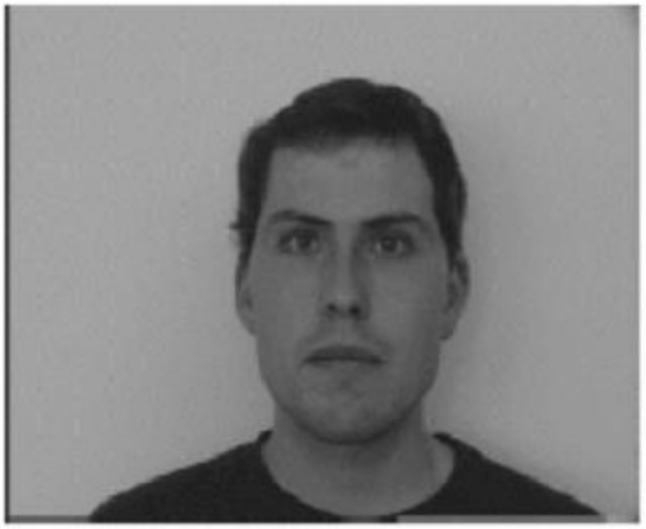
- Segmentation of an object of interest from a background



Point Processing Example: Intensity Scaling

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

Original image



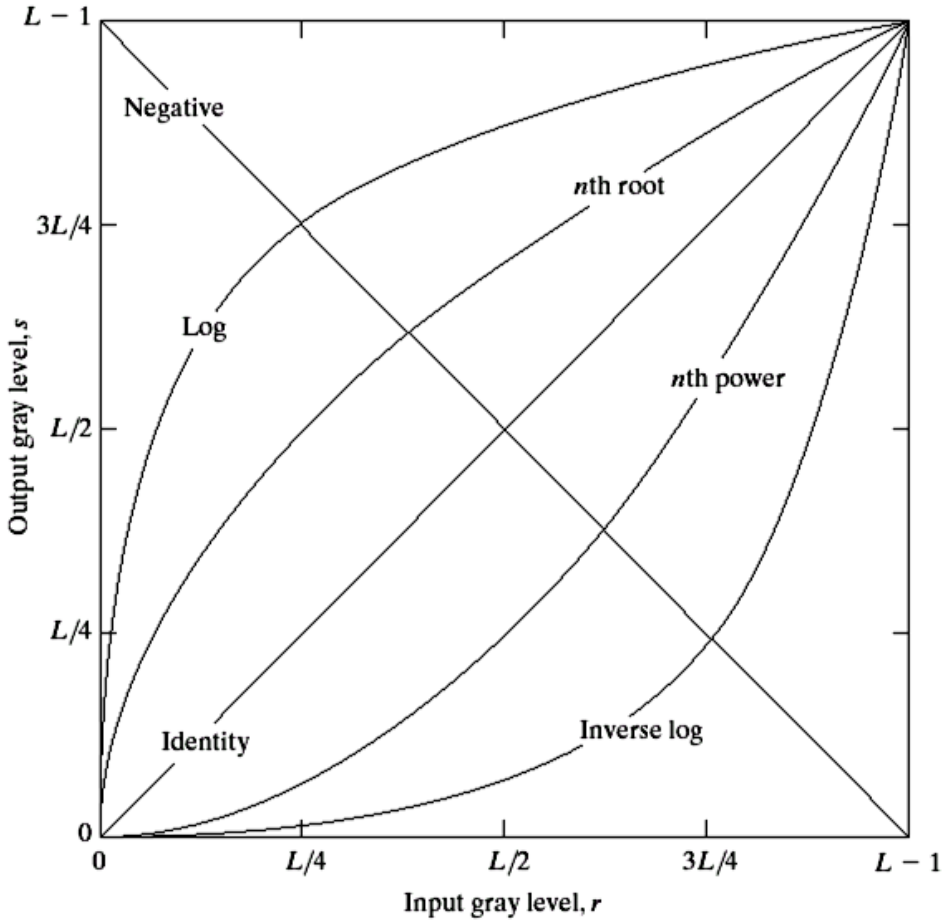
$f(x, y)$

Scaled image

$a \cdot f(x, y)$

Point Processing Transformations

- There are many different kinds of grey level transformations
- Three of the most common are shown here
  - Linear
    - Negative/Identity
  - Logarithmic
    - Log/Inverse log
  - Power law
    - n^{th} power/n^{th} root



Point Processing Example: Negative Images

- Reverses the gray level order
- For L gray levels, the transformation has the form:

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

- Negative images are useful for enhancing white or grey detail embedded in dark regions of an image

Point Processing Example: Negative Images

Input image (X-ray image)

Output image (negative)

Logarithmic Transformations

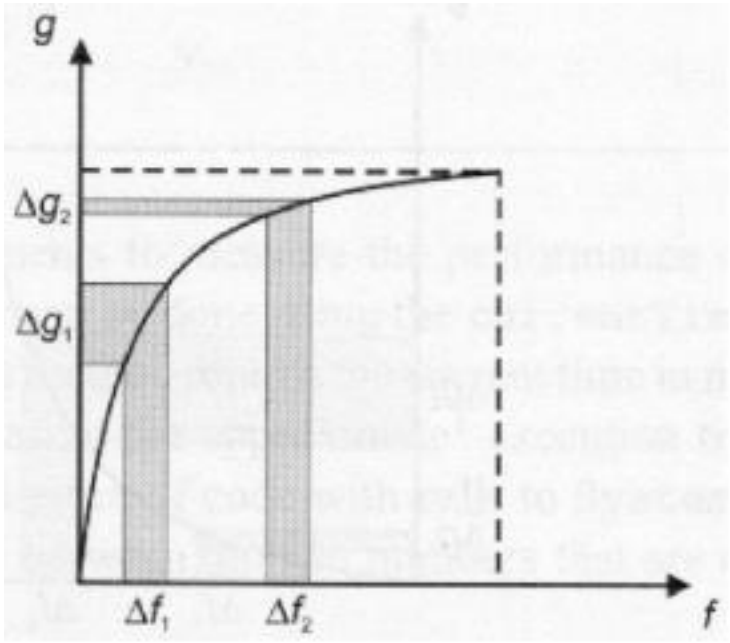
- The general form of the log transformation is

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

- The log transformation maps a narrow range of low input grey level values into a wider range of output values
- The inverse log transformation performs the opposite transformation

Logarithmic Transformations

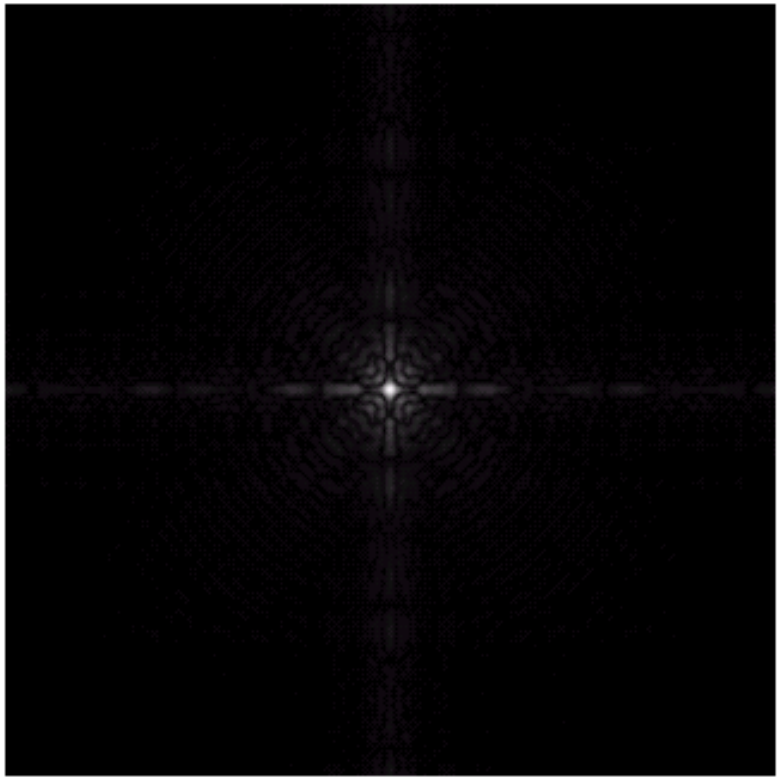
- **Properties**
  - For lower amplitudes of input image the range of gray levels is expanded
  - For higher amplitudes of input image the range of gray levels is compressed



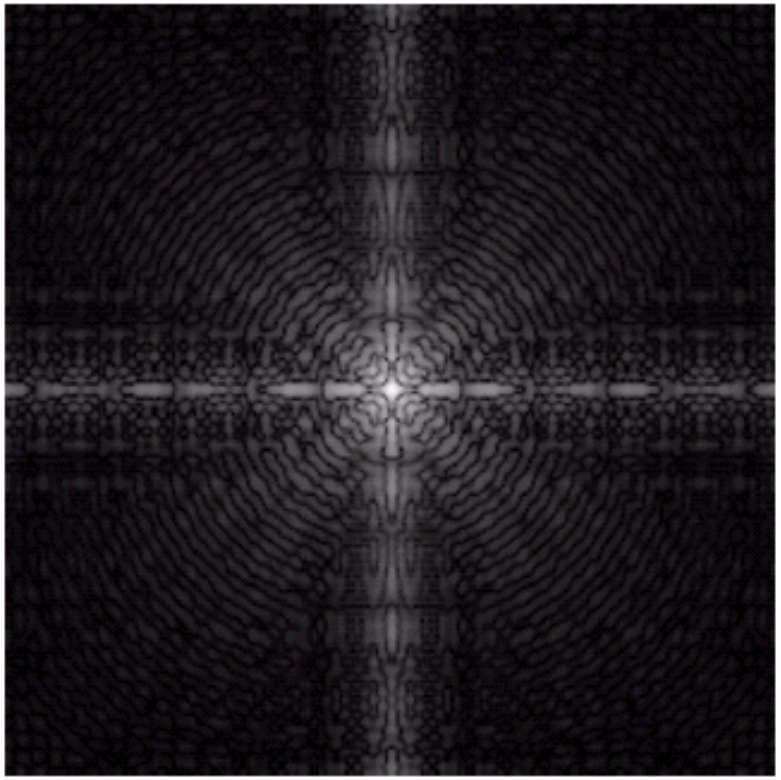
Logarithmic Transformations

- **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"

Logarithmic Transformations



Fourier spectrum: image values ranging from 0 to 1.5×10^6



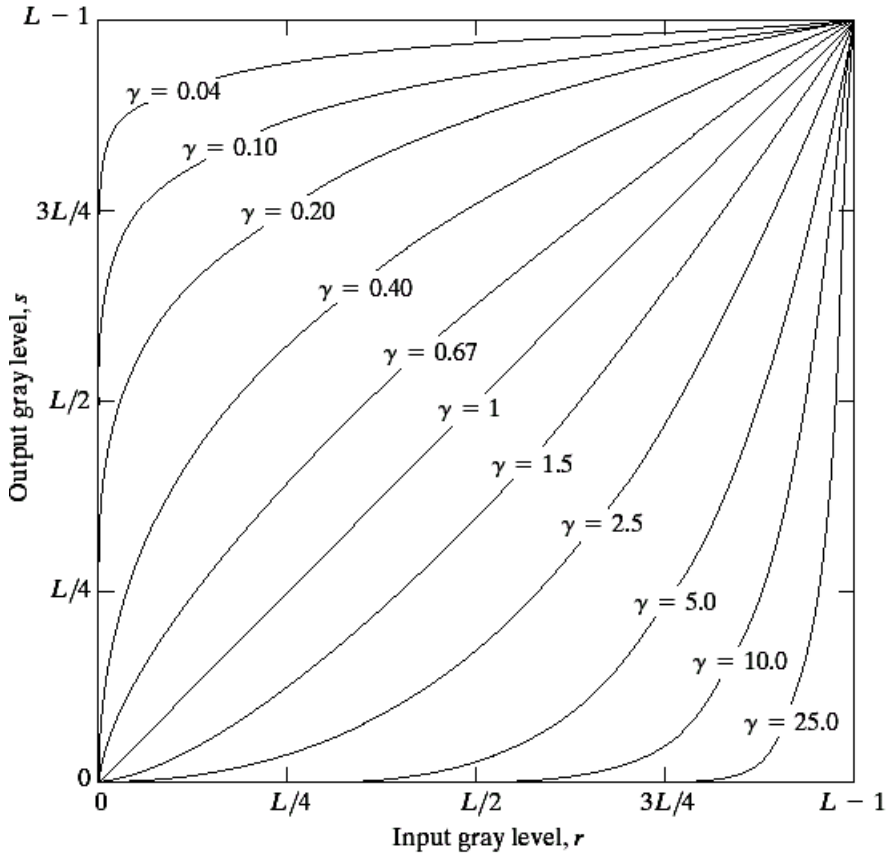
The result of log transformation with c = 1

Power Law Transformations

- Power law transformations have the following form

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

- Map a narrow range of dark input values into a wider range of output values or vice versa
- Varying γ gives a whole family of curves



Power Law Transformations

- 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 $\gamma=1$ & $c=1$: Identity transformation (s = r)

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

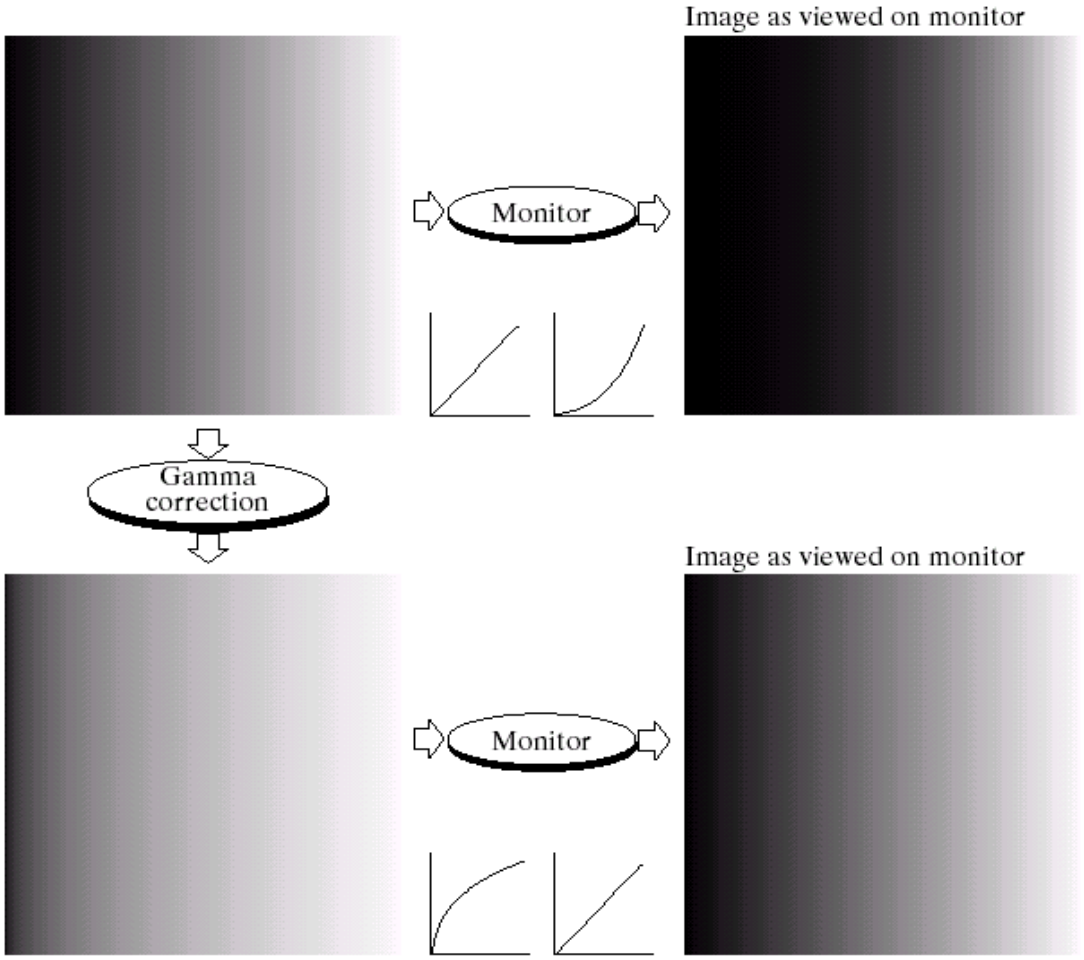
- **Gamma (γ) correction**

  The process used to correct the power-law response phenomena

Power Law Transformations: Gamma Correction

a b
c d

FIGURE 3.7
(a) Linear-wedge gray-scale image. (b) Response of monitor to linear wedge. (c) Gamma-corrected wedge. (d) Output of monitor.

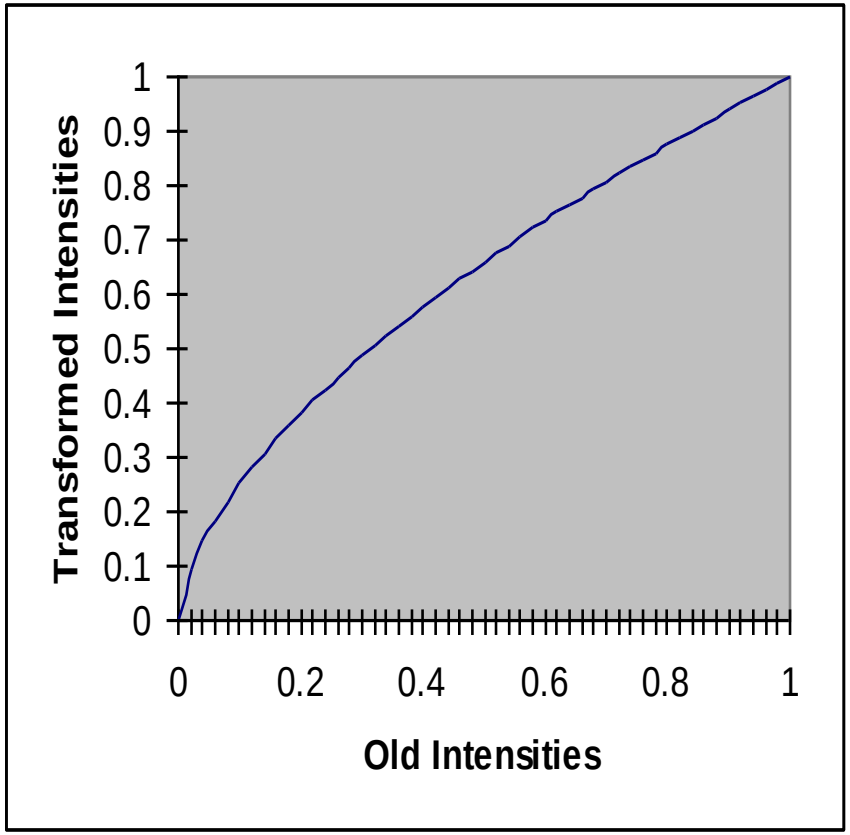


Power Law Transformations
Contrast Enhancement

The images to the right show a magnetic resonance (MR) image of a fractured human spine

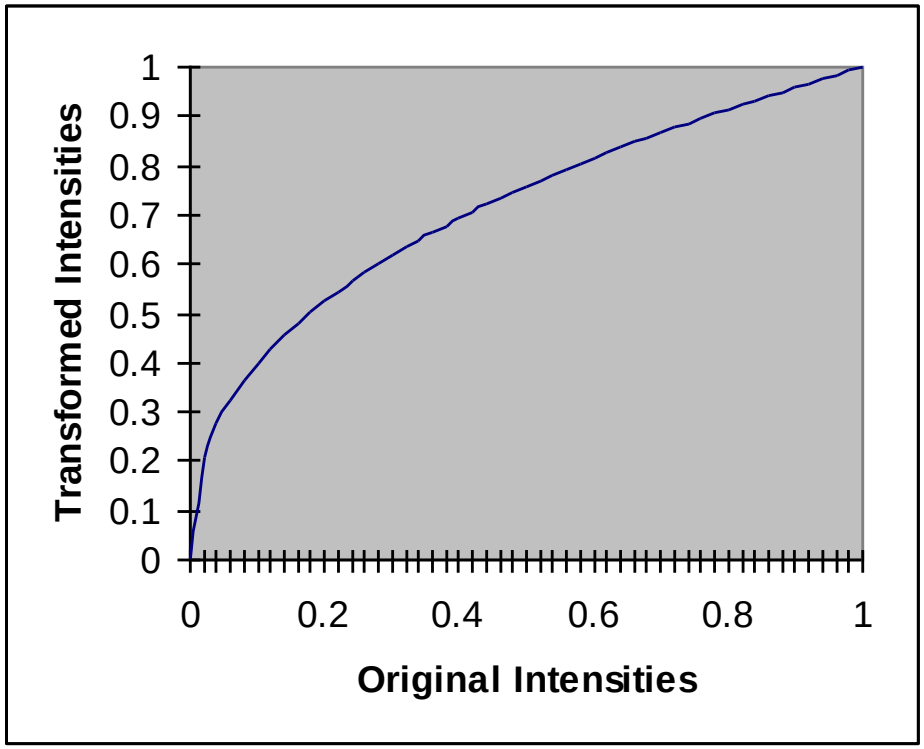
Power Law Transformations
Contrast Enhancement

$\gamma = 0.6$



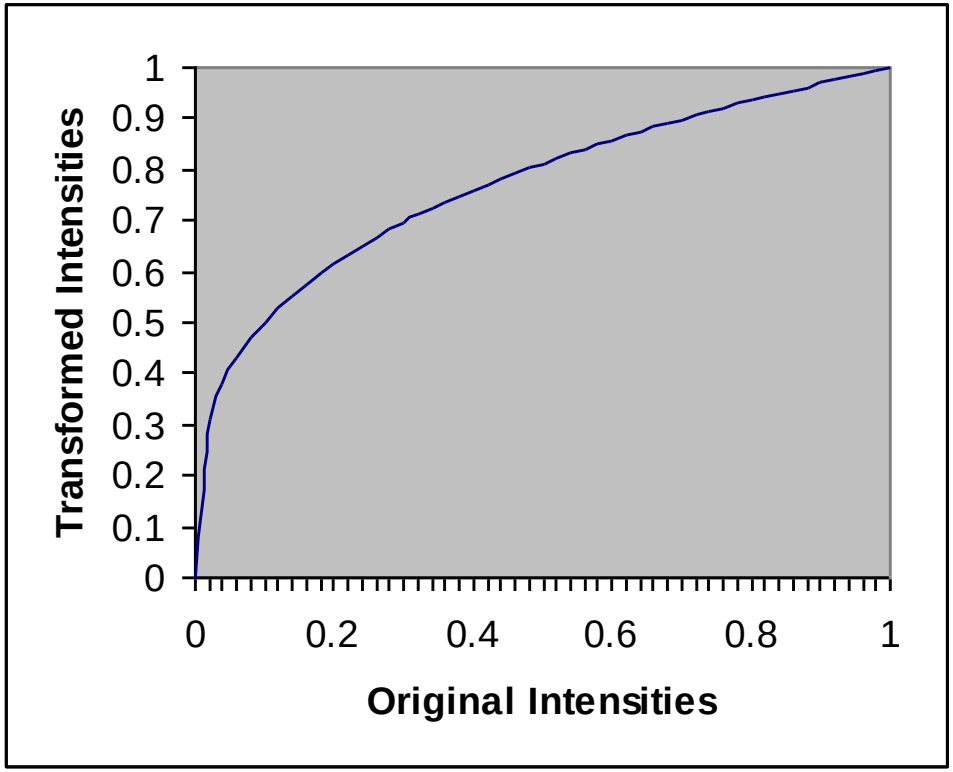
Power Law Transformations
Contrast Enhancement

$\gamma = 0.4$



Power Law Transformations
Contrast Enhancement

$\gamma = 0.3$



Power Law Transformations
Contrast Enhancement

MR image of

fractured human spine

Result after

Power law transformation

c = 1, γ = 0.6

Result after

Power law transformation

c = 1, γ = 0.4

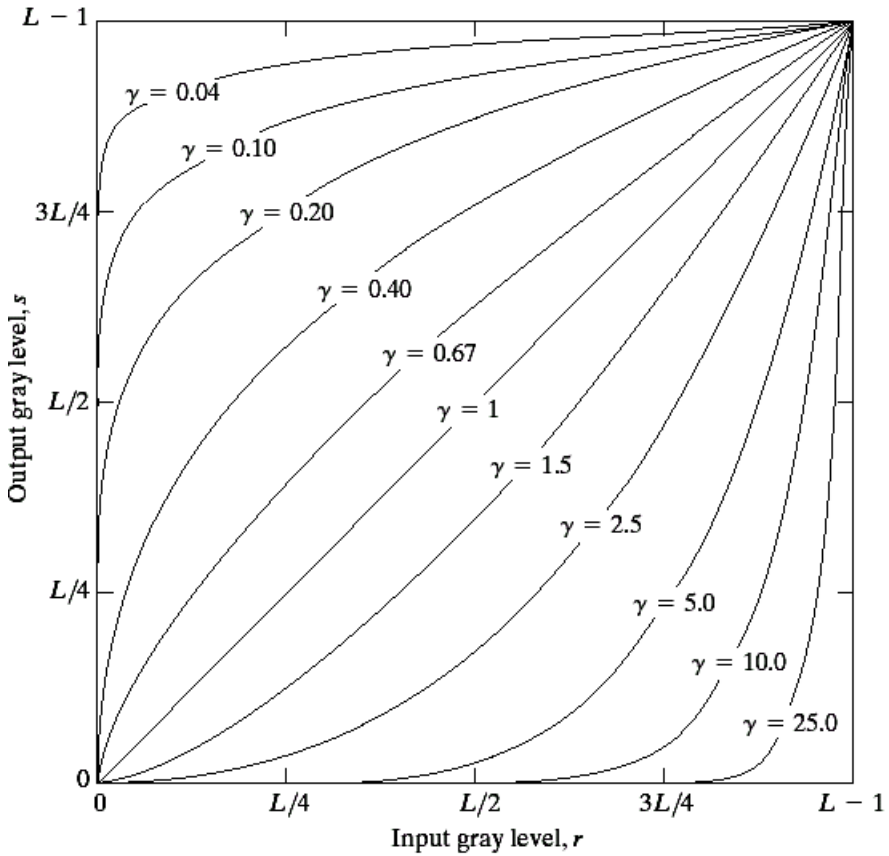
Result after

Power law transformation

c = 1, γ = 0.3

Power Law Transformations
Contrast Enhancement

When the γ is reduced too much, the image begins to reduce contrast to the point where the image started to have very slight "wash-out" look.



Power Law Transformations
Contrast Enhancement

Image has a washed-out appearance – needs $\gamma > 1$

Image Enhancement

Aerial Image

Result of Power law transformation c = 1, γ = 3.0 (suitable)

Result of Power law transformation c = 1, γ = 4.0 (suitable)

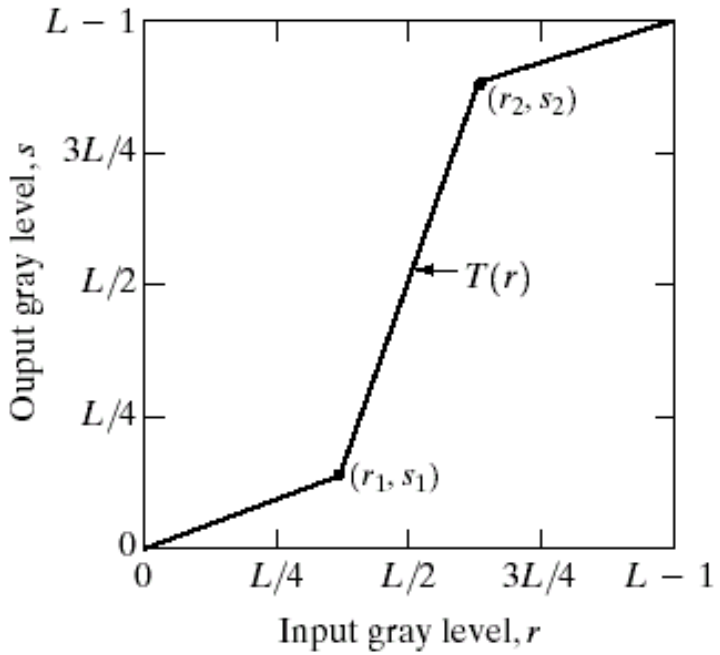
Result of Power law transformation c = 1, γ = 5.0 (high contrast, some regions are too dark)

Piecewise Linear Transformation Functions

- Contrast stretching
- Intensity level slicing

Contrast Stretching

- Objective
  - Increase the dynamic range of the gray levels for low contrast images
- Rather than using a well defined mathematical function we can use arbitrary user-defined transforms

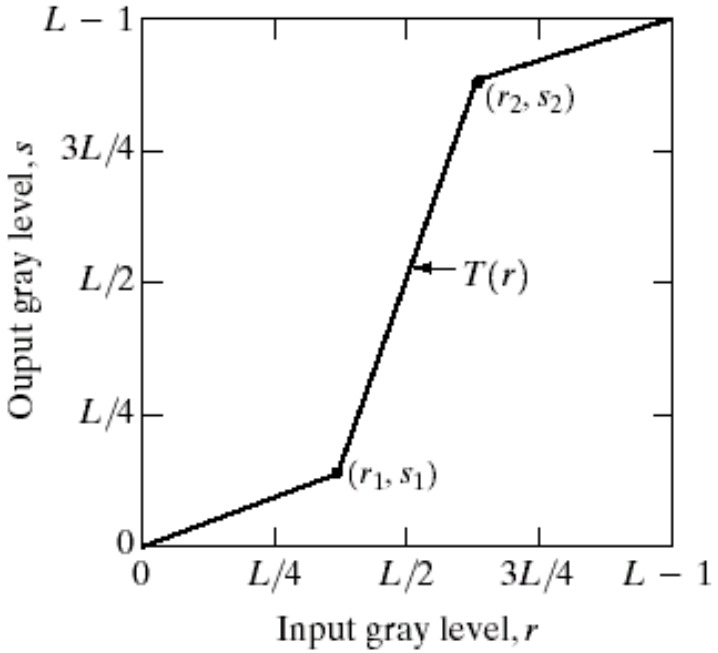


- If $r_1 = s_1$ & $r_2 = s_2$, no change in gray levels
- If $r_1 = r_2$, $s_1 = 0$ & $s_2 = L-1$, then it is a threshold function. The resulting image is binary

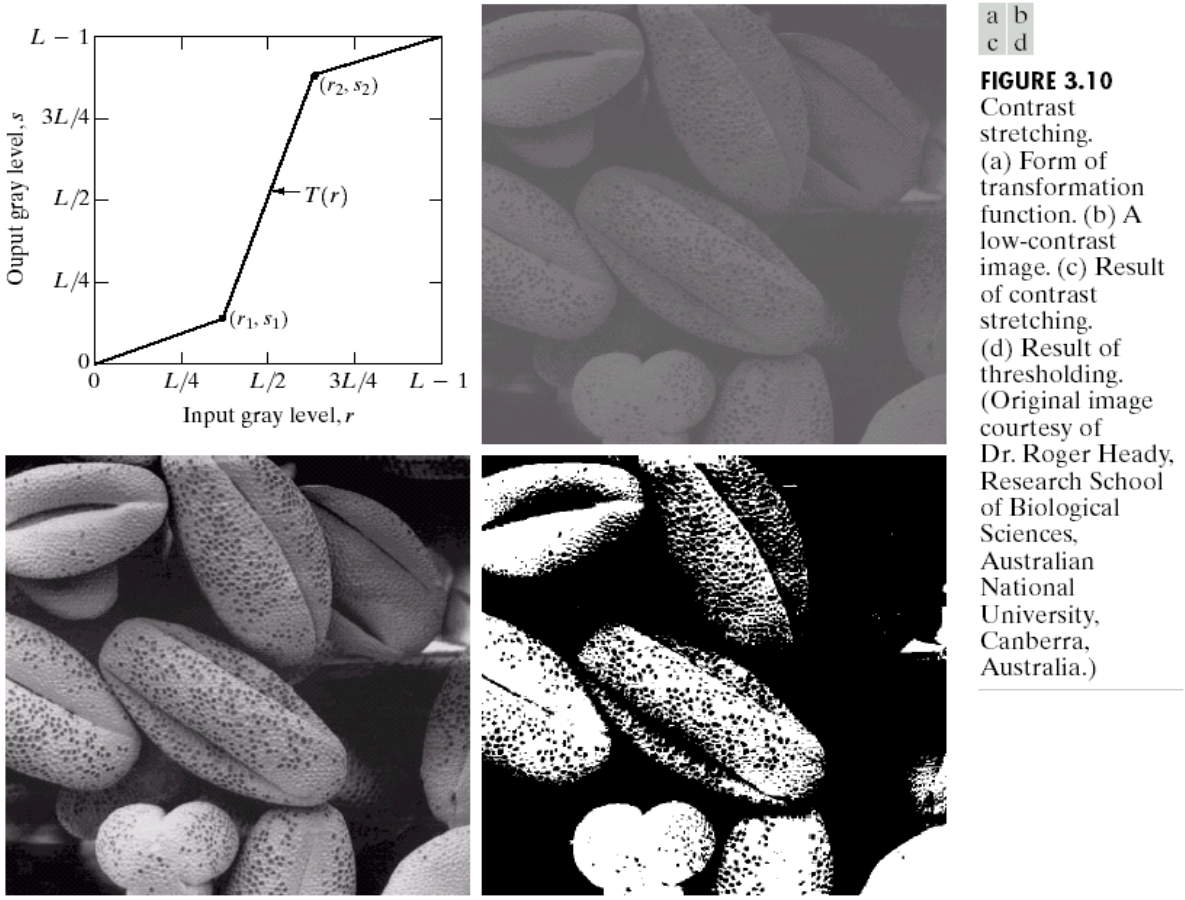
Contrast Stretching

$r_1 = r_{min}$ & $s_1 = 0$

$r_2 = r_{max}$ & $s_2 = L\text{-}1$



Contrast Stretching



a b
c d

FIGURE 3.10 Contrast stretching. (a) Form of transformation function. (b) A low-contrast image. (c) Result of contrast stretching. (d) Result of thresholding. (Original image courtesy of Dr. Roger Heady, Research School of Biological Sciences, Australian National University, Canberra, Australia.)

Readings from Book (3rd Edn.)

- 2.3 Image Sensing and Acquisition
- 2.4 Image Sampling & Quantization
- 2.5 Basic Relationships between Pixels
- 2.6 (Reading Assignment)
- Connectivity Algorithm
- 3.1 Image Enhancement & Transformations

Acknowledgements

- Digital Image Processing", Rafael C. Gonzalez & Richard E. Woods, Addison-Wesley, 2008

Material in these slides has been taken from, the following resources