BME4120
Biomedical Image Processing

Lecture 2

Textbooks

- Machine Vision, Wesley E. Snyder & Hairong Qi,
- Medical Image Processing: Concepts And Applications, Sinha G. R, Patel, B. C., Prentice Hall, 2014.
- Insight into Images: Principles and Practice for Segmentation, Registration and Image Analysis, Terry S. Yoo
- Biosignal and Medical Image Processing, John L. Semmlow, , CRC Taylor and Francis, 2008

Weekly Subjects

WEEKS	COURSE OUTLINE	Related Preparation
1	What is image? Fundamentals and characteristics of digital images.	Textbooks – Lecture Notes
2	Acquiring biomedical Images	Textbooks – Lecture Notes
3	Basic mathematical and statistical concepts in biomedical image processing	Textbooks – Lecture Notes
4	Image restoration in spatial domain: gray color transormations, histogram processing	Textbooks – Lecture Notes
5	Image restoration in spatial domain: Basics of spatial domain filter, smoothing and sharpening filters	Textbooks – Lecture Notes
6	Image restoration in frequency domain: 1D and 2D Fourier transformation, basics of frequency domain filters	Textbooks – Lecture Notes
7	Image restoration in frequency domain: Image smoothing and sharpening with frequency domain filters	Textbooks – Lecture Notes
8	Midterm 1	
9	Feature extraction and statistical measurements from biomedical images	Textbooks – Lecture Notes
10	Image restoration: Degredation models and image quality determination	Textbooks – Lecture Notes
11	Image restoration: Filters and their applications	Textbooks – Lecture Notes
12	Image segmentation: Point and line detection	Textbooks – Lecture Notes
13	Image segmentation: Edge detection	Textbooks – Lecture Notes
14	Image segmentation: Splitting and Merging Techniques	Textbooks – Lecture Notes
15	Final	

Images – Capturing and Processing

Capturing Real-World Images

- Picture – two dimensional image captured from a real-world scene that represents a momentary event from the 3D spatial world

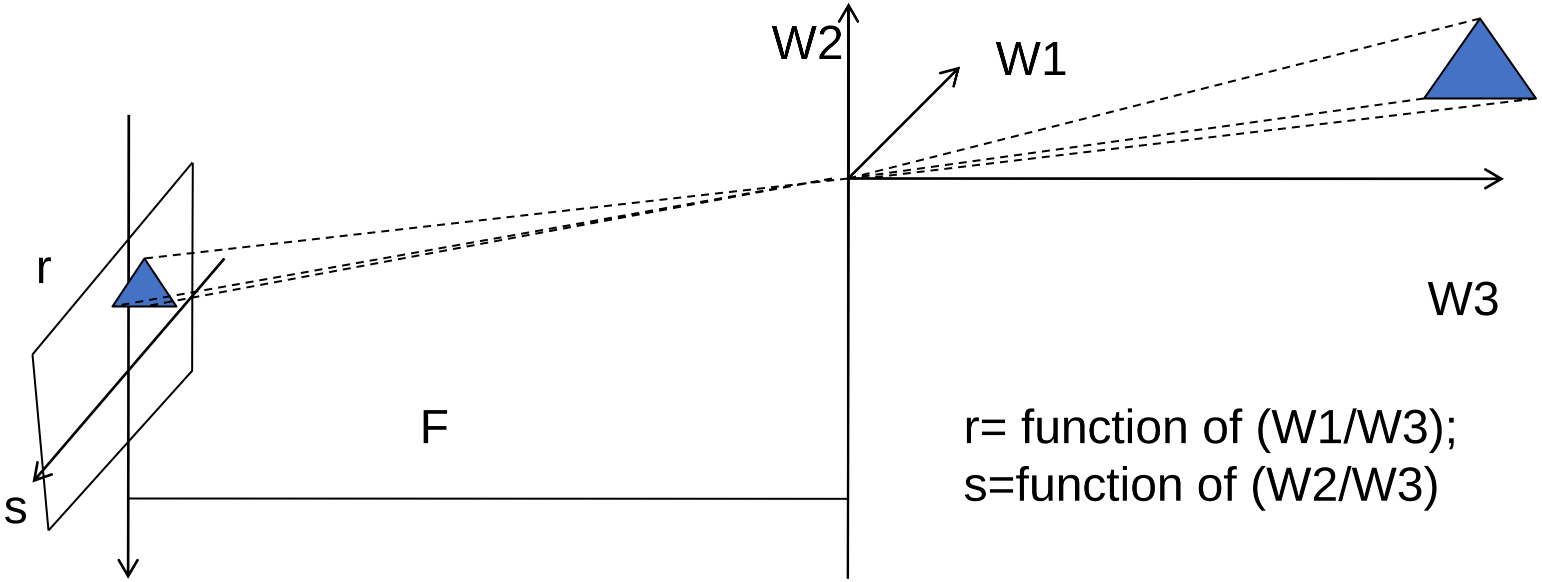


Image Concepts

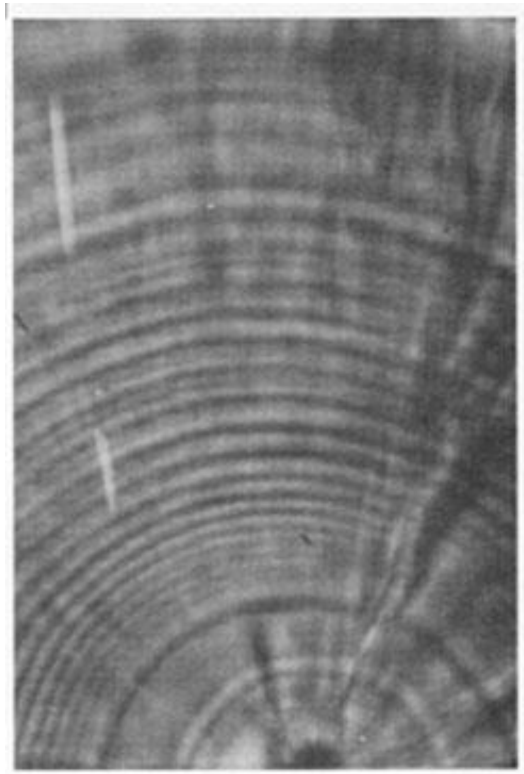
- An image is a function of intensity values over a 2D plane $I(r,s)$
- Sample function at discrete intervals to represent an image in digital form
  - matrix of intensity values for each color plane
  - intensity typically represented with 8 bits
- Sample points are called pixels

Digital Images

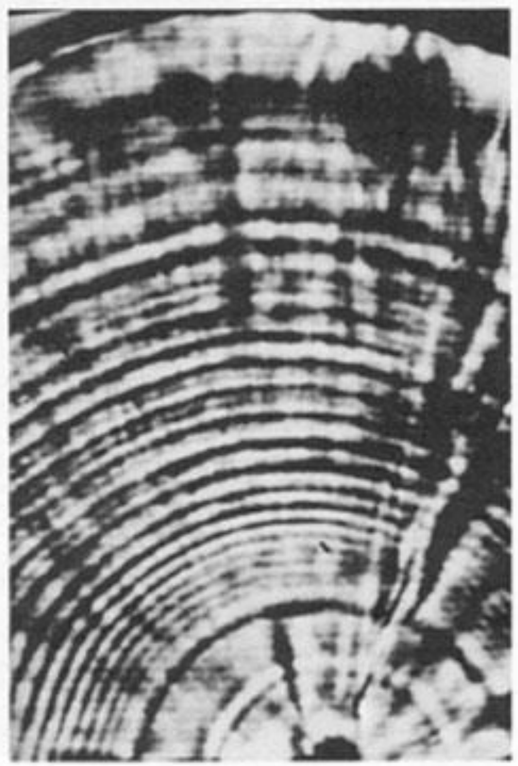
- Samples = pixels
- Quantization = number of bits per pixel
- Example: if we would sample and quantize standard TV picture (525 lines) by using VGA (Video Graphics Array), video controller creates matrix 640x480pixels, and each pixel is represented by 8 bit integer (256 discrete gray levels)

Image Representations

- Black and white image
  - single color plane with 2 bits
- Grey scale image
  - single color plane with 8 bits
- Color image
  - three color planes each with 8 bits
  - RGB, CMY, YIQ, etc.
- Indexed color image
  - single plane that indexes a color table
- Compressed images
  - TIFF, JPEG, BMP, etc.



4 gray levels



2 gray levels

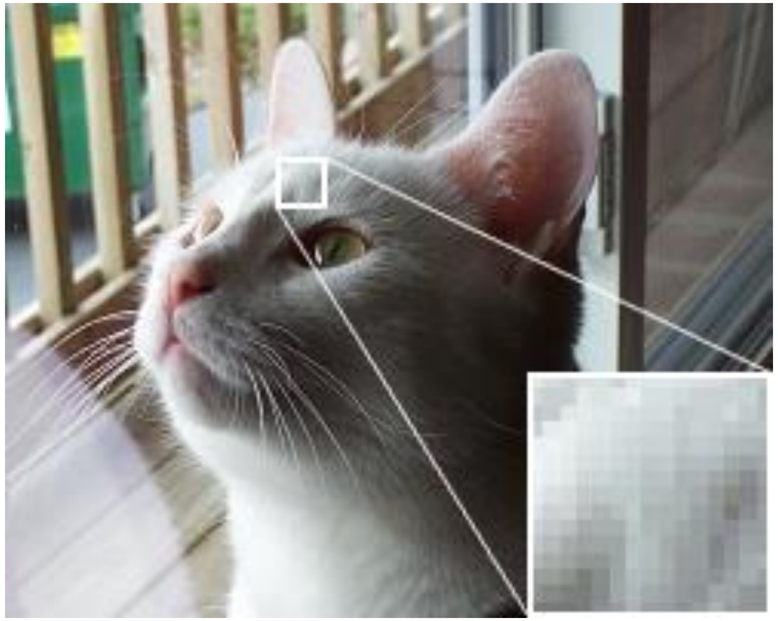
Digital Image Representation

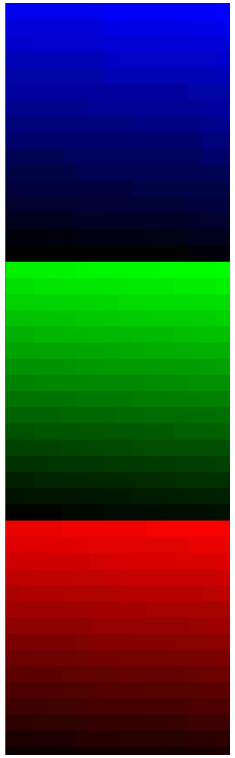
(3 Bit Quantization)

111	111	011	011	011	011	111	111
111	011	111	111	111	111	011	111
000	111	001	111	111	001	111	000
010	111	111	111	111	111	111	010
000	111	100	111	111	100	111	000
000	111	111	100	100	111	111	000
111	000	111	111	111	111	000	111
111	111	000	000	000	000	111	111

Color Quantization

Example of 24 bit RGB Image





24-bit Color Monitor

Image Representation Example

24 bit RGB Representation (uncompressed)

128	135	166	138	190	132
129	255	105	189	167	190
229	213	134	111	138	187

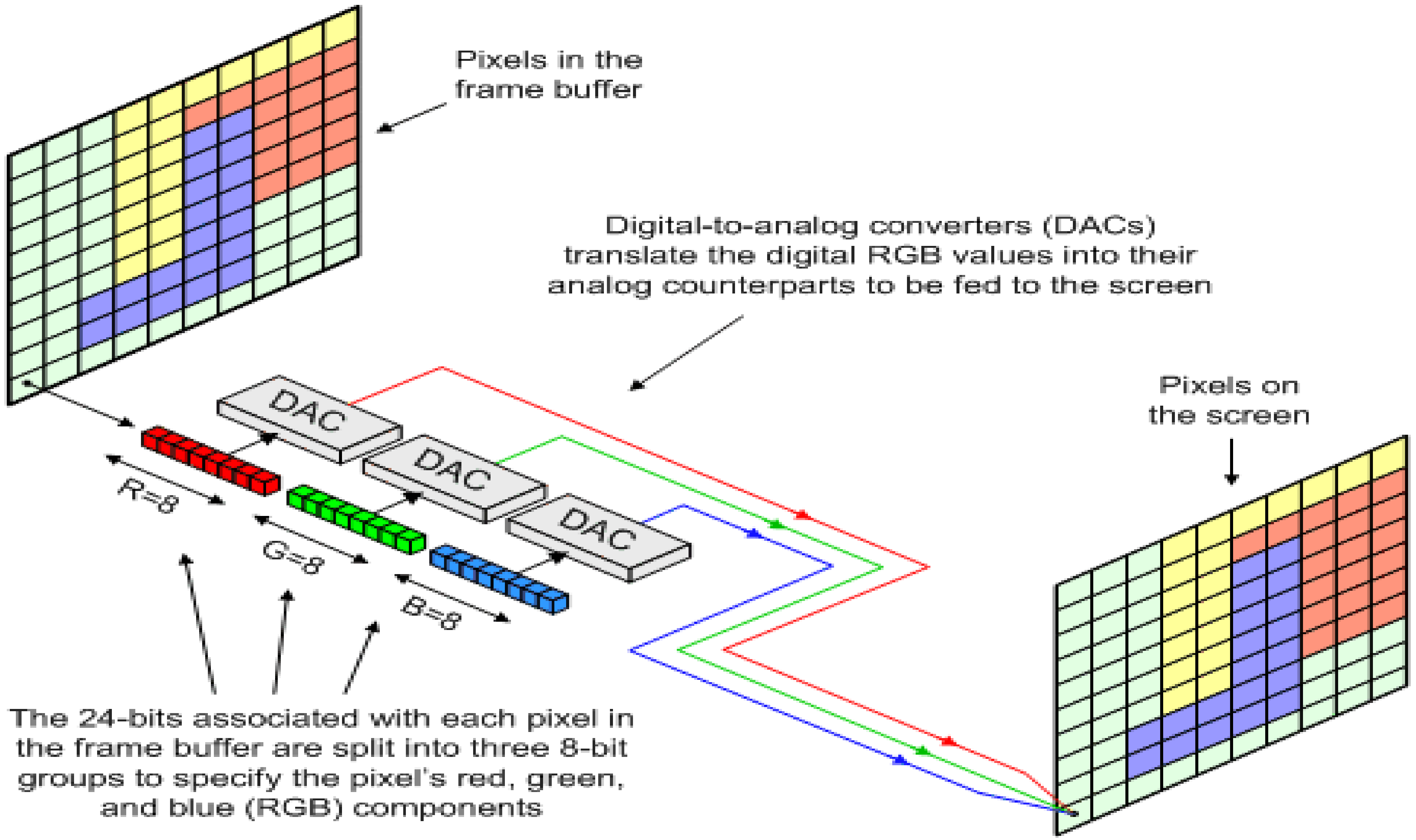
128	138
129	189
229	111

135	190
255	167
213	138

166	132
105	190
134	187

Color Planes

Graphical Representation

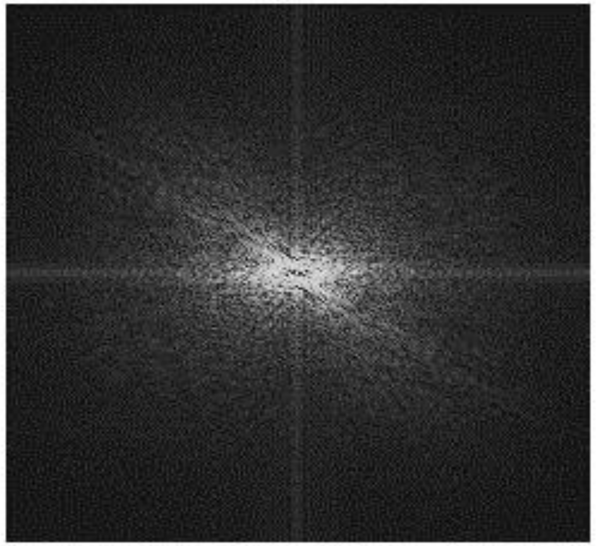


Graphical representation of 24-bit "true color"

Spatial and Frequency Domains

- Spatial domain
  - refers to planar region of intensity values at time t

- Frequency domain
  - think of each color plane as a sinusoidal function of changing intensity values
  - refers to organizing pixels according to their changing intensity (frequency)



Why Is *Medical* Image Analysis Special?

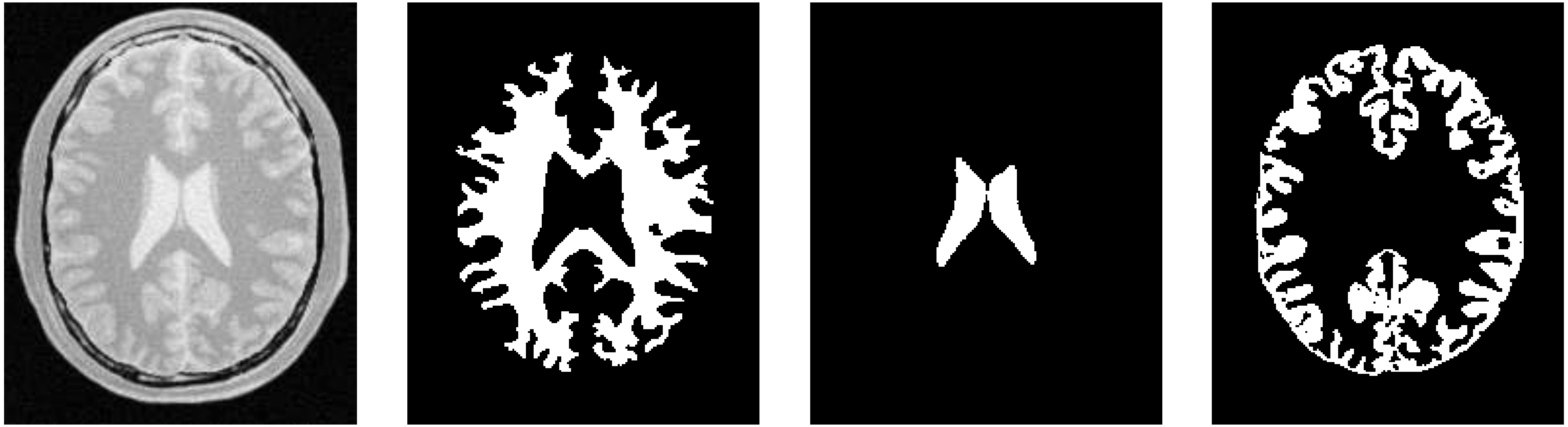
- Because of the *patient*
- Computer Vision:
  - Good at detecting irregulars, e.g., on the factory floor
  - But no two patients are alike—everyone is "irregular"
- Medicine is war
  - Radiology is primarily for reconnaissance
  - Surgeons are the marines
  - Life/death decisions made on insufficient information
- Success measured by patient recovery
- You're not in "theory land" anymore

What is meant by *Analysis*?

- Different from “Image Processing”
- Results in identification, measurement, &/or judgment
- Produces numbers, words, & actions
- Holy Grail: *complete image understanding* automated within a computer to perform diagnosis & control robotic intervention
- State of the art: segmentation & registration

Segmentation

- ❑Labeling every voxel
- ❑Discrete vs. fuzzy
- ❑How good are such labels?
  - ❑Gray matter (circuits) vs. white matter (cables).
  - ❑Tremendous oversimplification
- ❑Requires a model



Registration

- Image to Image
  - same vs. different imaging modality
  - same vs. different patient
  - topological variation
- Image to Model
  - deformable models
- Model to Model
  - matching graphs

Visualization

- *Visualization* used to mean *to picture in the mind*.
- Retina is a 2D device
- Analysis needed to visualize surfaces
- Doctors prefer slices to renderings
- Visualization is required to reach visual cortex
- Computers have an advantage over humans in 3D

From Processing to Analysis

Low level

Mid level

High level

Image acquisition

Image enhancement

Image compression

Image segmentation

Object recognition

Scene understanding

Semantics

Image processing

Image analysis
(Computer vision,
Pattern recognition, etc.)

Image Acquisition and Representation

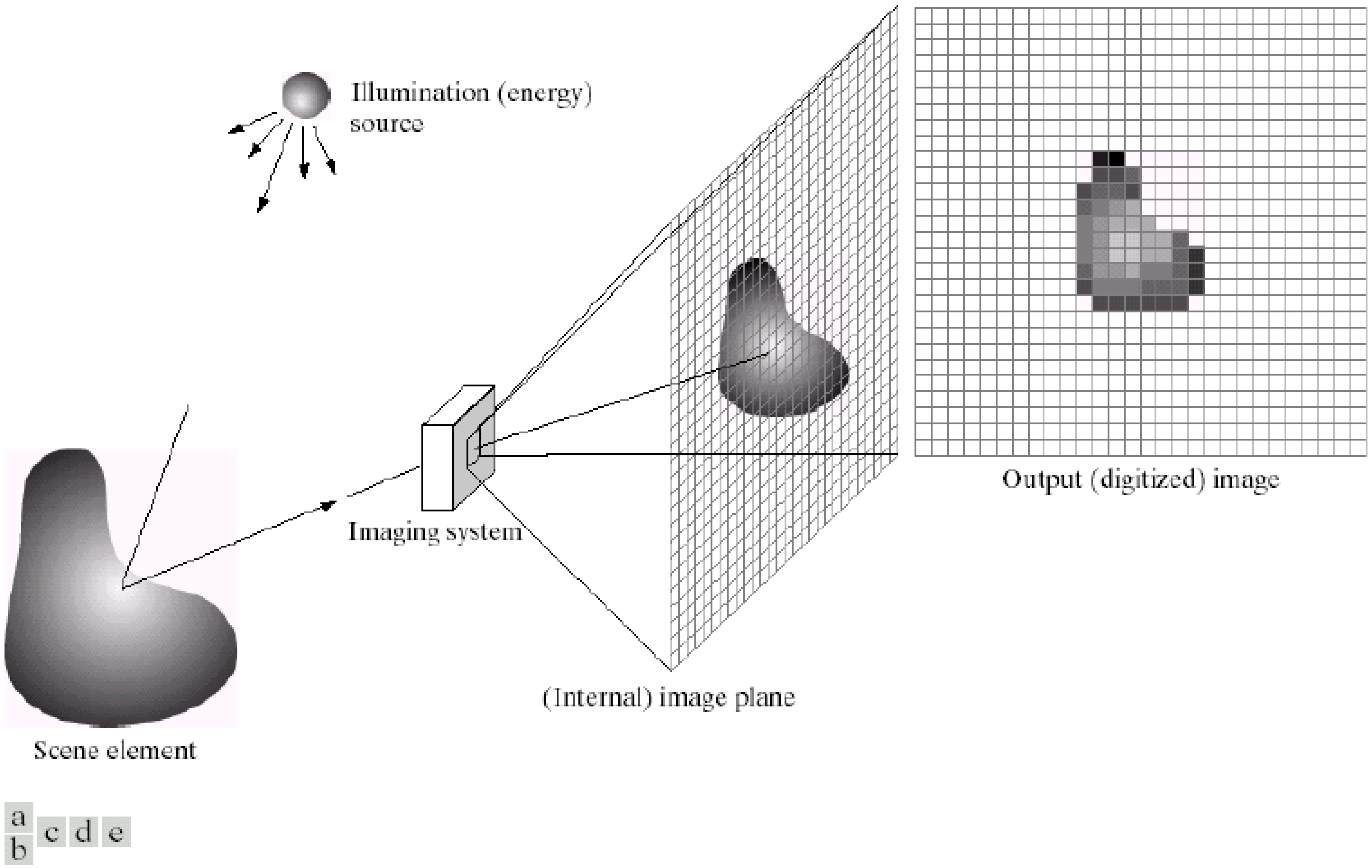
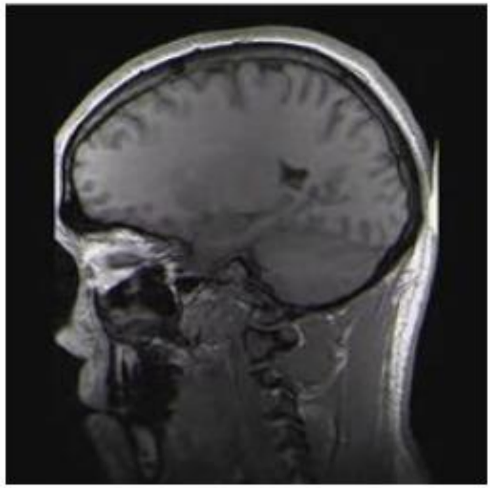


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Imaging Examples



1. Brain MRI

2. Cardiac CT

3. Fetus Ultrasound

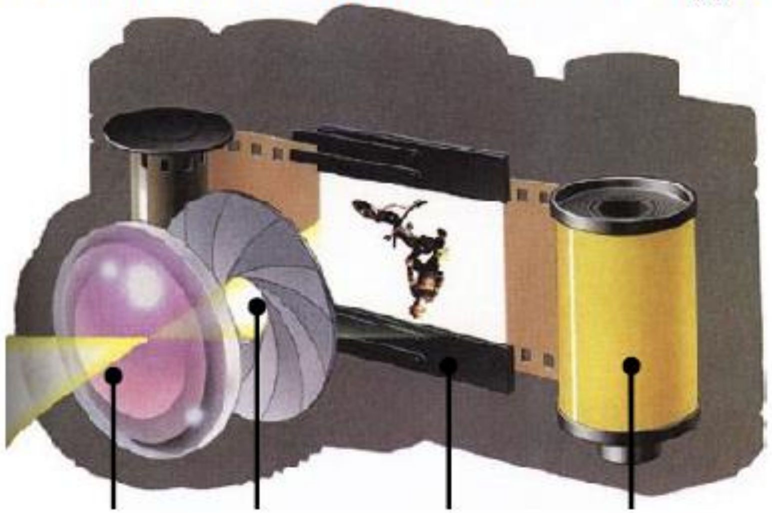
4. Satellite image

5. IR image

1 and 3. http://en.wikipedia.org
2. http://radiology.rsna.org
4. http://emap-int.com
5. http://www.imaging1.com

Acquisition

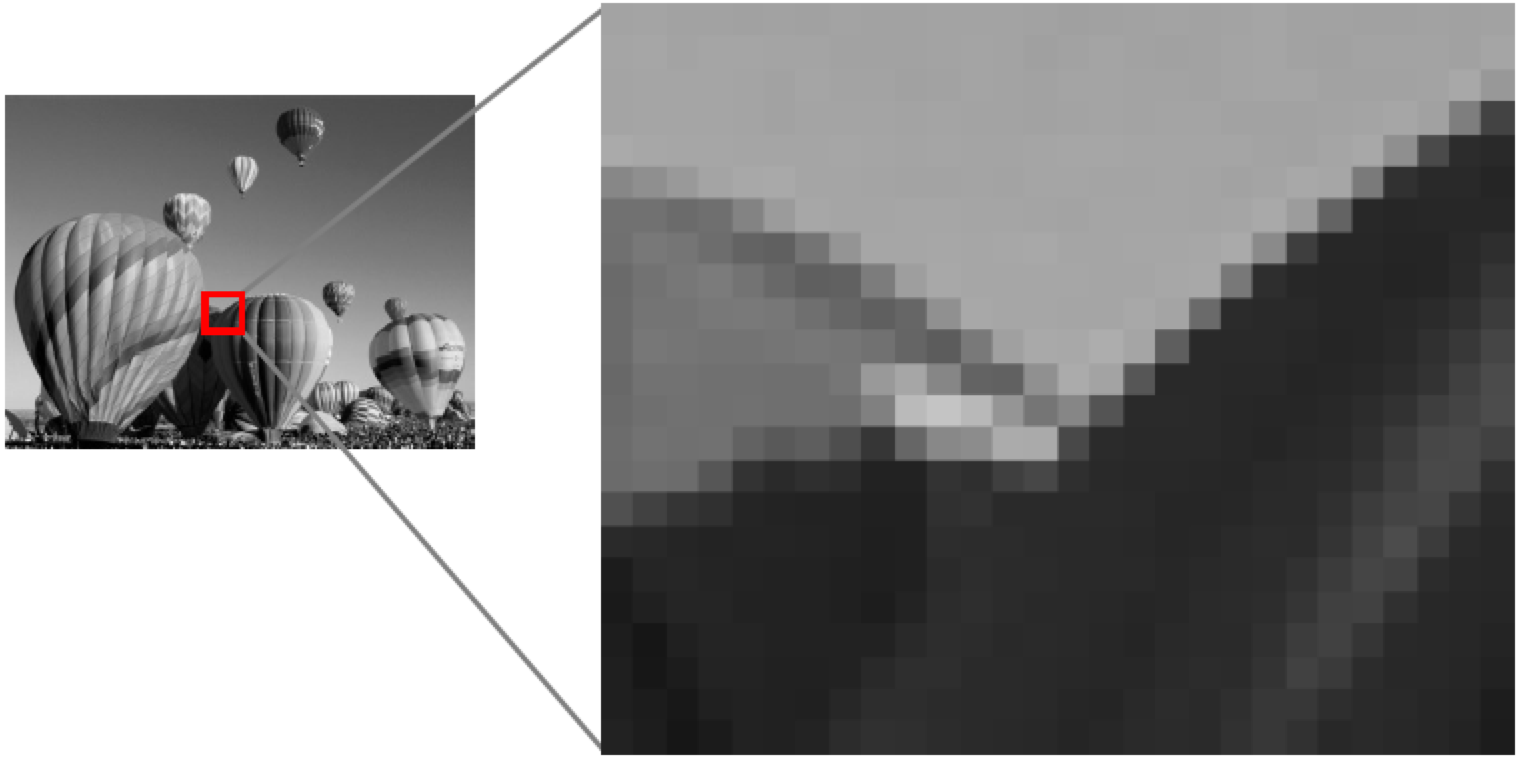
Camera + Scanner → Digital Camera: Get images into computer

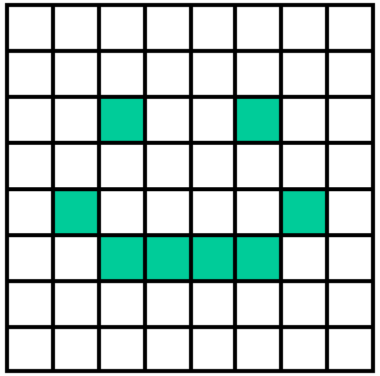


Representation

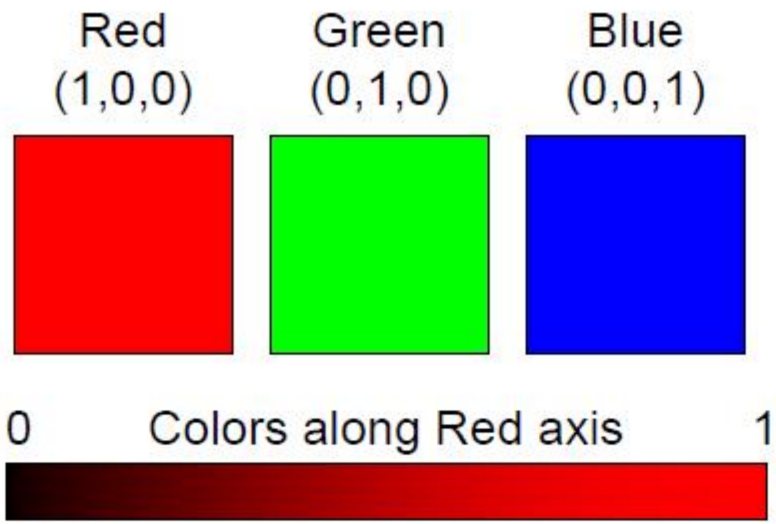
Discrete representation of images

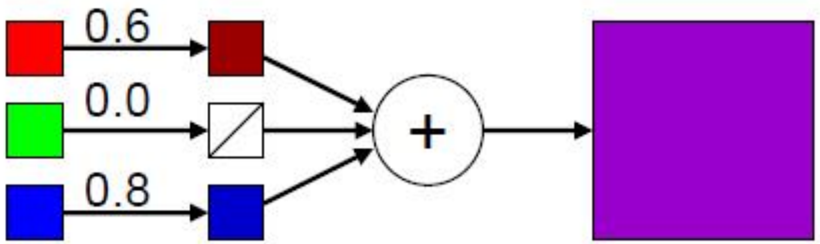
- we'll carve up image into a rectangular grid of pixels $P[x,y]$
- each pixel p will store an intensity value in [0 1]
- 0 → black; 1 → white; in-between → gray
- Image size mxn → (mn) pixels



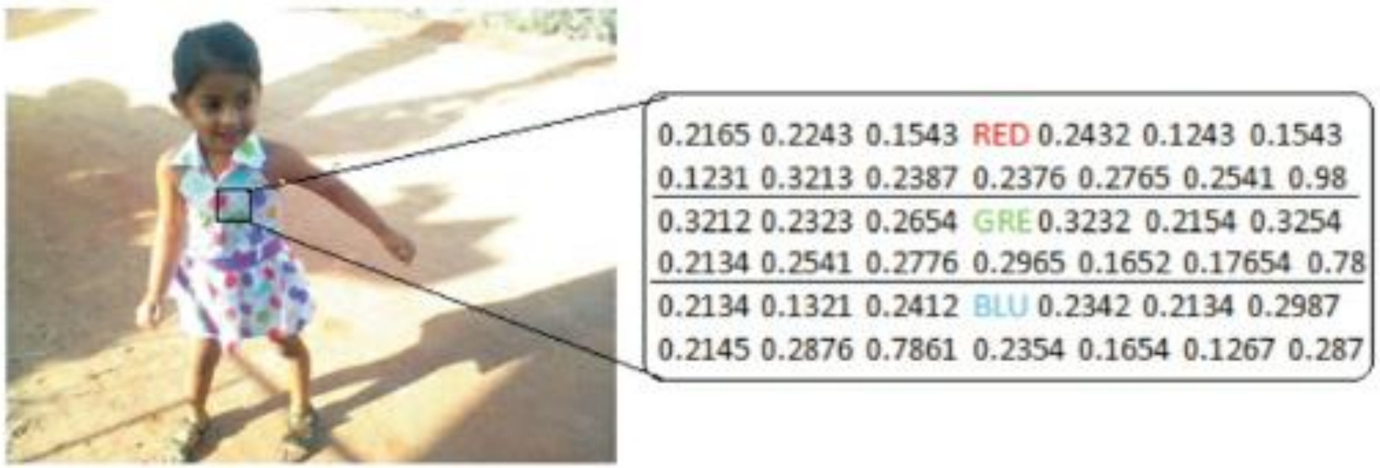


Color


Red
(1,0,0)
Green
(0,1,0)
Blue
(0,0,1)
0
Colors along Red axis
1

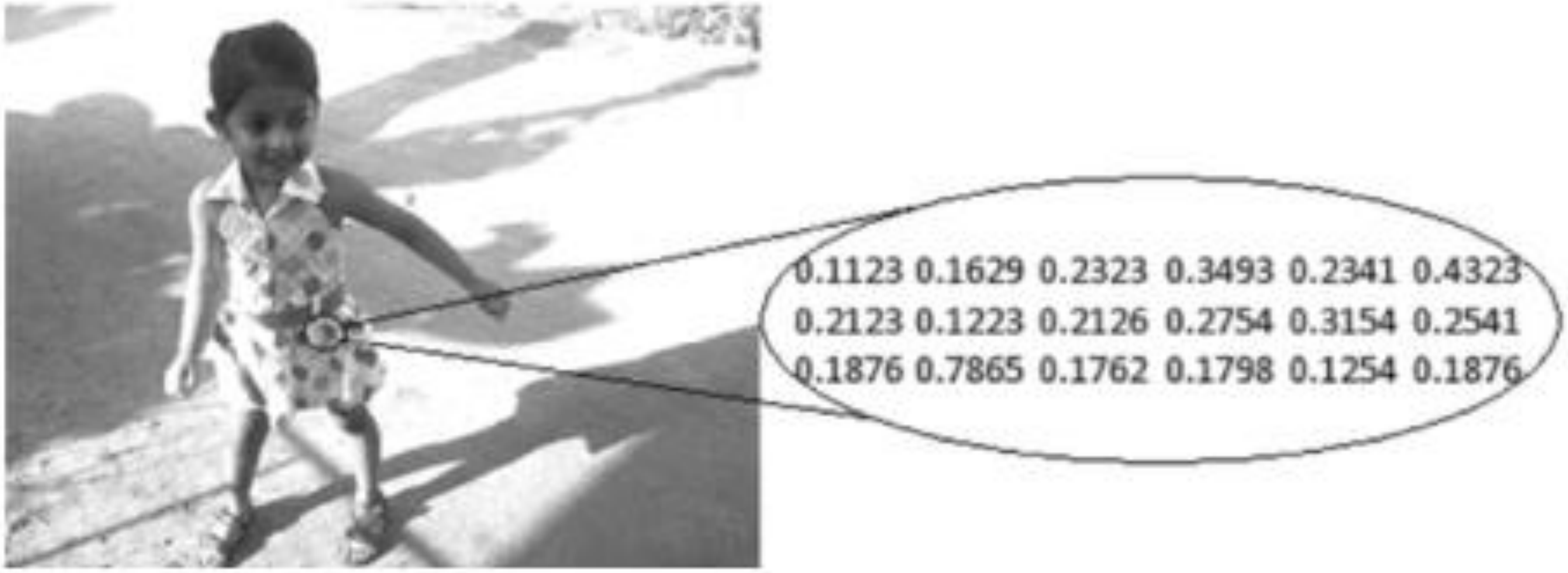

0.6
0.0
0.8
+


RGB
channels



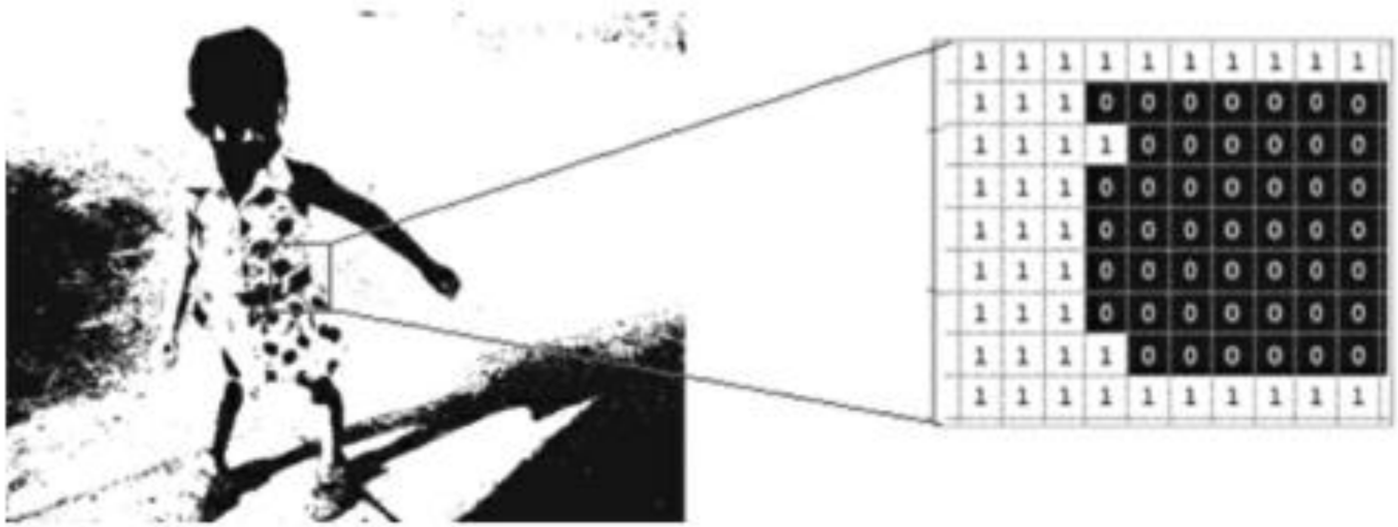
The intensity value is expressed in 8 bits for a pixel, then in the color image, each pixel requires 24 bits including those three components.

Grayscale Image

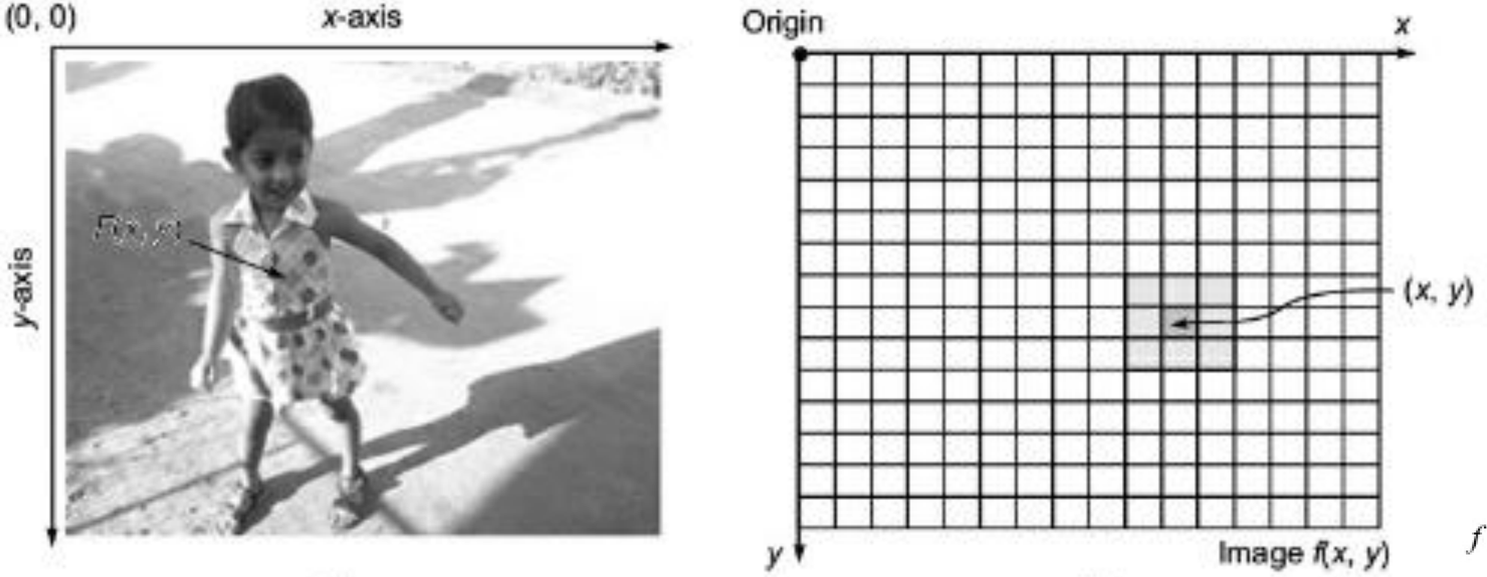


The pixel intensity of eight-bit images is in the range of 0 to 255, total of 256 levels.

Binary Scale Image



Two gray levels, 0 and 1



(a) (b)

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

1. Red component $(m, n, 1)$
2. Green component $(m, n, 2)$
3. Blue component $(m, n, 3)$

Image Resolution & Aspect Ratio

Resolution: Represents pixel count in an image. In (M x N) image, M is the number of pixels in horizontal direction and N is the number of pixels in vertical direction. The image resolution is defined as the total number of pixels present in an image. (e.g., 256 x 256 pixels, also given with dpi: dots per inch, i.e., the # of pixels per inch area)

Aspect ratio: The aspect ratio relates width of an image to its height. This is usually expressed as P:Q which means that the ratio of number of pixels in width of image to that of number of pixels in height is P:Q.

From Processing to Analysis

Low level	Image acquisition Image enhancement Image compression	**Image processing**
Mid level	Image segmentation Object recognition	
High level	Scene understanding Semantics	Image analysis (Computer vision, Pattern recognition, etc.)

Flow of Digital Image Processing

Image acquisition: It deals with capturing images or samples.

Image enhancement: It deals with the improvement of quality of images.

Image representation: It deals with different ways in which image can be represented mathematically, graphically and statistically.

Image transformation: It is used to transform the input image from one domain into another, e.g. an image in spatial domain can be converted into frequency domain by using Fourier transform.

Image restoration: It deals with the analysis and modeling of different types of noise mixed in images.

Color image processing: Various colour spaces and formats are covered in it.

Flow of Digital Image Processing

Image compression: It is used to reduce the size of image or reduce redundancy without any significant change in the inherent content of the image.

Morphological image processing: It is used to represent or convert into suitable forms so that edges can be easily recovered. These operations are generally used with image segmentation.

Image segmentation, representation and description: The selected region of interests can be extracted and various boundaries, edges and other similar information could be obtained.

Object recognition: It deals with the pattern recognition and matching.

Video: Still Images taken with time intervals

30 frames/second

Image Enhancement

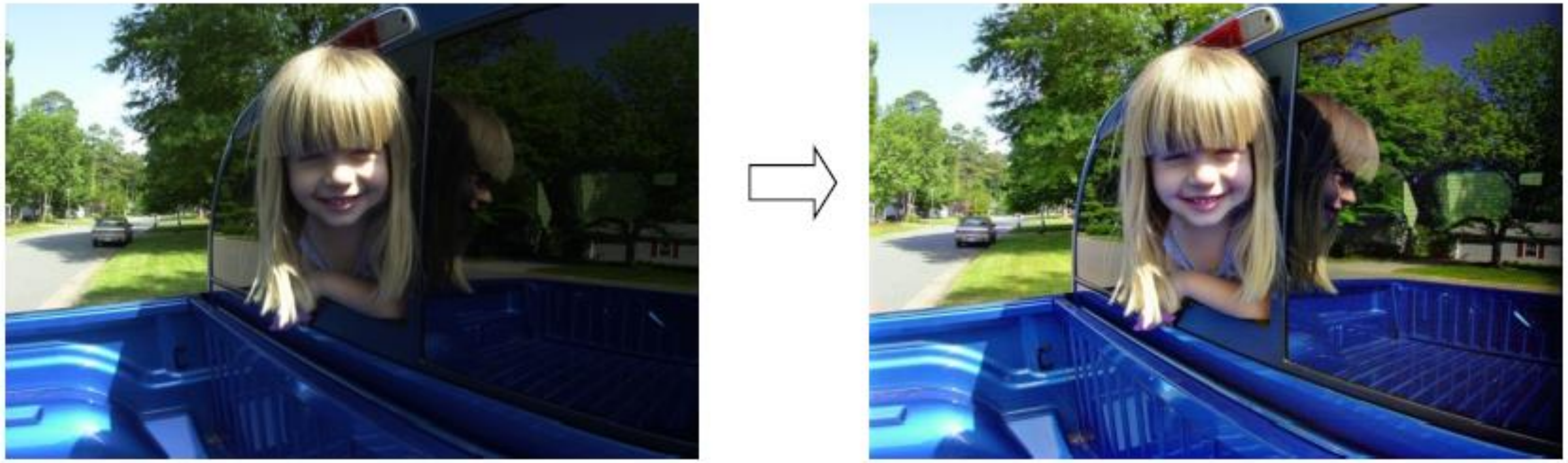


Image Restoration

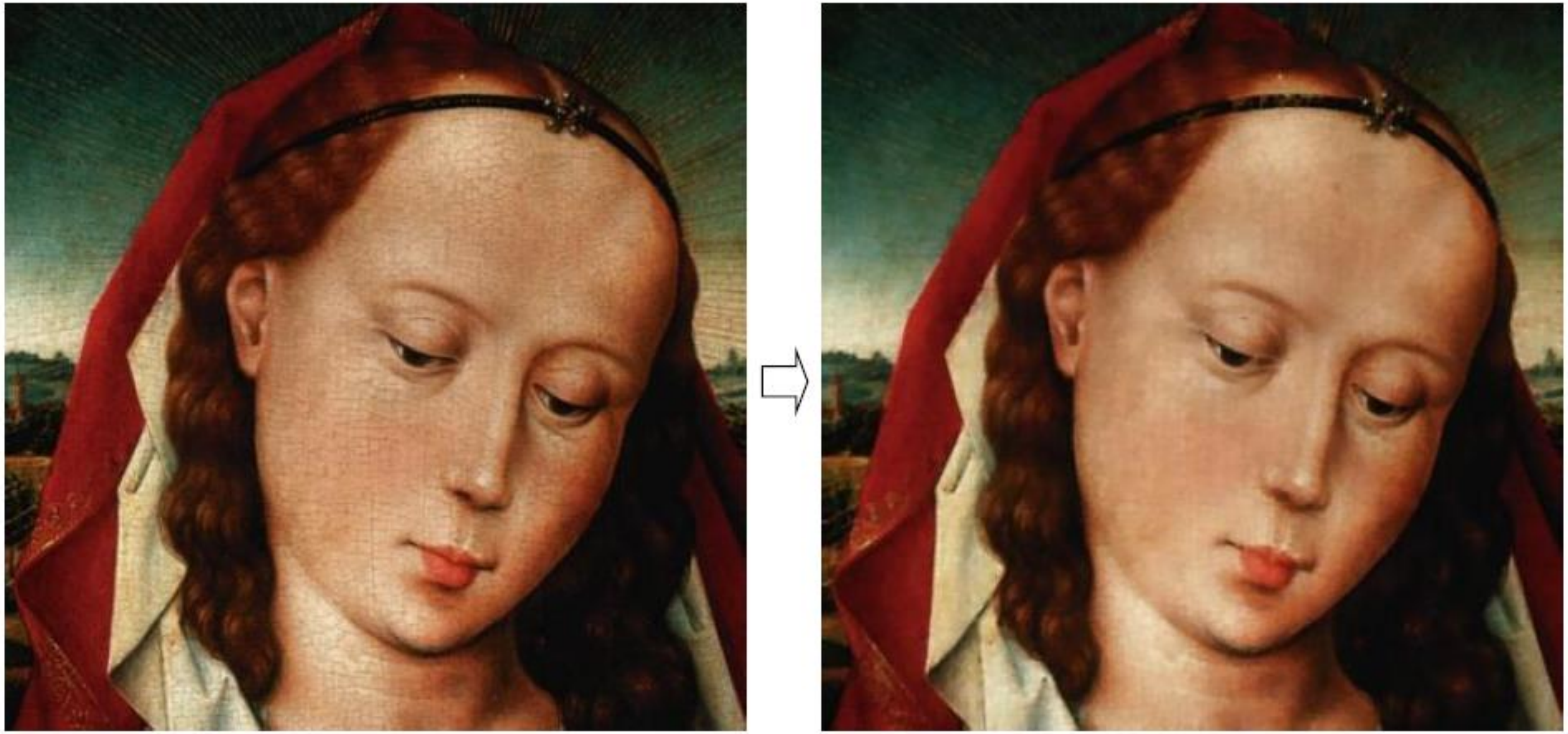


Image Compression

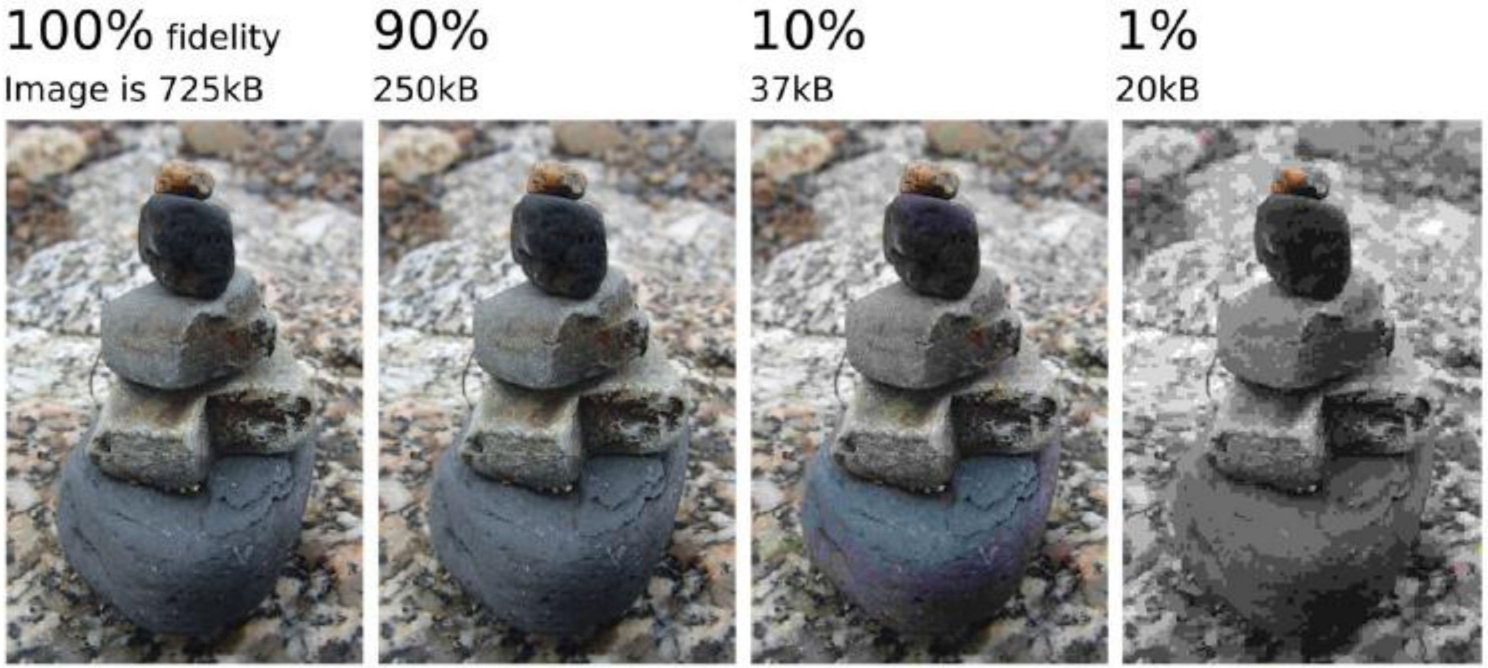
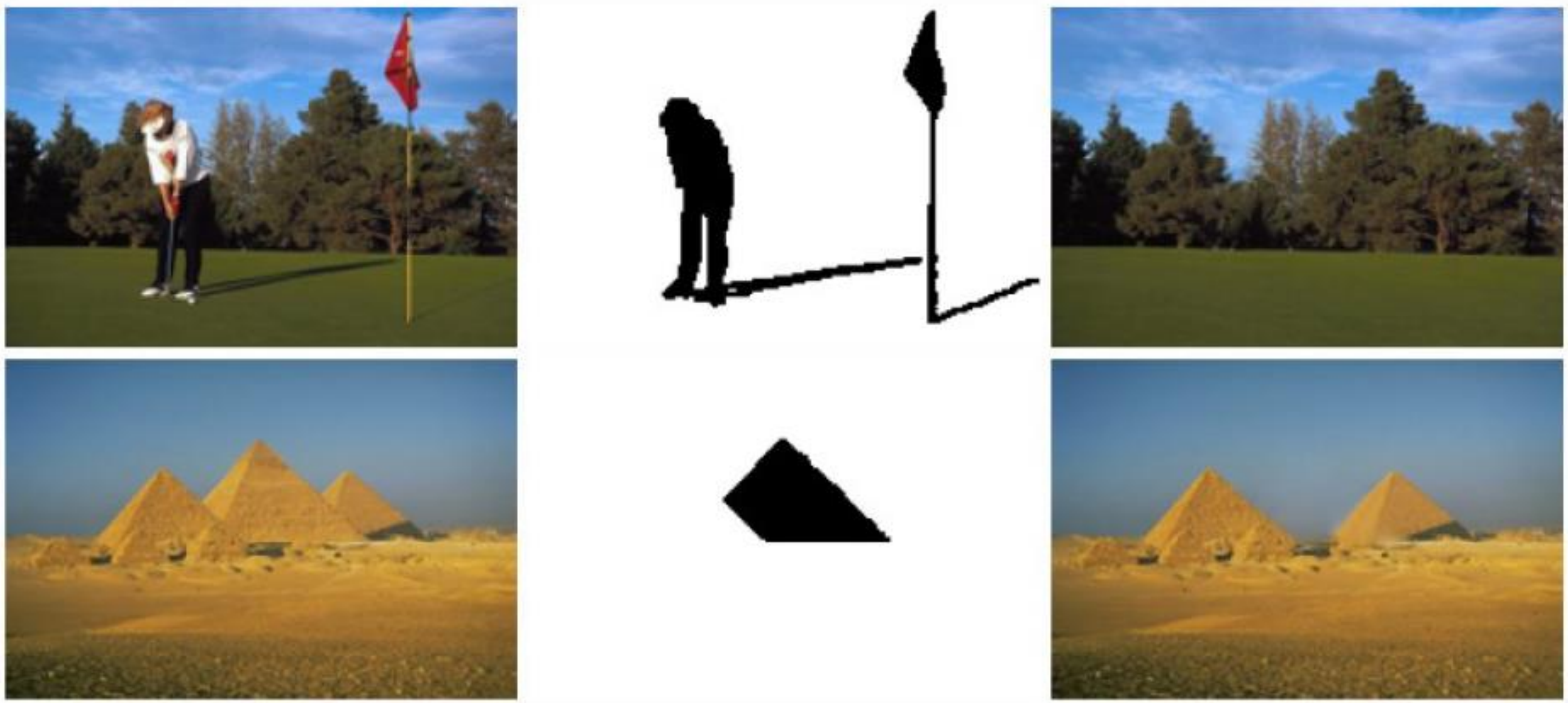


Image Segmentation

Microsoft multiclass segmentation data set

Image Completion

Interactively select objects. Remove them and automatically fill with similar background (from the same image)



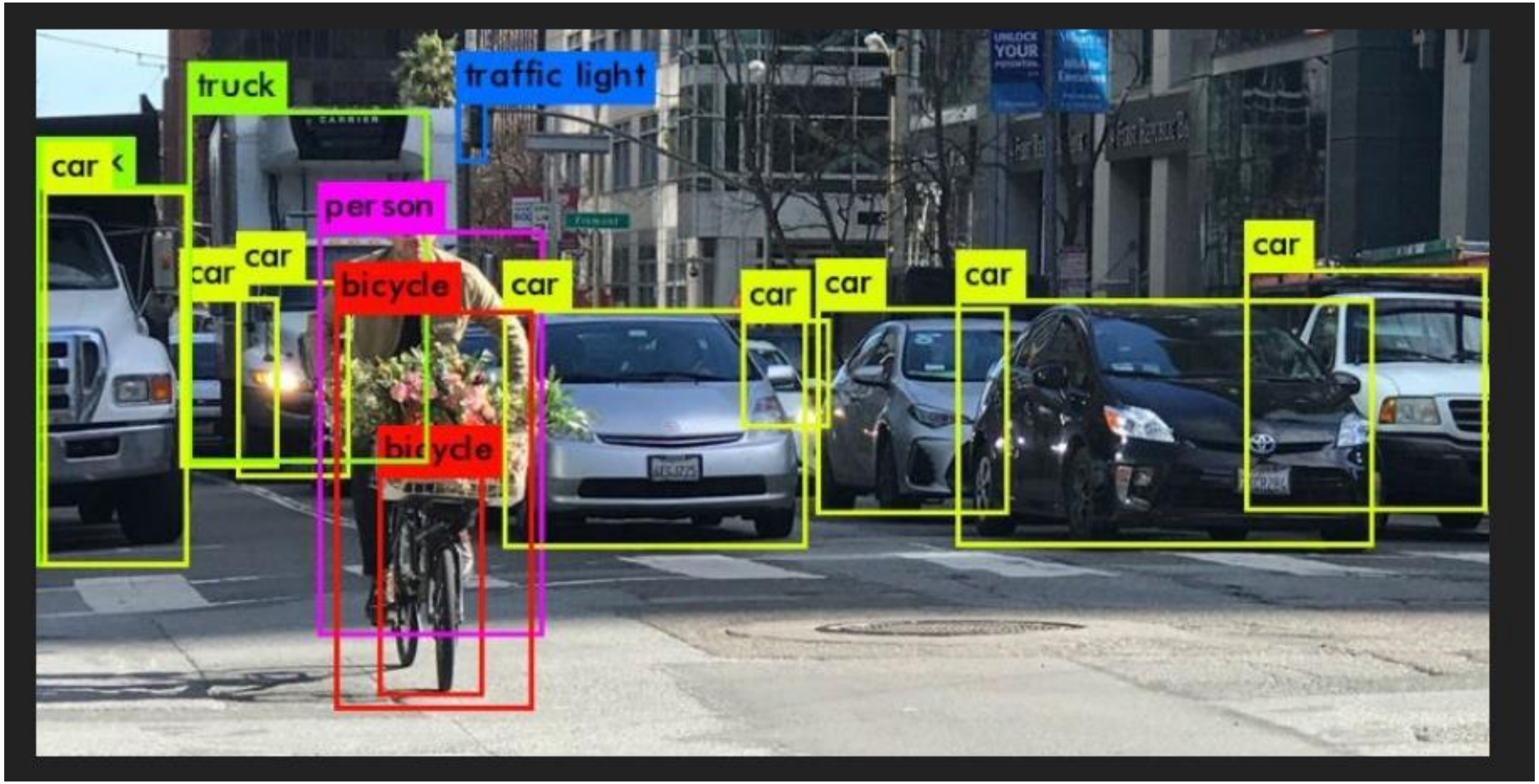
I. Drori, D. Cohen-Or,H. Yeshurun, SIGGRPAH’03

Morphological Image Processing

Broad set of image processing operations that process images based on shapes. Morphological operations apply a structuring element to an input image, creating an output image of the same size.

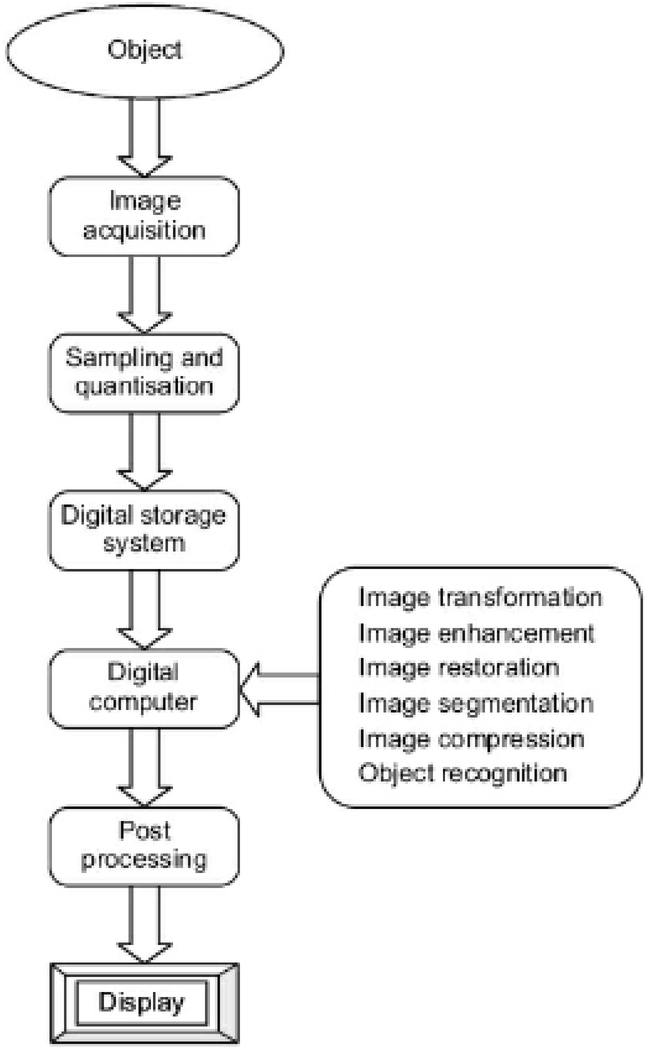
Morphological Operation applied to the Letter J | ResearchGate

Object Detection/Recognition



https://medium.com/ai-techsystems/image-detection-recognition-and-image-classification-with-machine-learning-92226ea5f595

Digital Image Processing



Sampling & Quantization

The process of conversion from analog image into digital one is known as sampling and quantization.

For a continuous image f(x, y), the process of digitizing the coordinate value is called sampling and the digitizing of amplitude or intensity values is called quantization.

A digital image is defined as a set of discrete values representing intensity values of various coordinate points highlighting pixels.

The analog signal, if expressed as X(t), is continuous in both time and amplitude.

The sampling operation results in a signal that is still continuous in amplitude but discrete in time. A digital signal is formed from a sampled data or signal by encoding the sampled values into a finite set of values.

$$X_s(t) = X(kT_s) = X(k)$$

Sampled signal

T_S = sampling period as a reciprocal of the sampling frequency f_S, i.e.,

$T_S = 1/f_S$

k = number of discrete values

Sampling & Quantization

$$X_s(t) = X(t)P(t)$$

The signal P(t) is referred to as the sampling function.
Its value is 0 or 1.
$X_s(t) = X(t)$ when $P(t) = 1$
$X(t) = 0$ when $P(t) = 0$.

Sampling helps in mapping an image from a continuum of points in space (and possibly time) to a discrete set of values.

For a given a digital image, sampling represents a mapping from one discrete set of points to another set of points.

An analog signal is sampled and quantized to three-bit ($n = 3$ and $M = 8$) digital word. After quantization, sampled values are represented by the digital word corresponding to the quantizing level into which the sampled value falls and the digital processing of the waveform is accomplished by processing these digital words.

$$M = 2^n$$

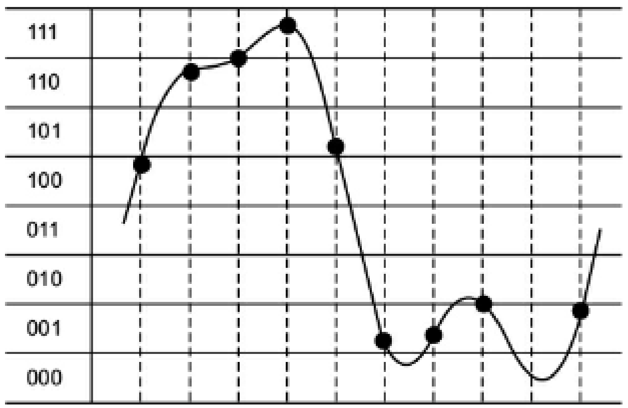


Figure 1.10 Quantisation and encoding.

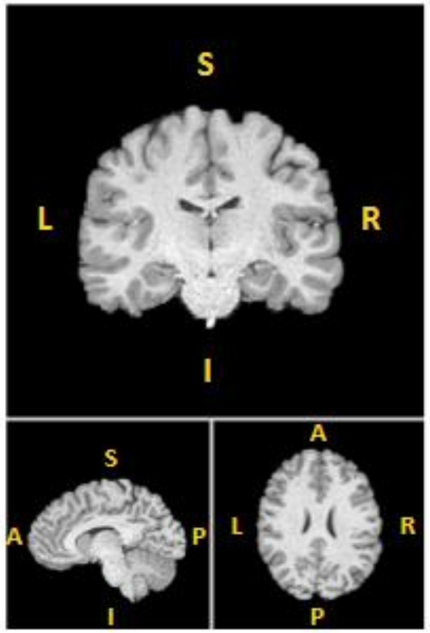
Patel, G.R.. Medical Image Processing: Concepts and Applications

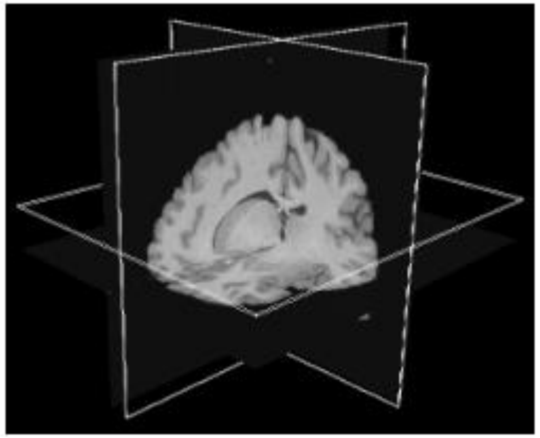
Sampling & Quantization

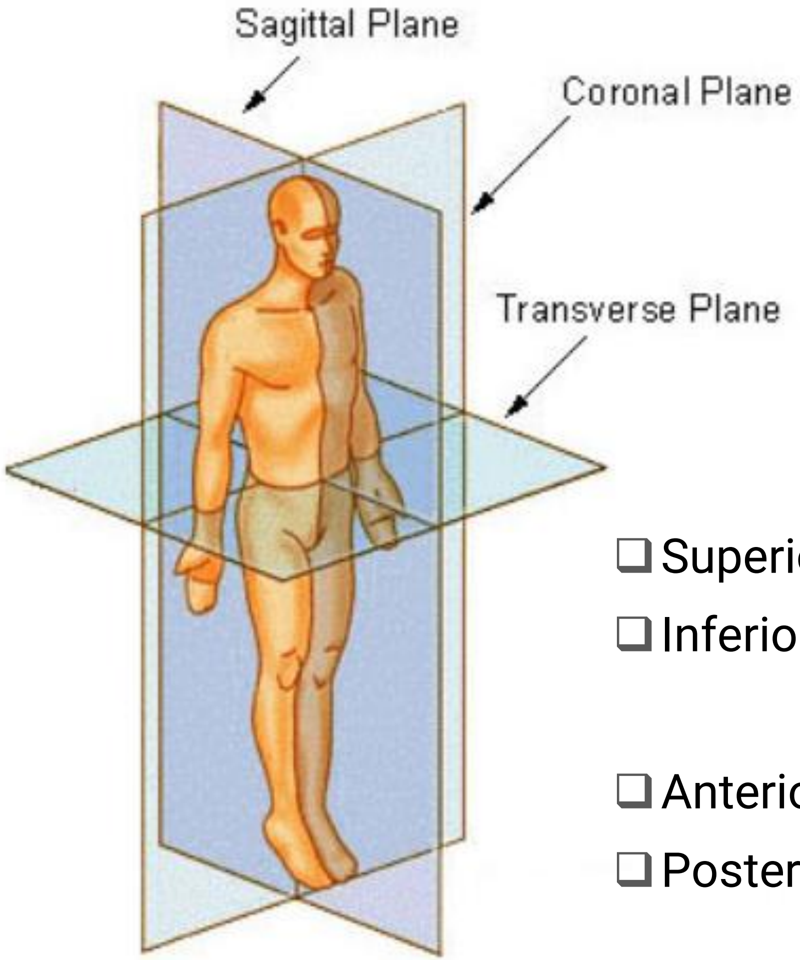
After image is sampling, the number of samples along x and y direction are denoted as M and N,
Image is represented by integer power of 2, i.e., $M = 2^n$ and $N = 2^k$
n and k are the number of bits used.

Medical images usually displayed by **anatomical planes**

- Sagittal
  - divides *left* (L) and *right* (R)
- Coronal
  - divides *anterior* (A) and *posterior* (P)
- Transverse (or axial)
  - divides *superior* (S) and *inferior* (I)







- ❑ Superior = head
- ❑ Inferior = feet

- ❑ Anterior = front
- ❑ Posterior = back

- ❑ Proximal = central
- ❑ Distal = peripheral