Introduction to Image Processing

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Definition of image processing

- Digital image processing system

Input: image

System

Output: image

Image Processing overview

- **Image processing**
- Image analysis
- Image data types
- Related disciplines

Image Processing overview

- Image acquisition
- Image filtering
  - Contrast Enhancement
  - Pseudocoloring
  - Image Halftoning
  - Image Interpolation
- Image compression

Digital image filtering

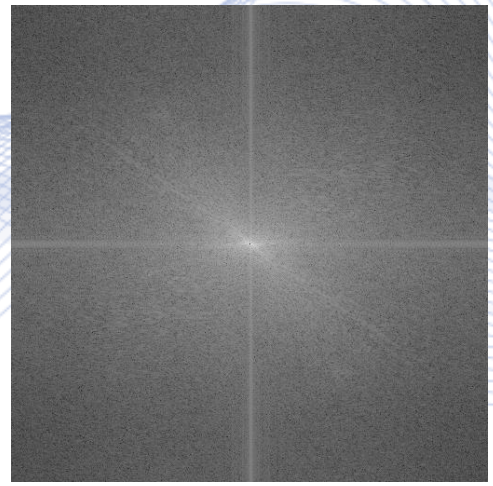
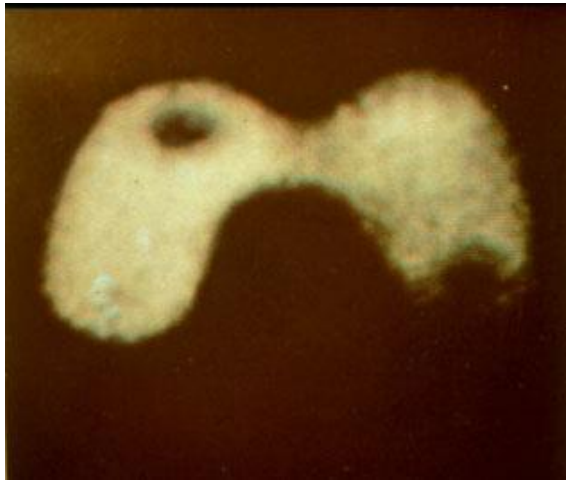
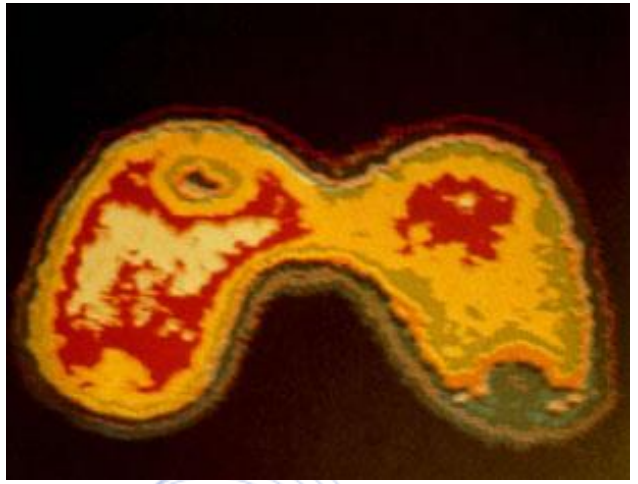


Image contrast enhancement

Image pseudocoloring





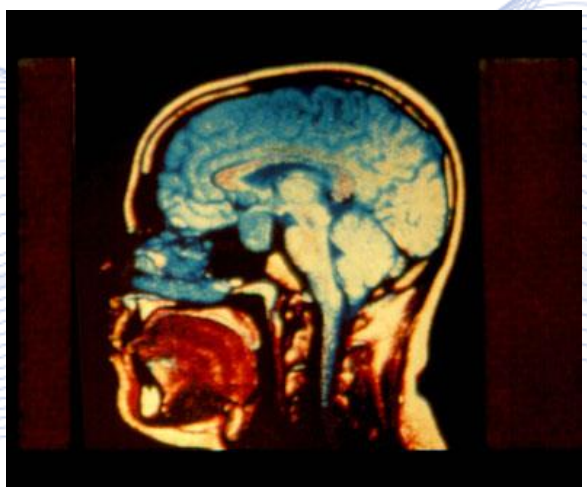
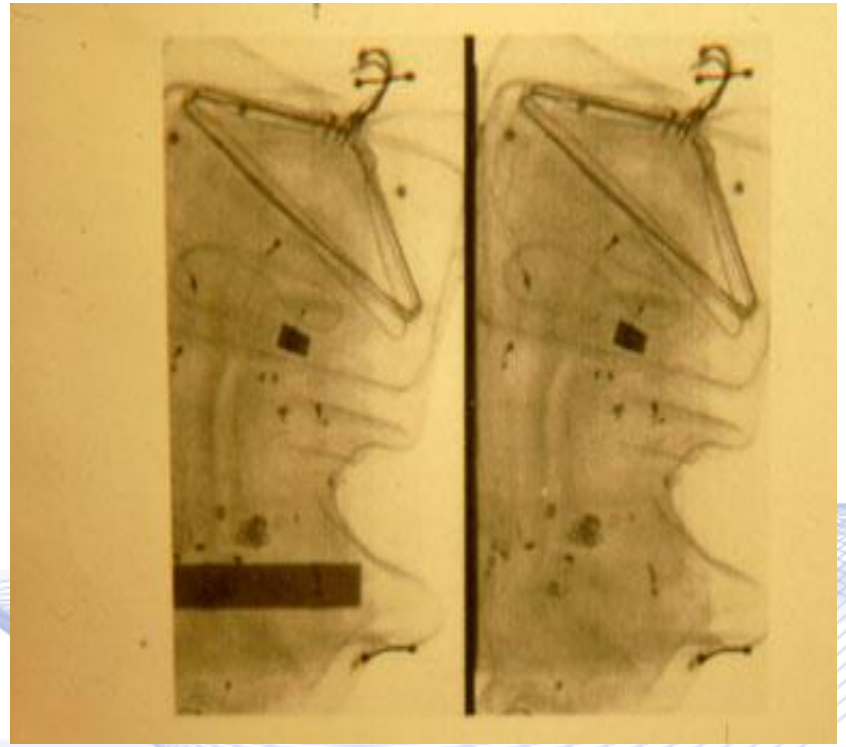
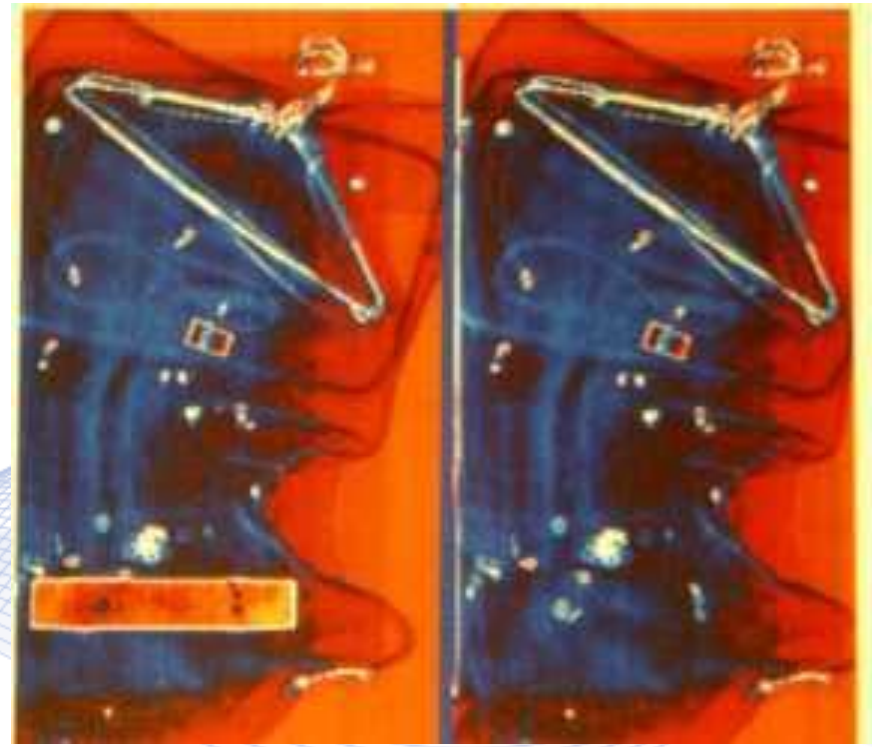


Image pseudocoloring



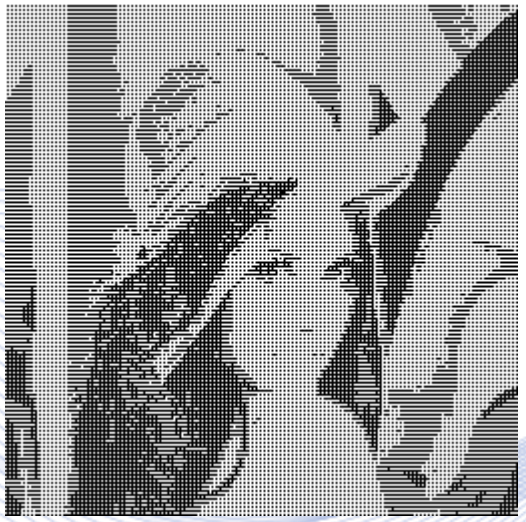


Digital image halftoning

- Greyscale Binary Fonts

Original Image

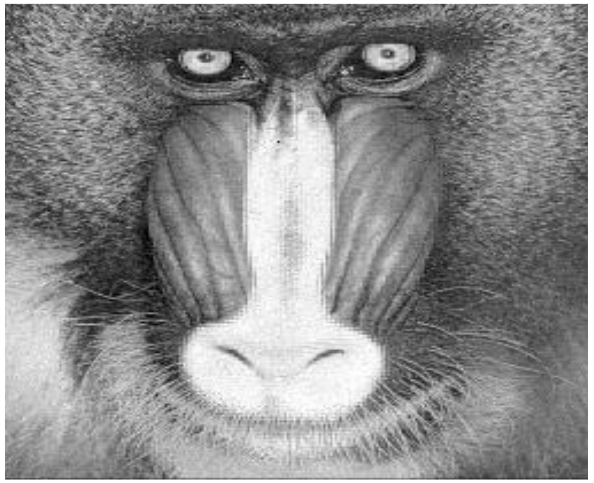
Original Image subsampled by a factor of 2

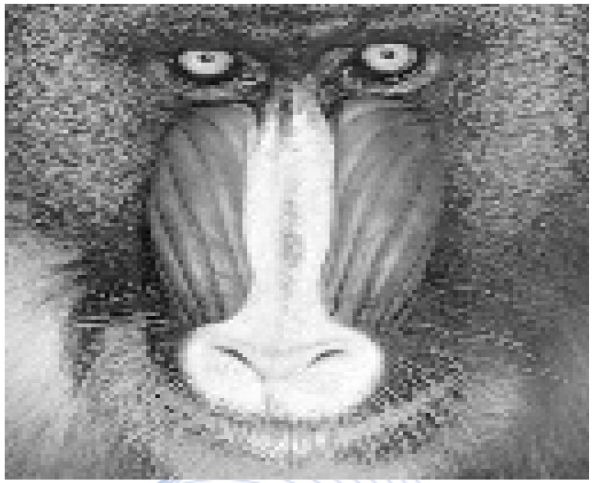


Halftoned Image using grayscale binary fronts

Image interpolation

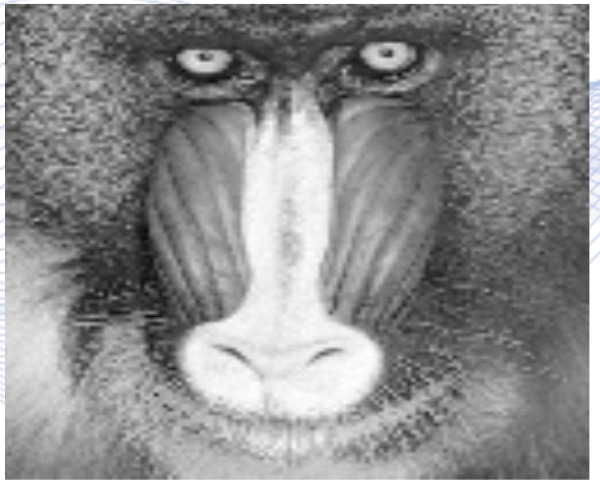
BABOON image





Output image after zero-order interpolation

Output image after linear interpolation



Output image after cubic spline interpolation

Image compression

(a)
Original image

(b)
JPEG compressed image

Image Processing overview

- Image processing
- **Image analysis**
- Image data types
- Related disciplines

Definition of image analysis

- Input: image

Output: symbolic description

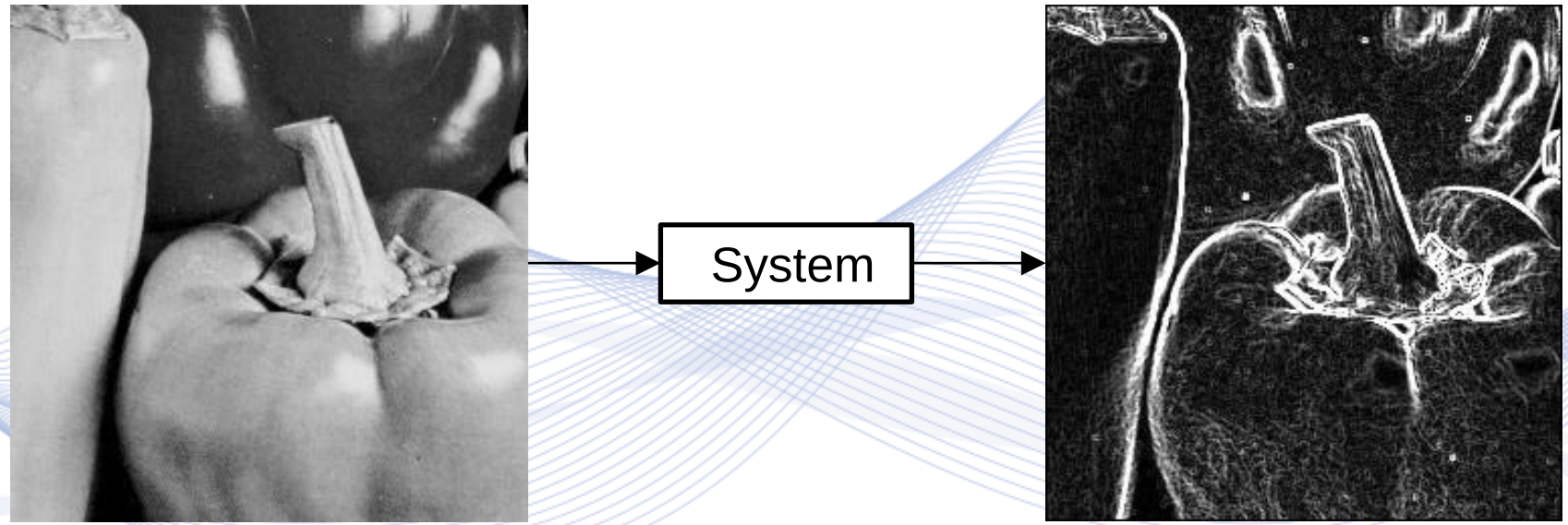
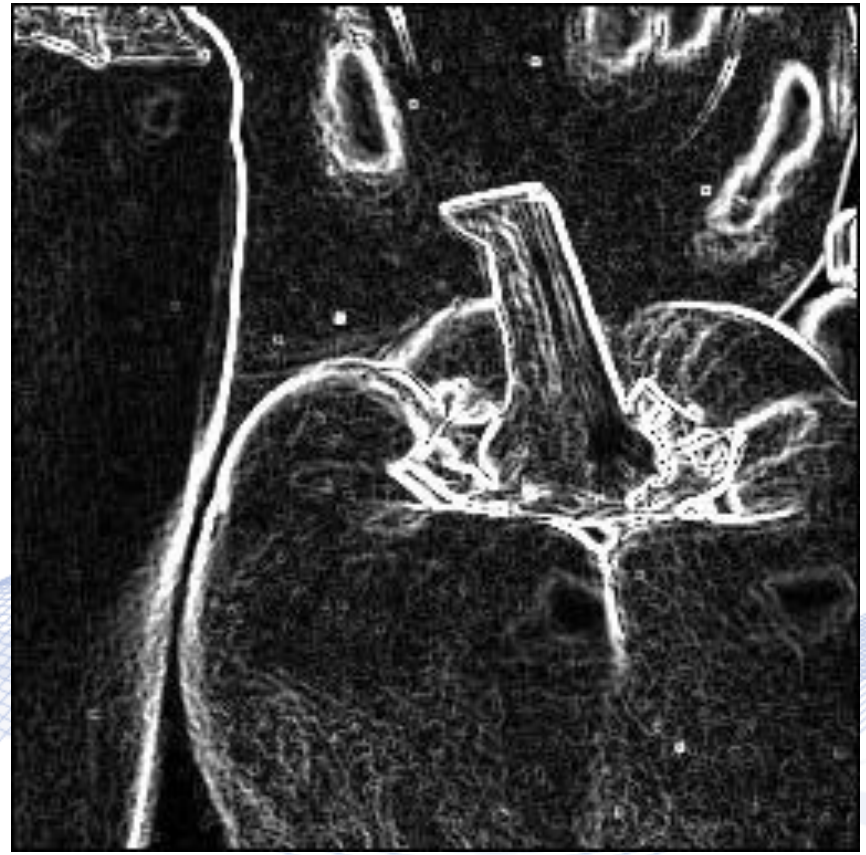


Image Analysis overview

- Region segmentation
- Edge detection
- Shape description

- Other terms used: ***2D computer vision***.

Edge detection



Region segmentation

Image thresholding.

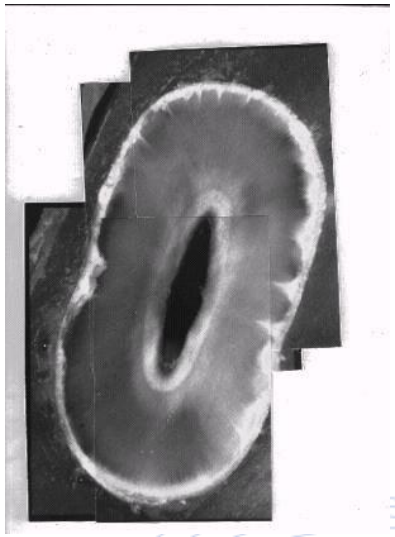
Region segmentation

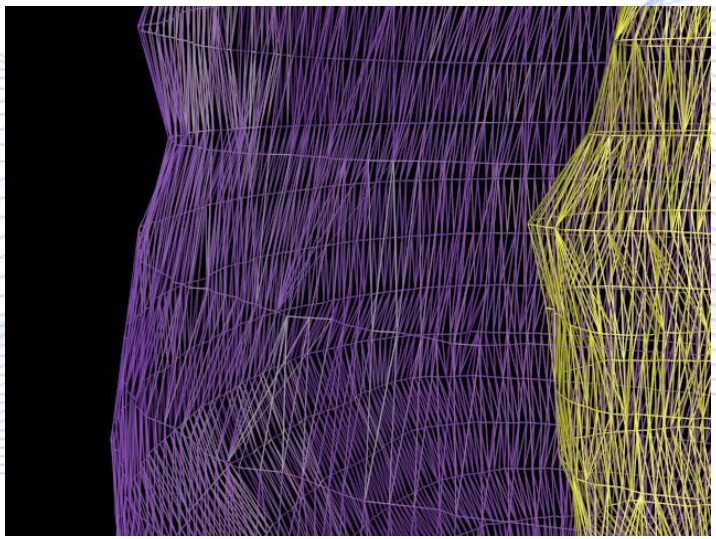
Foreground and background segmentation.

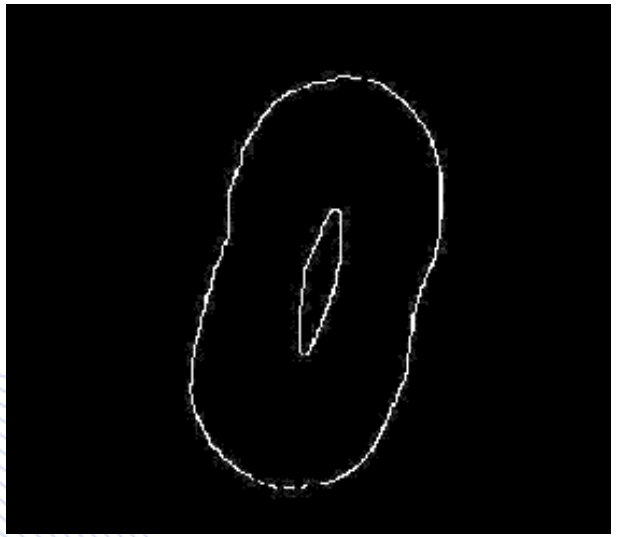
Region segmentation

Street scene segmentation [APOLLO].

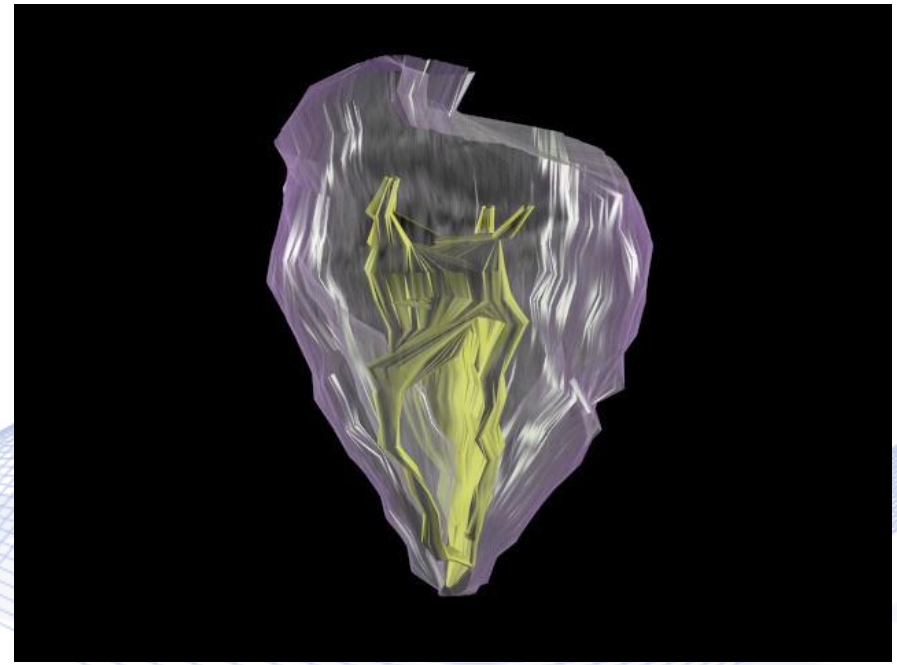
Contour following



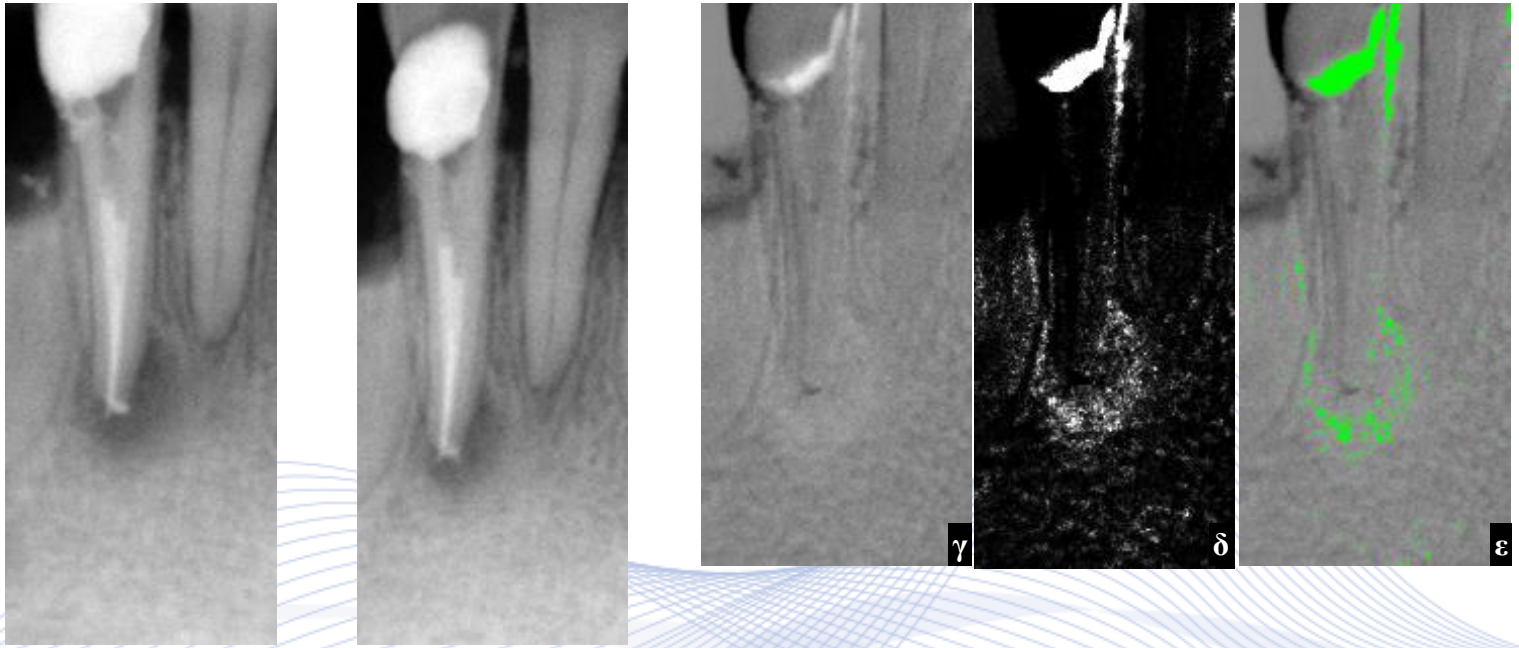




3D object modeling



2D Image registration

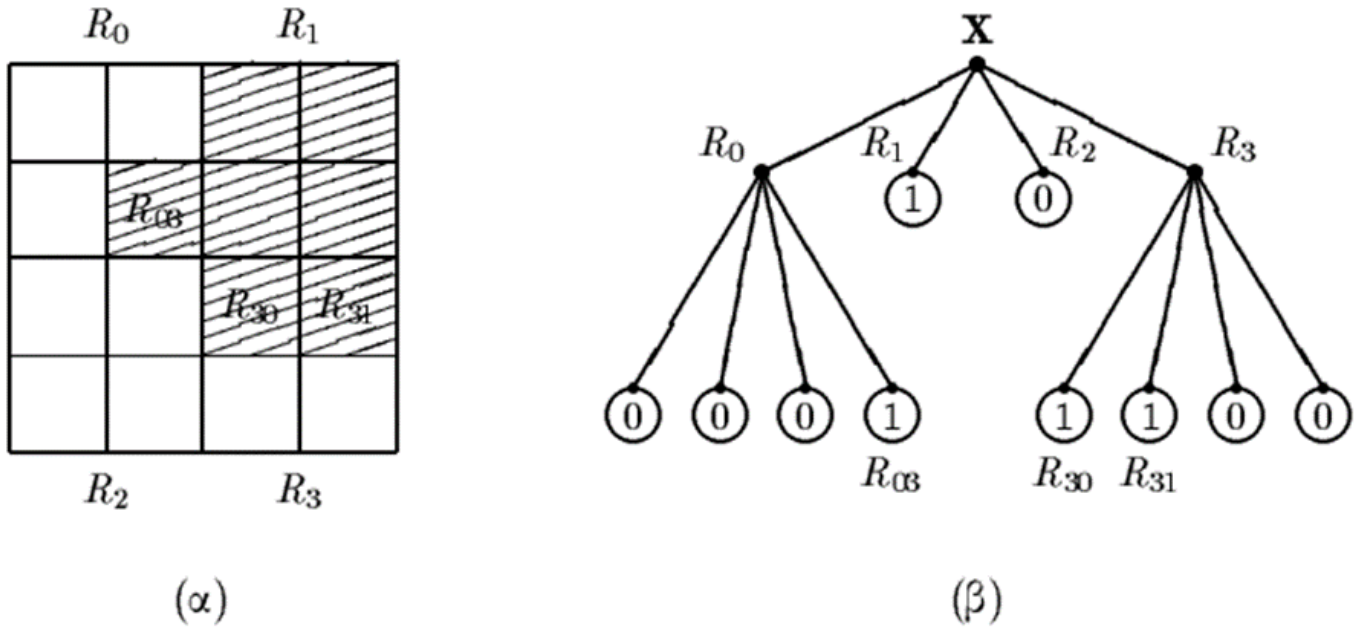


2D image registration and subtractive radiography.

2D Image registration

2D image registration: visible+xray painting image.

Shape description



Binary image

Quadtree representation

Image Processing overview

- Image processing
- Image analysis
- **Image data types**
- Related disciplines

1D data types: 1D signals

- **1D signals**:
- temporal 1D signals of the form: $f(t): \mathbb{R} \rightarrow \mathbb{R}$, having:
  - domain$\mathbb{R}$ and codomain $\mathbb{R}$.
- Audio signals, music signals,
- Biomedical signals: ECG. EEG, EMG
- 1D spatial signals of the form: $f(x): \mathbb{R} \rightarrow \mathbb{R}$
  - Traffic load along a street.

1D data types: 1D signals

Single variable functions are 1D signals:

- Sine/cosine functions/signals $\mathbb{R} \to \mathbb{R}$:

$$f(t) = \cos(\Omega t) = \cos(2\pi F t)\,.$$

- Complex-valued 1D signals $\mathbb{R} \to \mathbb{C}$:

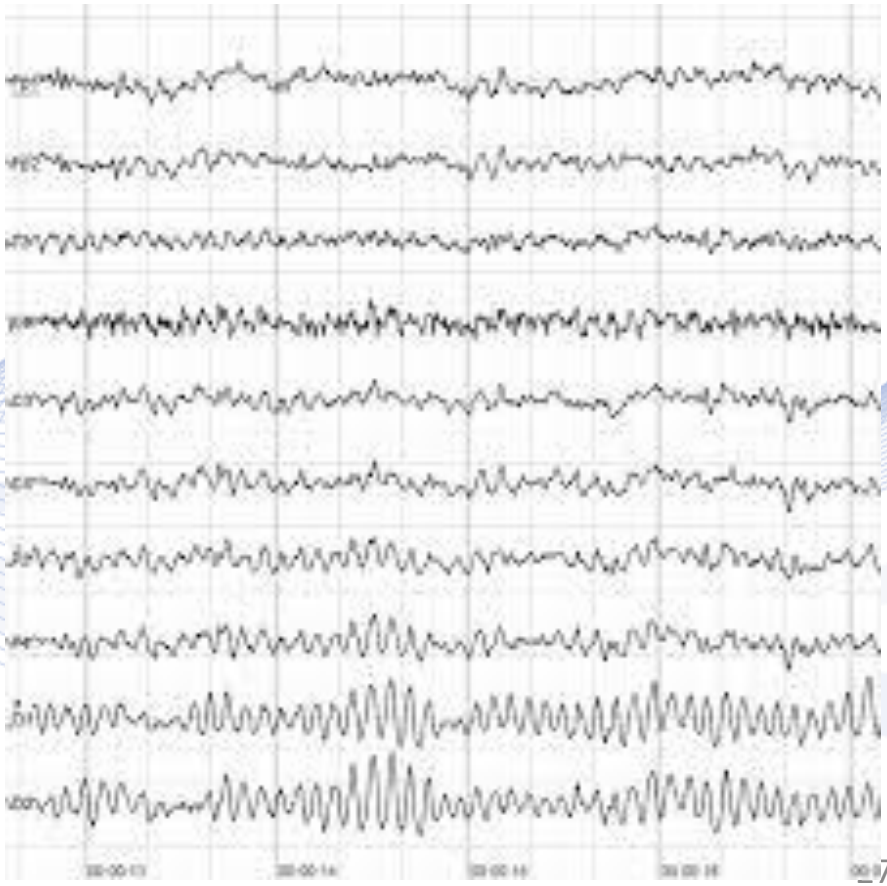
$$f(t) = \exp(i\Omega t) = \cos(\Omega t) + i\sin(\Omega t)\,.$$

Multichannel signals have the form: $\boldsymbol{f}(t)\colon \mathbb{R} \to \mathbb{R}^n$

- Stereo music signal: $\boldsymbol{f}(t) = [f_l(t), f_r(t)]^T\colon\ \mathbb{R} \to \mathbb{R}^2$
- 7.1 surround music sound: $\boldsymbol{f}(t) = [f_0(t), \ldots, f_7(t)]^T\colon\ \mathbb{R} \to \mathbb{R}^8$

1D data types: 1D signals

- Multichannel biomedical recordings $\boldsymbol{f}(t)\colon \mathbb{R} \to \mathbb{R}^n$.
  - ECG, EEG recordings.



2D data types: images

Spatial coordinates x, y.

2D data types: images

- ***Still images/pictures***: spatial 2D signals of the form $f(x, y)\colon \mathbb{R}^2 \to \mathbb{R}$, having:
  - domain $\mathbb{R}^2$ and codomain $\mathbb{R}$.
  - two spatial coordinates x, y.

- ***Image sampling/digitazation*** transforms continuous coordinates images to ***digital images***:

$$f(n_1, n_2)\colon \mathbb{Z}^2 \to [0, \dots, 2^B - 1].$$

2D data types: images

a) Grayscale image b) binary image.

2D data types: images

- Digital images consist of ***pixels*** (picture elements).
- A ***grayscale image*** has B bits per pixel. If $B = 8$, each pixel has 256 gray shades:
  - 0 black, 255 ‘white’.
- Also called ***Black and white*** (***BW***) ***images***.

- A ***binary image*** has 1 bit per pixel: black/white.

2D data types: images

- ***Color digital images*** are multichannel (vectorial) images with three channels ***Red*** (***R***), ***Green*** (***G***), ***Blue*** (***B***):

$$\boldsymbol{f}(n_1, n_2) = [f_R(n_1, n_2), f_G(n_1, n_2), f_B(n_1, n_2)]^T : \mathbb{Z}^2 \rightarrow [0, \dots, 2^B - 1]^3.$$

2D data types: images

Color image.

3D data types: hyperpectral images

- ***Multispectral/ multichannel images*** have the form:

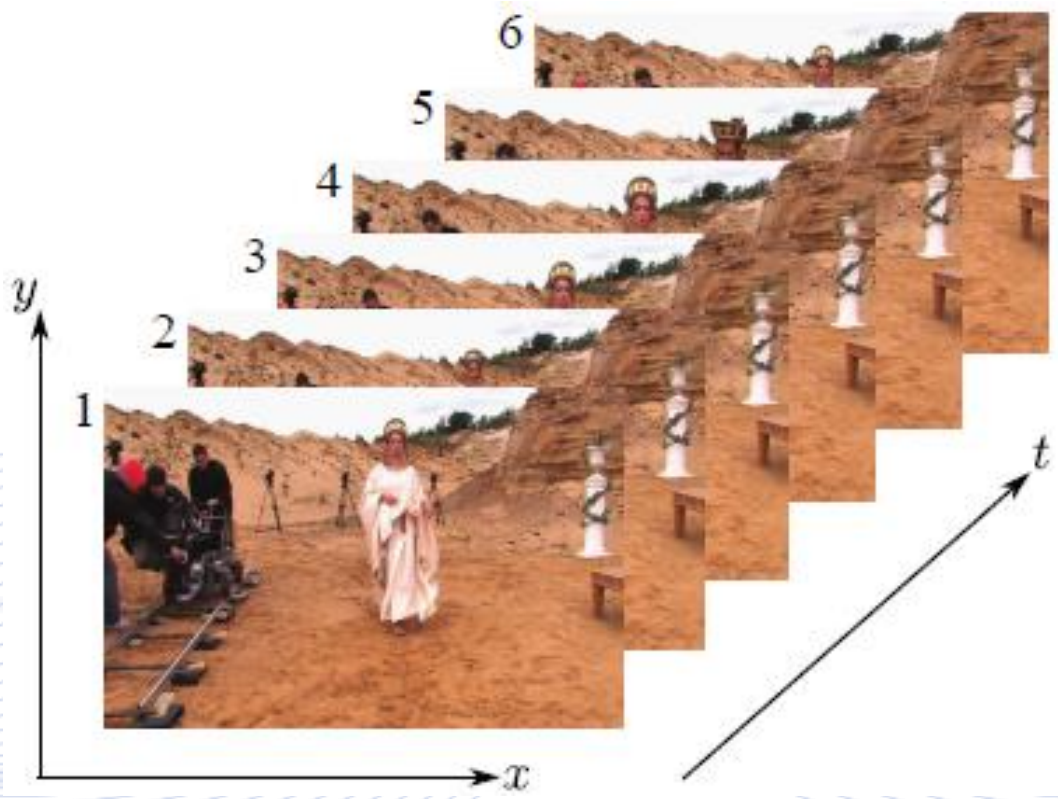
$$\boldsymbol{f}(x, y): \ \mathbb{R}^2 \rightarrow \mathbb{R}^n.$$

- color images ($n = 3$): $\boldsymbol{f}(x, y): \ \mathbb{R}^2 \rightarrow \mathbb{R}^3$.
- digital color images (assigning 8 bits per color channel to each voxel):

$$\boldsymbol{f}(n_1, n_2): \ \mathbb{Z}^2 \rightarrow \{0, \dots, 255\}^3.$$

- ***Hyperspectral images*** : $f(x, y, \lambda): \mathbb{R}^3 \rightarrow \mathbb{R}$.
  - λ wavelength.

3D data types: video



3D data types: video

- ***Moving images*** (***videos***) are spatiotemporal 3D signals of the form: $f(x, y, t)$: $\mathbb{R}^3 \rightarrow \mathbb{R}$, having:
  - domain $\mathbb{R}^3$ and codomain $\mathbb{R}$.
  - the time t coordinate has a different nature than the spatial coordinates x, y.
- ***Video scanning***: the process for obtaining an 1D analog video signal, by sampling video (luminance or RGB channels) along the vertical axis y and time t.

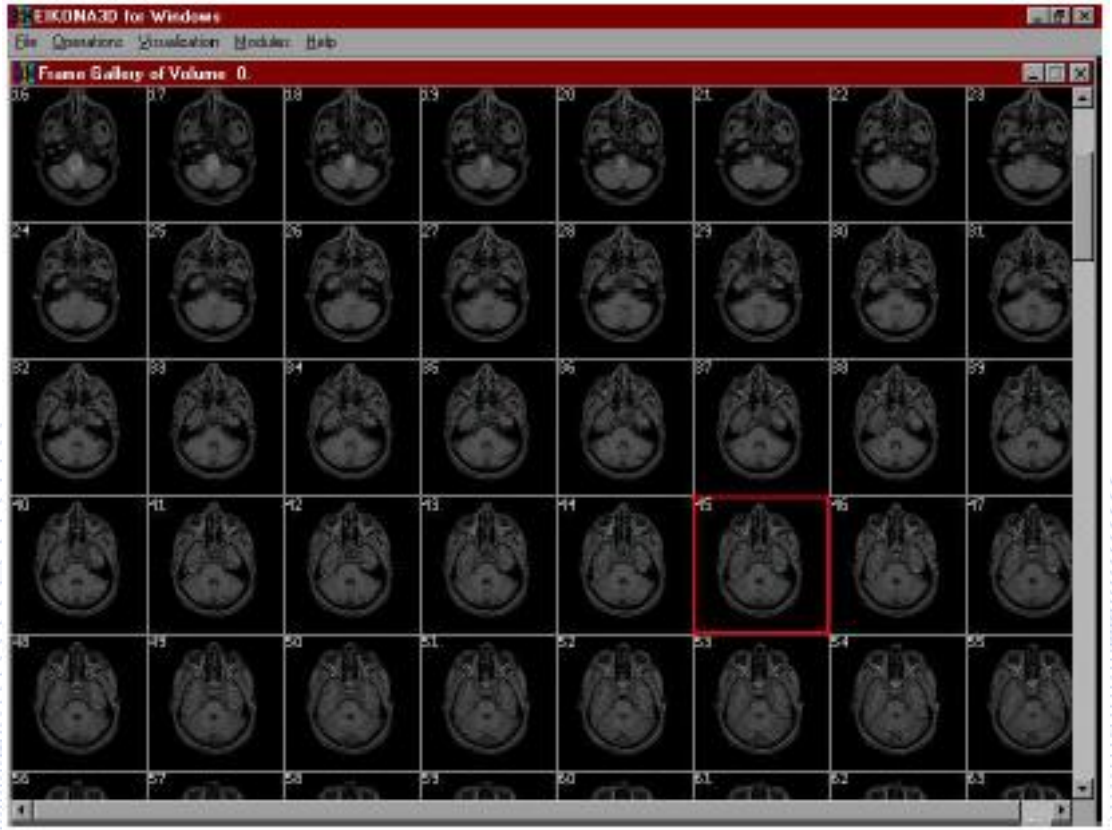
3D data types: video

- ***Analog video signal*** $f(x, j\Delta y, k\Delta t)$: $\mathbb{R} \times \mathbb{Z}^2 \rightarrow \mathbb{R}$.
  - discrete along y and t axes
  - continuous along x axis.
- ***Digital video signal*** $f(n_1\Delta x, n_2\Delta y, n_t\Delta t)$: $\mathbb{Z}^3 \rightarrow \mathbb{R}$.
- Spatial sampling intervals $\Delta x, \Delta y$ define ***image resolution***:
  - the smaller they are, the smaller the pixel size is.
- Temporal sampling interval Δt defines the ***video frame rate*** in ***frames per second*** (***fps***).

3D data types: volumetric images

- ***3D volumetric images***: 3D signals of the form $f(x, y, z): \mathbb{R}^3 \rightarrow \mathbb{R}$.
- Discrete versions (defined on a Euclidean grid $\mathbb{Z}^3$) : $f(n_1, n_2, n_3): \mathbb{Z}^3 \rightarrow \mathbb{R}$.
  - $x = n_1 \Delta x,\ y = n_2 \Delta y,\ z = n_3 \Delta z$
  - $\Delta x, \Delta y, \Delta z$: ***spatial sampling intervals*** defining 3D image resolution.
  - Each ***voxel*** (volume element) is a real number.

3D data types : volumetric images



3D data types

- ***Multiview images*** of an object or set are taken from different view points, typically using different cameras.
- ***Stereo images***: a special multiview image case, employing only two cameras (left and right):

  $\boldsymbol{f}(n_1, n_2) = [f_l(n_1, n_2), f_r(n_1, n_2)]^T$: $\mathbb{Z}^2 \rightarrow [0, \ldots, 2^B - 1]^2$.
- They both carry only implicit geometrical information about the visualized 3D object.
  - They are not 3D data.
  - 3D object geometry can be derived using stereo or multiview 3D geometry reconstruction techniques.

3D data types

Multiview images.

Image Processing overview

- Image processing
- Image analysis
- Image data types
- **Related disciplines**

Related disciplines

- Digital signal processing (1D signals)
- Graphics (Digital image/animation synthesis)
- Machine Learning and Pattern Recognition
  - Application in image analysis.
- Artificial intelligence
- Social media
- Image/video communication
- Multimedia data bases
- Digital media and television.

Bibliography

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[NIK2000] N. Nikolaidis and I. Pitas, “3D Image Processing Algorithms”, J. Wiley, 2000.
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Q & A

Thank you very much for your attention!

More material in
http://icarus.csd.auth.gr/cvml-web-lecture-series/

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