Lecture 9

Introduction to Image Processing

UTAS
Sultanate of Oman
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CSSY2201 : Introduction to Cryptography

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Plan

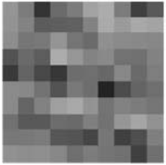
What is an Image ?

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

Set of Intensity values

Image coordinates are integers

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



$F(x,y)$

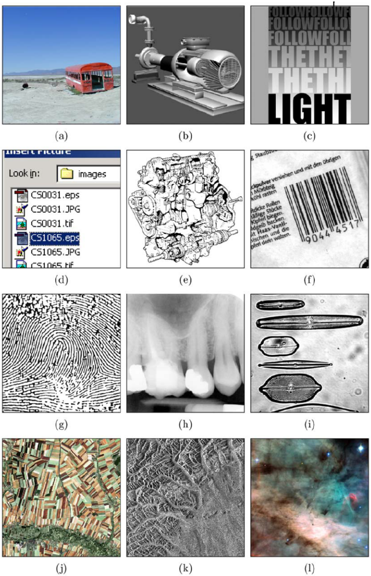
$\rightarrow$

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	⋯
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	

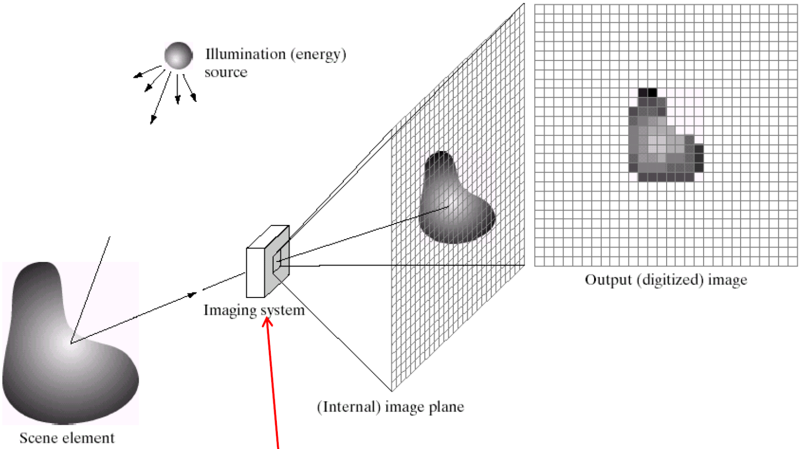
$I(u,v)$

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) Microscope slide
- (i) Radar image
- (j) Astronomical object



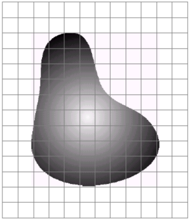
Imaging System



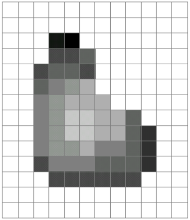
Example: a camera
Converts light to image

Digital Image ?

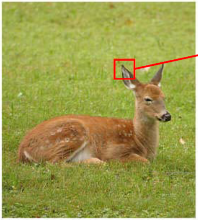
- **Remember:** *digitization* causes a digital image to become an *approximation* of a real scene



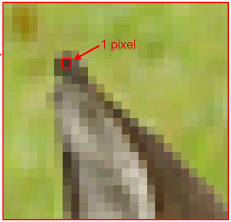
Real image



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)

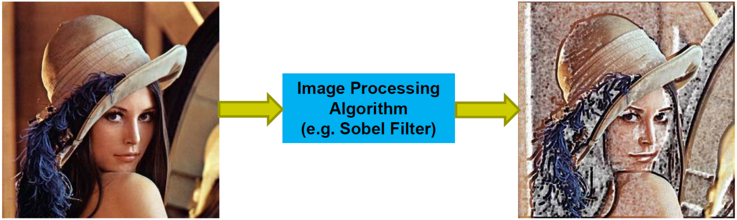
Grayscale

RGB

RGBA

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 editting
  - Image enhancement
  - Image compression

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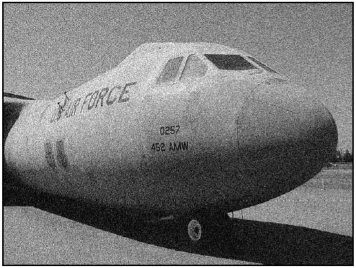
Example Operation : Noise Removal

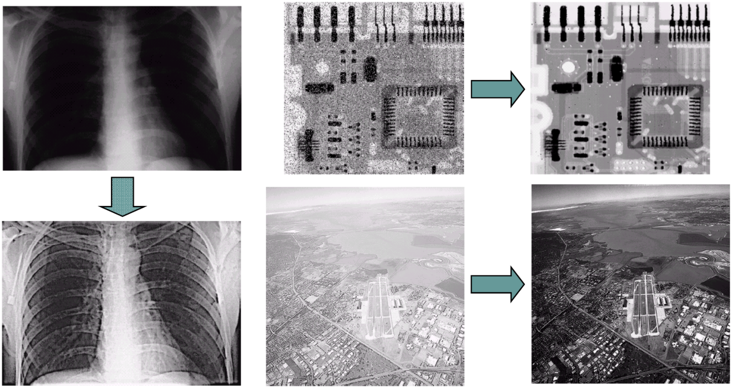
Noisy Image



Denoised Image

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

Example Operation : Noise Removal



Example : Contrast Adjustment

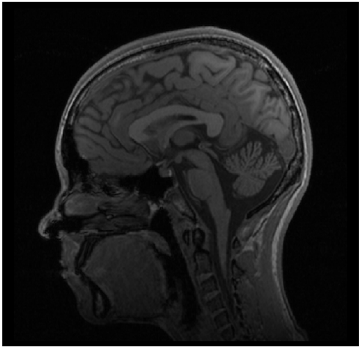
Low Contrast

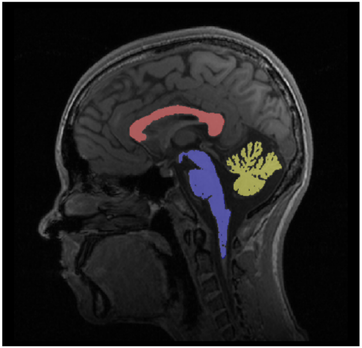
Original Contrast

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

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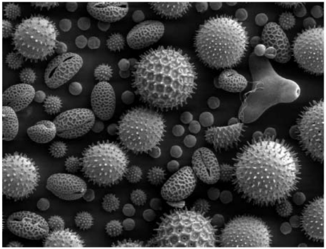
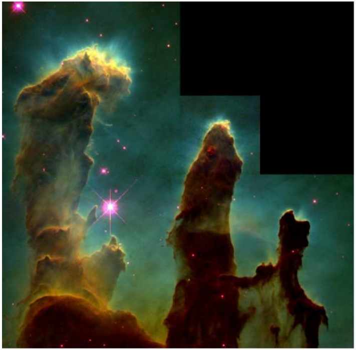
Applications of Image Processing

Biology



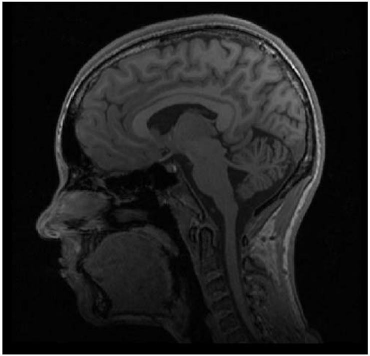
Credit: Dartmouth Electron Microscopy Facility

Astronomy



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

Medicine



Credit: Dr. Janet Lainhart, UofU Psychiatry

Security, Biometrics

Satellite Imagery

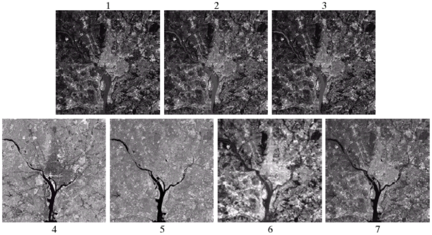
Credit: NASA

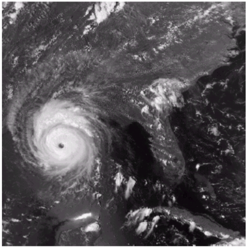
Personal Photos

Credit: Tom Fletcher

Applications of Image Processing : Geographic Information Systems (GIS)

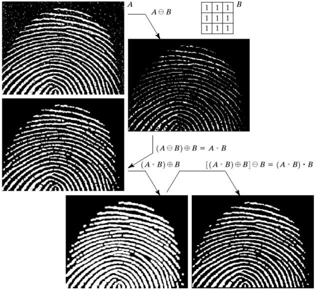
- Terrain classification
- Meteorology (weather)





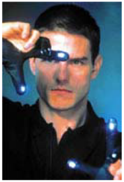
Applications of Image Processing : Law Enforcement

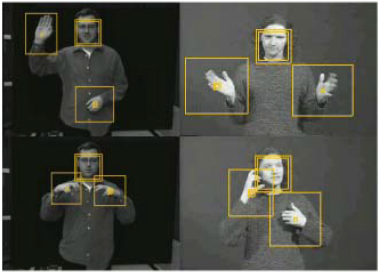
- Number plate recognition for speed cameras or automated toll systems
- Fingerprint recognition

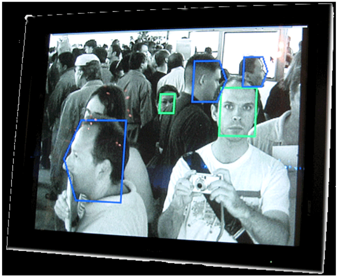


Applications of Image Processing : HCI

- Face recognition
- Gesture recognition

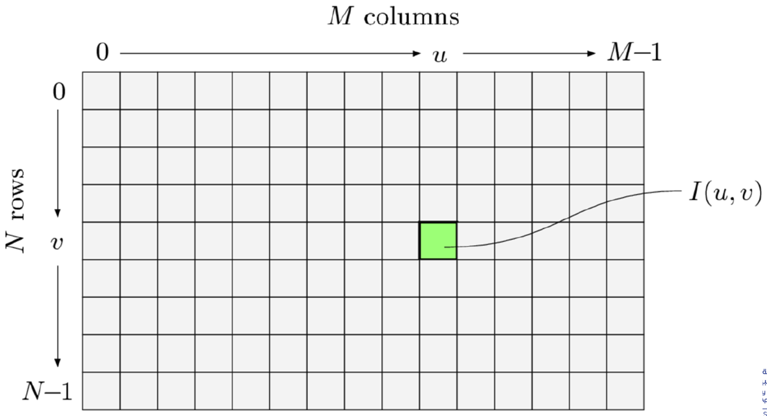






Representing Images

- 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.)



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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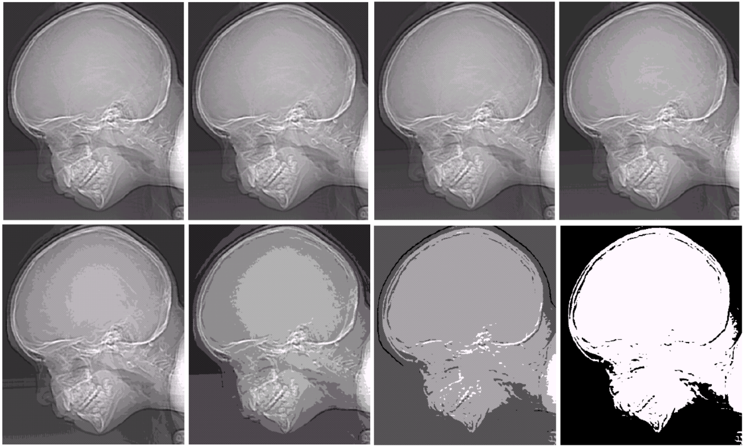
Intensity Level Resolution



Resolution : How Much Is Enough ?

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

Image File Formats

- Hundreds of image file formats. Examples
  - Tagged Image File Format (TIFF)
  - Graphics Interchange Format (GIF)
  - Portable Network Graphics (PNG)
  - PEG, 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):

Chan.	*Bits/Pix.*	*Range*	*Use*
1	1	$0\ldots1$	Binary image: document, illustration, fax
1	8	$0\ldots255$	Universal: photo, scan, print
1	12	$0\ldots4095$	High quality: photo, scan, print
1	14	$0\ldots16383$	Professional: photo, scan, print
1	16	$0\ldots65535$	Highest quality: medicine, astronomy

Color Images:

Chan.	*Bits/Pix.*	*Range*	*Use*
3	24	$[0\ldots255]^3$	RGB, universal: photo, scan, print
3	36	$[0\ldots4095]^3$	RGB, high quality: photo, scan, print
3	42	$[0\ldots16383]^3$	RGB, professional: photo, scan, print
4	32	$[0\ldots255]^4$	CMYK, digital prepress

Special Images:

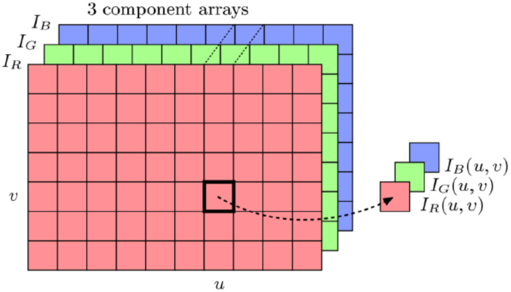
Chan.	*Bits/Pix.*	*Range*	*Use*
1	16	$-32768\ldots32767$	Whole numbers pos./neg., increased range
1	32	$\pm3.4\cdot10^{38}$	Floating point: medicine, astronomy
1	64	$\pm1.8\cdot10^{308}$	Floating point: internal processing

Organization of Color Images

- True color : Uses all colors in color space
  - used in applications that contain many colors with subtle differences
  - E.g. digital photography or photorealistic rendering
- Indexed color : Uses only some colors
  - Which subset of colors to use ? Depends on application

True Color

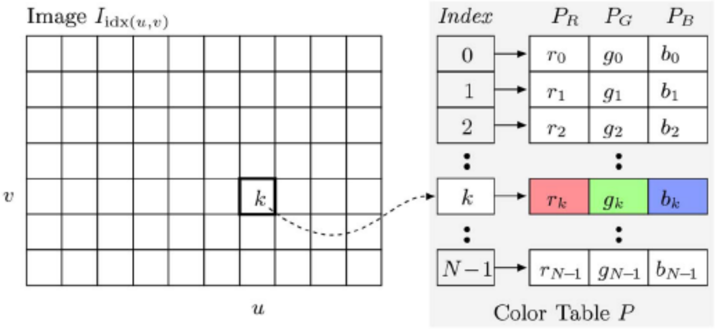
- Colors in 3 separate arrays of similar length
- Retrieve same location (u,v) in each R, G and B array



$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} \leftarrow \begin{pmatrix} I_R(u,v) \\ I_G(u,v) \\ I_B(u,v) \end{pmatrix}$$

Indexed Images

- Permit only limited number of distinct colors (N = 2 to 256)
- Used in illustrations or graphics containing large regions with same color
- Instead of intensity values, image contains indices into color table or palette
- Palette saved as part of image
- Converting from true color to indexed color requires quantization

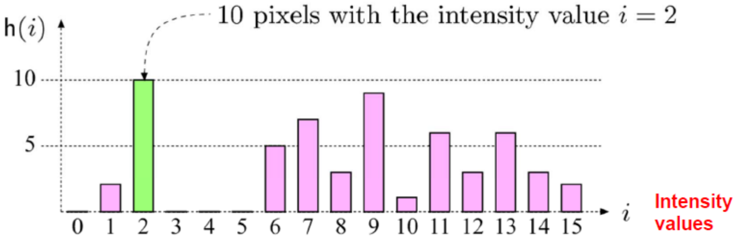


color images

- RGB full-color images (24-bit "RGB color"),
  - packed order
  - Supports TIFF, BMP, JPEG, PNG and RAW file formats
- Indexed images ("8-bit color")
  - Up to 256 colors max (8 bits)
  - Supports GIF, PNG, BMP and TIFF (uncompressed) file formats

Histograms

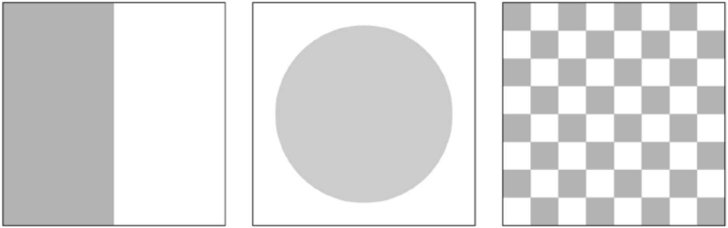
- Histograms plots how many times (frequency) each intensity value in image occurs
- Example :
  - Image (left) has 256 distinct gray levels (8 bits)
  - Histogram (right) shows frequency (how many times) each gray level occurs



h(i)	0	2	10	0	0	0	5	7	3	9	1	6	3	6	3	2
i	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

- E.g. K = 16, 10 pixels have intensity value = 2
- Histograms : only statistical information
- No indication of location of pixels

- Different images can have same histogram
- 3 images below have same histogram



- Half of pixels are gray, half are white
    - Same histogram = same statisics
    - Distribution of intensities could be different
- Can we reconstruct image from histogram ? No !

- So, a histogram for a grayscale image with intensity values in range

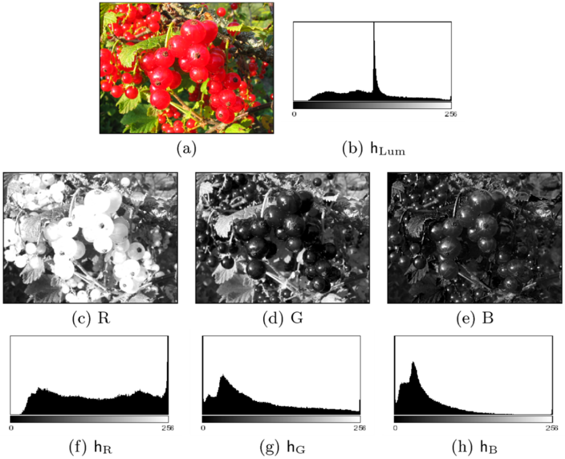
$$I(u, v) \in [0, K - 1]$$

  would contain exactly K entries
- E.g. 8-bit grayscale image, $K = 2^8 = 256$
- Each histogram entry is defined as :
  h(i) = number of pixels with intensity i
- E.g : h(255) = number of pixels with intensity 255
- formal definition : $h(i) = card\{(u, v) | I(u, v) = i\}$

Color Image Histograms

Two types :

1. Intensity histogram :
   - Convert color image to gray scale
   - Display histogram of gray scale
2. Individual Color Channel Histograms : 3 histograms (R,G,B)



PSNR and MSE

- Peak Signal to Noise Ratio (PSNR) is an engineering formulation determined through mean square error (MSE). It is generally utilized for image quality evaluation as follows :

$$PSNR = 10 \log_{10} \frac{d^2}{MSE}$$

where

$$MSE = \frac{1}{M \times N} \sum_{i=1}^{M} \sum_{j=1}^{N} (X(i,j) - Y(i,j))^2$$

- d stands for the maximal intensity value that can be taken. for example in a gray scale image $d = 255$.
- M and N are the height and width of the images.
- To use PSNR and MSE, the two compared images should be with the same dimensions.
- values of PSNR between 30 dB and 40 dB (decibels) indicate that images are very similar.

NPCR

Number of Pixels Change Rate (NPCR) :

$$NPCR = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} D(i,j)}{M \times N} \times 100\%$$

M and N are the height and width of the images

$$D(i,j) = \begin{cases} 0 \ \ if \ \ S(i,j) = S'(i,j) \\ 1 \ \ if \ \ S(i,j) \neq S'(i,j) \end{cases}$$

$S(i,j)$ and $S'(i,j)$ are the values of pixels.
for two random images : $NPCR = 99.609375\%$

UACI

Unified Average Changing Intensity (UACI) :

$$UACI = \frac{1}{M \times N}\left(\sum_{i=1}^{M}\sum_{j=1}^{N}\frac{|S(i,j) - S'(i,j)|}{2^B - 1}\right) \times 100\%$$

M and N are the height and width of the images.
$S(i,j)$ and $S'(i,j)$ are the values of pixels.
and B is the intensity level (E.g for a gray scale image $B = 8$).
For two random images : $UACI = 33.46354\%$