# Image Processing
# INT3404 20

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1

## Schedule

| Tuần | Nội dung | Yêu cầu đối với sinh viên (ngoài việc đọc tài liệu tham khảo) |
|---|---|---|
| 1 | Giới thiệu môn học | Cài đặt môi trường: Python 3, OpenCV 3, Numpy, Jupyter Notebook |
| 2 | Ảnh số (Digital image) – Phép toán điểm (Point operations)<br>Làm quen với OpenCV + Python | |
| 3 | Điều chỉnh độ tương phản (Contrast adjust)– Ghép ảnh (Combining images) | Làm bài tập 1: điều chỉnh gamma tìm contrast hợp lý |
| 4 | Histogram - Histogram equalization | Thực hành ở nhà |
| 5 | Phép lọc trong không gian điểm ảnh (linear processing filtering) | Thực hành ở nhà |
| 6 | Thực hành: Ứng dụng của histogram; Tìm ảnh mẫu (Template matching) | Bài tập mid-term |
| 7 | Trích rút đặc trưng của ảnh<br>Cạnh (Edge) và đường (Line) và texture | Thực hành ở nhà |
| 8 | Các phép biến đổi hình thái (Morphological operations) | Làm bài tập 2: tìm barcode |
| 9 | Chuyển đổi không gian – Miền tần số – Phép lọc trên miền tần số<br>Thông báo liên quan đồ án môn học | Đăng ký thực hiện đồ án môn học |
| 10 | Xử lý ảnh màu (Color digital image) | Làm bài tập 3: Chuyển đổi mô hình màu và thực hiện phân vùng |
| 11 | Các phép biến đổi hình học (Geometric transformations) | Thực hành ở nhà |
| 12 | Nhiễu – Mô hình nhiễu – Khôi phục ảnh (Noise and restoration) | Thực hành ở nhà |
| 13 | Nén ảnh (Compression) | Thực hành ở nhà |
| 14 | Hướng dẫn thực hiện đồ án môn học | Trình bày đồ án môn học |
| 15 | Hướng dẫn thực hiện đồ án môn học<br>Tổng kết cuối kỳ | Trình bày đồ án môn học |

2

2

## Recall week 1

- Three main levels in image processing
  - Low level:
    - Input:: image → Output:: image
    - Objective: Change the values of pixels
  - Middle level:
    - Input:: image → Output:: features or regions of interest (ROI)
    - Objective: Extract information from image
  - High level:
    - Input:: image → Output:: description, evaluation
    - Objective: Recognize objects, characteristics; describe the information of the image

Topics in this class

3

# Week 2:
# Digital image fundamentals

- Digital image
- Point operations

4

## Human visual perception

- Why study visual perception?
  - Image processing algorithms are designed based on how our visual system works
  - In image compression, we need to know what information is not perceptually important and can be ignored
  - In image enhancement, we need to know what types of operations that are likely to improve an image visually

5

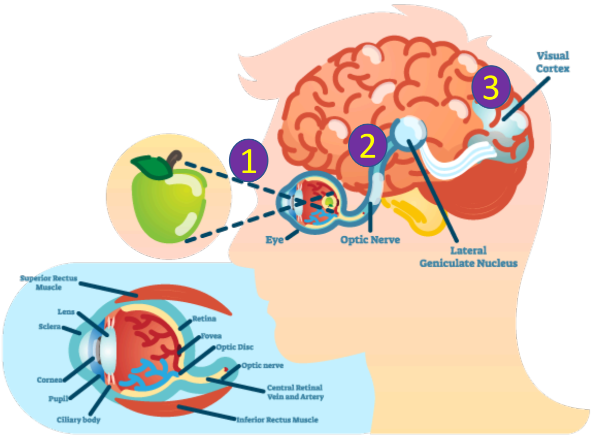
## The human visual system

- The human visual system consists of two primary components – the eye and the brain, which are connected by the optic nerve
  - Eye: receiving sensor (~ camera, scanner)
  - Brain: information processing unit ( ~ computer system)
  - Optic nerve: connection cable (~ physical wire)

6

# How visual system works

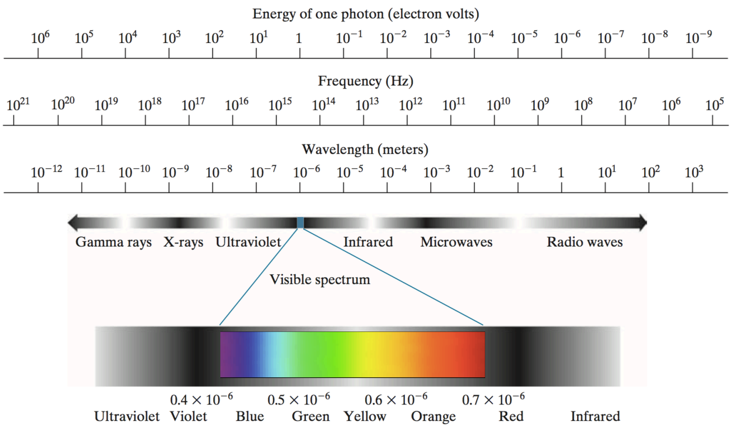
1. Light energy is focused by the lens of the eye into sensors and retina
2. The sensors respond to the light by an electrochemical reaction that sends an electrical signal to the brain (through the optic nerve)
3. The brain uses the signals to create neurological patterns that we perceive as images




Source: https://www.brainhq.com/brain-resources/cool-brain-facts-myths/how-vision-works

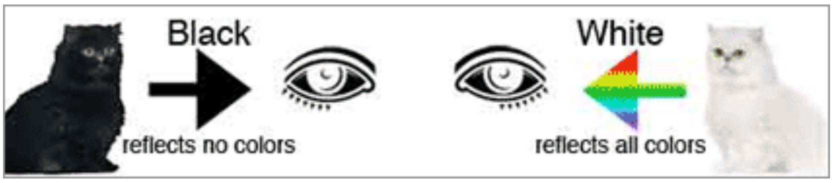
7

# Electromagnetic spectrum & visible spectrum




8

# Grayscale: black – gray – white




Ref: https://www.colormatters.com/color-and-design/are-black-and-white-colors

9

# Brightness adaptation and discrimination

- The range of light intensity levels to which the HVS can adapt is enormous – on the order of 10^10
- However, HVS cannot operate over such a range *simultaneously*
  - *Brightness adaptation*: changing overall sensitivity when perceiving light intensity
  - At a given light intensity level, HVS can only discriminate between changes of a smaller range

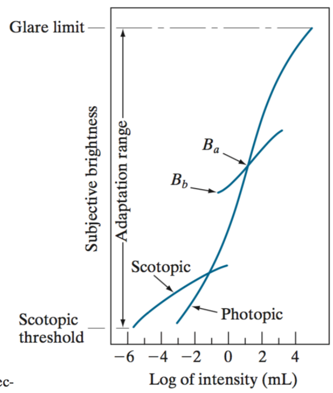
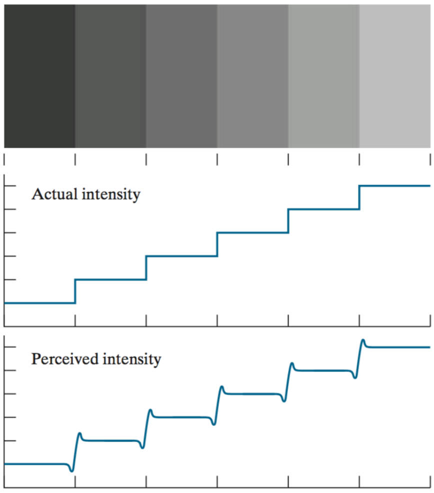



**FIGURE 2.4** Range of subjective brightness sensations showing a particular adaptation level, $B_a$.

10

# Mach band effect

- Perceived brightness is not a simple function of intensity
- HVS tends to undershoot or overshoot around the boundary of regions of different intensities




Source: Fig. 2.7, Gonzalez

11

# Simultaneous contrast

- A region's perceived brightness does not depend only on its intensity

a b c

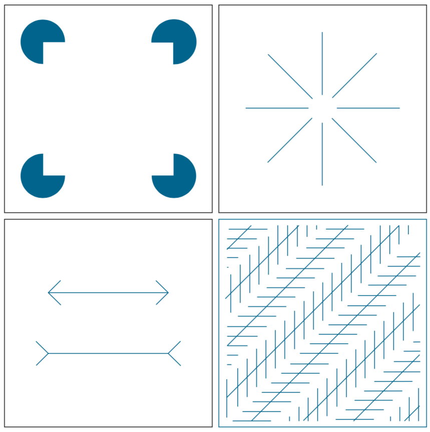
**FIGURE 2.8** Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.

12

# Some optical illusions

Outline of a square is seen clearly, despite the fact that no lines defining such a figure.

Outline of a circle



Two horizontal line segments are of the same length, but one appears shorter than the other.

All long lines are equidistant and parallel, yet, the crosshatching creates the illusion that those lines are far from being parallel

Source: Fig. 2.9, Gonzalez

13

# Digital image

14

# Definition of “digital image”

An image may be defined as a two-dimensional function, $f(x, y)$, where $x$ and $y$ are *spatial* (plane) coordinates, and the amplitude of $f$ at any pair of coordinates $(x, y)$ is called the *intensity* or *gray level* of the image at that point. When $x$, $y$, and the intensity values of $f$ are all finite, discrete quantities, we call the image a *digital image*.

- Value of *f* at *(x, y)* : *picture element, image element, pel,* or *pixel*
  - Nonnegative and finite
  - A scalar quantity whose physical meaning is determined by the source of the image, and whose values are proportional to energy radiated by a physical source

15

# Image acquisition: generate digital images from sensed data

Note: There are numerous ways to acquire images

For examples:
- Sensor arrays (e.g., CCD)
- Sensor strips (e.g., X-ray, CAT, PET, MRI...)

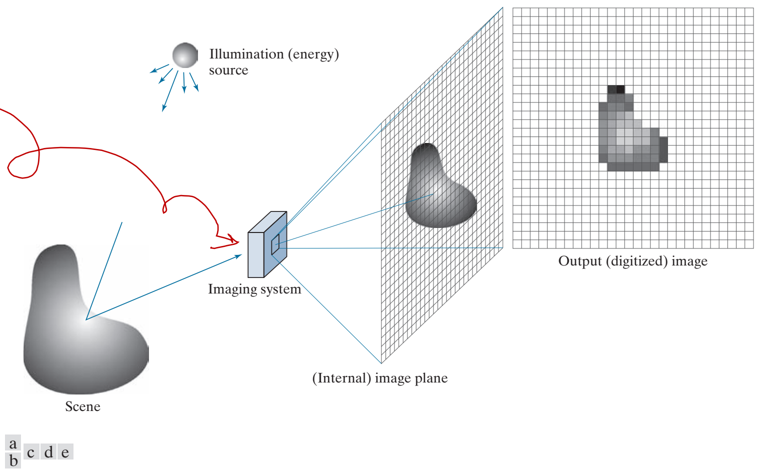
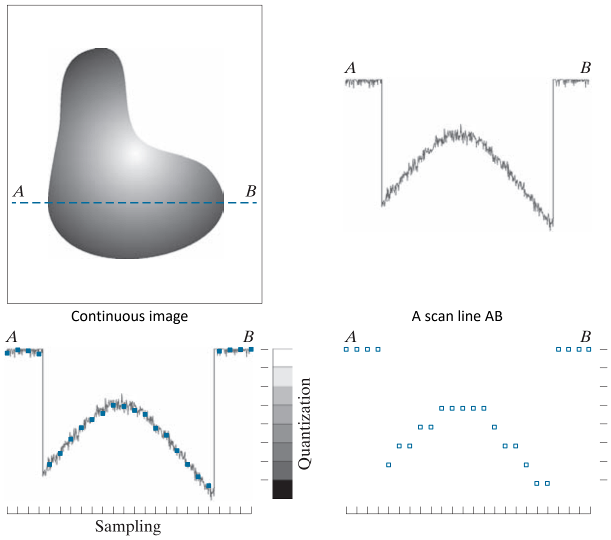



**FIGURE 2.15** An example of digital image acquisition. (a) Illumination (energy) source. (b) A scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

16

# Image sampling and quantization

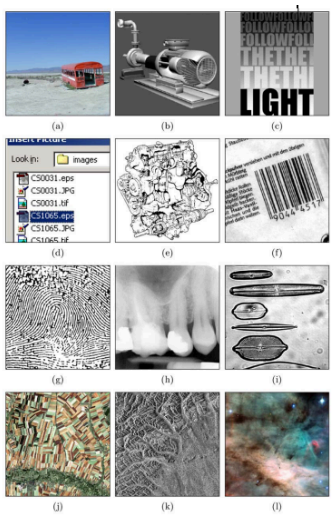
To digitize function f(x,y), we have to sample the function in both coordinates and amplitude.
- Sampling: digitizing the coordinate values
- Quantization: digitizing the amplitude values




17

# Examples of Digital images

a) Natural landscape
b) Synthetically generated scene
c) Poster graphic
d) Computer screenshot
e) Black and white illustration
f) Barcode
g) Fingerprint
h) X-ray
i) Microscope slide
j) Satellite Image
k) Radar image
l) Astronomical object




Note: although imaging is based predominantly on energy from electromagnetic wave radiation, this is not the only method for generating images.
Others: sound -> ultrasonic images, software -> synthetic images

Ref: https://web.cs.wpi.edu/~emmanuel/courses/cs545/S14/slides/lecture01.pdf

18

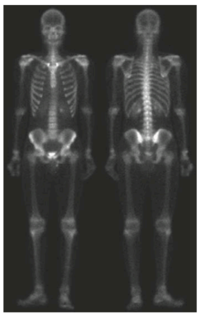
# Digital image example (1/4)

Photo of painting


Graphical image

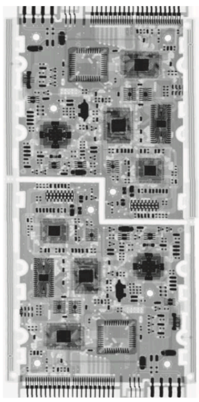
19

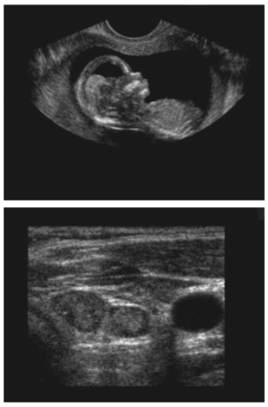
# Digital image example (2/4)



gamma

X-ray





ultrasound

20

# Digital image example (3/4)

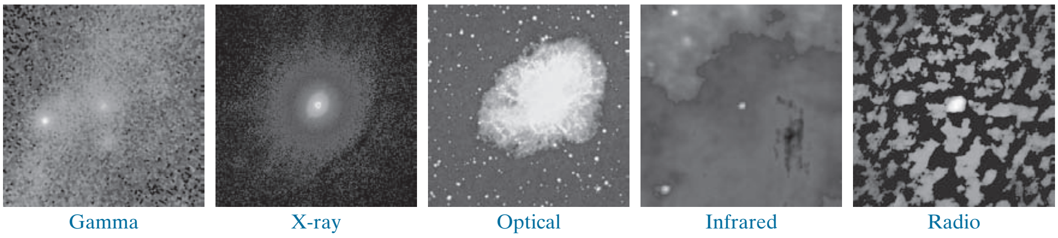



**FIGURE 1.18** Images of the Crab Pulsar (in the center of each image) covering the electromagnetic spectrum. (Courtesy of NASA.)

21

# Digital image example (4/4)

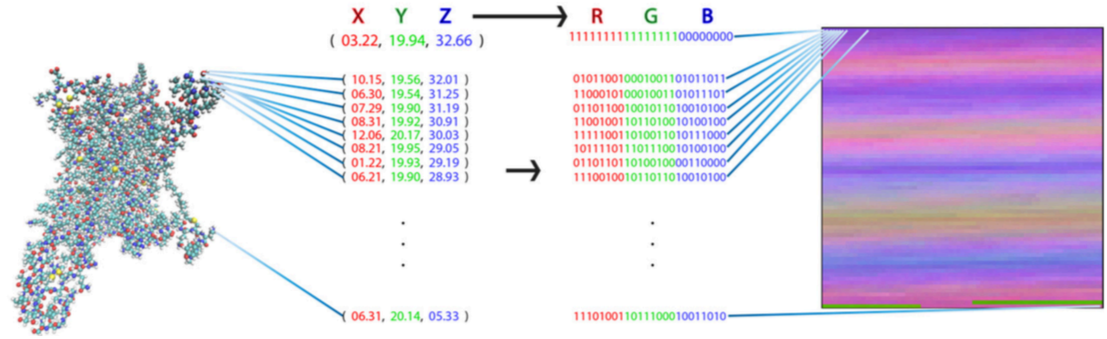



**Figure 1.** Visual representation of a molecular structure. Each atom of the molecule (left) is identified by the set of (X,Y,Z) coordinates as illustrated by the numerical set. The transformation to a 2D picture-like representation is obtained by assignment to each pixel representing an atom (in sequential order from top left to bottom right) by a pixel whose red, green, blue (RGB) value is the XYZ coordinate of the atom it represents (identified by the set of digital values). This representation has the special property that each pixel (i.e., matrix element) always represents the same atom in each frame from the trajectory of a particular protein.

Plante, Ambrose, et al. "A Machine Learning Approach for the Discovery of Ligand-Specific Functional Mechanisms of GPCRs." *Molecules* 24.11 (2019): 2097.

22

22

# Image representation

23

## Representing digital images

- *f(x,y)* containing *M* rows and *N* columns, where *(x,y)* are discrete coordinates
- Image origin: f(0,0)
- *f(x,y)* as an *M x N* numerical array or a 2D matrix

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

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

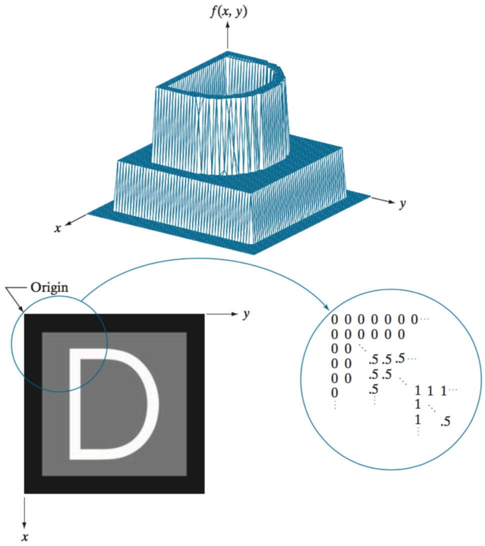
$$a_{ij} = f(i,j)$$

24

# Representing images - plotting

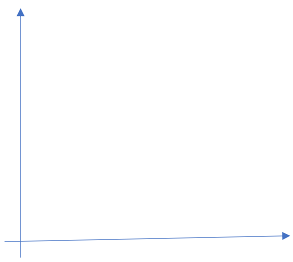
a
b c

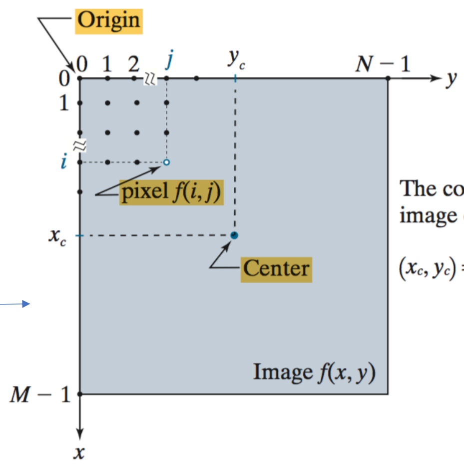
**FIGURE 2.18**
(a) Image plotted as a surface. (b) Image displayed as a visual intensity array. (c) Image shown as a 2-D numerical array. (The numbers 0, .5, and 1 represent black, gray, and white, respectively.)




25

# Image coordinate






The coordinates of the image center are

$$(x_c, y_c) = \left(\text{floor}\left(\frac{M}{2}\right), \text{floor}\left(\frac{N}{2}\right)\right)$$

26

# Image digitization

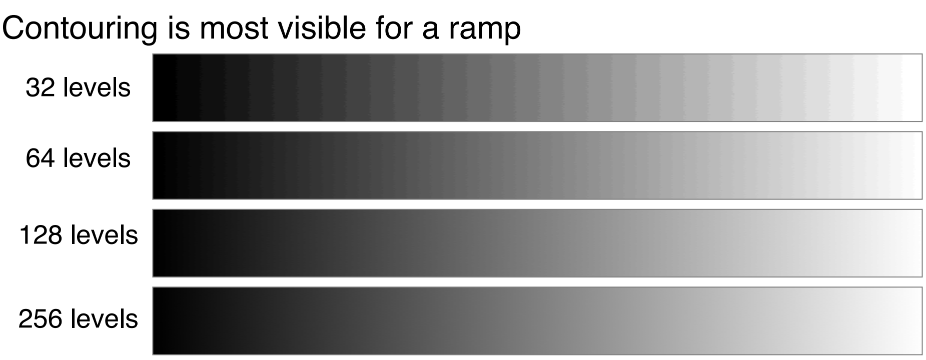
- Image digitization requires that decisions be made regarding the values for M, N, and for the number, L, of discrete intensity levels
  - M, N: positive integers
  - L: depends on digital storage, and quantizing hardware considerations

$$L = 2^k$$

  - K=8 →L=256
  - Contrast ratio = ratio of the highest and lowest intensity levels in an image

27

# Quantization levels




Conventional grayscale image has 256 levels

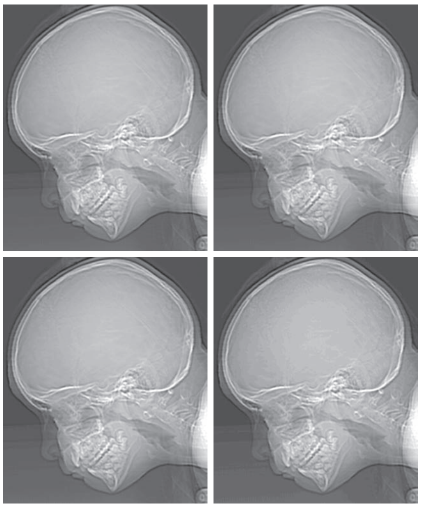
Image credit: Bernd Girod

28

# Effects of varying number of intensity levels

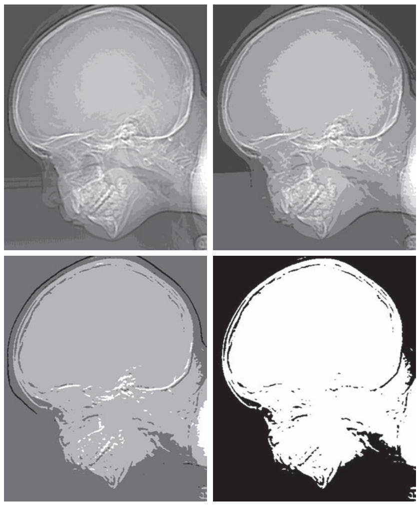
a b
c d

FIGURE 2.24
(a) 774 × 640, 256-level image. (b)-(d) Image displayed in 128, 64, and 32 intensity levels, while keeping the spatial resolution constant. (Original image courtesy of the Dr. David R. Pickens, Department of Radiology & Radiological Sciences, Vanderbilt University Medical Center.)



e f
g h

FIGURE 2.24
(*Continued*)
(e)-(h) Image displayed in 16, 8, 4, and 2 intensity levels.



Appear "false contouring"

29

# Spatial resolution

- Spatial resolution: a measure of the smallest discernible detail in an image
- Measurement:
  - *"line pairs per unit distance",*
  - *"dot (pixels) per unit distance"*

a b
c d

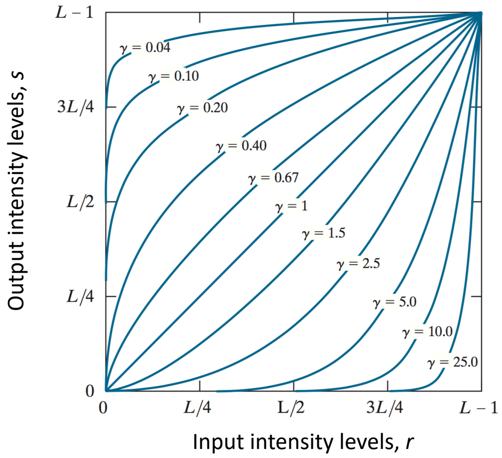
FIGURE 2.23
Effects of reducing spatial resolution. The images shown are at:
(a) 930 dpi,
(b) 300 dpi,
(c) 150 dpi, and
(d) 72 dpi.

30

# Point operations

31

## Power-law (Gamma) transformations




Gonzalez et. al. (fig. 3.6)

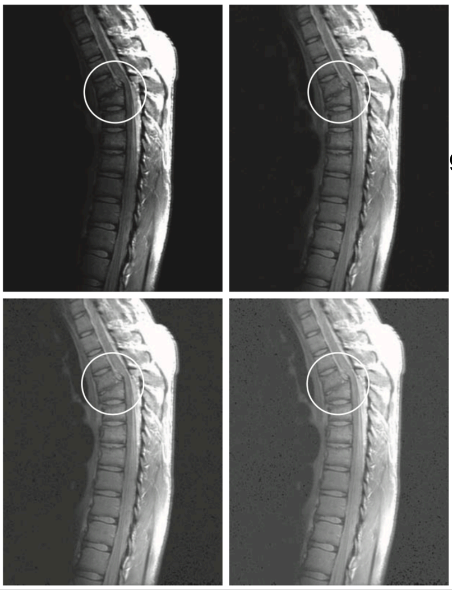
$$s = cr^{\gamma}$$

- With fractional values of gamma, power-law curves map a narrow range of dark input values into a wider range of output values
- The opposite being true for higher values of input levels

32

# Gamma transformation

- Gamma decreased from 0.6 to 0.4: more detail became visible
- A further decrease of gamma to 0.3 enhanced a little more detail in the background, but began to reduce contrast, the image started to have a very slight “washed-out” appearance



gamma = 0.6

gamma = 0.4

gamma = 0.3

Gonzalez et. al. (fig. 3.8)

33

# Gamma transformation

Low contrast is enhanced by gamma > 1

gamma = 3.0

gamma = 4.0

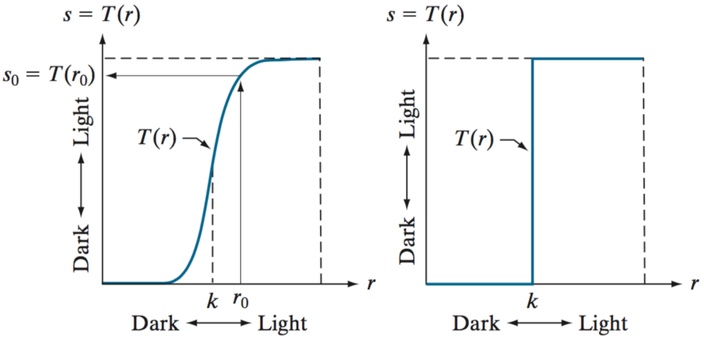
gamma = 5.0

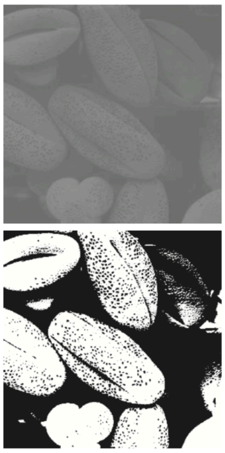
Gonzalez et. al. (fig. 3.9)

34

# Thresholding

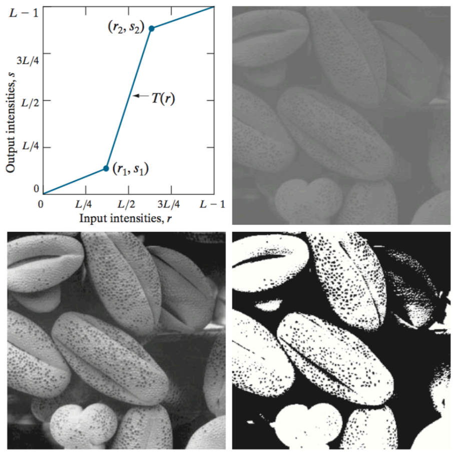
Example:



35

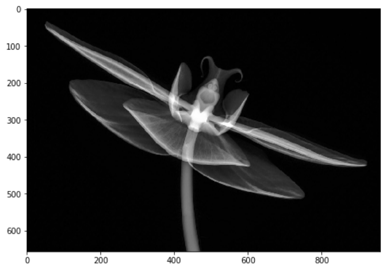
# Piecewise linear transformation
# Contrast stretching

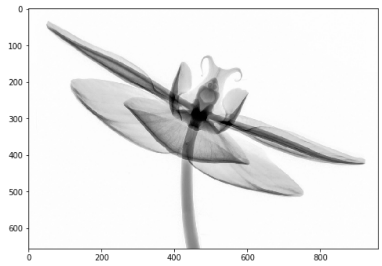



Gonzalez et. al. (fig. 3.10)

36

# Image negatives




out = L – 1 – in
for example: out = 256 - 1 - in

37

37

# Arithmetic operations

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38

38

# Arithmetic operations

between two images $f(x, y)$ and $g(x, y)$

$$\underbrace{\begin{aligned} s(x,y) &= f(x,y) + g(x,y) \\ d(x,y) &= f(x,y) - g(x,y) \\ p(x,y) &= f(x,y) \times g(x,y) \\ v(x,y) &= f(x,y) \div g(x,y) \end{aligned}}_{\text{Element-wise}}$$

39

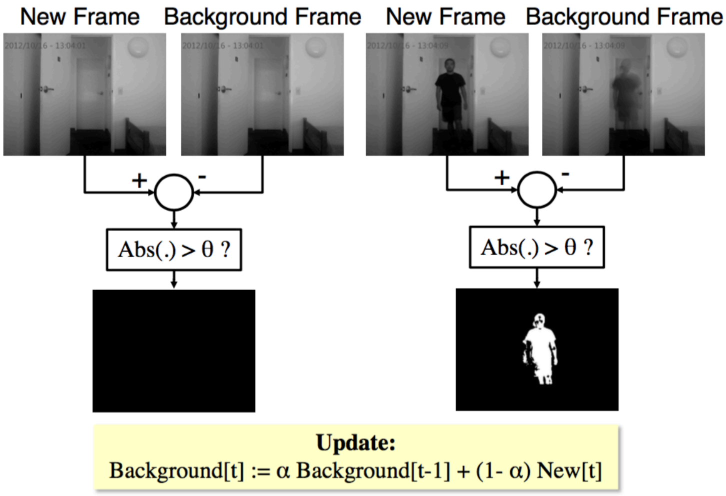
# Image subtraction

Find differences between two images


Credit: Bernd Girod, CS232

40

# Video background subtraction




Credit: Bernd Girod, CS232

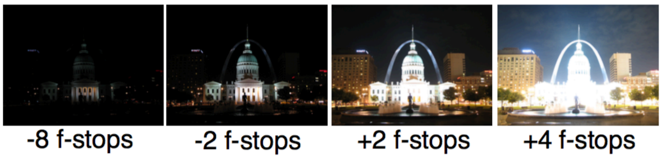
41

# Image Averaging

Image sources: Wikipedia

42

# High-dynamic range imaging




Blended image from Exposure Fusion

[Tom Mertens et al. 2007]

Credit: Bernd Girod, CS232

43

# Shading correction (image division)

$$g(x,y) = f(x,y)h(x,y)$$

g: sensed image

h: shading function (known, or estimated)

f: "perfect image"

Image credit: Gonzalez, fig. 2.33

44

# ROI masking (image multiplication)

For isolating teeth with fillings (white corresponds to 1 and black corresponds to 0)

Masking

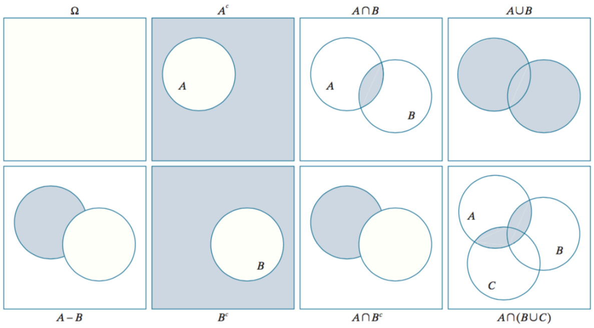

Image credit: Gonzalez, fig. 2.34

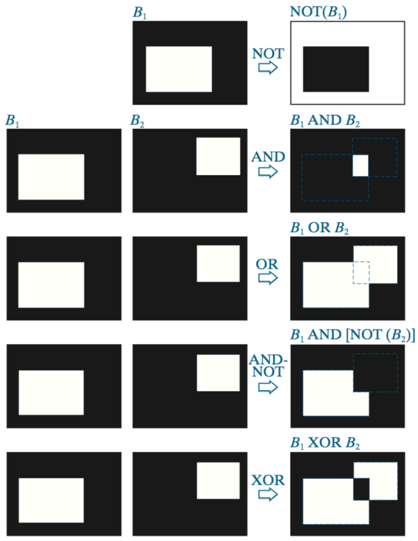
45

# Set operations

46

# Set/Logical operations




Use set: use the coordinates of individual regions of foreground pixels in a single image as sets
Use logic: work with images of same size, and operate between corresponding pixels

Image credit: Gonzalez, fig. 2.35, 2.37

47

# Homeworks

- Run the code!

48