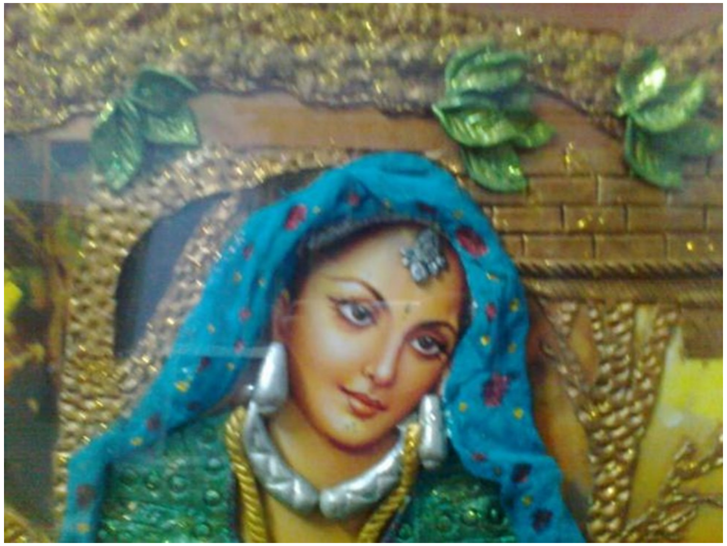
Digital Image Processing

Fundamentals

What is a Digital Image?

- An image is non-textual information that can be displayed and printed.
- A **digital image** is a representation of a two-dimensional image as a finite set of digital values, called picture elements or pixels
- The smallest addressable image element is called PIXEL (picture element). The array is called a bitmap
- Pixel values typically represent gray levels, colors, heights, opacities and so on
- Images can be from real world or virtual
- Image can also be described as spatial arrays of values

Example Images



More formally: Image is -

A two dimensional light intensity function

$$\begin{tikzcd} \text{Analog Image : } f(x\in R,\ y\in R) \arrow[r] \arrow[d, "\text{Sampling}"'] & v\in R = i(x,y) * r(x,y) \arrow[d, "\text{Quantization}"] \\ \text{Digital Image : } f(x\in Z,\ y\in Z) \arrow[r] & v\in Z \end{tikzcd}$$

PROCESSING:

Analysis + Understanding

Two Dimensional Representation of an Image

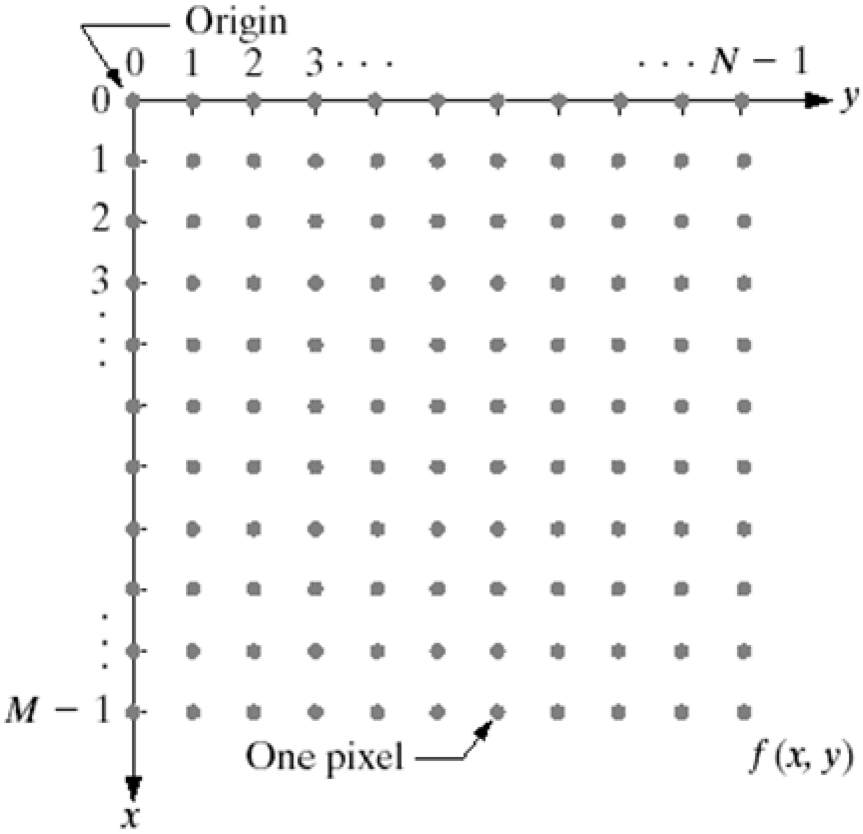


Fig. Coordinate conventions used in digital image processing text books to represent digital images

Memory Requirement?

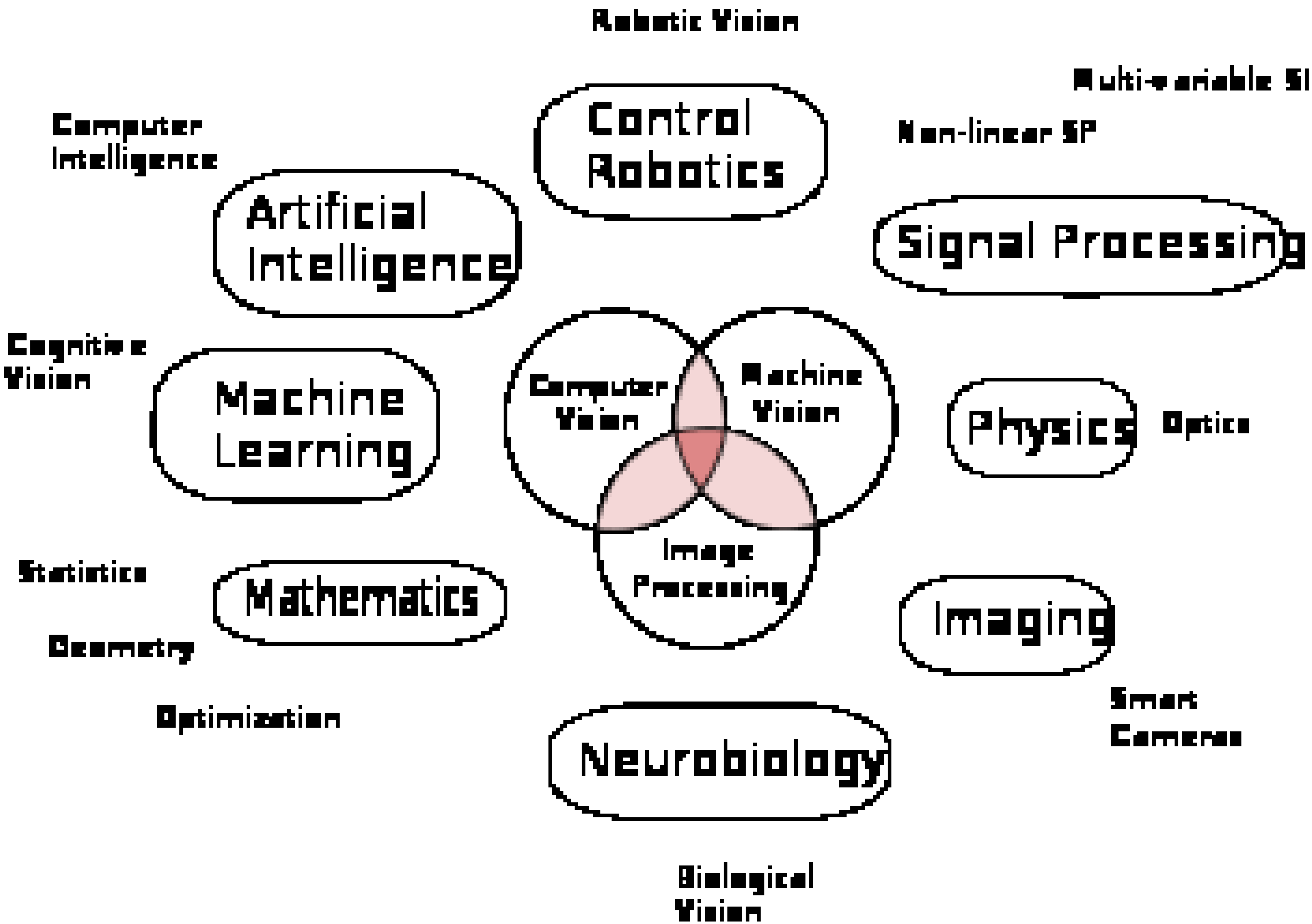
Why digital image processing?

- Image is better than any other information form for human being to perceive.
- Humans are primarily visual creatures – above 90% of the information about the world (a picture is better than a thousand words)
- However, vision is not intuitive for machines
  - Projection of 3D world to 2D images => loss of information
  - Interpretation of dynamic scenes, such as a moving camera and moving objects
- To improve the visual quality of an image for human interpretation
- To analyze the contents of the image for autonomous machine perception

What is Digital Image Processing?

- Digital Image processing involves
  - Image understanding, Image analysis, and Computer vision which are aim to imitate the process of human vision electronically
- Digital Image Processing deals with image acquisition, pre-processing, segmentation, representation and description (feature extraction), and recognition and interpretation (image understanding) thereby enabling the scene analysis and understanding

Fundamental Areas



Digital Image Processing - Steps

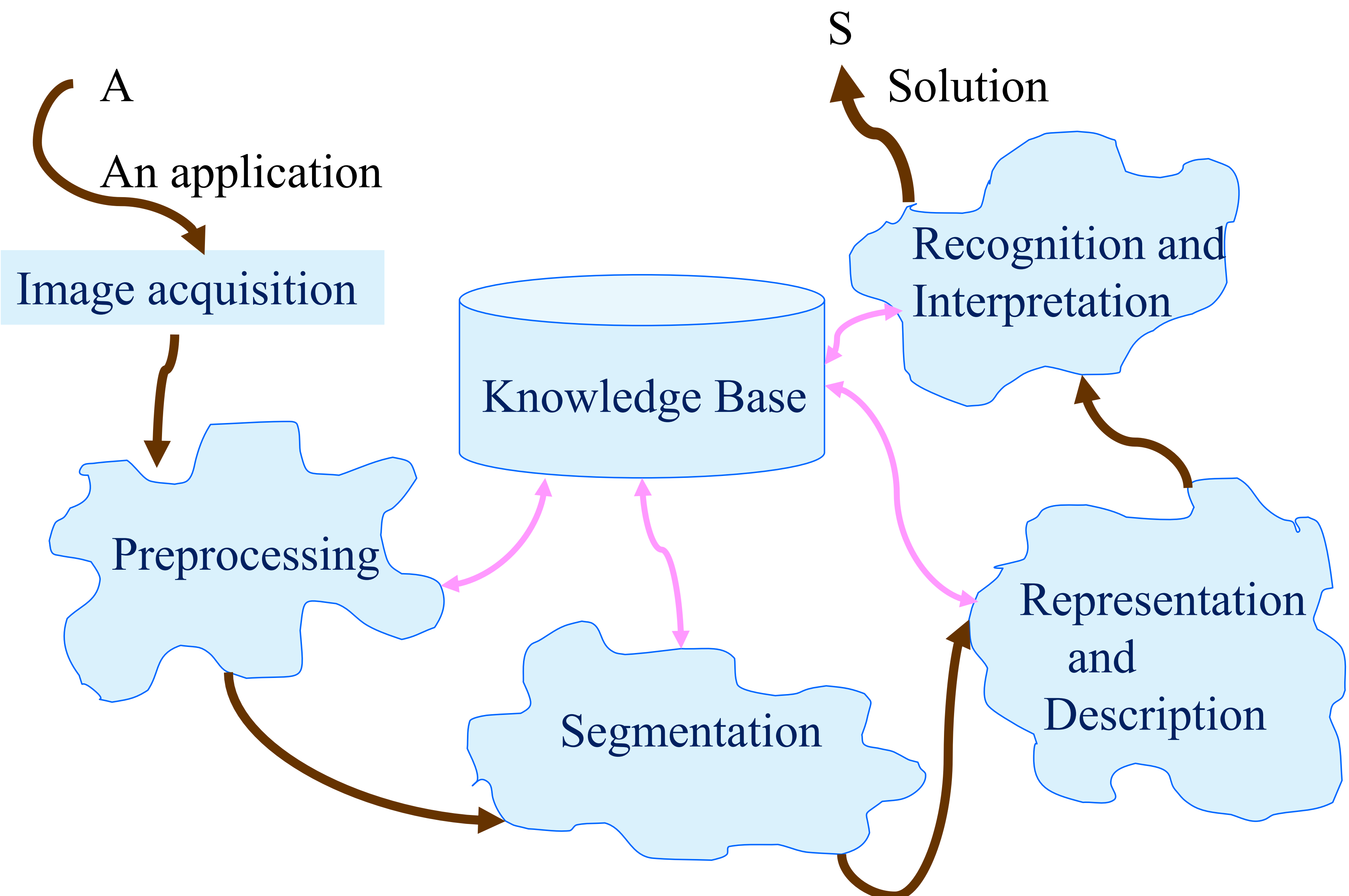


Image Acquisition

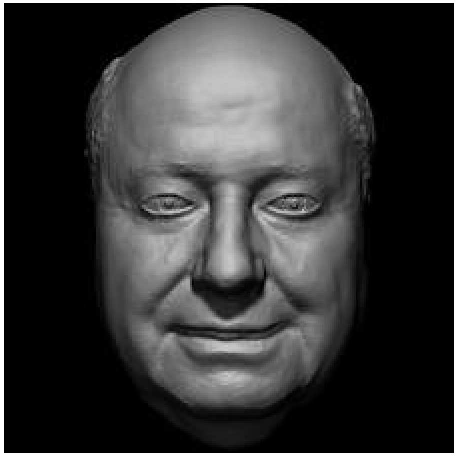
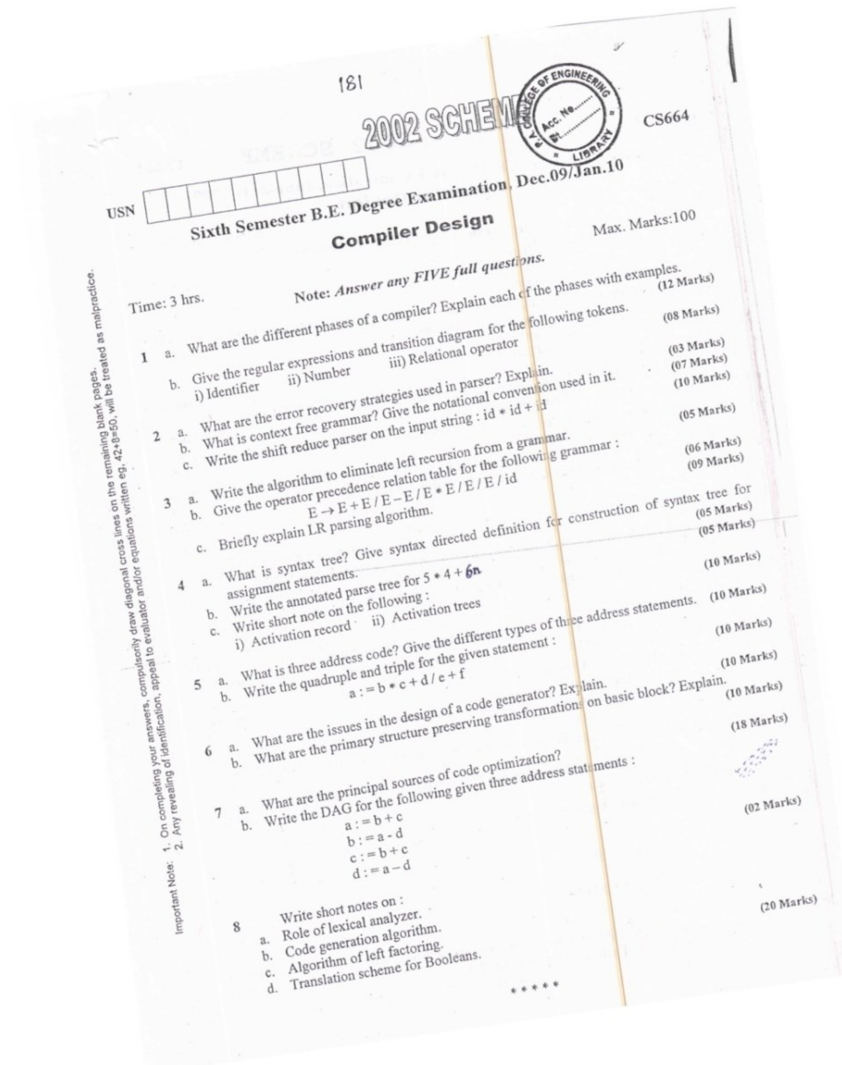


Image Acquisition



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2002 SCHEME

CS664

USN

Sixth Semester B.E. Degree Examination, Dec.09/Jan.10

Compiler Design

Time: 3 hrs. Max. Marks:100

Note: ***Answer any FIVE full questions.***

1 a. What are the different phases of a compiler? Explain each of the phases with examples. (12 Marks)

b. Give the regular expressions and transition diagram for the following tokens.
i) Identifier ii) Number iii) Relational operator (08 Marks)

2 a. What are the error recovery strategies used in parser? Explain. (03 Marks)

b. What is context free grammar? Give the notational convention used in it. (07 Marks)

c. Write the shift reduce parser on the input string : id * id + id (10 Marks)

3 a. Write the algorithm to eliminate left recursion from a grammar. (05 Marks)

b. Give the operator precedence relation table for the following grammar :
E → E + E / E – E / E * E / E / E / id (06 Marks)

c. Briefly explain LR parsing algorithm. (09 Marks)

4 a. What is syntax tree? Give syntax directed definition for construction of syntax tree for assignment statements. (05 Marks)

b. Write the annotated parse tree for 5 * 4 + 6n (05 Marks)

c. Write short note on the following :
i) Activation record ii) Activation trees (10 Marks)

5 a. What is three address code? Give the different types of three address statements. (10 Marks)

b. Write the quadruple and triple for the given statement :
a : = b * c + d / e + f (10 Marks)

6 a. What are the issues in the design of a code generator? Explain. (10 Marks)

b. What are the primary structure preserving transformations on basic block? Explain. (10 Marks)

7 a. What are the principal sources of code optimization? (18 Marks)

b. Write the DAG for the following given three address statements :
a : = b + c
b : = a - d
c : = b + c
d : = a – d (02 Marks)

8 Write short notes on :
a. Role of lexical analyzer.
b. Code generation algorithm.
c. Algorithm of left factoring.
d. Translation scheme for Booleans. (20 Marks)

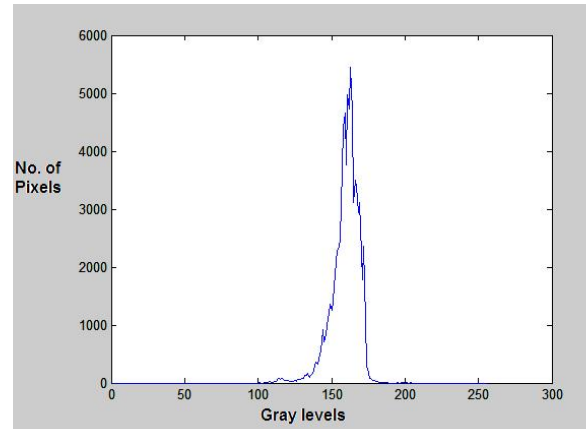
* * * * *

Important Note: 1. On completing your answers, compulsorily draw diagonal cross lines on the remaining blank pages.
2. Any revealing of identification, appeal to evaluator and/or equations written eg, 42+8=50, will be treated as malpractice.

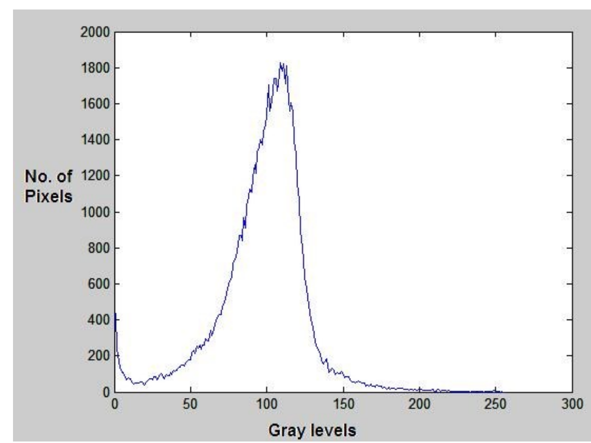
Image Enhancement

Low Contrast Image

High Contrast Image



It's Histogram



Stretched Histogram

Image Enhancement

Low quality images **Images after processing**

Image Enhancement

Equalization

Histogram Equalization

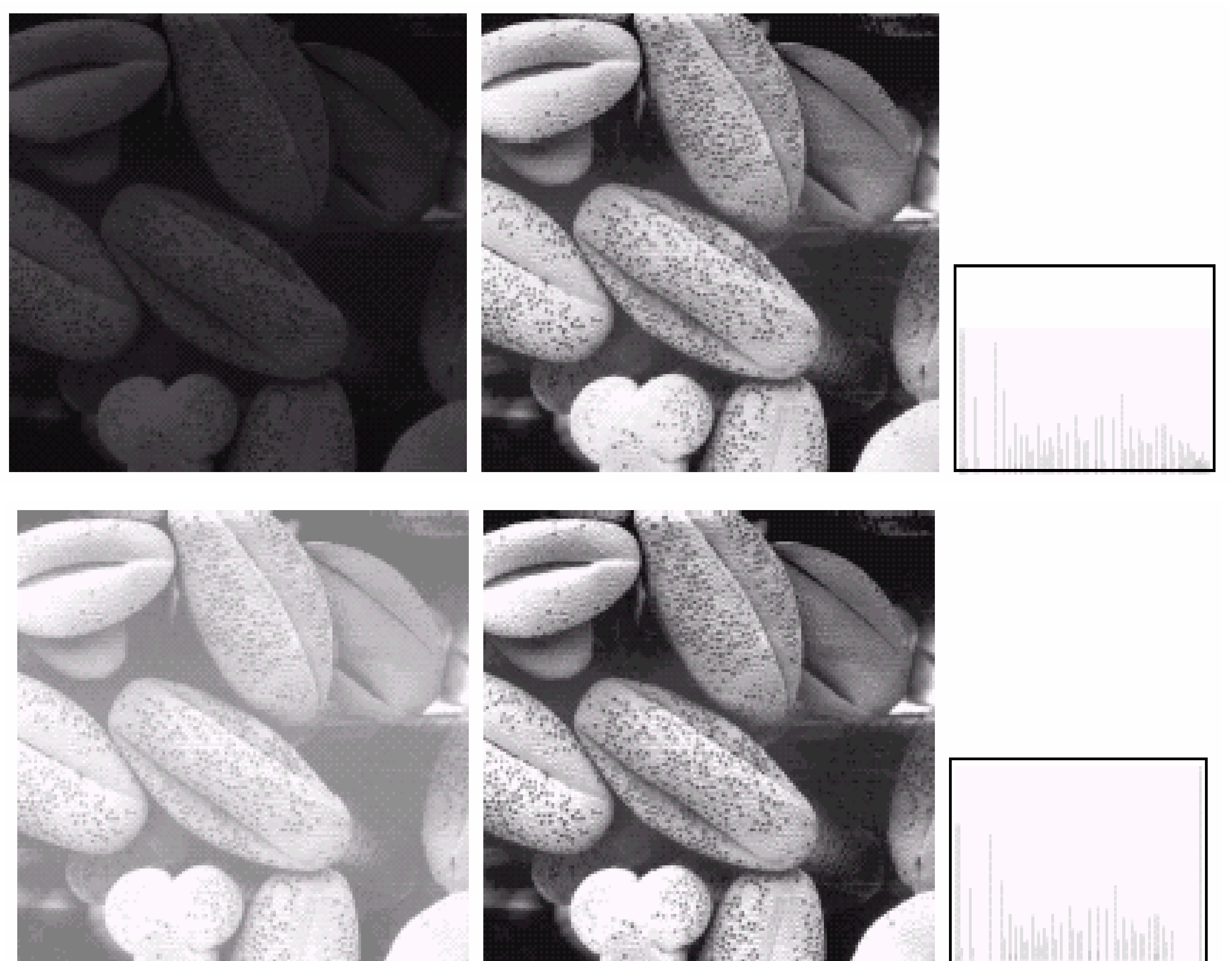
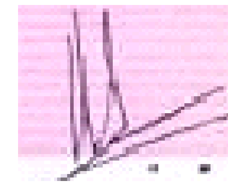
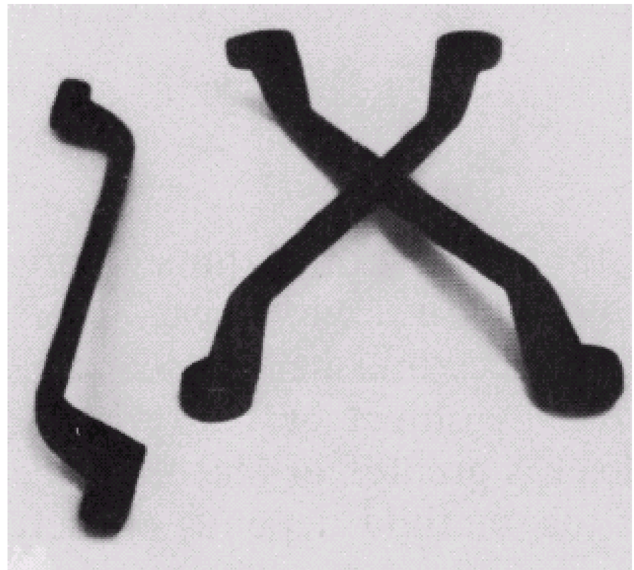


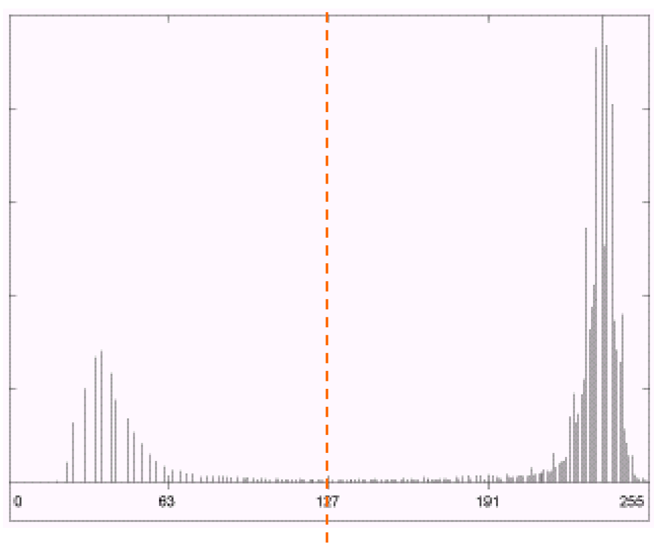
Image Segmentation

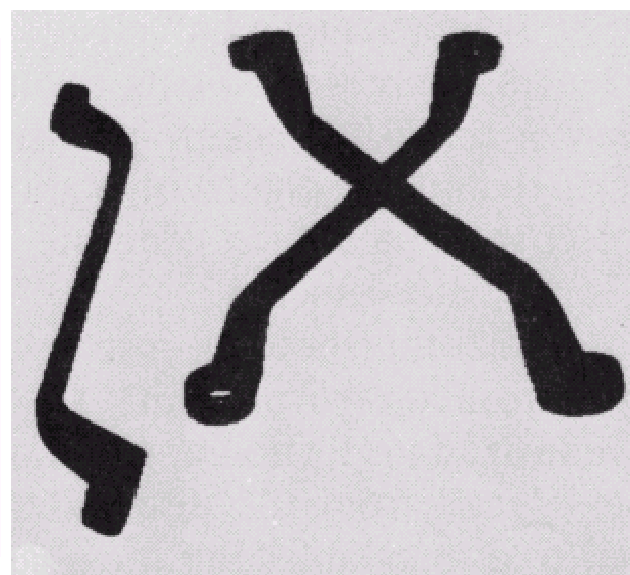


Thresholding: Example 1

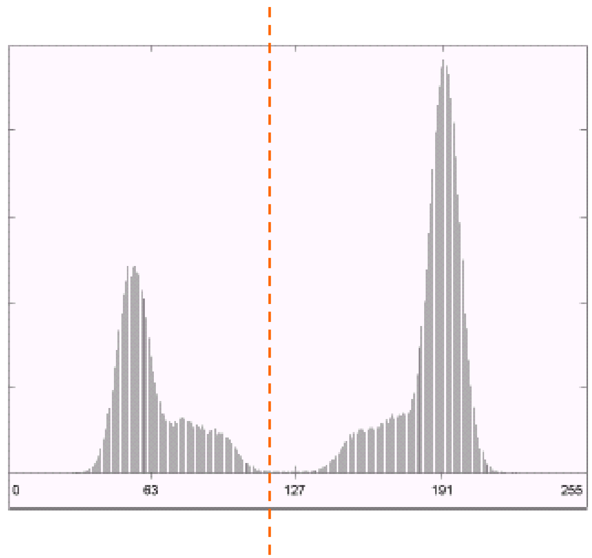
Images taken from Gonzalez & Woods, Digital Image Processing (2002)





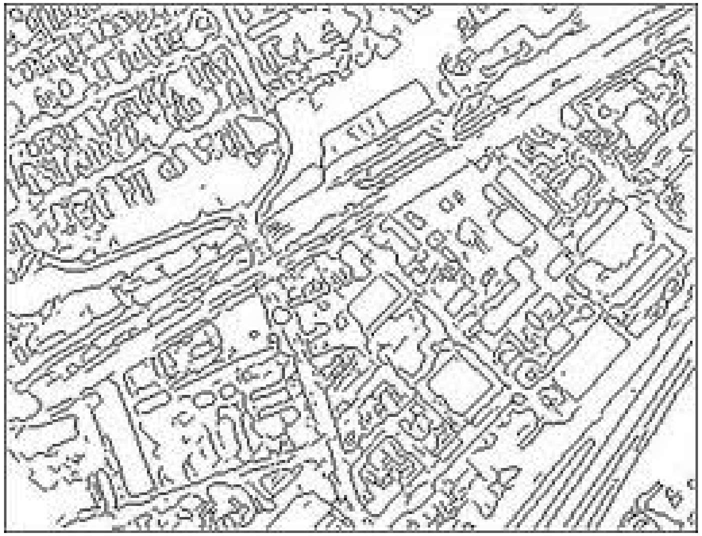


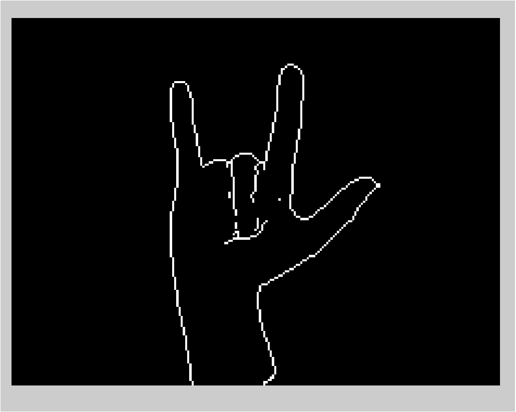
Thresholding: Example 2



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

Edge Based Segmentation





Feature Extraction

- Appearance based models/Global Approaches:
  - Principal Component Analysis
  - Linear discriminant analysis
  - Texture features
  - Shape based features
  - Discrete cosine transform
  - Wavelet transform and so on
- Descriptor based models/Local Approaches
  - Scale Invariant Feature Transform
  - Local Binary Pattern
  - Histogram of Gradients
  - Region Covariance Matrix and so on

Applications...

- Agriculture
- Augmented reality
- Autonomous vehicles
- Biometrics
- Character recognition
- Forensics
- Industrial quality inspection
- Face recognition
- Gesture analysis
- Geo-science
- Image restoration
- Medical image analysis
- Pollution monitoring
- Process control
- Remote sensing
- Robotics
- Security and surveillance
- Transport

Agriculture

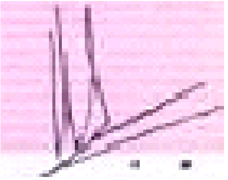
- For Harvesting
- For Cleaning
- For quality inspection
- For disease identification and so on

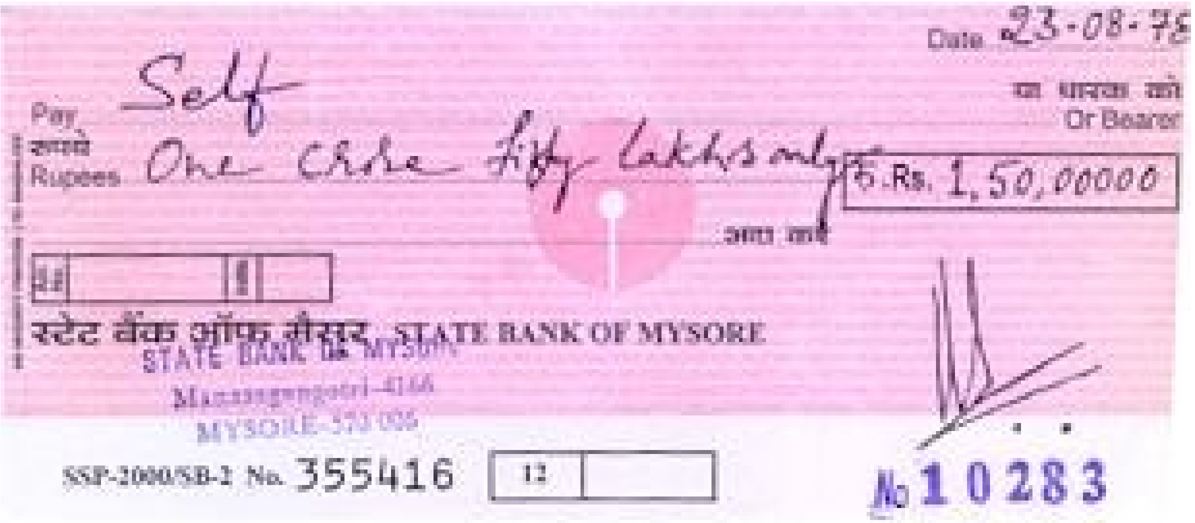
Banking

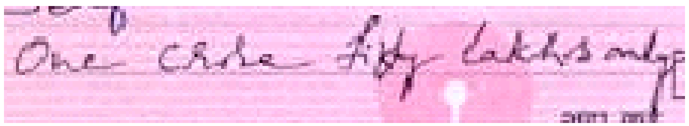
- Typical tasks include:
  - Document verification
  - Person authentication
  - Bankers Cheque analysis

- How these tasks can be achieved efficiently

Cheque Validation





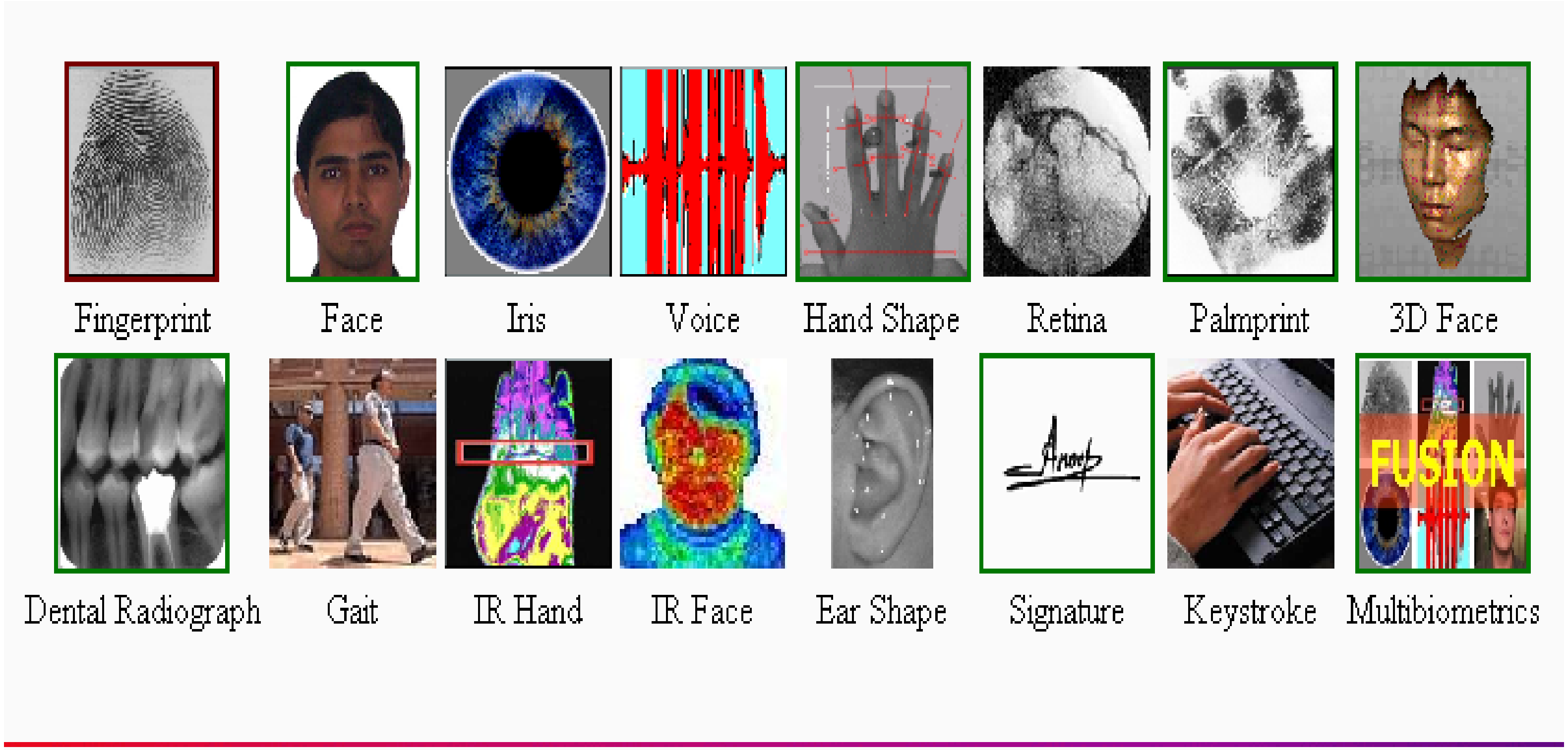


Autonomous Vehicles

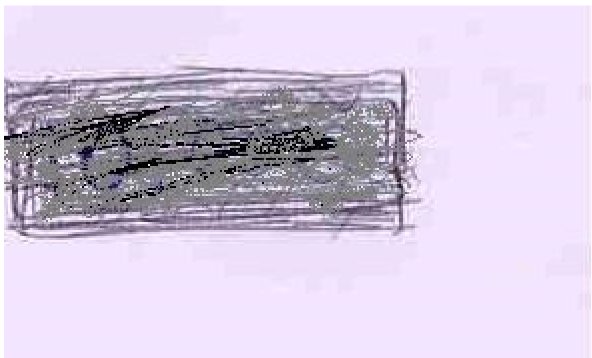
- In Highways

Biometrics

- Authentication of a person
  - Banking
  - Airport
  - Electronic Voting
  - Defense sectors
  - Secured transactions

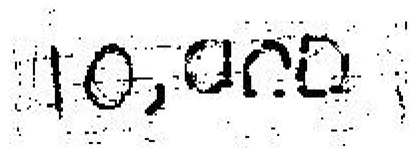


Forensic Application



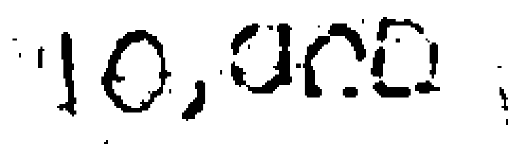
Obliterated Image

Thresholding operation



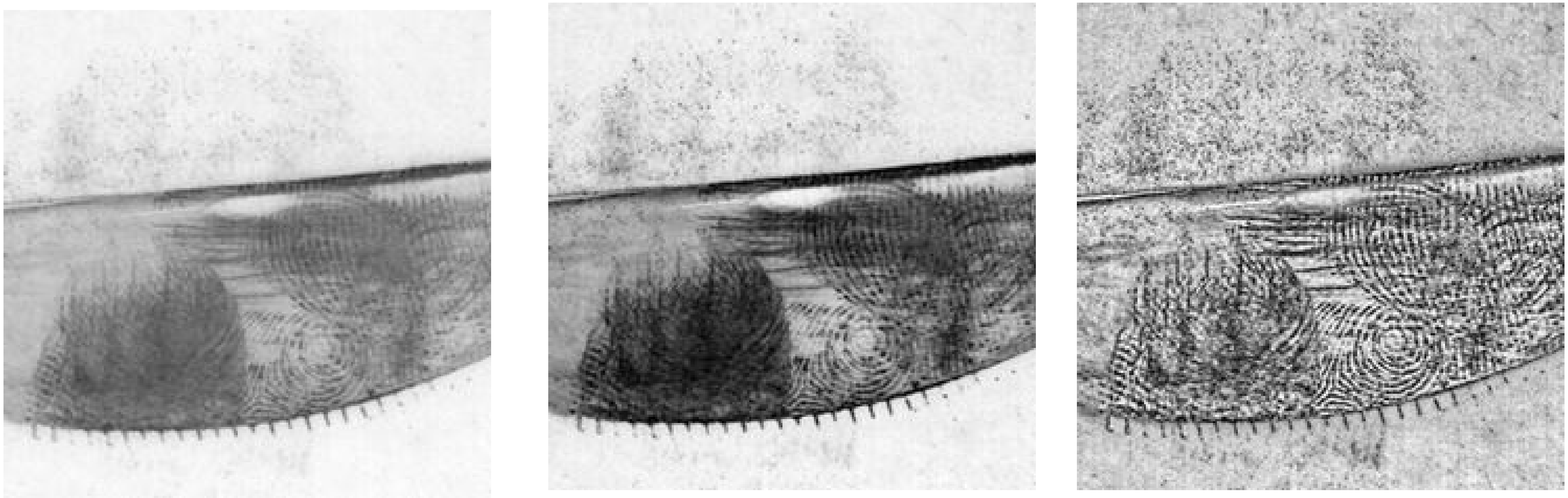
Deciphered Image

Median Filtering



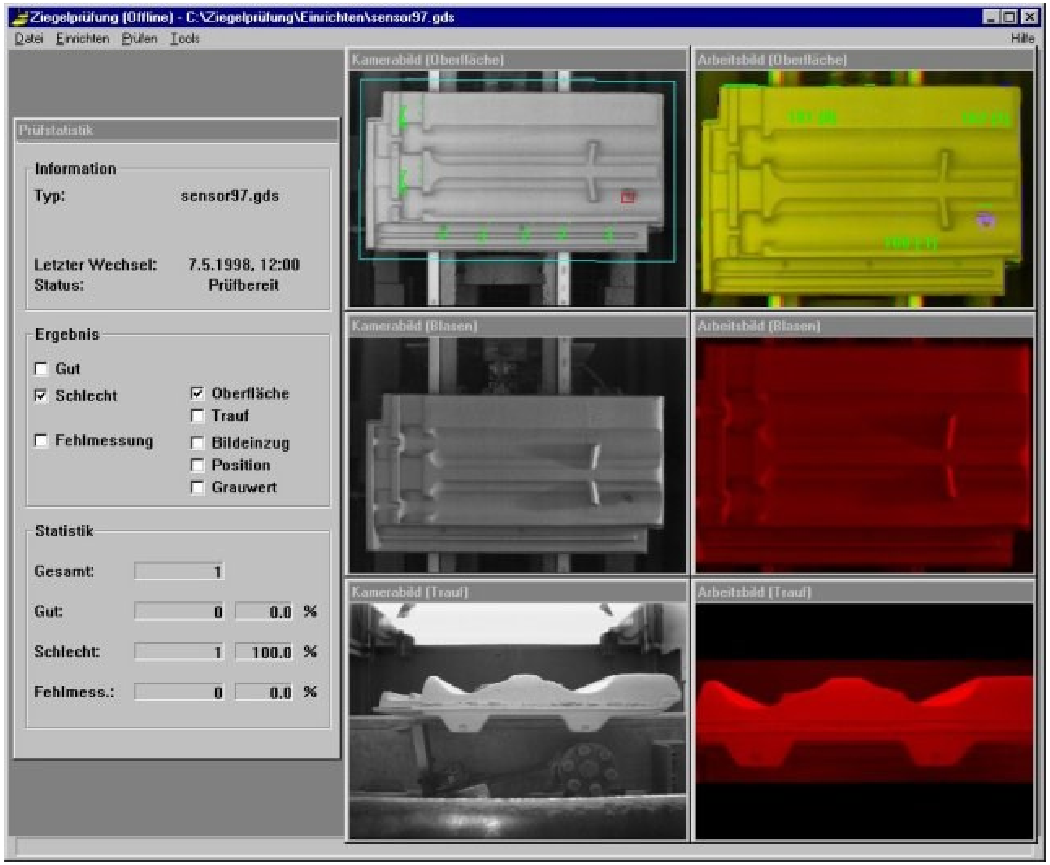
Enhanced Image

Applications: Crime Investigation



Fingerprint Enhancement

Industrial Quality Inspection



Courtesy: **Thüringen research program** "Image Processing, Pattern Recognition and Engineering Vision Systems" (Germany)

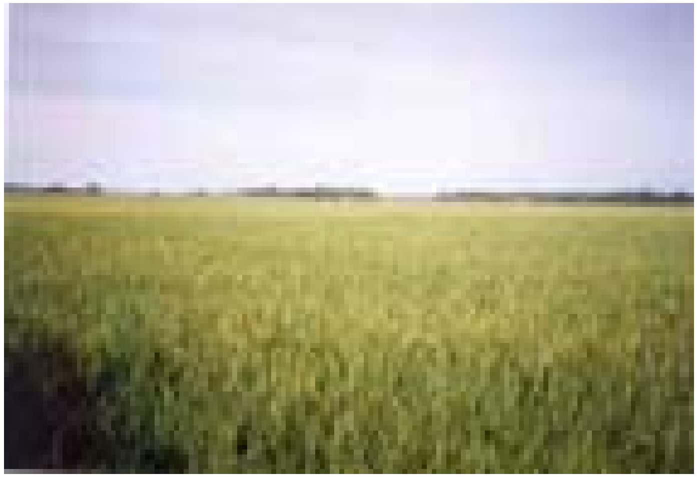
Quality Assurance

Remote Sensing

- **Remote sensing** is the acquisition of information about an object or phenomenon without making physical contact with the object.

Remote Sensing for Rice Yield Estimation

Planting



Heading

Ripening

Harvest

Rice main growth stages

Robotics: Services

Security and Surveillance

Surveillance cameras such as these are installed by the millions in many countries, and are nowadays monitored by automated computer programs instead of humans.

Micro Air Vehicle with attached surveillance camera

Fingerprints being scanned as part of the US-VISIT program

Traffic Management

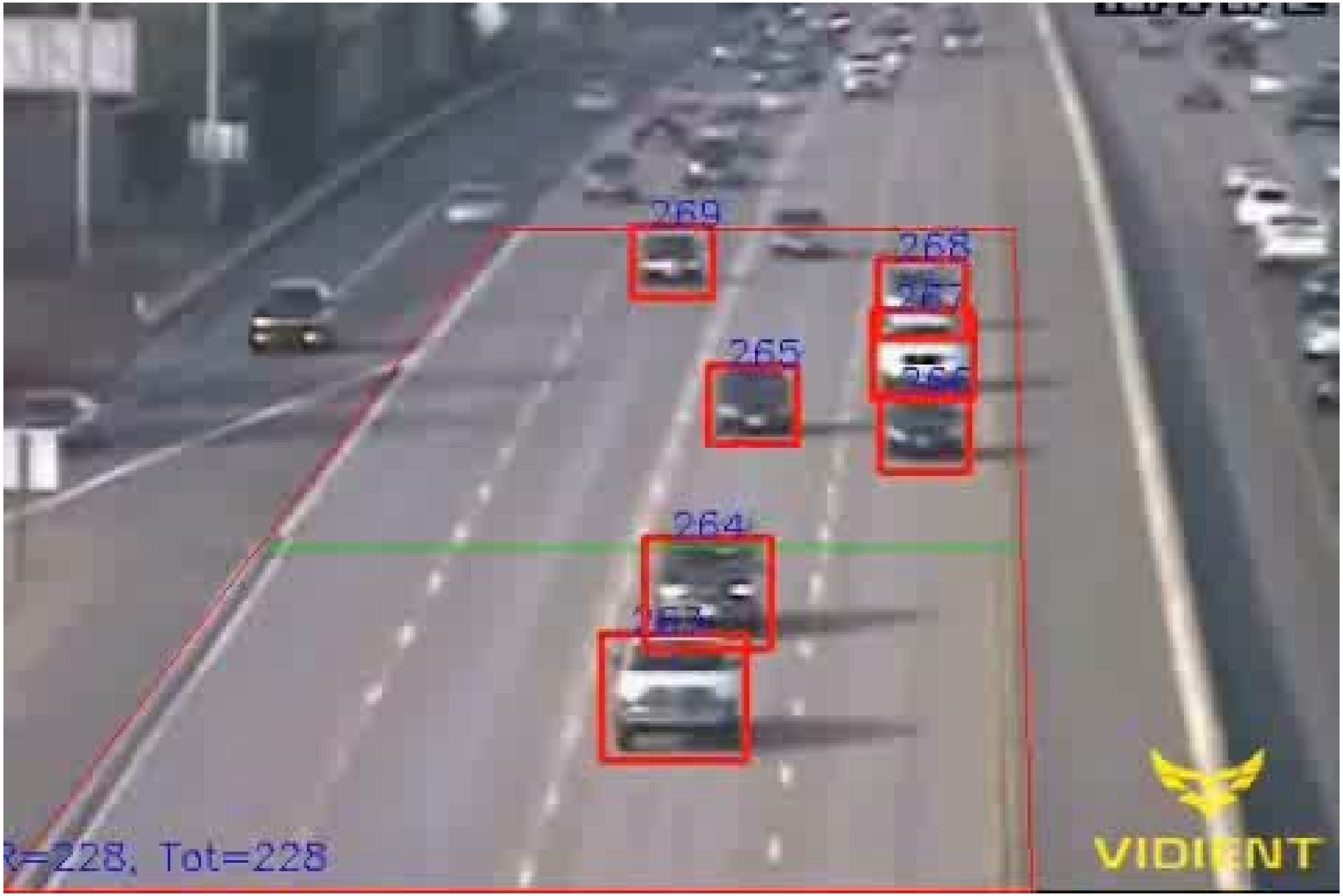
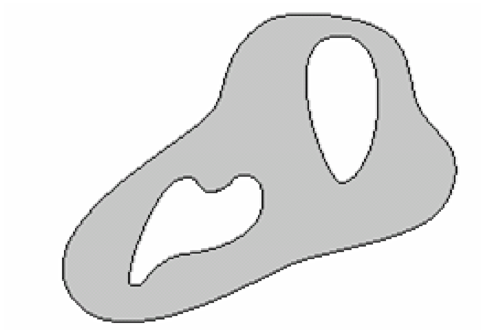


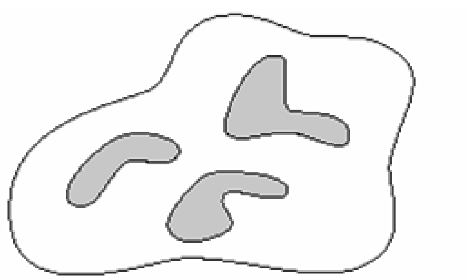
Image Topology

Introduction

- **Definition:** The study of properties of a figure that are unaffected by any deformation, as long as there is no tearing or joining of the figure.



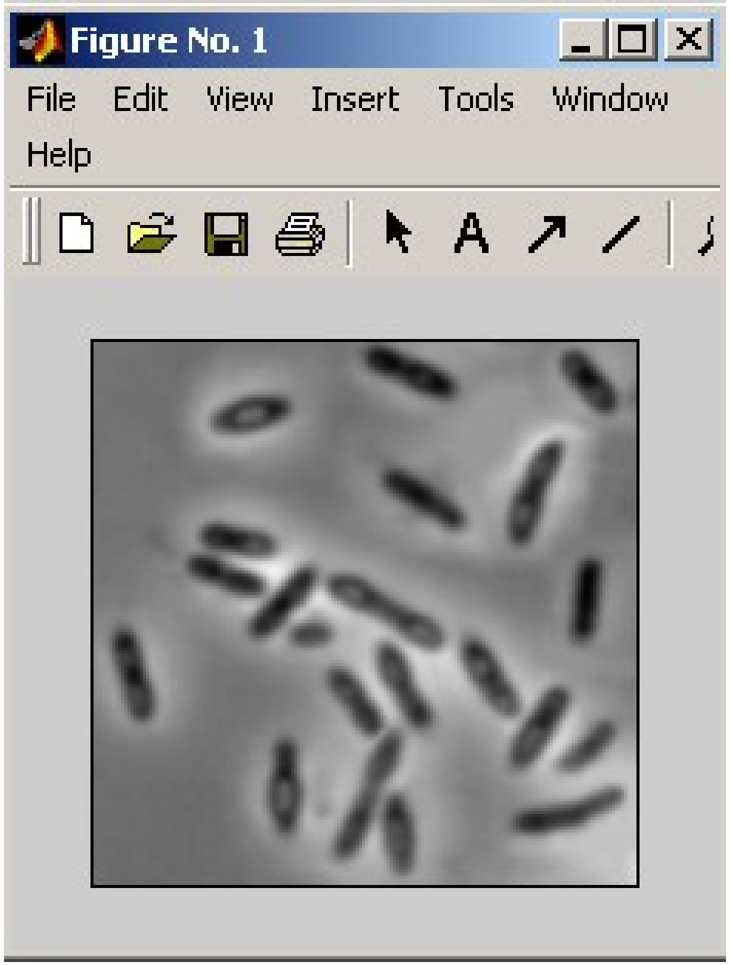
A region with 2 holes



A region with 3 connected components (objects)

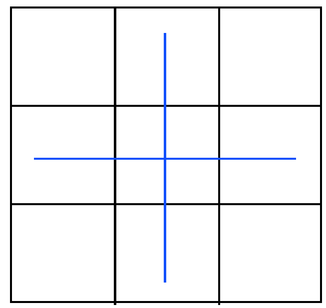
Another example

- How many bacteria here?

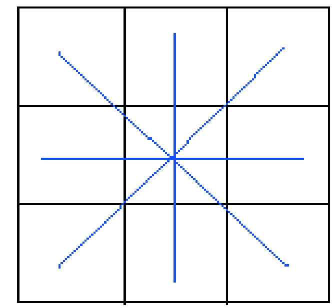


Neighbors and Adjacency

- We have interests in classifying pixels into different categories
- Neighbourhoods



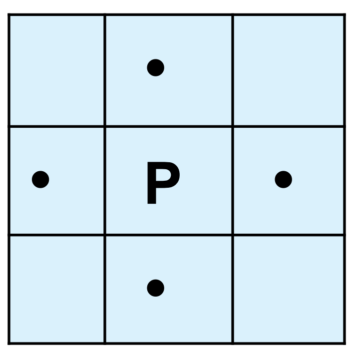
4-neighbour

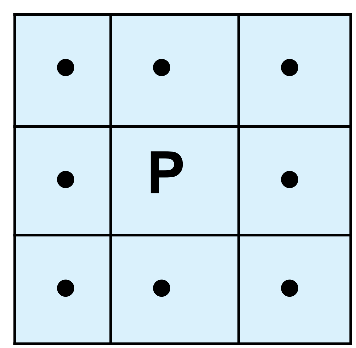


8-neighbour

- Two pixels **P** and **Q** are **4-adjacent** if they are 4-neighbours of one another, and **8-adjacent** if they are 8-neighbours of one another.

4-adjacent





8-adjacent

Pixels' Relationships

x-1, y-1	x, y-1	x+1, y-1
x-1, y	p_i (x, y)	x+1, y
x-1, y+1	x, y+1	x+1, y+1

Neighbors of pixel p_i

1. Four Neighbors : $N_4(p_i) = \{(x, y-1), (x+1, y), (x, y+1), (x-1, y)\}$
2. Diagonal Neighbors : $N_D(p_i) = \{(x+1, y-1), (x+1, y+1),$

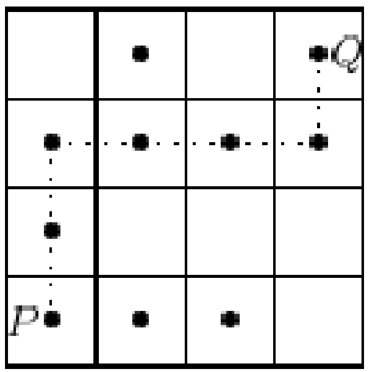
   $(x-1, y+1), (x-1, y-1)\}$
3. Eight Neighbors : $N_8(p_i) = N_4(p_i) \cup N_D(p_i)$

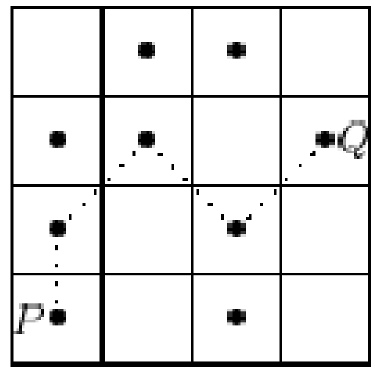
Paths

- Suppose that **P** and **Q** are any two pixels (not necessarily adjacent), and suppose **P** and **Q** can be joined by a sequence of pixels as shown:

4-adjacent

4-connected





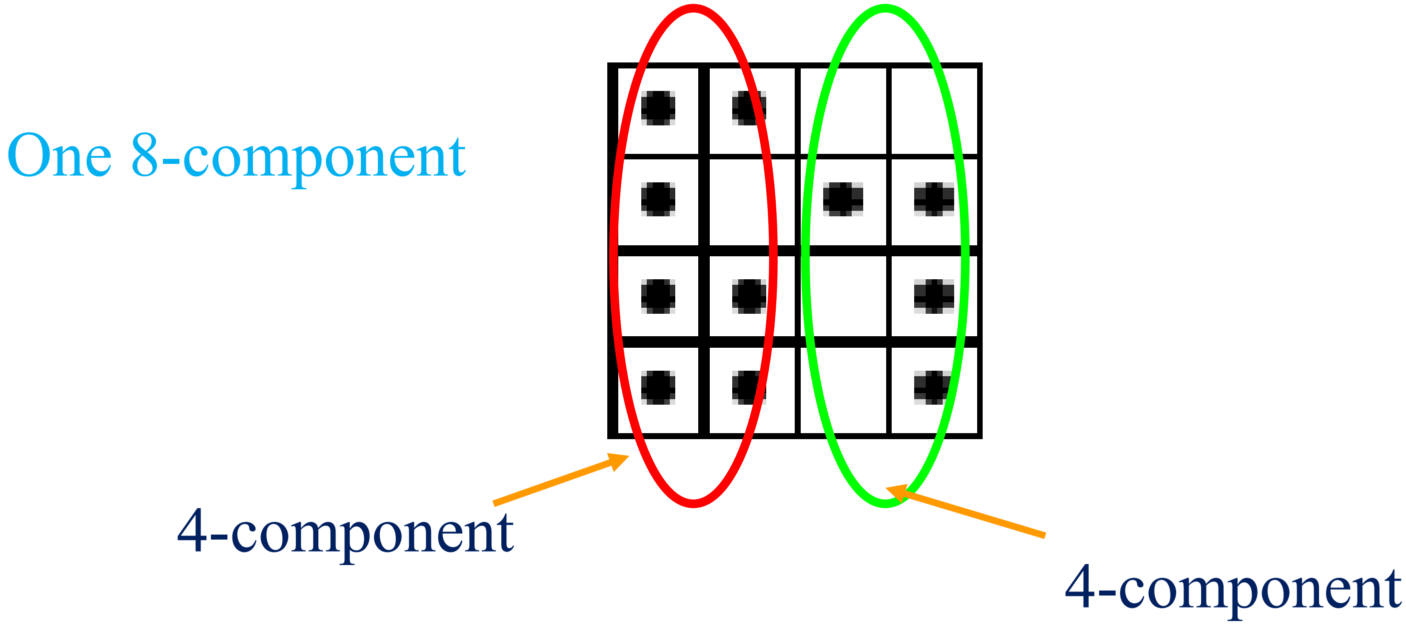
8-adjacent

8-connected

- If the path contains only 4-adjacent pixels, then P, Q are 4-connected.
- If the path contains 8-adjacent pixels, then P and Q are 8-connected

Components

- A set of pixels all of which are 4-connected to each other is called a **4-component**; if all the pixels are 8-connected the set is an **8-component**.



Pixel Connectivity

4-Connectivity : Pixels p and q are four connected if

1. p and q bear values in V 2. $p \in N_4(q)$

D-Connectivity : Pixels p and q are diagonally connected if

1. p and q bear values in V 2. $p \in N_D(q)$

8-Connectivity : Pixels p and q are eight connected if

1. p and q bear values in V 2. $p \in N_8(q)$

m-connectivity: Pixels p and q are mixed connected if

1. p and q bear values in V
2. $p \in N_4(q)$ or ($p \in N_D(q)$ and $N_4(p) \cap N_4(q) = \varnothing$)

0	1	1
0	1	0
0	0	1

0	1	1
0	1	0
0	0	1

0	1	1
0	1	0
0	0	1

Formal Definition of a Path

- A 4-path from **P** to **Q** is a sequence of pixels

$$P = p0,\ p1,\ p2,\ \ldots,\ pn = Q$$

  such that for each i=0,1,…, n-1, pixel pi is 4-adjacent to pixel pi+1.

- An 8-path is where the pixels in the sequence connecting **P** and **Q** are 8-adjacent

Properties of Connectivity – Equivalence Relations

- A relation x~y between two objects x and y is an equivalence relation if the relation is
  - Reflexive: $x \sim x$ for all x,
  - Symmetric: $x \sim y \iff y \sim x$ for all x and y,
  - Transitive: if $x \sim y$ and $y \sim z$ then $x \sim z$ for all x, y and z.

- Examples for equivalence relation?
- Examples that are not equivalence relation?

Equivalence Relations

- Some examples:
  - Numeric equality
  - Set cardinality
  - Connectedness

- Examples of some relations which are not equivalence:
  - Personal relations
  - Subset relation

- The importance of the equivalence relation concept is that it allows us a very neat way of dealing with issues of connectedness.
- **Equivalence class**: the set of all objects equivalent to each other.

Connected Component Labelling

- Define the components of a binary image as being the equivalence classes of the connectedness equivalence relation.
- Finding all equivalence classes of connected pixels in a binary image is called **connected component labelling.**
- The result of connected component labelling is another image in which everything in one connected region is labelled "1" (for example), everything in another connected region is labelled "2", etc.
- Labelling all the 4-components of a binary image, starting a the top left and working across and down.
- “Scan” the image row by row moving across from left to right.
- Assign labels to pixels in the image; these labels will be the numbers of the components of the image.
- A pixel in the image will be called a foreground pixel (fp); a pixel not in the image will be called a background pixel (bp).

Connected Component Labelling: Algorithm

- Check the state of *p*. If it is a bp, move on to the next scanning position. If it is fp, check the state of *u* and *l*. If they are both bp, assign *p* a new label.
  - If only one of *u* and *l* are fp, assign the label to *p*
  - If both *u* and *l* are fp, but different labels, assign either label to *p*, and make the 2 labels equivalent.

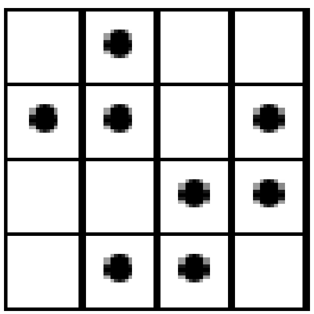
	u	
l	*p*	

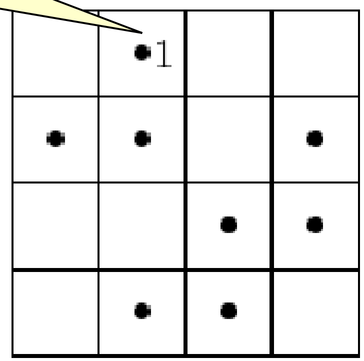
- At the end of the scan, all foreground pixels have been labelled, but some labels may be equivalent. Then sort the labels into equivalence classes, and assign a different label to each class.
- Do a second pass through the image, replacing the label on each foreground pixel with the label assigned to its equivalence class in the previous step

Example 1

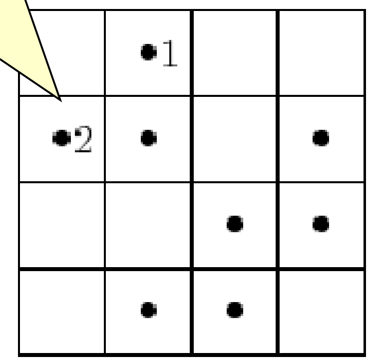
The first foreground pixel
Upper neighbor : non-existent
Left neighbor : background

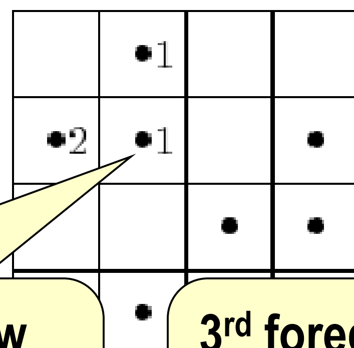
Step 1.



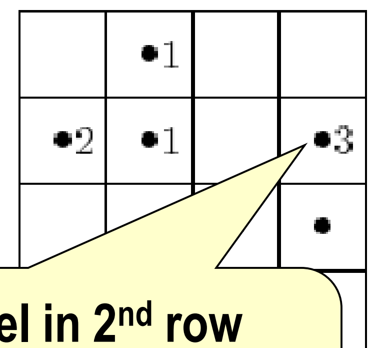


First foreground pixel in 2nd row
Upper neighbor : background
Left neighbor : non-existent

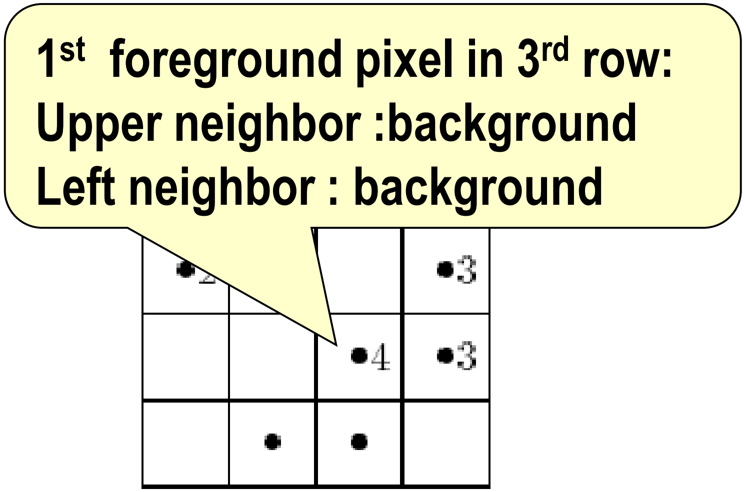


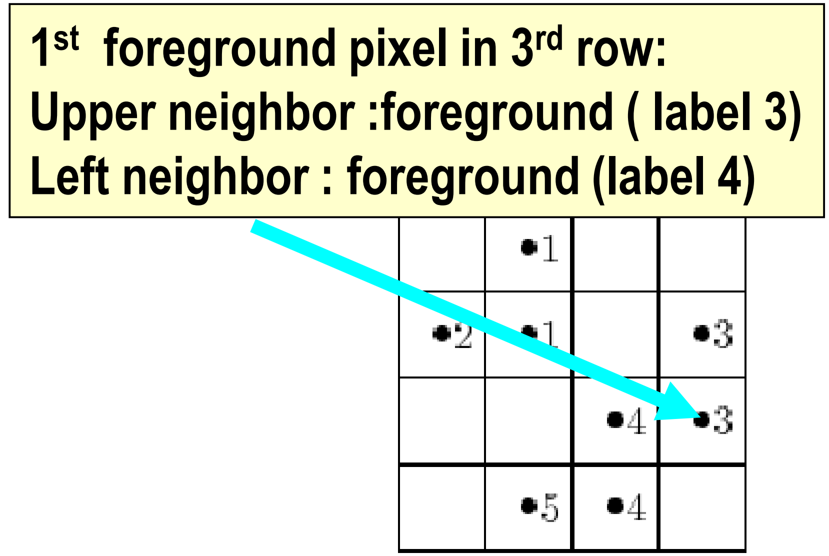


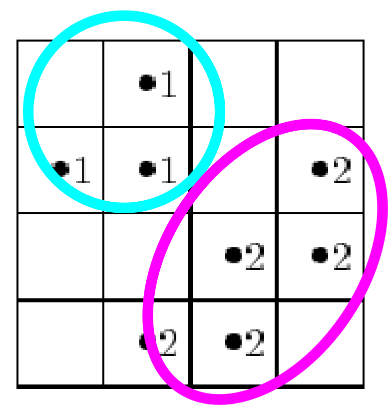
2nd foreground pixel in 2nd row
Upper neighbor : foreground
Left neighbor : foreground



3rd foreground pixel in 2nd row
Upper neighbor : background
Left neighbor : background







Step 2. We have the following equivalent classes of labels: {1,2} and {3, 4,5}

Step 3. E Assign label 1 to the first class, and label 2 to the second class

Example 2

Original Binary image

		1	1				
1	1	1	1		1	1	1

Pass 1:

		1	1				
2	2	2	2		3	3	3

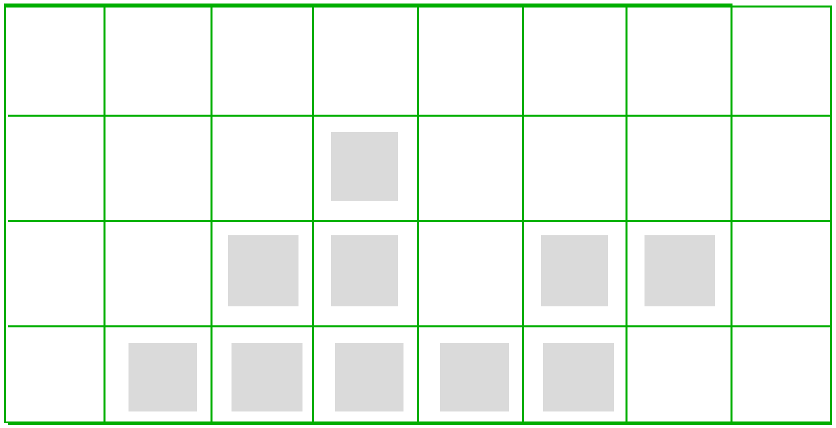
Pass 2:

		1	1				
1	1	1	1		2	2	2

Equivalence Class number	Original mark
1	1,2
2	3

Example 3

Original Binary image



Pass 1:

			1				
		2	2		3	3	
	4	4	4	4	4		

Pass 2:

			1				
		1	1		1	1	
	1	1	1	1	1		

Equivalence Class number	Original mark
1	1,2,3,4

Distances and Metrics

- A distance function *d(x,y)* is called a metric if it satisfies the following:

$$d(x,y) = d(y,x) \text{ (symmetry)}$$

$$d(x,y) \geq 0 \text{ and } d(x,y) = 0 \text{ iff } x = y \text{ (positivity)}$$

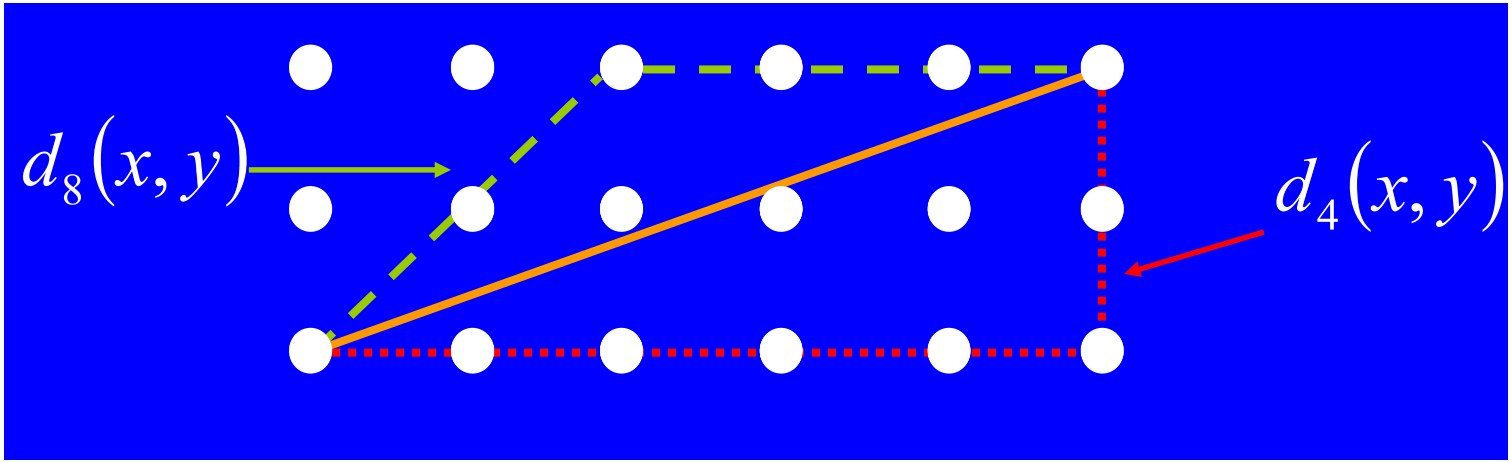
$$d(x,y) + d(y,z) \leq d(x,z) \text{ (the triangle inquality)}$$

- A standard distance metric is Euclidean distance (a straight line between 2 points)

$$d(x,y) = \sqrt{(x_1 - y_1)^2 + (x_2 - y_2)^2}$$

where $x = (x_1, x_2) \text{ and } y = (y_1, y_2)$

Distance Metrics for Grid



- The Euclidean distance is $\sqrt{5^2 + 2^2} \approx 5.39$

- For 4-path and 8-path?

$$d_4(x, y) = |x_1 - y_1| + |x_2 - y_2| \text{ (taxicab metric)}$$

$$d_8(x, y) = \max\{|x_1 - y_1|, |x_2 - y_2|\}$$

Color Models

Color Image Processing

- Color and electromagnetic spectrum
- Primary colors
- Chromaticity diagram
- Color models
  - RGB model
  - CMY model
  - HSI model
- We need to know about the following
  - What does it mean when we say an object is in certain color?
  - Why the primary colors of human vision are red, green, and blue?
  - Is it true that different portions of red, green, and blue can produce all the visible color?
  - What kind of color model is the most suitable one to describe the human vision?

Color models

- RGB model
  - Color monitor, color video cameras
- CMY model
  - Color printer
- HSI model
  - Color image manipulation
- XYZ (CIE standard, Y directly measures the luminance)
- YUV (used in PAL color TV)
- YIQ (used in NTSC color TV)
- YCbCr (used in digital color TV standard BT.601)

Color spectrum

- When passing through a prism, a beam of sunlight is decomposed into a spectrum of colors : violet, blue, green, yellow, orange, red

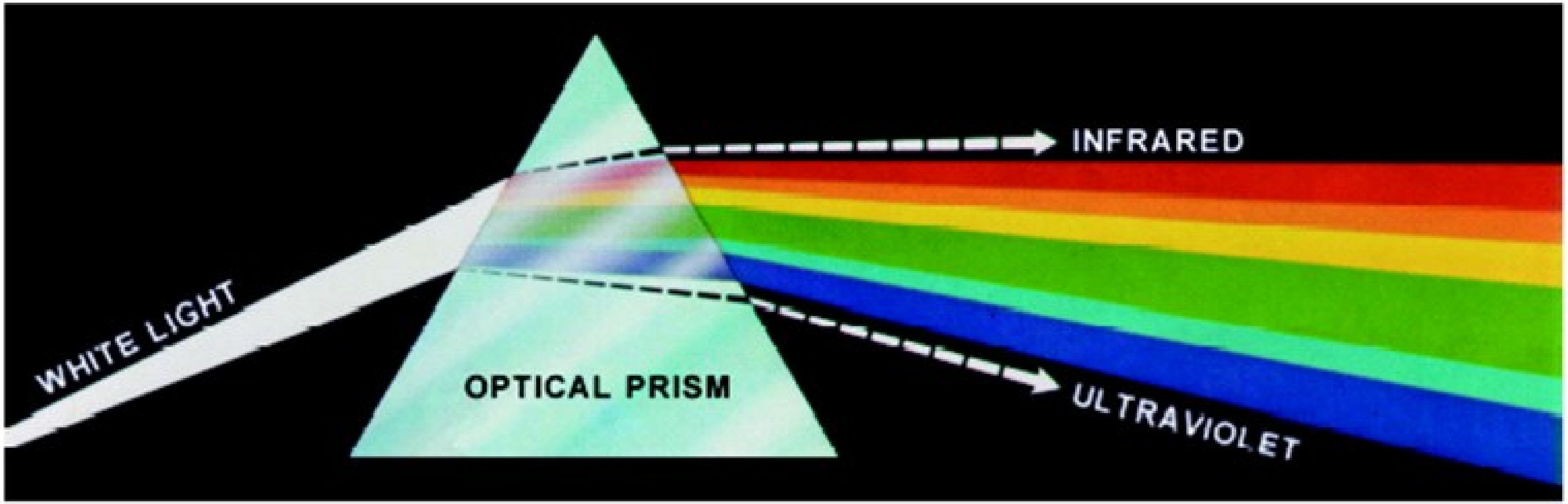


FIGURE. Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

Electromagnetic spectrum

- Ultraviolet – visible light – infrared
- The longer the wavelength (meter), the lower the frequency (Hz), the lower the energy (electron volts)

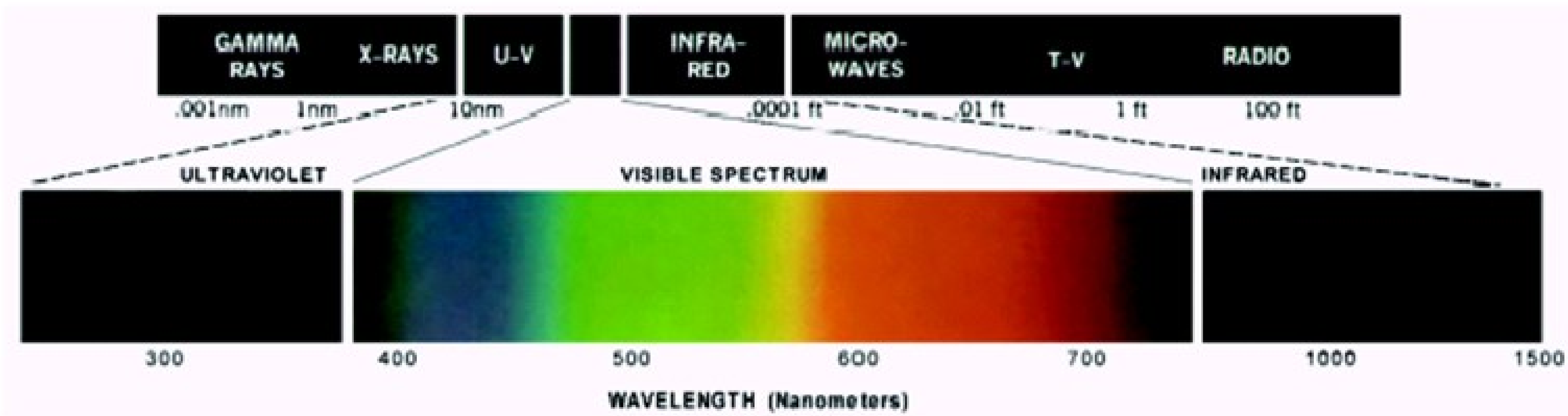


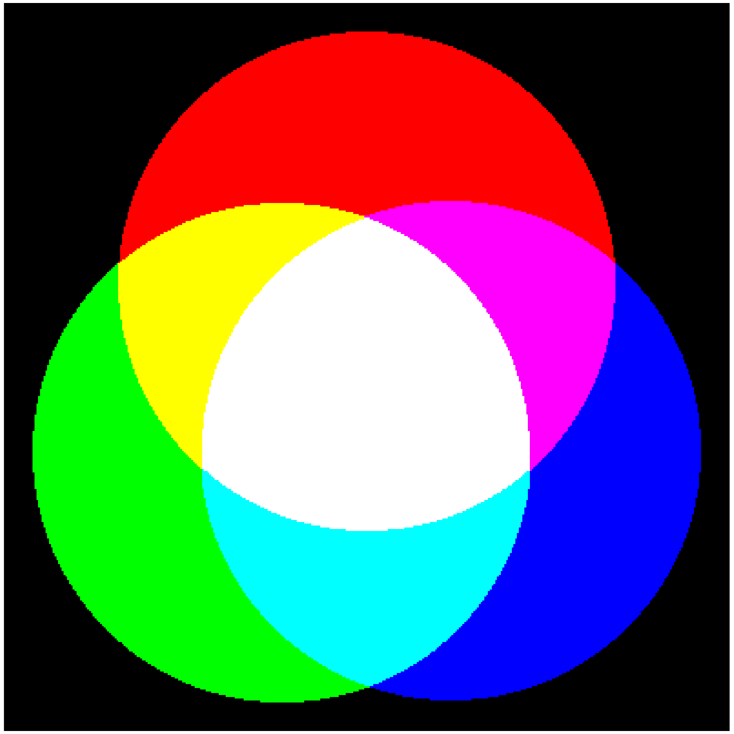
FIGURE Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Primary colors of human vision

- For this reason, red, green, and blue are referred to as the primary colors of human vision. CIE (the international Commission on Illumination) standard designated three specific wavelength to these three colors in 1931.
  - Red : 700 nm
  - Green : 546.1 nm
  - Blue : 435.8 nm

RGB Color model

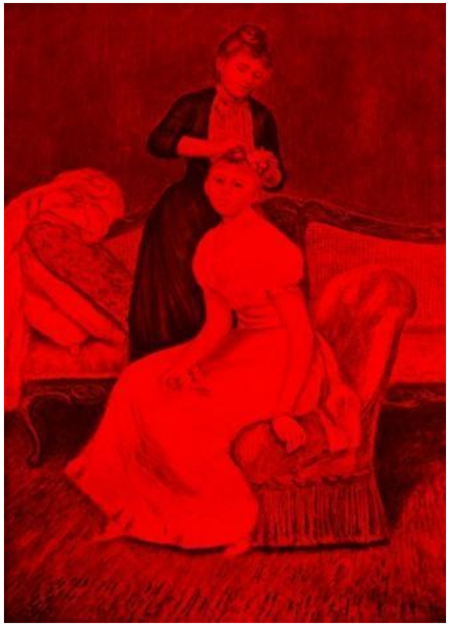
Source: www.mitsubishi.com



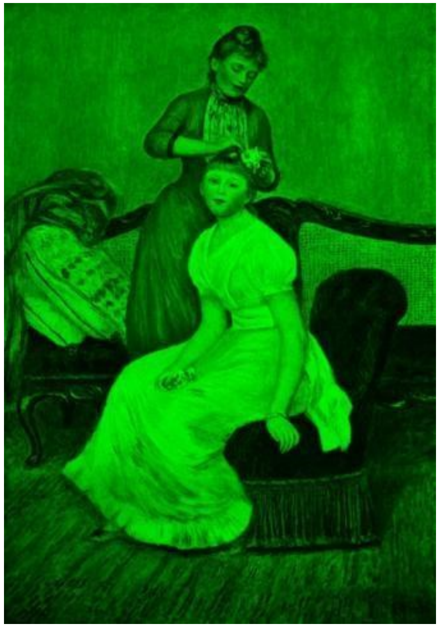
Active displays, such as computer monitors and television sets, emit combinations of red, green and blue light. This is an **additive** color model

RGB Example

Original



Red Band



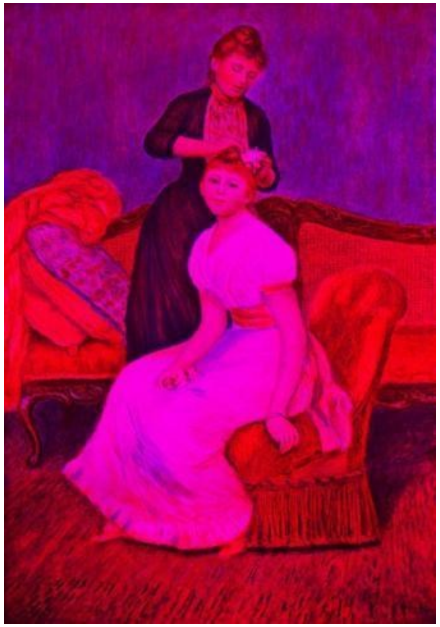
Green Band

Blue Band

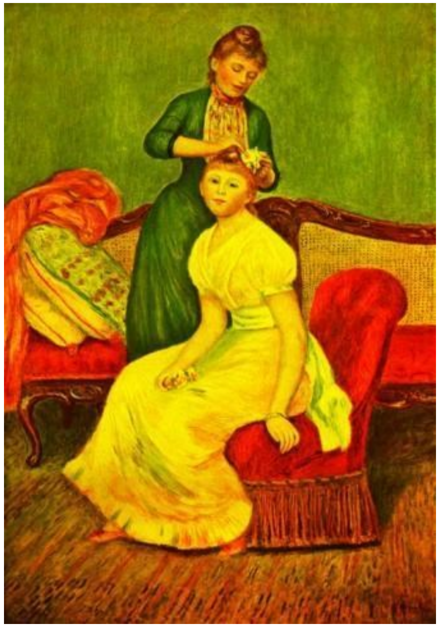
RGB Example

Original

No Red



No Green



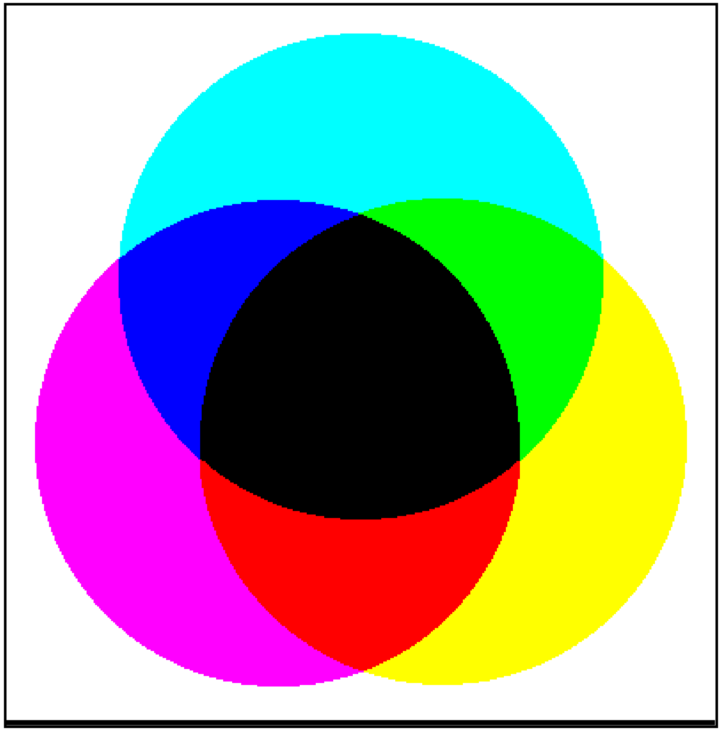
No Blue

Some Remarks:

- ❖ **No single color may be called red, green, or blue.**
- ❖ **R, G, B are only specified by standard.**
- ❖ **The primary colors can not produce all the visible colors.**

CMY Color model

Source:
www.hp.com

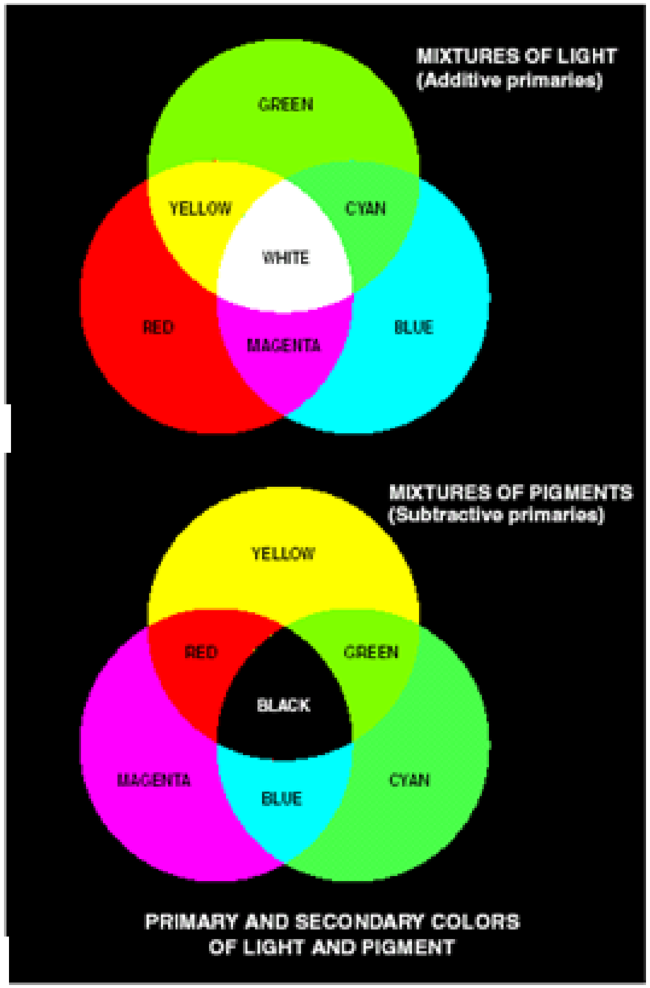


Passive displays, such as color inkjet printers, **absorb** light instead of emitting it. Combinations of **cyan**, **magenta** and **yellow** inks are used. This is a **subtractive** color model.

Secondary colors

- Magenta (R+B)
- Cyan (G+B)
- Yellow (R+G)

a

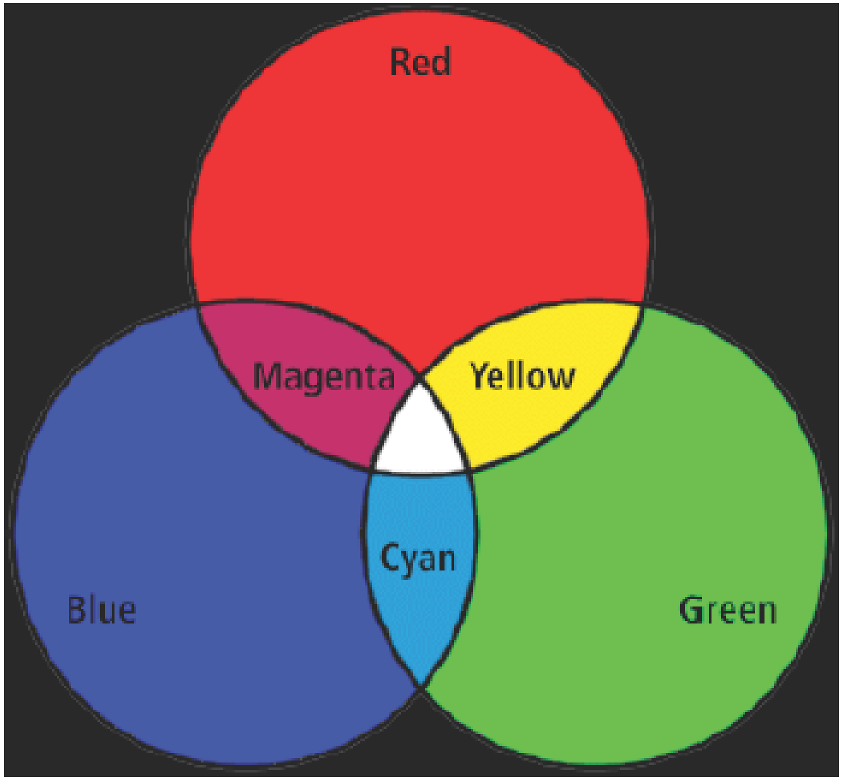


b

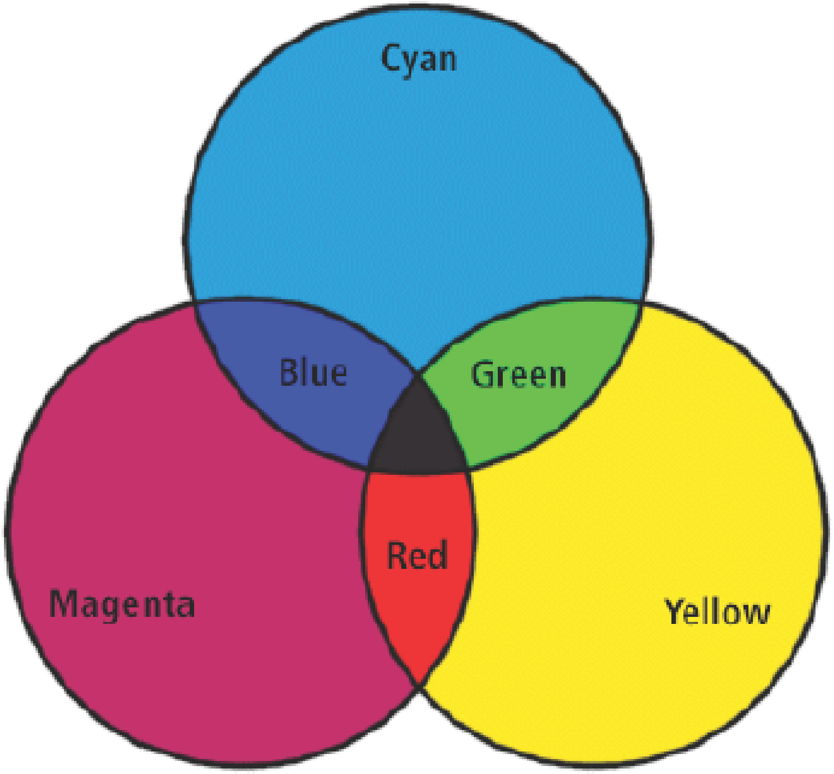
a
b

FIGURE . Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lamp Business Division.)

RGB vs CMY



Magenta = Red + Blue
Cyan = Blue + Green
Yellow = Green + Red



Magenta = White - Green
Cyan = White - Red
Yellow = White - Blue

CMY model

- Color printer and copier
- Deposit colored pigment on paper
- Relationship with RGB model: $\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = 1 - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$

HSI model

- The intensity component (I) is decoupled from the color components (H and S), so it is ideal for image processing algorithm development.
- H and S are closely related to the way human visual system perceives colors.

Converting From RGB To HSI

Given a colour as R, G, and B its H, S, and I values are calculated as follows:

$$H = \begin{cases} \theta & if\ B \le G \\ 360 - \theta & if\ B > G \end{cases} \qquad \theta = \cos^{-1}\left\{ \frac{\frac{1}{2}\left[(R-G)+(R-B)\right]}{\left[(R-G)^2+(R-B)(G-B)\right]^{\frac{1}{2}}} \right\}$$

$$S = 1 - \frac{3}{(R+G+B)}\left[\min(R,G,B)\right]$$

$$I = \tfrac{1}{3}(R+G+B)$$

Converting From HSI To RGB

Given a colour as H, S, and I it's R, G, and B values are calculated as follows:

- RG sector ($0 <= H < 120°$)

$$R = I\left[1 + \frac{S\cos H}{\cos(60 - H)}\right] \qquad G = 3I - (R + B) \qquad B = I(1 - S)$$

- GB sector ($120° <= H < 240°$)

$$R = I(1 - S) \qquad G = I\left[1 + \frac{S\cos(H - 120)}{\cos(H - 60)}\right] \qquad B = 3I - (R + G)$$

Model conversion between RGB and YCbCr

$$\begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 0.257 & 0.504 & 0.098 \\ -0.148 & -0.291 & 0.439 \\ 0.439 & -0.368 & -0.071 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} + \begin{bmatrix} 16 \\ 128 \\ 128 \end{bmatrix}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1.164 & 0.000 & 1.598 \\ 1.164 & -0.329 & -0.813 \\ 1.164 & 2.017 & 0.000 \end{bmatrix} \begin{bmatrix} Y-16 \\ Cb-128 \\ Cr-128 \end{bmatrix}$$

$$Y \in [16,235], Cb, Cr \in [16-240]$$

QUESTIONS

THANK YOU