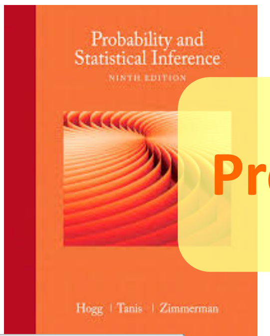
Digital Image Processing

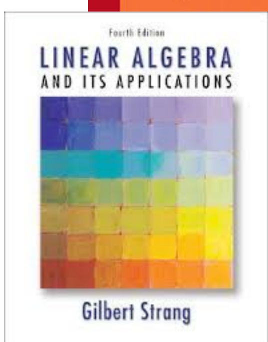
Ming-Sui (Amy) Lee

Lecture 01

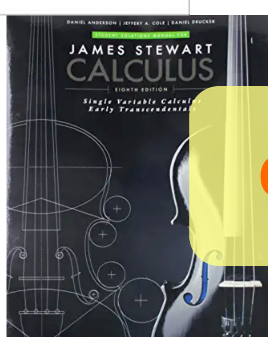
Prerequisites



Probability



Linear Algebra



Calculus

Digital Image Processing → ?

Related Courses

- 醫學影像處理: 張瑞峰教授
  Medical Image Processing
- 多媒體資訊分析與檢索:徐宏民教授
  Multimedia Analysis and Indexing
- 資訊理論與編碼技巧:吳家麟教授、李明穗教授
  Information Theory and Coding Techniques
- 數位訊號處理導論:吳家麟教授、陳祝嵩教授、李明穗教授
  Introduction to Digital Signal Processing
- 電腦視覺:傅楸善教授
  Computer Vision

Related Courses

- 圖形分析辨認:洪一平教授
  Pattern Analysis and Classification
- 數位影像生成 & 數位視覺效果:莊永裕教授
  Digital Image Synthesis & Digital Visual Effects
- 電腦圖學:歐陽明教授
  Computer Graphics
- 多媒體安全:吳家麟教授
  Multimedia Security
- 視訊通訊:李明穗教授
  Video Communications

Important Journals

- IEEE Trans. Pattern Analysis and Machine Intelligence (IEEE-T-PAMI)
- IEEE Trans. Image Processing
- IEEE Trans. Circuits and Systems for Video Technology
- Journal of Visual Communication & Image Representation
- Journal of Electronic Imaging
- Pattern Recognition Letter
- Computer Vision and Image Understanding
- 影像與識別 Image Processing and Pattern Recognition (中華民國影像處理與圖形識別會刊, IPPR)

Important Conferences

- IEEE International Conference on Multimedia & Expo (ICME)
- IEEE International Conference on Image Processing (ICIP)
- IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)
- IEEE International Symposium on Circuit and System (ISCAS)
- IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR)
- International Conference on Computer Vision (ICCV)
- Asian Conference on Computer Vision (ACCV)
- European Conference on Computer Vision (ECCV)

Important Conferences

- SPIE conference on Visual Communication and Image Processing (VCIP)
- IPPR Conference on Computer Vision, Graphics and Image Processing (CVGIP @ Taiwan)
- International Computer Symposium (ICS or NCS @ Taiwan)

What is this course about?

- **Digital Image Processing**
  → process digital images

images →	Low level	reduce noise, contrast enhancement, image sharpening…	→ images
images →	Middle level	segmentation, description…	→ corners, contours, edges… regions
images →	High level	recognize the objects	→ recognized objects

Announcement

- **Instructor:**
  - Dr. Ming-Sui (Amy) Lee
  - Department of Computer Science and Information Engineering
  - CSIE Building, Room #520
  - National Taiwan University
  - E-mail: mslee@csie.ntu.edu.tw
  - Phone: (02) 3366-4888 Ext 520

Announcement

- **Class Information**
  - **Class website**
    - NTU COOL https://cool.ntu.edu.tw/courses/5350
    - Syllabus
    - Lecture #1
    - Student Information Form (Mail to TA by Mar. 3)
  - **Teaching Assistant**
    - 黃偉綸 &朱世耘 @532
      Office Hours: 14:00 ~ 16:00, Tuesday
      10:00 ~ 12:00, Friday
    - Email: dip.mslee@gmail.com

Announcement

- **Textbook:**
  - William K. Pratt: Digital Image Processing, 3rd Edition, John Wiley & Sons Inc., 2001.
- **Reference Books:**
  - 1. D. E. Dudgeon and R. M. Mersereau: Multidimensional Digital Signal Processing, Prentice Hall, 1984.
  - 2. Anil K. Jain: Fundamentals of Digital Image Processing, Prentice Hall, 1989.
  - 3. J. S. Lim: Two-Dimensional Signal and Image Processing, Prentice Hall, 1990.
  - 4. Rafael C. Gonzalez and Richard E. Woods: Digital Image Processing, Prentice Hall, 2010.
  - 5. Ronald N. Bracewell: Two-Dimensional Imaging, Prentice Hall, 1995.
  - 6. Kenneth R. Castleman: Digital Image Processing, Prentice Hall, 1996.

Announcement

- **Homework Related**
  - There will be 5~6 assignments
  - All assignments require computer programming
  - Due at 11:59 am (noon) on the due date
  - **Note**
    - may discuss but no duplicating
    - TA's NOT responsible for debugging
    - No late homework will be accepted
- **Grading Policy**
  - 1. Homework: 40%
  - 2. Midterm Exam: 30%
  - 3. Term Project: 30%

Announcement

- **Tentative Schedule:**
  - Introduction and Digital Image Fundamentals
  - Image Enhancement in Spatial Domain
  - Edge Detection
  - Geometrical Modification
  - Morphological Processing
  - Digital Halftoning and Inverse Halftoning
  - Texture Analysis
  - Document Processing
  - Image Sampling and Transforms
  - Image Enhancement in Frequency Domain
  - Color Image Processing
  - Image Compression

Announcement

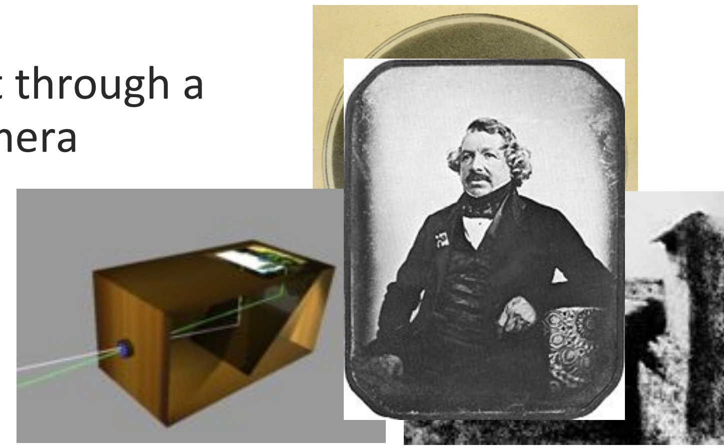
- Tentative schedule

02/25	Lecture 1	04/29	Lecture 8
03/04	Lecture 2	05/06	Proposal
03/11	Lecture 3	05/13	Lecture 9
03/18	Lecture 4	05/20	Lecture 10
03/25	Lecture 5	05/27	Lecture 11
04/01	溫書假	06/03	Lecture 12
04/08	Lecture 6	06/10	Demo
04/15	Lecture 7	06/17	Demo
04/22	Midterm	06/24	Final Package Due

Introduction

Invention of Photography

- **1826** -- first world negative on the idea
  "making permanent photographs on a support through a compound, the images seen at the back of camera obscura."
  - Joseph Nicephore Niepce (France)
  "heliography"(照相製版法) – sun writing
- **1839** -- "Daguerreotypes " (銀版照相法)
  - French painter, Louis J. M. Daguerre
- **1839** "Photography", "Negative", "Snapshot"
  - England astronomer Sir Johe Herschel
- **1880** "paper-backed film "
  - instead of "glutted dry plate"
  - USA George Eastman
- **1884** -- "Kodak Camera"
  - Eastman Kodak
- **1889** -- "Pocket Kodak Camera"
  - Eastman



Camera Obscura

The first Kodak handheld camera

Pocket Kodak Camera

Film Camera

Once Time Use Camera

Polaroid Camera

Portable Camera

Professional SLR
(single lens reflex)

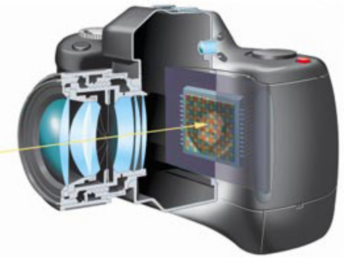
Medium Format Camera


Leica
Universal-Kleinkamera
mit automatischer Scharfstellung
LEITZ, WETZLAR

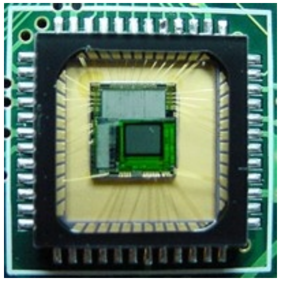

Drei-Farben-Kamera, 1930
Naturfarbenkamera, Bermpohl & CO., Berlin
Plasmat-Objektiv, Meyer, Görlitz
Strahlenteilerkamera für drei simultan aufzunehmende Farbauszüge über halbdurchlässige Spiegel
KROMOGRAM

Digital Still Camera (DSC)

- **Main difference**
  - no film needed
  - has a sensor that converts light into electrical charges



- **Image sensor**
  - most DSC: charge coupled device (CCD)
  - some low-end camera: complementary metal oxide semiconductor (CMOS) technology

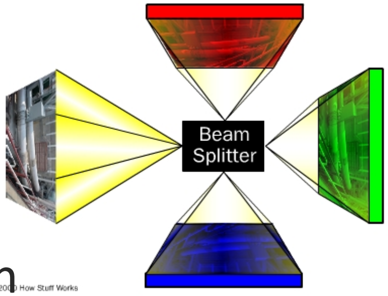


CMOS

- **Resolution**
  - measured in pixels
  - 256x256 pixels: cheap cameras
  - 640x480 pixels: low-end cameras. Great for e-mail exchange
  - 1216x912 pixels: (1.1 megapixel) good for print images
  - 1600x1200 pixels: (2 million pixels) good for 8x10 inches image

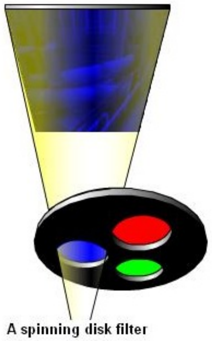
Digital Still Camera (DSC)

- Several ways of recording RGB color
  - Beam Splitter
    - separates the light into different sensors
    - each sensor responds to one of the primary colors
    - Advantage: records each of the three colors at each pixel location



Beam Splitter

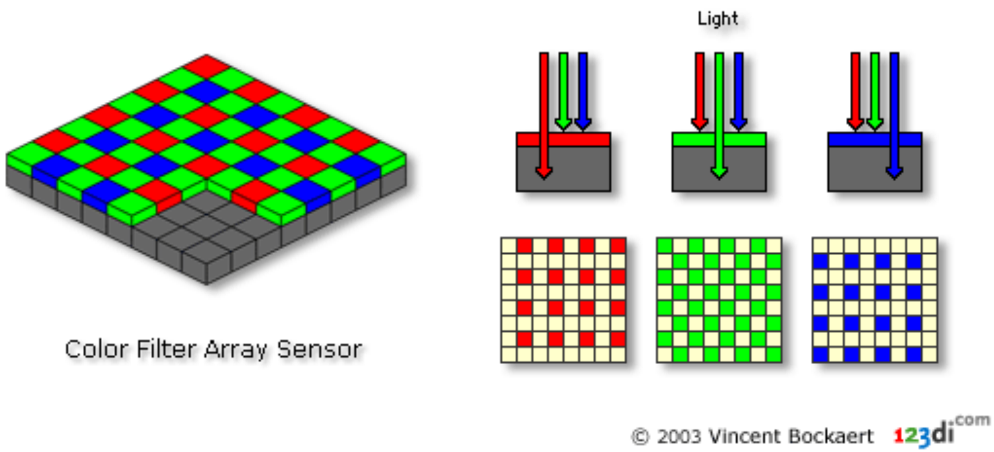
  - Spinning Disk
    - rotating a series of red, blue and green filters in front of a single sensor
    - camera and the target of the photo remain stationary for all three readings
    - not practical for candid photography or handheld cameras



Spinning Disk

Digital Still Camera (DSC)

- **Several ways of recording RGB color**
  - **Bayer Filter**
    - alternates a row of R and G filter with a row of B and G filters
    - not evenly divided
    - Advantage: only one sensor is required and all the color information is recorded at the same moment. Smaller, cheaper in camera design

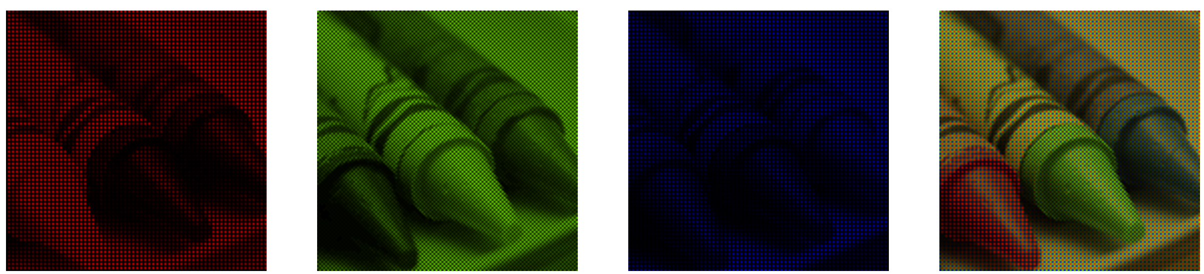


- **Balance between low computational complexity and high quality of resultant image/video**

Digital Still Camera (DSC)

- **Several ways of recording RGB color**
  - **De-mosaicking Algorithms**
    - convert the mosaic of separate colors into an equally sized mosaic of true colors
    - each colored pixel can be used more than once
    - true color can be determined by averaging the values from the closest surrounding pixels

Before



Digital Image Processing

Storage and Image Capacity

- **A number of storage systems (reusable digital film)**
  - Build-in memory
  - Smart Media cards
  - Compact Flash
  - Floppy Disk and Hard Disk
  - Writeable CD and DVD

- **Two main file formats**
  - TIFF: uncompressed format
  - JPEG: compressed format and also providing quality setting

Image Size	TIFF (uncompressed)	JPEG (high quality)	JPEG (medium quality)
640x480	1.0 MB	300 KB	90 KB
800x600	1.5 MB	500 KB	130 KB
1024x768	2.5 MB	800 KB	200 KB
1600x1200	6.0 MB	1.7 MB	420 KB

Applications of DIP

- Industry
  - Digital camera, camcoder, scanner,…
  - LCD TV, Plasma TV, …
  - Vision-based vehicle detection
  - OCR, alignment, positioning
- Medical Imaging & Image Analysis
  - CT, MRI, X-ray, Ultrasound
  - Bioinformatics for drug design
- Others
  - Satellite imaging, resource analysis, national defense

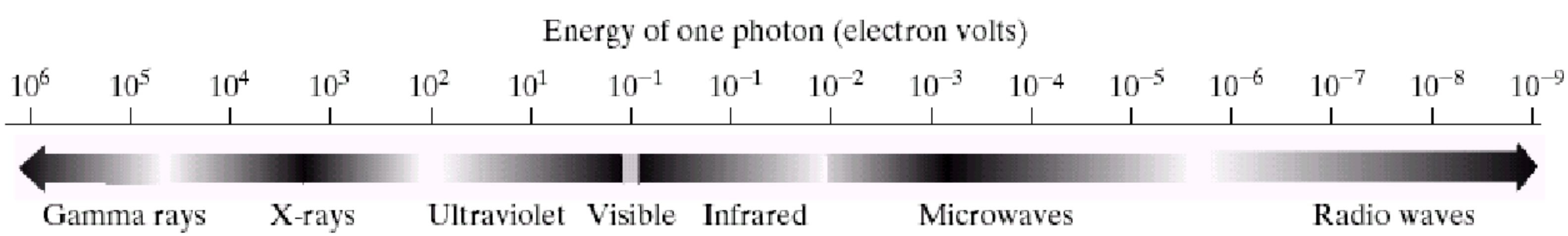
Categorize Images via Source

- **Image sources may come from:**

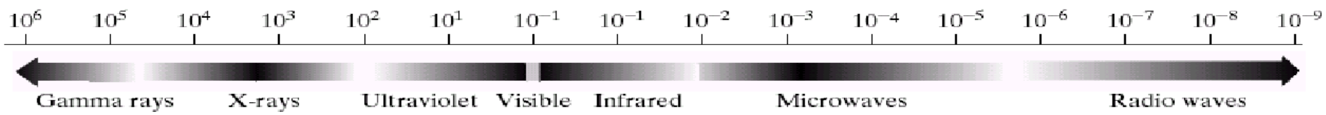
  electromagnetic (EM) bands (see below), acoustics, ultrasound, electron, range measurement or simply computer-generated

- **Others**
  - **Electron Microscopy, Synthetic Imaging**

- **Electromagnetic (EM) Spectrum**

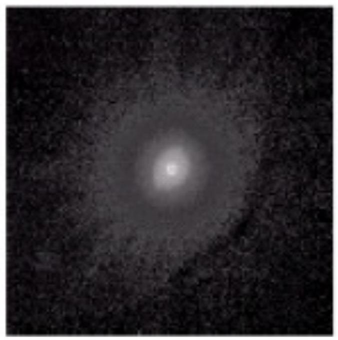


Examples

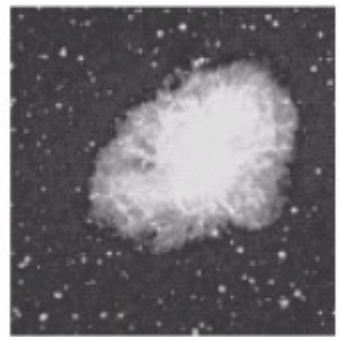


蟹狀星雲(Crab Nebula)

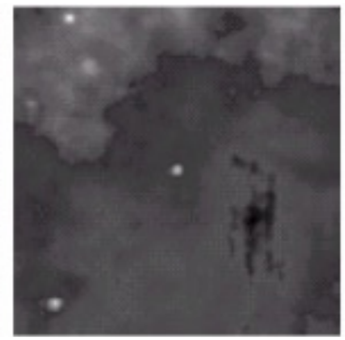
Gamma



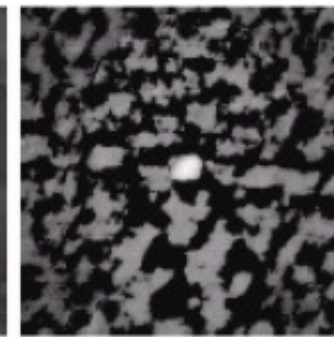
X-ray



Optical

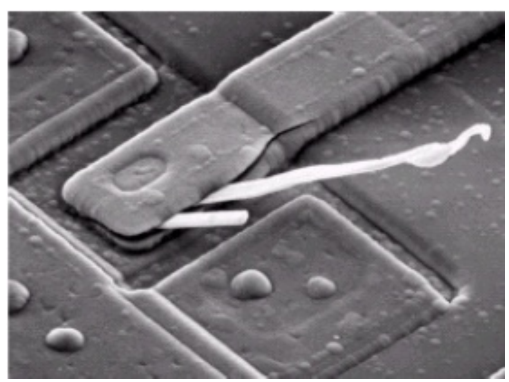


Infrared



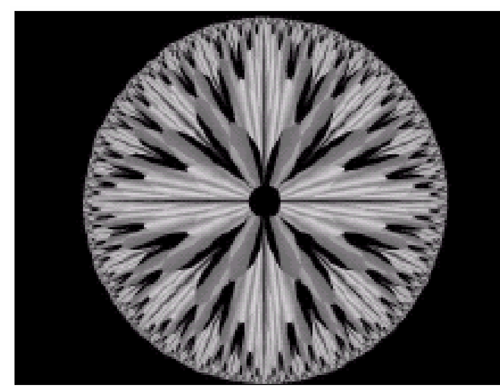
Radio

Ultrasound



SEM

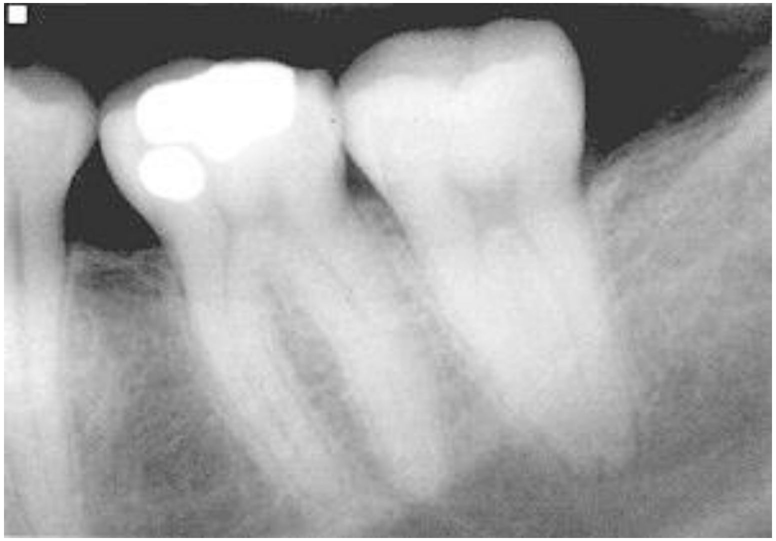
Scanning Electron Microscope



synthetic

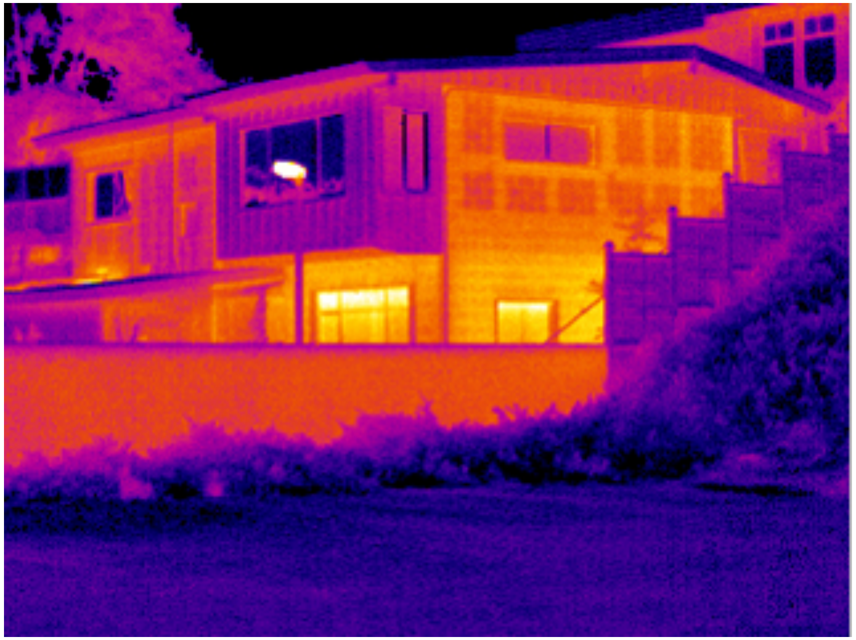
Examples

- **X-Ray Imaging**



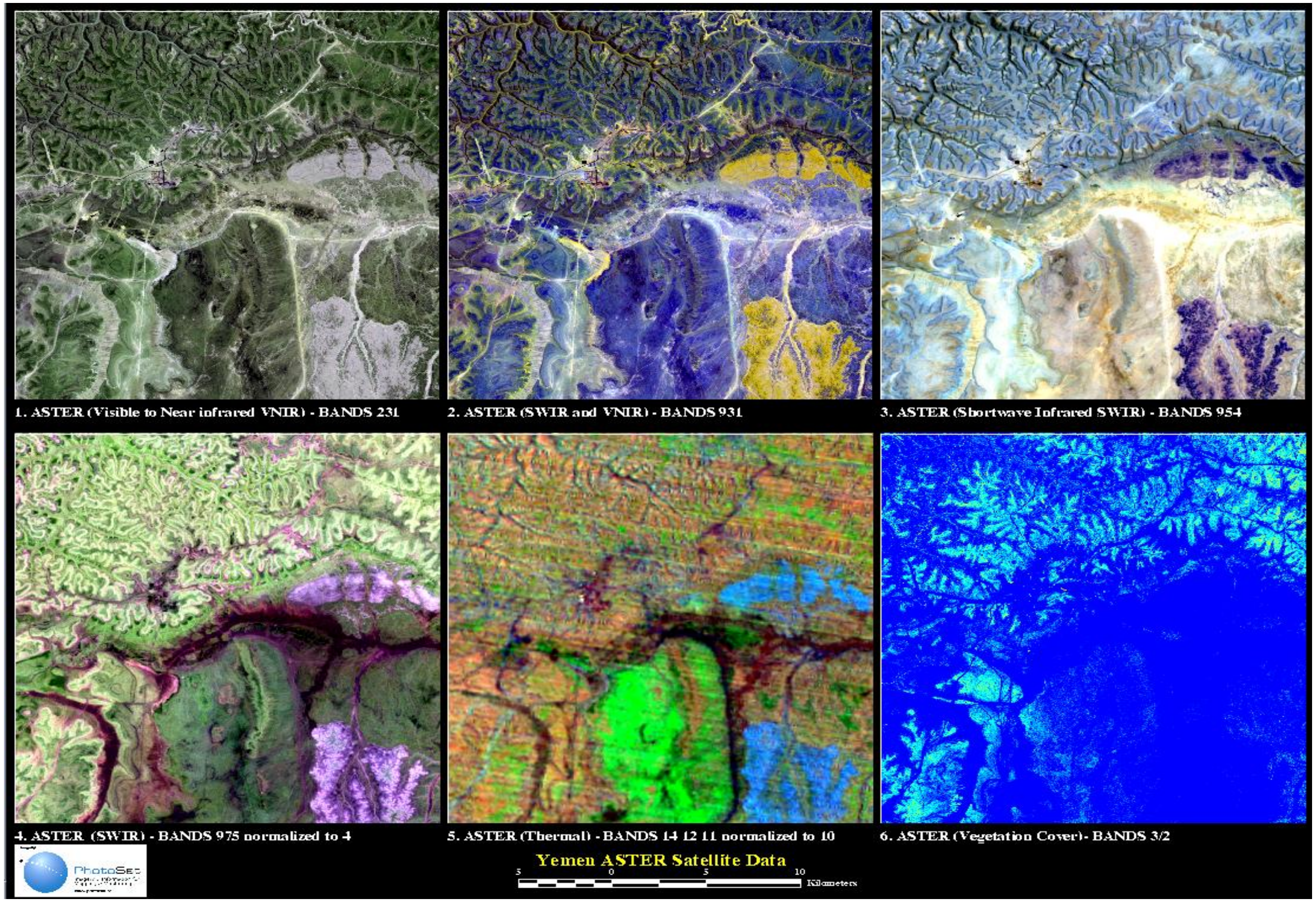
Examples

- **Infrared and Thermal Imaging**



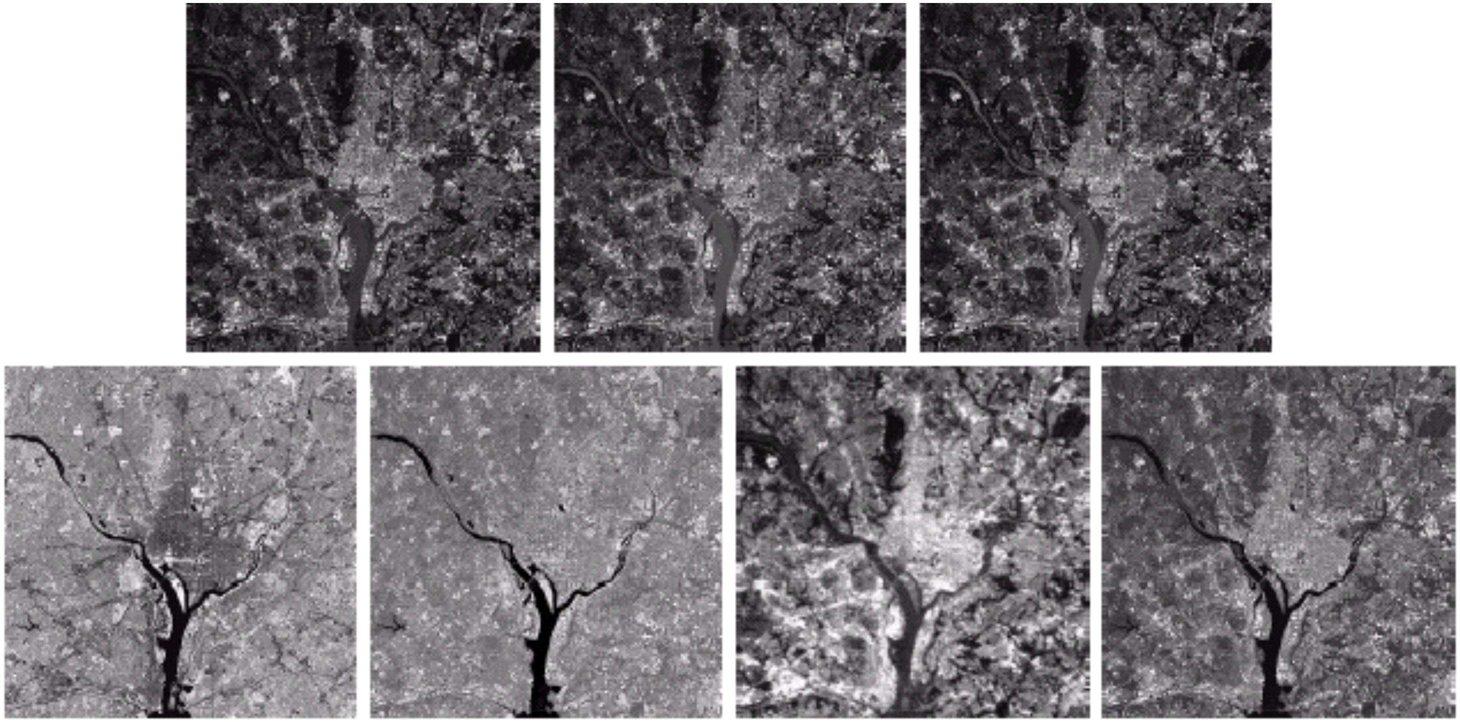
Examples

- **Multispectral Imaging**



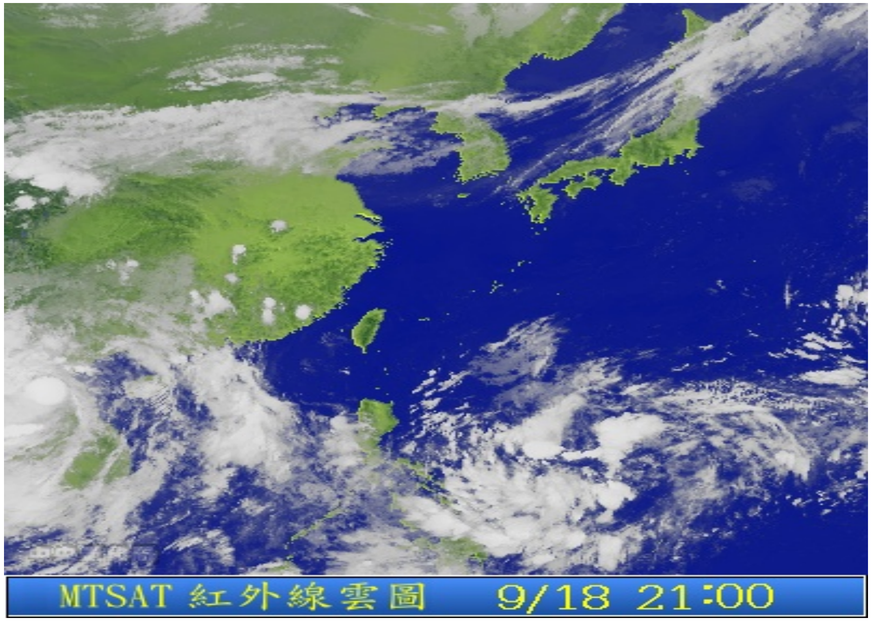
Examples

- **Multispectral Imaging**
  - Satellite images of the D.C. area



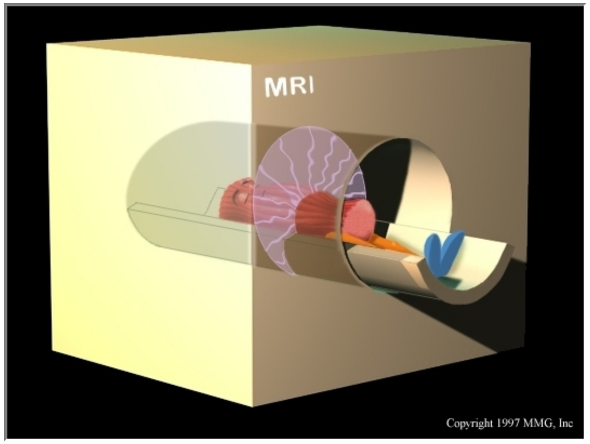
Examples

- Satellite Imaging



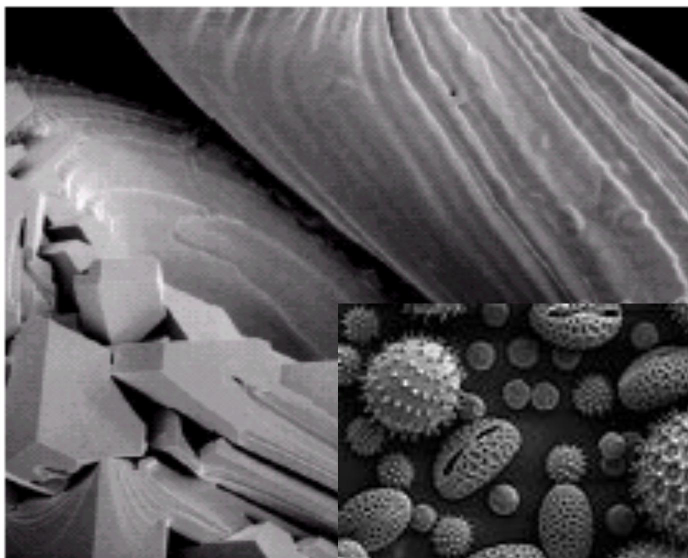
Examples

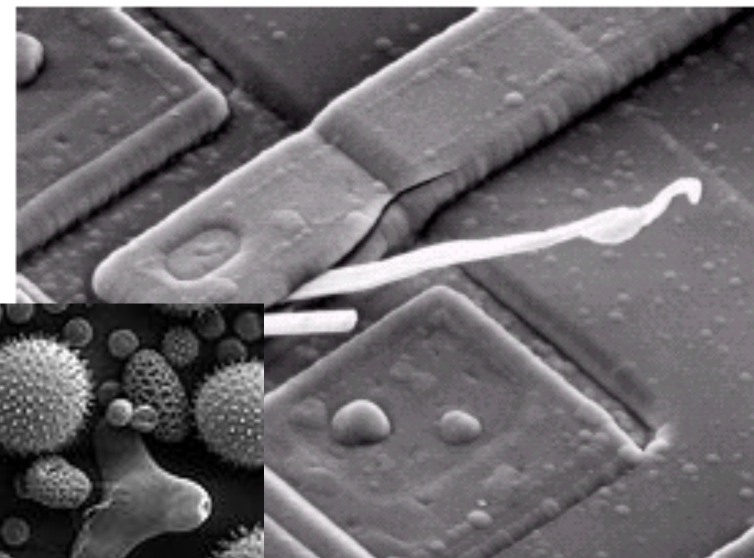
- **MRI (Magnetic Resonance Imaging)**

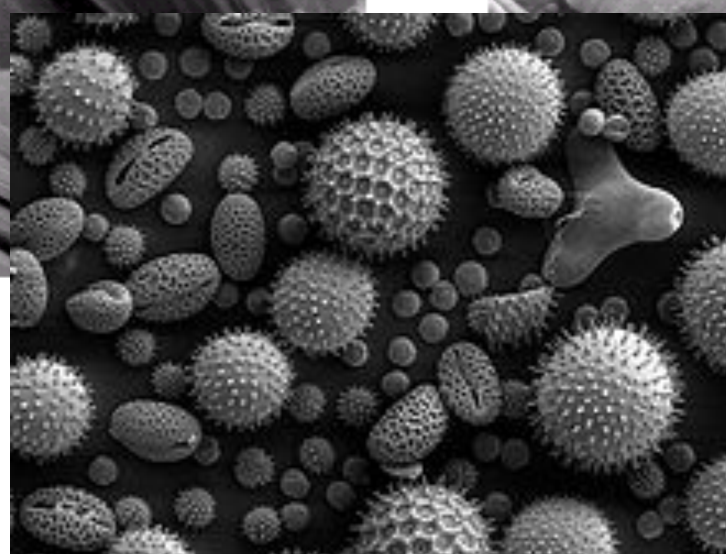


Examples

- SEM (Scanning Electron Microscope)







Traditional Topics

Traditional Topics

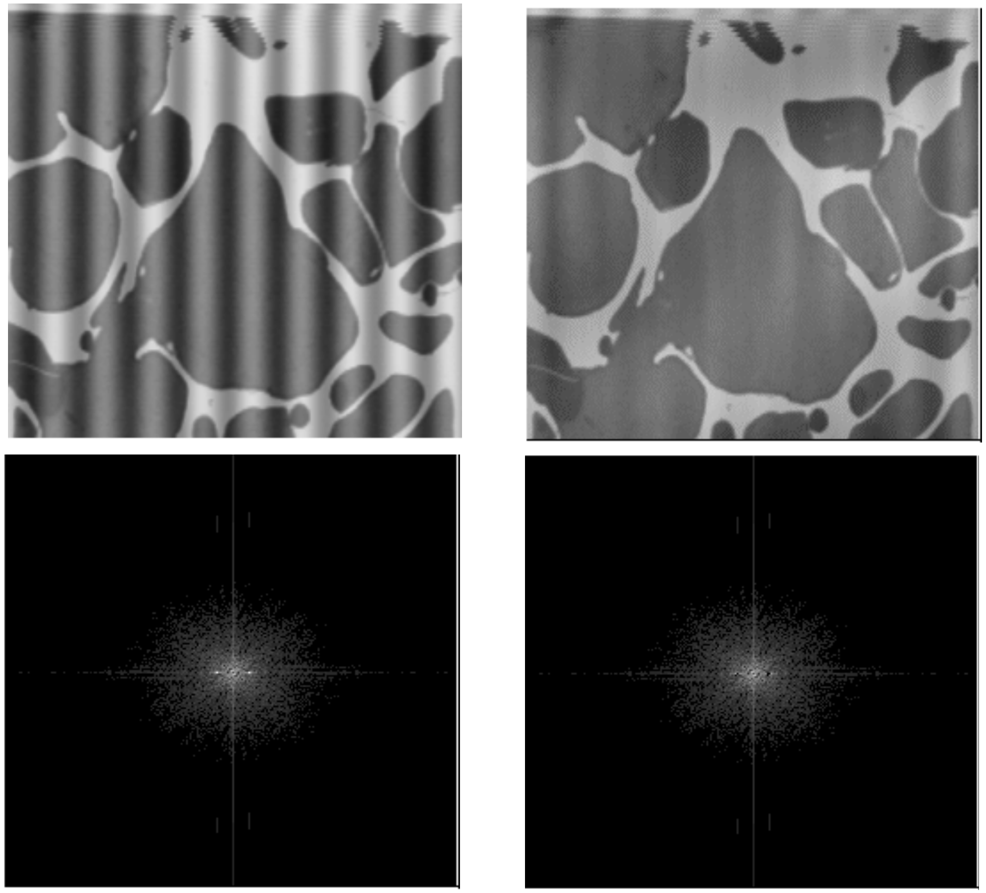
- Image Enhancement
  - Improve image contrast by adjusting its histogram

Traditional Topics

- **Image Restoration**
  - Remove the degradation effects to recover an image to its original condition

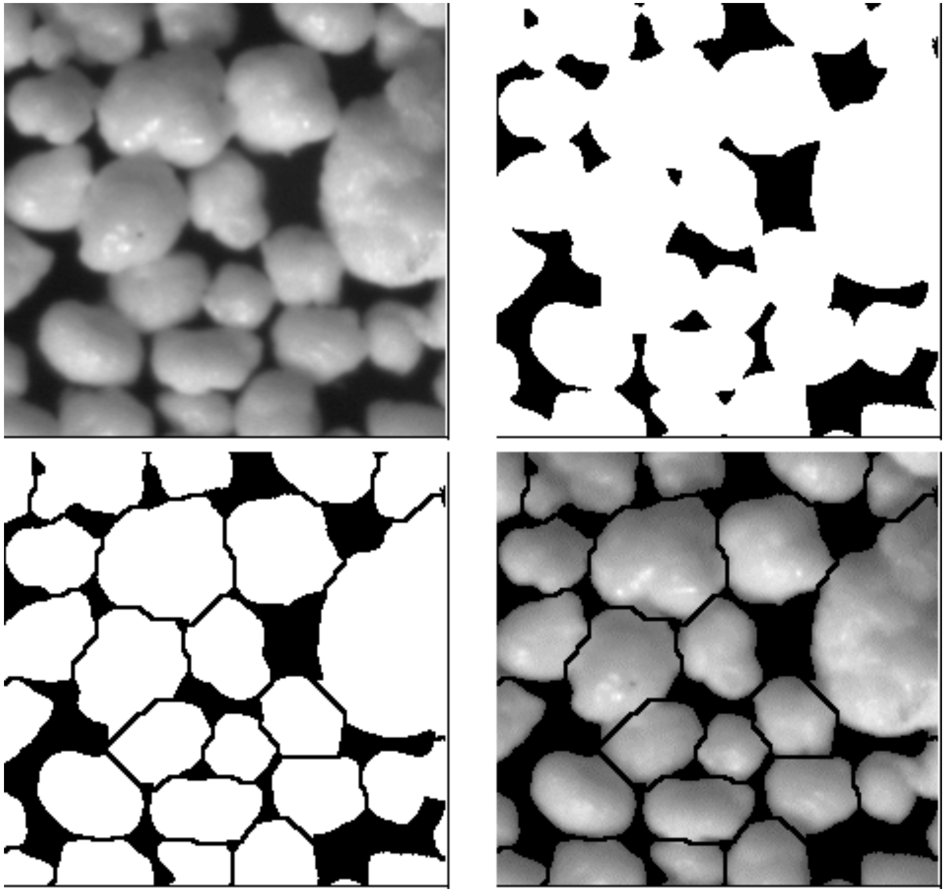
Traditional Topics

- **Image Transformation**



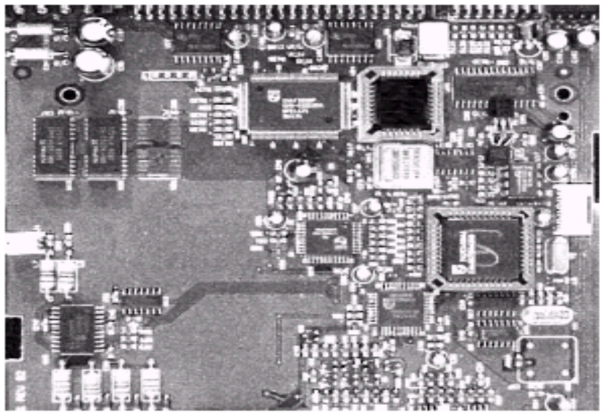
Traditional Topics

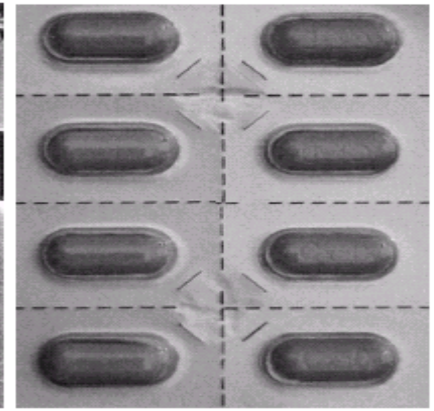
- **Image Segmentation**



Examples

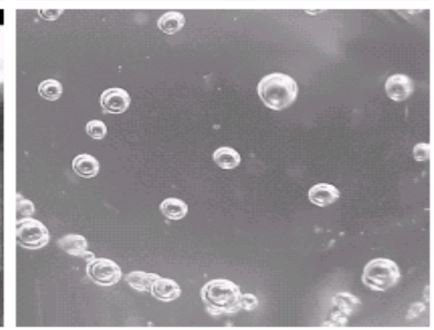
A circuit board





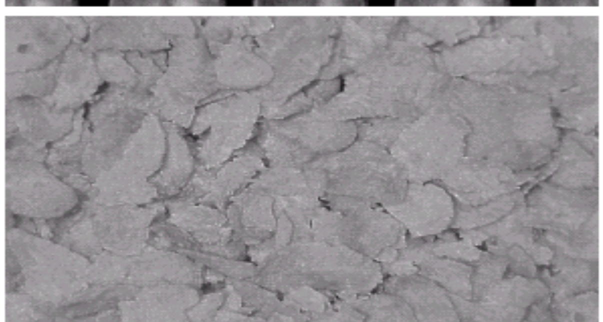
Packaged pills

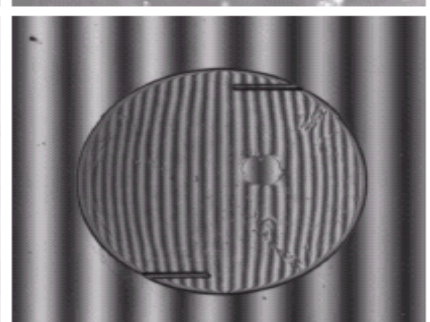
bottles



bubbles

cereal

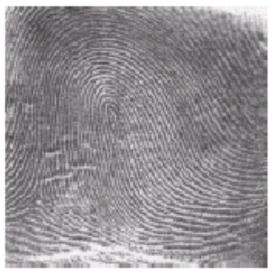




Intraocular implant

Examples

Fingerprint



Serial number

License plates

Student Information Form

- Name, Student ID and Department
- Email address
- Your portraits

  including a sketch and a photo, both 512x512
- Why do you want to take this course?

  What do you expect to learn?
- What do you want to do in the Final Project?

- Students who registered already

  Submit to NTU COOL
- Students who has not registered

  Email TA: dip.mslee@gmail.com

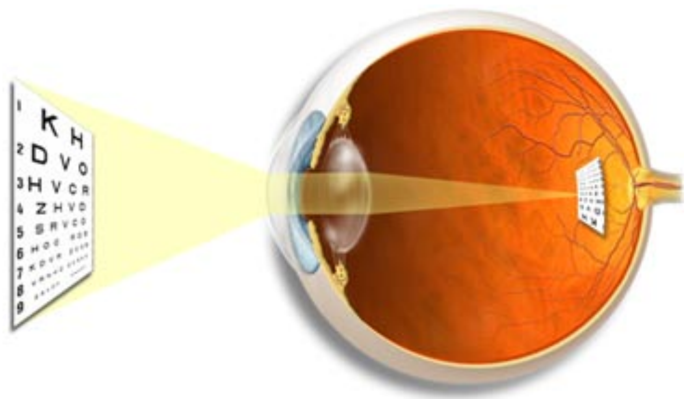
  [DIP] Student xxxxxx

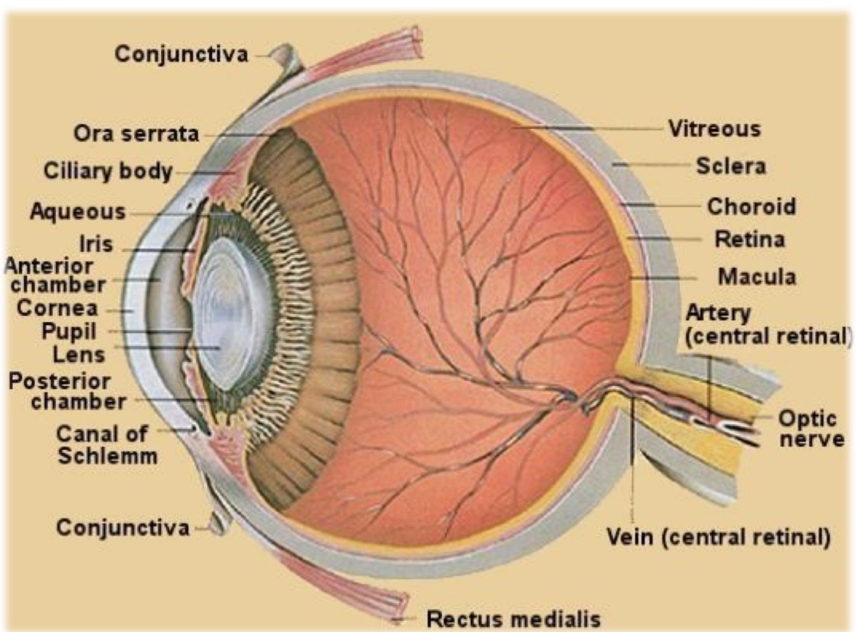
Digital Image Fundamentals

Image Quality

- **Objective / subjective**
  - Machine/human beings
  - Mathematical and Probabilistic/ human intuition and perception

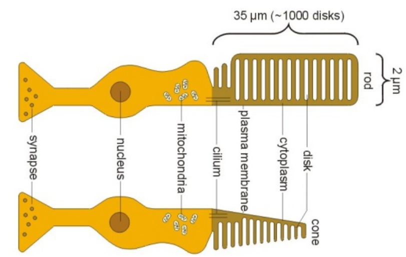
Structure of the Human Eye





photoreceptor cells

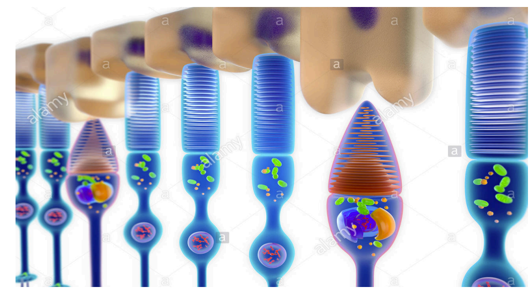
Rod cell



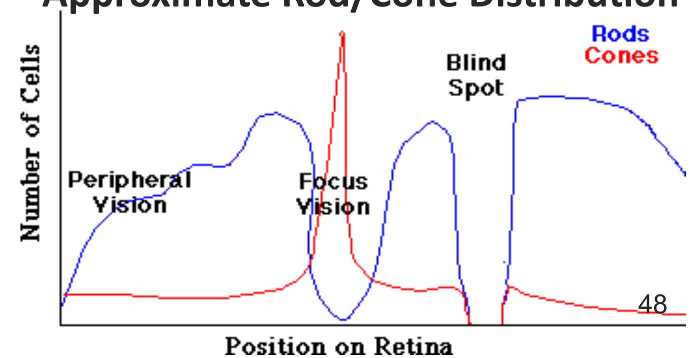
75~150 million

Cone cell

6~7 million



Approximate Rod/Cone Distribution



alamy.com & http://en.wikipedia.org/wiki/Blind_spot_(vision)

Structure of the Human Eye

- **The Blind Spot**

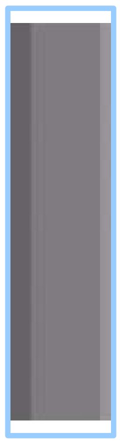
R **L**

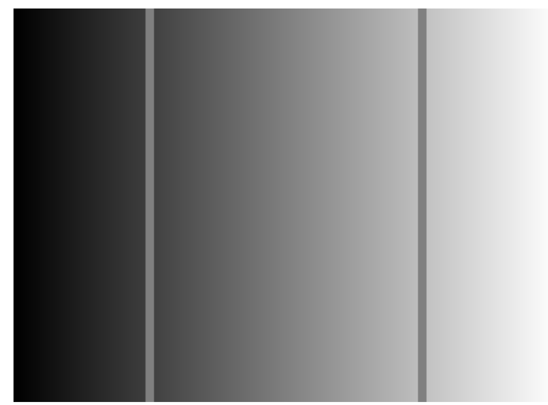
Instructions: Close one eye and focus the other on the appropriate letter (**R** for right or **L** for left). Place your eye a distance from the screen approximately equal to 3$\times$ the distance between the **R** and the **L**. Move your eye towards or away from the screen until you notice the other letter disappear. For example, close your right eye, look at the "L" with your left eye, and the "R" will disappear

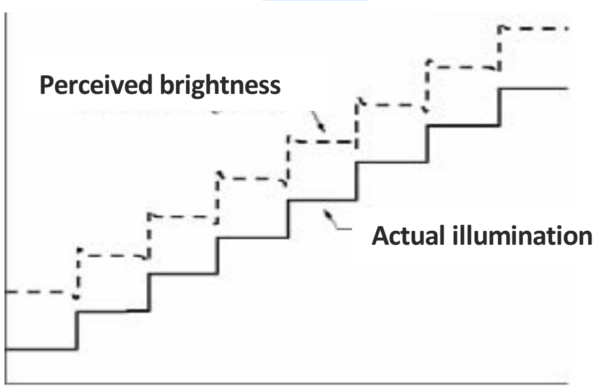
http://en.wikipedia.org/wiki/Blind_spot_(vision)

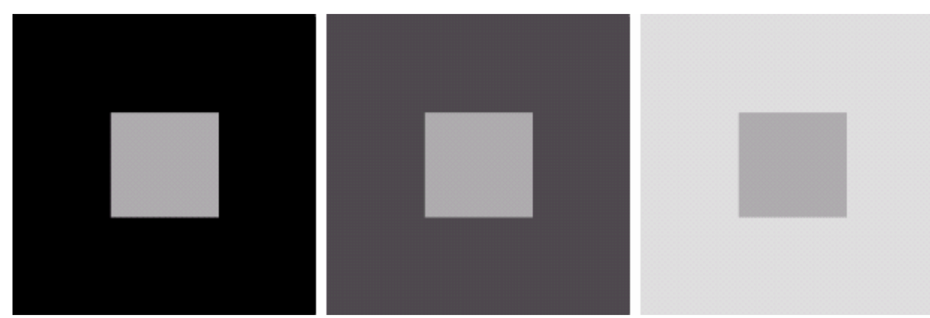
Human Visual Perception

- **Perceived brightness is NOT a simple function of intensity**



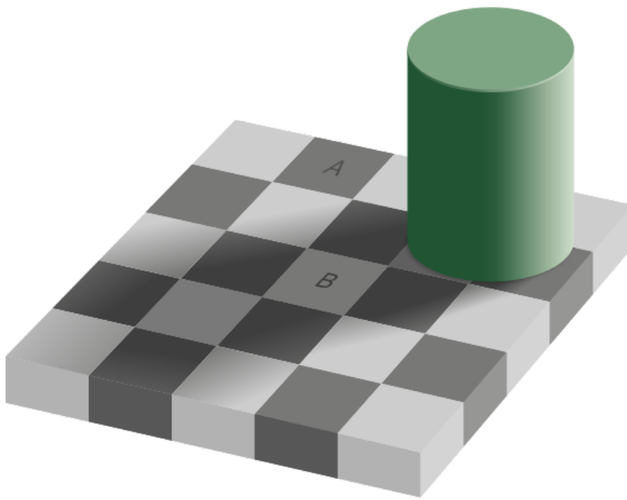


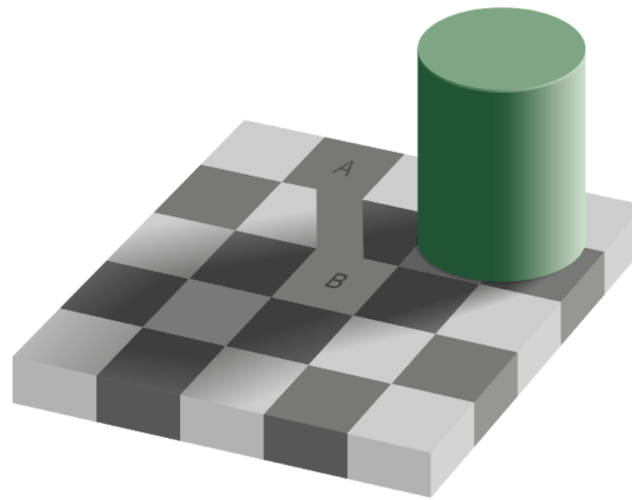


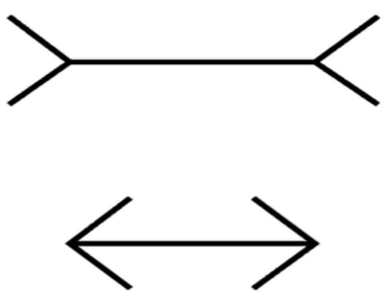


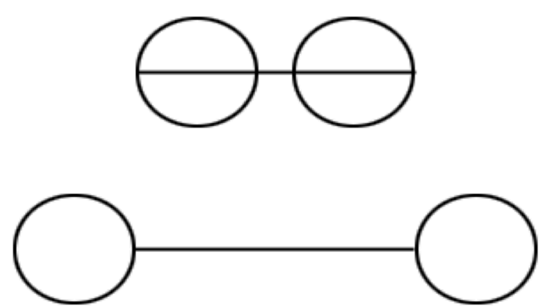
Human Visual Perception

- **Optical Illusion**



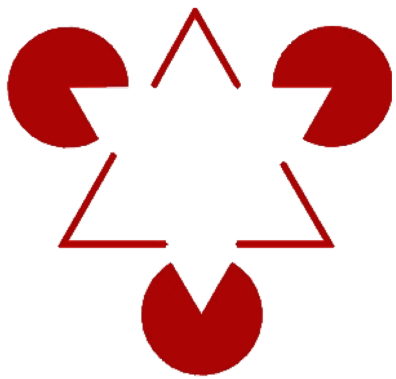


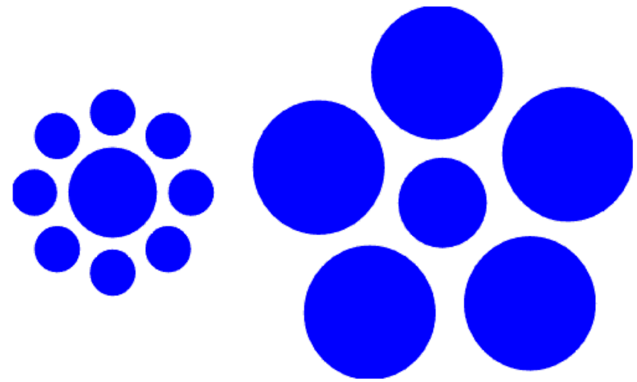


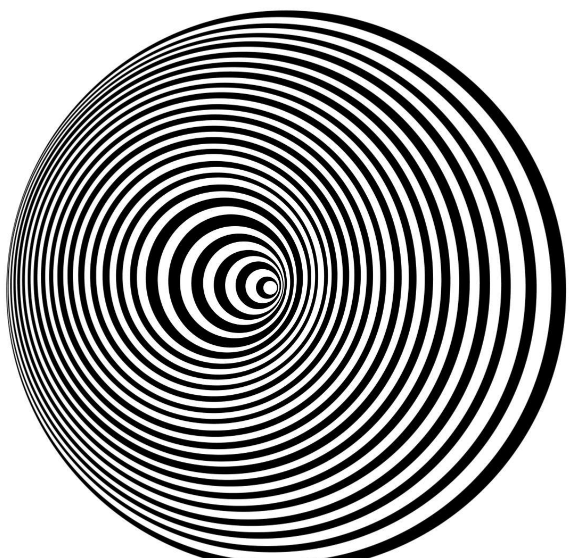


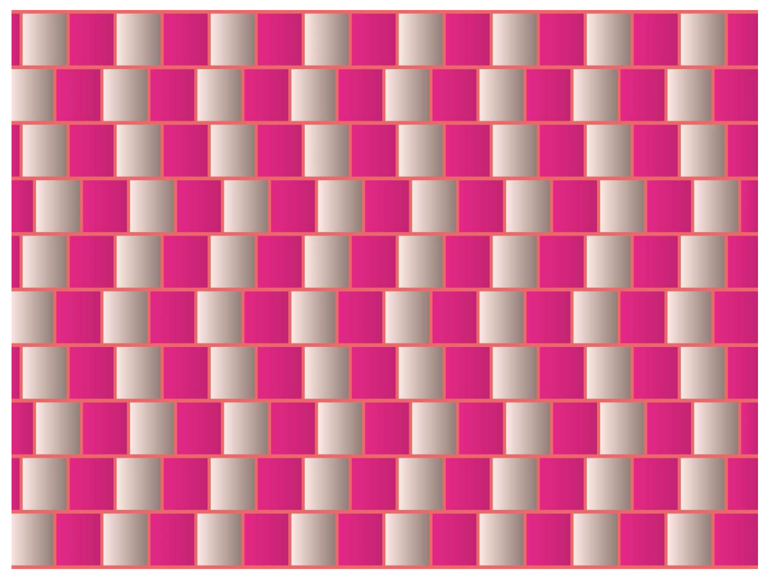
Human Visual Perception

- **Optical Illusion**



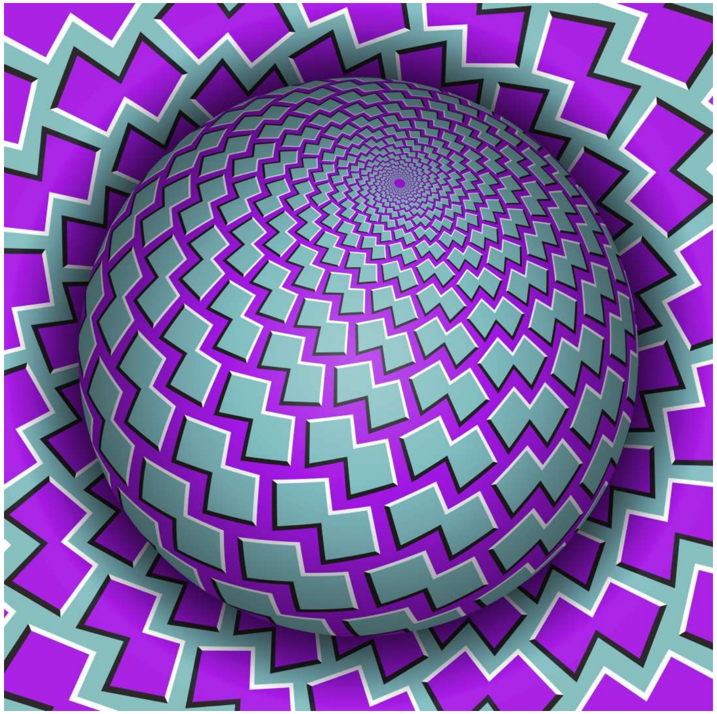


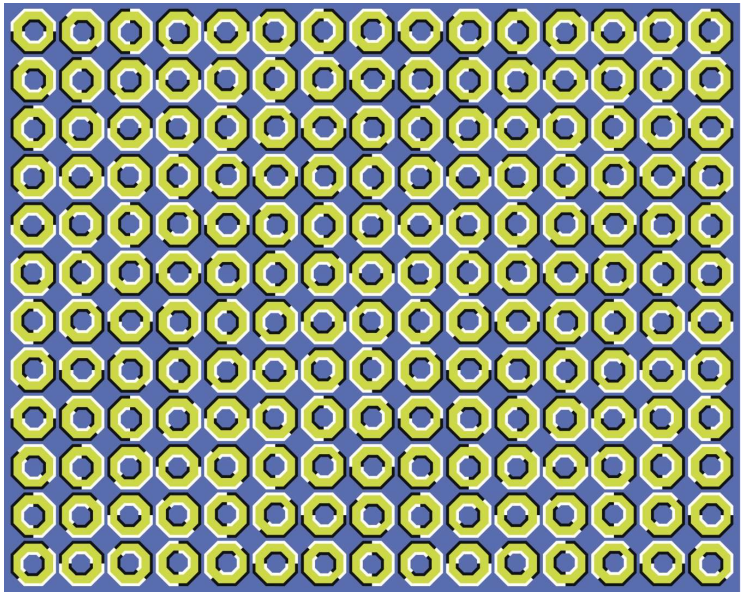




Human Visual Perception

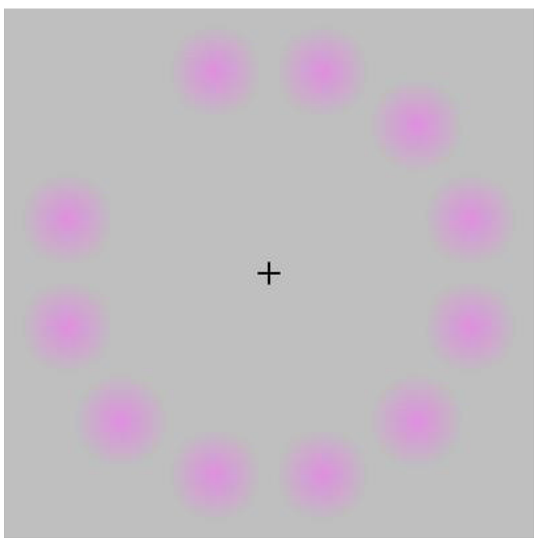
- **Optical Illusion**

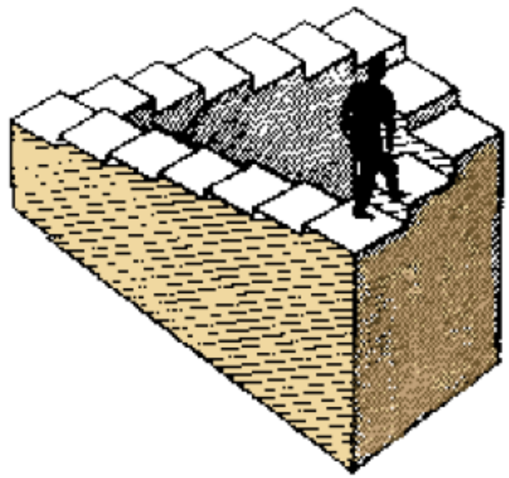


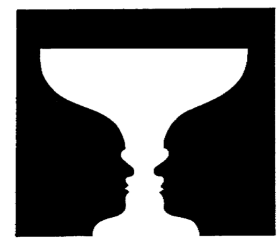


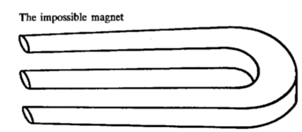
Human Visual Perception

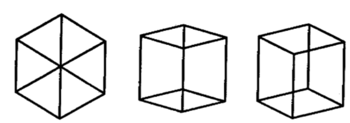
- **Optical Illusion**

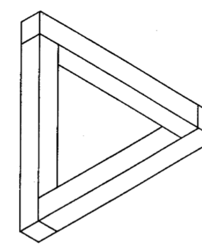


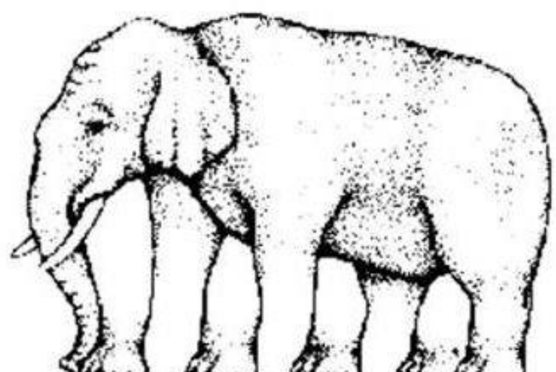






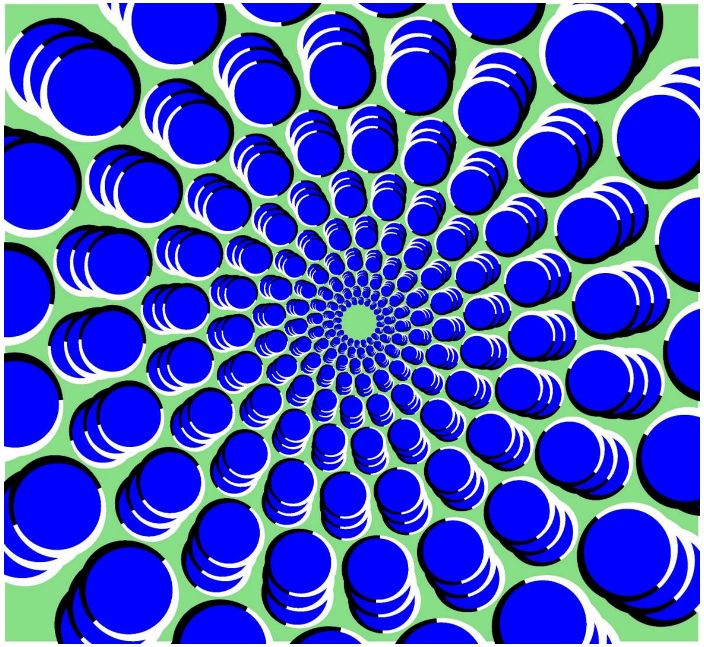


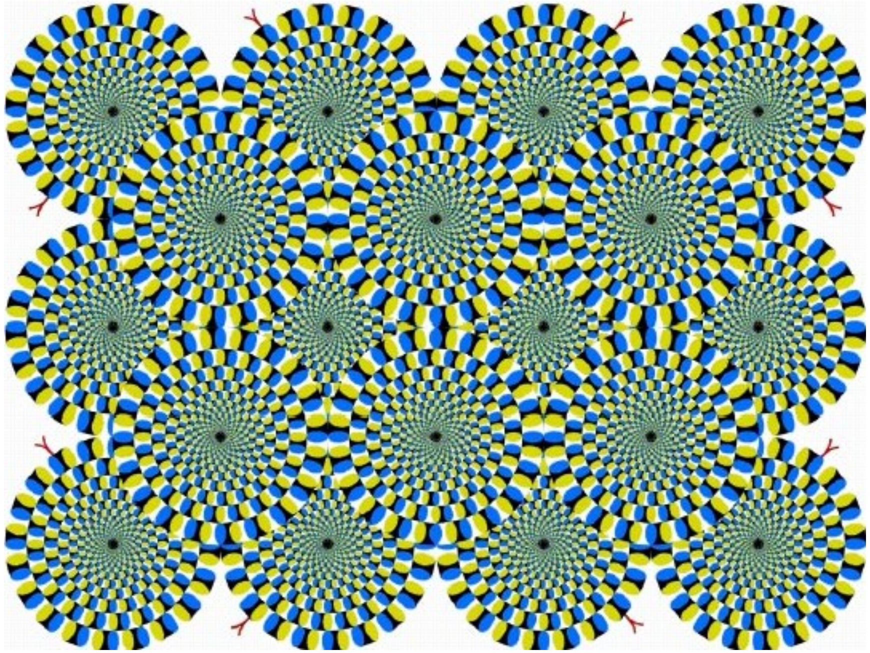




Human Visual Perception

- **Optical Illusion**



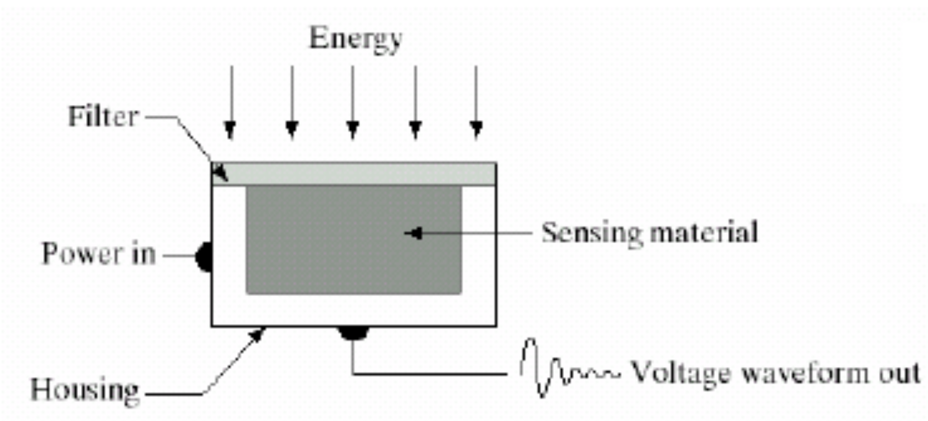


http://architecturehell.wordpress.com/

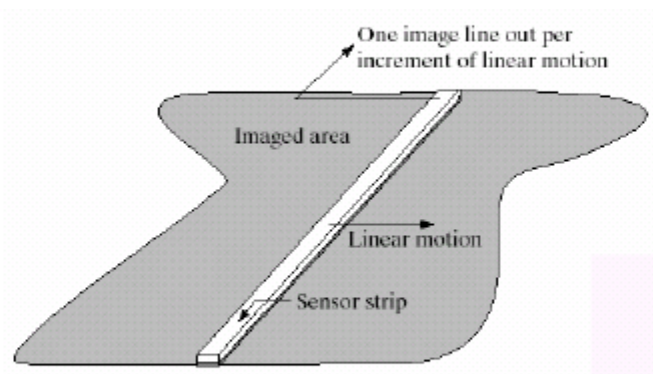
Image Sensing and Acquisition

- **Illumination Source**
  - EM energy, ultrasound, synthesized, …
- **Scene Element**
  - Objects, human organs, buried mineral,…
- **Sensing Material**
  - Single sensor: photodiode
  - Sensor strips: require extensive processing
  - Sensor arrays: CCD & CMOS

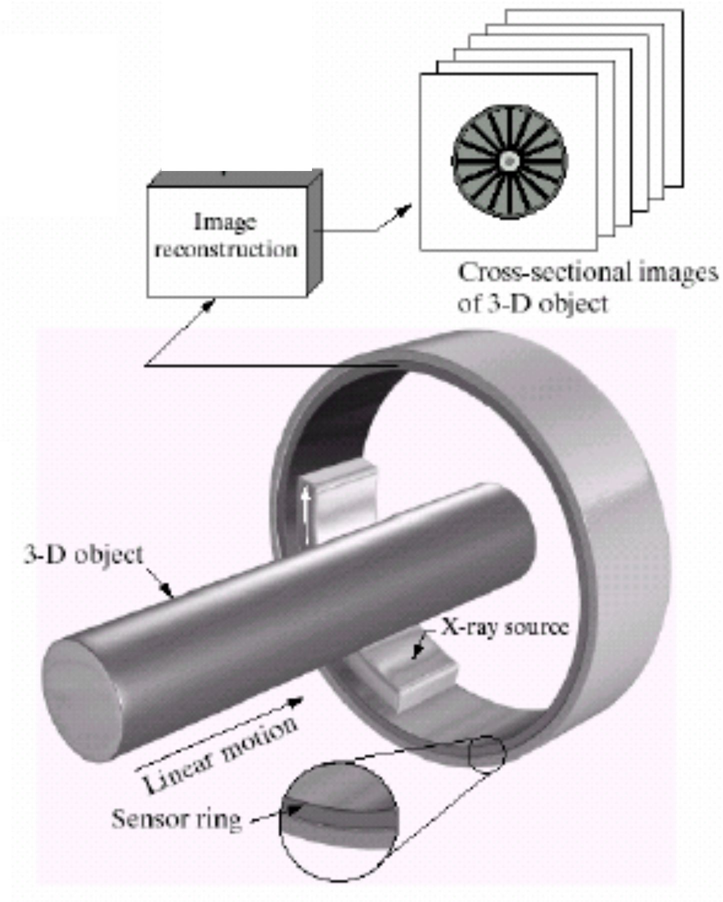
Image Sensing and Acquisition



Single sensor



Sensor Strip



Circular Sensor Strip

Image Sensing and Acquisition

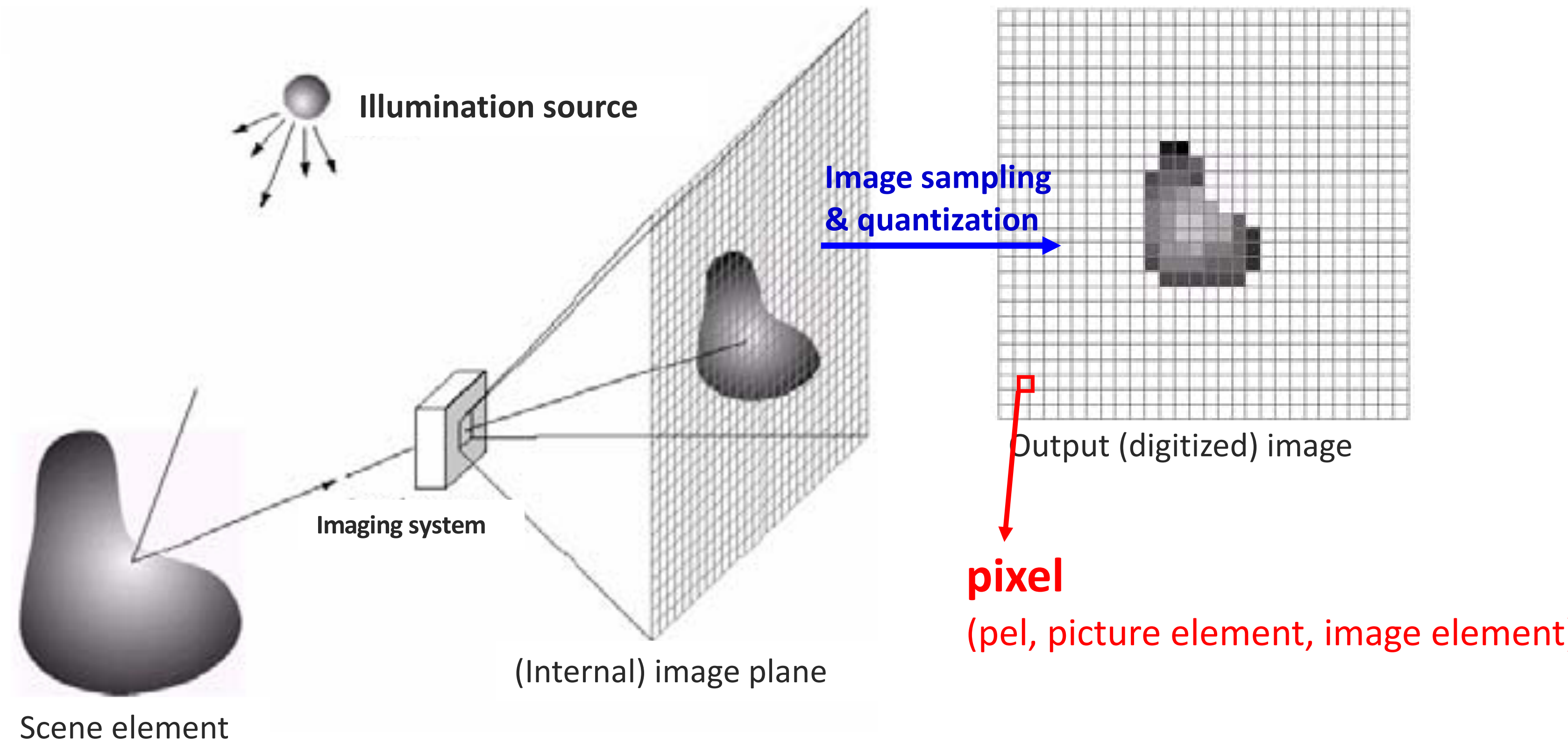
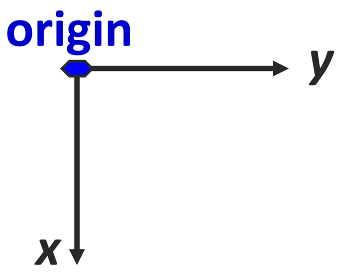


Image Formation Model

- **An image → 2D function**



$$0 < f(x,y) < \infty$$

where *x* and *y* are spatial coordinates

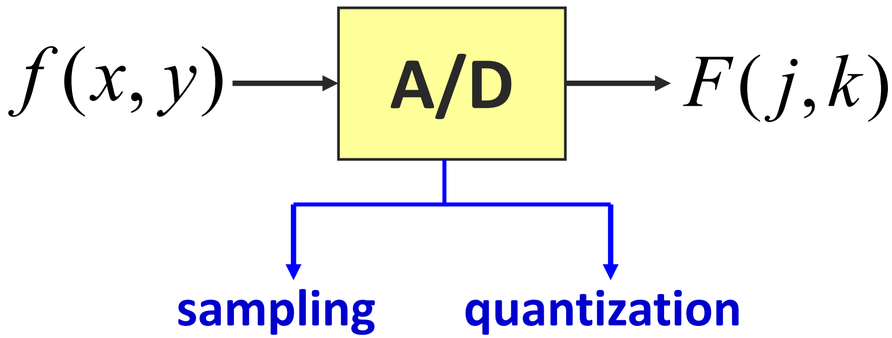
- **Categorized by two components**

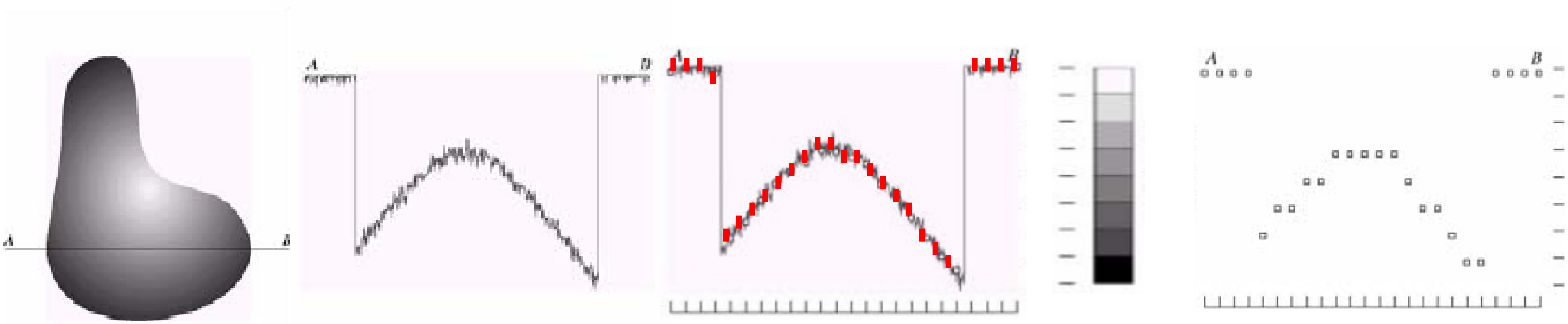
$$f(x,y) = i(x,y)r(x,y)$$

  - **Illumination:** $0 < i(x,y) < \infty$
  - **Reflectance:** $0 < r(x,y) < 1$
    - black velvet/ flat-white wall paint/ snow/ silver-plated metal

black velvet	flat-white wall paint	snow	silver-plated metal
0.1	0.8	0.93	0.9

Image Sampling & Quantization

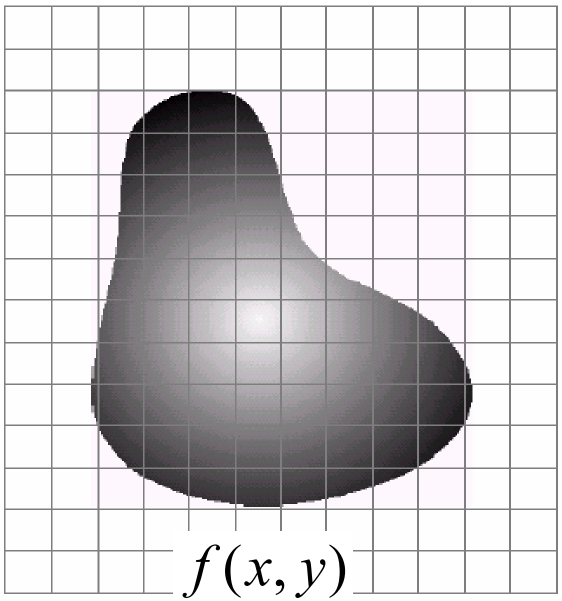


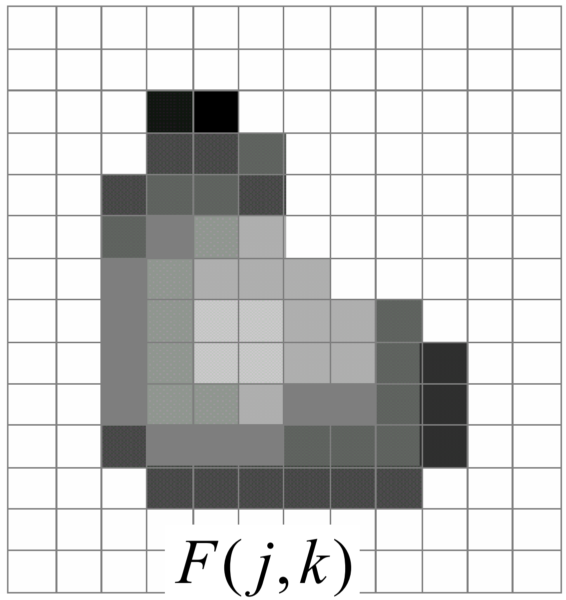


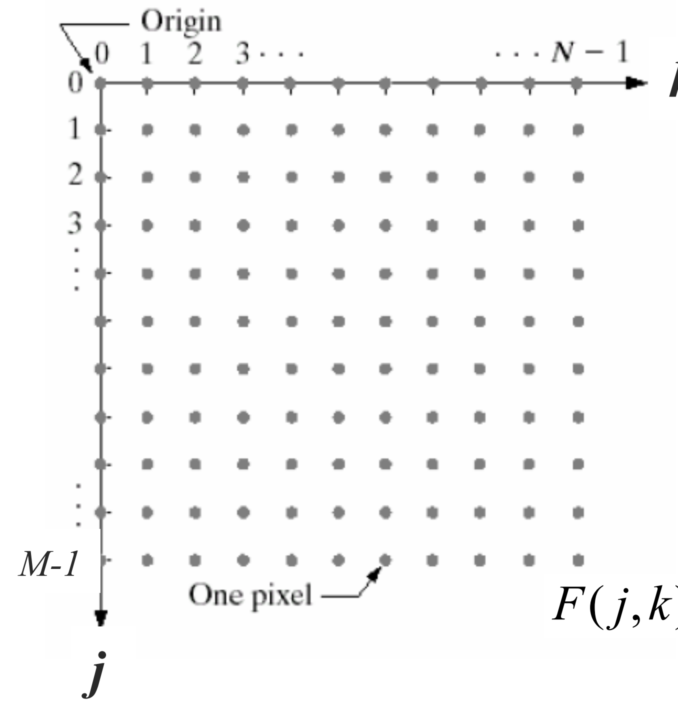
Original image $f(x,y)$ sampling quantization $F(j,k)$

coordinates amplitude

Image Sampling & Quantization







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

$$F(j,k) = \begin{bmatrix} F(0,0) & F(0,1) & \cdots & F(0,N-1) \\ F(1,0) & F(1,1) & \cdots & F(1,N-1) \\ \vdots & \vdots & \ddots & \vdots \\ F(M-1,0) & F(M-1,1) & \cdots & F(M-1,N-1) \end{bmatrix}$$

Digital Image Representation

- **Dynamic Range**
  - The range of values spanned by the gray scale

    $\{0, 1, \dots, L-1\}$ $\quad L = 2^k$

- **Image Size**
  - for a square image, $M = N$

    total number of bits required to store the image: $b = N^2 \cdot k$

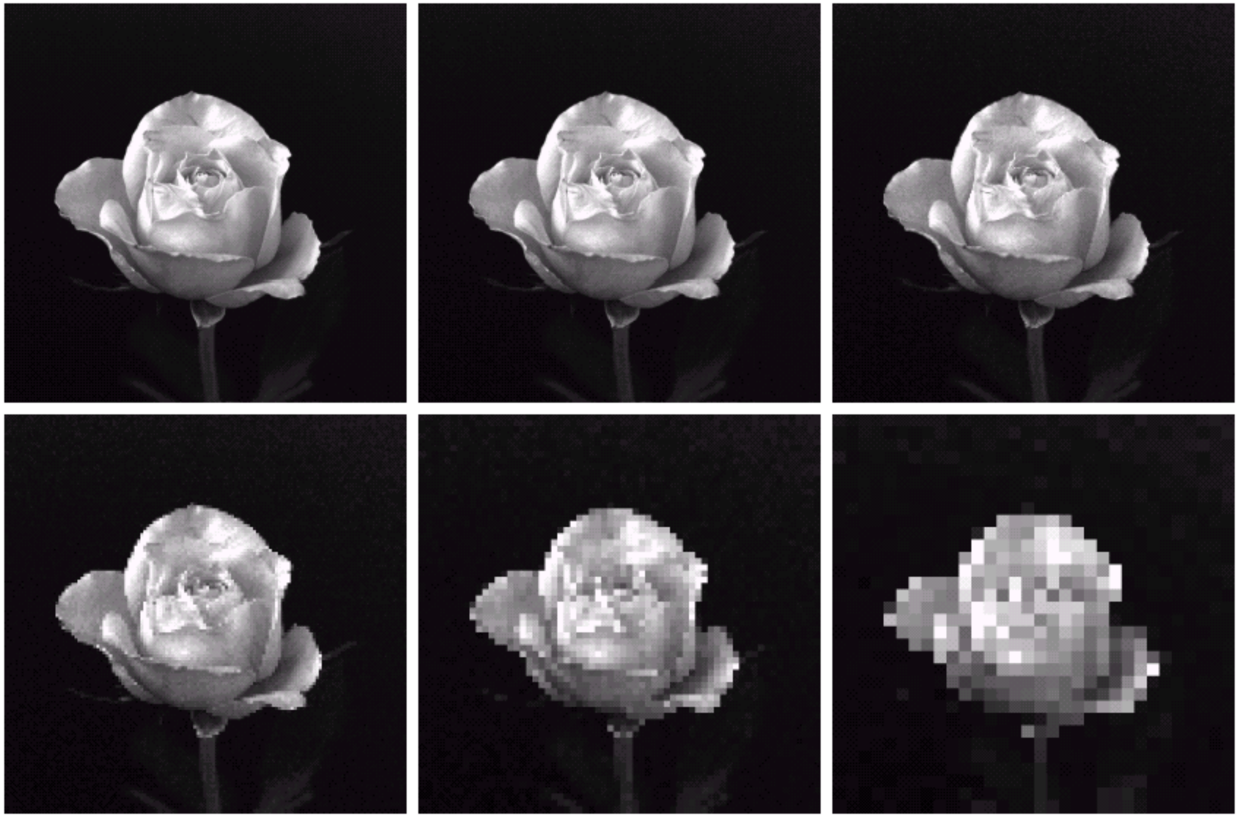
N/k	1 (L = 2)	2 (L = 4)	3 (L = 8)	4 (L = 16)	5 (L = 32)	6 (L = 64)	7 (L = 128)	8 (L = 256)
32	1,024	2,048	3,072	4,096	5,120	6,144	7,168	8,192
64	4,096	8,192	12,288	16,384	20,480	24,576	28,672	32,768
128	16,384	32,768	49,152	65,536	81,920	98,304	114,688	131,072
256	65,536	131,072	196,608	262,144	327,680	393,216	458,752	524,288
512	262,144	524,288	786,432	1,048,576	1,310,720	1,572,864	1,835,008	2,097,152
1024	1,048,576	2,097,152	3,145,728	4,194,304	5,242,880	6,291,456	7,340,032	8,388,608
2048	4,194,304	8,388,608	12,582,912	16,777,216	20,971,520	25,165,824	29,369,128	33,554,432
4096	16,777,216	33,554,432	50,331,648	67,108,864	83,886,080	100,663,296	117,440,512	134,217,728
8192	67,108,864	134,217,728	201,326,592	268,435,456	335,544,320	402,653,184	469,762,048	536,870,912

Downsampling

- **1024x1024 → 32x32**
  - **Downsampled by a factor of 2**

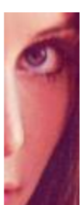
Re-Sampling

- Zero-Order-Hold Method (ZOH)
  - Row and column duplication



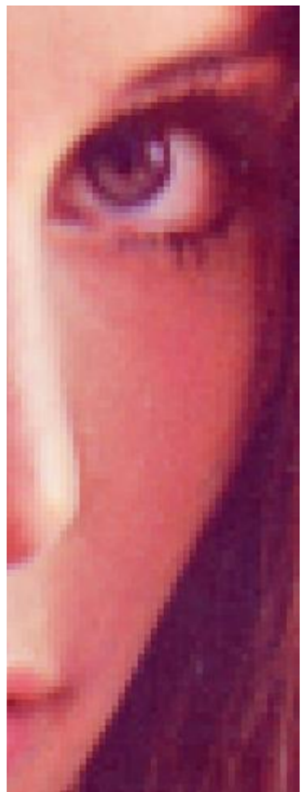
Re-Sampling

1x



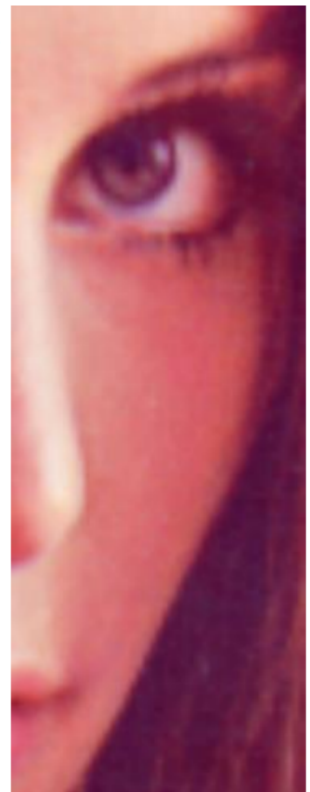
Original

4x



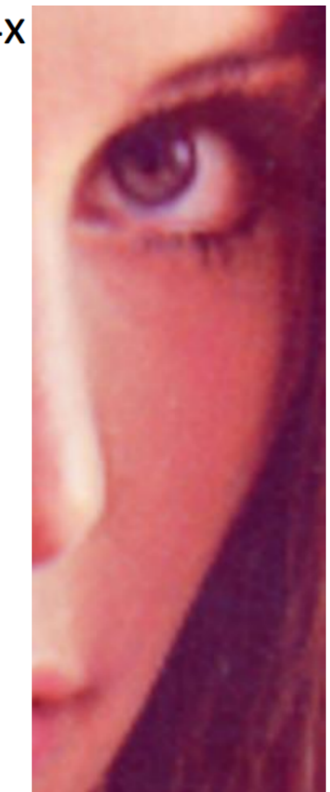
Nearest neighbor

4x



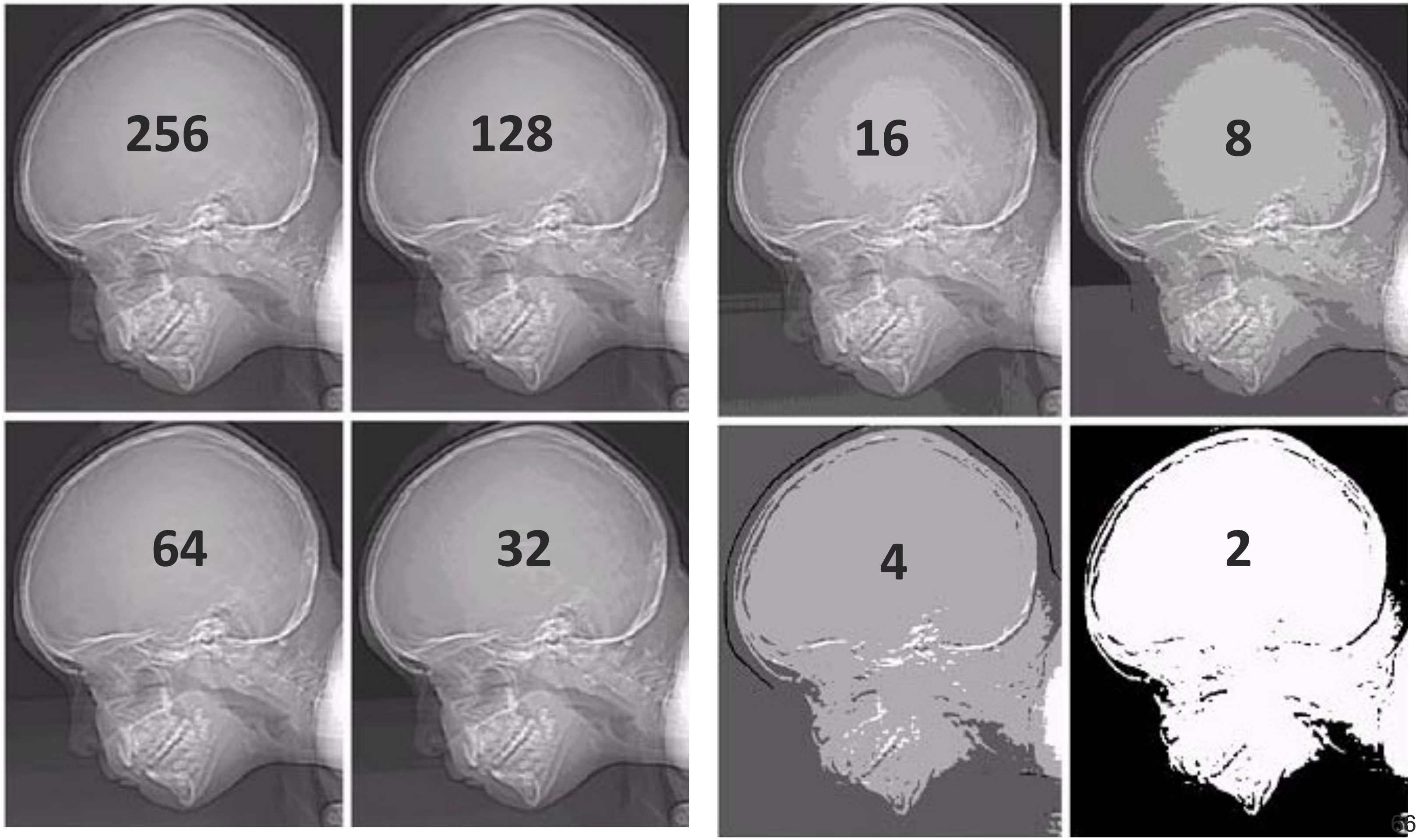
bilinear

4x



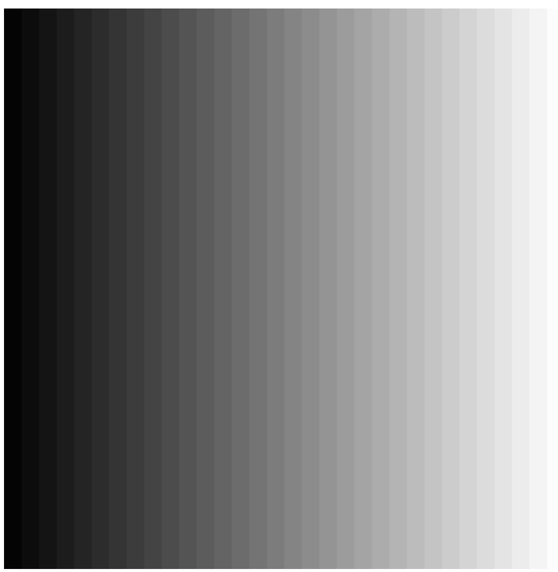
bicubic

L=256,128,64,32,16,8,4,2

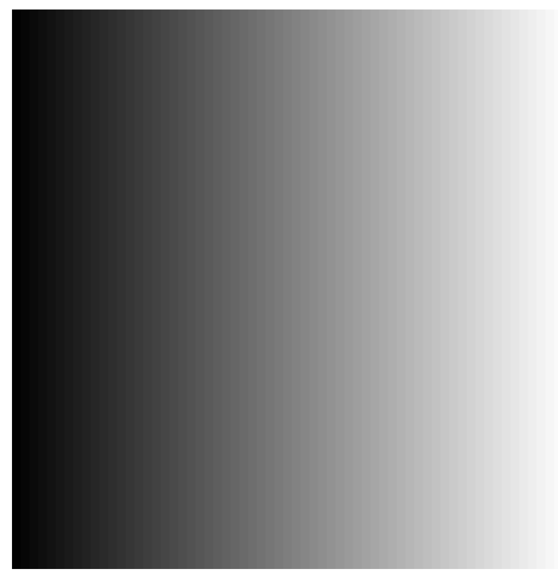


Digital Image Representation

- **8-bit image is commonly used**
  - Storage
  - Human perception



32 steps (5 bits) in gray level



64 steps (6 bits) in gray level