



EIE4512

Digital Image Processing

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School of Science and Engineering,
The Chinese University of Hong Kong, Shen Zhen

Basic Information

- Time & Venue
 - Tuesday: 10:30 am – 12:00 pm, TA207
 - Thursday: 10:30 am – 12:00 pm, TA 207
- Staff
 - Instructor: Zhen Li (lizhen@cuhk.edu.cn)
 - Tutors: Qin Wang (wangqin4377@qq.com)
Bin Zeng (zeng_bin8888@163.com)
- One tutorial per week:
Thursday: 8:00pm – 9:00pm, TA 207

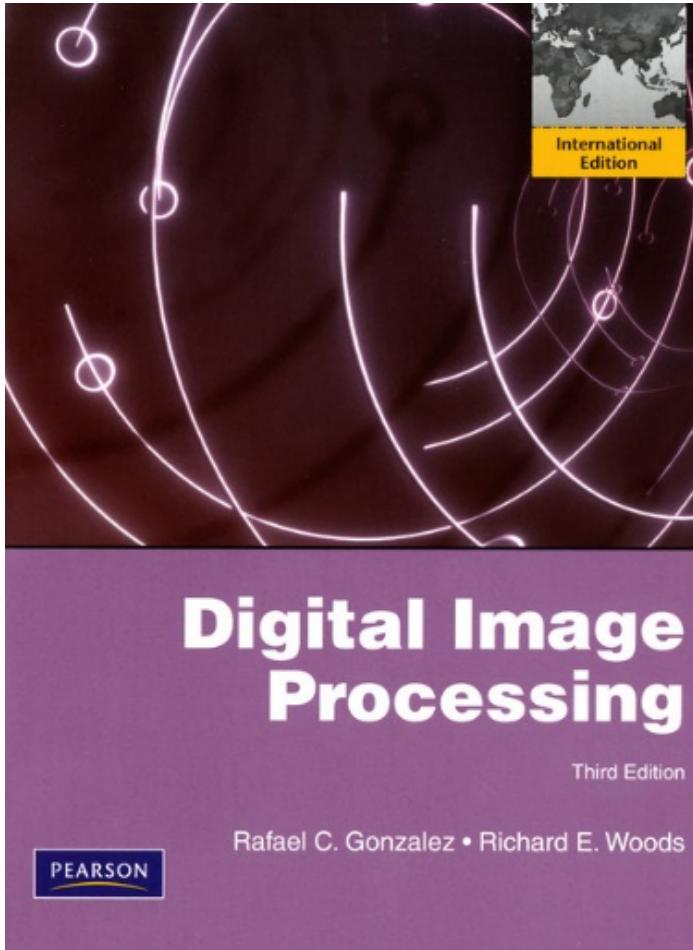
Slides

- Online address:
 - https://github.com/icemansina/CUHK SZ_DIP
- We use this repository for:
 - Make announcements
 - Release lecture slides
 - Release homework assignments and solutions
 - Discussions: wechat group



该二维码7天内(1月14日前)有效，重新进入将更新

Reference Textbook



Digital Image Processing

By *Rafael C. Gonzalez & Richard E. Woods*

Grading

- Three assignments: 10% x 3
- Mid-term exam: 30%
- Final project: 40%
 - Topics
 - Applications of digital image processing
 - Implementation of digital image processing
 - Study digital image processing algorithms
 - You (at most two students as a group) should submit
 - One page proposal which briefly introduces the topic, idea, method, experiments.
 - A term paper of 4 pages (excluding figures) in maximum, double column, font size is equal or no larger than 10.
 - Code and sample data
 - Project presentation (5mins – 10mins)

What is this course about?

Face Beautification



Image Filtering

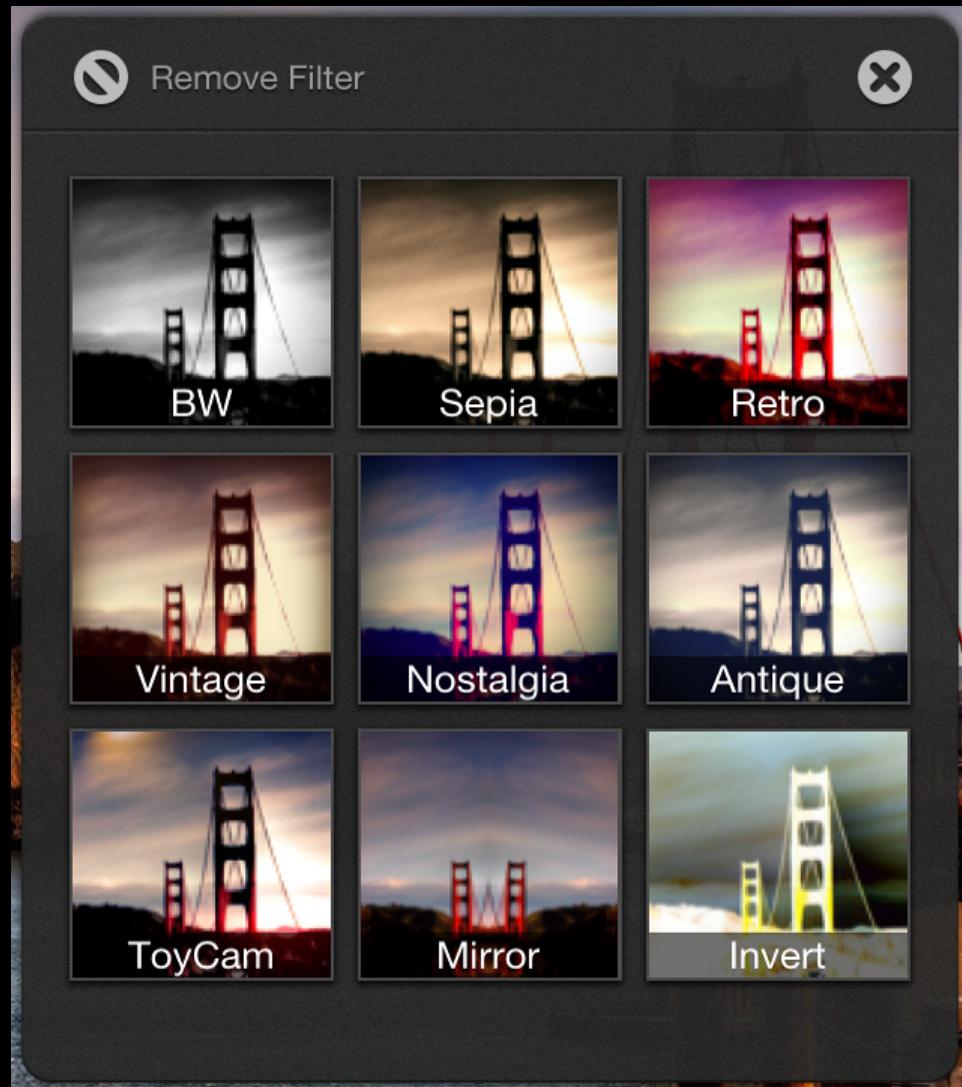


Image Superresolution



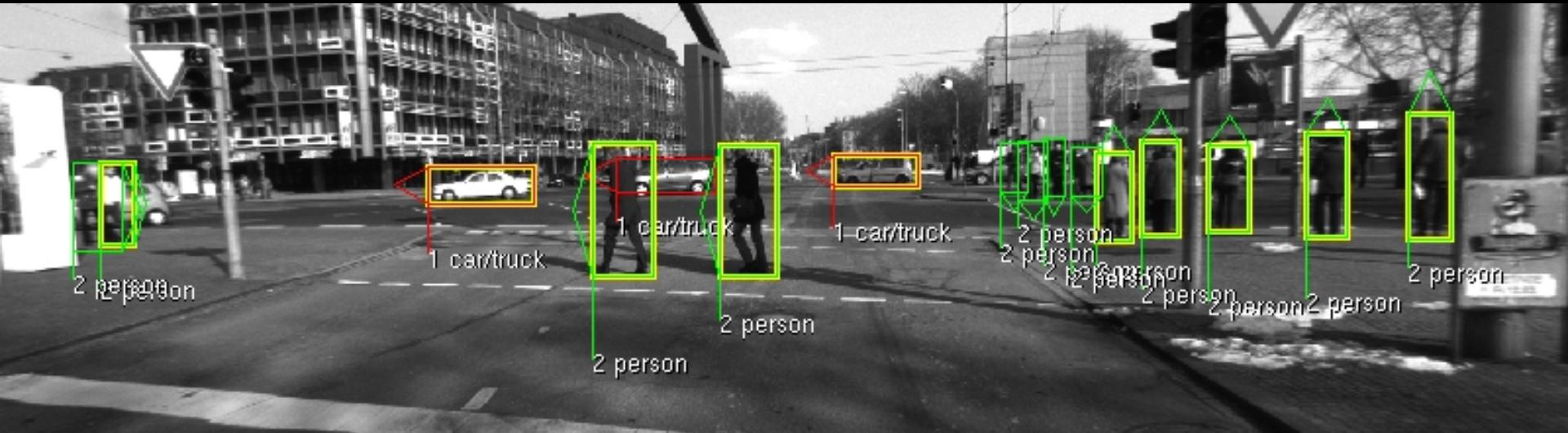
Face Recognition



Object Recognition



Pedestrian Detection



Scene Parsing



Topics



Image Representations

- Image Sensing and Acquisition
- Sampling and Quantization
- Basic Relationships between Pixels

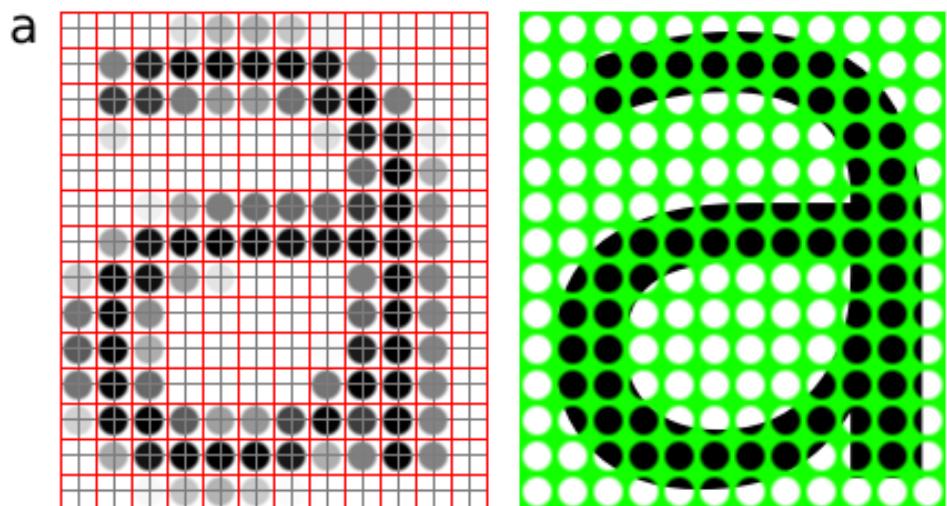


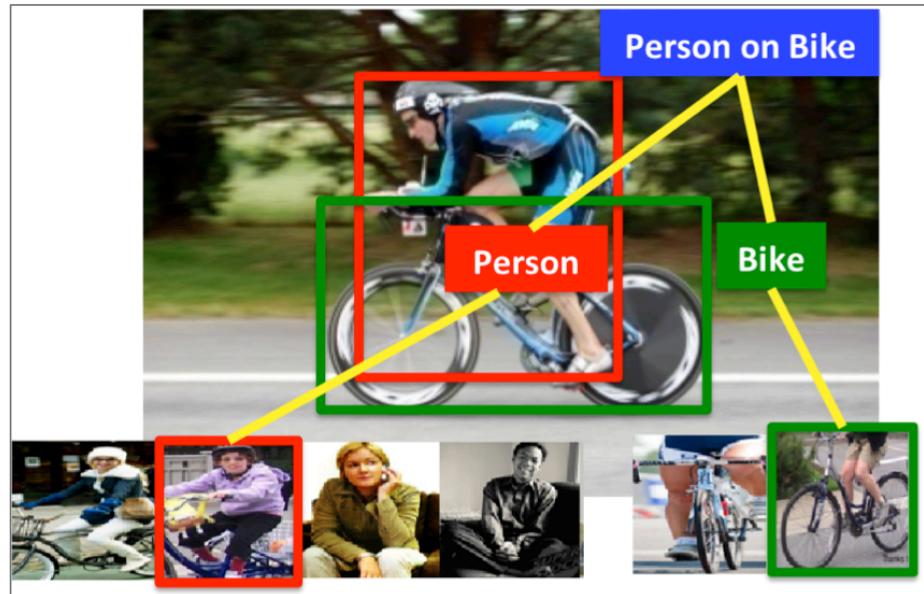
Image Processing

- Gray-level processing
- Image filtering
- Image restoration
- Morphological processing



Visual Understanding

- Features
- Image recognition
- Object detection
- Image segmentation





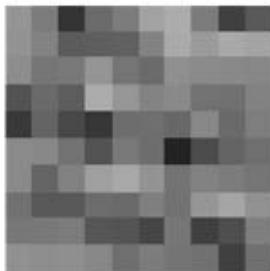
What is an Image?

- 2-dimensional matrix of Intensity (gray or color) values

Set of Intensity values

Image coordinates
are integers

$$I(u, v) \in \mathbb{P} \quad \text{and} \quad u, v \in \mathbb{N}.$$



$F(x, y)$



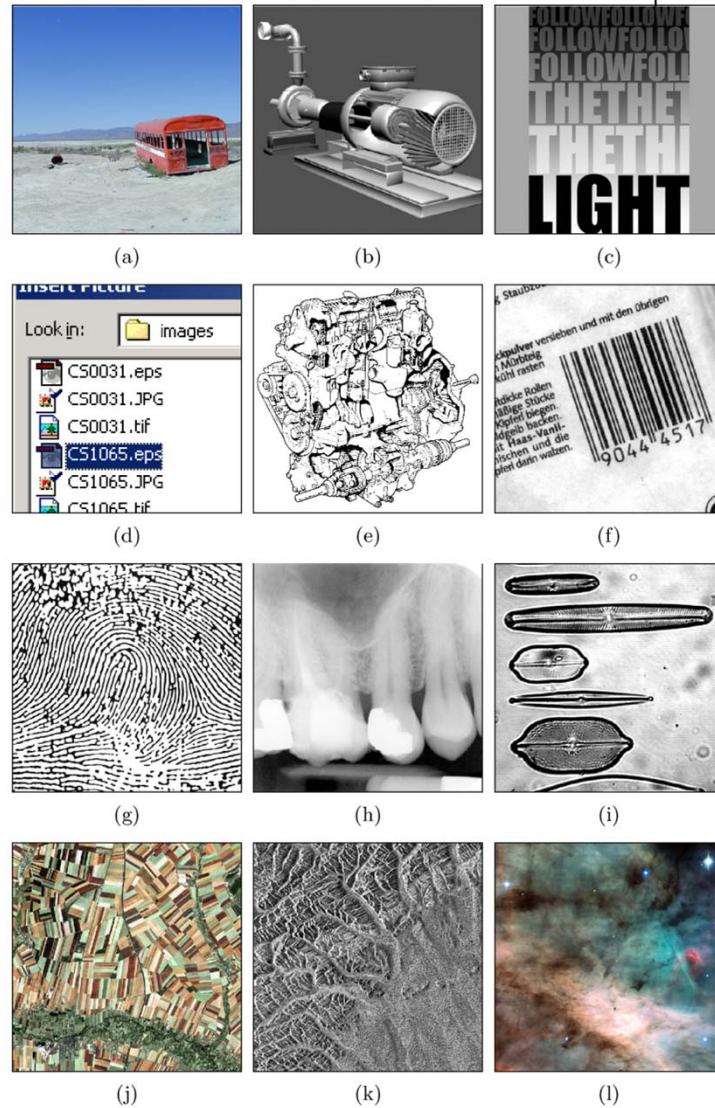
148	123	52	107	123	162	172	123	64	89	...
147	130	92	95	98	130	171	155	169	163	...
141	118	121	148	117	107	144	137	136	134	...
82	106	93	172	149	131	138	114	113	129	...
57	101	72	54	109	111	104	135	106	125	...
138	135	114	82	121	110	34	76	101	111	...
138	102	128	159	168	147	116	129	124	117	...
113	89	89	109	106	126	114	150	164	145	...
120	121	123	87	85	70	119	64	79	127	...
145	141	143	134	111	124	117	113	64	112	...
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

$I(u, v)$



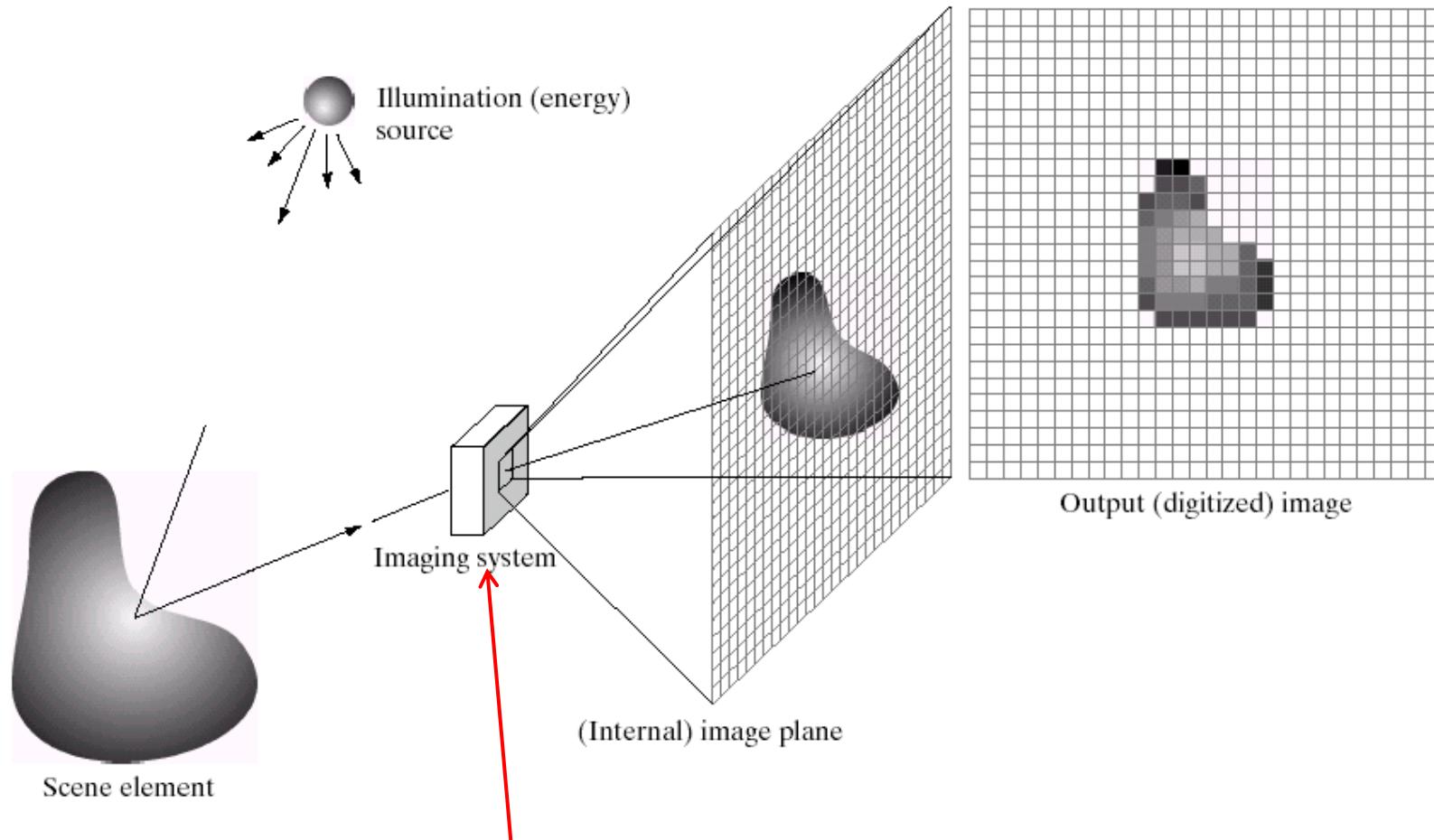
Example of Digital Images

- 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





Imaging System



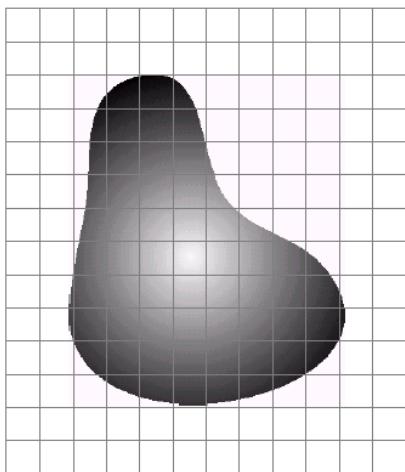
Example: a camera
Converts light to image

Credits: Gonzales and Woods

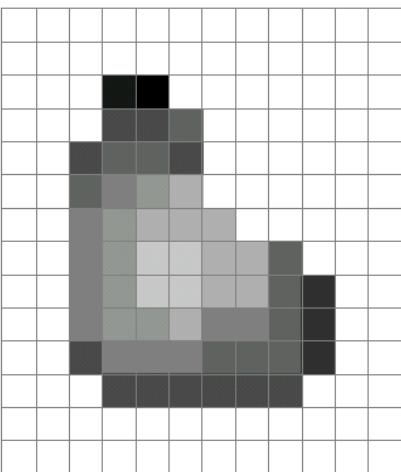


Digital Image?

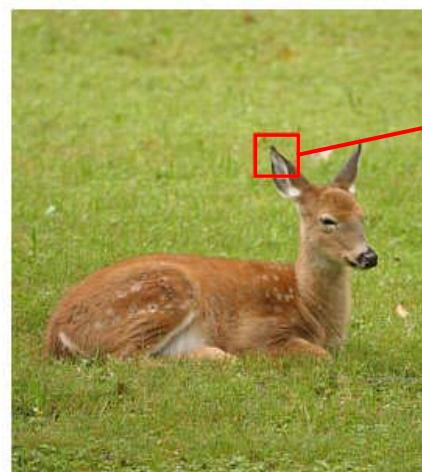
- Remember: *digitization* causes a digital image to become an *approximation* of a real scene



Real image



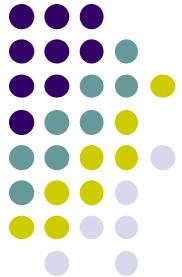
Digital Image
(an approximation)



Real image



Digital Image
(an approximation)



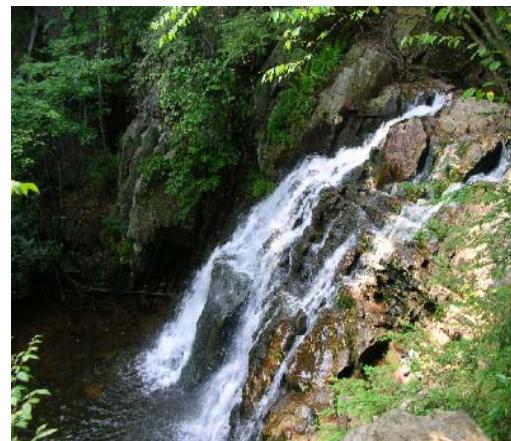
Digital Image

- Common image formats include:

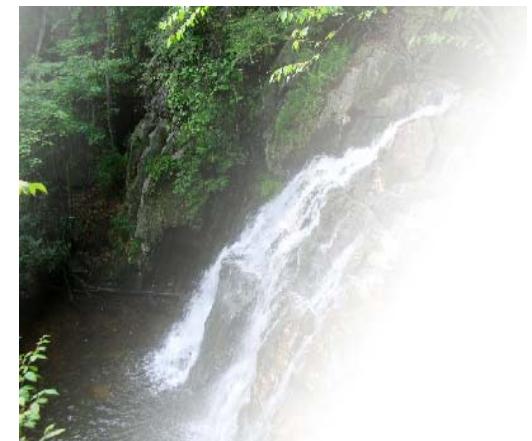
- 1 values per point/pixel (B&W or Grayscale)
- 3 values per point/pixel (Red, Green, and Blue)
- 4 values per point/pixel (Red, Green, Blue, + “Alpha” or Opacity)



Grayscale

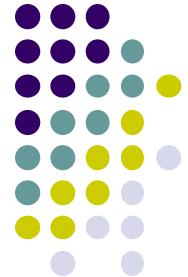


RGB



RGBA

- We will start with gray-scale images, extend to color later



What is image Processing?

- Algorithms that alter an input image to create new image
- Input is image, output is image



Original Image



Processed Image

- Improves an image for human interpretation in ways including:
 - Image display and printing
 - Image editing
 - Image enhancement
 - Image compression



Example Operation: Noise Removal

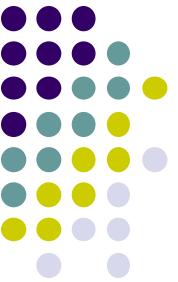
Noisy Image



Denoised Image

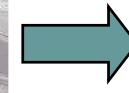
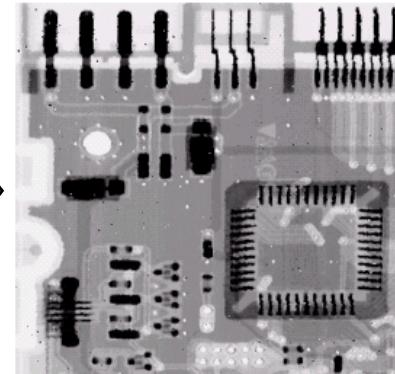
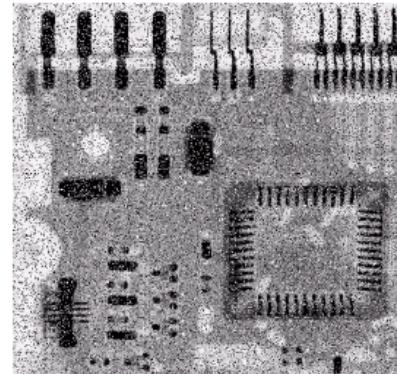
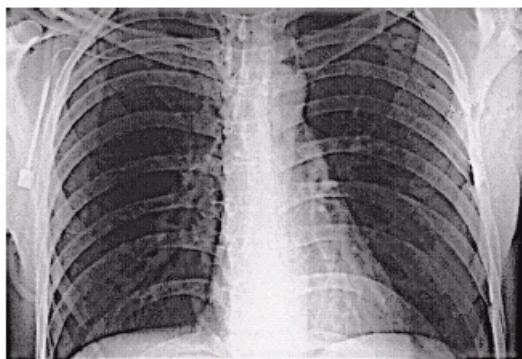
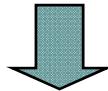
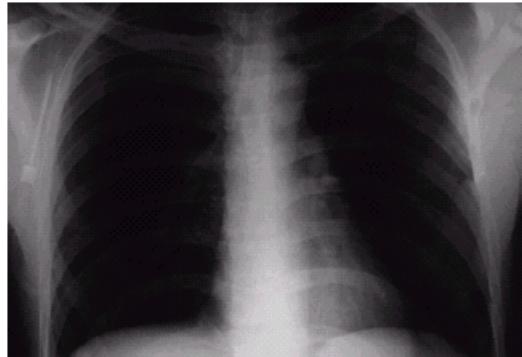


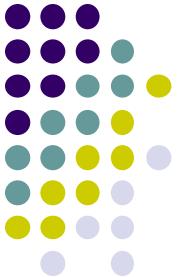
Think of noise as white specks on a picture (random or non-random)



Examples: Noise Removal

Images taken from Gonzalez & Woods, Digital Image Processing (2002)





Example: Contrast Adjustment



Low Contrast



Original Contrast



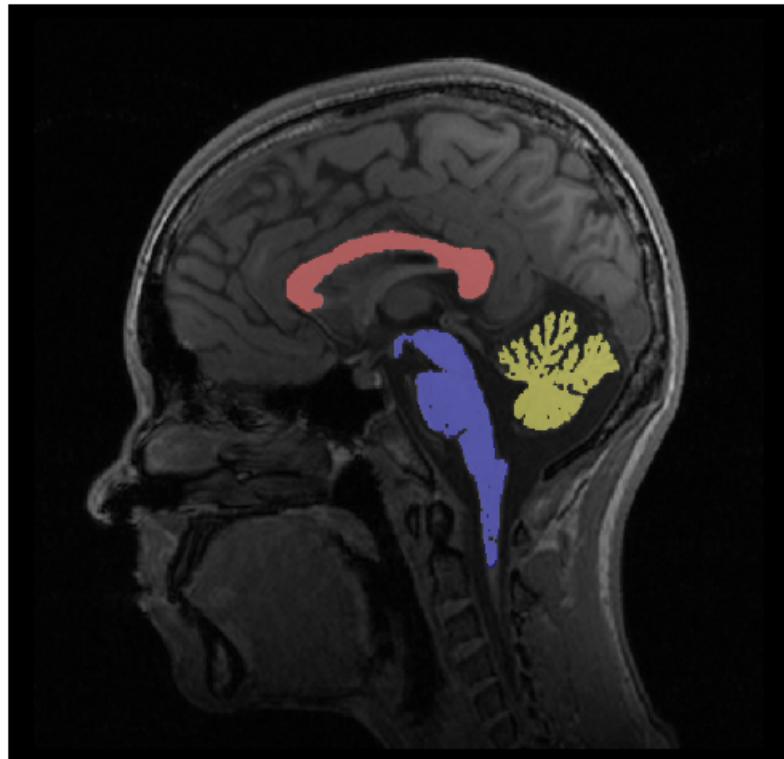
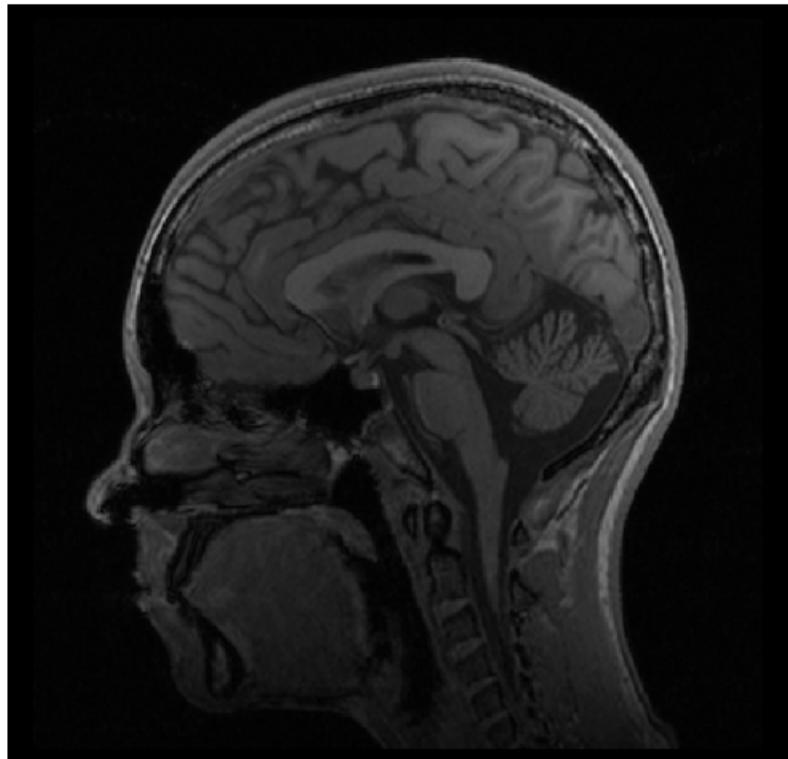
High Contrast



Example: Edge Detection



Example: Region Detection, Segmentation





Example: Image Compression



Original, 2.1MB



JPEG Compression, 308KB (15%)



Example: Image Inpainting

Damaged Image

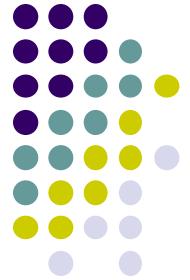


Restored Image



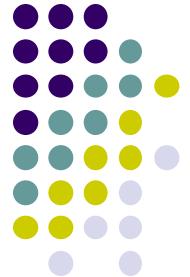
Credit: M. Bertalmio, G. Sapiro, V. Caselles, C. Ballester: *Image Inpainting*, SIGGRAPH 2000

Inpainting? Reconstruct corrupted/destroyed parts of an image



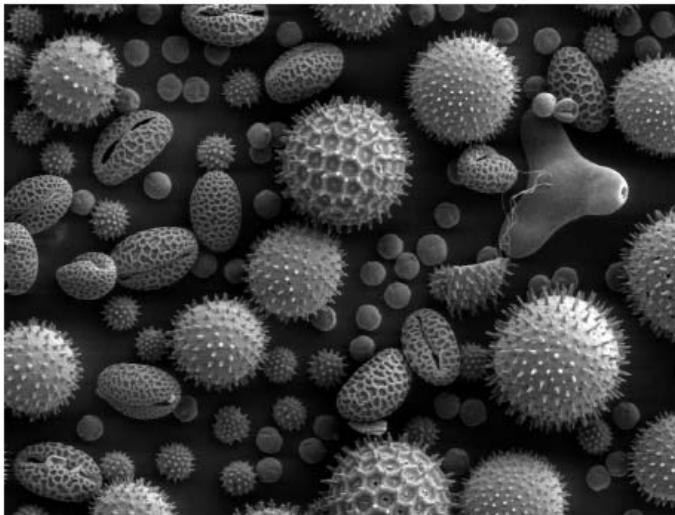
Examples: Artistic (Movie Special)Effects





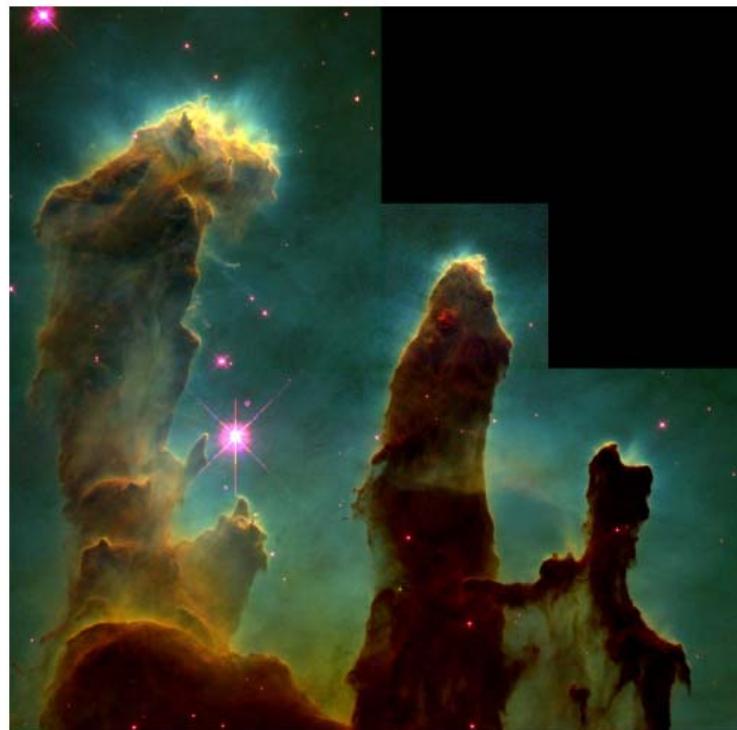
Applications of Image Processing

Biology

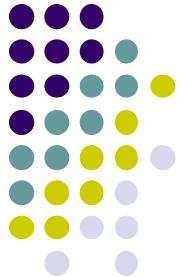


Credit: Dartmouth Electron Microscopy Facility

Astronomy

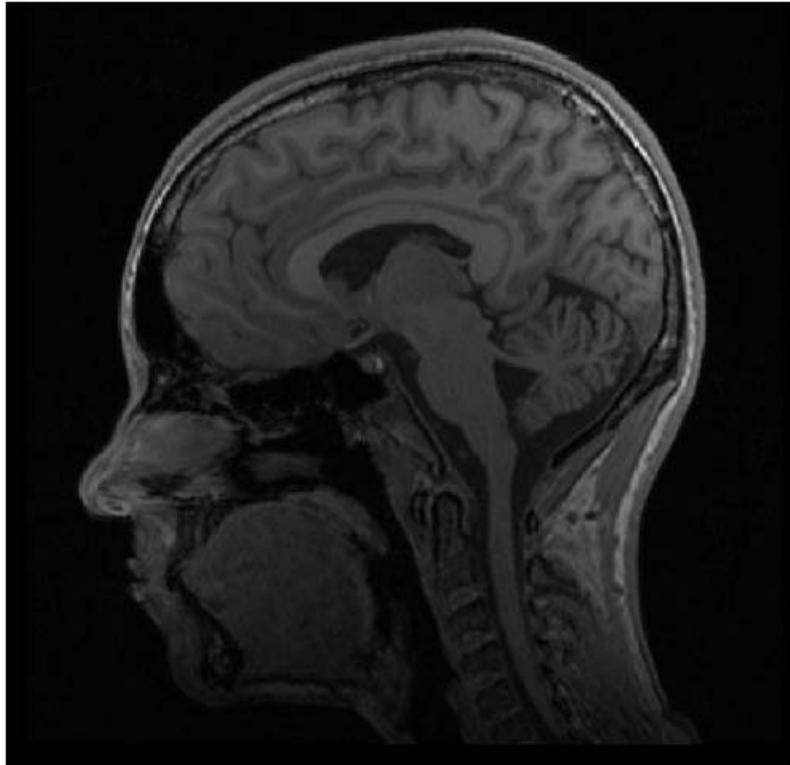


*Credit: NASA, Jeff Hester, and Paul Scowen (Arizona State)
More info here*



Applications of Image Processing

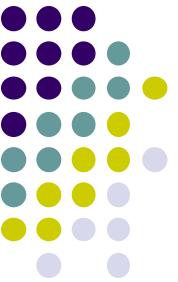
Medicine



Credit: Dr. Janet Lainhart, UofU Psychiatry

Security, Biometrics



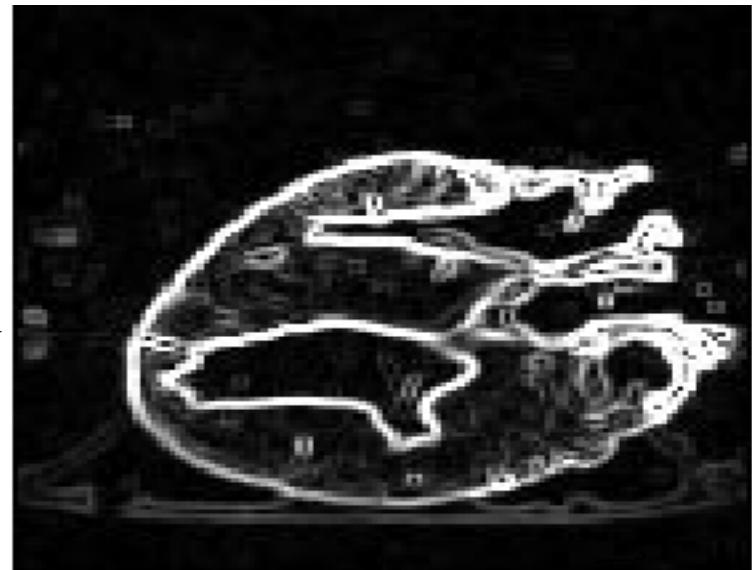


Applications of Image Processing: Medicine

Images taken from Gonzalez & Woods, Digital Image Processing (2002)



Original MRI Image of a Dog Heart



Edge Detection Image



Applications of Image Processing

Satellite Imagery



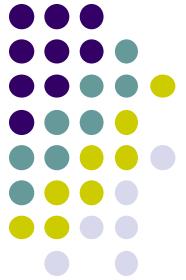
Credit: NASA

Personal Photos

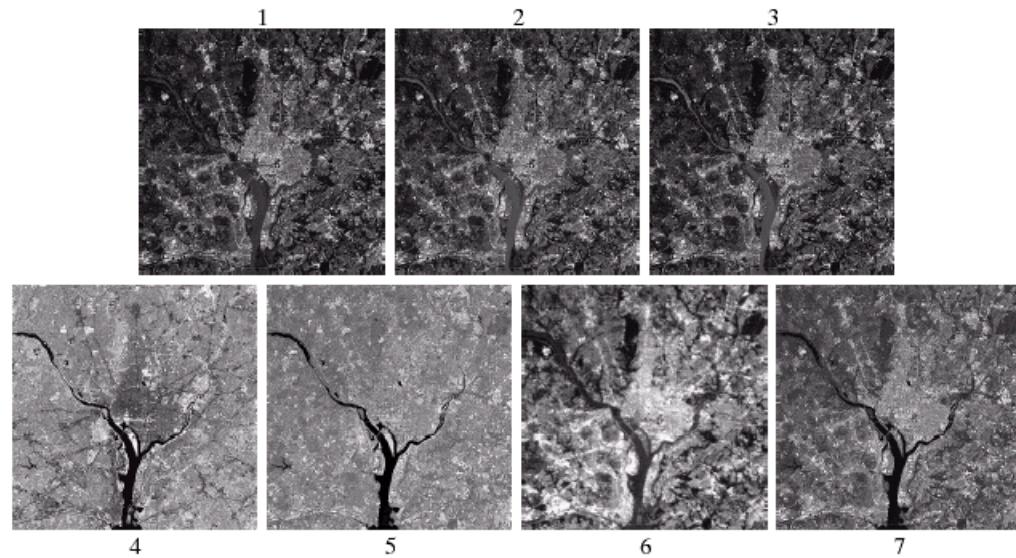


Credit: Tom Fletcher

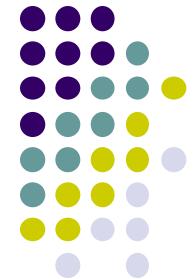
Applications of Image Processing: Geographic Information Systems (GIS)



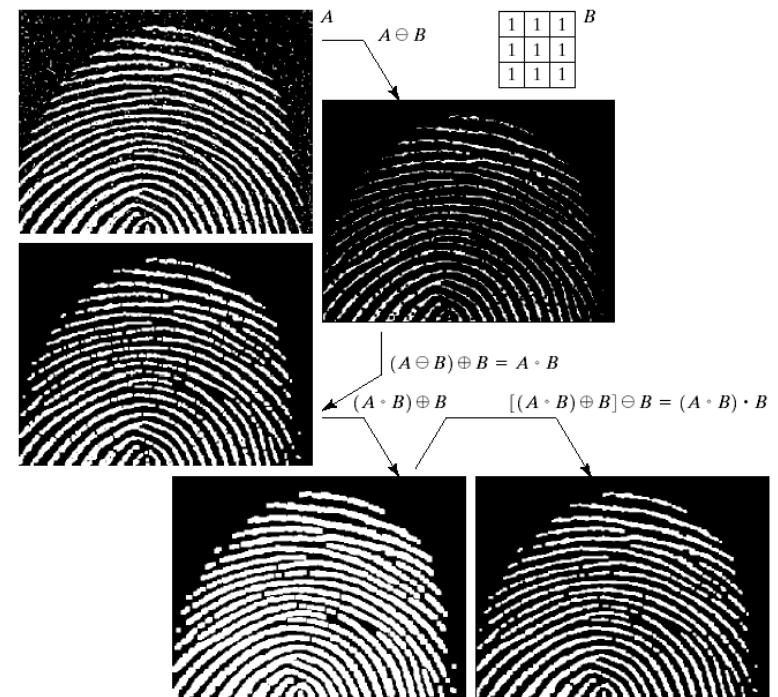
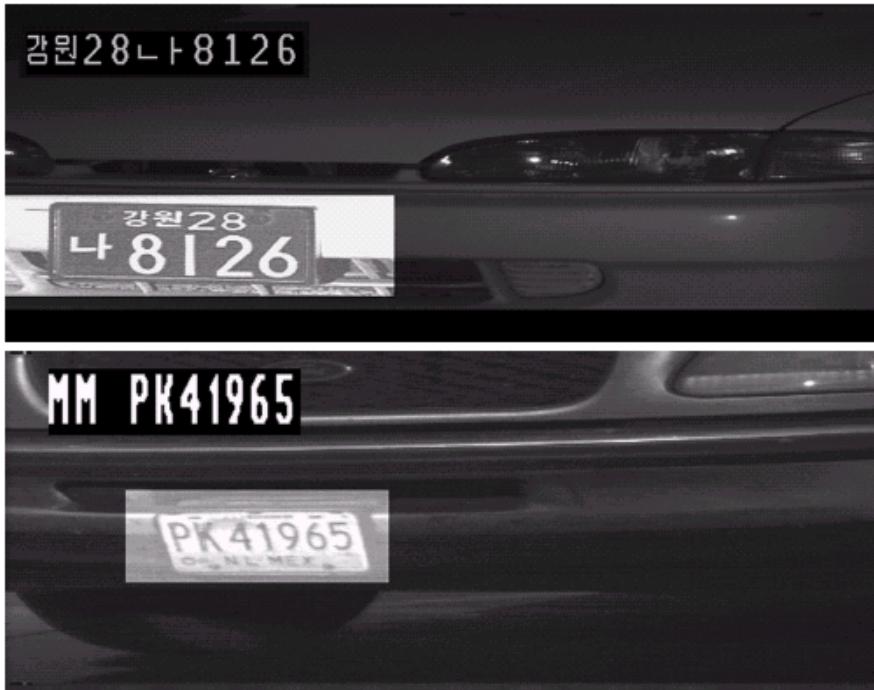
- Terrain classification
- Meteorology (weather)



Applications of Image Processing: Law Enforcement



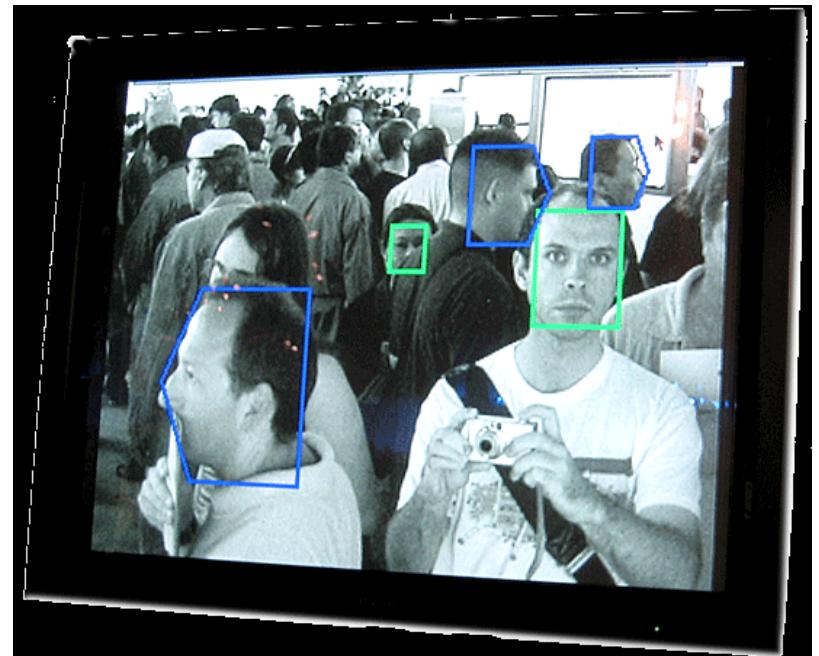
- Number plate recognition for speed cameras or automated toll systems
- Fingerprint recognition





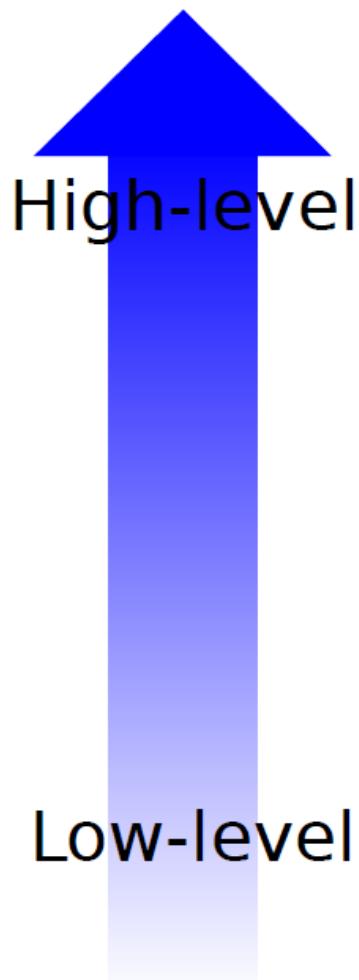
Applications of Image Processing: HCI

- Face recognition
- Gesture recognition





Relationship with other Fields



Computer Vision

Object detection, recognition, shape analysis, tracking
Use of Artificial Intelligence and Machine Learning

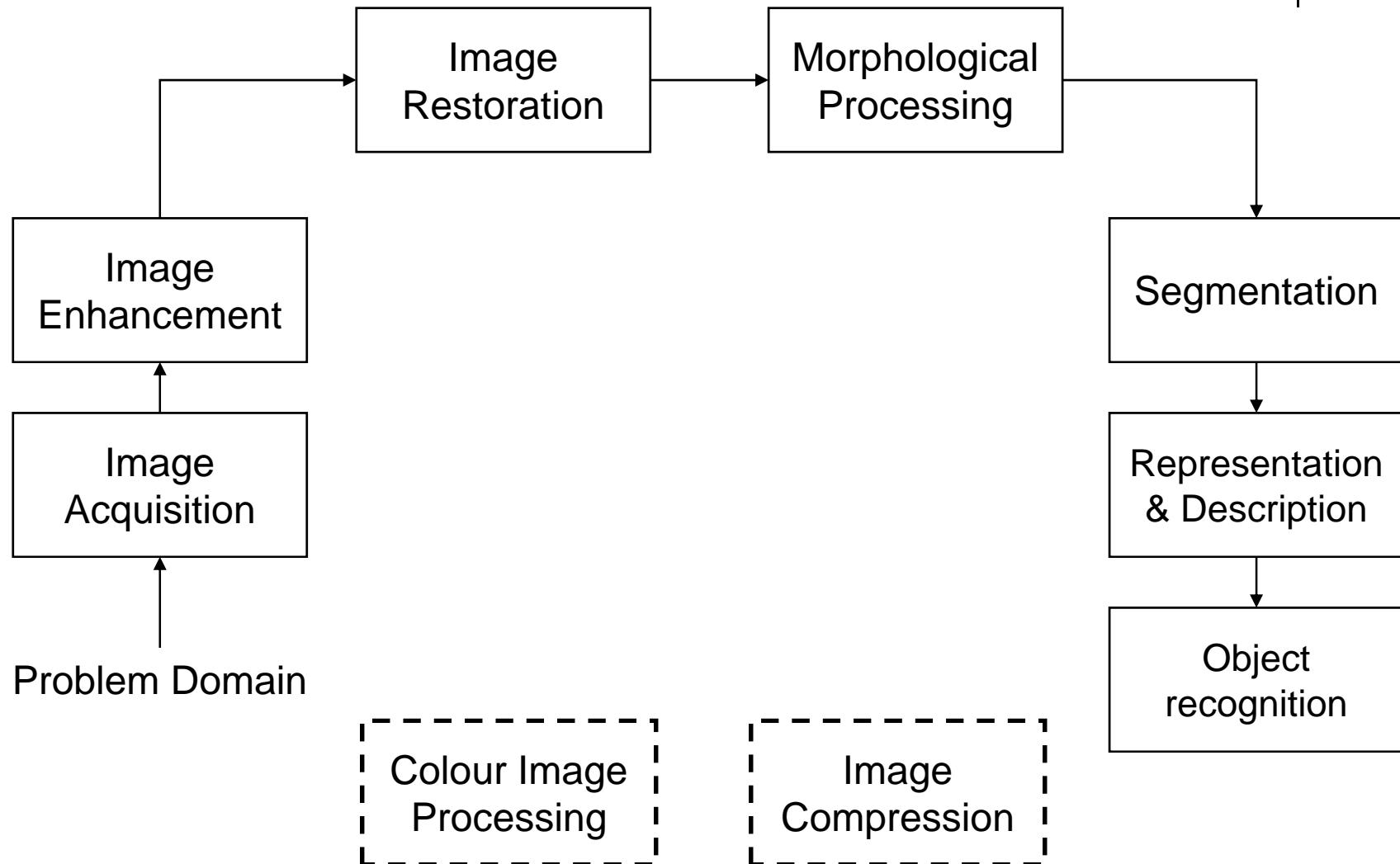
Image Analysis

Segmentation, image registration, matching

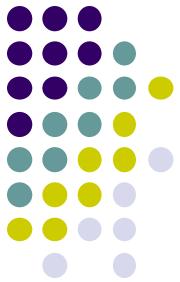
Image Processing

Image enhancement, noise removal, restoration,
feature detection, compression

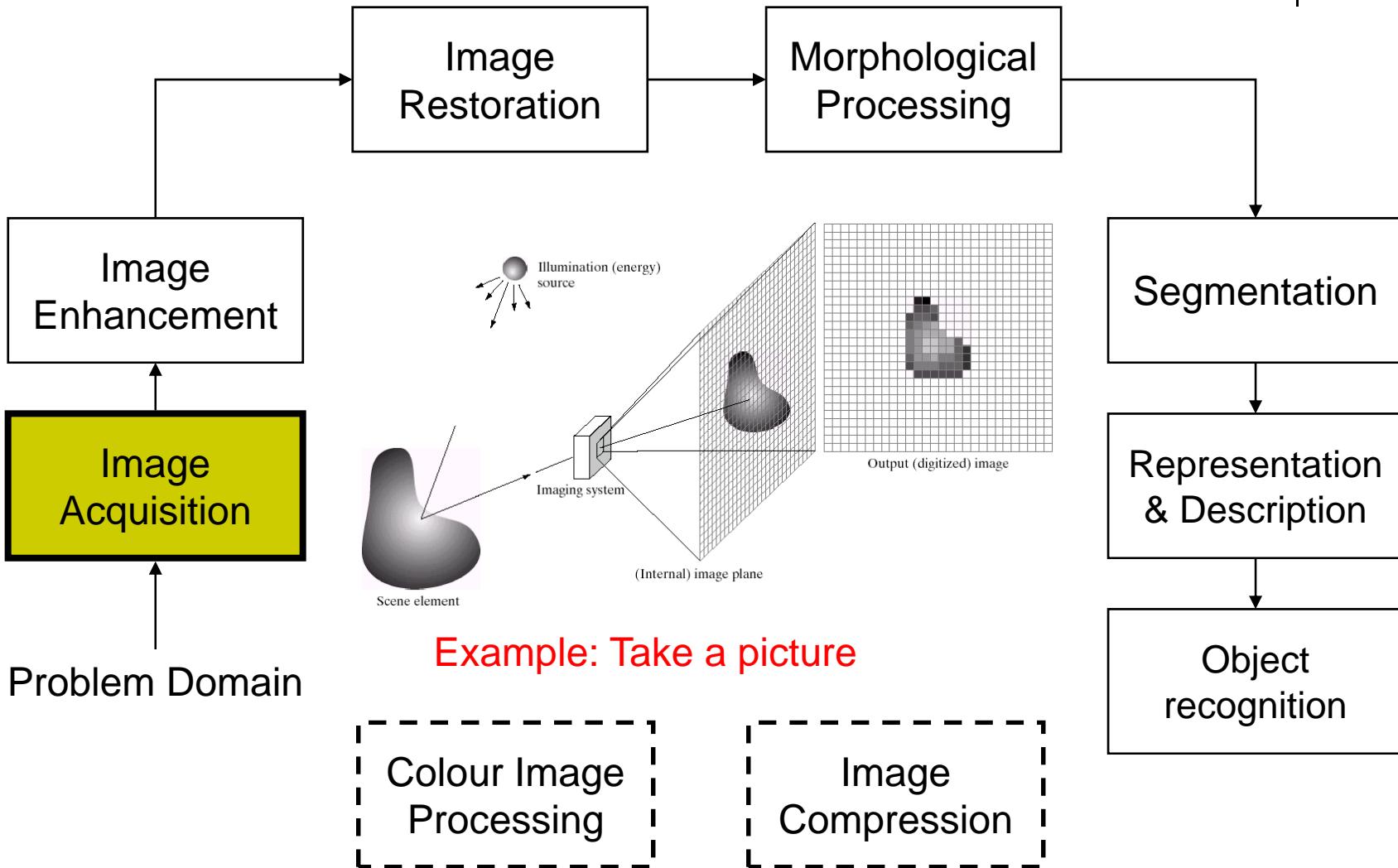
Key Stages in Digital Image Processing



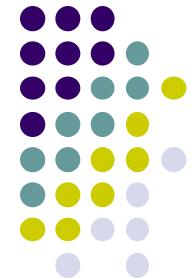
Key Stages in Digital Image Processing: Image Acquisition



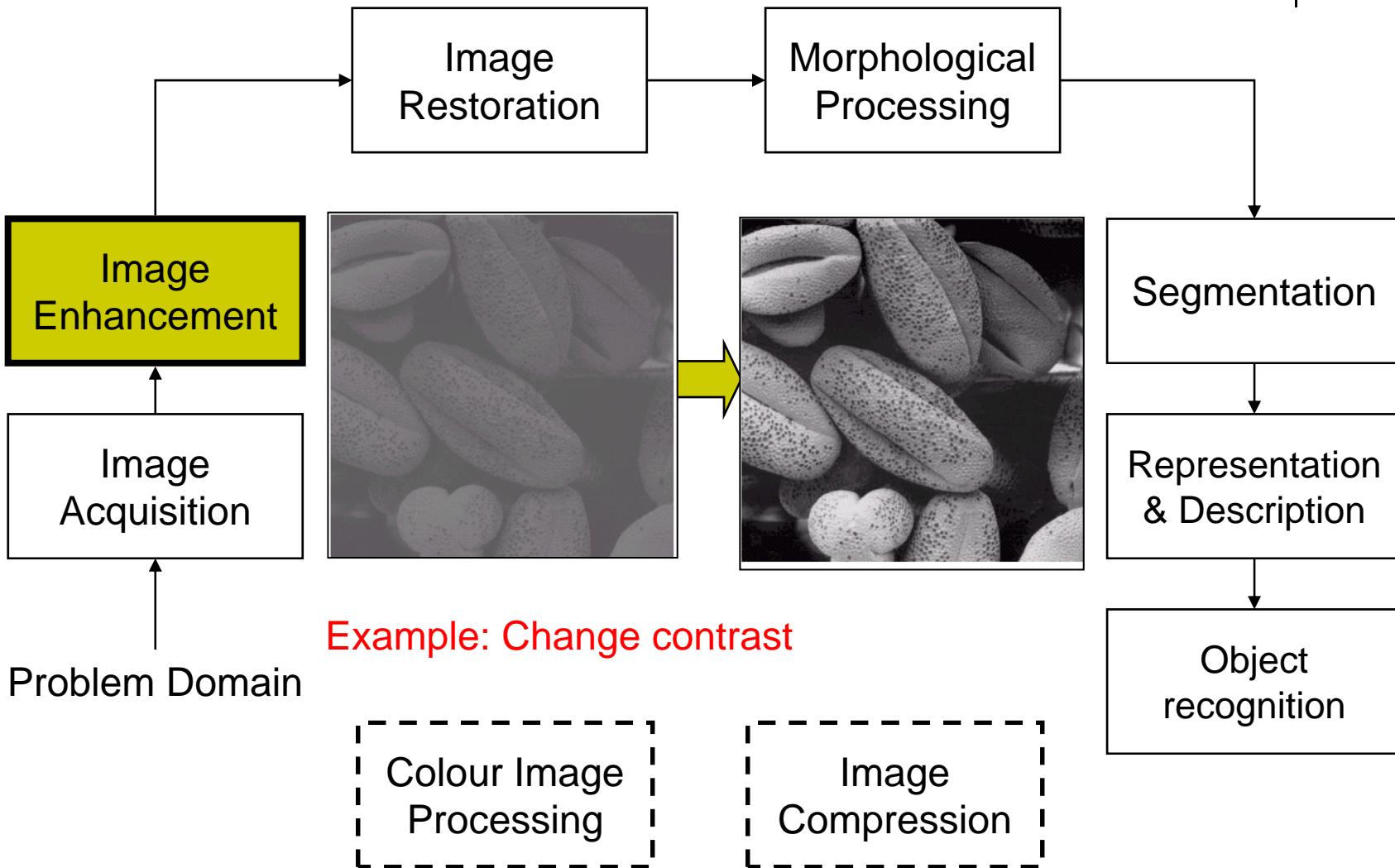
Images taken from Gonzalez & Woods, Digital Image Processing (2002)



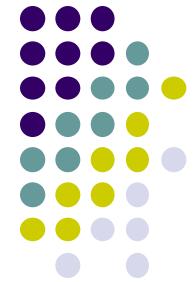
Key Stages in Digital Image Processing: Image Enhancement



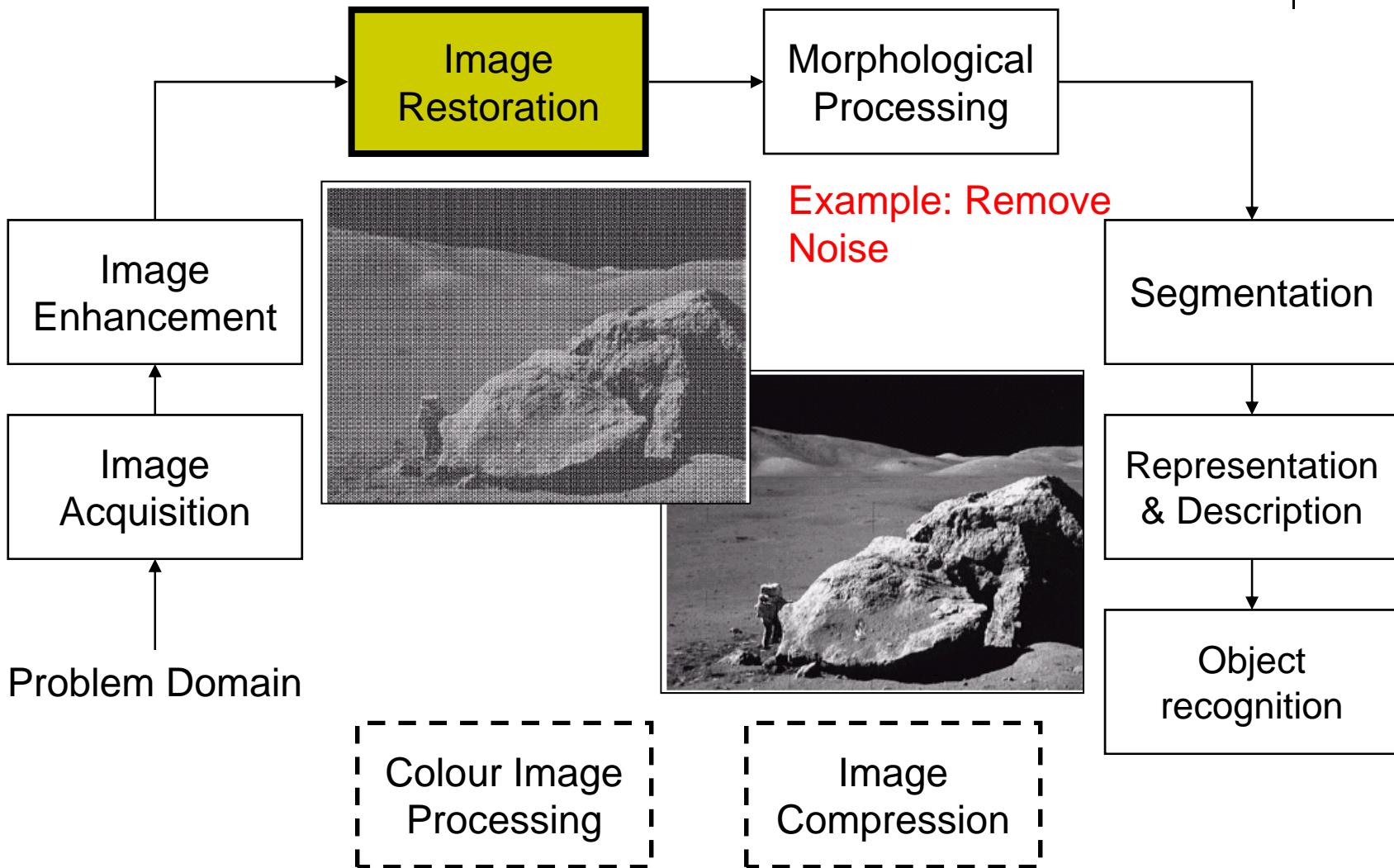
Images taken from Gonzalez & Woods, Digital Image Processing (2002)



Key Stages in Digital Image Processing: Image Restoration



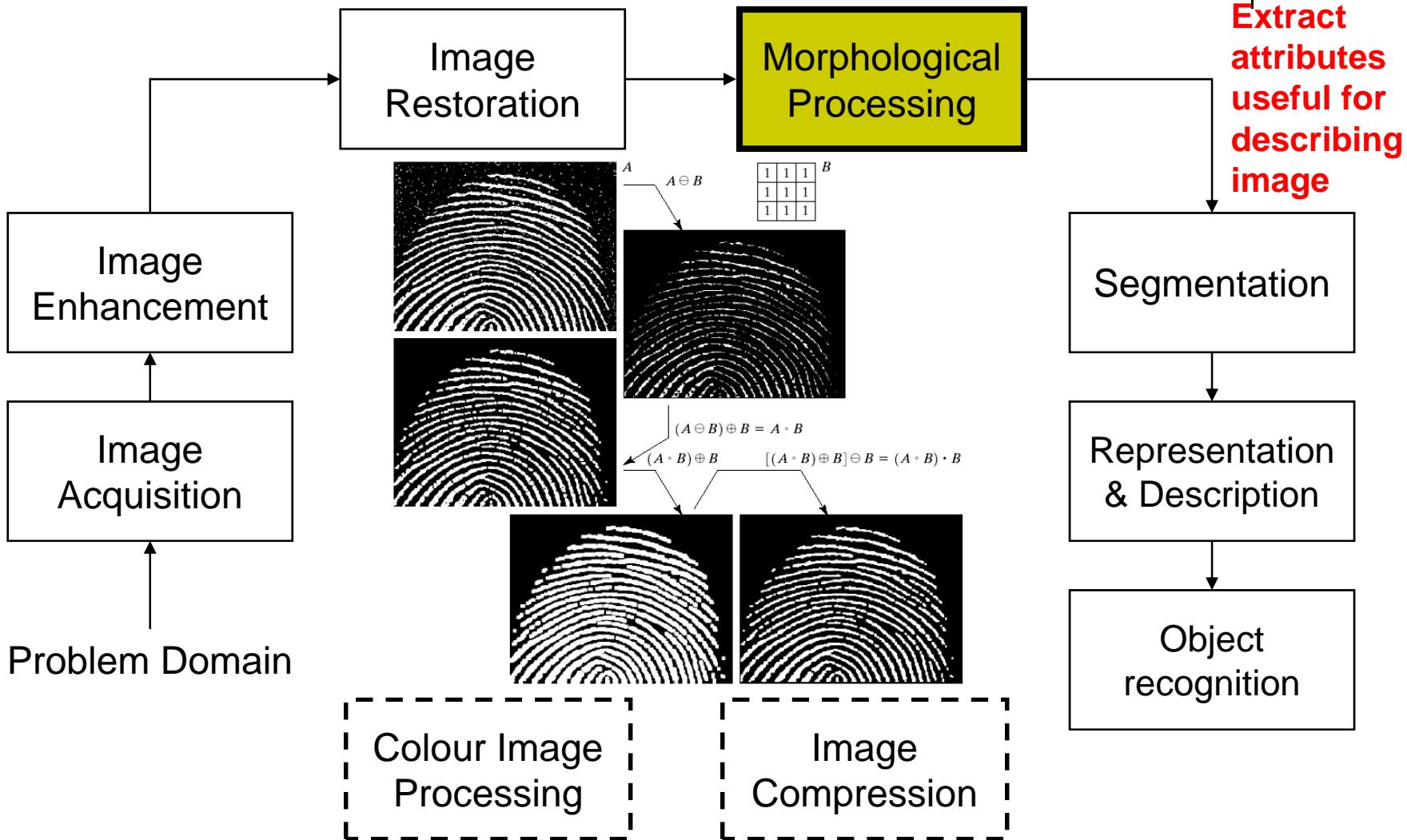
Images taken from Gonzalez & Woods, Digital Image Processing (2002)



Key Stages in Digital Image Processing: Morphological Processing



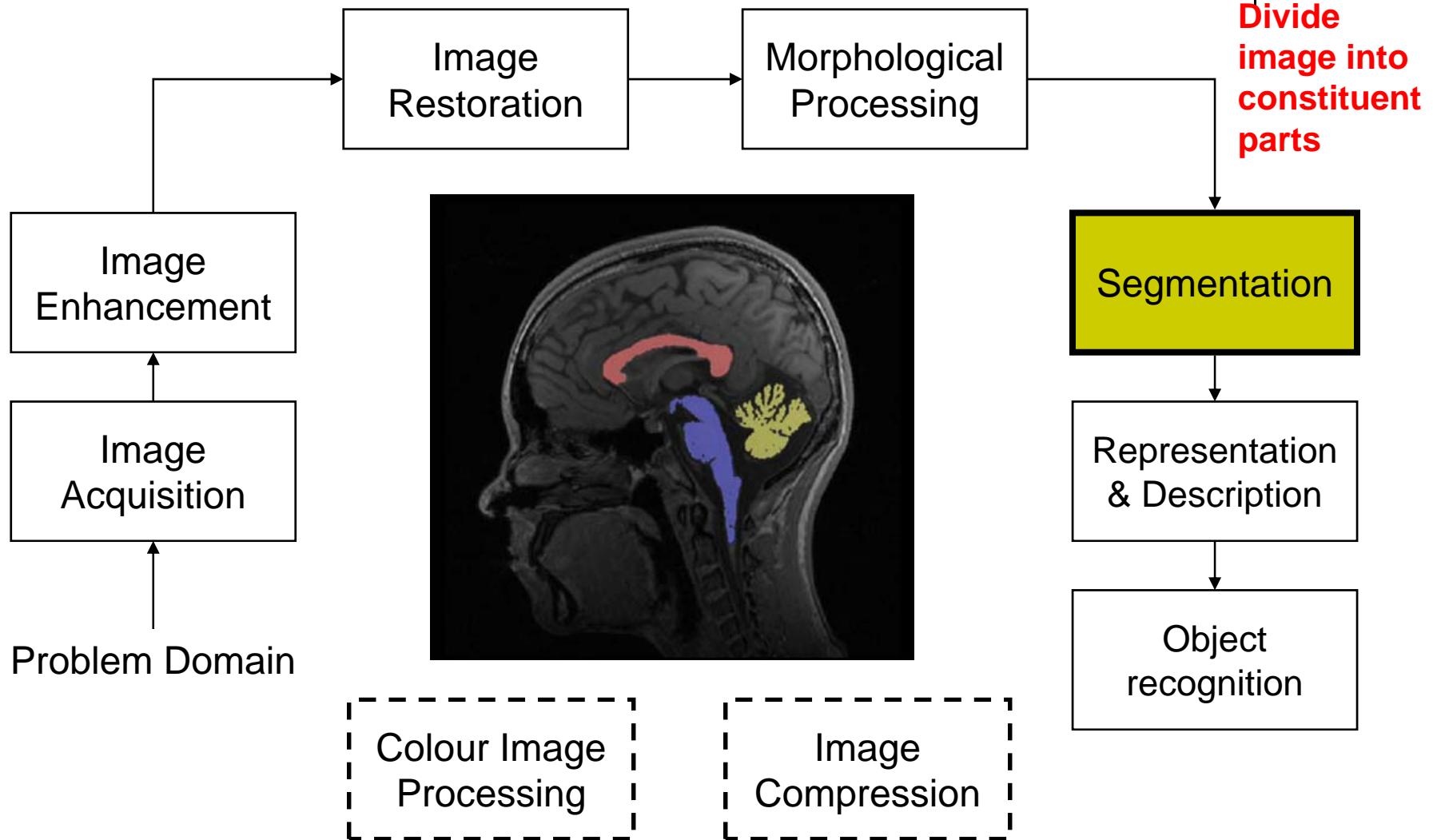
Extract
attributes
useful for
describing
image



Key Stages in Digital Image Processing: Segmentation



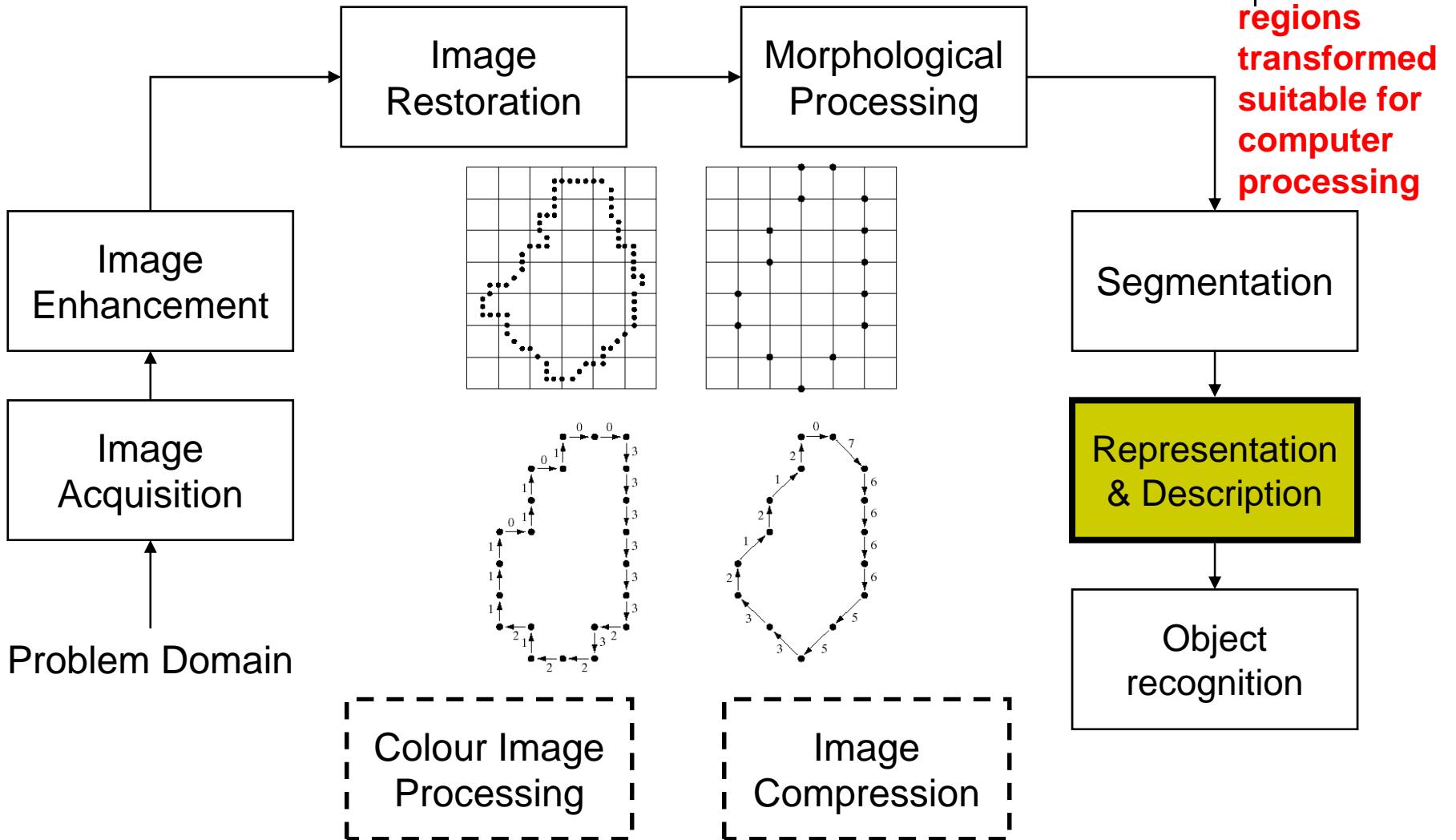
Divide
image into
constituent
parts



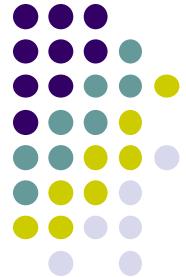
Key Stages in Digital Image Processing: Object Recognition



Image regions transformed suitable for computer processing

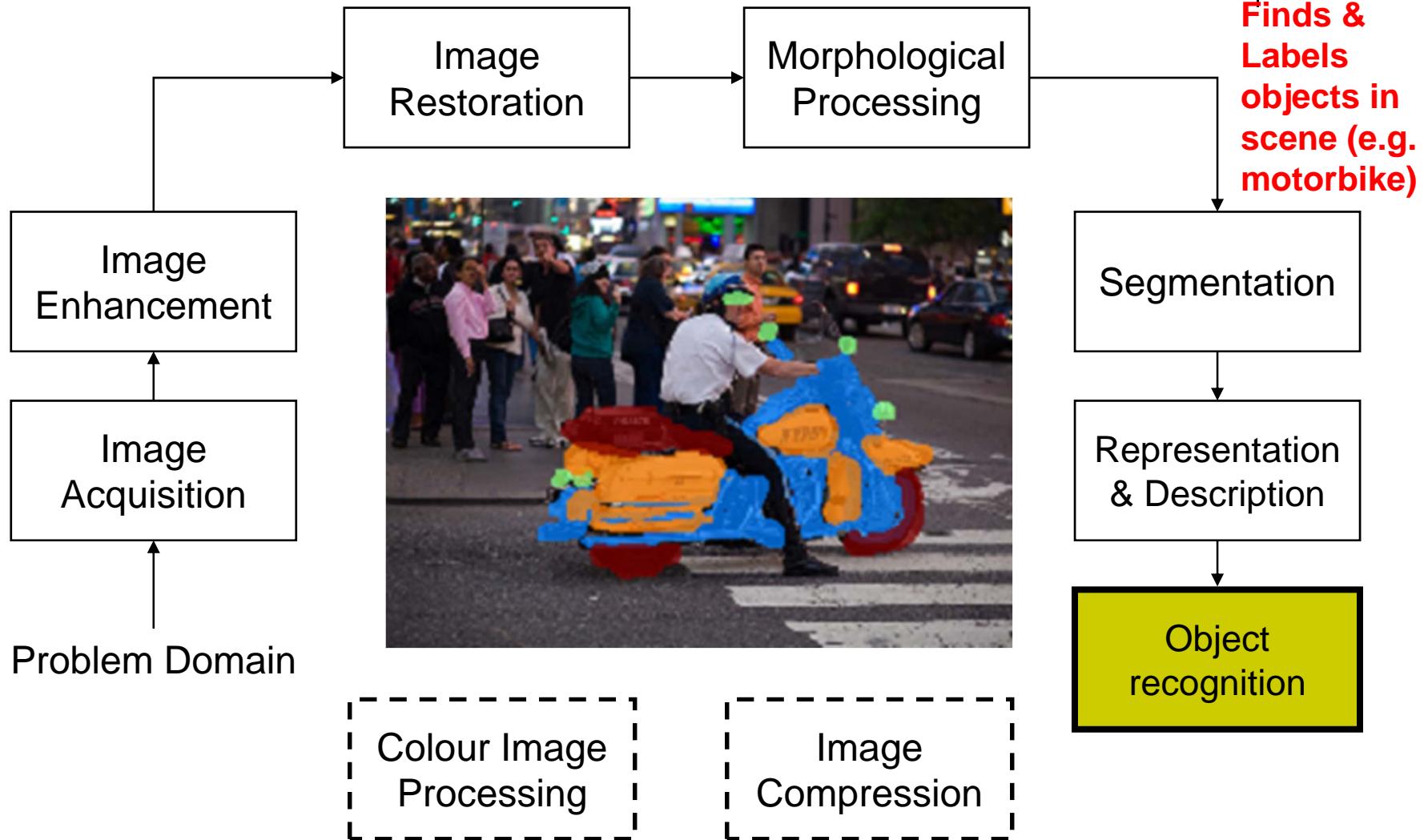


Key Stages in Digital Image Processing: Representation & Description

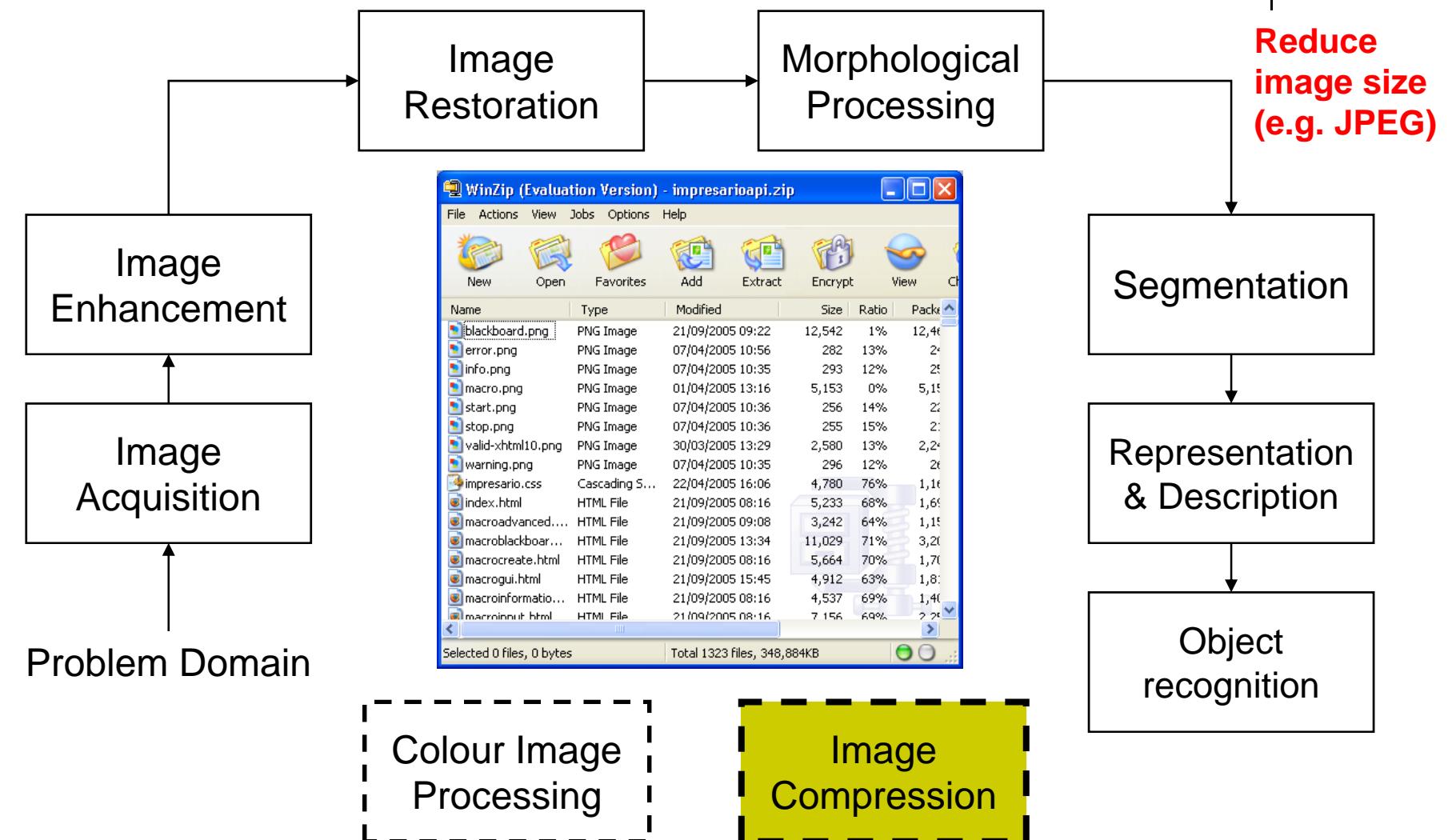


Finds &
Labels
objects in
scene (e.g.
motorbike)

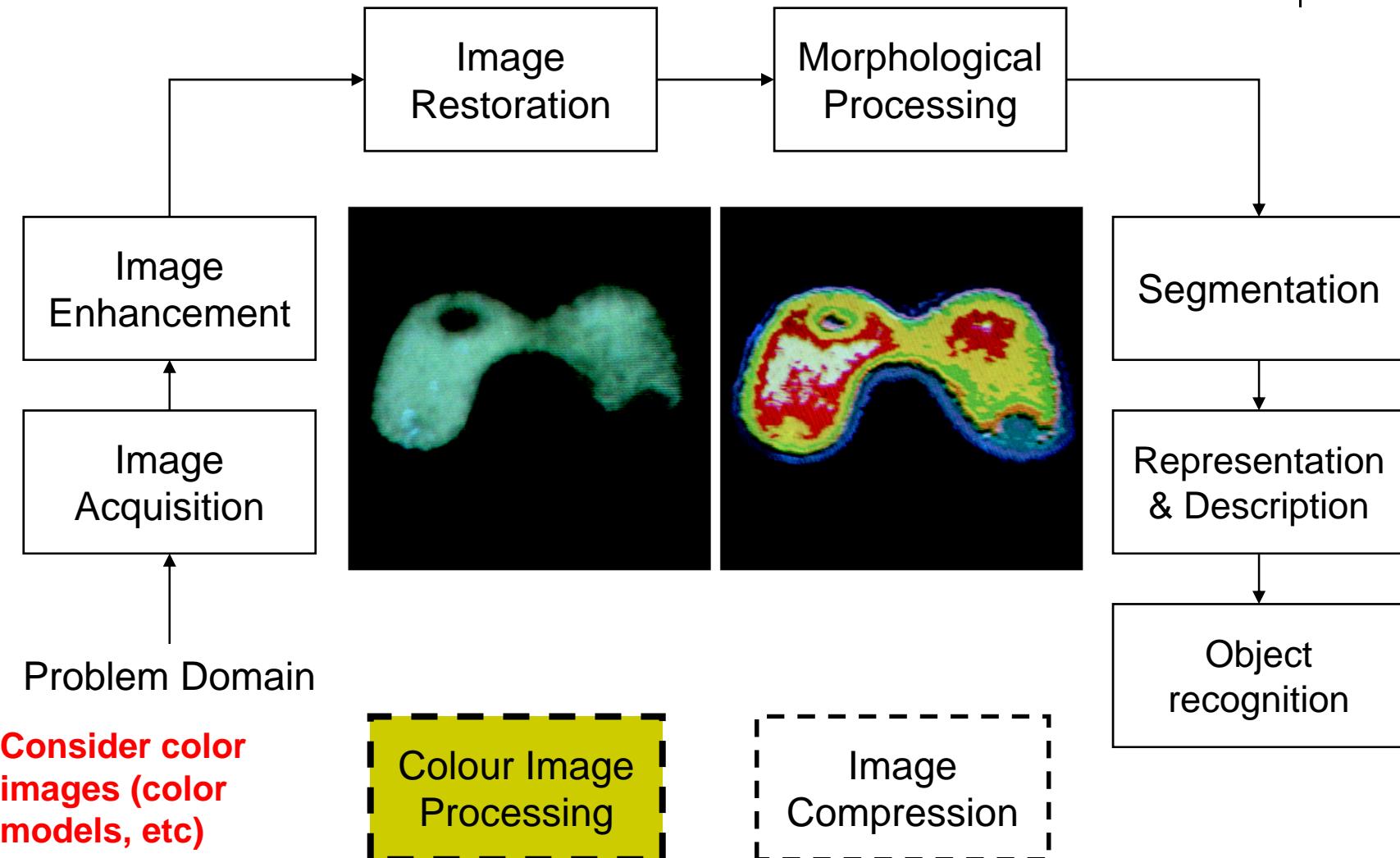
Images taken from Gonzalez & Woods, Digital Image Processing (2002)



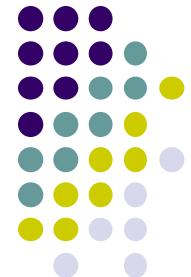
Key Stages in Digital Image Processing: Image Compression



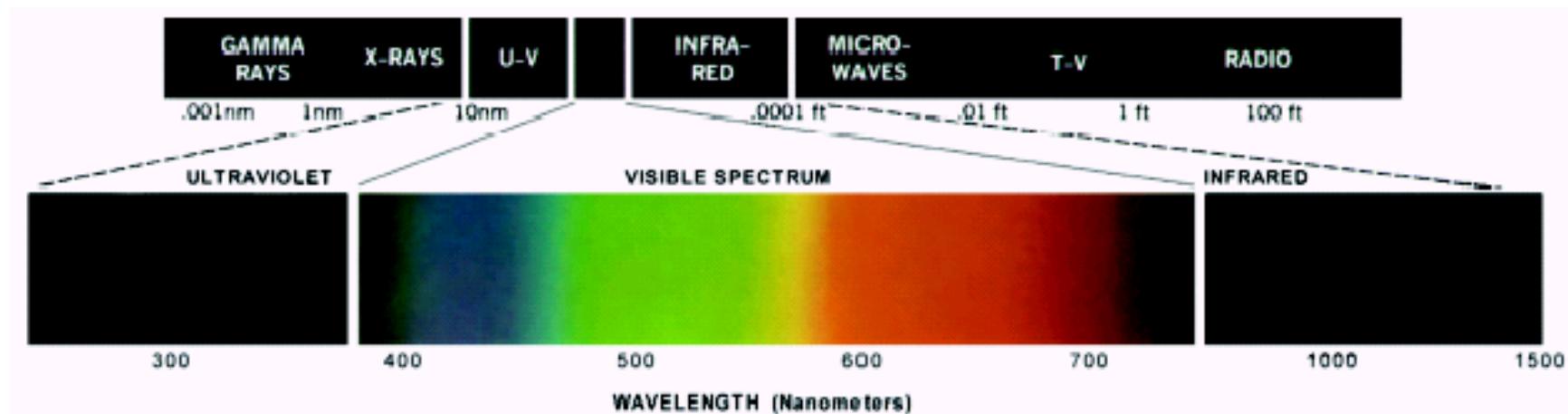
Key Stages in Digital Image Processing: Colour Image Processing



Light And The Electromagnetic Spectrum



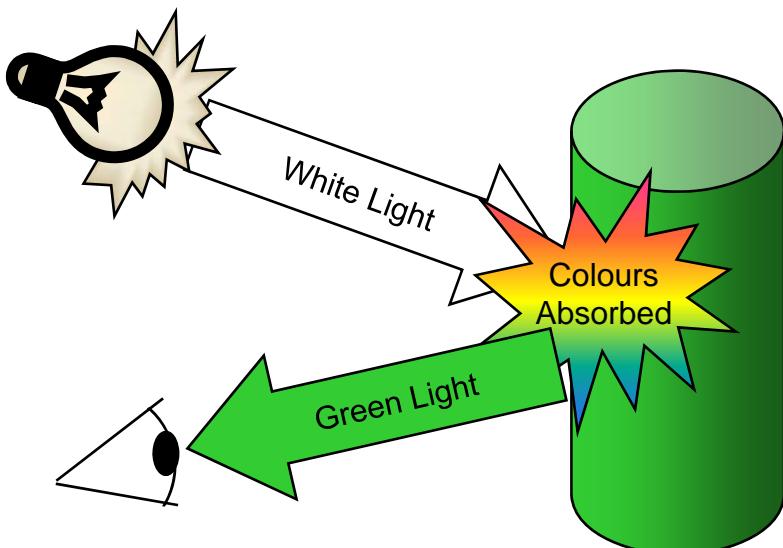
- Light: just a particular part of electromagnetic spectrum that can be sensed by the human eye
- The electromagnetic spectrum is split up according to the wavelengths of different forms of energy





Reflected Light

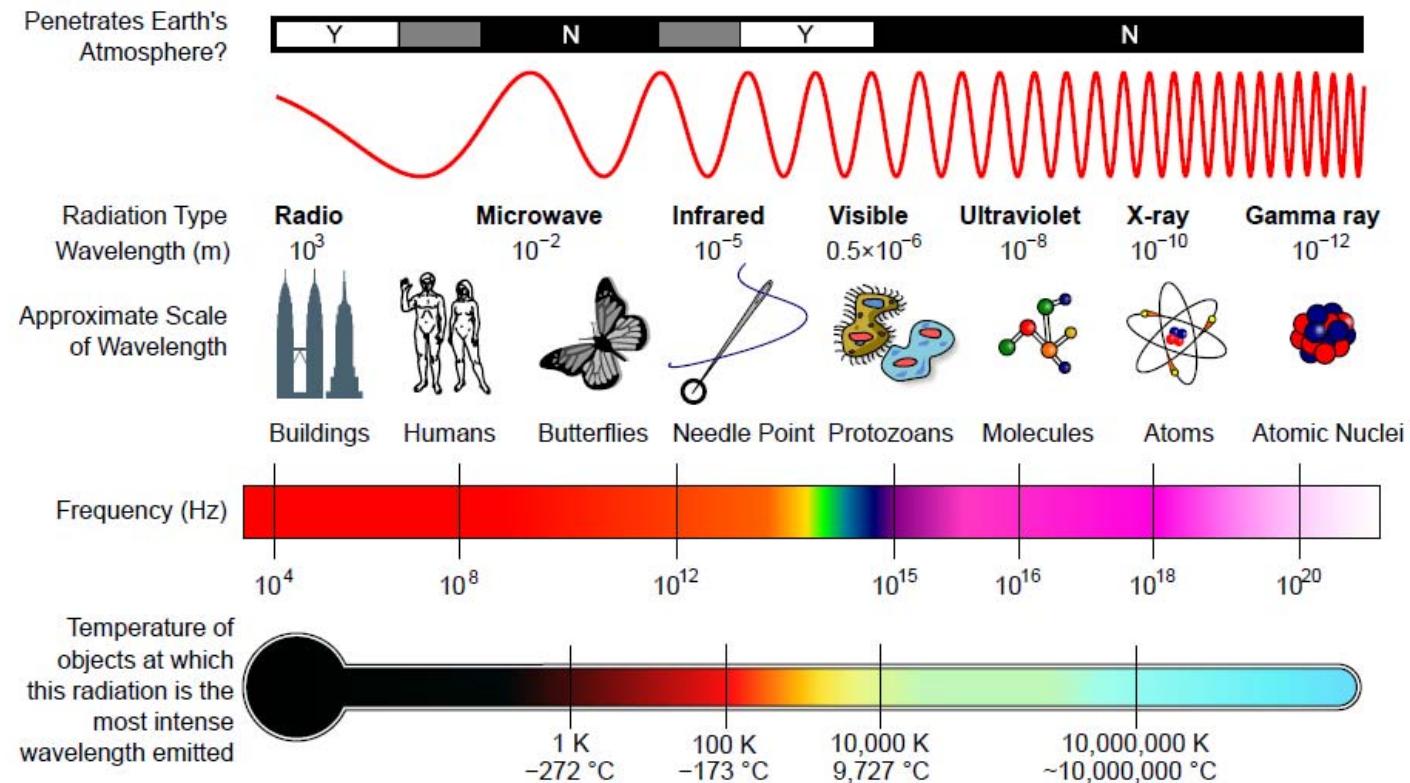
- The colours humans perceive are determined by nature of light reflected from an object
- For example, if white light (contains all wavelengths) is shone onto green object it absorbs most wavelengths absorbed except green wavelength (color)





Electromagnetic Spectrum and IP

- Images can be made from any form of EM radiation



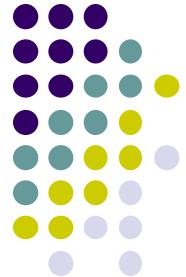
From Wikipedia



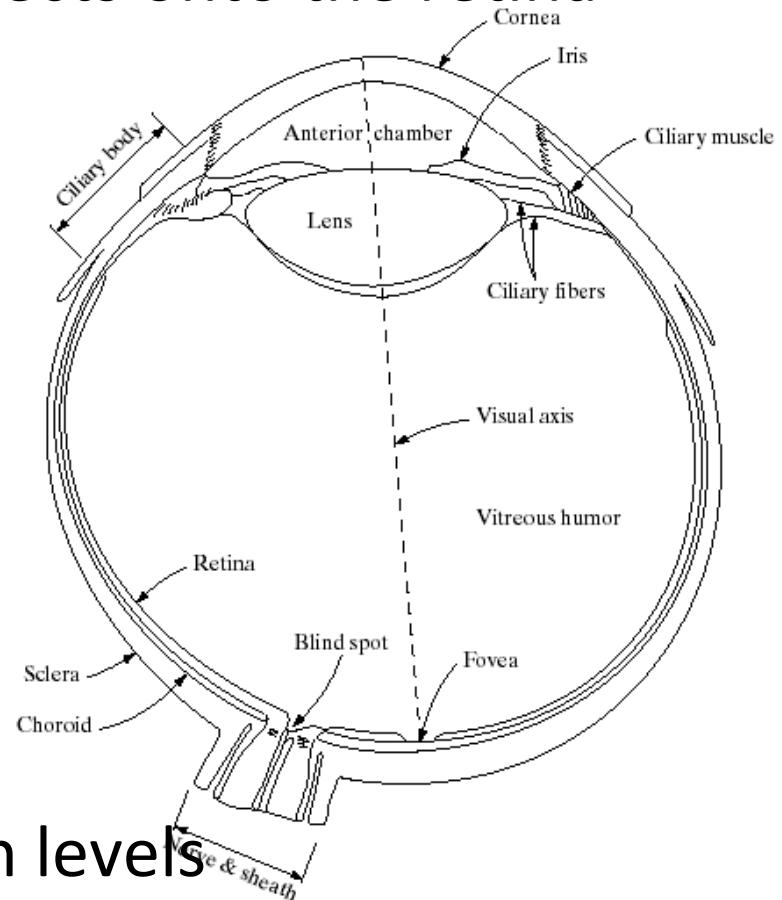
Images from Different EM Radiation

- Radar imaging (radio waves)
- Magnetic Resonance Imaging (MRI) (Radio waves)
- Microwave imaging
- Infrared imaging
- Photographs
- Ultraviolet imaging telescopes
- X-rays and Computed tomography
- Positron emission tomography (gamma rays)
- Ultrasound (not EM waves)

Human Visual System: Structure Of The Human Eye



- The lens focuses light from objects onto the retina
- Retina covered with light receptors called **cones** (6-7 million) and **rods** (75-150 million)
 - 视椎细胞
- Cones concentrated around fovea. Very sensitive to colour
 - 视杆细胞
- Rods more spread out and sensitive to low illumination levels



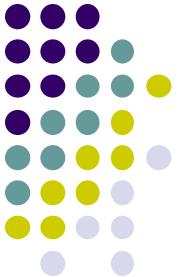


Image Formation In The Eye

- Muscles in eye can change the shape of the lens allowing us focus on near or far objects
- An image is focused onto retina exciting the rods and cones and send signals to the brain

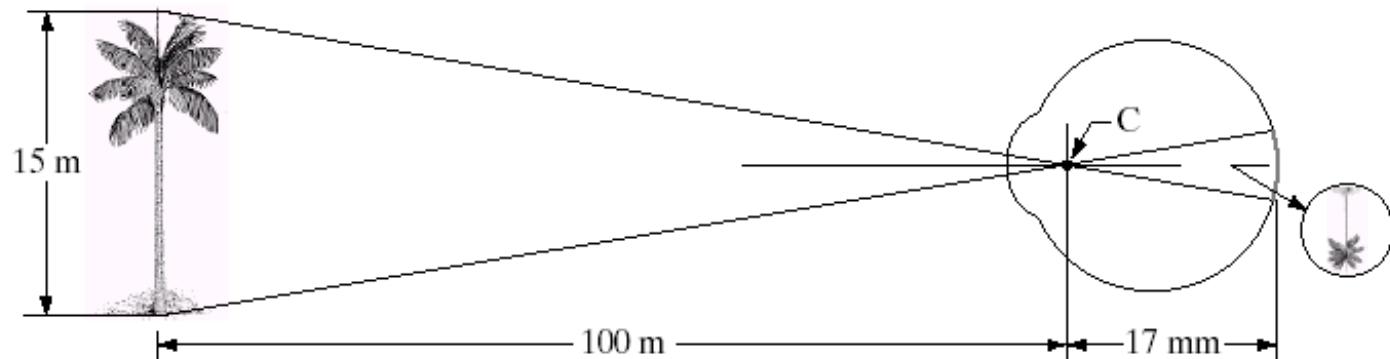
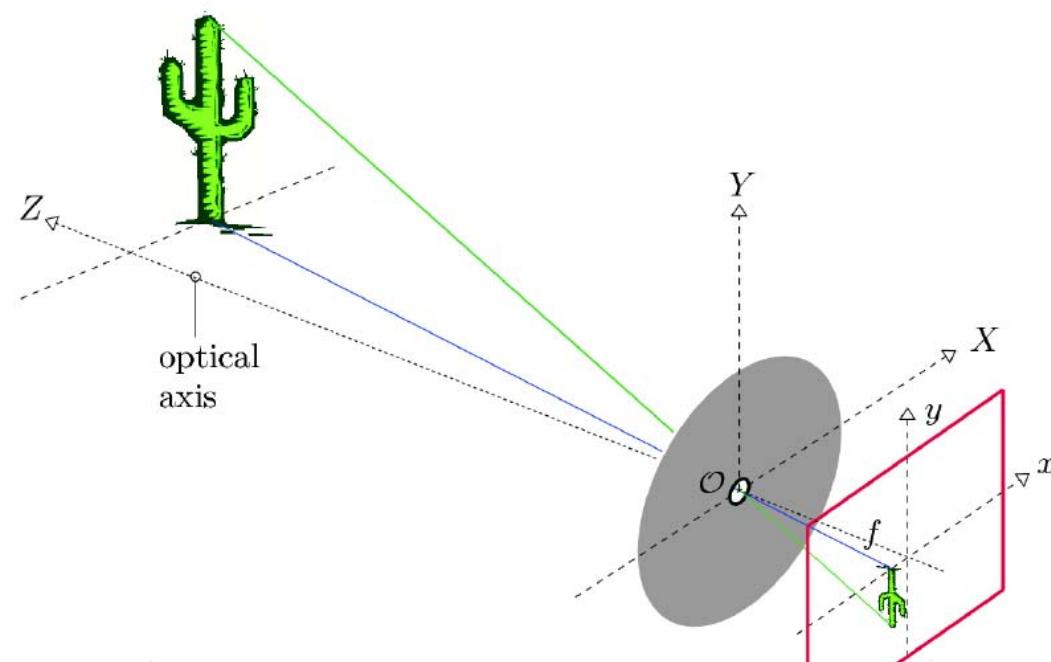




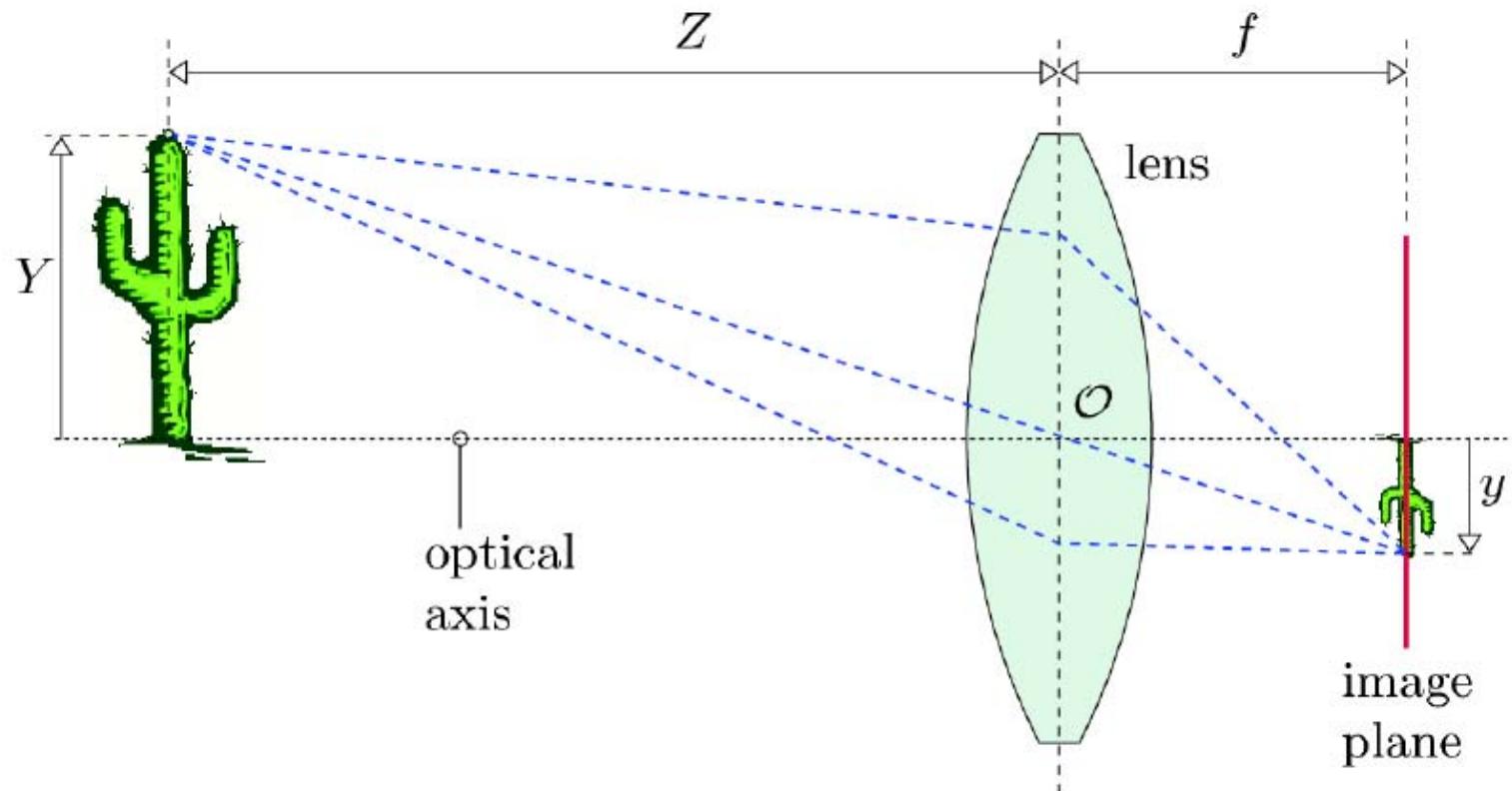
Image Formation

- The Pinhole Camera (abstraction)
 - First described by ancient Chinese and Greeks (300-400AD)

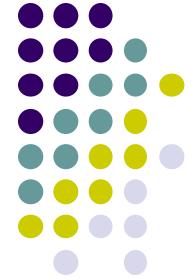


$$x = -\frac{f}{Z}X, \quad y = -\frac{f}{Z}Y$$

Thin Lens



Brightness Adaptation & Discrimination

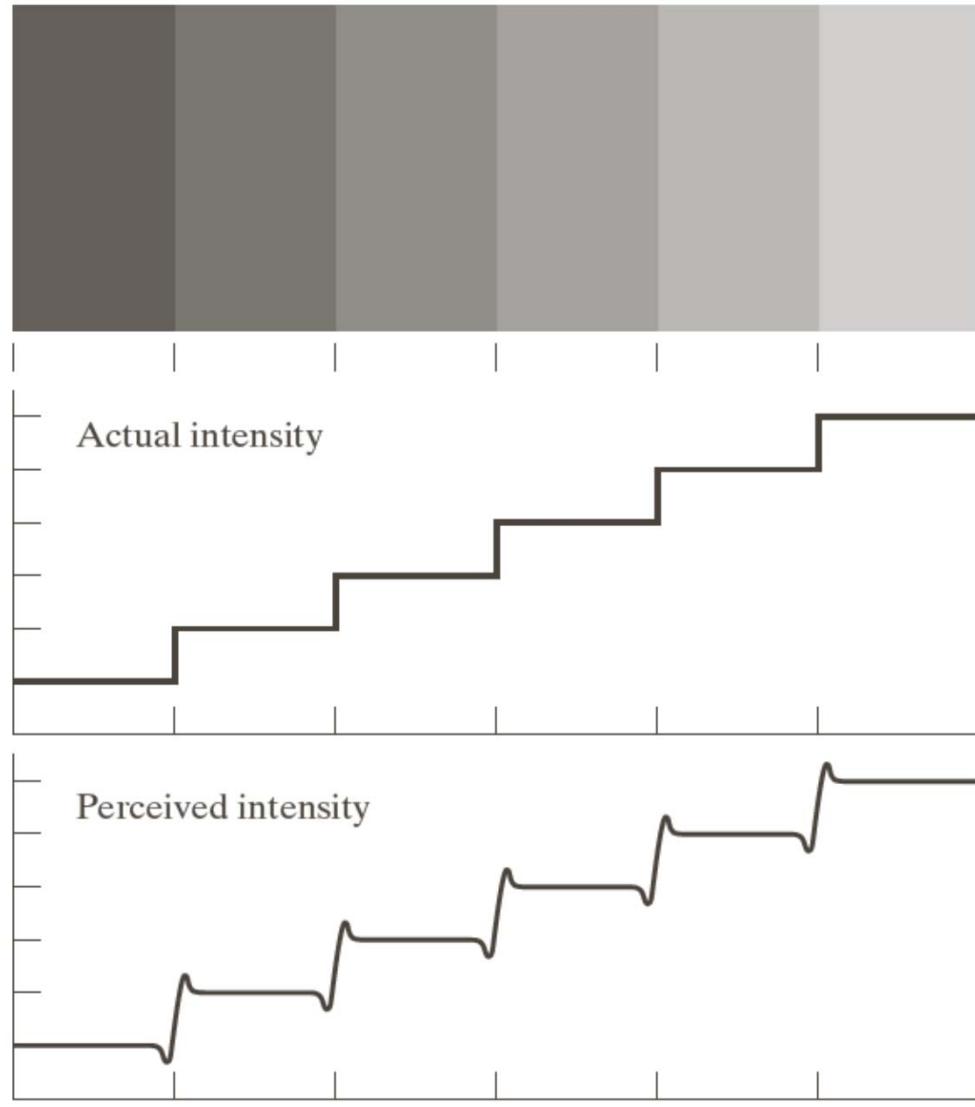


- The human visual system can perceive approximately 10^{10} different light intensity levels
- However, at any one time we can only discriminate between a much smaller number – *brightness adaptation*
- Similarly, *perceived intensity* of a region is related to the light intensities of the regions surrounding it

Brightness Adaptation & Discrimination: Mach Band Effect

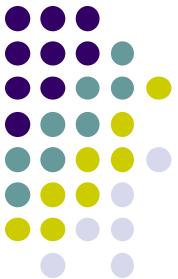


Images taken from Gonzalez & Woods, Digital Image Processing (2002)

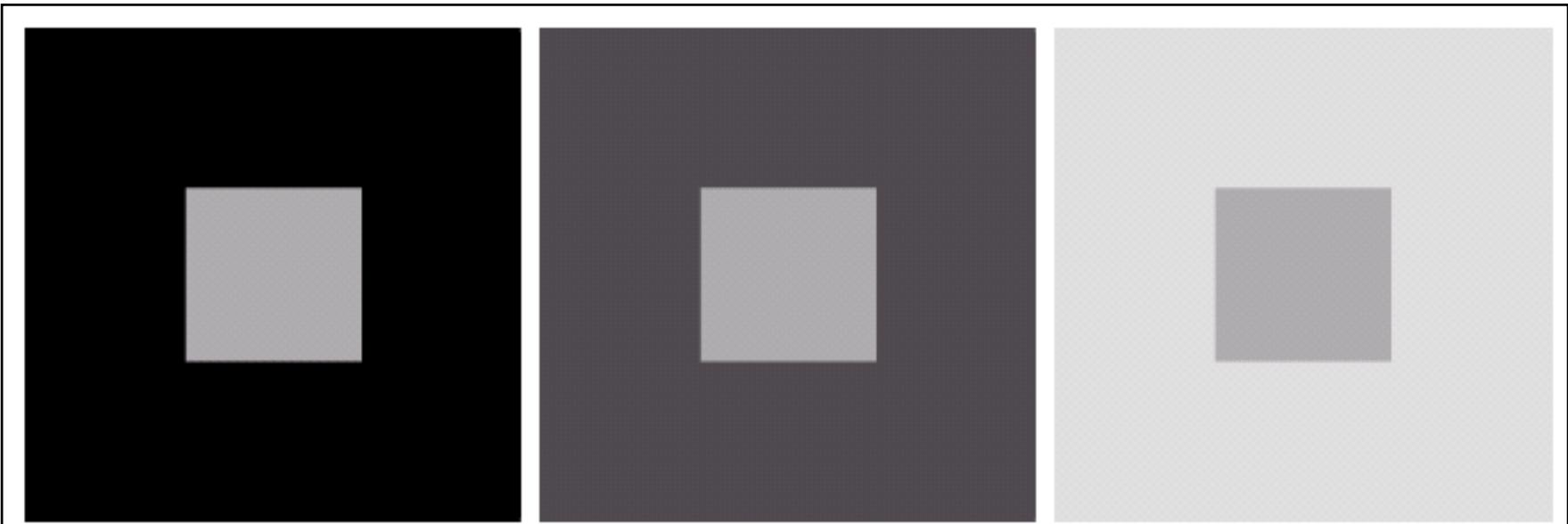


Perceived intensity
overshoots or undershoots
at areas of intensity change

Brightness Adaptation & Discrimination



Images taken from Gonzalez & Woods, Digital Image Processing (2002)



An example of *simultaneous contrast*

All inner squares have same intensity but appear darker as outer square (surrounding area) gets lighter



Image Acquisition

- Images typically generated by *illuminating a scene* and absorbing energy reflected by scene objects

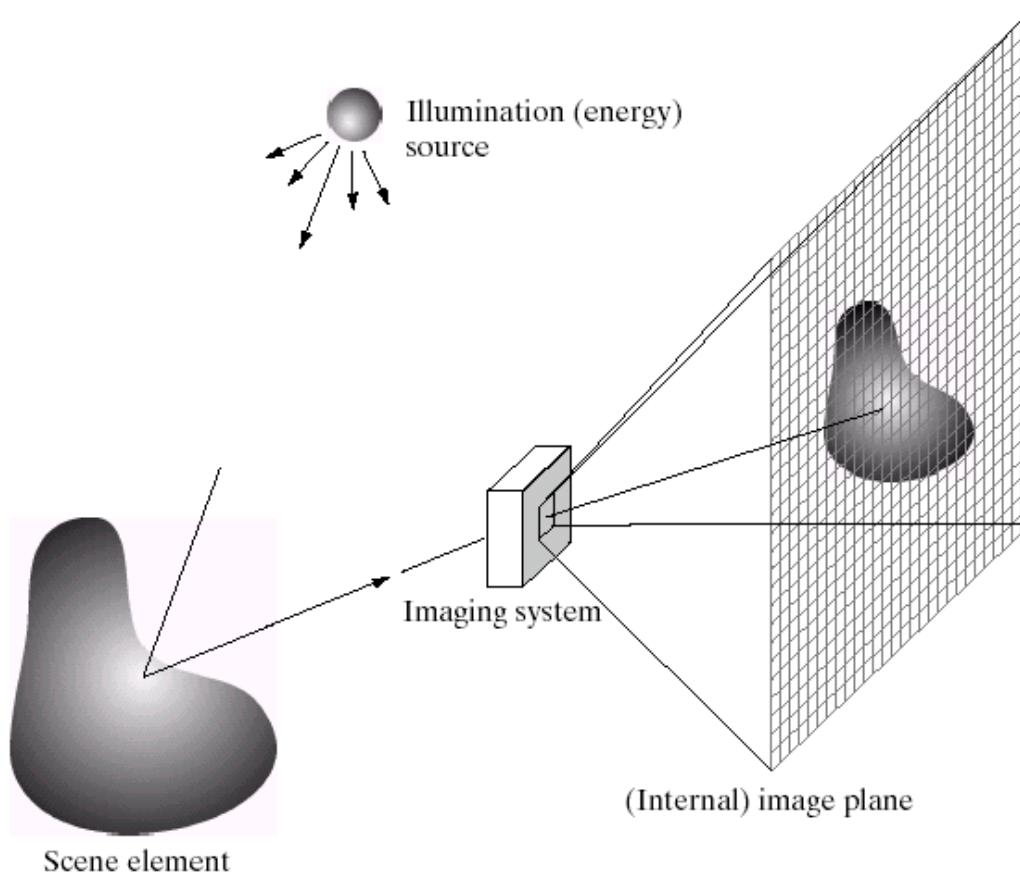
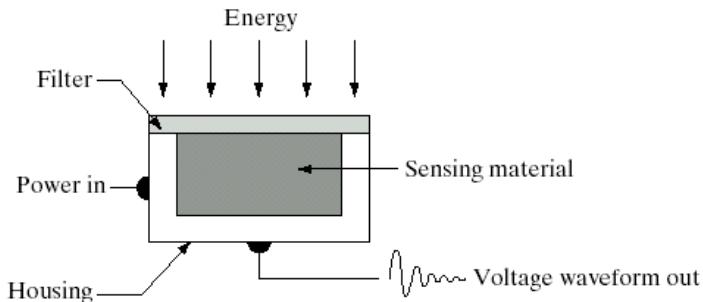


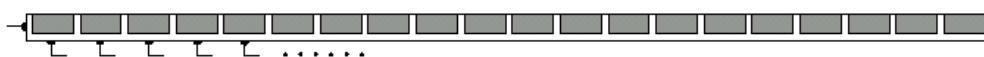


Image Sensing

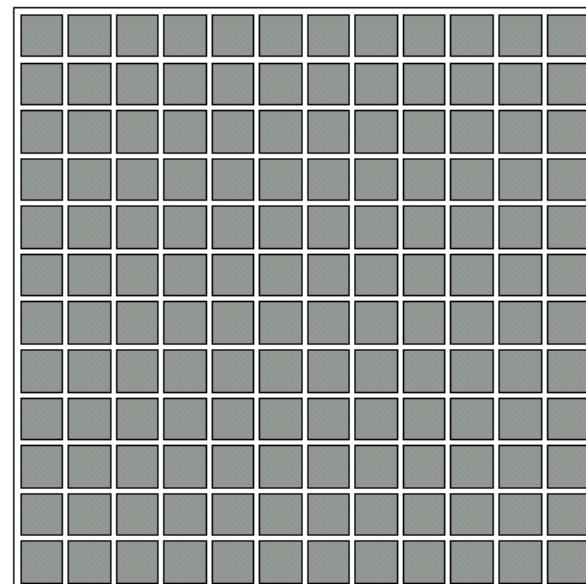
- Incoming energy (e.g. light) lands on a sensor material responsive to that type of energy, generating a voltage
- Collections of sensors are arranged to capture images



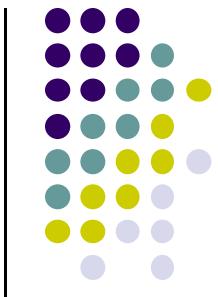
Imaging Sensor



Line of Image Sensors

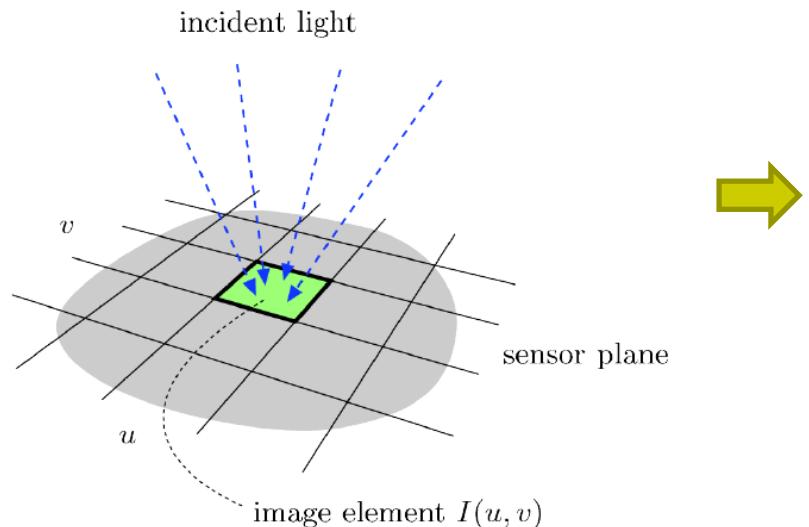


Array of Image Sensors



Spatial Sampling

- Cannot record image values for all (x,y)
 - Sample/record image values at discrete (x,y)
 - Sensors arranged in grid to sample image



$$F(x, y)$$

$$I(u, v)$$



Image (Spatial) Sampling

- A digital sensor can only measure a limited number of **samples** at a **discrete** set of energy levels
- **Sampling** can be thought of as:
Continuous signal \times comb function

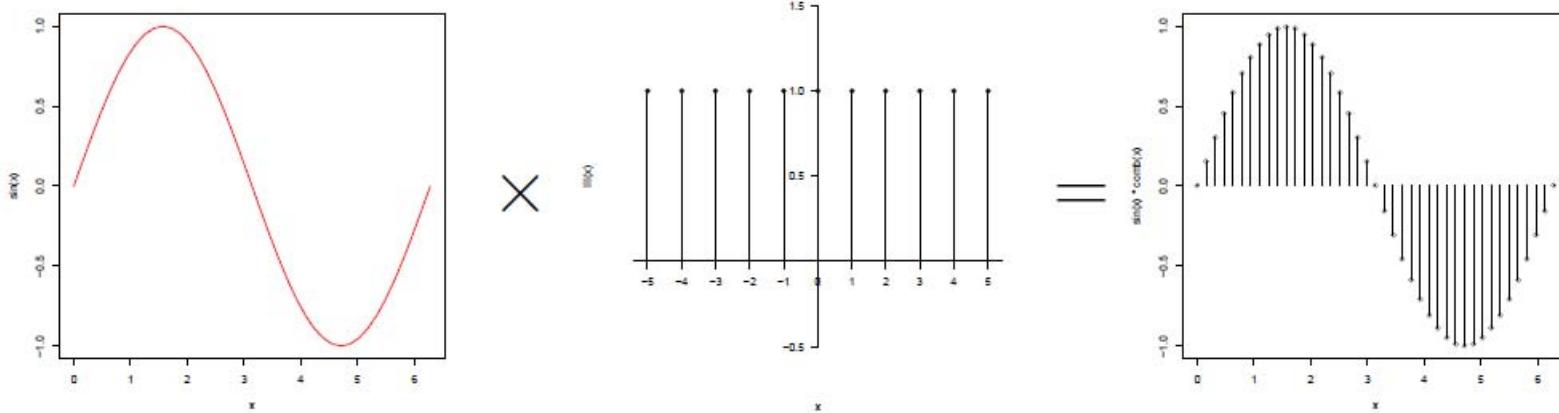




Image Quantization

- **Quantization:** process of converting continuous **analog** signal into its digital representation
- Discretize image $I(u,v)$ values
- Limit values image can take

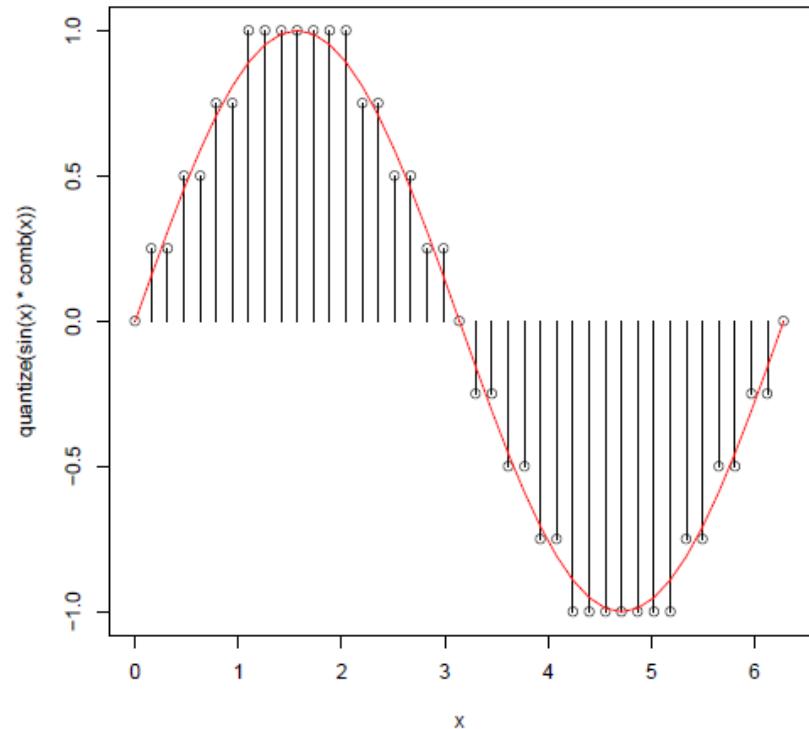
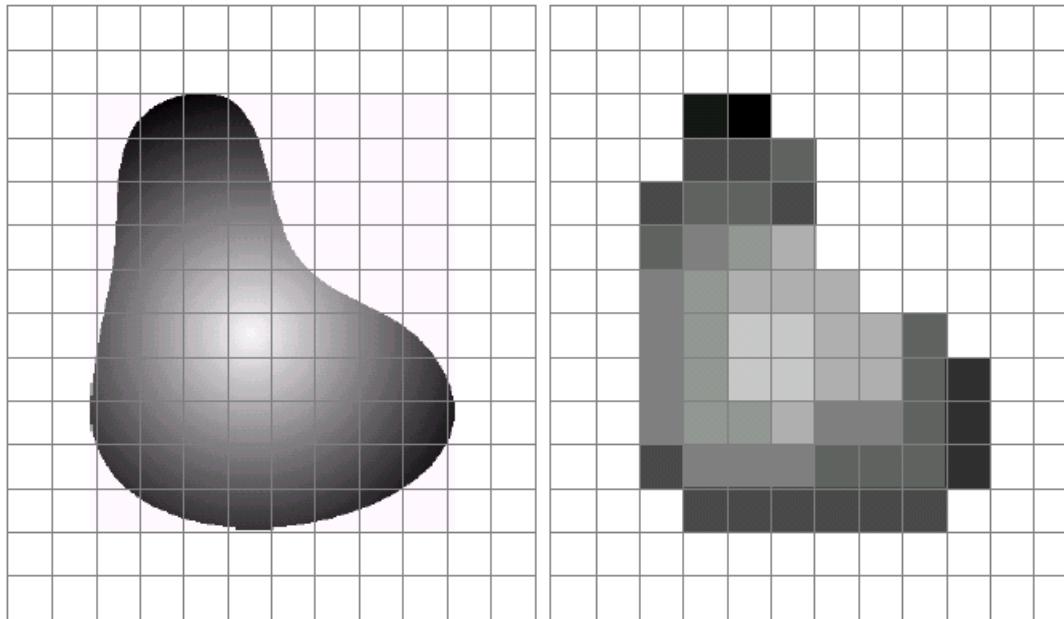




Image Sampling And Quantization

- Sampling and quantization generates **approximation** of a real world scene



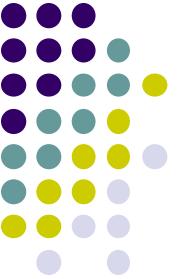


Image as Discrete Function

After spatial sampling and quantization, an image is a discrete function. The image domain Ω is now discrete:

$$\Omega \subset \mathbb{N}^2,$$

and so is the image range:

$$I : \Omega \rightarrow \{1, \dots, K\},$$

where $K \in \mathbb{N}$.

Image as a Function



A simple image

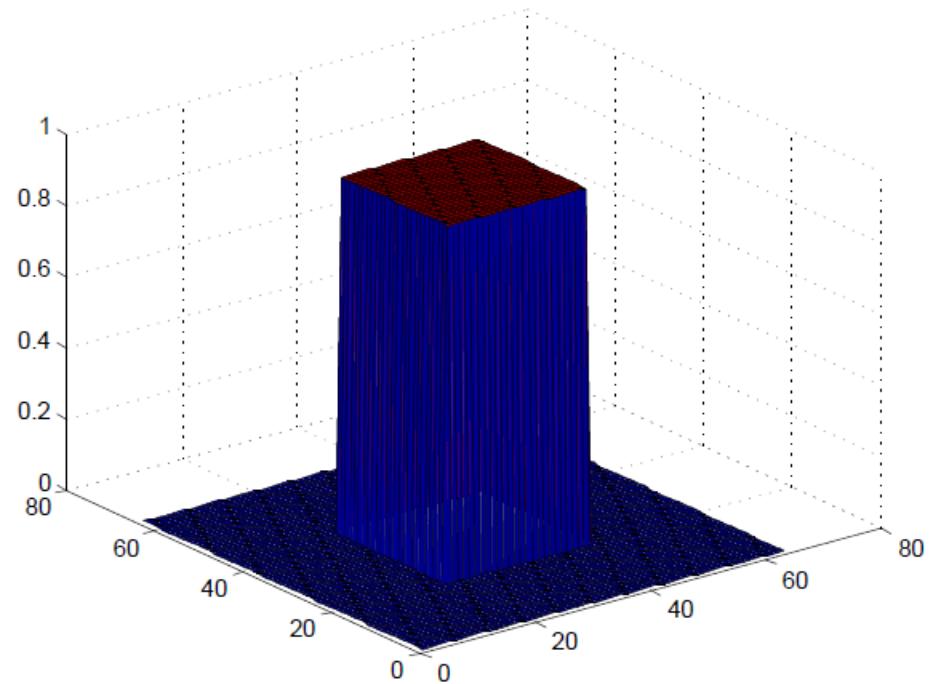
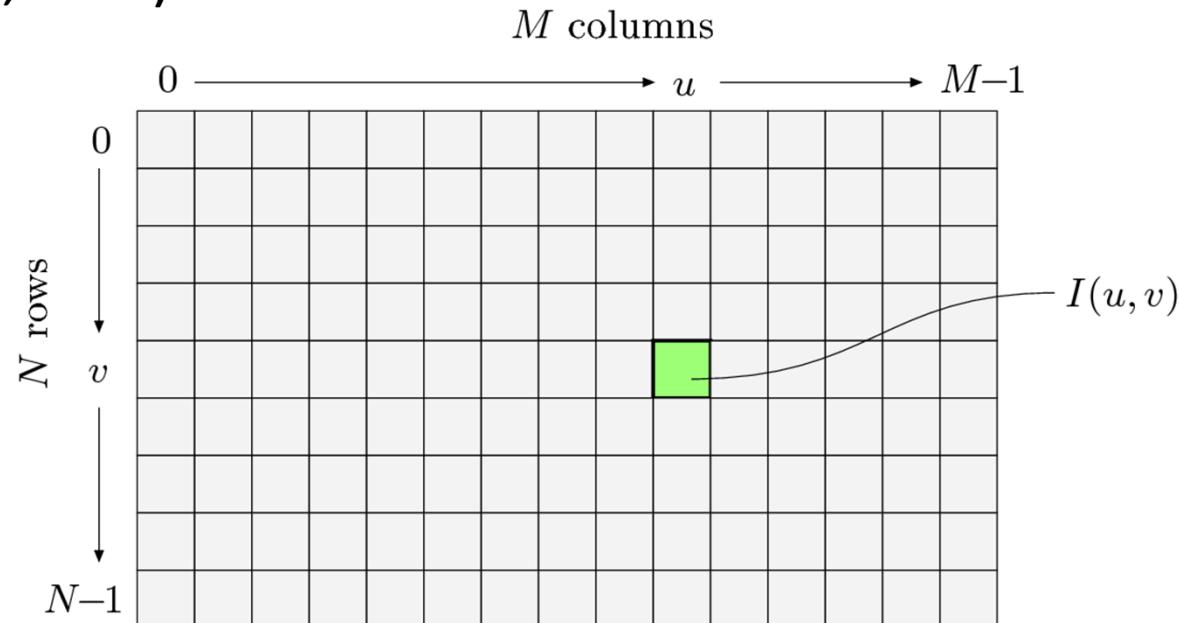


Image function as a
height field



Representing Images

- Image data structure is 2D array of pixel values
- Pixel values are gray levels in range 0-255 or RGB colors
- Array values can be any data type (bit, byte, int, float, double, etc.)



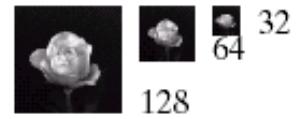


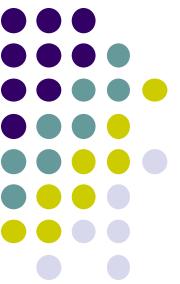
Spatial Resolution

- The ***spatial resolution*** of an image is determined by how fine/coarse sampling was carried out
- **Spatial resolution:** smallest discernable image detail
 - Vision specialists talk about image resolution
 - Graphic designers talk about *dots per inch* (DPI)



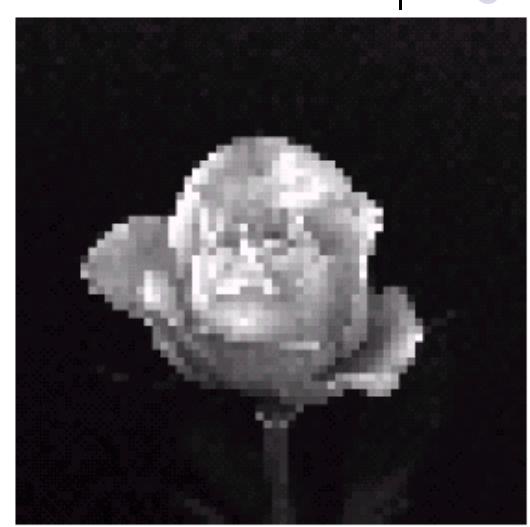
Spatial Resolution

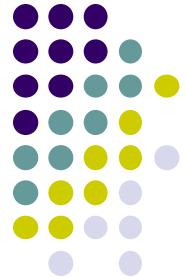




Spatial Resolution: Stretched Images

Images taken from Gonzalez & Woods, Digital Image Processing (2002)





Intensity Level Resolution

- ***Intensity level resolution:*** number of intensity levels used to represent the image

- The more intensity levels used, the finer the level of detail discernable in an image
- Intensity level resolution usually given in terms of number of bits used to store each intensity level

Number of Bits	Number of Intensity Levels	Examples
1	2	0, 1
2	4	00, 01, 10, 11
4	16	0000, 0101, 1111
8	256	00110011, 01010101
16	65,536	10101010101010



Intensity Level Resolution

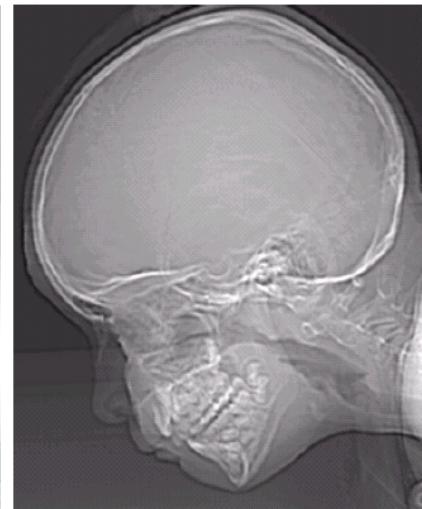
256 grey levels (8 bits per pixel)



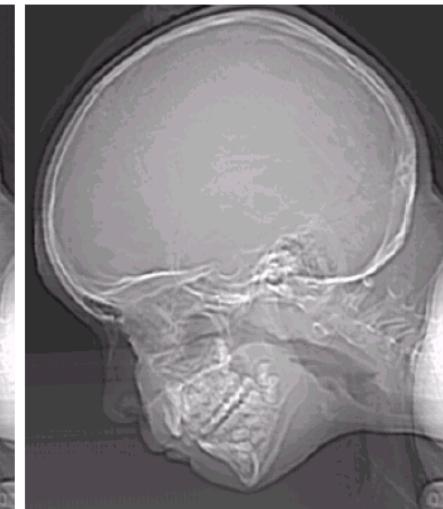
128 grey levels (7 bpp)



64 grey levels (6 bpp)



32 grey levels (5 bpp)



Images taken from Gonzalez & Woods, Digital Image Processing (2002)

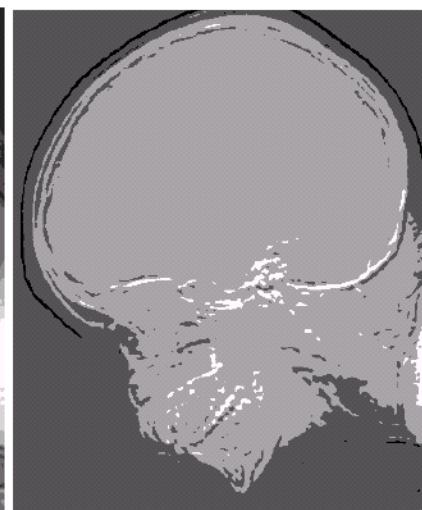
16 grey levels (4 bpp)



8 grey levels (3 bpp)

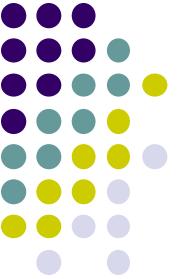


4 grey levels (2 bpp)



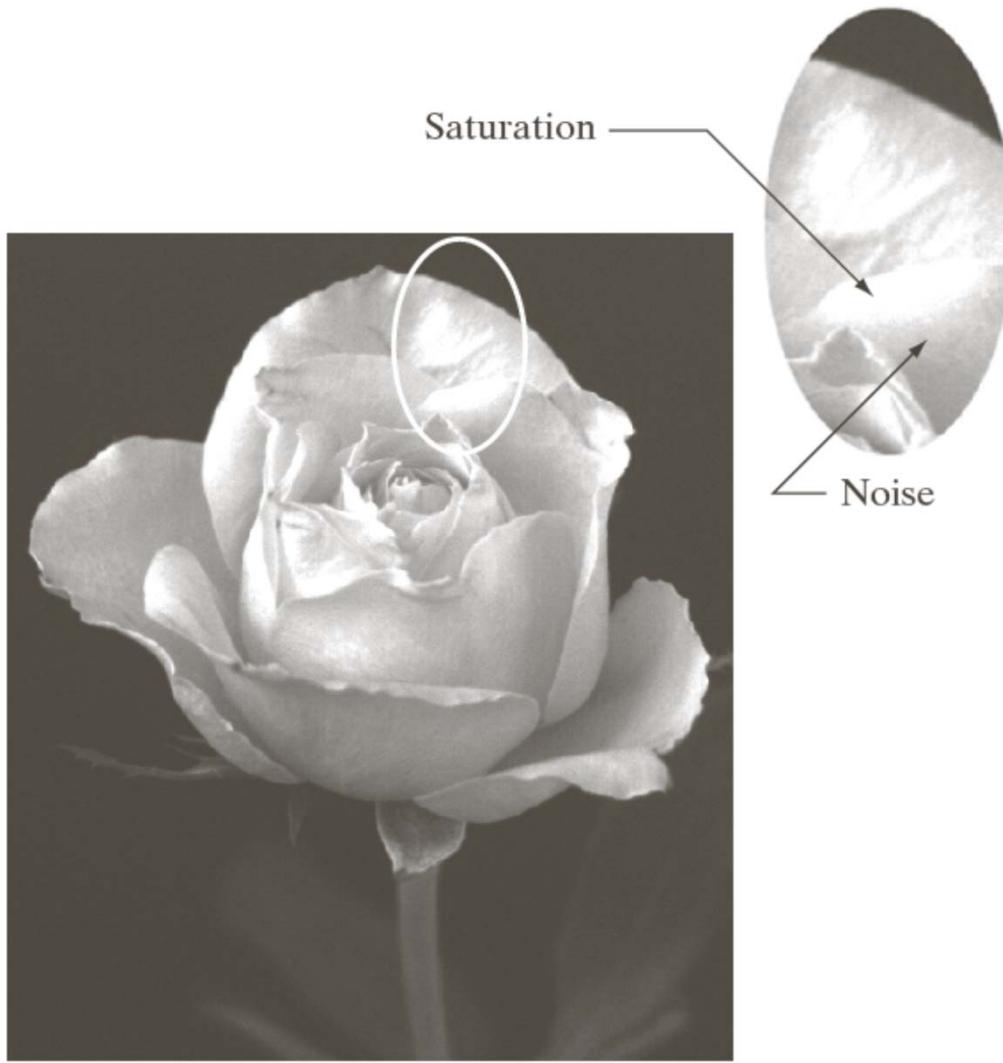
2 grey levels (1 bpp)





Saturation & Noise

Images taken from Gonzalez & Woods, Digital Image Processing (2002)



Saturation: highest intensity value above which color is washed out

Noise: grainy texture pattern



Resolution: How Much Is Enough?

- The big question with resolution is always *how much is enough?*
 - Depends on what is in the image (*details*) and what you would like to do with it (*applications*)
 - Key questions:
 - Does image look aesthetically pleasing?
 - Can you see what you need to see in image?



Resolution: How Much Is Enough?



- **Example:** Picture on right okay for counting number of cars, but not for reading the number plate



Intensity Level Resolution

Images taken from Gonzalez & Woods, Digital Image Processing (2002)



Low Detail



Medium Detail



High Detail



Image File Formats

- Hundreds of image file formats. Examples
 - Tagged Image File Format (TIFF)
 - Graphics Interchange Format (GIF)
 - Portable Network Graphics (PNG)
 - JPEG, BMP, Portable Bitmap Format (PBM), etc
- Image pixel values can be
 - **Grayscale:** 0 – 255 range
 - **Binary:** 0 or 1
 - **Color:** RGB colors in 0-255 range (or other color model)
 - **Application specific** (e.g. floating point values in astronomy)



How many Bits Per Image Element?

Grayscale (Intensity Images):

<i>Chan.</i>	<i>Bits/Pix.</i>	<i>Range</i>	<i>Use</i>
1	1	0...1	Binary image: document, illustration, fax
1	8	0...255	Universal: photo, scan, print
1	12	0...4095	High quality: photo, scan, print
1	14	0...16383	Professional: photo, scan, print
1	16	0...65535	Highest quality: medicine, astronomy

Color Images:

<i>Chan.</i>	<i>Bits/Pix.</i>	<i>Range</i>	<i>Use</i>
3	24	$[0...255]^3$	RGB, universal: photo, scan, print
3	36	$[0...4095]^3$	RGB, high quality: photo, scan, print
3	42	$[0...16383]^3$	RGB, professional: photo, scan, print
4	32	$[0...255]^4$	CMYK, digital prepress

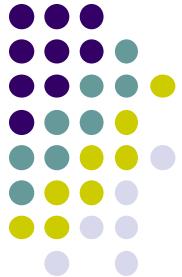
Special Images:

<i>Chan.</i>	<i>Bits/Pix.</i>	<i>Range</i>	<i>Use</i>
1	16	$-32768\dots32767$	Whole numbers pos./neg., increased range
1	32	$\pm3.4 \cdot 10^{38}$	Floating point: medicine, astronomy
1	64	$\pm1.8 \cdot 10^{308}$	Floating point: internal processing



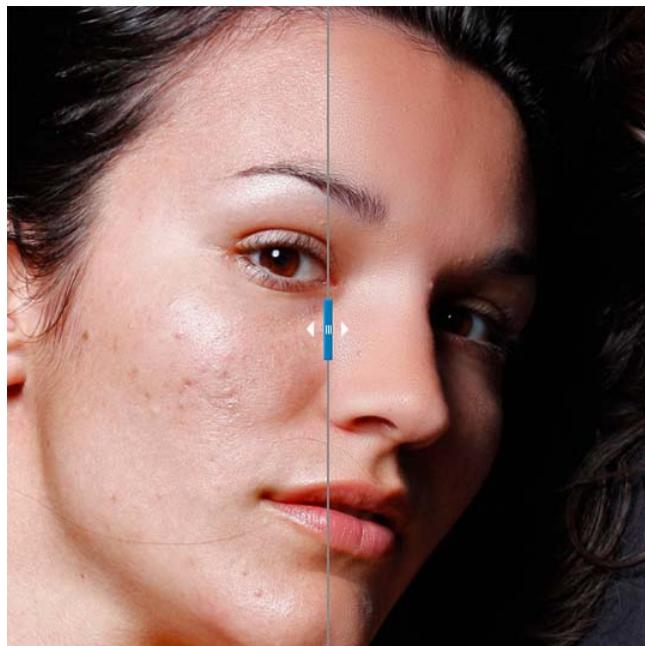
Mathematics for Image Processing

- Calculus
- Linear algebra
- Probability and statistics
- Differential Equations (PDEs and ODEs)
- Differential Geometry
- Harmonic Analysis (Fourier, wavelet, etc)



About This Course

- Image Processing has many aspects
 - **Computer Scientists/Engineers** develop tools (e.g. photoshop)
 - **Requires** knowledge of maths, algorithms, programming
 - **Artists** use image processing tools to modify pictures
 - **DOES NOT** require knowledge of maths, algorithms, programming



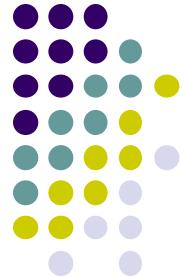
Example: Portraiture photoshop plugin



Example: Knoll Light Factory photoshop plugin

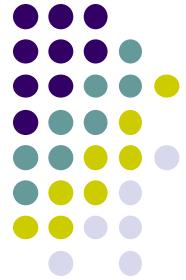


Example: ToonIt photoshop plugin



About This Course

- Most hobbyists follow artist path. Not much math!
- **This Course: Image Processing for computer scientists and Engineers!!!**
- Teaches concepts, uses Matlab/Python as concrete example
- Matlab Image Processing Toolbox
 - Includes lots of already working algorithms,
 - Can be extended by programming new image processing techniques
- Course is **NOT**
 - just about programming Matlab image processing toolbox
 - a comprehensive course in matlab image processing toolbox and python image processing library (PIL, scipy, opencv-python and so on)
 - about using packages like Photoshop



About This Course

- Class is concerned with:
 - How to implement image processing algorithms
 - Underlying mathematics
 - Underlying algorithms
- This course is a lot of work. **Especially heavy coding!!!**
Requires:
 - Lots of programming (maybe in MATLAB/Python)
 - Lots of math, linear systems, fourier analysis



Administrivia: Syllabus Summary

- 3 Assignments (30%), one Mid-Exam (30%), 1 final Projects (40%)
- Projects:
 - Develop image processing algorithm on any platform using MATLAB/Python
 - May discuss projects but turn in individual projects
- Text:
 - *Digital Image Processing: An Algorithmic Introduction using Java* by Wilhelm Burger and Mark J. Burge, Springer Verlag, 2008
- Cheating: Immediate ‘F’ in the course
- My advice:
 - Come to class
 - Read the text
 - Understand concepts before coding



References

- Wilhelm Burger and Mark J. Burge, Digital Image Processing, Springer, 2008
- University of Utah, CS 4640: Image Processing Basics, Spring 2012
- Gonzales and Woods, Digital Image Processing (3rd edition), Prentice Hall
- Digital Image Processing slides by Brian Mac Namee

Thank You