Introduction to Digital Image Processing

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- **Related Courses:**

ECE 8741: Digital Image Processing

ECE 5741: Digital Signal Processing

ECE 5742: Pattern Recocnition

ECE 8742: Signal Detection And Estimation

ECE 5745 Medical Imaging

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

The first photograph in the world

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

Textbook

- Suggested textbook:
  - R.C. Gonzalez and R.E. Woods, “Digital Image Processing”, 3rd Ed., Prentice-Hall’2008
  - Any other book with a similar title will work too

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)

What is an image?

- We can think of an **image** as a function, *f*,
- from R^2 to 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*]x[*c*,*d*] → [0,1]
- A color image is just three functions pasted together. We can write this as a "vector-valued" function:

$$f(x,y) = \begin{bmatrix} r(x,y) \\ g(x,y) \\ b(x,y) \end{bmatrix}$$

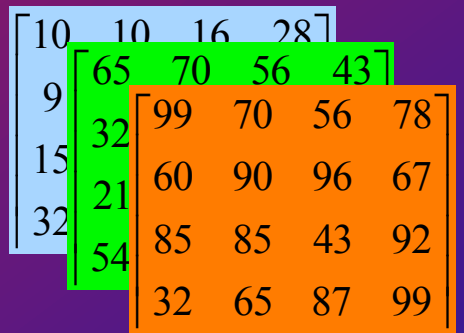
Digital Image Representation

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

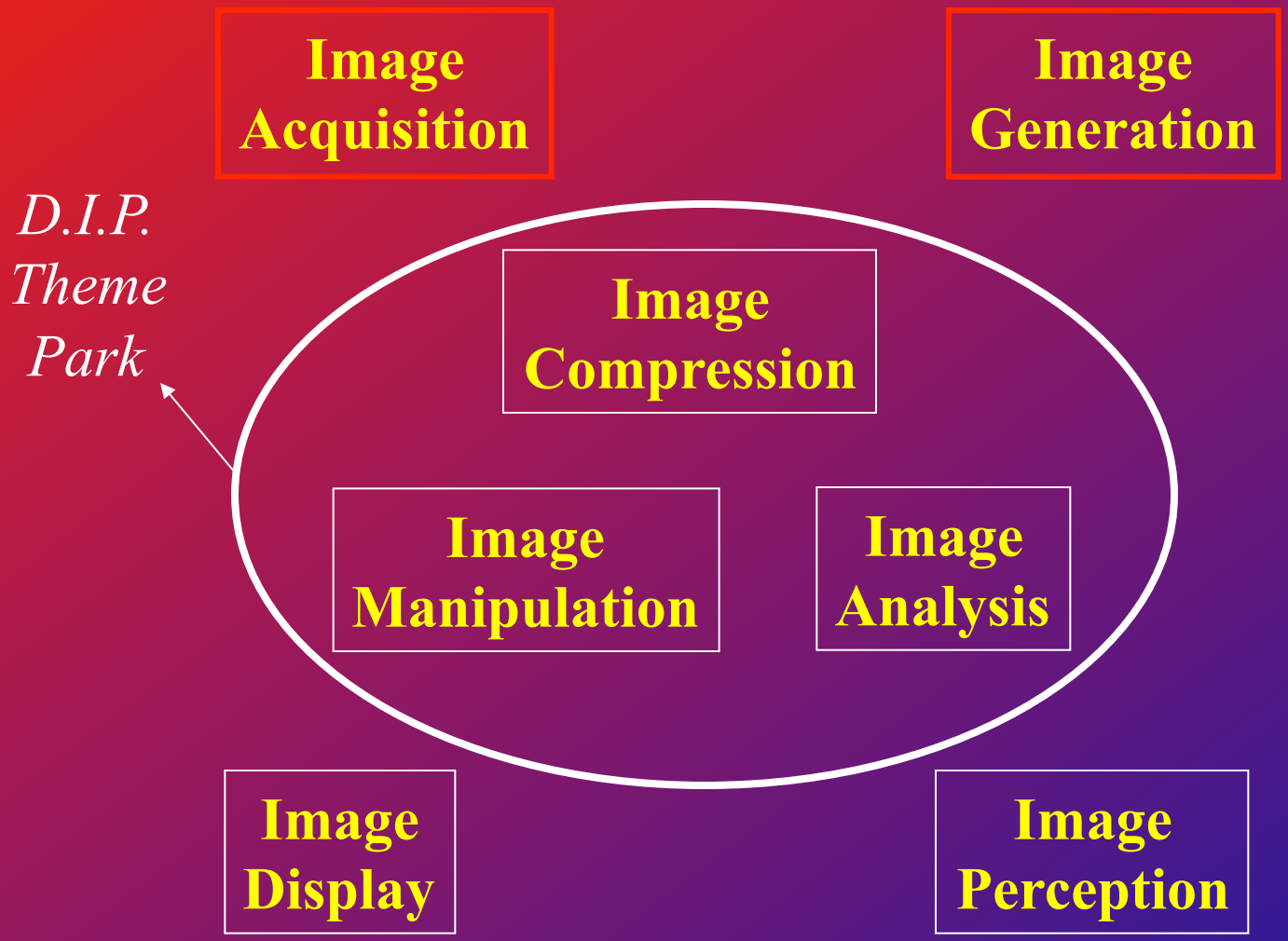
0:darkest

255: Brightest

- Each number in the image represent a pixel



Tour Guide To DIP



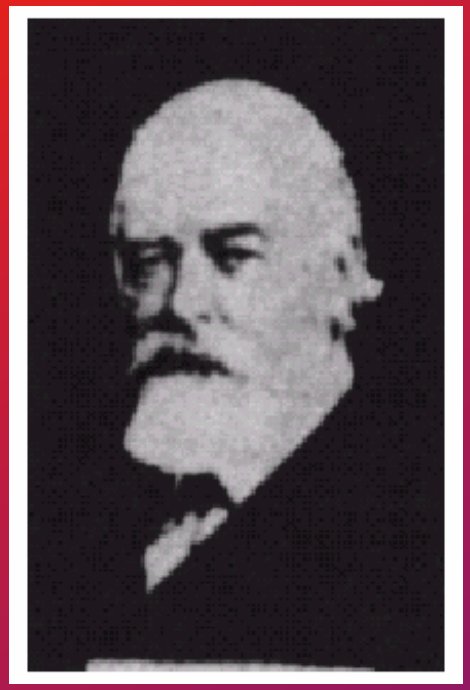
Relation to Computer Vision

- Computer Vision (High Level)
  - strives to emulate the human visual system and interpret our 3D world from 2D images or video
  - Object detection, recognition, shape analysis, tracking
  - Use of Artificial Intelligence and Machine Learning
- Image Analysis
  - Segmentation, image registration, matching
- Image Processing(Low Level)
  - Image enhancement, noise removal, restoration,
  - feature detection, compression

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

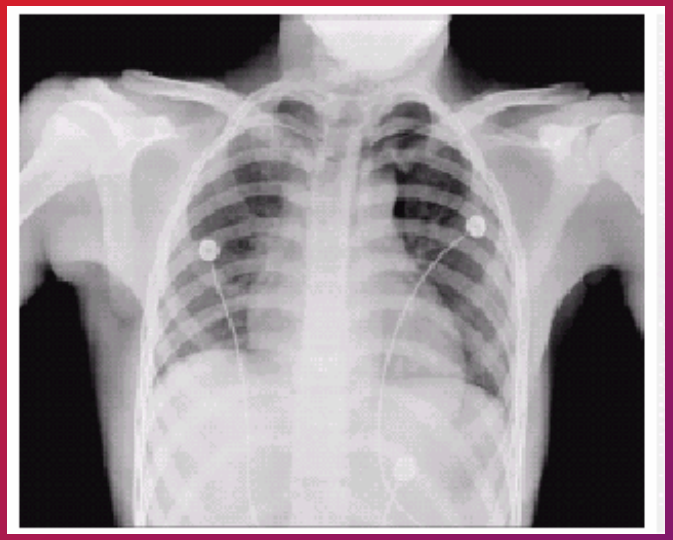
The Born of Digital Computers

- 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



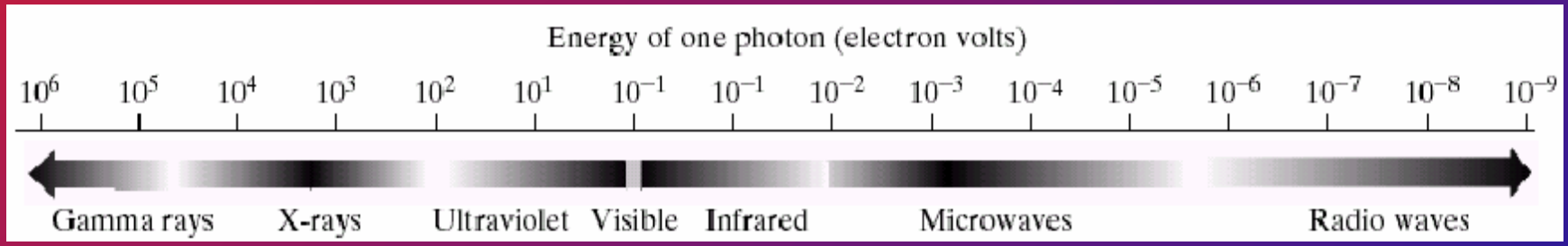
Sir Godfrey N. Housefield and Prof. Allan M. Cormack shared 1979 Nobel Prize in Medicine for the invention of CT

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
  - Falsh memory, Phase-change memory
- Display
  - Printers, LCD monitor, digital TV
  - Portable DVD player, PDAs, cell-phone

A Physical Perspective of Image Acquisition

- Extend the capabilities of human vision systems
  - From visible spectrum to non-visible electromagnetic power spectrum
  - From close-distance sensing to remote sensing



Importance of Visual Information

- Importance of Visual Information
- Various imaging modalities help us to see invisible objects due to
  - Opaqueness (e.g., see through human body)
  - Far distance (e.g., remote sensing)
  - Small size (e.g., light microscopy)
- Other signals (e.g., seismic) can also be translated into images to facilitate the analysis
- Images are important to convey information and support reasoning

Visible (I): Photography

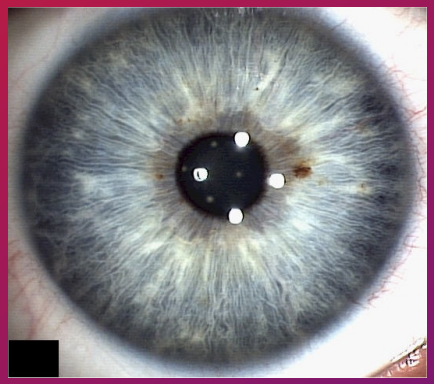
First working camera obscura built by Ibn al-Haytham (around 1000 AD)

Which camera is the most expensive, Leica M8, Canon 40D or Nikon D700?

Canon EOS 5D Mark III DSLR Camera Kit with Canon 24-105mm f/4L IS USM AF Lens $4,000

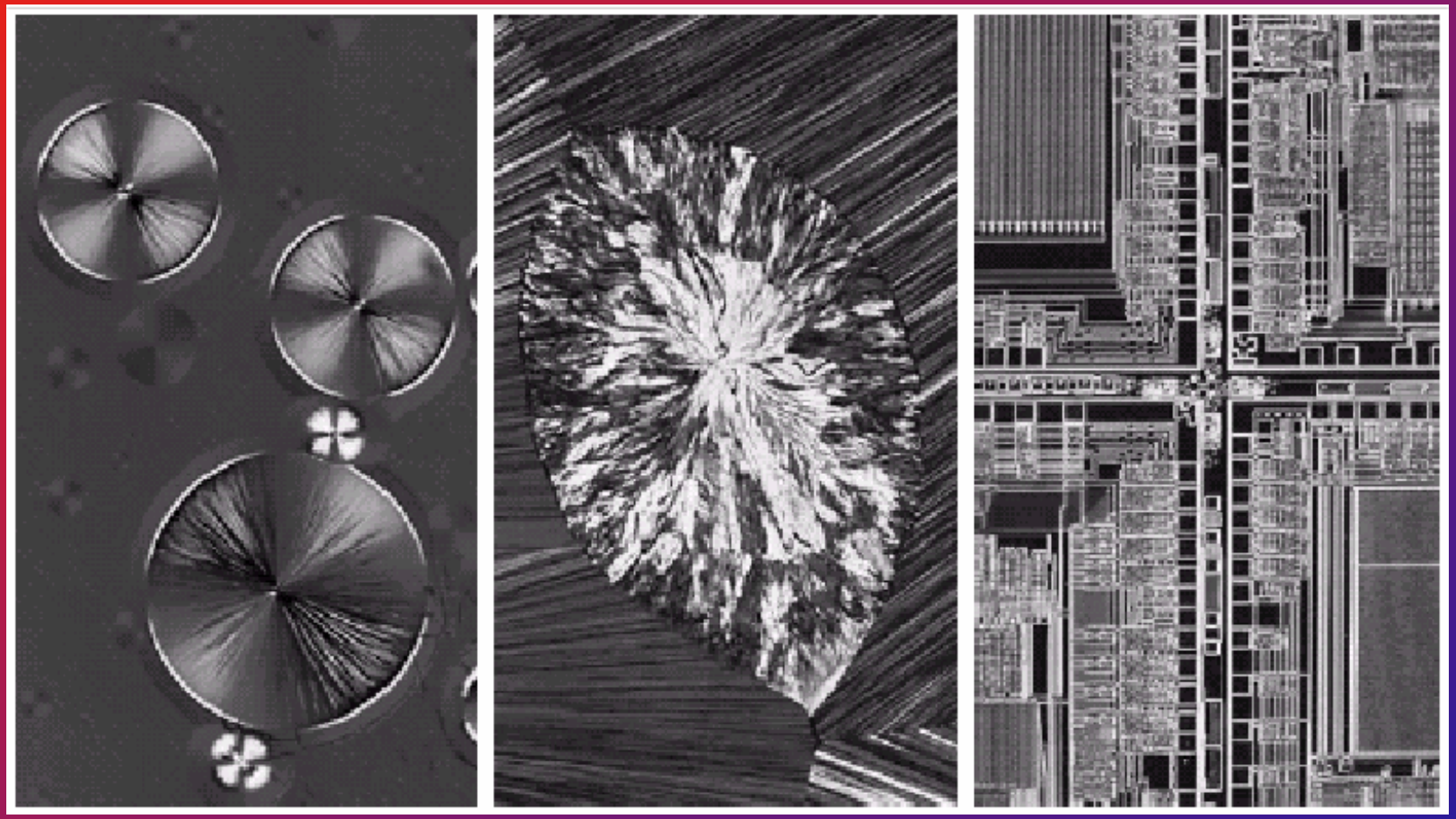
Visible (II): Motion Pictures

Visible (III): Biometrics and Forensics



You=ID

Visible (IV): Light Microscopy



Taxol (250㎛) Cholesterol (40㎛) Microprocessor (60㎛)

Visible (V): Remote Sensing

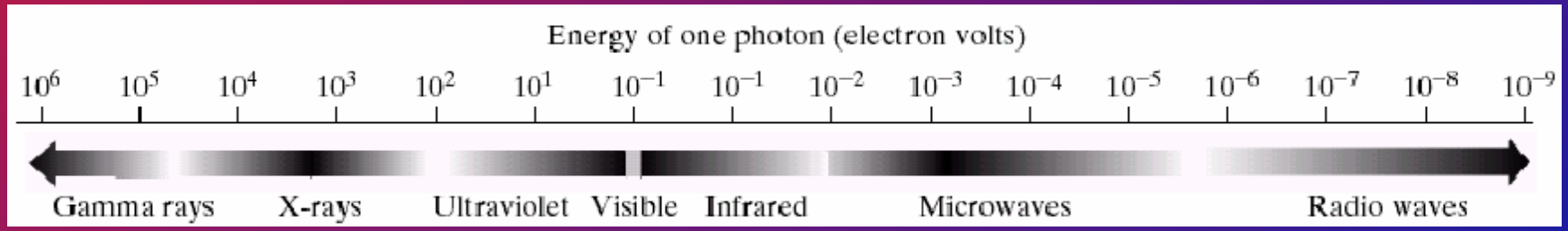
Earth at night (Only Asia/Europe shown)

Beyond Visible (I): Thermal Images

Operate in infrared frequency

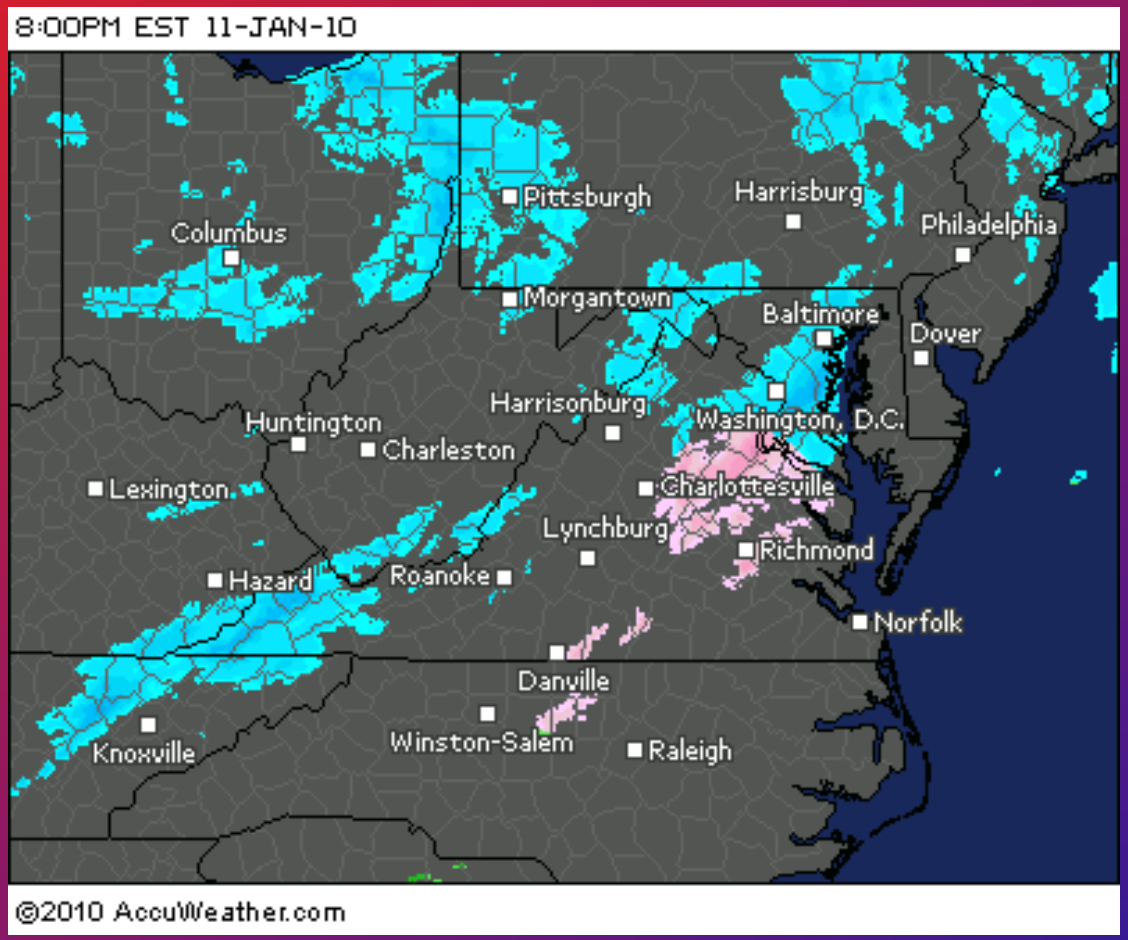
Human body disperses heat (red pixels)

Autoliv's night vision system on the BMW 7 series

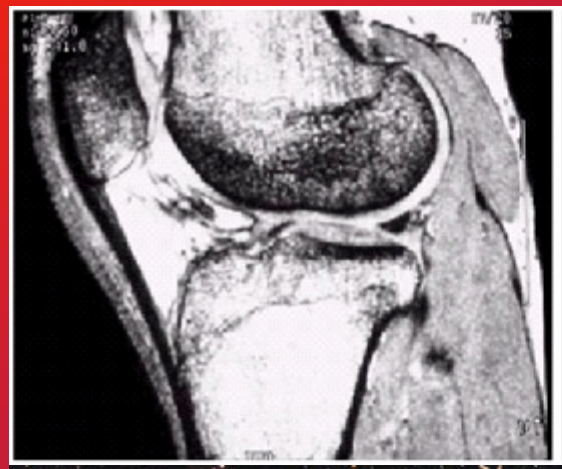


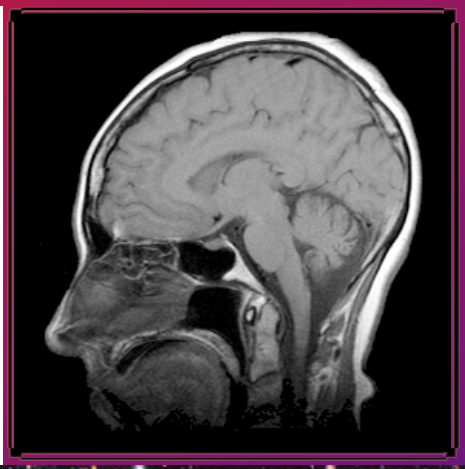
Beyond Visible (II): Radar Images

Operate in microwave frequency



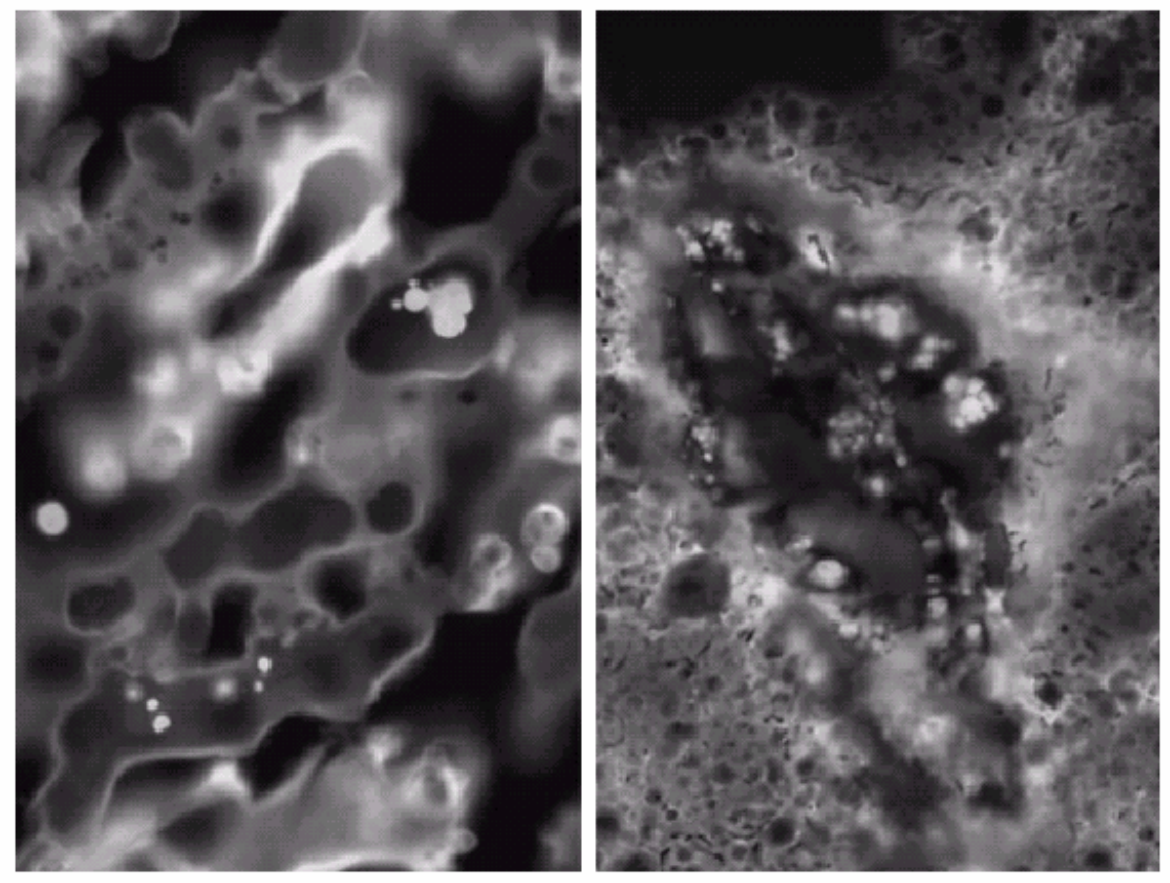
Beyond Visible (III): MRI and Astronomy





Beyond Visible (IV): Fluorescence Microscopy

Operate in ultraviolet frequency

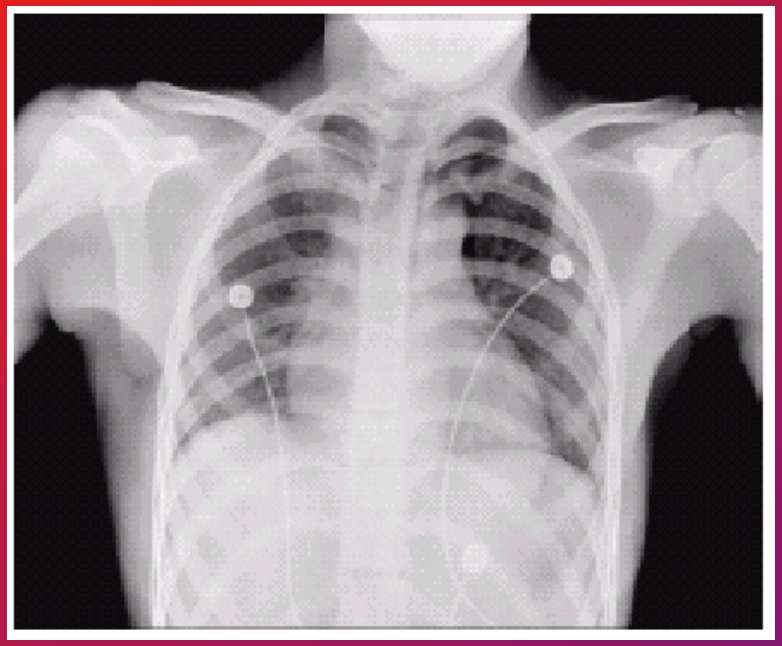


normal corn

smut corn

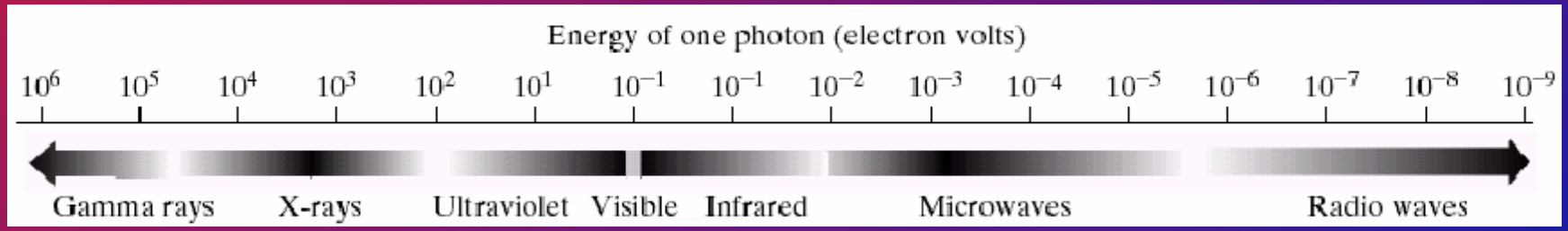
Beyond Visible (V): Medical Diagnostics

Operate in X-ray frequency



chest

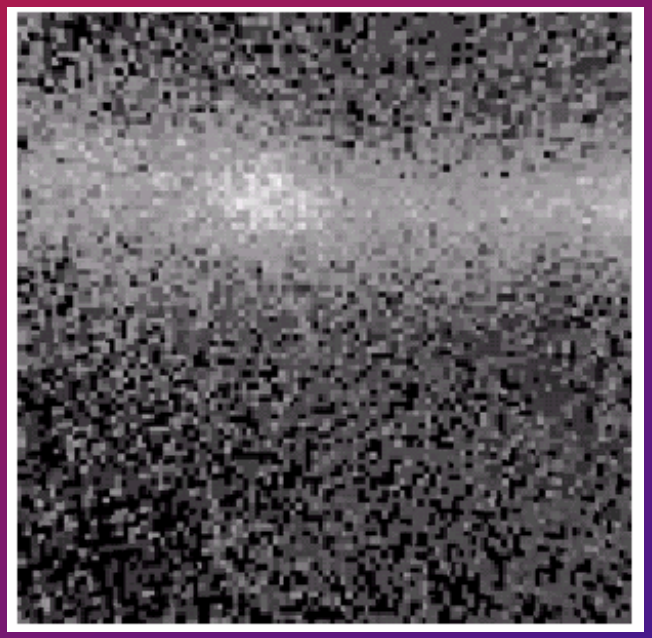
head



Beyond Visible (VI): PET and Astronomy

Operate in gamma-ray frequency

Positron Emission Tomography



Cygnus Loop in the constellation of Cygnus

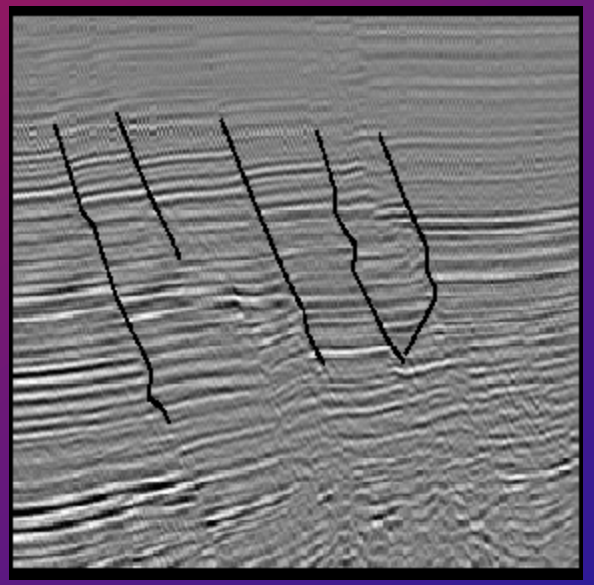
Other Non-Electro-Magnetic Imaging Modalities

- Acoustic imaging
  - Translate “sound waves” into image signals
- Electron microscopy
  - Shine a beam of electrons through a speciman
- Synthetic images in Computer Graphics
  - Computer generated (non-existent in the real world)

Acoustic Imaging

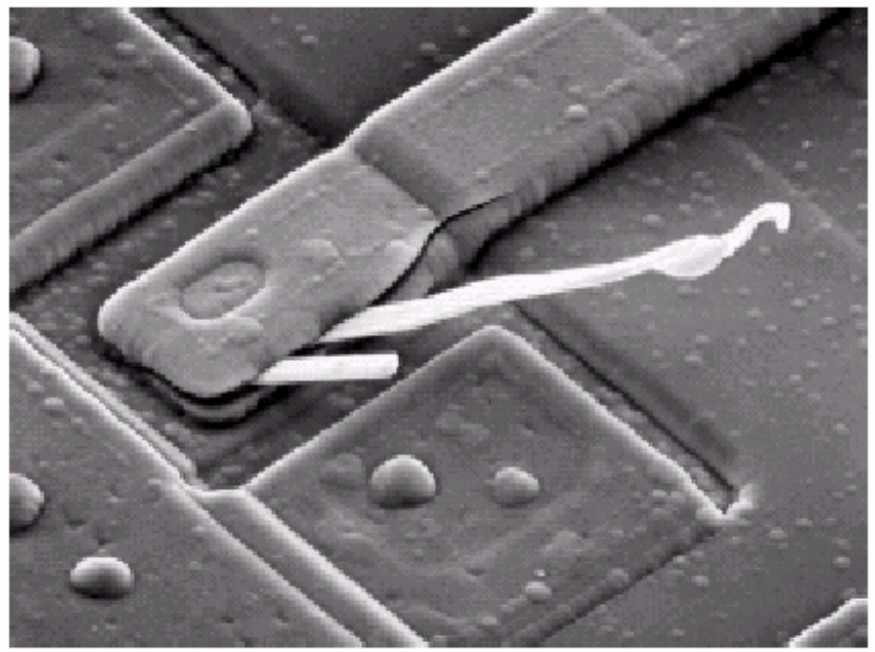
visible

seismic



potential locations of oil/g

Electron Microscope



2500× Scanning Electron Microscopy (SEM) image of damaged integrated circuit
(white fibers are oxides resulting from thermal destruction)

Cartoon Pictures (Non-photorealistic)

Hayao Miyazaki’ 2008

Synthetic Images in Gaming

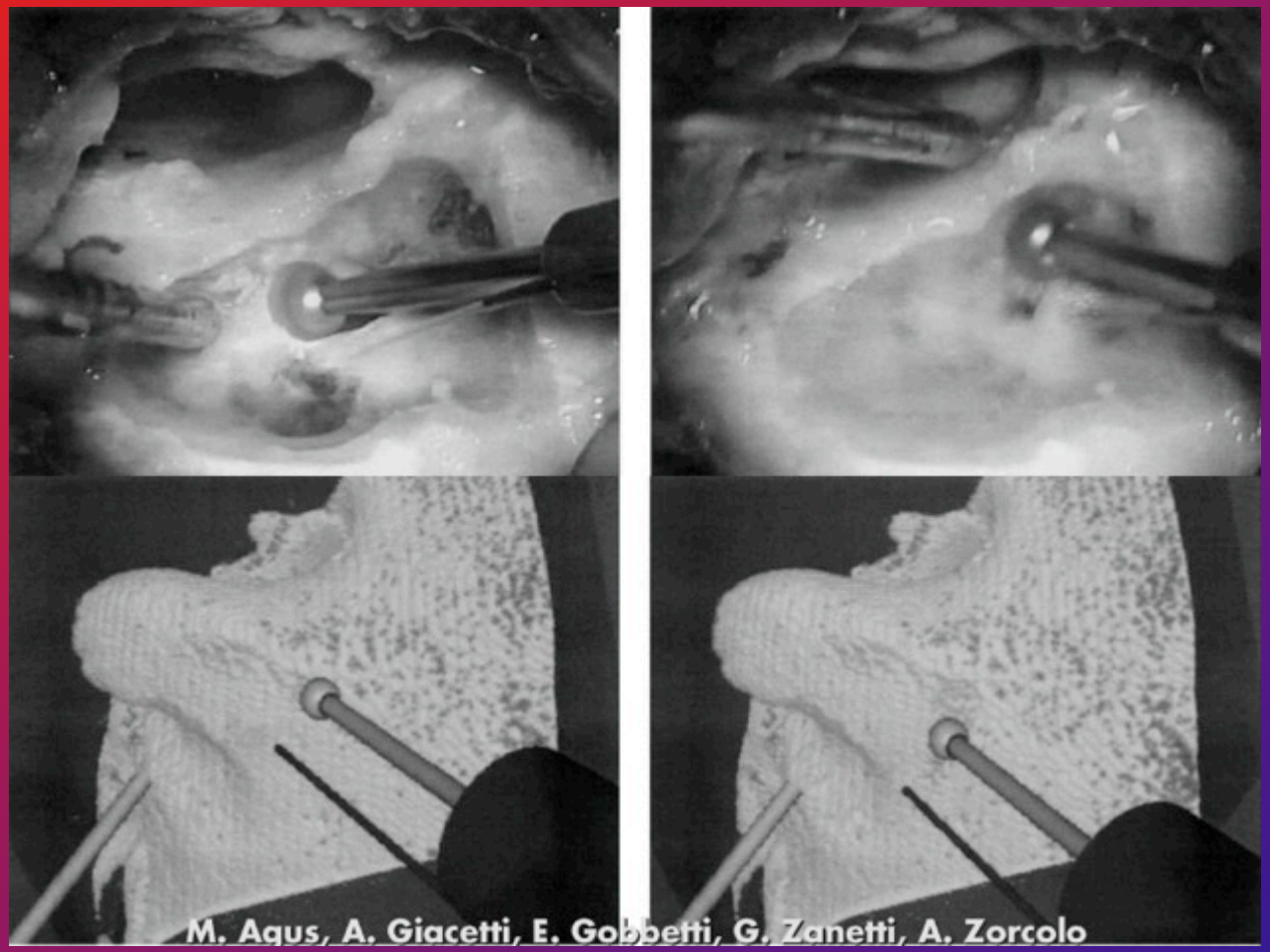
Warcraft III by Blizzard

Virtual Reality (Photorealistic)

Graphics in Art

Discovered by Denis Zorin

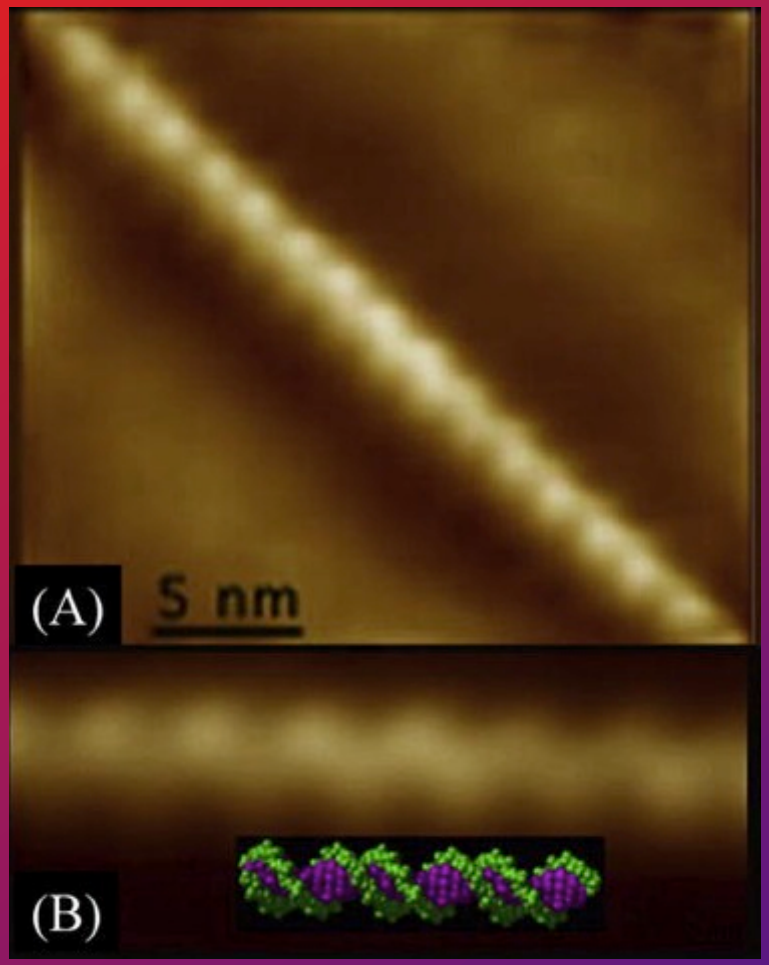
Graphics in Medicine



Mixture of Graphics and Photos

Morgantown, WV in Google Map

Toward the Future: Nano-scale Imaging



New imaging technology that can reveal fine structures at the nano scale is going to be useful In biology (e.g., protein sequencing and folding)

Tour Guide

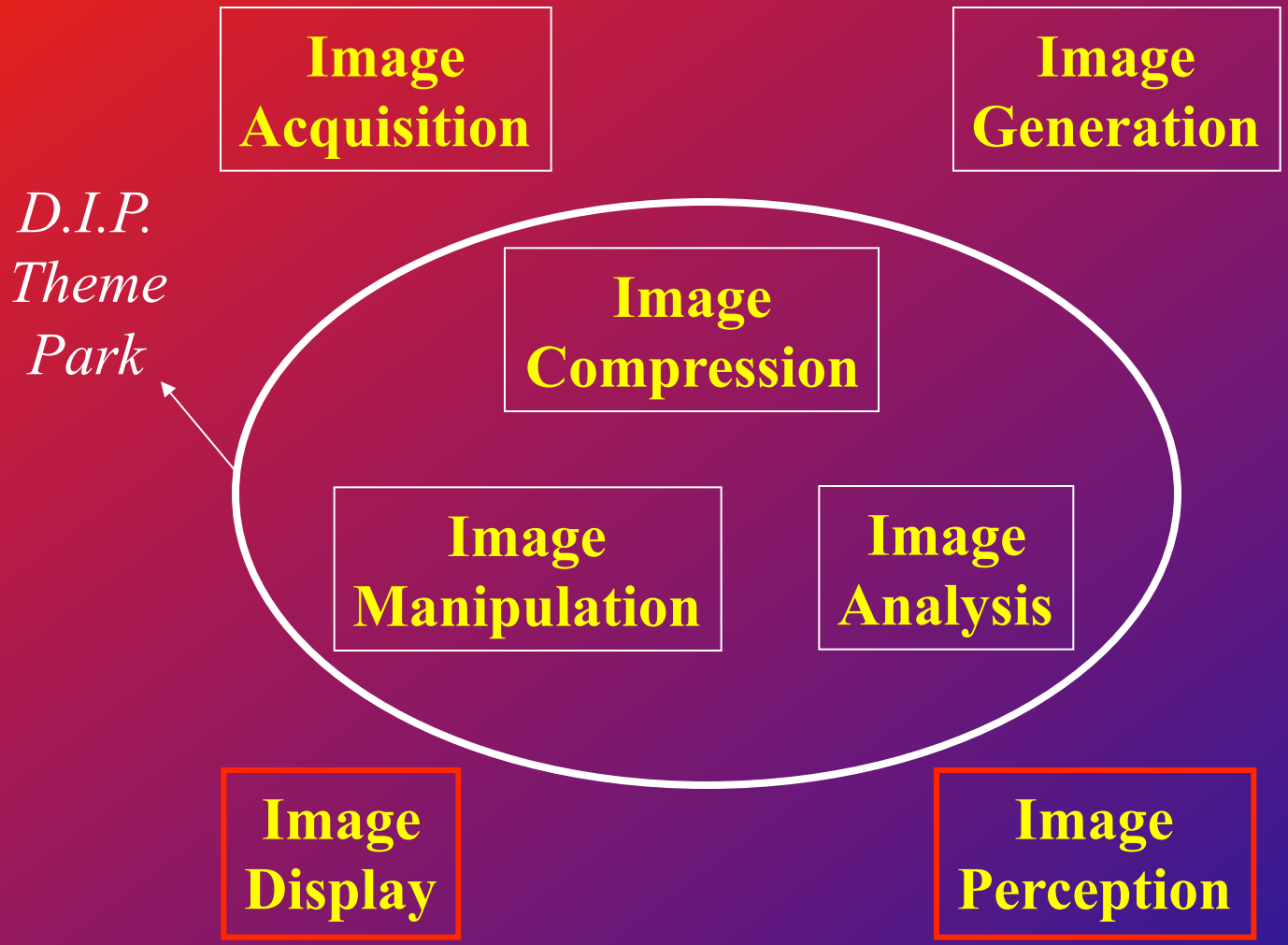


Image Acquisition
Image Generation
D.I.P. Theme Park
Image Compression
Image Manipulation
Image Analysis
Image Display
Image Perception

Image Display and Perception

- Display
  - CRT, LCD, DLP, Plasma, LCOS, D-ILA
  - HDTV, display wall
  - PDA, cellular phone, Gameboy
  - Stereoscopic (3D)
- Perception
  - Human Vision System (HVS)
  - Vision-related diseases and healthcare

CRT: Cathode Ray Tube

Mitsubishi WS-55813
Rear Projection CRT

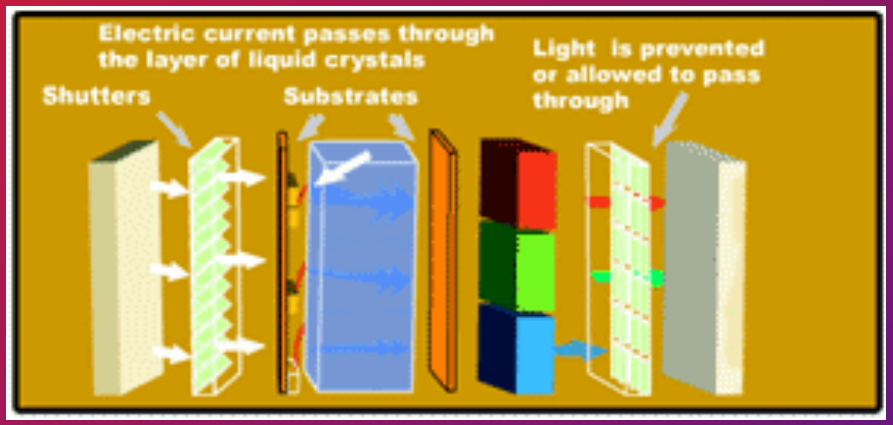
Sony KV34XBR910
Direct View CRT

CRT Direct View/Rear Projection Advantages	CRT Direct View/Rear Projection Disadvantages
• Among the brightest and clearest alternatives • Excellent color and contrast potential • Relatively inexpensive • Excellent life expectancy	• Heavy • Very deep • Analogue connectivity or D/A conversion of digital input connections • Potential for screen burn-in

Future: extinction

LCD: Liquid Crystal Display

Philips 42FD9954 Flat Screen LCD Display



Future: bigger, faster, cheaper

LCD Display Advantages	LCD Display Disadvantages
• Good color reproduction • Very thin • Lightweight • Perfect sharpness at native resolution • Excellent longevity • No screen burn-in effect	• Fixed resolution • Notorious "screen door" effect on lesser models • Poor contrast ratios (even excellent units have only 700:1) • Very difficult to produce deep blacks (see above) • Weak and "stuck" pixels are common • Viewing angle on older models may be narrow • Potential for slower refresh rates than plasma (some newer models are getting better)

Virtual Wall

NASA Space Shuttle on the display wall, March 1999

Display on Mobile Devices

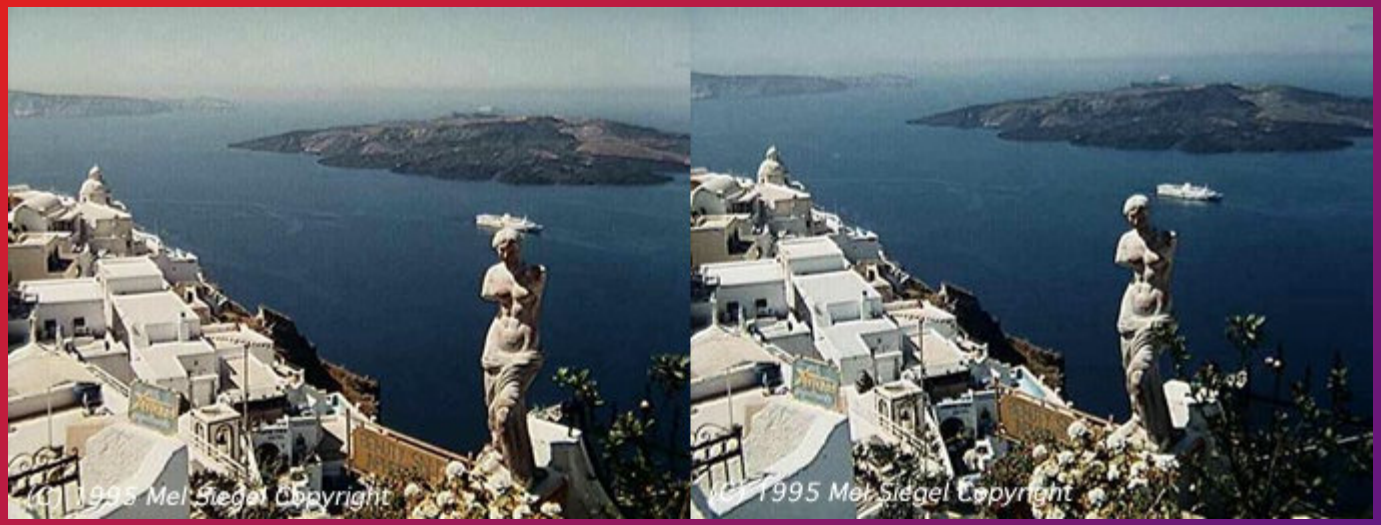
cell phone

Gameboy

portable DVD

PDA

3D Display

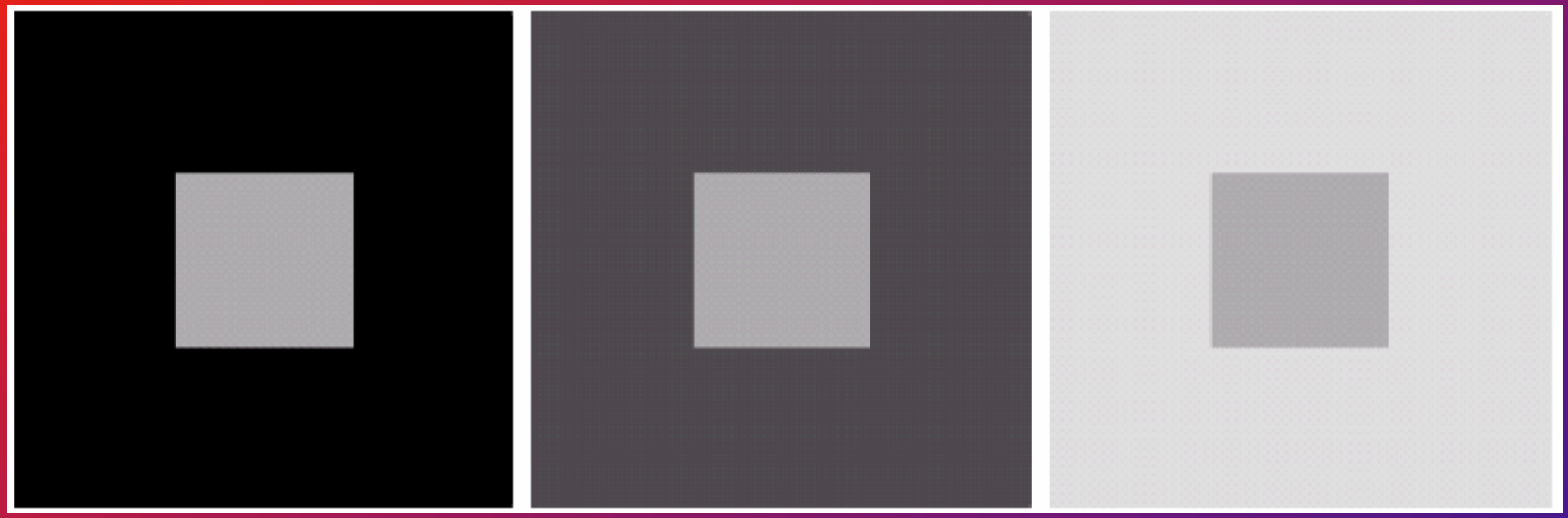


The Ultimate Display: Virtual Retinal Display

Optical Illusion

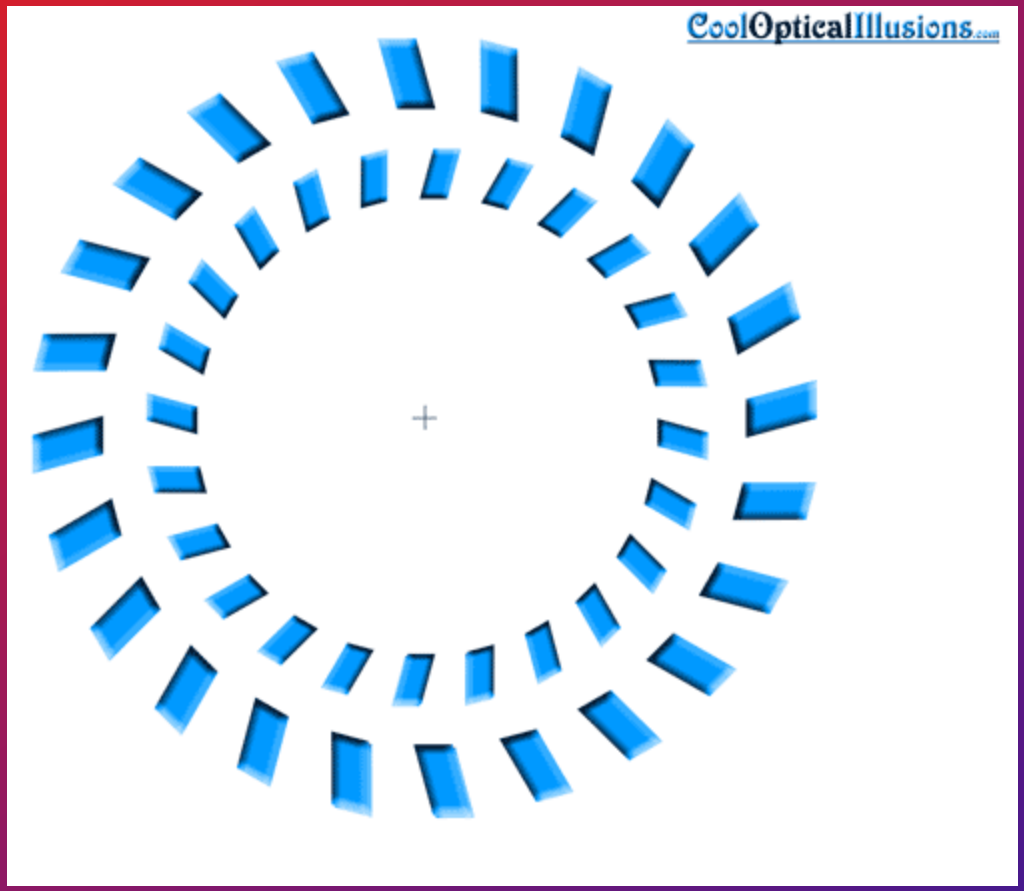
In image analysis, you will see why you need to know about neuroscience and psychology

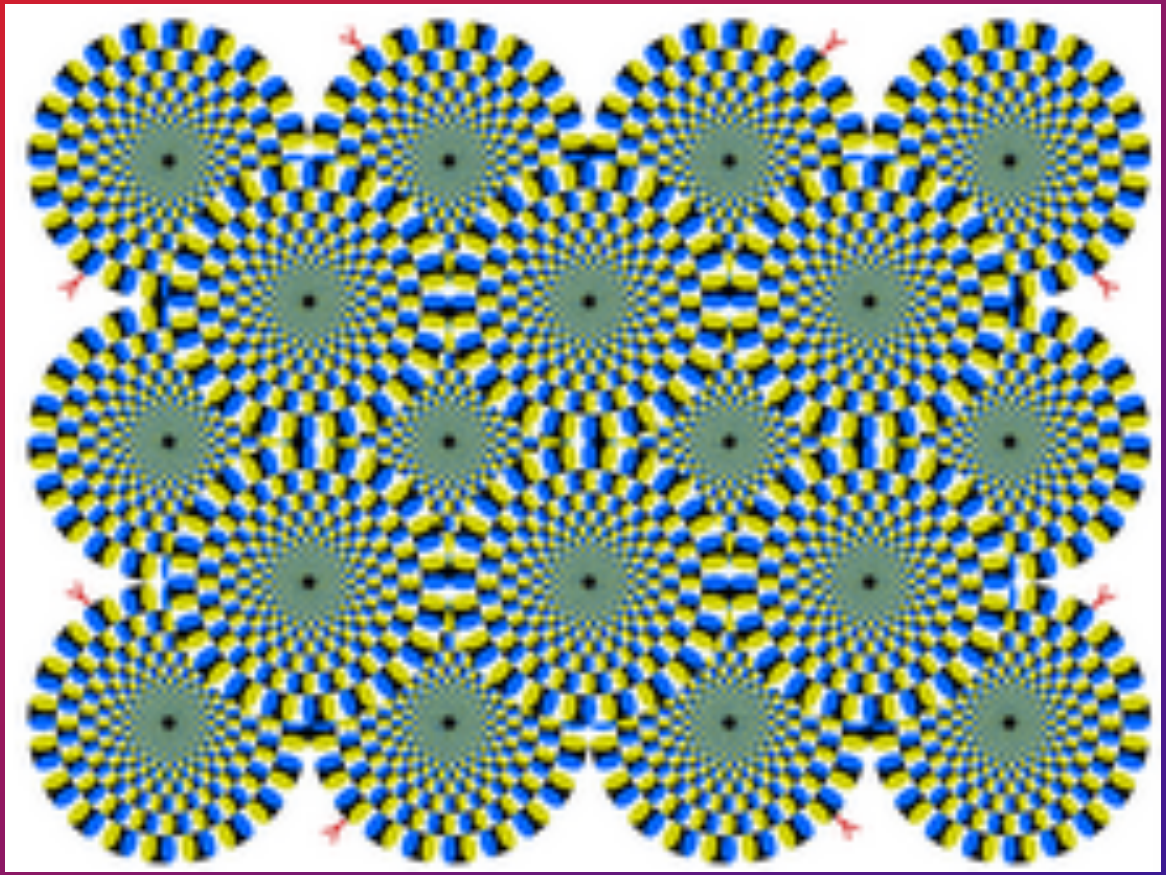
Human Vision System

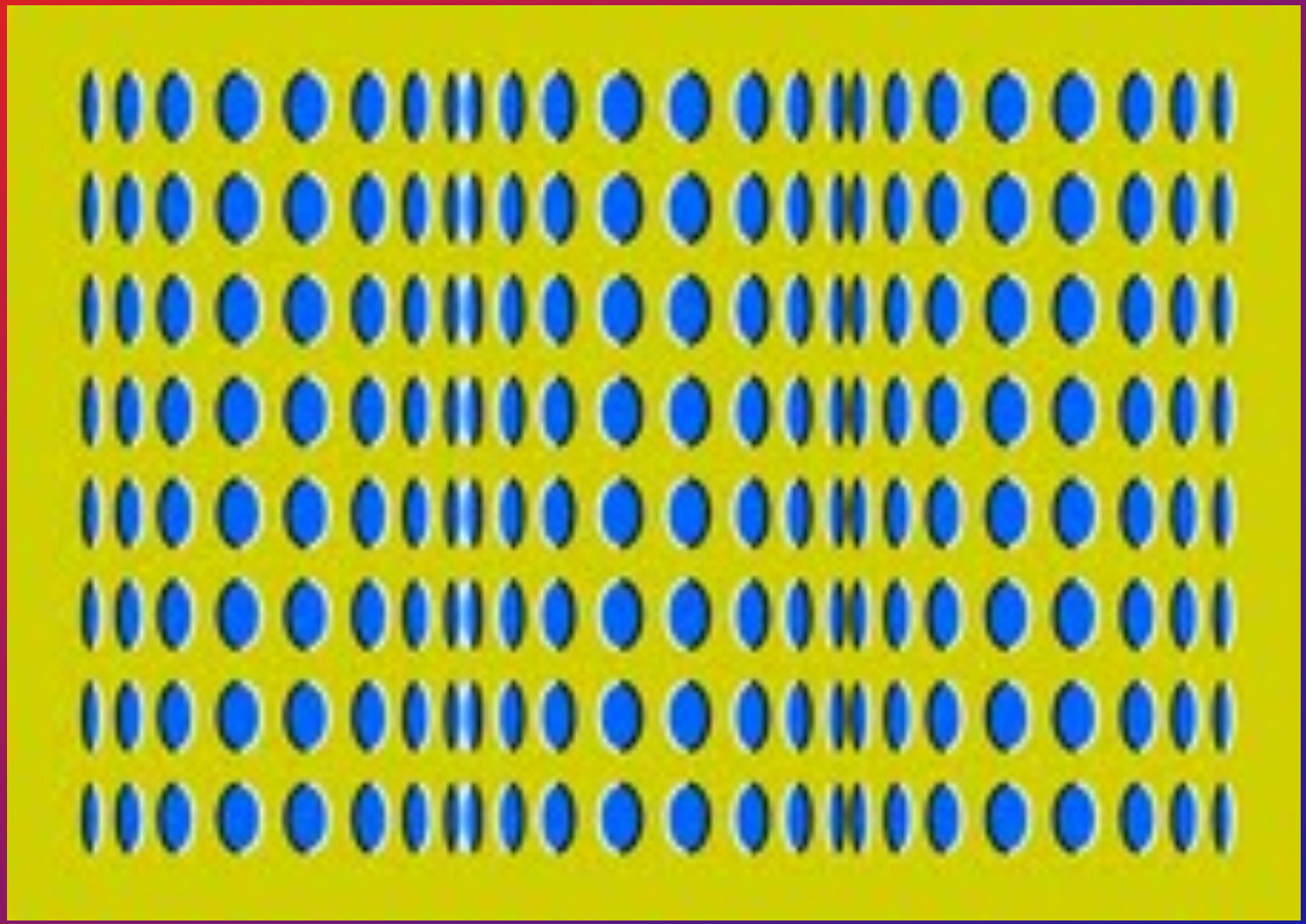


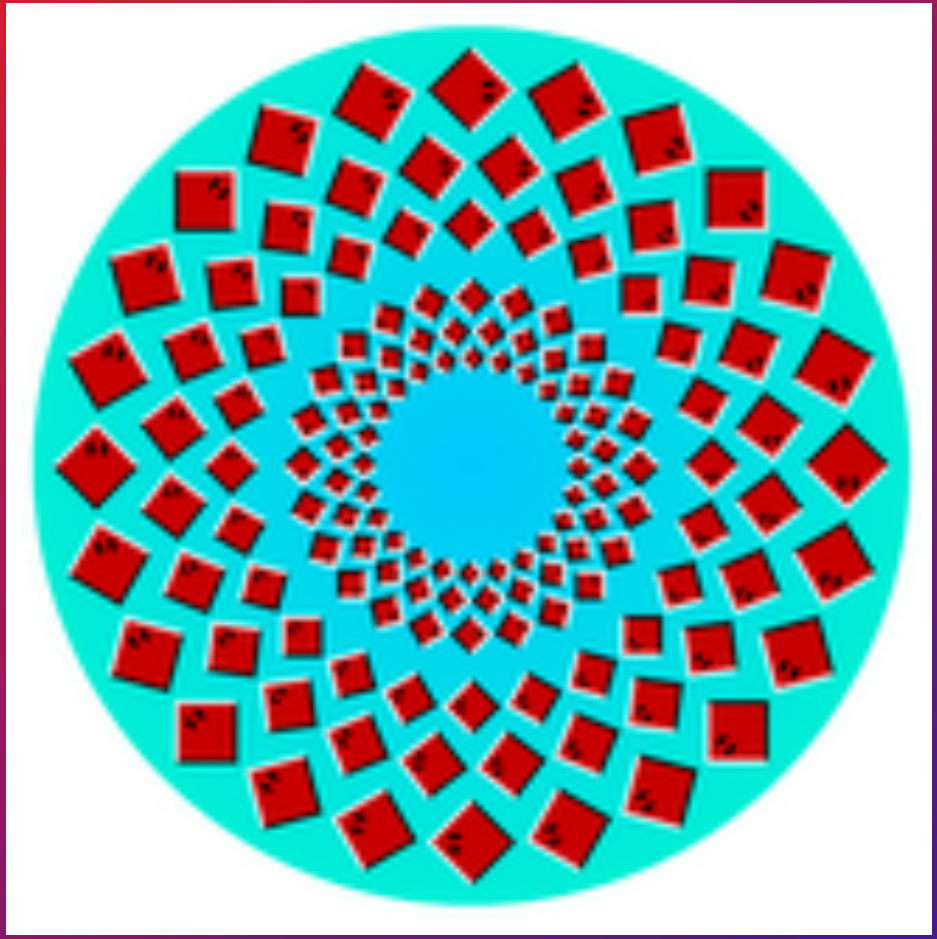
Simultaneous contrast

Fascinating Optical Illusions



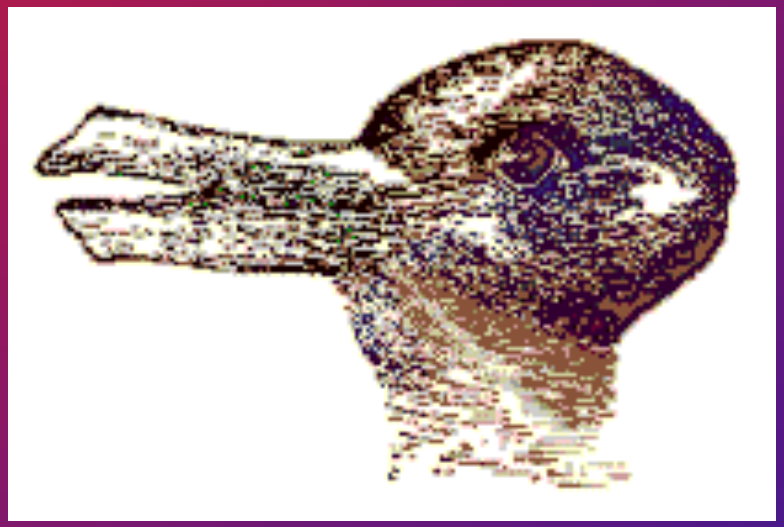




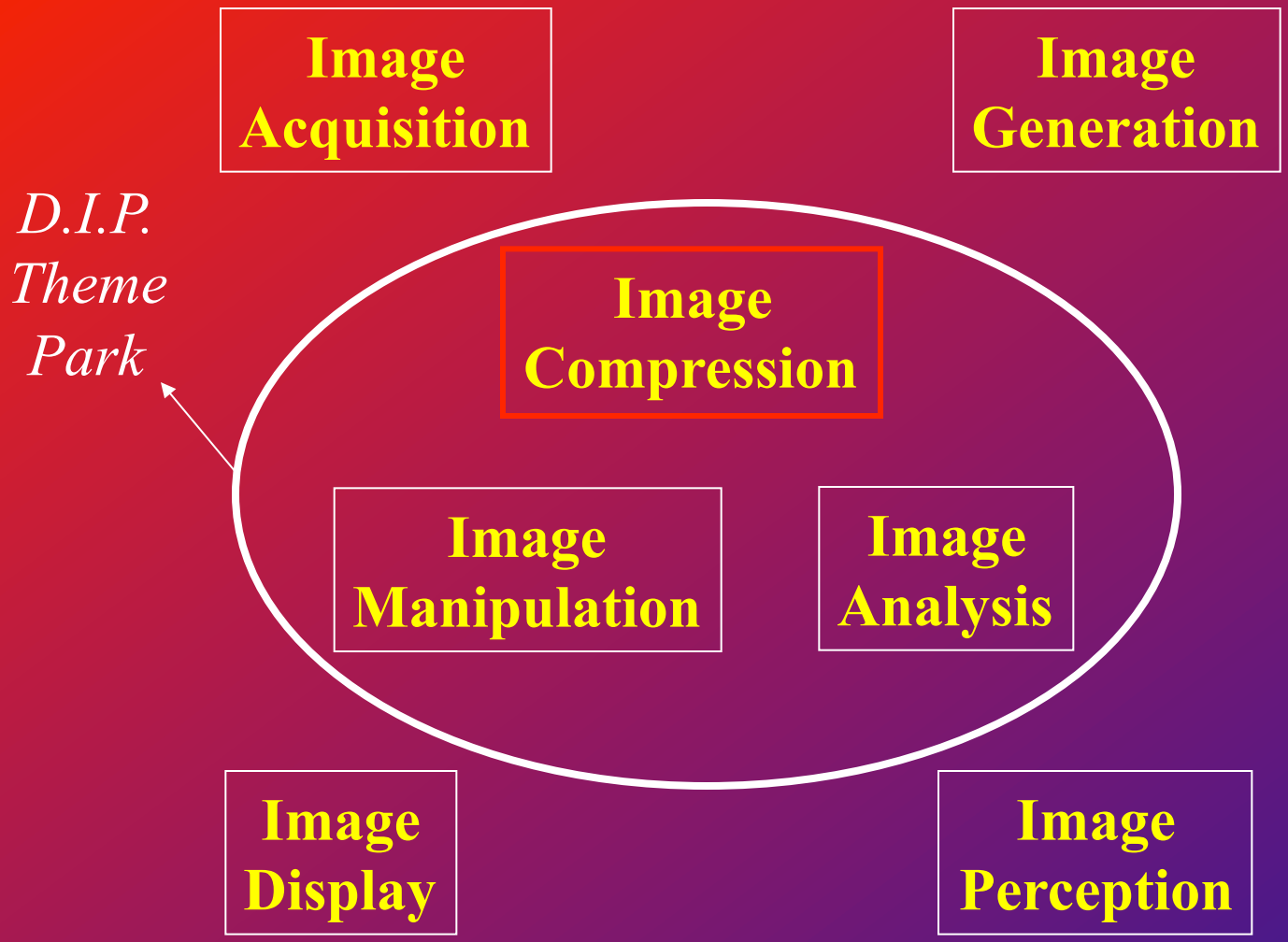


Interpretation Ambiguity

Is it seal or donkey?



Is it duck or hare?



DIP is also about connecting dots – in image compression, will see why you need to learn matrix theory and statistics

Compression
Manipulation
Analysis

- Compression
  - Image data need to be accessed at a different time or location
  - Limited storage space and transmission bandwidth
- Manipulation
  - Image data might experience nonideal acquisition, transmission or display (e.g., restoration, enhancement and interpolation)
  - Image data might contain sensitive content (e.g., fight against piracy, conterfeit and forgery)
  - To produce images with artistic effect (e.g., pointellism)
- Analysis
  - Image data need to be analyzed automatically in order to reduce the burden of human operators
  - To teach a computer to "see" in A.I. tasks

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

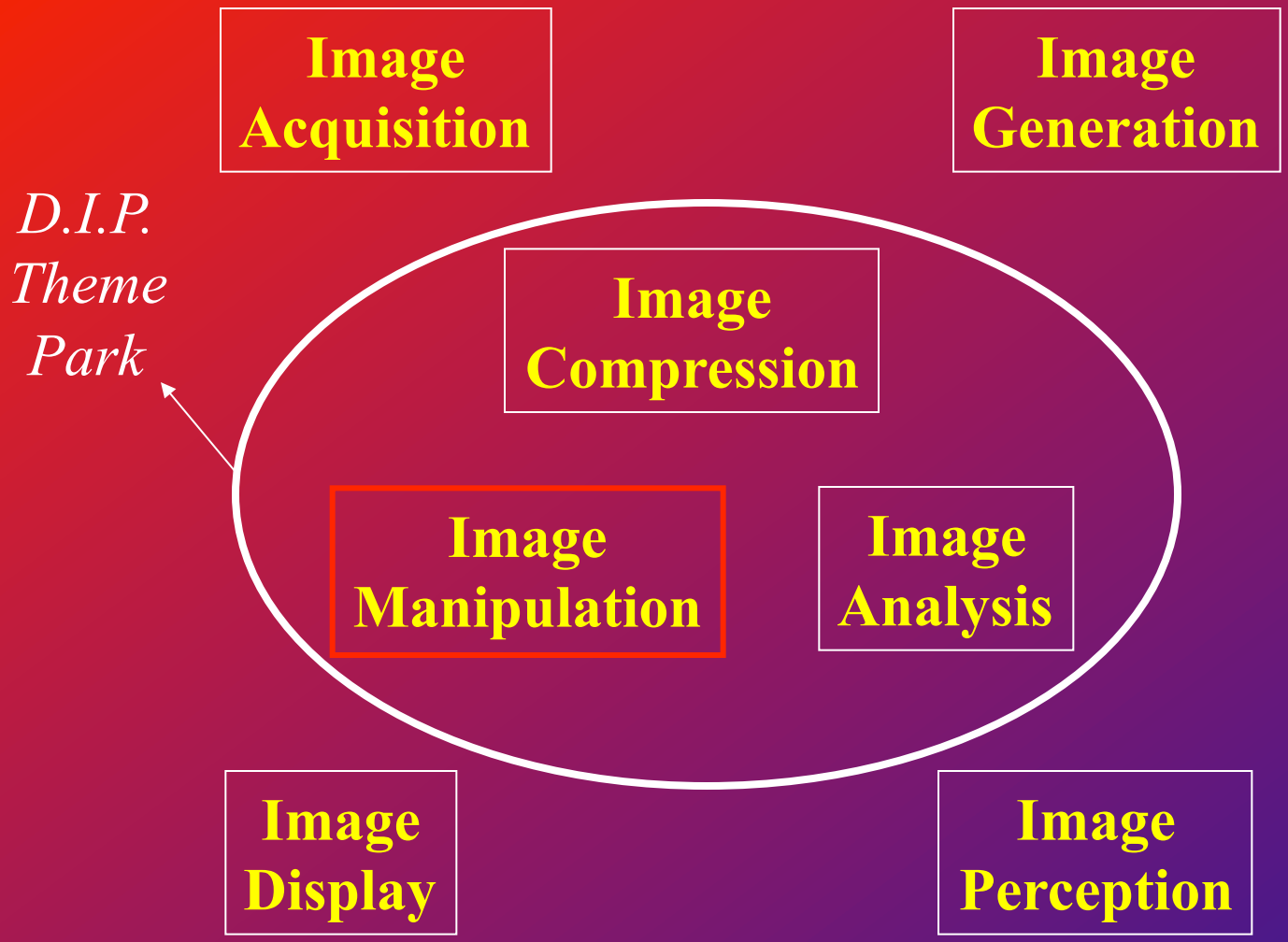
From JPEG to JPEG2000

discrete cosine transform based

JPEG (CR=64)

wavelet transform based

JPEG2000 (CR=64)



DIP is also about connecting dots – in image manipulation, will see why you need to learn calculus and Fourier transfor

Image Manipulation (I): 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 w

- Lena is contaminated with periodic noise

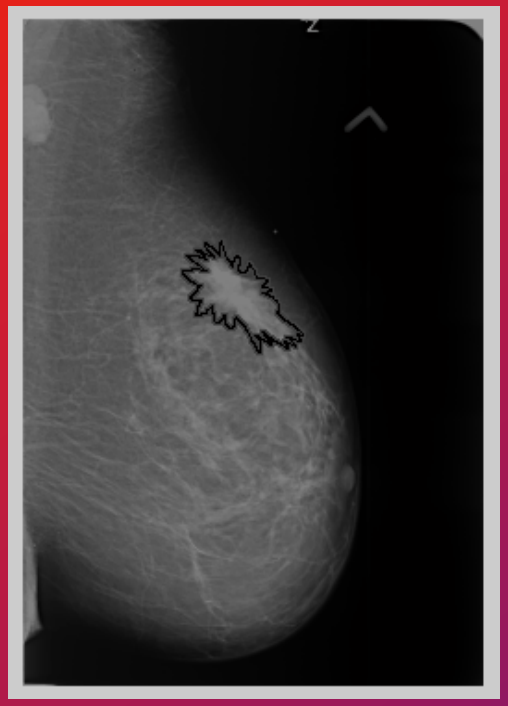
High-Pass Filter:(Butterworth Type)

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

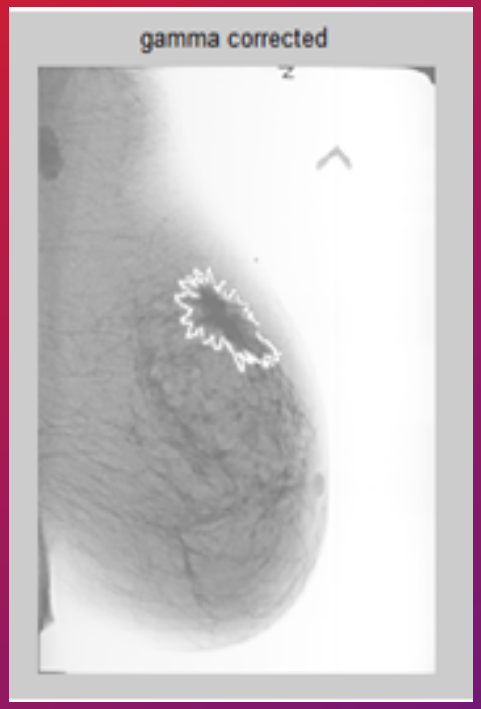
Low-Pass Filter:(Butterworth Type)

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

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:

$$s = cr^{\gamma}$$

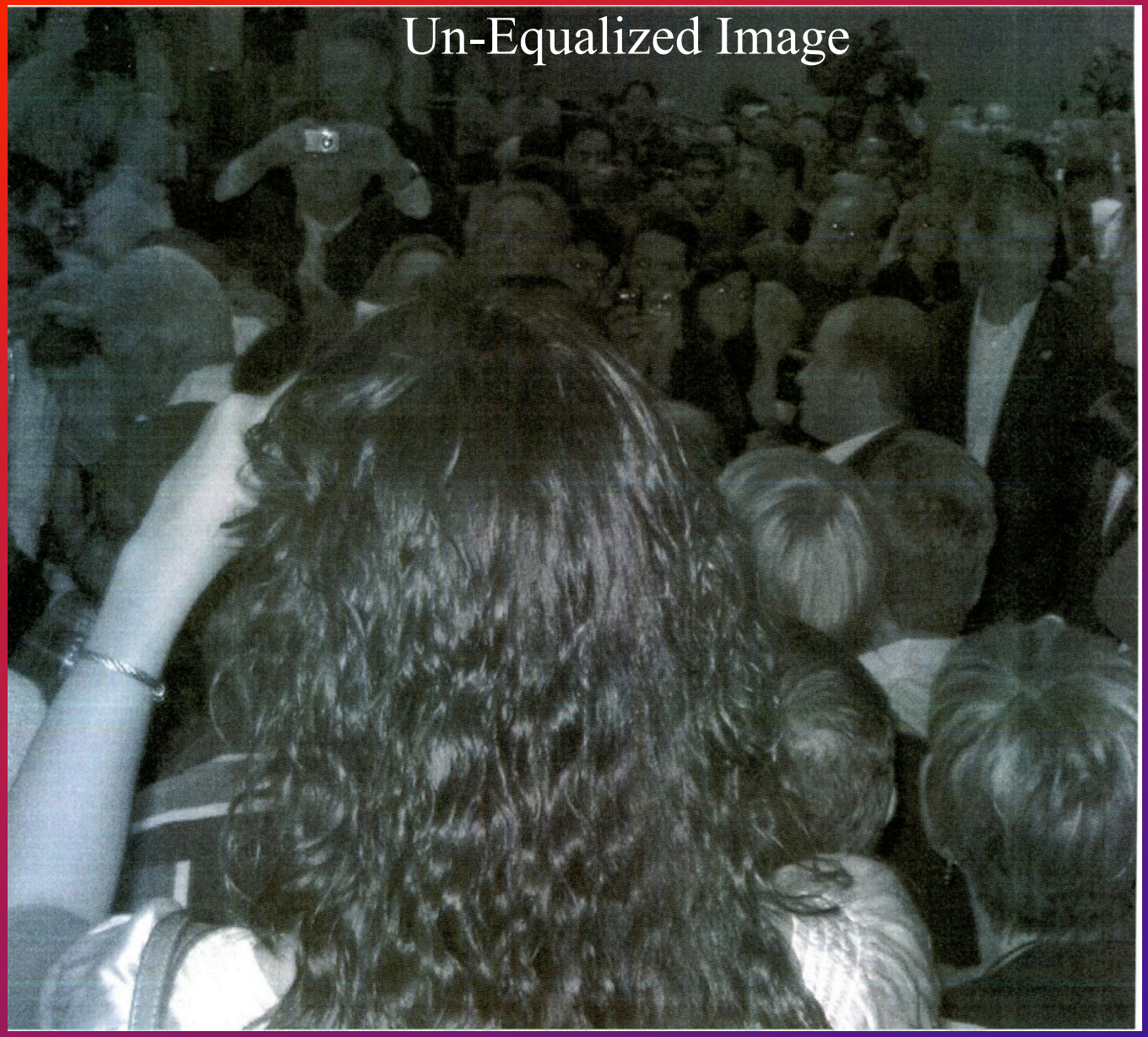
- If gamma <1, mapping weighted towards brighter (enhanced) and gamma>1, weighted towards darker (de enhanced).

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.

Un-Equalized Image



Equalized Image

Un-Equalized Image

Equalization

Equalized Image

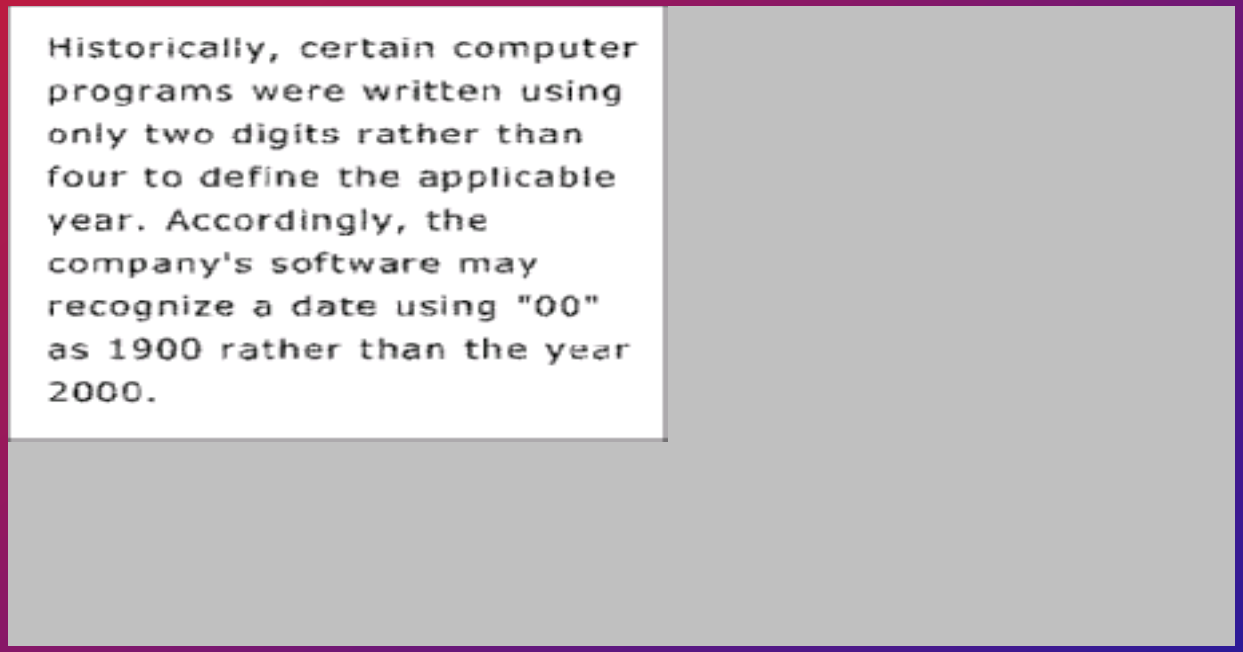
Image Manipulation (II): Deblurring

License plate is barely legible due to motion blurring

This can be deblurred using Wiener Filter

Low Pass Filtering: Document Processing

- Sample Text



Smoothing Text Using Gaussian Filter

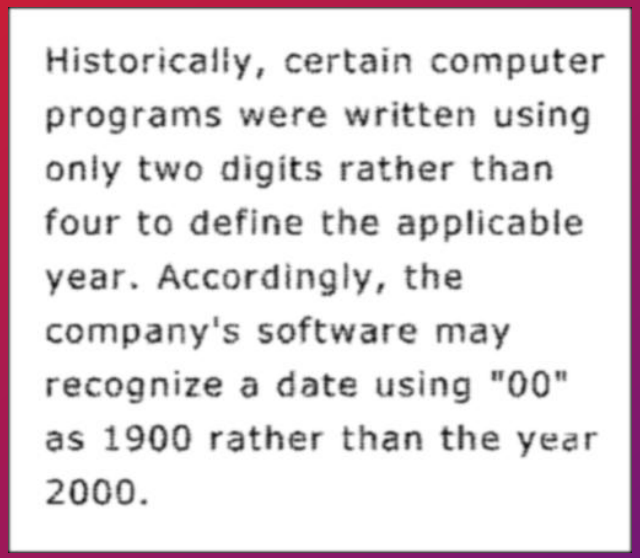
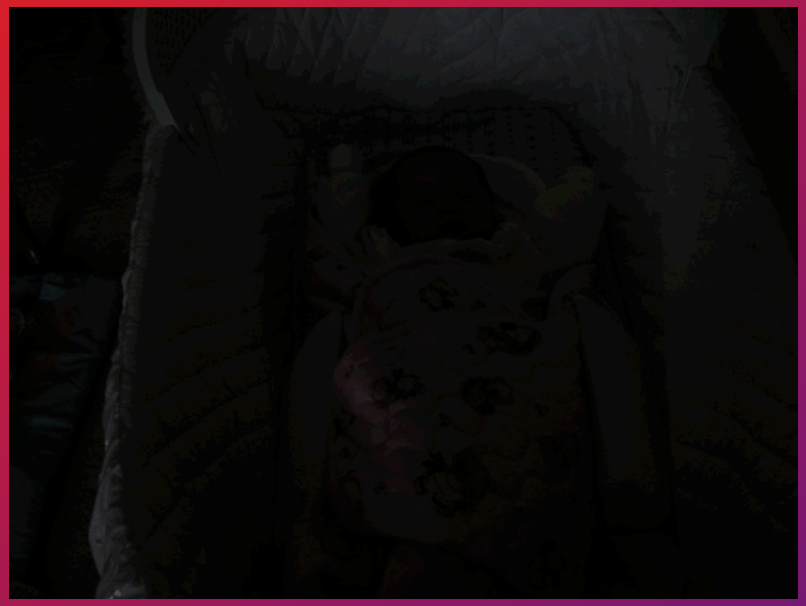
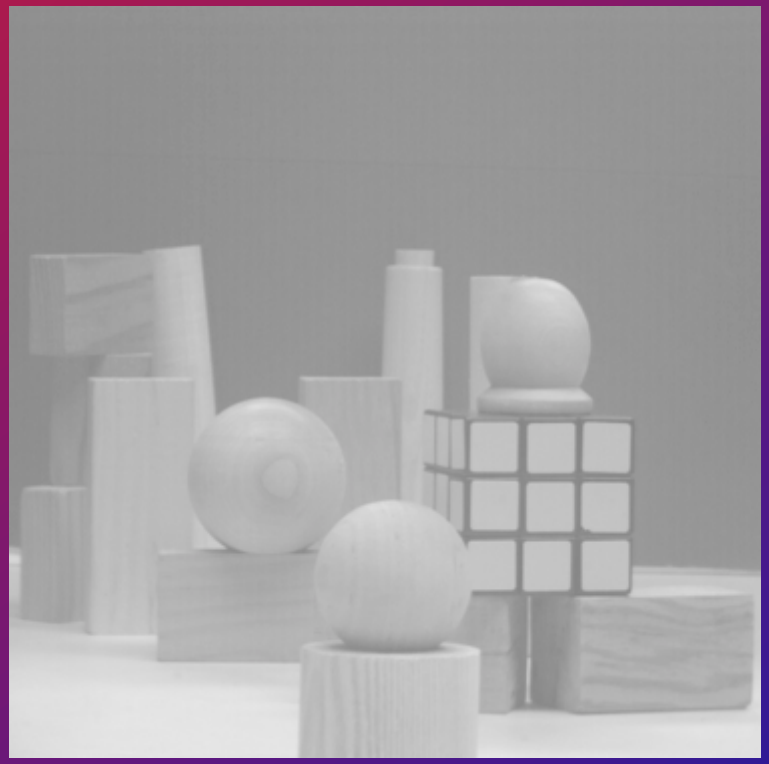


Image Manipulation (III): Contrast Enhancement



under-exposed image



overly-exposed image

You will learn how to modify the histogram of an image

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

Image Inpainting Application: Restore Old Photos

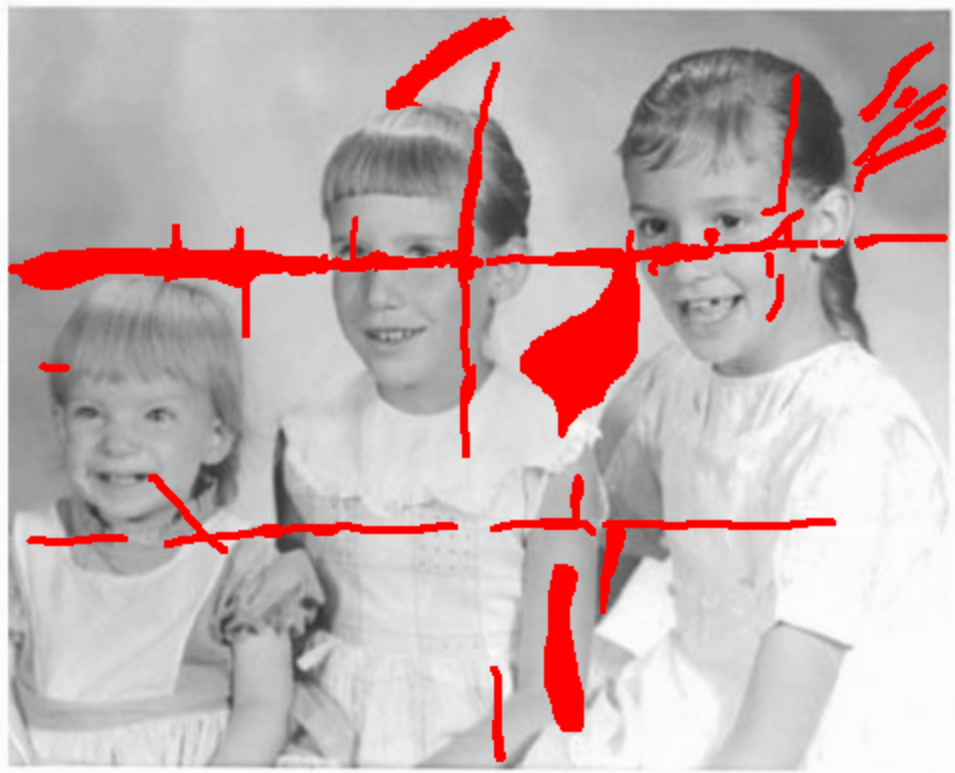


Image Manipulation (XI): Color Quantization

25,680 colors (24 bits)

256 colors (8 bits)

Applications: video cell-phone, gameboy, portable DVD

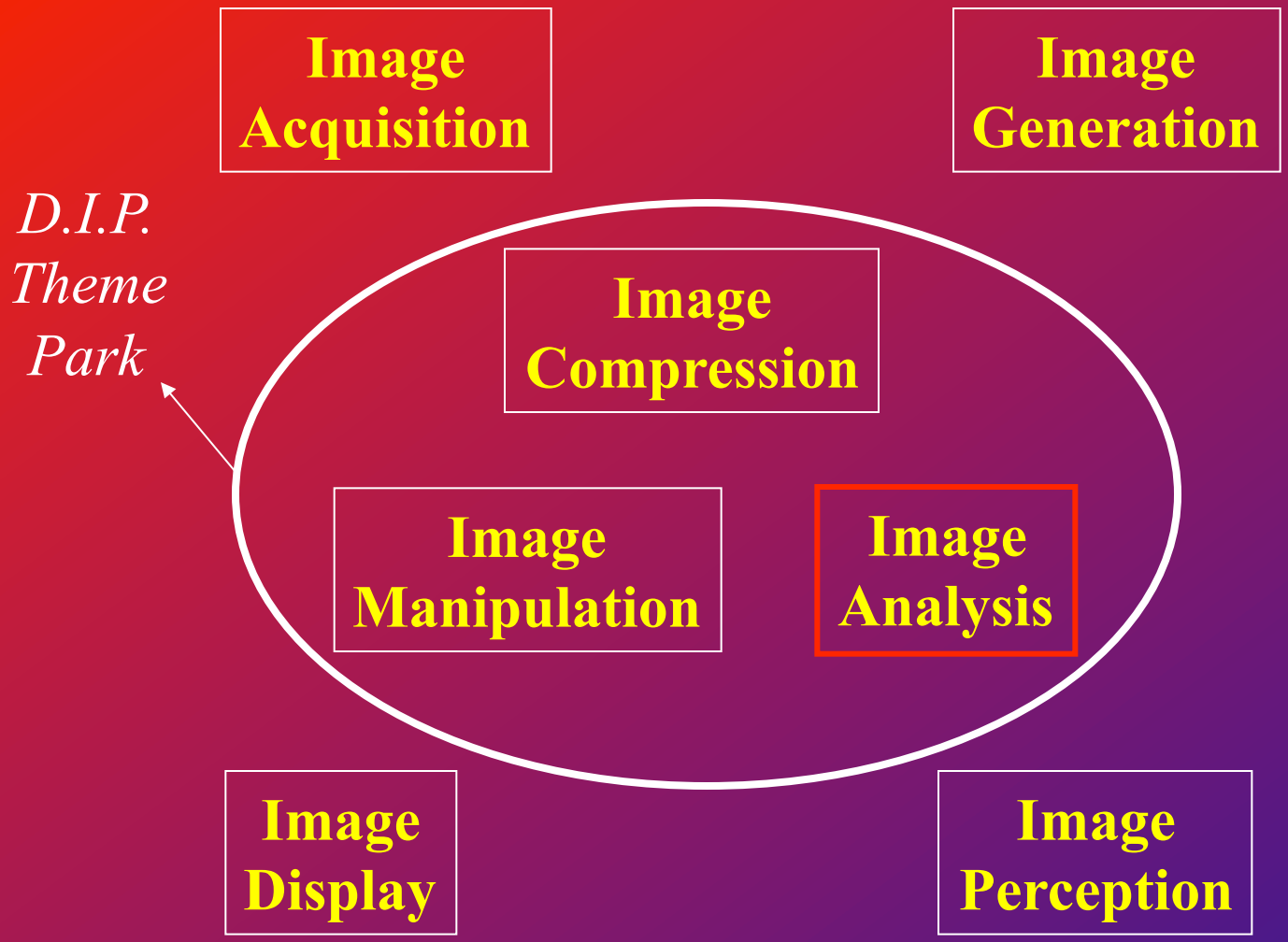


Image Acquisition
Image Generation
D.I.P. Theme Park
Image Compression
Image Manipulation
Image Analysis
Image Display
Image Perception

Region Detection, Segmentation

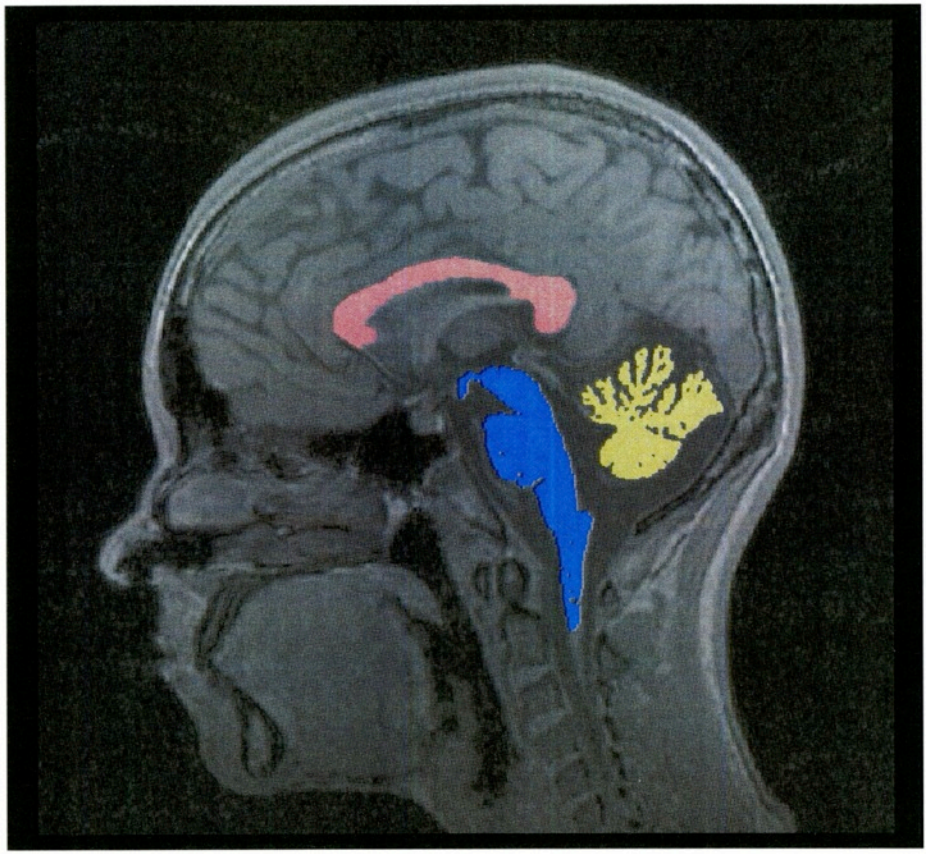
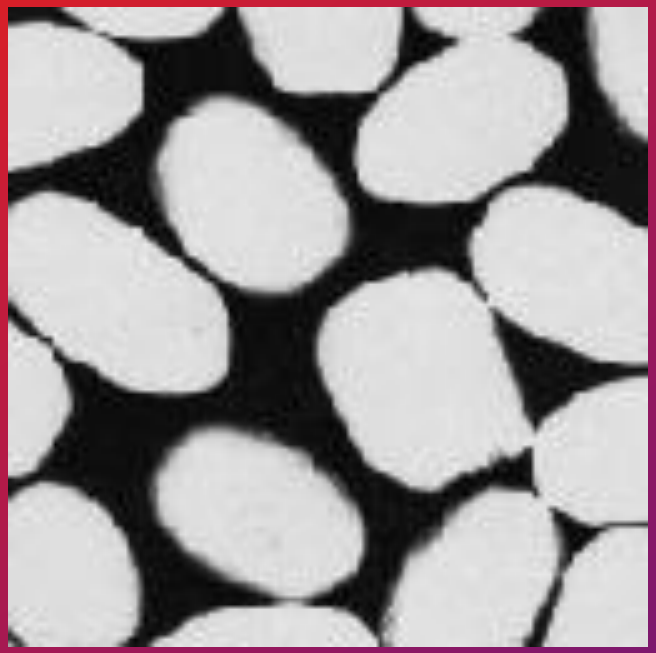
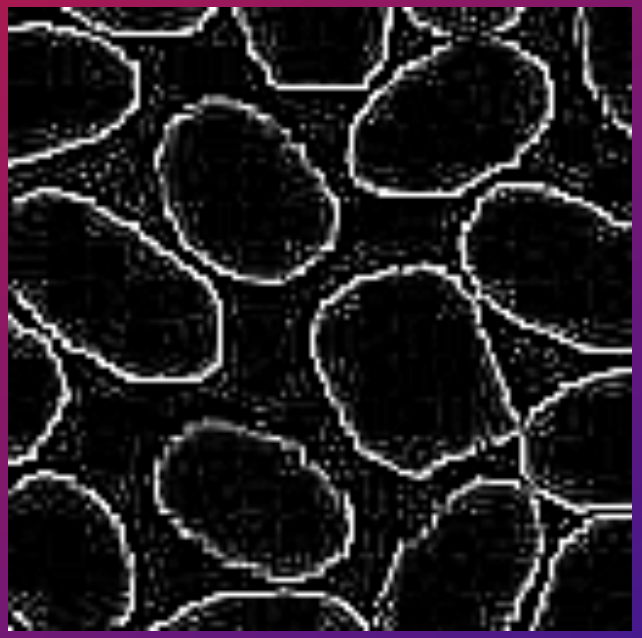


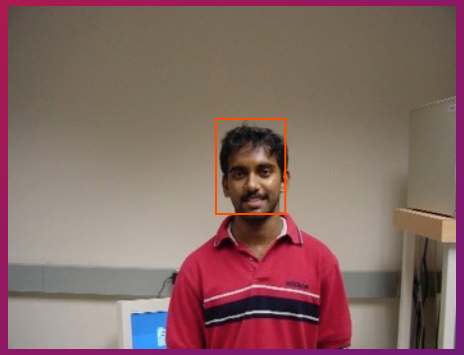
Image Analysis (I): Edge Detection





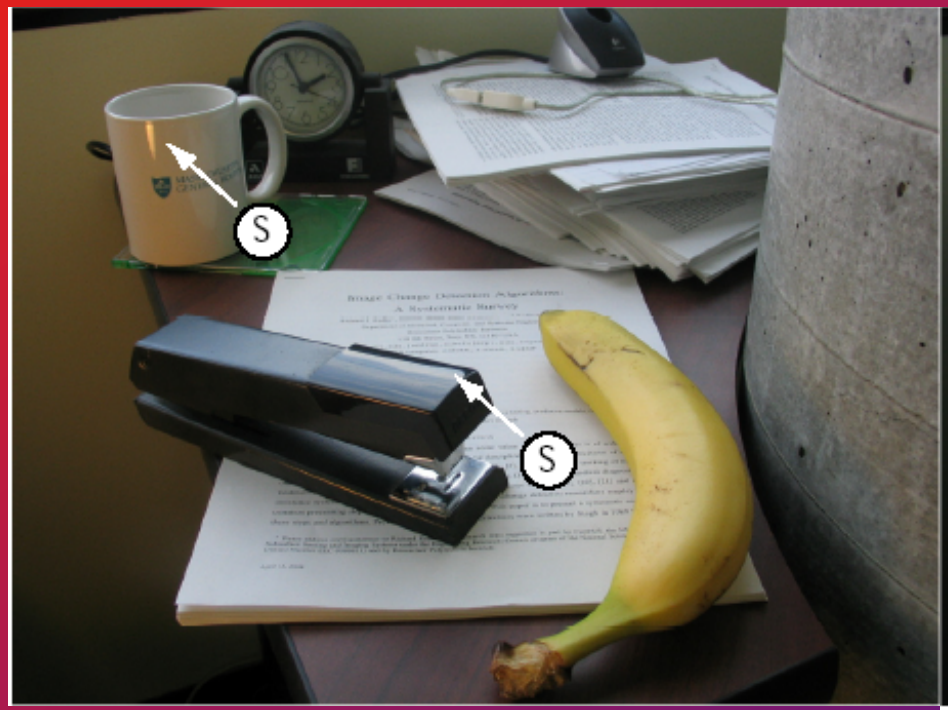
You will learn basic edge detectors based on derivatives

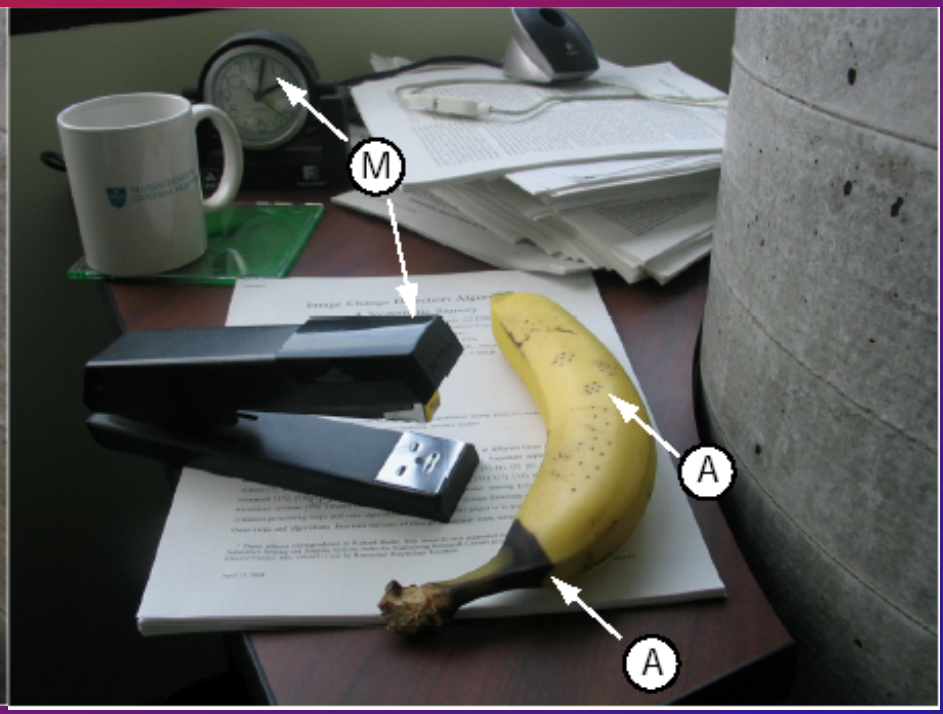
Image Analysis (II): Face Detection



Deceivingly simple for humans but notoriously difficult for machines

Image Analysis (III): Change Detection





Change Detection in Medical Application

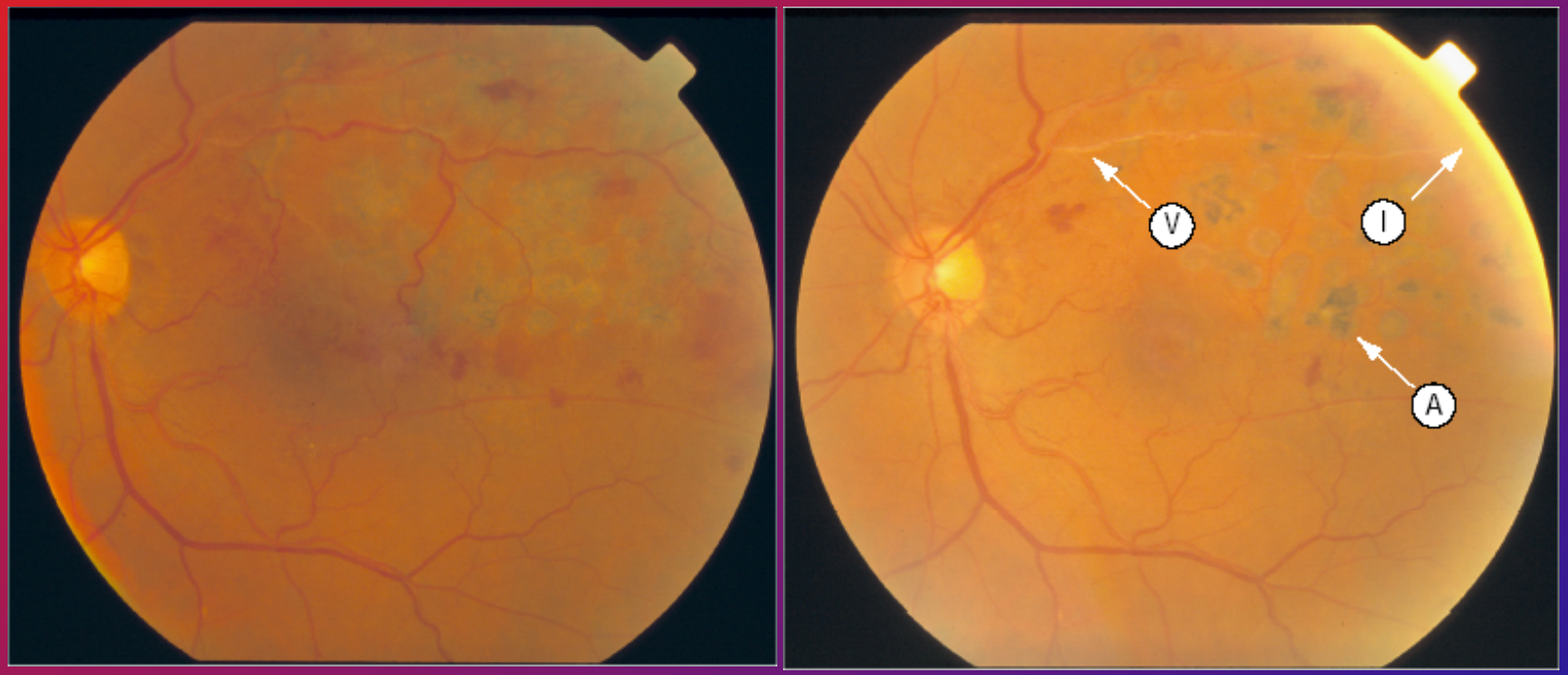
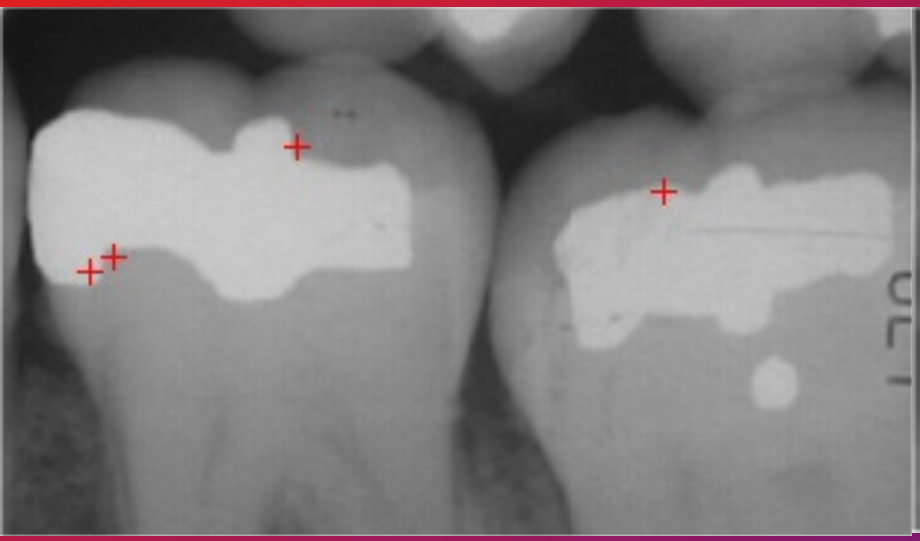
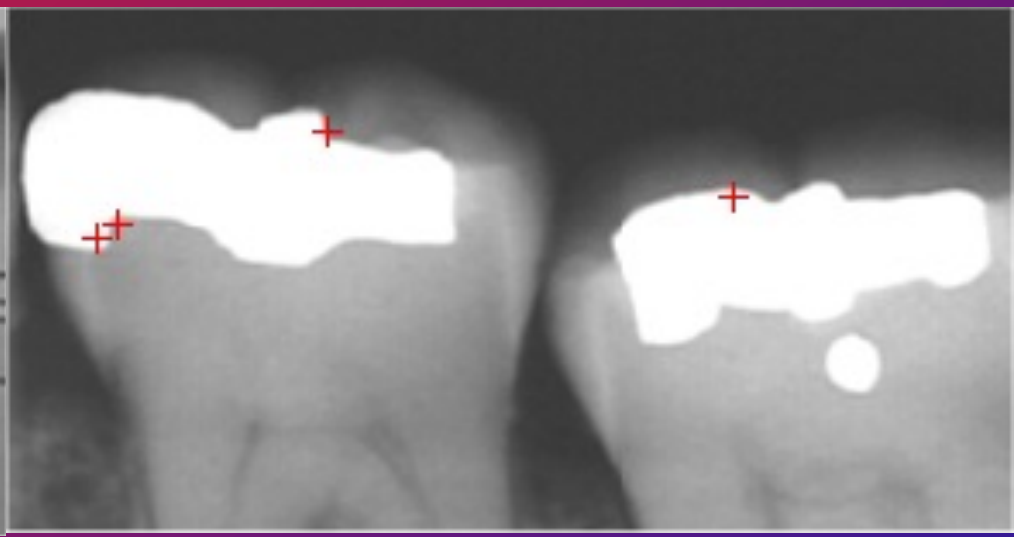


Image Analysis: Image Matching



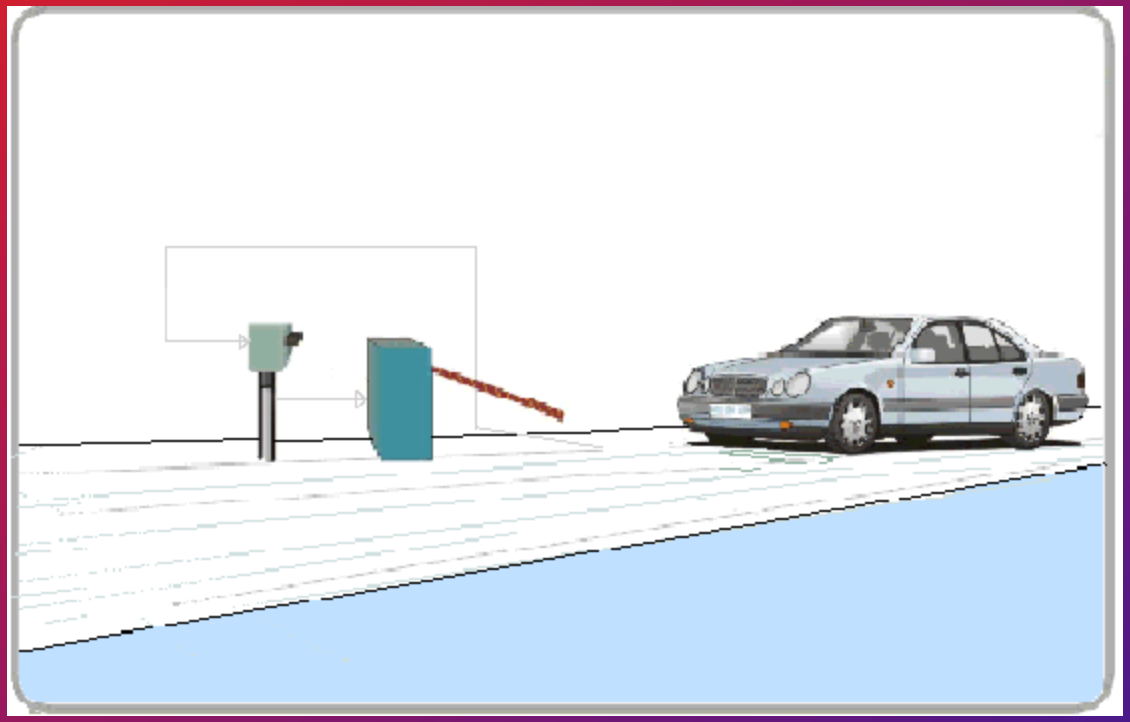


Antemortem dental X-ray record Postmortem dental X-ray record

Image Matching in Biometrics

Two **deceivingly** similar fingerprints of two different people

Image Analysis: Object Recognition



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