INF250

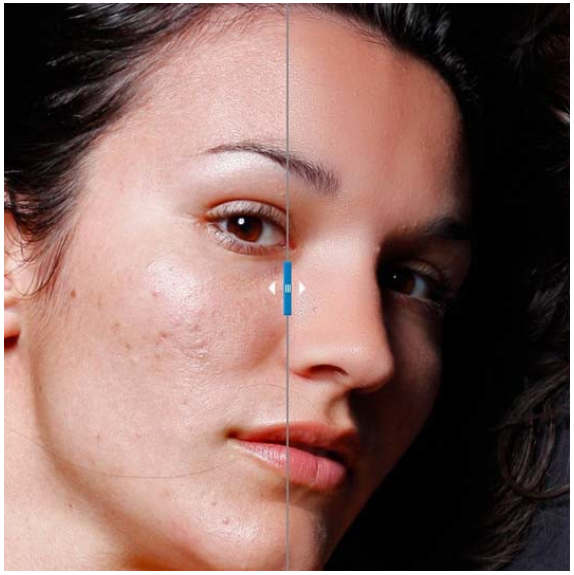
Digital Images

Introduction

- Chapter 1,2 in book
- Fundamental principles of digital imaging
- Demonstrations

About INF250

- 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

Image processing and analysis

- Image processing
  - Improvement
  - Making ready for analysis
- Image analysis
  - Properties
  - Modelling of nature
  - Classification of images
  - Objects in images

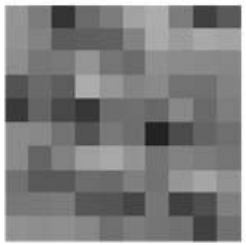
What is an Image?

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

Set of Intensity values

Image coordinates are integers

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



$F(x,y)$

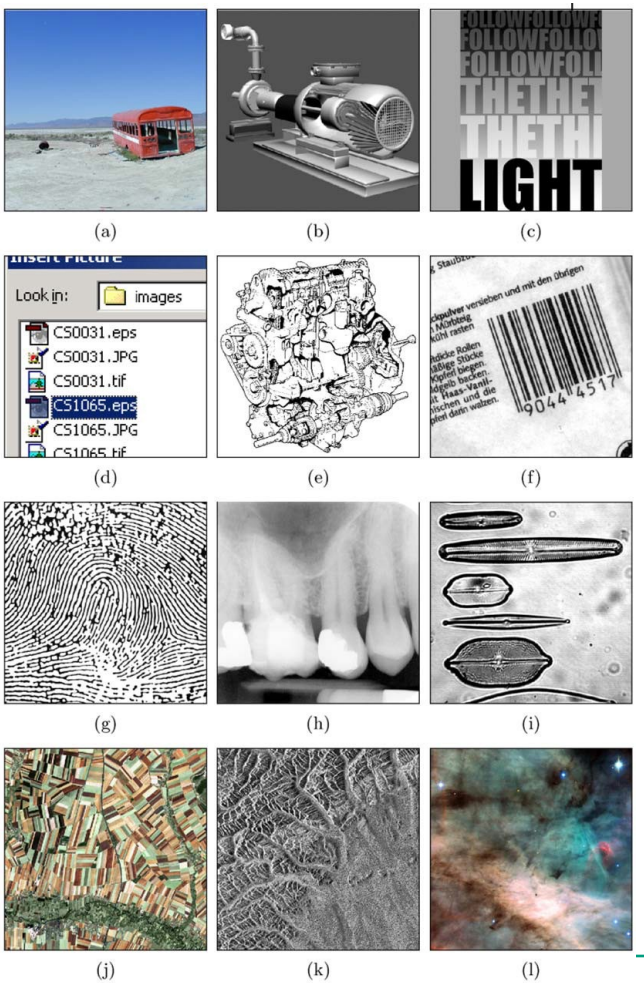
$$\rightarrow$$

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 ···
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

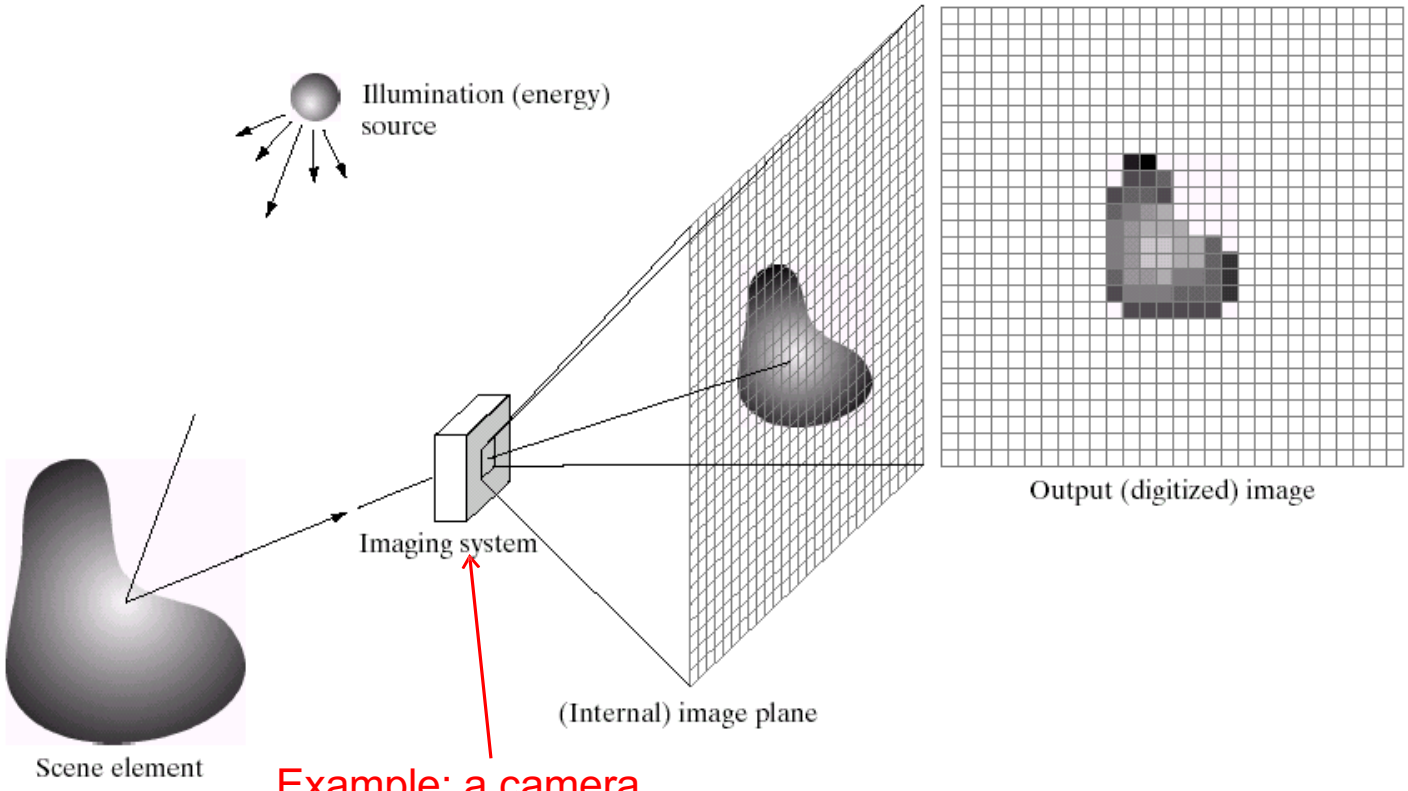
$I(u,v)$

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

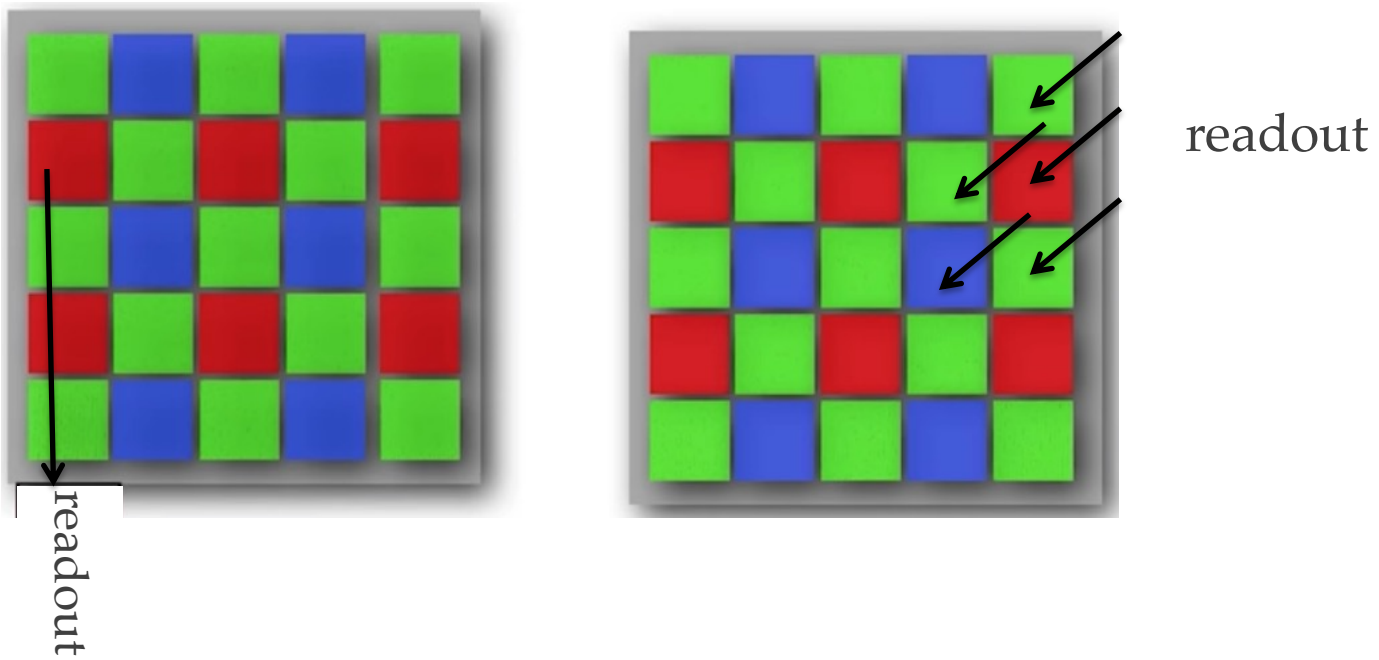


Example: a camera
Converts light to image

Ref: Gonzales and Woods

CCD and CMOS

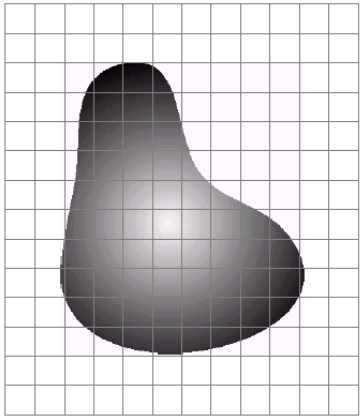
- Detector in camera is usually a Charge Coupled Device (CCD) or Complementary Metal Oxide Seminconductor (CMOS)



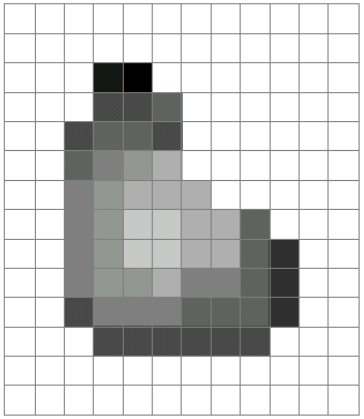
  - http://www.specinst.com/What_Is_A_CCD.html
  - https://www.youtube.com/watch?v=9vgtJJ2wwMA

Digital Image?

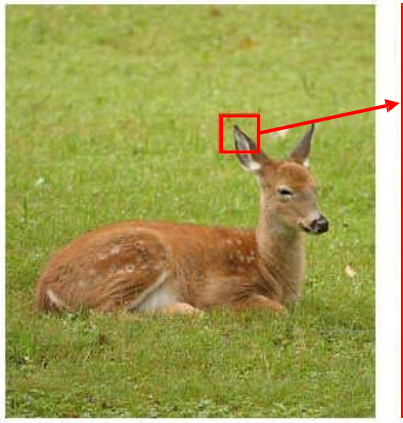
- **Remember:** *digitization* causes a digital image to become an *approximation* of a real scene



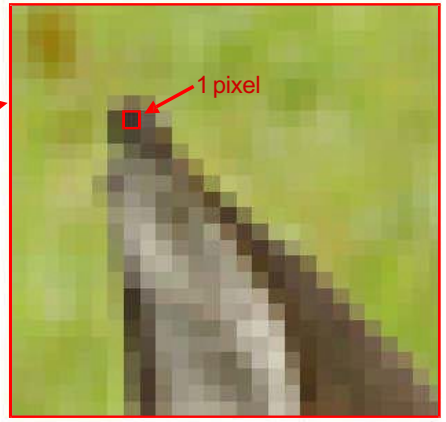
Real image



Digital Image
(an approximation)



Real image



Digital Image
(an approximation)

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

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)

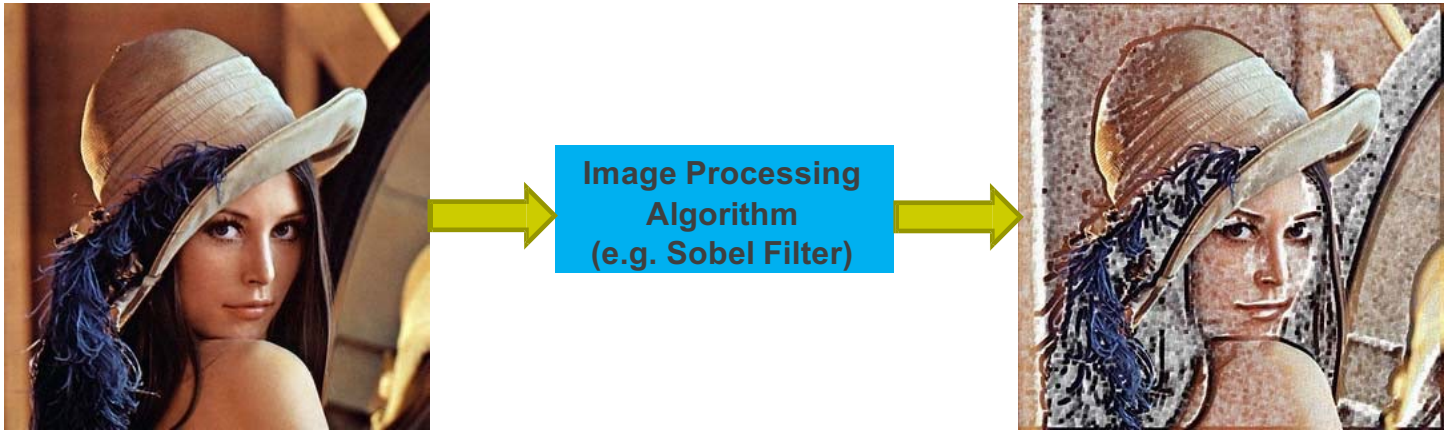
Grayscale

RGB

RGBA

What is image Processing?

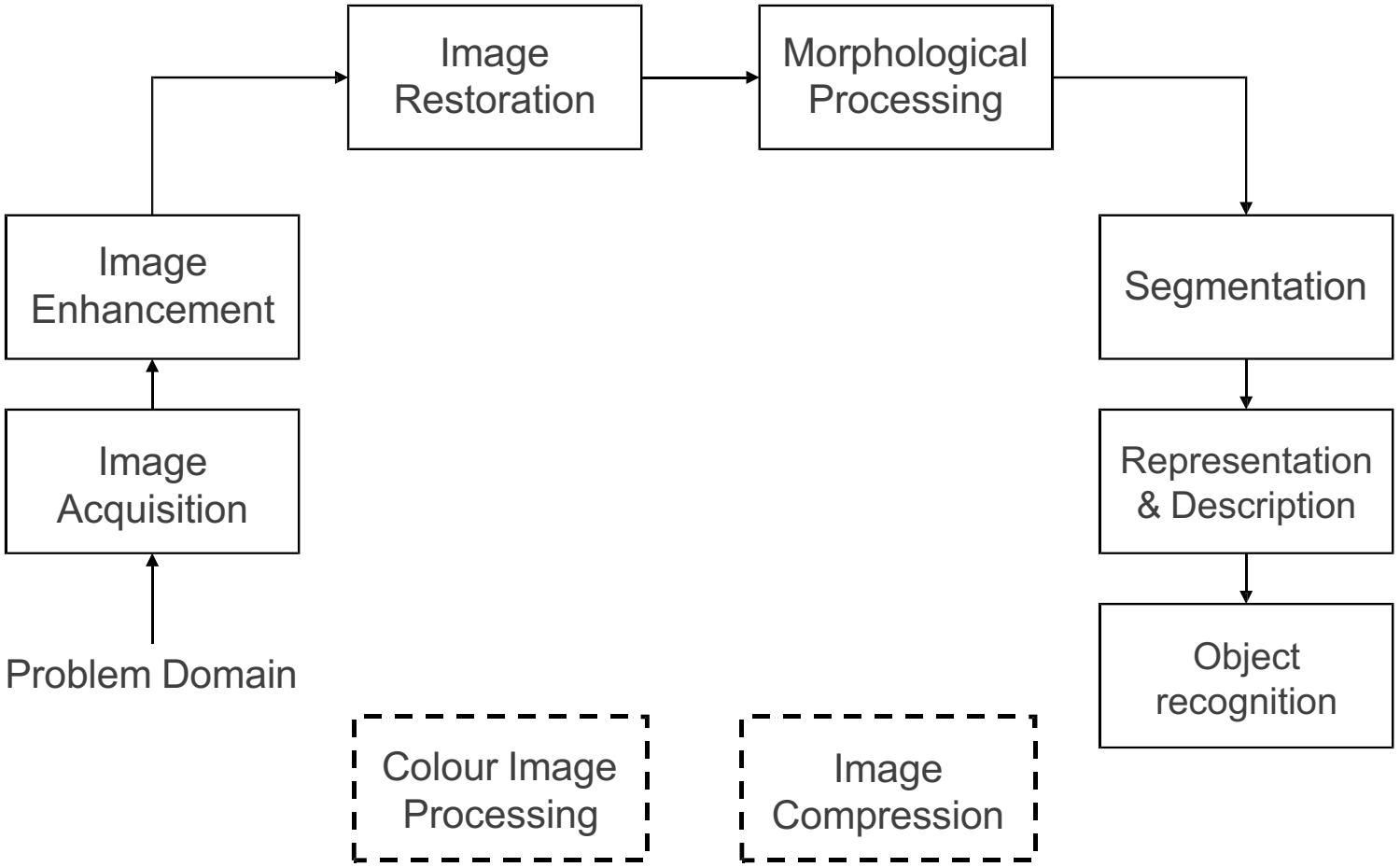
- **Algorithms that alter an input image to create new image**
- **Input is image, output is image**



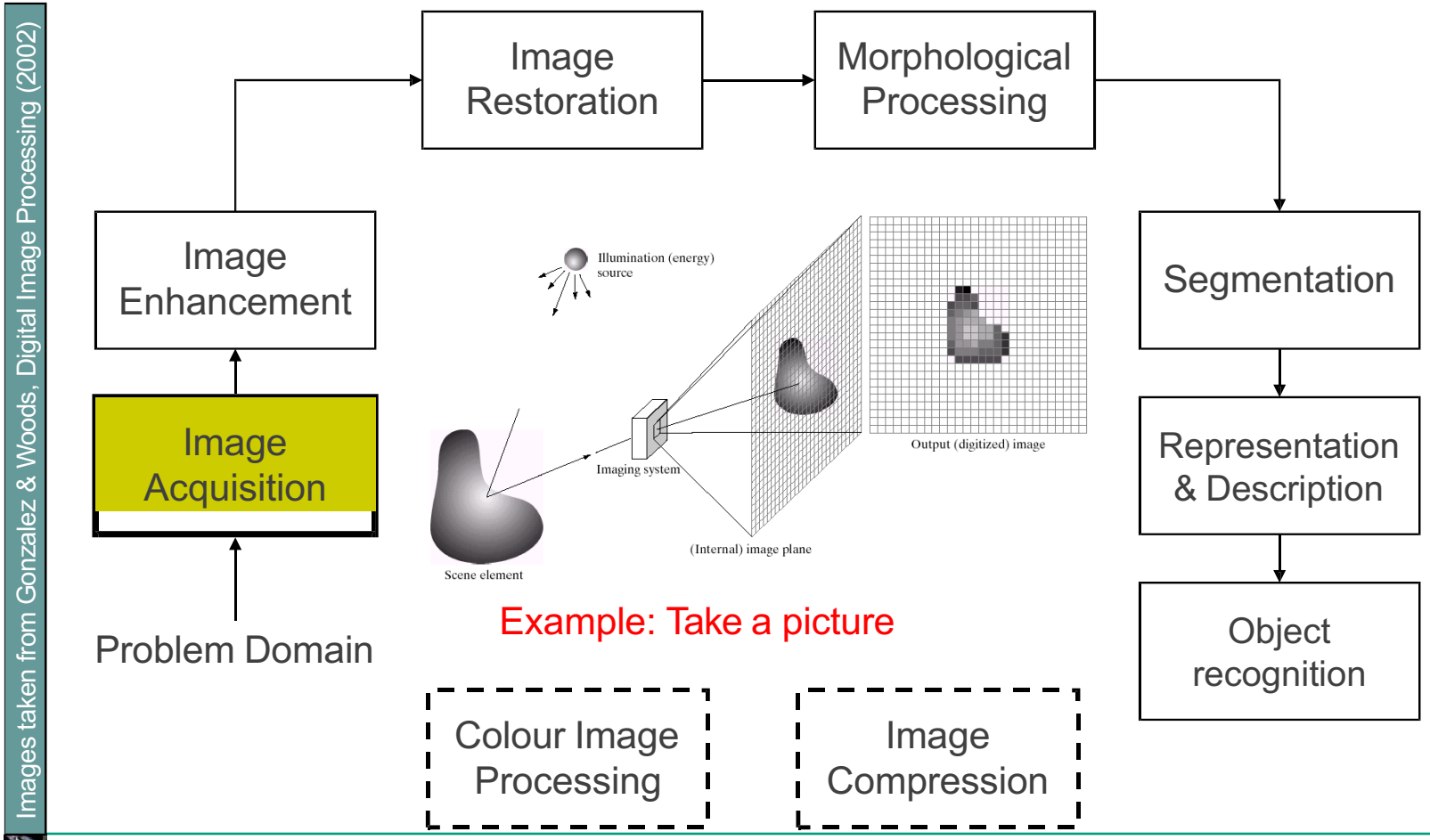
Original Image *Processed Image*

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

Key Stages in Digital Image Processing

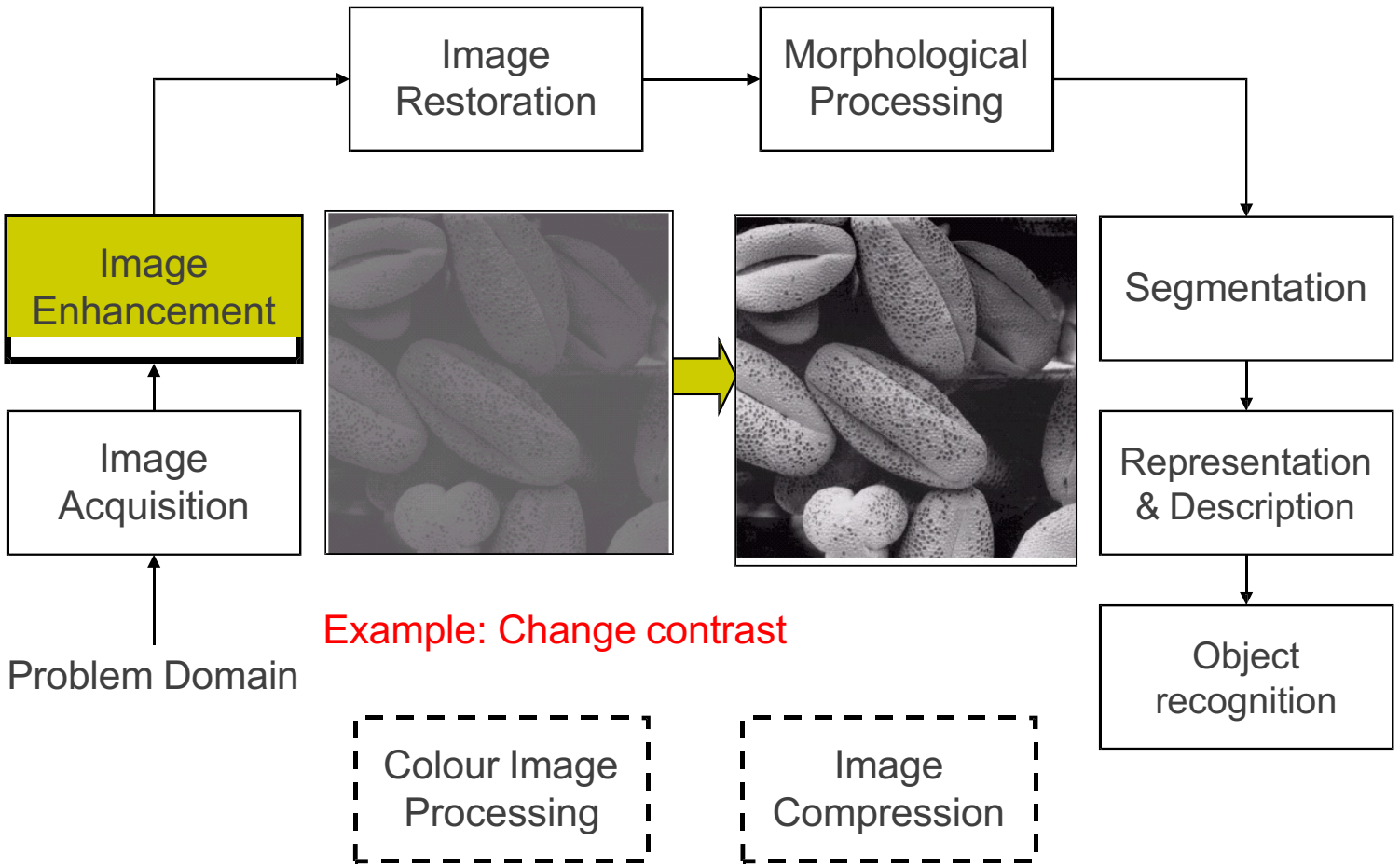


Key Stages in Digital Image Processing: Image Aquisition



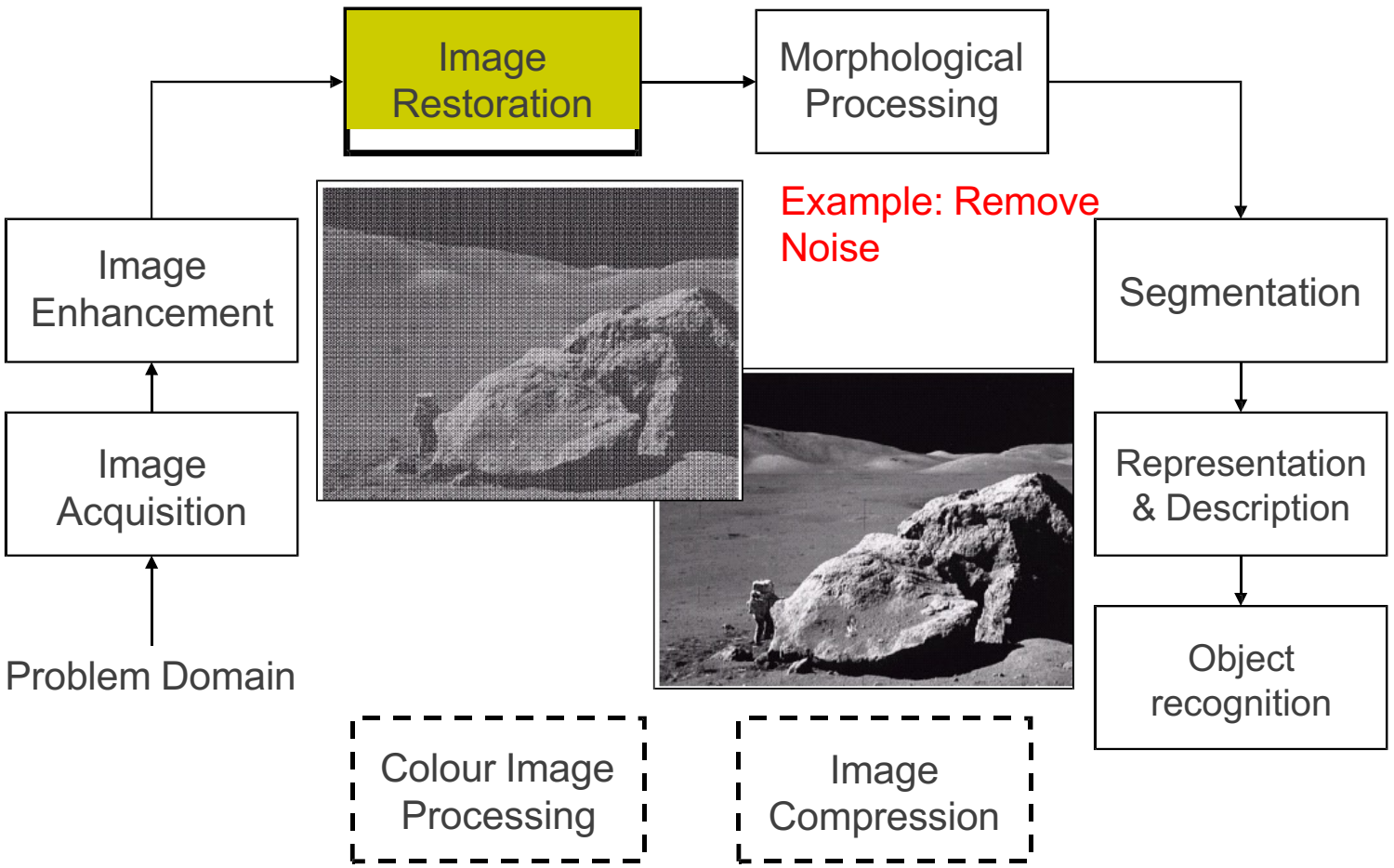
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Key Stages in Digital Image Processing: Image Enhancement



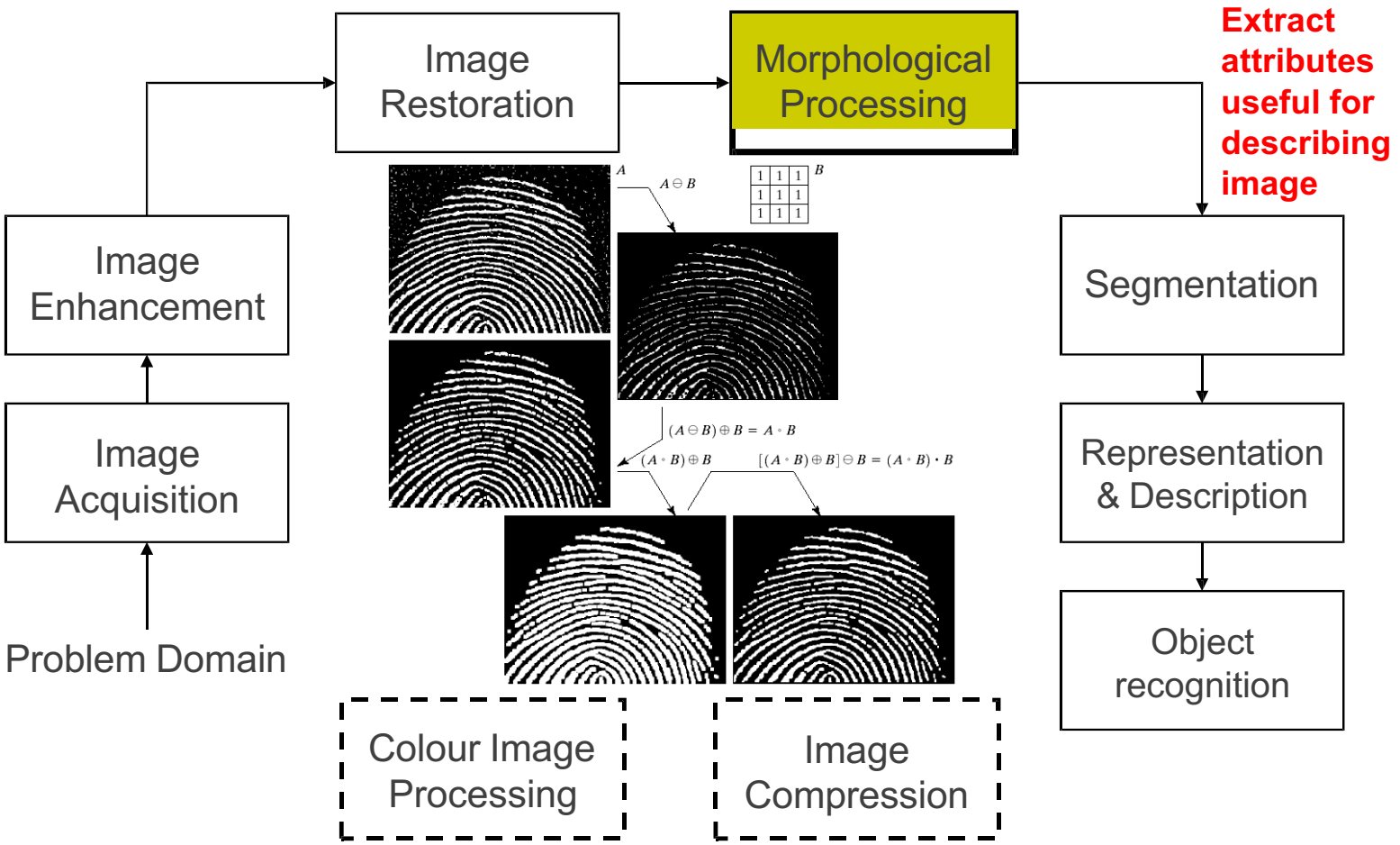
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Key Stages in Digital Image Processing: Image Restoration



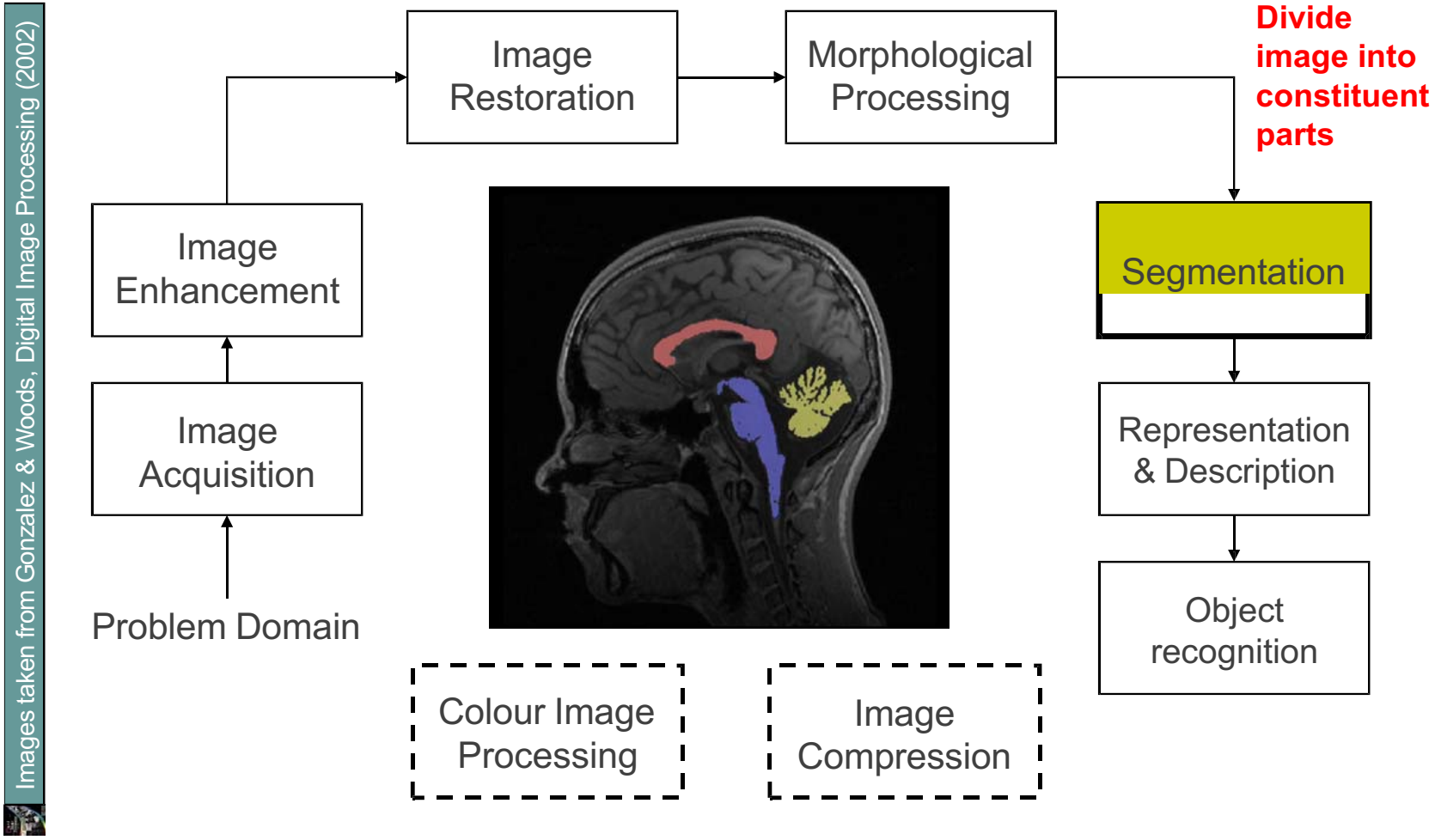
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Key Stages in Digital Image Processing: Morphological Processing

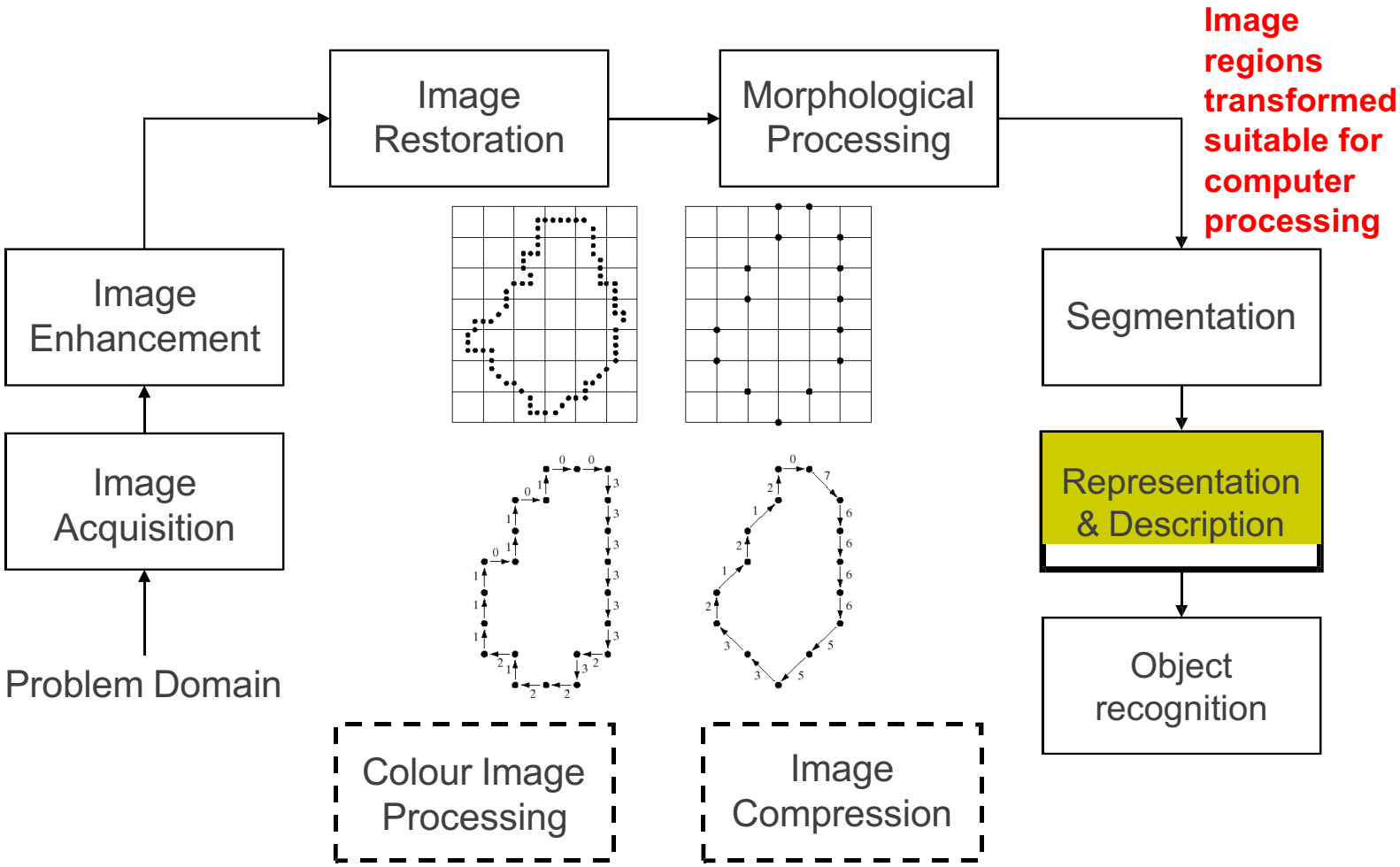


Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Key Stages in Digital Image Processing: Segmentation

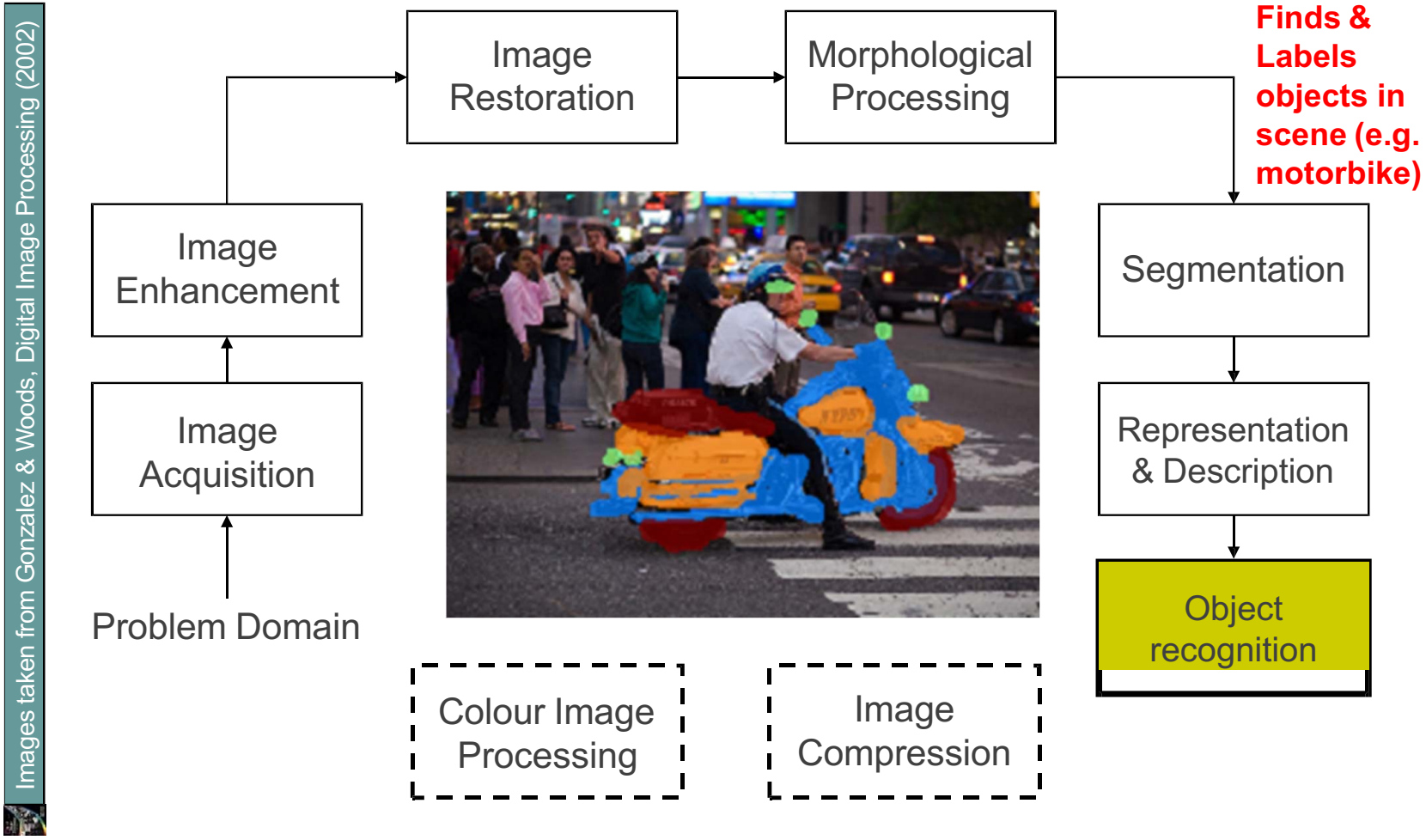


Key Stages in Digital Image Processing: Object Recognition

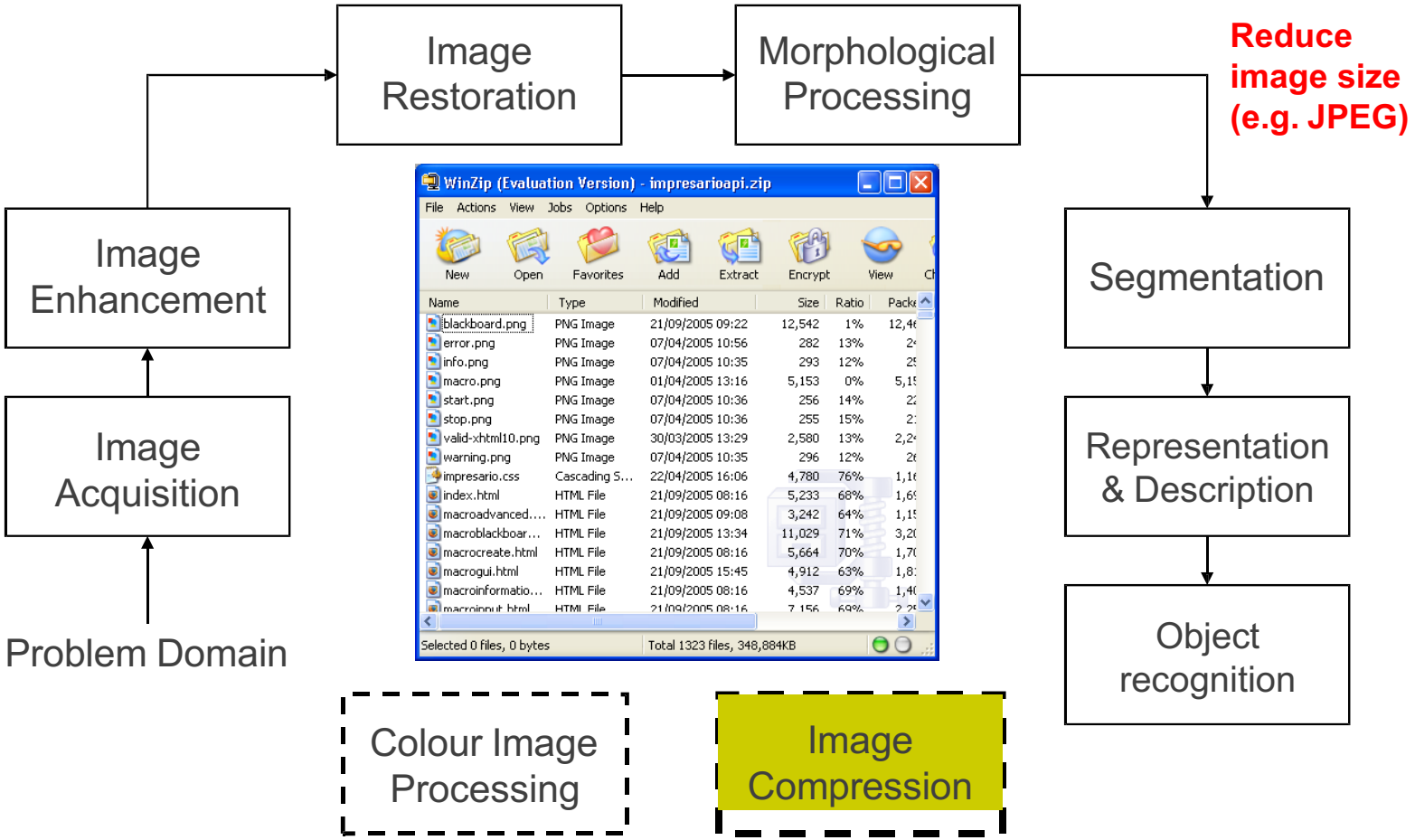


Images taken from Gonzalez & Woods, Digital Image Processing (2002)

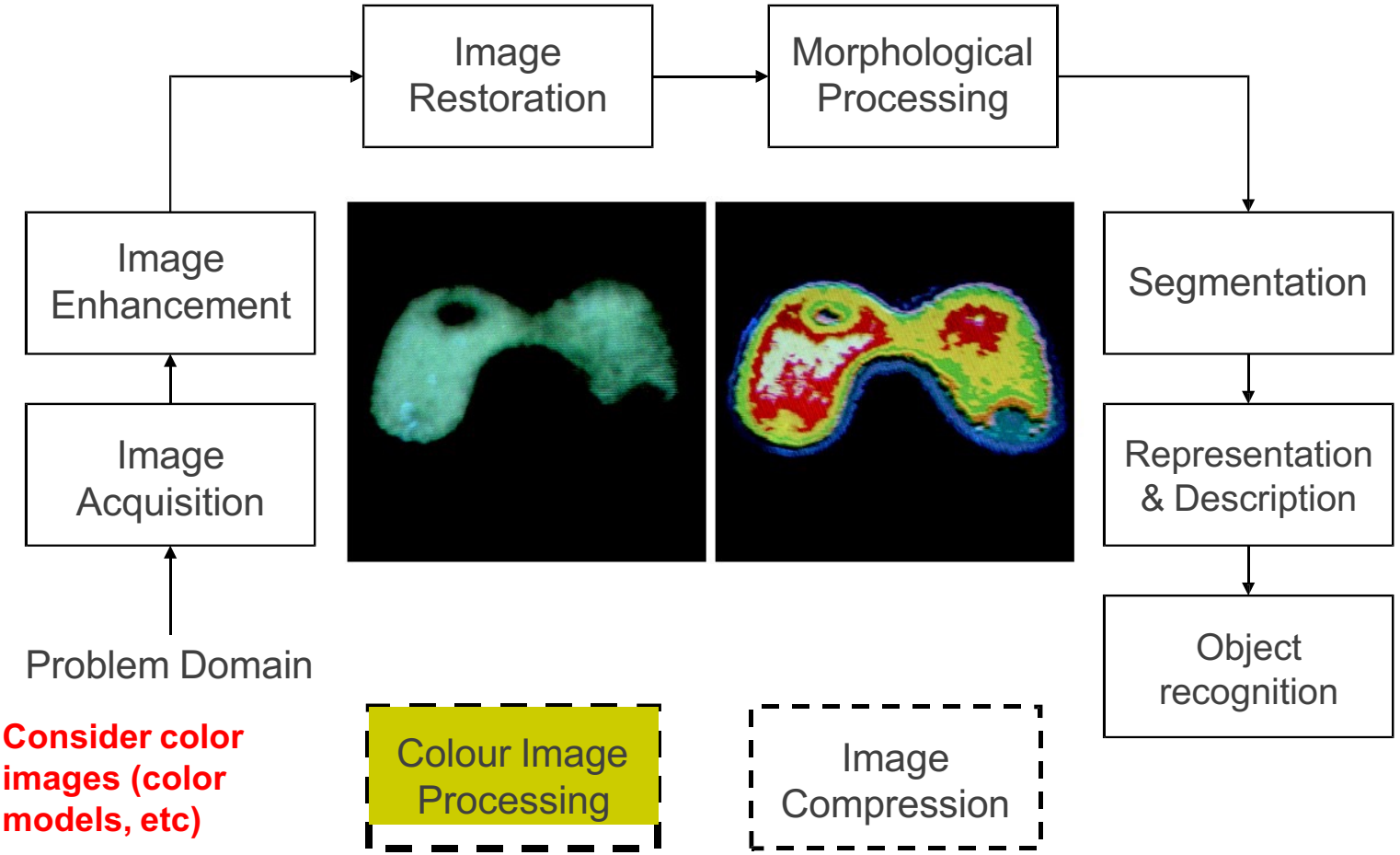
Key Stages in Digital Image Processing: Representation & Description



Key Stages in Digital Image Processing: Image Compression

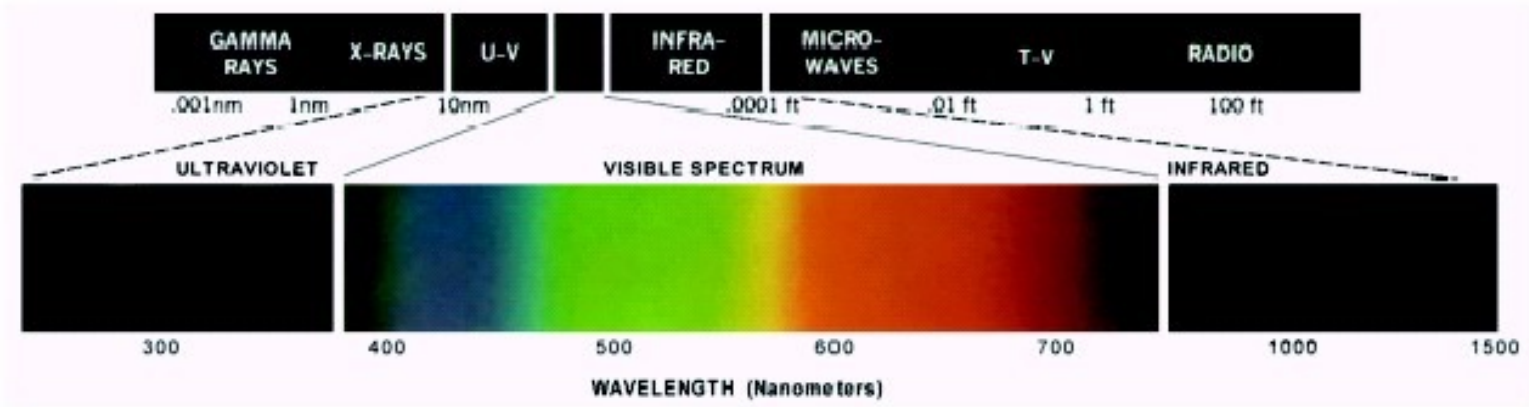


Key Stages in Digital Image Processing: Colour Image Processing



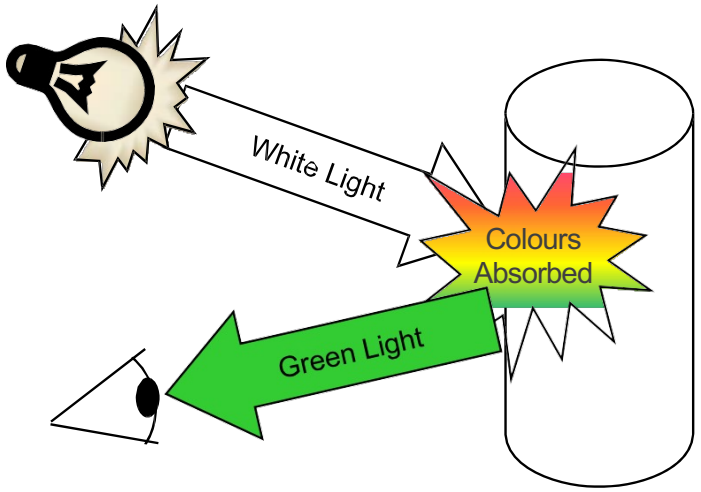
Light And The Electromagnetic Spectrum

- 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

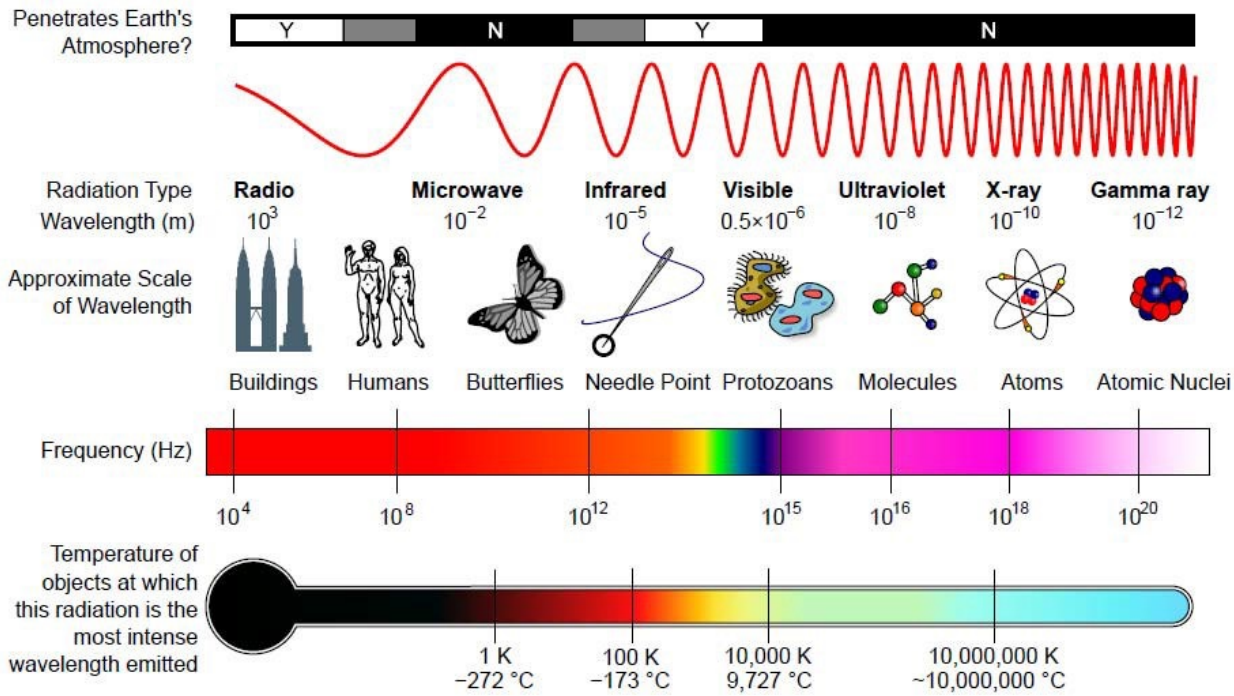
- The colours humans perceive are determined by nature of light reflected from an object
- For example, if white light (contains all wavelengths) is shone onto green object



Most wavelengths absorbed except green wavelength (color)

Electromagnetic Spectrum

- Images can be made from any form of EMradiation



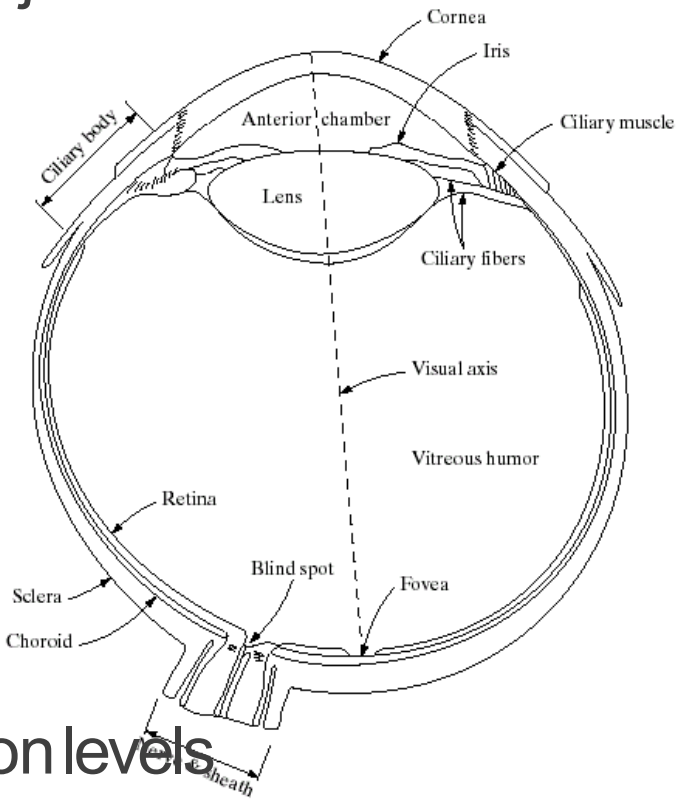
From Wikipedia

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)
- Cones concentrated around fovea. Very sensitive to colour
- Rods more spread out and sensitive to low illumination levels

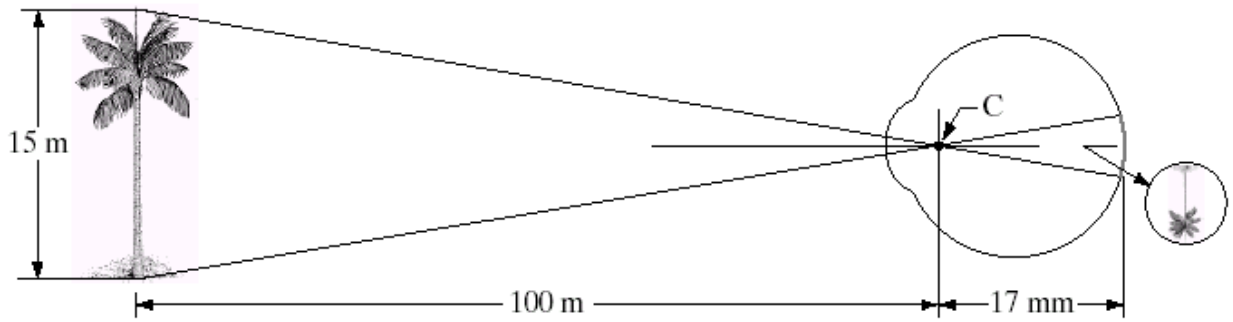


Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Image Formation In The Eye

- Muscles in eye can change the shape of the lens allowing us focus on near or far objects

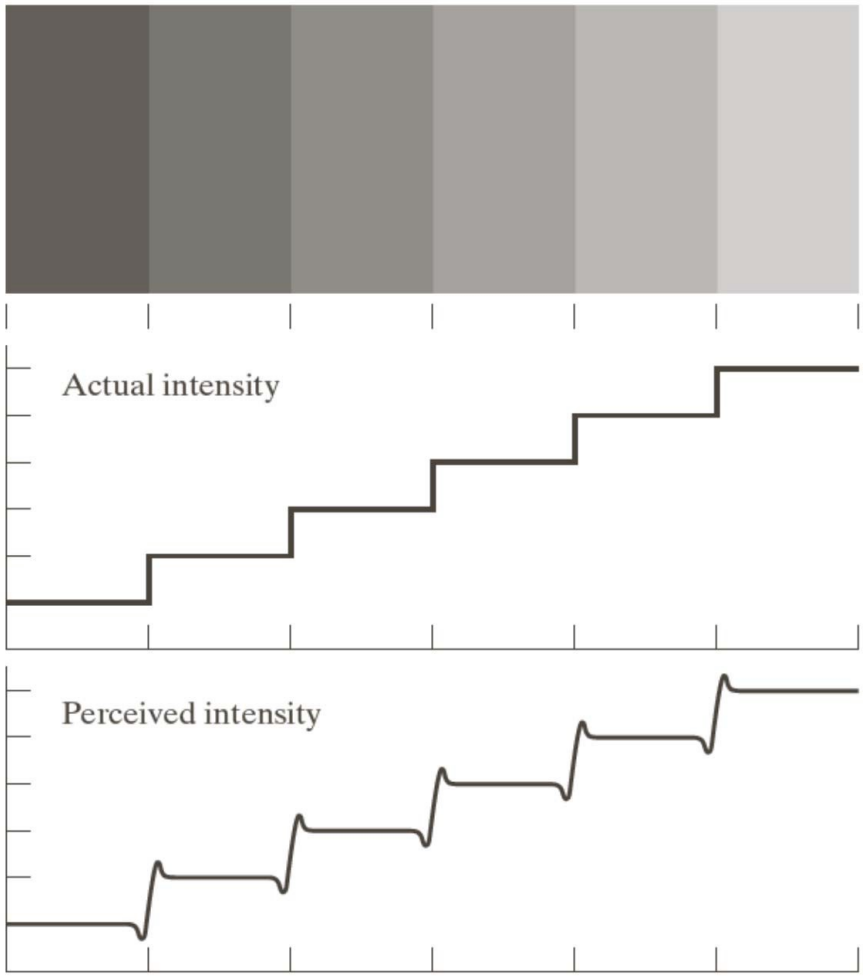
- An image is focused onto retina exciting the rods and cones and send signals to the brain



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

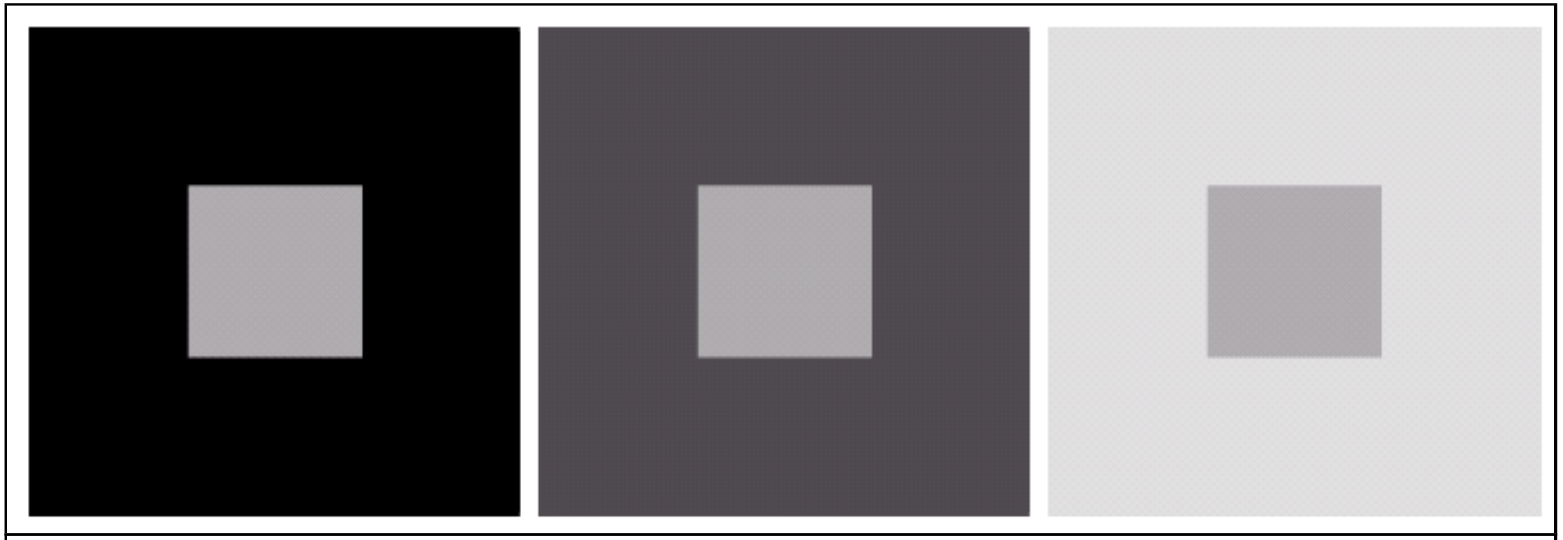
Brightness adaptation & discrimination



Perceived intensity overshoots or undershoots at areas of intensity change

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

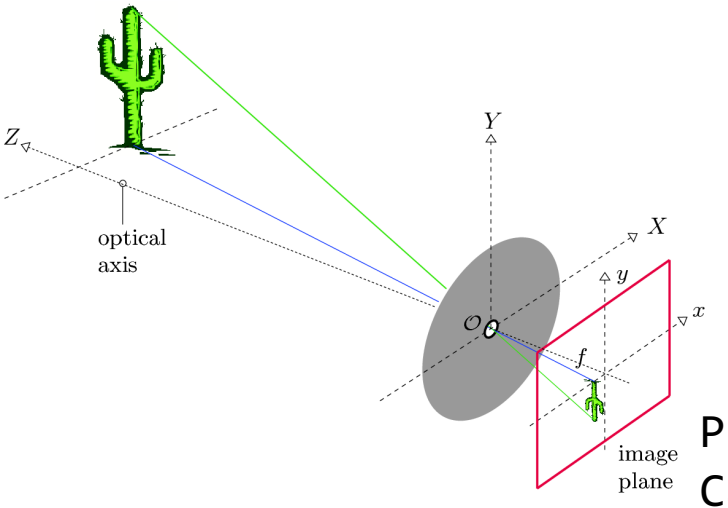
Brightness adaptation & discrimination



An example of *simultaneous contrast*

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

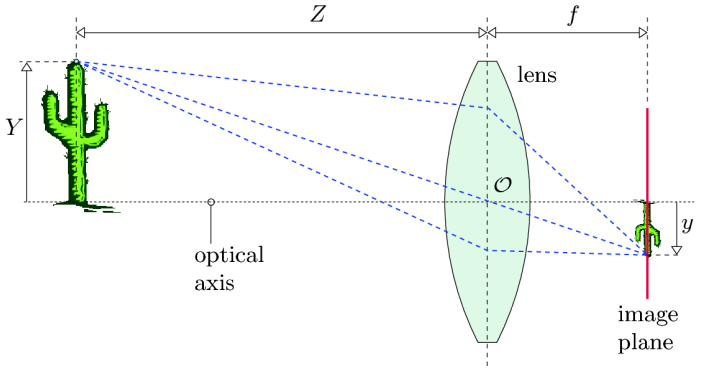
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

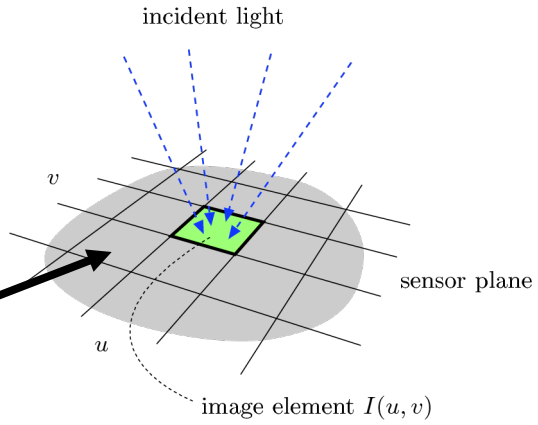


$$y = -f\frac{Y}{Z}$$

$$x = -f\frac{X}{Z}$$

Pinhole Camera



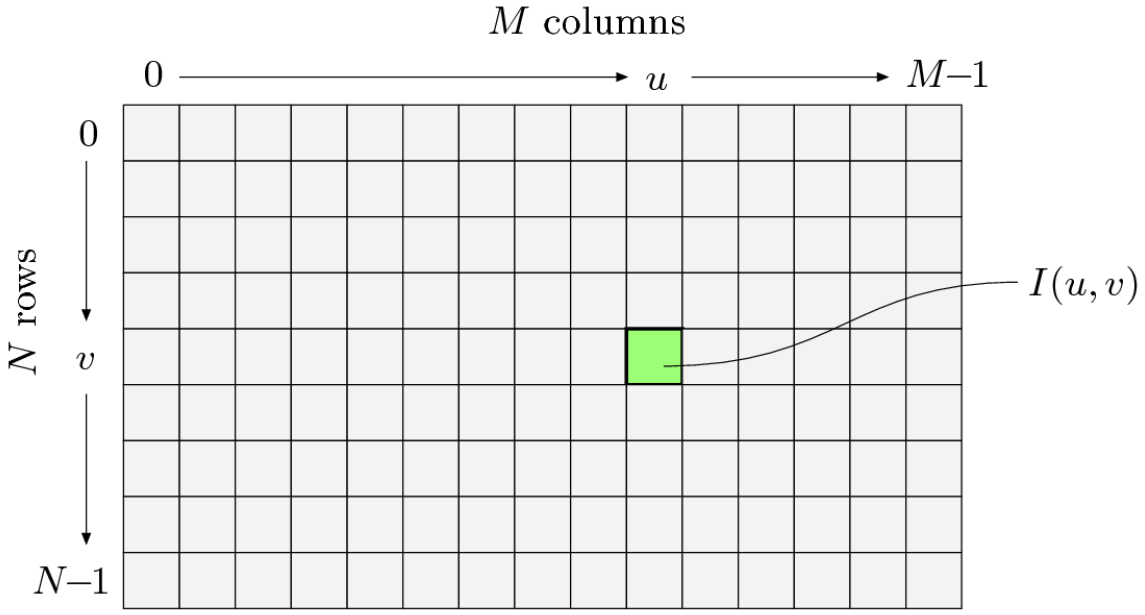


Lens Camera

Digitalisation

- Images are represented as descrete functions and matrices

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



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.)

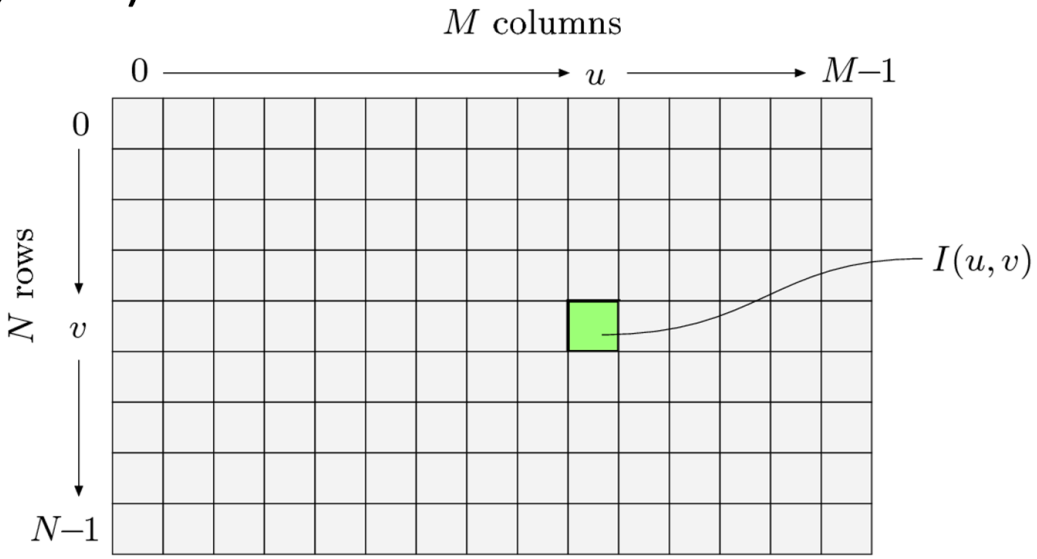
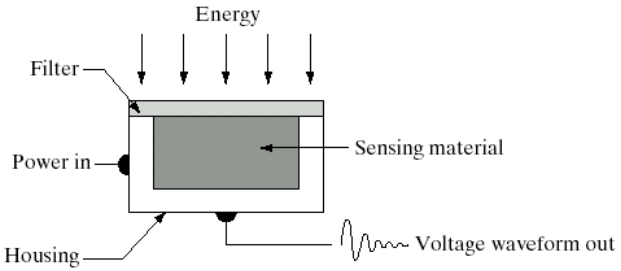


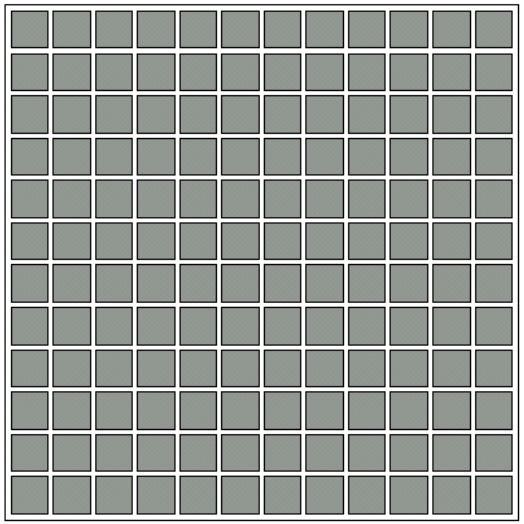
Image Sensing

- 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

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

Sampling

- Spatial sampling (spatial resolution)
- Quantifications of pixel values (intensity level resolution
- Temporal sampling (time series)

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

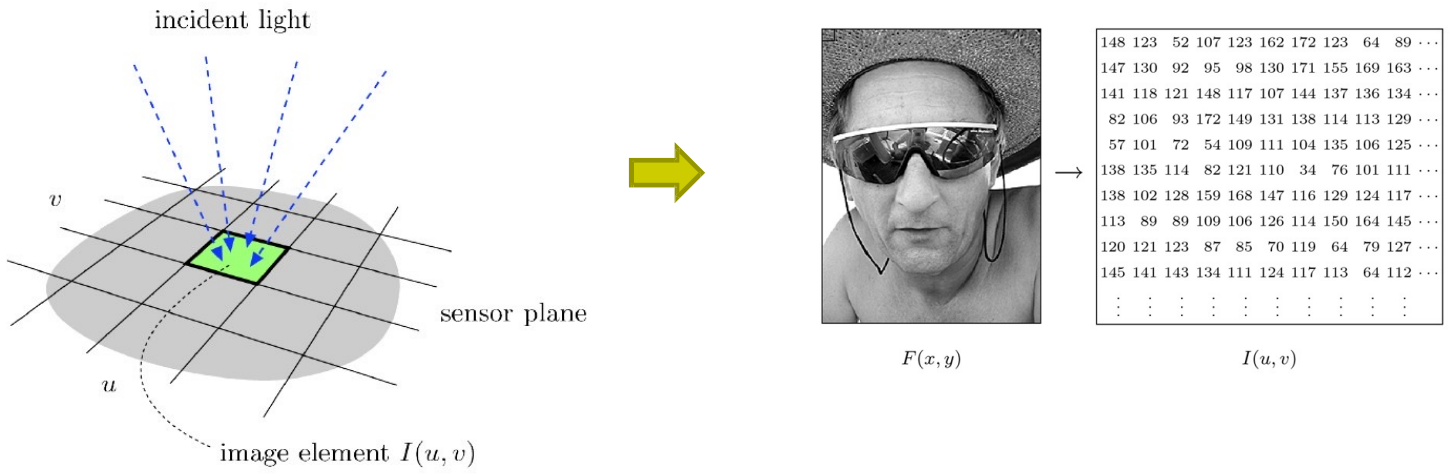


Image (Spatial) Sampling

- 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 x comb function

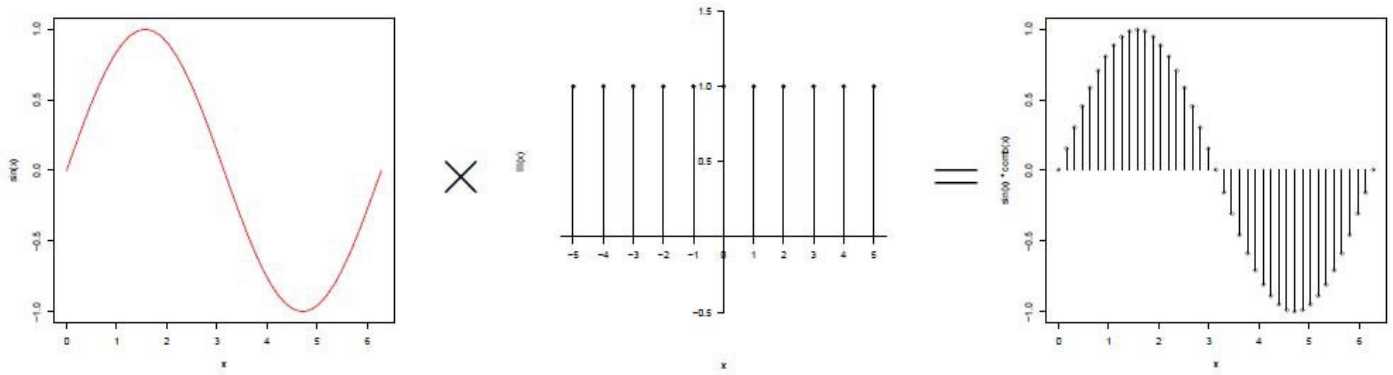


Image Quantization

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

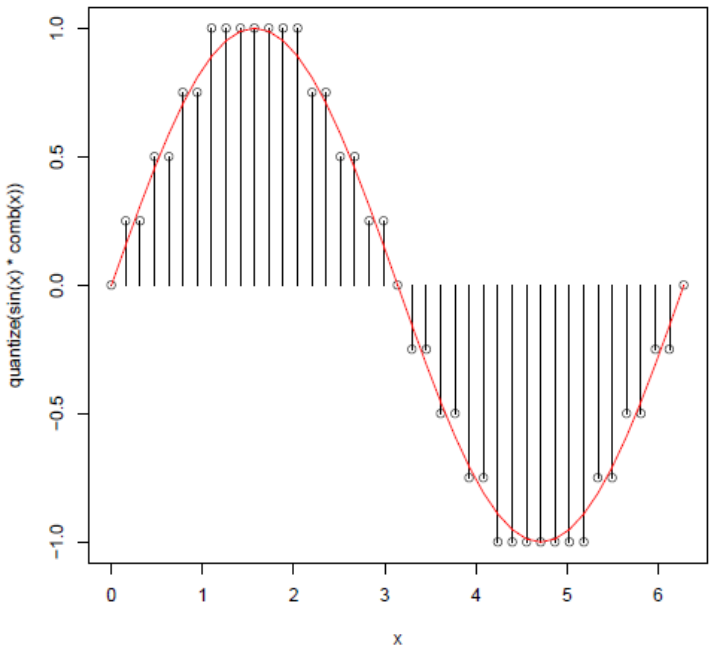
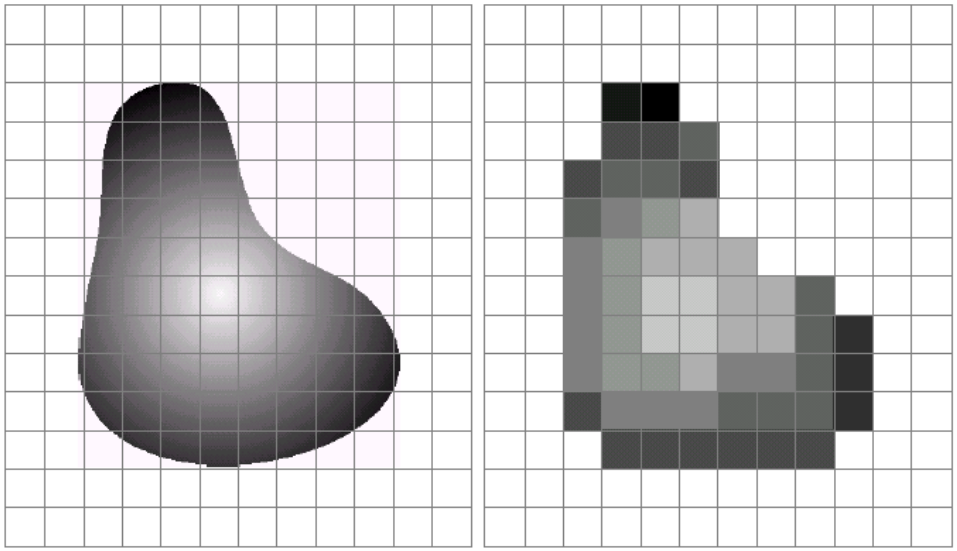


Image Sampling And Quantization

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

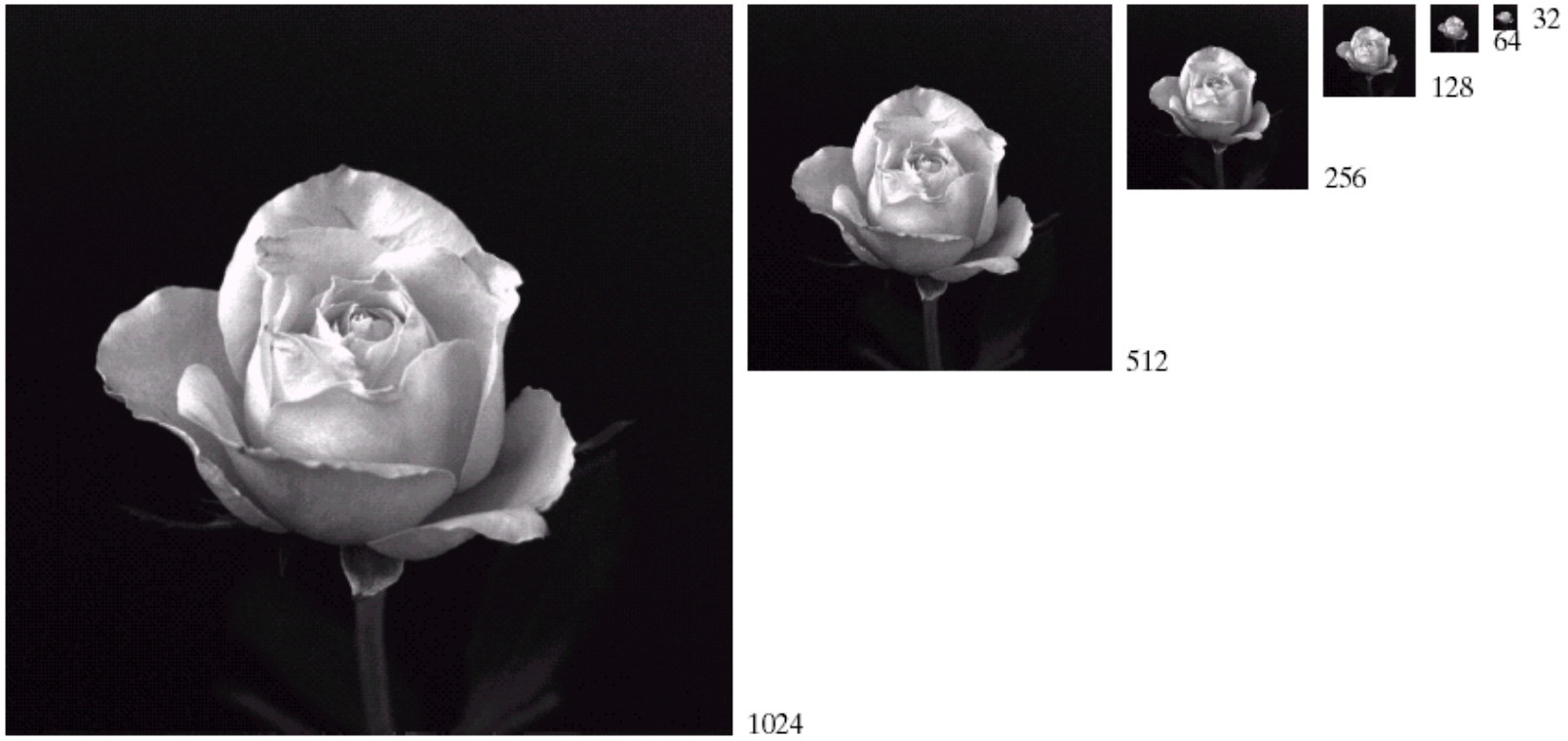


Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Spatial Resolution

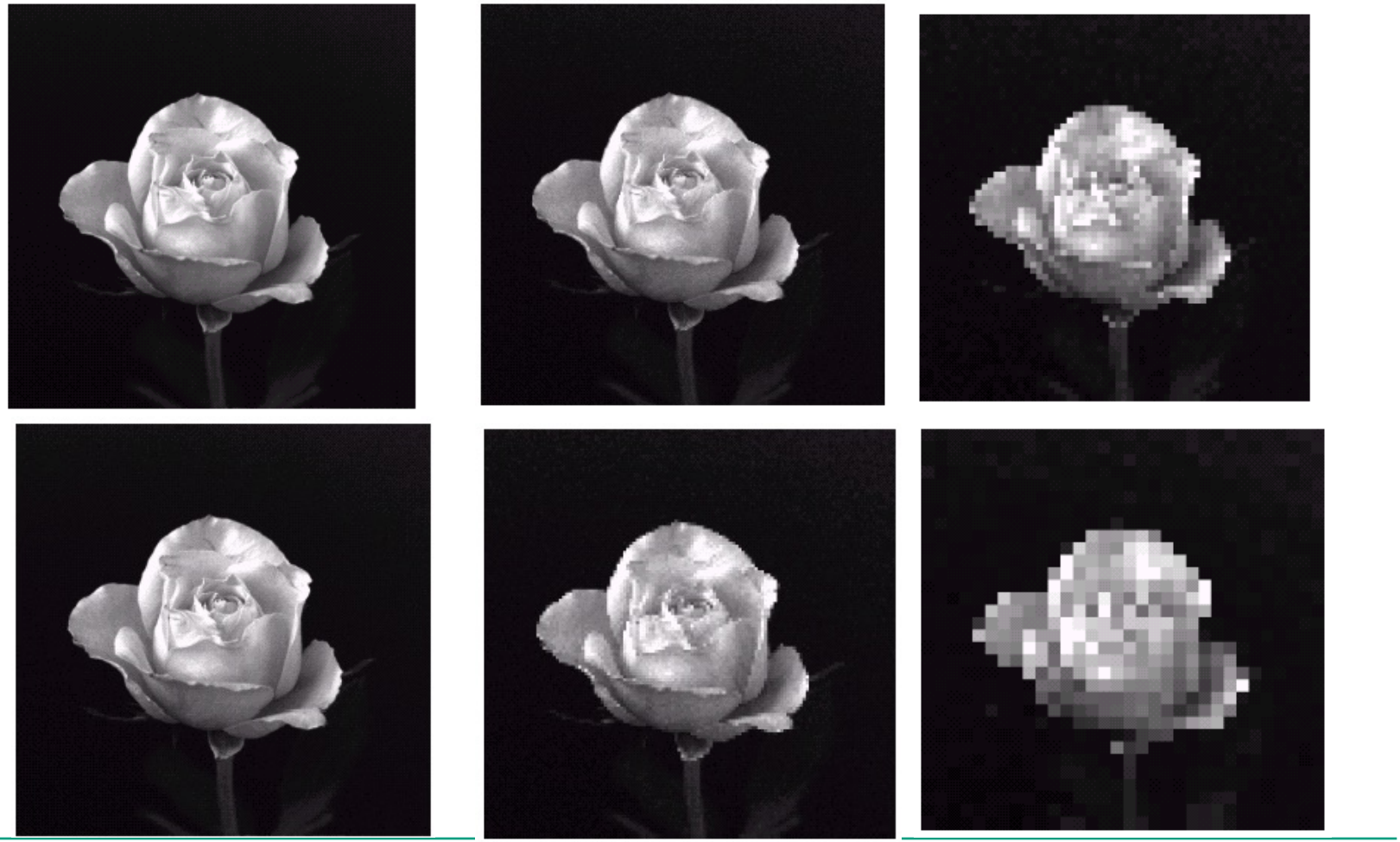
- *The **spatial resolution*** of an image is determined by how fine/coarse sampling was carried out
- **Spatial resolution:** smallest discernable image detail
  - Vision specialists talk about image resolution
  - Graphic designers talk about *dots per inch* (DPI)

Spatial Resolution



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

Spatial Resolution: Stretched Images



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

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

Low Detail

Medium Detail

High Detail

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

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?

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	1010101010101010

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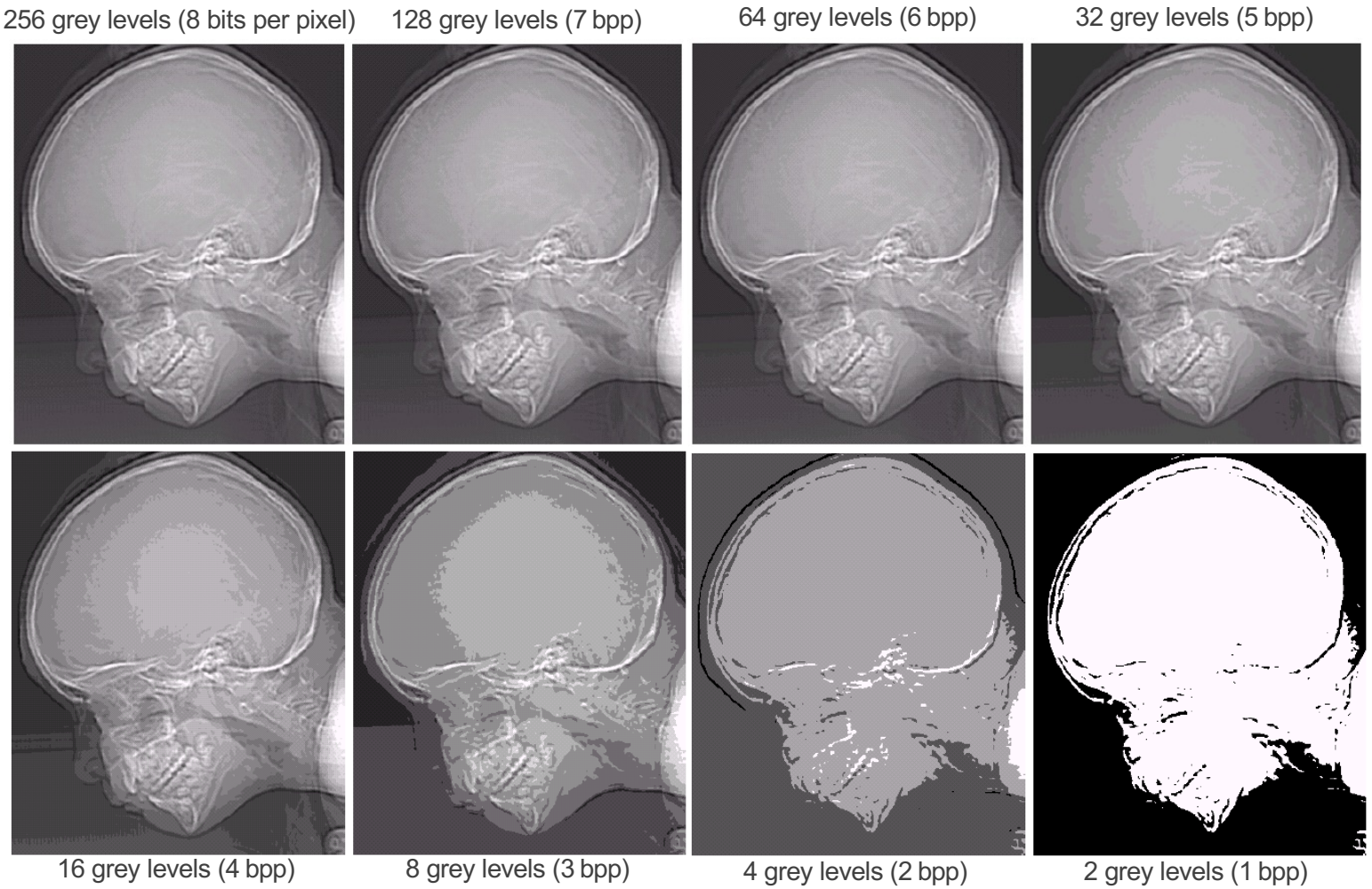
$$\text{Int\_levels} = 2^{(\text{bits})}$$

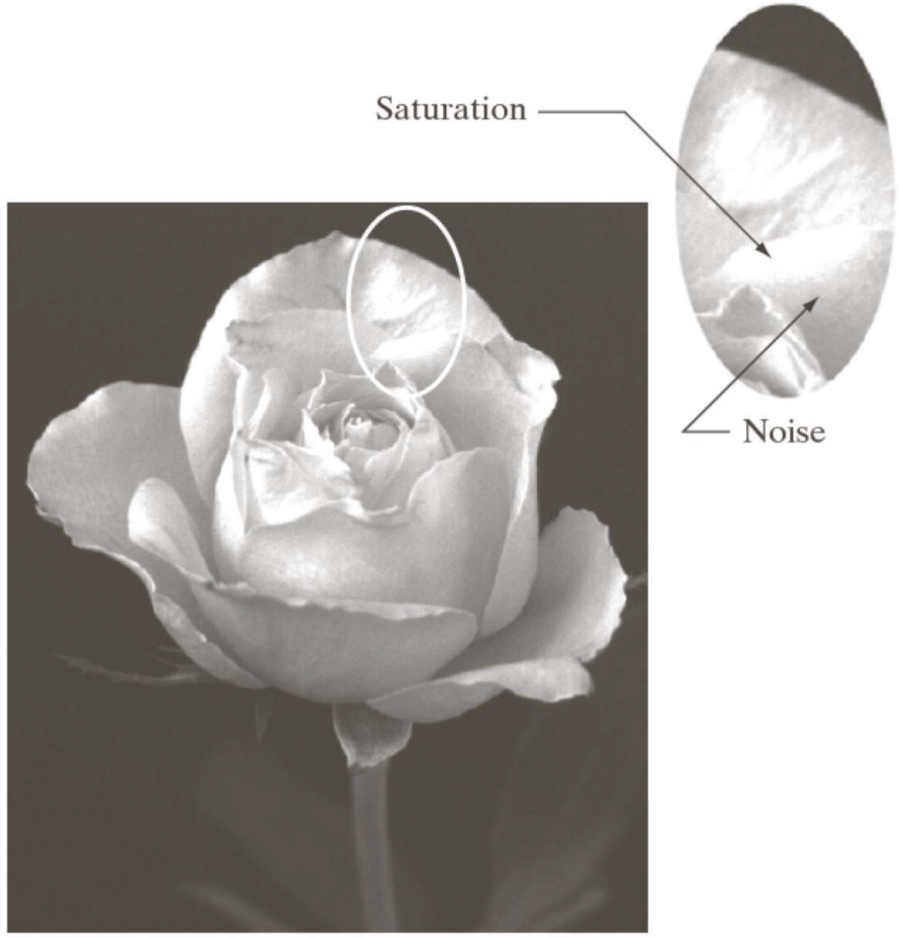
Number of Bits	Number of Intensity Levels	Examples
		0, 1
		00, 01, 10, 11
4	16	0000, 0101, 1111
8	256	00110011, 01010101
16	65,536	1010101010101010

Intensity Level Resolution



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

Saturation & Noise



Saturation: highest intensity value above which color is washed out

Noise: grainy texture pattern

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

Number of gray levels

Figure 1.25 *Four representations of the same image, with variation in the number of gray levels used. From the upper left: 32; 16; 8; 4. In all cases, a full 256 × 256 array of pixels is retained. Each step in the coarsening of the image is accomplished by rounding the brightness of the original pixel value.*

Bits & Bytes

Everything in a computer is 0's and 1's ... what does that mean? The **bit** stores just a 0 or 1 .. it's the smallest building block of storage.

Byte

- One byte = grouping of 8 bits
- e.g. 0 1 0 1 1 0 1 0
- One byte can store one letter, e.g. 'A' or 'x'

https://web.stanford.edu/class/cs101/bits-bytes.html

Bits & Bytes

- In general: add 1 bit, double the number of patterns
- 1 bit - 2 patterns
- 2 bits - 4
- 3 bits - 8
- 4 bits - 16
- 5 bits - 32
- 6 bits - 64
- 7 bits - 128
- 8 bits - 256
- Mathematically: n bits yields 2^n patterns (2 to the nth power)

https://web.stanford.edu/class/cs101/bits-bytes.html

Bits & Bytes

One Byte - 256 Patterns

- Need to know:
- 1 byte is group of 8 bits
- 8 bits can make 256 different patterns
- How to use the 256 patterns?
- How to store a number in a byte?
- Start with 0, go up, one pattern per number, until run out of patterns
- 0, 1, 2, 3, 4, 5, ... 254, 255
- One byte holds a number 0..255
- i.e. with 256 distinct patterns, we can store a number in the range 0..255
- Code: pixel.setRed(n) took a number 0..255. Why?
- The red/green/blue image numbers are each stored in **one byte**

https://web.stanford.edu/class/cs101/bits-bytes.html

Bits & Bytes

Closest 1000 is
$2^{10} = 1024$
1kb =1024 bytes

Bytes

- "Byte" - unit of information storage
- A document, an image, a movie .. how many bytes?
- 1 byte is enough to hold 1 typed letter, e.g. 'b' or 'X'
- Later we'll look at storage in: RAM, hard drives, flash drives
- All measured in bytes, despite being very different hardware
- **Kilobyte**, KB, about 1 thousand bytes
- **Megabyte**, MB, about 1 million bytes
- **Gigabyte**, GB, about 1 billion bytes
- **Terabyte**, TB, about 1 trillion bytes (rare)

Digitalisation of images

Grayscale (Intensity Images):

Chan.	*Bits/Pix.*	*Range*	*Use*
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:

Chan.	*Bits/Pix.*	*Range*	*Use*
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:

Chan.	*Bits/Pix.*	*Range*	*Use*
1	16	$-32768...32767$	Whole numbers pos./neg., increased range
1	32	$\pm 3.4 \cdot 10^{38}$	Floating point: medicine, astronomy
1	64	$\pm 1.8 \cdot 10^{308}$	Floating point: internal processing

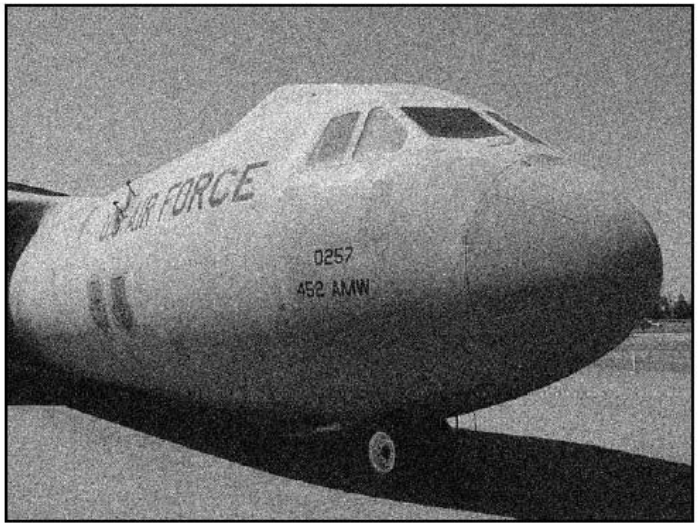
Sampling

- Spatial sampling (spatial resolution)
- Quantifications of pixel values (intensity level resolution
- Temporal sampling (time series)

Examples of image processing

Example Operation: Noise Removal

Noisy Image



Denoised Image

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

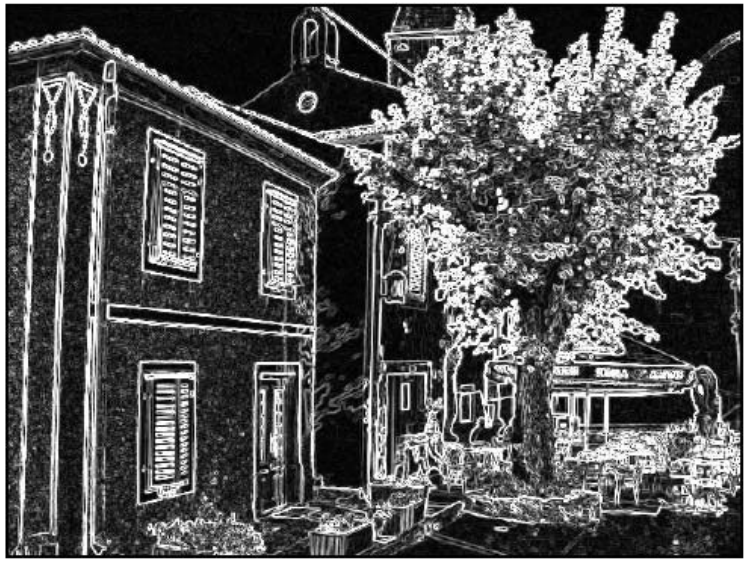
Example: Contrast Adjustment

Low Contrast

Original Contrast

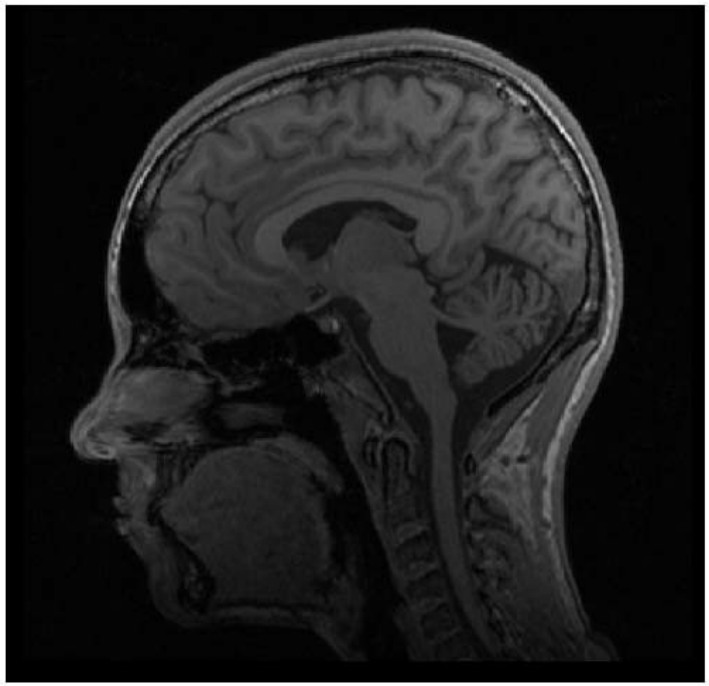
High Contrast

Example: Edge Detection



Applications of Image Processing/Analysis

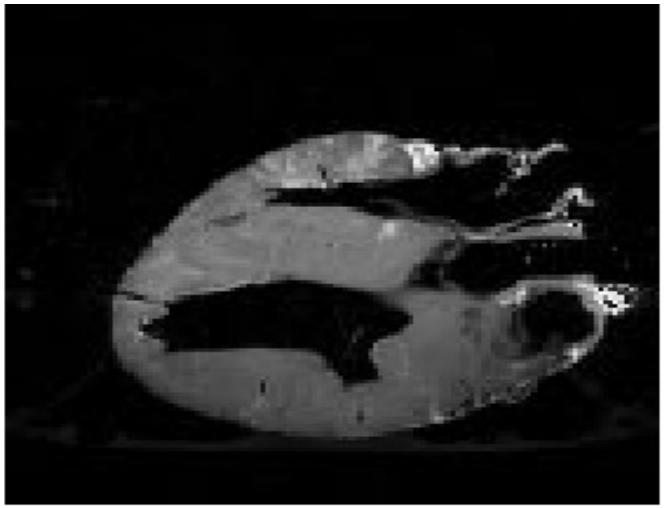
Medicine



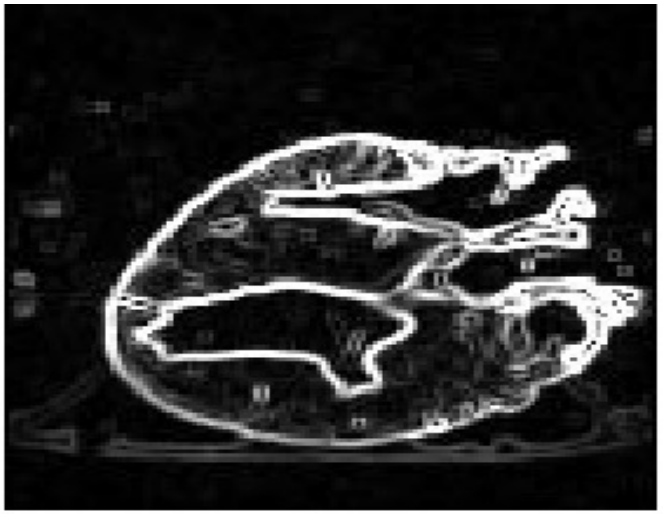
Credit: Dr. Janet Lainhart, UofU Psychiatry

Security, Biometrics

Applications of Image Processing: Medicine



Original MRI Image of a Dog Heart



Edge Detection Image

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

Applications of Image Processing

Satellite Imagery

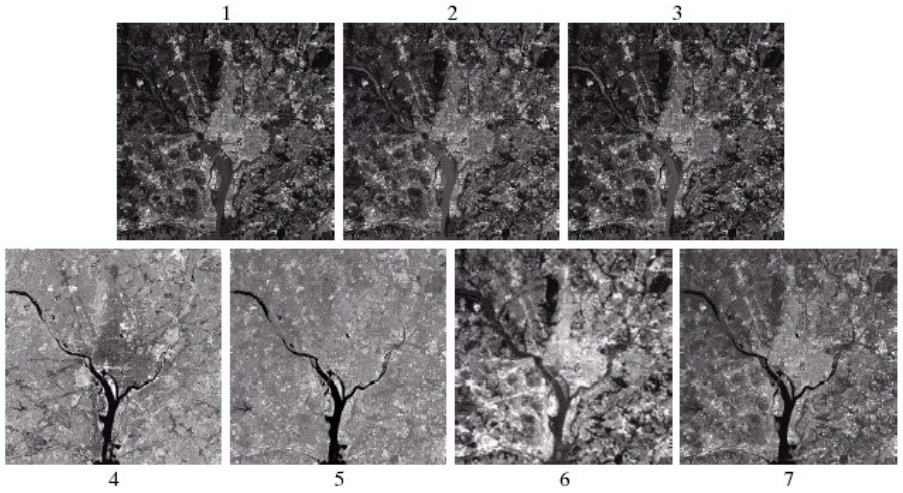
Credit: NASA

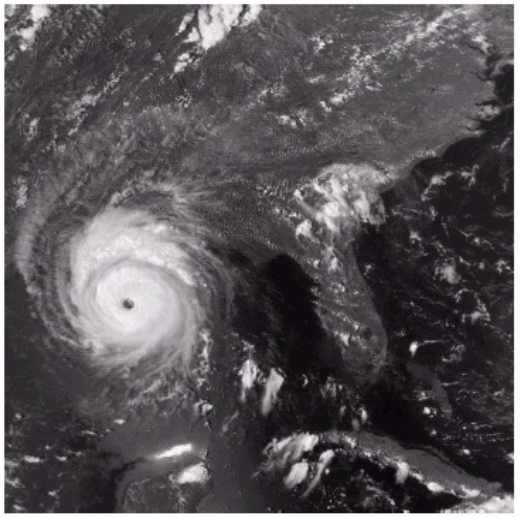
Personal Photos

Credit: Tom Fletcher

Applications of Image Processing: Geographic Information Systems (GIS)

- Terrain classification
- Meteorology (weather)

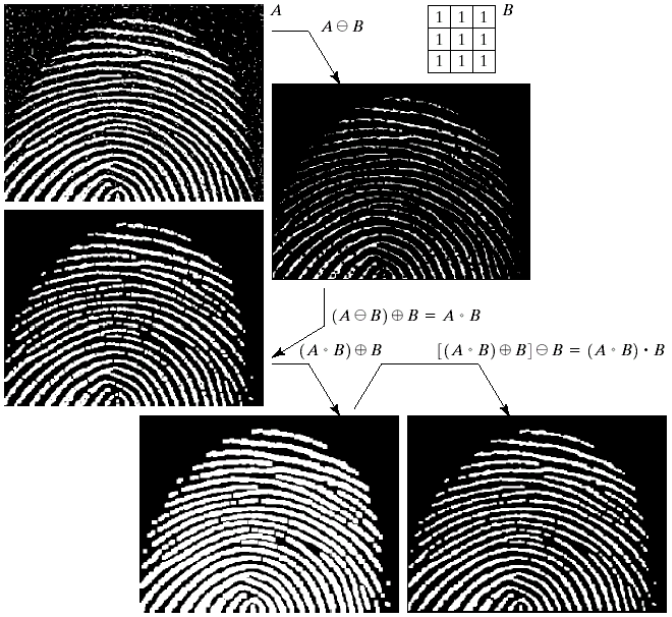




Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Applications of Image Processing: Law Enforcement

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

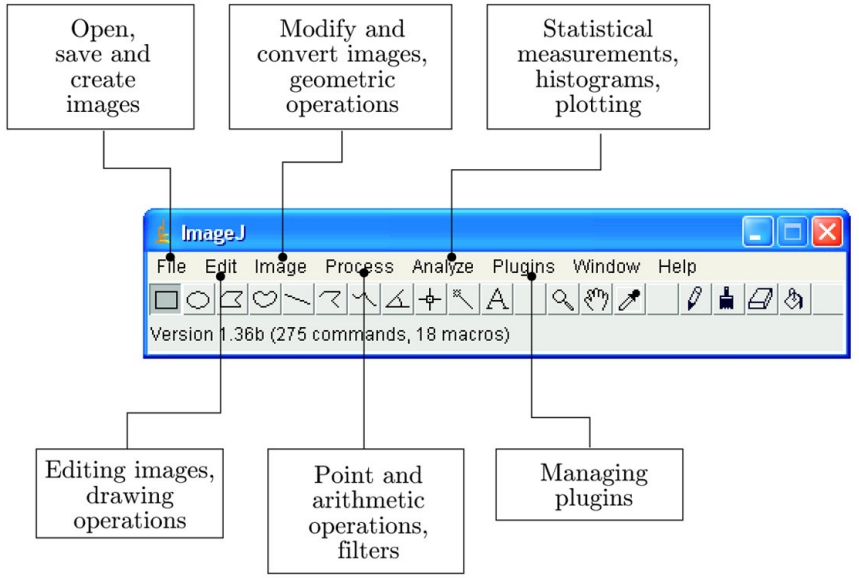


Images taken from Gonzalez & Woods, Digital Image Processing (2002)

ImageJ/Fiji

- Open source Java Image processing software
- Developed by Wayne Rasband at Nat. Inst for Health (NIH)
  - Many image processing algorithms **already implemented**
  - New image processing algorithms can also be implemented easily
  - Nice click-and-drag interface

Wayne Rasband (right)



ImageJ: Key Features

- **Interactive tools** for image processing of images
  - Supports many image file formats (JPEG, PNG, GIF, TIFF, BMP, DICOM, FITS)
- **Plug-in mechanism** for implementing new functionality, extending ImageJ
- **Macro language + interpreter:** Easy to implement large blocks from small pieces without knowing Java

Useful image formats

- JPEG
  - Destructive compression
- TIFF (Tagged IMage File Format)
  - Non destructive compression
  - Used in ImageJ for storage of images and stacks of images
- GIF
  - Graphics Interchange Format
  - Used much on internet. Transparancy, animated images
- PNG (Portable Network Format)
  - A good alternative to JPEG.
  - Non destructive
  - Transparancy
- Raw images
  - Digital photo «negative film»
  - RAW (Canon)
  - NEF (Nikon)

Formats for image analysis

- Record in JPEG or RAW
- Convert to TIFF or PNG
- In between savings in TIFF or PNG

Nice video on JPEG compression:

https://www.youtube.com/watch?v=Ba89cI9eIg8&ab_channel=LeoIsikdogan

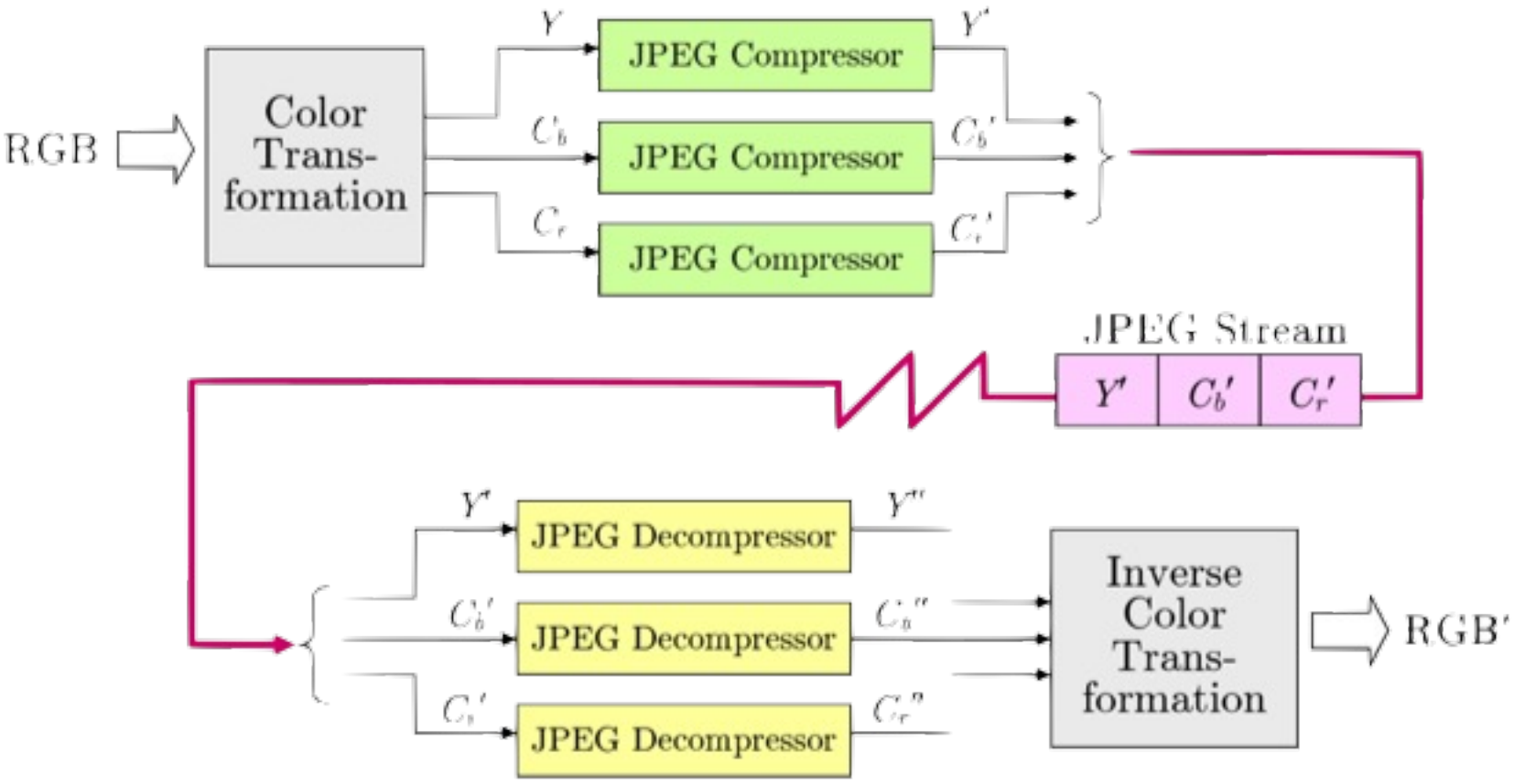
JPEG

- JPEG (or JPG) is an electronic image format developed by Joint Photographic Experts Group
- Uses lossy compression techniques
- The files end up smaller than with other non lossy compression techniques
- JPEG is often used to store digital images, especially images on the internet

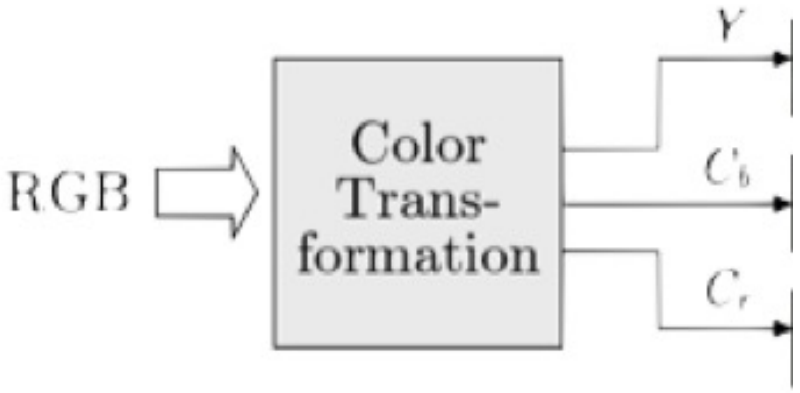
JPEG

- Converting colours and downsampling
  - The human eye is not so sensitive to colour changes as to intensity variations
  - The colour component is more compressed than the intensity component
  - The compression is carried out to simulate the ”reality” using COSINE transformations
  - Higher frequencies are not important for the visual perception

JPEG algorithm



JPEG algorithm part 1



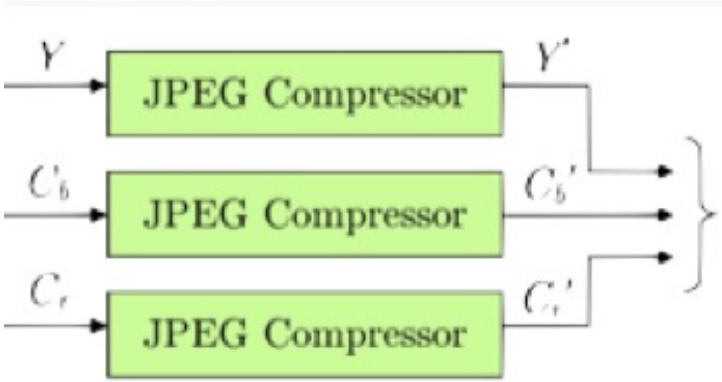
- Colour transformation from RGB to YC_bC_r

  RGB = red, green, blue

  Y=lightness

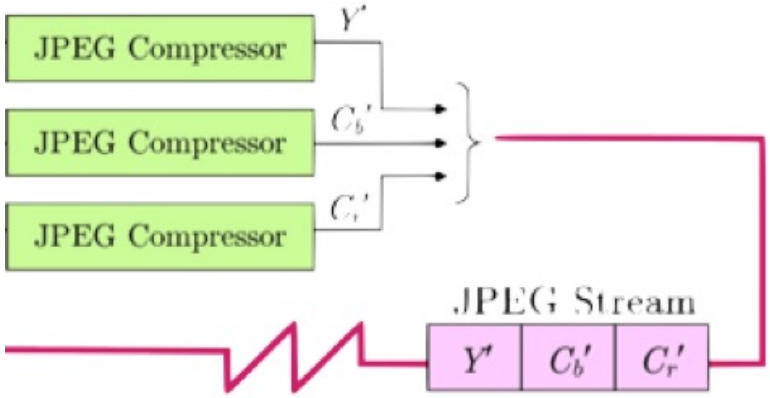
  C_b,C_r = colour chanels blue and red

JPEG algorithm part 2



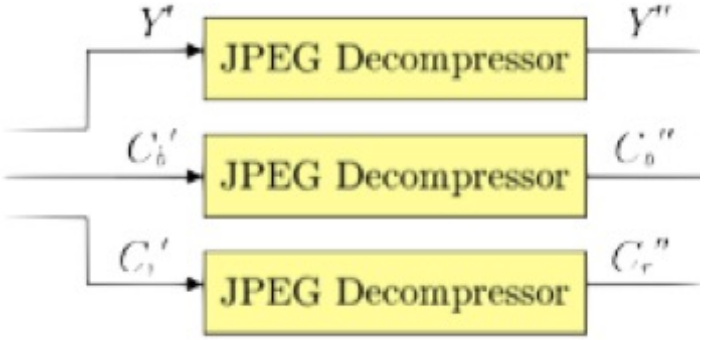
- YC_bC_r is compressed via cosine transformation
  - Coefficients (frequencies) are produced in the transformation
  - High frequencies (sharpness) are removed
  - Cb and Cr are treated differently
    - Humans seperate red/green better than blue/yellow

JPEG algorithm part 3



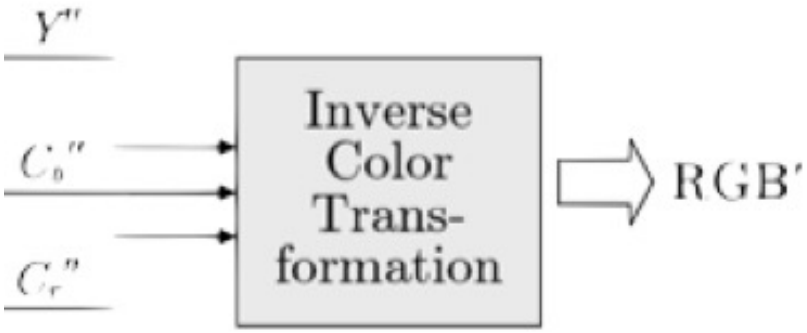
- The remaining table of coefficients are compressed without loss (JPEG stream)

JPEG algorithm part 4



- Decompression is done with the inverse cosine transformation

JPEG algorithm part 5



- Y''C''$_b$C''$_r$ are converted to RGB'
- RGB' is unpacked different from RGB
- RGB' comes with a factor of "Quality"

JPEG and “artifacts”

- Quality of the compression: Q_{jpeg}
- Digital cameras use JPEG with a defined compression
- JPEG should not be used when storing images during processing and analysis
- Use TIF, PNG