Digital Image Processing

Ming-Sui (Amy) Lee

Mar. 8, 2007

Announcement

- Class Information
  - Class website
    - www.csie.ntu.edu.tw/~mslee (temporary)
    - Syllabus/Lecture #1/Lecture #2
    - Homework #1/sample codes/submission guidelines
  - Teaching Assistant
    - 陳映睿 Room 306 dip@csie.ntu.edu.tw
    - Office Hour: TBA
  - Exams
    - Midterm → 4/19
    - Final → 6/21

Announcement

- Homework Related
  - Submission guideline
    - Electronic version → email to TA
    - Written report → submit in class
    - Due by noon on the due date
  - Note
    - may discuss/no duplicating
    - all in English
    - TA's not responsible for debugging

Announcement

- Others
  - Professor C.-C. Jay Kuo

    University of Southern California

    “Techniques for Blind Audio Source Separation”

    Time: March 13 (Tuesday), 4:00~5:00 pm

    Place: CSIE Building, Room #110

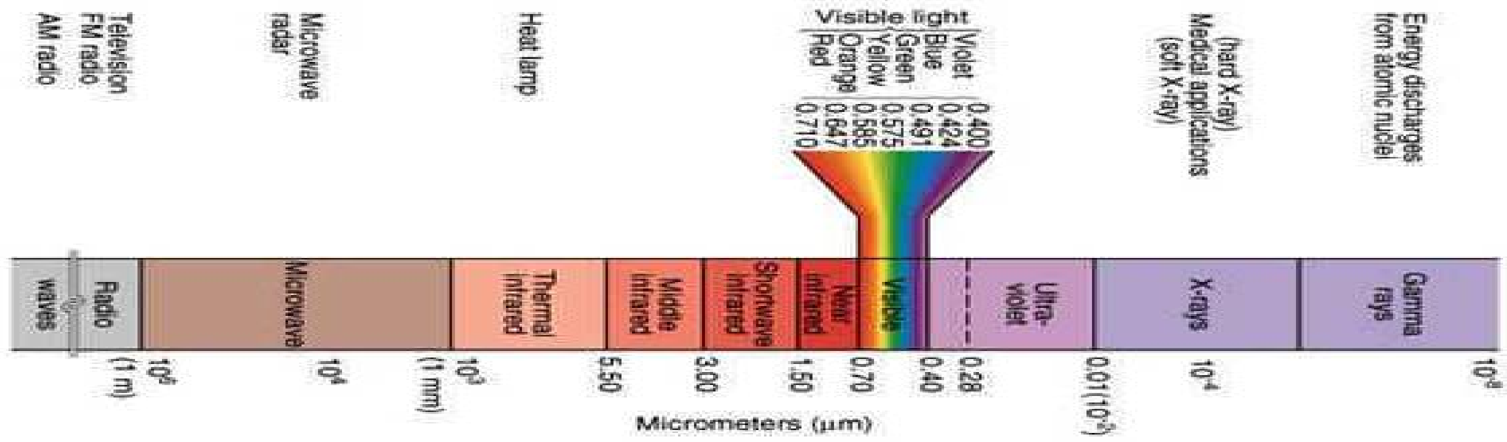
Introduction

Application of DIP

- Industry
  - Digital camera, camcoder, scanner,…
  - LCD TV, Plasma TV, …
- Medical Imaging & Image Analysis
  - CT, MRI, X-ray
  - Bioinformatics for drug design
- Others
  - Satellite imaging, resource analysis, national defense

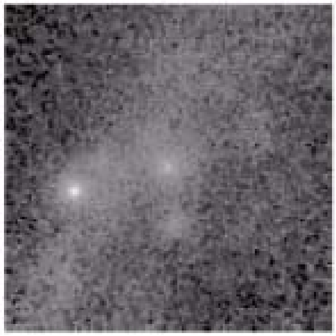
Categorize Images via Source

- Electromagnetic (EM) Spectrum

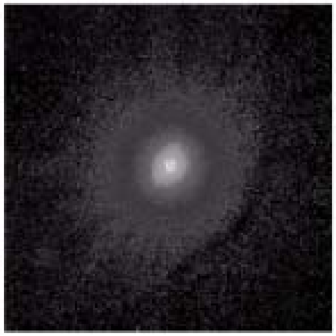


- Others
  - Acoustic Imaging, Electron Microscopy, Synthetic Imaging

Examples



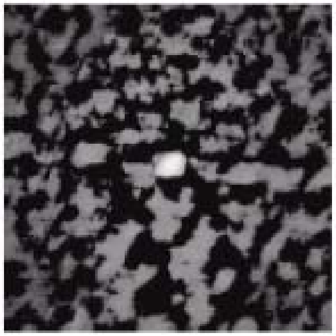
Gamma



X-ray

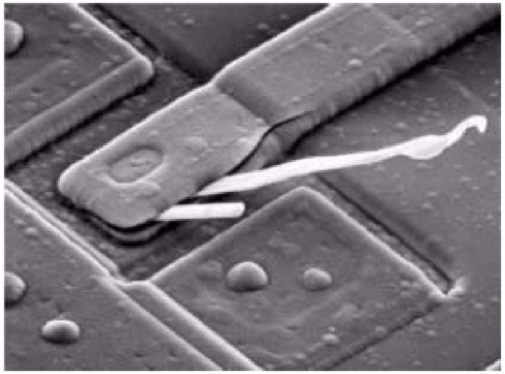
Optical

Infrared

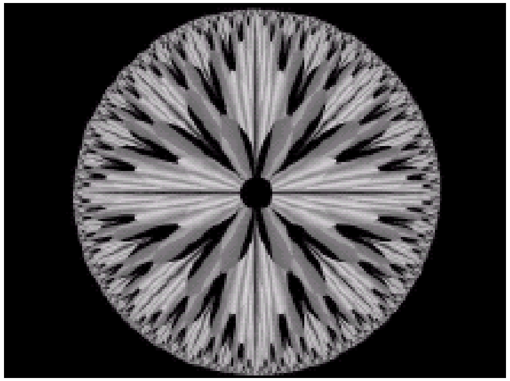


Radio

Ultrasound



SEM



synthetic

Traditional Topics

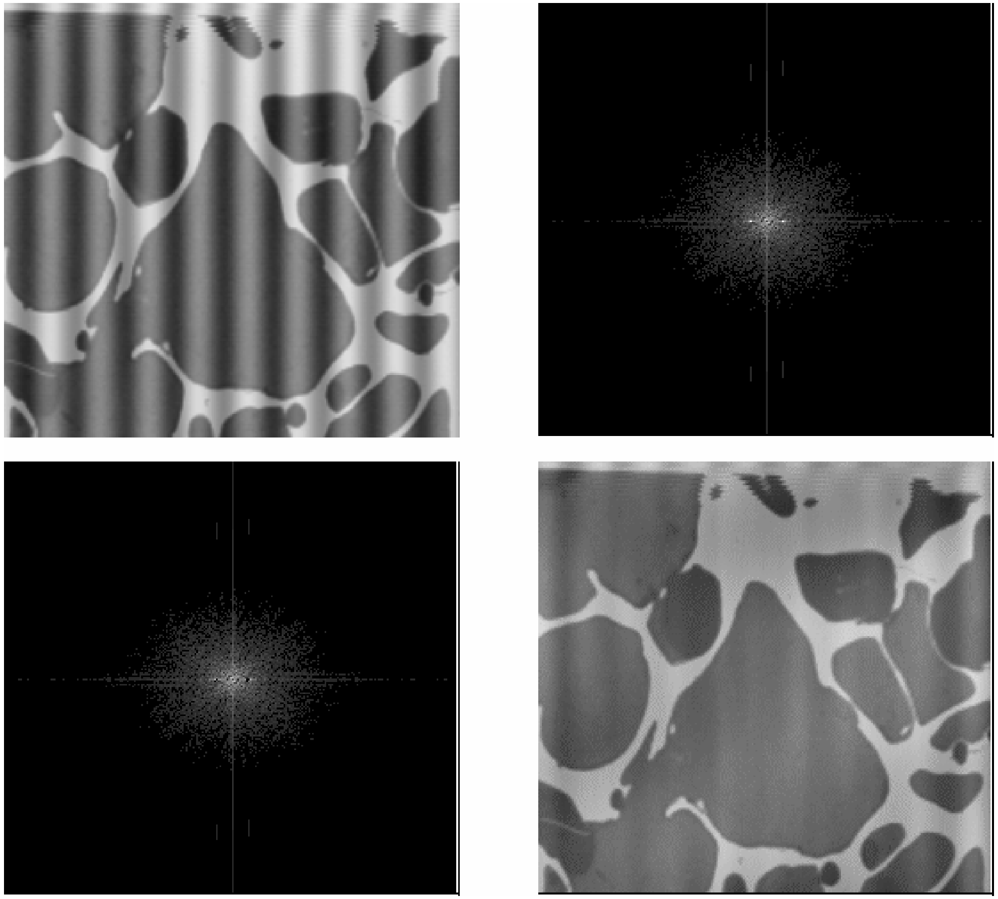
- Image Enhancement
  - Improve image contrast by adjusting its histogram

Traditional Topics

- Image Restoration
  - Remove the degradation effects to recover an image to its original condition

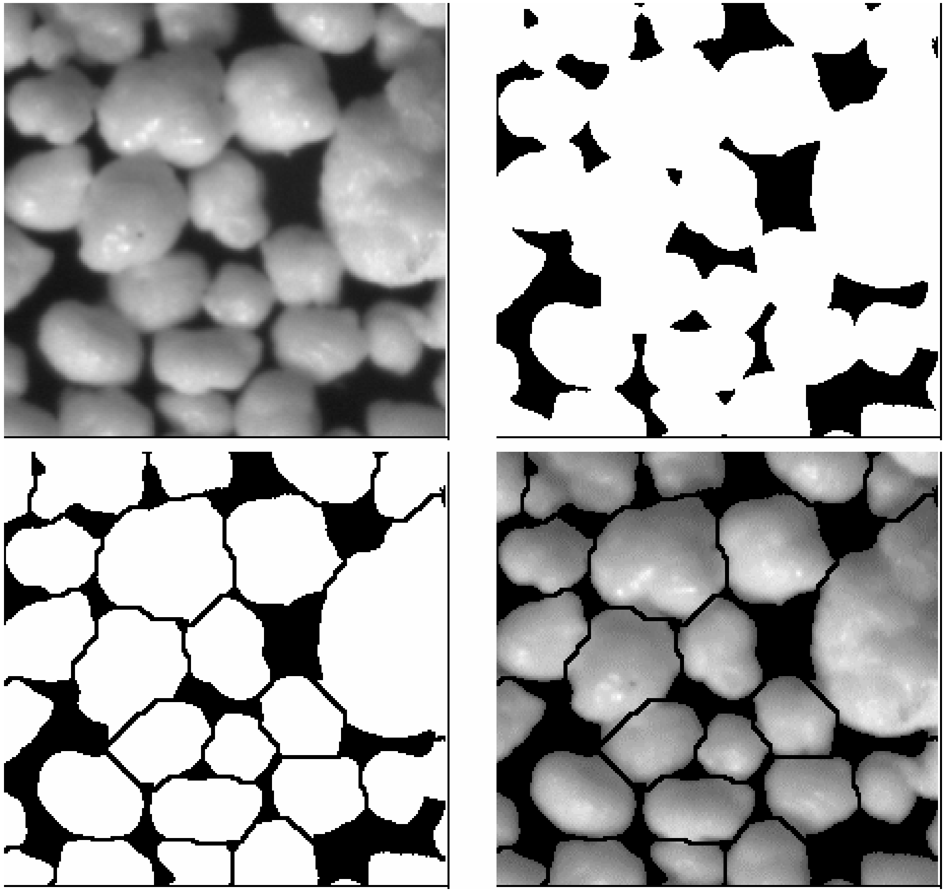
Traditional Topics

- Image Transformation



Traditional Topics

- **Image Segmentation**

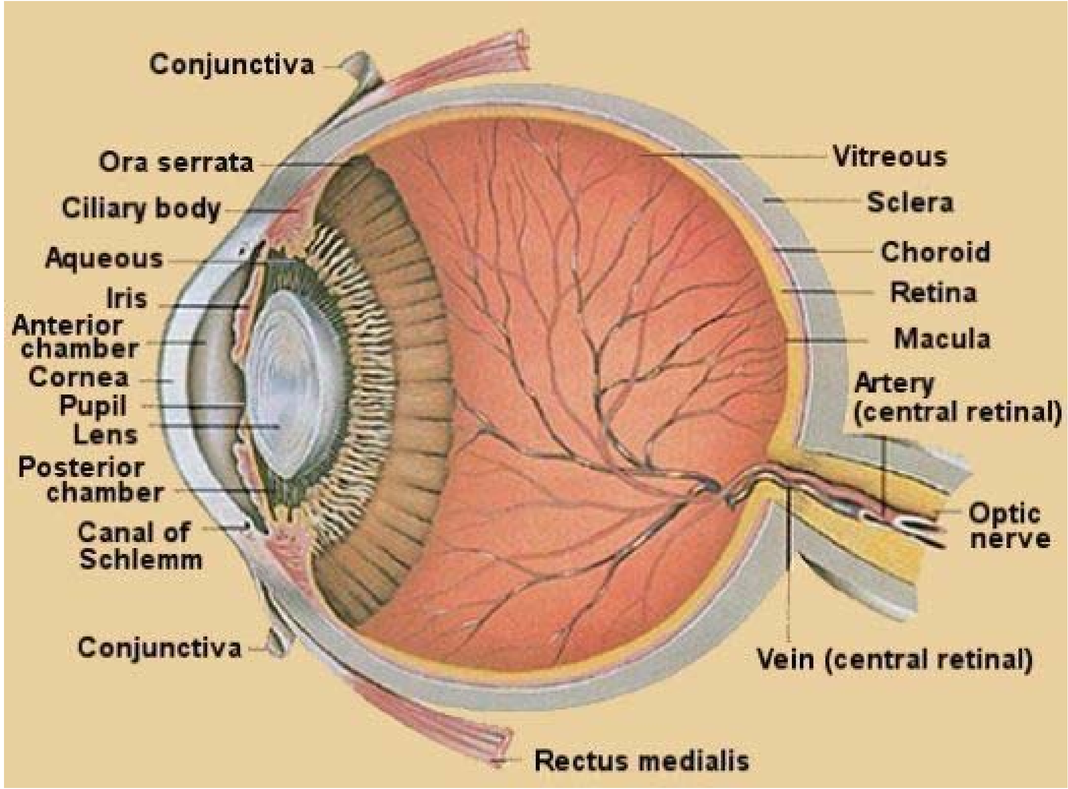


Digital Image Fundamentals

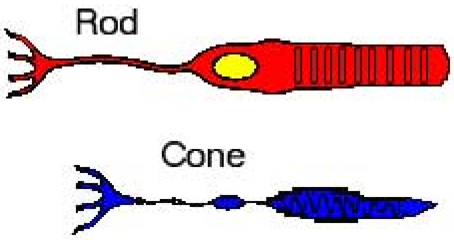
Image Quality

- Objective/ subjective
  - Machine/human beings
  - Mathematical and Probabilistic/ human intuition and perception

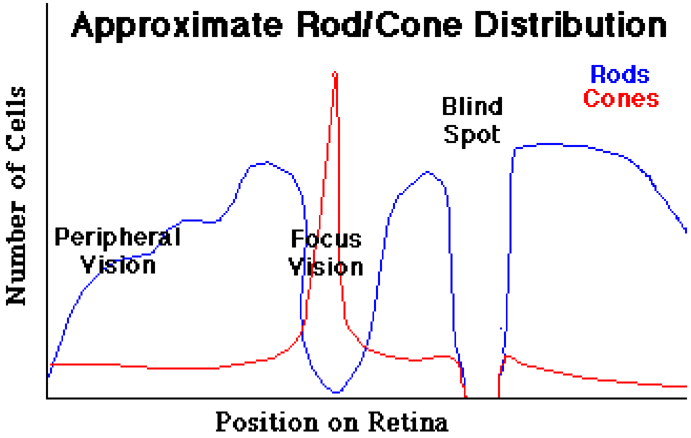
Structure of the Human Eye



75~150 million

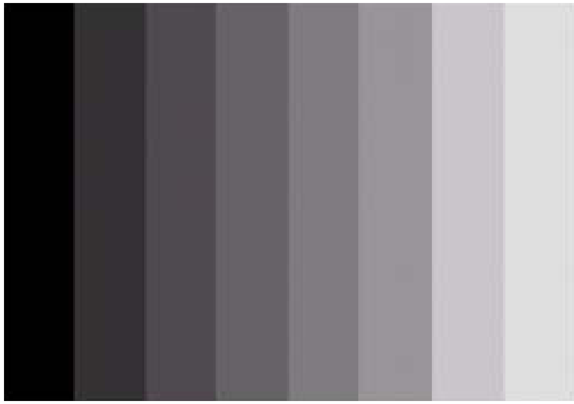


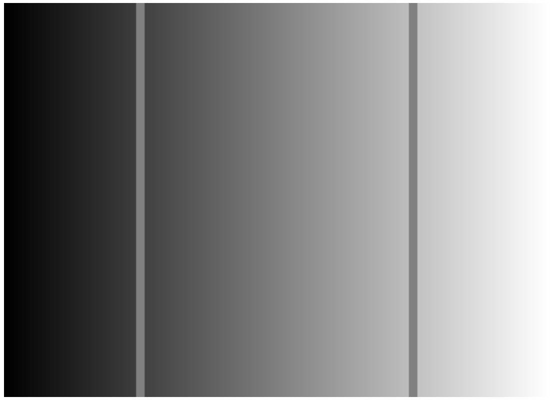
6~7 million

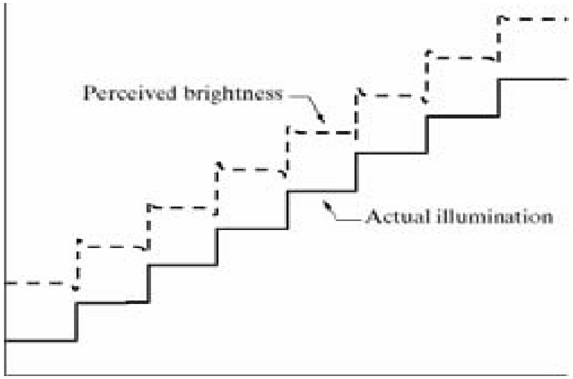


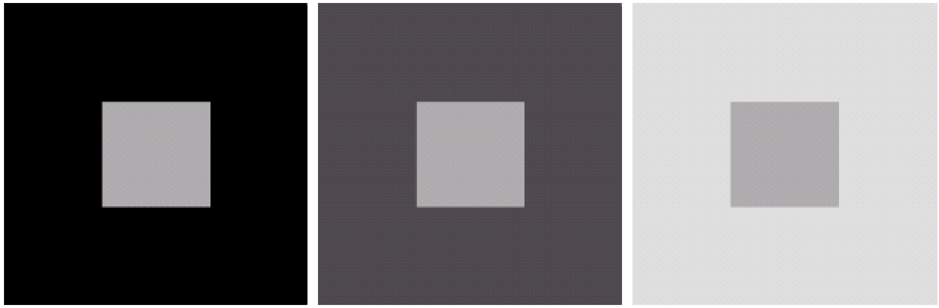
Human Visual Perception

- **Perceived brightness is NOT a simple function of intensity**



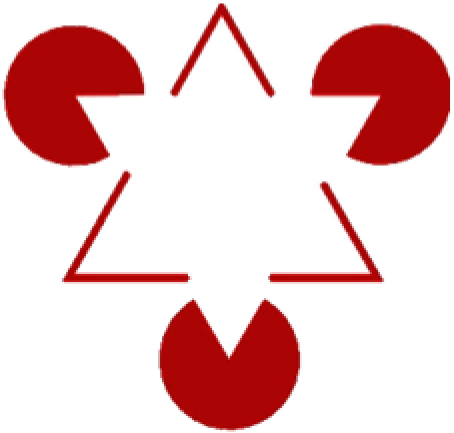


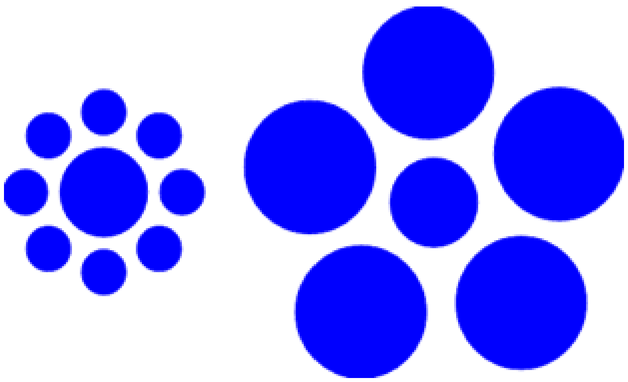




Human Visual Perception

- **Optical Illusion**





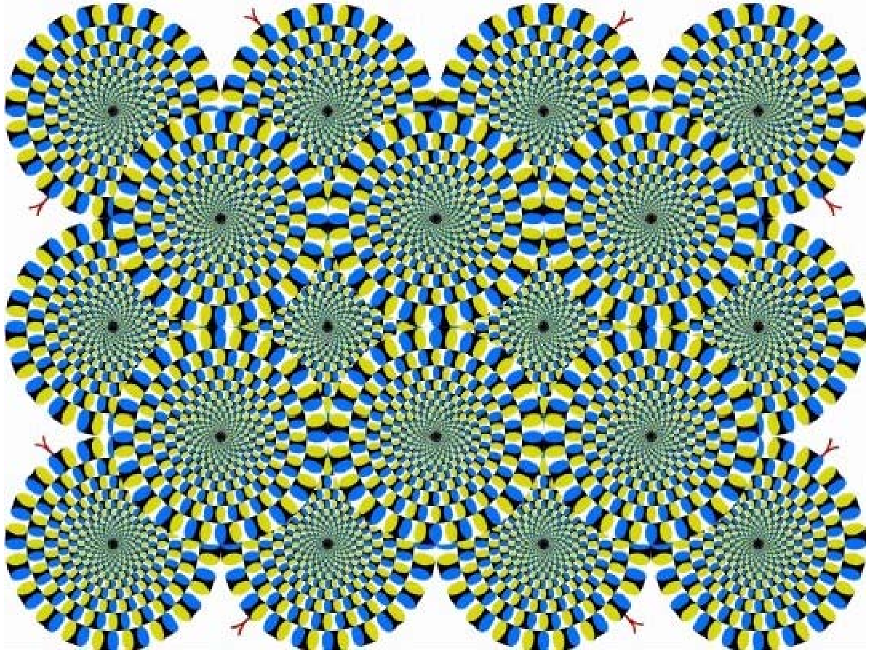


Image Sensing and Acquisition

- Illumination Source
  - EM energy, ultrasound, synthesized, …
- Scene Element
  - Objects, human organs, buried mineral,…
- Sensing Material
  - Single sensor: photodiode
  - Sensor strips: require extensive processing
  - Sensor arrays: CCD & CMOS

Image Sensing and Acquisition

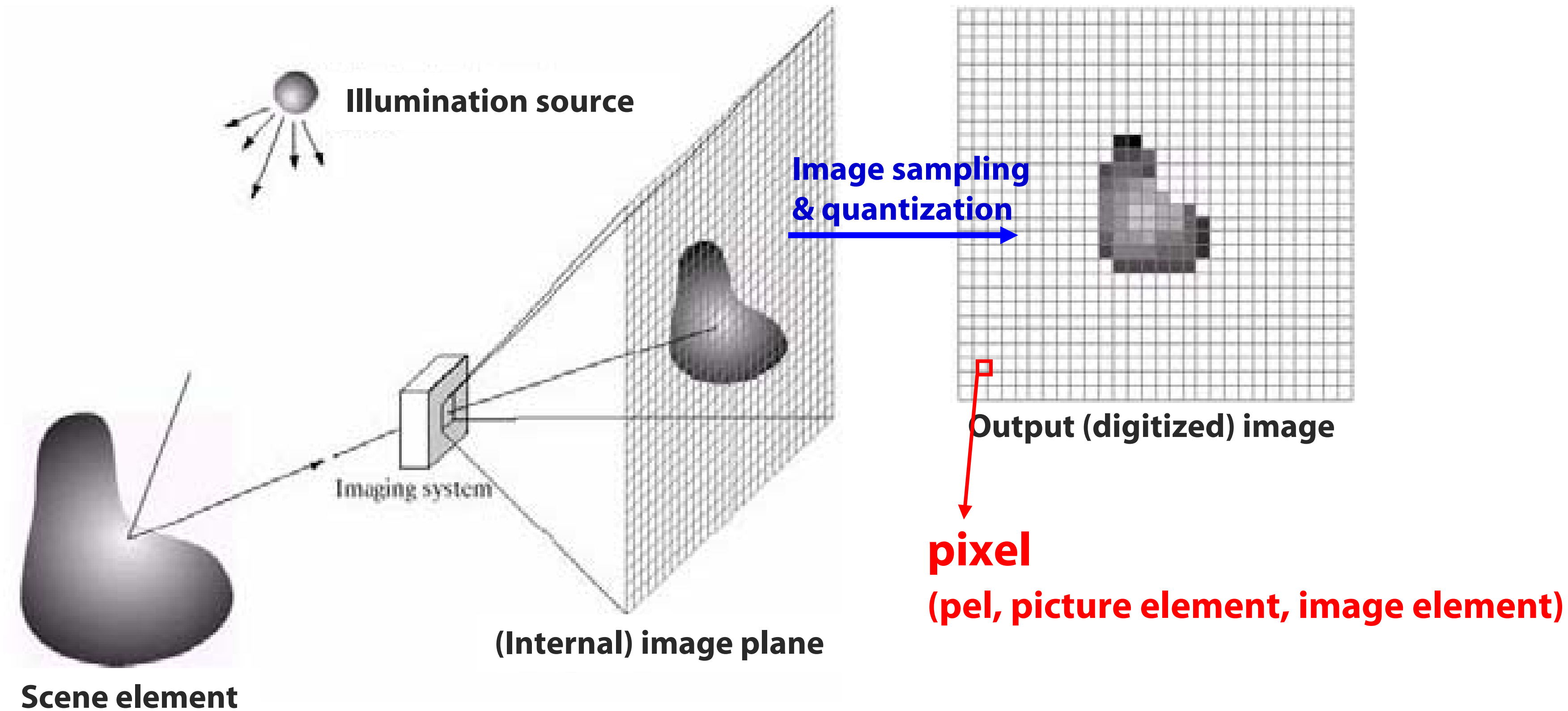
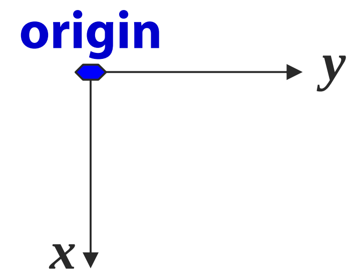


Image Formation Model

- **An image → 2D function**



$$0 < f(x, y) < \infty$$

where x and y are spatial coordinates

- **Categorized by two components**

$$f(x, y) = i(x, y)r(x, y)$$

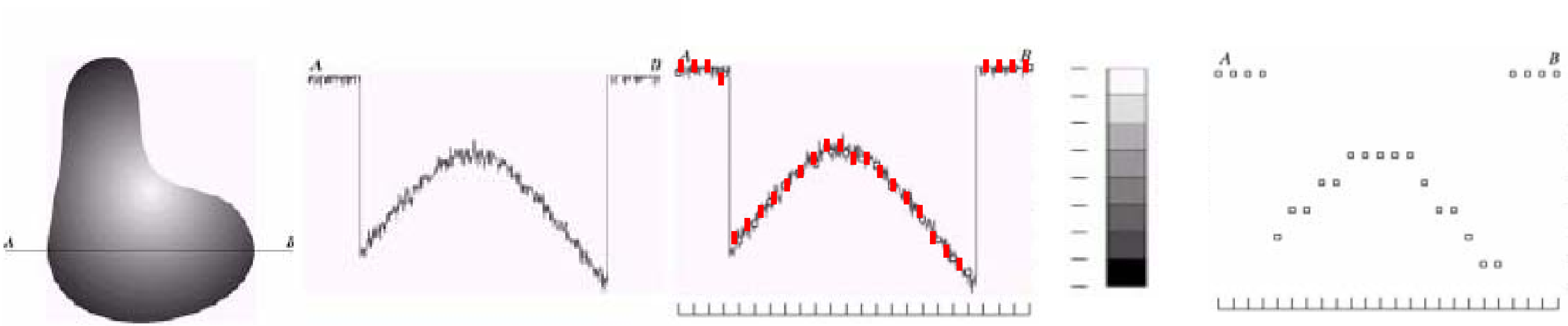
  - **Illumination:** $0 < i(x, y) < \infty$
  - **Reflectance:** $0 < r(x, y) < 1$
    - black velvet, flat-white wall paint, snow, silver-plated metal

      0.1 0.8 0.93 0.9

Image Sampling & Quantization

$$f(x,y) \longrightarrow \boxed{\textbf{A/D}} \longrightarrow F(j,k)$$

sampling **quantization**

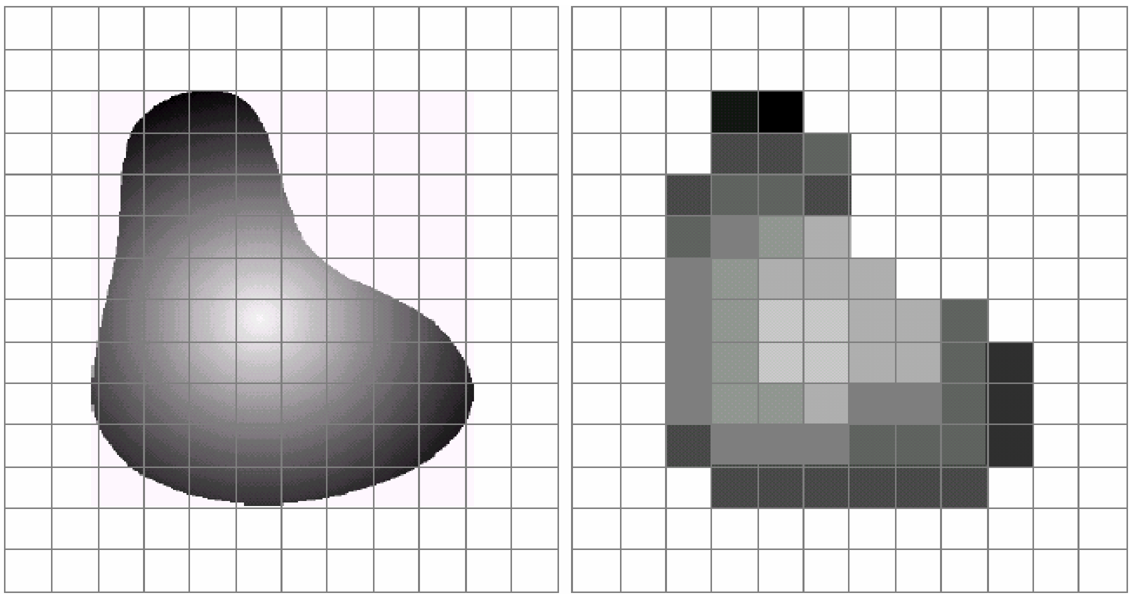


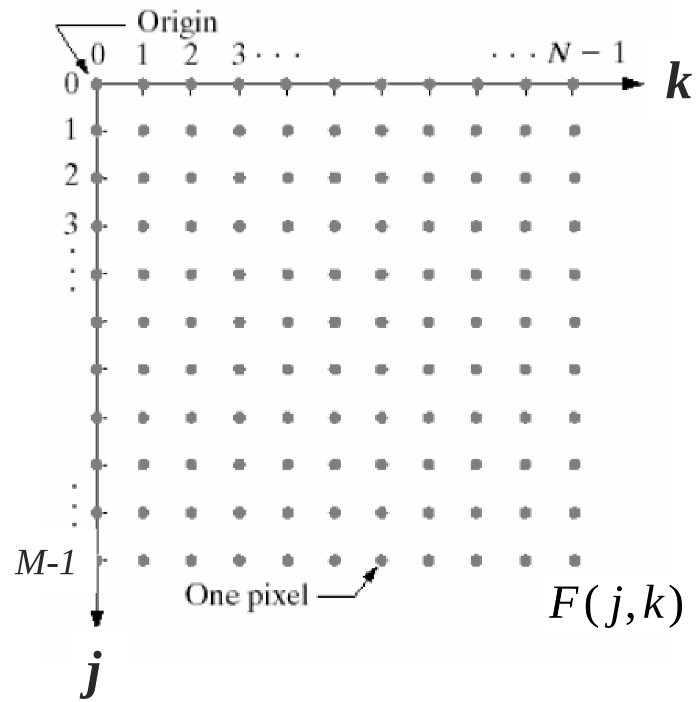
Original image $f(x,y)$ **sampling** **quantization** $F(j,k)$

sampling $\downarrow$ **coordinates**

quantization $\downarrow$ **amplitude**

Image Sampling & Quantization





$$A = \begin{bmatrix} a_{0,0} & a_{0,1} & \cdots & a_{0,N-1} \\ a_{1,0} & a_{1,1} & \cdots & a_{1,N-1} \\ \vdots & \vdots & \ddots & \vdots \\ a_{M-1,0} & a_{M-1,1} & \cdots & a_{M-1,N-1} \end{bmatrix} \qquad F(j,k) = \begin{bmatrix} F(0,0) & F(0,1) & \cdots & F(0,N-1) \\ F(1,0) & F(1,1) & \cdots & F(1,N-1) \\ \vdots & \vdots & \ddots & \vdots \\ F(M-1,0) & F(M-1,1) & \cdots & F(M-1,N-1) \end{bmatrix}$$

Digital Image Representation

- **Dynamic Range**
  - **The range of values spanned by the gray scale**

    $$\{0,\ \ 1,\ldots,L-1\} \qquad L=2^k$$

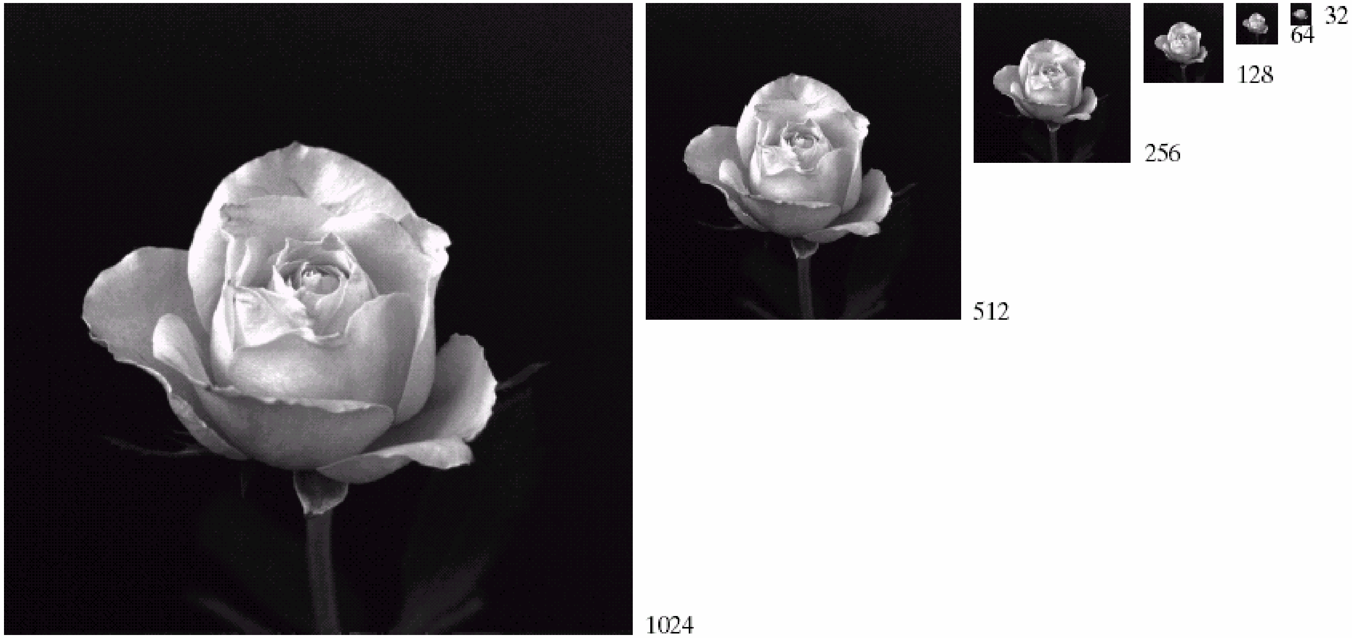
- **Image Size**
  - **for a square image,** $M=N$

    total number of bits required to store the image: $b=N^2\cdot k$

N/k	1 (L = 2)	2 (L = 4)	3 (L = 8)	4 (L = 16)	5 (L = 32)	6 (L = 64)	7 (L = 128)	8 (L = 256)
32	1,024	2,048	3,072	4,096	5,120	6,144	7,168	8,192
64	4,096	8,192	12,288	16,384	20,480	24,576	28,672	32,768
128	16,384	32,768	49,152	65,536	81,920	98,304	114,688	131,072
256	65,536	131,072	196,608	262,144	327,680	393,216	458,752	524,288
512	262,144	524,288	786,432	1,048,576	1,310,720	1,572,864	1,835,008	2,097,152
1024	1,048,576	2,097,152	3,145,728	4,194,304	5,242,880	6,291,456	7,340,032	8,388,608
2048	4,194,304	8,388,608	12,582,912	16,777,216	20,971,520	25,165,824	29,369,128	33,554,432
4096	16,777,216	33,554,432	50,331,648	67,108,864	83,886,080	100,663,296	117,440,512	134,217,728
8192	67,108,864	134,217,728	201,326,592	268,435,456	335,544,320	402,653,184	469,762,048	536,870,912

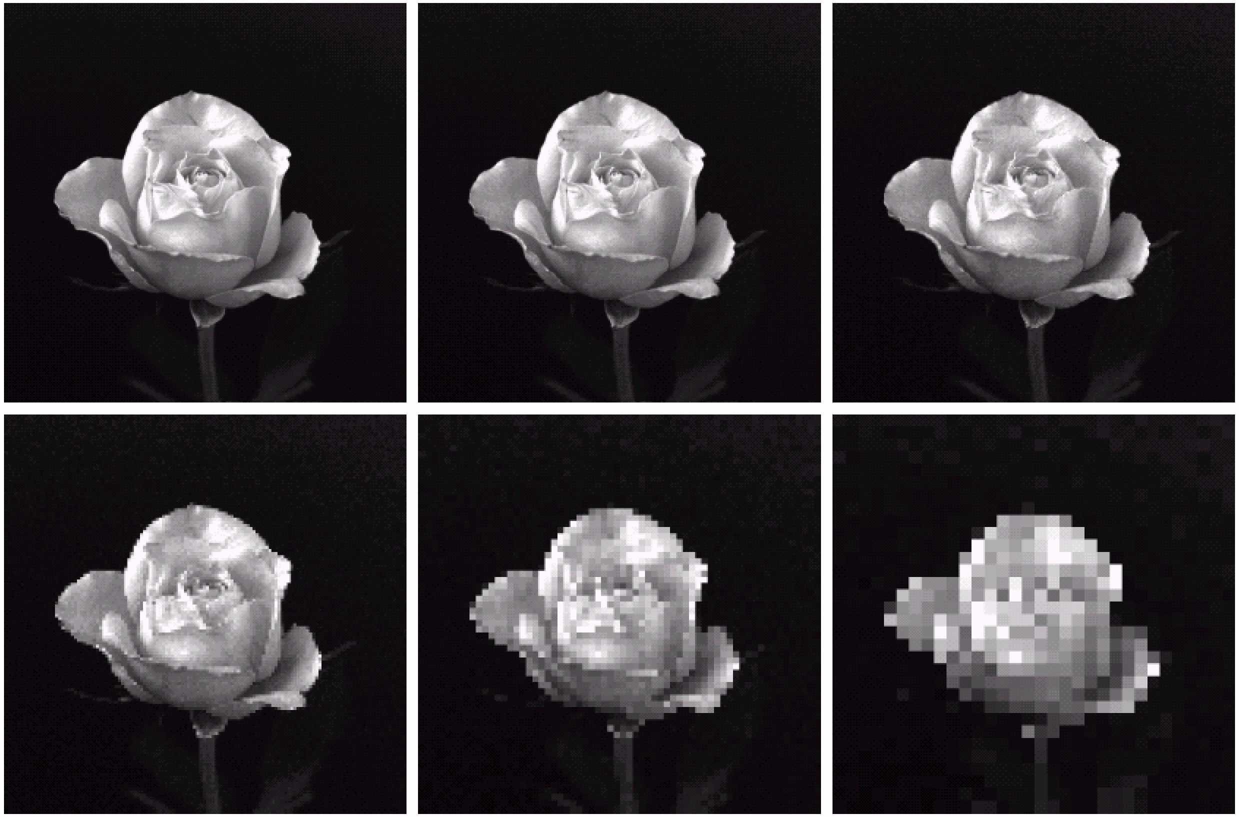
Downsampling

- 1024x1024 → 32x32
  - Downsampled by a factor of 2

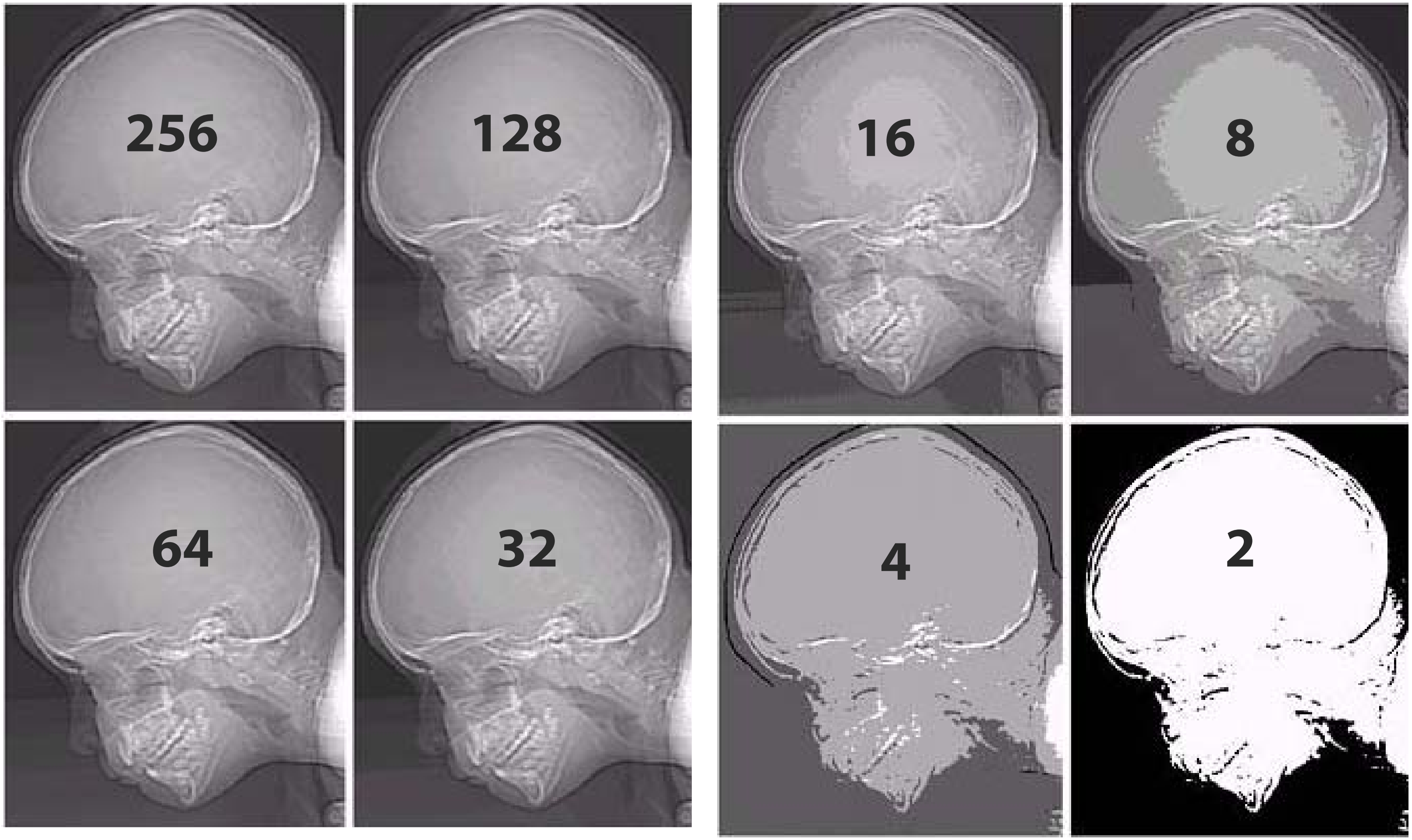


Re-Sampling

- **Zero-Order-Hold Method (ZOH)**
  - **Row and column duplication**

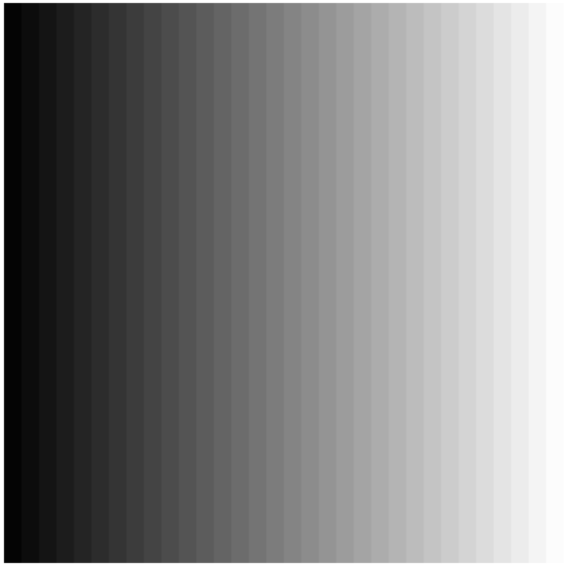


L=256,128,64,32,16,8,4,2

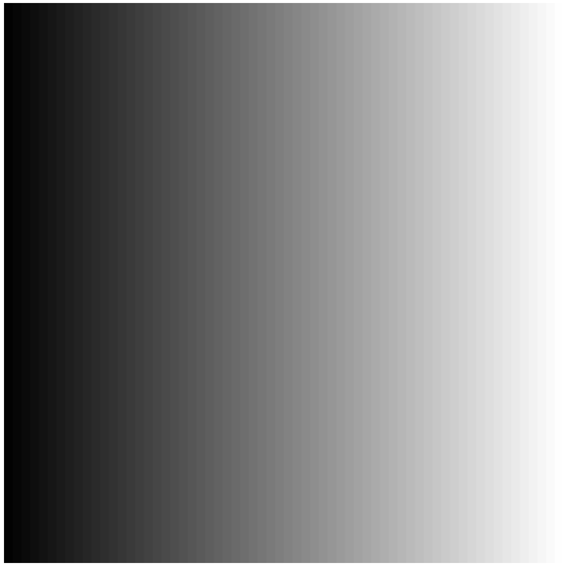


Digital Image Representation

- 8-bit image is commonly used
  - Storage
  - Human perception



32 steps (5 bits) in gray level



64 steps (6 bits) in gray level

Image Enhancement

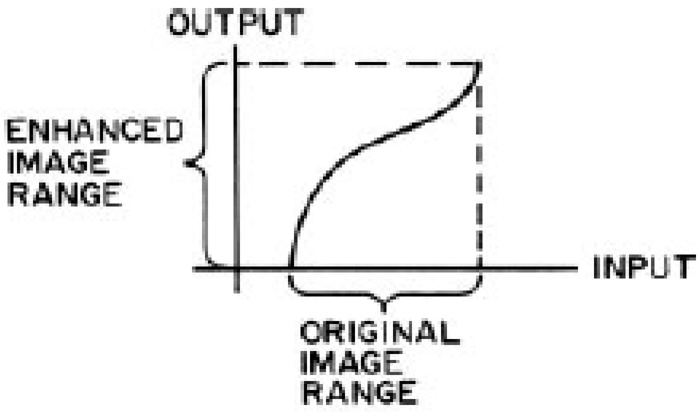
Image Enhancement

- **Goal of Image Enhancement**
  - make images more appealing
  - no theory, ad-hoc rules, derived with insights

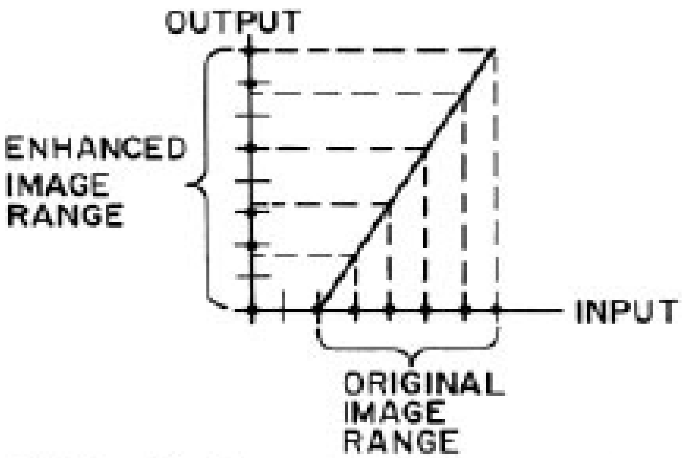
- **Two Approaches**
  - Contrast Manipulation
  - Histogram Modification

Contrast Manipulation

- **Transfer Function**
  - Linear
  - Nonlinear
  - piecewise



Continuous Image



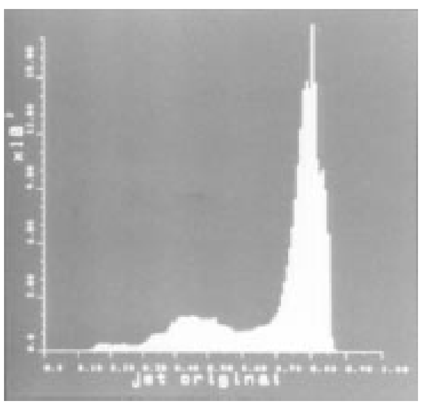
Quantized Image

Contrast Manipulation

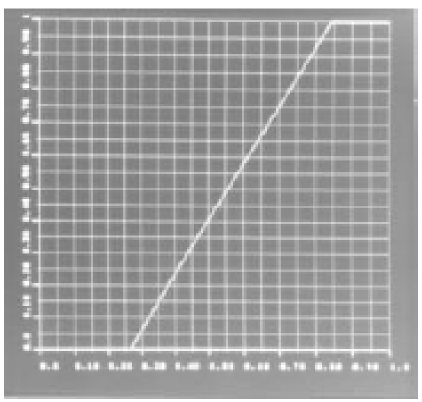
- **Linear scaling and clipping**

$$G(j,k) = T\left[F(j,k)\right]$$

(*a*) Original



(*b*) Original histogram



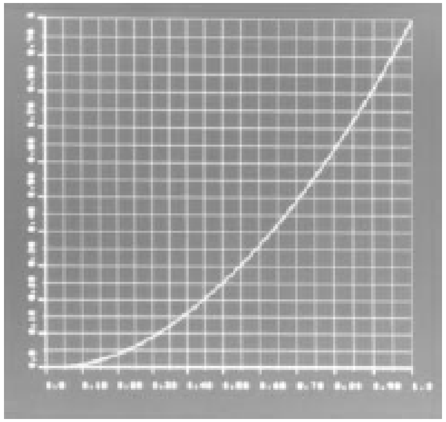
(*c*) Transfer function

(*d*) Contrast stretched

Contrast Manipulation

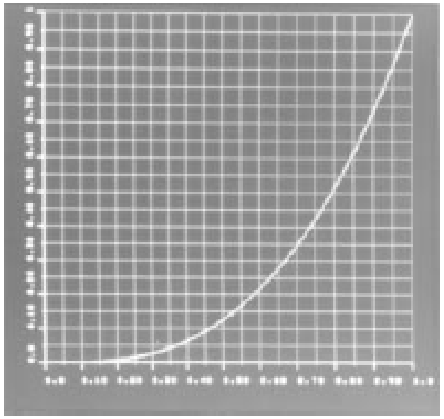
- **Power-Law**

$$G(j,k) = \left[F(j,k)\right]^p \qquad 0 \le F(j,k) \le 1$$



(a) Square function

(b) Square output



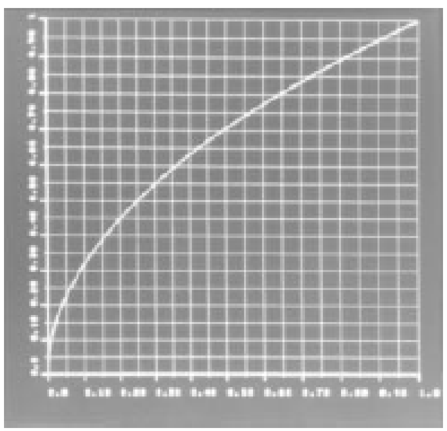
(c) Cube function

(d) Cube output

Contrast Manipulation

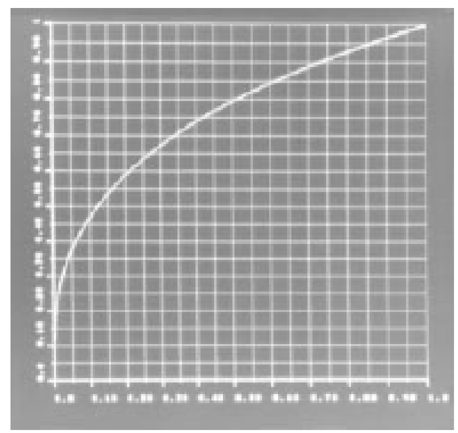
- **Power-Law**

$$G(j,k) = \left[F(j,k)\right]^{p} \quad 0 \le F(j,k) \le 1$$



(a) Square root function

(b) Square root output

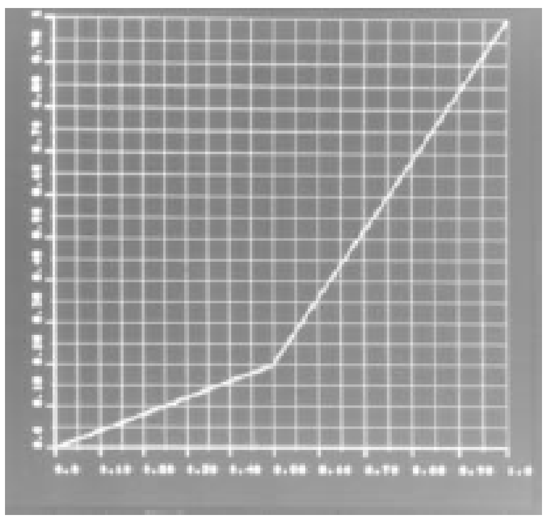


(c) Cube root function

(d) Cube root output

Contrast Manipulation

- **Rubber Band Transfer Function**
  - **Piecewise linear transformation**
  - **Inflection point (control point)**



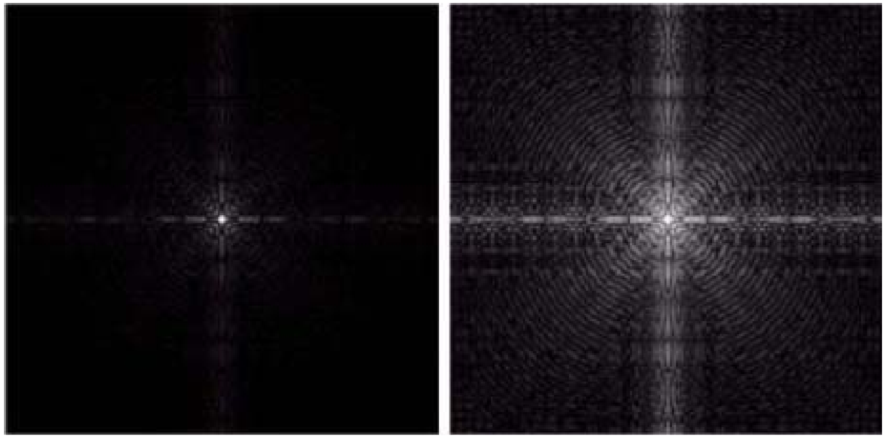
Can choose the area where we want to stretch or reduce the contrast

Contrast Manipulation

- **Logarithmic Point Transformation**

$$G(j,k) = \frac{\log_e\{1 + aF(j,k)\}}{\log_e\{2.0\}} \qquad 0 \le F(j,k) \le 1$$

Fourier Spectrum



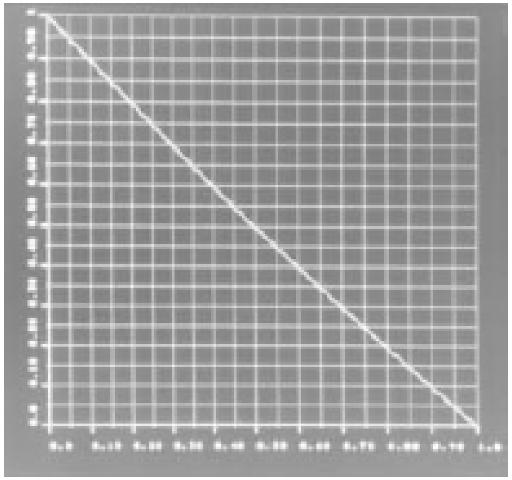
$0 \sim 1.5 \times 10^6 \longrightarrow$ 0~6.2

Useful for scaling image arrays with a very wide dynamic range

Contrast Manipulation

- **Reverse Function**

$$G(j,k) = 1 - F(j,k) \quad 0 \le F(j,k) \le 1$$



(a) Reverse function

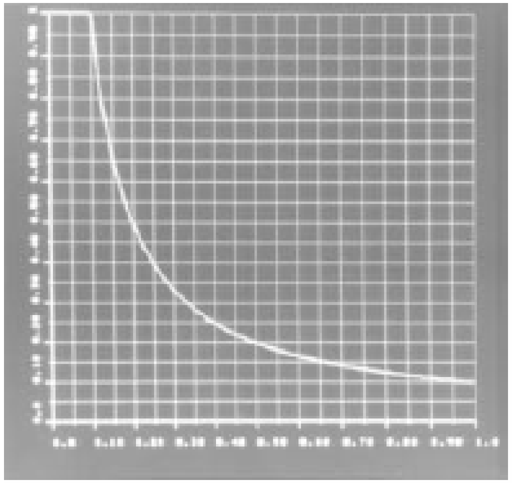
(b) Reverse function output

Able to see more detail in dark areas of an image

Contrast Manipulation

- **Inverse Function**

$$G(j,k)=\begin{cases} 1 & 0 \le F(j,k) \le 0.1 \\ \dfrac{0.1}{F(j,k)} & 0.1 \le F(j,k) \le 1 \end{cases}$$

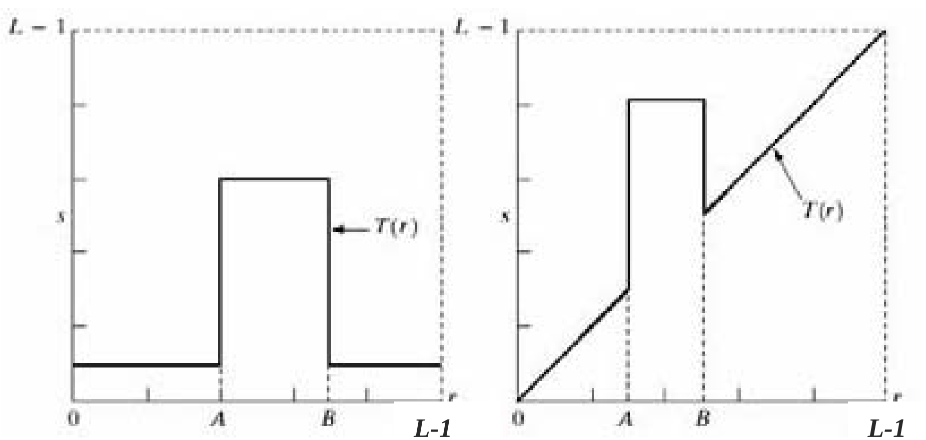


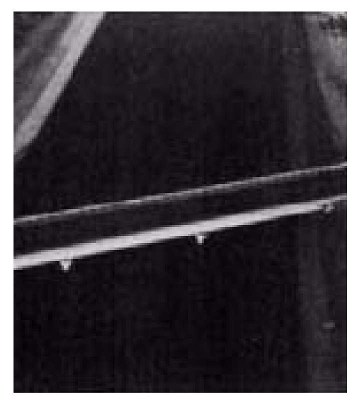
(*c*) Inverse function

(*d*) Inverse function output

Contrast Manipulation

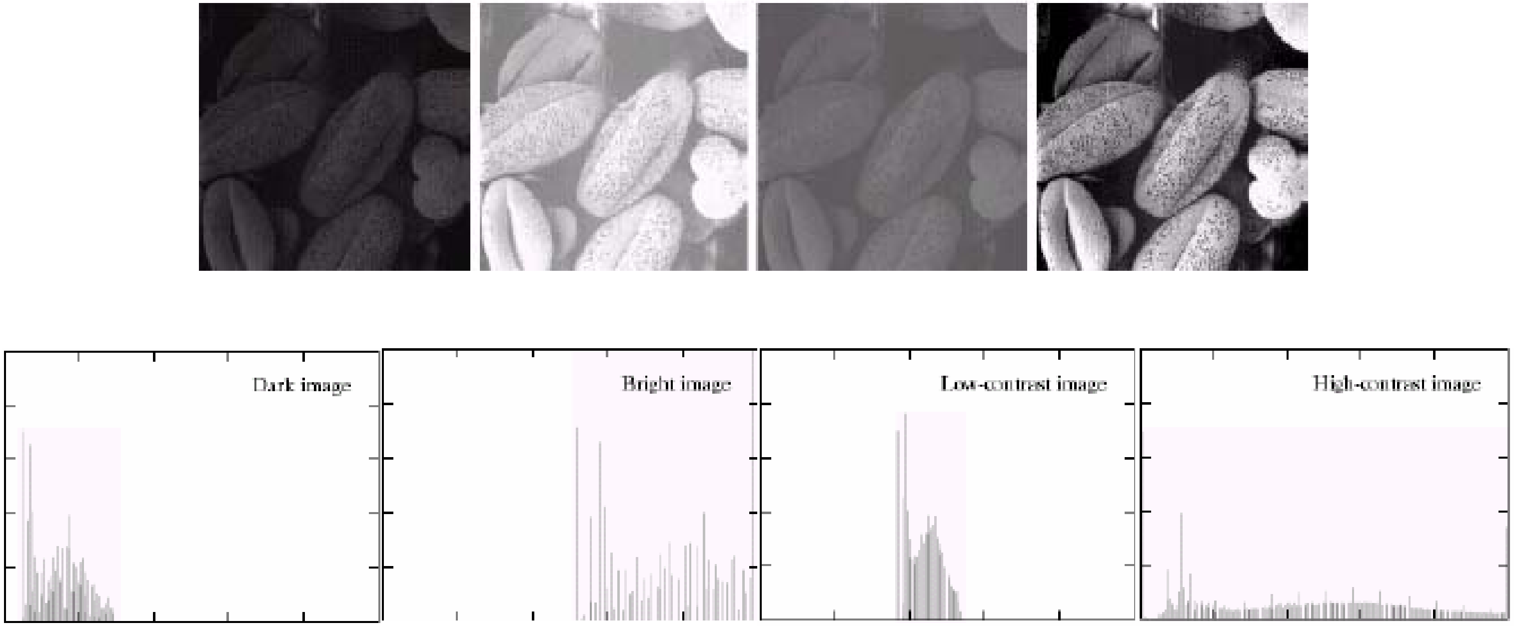
- **Amplitude-Level Slicing (Gray-Level Slicing)**





Histogram Modification

- **Goal**
  - Rescale the original image so that the histogram of the enhanced image follows some desired form

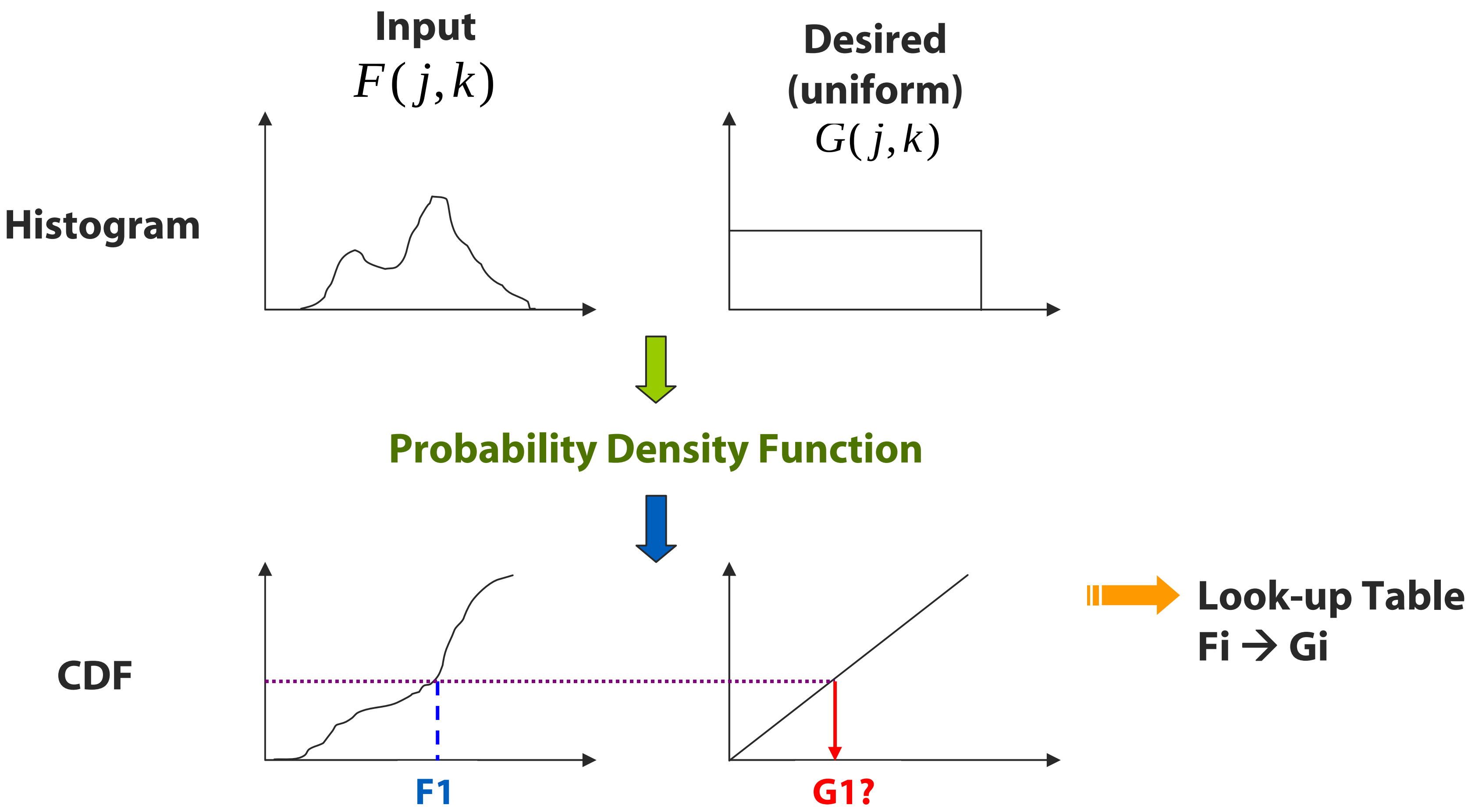


Histogram Modification

- Histogram Equalization
  - make the output histogram to be uniformly distributed
    - Transfer function
    - Bucket filling

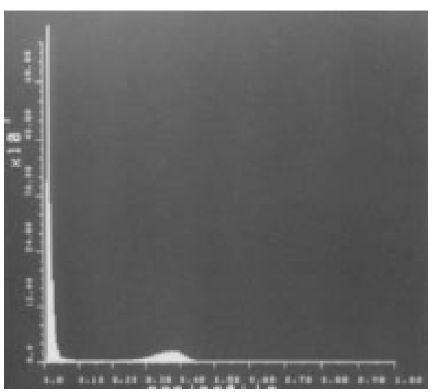
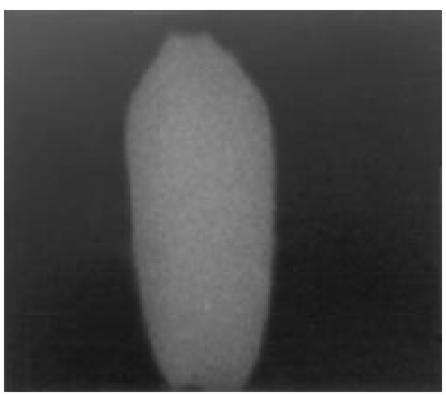
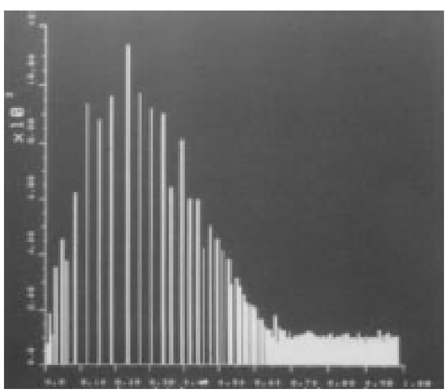
Histogram Equalization

- **Transfer Function**



Histogram Equalization

- Transfer Function
  - Output histogram not really uniformly distributed
  - Still keep the shape
  - More flat than the original histogram

Histogram Equalization

- Bucket Filling

arbitrary

F(j,k)	# of pixels
0	1
1	2
2	5
⋮	⋮
255	3

uniform

G(j,k)	# of pixels
0	N/256
1	N/256
2	N/256
⋮	⋮
255	N/256

N: # of total pixels

  - Not 1-1 mapping
  - Accumulated probability may not end exactly at the boundary of a bin → split it out