

Introduction to Digital Image Processing

Presentation to EE1001 Class of the Department of Electrical Engineering at the University of Minnesota Duluth, November 5th, 2015

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■ Related Courses:

ECE 8741: Digital Image Processing

ECE 5741: Digital Signal Processing

ECE 5742: Pattern Recognition

ECE 8742: Signal Detection And Estimation

ECE 5745 Medical Imaging

The materials of this lecture is taken from many sources including Textbooks and websites ¹



The first photograph in the world

Joseph Nicéphore Niépce, *View from the Window at Le Gras*, 1826.

https://en.wikipedia.org/wiki/History_of_photography

Textbook

■ Suggested textbook:

R.C. Gonzalez and R.E. Woods, “Digital Image Processing”, 3rd Ed., Prentice-Hall’2008

Digital Image Processing by Kenneth R.
Castleman 1995

Any other book with a similar title will work too

Some Related Disciplines

- Computer Vision
- Computer Graphics
- Pattern Recognition
- Robotics
- Artificial Intelligence

General Information

- Prerequisites

Knowledge of at least two of the following three areas:

Linear algebra

Elementary probability theory

Signals and systems

Software: MATLAB (Image processing Toolbox)

Mathematics in Image Processing Research

Calculus

Linear Algebra

Probability and Statistics

Differential Equations (ODEs and PDEs)

Differential Geometry

Harmonic Analysis (Fourier, wavelets, etc)

Companies In this Field

- Google
- Facebook
- IBM
- National Instruments
- GE Laboratories
- Yahoo (Multimedia Searching)
- nVidia Graphics

What is an image?

- We can think of an **image** as a function, f ,
- from \mathbb{R}^2 to \mathbb{R} :
 - $f(x, y)$ gives the **intensity** at position (x, y)
 - Realistically, we expect the image only to be defined over a rectangle, with a finite range:
 - $f: [a, b] \times [c, d] \rightarrow [0, 1]$
- A color image is just three functions pasted together. We can write this as a “vector-valued” function:
$$f(x, y) = \begin{bmatrix} r(x, y) \\ g(x, y) \\ b(x, y) \end{bmatrix}$$

Digital Image Representation

- Color Images are described by three image planes R, G, B. Each Plane is matrix of integers $0 < f(x,y) < 256$: Gray Levels

0:darkest

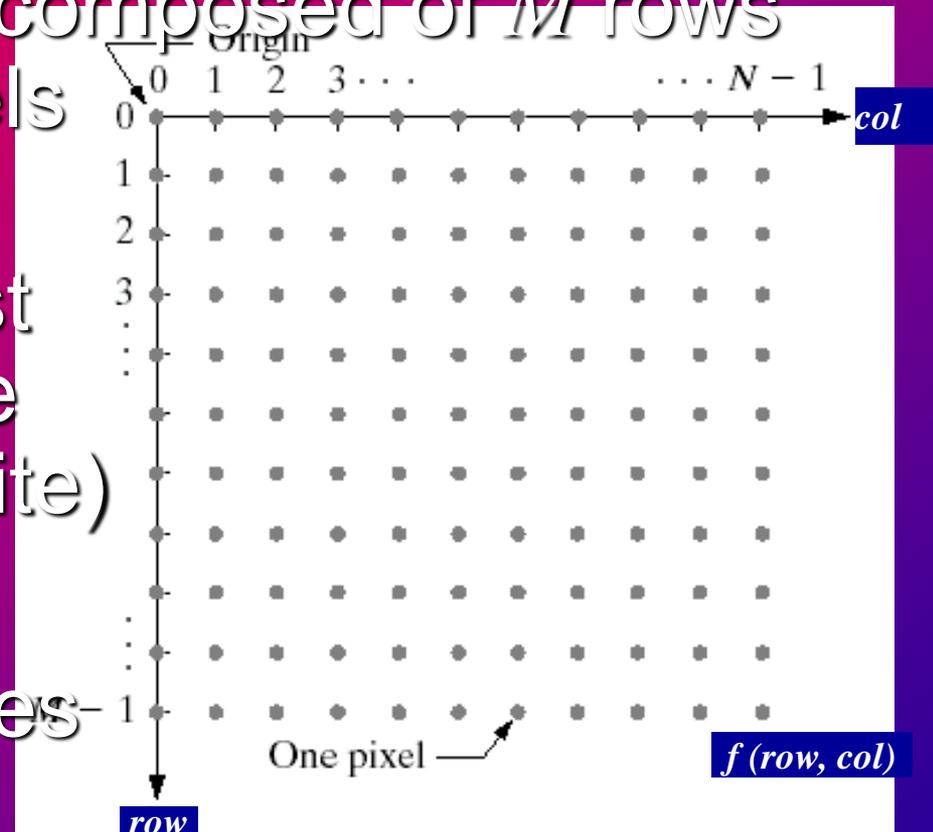
255: Brightest

- Each number in the image represent a pixel

10	10	16	28		
9	65	70	56	43	
15	32	99	70	56	78
32	21	60	90	96	67
	54	85	85	43	92
		32	65	87	99

Image Representation

- Before we discuss image acquisition recall that a digital image is composed of M rows and N columns of pixels each storing a value
- Pixel values are most often grey levels in the range 0-255 (black-white)
- Images can be represented as matrices

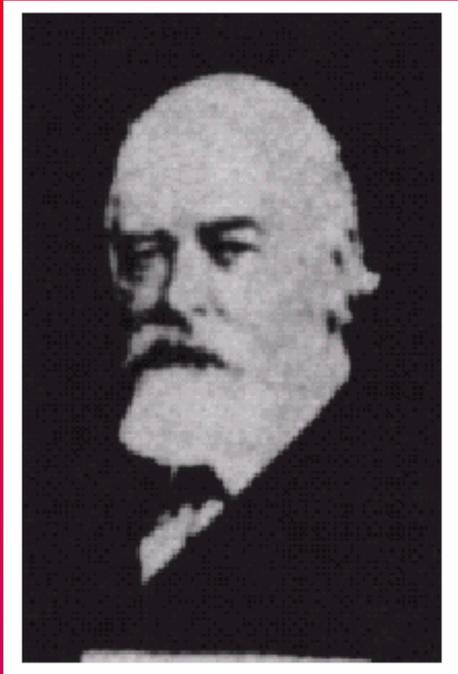


A Historical Overview of DIP



Newspaper industry used Bartlane cable picture transmission system to send pictures by submarine cable between London and New York in 1920s

Early Improvement



The number of distinct gray levels coded by Bartlane system was improved from 5 to 15 by the end of 1920s

The Born of Digital Computers

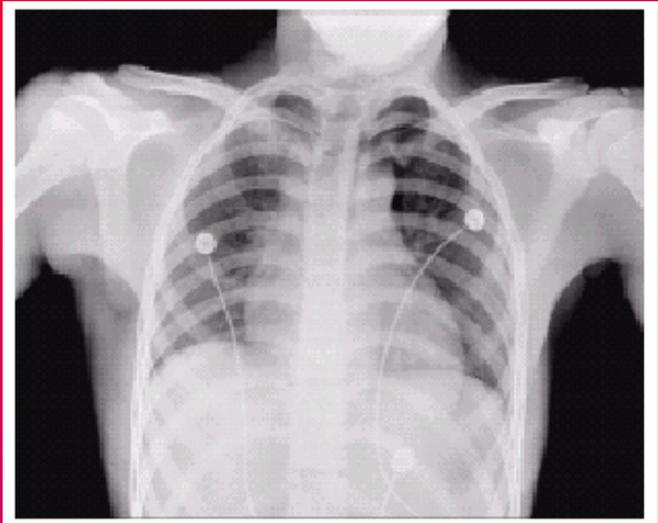
- What do we mean by *Digital Image Processing*
 - **Processing digital images by a digital computer**
- DIP has been dependent on the development of digital computers and other supporting technologies (e.g., data storage, display and transmission)

Soar Into Outer Space



The first picture of moon by US spacecraft *Ranger 7* on July 31, 1964 at 9:09AM EDT

The Born of Computed Tomography



Sir Godfrey N. Housefield and Prof. Allan M. Cormack shared 1979 Nobel Prize in Medicine for the invention of CT

The Boom of Digital Images in the Last 20 Years

■ Acquisition

- Digital cameras, scanners
- MRI and Ultrasound imaging
- Infrared and microwave imaging

■ Transmission

- Internet, satellite and wireless communication

■ Storage

- CD/DVD, Blu-ray
- Flash memory, Phase-change memory

■ Display

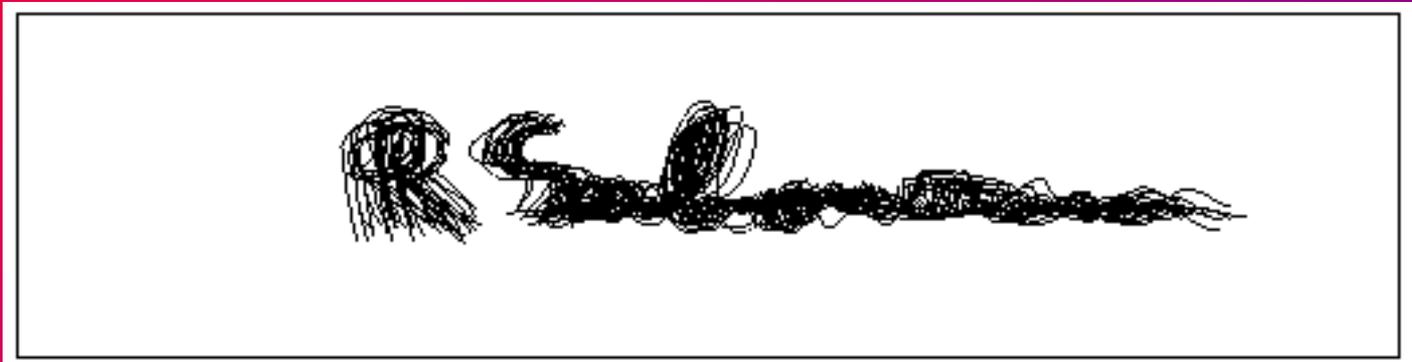
- Printers, LCD monitor, digital TV
- Portable DVD player, PDAs, cell-phone

Applications of digital image processing

... virtually, *everywhere!*

- **Industry:** inspection/sorting; manufacturing (robot vision)
 - **Environment:** strategic surveillance (hydro-dams, forests, forest fires, mine galleries) by surveillance cameras, autonomous robots
 - **Medicine:** medical imaging (ultrasound, MRI, CT, visible)
 - **Culture:** digital libraries; cultural heritage preservation (storage, restoration, analysis – indexing)
 - **Television:** broadcasting, video editing, efficient storage
 - **Education & tourism:** multi-modal, intelligent human-computer interfaces, with emotion recognition components
 - **Security/authentication** (iris recognition, signature verification)
- ... *etc...*

Signature Verification



Character Recognition

demodulation

demodulation

Visual Inspection

Image Analysis: Change Detection

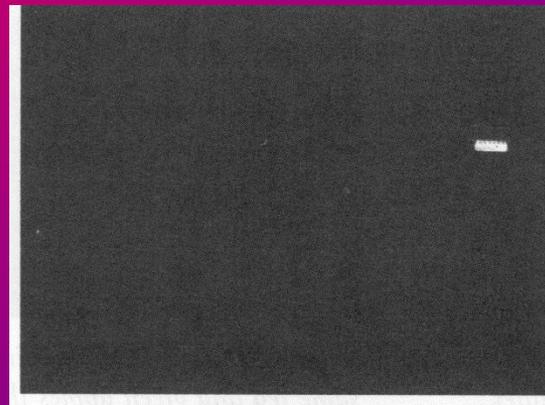
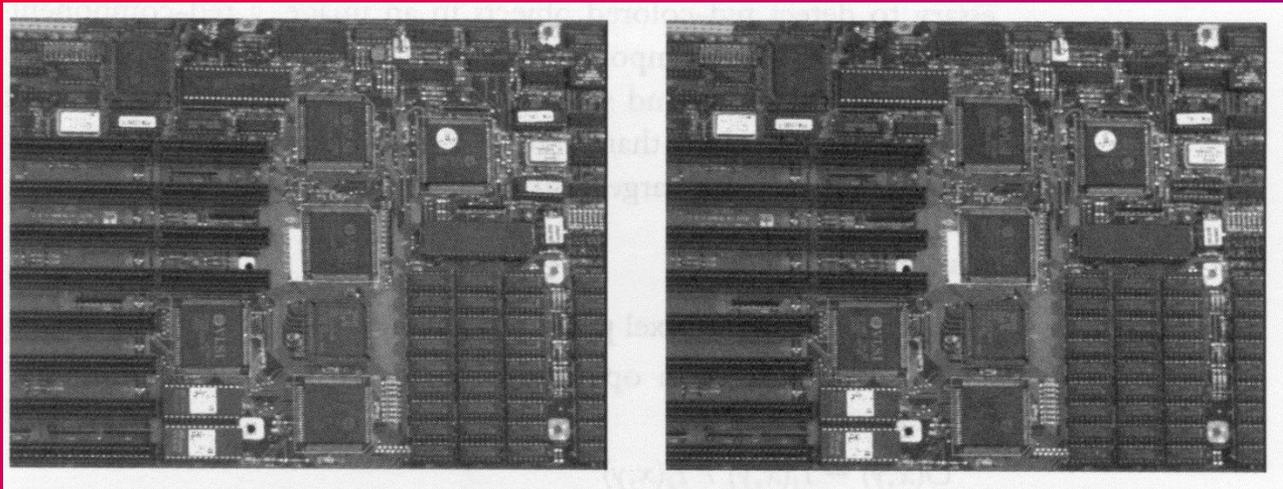
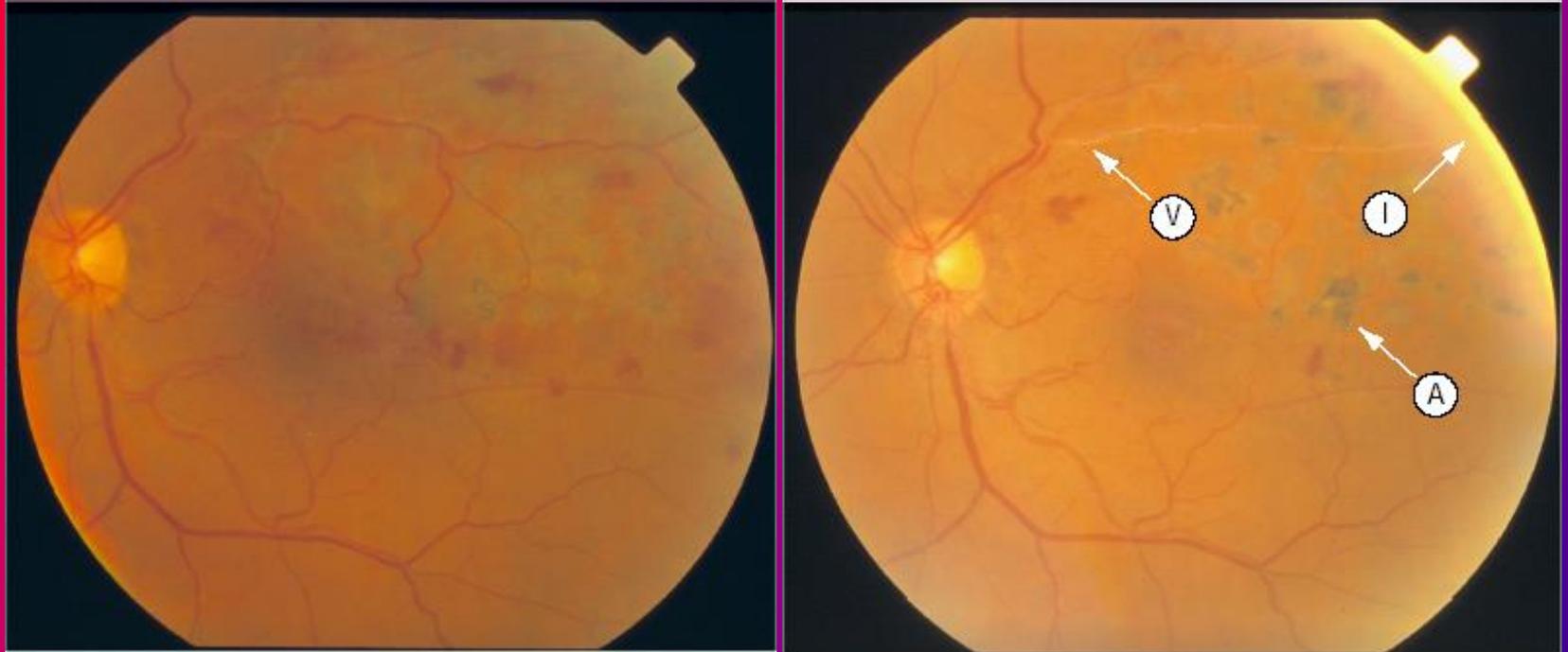


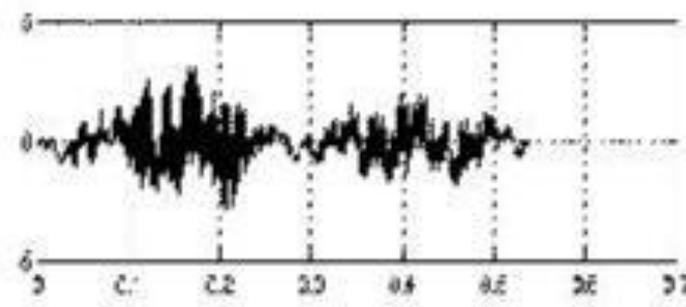
Image Analysis: Change Detection



Change Detection in Medical Application



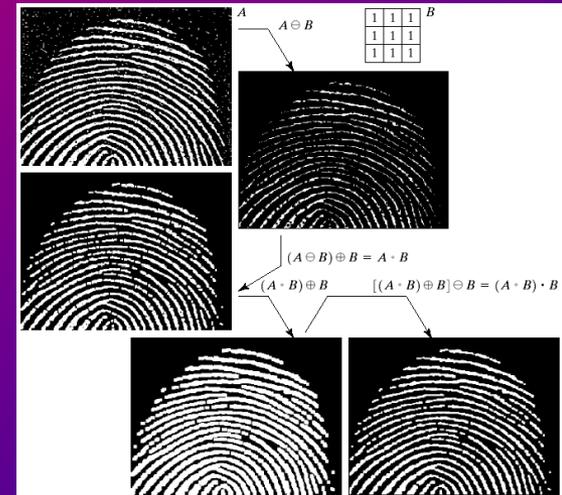
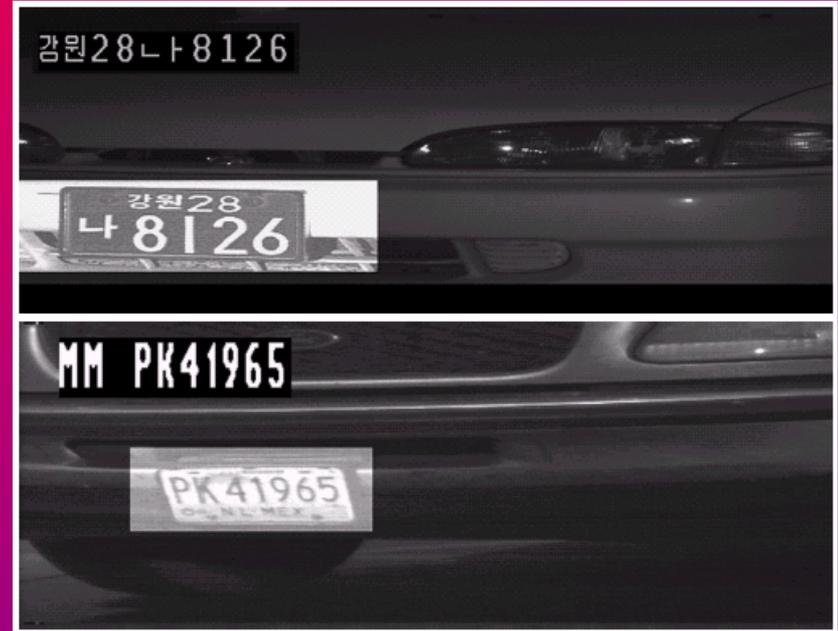
Biometrics



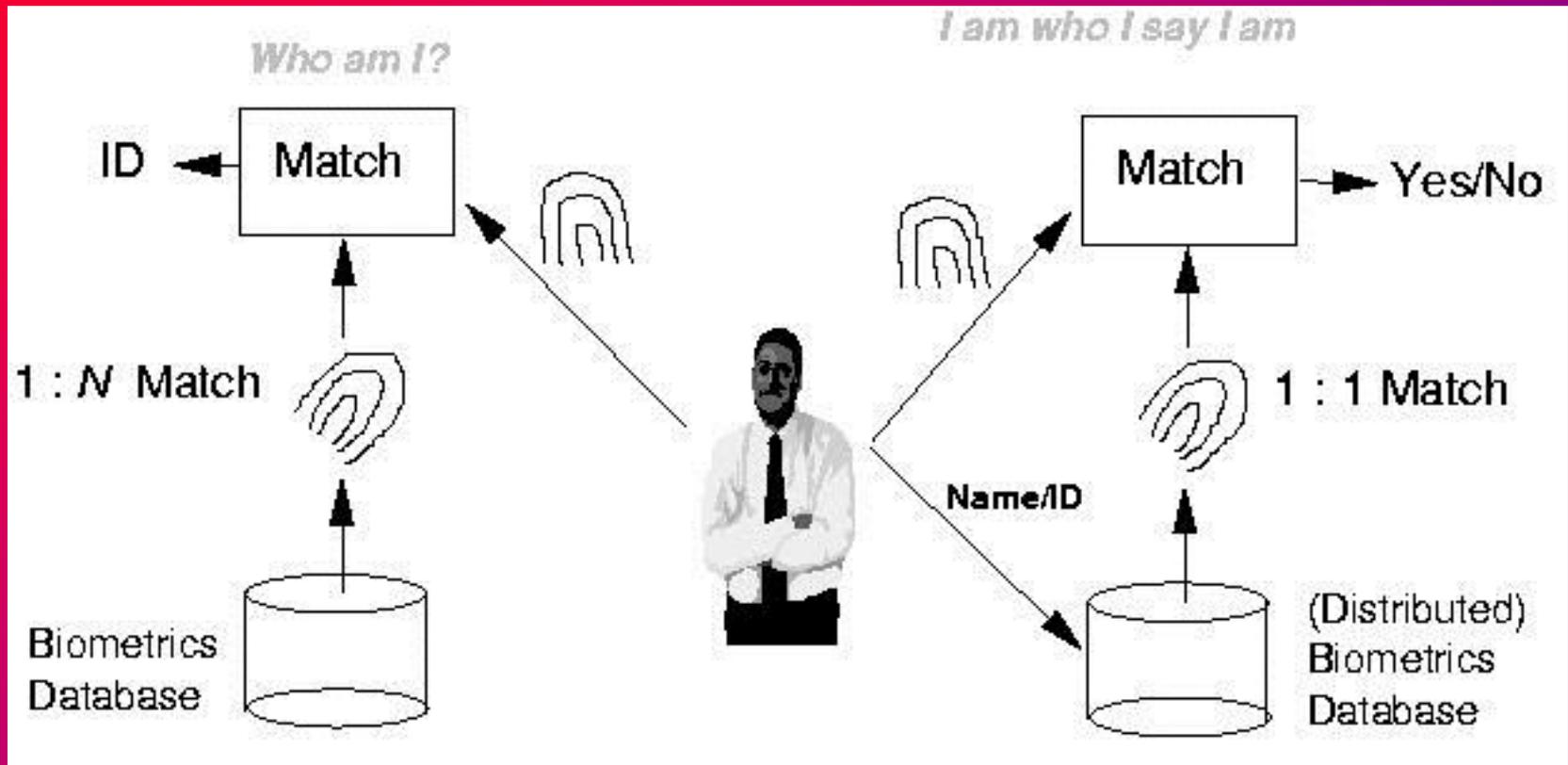
John Smith

Examples: Law Enforcement

- Image processing techniques are used extensively by law enforcers
 - Number plate recognition for speed cameras/automated toll systems
 - Fingerprint recognition
 - Enhancement of CCTV images

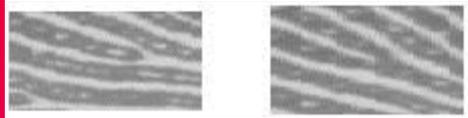


Fingerprint Verification / Identification

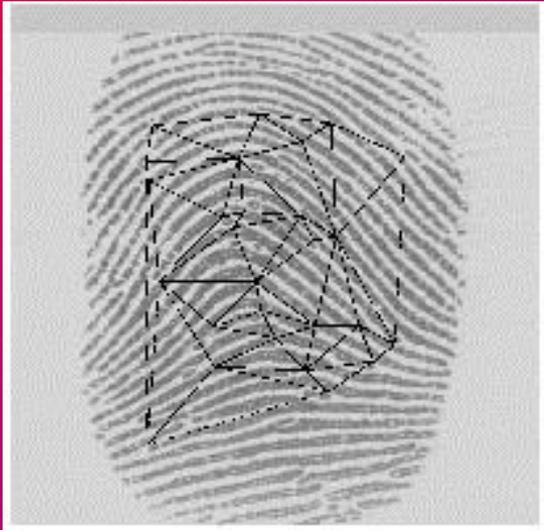


Fingerprint Identification

Minutiae



Delaunay Triangulation



Matching

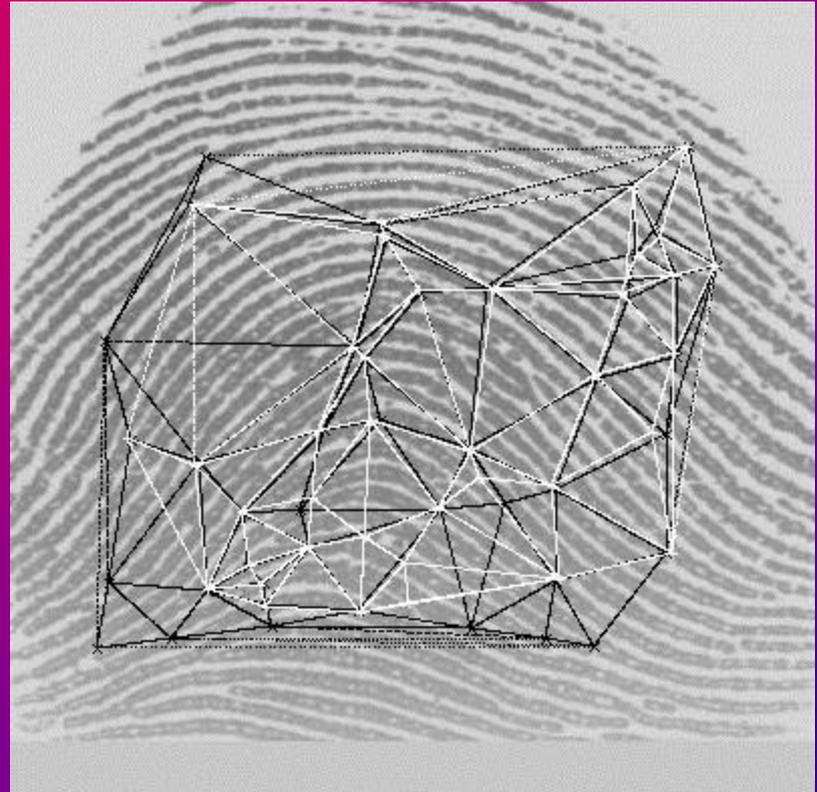
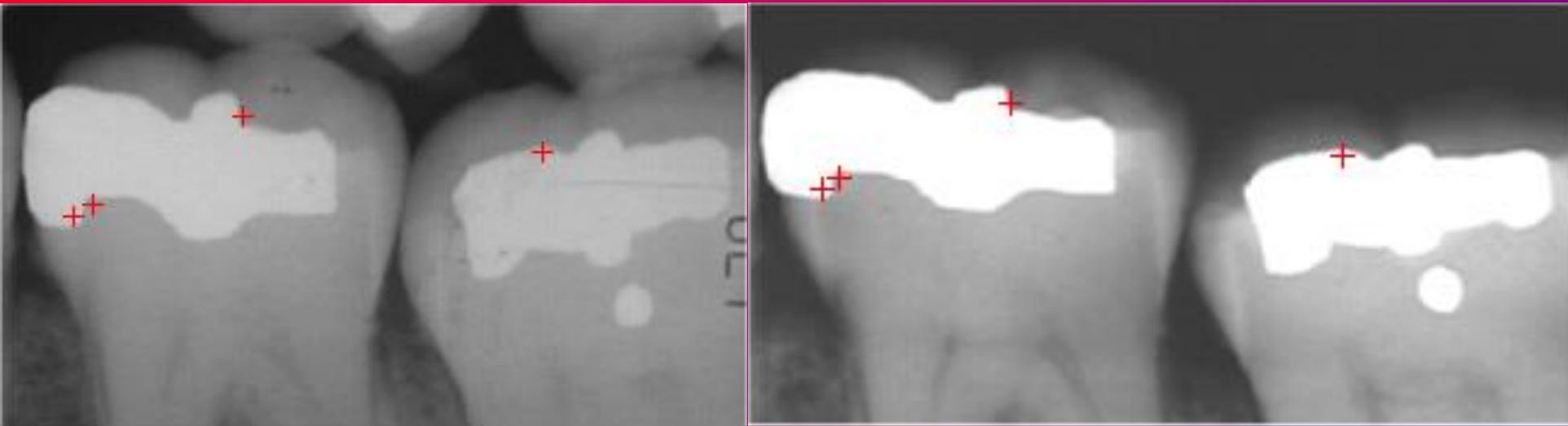


Image Analysis: Image Matching



Antemortem dental X-ray record Postmortem dental X-ray record

Target Recognition

- Department of Defense (Army, Airforce, Navy)



Interpretation of Aerial Photography

Interpretation of aerial photography is a problem domain in both computer vision and registration.

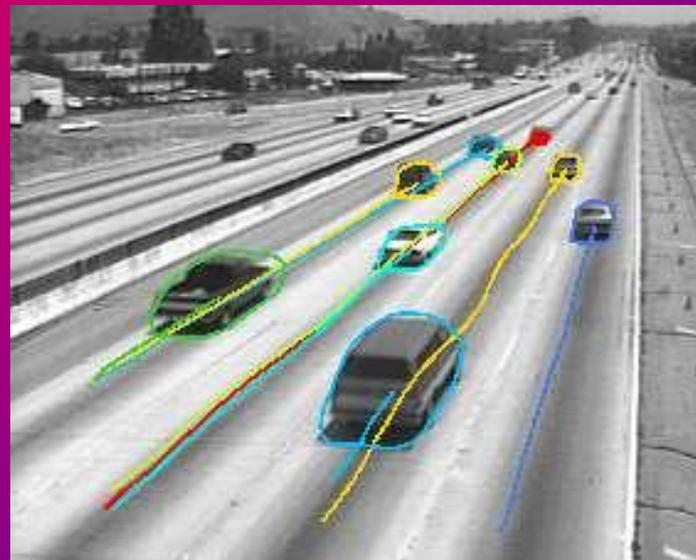
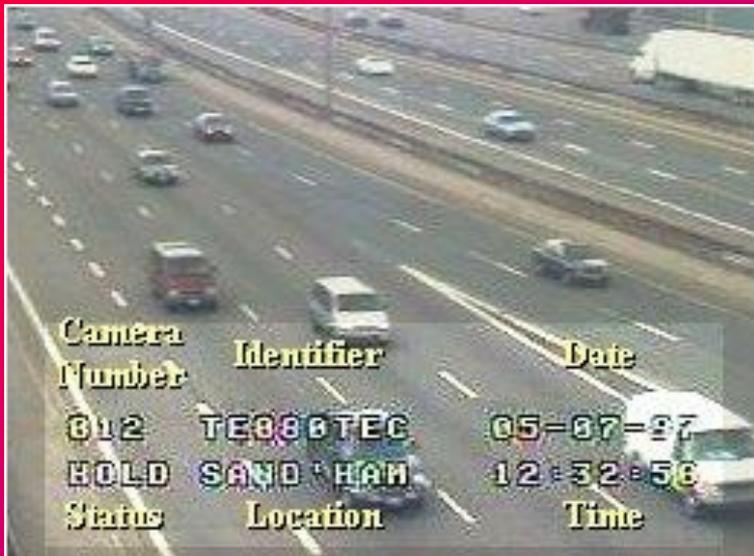


Autonomous Vehicles

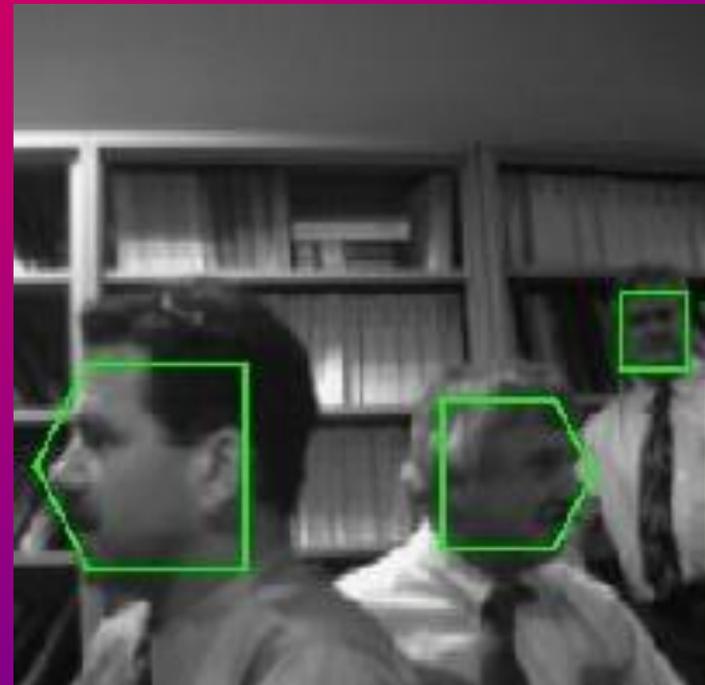
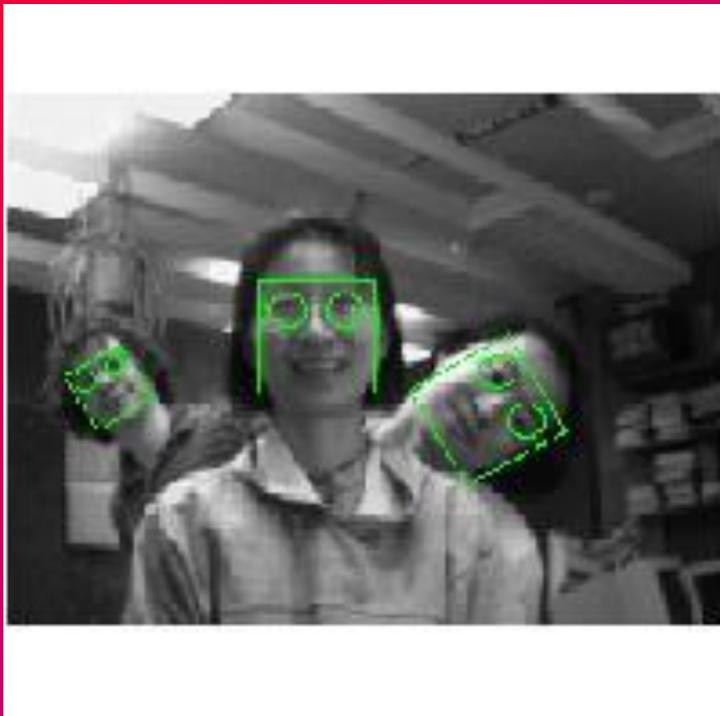
■ Land, Underwater, Space



Traffic Monitoring



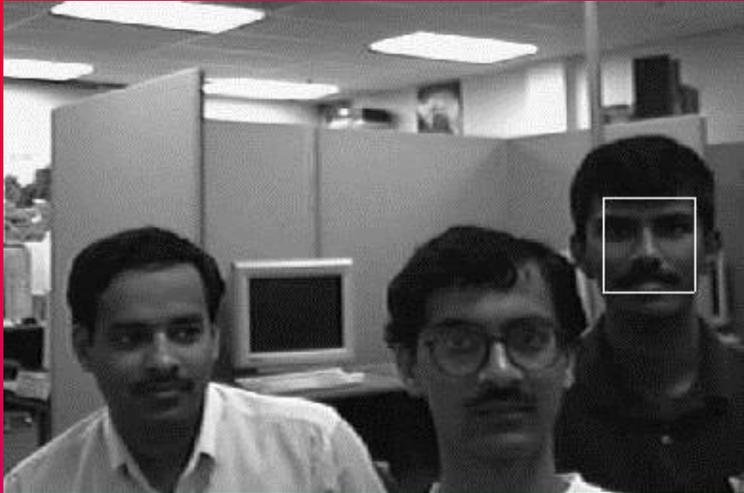
Face Detection



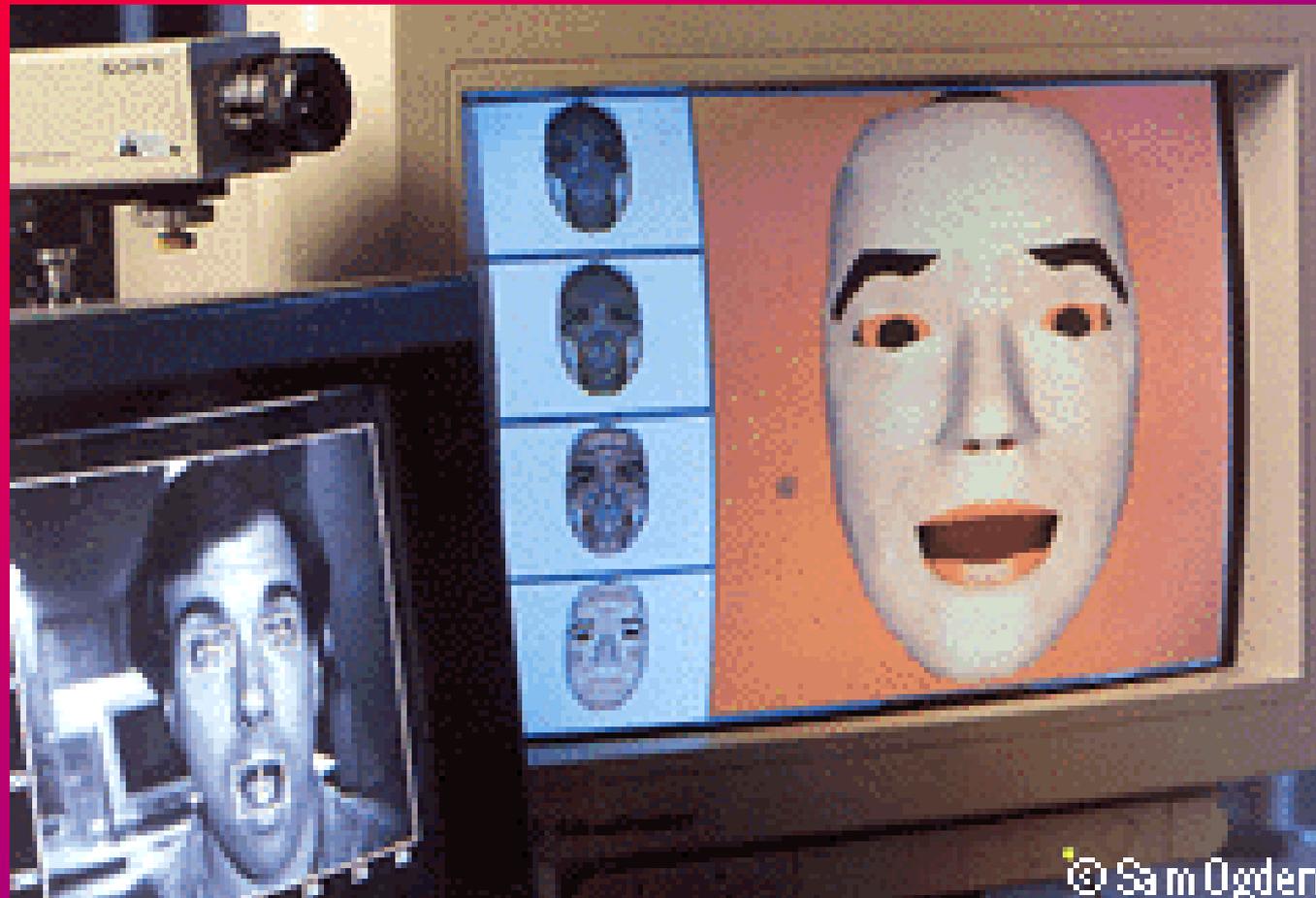
Face Recognition



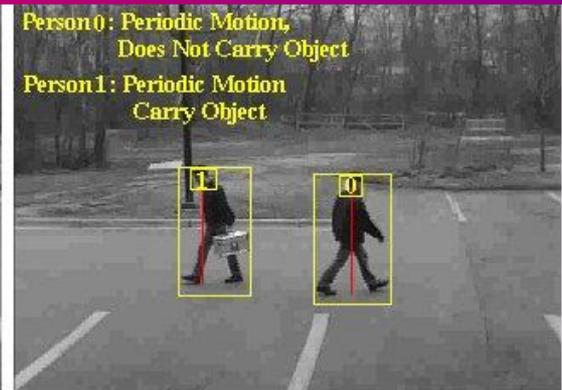
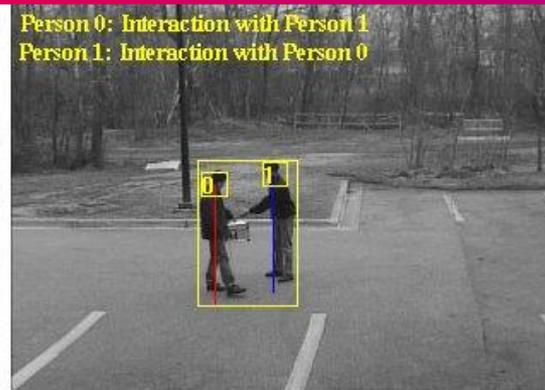
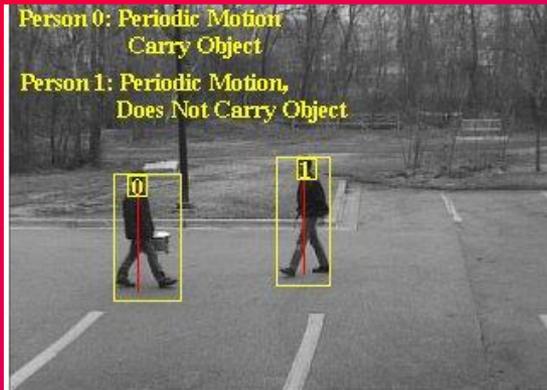
Face Detection/Recognition



Facial Expression Recognition



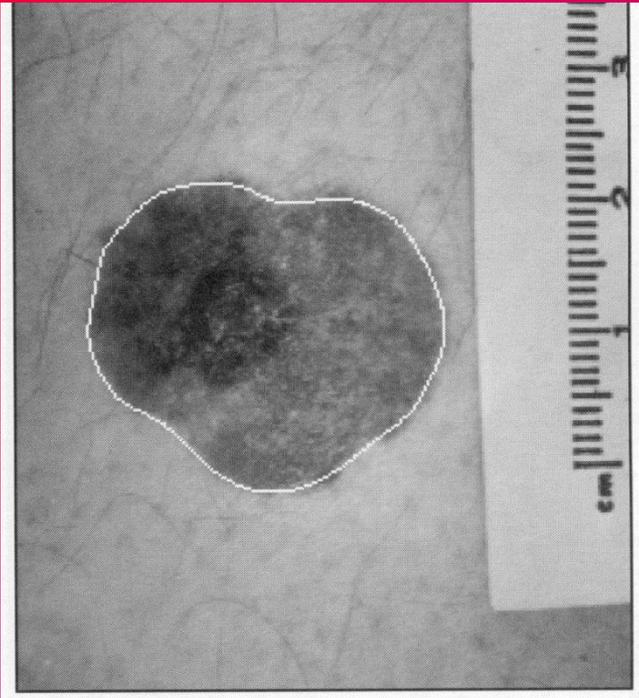
Human Activity Recognition



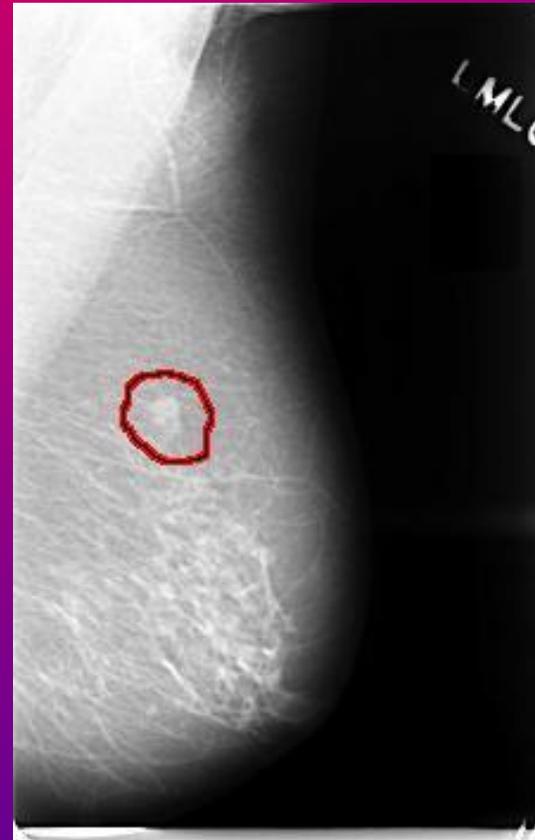
Medical Applications



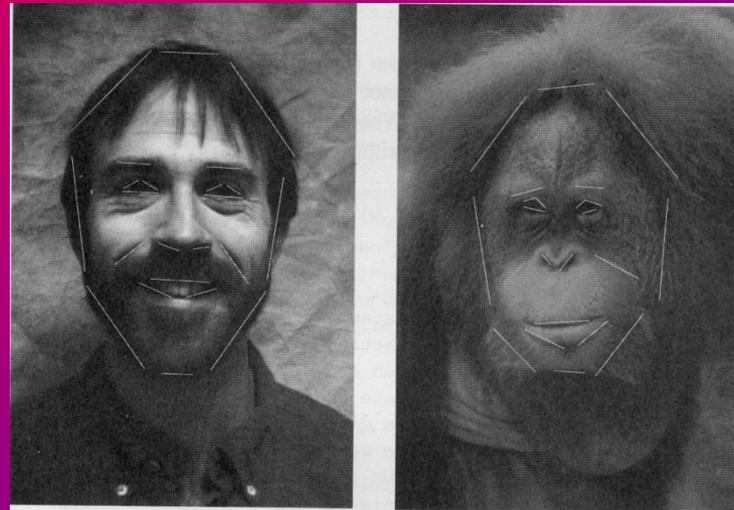
skin cancer



breast cancer



Morphing



Fundamental Steps in Digital Image Processing:

Outputs of these processes generally are images

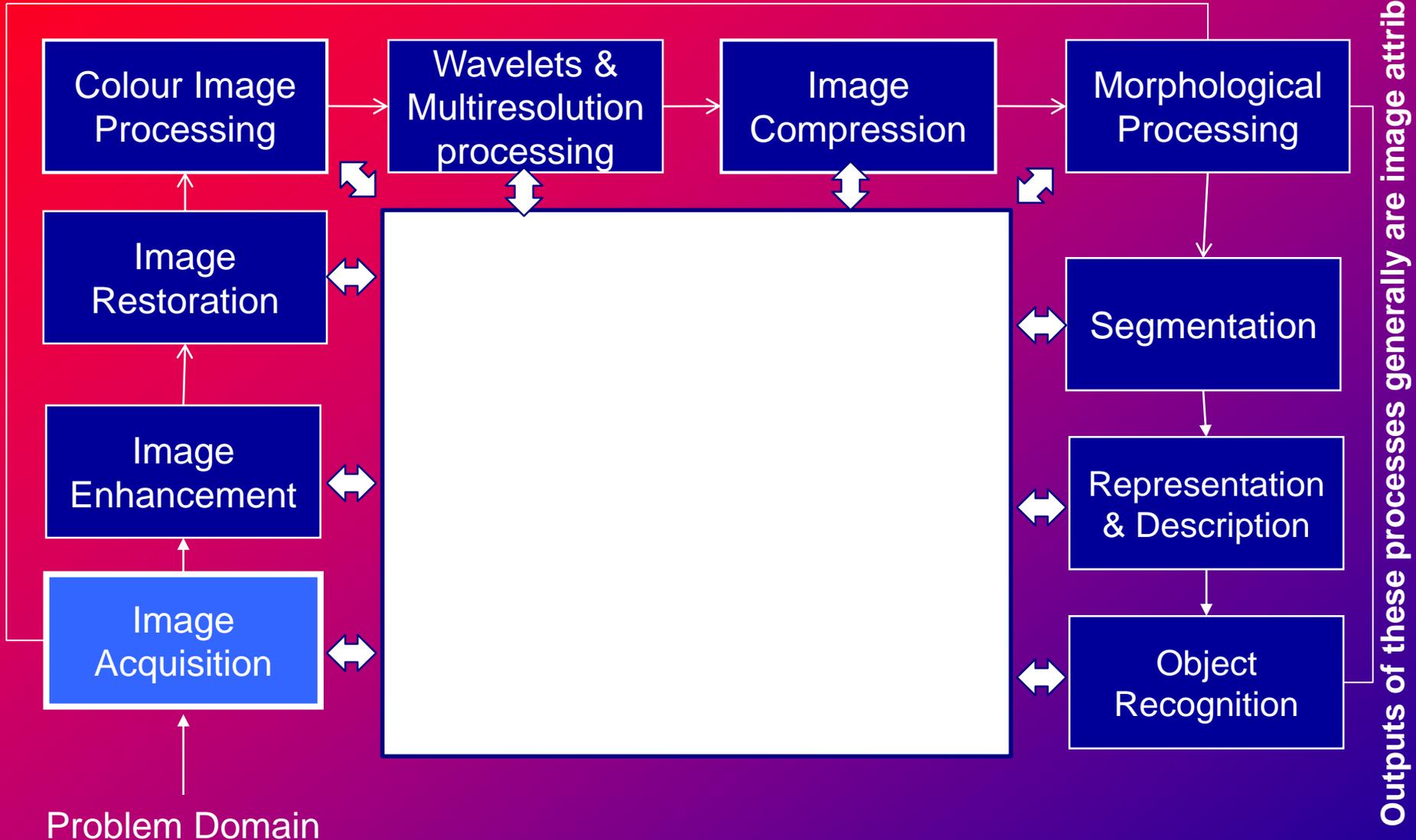


Image Processing

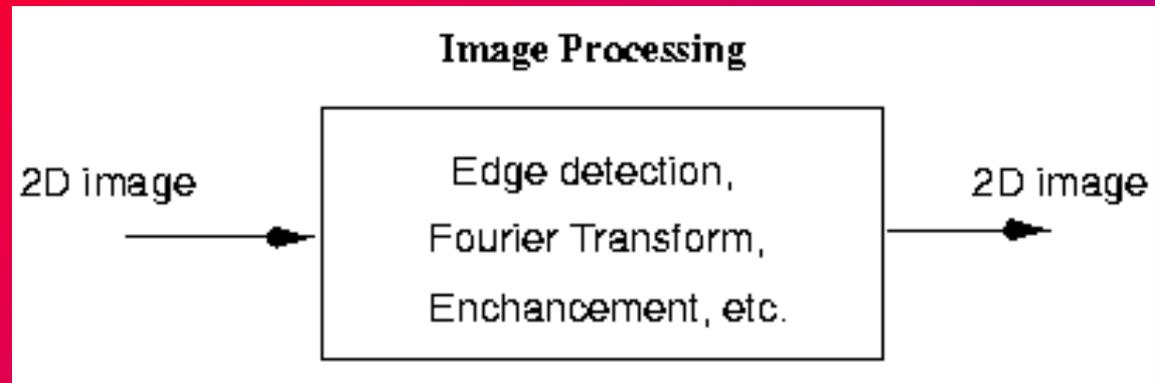
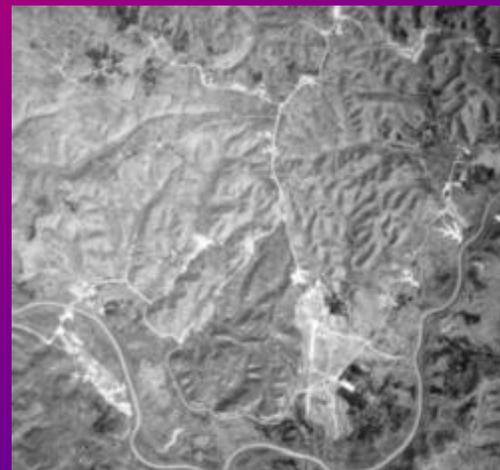
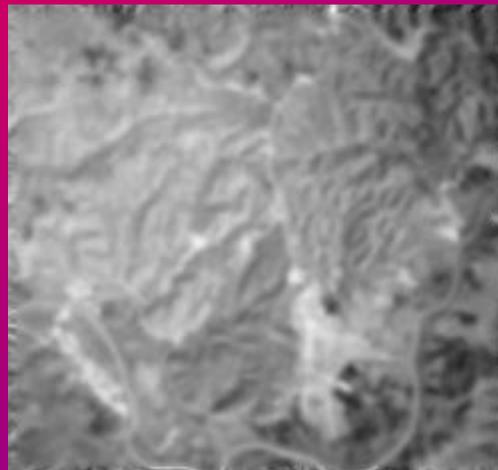
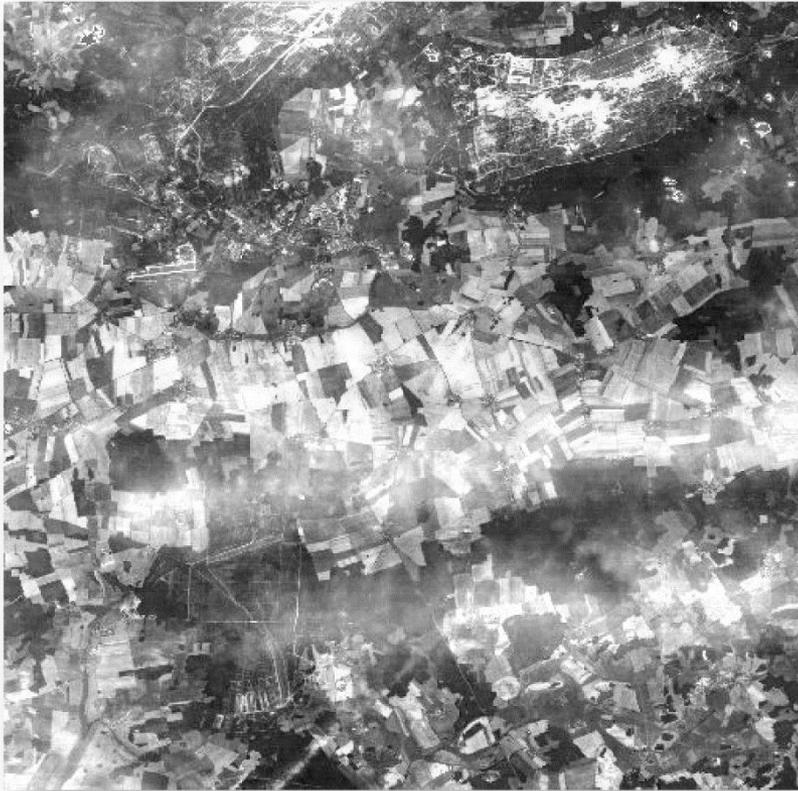
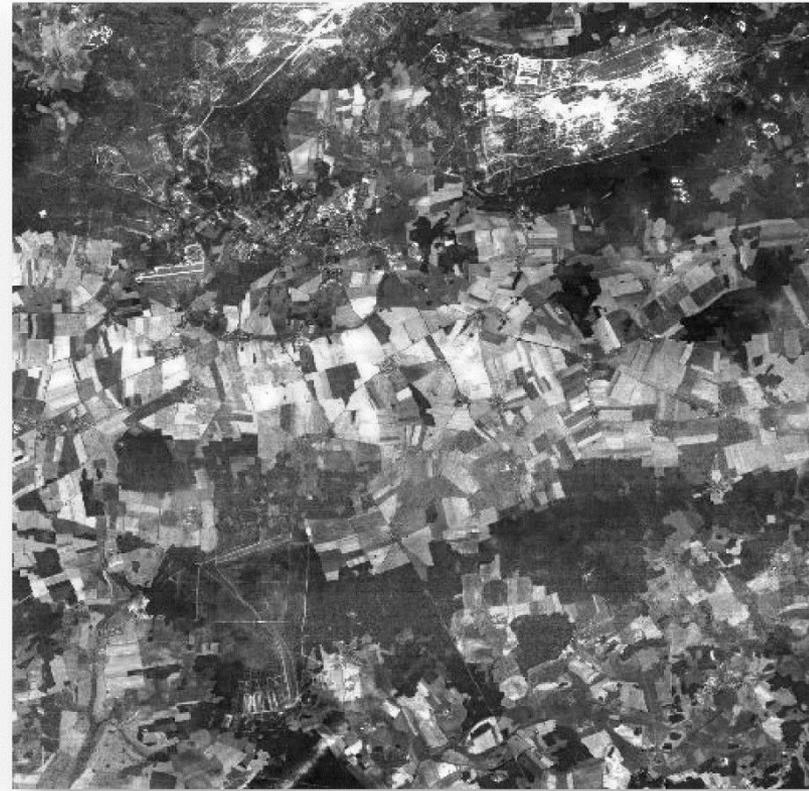


Image Enhancement





a. Before atmospheric correction.



b. After atmospheric correction.

a) Image containing substantial haze prior to atmospheric correction. b) Image after atmospheric correction using ATCOR (Courtesy Leica Geosystems and DLR, the German Aerospace Centre).

Image Manipulation (V): Image Interpolation



small

1M pixels

**digital
zooming**



large

4M pixels

Resolution enhancement can be obtained by common image processing software such as Photoshop or Paint Shop Pro

Image Manipulation (X): Image Inpainting

Since 1699, when French explorers landed at the great bend of the Mississippi River and celebrated the first Mardi Gras in North America, New Orleans has brewed a fascinating melange of cultures. It was French, then Spanish, then French again, then sold to the United States. Through all these years, and even into the 1900s, others arrived from everywhere: Acadians (Cajuns), Africans, indige-



Image Inpainting Application: Restore Old Photos

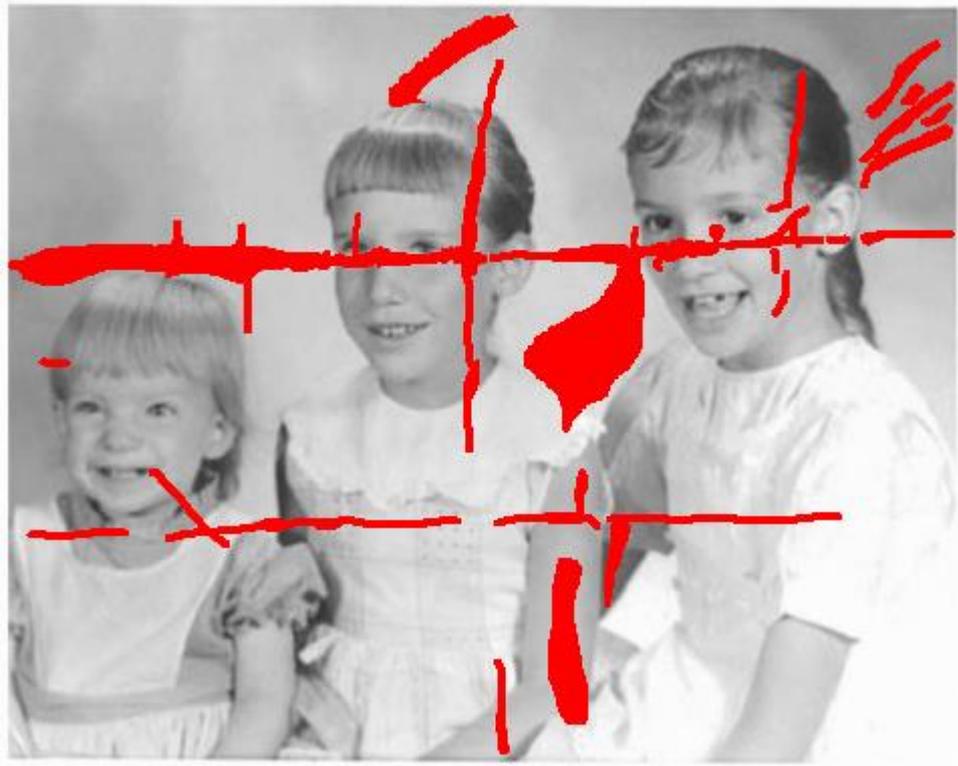


Image Manipulation (XI): Color Quantization



25,680 colors (24 bits)

256 colors (8 bits)

Applications: video cell-phone, gameboy, portable DVD

■ Low Pass Filtering: Document Processing

■ Sample Text

Historically, certain computer programs were written using only two digits rather than four to define the applicable year. Accordingly, the company's software may recognize a date using "00" as 1900 rather than the year 2000.

Smoothing Text Using Gaussian Filter

Historically, certain computer programs were written using only two digits rather than four to define the applicable year. Accordingly, the company's software may recognize a date using "00" as 1900 rather than the year 2000.

High-Pass Filter:(Butterworth Type)

$$H_h(u,v)=1/\{1+[D_0^2/(u^2+v^2)]^N\}$$

Low-Pass Filter:(Butterworth Type)

$$H_l(u,v)=1/\{1+(u^2+v^2)/D_0^2\}^N$$

Image Processing (cont'd)

- Image Restoration: image contaminated with periodic noise

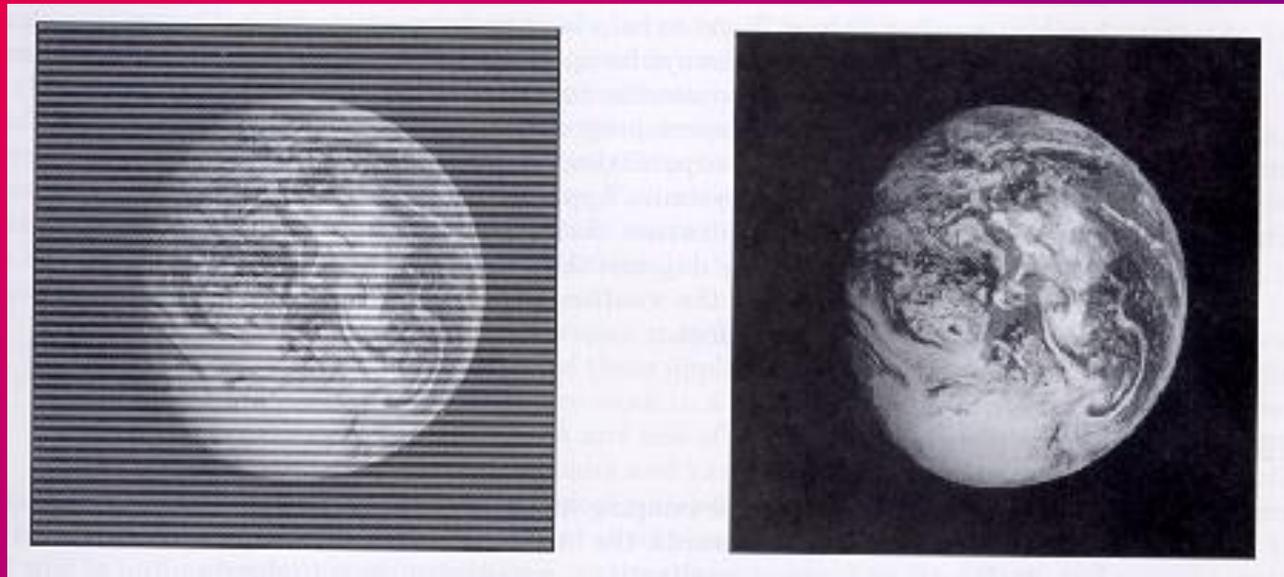


Image Manipulation

Noise Removal

Noise contamination is often inevitable during the acquisition



salt and pepper (impulse) noise



additive white Gaussian noise

You will learn how to design image filter in a **principled** way

Image manipulations include
algebraic, differential, and
Statistical Operations:

Image addition and subtraction,
Image multiplication (e.g.
Convolution)

Power Correction

Edge detection: Gradient,
Laplacian

Median Filters (statistical)

$$g(x) = \frac{df}{dx} = f(x+1) - f(x)$$

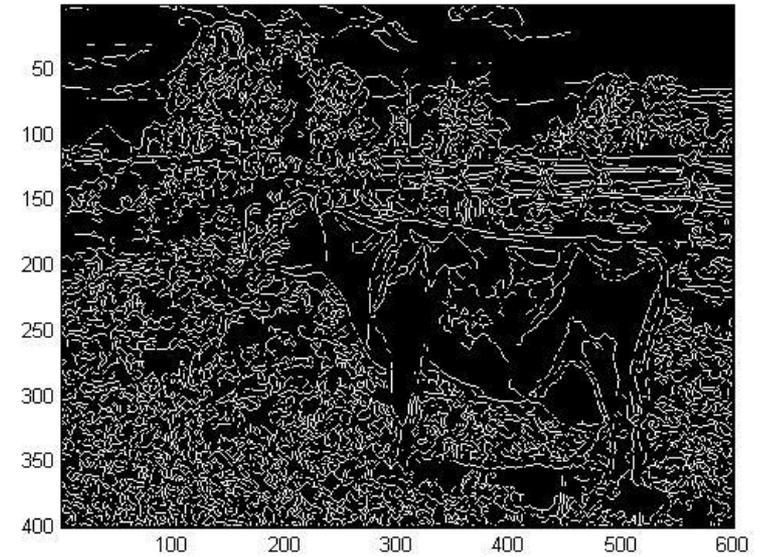
$$h(x) = \frac{d^2 f}{dx^2} = f(x+1) - 2f(x) + f(x-1)$$

$$\Delta f = \nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} =$$

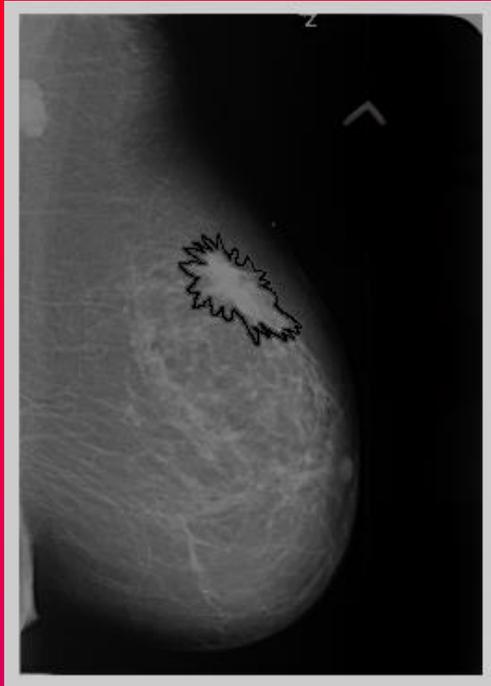
$$= f(x+1, y) + f(x, y+1) + f(x-1, y) + f(x, y-1) - 4f(x, y)$$

$$g(x, y) = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2}$$

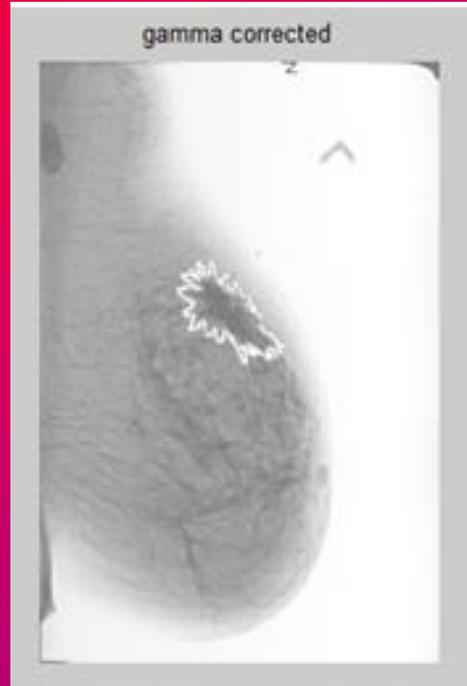
Edge detection



Gamma Correction



Original mammo



Gamma corrected
mammogram

➤ It is a non linear operation that stretches and compress intensities to improve object visibility in an image.

➤ Mathematical expression:

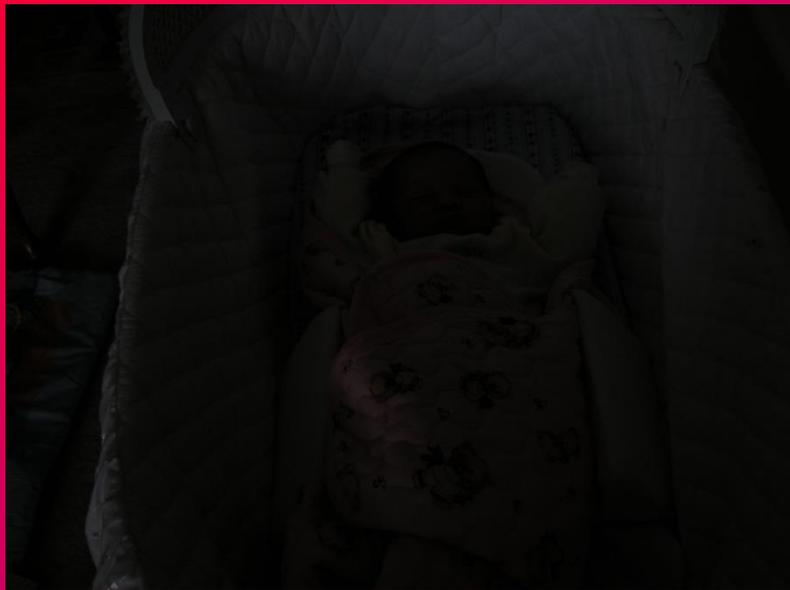
$$s = cr^\gamma$$

➤ If gamma < 1, mapping weighted towards brighter (enhanced) and gamma > 1, weighted towards darker (de enhanced).

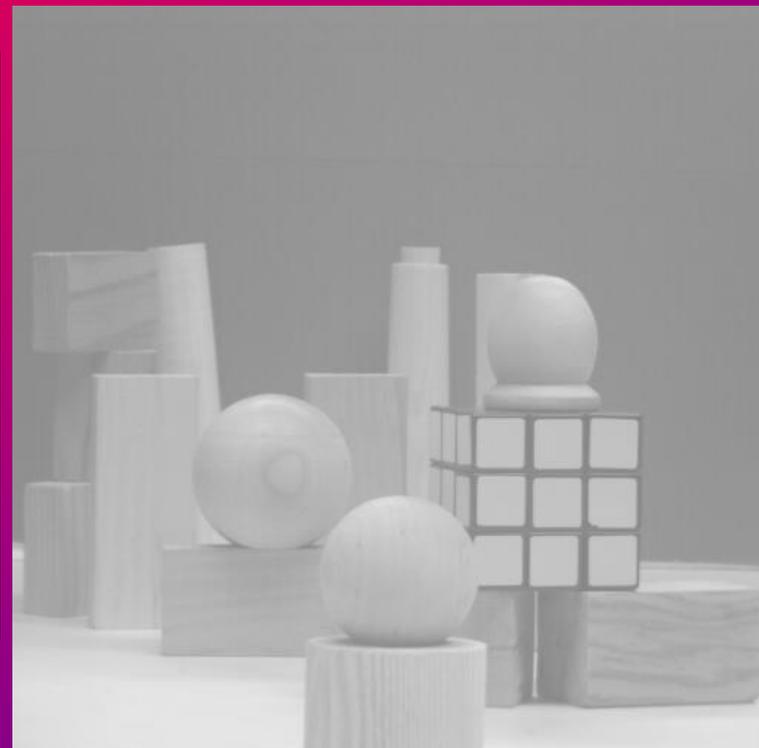
Contrast Enhancement Using Histogram Equalization

- The Histogram approximates the probability of occurrence of grey levels in the given image.
- Histogram Equalization means redistribute the grey levels so that the pixels values in the new image have uniform distribution.

Contrast Enhancement



under-exposed image



overly-exposed image

You will learn how to modify the **histogram** of an image





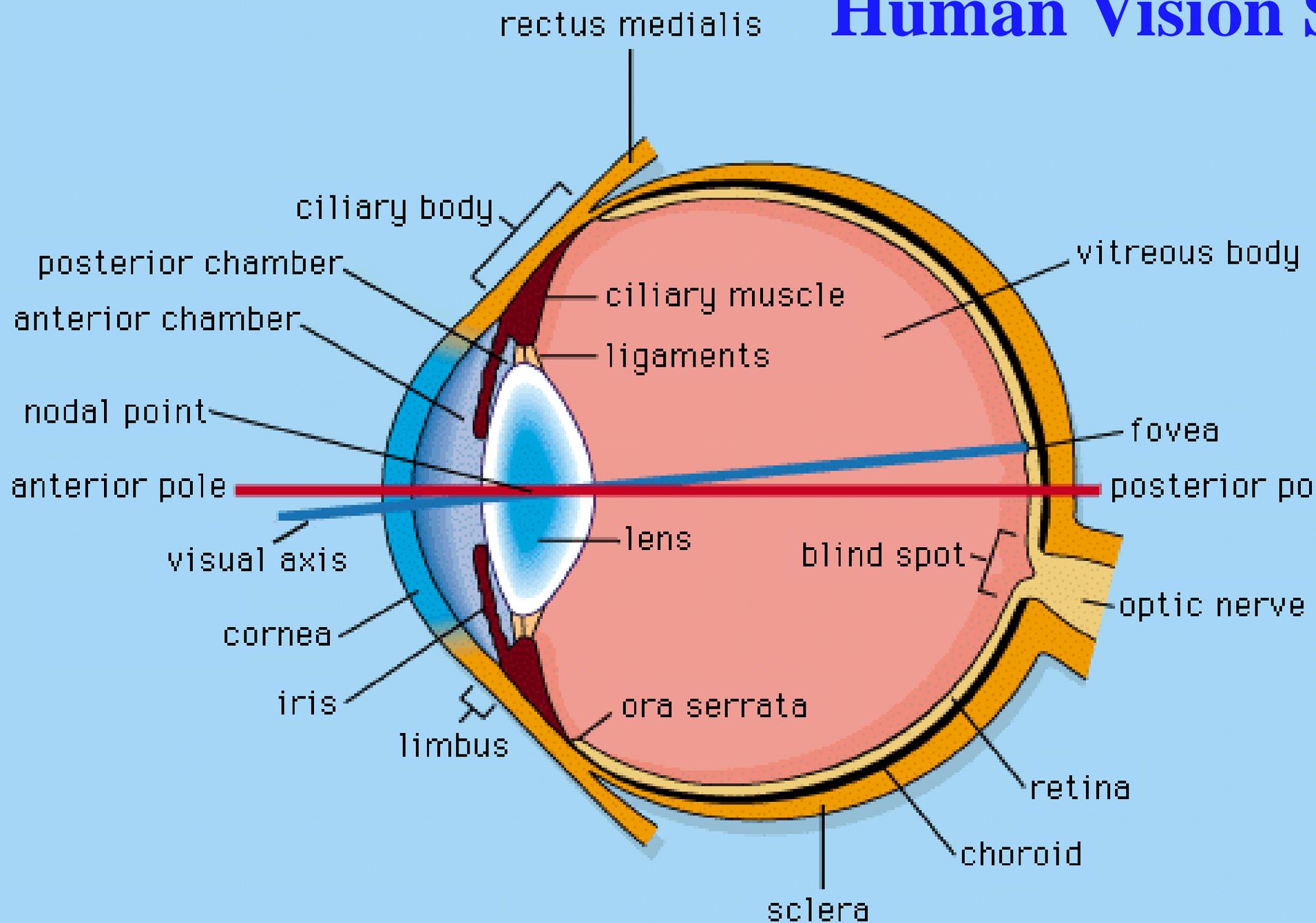
Un-Equalized Image



Equalized Image



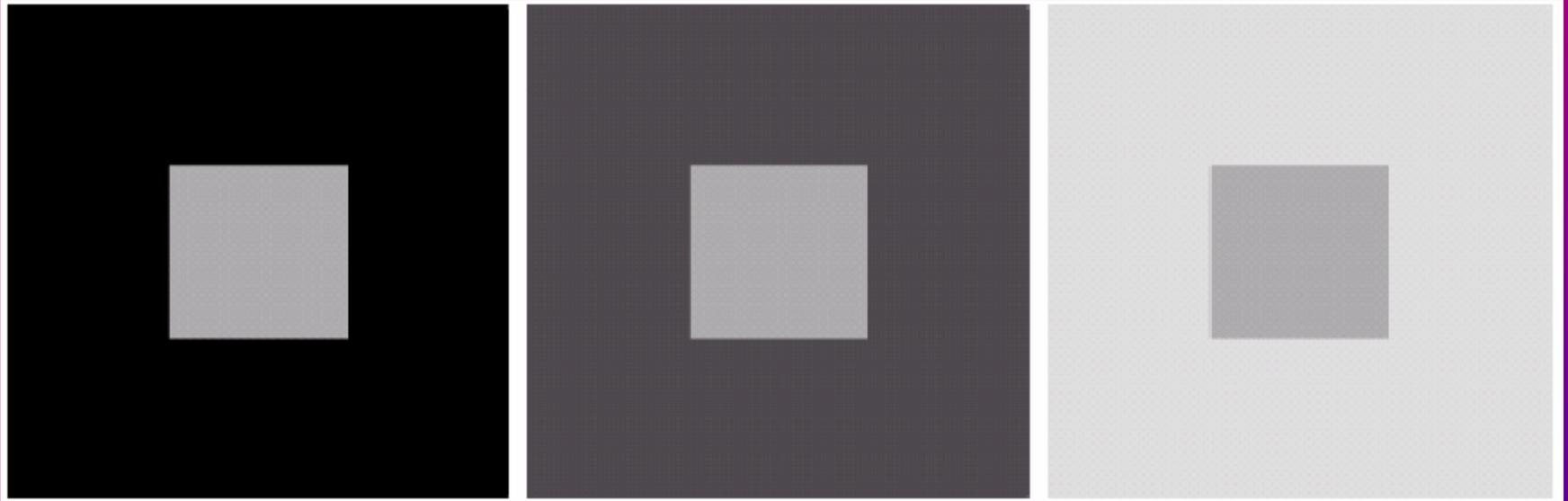
Human Vision S



Optical Illusion

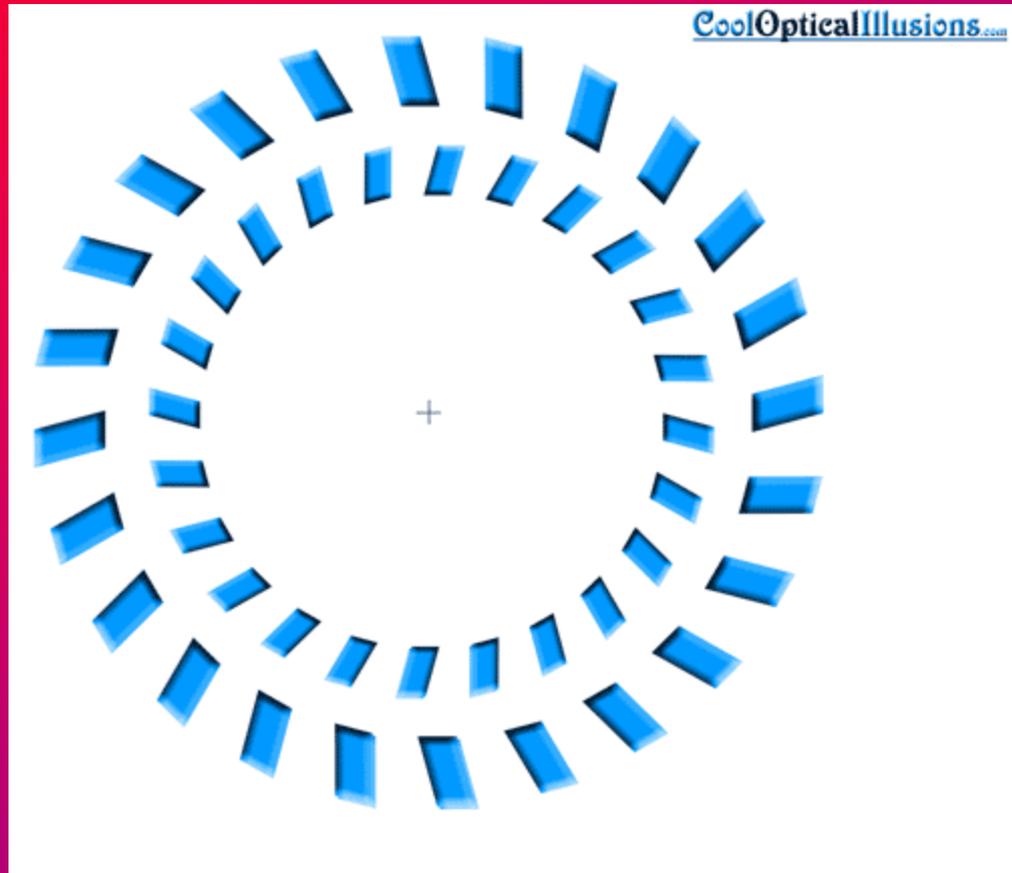
In image Perception, we will see why we need to know about neuroscience and psychology

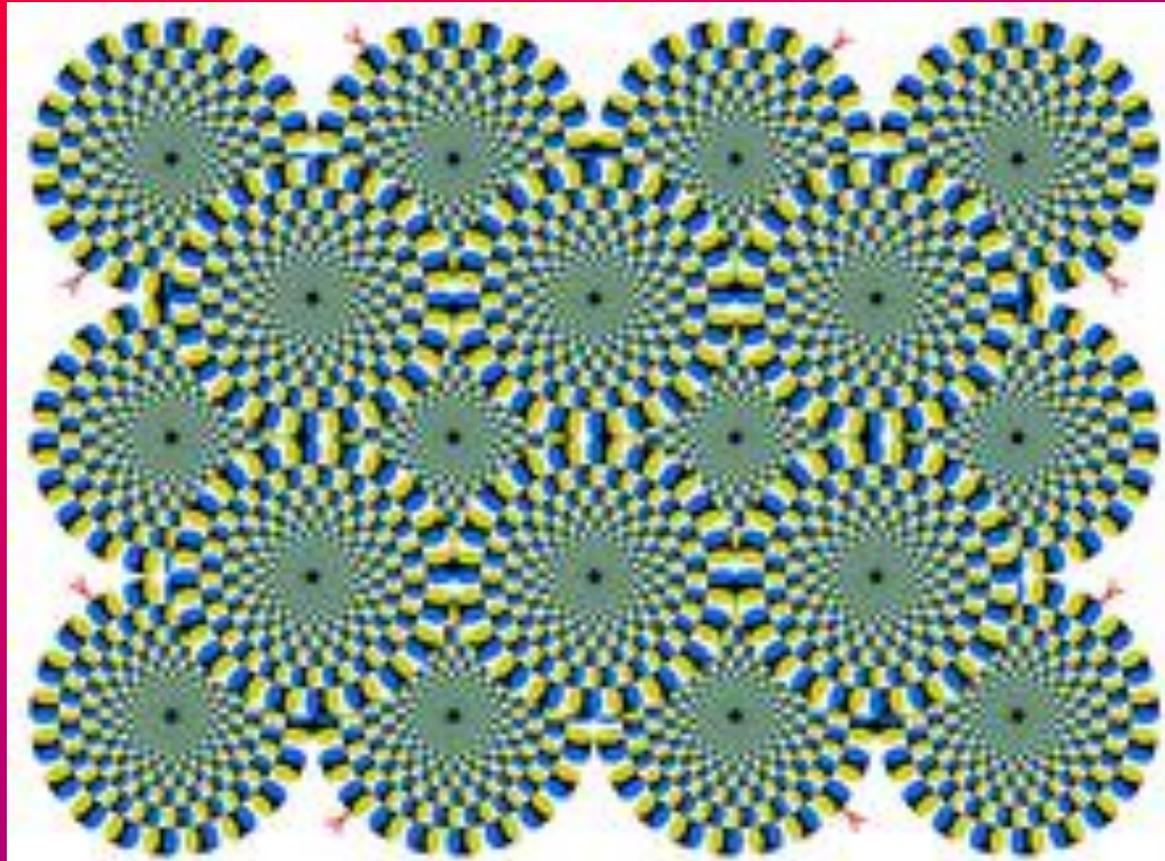
Human Vision System

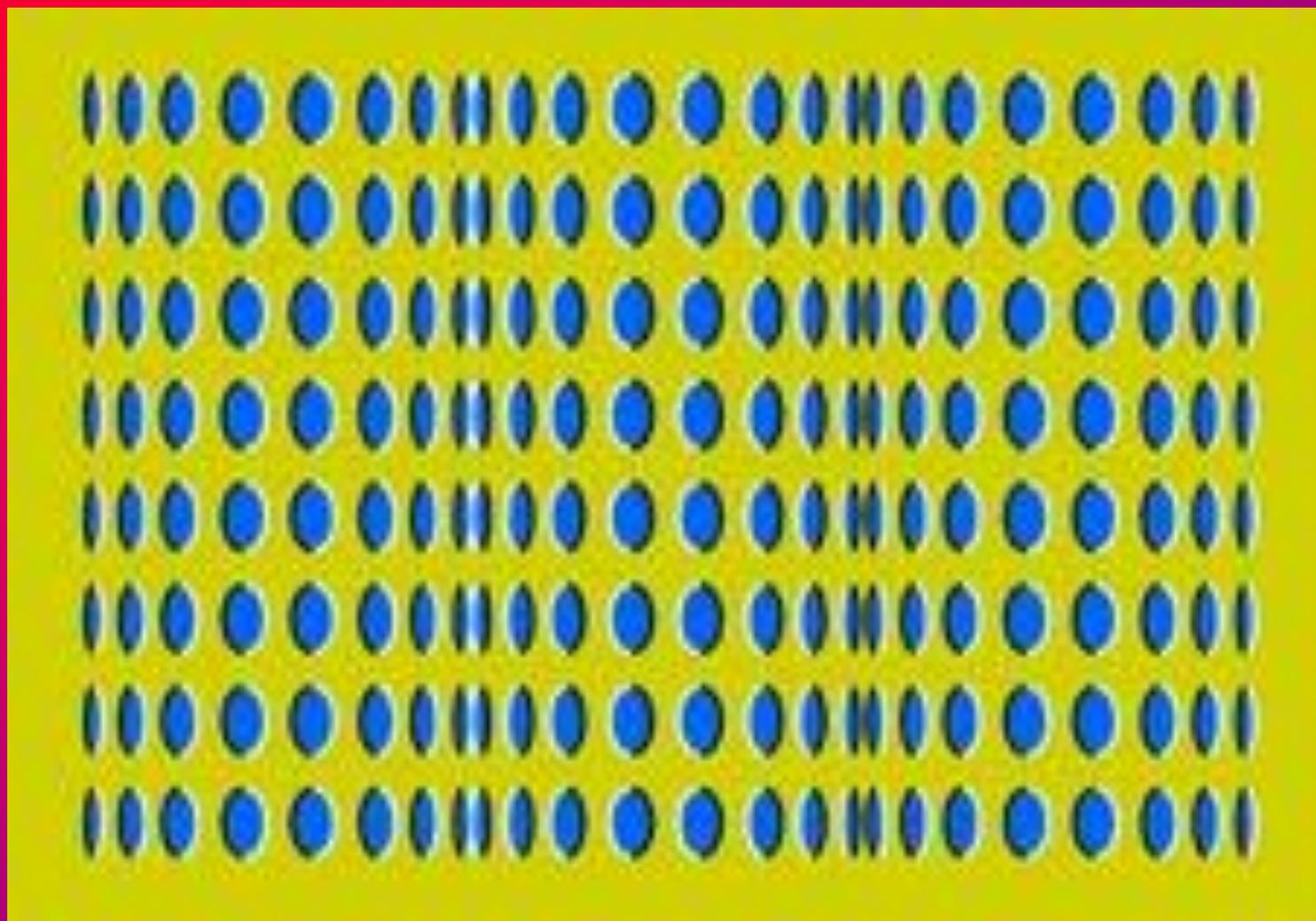


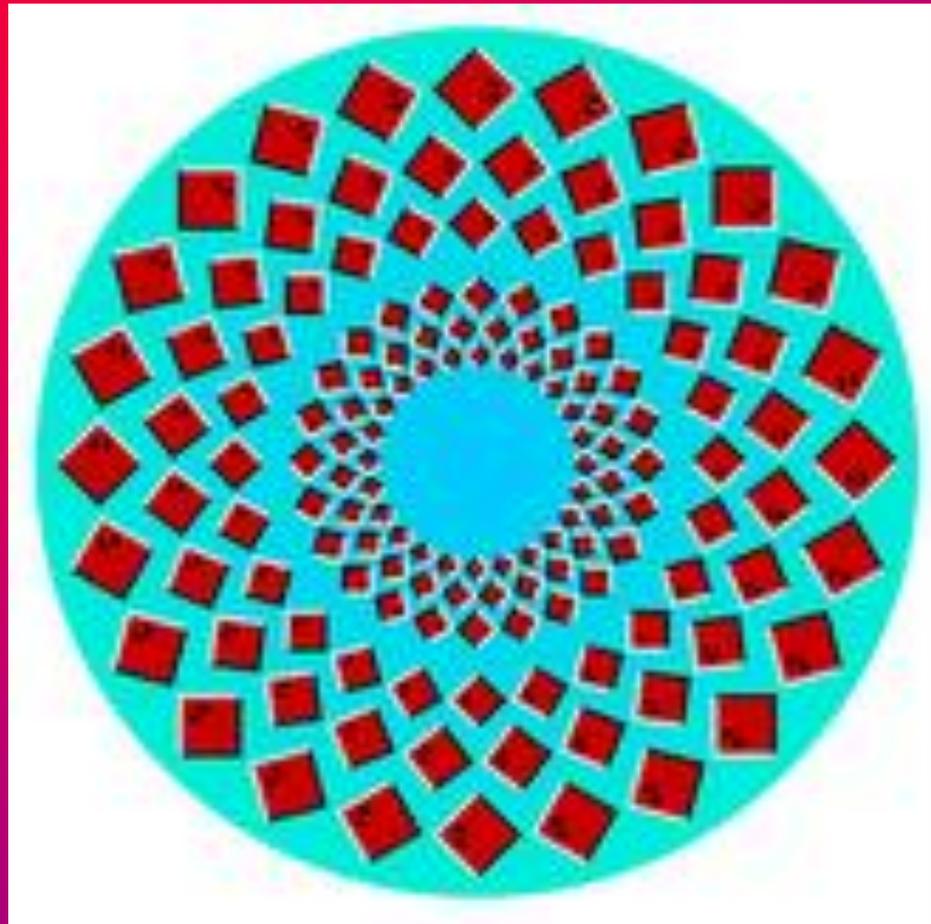
Simultaneous contrast

Fascinating Optical Illusions





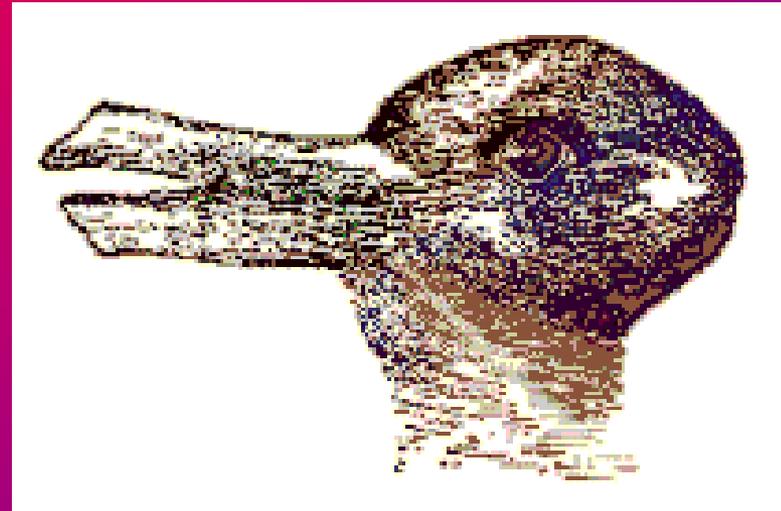




Interpretation Ambiguity



Is it seal or donkey?

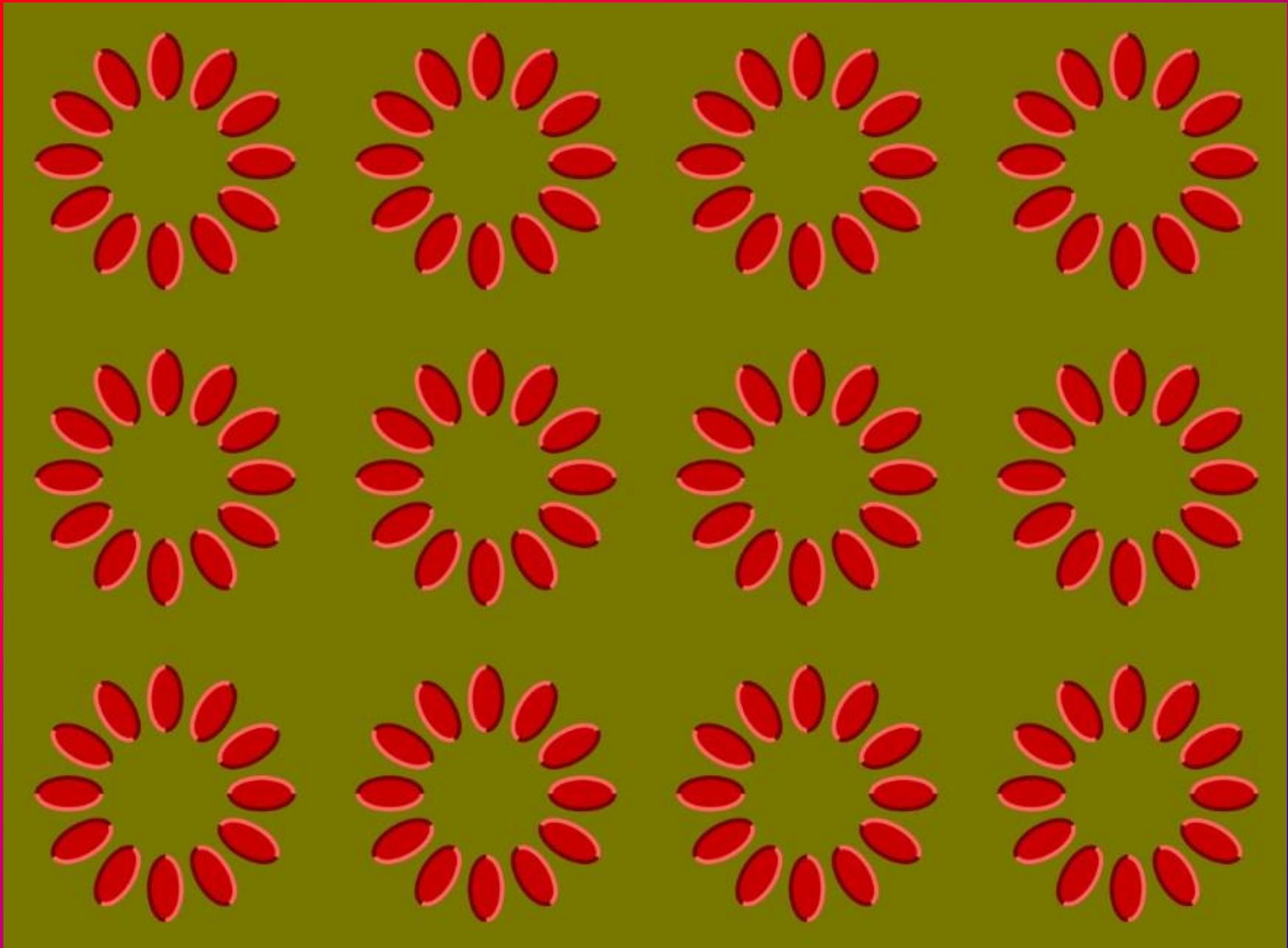


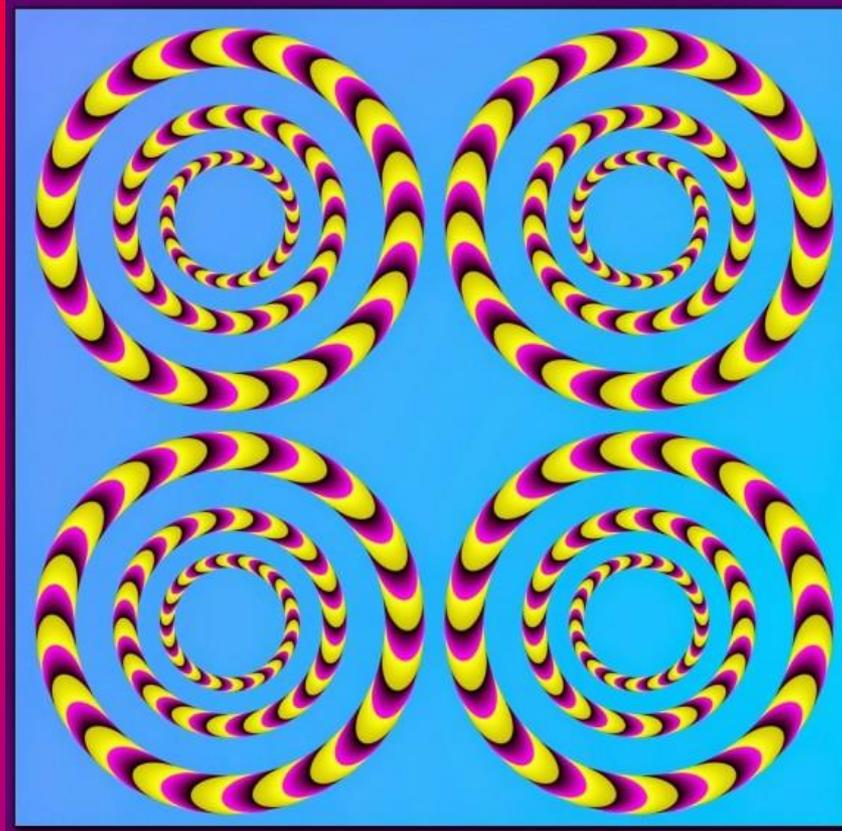
Is it duck or hare?

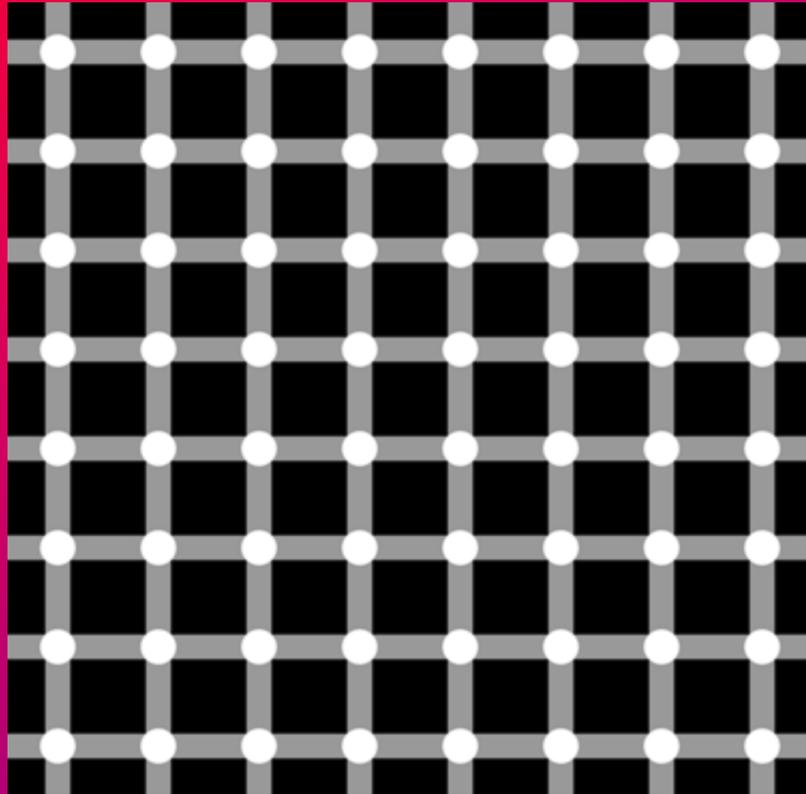
The Man in the Coffee Beans

The "illusion" is that this is just a picture of coffee beans; but it is not. Can you find a man's face among the beans?





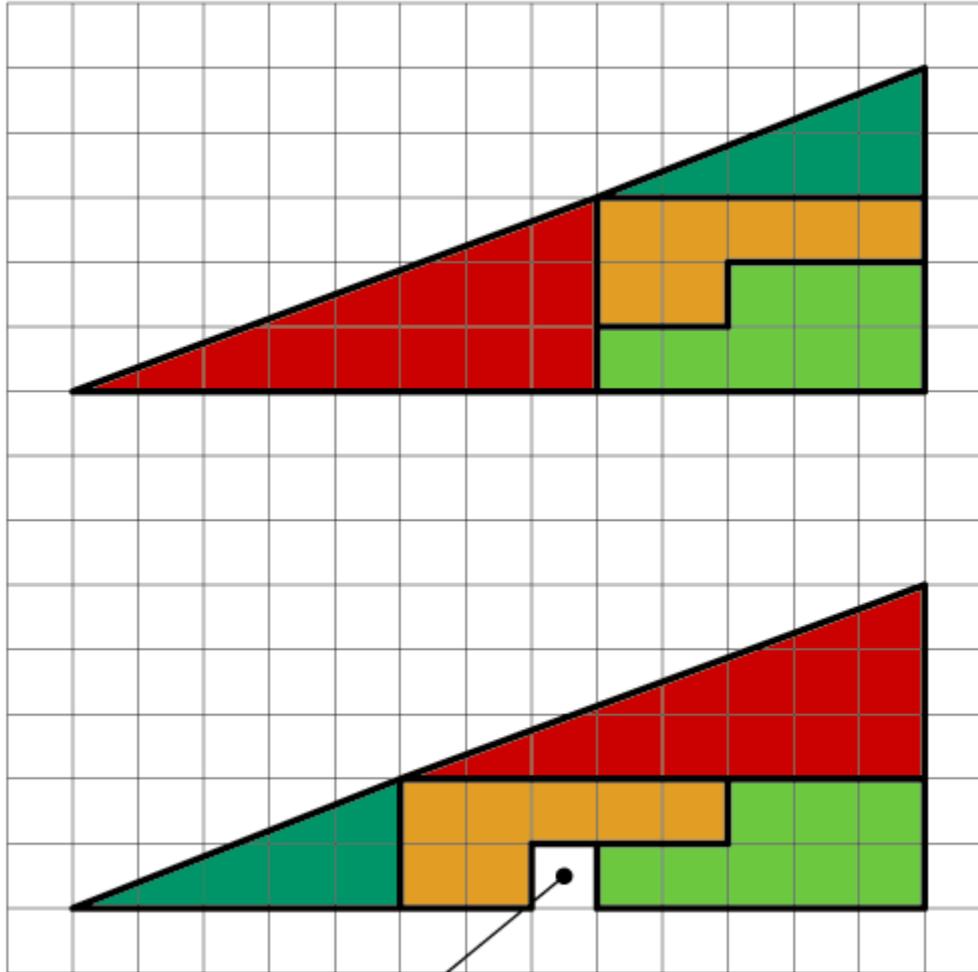




http://kids.niehs.nih.gov/games/illusions/lots_of_illusions.htm

<http://www.psy.ritsumei.ac.jp/~akitaoka/saishin52e.html>

HOW CAN THIS BE TRUE ?



*Below the four
parts are
moved around*

*The partitions
are exactly the
same, as those
used above*

From where comes this "hole" ?

Summary

DIP is very interesting multi-disciplinary subject that has powerful real life applications.

Thank you

Questions

The Art of Image Compression

- Why are images compressible?
 - Redundancy in images (NOT random)
- How data compression works?
 - Probability theory and statistics
 - Shannon's information theory

From JPEG to JPEG2000



discrete cosine transform based
JPEG (CR=64)



wavelet transform based
JPEG2000 (CR=64)