Digital Image Processing-Basics, Sampling and Quantization

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Why do you process an ‘Image’ ?

- ✓ Improvement of pictorial/image information for human perceptions/interpretations
  (better understanding)
- ✓ Image processing (image/video) for autonomous machine perception and applications (HMI) (Automation)
- ✓ Efficient storage and Transmission
  (Communication and Reuse)

Before starting study of Digital Image processing one should first brush up basic concepts of the following...

- Linear Algebra and Calculus

  Point operation and matrix operations, Eigen vectors, Eigen values, Images as matrices and matrices as images : Max/Min/std/var/etc., Sampling, ADC, DAC, etc.
- Differential Equations
- Probability and Statistics
- Digital Electronics
- Signals and systems
- Digital Signal Processing
- Programming skills

  (C++, MATLAB, Python or any applicable coding)

Digital Image Processing has broad spectrum of applications…

- Remote sensing via satellites: Space photographs, satellite imaging, weather predictions, Astronomy, etc.
- Entertainment and Consumer Electronics: Commercial images, movies, image special effects, etc.
- Scientific Metrology: Earthquake, Natural resources surveys, under earth data acquisition, etc.
- Information Technology: I-net, Intranet, Multimedia, etc.
- Storage and Business applications

- Medical image processing: Diagnostic Imaging (X-rays, CT, MRI, fMRI, USG, Color Doppler, hematology Image, etc.)
- Acoustic image processing

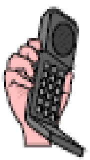
- Robotics and automation, Unmanned vehicles, etc.
- Quality control in industrial Automation, etc.
- Document image processing: Office Automation, OCR, etc.

- Military: RADAR, SONAR, target and missile detection, etc.

Applications of DSP+DIP

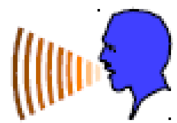
COMMUNICATIONS

- Echo Cancellation
- Adaptive Equalization
- Digital PBXs
- Line Repeaters
- Modems
- Global Positioning
- Sound/Modem/Fax Cards
- Cellular Phones
- Speaker Phones
- Video Conferencing
- ATMs

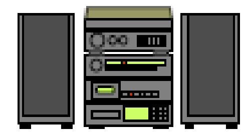


VOICE/SPEECH

- Speech Recognition
- Speech Processing/Vocoding
- Speech Enhancement
- Text-to-Speech
- Voice Mail



AUDIO



- AV Editing
- Digital Mixers
- Home Theater
- Pro Audio

DIP +

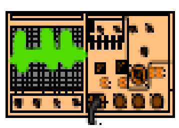
+ DSP

CONSUMER

- digital television
- digital camera
- internet music, phones and video
- digital answer machines, fax and modems
- voice mail system
- interactive entertainment systems

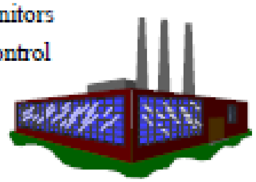
INSTRUMENTATION

- Spectrum Analyzers
- Seismic Processors
- Digital Oscilloscopes
- Mass Spectrometers



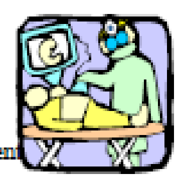
INDUSTRIAL/CONTROL

- Robotics
- Numeric Control
- Power Line Monitors
- Motor/Servo Control

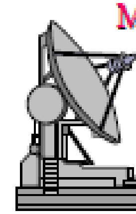


BIO MEDICAL

- Patient Monitoring
- Ultrasound Equipment
- Diagnostic Tools
- Fetal Monitors
- Life Support Systems
- Image Enhancement
- X-ray storage/enhancement



MILITARY



- Secure Communications
- Sonar Processing
- Image Processing
- Radar Processing
- Navigation
- Missile Guidance

Why Digital Representations?

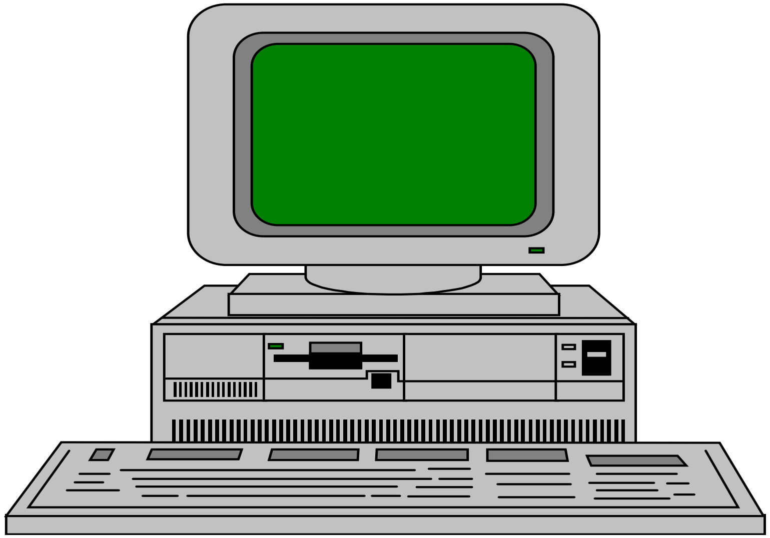
- Computers handle all types of data, but convert it to digital form for processing, much like we think our brains do (logical way).

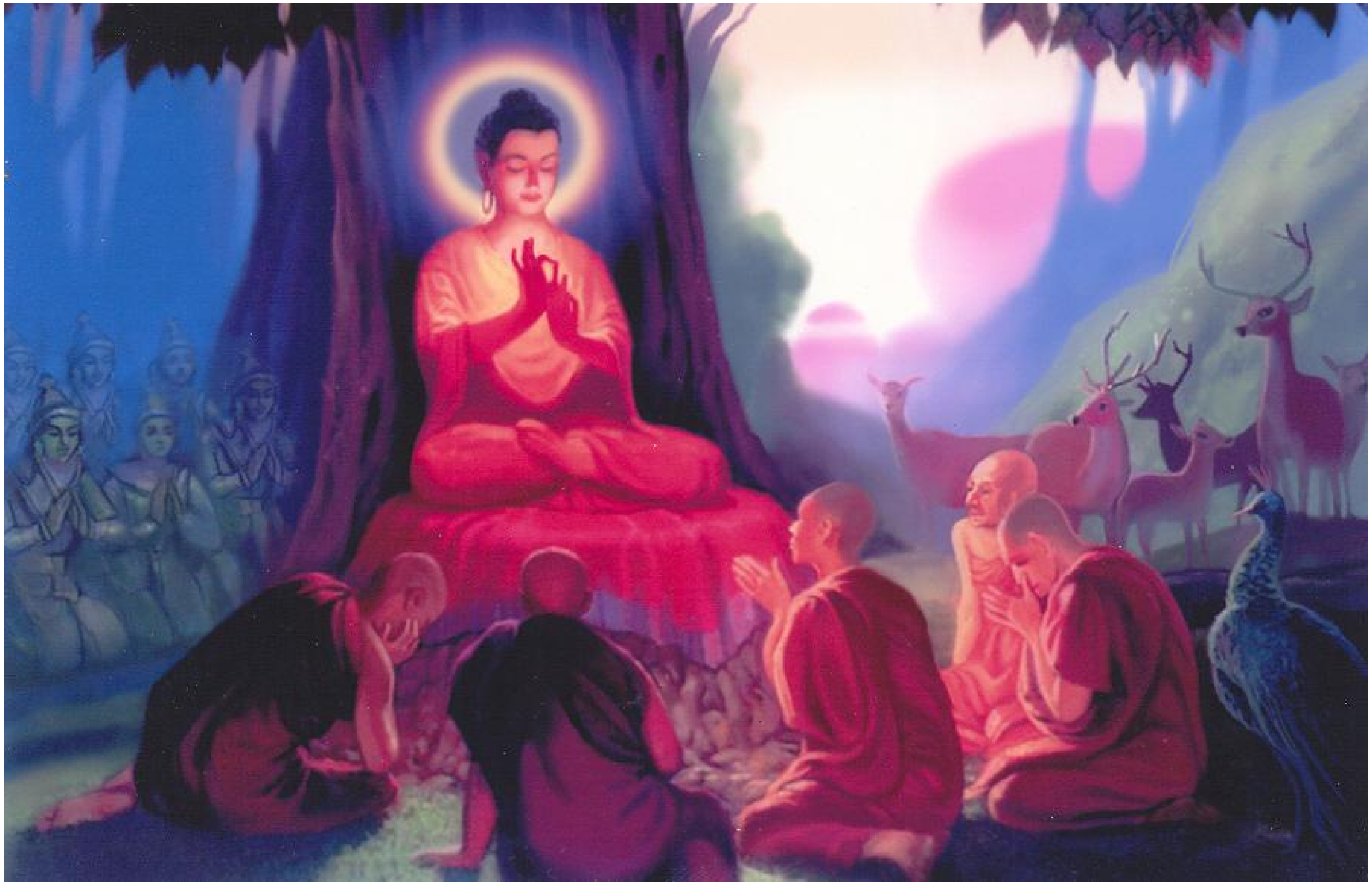
- When in digital form, data can be easily handled (processed, transmitted, presented, storage).
- Digital data can be integrated and shared.

- More reliable... i.e. more tolerable to noise
- Digital Data is conceptually simpler and it can represent analog data.

What is the Digital Domain?

- Computers process discrete or digital data
- Data is information represented by a digital symbol system
- All forms of information must be converted to a digital form for processing





An Image is worth more than thousand words

What is an Image ?

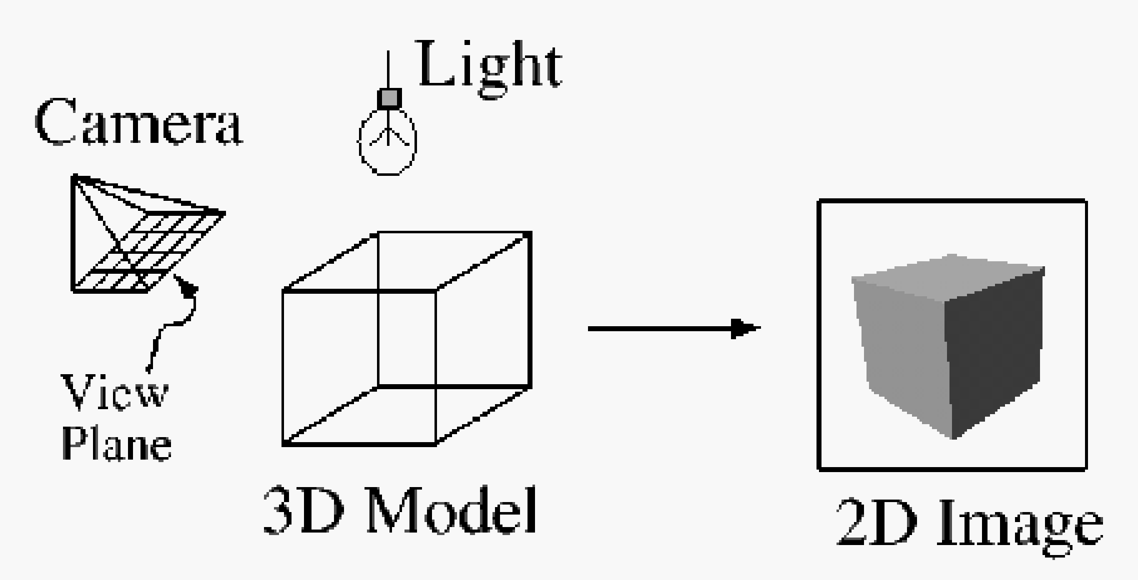
- Image: a 2-D light-intensity function $f(x,y)$
- Image: Energy per unit photon
- The value of f at $(x,y) \rightarrow$ the intensity (brightness) of the image at that point
- $0 < f(x,y) < \infty$

Image formation

- There are two parts to the image formation process:
  - The **geometry of image formation**, which determines where in the image plane the projection of a point in the scene will be located.
  - The **physics of light**, which determines the brightness of a point in the image plane as a function of illumination and surface properties.

Image Acquisition

- Pixels are samples from continuous function
  - Photoreceptors in eye
  - CCD cells in digital camera
  - Rays in virtual camera



Digital Image Acquisition

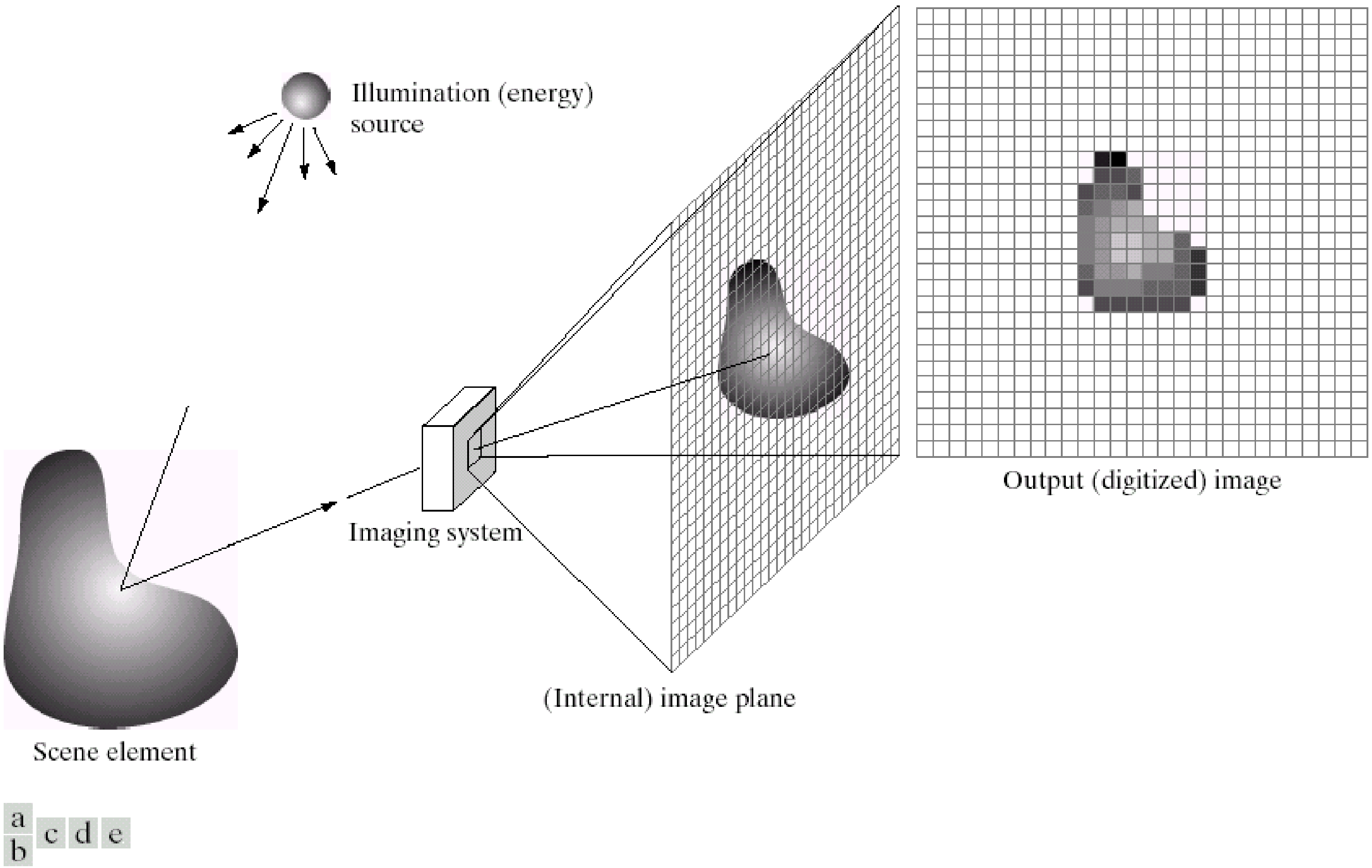
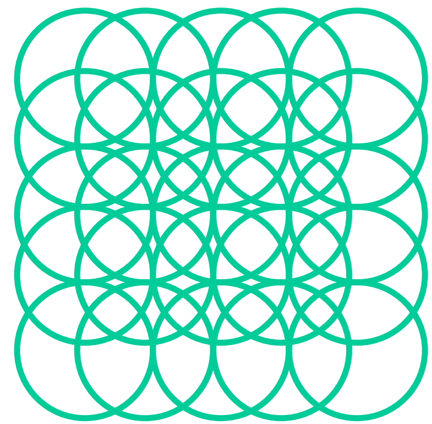


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Analog Image Display

- Re-create continuous function from samples
  - Example: cathode ray tube-



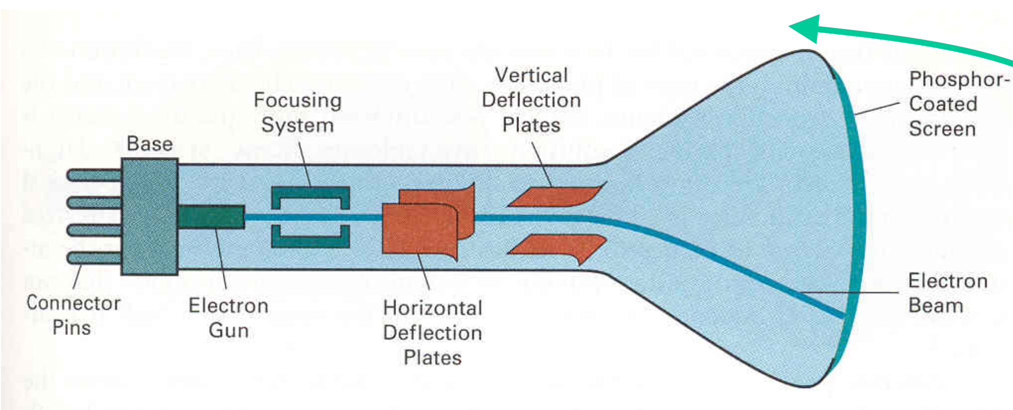


Image is reconstructed by displaying pixels with finite area

Image Resolution

- Intensity resolution
  - Each pixel has only "Depth" bits for colors/intensities
- Spatial resolution
  - Image has only "Width" x "Height" pixels
- Temporal resolution
  - Monitor refreshes images at only "Rate" Hz

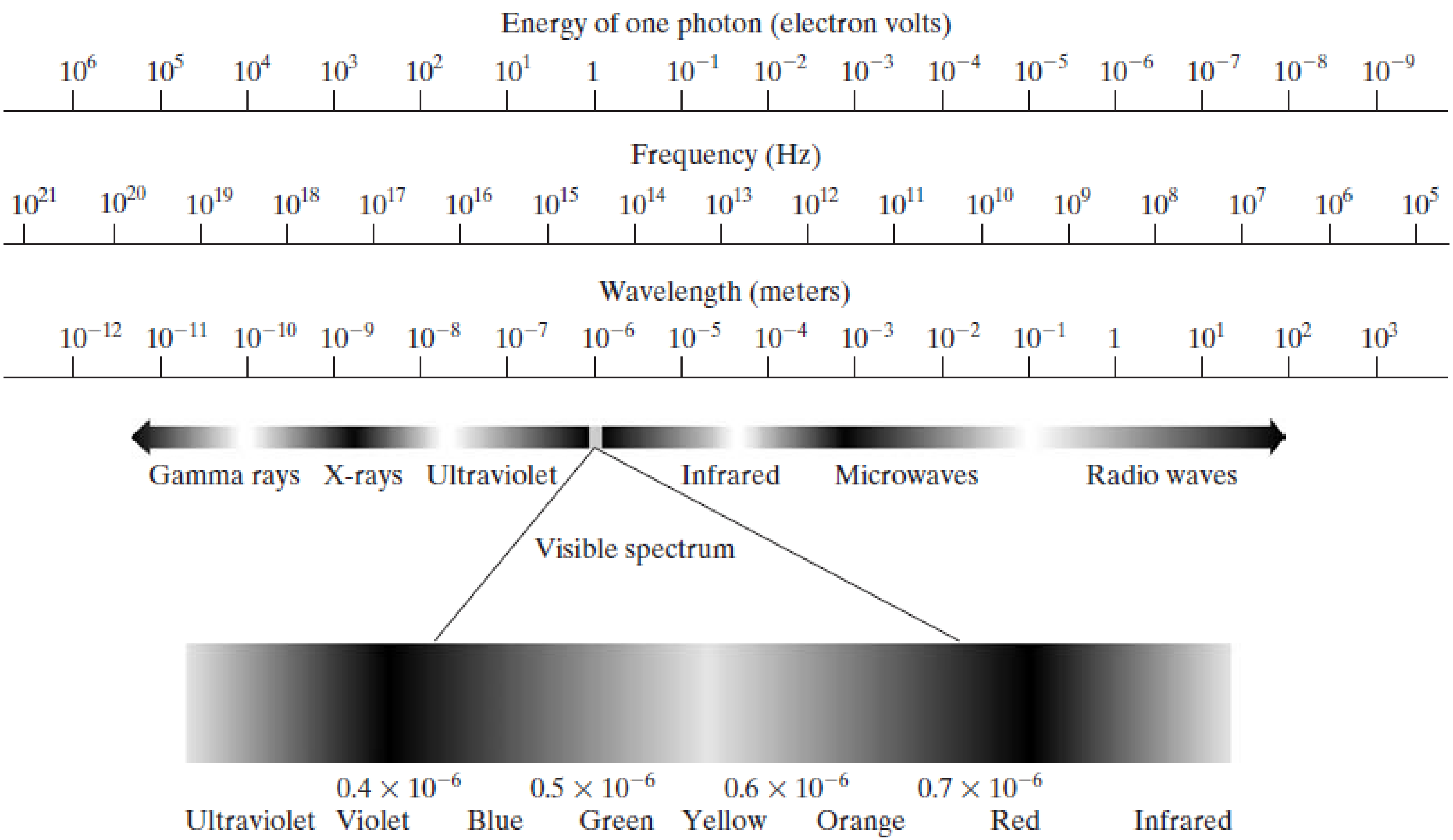
	Width x Height	Depth	Rate
NTSC	640 x 480	8	30
Workstation	1280 x 1024	24	75
Film	3000 x 2000	12	24
Laser Printer	6600 x 5100	1	-
PAL	720 x 576	8x3	25

- Frame Standard

National Television Standard Committee (NTSC) is the TV standard used in the America and Japan, whereas Phase Alternating line (PAL) is used in Europe, Australia, the Middle East, and Asia.

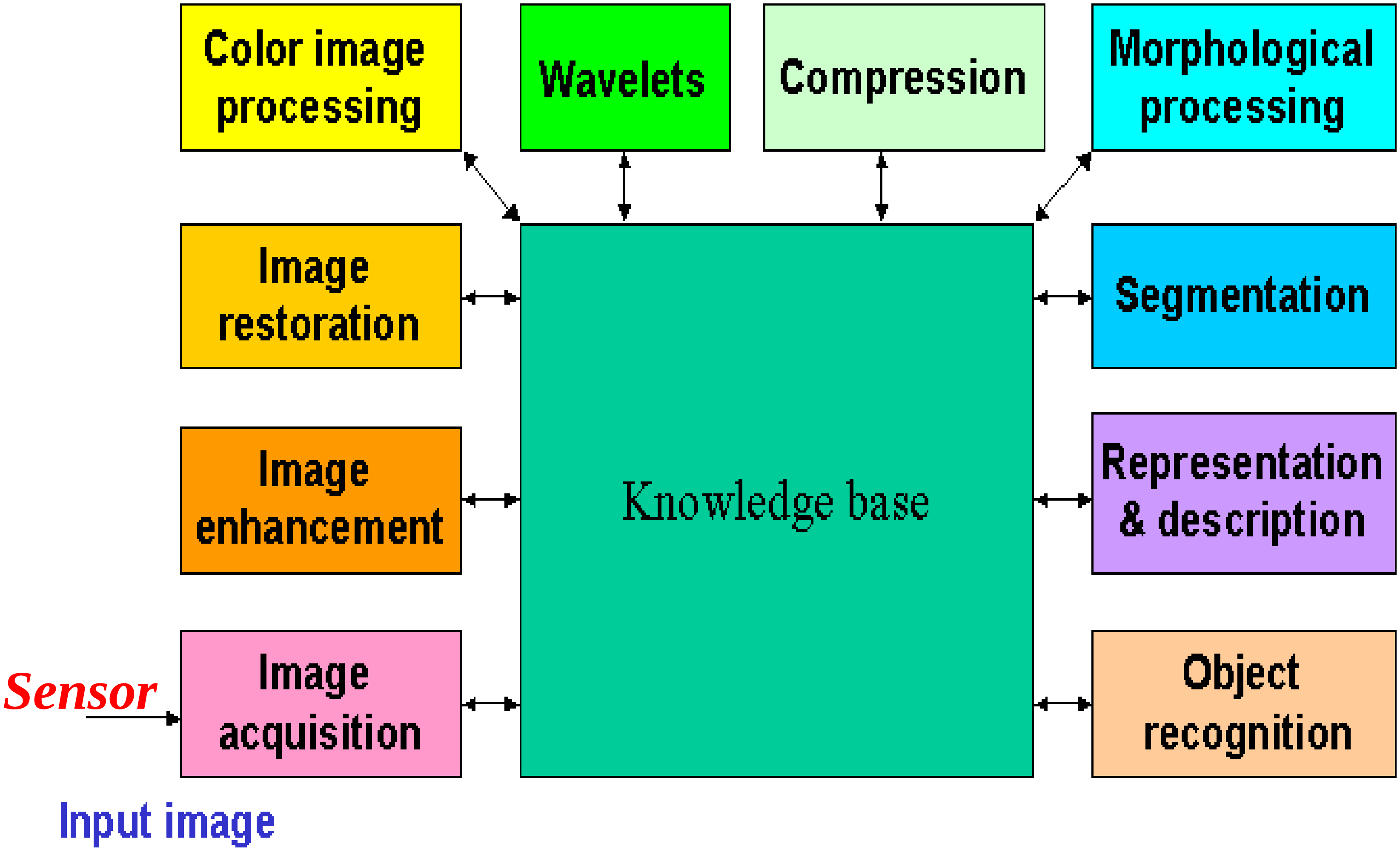
- Frame size

Conventional television screens are made up of horizontal lines, while computer monitors consist of a series of horizontal and vertical pixels. The standard line resolution for an NTSC television is 525 lines; for PAL, it is 576 lines.



The electromagnetic spectrum. The visible spectrum (zoom to see) is a very narrow portion of the EM spectrum

Steps in Digital Image Processing…



A Simple Image Model

- Nature of f(x,y):
  - The amount of source light incident on the scene being viewed: i(x,y)
  - The amount of light reflected by the objects in the scene: r(x,y)

A Simple Image Model

- Illumination & reflectance components:

  - Illumination: $i(x,y)$– the luminous flux incident per unit area.
  - Reflectance: $r(x,y)$- a measure of the ability of a surface to reflect light (electromagnetic radiation) equal to the ratio of the reflected flux to the incident flux.

  - $f(x,y) = i(x,y) \cdot r(x,y)$
  - $0 < i(x,y) < \infty$

    and $0 < r(x,y) < 1$

    (from total absorption to total reflectance)

A Simple Image Model

- Sample values of $r(x,y)$:
  - 0.01: black velvet
  - 0.93: snow

- Sample values of $i(x,y)$:
  - 9000 foot-candles: sunny day
  - 1000 foot-candles: cloudy day
  - 0.01 foot-candles: full moon

A Simple Image Model

- Intensity of a monochrome image f at (x_o, y_o): gray level l of the image at that point

$$l = f(x_o, y_o)$$

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

- $L_{min} \le l \le L_{max}$
  - Where L_{min}: positive
    L_{max}: finite

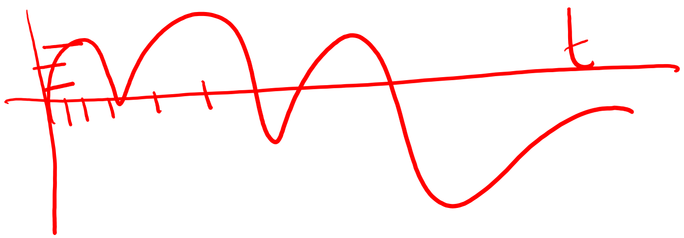
A Simple Image Model

- In practice:
  - $L_{min} = i_{min}\ r_{min}$ and
  - $L_{max} = i_{max}\ r_{max}$
- e.g. for indoor image processing:
  - $L_{min} \approx 10$ $L_{max} \approx 1000$
- $[L_{min}, L_{max}]$: gray scale
  - Often shifted to [0,L-1] → L_{min}=0: black

    L_{max}=L-1: white

Sampling and Quantization

- The spatial components and amplitude digitization of f(x,y) is called:
  - image sampling when it refers to spatial coordinates (x,y) and
  - gray-level quantization when it refers to the amplitude.



Example: Digitizing Images

- Images are digitized using a two step process…

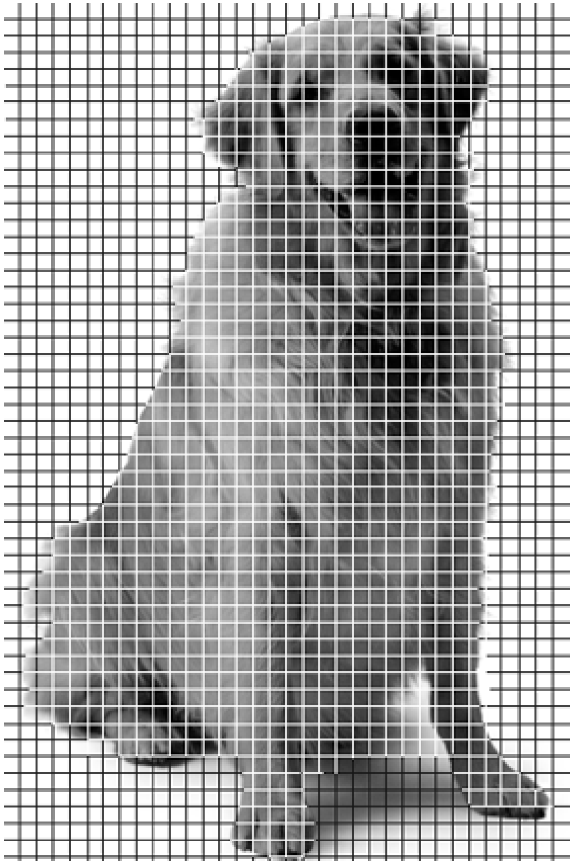
1. sampling the continuous tone image for pixels
2. quantizing pixels

Example: Digitizing Images

- images are digitized using a two steps-

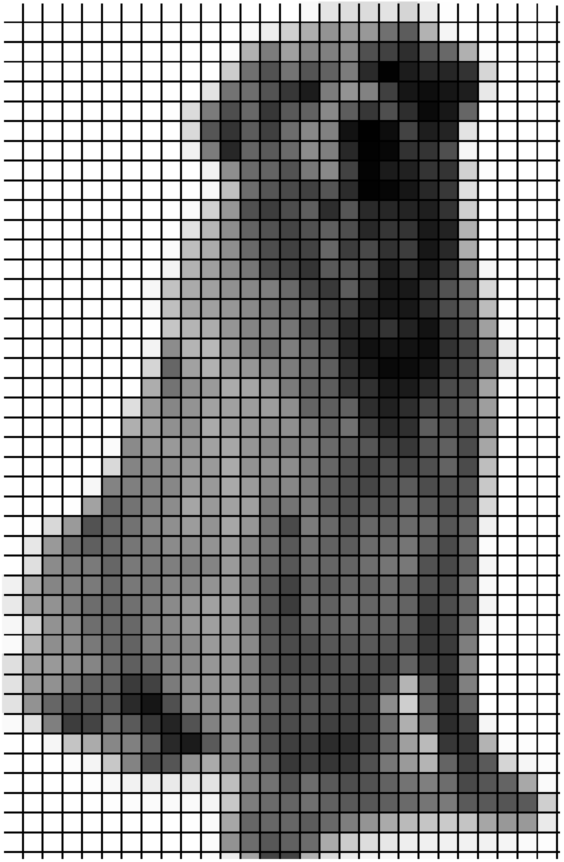
1. Sampling is the digitization of coordinates.
2. Quantizing pixels value means digitized it.

image is sampled by pixel resolution

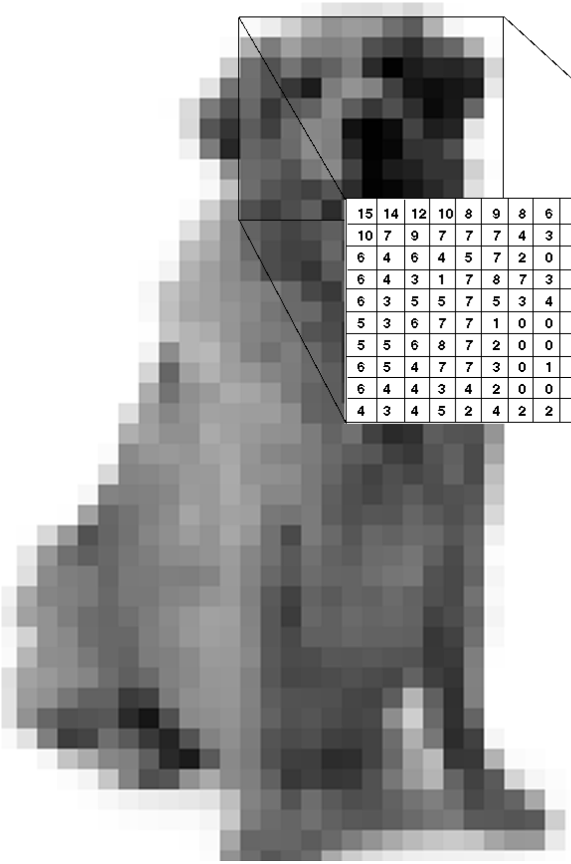


Example: Digitizing Images

pixels samples are averaged



pixels are converted to numeric form



15	14	12	10	8	9	8	6	5	10	14	15	15
10	7	9	7	7	7	4	3	2	4	6	10	15
6	4	6	4	5	7	2	0	1	2	2	2	12
6	4	3	1	7	8	7	3	1	0	1	1	14
6	3	5	5	7	5	3	4	2	0	1	5	15
5	3	6	7	7	1	0	0	3	1	2	13	15
5	5	6	8	7	2	0	0	2	3	4	14	15
6	5	4	7	7	3	0	1	1	3	3	12	15
6	4	4	3	4	2	0	0	1	2	3	13	15
4	3	4	5	2	4	2	2	2	1	2	12	15

Digital Image

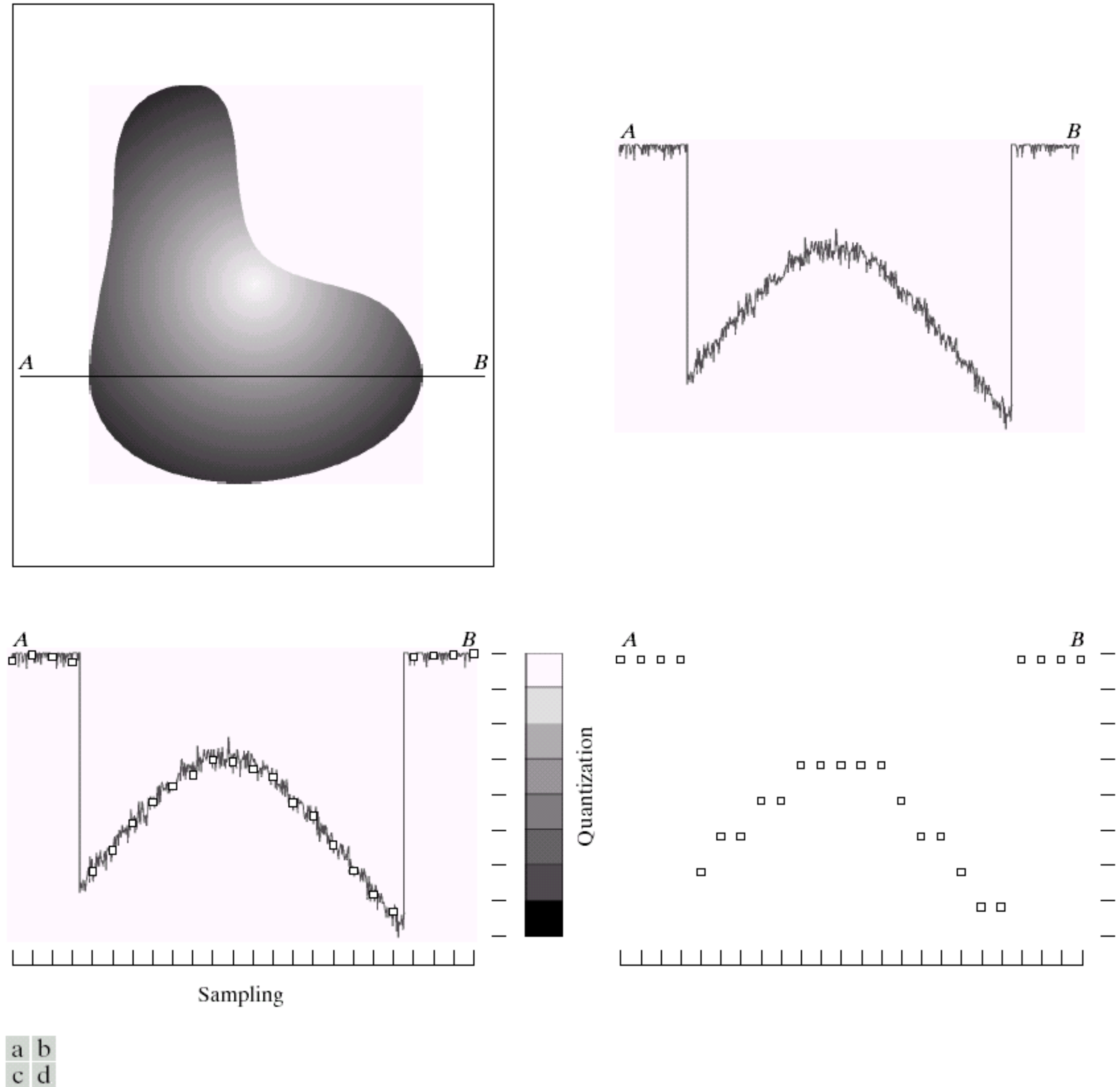


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

Sampling and Quantization

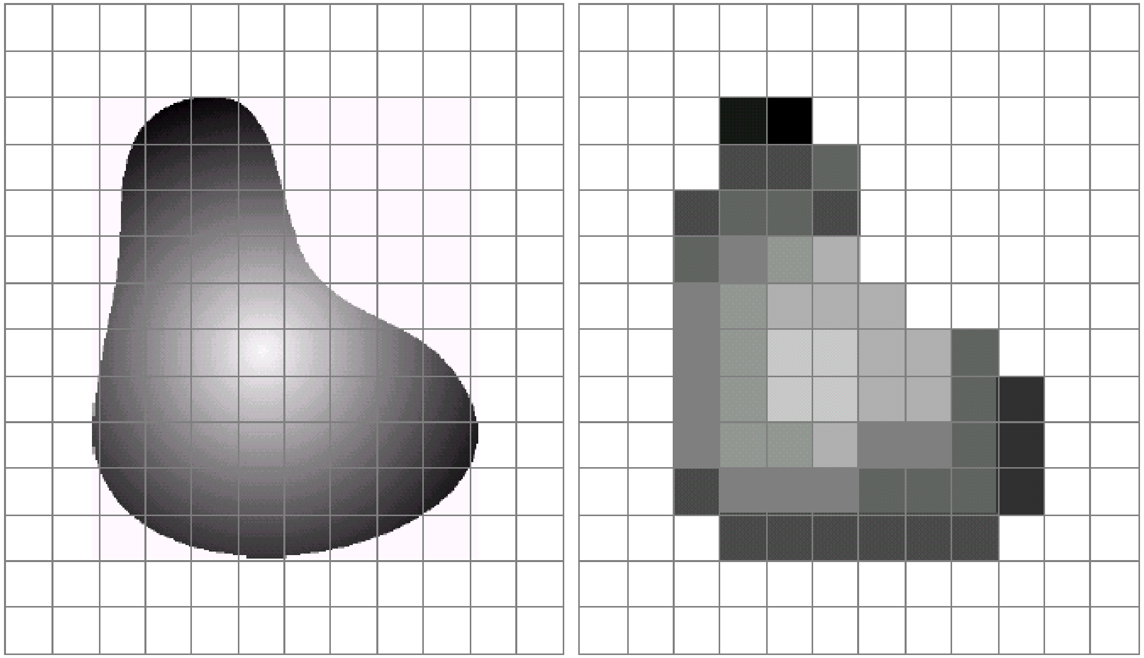
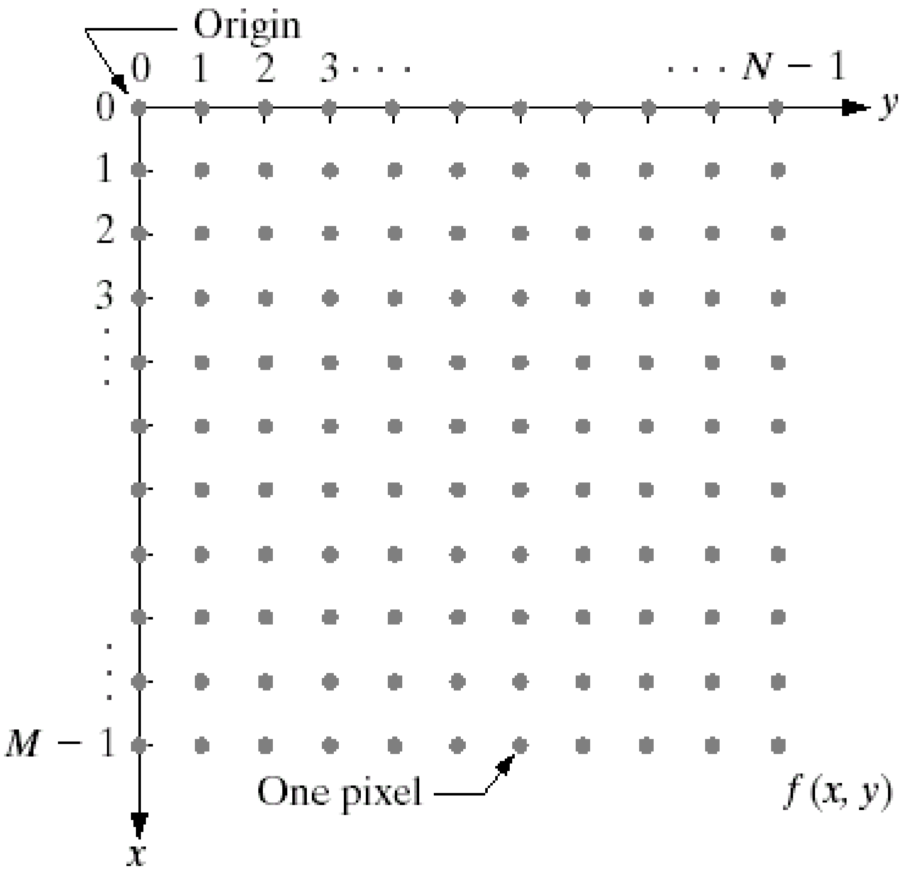


FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.

Sampling: partitioning xy plane into a grid

A Digital Image



Coordinate convention used to represent digital images

Sampling and Quantization

$$f(x,y)=\begin{bmatrix} f(0,0) & f(0,1) & \dots & f(0,N-1) \\ f(1,0) & \dots & \dots & f(1,N-1) \\ \dots & \dots & \dots & \dots \\ f(M-1,0) & f(M-1,1) & \dots & f(M-1,N-1) \end{bmatrix}$$

Digital Image

Image Elements (Pixels) for e.g. f(0,0) = 153

Sampling and Quantization

- The digitization process requires decisions about:
  - values for M,N (where M x N: the image array)

    and

  - the number of discrete gray levels allowed for each pixel.

Sampling and Quantization

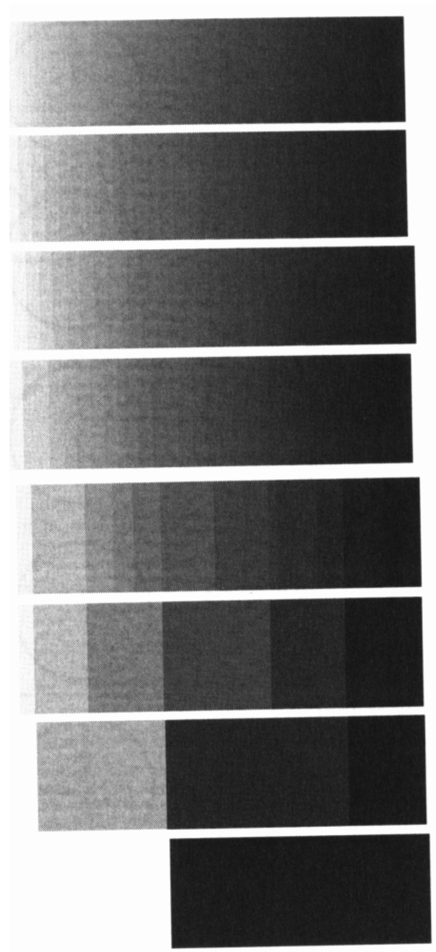
- Usually, in digital image processing these quantities are integer powers of two:

$$M=2^m \;,\; N=2^n \;\; \text{and} \;\; G=2^k$$

(number of gray levels)

- Another assumption is that the discrete levels are equally spaced between 0 and L-1 in the gray scale.

Effect of differentiating Quantization levels



Grey Levels	Resolution
256	8 bits
128	7 bits
64	6 bits
32	5 bits
16	4 bits
8	3 bits
4	2 bits
2	1 bit

Noticeable

Examples

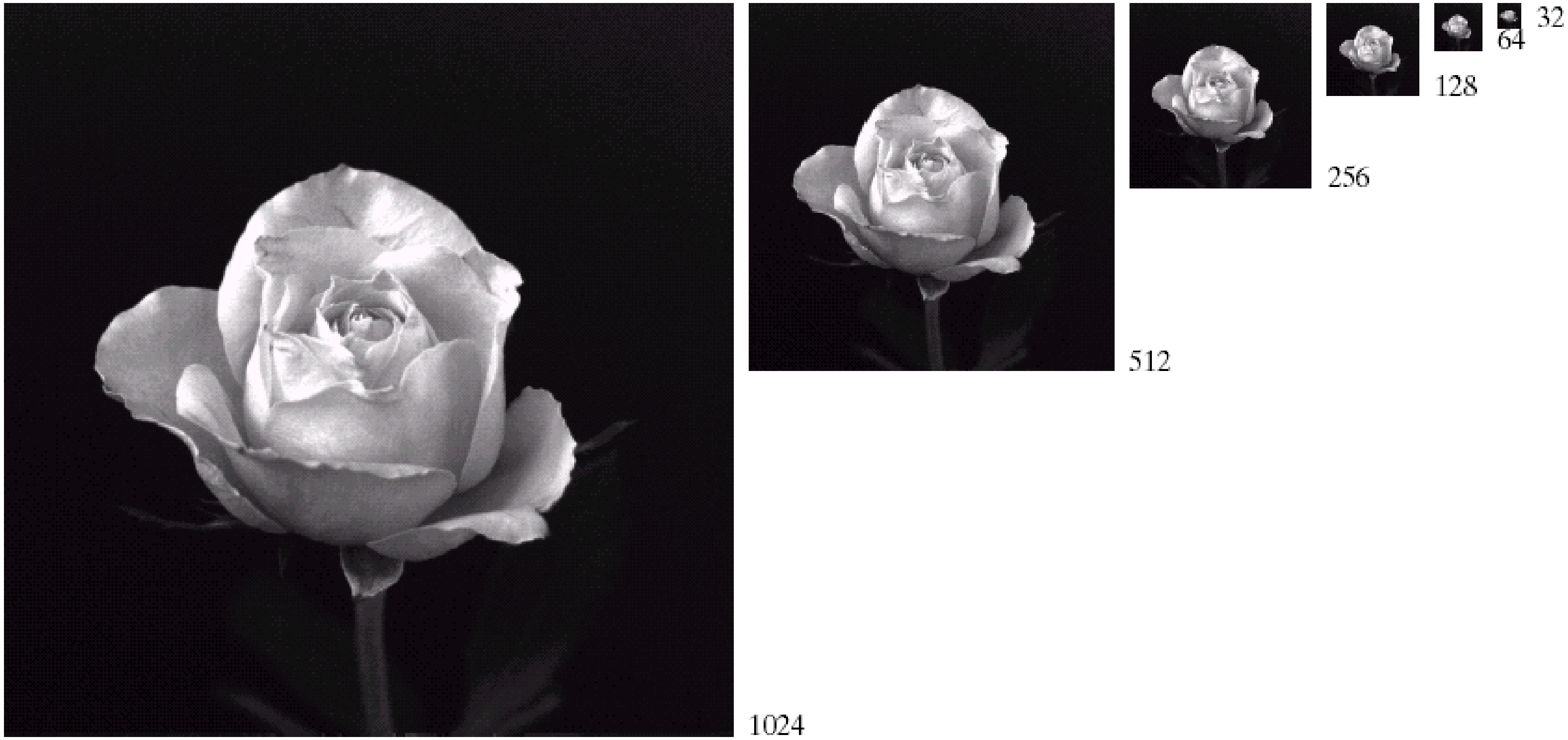


FIGURE 2.19 A 1024 × 1024, 8-bit image subsampled down to size 32 × 32 pixels. The number of allowable gray levels was kept at 256.

Examples

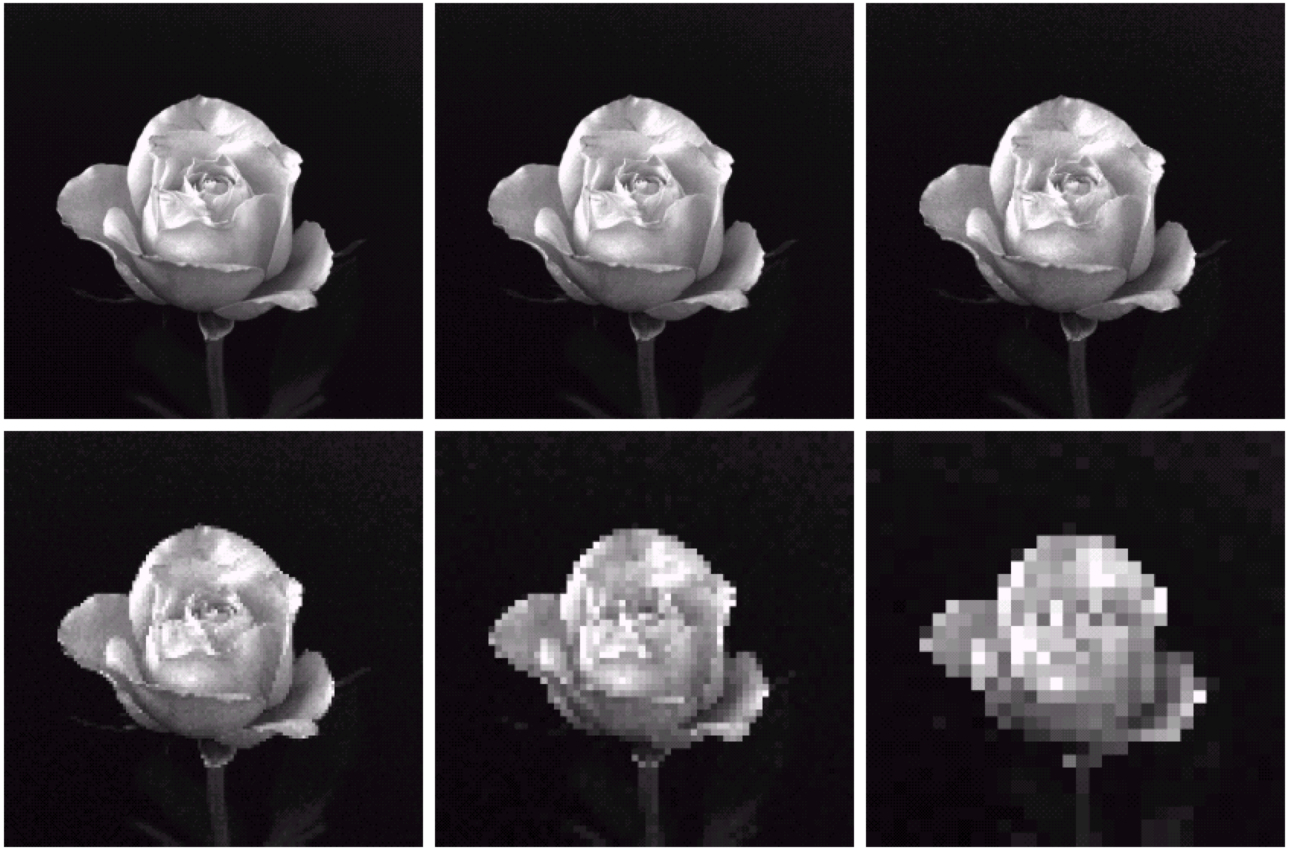
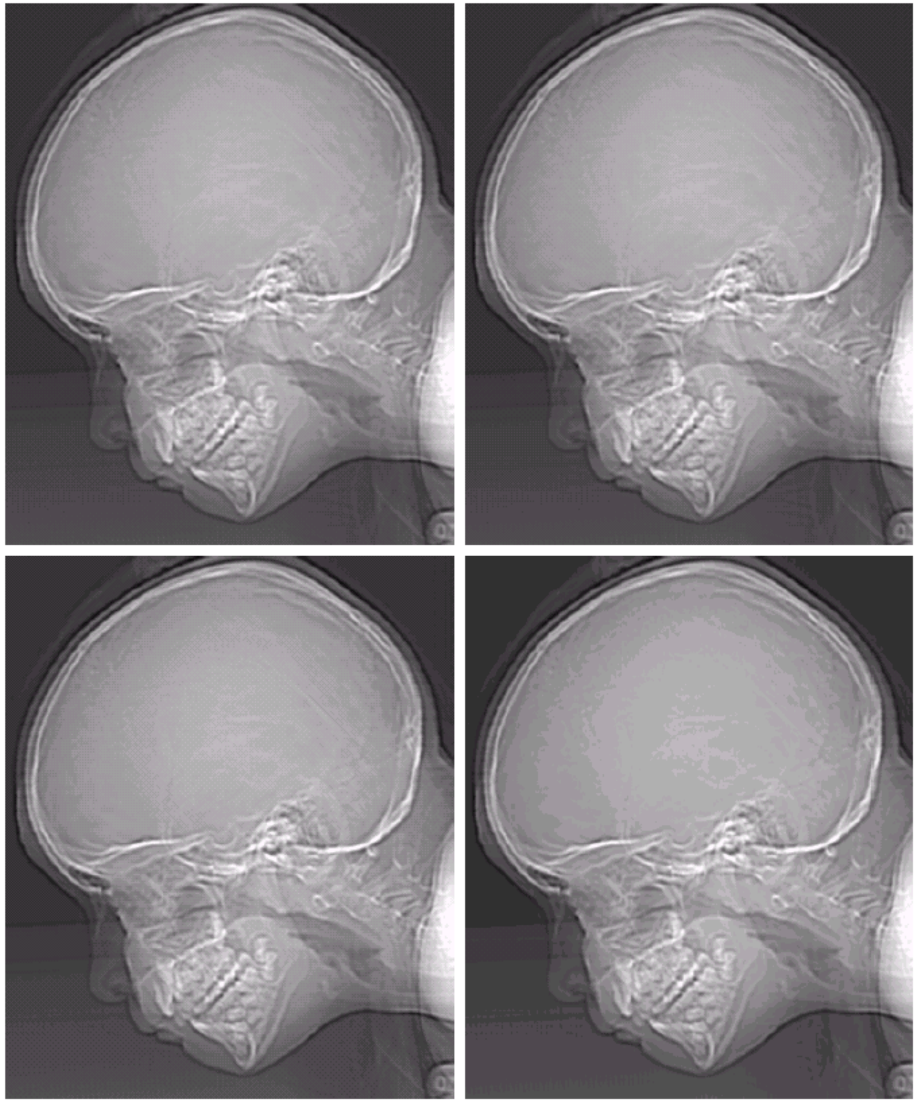


FIGURE 2.20 (a) 1024 × 1024, 8-bit image. (b) 512 × 512 image resampled into 1024 × 1024 pixels by row and column duplication. (c) through (f) 256 × 256, 128 × 128, 64 × 64, and 32 × 32 images resampled into 1024 × 1024 pixels.

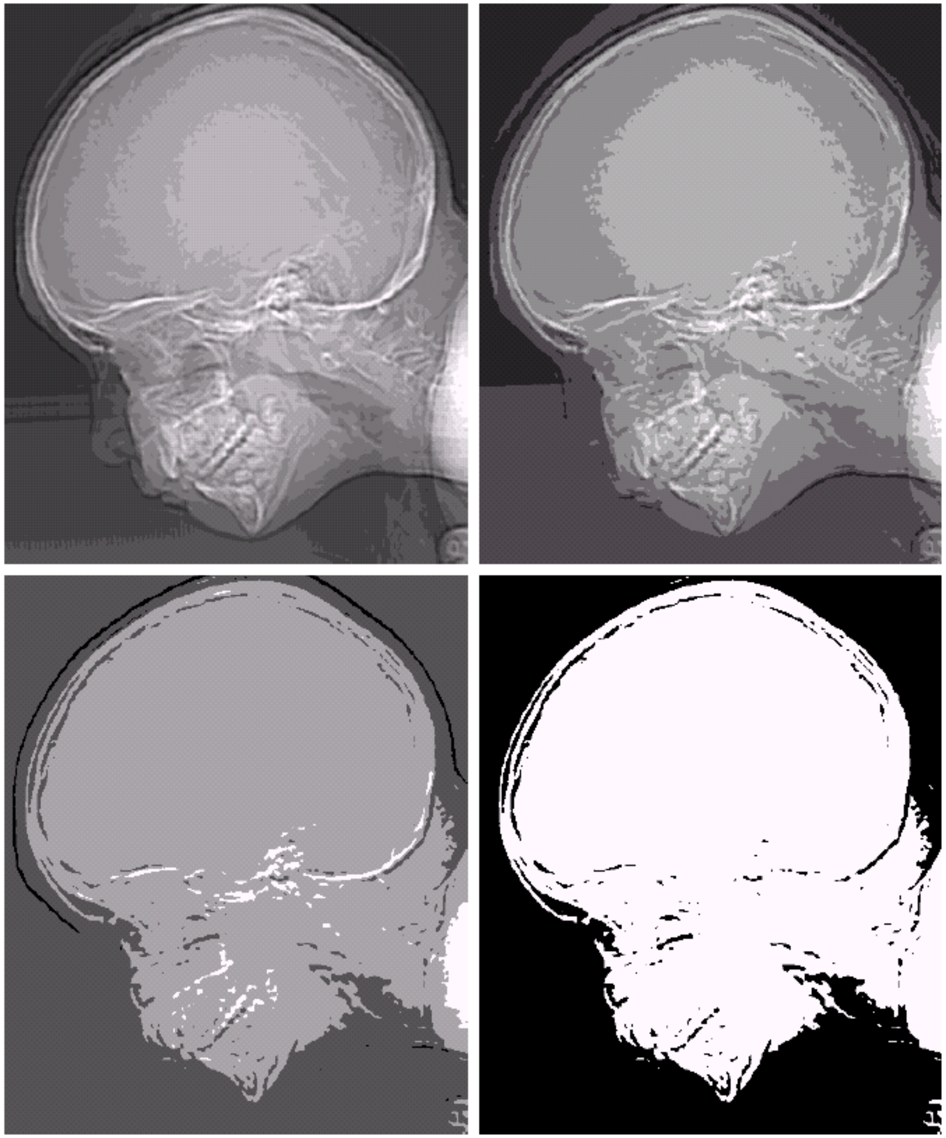
X-Ray Image with Constant Spatial Resolution



a b
c d

FIGURE 2.21 (a) 452 × 374, 256-level image. (b)–(d) Image displayed in 128, 64, and 32 gray levels, while keeping the spatial resolution constant.

Continued ...with different gray levels



e f
g h

FIGURE 2.21 *(Continued)* (e)–(h) Image displayed in 16, 8, 4, and 2 gray levels. (Original courtesy of Dr. David R. Pickens, Department of Radiology & Radiological Sciences, Vanderbilt University Medical Center.)

Size of an Image

- If b is the number of bits required to store a digitized image then:
  - $b = M \times N \times k$ (if $M=N$, then $b=N^2k$)

Storage

TABLE 2.1
Number of storage bits for various values of N and 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

Sampling and Quantization

Ques.: How many samples and gray levels are required for a good approximation?

- Resolution (the degree of discernible detail) of an image depends on sample number and gray level number.
- i.e. the more these parameters are increased, the closer the digitized array approximates the original image.

Sampling and Quantization

Contd….

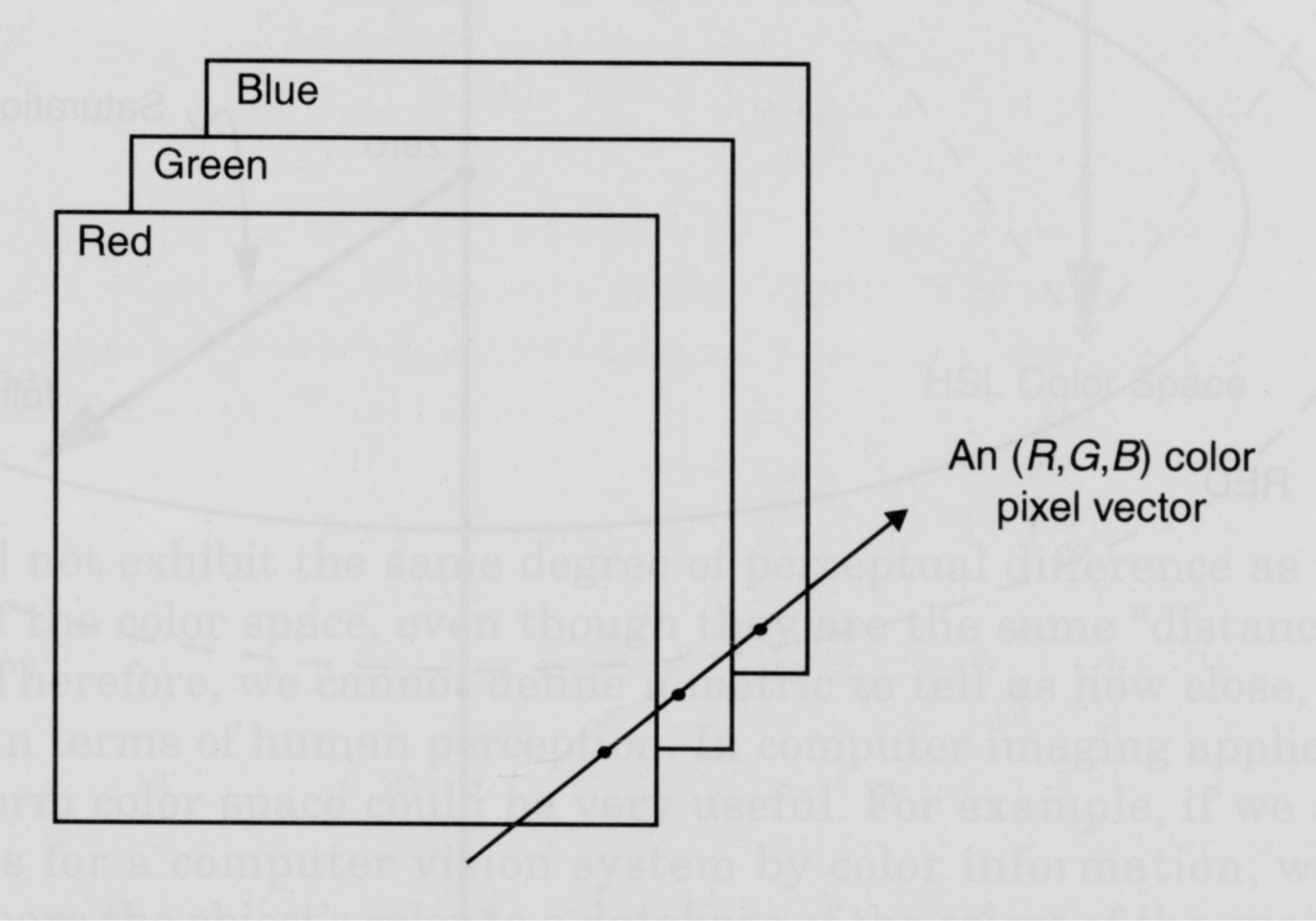
– But: storage & processing requirements increase rapidly as a function of M, N and k.

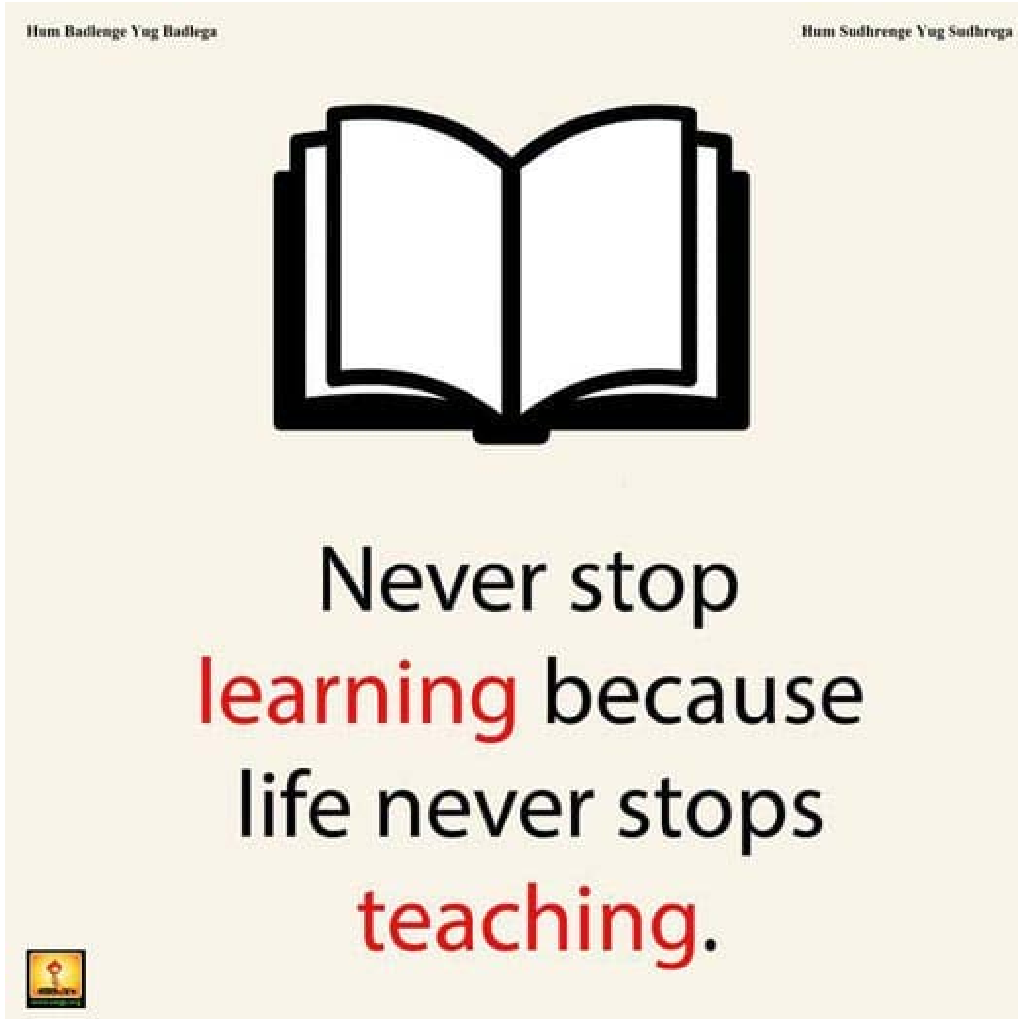
- Different versions (images) of the same object can be generated through:
  – Varying M, N numbers
  – Varying k (number of bits)
  – Varying both

Sampling and Quantization

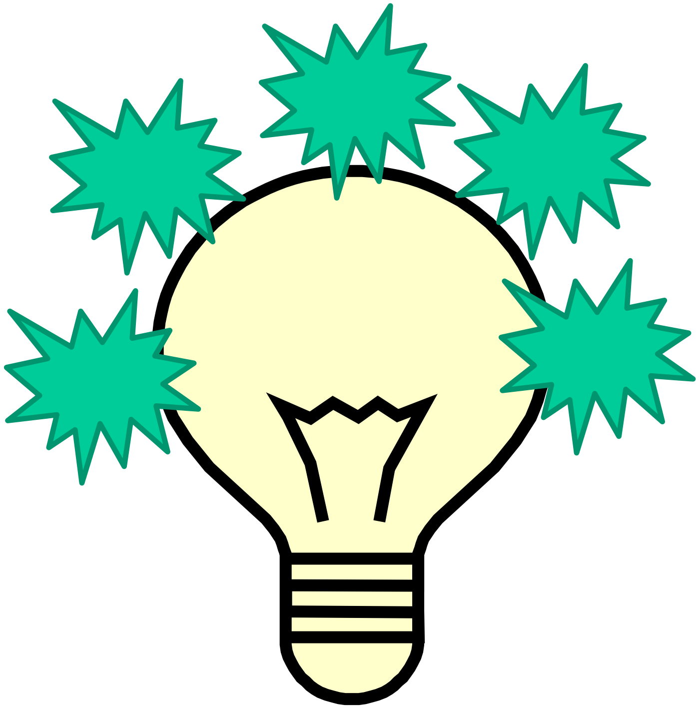
- Conclusions:
  - Quality of images increases as N & k increase.
  - Sometimes, for fixed N, the quality improved by decreasing k (increased contrast).
  - For images with large amounts of detail, few gray levels are needed.

Color images




Hum Badlenge Yug Badlega
Hum Sudhrenge Yug Sudhrega
Never stop learning because life never stops teaching.

Any Questions..?



Thanks!