Image Processing INT3404 20

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Slide & code: https://github.com/chupibk/INT3404_20

Schedule

Week	Content	Homework
1	Introduction	Set up environments: Python 3, OpenCV 3, Numpy, Jupyter Notebook
2	Digital image – Point operations Contrast adjust – Combining images	HW1: adjust gamma to find the best contrast
3	Histogram - Histogram equalization – Histogram-based image classification	Self-study
4	Spatial filtering - Template matching	Self-study
5	Feature extraction Edge, Line, and Texture	Self-study
6	Morphological operations	HW2: Barcode detection → Require submission as mid-term test
7	Filtering in the Frequency domain Announcement of Final project topics	Final project registration
8	Color image processing	HW3: Conversion between color spaces, color image segmentation
9	Geometric transformations	Self-study
10	Noise and restoration	Self-study
11	Compression	Self-study
12	Final project presentation	Self-study
13	Final project presentation Class summarization	Self-study

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Important announcement

- Office of Academic Affairs demands English to be the primary language in this class

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

Week 2:
Digital image fundamentals

- Digital image
- Point operations

Human visual perception

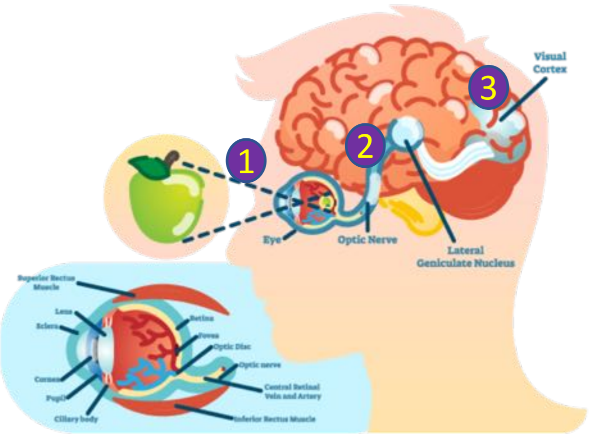
- Why study visual perception?
  - Image processing algorithms are designed based on how our visual system works
  - In image compression, we need to know what information is not perceptually important and can be ignored
  - In image enhancement, we need to know what types of operations that are likely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

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)

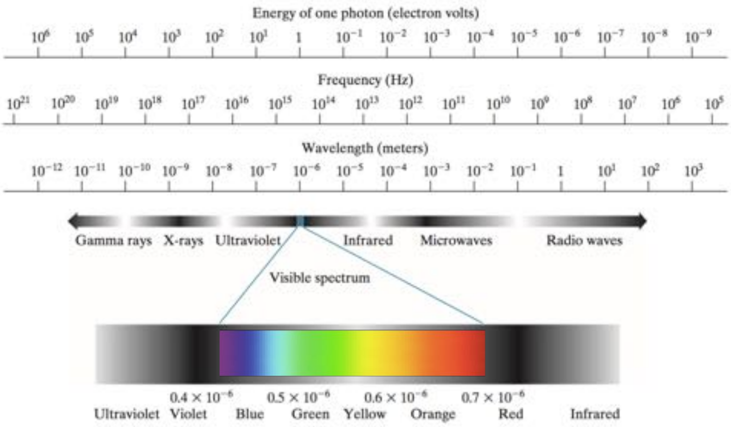
How visual system works

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

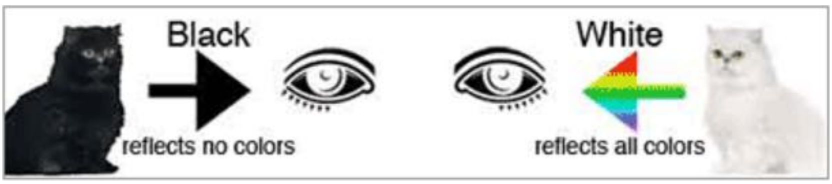


Source: https://www.brainhq.com/brain-resources/cool-brain-facts-myths/how-vision-works

Electromagnetic spectrum & visible spectrum



Grayscale: black – gray – white



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

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

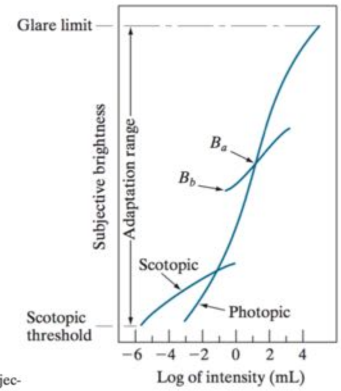
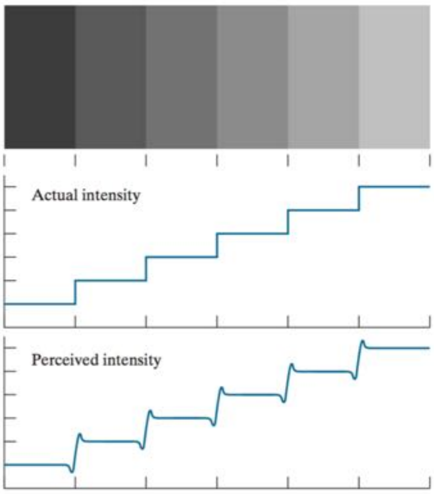


FIGURE 2.4 Range of subjective brightness sensations showing a particular adaptation level, B_a.

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

Simultaneous contrast

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

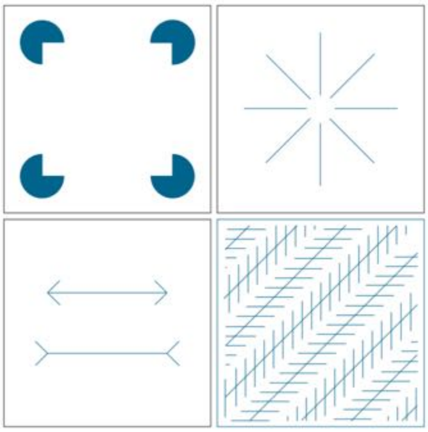
a b c

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.

Some optical illusions

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

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



Outline of a circle

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

Digital image

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

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...)

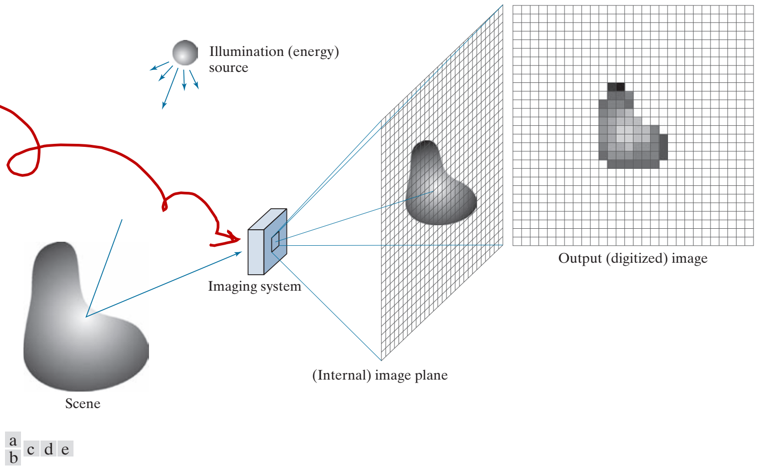
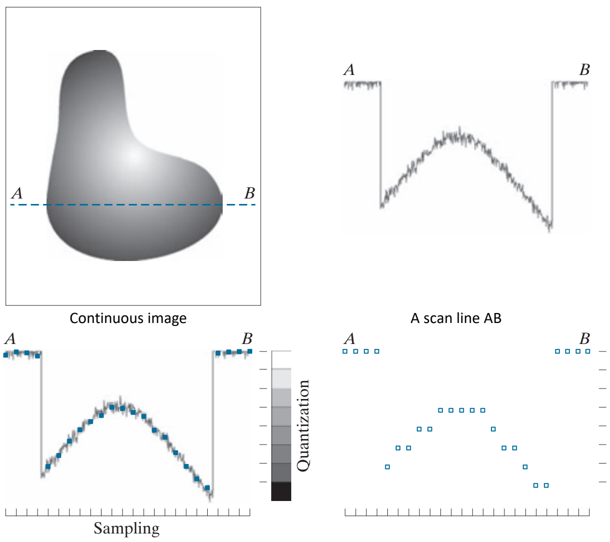


FIGURE 2.15 An example of digital image acquisition. (a) Illumination (energy) source. (b) A scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

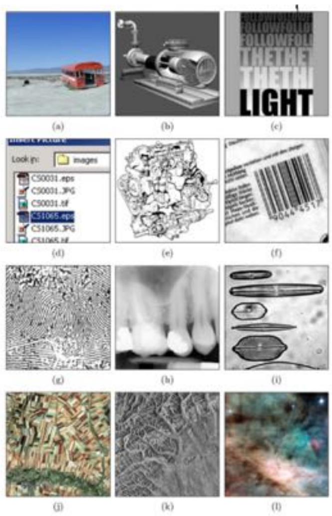
Image sampling and quantization

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



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

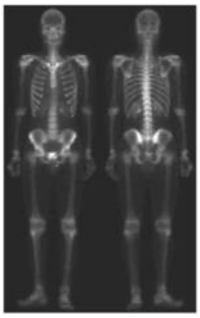
Ref: https://web.cs.wpi.edu/~emmanuel/courses/cs545/S14/slides/lecture01.pdf

Digital image example (1/4)

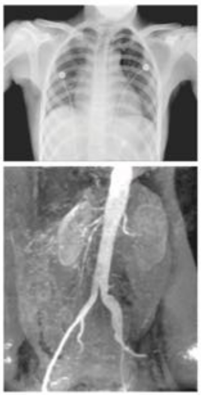

Photo of painting

Graphical image

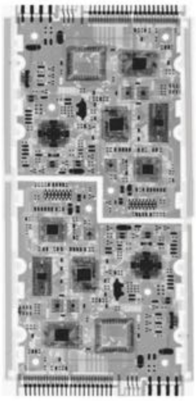
Digital image example (2/4)

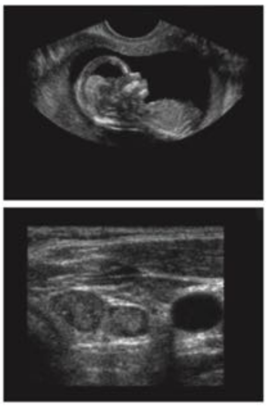


gamma



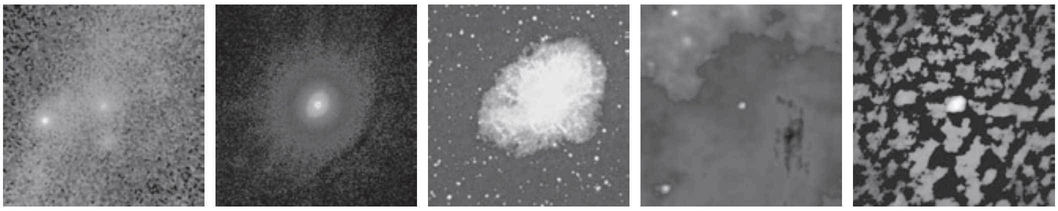
X-ray





ultrasound

Digital image example (3/4)



Gamma X-ray Optical Infrared Radio

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

Digital image example (4/4)

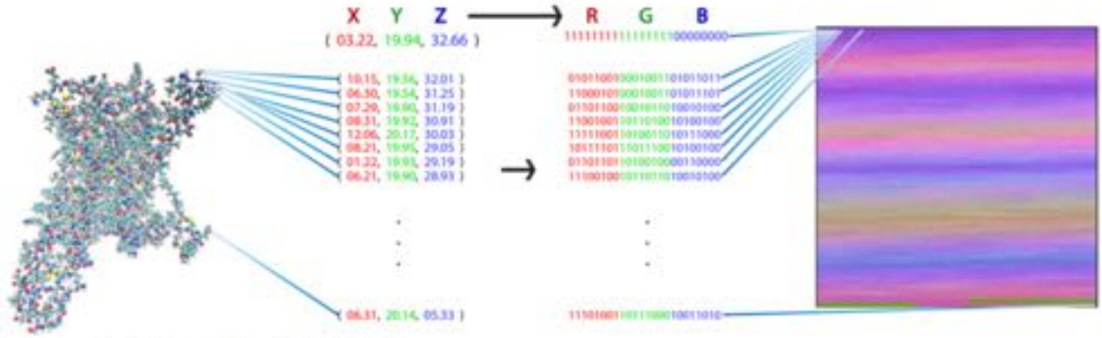


Figure 1. Visual representation of a molecular structure. Each atom of the molecule (left) is identified by the set of (X,Y,Z) coordinates as illustrated by the numerical set. The transformation to a 2D picture-like representation is obtained by assignment to each pixel representing an atom (in sequential 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.

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Image representation

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

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

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

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

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.)

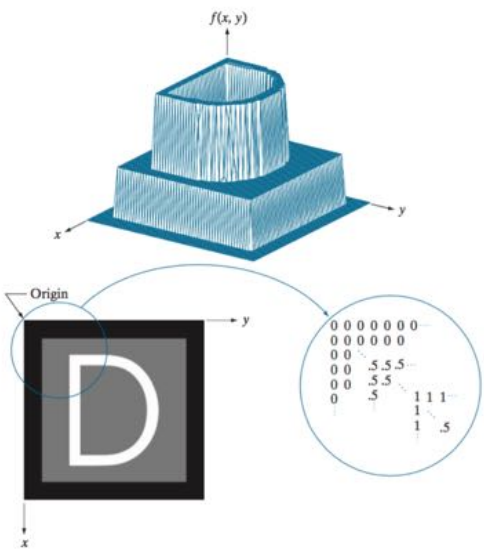


Image coordinate

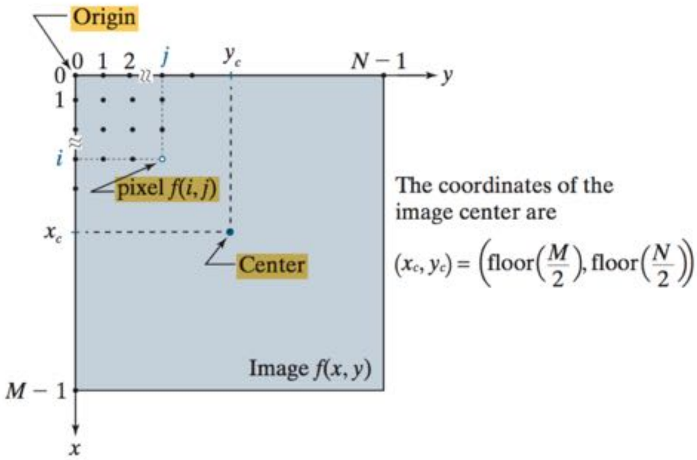


Image digitization

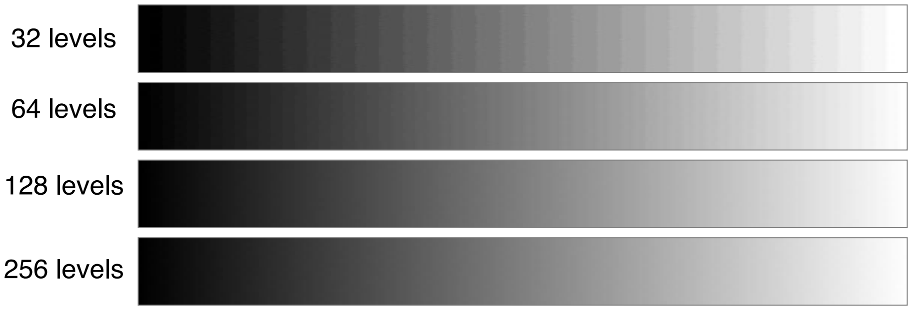
- Image digitization requires that decisions be made regarding the values for M, N, and for the number, L, of discrete intensity levels
  - M, N: positive integers
  - L: depends on digital storage, and quantizing hardware considerations

$$L = 2^k$$

  - Contrast ratio = ratio of the highest and lowest intensity levels in an image

Quantization levels

Contouring is most visible for a ramp



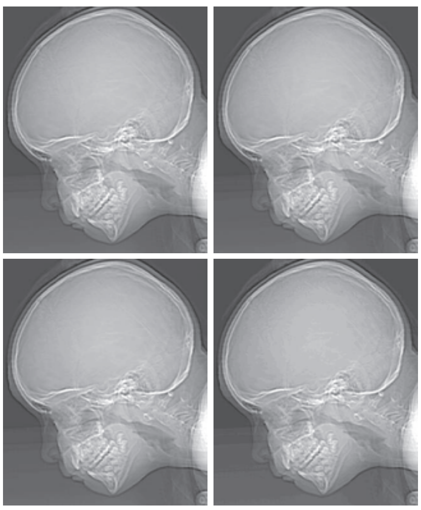
Conventional grayscale image has 256 levels

Image credit: Bernd Girod

Effects of varying number of intensity levels

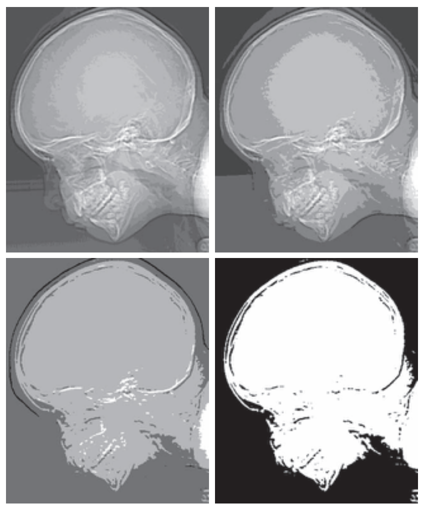
a b
c d

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”

Spatial resolution

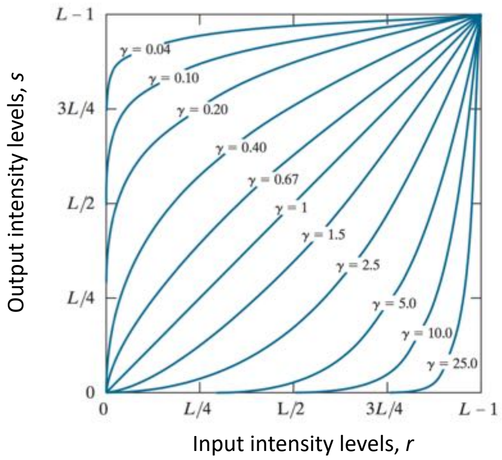
- Spatial resolution: a measure of the smallest discernible detail in an image
- Measurement:
  - *"line pairs per unit distance",*
  - *"dot (pixels) per unit distance"*

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.

Point operations

Power-law (Gamma) transformations



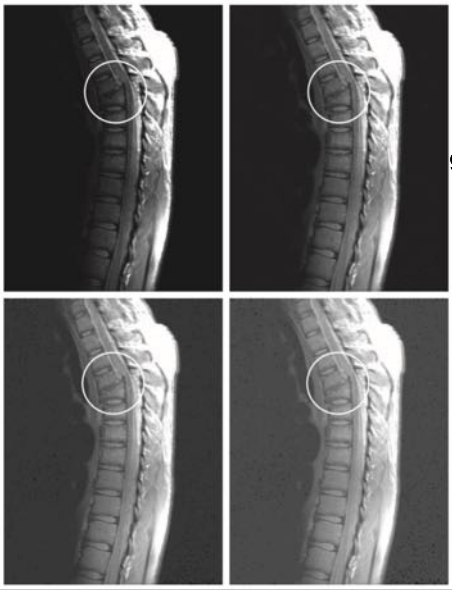
Gonzalez et. al. (fig. 3.6)

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

- 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

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)

Gamma transformation

Low contrast is enhanced by gamma > 1

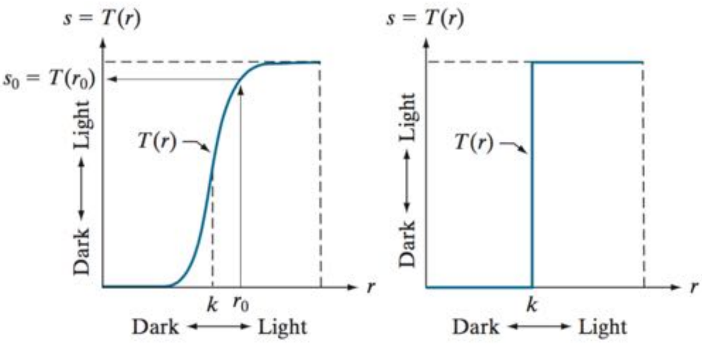
gamma = 3.0

gamma = 4.0

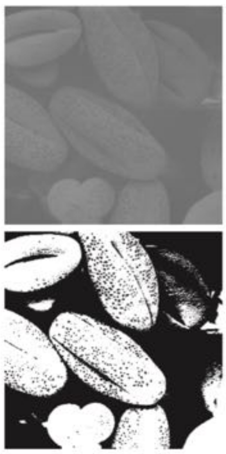
gamma = 5.0

Gonzalez et. al. (fig. 3.9)

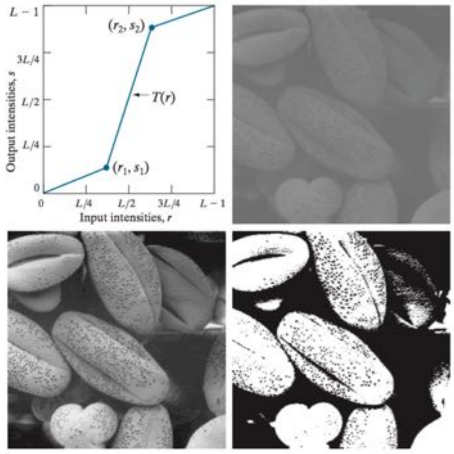
Thresholding



Example:

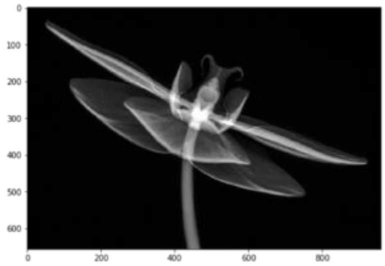


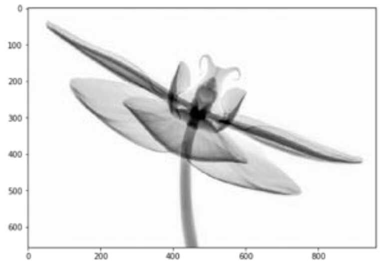
Piecewise linear transformation
Contrast stretching



Gonzalez et. al. (fig. 3.10)

Image negatives





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

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Arithmetic operations

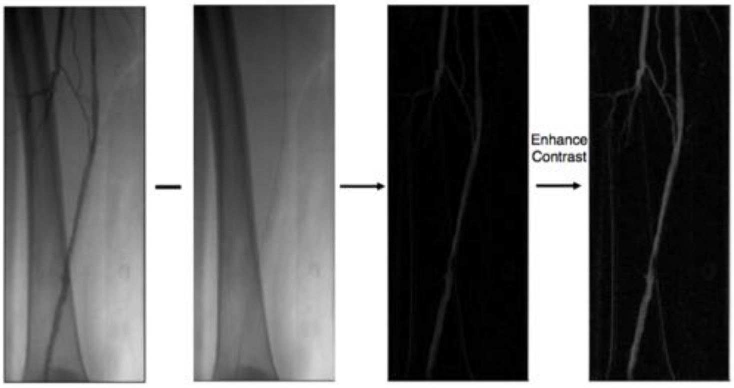
Arithmetic operations

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

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

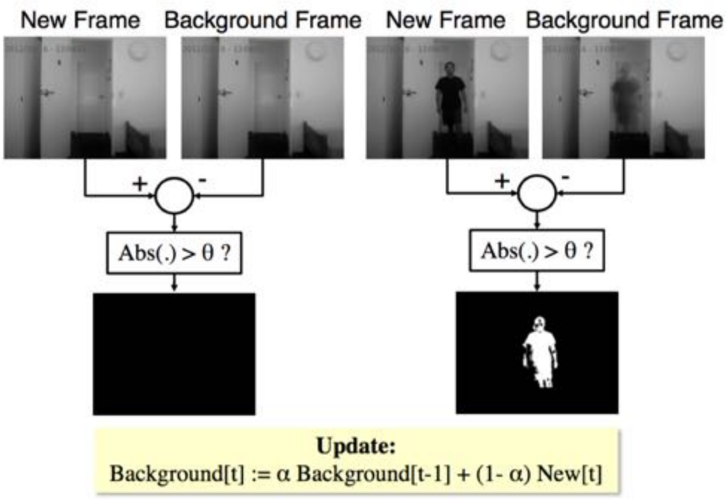
Image subtraction

Find differences between two images



Credit: Bernd Girod, CS232

Video background subtraction



Credit: Bernd Girod, CS232

Image Averaging

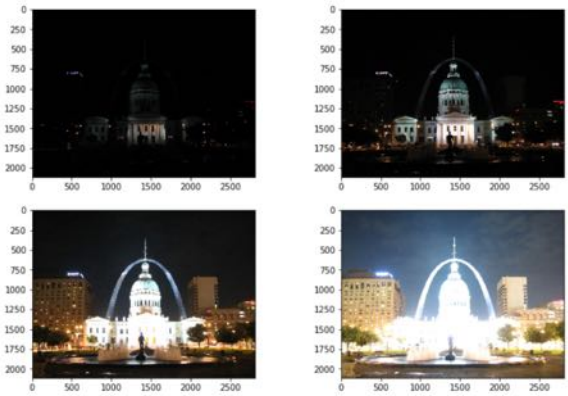


Image sources: Wikipedia

High-dynamic range imaging

-8 f-stops -2 f-stops +2 f-stops +4 f-stops

Blended image from Exposure Fusion
[Tom Mertens et al. 2007]

Credit: Bernd Girod, CS232

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

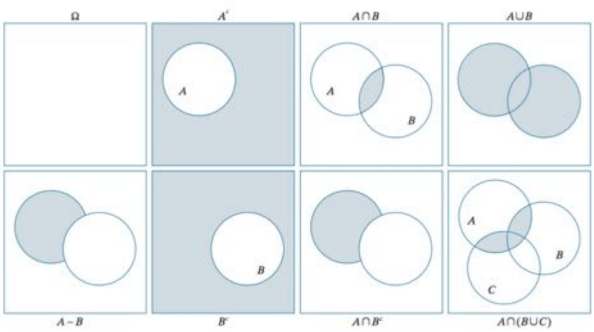
ROI masking (image multiplication)

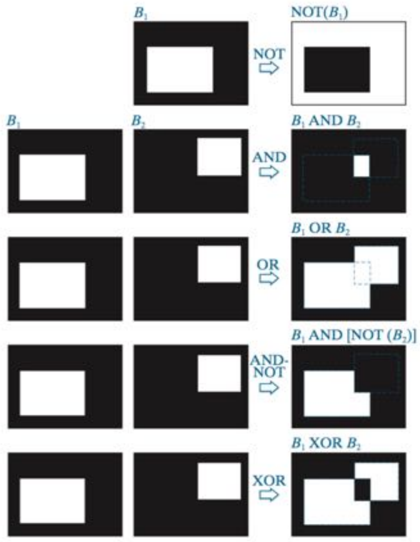
For isolating teeth with fillings (white corresponds to 1 and black corresponds to 0)

Image credit: Gonzalez, fig. 2.34

Set operations

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

Homeworks

- Run the code!