IN433
Multimedia Processing

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Outline

- Analog and digital information
- Sampling and quantization of signals
- What’s an image?
- Image layout
- Sampling and quantization for images
- Types of images
- Image formats
- Neighborhood

Multimedia

Analog and Digital Signals

Analog and Digital Signals

- Analog signal → Representation by a continuous function
- Digital signals → Representation by a discrete set of values at specific instances of the input domain (time, space or both)

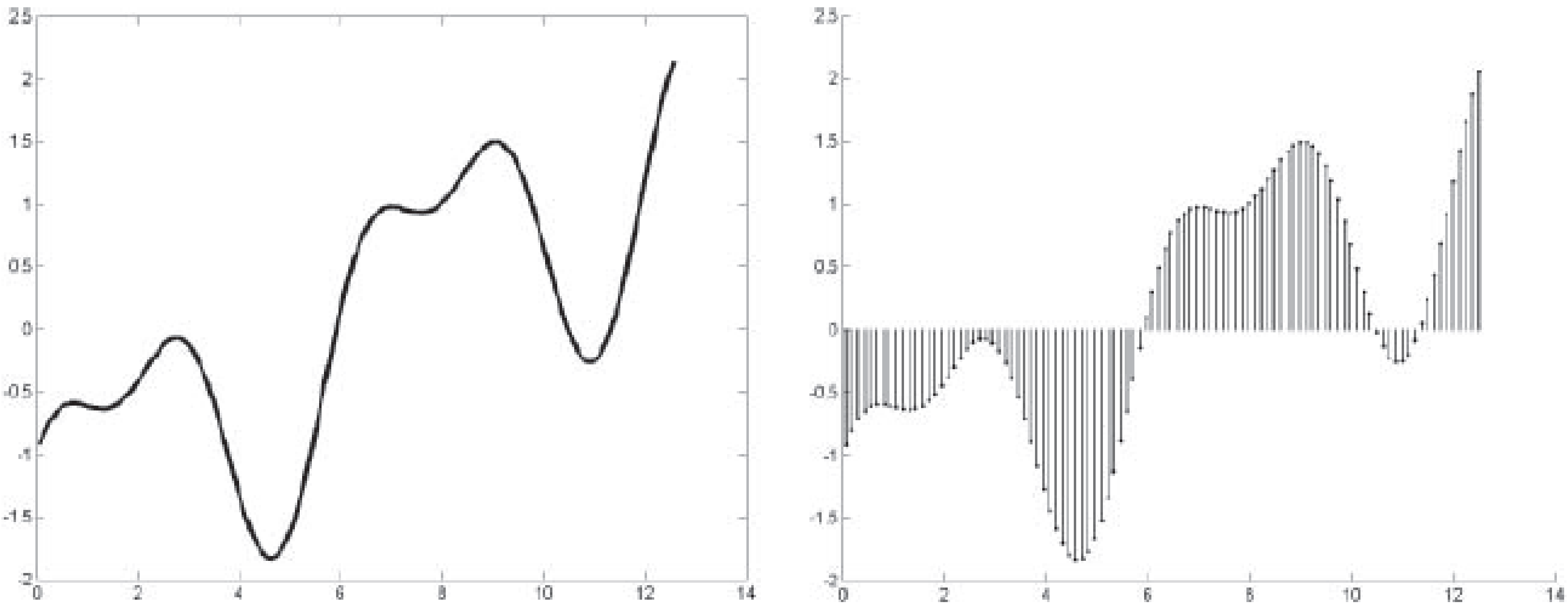


Figure 2-1 Example of an analog signal (left) and a digital signal (right) in one dimension

Analog and Digital Signals

Advantages of Digital over Analog

- Create complex and interactive content
- Stored digital signals don't degrade over time
- Digital data can be efficiently compressed and transmitted across networks
- Easy to store digital signals

Analog to Digital Conversion

Two steps to convert from A. to D.:

- **Sampling**
- **Quantization**

Conversion back from D to A need interpolation techniques

Analog to Digital Conversion

STEP 1: Sampling

- In brief, choosing "some" values, i.e. **samples**, from the signal and not all the values of the signals.
- Given a signal x(t), the sampled signal:

$$x_s(n) = x(nT), \text{ where } T \text{ is the sampling period and}$$
$$f = 1/T \text{ is the sampling frequency.}$$

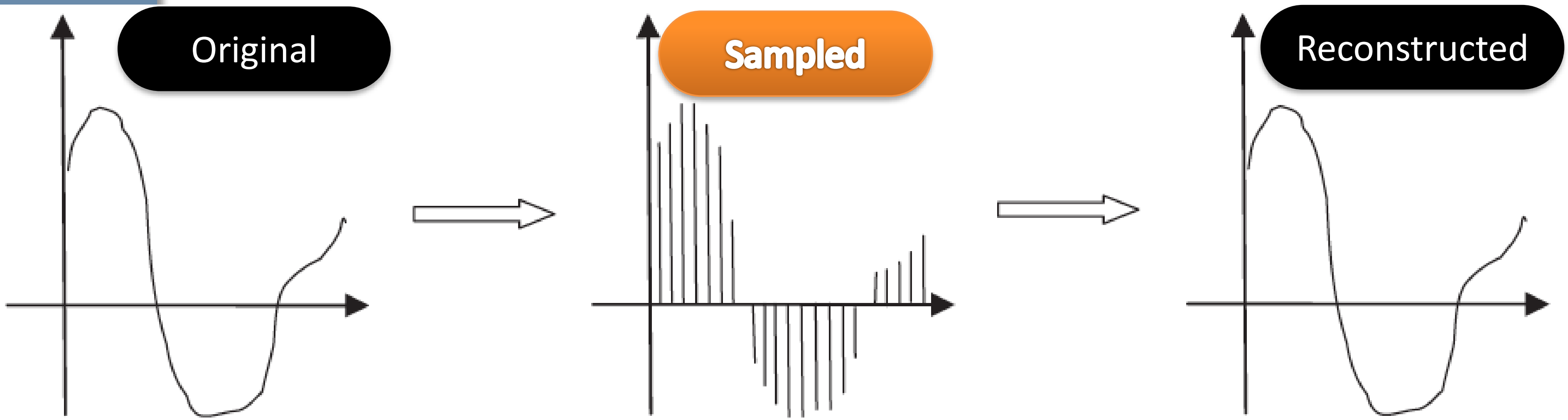
T ↓ → f ↑→ number of samples ↑ → storage ↑

T ↑ → f ↓→ number of samples ↓ → under-sampled (artifacts)

Analog to Digital Conversion

STEP 1: Sampling

- Sampling is done in 1-D (time) for sound signals
- In 2-D (x,y) for images
- In 3-D (x,y,time) for video



Analog to Digital Conversion

STEP 2: Quantization

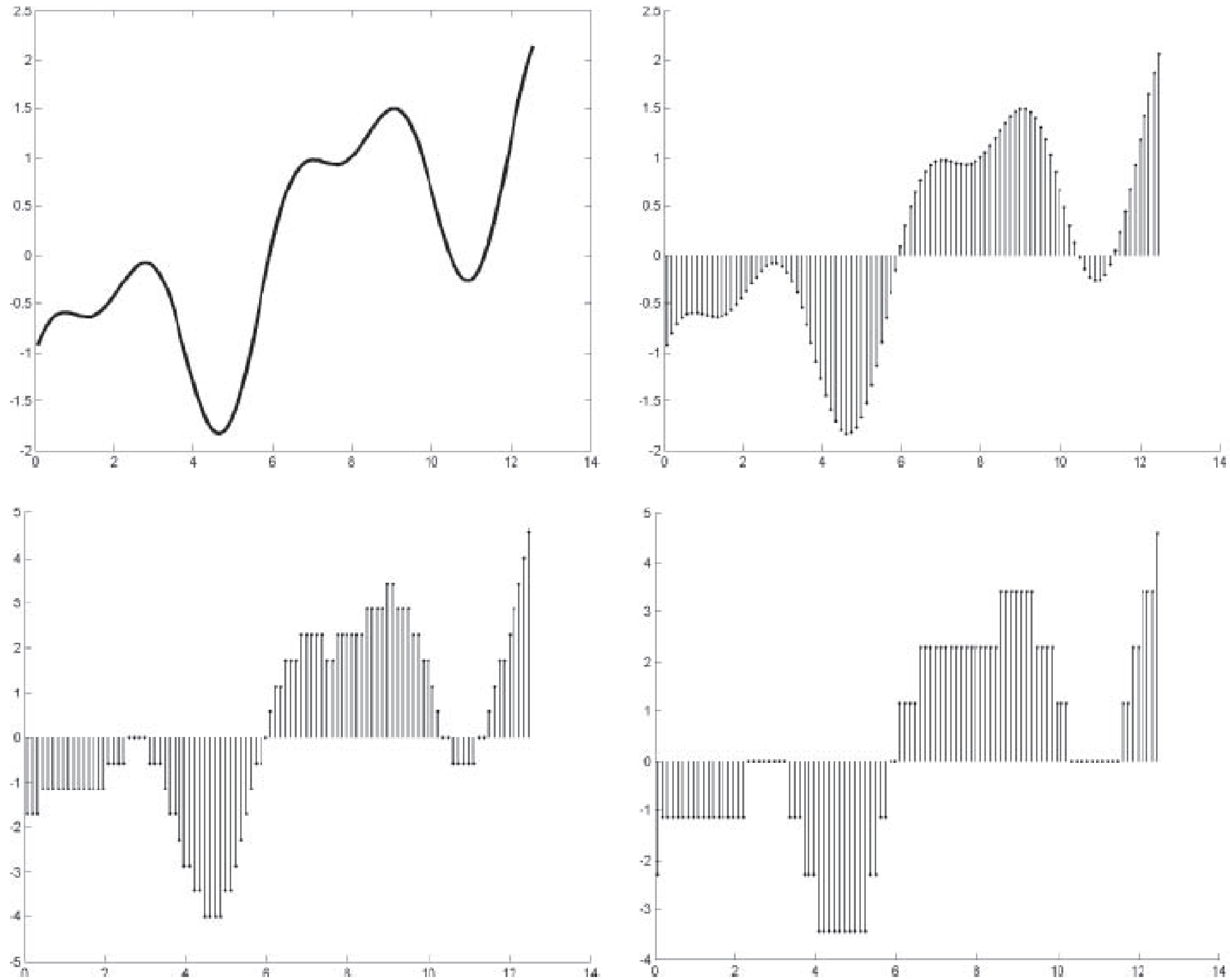
- Encoding the signal value at every sampled location with a pre-defined precision, i.e. number of levels

- How many levels should we use? How many bits should be used?

- A signal which values range from 0 to 8 can be represented by 2 bits or by 3 bits or 4 bits … which is better?

STEP 2: Quantization

- What is the difference?



Analog to Digital Conversion

STEP 2: Quantization

- The entire range R of the signal is represented by a finite number of bits b.

$$x_q(n) = Q[x_s(n)], \text{ where Q is the rounding function.}$$

- Q[] maps the continuous value xs(n) to the nearest digital value xq(n) using b bits.
- With b bits, we have 2^b levels (3 bits → 8 levels)

- Quantization Step Delta=$R/2^b$
- Quantization error decreases when b increases

Analog to Digital Conversion

STEP 2: Quantization

What they mean by the number of bits here?


6 bits


5 bits


4 bits


3 bits


2 bits


1 bit

Multimedia

Image representation

What’s an image

- A digital image → considered as a discrete representation of data.
- The data contains both spatial (layout) and intensity (color) information.
- As we shall see later, process an image = treating a multidimensional signal.

Image layout

- (2-D) discrete digital image I(m, n)
  - → response of some sensor
    - at a series of fixed positions (m=1, 2, ... M; n = 1, 2, ... N) in 2-D Cartesian coordinates.
    - is derived from the 2-D continuous spatial signal I (x, y) through a sampling process frequently referred to as discretization.
- Discretization occurs naturally with certain types of imaging sensor
  - basically effects a local averaging of the continuous signal over some small (typically square) region in the receiving domain.

Image layout

- m and n = rows and columns of the image.
- picture elements = pixels of the image
- Pixels are referred by their 2-D (m,n) index.
- Some consider images as discrete.
  - Theoretically convenient to treat an image as a continuous spatial signal: I(x, y) .
  - allows us to make more natural use of the powerful techniques of integral and differential calculus
  - Allow us to understand properties of images and to effectively manipulate and process them.
  - Mathematical analysis of discrete images generally leads to a linear algebraic formulation which is better in some instances.

Image layout

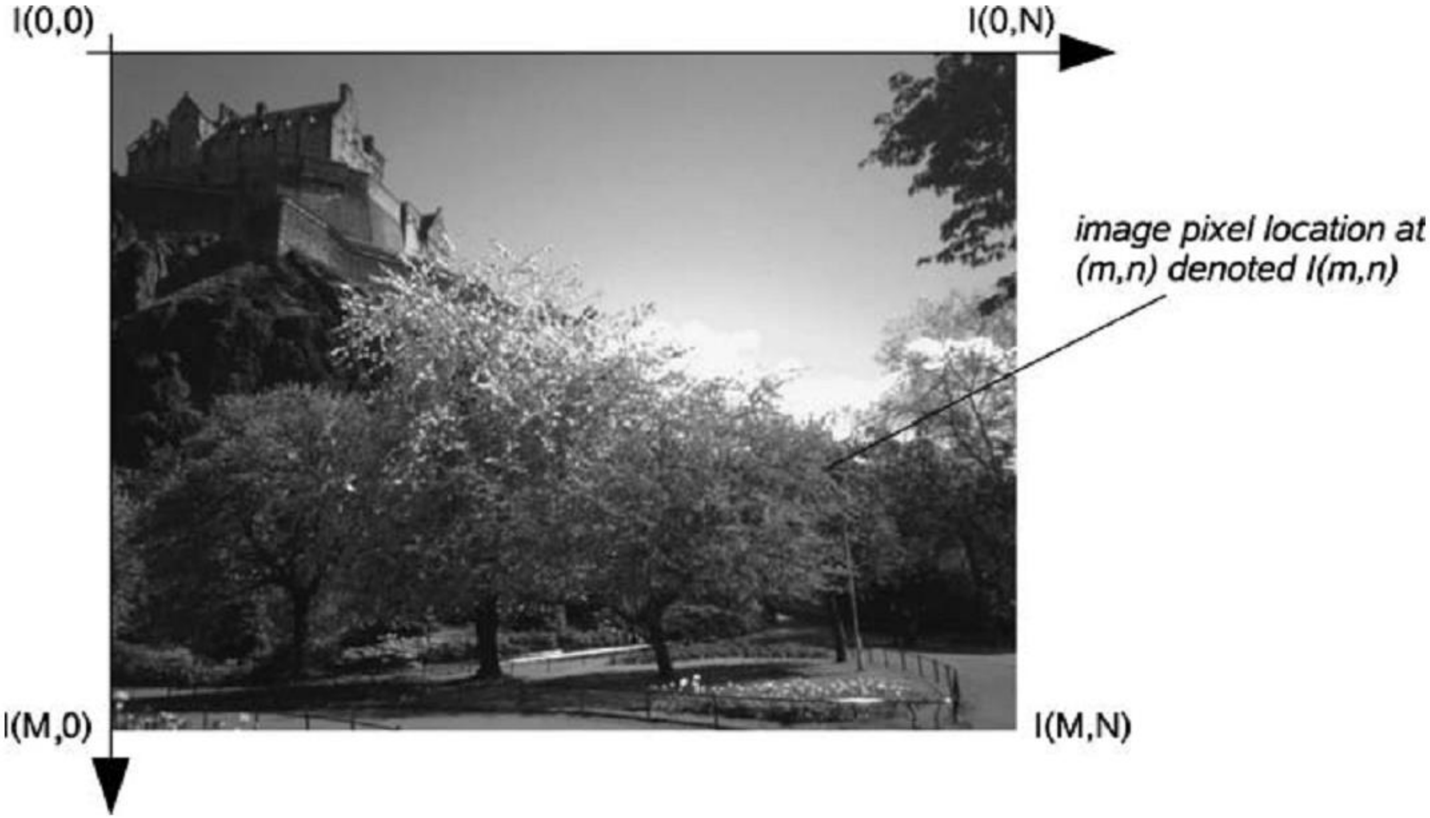


Figure 1.1 The 2-D Cartesian coordinate space of an M x N digital image

Image layout

Image "After snow storm"

- **An image**: **a multidimensional function of spatial coordinates**.
- **Spatial coordinate**: (x,y) for 2-D case such as photograph,
  (x,y,z) for 3-D case such as CT scan images (voxel)
  (x,y,t) for movies
  (x,y,z,t) 4-D images (biomedical, ex: organ + heart bit)
- The function f may represent intensity (for monochrome images) or color (for color images) or other associated values.

Image layout

- **Digital image**: an image that has been discretized both in spatial coordinates and associated value.

- Consist of 2 sets:(1) a point set and (2) a value set

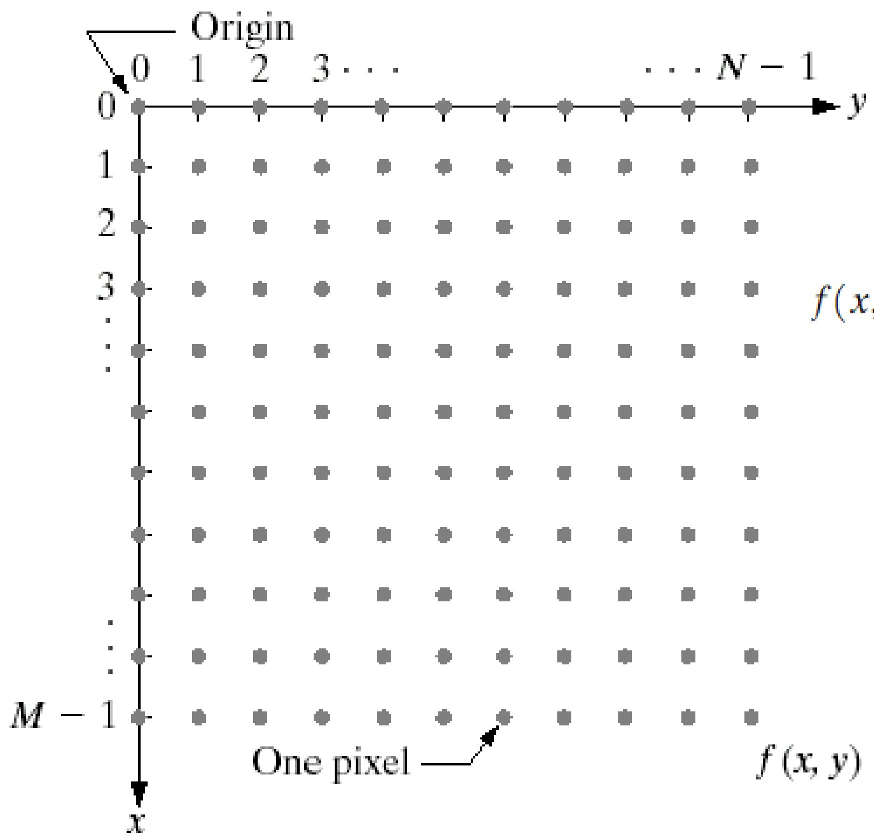
- Can be represented in the form

$$I = \{(x, p(x)): x \in X, p(x) \in F\}$$

where X and F are a point set and value set, respectively.

- An element of the image, $(x, p(x))$ is called a ***pixel*** where
- - x is called the pixel location and
- - $p(x)$ is the pixel value at the location x

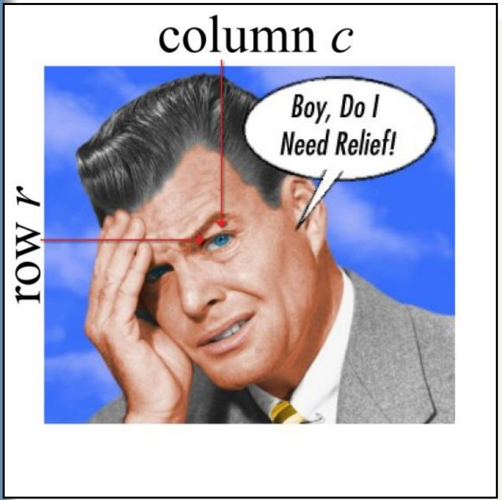
Image layout

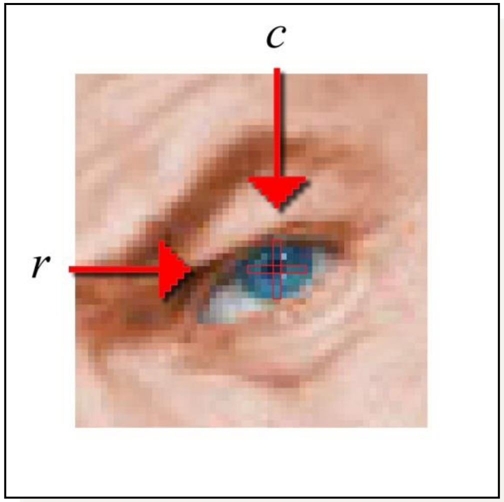


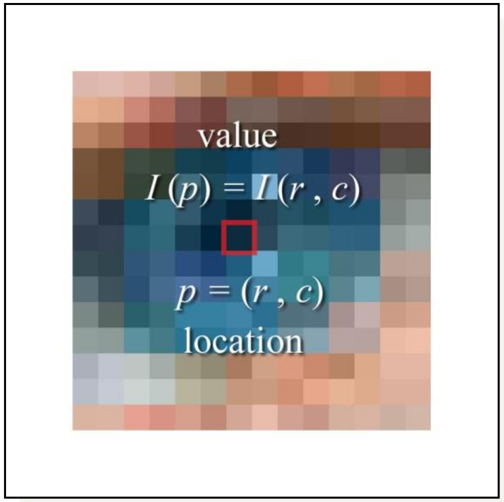
$$f(x,y) = \begin{bmatrix} f(0,0) & f(0,1) & \cdots & f(0,N-1) \\ f(1,0) & f(1,1) & \cdots & f(1,N-1) \\ \vdots & \vdots & & \vdots \\ f(M-1,0) & f(M-1,1) & \cdots & f(M-1,N-1) \end{bmatrix}$$

$$\mathbf{A} = \begin{bmatrix} a_{0,0} & a_{0,1} & \cdots & a_{0,N-1} \\ a_{1,0} & a_{1,1} & \cdots & a_{1,N-1} \\ \vdots & \vdots & & \vdots \\ a_{M-1,0} & a_{M-1,1} & \cdots & a_{M-1,N-1} \end{bmatrix}.$$

Image layout







Pixel Location: $p = (r\,,\,c)$

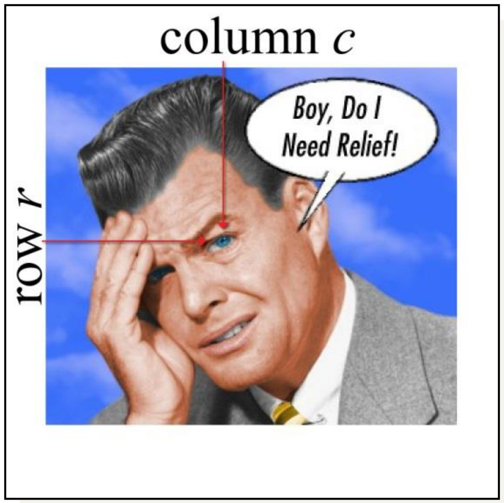
Pixel Value: $I(p) = I(r\,,\,c)$

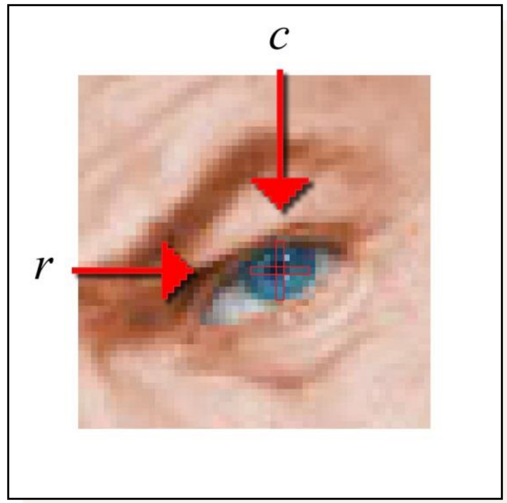
Pixel : $[\,p,\, I(p)]$

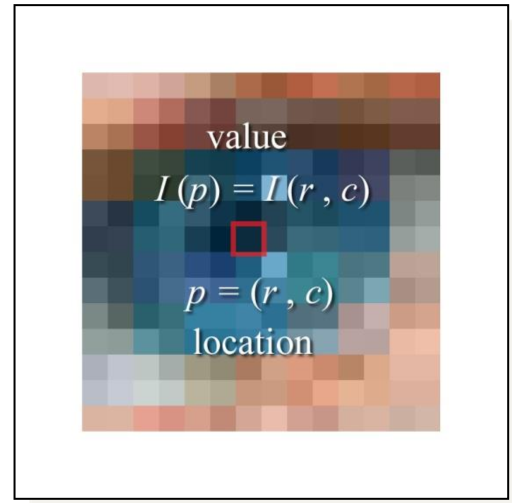
Image layout

Pixels

Pixel : [p, $I(p)$]



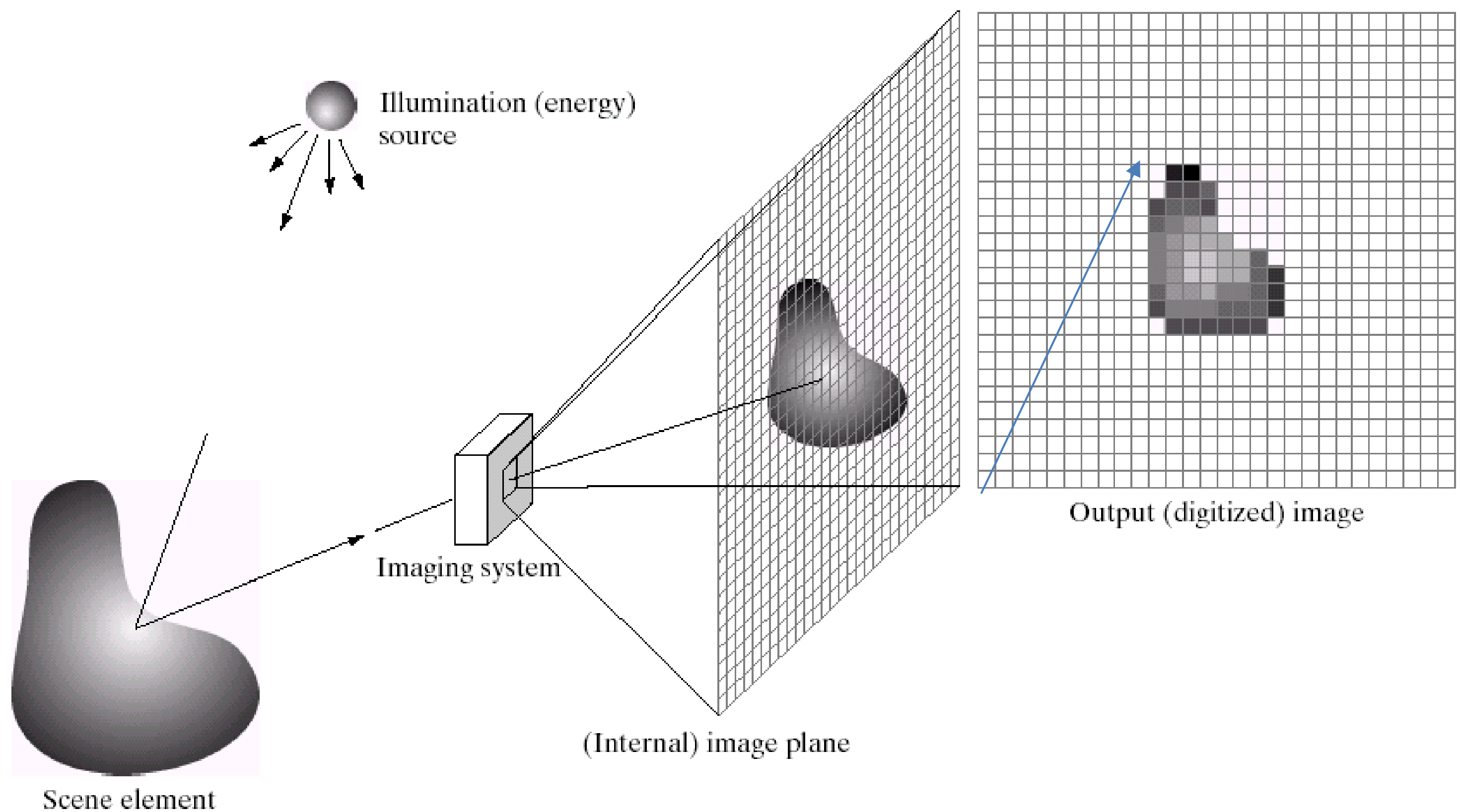




$$
\begin{aligned}
p &= (r, c) \\
&= (\text{row } \#,\ \text{col } \#) \\
&= (272,\ 277)
\end{aligned}
$$

$$
I(p) = \begin{bmatrix} \text{red} \\ \text{green} \\ \text{blue} \end{bmatrix} = \begin{bmatrix} 12 \\ 43 \\ 61 \end{bmatrix}
$$

Sampling & Quantization



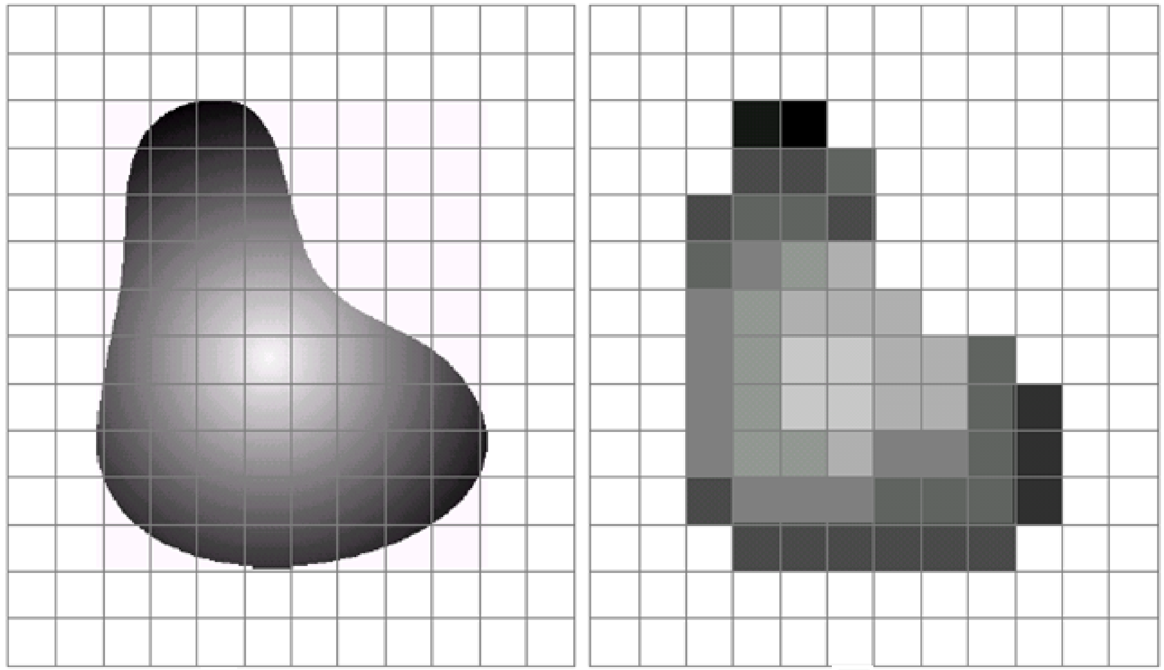
$f(x,y) = i(x,y) * r(x,y)$

$i(x,y)$ = amount of source illumination

$r(x,y)$ = amount of illumination reflected

$0 < i(x,y) < \infty$ and $0 < r(x,y) < 1$ (0=total absorption and 1 = total reflectance)

Sampling and quantization



(a) Continuos image projected onto a sensor array.

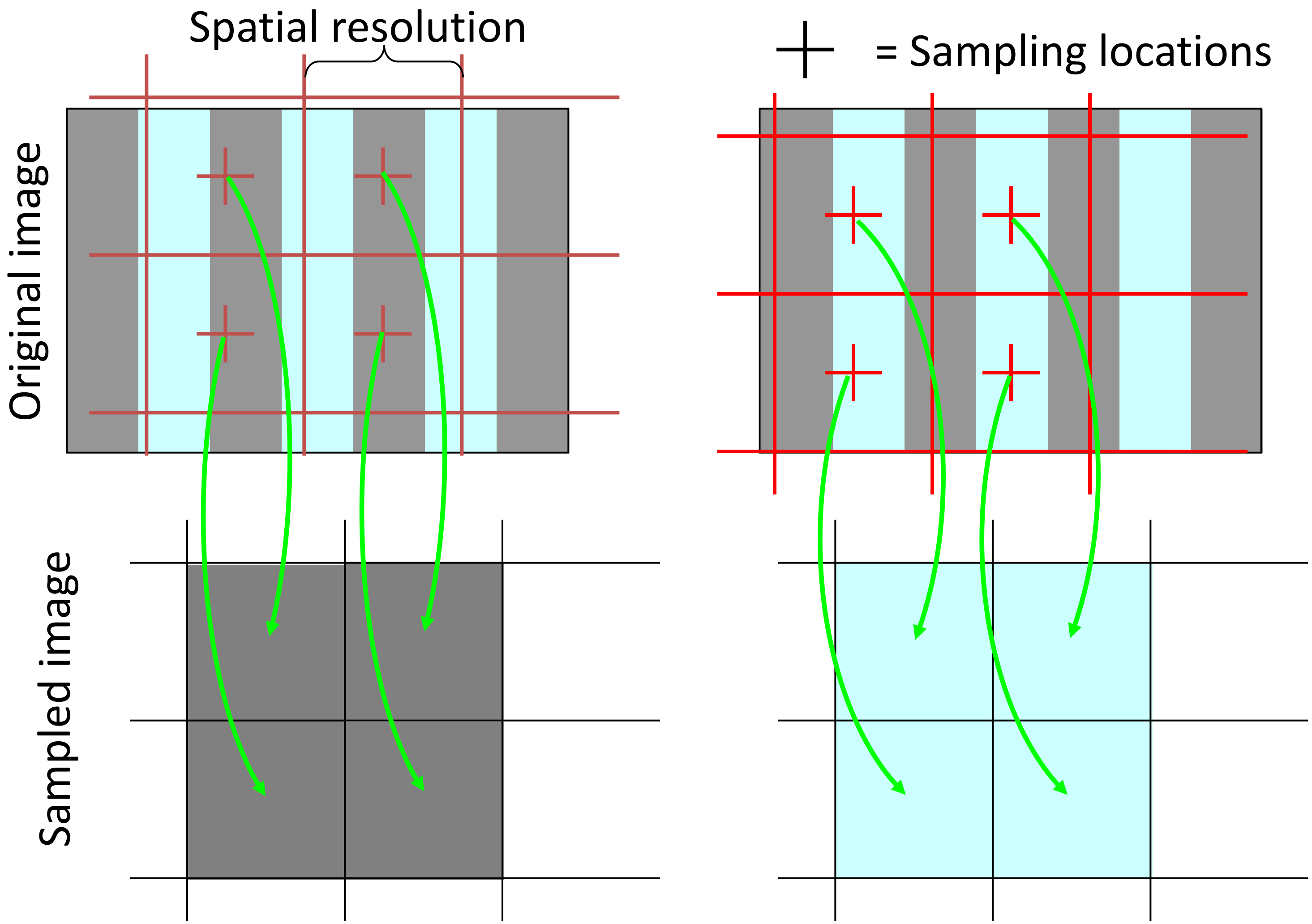
(b) Result of image sampling and quantization.

Image sampling: Digitizing the coordinate values of the spatial domain

Image quantization: Discretizing the amplitude values.

Spatial resolution / image resolution: pixel size or number of pixels

Sampling



Under sampling, we lost some image details!

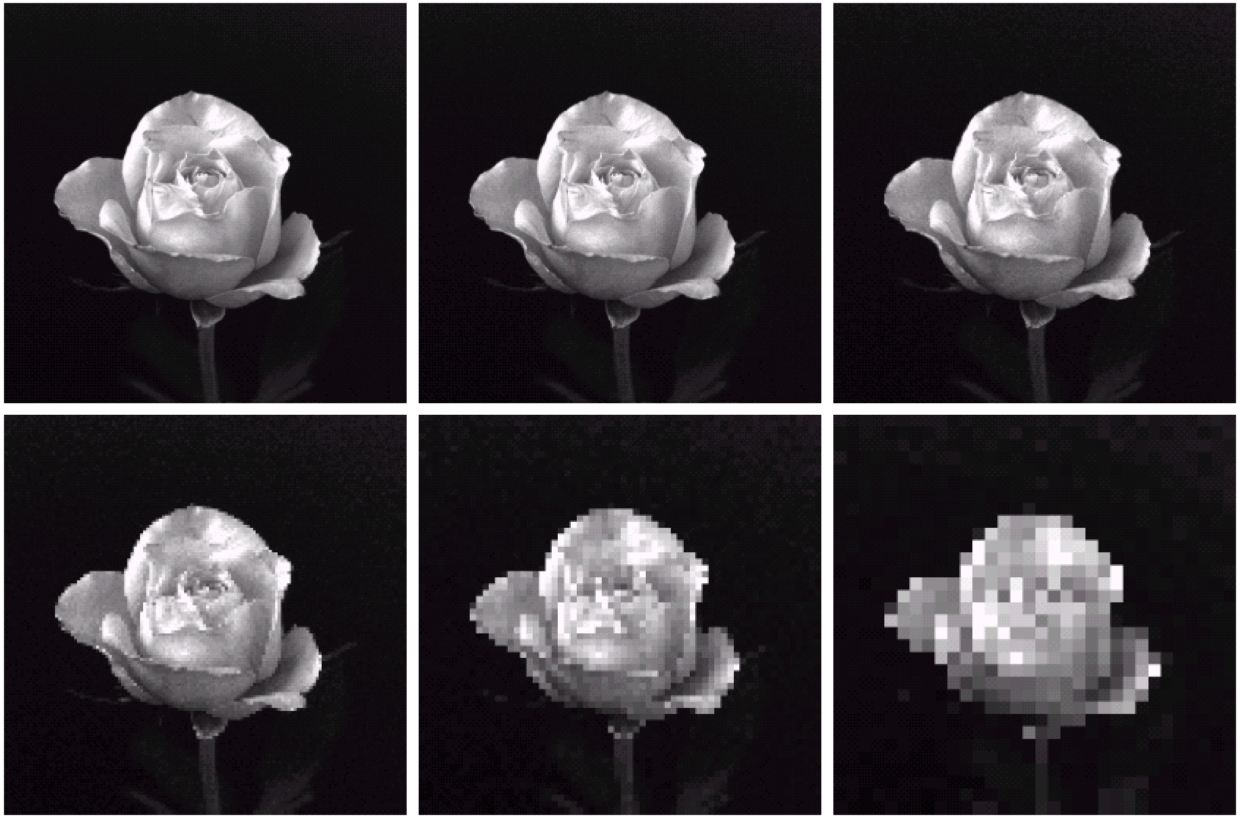
Subsampling

- Image subsampling → reduce the size of the image by throwing away rows and columns

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.

Subsampling

- Make the subsampled images same size → resampling (duplicate pixels)

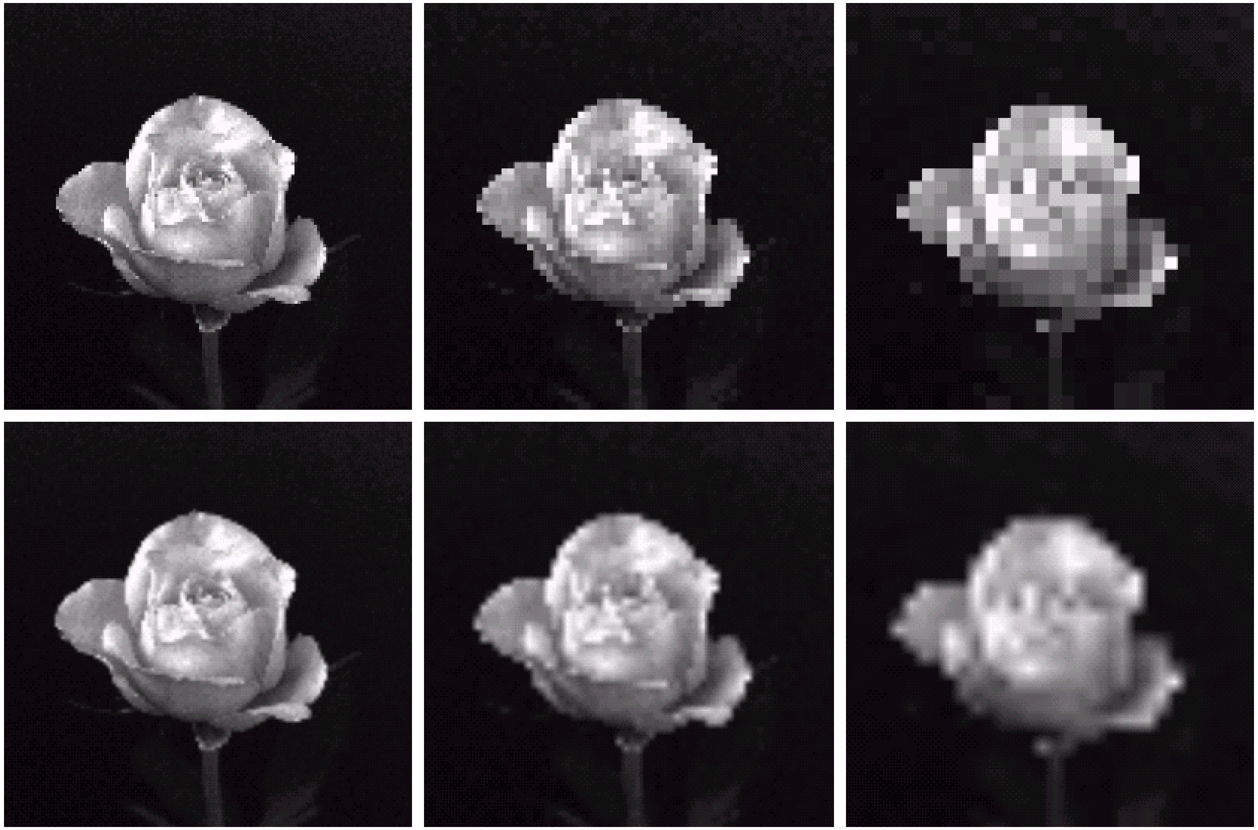


a b c
d e f

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.

Subsampling + interpolation

- Resampled pixel values can be interpolated to avoid pixelization phenomena



a	b	c
d	e	f

FIGURE 2.25 Top row: images zoomed from 128 × 128, 64 × 64, and 32 × 32 pixels to 1024 × 1024 pixels, using nearest neighbor gray-level interpolation. Bottom row: same sequence, but using bilinear interpolation.

Quantization

Image quantization:

– discretize continuous pixel values into discrete numbers

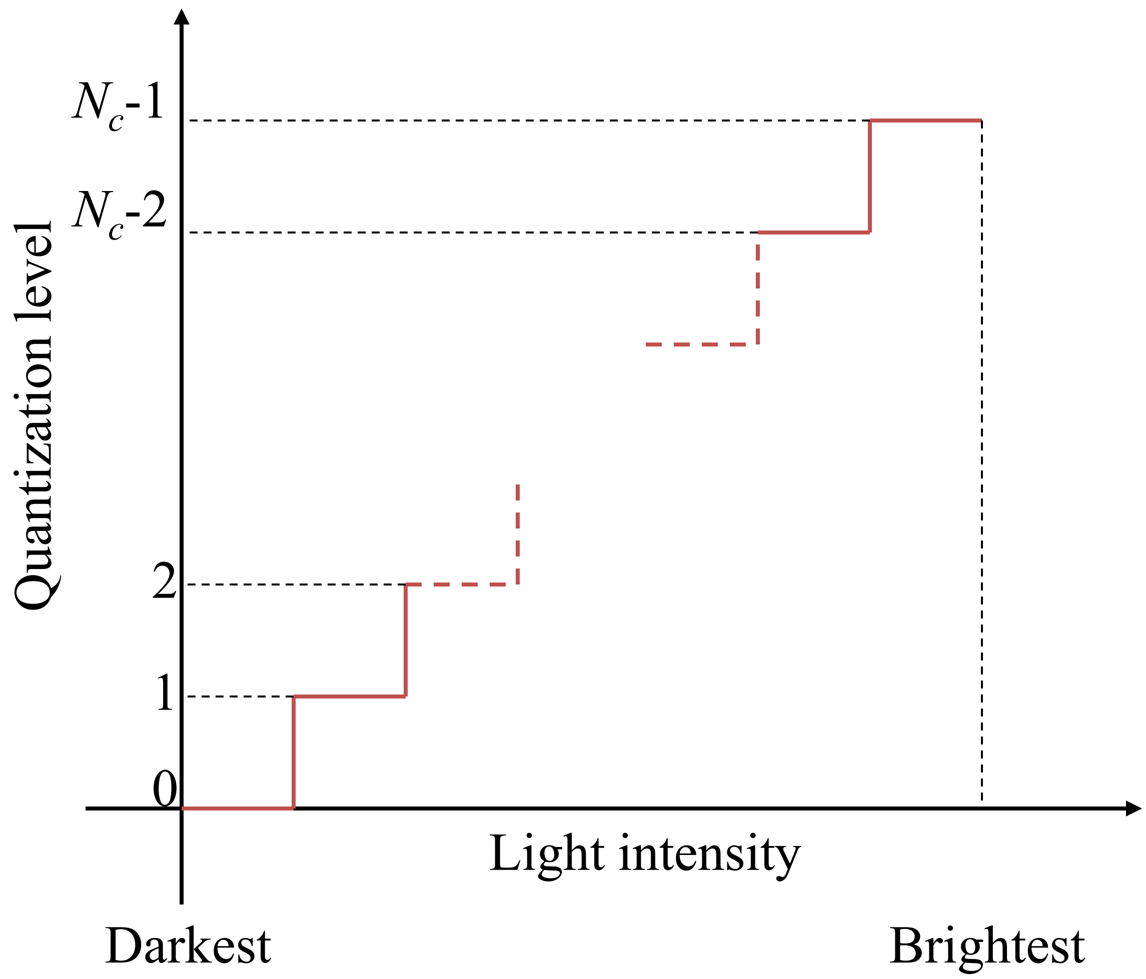
Color resolution/ color depth/ levels:

- No. of colors or gray levels or
- No. of bits representing each pixel value
- No. of colors or gray levels N_c is given by

$$N_c = 2^b$$

where b = no. of bits

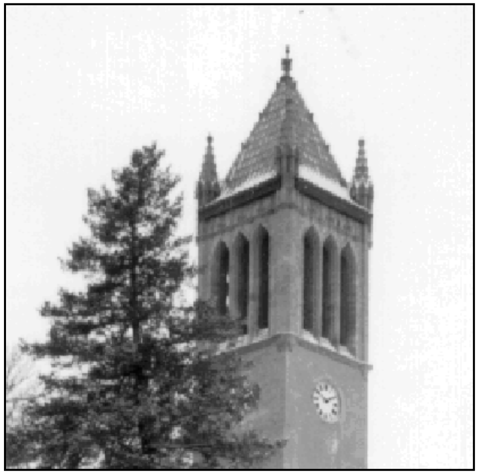
Quantization function



Effects of Quantization Levels

256 levels

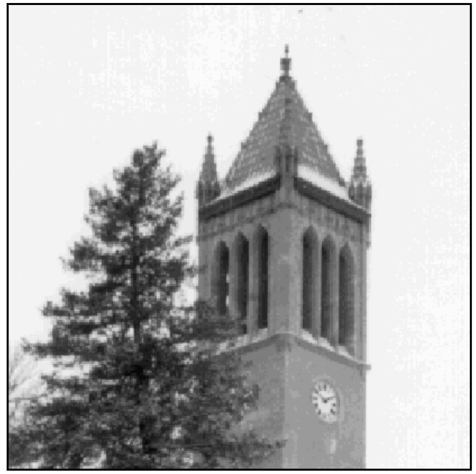
128 levels



64 levels

32 levels

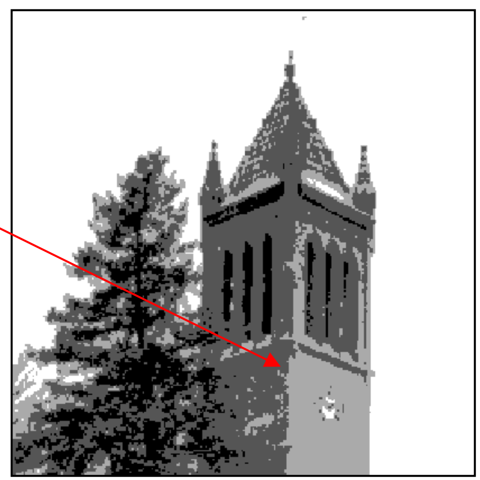
Effects of Quantization Levels



16 levels

8 levels

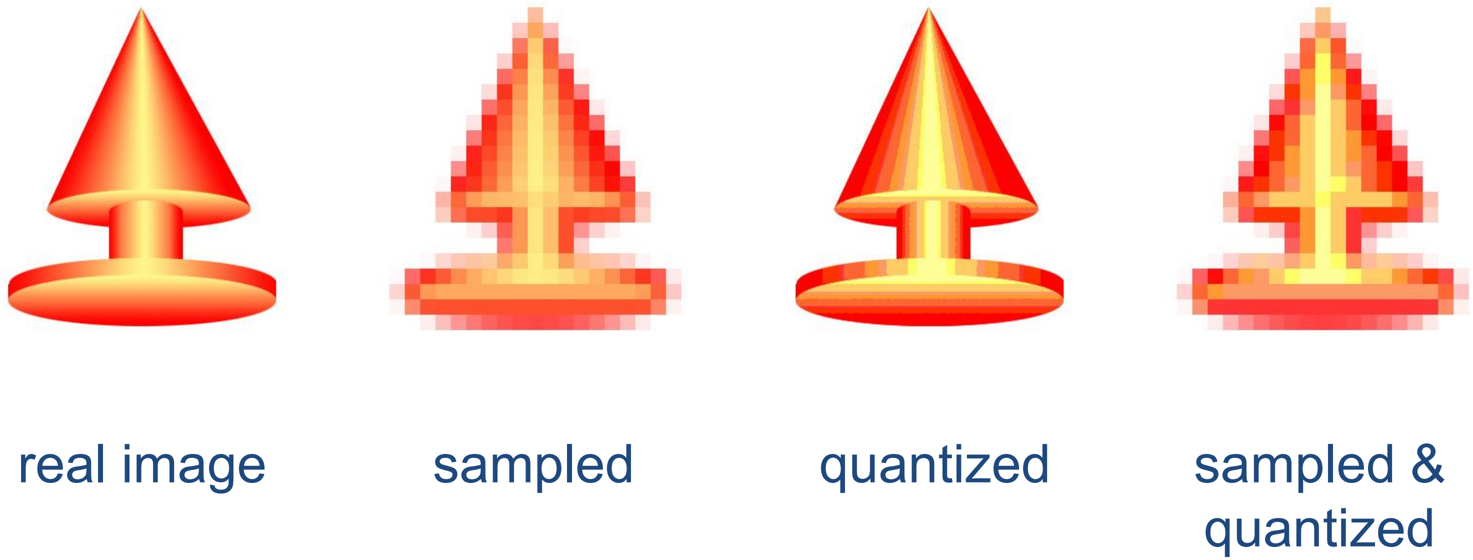
In this image, it is easy to see false contour.



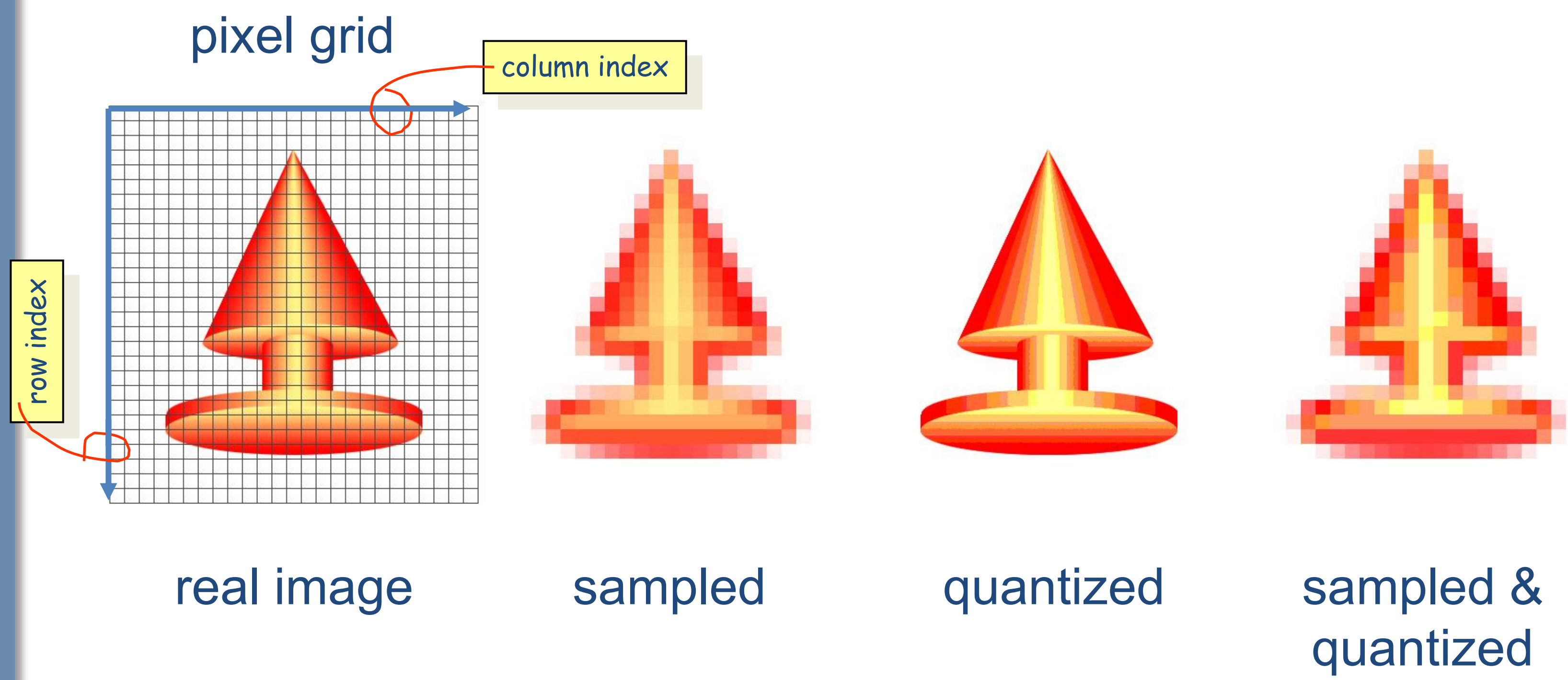
4 levels

2 levels

Sampling & Quantization



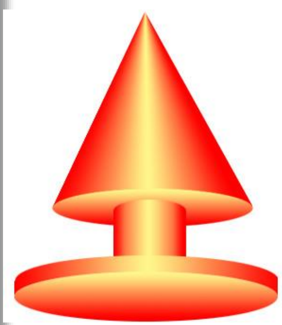
Sampling & Quantization



Sampling & Quantization

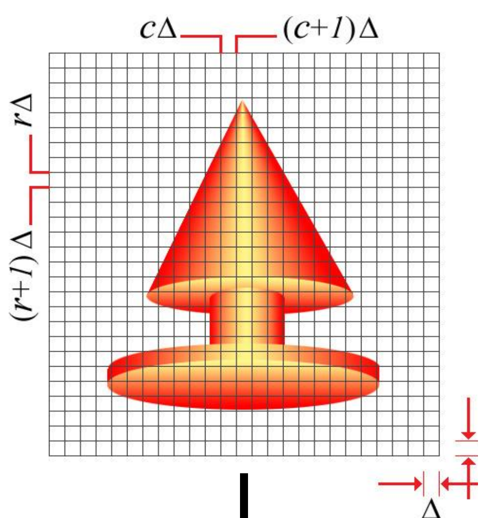
Sampling

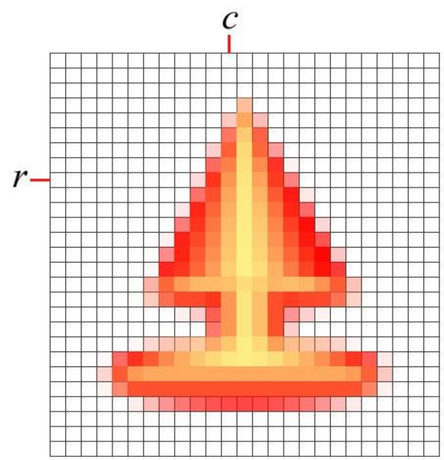
Take the average within each square.



$I_C(\rho, \chi)$

continuous image





$I_S(r, c)$

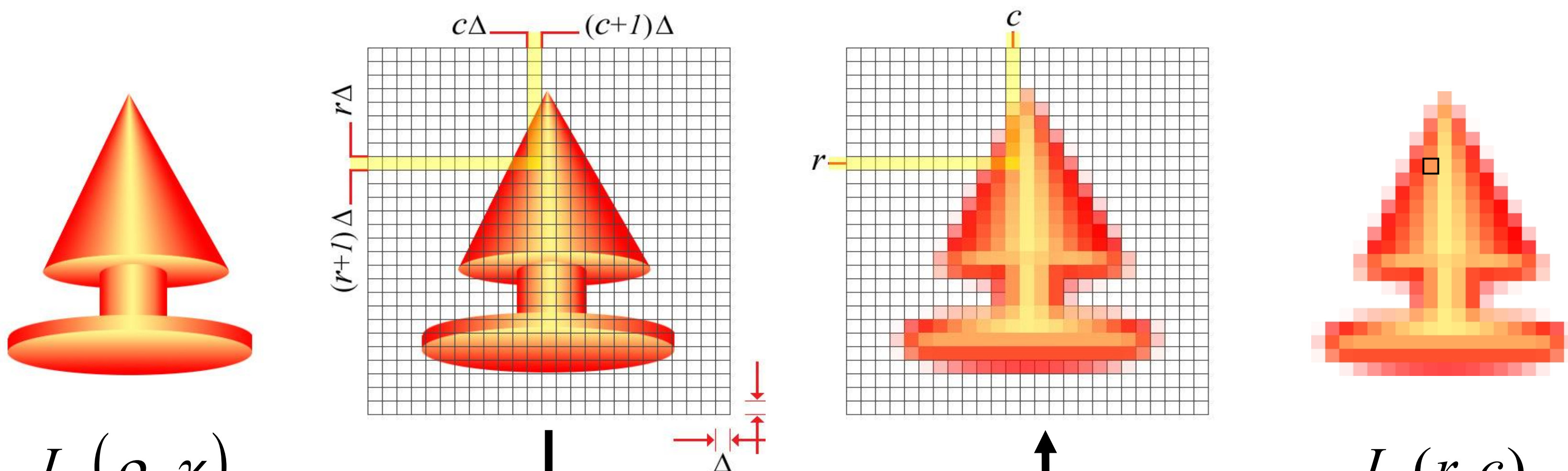
sampled image

$$I_S(r,c) = \frac{1}{\Delta^2} \int_{r\Delta}^{(r+1)\Delta} \int_{c\Delta}^{(c+1)\Delta} I_C(\rho,\chi)\,\delta\rho\,\delta\chi$$

Sampling & Quantization

Sampling

Take the average within each square.



$I_C(\rho,\chi)$

continuous image

$$I_S(r,c)=\frac{1}{\Delta^2}\int_{r\Delta}^{(r+1)\Delta}\int_{c\Delta}^{(c+1)\Delta} I_C(\rho,\chi)\,\delta\rho\,\delta\chi$$

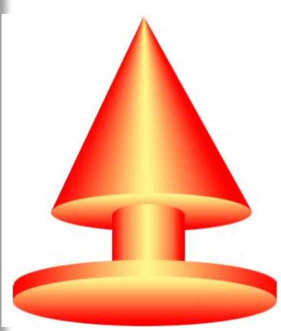
$I_S(r,c)$

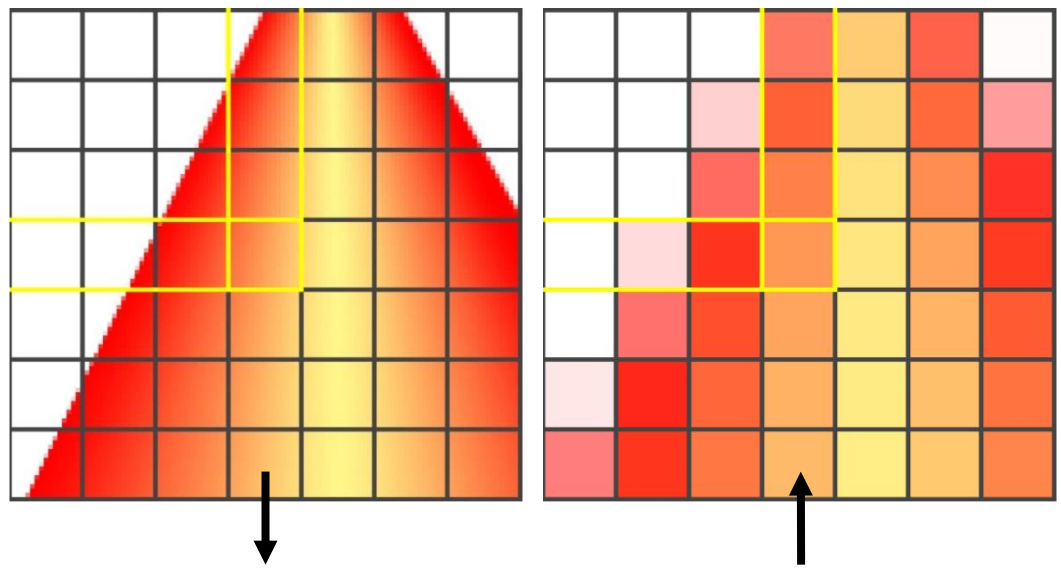
sampled image

Sampling & Quantization

Sampling

Take the average within each square.





$I_C(\rho,\chi)$

continuous image

$I_S(r,c)$

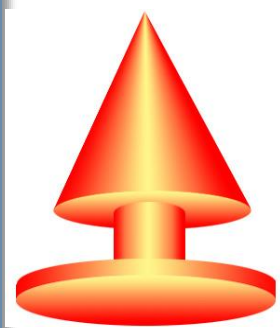
sampled image

$$I_S(r,c) = \frac{1}{\Delta^2} \int_{r\Delta}^{(r+1)\Delta} \int_{c\Delta}^{(c+1)\Delta} I_C(\rho,\chi)\,\delta\rho\,\delta\chi$$

Sampling & Quantization

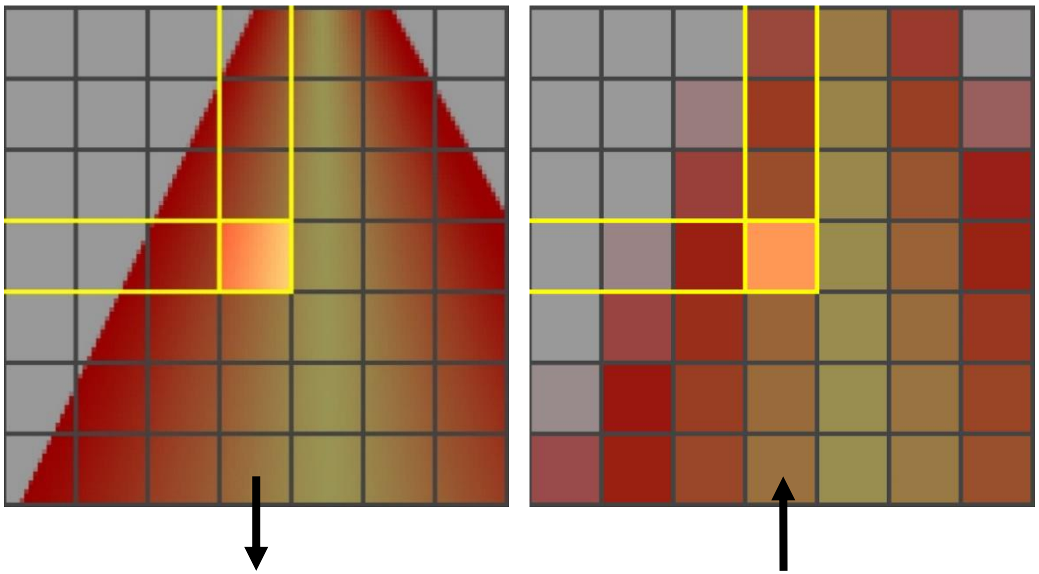
Sampling

Take the average within each square.



$I_C(\rho,\chi)$

continuous image



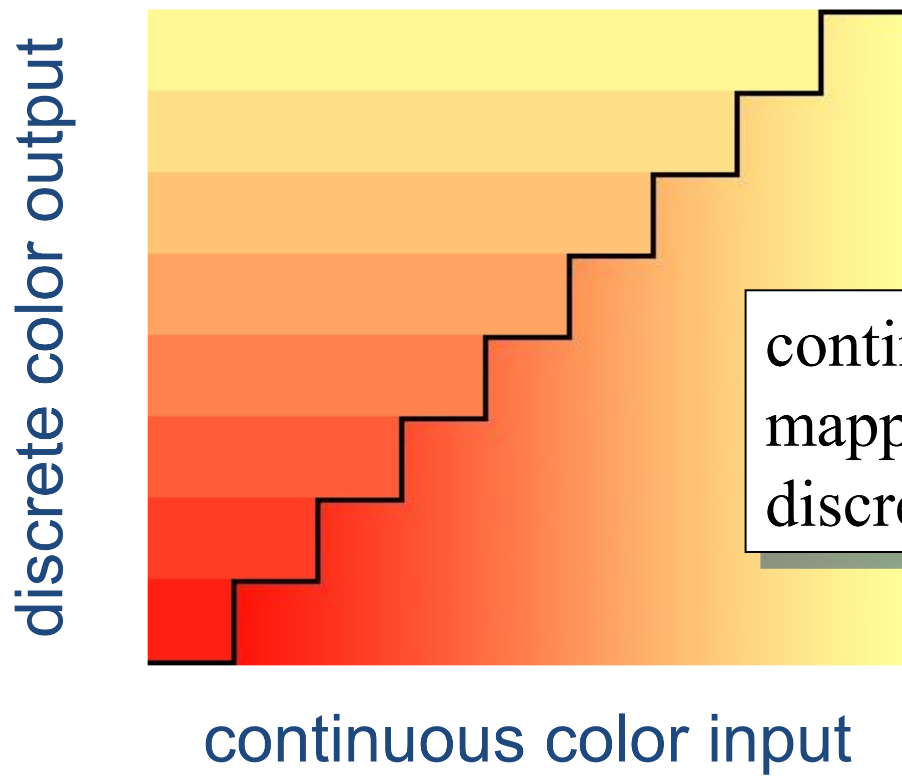
$$I_S(r,c)=\frac{1}{\Delta^2}\int_{r\Delta}^{(r+1)\Delta}\int_{c\Delta}^{(c+1)\Delta} I_C(\rho,\chi)\,\delta\rho\,\delta\chi$$

$I_S(r,c)$

sampled image

Sampling & Quantization

Digital Image Formation: Quantization

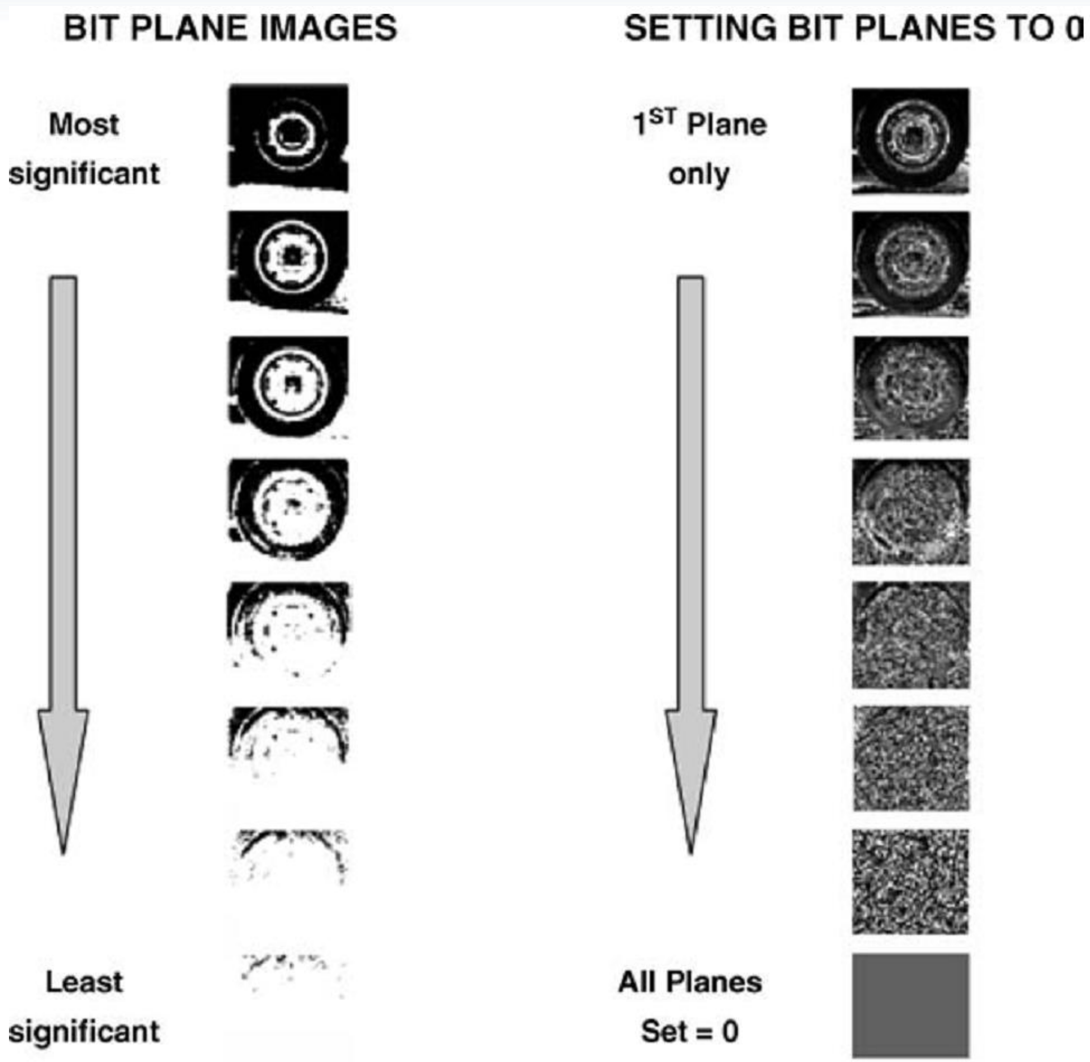


continuous colors mapped to a finite, discrete set of colors.

Bit-plane splicing

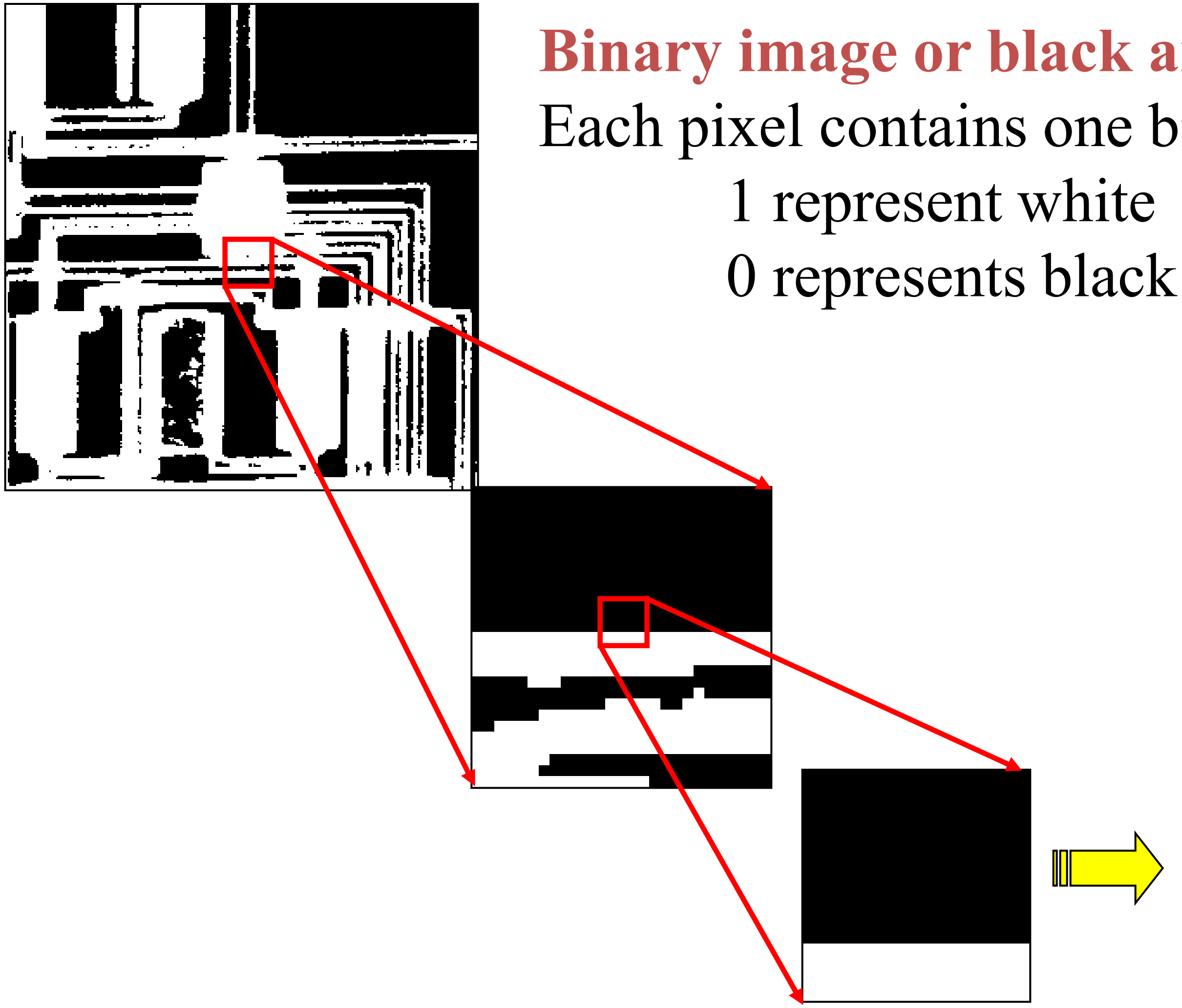
- Visual significance of individual pixel bits in an image.
  - Ex: 8-bit image → values from 0 to 255.
  - Can be divided into eight separate image planes.
  - Each plane corresponds to the values of a given bit across all of the image pixels.
  - The first bit plane comprises the first and most significant bit of information (intensity=128), the second, the second most significant bit (intensity=64) and so on.

Bit-plane splicing



An example of bit-plane slicing a grey-scale image

Binary Image



Binary image or black and white image

Each pixel contains one bit :

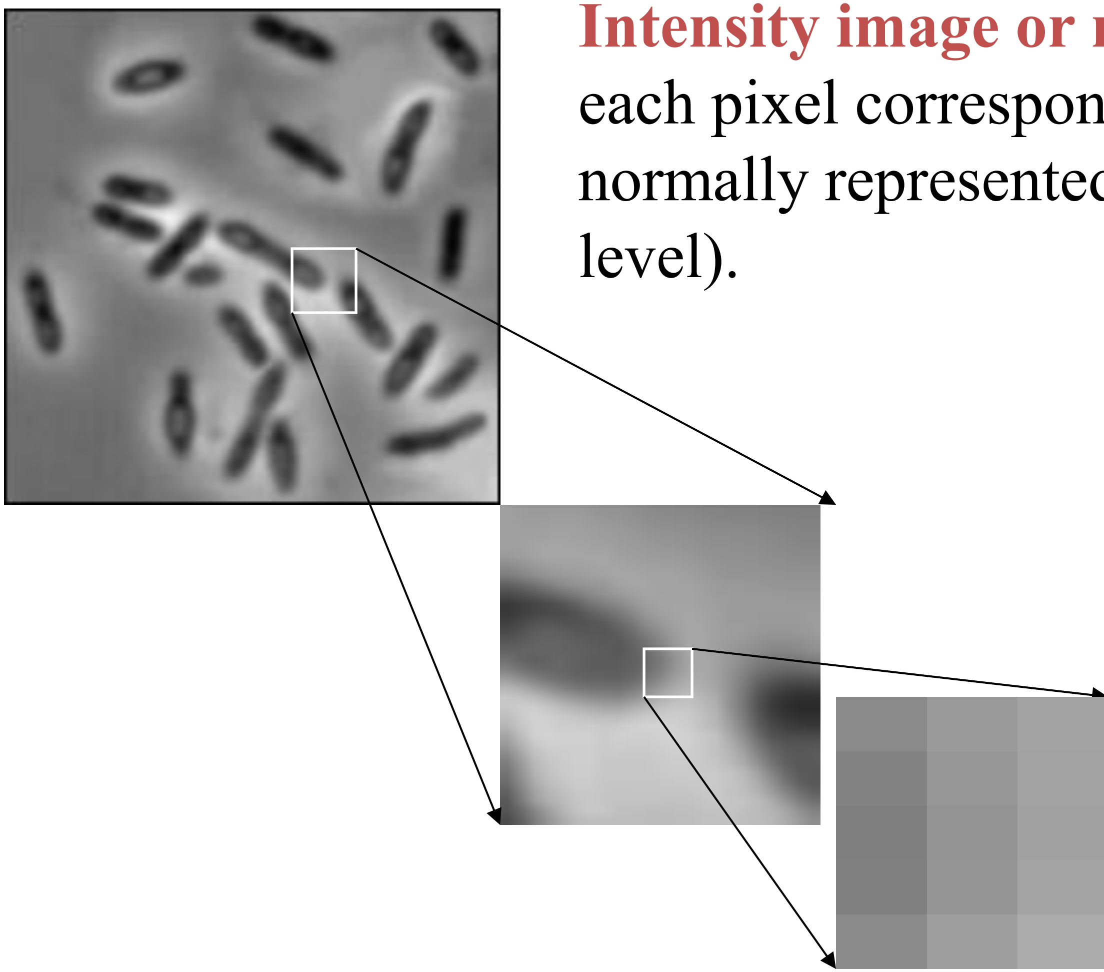
1 represent white

0 represents black

Binary data

$$\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix}$$

Grayscale Image

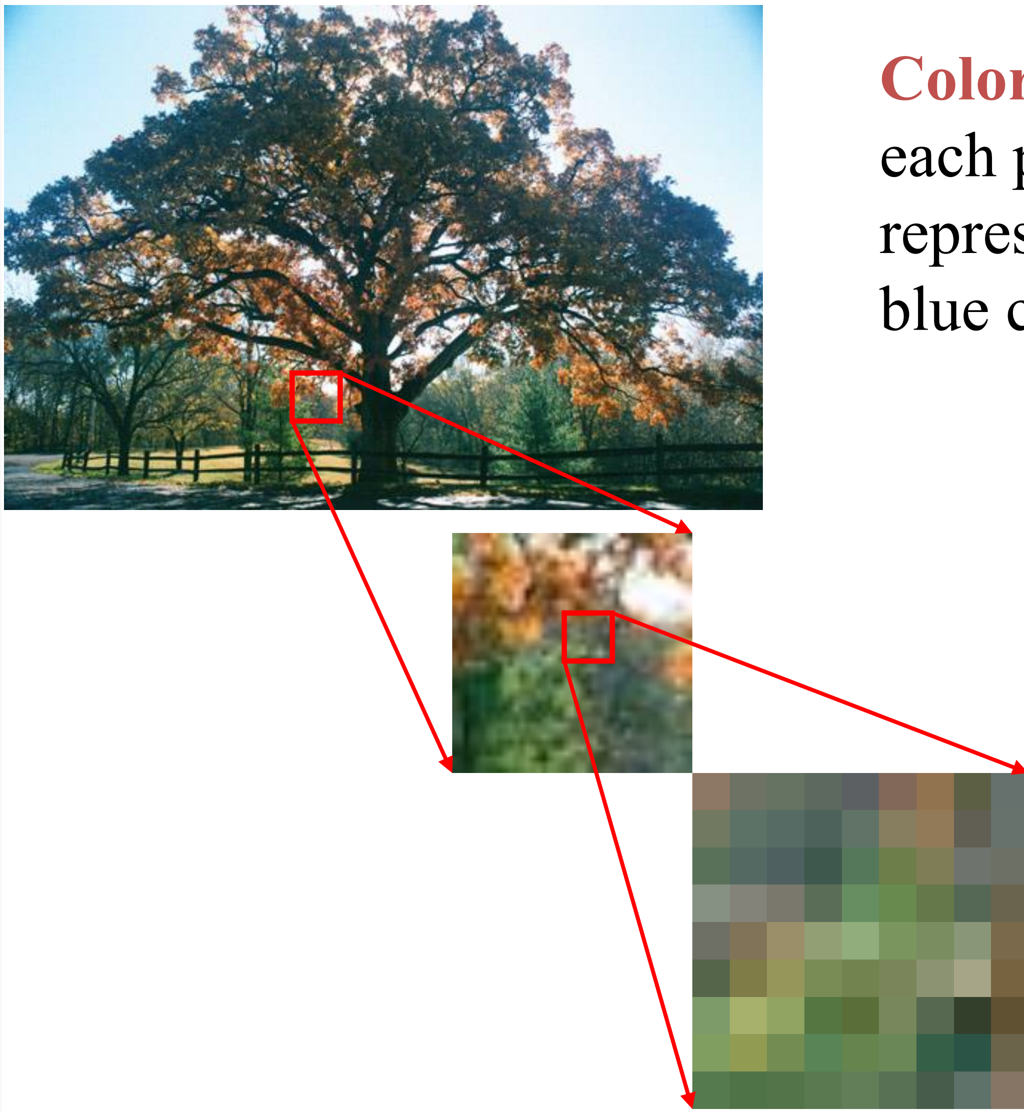


Intensity image or monochrome image each pixel corresponds to light intensity normally represented in gray scale (gray level).

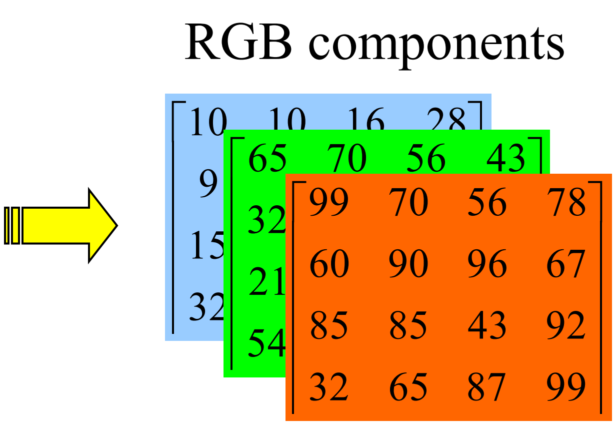
Gray scale values

$$\begin{bmatrix} 10 & 10 & 16 & 28 \\ 9 & 6 & 26 & 37 \\ 15 & 25 & 13 & 22 \\ 32 & 15 & 87 & 39 \end{bmatrix}$$

RGB Image



Color image or RGB image: each pixel contains a vector representing red, green and blue components.



RGB Image

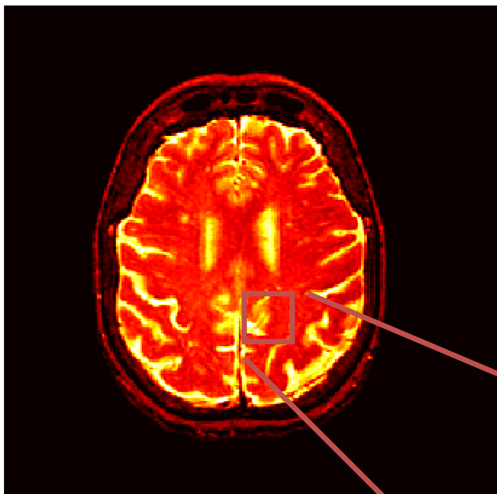
- 24-bit (true color) RGB images

(a) (b) (c) (d)

Index Image

Index image

Each pixel contains index number pointing to a color in a color table



$$\begin{bmatrix} 1 & 4 & 9 \\ 6 & 4 & 7 \\ 6 & 5 & 2 \end{bmatrix}$$

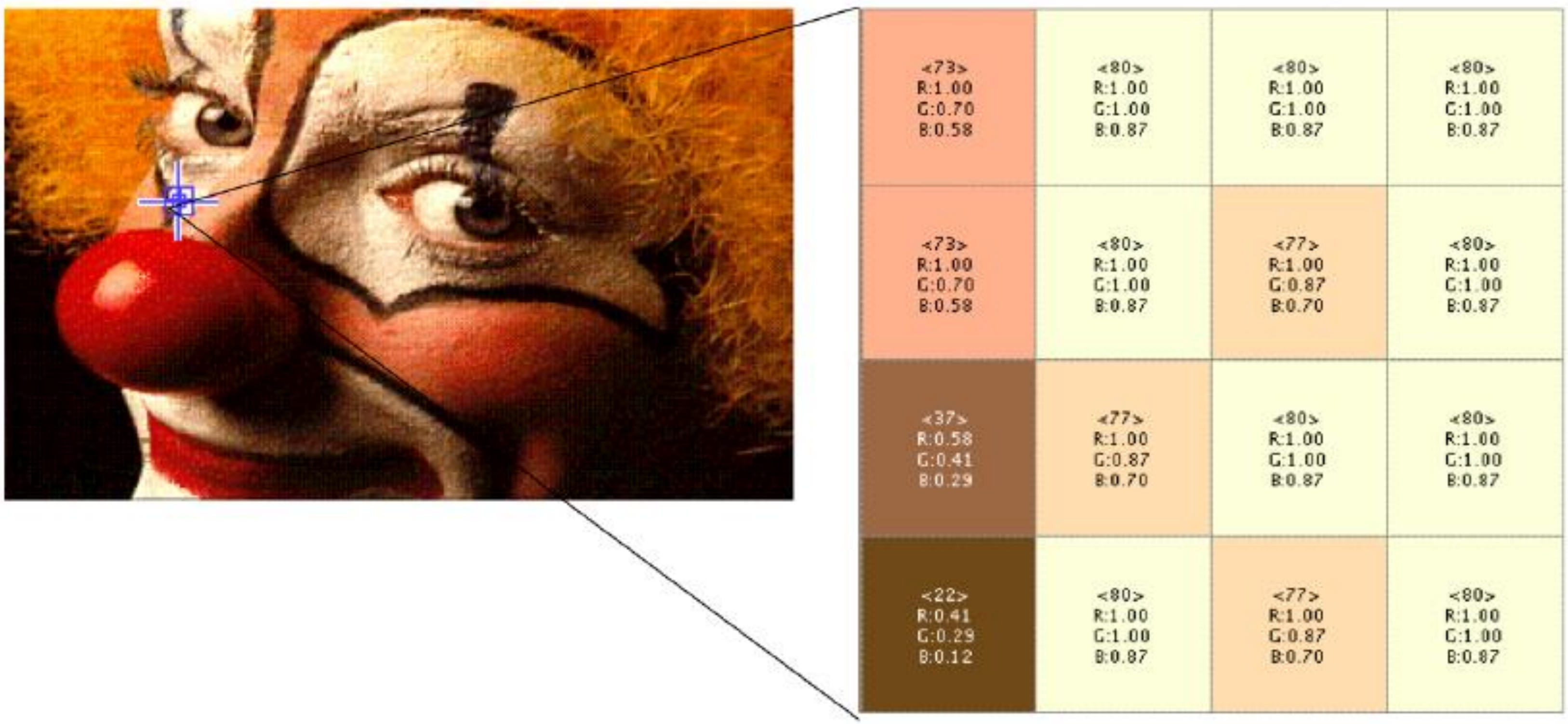
Index value

Color Table or LUT

Index No.	Red component	Green component	Blue component
1	0.1	0.5	0.3
2	1.0	0.0	0.0
3	0.0	1.0	0.0
4	0.5	0.5	0.5
5	0.2	0.8	0.9
…	…	…	…

Index Image

- Indexed color images



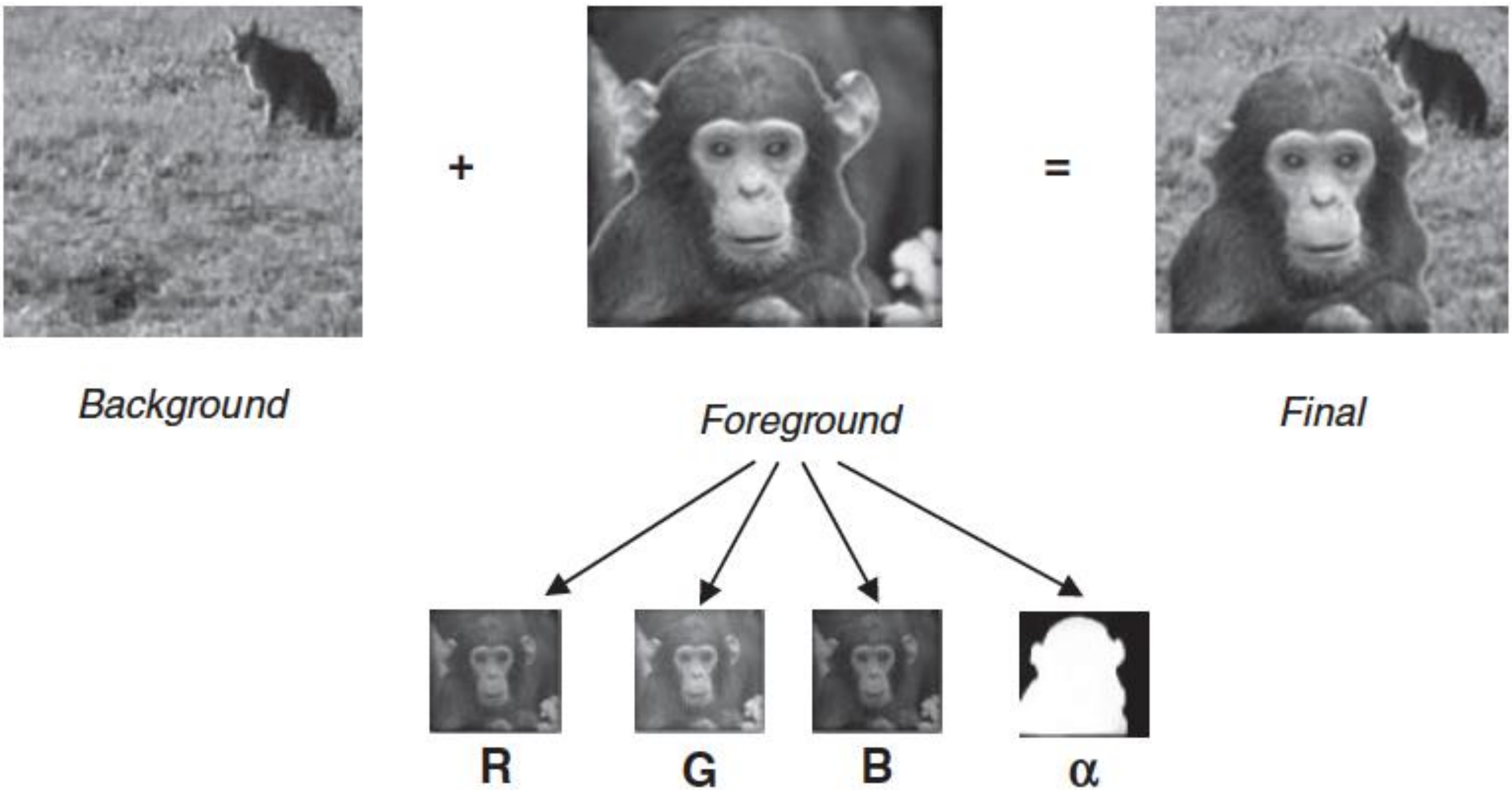
Resolution

- **Spatial resolution**: (C x R) dimensions of the image → number of pixels used to cover the visual space captured by the image.
  - Sampling of the image signal.
- **Bit resolution**: number of possible intensity/color values that a pixel may have.
  - Quantization → number of binary bits required to store the values, e.g. binary is 2 bit, grey-scale is 8 bit and color (most commonly) is 24 bit.
- **Temporal resolution**: For continuous capturing systems such as video → number of images captured in a given time period (fps).

The Alpha Channel

- Additional channel
- Gray images will have 2 channels
- Color images will have 4 channels
- It denotes the transparency measure for the pixel
- Also 8 bits (32 bits total per pixel for color images)
- A value of 0 means the pixel will not be composited
- A high value means it will be totally composited
- Intermediate value, medium transparency to blend it with background or other images.

The Alpha Channel



$$Final[i][j] = Foreground[i][j] * \alpha[i][j] + Background[i][j] * (1 - \alpha[i][j])$$

Notes

- In film industry, they use 16 bits per channel resulting in 48 bits total per pixel, or 64 if alfa is used

- In Video games, we have limited bandwidth, they use a total of 16 bits: 5 per each color channel and 1 bit for alfa.

Aspect Ratios

- Aspect ratio = Width/height of the images
- Plays important role in standards
- Different aspect ratios according to the application:
  - 3:2 for photographs
  - 4:3 for television
  - 16:9 for high definition
  - 47:20 anamorphic for cinemas

Aspect Ratios

- Pixel aspect ratio (PAR)
  - SAR = storage aspect ratio based on the real size of the image
  - DAR = display aspect ratio based on the display screen used
  - PAR = DAR / SAR
- A square pixel has 1:1 PAR
- Ex: 640 x 480 image has SAR = 4:3, displayed on 4:3 screen so DAR = 4:3, so PAR = 1:1
- Ex: 720 x 576 image has SAR = 5:4 = 5/4:1, displayed on 4:3 screen so DAR = 4:3 = 4/3:1, so PAR = (4/3)/(5/4):1 = 1.066:1 → stretch horizontally

Aspect Ratios

- A change from 4:3 to 16:9 causes the content to stretch horizontally, PAR becomes 1.33:1
- From anamorphic to television, PAR 1:0.75
- Preformatting is used before displaying on tv

Example

4:3

16:9

anamorphic

Aspect Ratios Changes

Image operations

- Mathematical point of view → any meaningful 2-D array of numbers can be considered as an image. We need to:
  - display images;
  - store images (preferably compactly);
  - transmit images over networks;
  - process them in order to enhance and correct them;
  - recognize bodies of numerical data as corresponding to images.
  - Classify them

Image compression

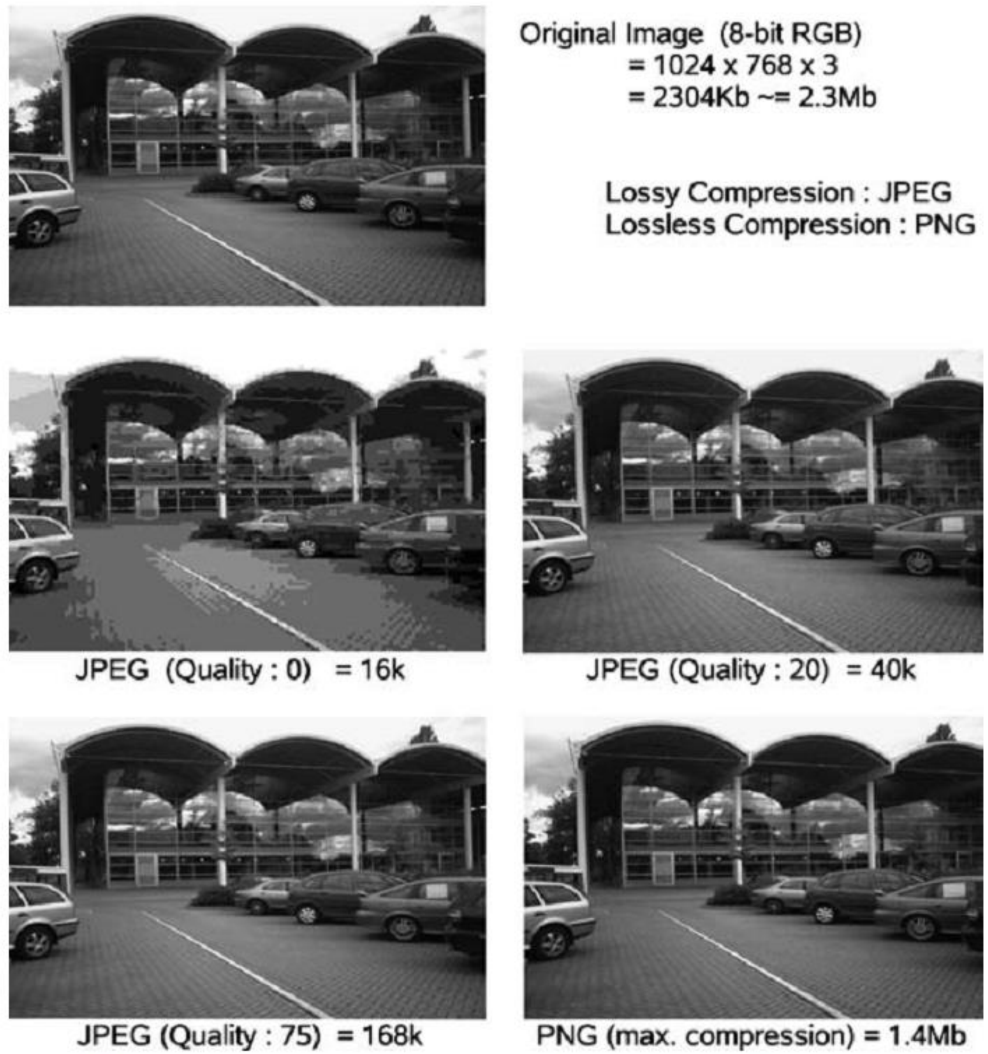
- Choosing an image storage format → compression.
- Compressing an image → Removing redundant or details information from the original image
  - taking up less disk storage.
  - can be transferred over a network in less time,

1. **Lossless** compression techniques
   - allows the original image to be reconstructed
2. **Lossy** compression techniques
   - some loss of the details in the original image.

Image compression

- Storage of compressed image formats → various algorithmic procedures to reduce the raw image data to an equivalent image
- Reconstructed images appears identical (or at least nearly) but requires less storage.
  - Limit later image process and analysis.

Image compression



Example image compressed using lossless and varying levels of lossy compression

Digital Image Formats

- Both raw and compressed are RASTER images: stored as row of pixels and have width and height
- Nowadays, we have also vector image files formats using parameters such as line styles, colors, shapes, …
- Some combine both → metafiles

Vector File Format

```
Object myRectangle
LineType Dotted
LineWidth 4
LineColor  0 0 0
FillColor 255 0 0
Rectangle (100,200) (200,220)
EndObject
Object myCircle
LineColor 0, 0, 0
FillColor 0 0 255
Circle (200, 200), 50
EndObject
```

Figure 3-6 Vector file description showing two objects—a red rectangle and a blue circle

Image formats

- ➢ To reply to such problems → development of standard digital image formats.
  - – image formats include a file header →information on how exactly the image data is stored,
  - – actual numeric pixel values.
- ➢ large number of recognized image formats exist now, dating back over more than 30 years of digital image storage.
  - – Some of the most common 2-D image formats.
    - lossy compression
    - lossless compression

Image formats

File suffix	File name	File type	Features
.bmp	Windows bitmap	Uncompressed raster	Represents from 1 to 24 bits per pixel. Normally uncompressed but can use lossless run length encoding (RLE)
.pcx	Windows Paintbrush	Uncompressed/ compressed raster	Used only on Microsoft Windows platforms. Has similar features to .bmp.
.gif	Graphics Interchange Format	Compressed raster	Predominantly used on the Web. Allows 256 indexed colors and simple animations. Alpha channel supported. Uses LZW compression Proprietary to CompuServe

Image formats

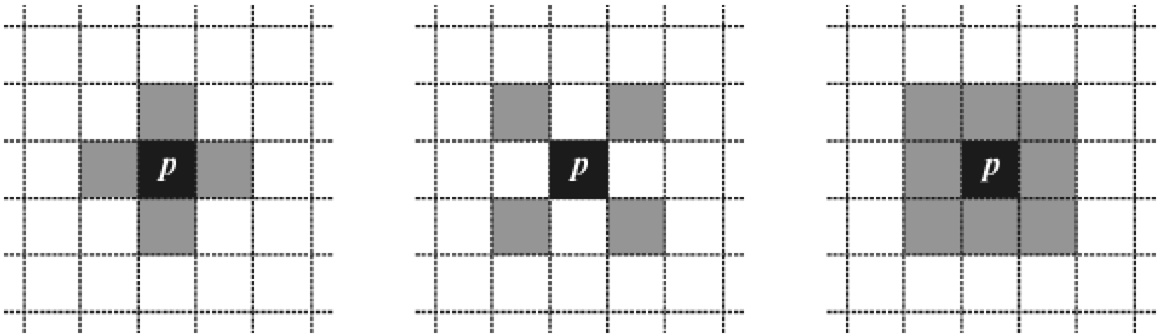
.jpg, .jpeg	Joint Photographic Experts Group	Compressed raster	For continuous tone pictures (photographs). Lossy and lossless compression supported. No alpha channel supported. Level of compression can be specified. Commonly used on the Web
.png	Portable Network Graphics	Compressed raster	Allows 1–48 bits of color. Supports alpha channel. Designed to replace proprietary .gif files. File format approved by W3C
.psd	Adobe Photoshop	Uncompressed layered raster	Used for image editing. Supports a variety of color models. Supports varying pixel bit depths Image can be organized into layers. Commonly used processing file format.
.psp	Paint Shop Pro	Uncompressed layered raster	Similar to .psd

Image formats

.tif, .tiff	Tagged Image File Format	Uncompressed raster, also compressed raster	Used in traditional print graphics. Can be compressed using lossless and lossy methods of compression, including RLE, JPEG, and LZW. TIFF comes in many flavors
.fh	Macromedia Freehand	Compressed vector format	Proprietary to Macromedia, used by Flash Players. Supports animation
.cdr	CorelDRAW	Uncompressed vector format	Proprietary to Corel
.swf	Macromedia Shockwave Flash format	Uncompressed vector format	Proprietary format created by Macromedia (now Adobe). Contains vector representations and animations that can be put on the Web.
.dxf	AutoCAD ASCII Drawing Interchange Format	Uncompressed vector format	ASCII text stores vector data. Used for 2D/3D graphical images.
.ps or .eps	Postscript, or Encapsulated Postscript	Uncompressed metafile	Supports text, fonts, vectors, and images.
.ai	Adobe Illustrator	Metafile format	Proprietary format. Similar to .eps.
.pdf (portable document format)	Adobe PDF document	Compressed metafile	Supports text, fonts, and images. Commonly used document format. Supports hyperlinks. Supports authorized access.
.pict	Macintosh Quickdraw	Compressed metafile	Used predominantly on Macintosh platforms. Can use RLE or JPEG compression. Supports grayscale, RGB, CMYK, or indexed color.

Basic Terminology

- Neighborhood
  - In the context of image topology, neighborhood has a different meaning:
    - 4-neighborhood
    - Diagonal neighborhood
    - 8-neighborhood



Exercises

1. Given an image of size 1024 x 768, what is the size in bytes of the image if:
   a. is a binary one.
   b. is a grayscale one with 256 levels.
   c. is a RGB colored one with 8 bits per channel.
   d. is a RGB colored one with 2 bits per channel.
2. A RGB image uses 2 bits per channel to code a pixel, how many different colors we can use ?
3. Write the algorithm that transforms a gray scale image to a binary one.
4. Write the algorithm that transform a grayscale image of 256 gray levels to a gray scale one with 16 levels.

Exercises

5. What is the difference between an indexed image and a colored image ?
6. Can we convert a binary image to a grayscale one or indexed one ?
7. What are the aspect ratios of the following images:
   a. 300 x 300
   b. 600 x 480
   c. 1280 x 960
   d. 1440 x 810

Exercises

8. Given the following 1024 x 768 image, calculate the size for each situation:

6 bits, 5 bits, 4 bits, 3 bits, 2 bits, 1 bit