# Digital Image

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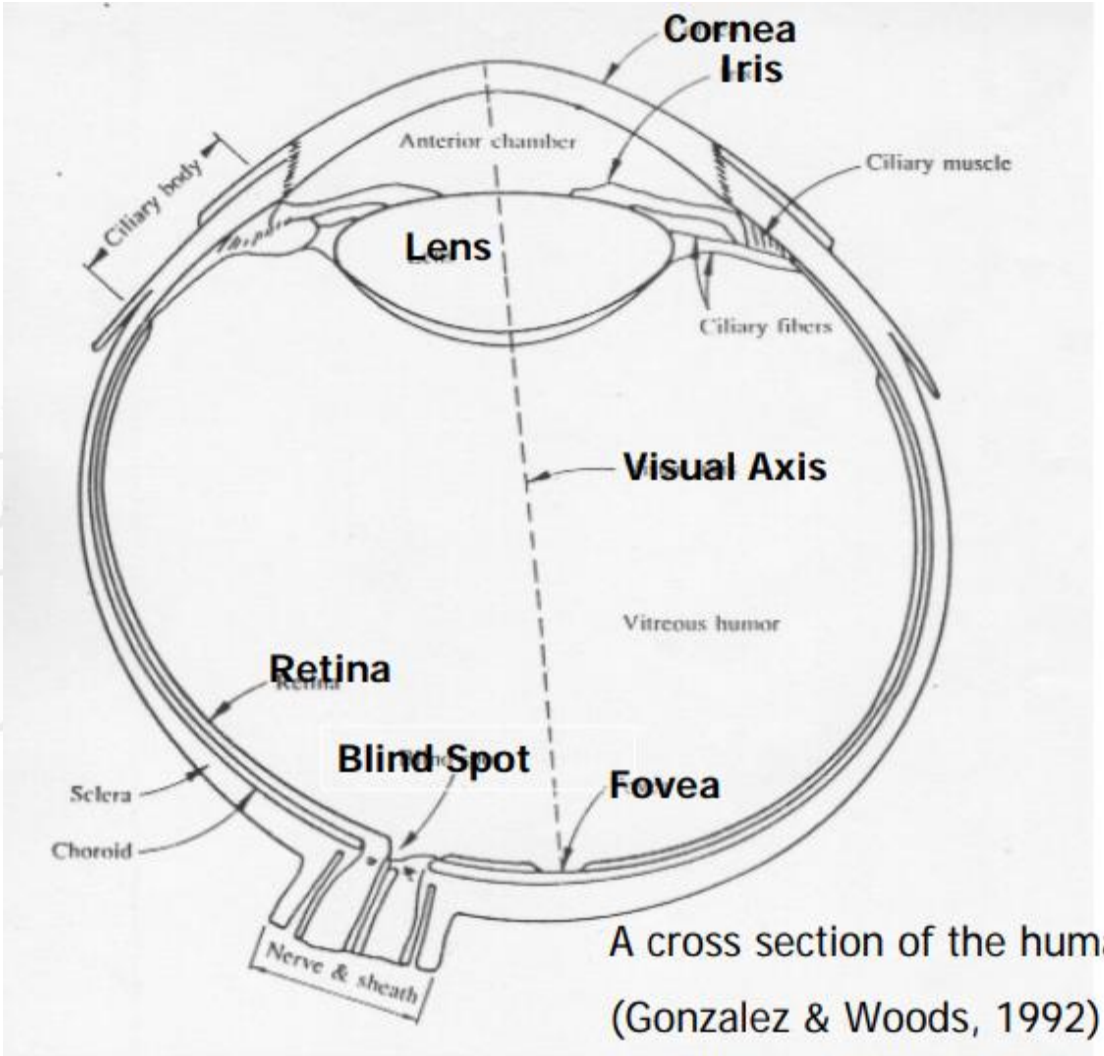
# Topics

- Human Visual System
- Image Formation
- Image Representation
- Image Acquisition
  - Sampling
  - Quantization

# Human Visual System

- Formation of the Image by the Eye Sensor
  - The intensity of light is captured by the iris and passed to the retina.
  - The image of an object on the retina is formed by the concept of an optical system where the focus of the lens lies between the retina and the lens of the eye.
  - The eyes and nerves of the brain can interpret shadows that are objects upside down.

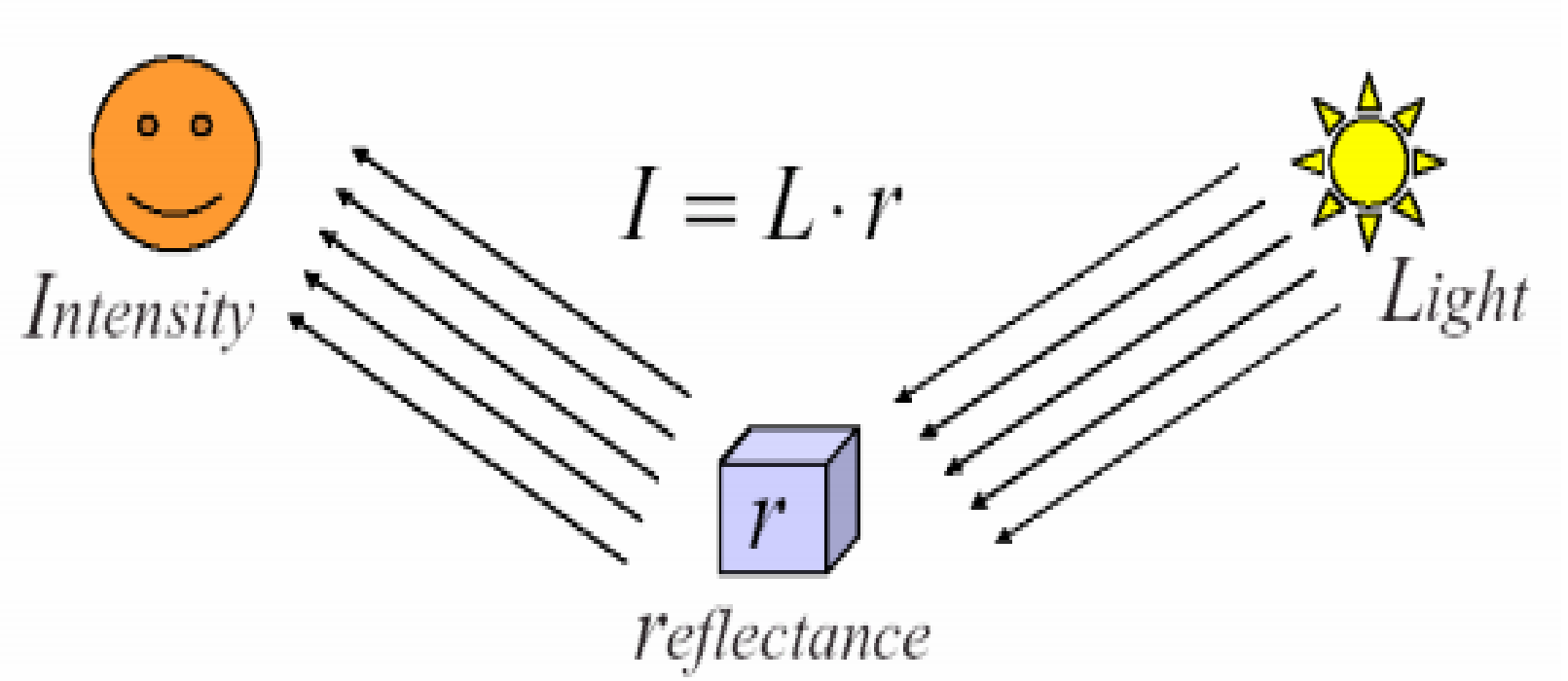
# Human Visual System




A cross section of the human eye

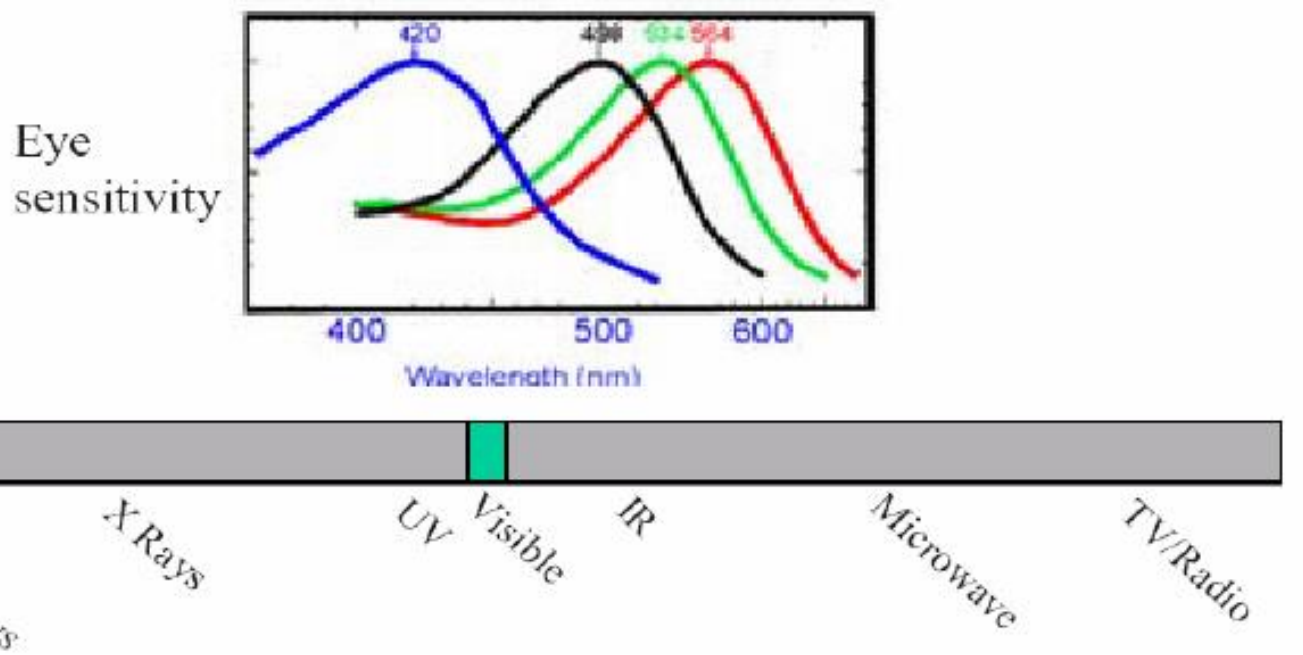
(Gonzalez & Woods, 1992)

# Image Formation



# Electromagnetic Radiation

- Visible Light Range: 350-780 nm
- Maximum Sun Energy: 450 nm
- Best Atmospheric Transmittance: Visible Range

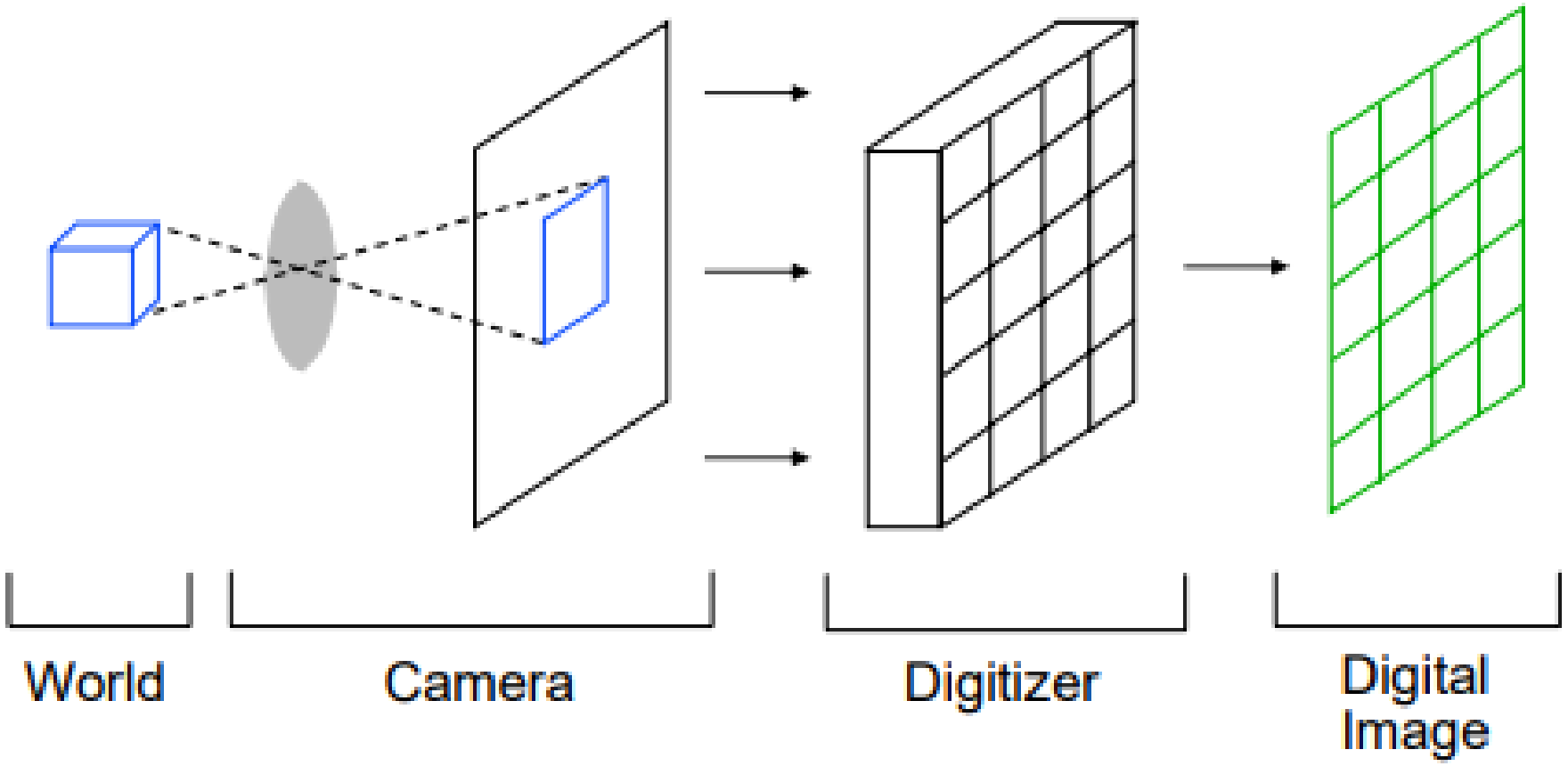


# Image Representation

- An image is a projection of a 3D scene into a 2D projection plane.
- Mathematically:
  - An image is a two-dimensional function f(x,y), where x and y are the spatial (plane) coordinates, and the amplitude of f at any pair of coordinates (x,y) is called the intensity of the image at that level.

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

# Acquisition




http://www1.idc.ac.il/toky/imageProc-08/lectures/02_acqusitionx4.pdf

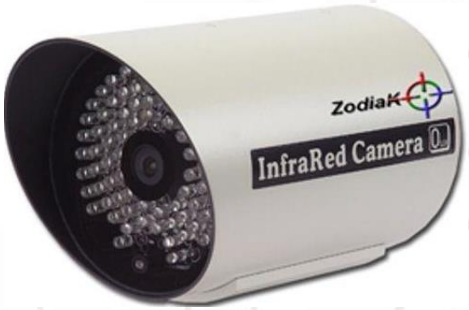
# Camera Devices


CCD Camera

IP Camera


IP Camera
(Outdoor)


Omnidirectinal
Camera




Infrared Camera

Thermal Camera

Stereo Camera
(Bumblebee)

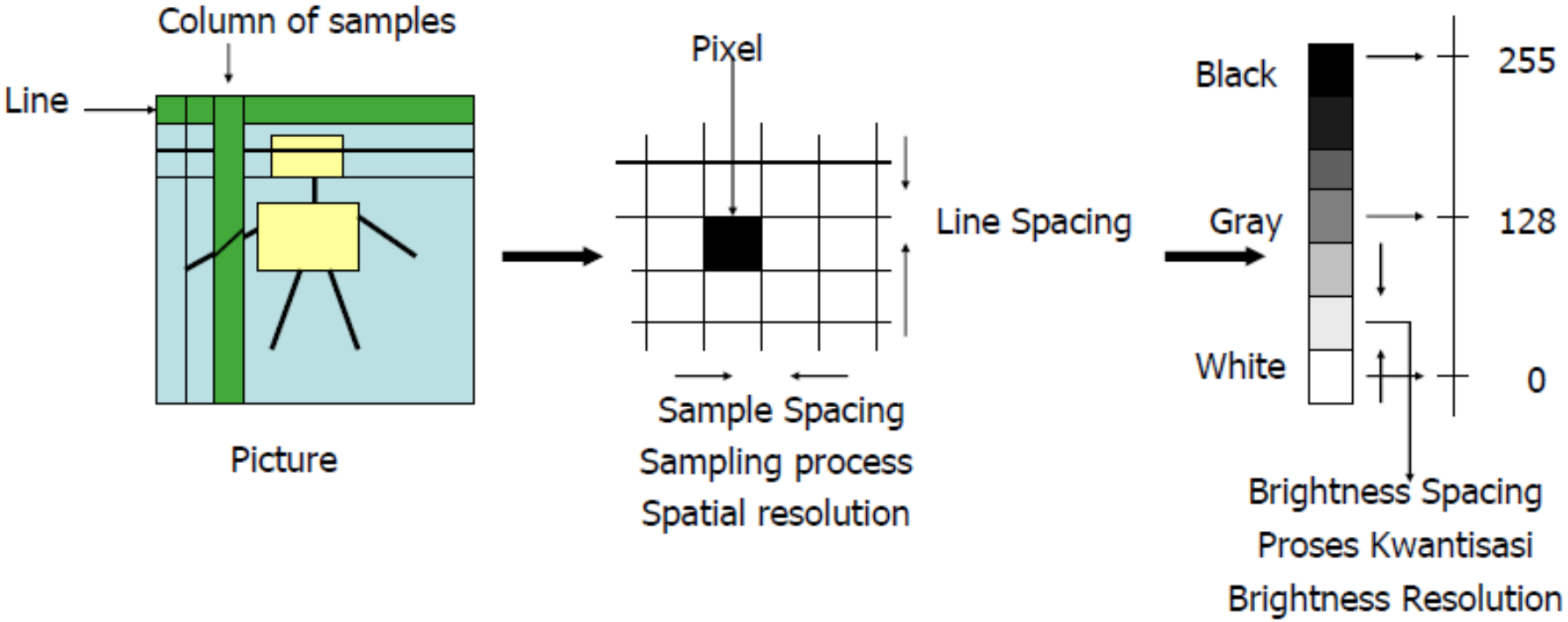
# Images are analog

- Notice that we defined images as functions in a continuous domain.
- Images are representations of an analog world.
- Hence, as with all digital signal processing, we need to digitize our images.

# Digitizing an Image

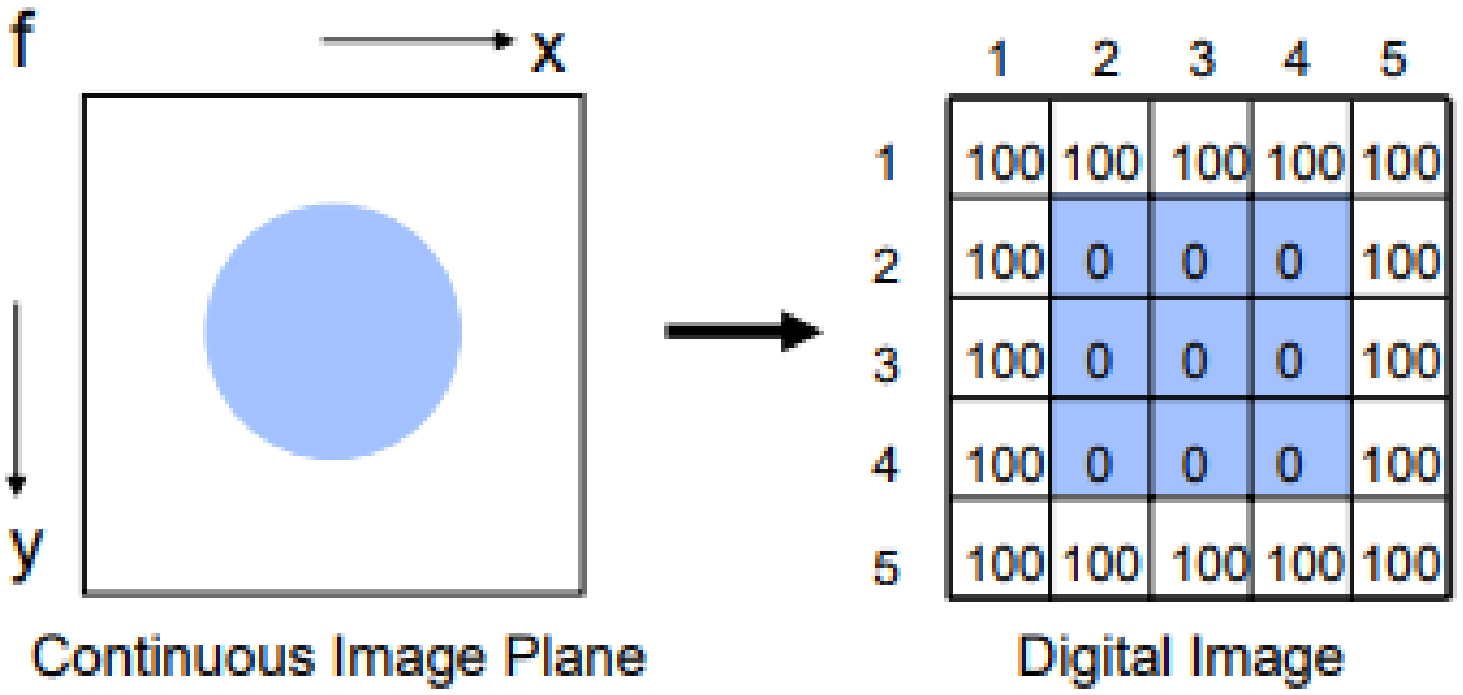
- Digitalization of an analog signal involves two operations:
  - Sampling (spatial)
  - Quantization (intensity level)
- The operations correspond to a discretization of a quantity, but in different domains.

# Digitizing an Image




Sumber: Dimodifikasi dari Castlemen, 1996

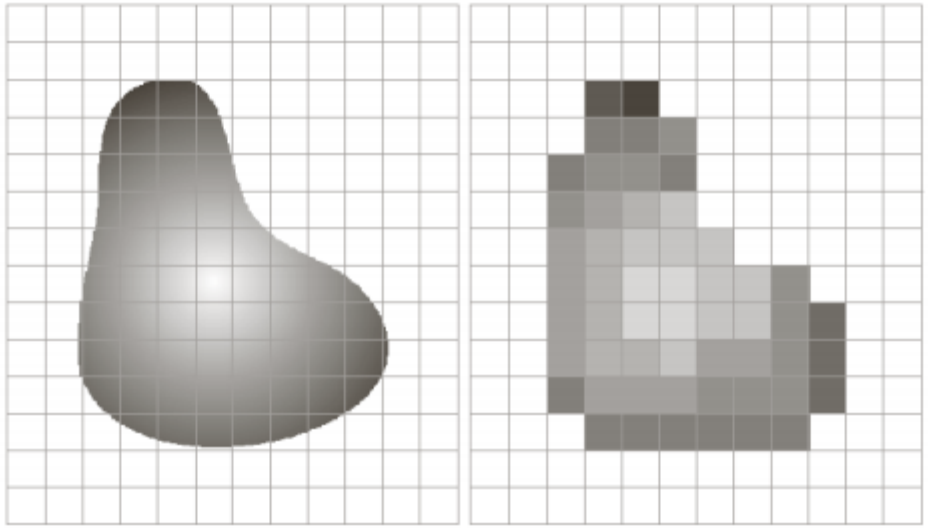
# Sampling




http://www1.idc.ac.il/toky/imageProc-08/lectures/02_acqusitionx4.pdf

# Sampling

- Sampling corresponds to a discretization of the space. That is, of the domain of the function, into $f : [1, \ldots, N] \times [1, \ldots, M] \longrightarrow \mathbb{R}^m$.



a b

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

# Sampling

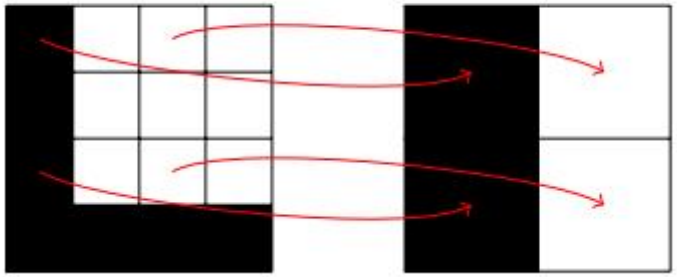
- The smallest element resulting from the discretization of the space is called a pixel (picture element).
- For 3-D images, this element is called a voxel (volumetric pixel).

# Sampling Types

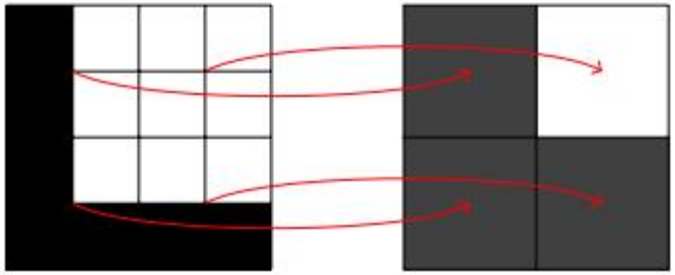
- Uniform sampling
  - Uniform sampling has the same row and column spacing in all areas of an image.
- Non-uniform sampling
  - Non-uniform sampling is adaptive depending on image characteristics and aims to avoid missing information.
  - Image areas that contain high detail are sampled finer, while homogeneous areas can be sampled more roughly.

# Reduction in Sampling Resolution

- Two possibilities:
  - Downsampling



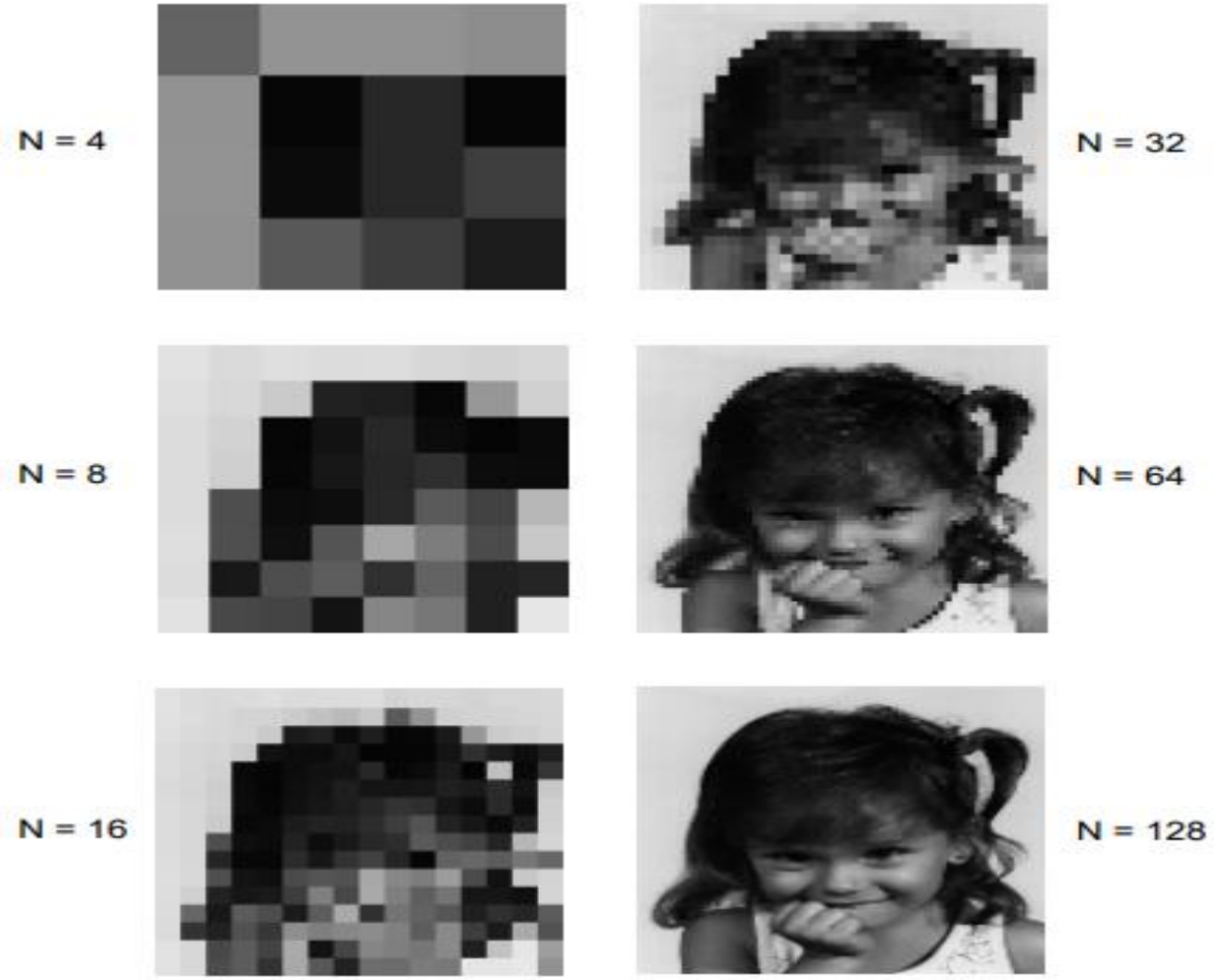
  - Decimation



# Increase in Sampling Resolution

- The main idea is to use interpolation.
- Common methods are:
  - Nearest neighbor
  - Bilinear interpolation
  - Bicubic interpolation

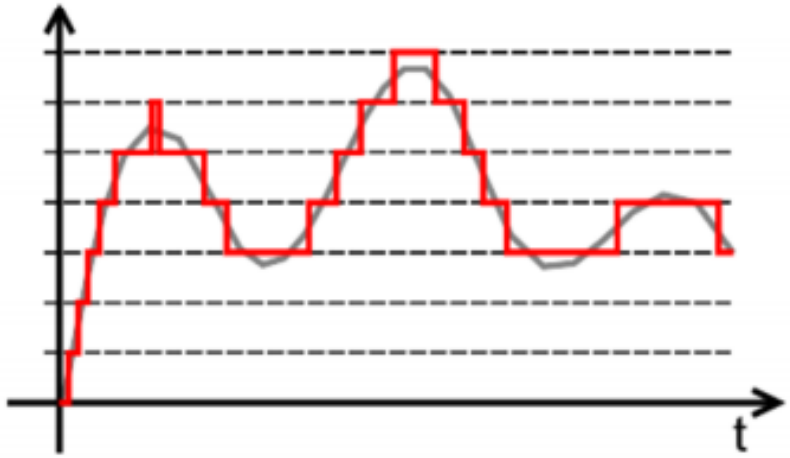
# Effect The Number of Samples




http://www1.idc.ac.il/toky/imageProc-08/lectures/02_acqusitionx4.pdf

# Quantization

- Quantization corresponds to a discretization of the intensity values. That is, of the co-domain of the function.



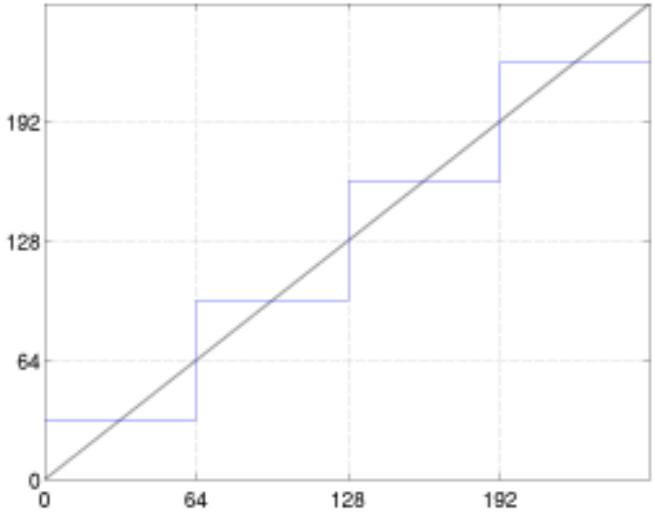

- After sampling and quantization, we get

$$f : [1, \ldots, N] \times [1, \ldots, M] \longrightarrow [0, \ldots, L].$$

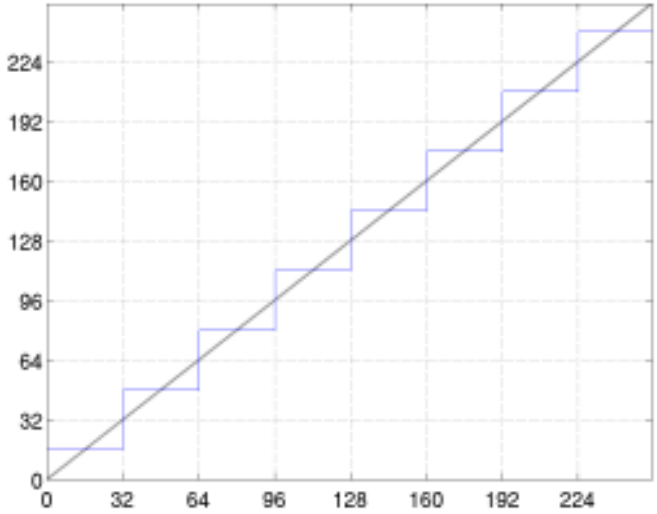
# Quantization

- Quantization corresponds to a transformation Q(f)

4 levels

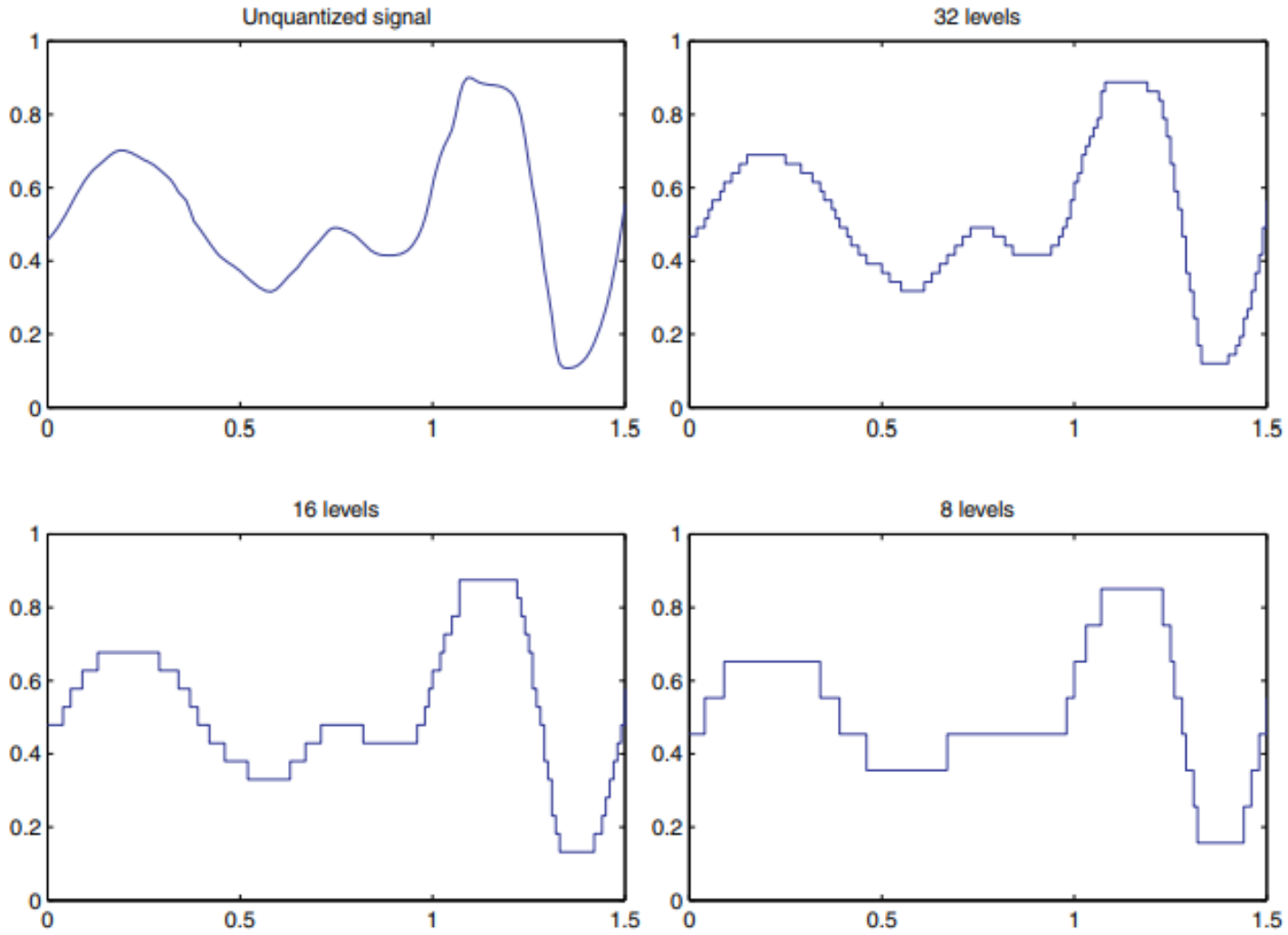



8 levels




- Typically, 256 levels (8 bits/pixel) suffices to represent the intensity. For color images, 256 levels are usually used for each color intensity

# Quantization



# Uniform Quantization

- The simplest type of quantizers are called zero memory quantizers.
- The simplest zero memory quantizer is the uniform quantizer
  - the transition and reconstruction levels are all equally spaced.

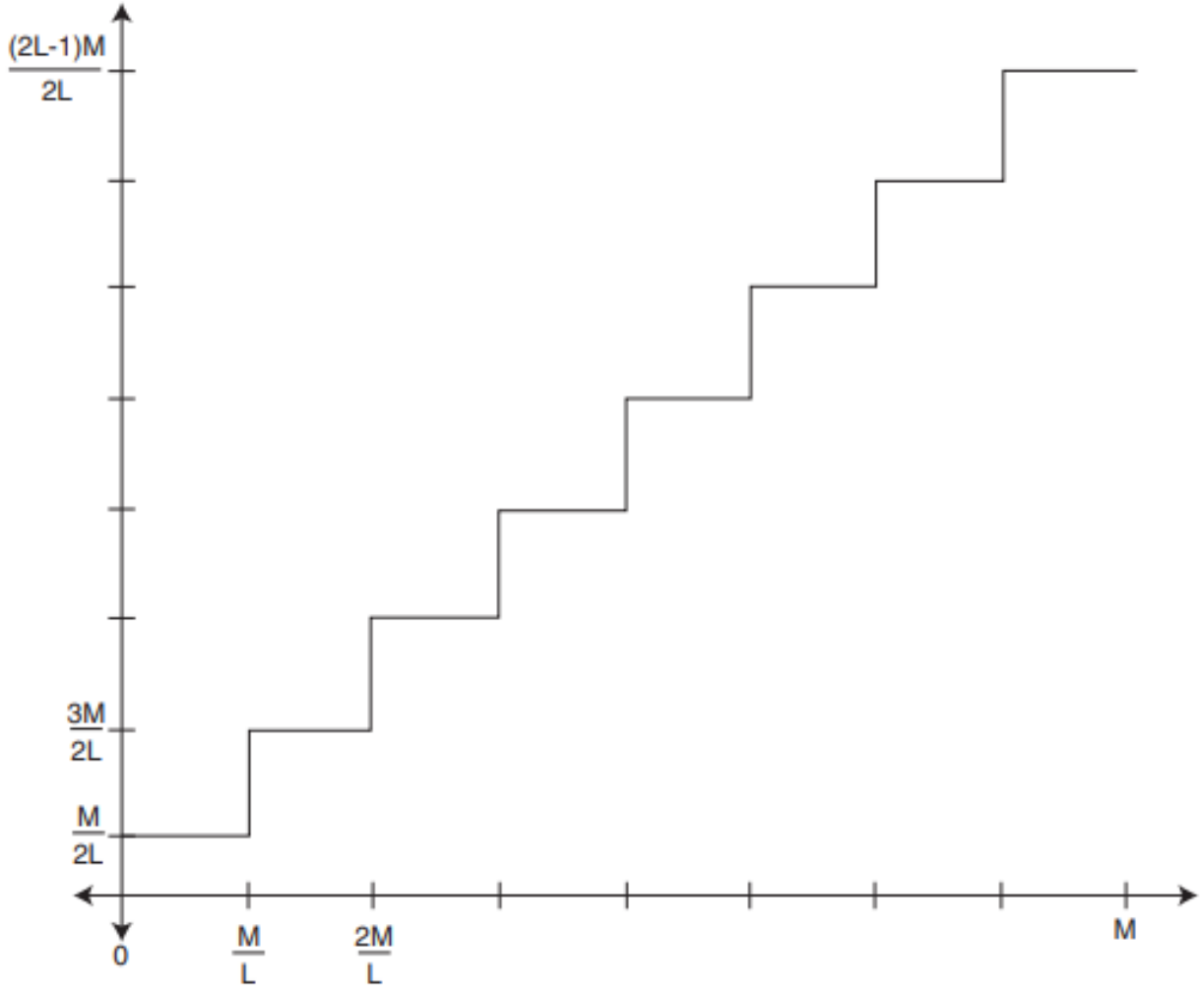
# Uniform Quantization

- For example, if the output of an image sensor takes values between 0 and M, and one wants L quantization levels, the uniform quantizer would take

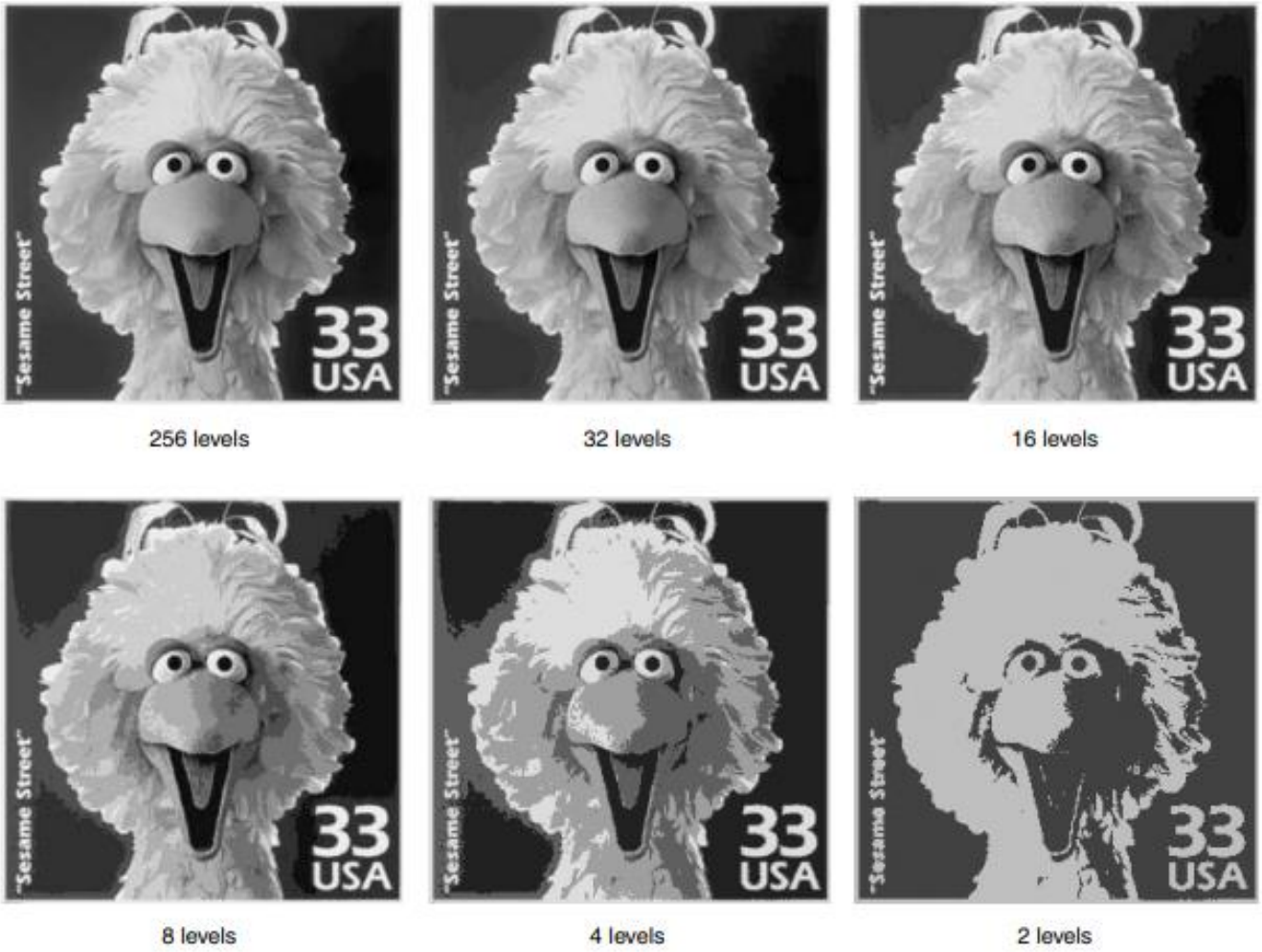
$$r_k = \frac{kM}{L} - \frac{M}{2L}, \quad k = 1, ..., L$$

$$t_k = \frac{M(k-1)}{L}, \quad k = 1, ..., L+1$$

# Uniform Quantization



# Uniform Quantization



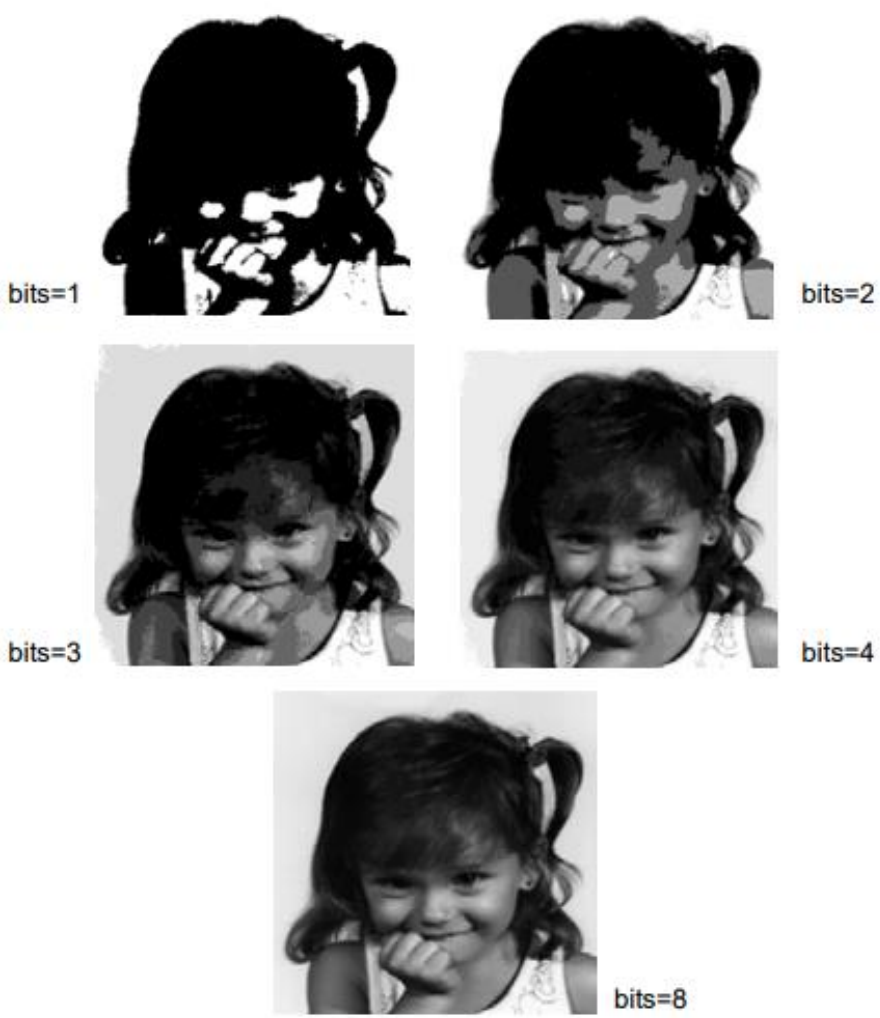

256 levels | 32 levels | 16 levels

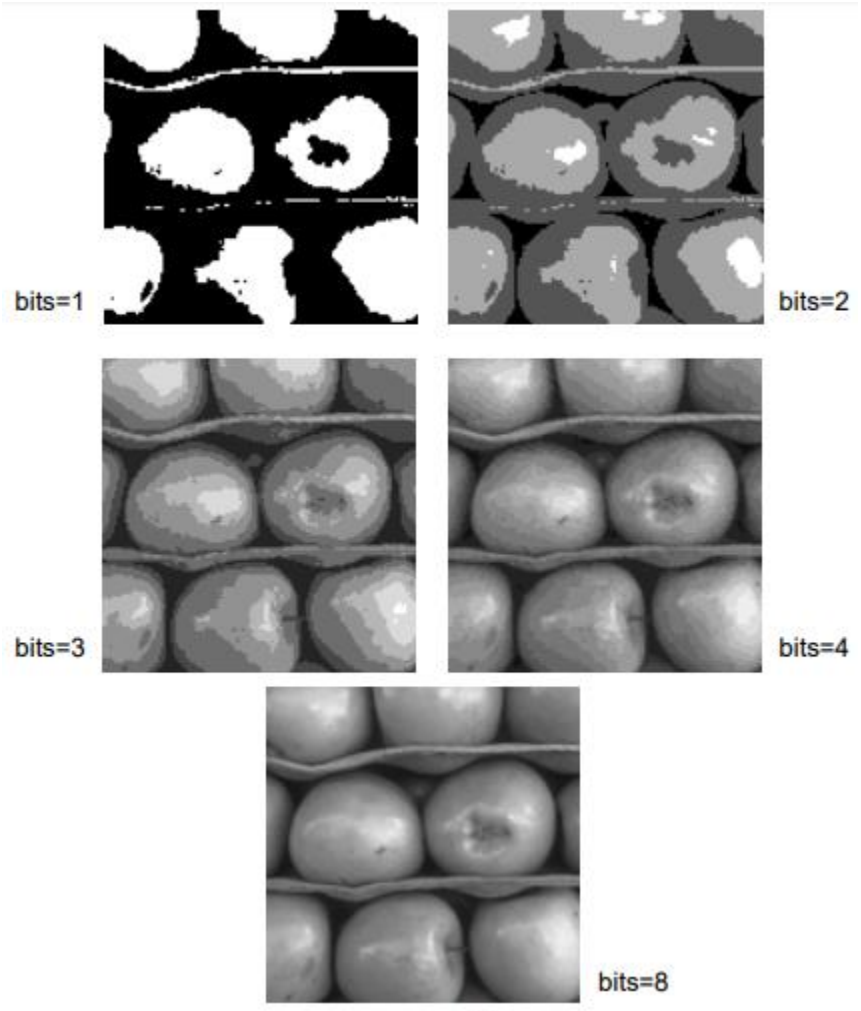
8 levels | 4 levels | 2 levels

# Color Depth

- The number of bits used to indicate the color of a single pixel.
  - Bits per pixel
- Direct color
  - 8-bit color → 3 bits on R and G channels, and 2 bits on B channel
  - 16-bit color → High color (RGBA)
  - 18-bit color → LCD
  - 24-bit color → true color

# Different Number of Gray Levels

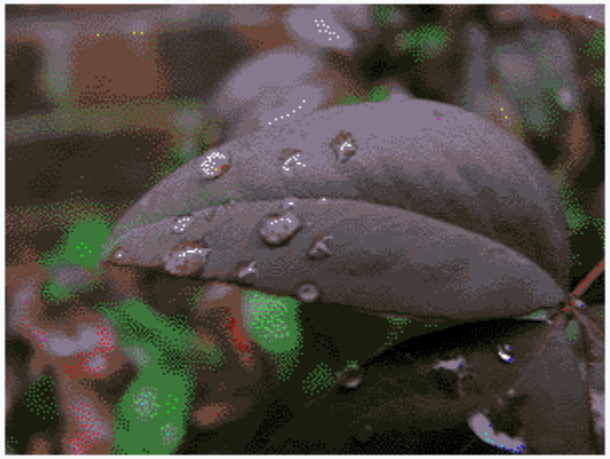


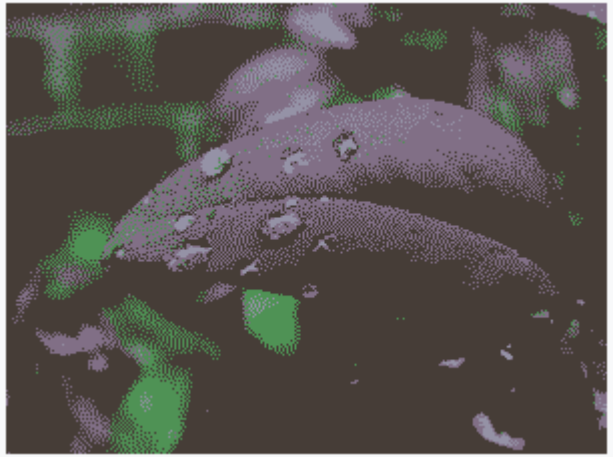

http://www1.idc.ac.il/toky/imageProc-08/lectures/02_acqusitionx4.pdf

32 Bit

8 Bit



4 Bit



2 Bit

# Non-Uniform Quantization

- The previous approach considers that all values are equally important and uniformly distributed.

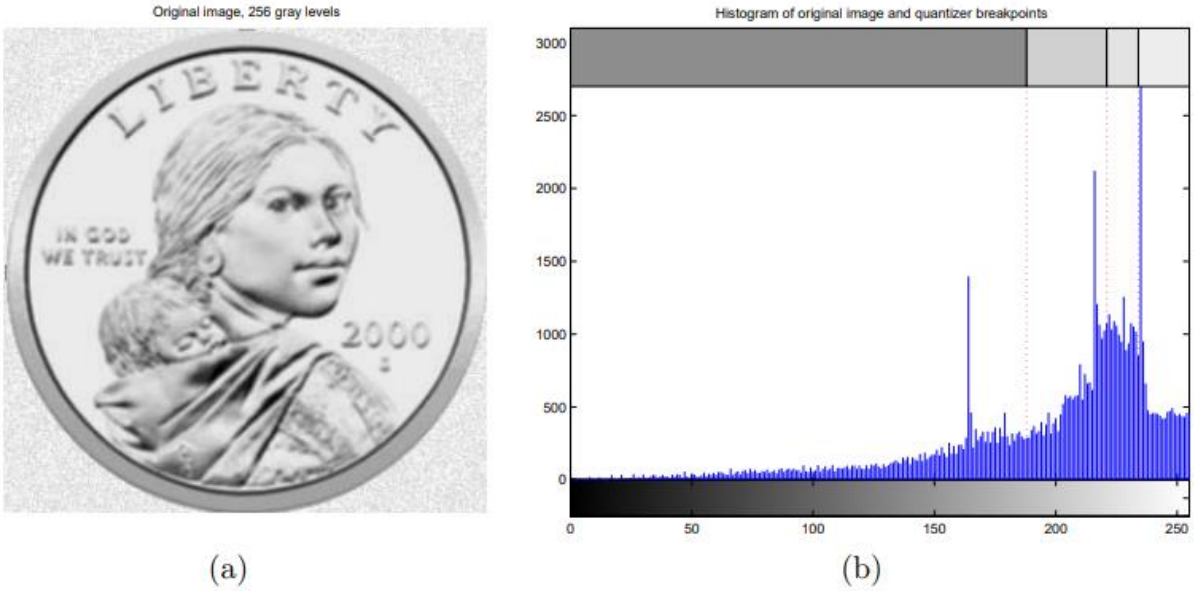
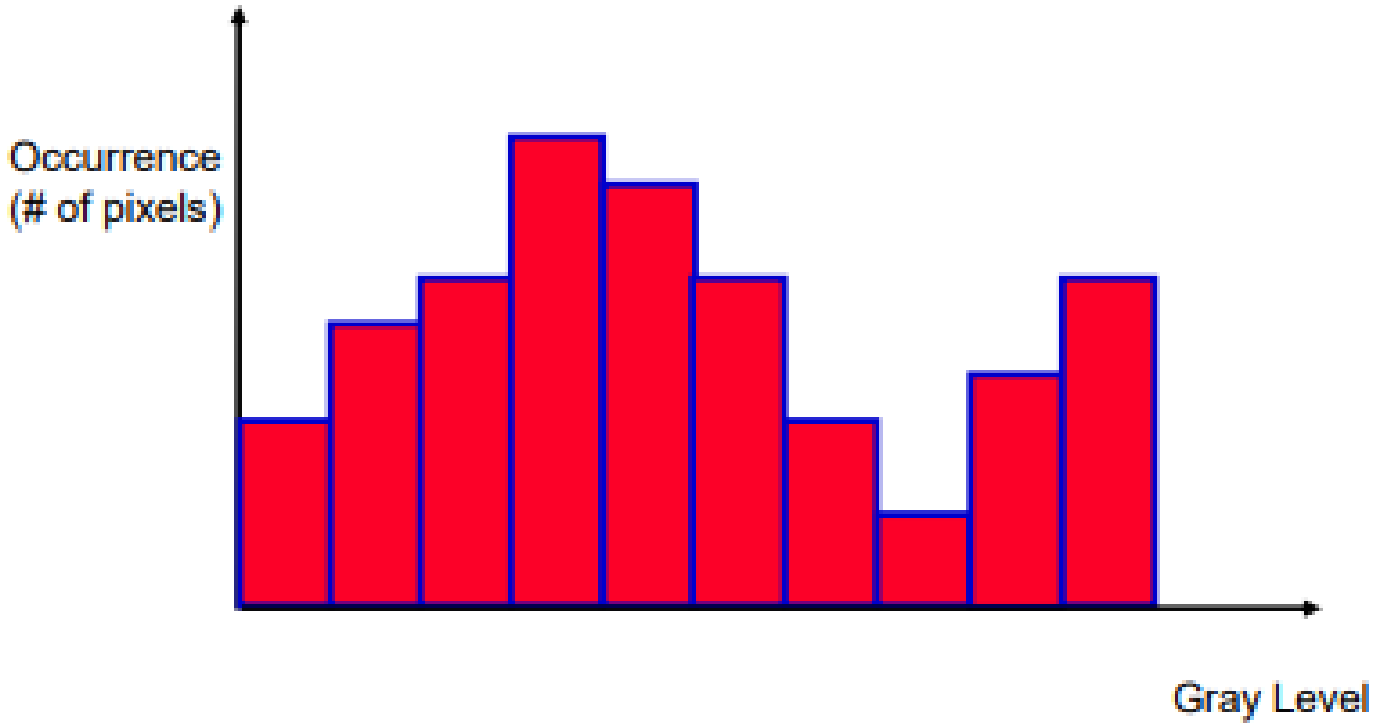


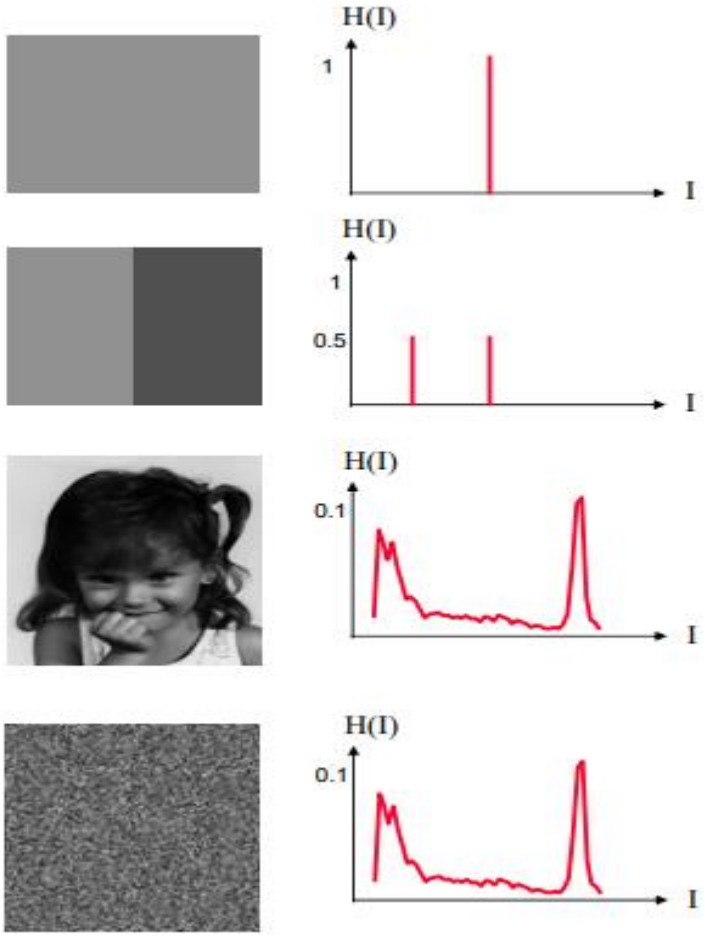

Figure 5.15: (a) Original image. (b) Image histogram.

# Image Histogram




http://www1.idc.ac.il/toky/imageProc-08/lectures/02_acqusitionx4.pdf

# Image Histogram Samples




http://www1.idc.ac.il/toky/imageProc-08/lectures/02_acqusitionx4.pdf

# Non-Uniform Quantization

- What to do if some values are more important than others?
- In general, we can look for quantization levels that “more accurately” represent the data.
- To minimize the mean square error (MSE) we can use the Max-Lloyd algorithm to find the quantization levels with minimum MSE.

# Non-Uniform Quantization

- Max-Lloyd algorithm:
  1. Choose initial quantization levels;
  2. Assign points to a quantization level and reconstruct image;
  3. Compute the new quantization levels as the mean of the value of all points assigned to each quantization level.
  4. Go back to 2 until reduction of MSE is minimal.

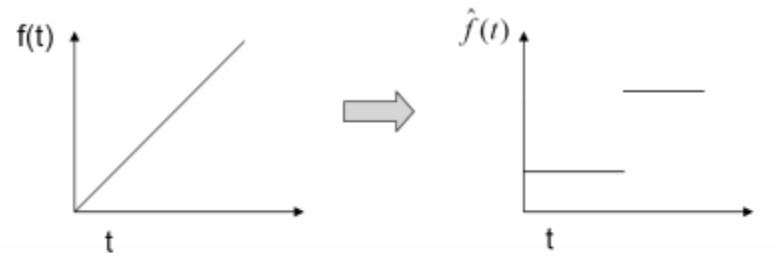
# Non-Uniform Quantization


(a) (b)

Figure 5.16: (a) Uniformly quantized image. (b) Non-uniformly quantized image

# The “false contour” Effect

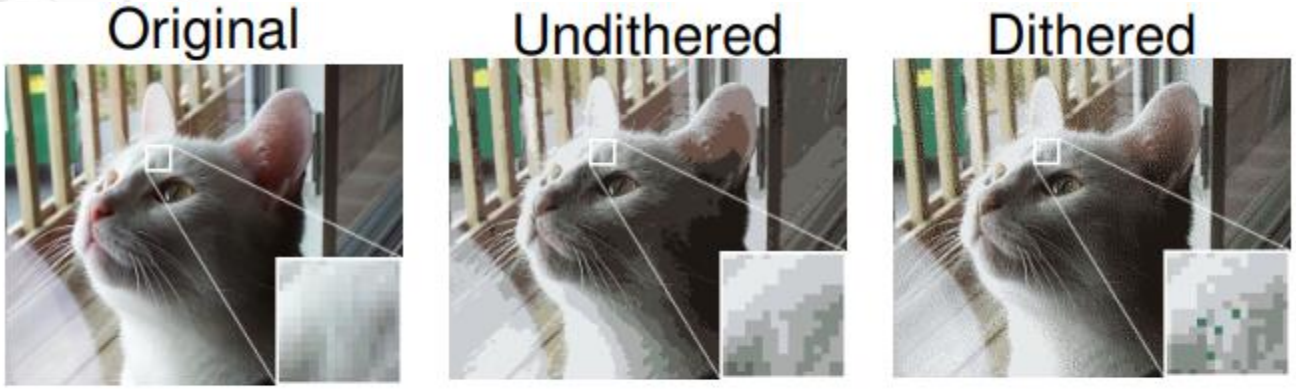
- By quantizing the images we introduce discontinuities in the image intensities which look like contours.
  - in 1-D,




  - in 2-D,

# The “false contour” Effect

- To mitigate the “false contour” effect we can use dither.
  - Basically, we add noise before quantization to create a more natural distribution of the new intensity values.




(Images from Wikipedia.)

# THANK YOU

Mengakar Kuat
Menjulang
Tinggi