Image Typology summary

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Artificial Intelligence & Information Analysis Lab

2D data types: images

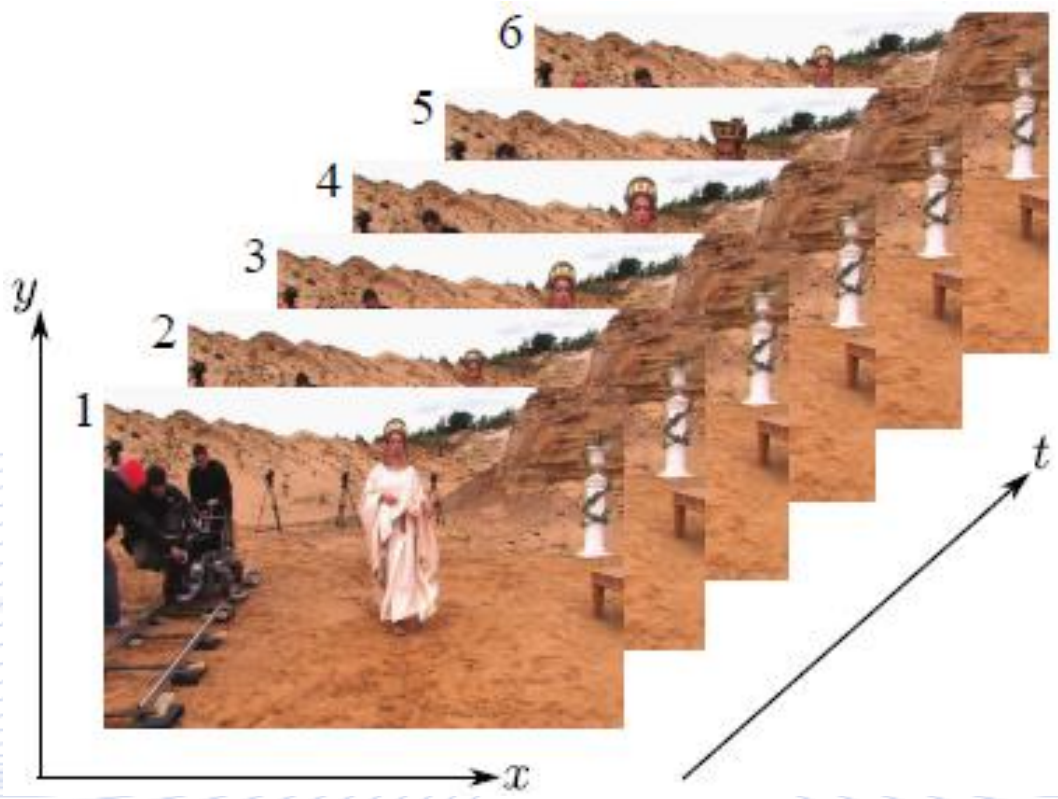
Spatial coordinates x, y.

2D data types: images

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

$$f(i, j): \mathbb{Z}^2 \rightarrow [0, \dots, 2^B - 1].$$

3D data types: video



3D data types: video

- Moving images: 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 the time-varying images (luminance or RGB channels) along the vertical axis y and time t.

3D data types: video

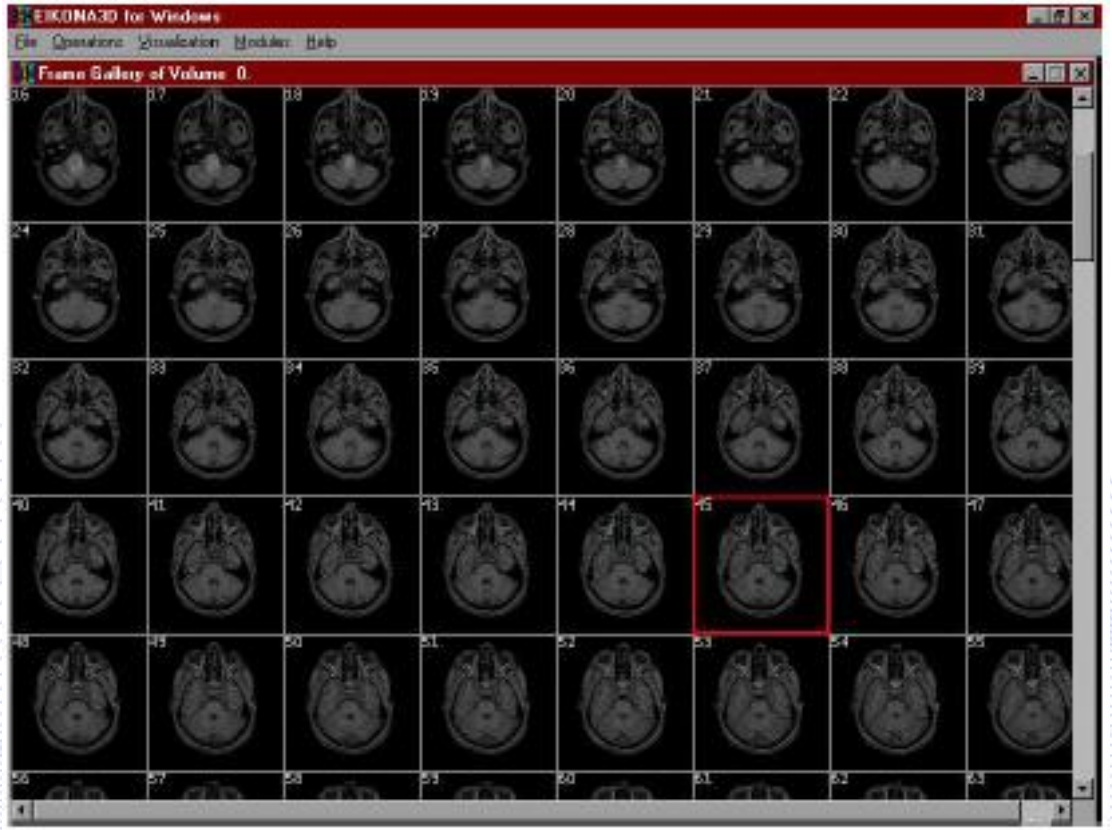
- Analog video signal $f(x, j\Delta y, k\Delta t)$: $\mathbb{R} \times \mathbb{Z}^2 \rightarrow \mathbb{R}$.
  - discrete along y and t axes
  - continuous along x axis.
- Digital video signal $f(i\Delta x, j\Delta y, k\Delta t)$: $\mathbb{Z}^3 \rightarrow \mathbb{R}$.
- Spatial sampling intervals $\Delta x, \Delta y$ 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* is a real number.

3D data types : volumetric images



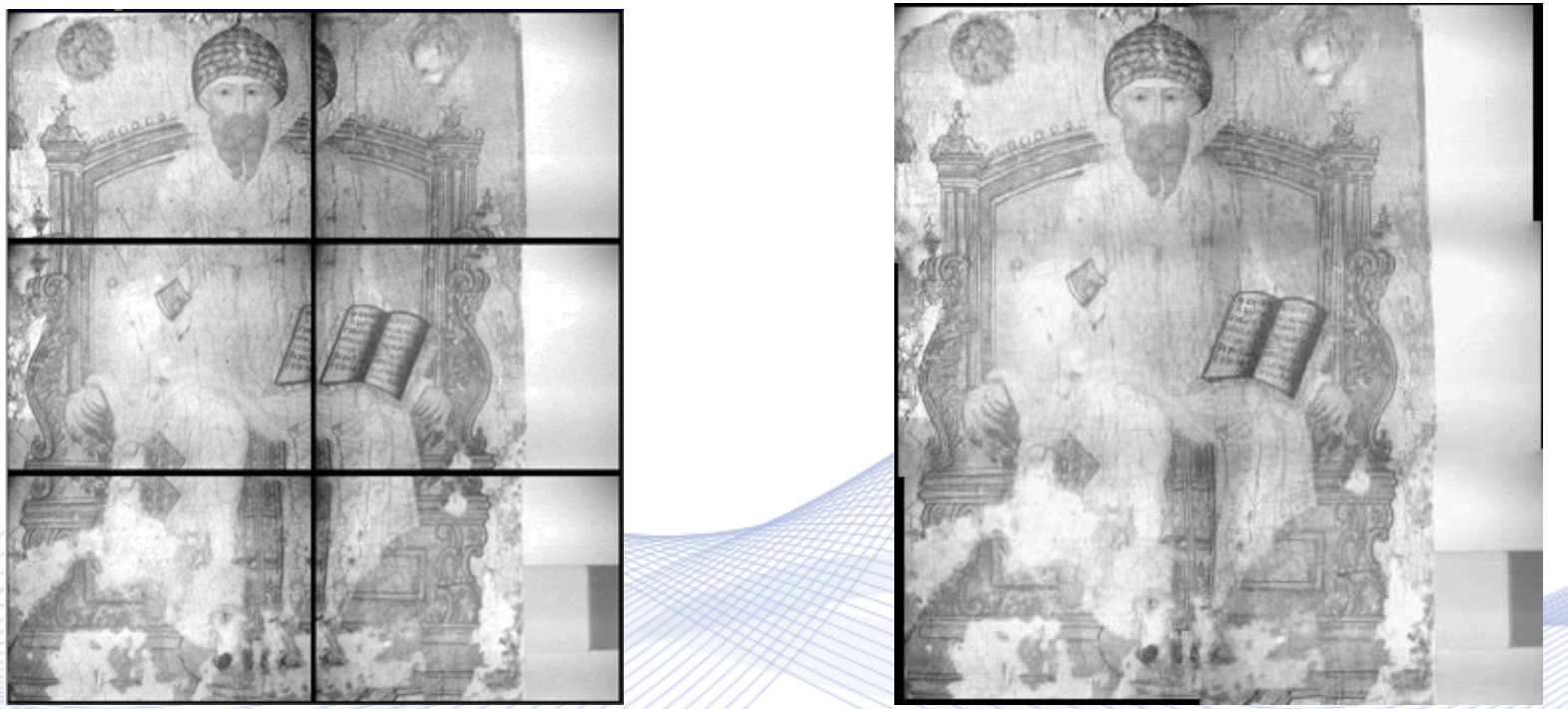
3D data types: multispectral images

- Multispectral / multichannel (n-channel) images have the form: $\mathbf{f}(x, y)$: $\mathbb{R}^2 \rightarrow \mathbb{R}^n$.
  - color images($n = 3$): $\mathbf{f}(x, y) = [f_R(x, y), f_G(x, y), f_B(x, y)]^T : \mathbb{R}^2 \rightarrow \mathbb{R}^3$.
  - digital color images (assigning 8 bits per color channel to each voxel): $\mathbf{f}(n_1, n_2)$: $\mathbb{Z}^2 \rightarrow \{0, \ldots, 255\}^3$.
  - Hyperspectral images : $f(x, y, \lambda)$: $\mathbb{R}^3 \rightarrow \mathbb{R}$
    - λ wavelength.

Infrared images

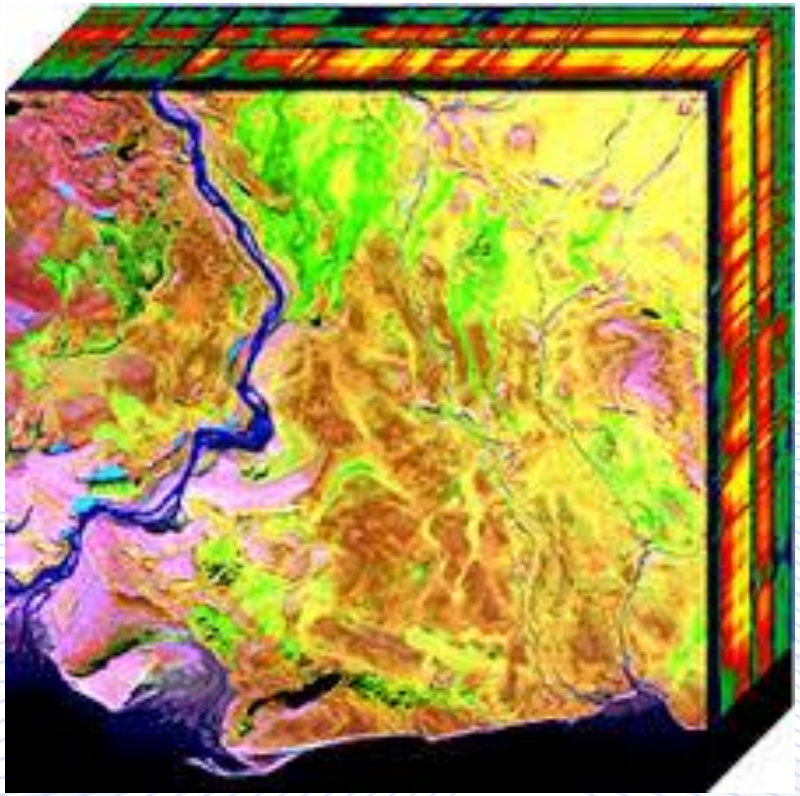
[www.Infrareddiagnostic.com]

Reflectography



a) IR image tiles of a painting; b) mosaiced IR image.

Hyperspectral images



[Wikipedia]

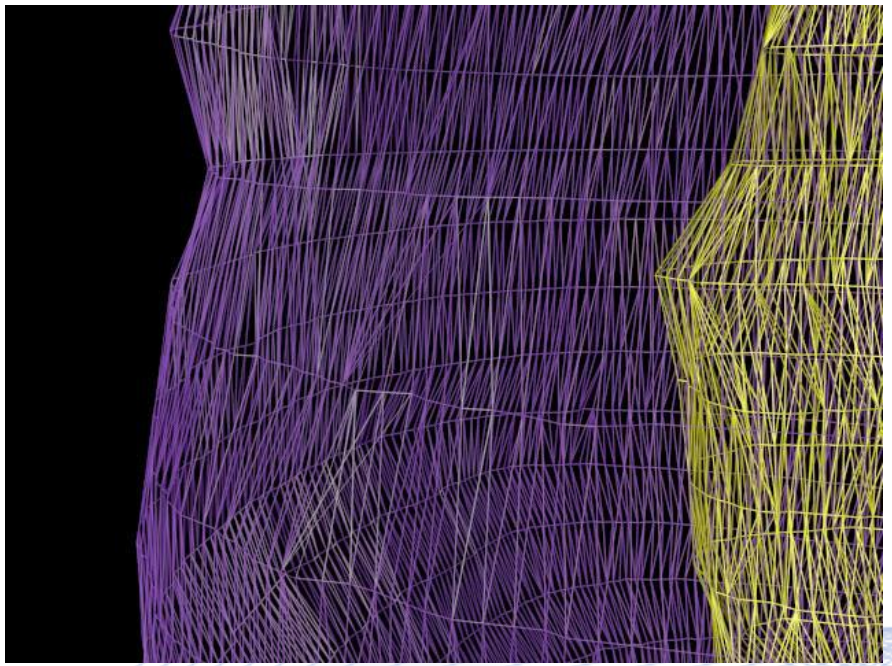
3D data types

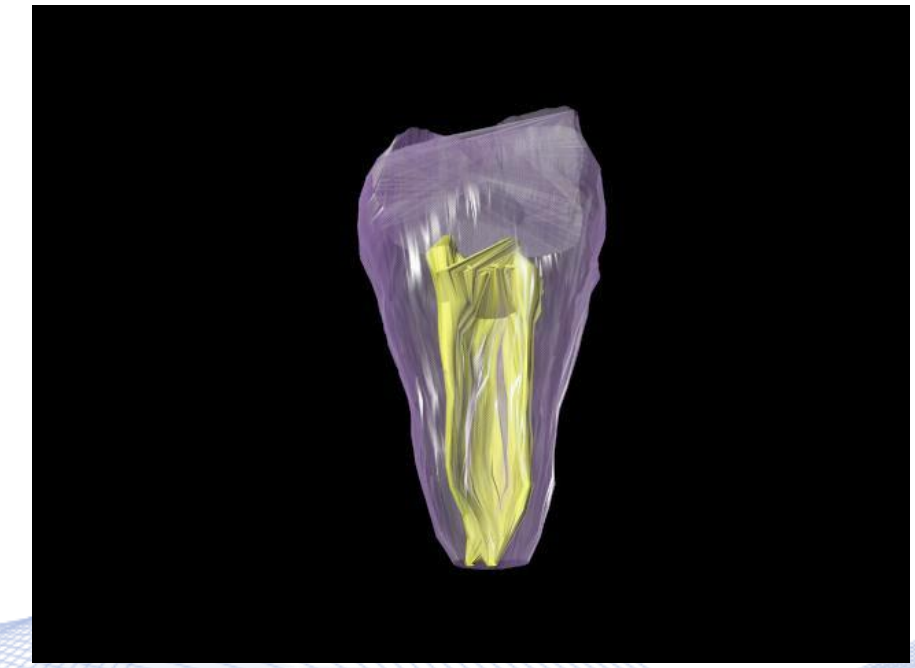
- *Multiview* images: images of an object or set, taken from different view points, typically using different cameras.
  - Stereo images: a special case, employing only two cameras (left and right).
- They both carry only implicit geometrical information about the visualized 3D object.
  - They are not 3D data.
  - 3D object geometry can be derived using stereo or multiview 3D geometry reconstruction techniques.

3D data types

- Multiview (or stereo) video: captured by synchronized video-cameras.

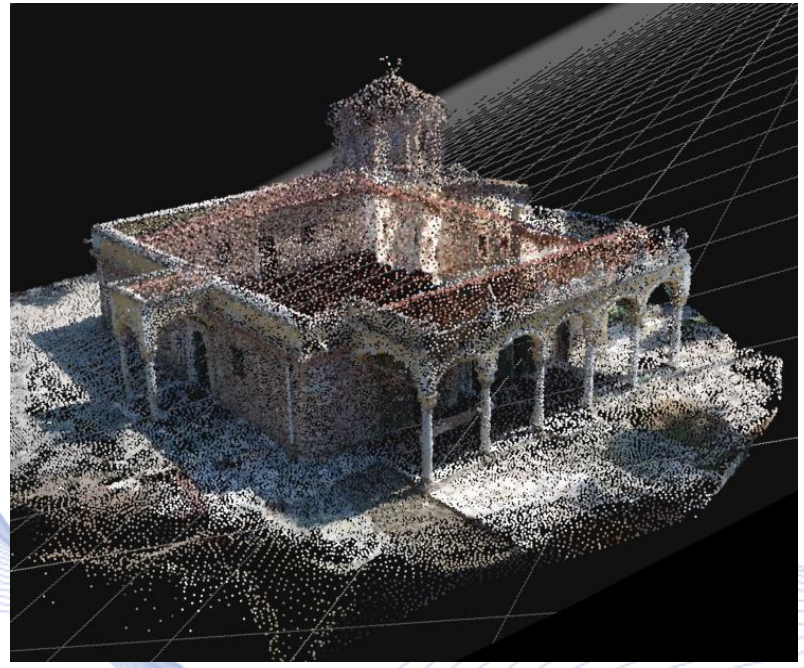
3D data types





- 3D Type equation here.surface $\mathcal{S} \subset \mathbb{R}^3$ (expressed, e.g., by a triangular mesh).
- 3D surface texture: $\mathbf{f}(X, Y, Z)$: $\mathcal{S} \subset \mathbb{R}^3 \rightarrow \mathbb{R}^3$.

3D data types



- 3D surface $\mathcal{S} \subset \mathbb{R}^3$ (expressed, e.g., by a 3D point cloud).
- 3D surface texture: $\mathbf{f}(X, Y, Z)$: $\mathcal{S} \subset \mathbb{R}^3 \rightarrow \mathbb{R}^3$.

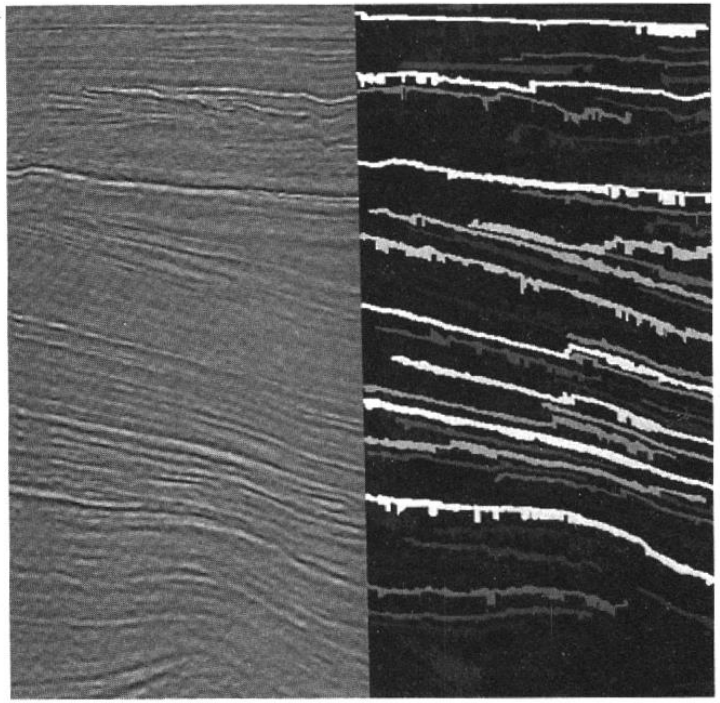
3D data types

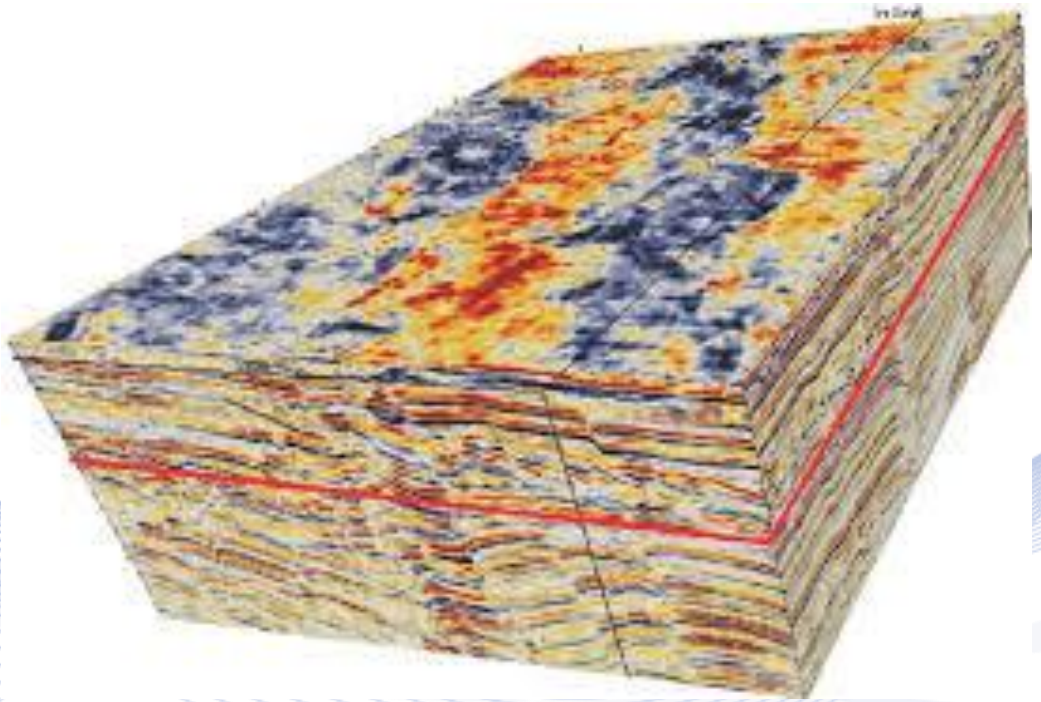
- RGB-D images have: a) RGB channels and b) D (depth) channel.
- They are acquired by RGB-D cameras.

3D data types

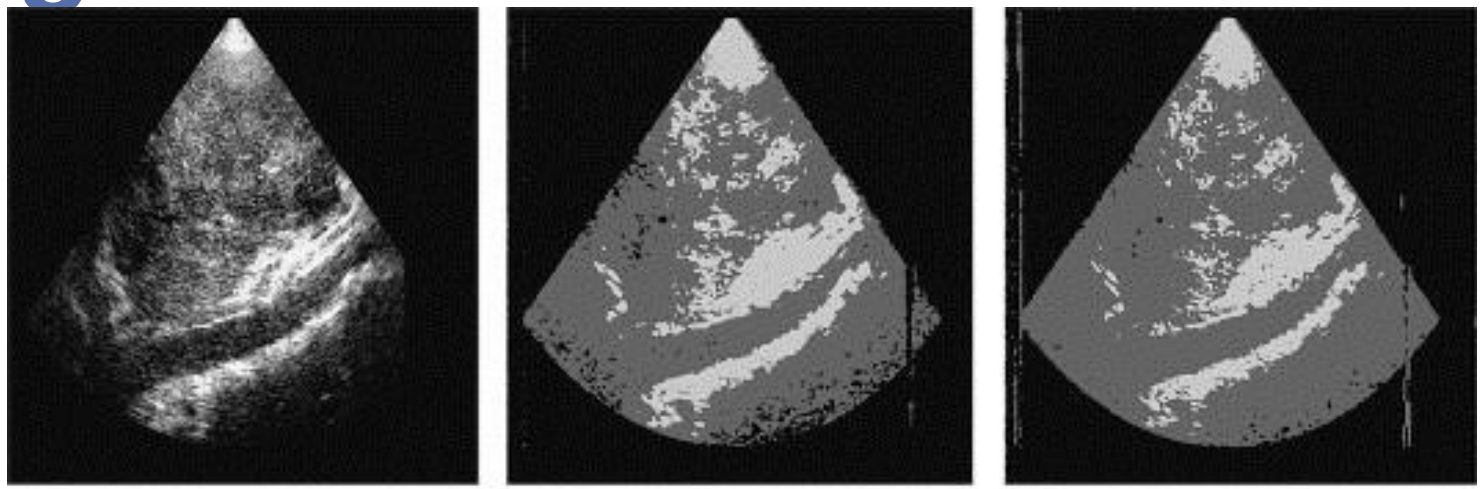
RGB-Depth image acquired from monocular video [APOLLO].

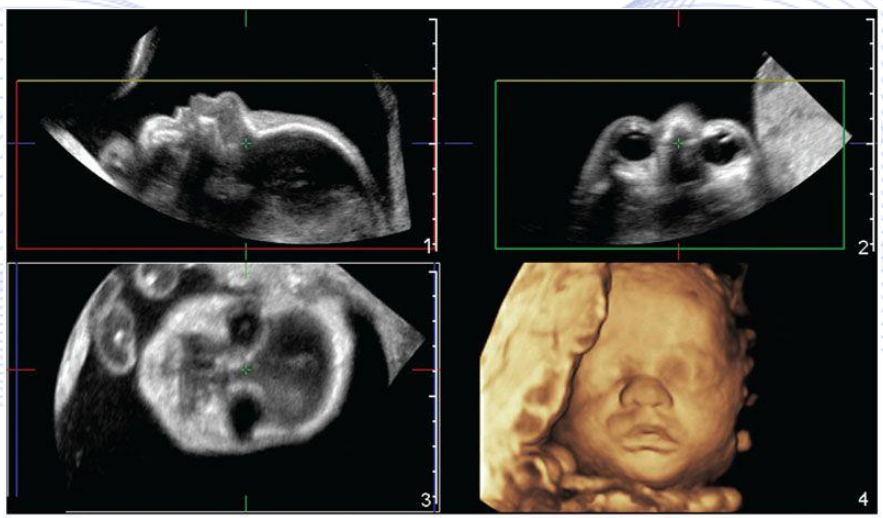
3D data types : seismic images and volumes



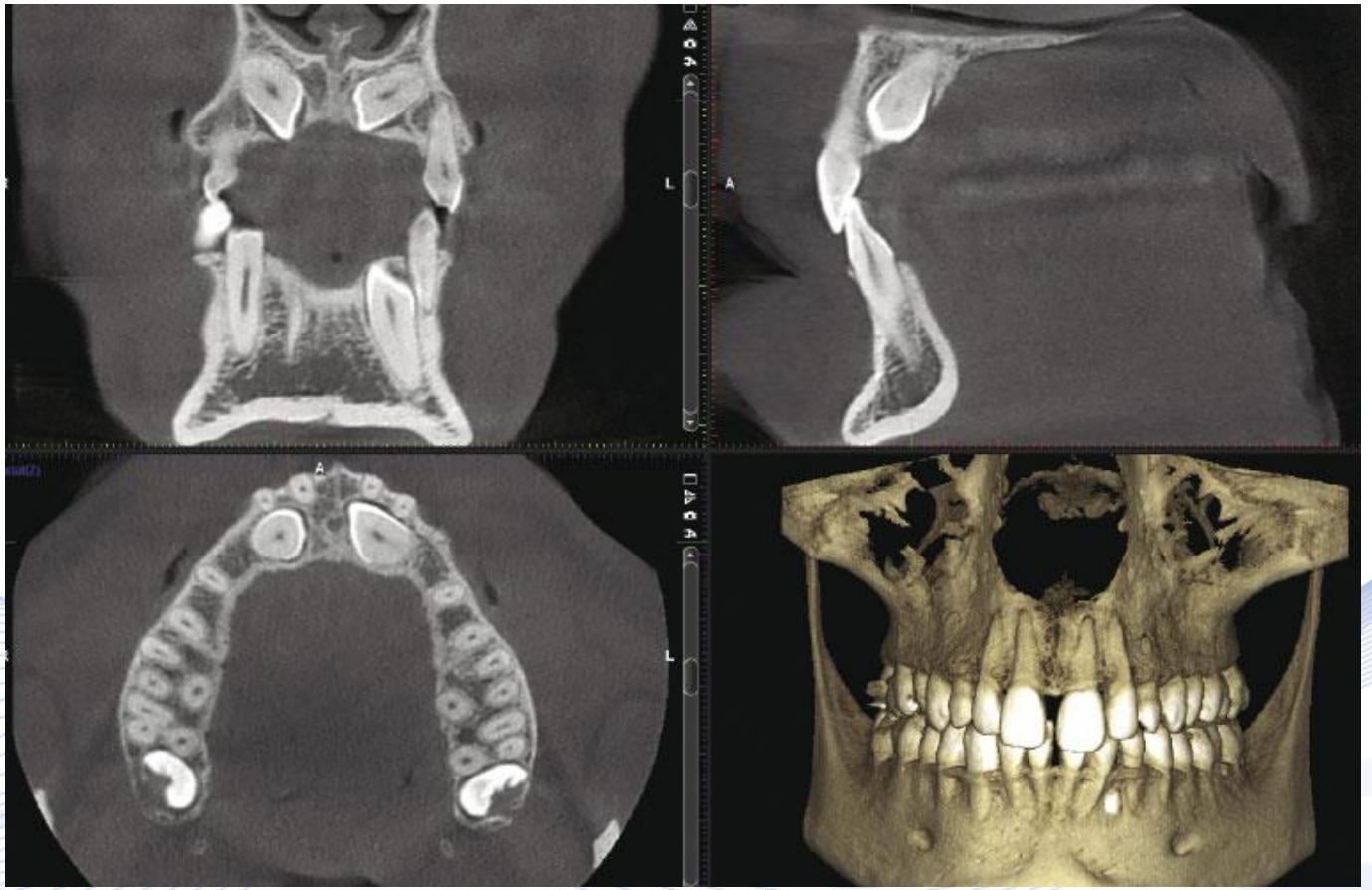


3D data types : ultrasound images and volumes



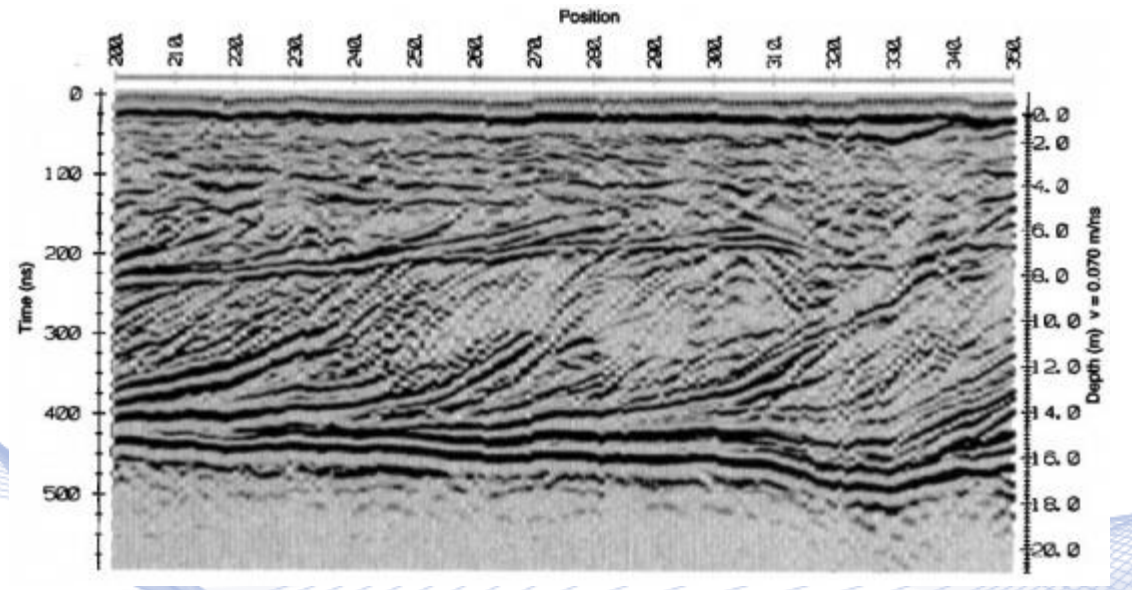


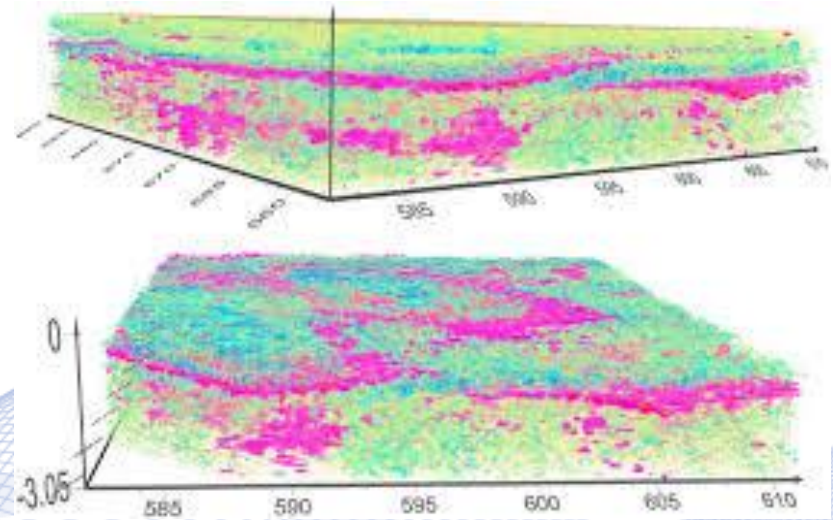
3D data types : x-ray images



a) Tooth X-ray; b) CBCT volume.

3D data types: Ground penetrating radar





Ground penetrating radar a) image; b) volume.

Color theory

- Visible light: an electromagnetic wave with wavelength λ varying in the range $380 - 780\ nm$.
- Perceived color: depends on the spectral content of the light.
  - Red light: a signal with energy concentrated around $700\ nm$.
  - White light: a signal with evenly distributed energy across the wavelength spectrum.
  - *Monochromatic* color: a color with a very narrow spectral content (typically single-wavelength).

Color theory

- Multispectral / multichannel (n-channel) images have the form: $\mathbf{f}(x, y)$: $\mathbb{R}^2 \rightarrow \mathbb{R}^n$.
  - color images($n = 3$): $\mathbf{f}(x, y) = [f_R(x, y), f_G(x, y), f_B(x, y)]^T : \mathbb{R}^2 \rightarrow \mathbb{R}^3$.
  - digital color images (assigning 8 bits per color channel to each voxel): $\mathbf{f}(n_1, n_2)$: $\mathbb{Z}^2 \rightarrow \{0, \dots, 255\}^3$.
  - They can also be considered as 3D images: $f(n_1, n_2, i), i = 1,2,3$.
  - Hyperspectral images (3D images): $f(x, y, \lambda)$: $\mathbb{R}^3 \rightarrow \mathbb{R}$
    - λ wavelength.

Color images

RGB color image.

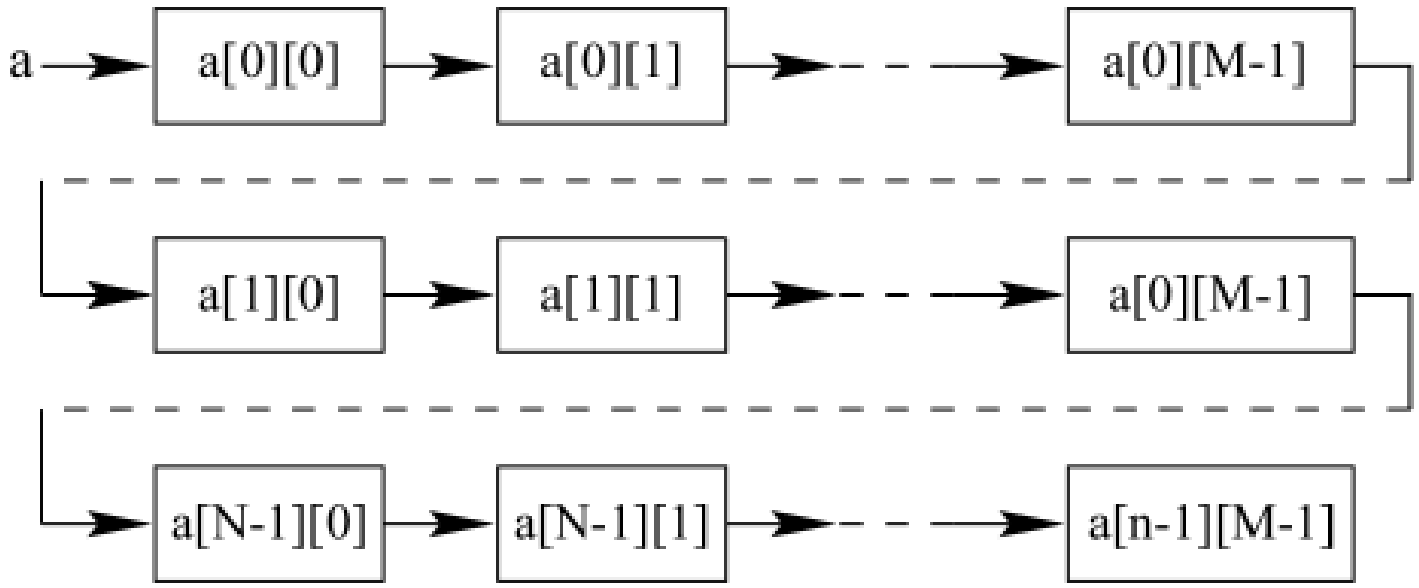
Digital Image Representation

Digital image representation by an $N \times M$ matrix $\boldsymbol{i}$:

$$\boldsymbol{i} = \begin{bmatrix} i(1,1) & i(1,2) & \dots & i(1,M) \\ i(2,1) & i(2,2) & \dots & i(2,M) \\ \vdots & \vdots & \dots & \vdots \\ i(N,1) & i(N,2) & \dots & i(N,M) \end{bmatrix}.$$

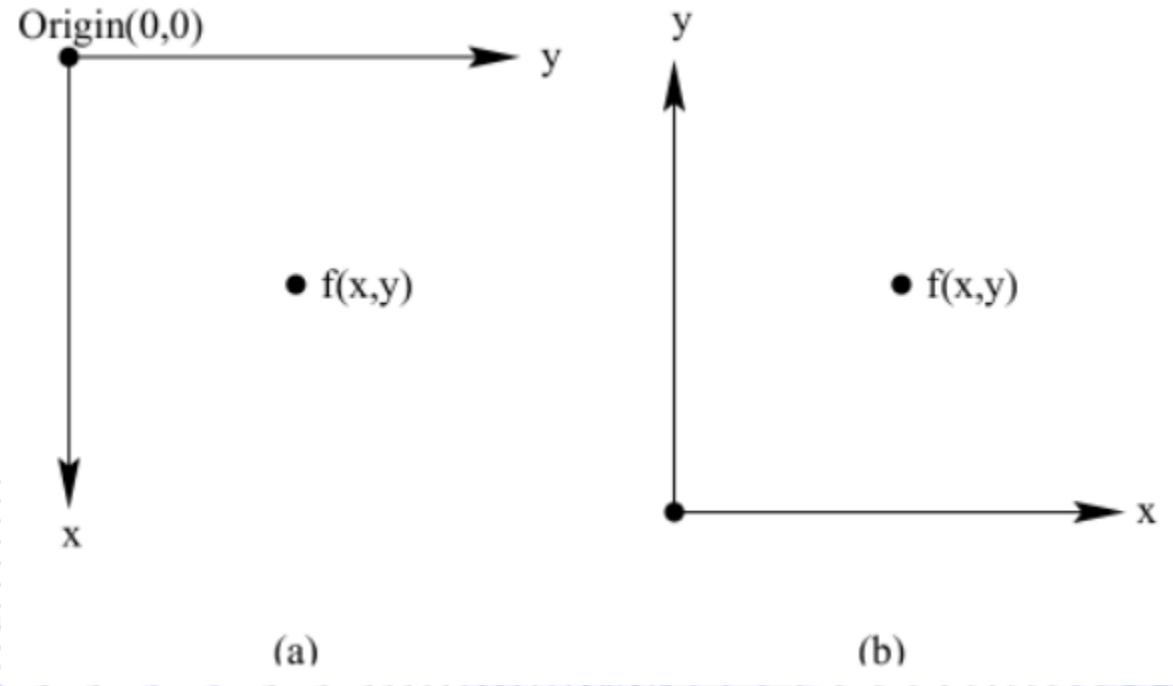
- Matrix elements (image pixels):
  - integers in the range $[0, \dots, 255]$ for 8 bit images.
  - unsigned character representation in the C language.

Digital Image Representation



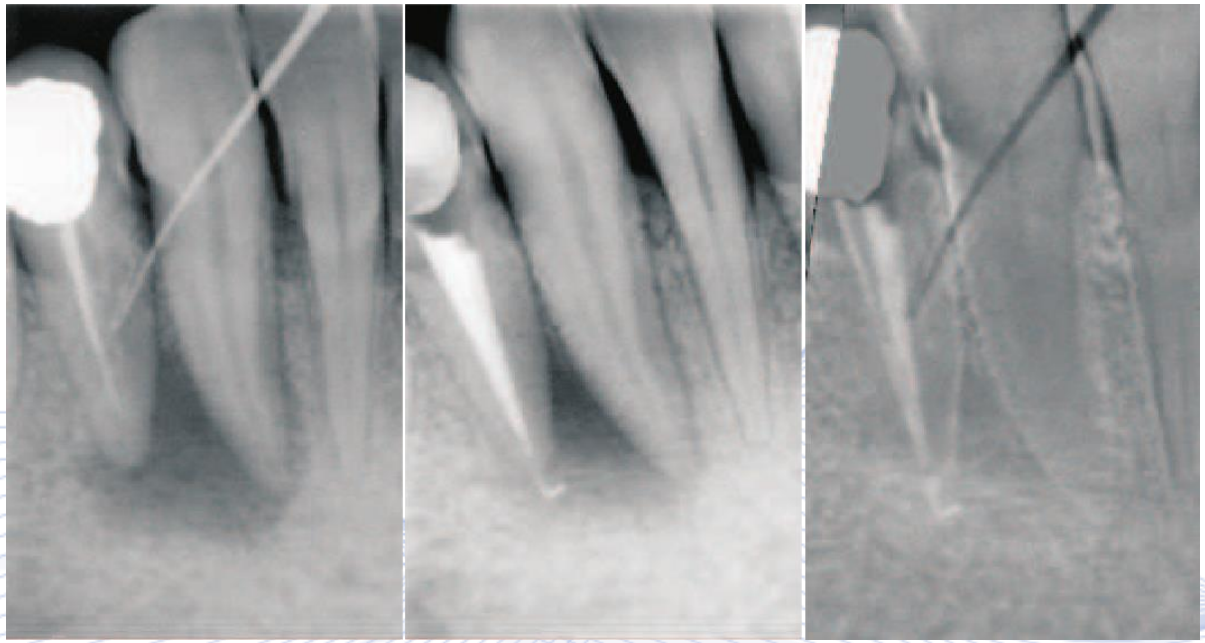
2D image storage.

Digital Image Representation



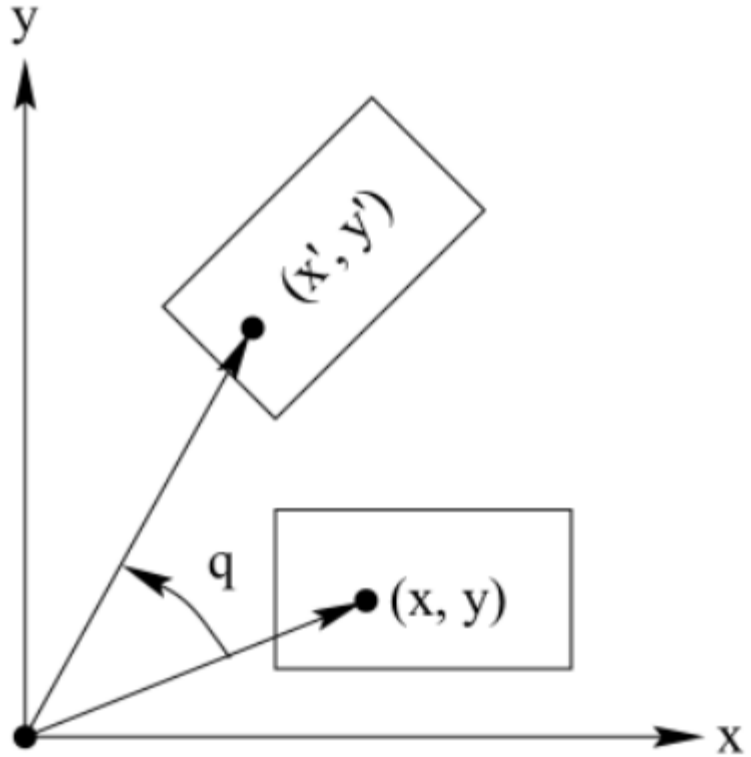
a) 2D matrix coordinates; b) Cartesian coordinates.

Elementary digital image processing operations



Subtractive radiography.

Elementary digital image processing operations



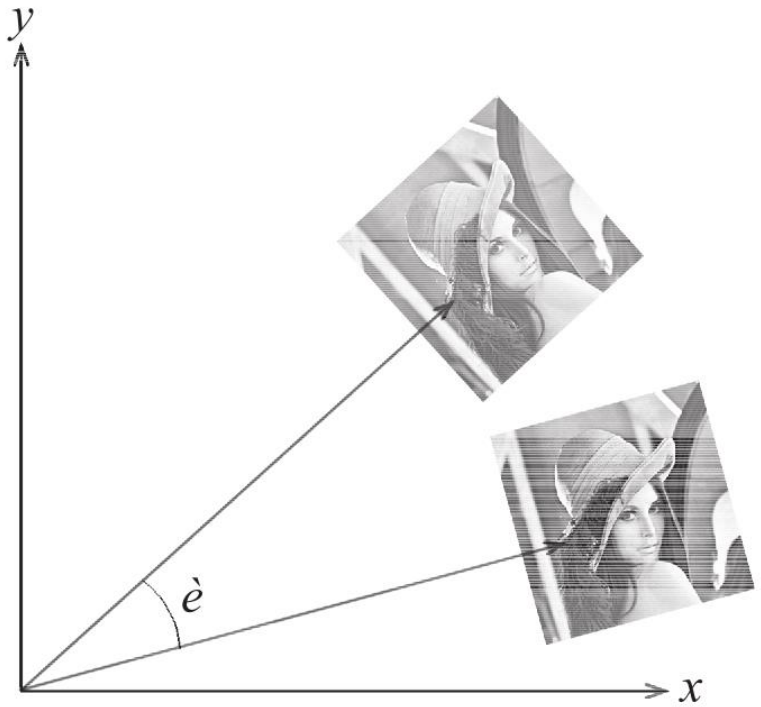
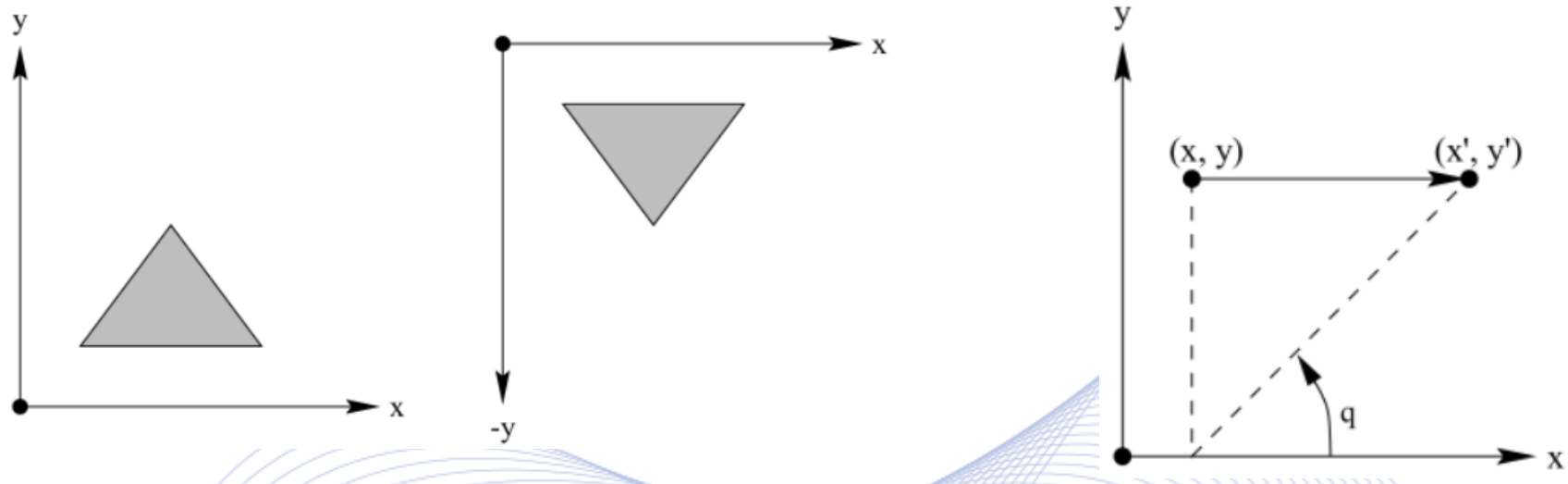


Image rotation.

Elementary digital image processing operations



a) b)

a) Geometrical reflection on the x-axis; b) Shear along the horizontal axis.

Image Noise Generation

Artificial noise generation is primarily needed for simulations.

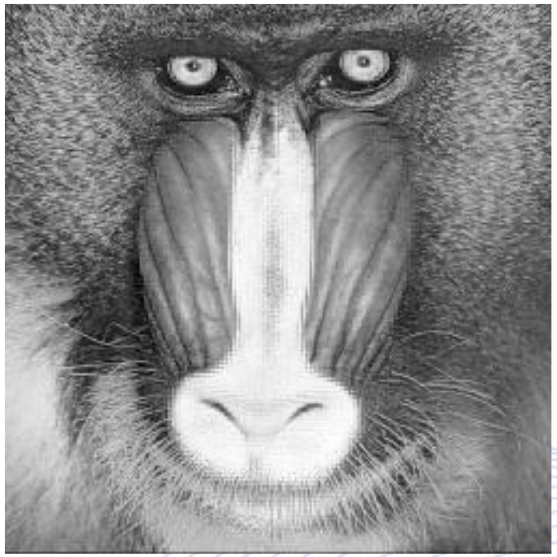
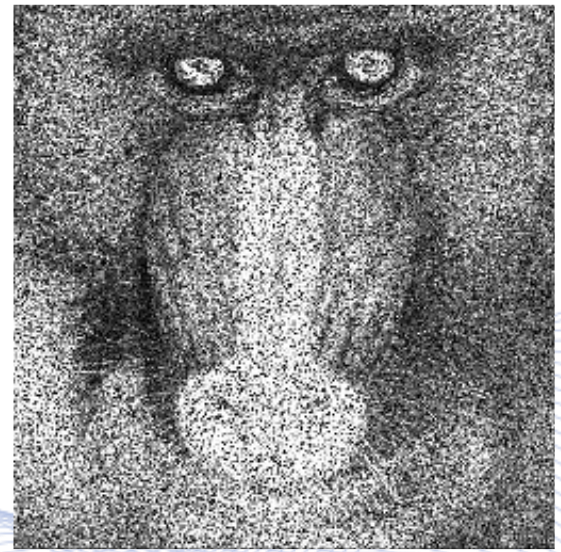
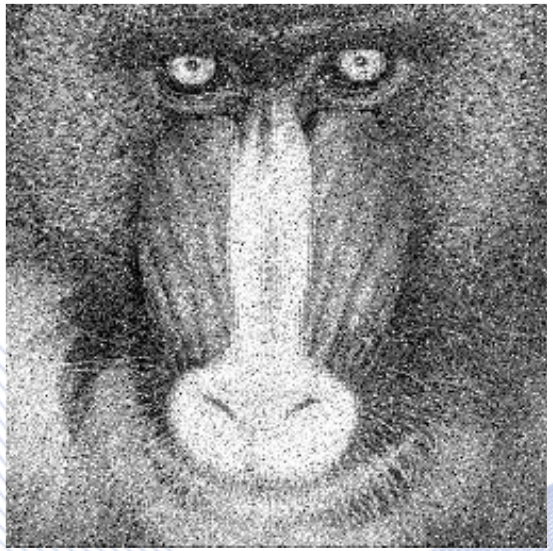
- Additive/multiplicative image noise generators:

$$g(i,j) = f(i,j) + n(i,j),$$

$$g(i,j) = f(i,j)n(i,j).$$

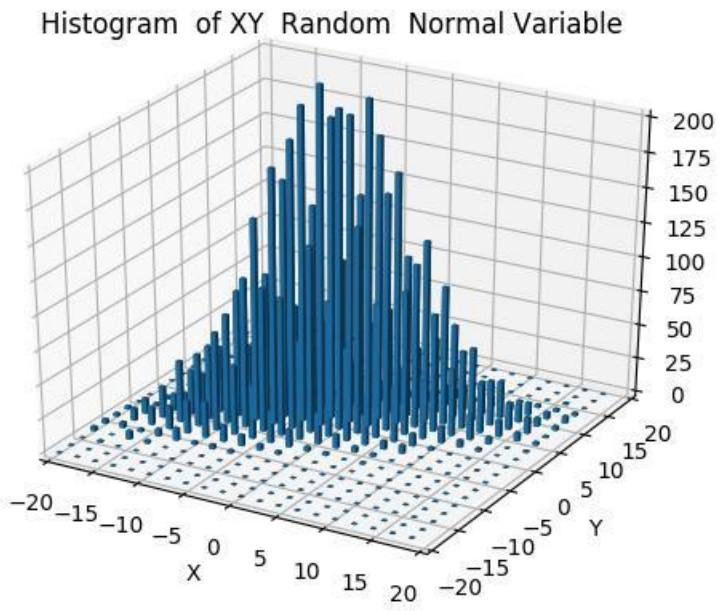
Random number generators: they produce uniform noise in $[0,1]$.

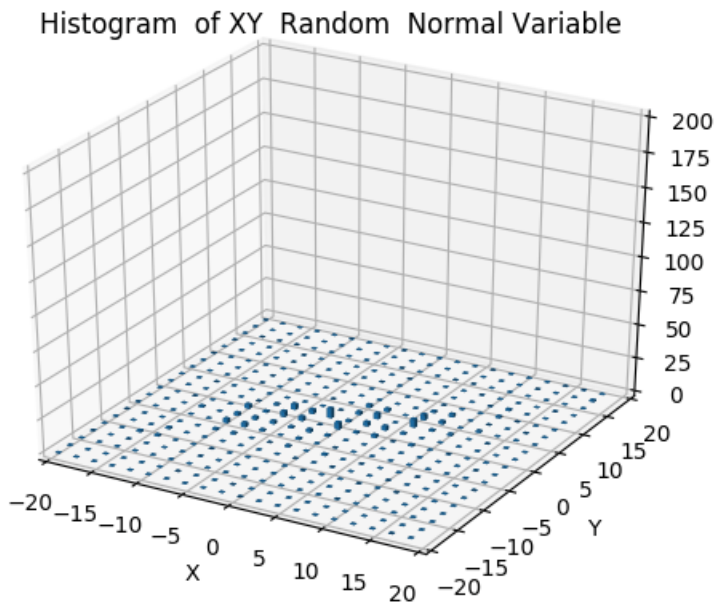
Noise generators for digital image processing

a) Original image; b) Image corrupted by multiplicative Gaussian noise;
c) image corrupted by additive Laplacian noise.

2D Gaussian Image Noise Generation





a) 2D Gaussian random number generator histogram; b) Its animation vs the number of generated samples.

Bibliography

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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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