Image Processing

15-463: Computational Photography
Alexei Efros, CMU, Fall 2005

Some figures from Steve Seitz, and Gonzalez et al.

What is an image?

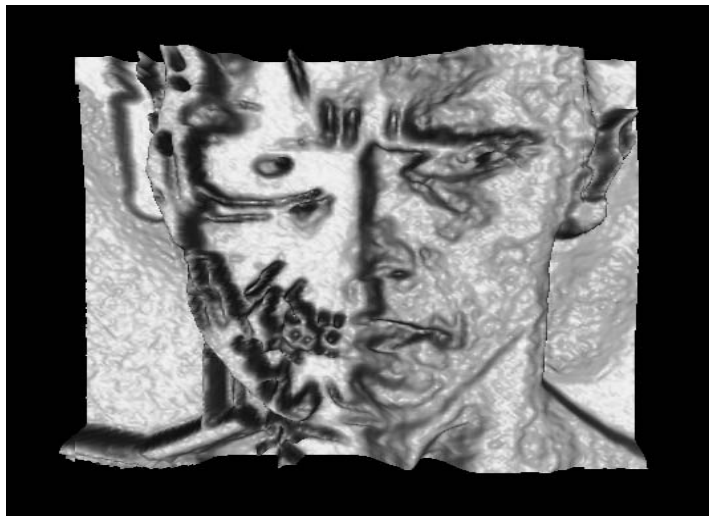
We can think of an **image** as a function, *f*, from $\mathbb{R}^2$ to $\mathbb{R}$:

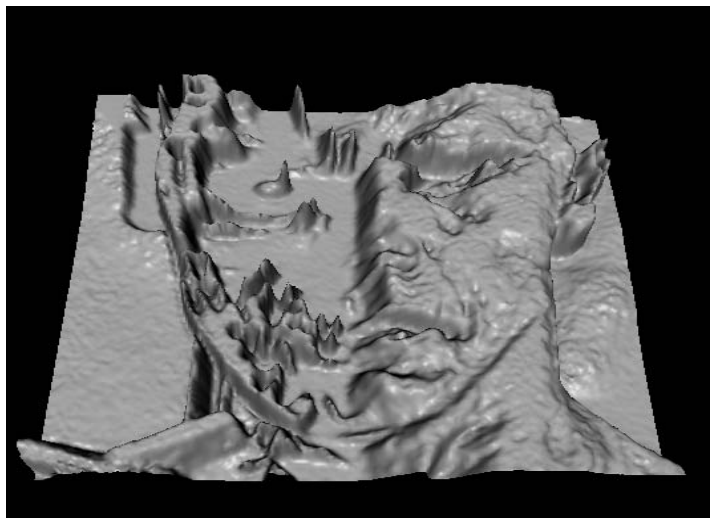
- $f(x, y)$ gives the **intensity** at position (x, y)
- Realistically, we expect the image only to be defined over a rectangle, with a finite range:
  - $f: [a,b] \times [c,d] \rightarrow [0,1]$

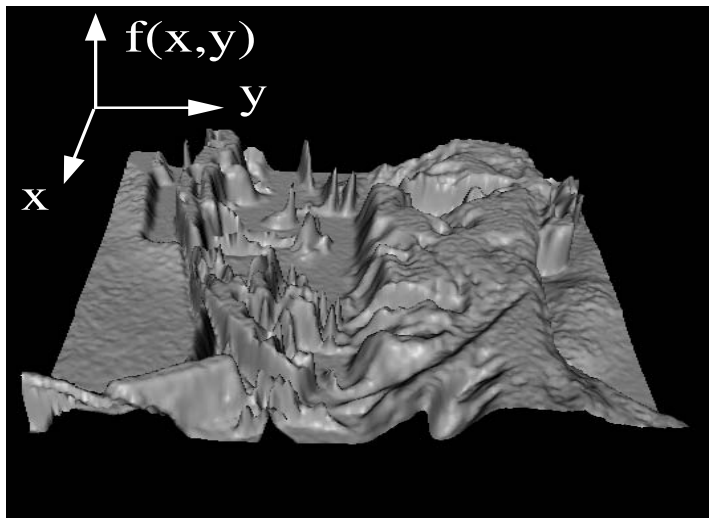
A color image is just three functions pasted together. We can write this as a "vector-valued" function:

$$f(x, y) = \begin{bmatrix} r(x, y) \\ g(x, y) \\ b(x, y) \end{bmatrix}$$

Images as functions







What is a digital image?

We usually operate on **digital** (**discrete**) images:

- **Sample** the 2D space on a regular grid
- **Quantize** each sample (round to nearest integer)

If our samples are Δ apart, we can write this as:

$f[i, j] = \text{Quantize}\{ f(i\,\Delta, j\,\Delta) \}$

The image can now be represented as a matrix of integer values

$j \longrightarrow$

$i \downarrow$

62	79	23	119	120	105	4	0
10	10	9	62	12	78	34	0
10	58	197	46	46	0	0	48
176	135	5	188	191	68	0	49
2	1	1	29	26	37	0	77
0	89	144	147	187	102	62	208
255	252	0	166	123	62	0	31
166	63	127	17	1	0	99	30

Image Processing

An **image processing** operation typically defines a new image g in terms of an existing image f.

We can transform either the range of f.

$$g(x, y) = t(f(x, y))$$

Or the domain of f:

$$g(x, y) = f(t_x(x, y), t_y(x, y))$$

What kinds of operations can each perform?

Image Processing

image filtering: change ***range*** of image

$$g(x) = h(f(x))$$

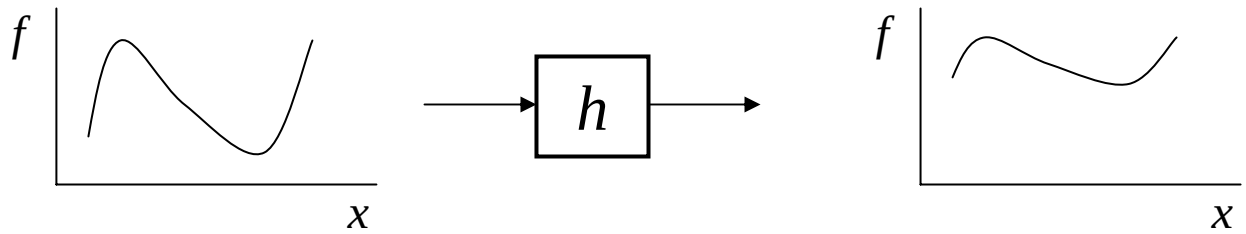


image warping: change ***domain*** of image

$$g(x) = f(h(x))$$

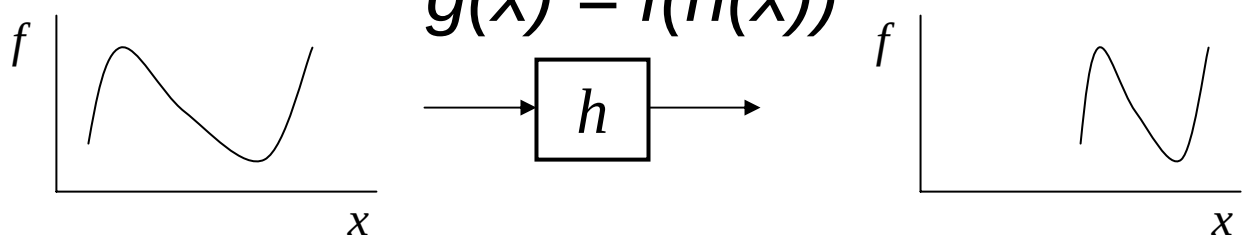


Image Processing

image filtering: change ***range*** of image

$$g(x) = h(f(x))$$

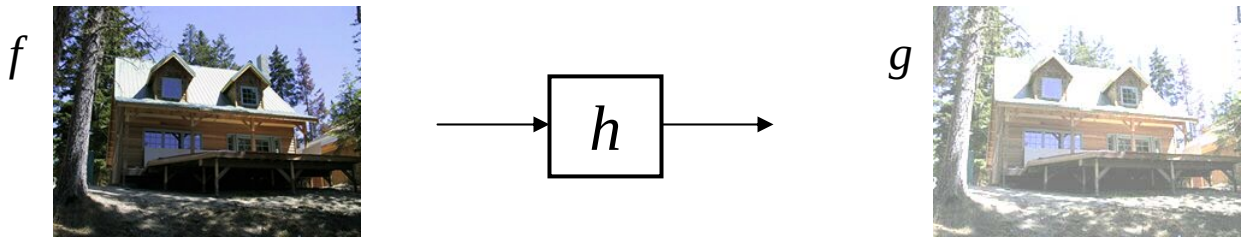
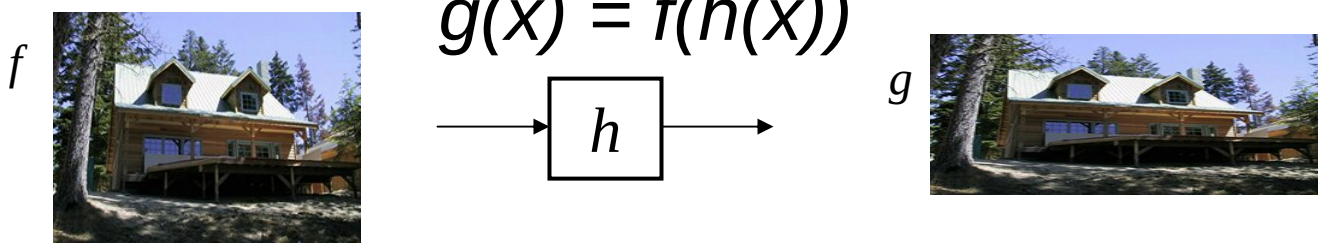


image warping: change ***domain*** of image

$$g(x) = f(h(x))$$



Point Processing

The simplest kind of range transformations are these independent of position x,y:

$$g = t(f)$$

This is called point processing.

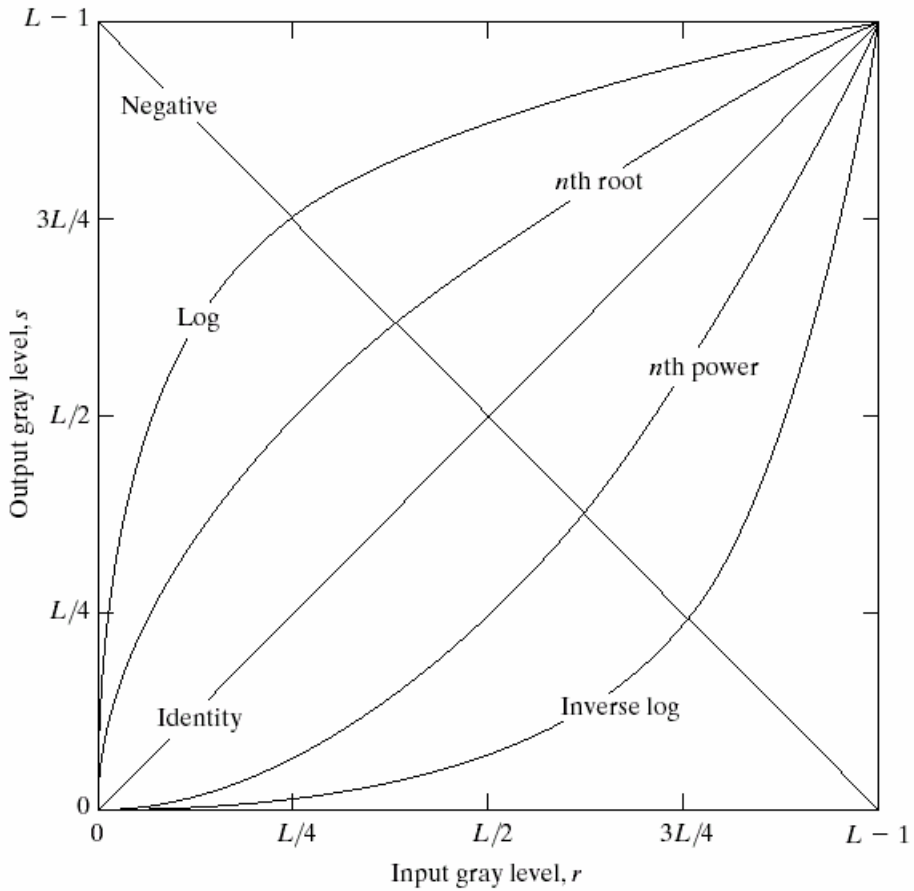
What can they do?

What's the form of *t*?

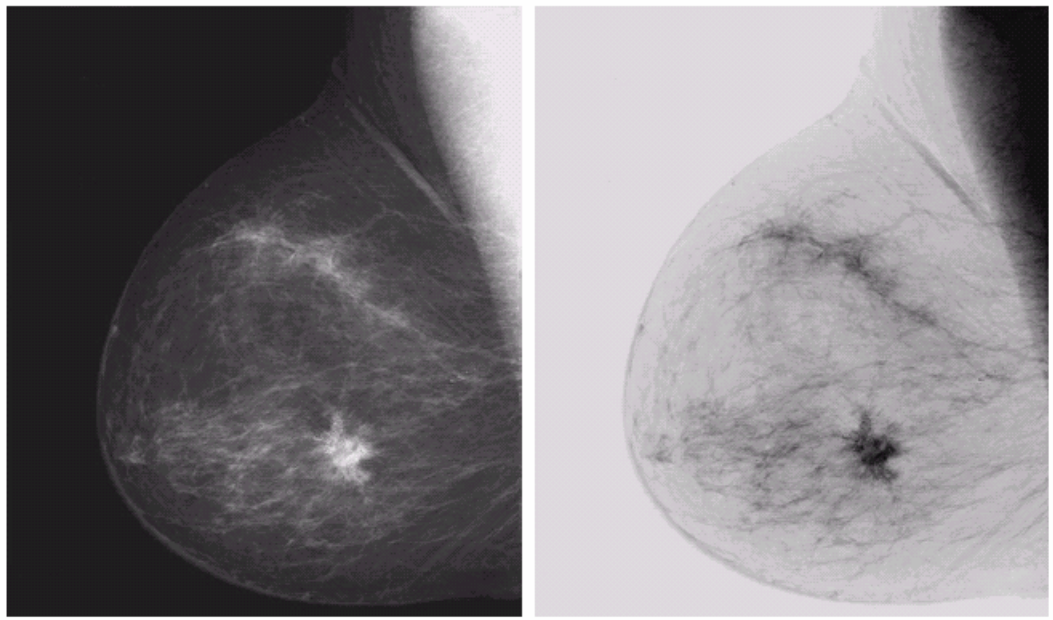
Important: every pixel for himself – spatial information completely lost!

Basic Point Processing

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



Negative



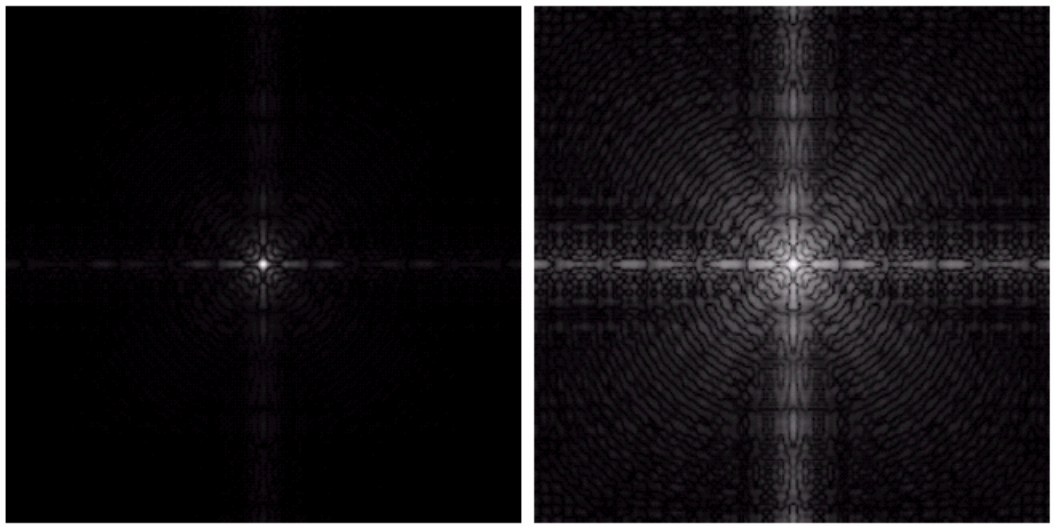
a b

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.)

Log

a b

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



Power-law transformations

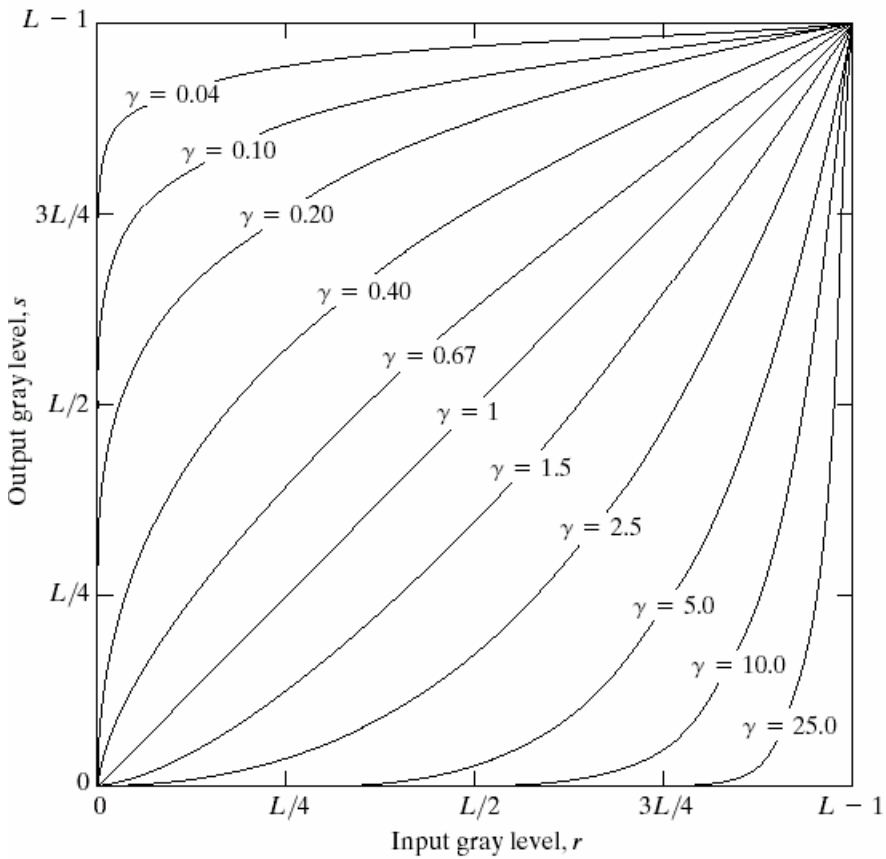


FIGURE 3.6 Plots of the equation $s = cr^{\gamma}$ for various values of γ ($c = 1$ in all cases).

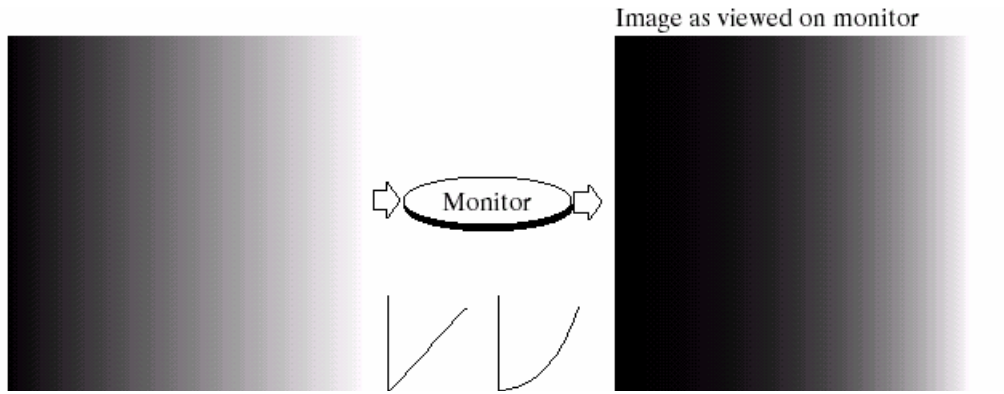
$$s = cr^{\gamma}$$

Image Enhancement

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.)

Example: Gamma Correction



a b
c d

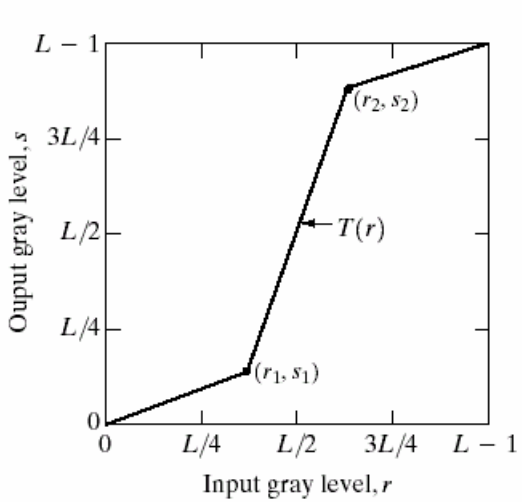
FIGURE 3.7
(a) Linear-wedge gray-scale image. (b) Response of monitor to linear wedge. (c) Gamma-corrected wedge. (d) Output of monitor.

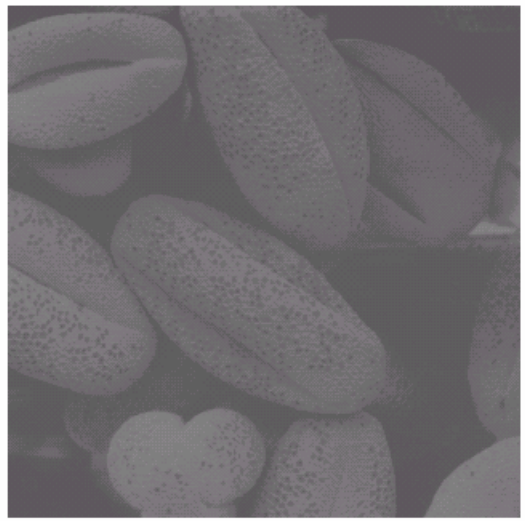
$$s = r^{\gamma}$$

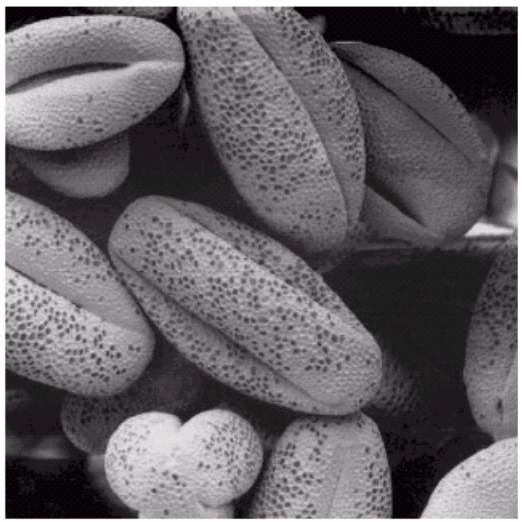
$$e.g.\quad 0.25 = 0.5^{2.0}$$

http://www.cs.berkeley.edu/~efros/java/gamma/gamma.html

Contrast Stretching



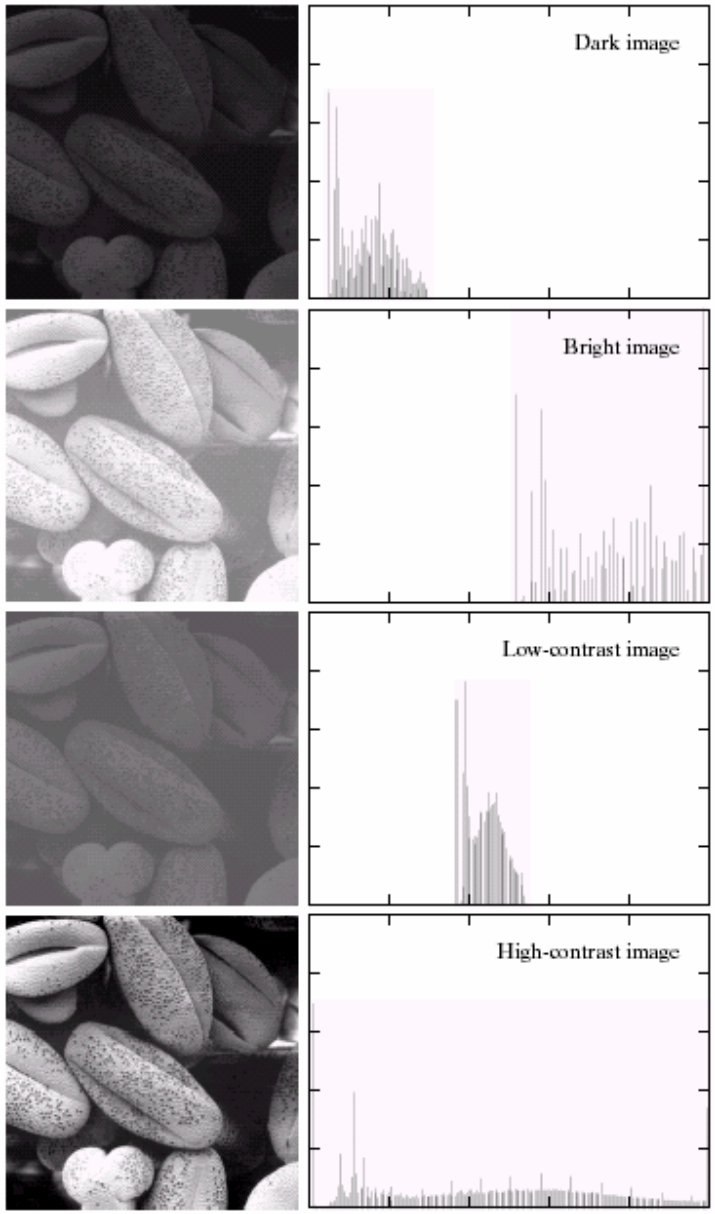


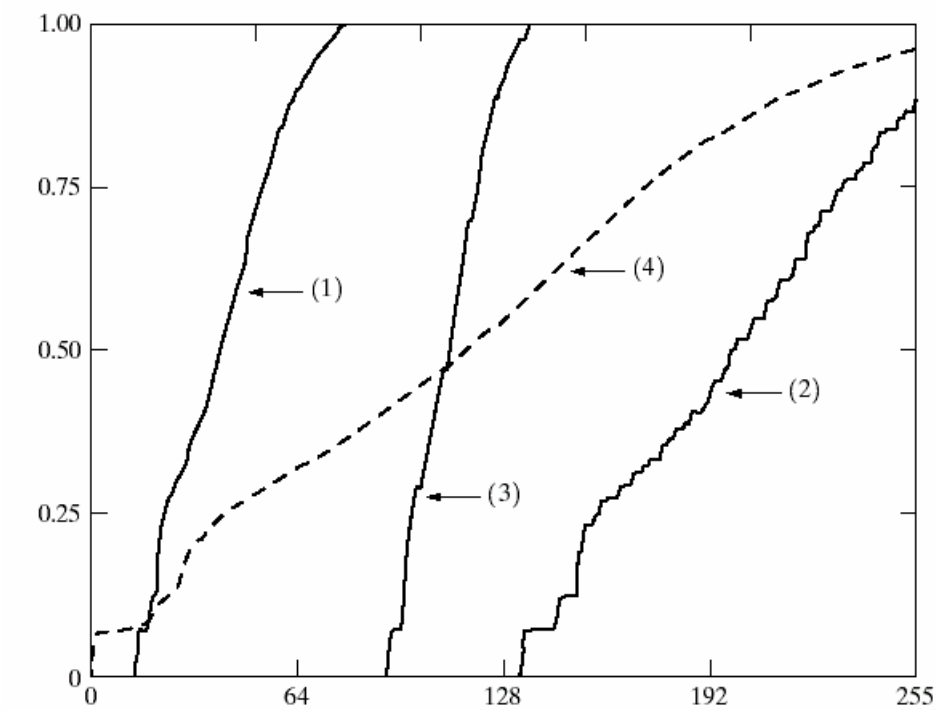


a b
c d

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.)

Image Histograms





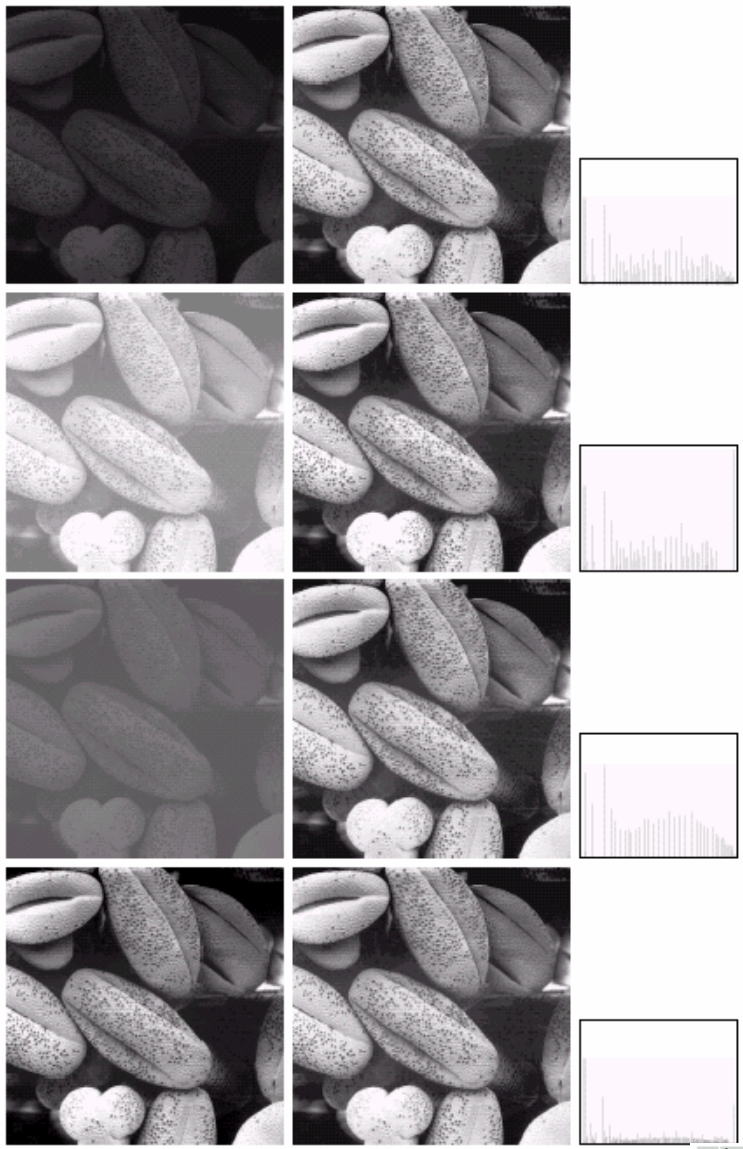
Cumulative Histograms

$s = T(r)$

a b

FIGURE 3.15 Four basic image types: dark, light, low contrast, high contrast, and their corresponding histograms. (Original image courtesy of Dr. Roger Heady, Research School of Biological Sciences, Australian National University, Canberra, Australia.)

Histogram Equalization

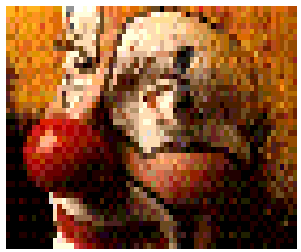


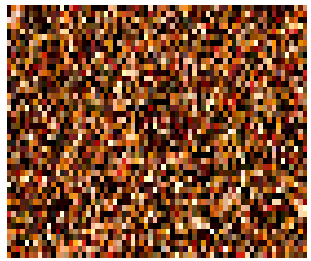
a b c

FIGURE 3.17 (a) Images from Fig. 3.15. (b) Results of histogram equalization. (c) Corresponding histograms.

Neighborhood Processing (filtering)

Q: What happens if I reshuffle all pixels within the image?





A: It's histogram won't change. No point processing will be affected…

Need spatial information to capture this…

…switch slides