Image Processing for Bioinformatics

AA 2010-2011

Facoltà di Scienze MM, FF e NN

Dipartimento di Informatica

Università di Verona

General information

- Teacher: Gloria Menegaz
- Assistant: Francesca Pizzorni
- Scheduling
  - Theory (4 CFU)
    - Tue. 8.30 to 10.30, room A
    - Wed. 14.30 to 15.30, room B
  - Laboratory (2 CFU)
    - Mon. 14.30 to 16.30, room I
  - Tutoring (*ricevimento*)
    - by appointment (email)
  - Start and end dates
    - March 1°, 2011 – May 25, 2011
- Exam
  - TBD, depending on the numerosity
  - Possibility to do a project for the Lab. part
- Support
  - Slides of the course
  - Books

Contents

Classical IP

- Review of Fourier Transform
- Extension to 2D
- Sampling in 2D
- Quantization
- Edge detection
  - Model-based, region-based
- Filtering
  - denoising, deblurring, image enhancement
- Segmentation techniques
- Basics of pattern recognition
  - Clustering, classification

Advanced Topics

- Color imaging
- Introduction to stochastic processes
- Hints for Wavelets and multiresolution
- The JPEG coding standard

Why do we process images?

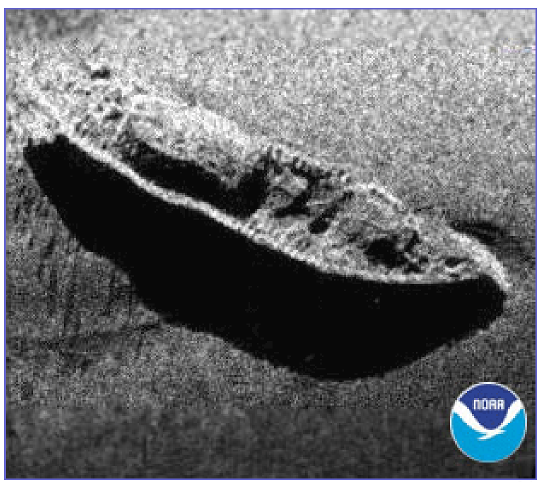
- To facilitate their storage and transmission
- To prepare them for display or printing
- To enhance or restore them
- To extract information from them
- To hide information in them

Image types

Optical (CCD)

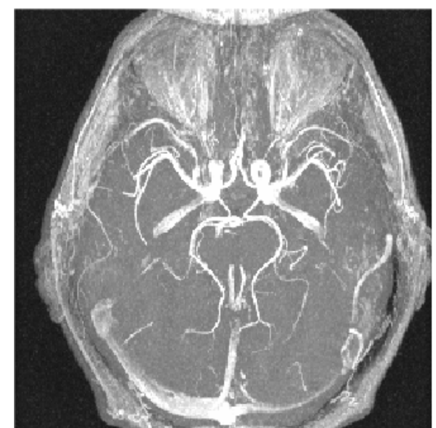
radar (SAR)

underwater



infrared

medical (MRI)



Microarray images

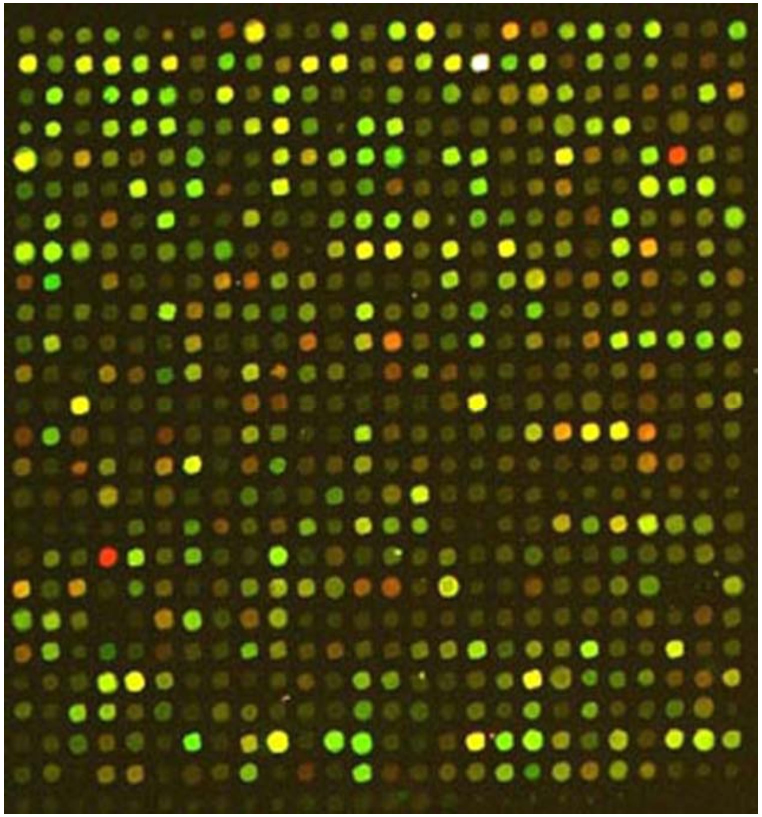


Image Processing Example

- Image Restoration

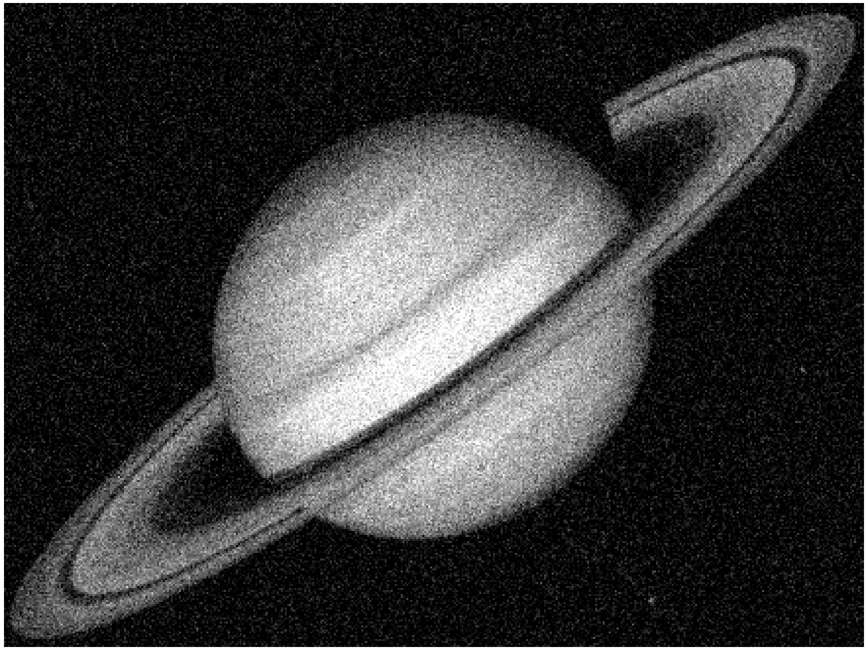

Original image


Blurred

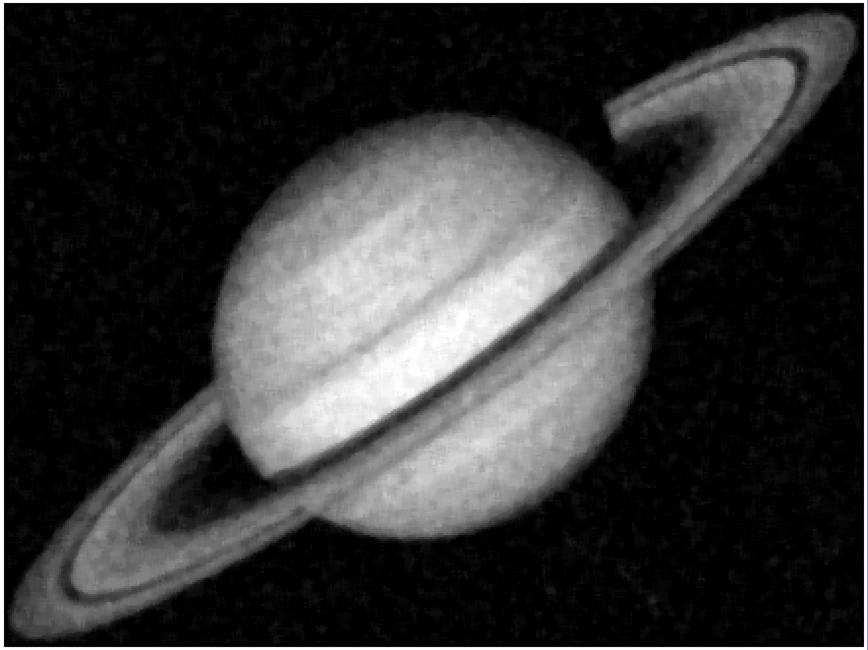

Restored by Wiener filter

Image Processing Example

- Noise Removal



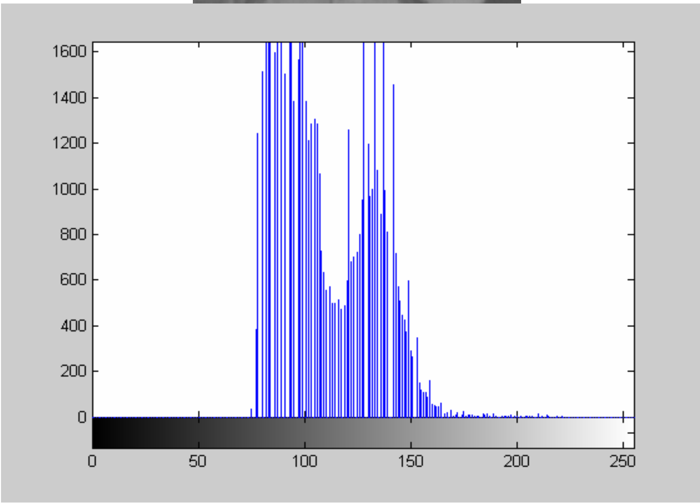
Noisy image

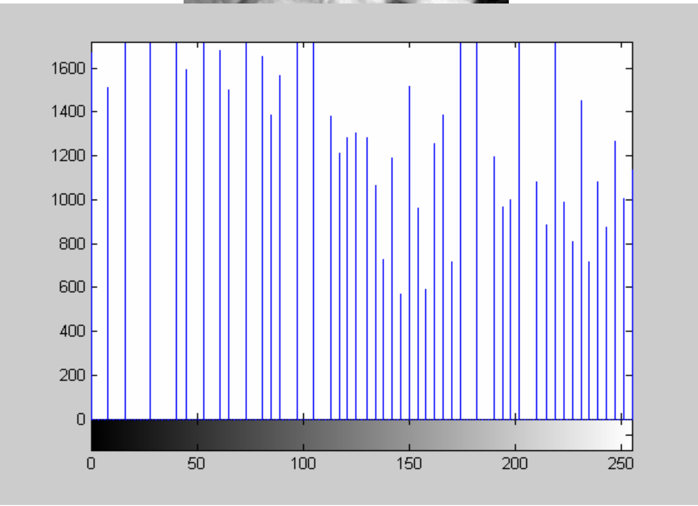


Denoised by Median filter

Image Processing Example

- Image Enhancement





Histogram equalization

Image Processing Example

- Artifact Reduction in Digital Cameras

Original scene

Captured by a digital camera

Processed to reduce artifacts

Image Processing Example

- Image Compression

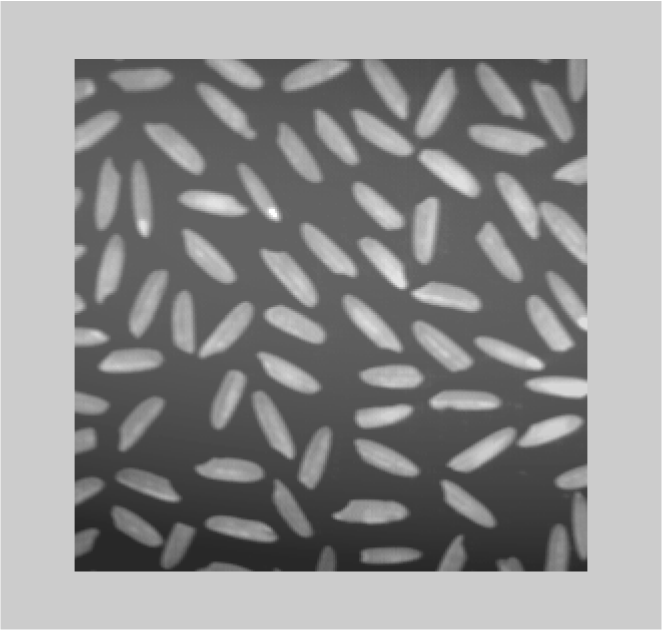
Original image
64 KB

JPEG compressed
15 KB

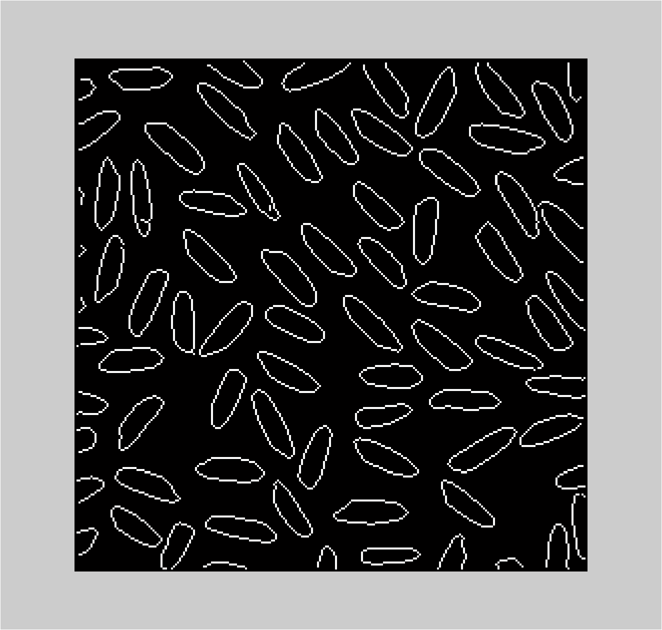
JPEG compressed
9 KB

Image Processing Example

- Object Segmentation



"Rice" image



Edges detected using Canny filter

Image Processing Example

- Resolution Enhancement

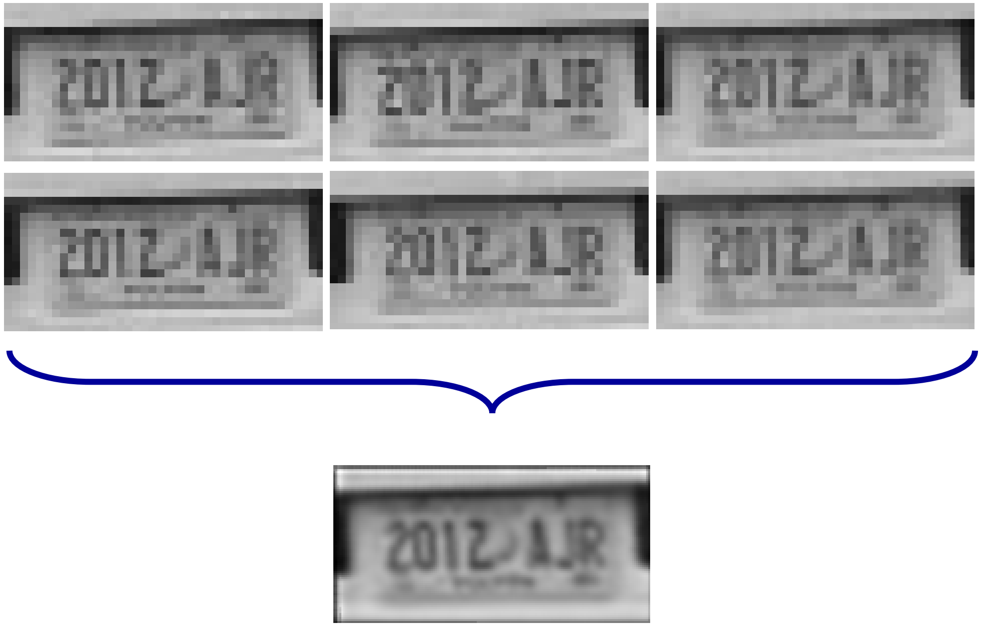


Image Processing Example

- Security and encryption
  - Watermarking

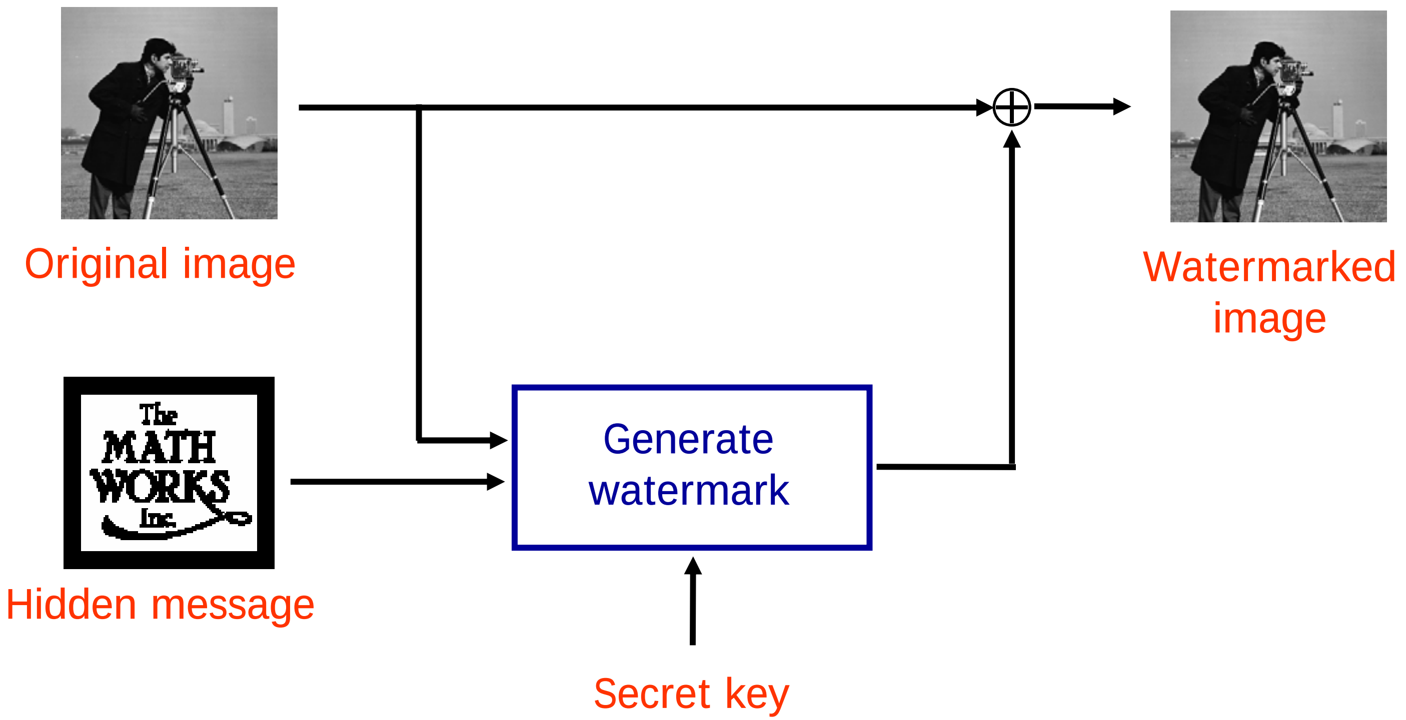


Image Processing Example

- Face Recognition

Image Processing Example

- Fingerprint Matching

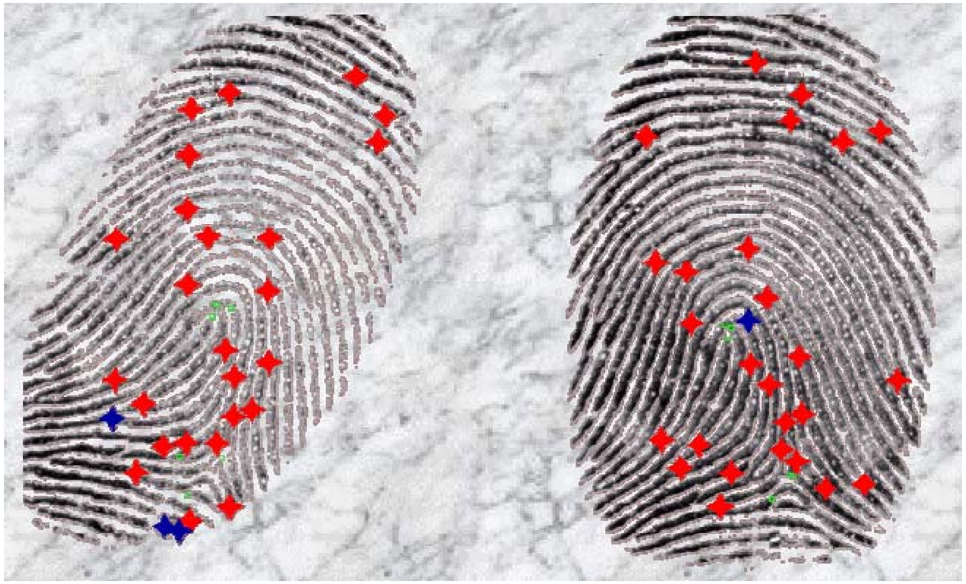


Image Processing Example

- Segmentation

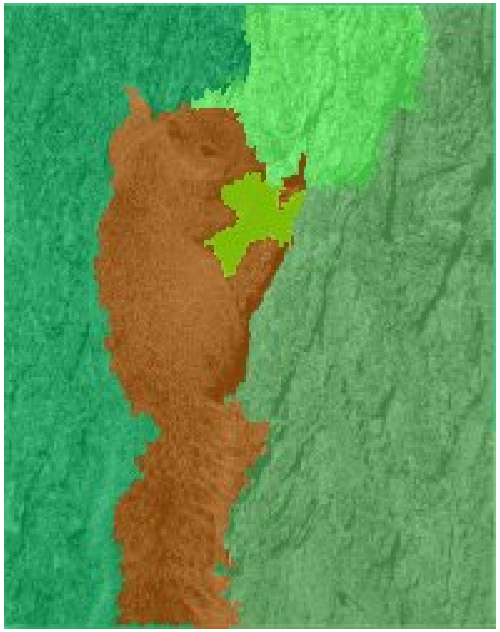
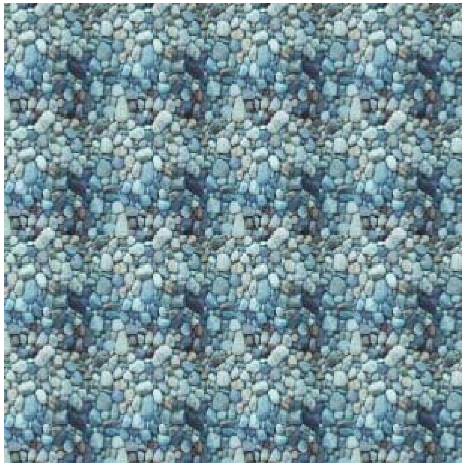


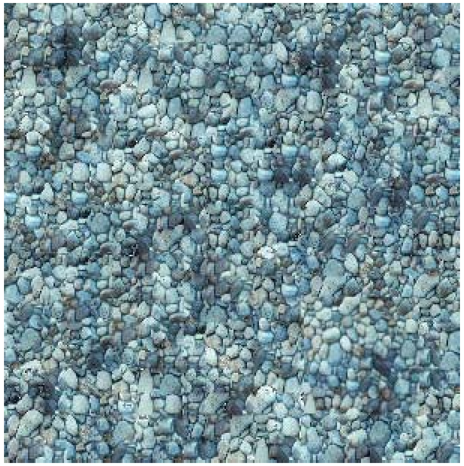
Image Processing Example

- Texture Analysis and Synthesis

Photo



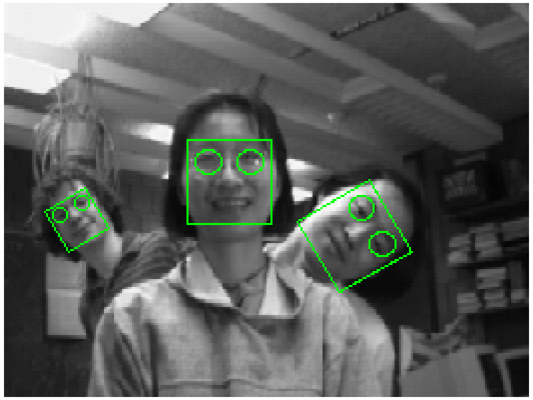
Pattern repeated

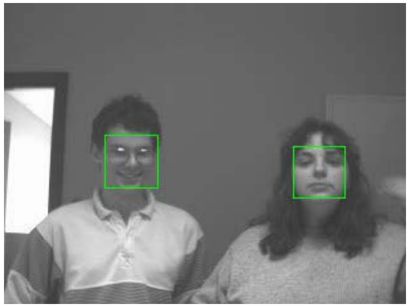


Computer generated

Image Processing Example

- Face detection and tracking





http://vasc.ri.cmu.edu/NNFaceDetector/

Image Processing Example

- Face Tracking

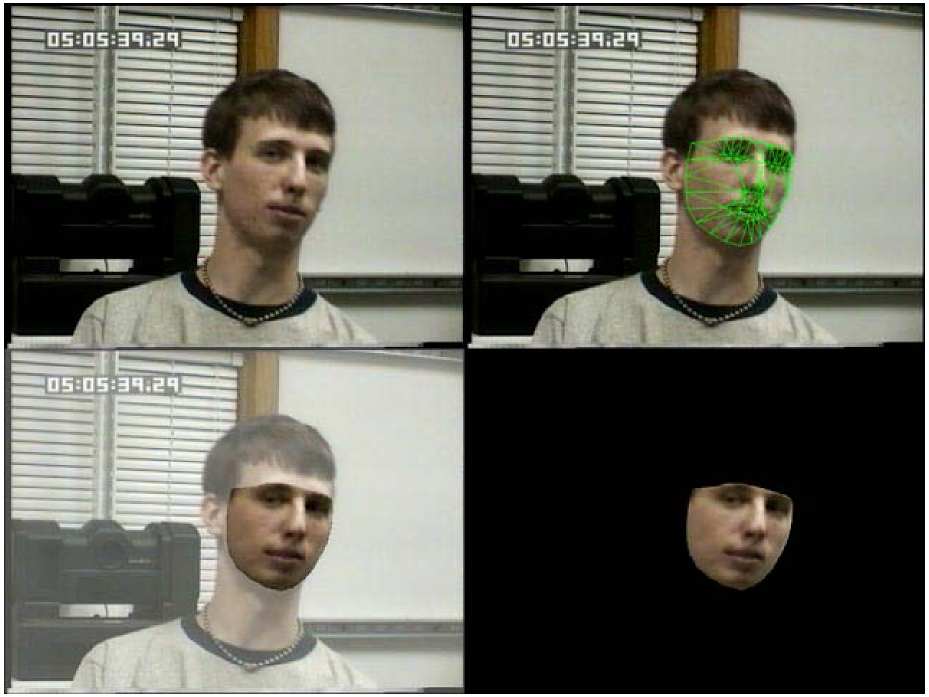


Image Processing Example

- Object Tracking

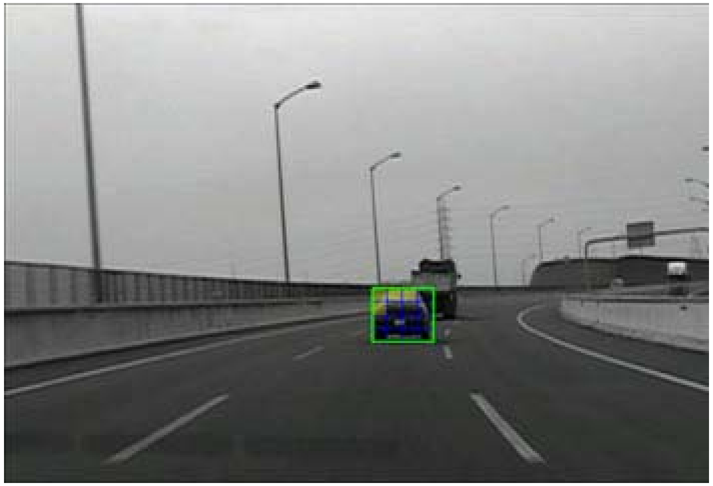
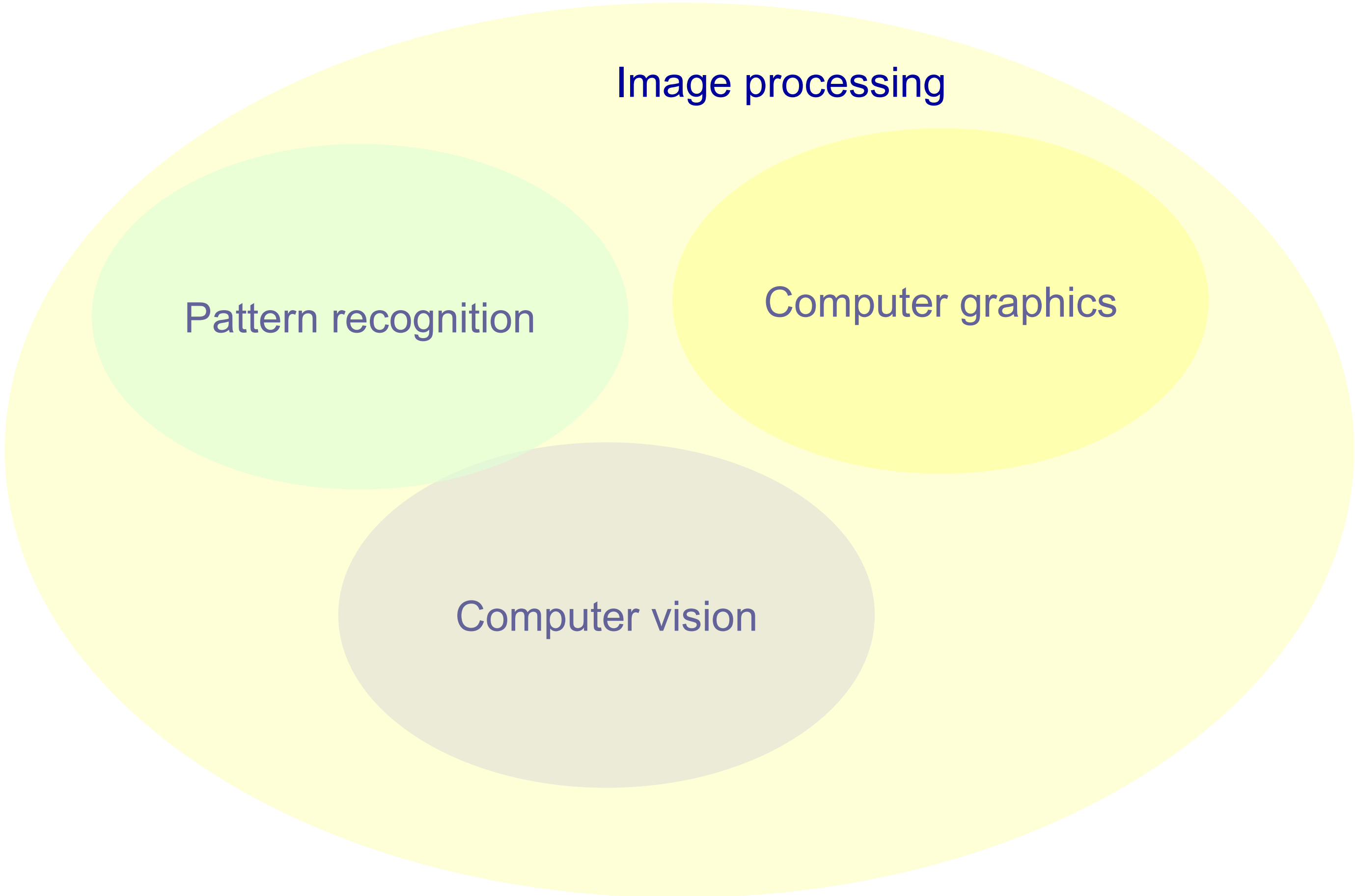


Image Processing Example

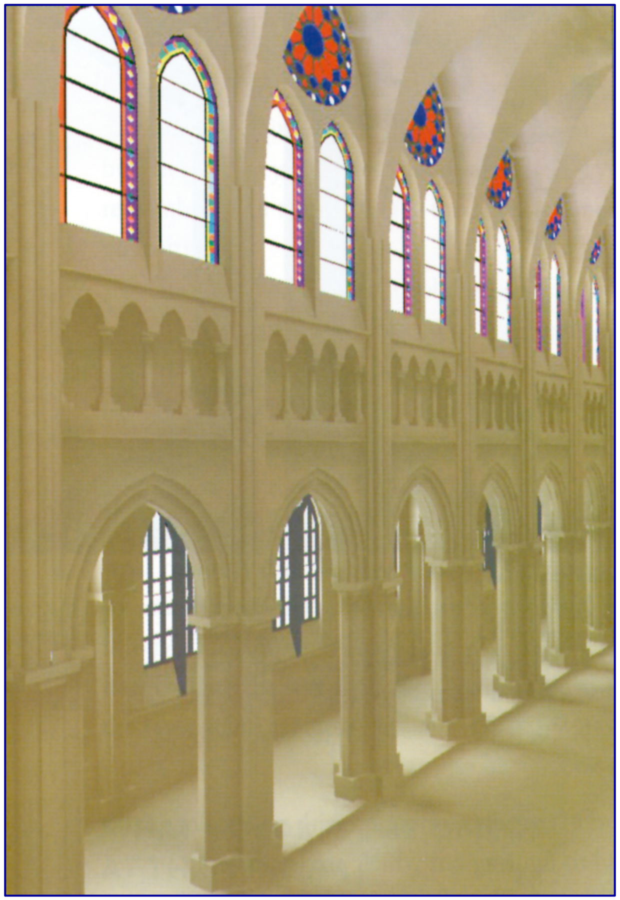
- Visually Guided Surgery

Taxonomy of the IP domain



Computer graphics

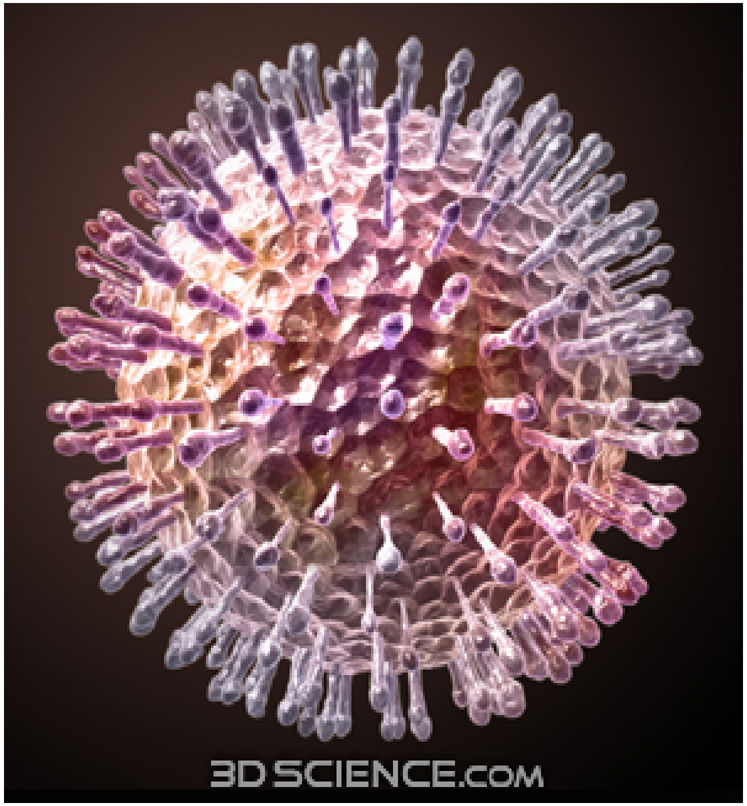
- Algorithms allowing to generate *artificial* images and scenes
- Model-based
    - Scenes are created based on models
- Visualization often rests on 2D projections
- Hot topic: generate perceptually credible scenes
    - Image-based modeling & rendering



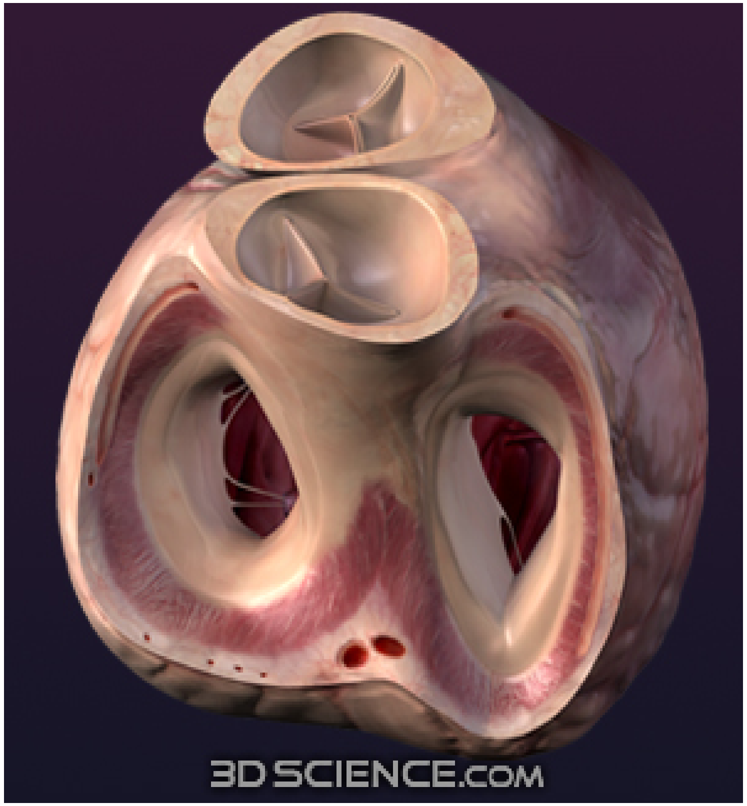

HOME
SWEET
HOME

DNA

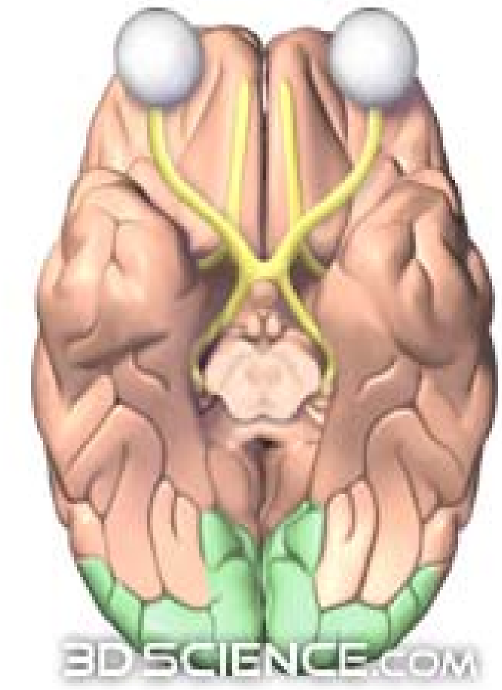
VIRUS - Herpes



HEARTH (interior)



BRAIN (visual cortex)



Computer vision

- Methods for estimating the *geometrical* and *dynamical* properties of the imaged scene based on the acquired images
  - Scene description based on image features
- Complementary to computer graphics
  - Get information about the 3D real world based on its 2D projections in order to automatically perform predefined tasks

Pattern Recognition

- Image interpretation
- Identification of basic and/or complex structures
  - implies pre-processing to reduce the intrinsic redundancy in the input data
  - knowledge-based
    - use of a-priori knowledge on the real world
    - stochastic inference to compensate for partial data
- Key to clustering and classification
- Applications
  - medical image analysis
  - microarray analysis
  - multimedia applications

Pattern Recognition

- Clustering
  - data analysis aiming at constructing and characterizing clusters (sets without prior knowledge)
- Feature extraction and selection
  - reduction of data dimensionality
- Classification
  - Structural (based on a predefined "syntax"):
    - each pattern is considered as a set of primitives
    - clustering in the form of parsing
  - Stochastic
    - Based on statistics (region-based descriptors)

Applications

- Efficiently manage different types of images
  - Satellite, radar, optical..
  - Medical (MRI, CT, US)
  - Image representation and modelling
- Quality enhancement
  - Image restoration
    - deblurring, denoising, hole filling
- Image analysis
  - Feature extraction and exploitation
- Image reconstruction from projections
  - scene reconstruction, CT, MRI
- Compression and coding

Typical issues

Context-independent

- Image resampling and interpolation
  - Sampling, quantization, filtering
- Visualization and rendering
- Multispectral imaging
  - Satellite, color
- Motion detection, tracking
- Automatic quality assessment
- Data mining
  - query by example

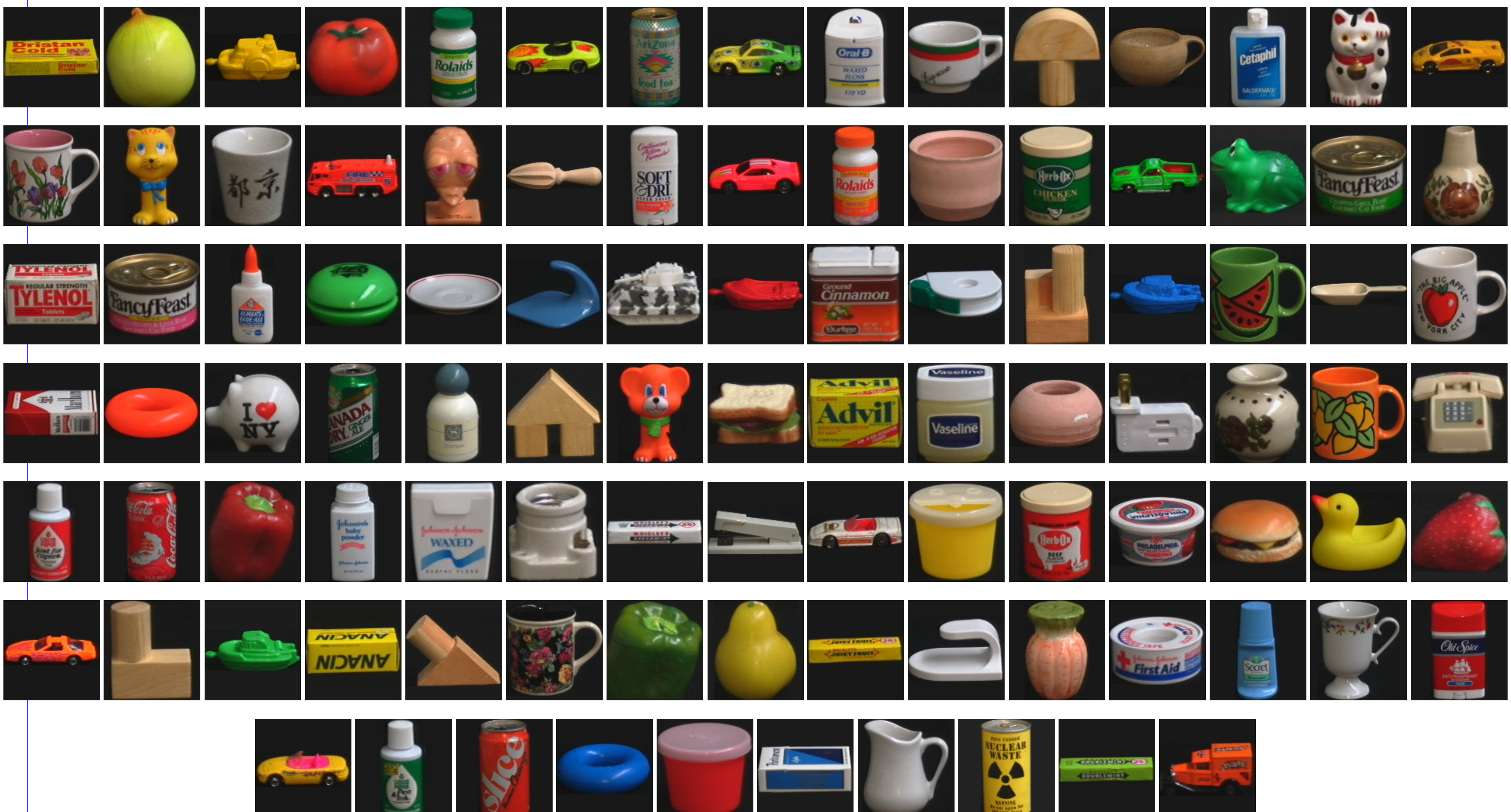
Medical imaging

- Image analysis
  - optical devices, MRI, CT, PET, US (2D to 4D)
- Image modeling
  - Analysis of hearth motion, models of tumor growth, computer assisted surgery
- Telemedicine
  - remote diagnosis, distributed systems, medical databases

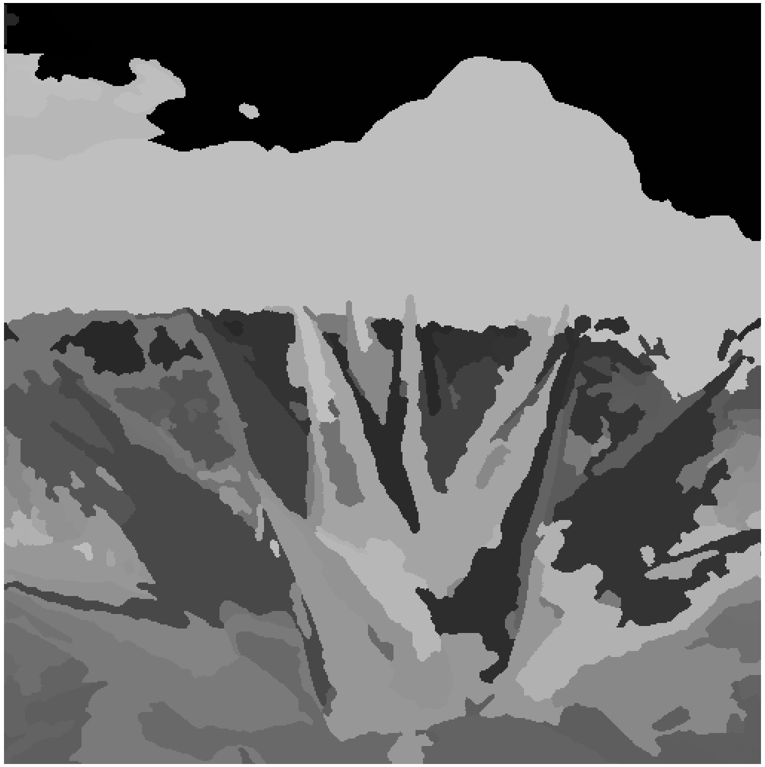
Other applications

- Quality control
- Reverse engineering
- Surveillance (monitoring and detection of potentially dangerous situations)
- Social computing (face and gesture recognition for biometrics and behavioural analysis)
- Robotics (machine vision)
- Virtual reality
- Telepresence

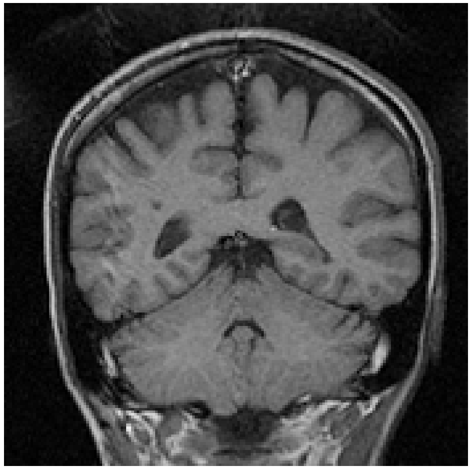
Query by example

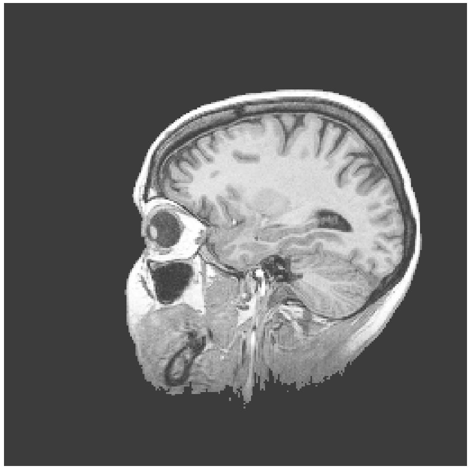


Segmentation



Medical Image Analysis



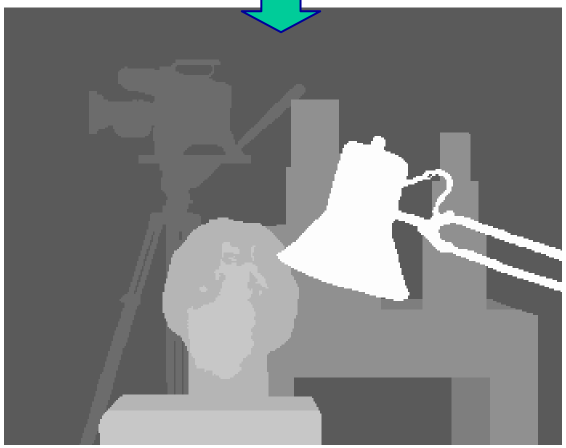


Technology for HCI

Face recognition

Stereo imaging

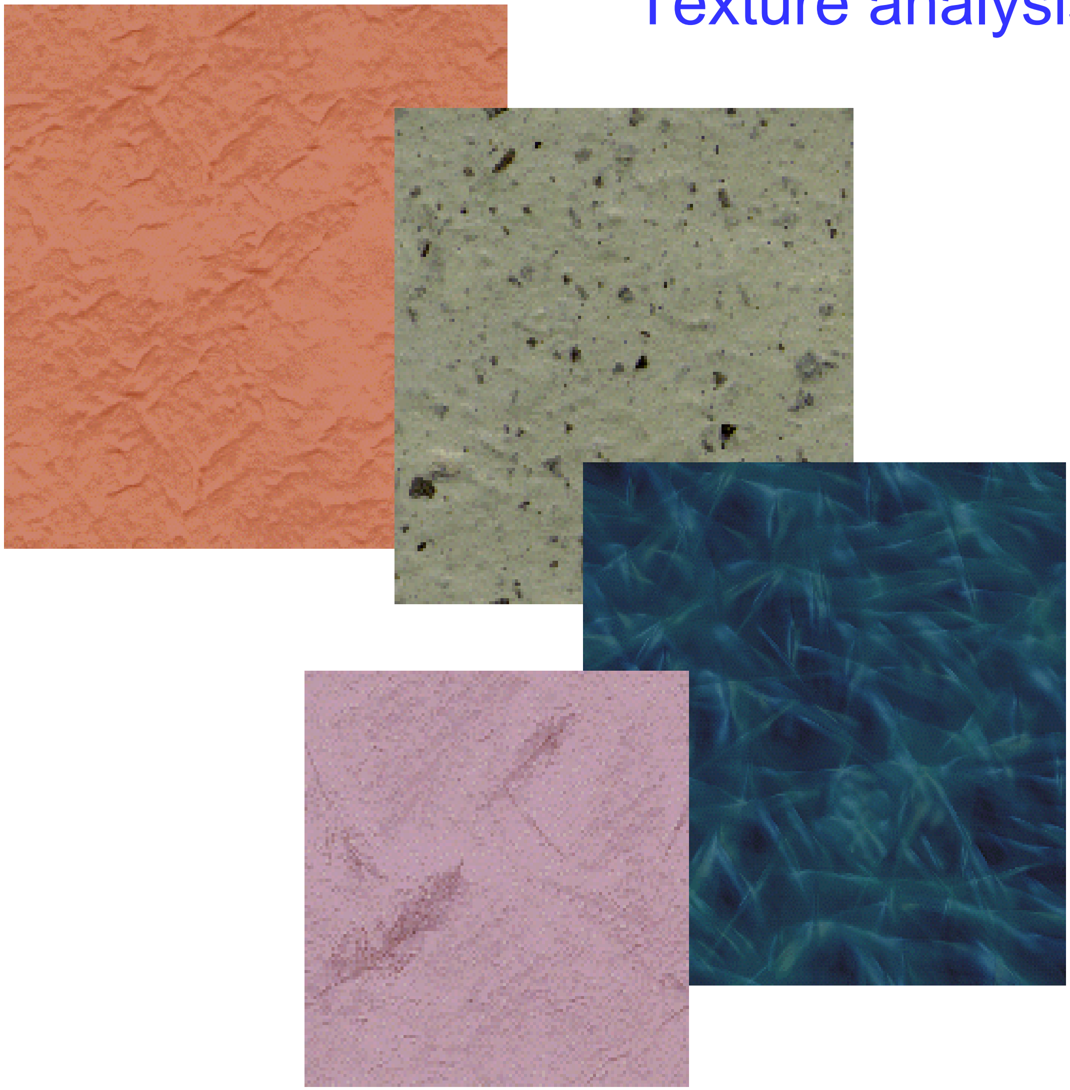
Stereo couple



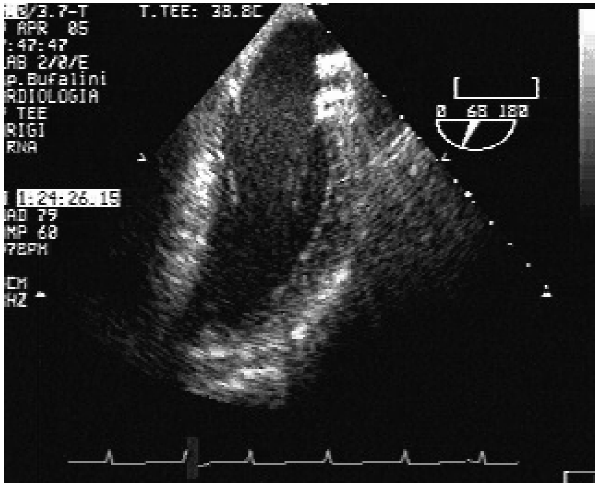
Disparity map: brighter pixels represent scene points closer to the observer

The disparity map is used to render 3D scenes

Texture analysis

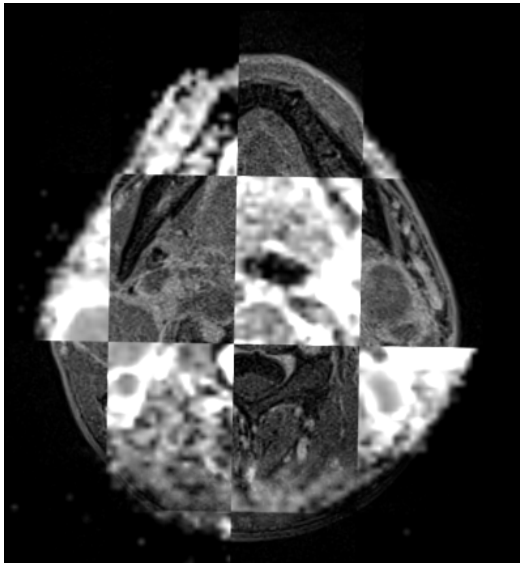


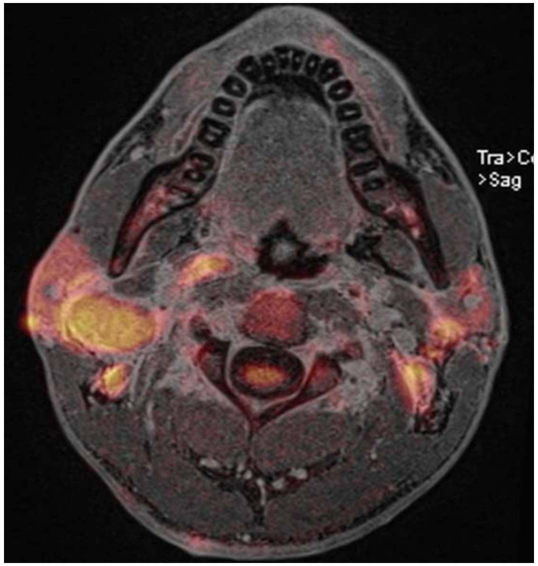
Medical textures



MI applications

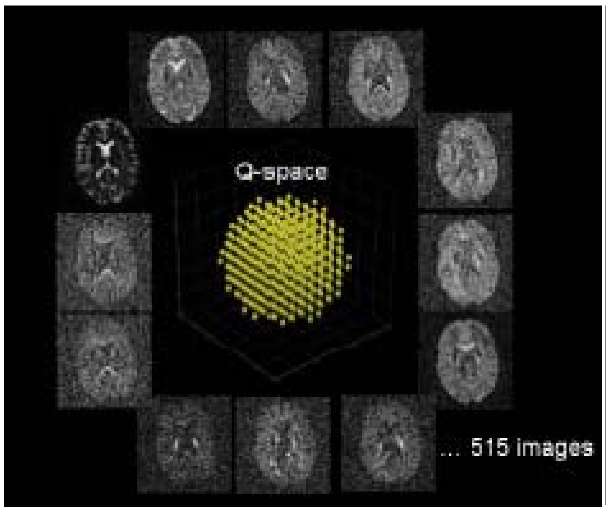
- Tumor identitication and staging

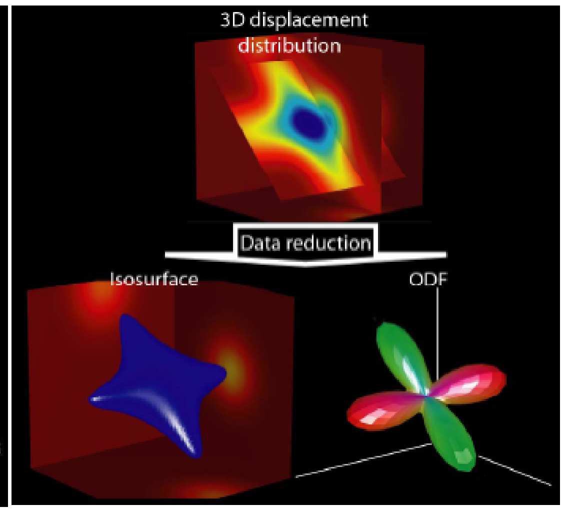


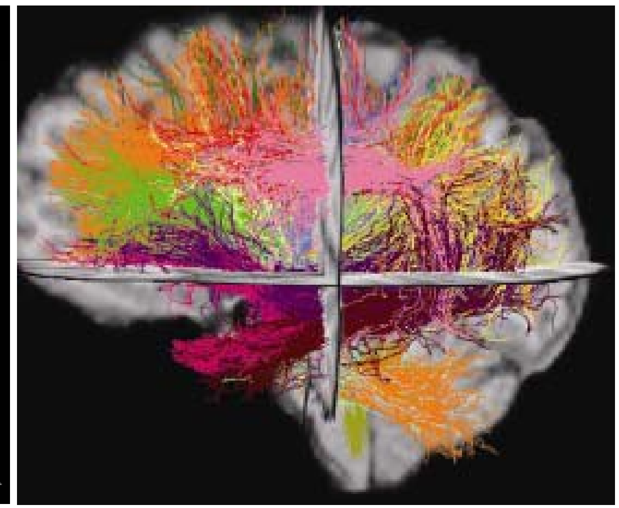


MI applications

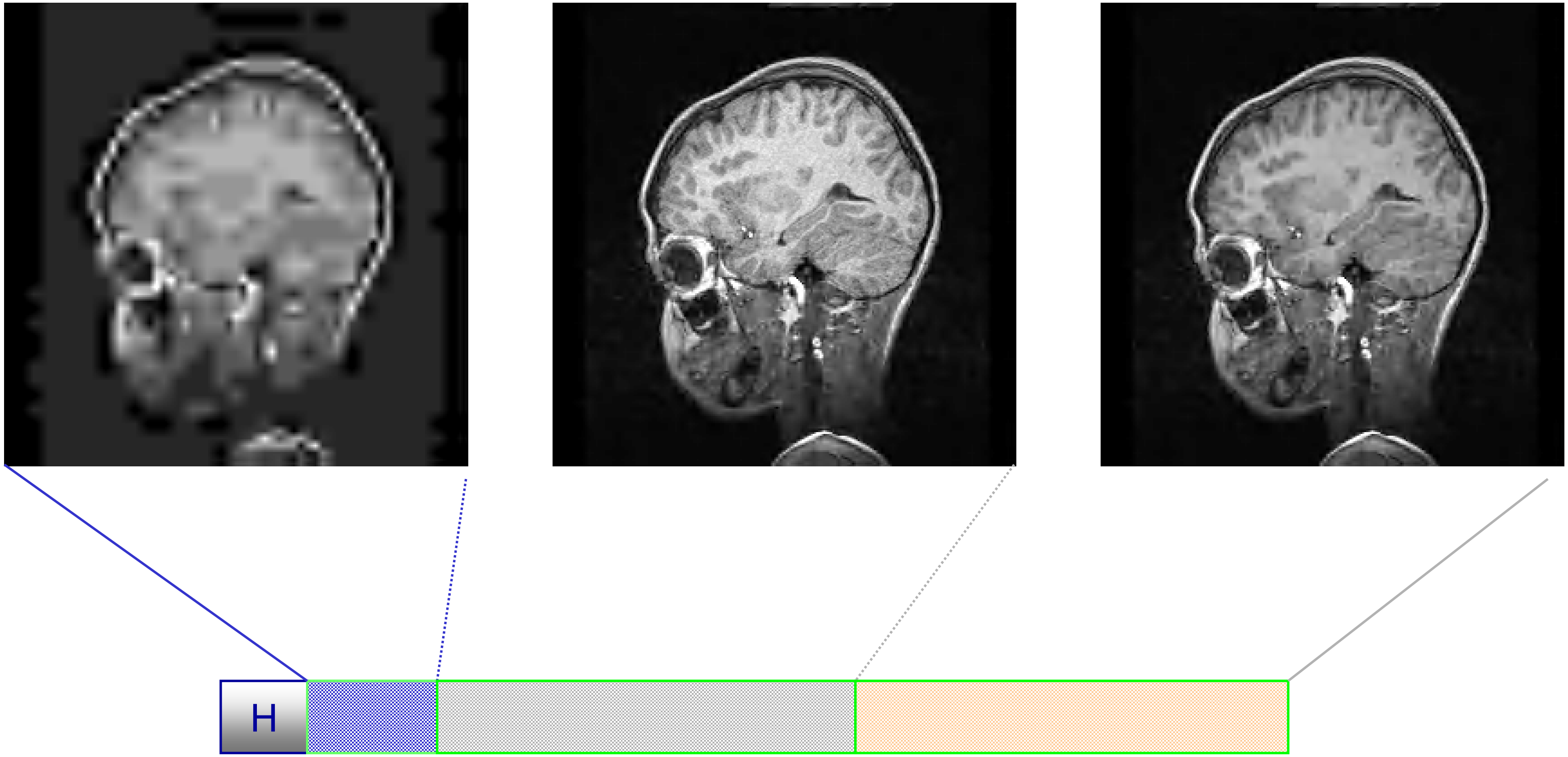
- Exploring brain anatomy by diffusion weighted MRI



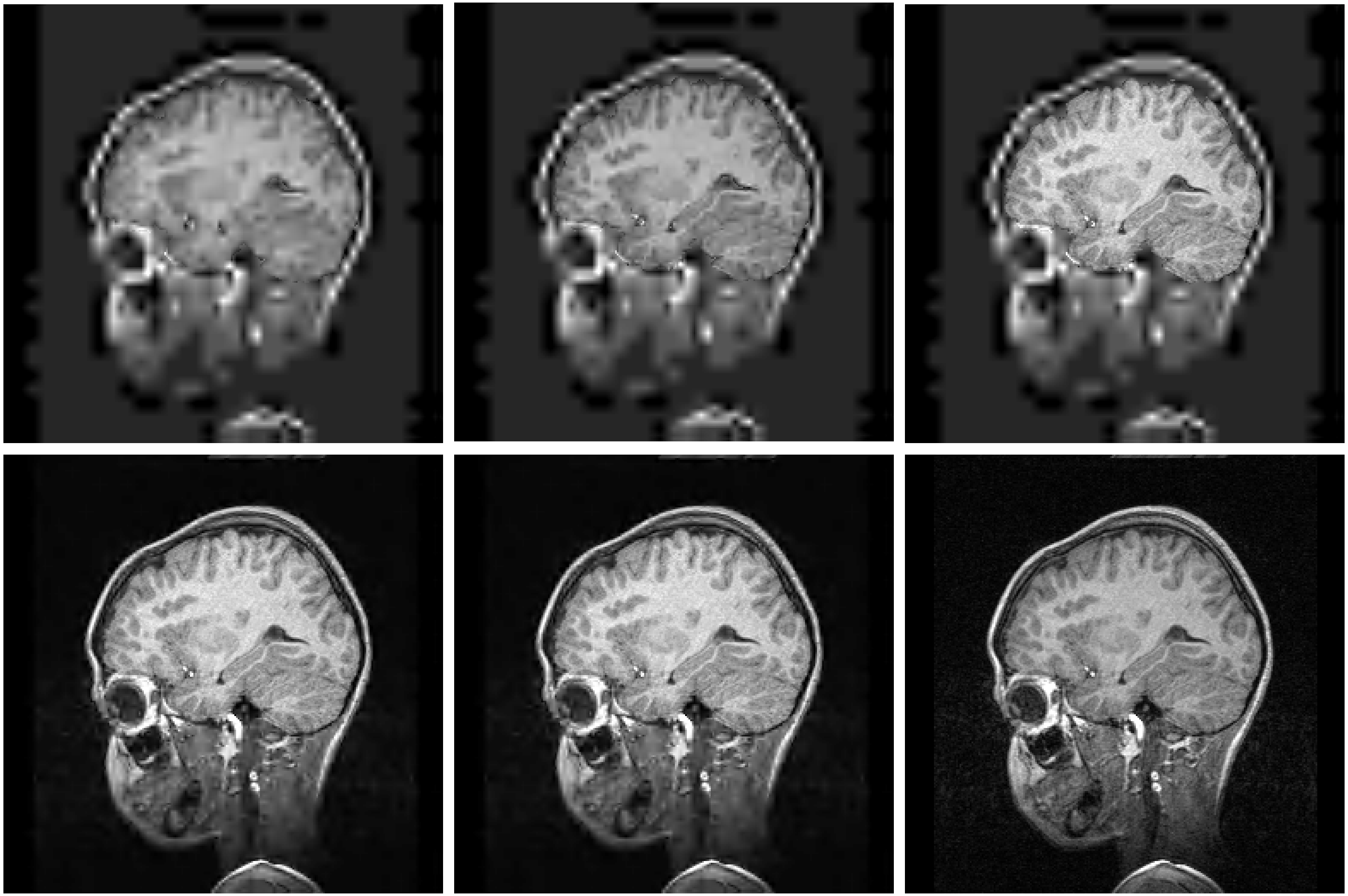




Compression and coding



Object-based processing



Mosaicing

Hierarchical Image Pyramid

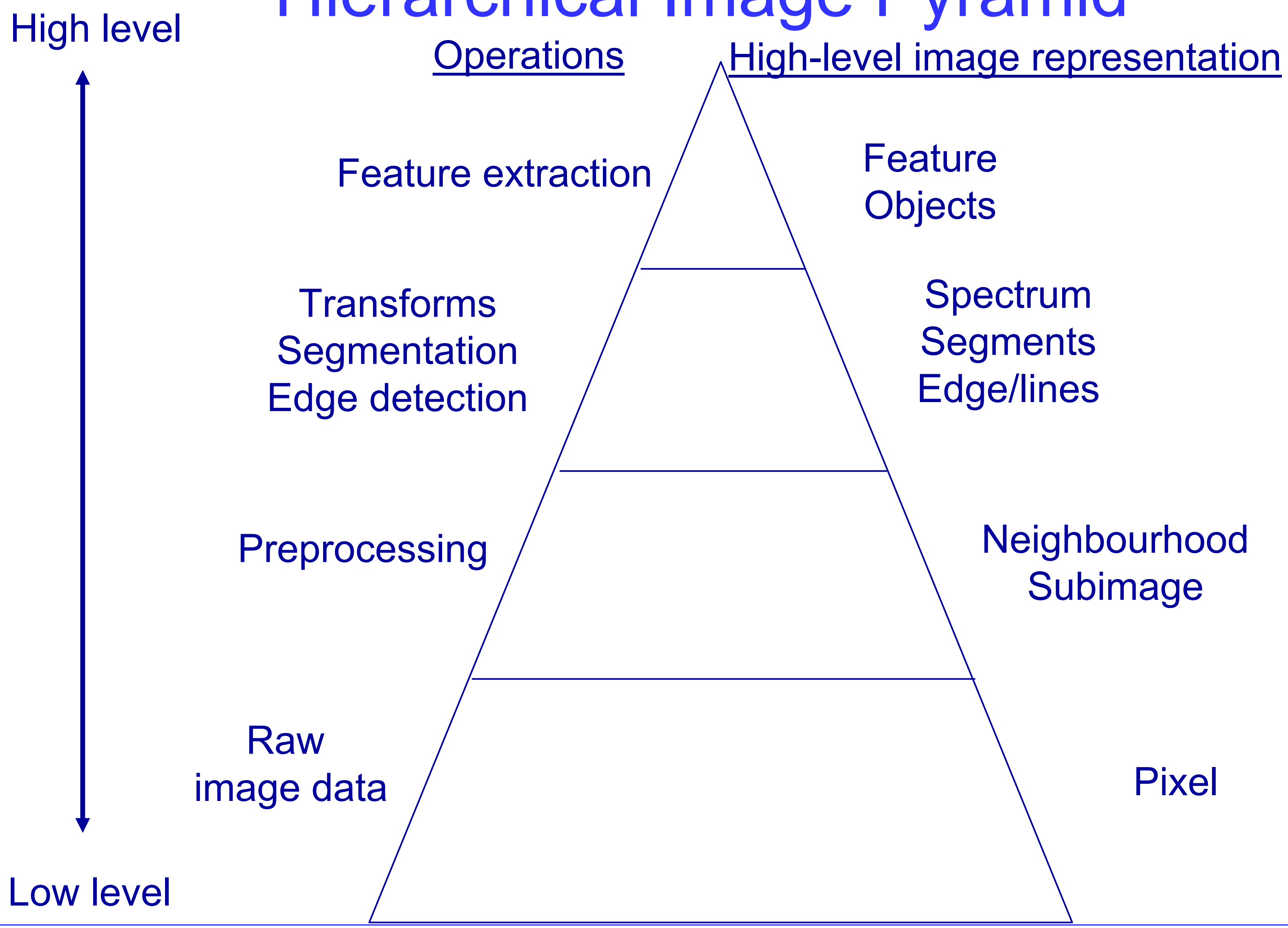
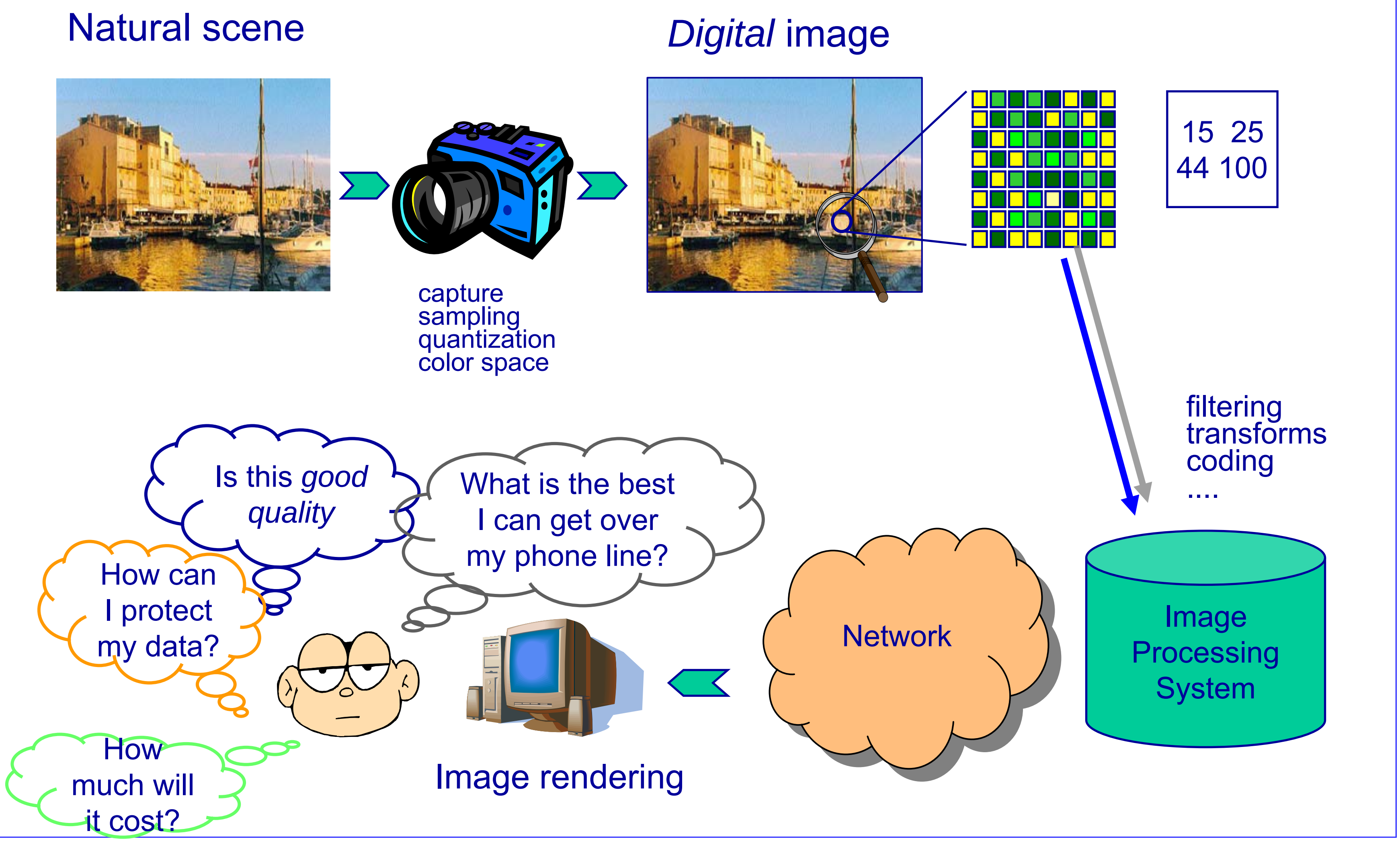


Image formation and fundamentals

IP framework



IP: basic steps

Analog image

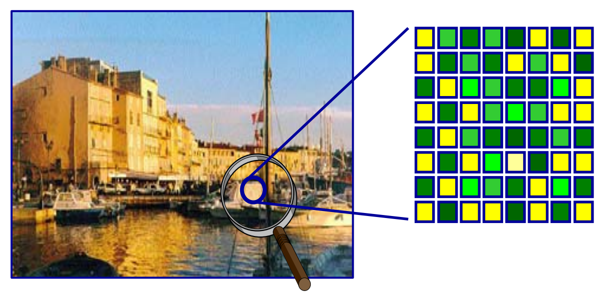
(capturing device)

A/D conversion

Sampling (2D)

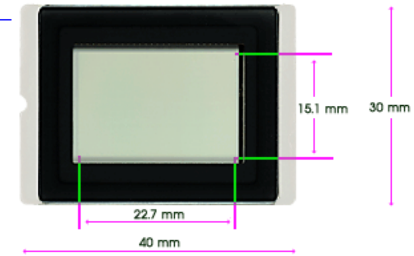
Quantization

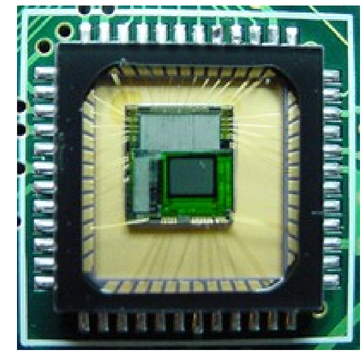
Digital image

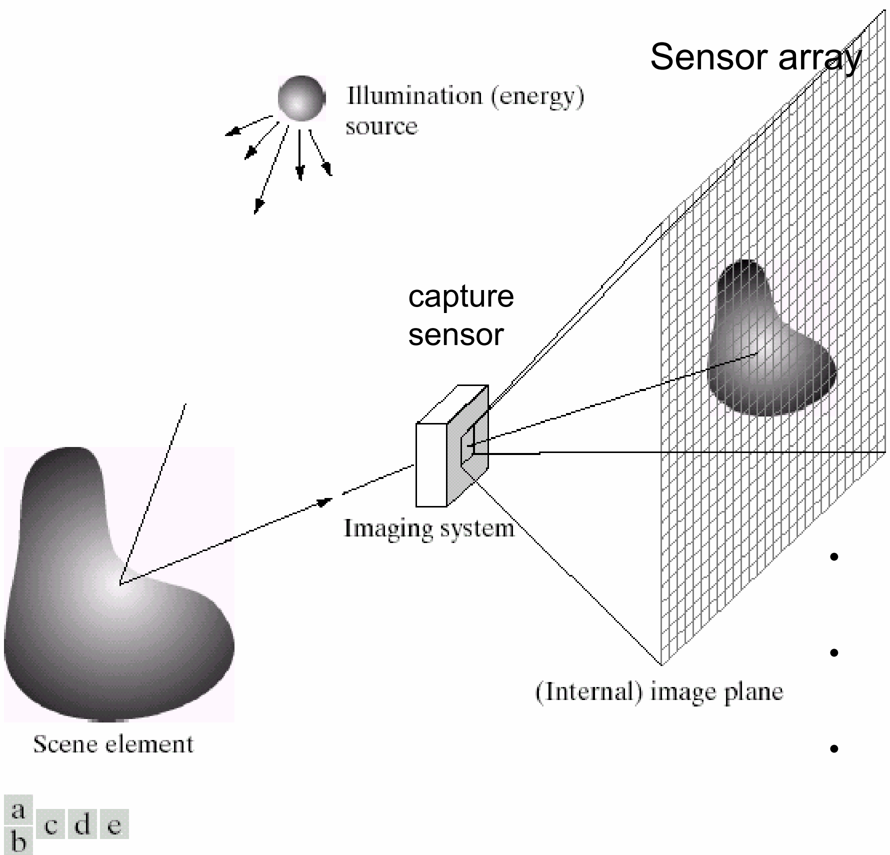


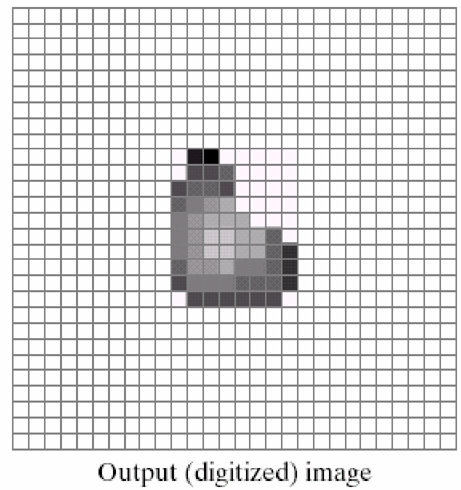
{15,1,2}
{25,44,1}
....

Digital Image Acquisition





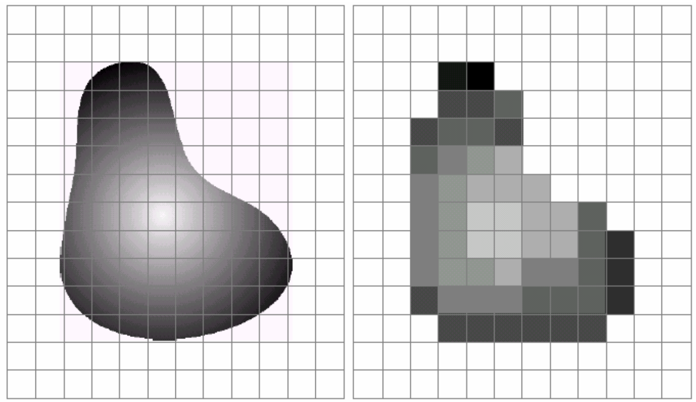




- When photons strike, electron-hole pairs are generated on sensor sites.
- Electrons generated are collected over a certain period of time.
- The number of electrons are converted to pixel values. (Pixel means *picture element*)

FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Digital Image Acquisition



a b

FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.

Two types of discretization:

- There are finite number of pixels
  - Sampling → Spatial resolution
- The amplitude of pixel is represented by a finite number of bits
  - Quantization → Gray-scale resolution

Digital Image Acquisition

Take a look at this cross section

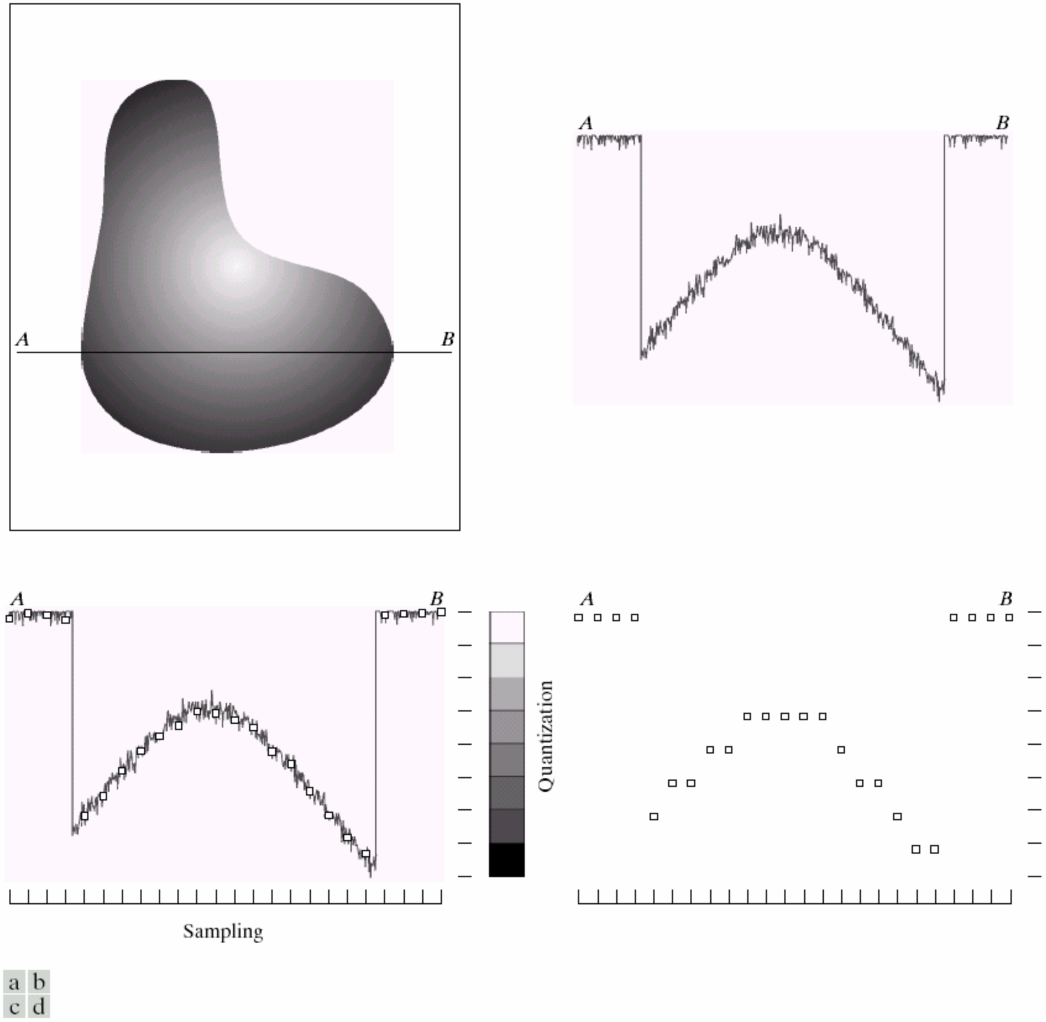
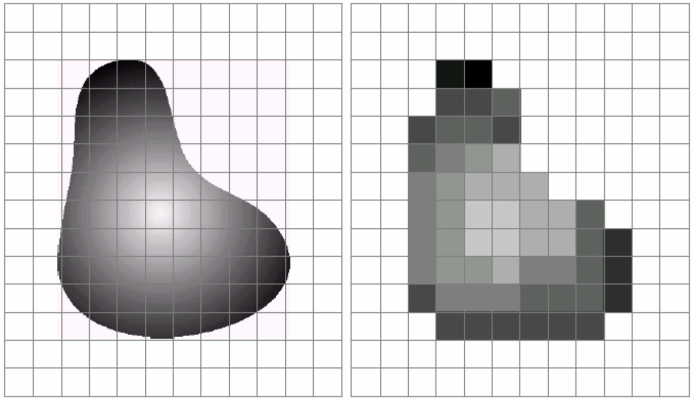


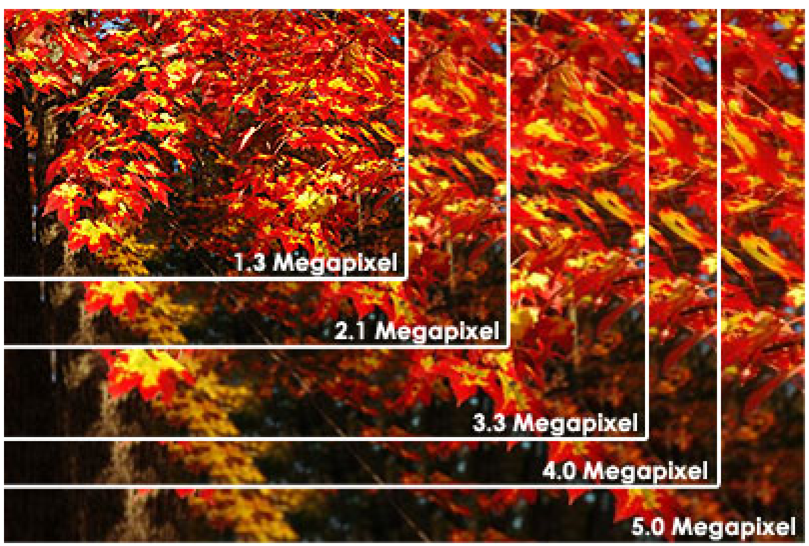
FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from *A* to *B* in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

Digital Image Acquisition



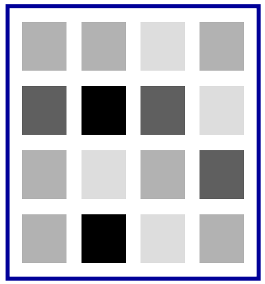
a b

FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.



- **256x256** - Found on very cheap cameras, this resolution is so low that the picture quality is almost always unacceptable. This is 65,000 total pixels.
- **640x480** - This is the low end cameras. This resolution is ideal for e-mailing pictures or posting pictures on a Web site.
- **1216x912** - This is a "megapixel" image size -- 1,109,000 total pixels -- good for printing pictures.
- **1600x1200** - With almost 2 million total pixels, this is "high resolution." You can print a 4x5 inch print taken at this resolution with the same quality that you would get from a photo lab.
- **2240x1680** - Found on 4 megapixel cameras -- the current standard -- this allows even larger printed photos, with good quality for prints up to 16x20 inches.
- **4064x2704** - A top-of-the-line digital camera with 11.1 megapixels takes pictures at this resolution. At this setting, you can create 13.5x9 inch prints with no loss of picture quality.

Basics: greylevel images



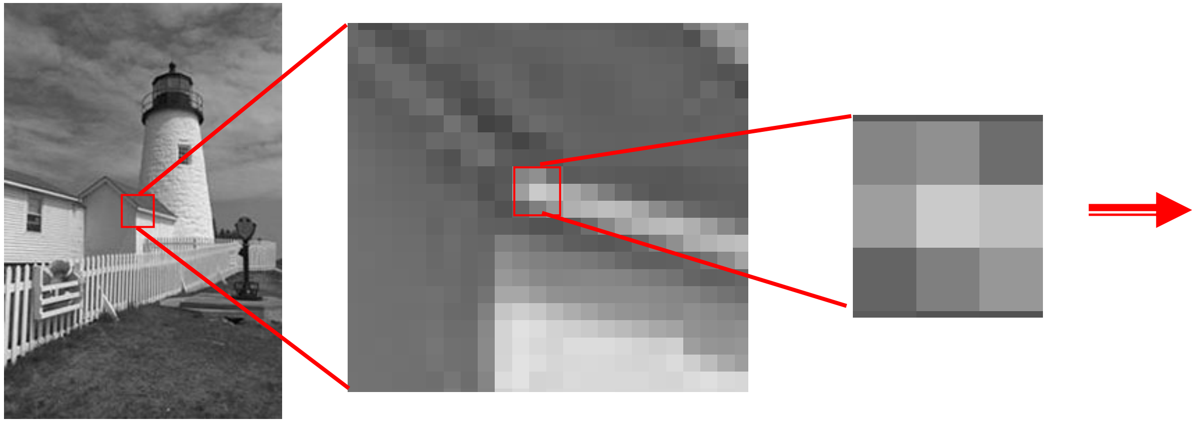
100	100	200	90
50	0	50	200
100	200	100	50
100	0	200	100

Images : Matrices of numbers
Image processing : Operations among numbers
bit depth : number of bits/pixel
N bit/pixel : 2^{N-1} shades of gray (typically N=8)

Matrix Representation of Images

- A digital image can be written as a matrix

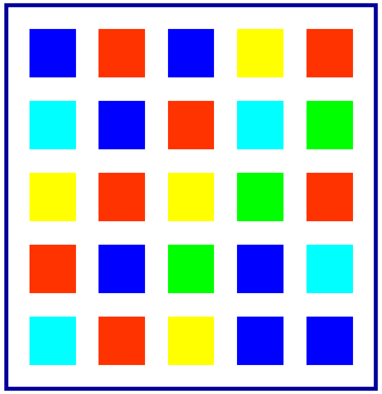
$$x[n_1, n_2] = \begin{bmatrix} x[0,0] & x[0,1] & \cdots & x[0, N-1] \\ x[1,0] & x[1,1] & \cdots & x[1, N-1] \\ \vdots & \vdots & \ddots & \vdots \\ x[M-1,0] & \cdots & \cdots & x[M-1, N-1] \end{bmatrix}_{MxN}$$



$$\begin{bmatrix} 35 & 45 & 20 \\ 43 & 64 & 52 \\ 10 & 29 & 39 \end{bmatrix}$$

Digital images acquisition

- Analog camera+A/D converter
- Digital cameras
  - CCDs (Charge Coupled Devices)
  - CMOS technology
- In both cases: optics
  - lenses, diaphragms



Matrices of photo sensors collecting photons of given wavelength

Features of the capture devices:

- Size and number of photo sites
- Noise
- Transfer function of the optical filter

Some definitions

- Digital images
  - Sampling+quantization
- Sampling
  - Determines the graylevel value of each pixel
    - Pixel = picture element
- Quantization
  - Reduces the resolution in the graylevel value to that set by the machine precision
- Images are stored as matrices of unsigned chars

Resolution

- Sensor resolution (CCD): Dots Per Inch (DPI)
  - Number of individual dots that can be placed within the span of one linear inch (2.54 cm)
- Image resolution
  - Pixel resolution: NxM
  - Spatial resolution: Pixels Per Inch (PPI)
  - Spectral resolution: bandwidth of each spectral component of the image
    - Color images: 3 components (R,G,B channels)
    - Multispectral images: many components (ex. SAR images)
  - Radiometric resolution: Bits Per Pixel (bpp)
    - Greylevel images: 8, 12, 16 bpp
    - Color images: 24bpp (8 bpp/channel)
  - Temporal resolution: for movies, number of frames/sec
    - Typically 25 Hz (=25 frames/sec)

Example: pixel resolution

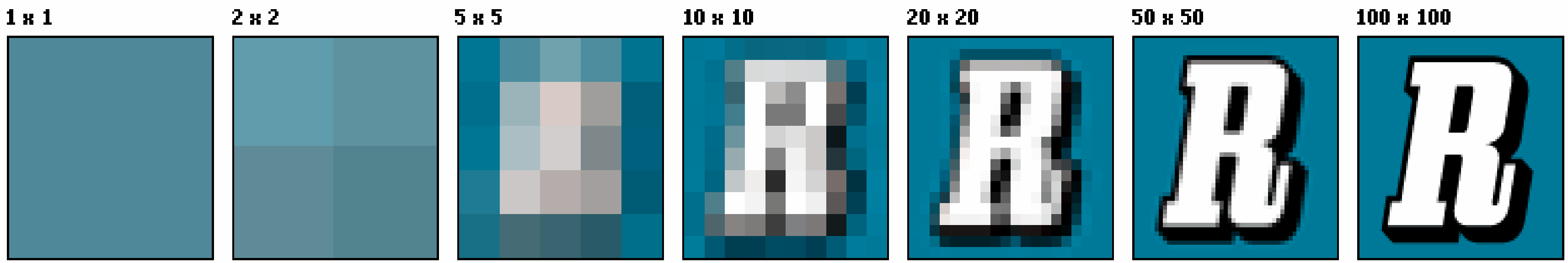


Image Resolution

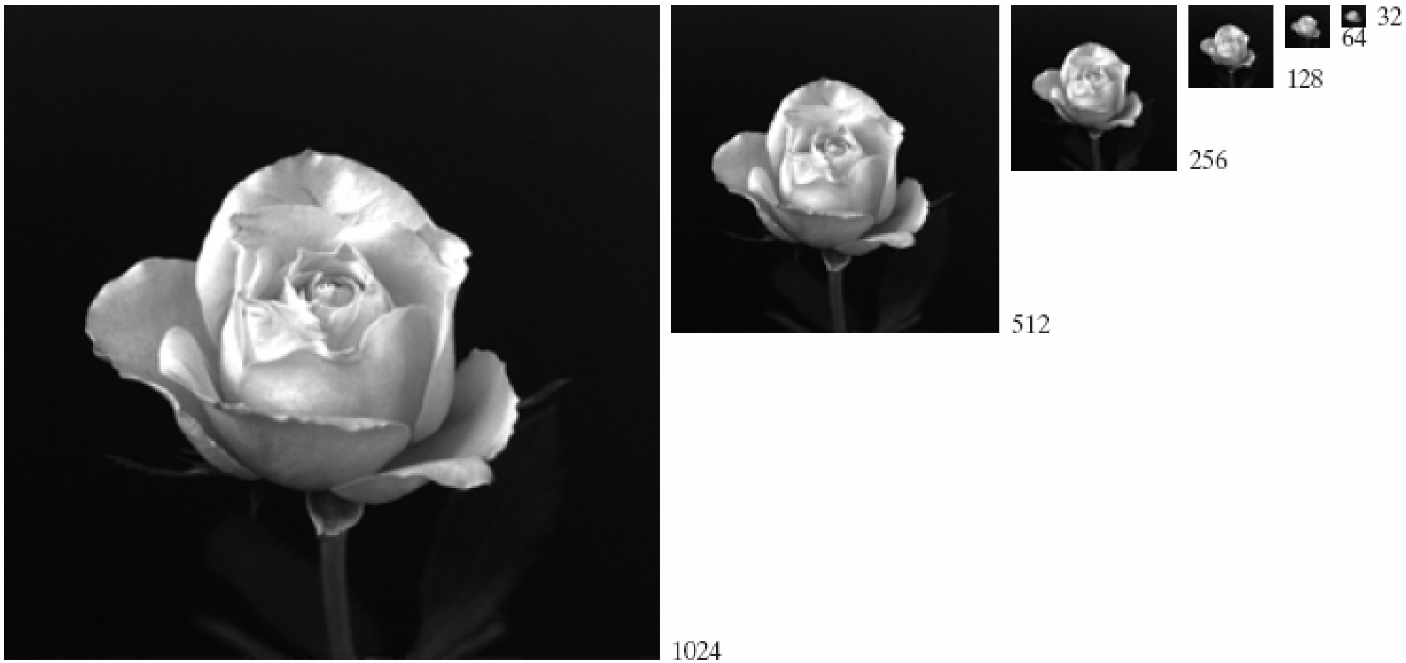


FIGURE 2.19 A 1024 × 1024, 8-bit image subsampled down to size 32 × 32 pixels. The number of allowable gray levels was kept at 256.

Image Resolution

Don't confuse image size and resolution.

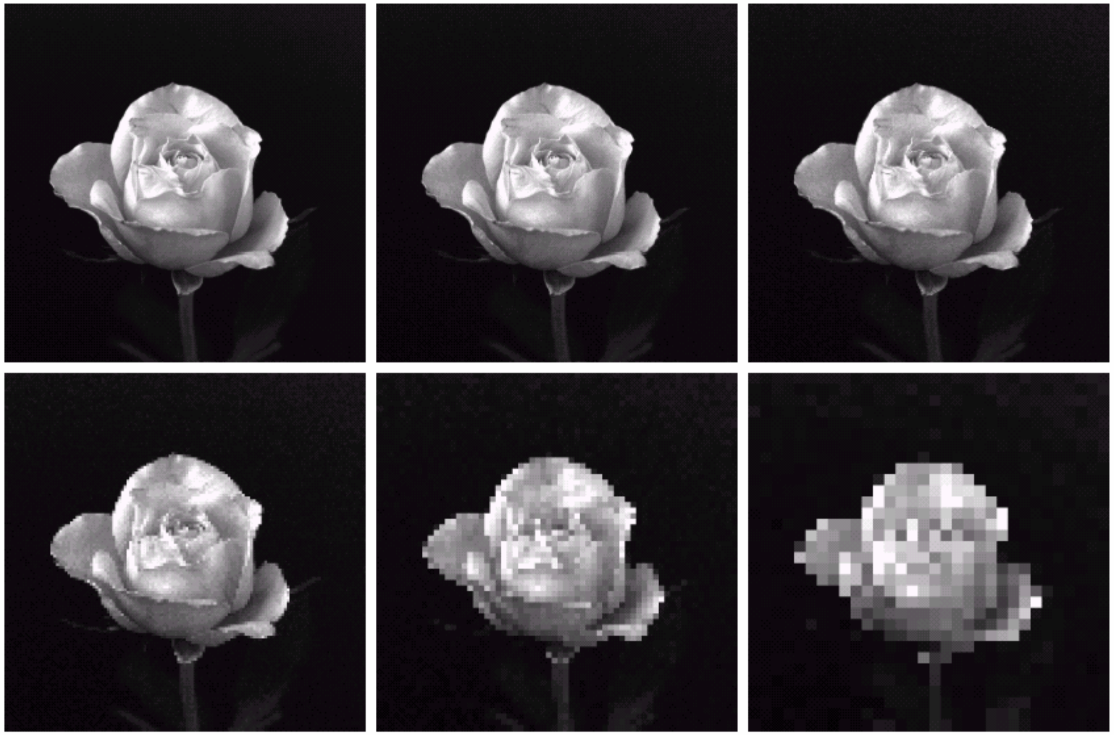
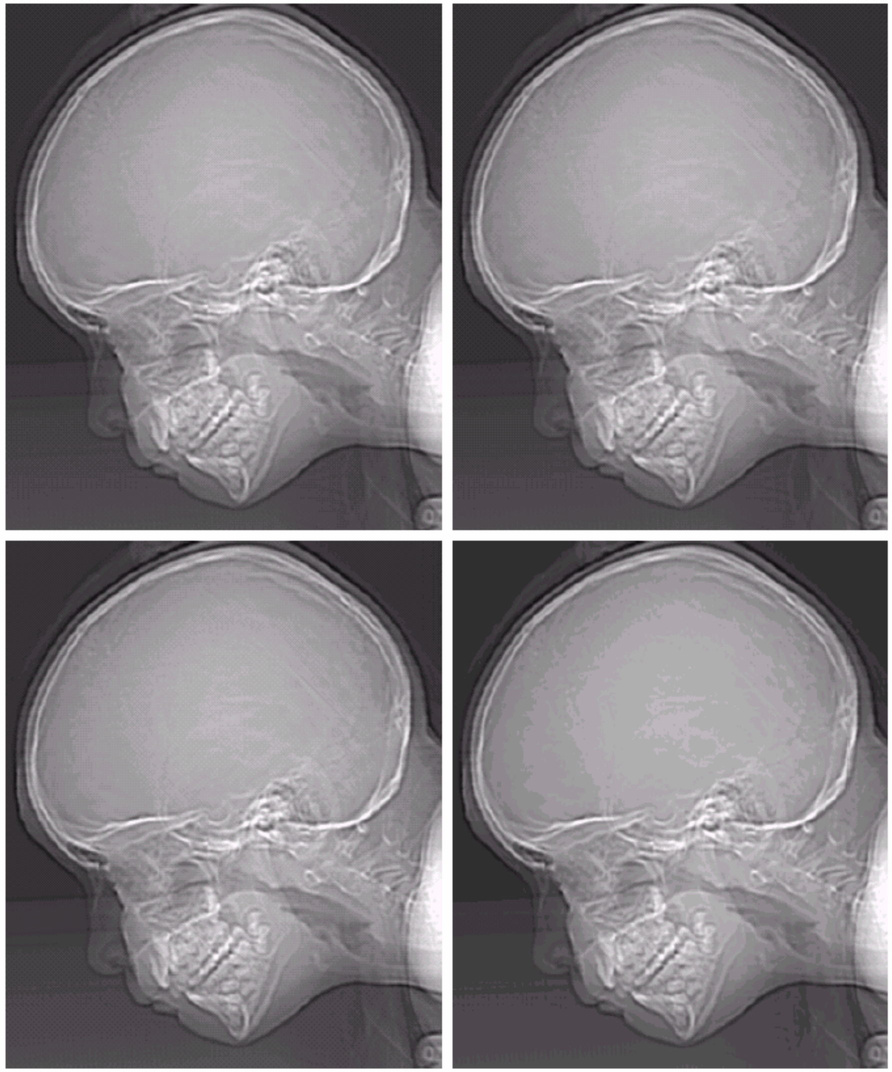


FIGURE 2.20 (a) 1024 × 1024, 8-bit image. (b) 512 × 512 image resampled into 1024 × 1024 pixels by row and column duplication. (c) through (f) 256 × 256, 128 × 128, 64 × 64, and 32 × 32 images resampled into 1024 × 1024 pixels.

Bit Depth – Grayscale Resolution

8 bits

7 bits



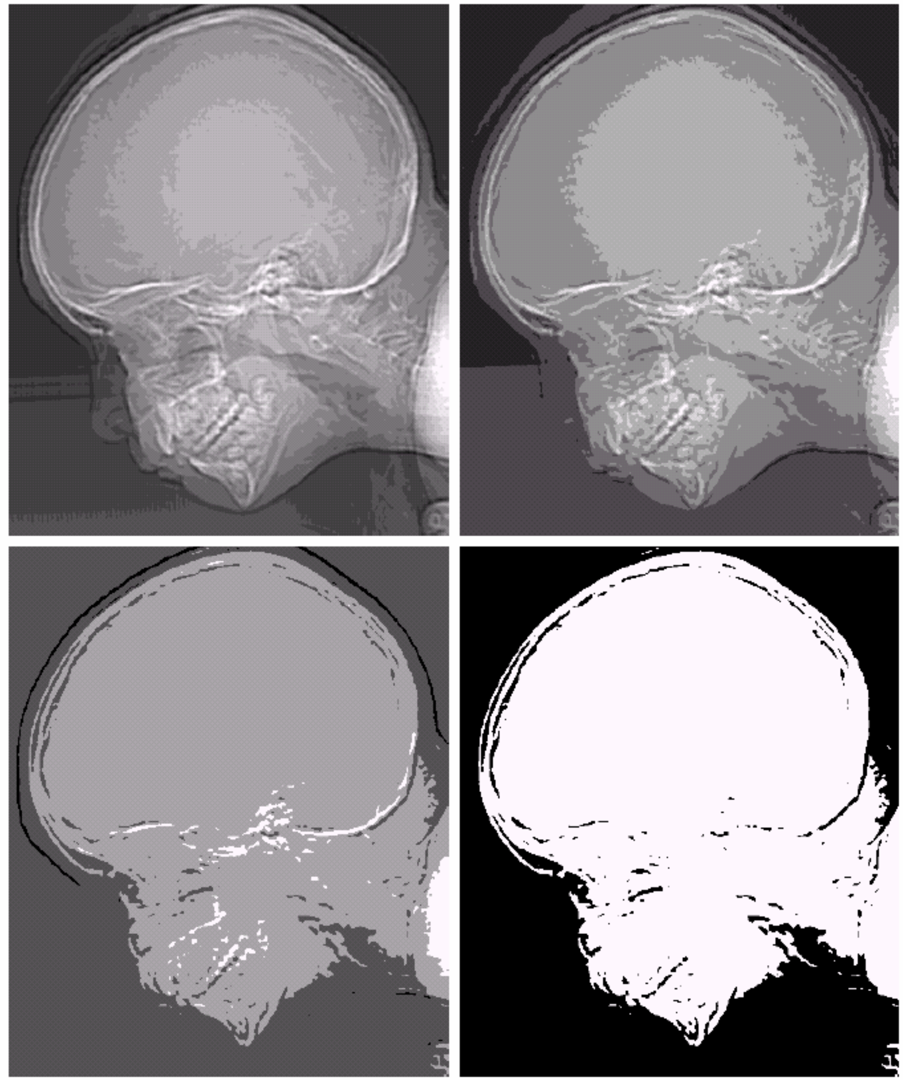
a b
c d

FIGURE 2.21 (a) 452 × 374, 256-level image. (b)–(d) Image displayed in 128, 64, and 32 gray levels, while keeping the spatial resolution constant.

6 bits

5 bits

Bit Depth – Grayscale Resolution



e f
g h

FIGURE 2.21 *(Continued)* (e)–(h) Image displayed in 16, 8, 4, and 2 gray levels. (Original courtesy of Dr. David R. Pickens, Department of Radiology & Radiological Sciences, Vanderbilt University Medical Center.)

Image file formats

- Many image formats (about 44)
- BMP, lossless
- TIFF, lossless/lossy
- GIF (Graphics Interchange Format)
  - Lossless, 256 colors, copyright protected
- JPEG (Joint Photographic Expert Group)
  - Lossless and lossy compression
  - 8 bits per color (red, green, blue) for a 24-bit total
- PNG (Portable Network Graphics)
  - Freewere
  - supports truecolor (16 million colours)
- ... more to come ..