EL5123 --- Image Processing

Introduction to Image Processing

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Adapted from slides by Zhu Liu

Lecture Outline

- Applications of image processing
- Demonstration of basic image processing tools
- Image formation and perception
- Image representation
- Matrix/Matlab primer

Application Areas of Image Processing

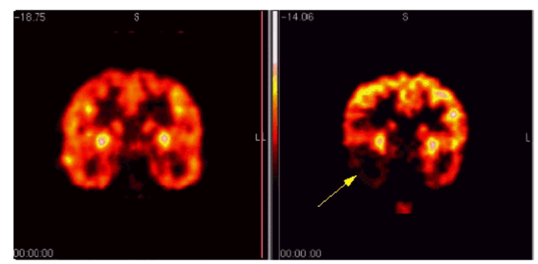
- Purpose of image processing
  - Improvement of pictorial information for human interpretation
  - Compression of image data for storage and transmission
  - Preprocessing to enable object detection, classification, and tracking
- Typical application areas
  - Television Signal Processing
  - Satellite Image Processing
  - Medical Image Processing
  - Robotics
  - Visual Communications
  - Law Enforcement
  - Etc.

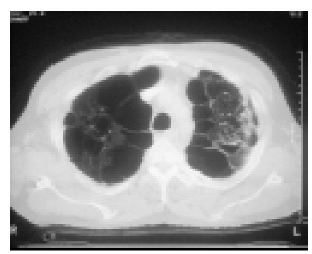
Television Signal Processing

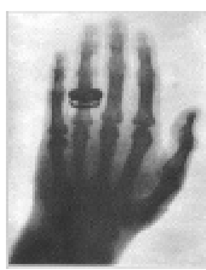
- Image brightness, contrast, color hue adjustment
- Video compression for efficient delivery and storage
- Conversion among different video formats
  - QVGA<->VGA<->XVGA
  - SDTV<->HDTV
  - NTSC<->PAL

Medical Image Processing

- Images are acquired to get information about **Anatomy** and **Physiology** of a patient
- How to reconstruct the image from captured data
- How to process/analyze the image to help diagnosis/treatment?
  - Ultra Sound (US)
  - Magnetic resonance Imaging
  - Positron Emission Tomography (PET)
  - Computer Tomography (CT)
  - XRays







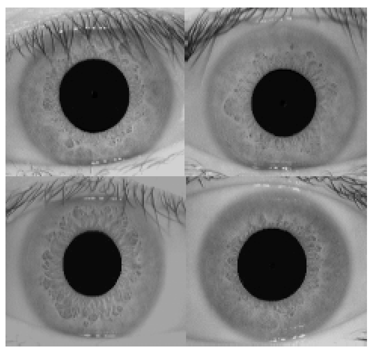
Visual Communication

- Videophone
- Tele-conferencing
- Tele-shopping
- How to compress the video to reduce bandwidth/storage requirements
- How to conceal artifacts due to transmission losses?

Law Enforcement

- Biometric identification / verification
  - Fingerprint

  - Face
  - Iris



AR Face Database

  - How to extract features that can be used to differentiate among different images?

Robot Control

- Automatic inspection
- Unmanned operations
  - Autonomous Vehicle driving
- How to detect and track the target?

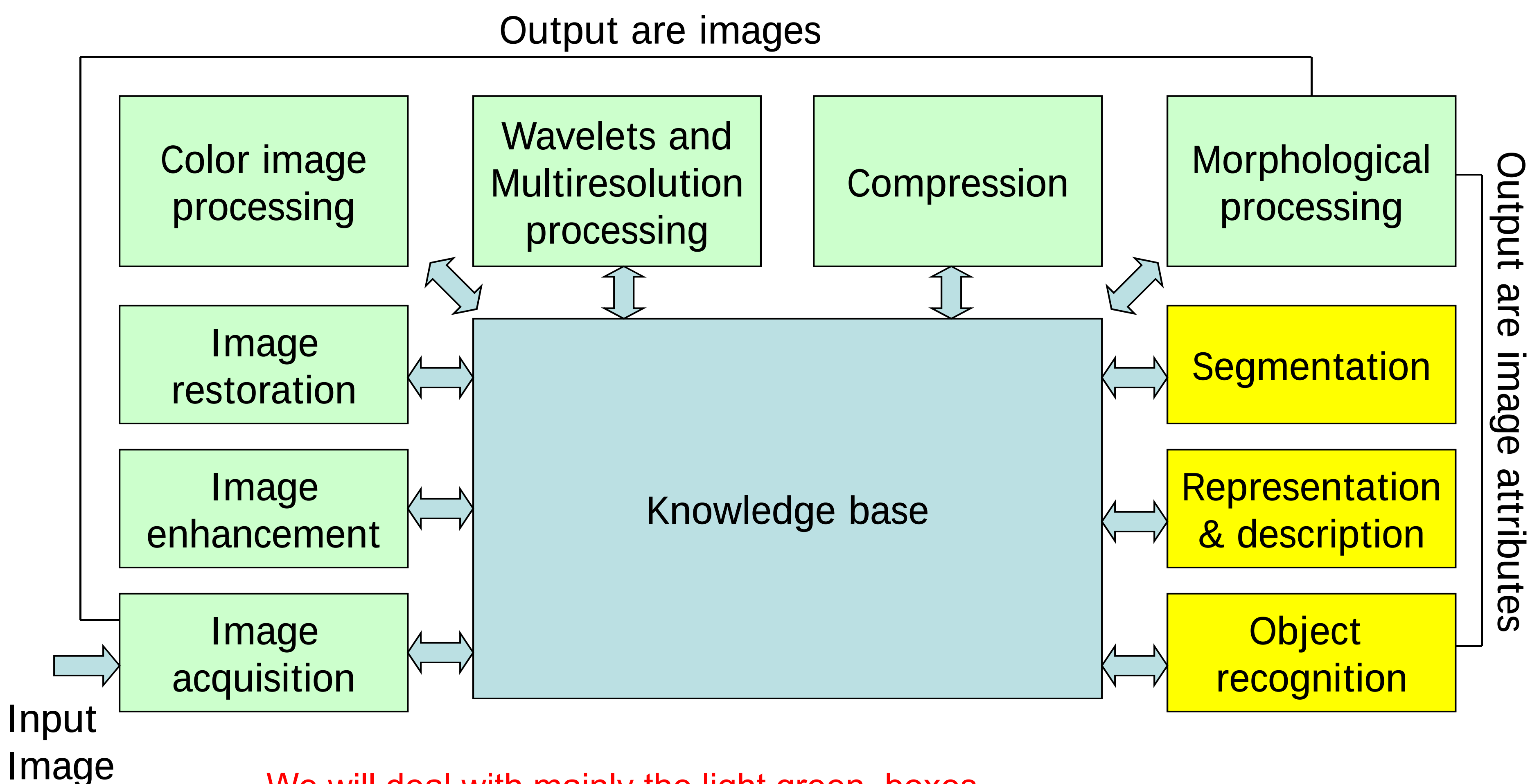
Mars Rover

Satellite Image Processing

- Remote sensing
- Climate
- Geology
- Land resource
- Flood monitor
- How to enhance the image to facilitate interpretation?
- How to analyze the image to detect certain phenomena?

New York (from Landast-5 TM)

Components in Digital Image Processing



We will deal with mainly the light green boxes.
Yellow boxes belong to "computer vision" and "pattern recognition"

Basic Image Processing Operations

- Simple point processing
- Special effects
- Noise reduction
- Image enhancement
- Image restoration
- Face detection
- Image segmentation

Simple point processing

Original image

Horizontal flip

Vertical flip

Digital Negative

Contrast Enhancement

Original image with low contrast

Enhanced image

Noise Reduction

Degraded Image
(salt and pepper noise)

Noise reduced Image
(after median filtering)

Image Sharpening

Observed Image

Enhanced Image
(sharpening)

Image Restoration

Degraded Image

Restored Image

Image debluring

a	b	c
d	e	f
g	h	i

FIGURE 5.29 (a) 8-bit image corrupted by motion blur and additive noise. (b) Result of inverse filtering. (c) Result of Wiener filtering. (d)–(f) Same sequence, but with noise variance one order of magnitude less. (g)–(i) Same sequence, but noise variance reduced by five orders of magnitude from (a). Note in (h) how the deblurred image is quite visible through a "curtain" of noise.

Special Effects

Original Image

Rotation

Wave

Swirl

Face Detection

- Face detection in an image or video
- Face tracking in a video

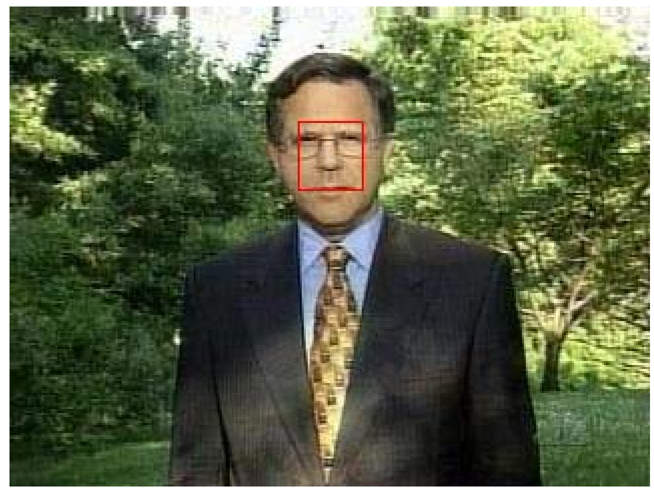


Image Segmentation

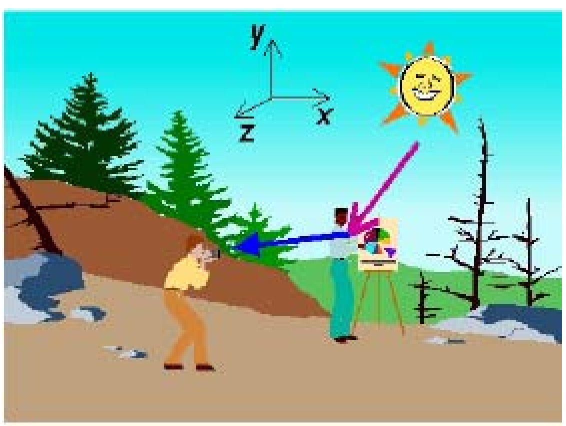
- Segmentation of different object in the scene

Image Formation and Representation

- Overview
- Light physics and color perception
- Grayscale image capture
- Color image capture
- Digital image representation

Image Formation

- Light source *(λ: wavelength of the source)*
  - $E(x, y, z, \lambda)$: incident light on a point *(x, y, z world coordinates of the point)*
- Each point of the scene has a reflectivity function.
  - $r(x, y, z, \lambda)$: reflectivity function
- Light reflects from a point and the reflected light is captured by an imaging device.
  - $c(x, y, z, \lambda) = E(x, y, z, \lambda) * r(x, y, z, \lambda)$: reflected light.



→ $E(x, y, z, \lambda)$

→ $c(x, y, z, \lambda) = E(x, y, z, \lambda) * r(x, y, z, \lambda)$

Camera($c(x, y, z, \lambda)$)

Light is part of the EM wave

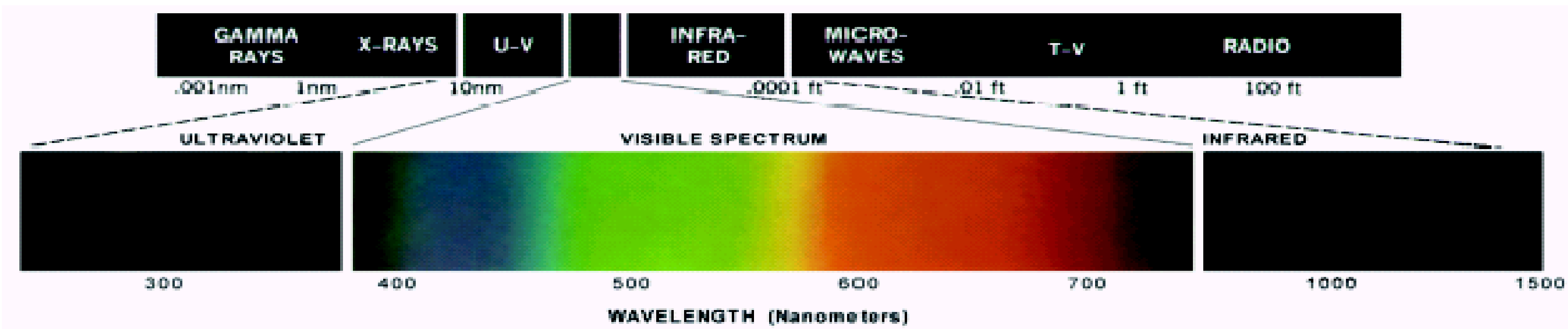
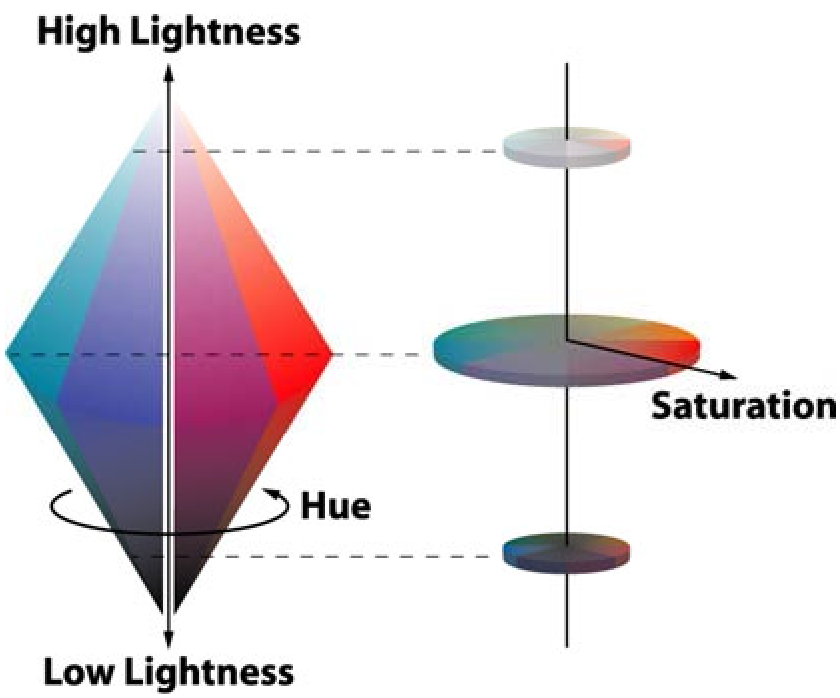


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Three Attributes of Color

- Luminance (brightness)
- Chrominance
  - Hue (color tone) and Saturation (color purity)
- Represented by a "color cone" or "color solid"



Tri-chromatic Color Mixing

- Tri-chromatic color mixing theory
  - Any color can be obtained by mixing three primary colors with a right proportion

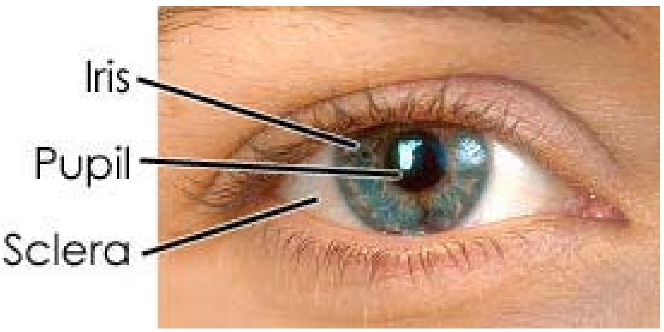
Gray and Color Image Capture

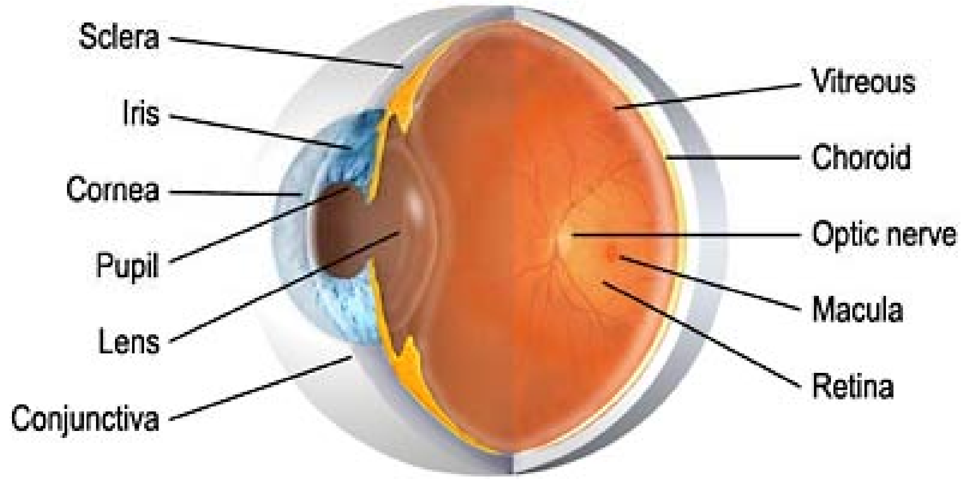
- Gray images are captured by a single sensor, sensitive to the entire visible spectrum, similar to the rods
- Color images are captured by having three sensors, each sensitive to a different primary color, similar to the cones

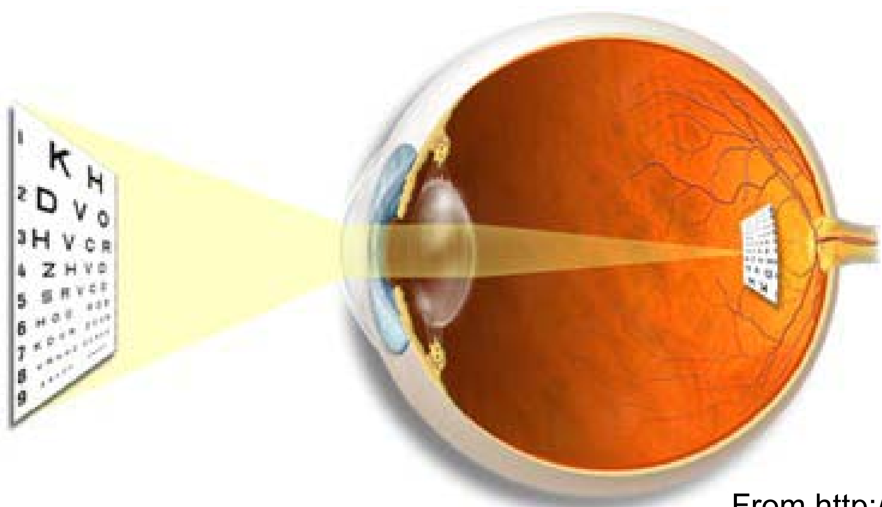
Gray and Color Image Display/Printing

- Gray images are displayed by a single light sensitive diode, with intensity proportional to gray level.
- LCD monitors display color images are displayed by having three phosphors at each pixel, each generating a different primary color (red, green, blue)
- Color images are printed by having three color inks (cyan, magenta, yellow)

Eye Anatomy

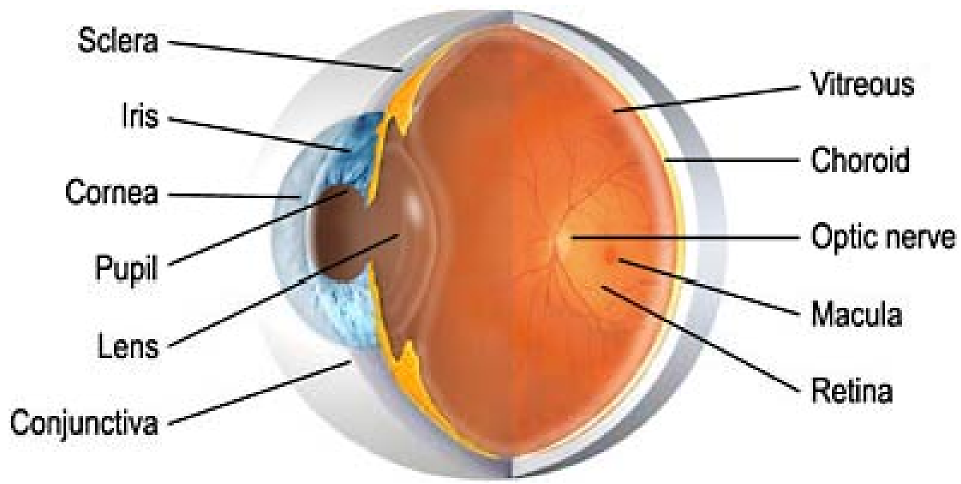






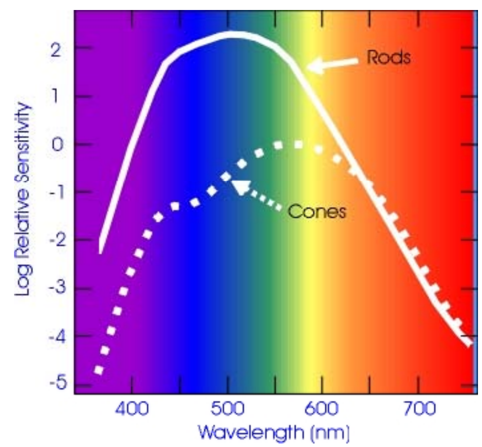
From http://www.stlukeseye.com/Anatomy.asp

Eye vs. Camera

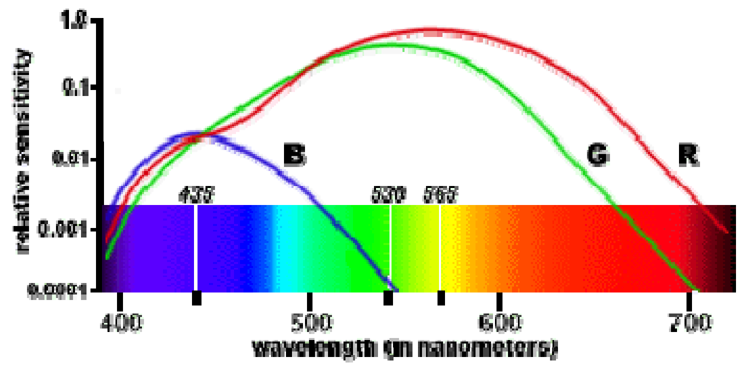


Camera components	Eye components
Lens	Lens, cornea
Shutter	Iris, pupil
Film	Retina
Cable to transfer images	Optic nerve send the info to the brain

Receptors in the Retina



- Rods
  - night vision
  - Low acuity
  - Achromatic
- Cones
  - Day vision
  - High acuity
  - Chromatic
  - Three sets, with different sensitivity functions
    - 700nm (R), 546nm (G), 435nm (B)



Color Representation

- Specify three primary colors directly
  - Red, Green, Blue (RGB)
  - Cyan, Magenta, Yellow (CMY)
- Specify the luminance and chrominance
  - HSB or HSI (Hue, saturation, and brightness or intensity)
  - YIQ (used in NTSC color TV)
  - YCbCr (used in digital color TV)
  - Can be determined from RGB or CMY
- Amplitude specification:
  - 8 bits per color component, or 24 bits per pixel
  - Total of 16 million colors
  - A 1kx1k true RGB color requires 3 MB memory

Analog to Digital Image Conversion

- Sampling: Dividing a continuous region into small squares (pixels), taking average value of each square
- Quantization: Map each value into one in a set of discrete values

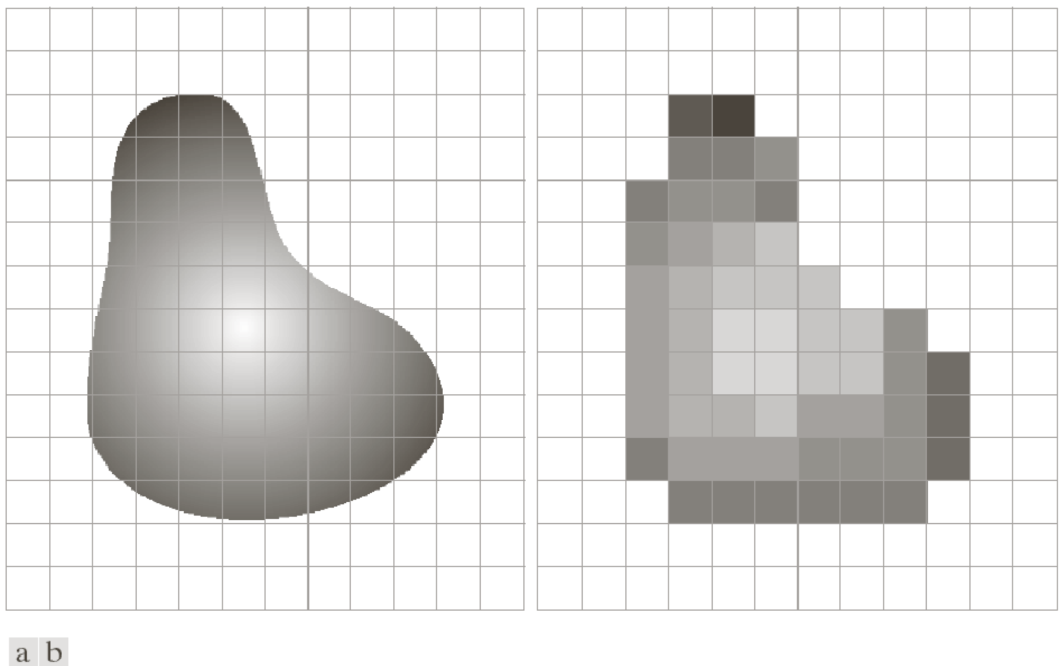
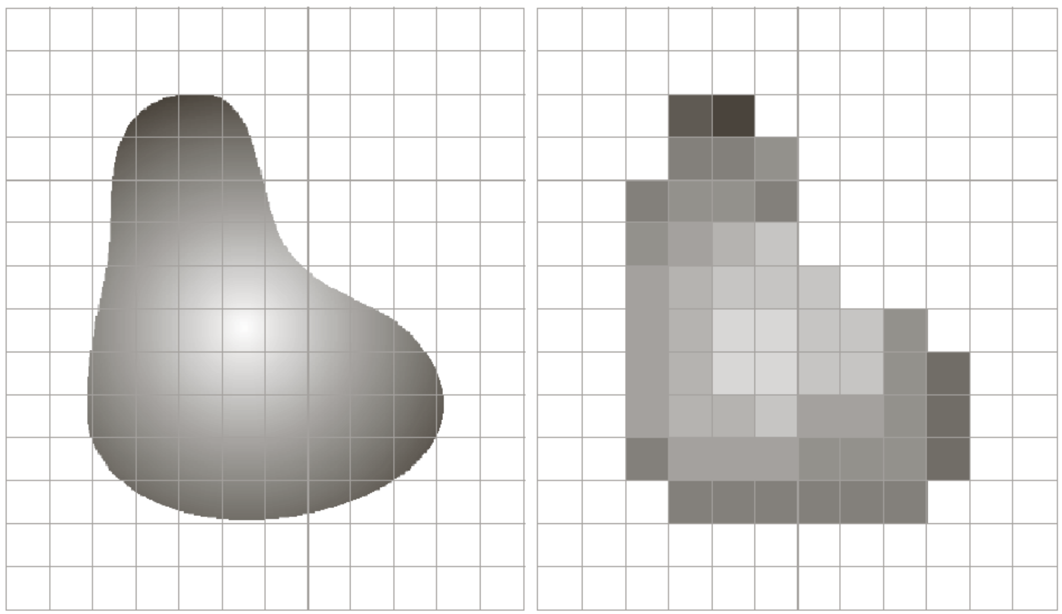


FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

Digital Image Capture by CCD Array

- Continuous Scene -> Digital image
  - Each CCD sensor averages the light intensity in a small region and output a discretized value



a b

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

Grayscale Image Specification

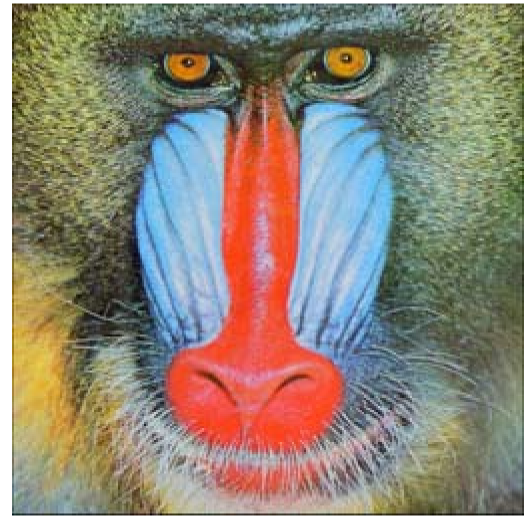
- Each pixel value represents the brightness of the pixel. With 8-bit image, the pixel value of each pixel is 0 ~ 255
- Matrix representation: An image of MxN pixels is represented by an MxN array, each element being an unsigned integer of 8 bits

$$M = \begin{bmatrix} 160 & 162 & \cdots & 166 & 154 \\ 162 & 158 & \cdots & 122 & 69 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 60 & 55 & \cdots & 79 & 94 \\ 58 & 55 & \cdots & 99 & 109 \end{bmatrix}$$

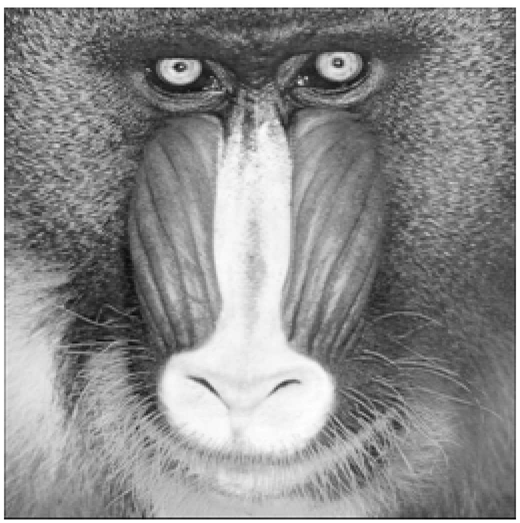
Color Image Specification

- Three components
  - M = {R, G, B}

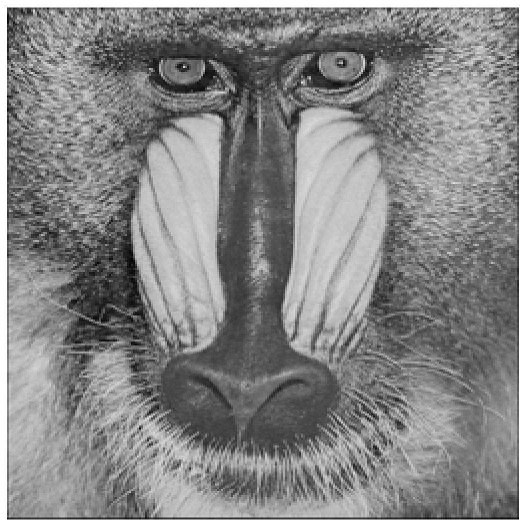
$$R=\begin{bmatrix}73 & \cdots & 87\\ \vdots & \ddots & \vdots\\ 27 & \cdots & 17\end{bmatrix},\ G=\begin{bmatrix}66 & \cdots & 98\\ \vdots & \ddots & \vdots\\ 36 & \cdots & 13\end{bmatrix},\ B=\begin{bmatrix}31 & \cdots & 61\\ \vdots & \ddots & \vdots\\ 36 & \cdots & 14\end{bmatrix}$$



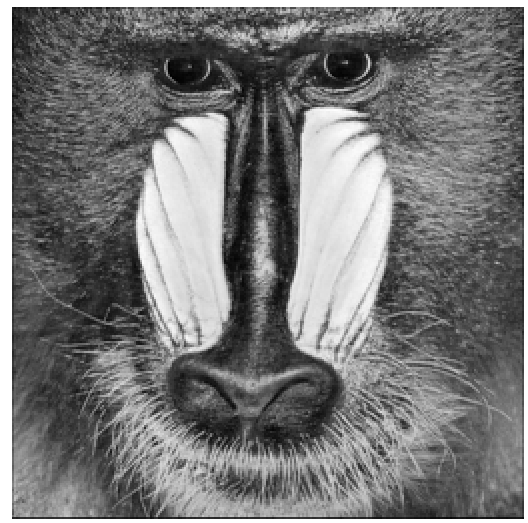
R



G



B



Red nose is brightest!

Blue Cheek is brightest

A Brief Matrix Tutorial

- A matrix is an NxM array of numbers
  - If M=N, A is a square matrix
  - If N = 1, A is a row vector
  - If M = 1, A is a column vector
  - If N=M=1, A is a scalar
  - a_{ij} is the element of A at row i and column j.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1M} \\ a_{21} & a_{22} & \cdots & a_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ a_{N1} & a_{N2} & \cdots & a_{NM} \end{bmatrix}$$

- Special Matrix
  - Identity (unit) matrix I

$$A = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \end{bmatrix}$$

  - Diagonal matrix

$$A = \begin{bmatrix} a_{11} & 0 & \cdots & 0 \\ 0 & a_{22} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & a_{NN} \end{bmatrix}$$

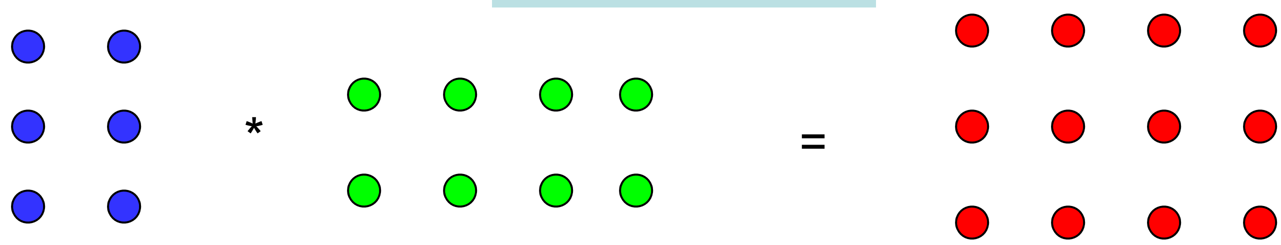
Matrix Operations

- Addition / Subtraction of matrices.
  – Matrices A and B are of the same order (NxM)

$$[C]=[A]+[B],\quad c_{ij}=a_{ij}+b_{ij};$$
$$[D]=[A]-[B],\quad d_{ij}=a_{ij}-b_{ij}.$$

- Multiplication of two matrices
  – A is an NxM matrix, B is an MxL matrix, note that the column number of A should be the same as the row number of B.
  – C=A*B, an NxL matrix

$$c_{ij}=\sum_{k=1}^{M}a_{ik}b_{kj}$$



Matrix Operations

- Multiplication of a matrix by a scalar

$$[C] = \lambda[A], \quad c_{ij} = \lambda a_{ij}$$

- Transpose of a matrix
  - Interchange of rows and columns

$$[C] = [A]^T, \quad c_{ij} = a_{ji}$$

- If A = A^T, A is symmetric
- Matrix inverse
  - A must be a square matrix
  - Some matrices are invertible (singular)

$$[C] = [A]^{-1}, \quad if \quad AC = I$$

- Trace of a square matrix

$$trace(A) = \sum_{i=1}^{N} a_{ii}$$

- Determinant of a square matrix

$$|A|, \quad \begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix} = a_{11} * a_{22} - a_{12} * a_{21}$$

A Brief Matlab Tutorial

- An interactive program from The MathWorks for high-performance numeric computation and visualization.
- Refer to Matlab Primer for general use
- Type "help plot" to see help information of function plot.
- Type "help image" to see functions in image processing toolkit

Matrix, Vector, and Scalar in Matlab

- A matrix is a 2 dimension array

```
>> a=[1 2 3; 4 5 6; 7 8 9]

a =

     1     2     3
     4     5     6
     7     8     9
```

- A vector is a 1XN or Nx1 matrix

```
>> a = [1 2 3]

a =

     1     2     3

>> b = [1;2;3]

b =

     1
     2
     3
```

- A scalar is a 1 x 1 matrix

```
>> a=1

a =

     1
```

Colon Operator in Matlab

- If two integer numbers are separated by a colon, Matlab will generate all of the integers between these two integers.
- If three numbers, integer or non-integer, are separated by two colons, the middle number is interpreted to be a ”step" and the first and third are interpreted to be "limits”
- The colon operator is useful in extracting smaller matrices from larger matrices.

```
>> a=[1:5]
a =
    1    2    3    4    5
```

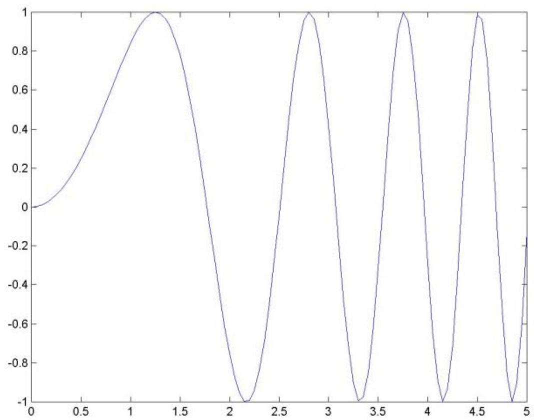
```
>> b=[0:2.0:9.6]
b =
    0    2    4    6    8
```

```
>> c=[1 2 3; 4 5 6; 7 8 9]
c =
    1    2    3
    4    5    6
    7    8    9
>> d=c(1:2,2:3)
d =
    2    3
    5    6
```

Plotting figures in Matlab

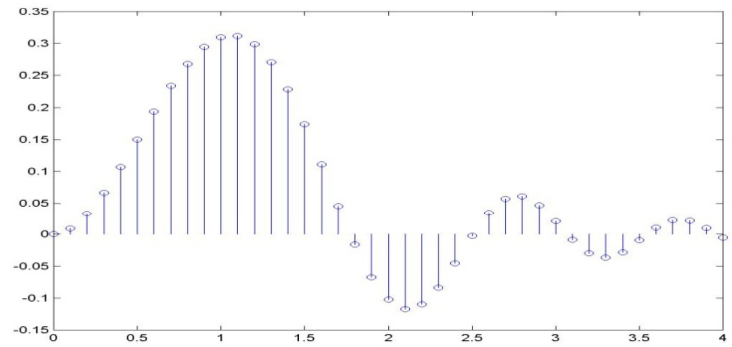
Line plot:

x=0:0.05:5;,y=sin(x.^2);,plot(x,y);



Stem plot:

x = 0:0.1:4;, y = sin(x.^2).*exp(-x);stem(x,y)



Surface plot:

z=peaks(25);, surf(z);,

colormap(jet);

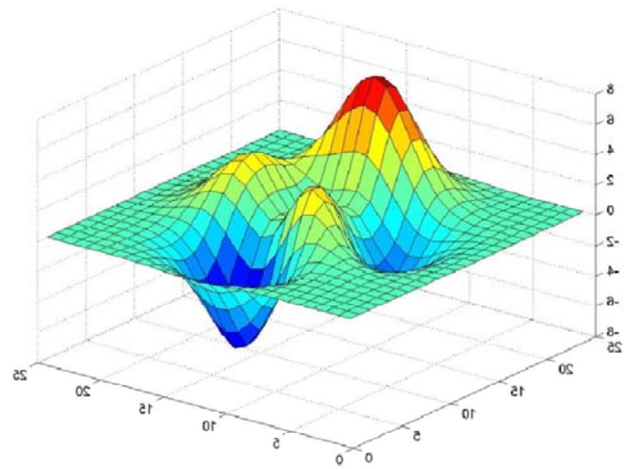
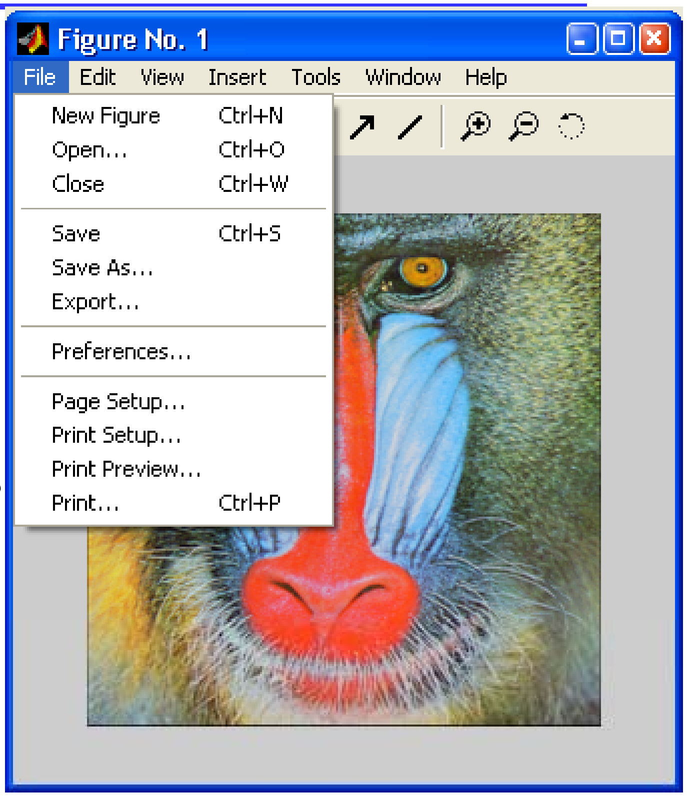


Image Toolbox in Matlab

```
>> x = imread('baboon.bmp');
>> whos
  Name      Size            Bytes  Class

  x         256x256x3      196608  uint8 array

Grand total is 196608 elements using 196608 bytes

>> imshow(x);
>> g = rgb2gray(x);
>> imshow(g);
>> g(1:2, 1:2)

ans =

    64    46
    77    75
```



Recommended Readings

- Gonzalez & Woods, “Digital Image Processing”, Chapter 1, Chapter 2 (Section 2.1 – 2.3)
- MATLAB tutorial
  - http://www.mathworks.com/help/pdf_doc/matlab/getstart.pdf.
- Matrix tutorial:
  - http://www.ece.utk.edu/~gonzalez/DIP_WEB_V3/downloads_V3/dip3e_downloads/dip3e_classroom_presentations/Review_of_matrices_and%20vectors.zip
  - http://www.imageprocessingplace.com/downloads_V3/root_downloads/review_material/review.zip
  - Introduction to Matrix Algebra. http://autarkaw.com/books/matrixalgebra/index.html
  - Free chapter texts are available at http://numericalmethods.eng.usf.edu/matrixalgebrabook/index.html

Homework (Due Next Lecture)

1. If you do not have a copy of MATLAB, get one installed by Poly IS helpdesk or use the PC Lab at Poly.
2. Get a picture of *yourself* taken in full colors. You could take the picture with a digital camera, and save it in the JPEG format. Alternatively, you could take the picture using the WebCam available at the Multimedia Lab (LC008).
3. Write a matlab program that can i) read your color image into a matrix (you can use imread() function in MATLAB); ii) covert it to a 8-bit grayscale image (you can use rgb2gray() in MATLAB), iii) generate a digital negative version of your image, and iv) display and print both the color image, the original gray scale and the negative image.
4. If you have not used Matlab before, go through Matlab getting started guide at http://www.mathworks.com/help/pdf_doc/matlab/getstart.pdf. Go through all exercises step by step. Make sure that you know basic operations and how to write m-files (scripts or functions).
5. If you have forgotten your matrix operations, go through first four chapters of Introduction to Matrix Algebra. Free chapter texts are available at http://autarkaw.com/books/matrixalgebra/index.html

Note: For this (and future) computer assignment, you should submit a lab report that includes a copy of your matlab programs, the pictures you created, as well as a description of your findings if applicable. All printed figures should have a caption that explains what they are. You should submit a printed copy of your report together with your other written homework.