COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

# Tools and Prerequisites for Image Processing

EE4830 Digital Image Processing
http://www.ee.columbia.edu/~xlx/ee4830/

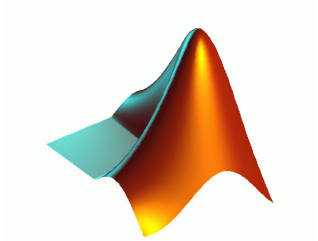
Lecture 1, Jan 26th, 2009
Part 2 by Lexing Xie

# Outline

- Review and intro in MATLAB
  - A light-weight review of linear algebra and probability
  - An introduction to image processing toolbox
- A few demo applications
- Image formats in a nutshell
- Pointers to image processing software and programming packages

# Matlab is …

: a numerical computing environment and programming language. Created by The MathWorks, MATLAB allows easy matrix manipulation, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs in other languages.



- Main Features:
  - basic data structure is matrix
  - optimized in speed and syntax for matrix computation
- Accessing Matlab on campus
  - Student Version
    - Matlab + Simulink $99
    - Image Processing Toolbox $59
    - Other relevant toolboxes $29~59 (signal processing, statistics, optimization, …)
  - CUNIX and EE lab (12th floor) has Matlab installed with CU site-license

# Why MATLAB?

- Shorter code, faster computation
- Focus on ideas, not implementation

$$f(x) = 2 \cdot \sin(x^3)/3 + 4.56, x \in \{1, 3, 5, \ldots, 9999\}$$

  - C:

```
#include <math.h>
double x, f[500];
for( x=1.; x < 1000; x=x+2)
        f[(x-1)/2]=2*sin(pow(x,3.))/3+4.56;
```

  - MATLAB:

```
f=2*sin((1:2:1000).^3)/3+4.56;
```

But: scripting language, interpreted, … …

# MATLAB basic constructs

- M-files:
  - functions
  - scripts
- Language constructs
  - Comment: %
  - if .. else… for… while… end
- Help:
  - help function_name, helpwin, helpdesk
  - lookfor, demo

# matrices

- … are rectangular "tables" of entries where the entries are numbers or abstract quantities …

- Some build-in matrix constructors
  - a = rand(2), b = ones(2), c=eye(2),
- Addition and scalar product
  - d = c*2;
- Dot product, dot-multiply and matrix multiplication
  - c(:)'*a(:), d.*a, d*a
- Matrix inverse, dot divide, etc.
  - inv(a), a./d

# matrixes as images, and vice versa

- Inner and outer product of vectors
  - x = 1 : 256;
  - y = ones(256,1);
  - a = x*y;
    b = y*x;

size(a) = ?  size(b) = ?

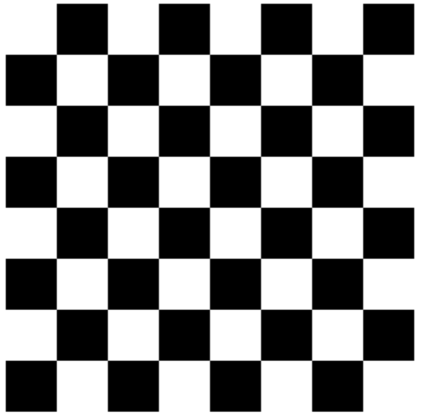
imagesc(b); colormap(gray(256))

- Creating a chessboard

  imagesc(checkerboard(32)>.5);

  or, from scratch:

  b = ones(1,8); b(2:2:end)=0
  b = [b; b(end:-1:1)]
  b = repmat(b, [4 1])
  chessb = kron(b,ones(32));



256x256 chess board

# eigen vectors and eigen values

- "eigenvectors" are exceptional vectors in the same direction as Ax
  Ax = λ x
  - λ are called *eigenvalues*

- Examples:
  - A = [.8 .3; .2 .7]
  - [v, d] = eig(A)
  - A*v(:, 1)
  - A*v(:, 2)

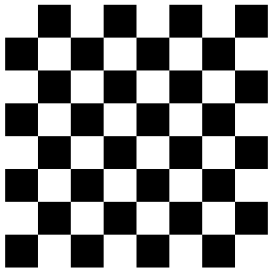
  - eigshow

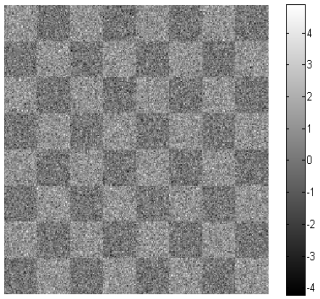
- properties of λ:
  - $\sum_{i=1}^{n} a_{ii} = \sum_{i=1}^{n} \lambda_i = \text{trace}(A)$
  - $\lambda_1 \cdot \lambda_2 \cdot \ldots \lambda_n = \det(A)$
- eigen-vectors and values are useful for:
  - Getting exponents of a matrix $A^{100000}$
  - Image compression
  - Object recognition
  - The search algorithm behind Google
  - …

# matlab tip and trick

- Matrix performance tip: pre-allocate, try to avoid incremental memory allocation

```
clear all; n = 5e4;
tic; for i=1:n, a(i)=0; end; toc
tic; b=zeros(1,n); toc
tic; c(n)=0; toc
```





- Chessboard + noise
  - x = chessb + randn(256);
- How to get the minimum and maximum value of x (in one line, with one function call) ?

[min(x(:)) max(x(:))]

the handy, esp. if x is more than three dimensions

prctile(x(:), [0 100])

the obscure, but exactly one function call.

# probability

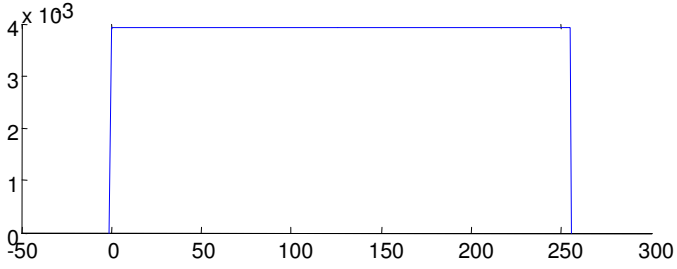
- *probability* refers to the *chance* that a particular event (or set of events) will occur.


Pr(head)=1/2,
Pr(tail)=1/2

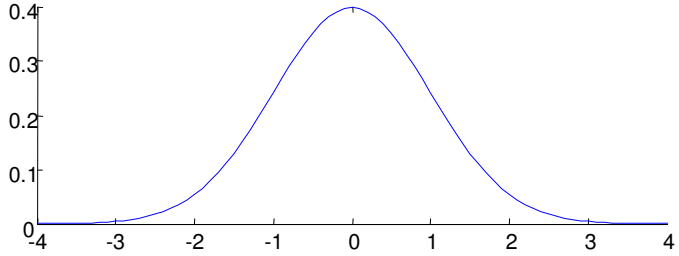
- *probability density function p(x)* is a non-negative intergrable function R→R such that for any interval [a, b]:

$\Pr(x \in [a,b]) = \int_a^b p(x)dx$

```
p  = pdf('uniform', -1:256, 0, 255);
plot(-1:256, p)
```

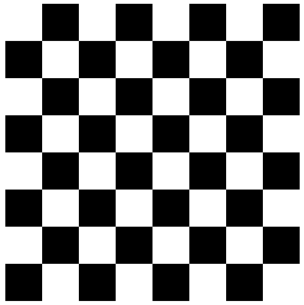



```
p  = pdf('normal', -4:.1:4, 0, 1);
plot(-4:.1:4, p)
```

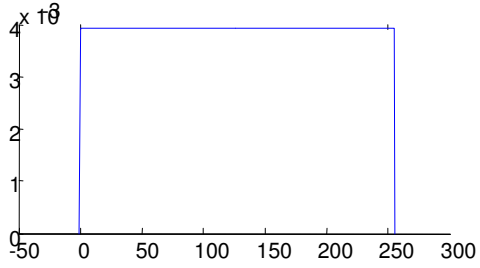


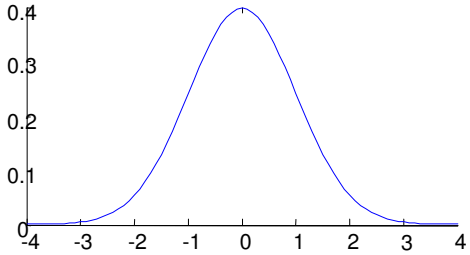
# probability

- Suppose you're blind-folded and points to a point in a cardboard with the following prints, after a friend rotates and shifts it randomly (i.e. randomly draw a pixel from the following images)



p(■)=1/2  p(□)=1/2




p(■)=p(■)=… = p(□) = 1/256

# mean and std

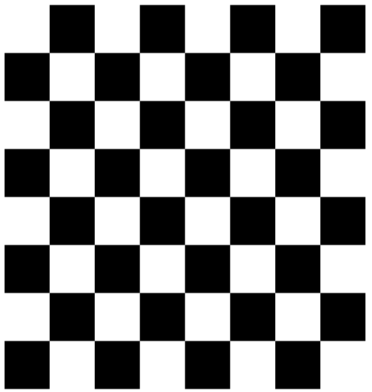
- Mean
  - $m_x = E[x] = \int x\, p(x)\, dx$
- Standard-deviation
  - $\sigma_x^2 = E[(x-m_x)^2] = \int (x-m_x)^2\, p(x)\, dx$

(a) and (b) are afore-mentioned gray-scale images with values between [0,1]. Which one of the following holds, if any?

$m_a < m_b$ X  $m_a = m_b$

$\sigma_a < \sigma_b$ X  $\sigma_a > \sigma_b$

(a)



(b)

# Image Processing Toolbox

- File I/O and display
  - imread(), imwrite()
  - imshow(), image(), imagesc(), movie()

? how different are these two images?

cu_home_low.bmp (382 KB)

cu_home_low_j40.jpg (29KB)

```
im1 = imread('cu_home_low_treebranch.bmp');
im2 = imread('cu_home_low_treebranch_j40.jpg');

sqrt( sum( (im1(:)-im2(:)).^2 ) / prod(size(im1)) )

imshow(im1- im2)
```

# Image Processing Toolbox (contd)

- Linear operations
  - fft2(), dct2(), conv2(), filter2()
- Non-linear operations
  - median(), dilate(), erode(), histeq()
- Statistics and analysis
  - imhist(), ,mean2(), corr2(), std2()
- Colormap and type conversions
  - colormap(), brighten(), rgbplot()
  - rgb2ycbcr(), hsv2rgb(), im2uint8()…

# Outline

- Review and intro in MATLAB
  - A light-weight review of linear algebra and probability
  - An introduction to image processing toolbox
- introduction and pointers to other image processing software and programming packages

# Demo of image processing software

- Enhancement
  "equalize" (lecture 4)

before

after

- Compression (lecture 12)
- Color manipulation (lecture 3)
  with GIMP www.gimp.org

- "unshake" http://www.hamangia.freeserve.co.uk/ (lecture 7)

before

after

# Image Processing Software

- Bitmap editing: Adobe Photoshop, Macromedia Fireworks
- Vector graphics editing: Adobe Illustrator, Corel Draw
- Consumer photo tools: Picassa, ACDSee, Windows Paint, XV, Photoshop Elements
  …
- GIMP

Send me <xlx@ee.columbia.edu> your suggestions of image editing/processing tools

# Video processing software

- Player
  - Windows media player, Real, Quicktime, iTunes, intervideo WinDVD, …
- Format conversion
  - ffmpeg
- Editing
  - Adobe premier, muvee,

Resource sites .. http://doom9.net/

# Image Processing API and Toolboxes

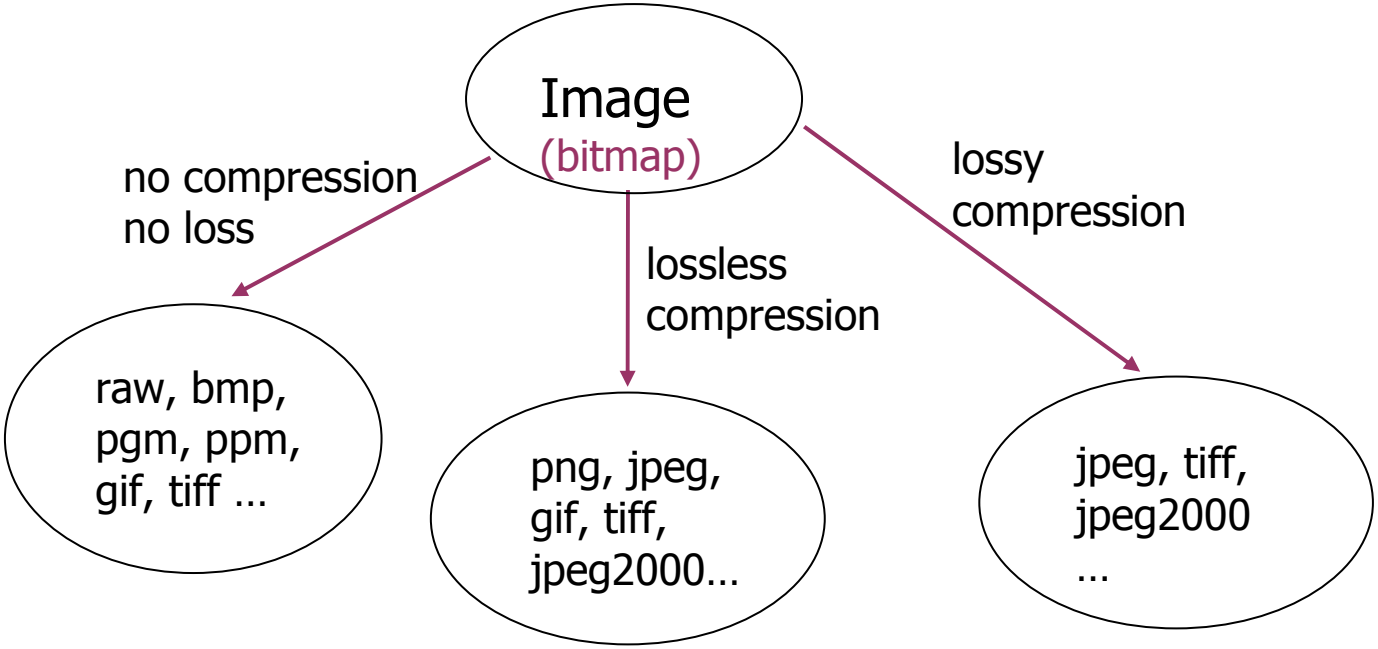
- Python
  - Imaging Library (PIL) http://www.pythonware.com/products/pil/
  - numpy, scipy, matplotlib, …
  - Pre-packaged python environments: SAGE, python(x,y)
- In C/C++
  - IPL … http://www.cs.nott.ac.uk/~jzg/nottsvision/old/index.html
  - OpenCV http://sourceforge.net/projects/opencvlibrary http://tech.groups.yahoo.com/group/OpenCV/
  - ImageMagick http://www.imagemagick.org/
  - Insight Toolkit ITK (medical image) http://www.itk.org/
  - List of tools at mathtools.net http://www.mathtools.net/C_C__/Image_Processing/
- In Java
  - Java Media APIs: JAI, JMF, Java image I/O … http://java.sun.com/javase/technologies/desktop/media/
  - http://www.mathtools.net/Java/Image_Processing/index.html
- Other …

# File Formats

- Why different file formats?
  - Convenient to use
  - Compact representation
- How many formats do we have?
  - e.g. 30+ in a consumer image software (ACDSee)
- Basic structure: Header + Data

# Image Format Classification

- Image/Graphics file formats
  - Bitmap/raster graphics: stores pixels at fixed resolution
  - Vector graphics: defines shapes in mathematical expressions and are scalable in resolution, commonly used for illustrations, line art, logos, CAD drawings, etc.
  - Metafile: can contain both raster and vector. e.g. WMF, EMF
  - Page description language: Postscript, PDF, PCL, …



# (raster) image data types

- Basic unit in disk: byte (8 bits)
- Images are stored as unsigned integers (0-255)

- Depends on the color space and the precision / bit depth
  - 1bit, 4bit, 8bit, 24bit, 32bit (+alpha channel), indexed colors (gif, 2-8 bits)

- In MATLAB:
  - uint8→double→uint8
- Image types that MATLAB supports:
  - BMP, JPEG, PNG, GIF, TIFF, XWD, HDF, PCX, …

# EXIF metadata for JPEG

flickr

Signed in as xlx Help Sign Out

Home You Organize Contacts Groups Explore Search

## More detail about "hello world\n"


Taken on
October 10, 2008 at 8.55pm EDT

Posted to Flickr
October 18, 2008 at 3.53pm EDT

Edit the photo dates

**What is EXIF data?**

Almost all new digital cameras save JPEG (jpg) files with EXIF (Exchangeable Image File) data. Camera settings and scene information are recorded by the camera into the image file. Examples of stored information are shutter speed, date and time, focal length, exposure compensation, metering pattern and if a flash was used.

Source: Digicamhelp.

**Your privacy**

If you like, you can prevent the link to your EXIF data from displaying on the photo page. Set this in your privacy options.

| | |
|---|---|
| **Camera:** | **Nikon D70** |
| **Exposure:** | **0.01 sec (1/100)** |
| **Aperture:** | **f/4.5** |
| **Focal Length:** | **70 mm** |
| **Exposure Bias:** | 0/6 EV |
| **ISO Speed:** | 200 |

| | |
|---|---|
| **Software:** | Ver.2.00 |
| **Date and Time:** | 2008:10:10 20:55:04 |
| **YCbCr Positioning:** | Co-Sited |
| **Exposure Program:** | Aperture priority |
| **Date and Time (Original):** | 2008:10:10 20:55:04 |
| **Date and Time (Digitized):** | 2008:10:10 20:55:04 |
| **Compressed Bits per Pixel:** | 4 bits |
| **Maximum Lens Aperture:** | 43/10 |
| **Metering Mode:** | Pattern |
| **Sub-Second Time:** | 90 |
| **Sub-Second Time (Original):** | 90 |
| **Sub-Second Time (Digitized):** | 90 |
| **Color Space:** | sRGB |
| **Sensing Method:** | One-chip colour area sensor |
| **CFA Pattern:** | BLUE GREEN GREEN RED |
| **Digital Zoom Ratio:** | 1/1 |
| **Focal Length In 35mm Film:** | 105 |
| **Contrast:** | Hard |
| **Quality:** | FINE |

# Format Comparison

Two 256x256 color images

| Format | RAW | BMP | GIF | PNG | JPG |
|---|---|---|---|---|---|
| Lossy? | N | N | N | N | Y |
| Compressed? | N | N | Y | Y | Y |
|  | 192K | 193K | 52.2K | 106K | 16K |
|  | 192K | 193K | 5K (4bit) | 23K | 20K |
| Fine prints | Raw data | Header ~1K | Look-up table + data | | Quality factor 80 |

Why do the two images have different sizes as GIF/PNG/JPG files ?

# Comparison of graphics file formats

| Format | Compression algorithm | Raster / Vector | Color depth | Indexed color | Transparency | Metadata | Interlacing* | Multi-page | Animation | Layers | Color manage-ment | Extendable |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AGP | RLE | Raster | 32 | No | Yes | No | No | No | No | Yes | No | No |
| AI | Lossy & Lossless | Vector & Raster | 1, 8, 24, 32 (multiple palettes ?) | Yes | Yes | Yes | No | No | No | Yes | Yes | ? |
| Windows bitmap | None, RLE, JPEG, PNG | Raster | 1, 4, 8, 16, 24, 32 | Yes | Yes | Yes | No | No | No | No | No | No |
| CDR | Lossy & Lossless | Vector & Raster | 1, 8, 24, 32 (multiple palettes) | Yes | Yes | Yes | No | Yes | No | Yes | Yes | ? |
| CPC | CPC | Raster | 1 | No | No | Yes | No | Yes | No | No | No | Yes, via embedded dictionary |
| EXR | None, RLE, ZIP, Piz, PXR24, B44 | Raster | 16 - 128 (floating-point) | No | Yes | Yes | No | No | No | No | Yes | Yes |
| GIF | LZW | Raster | 1, 2, 3, 4, 5, 6, 7, 8 | Yes | Yes, index | Yes | Yes | Yes | Yes | Yes | No | Yes (GIF89a) |
| HD Photo | Lossy & Lossless bi-orthogonal transform | Raster | 1, 2, 8, 16, 24, 32, 48, 64, 128 (floating-point) | No | Yes | Yes | Yes | Yes | No | No | Yes | Yes |
| ILBM | Optional run-length encoding | Raster | 1, 2, 4, 8, 16, 32, 64, 64EHB, 128, 256 (8-bit), 4096 (HAM6 pseudo 12-bit), 4096 pure 12-bit, 262,144 (HAM8 pseudo 18-bit), 24-bit | Yes | No | Yes | Yes | No | Yes, Palette-shifting | No | No | Yes |
| IMA | Lossy and lossless original mutiresolution analysis transformation | Raster | 8-bit, 16-bit integer, 32-bit floating-point | No | Yes | Yes | No | No | No | No | Yes | Yes |
| JPEG | Lossy & Lossless, DCT, RLE, Huffman predictive nearest neighbor | Raster | 8-bit (greyscale), 12-bit, 24-bit | No | No | Yes | Yes | No | No | No | Yes | No |
| JPEG 2000 | Lossy & Lossless (DWT) | Raster | 8, 16 (greyscale) Up to 48-bit color? | No | Yes | Yes | Yes | No | No | No | Yes | ? |
| PCX | None, RLE | Raster | 1, 2, 4, 8, 24 | Yes | No | No | No | No | No | No | No | No |
| PGF | Lossy & Lossless (DWT) | Raster | greyscale: 1, 8, 16, 31; color: 12, 16, 24, 32, 48 | Yes | Yes | Yes | Yes | No | No | No | No | ? |
| PICT | None, RLE, QuickTime | Raster & Vector | 1, 2, 4, 8, 16, 24, 32 | Yes | Yes | Yes | ? | No | No | No | ? | No? |
| Pixel | GZIP | Raster | 1, 4, 8, 16, 24, 32 | ? | Yes | Yes | ? | Yes | Yes | Yes | Yes | Yes |
| PLD | Optional ZIP, JPEG | Vector & Raster | 1, 4, 8, 16, 24, 32, 48, 64 | ? | Yes | Yes | ? | Yes | Yes | Yes | Yes | Yes |
| PNG | Lossless, DEFLATE | Raster | 1, 2, 4, 8, 16, 24, 32, 48, 64 | Yes (1-8 bit modes) | Yes; Alpha channel 8b, 16b; 8b for indexed per-entry | Yes | Yes, Adam7 algorithm | No | No (but see MNG and APNG) | No | Yes | Yes, via chunks |
| PPM | None | Raster | Up to 16 | No | No | Yes | No | Yes | No | No | No | No |
| PSD | None, RLE | Raster & Vector | 1, 2, 4, 8, 16, 24, 32, 48, 64 | Yes | Yes | Yes | N/A | No | Yes | Yes | Yes | No? |
| PSP | None | Raster & Vector | 1, 2, 8, 16, 24, 32, 48 | Yes | Yes | Yes | No | ? | No | Yes | ? | ? |
| SVG | None, lossless gzip | Vector | 24, 32 | No | Yes | Yes | N/A | Yes (1.2)[1] | No[2] | Yes | Yes[3] | Yes, XML based |
| TGA | None, RLE, and other | Raster | 1, 2, 4, 8, 16, 24, 32 | Yes | Yes | Yes | No | No | No | No | No | ? |
| TIFF | None, LZW, RLE, ZIP, and other | Raster & Vector | 1, 2, 4, 8, 16, 24, 32 | Yes (1-8 bit modes) | Yes | Yes | Yes, for JPEG compression | Yes | No | Yes | Yes | Yes, via tags |
| XAML | None | Vector | 32, 64 | No | Yes | Yes | N/A | Yes | Yes | Yes | No | Yes |
| XCF | None, lossless (gzip, bzip2) | Raster & Vector | 8, 24, 32 | Yes | Yes | ? | N/A | No | Yes | Yes | Yes | Yes |
| Format | Compression algorithm | Raster / Vector | Color depth | Indexed color | Transparency | Metadata | Interlacing* | Multi-page | Animation | Layers | Color management | Extendable |

http://en.wikipedia.org/wiki/Comparison_of_graphics_file_formats

# Resources and pointers

- Google, Wikipedia, Mathworld …


- Getting Help in Matlab
  - Matlab help, Image Processing Demos
  - DIP matlab tutorial online
  - Usenet groups

# Summary

- Review of matrixes and probability
- MATLAB for image processing

- Data type and file formats
- Resources and pointers

< the end; Q & A >

# Working With Matrices in MATLAB

- Everything is treated as a matrix
- Elementary matrix manipulation
  - zeros(), ones(), size(), eig(), inv()
- Operators and special characters
  - a(: ,1:2:256)=b'.*c
- String
  - imstr=['this is lena'];
    imglena=imread([imstr(9:end),'.png']);
  - ischar(), num2str(), …

- Review of linear algebra
  - Point operation and matrix operations
  - Eigen vectors, .. eigen values
  - Images as matrices, and matrices as images …
  - Question: max/min, subsampling,
- Review of probability
  - Coin-tossing, pdf, cdf, gaussian pdf
  - Expectations, std, variance
  - Question: pdf shape, expectation/expected value,
- Matlab
  - Getting started
  - Image I/O and display
  - Matrix manipulation
  - Image processing demos
- The daily practice of image manipulation
  - Image processing tools in C, Java, … and everything else
  - Data types and file formats
  - Resources, pointers and getting help