Introduction to
Basics in Image Processing

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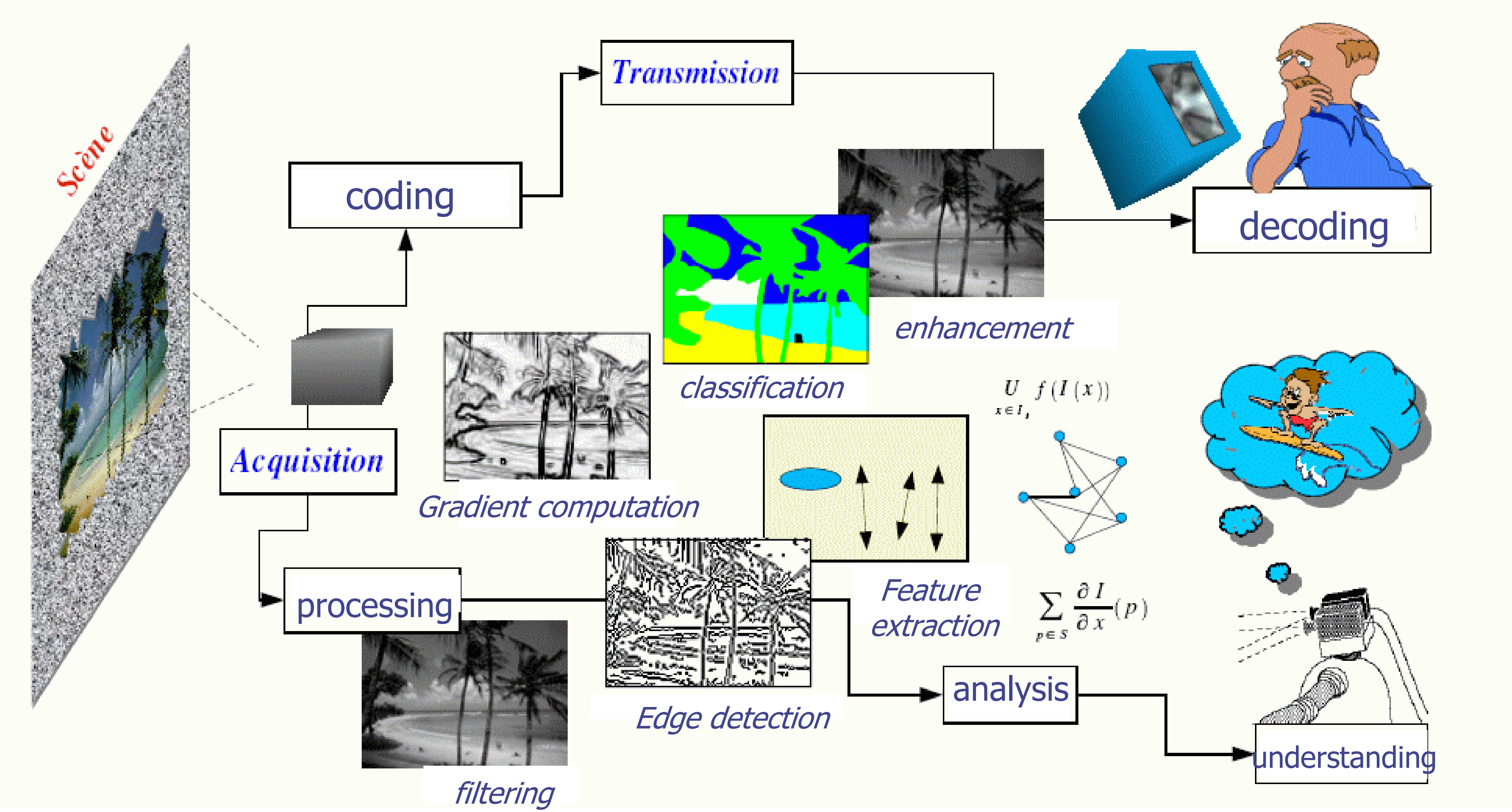
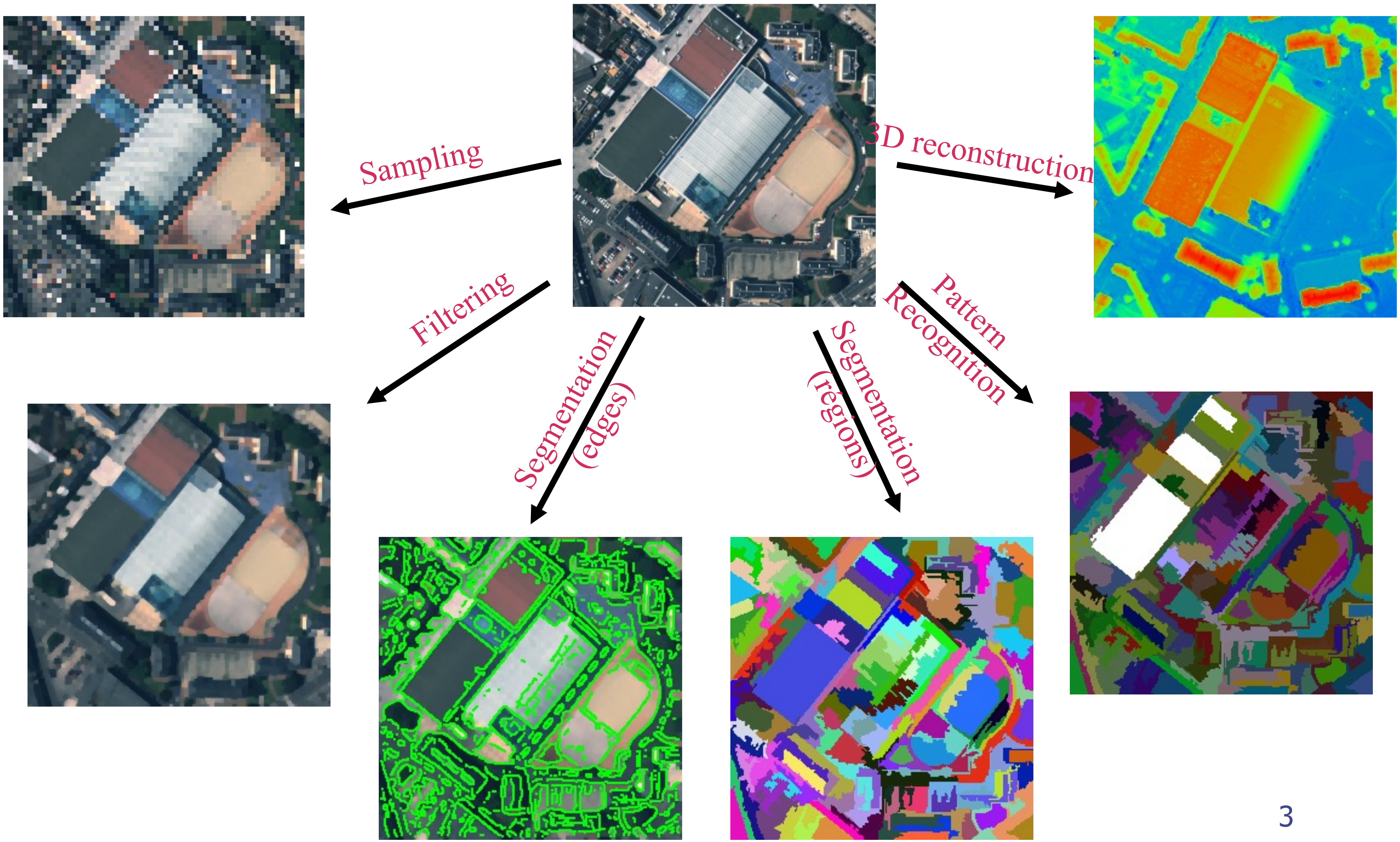
Some slides from the IMAGE group @Telecom – Tupin et al

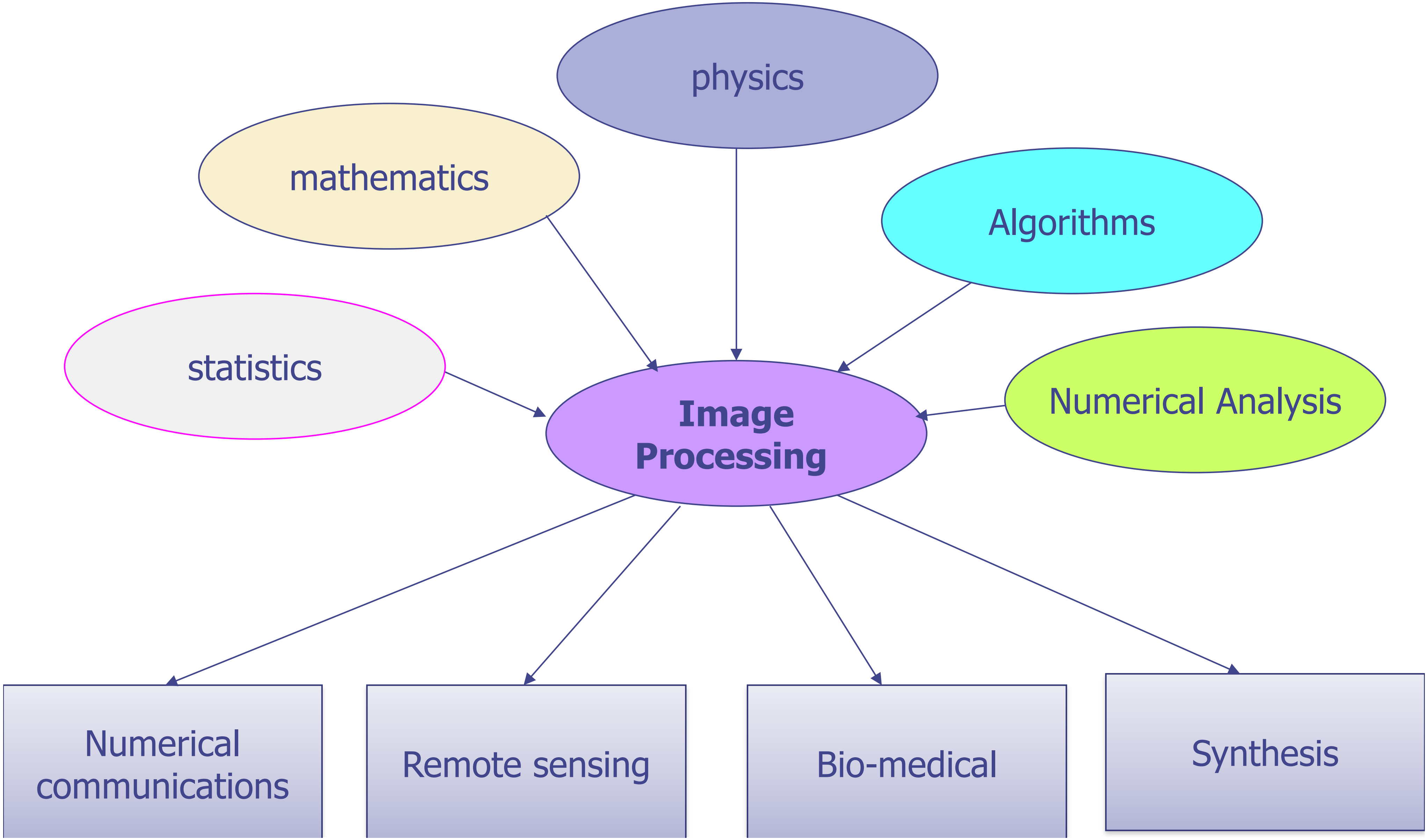
Introduction



Introduction: Image Processing Applications



Introduction



Overview

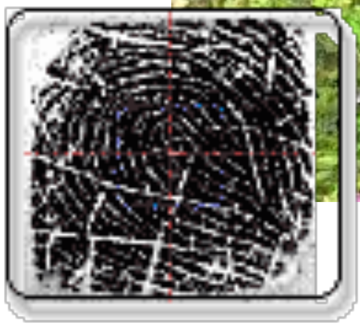
- What is an image ?
- Spatial resolution & sampling
- Quantification and histogram
- Image filtering
- Geometric image transformation

What is an image ?

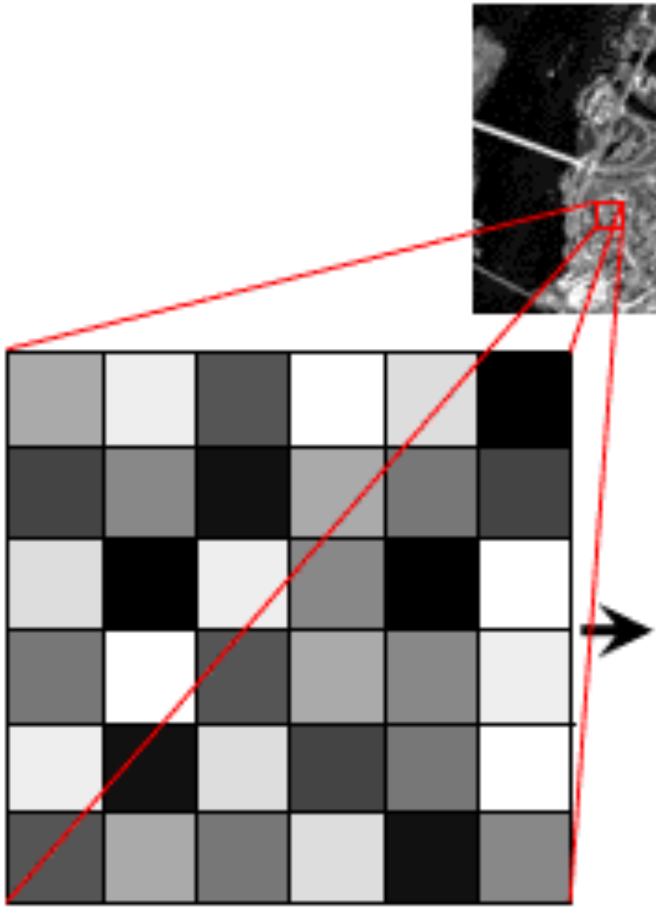
- Information support
- Signal (continuous 2D signal) of a physical measure
  - Passive imaging (Colour intensity)
  - Active imaging (X-ray transmission, electromagnetic radiation, …)
- Dimensions:
  - 2D (pictures)
  - Volumetric measures (3D medical images)
  - 2D ½ (stereo images + intensity)
  - Video (2D+t)
  - 3D+t (image sequences)

What is an Image ?

- A **digital** image (2D-3D) is a matrix defined by its:
  - resolution (pixel (“picture element”) size)
  - depth (range of values for each pixel)
  - colormap (color look up table (LUT))



Digital Images



170	238	85	255	221	0
68	136	17	170	119	68
221	0	238	136	0	255
119	255	85	170	136	238
238	17	221	68	119	255
85	170	119	221	17	136

Image Types

Image	Application	Size	# channels
Bio-medical	CT IRM XRay	512x512x512 256x256x256 1024 x 1024	1-3
Remote Sensing	1970-1980 1985-1990 1990-	2000 x 3000 6000 x 6000 15000 x 15000	3-7 3-20 3-256
Defense	Surveillance, tracking	256 x 256 512 x 512	1 2-3

Image Types

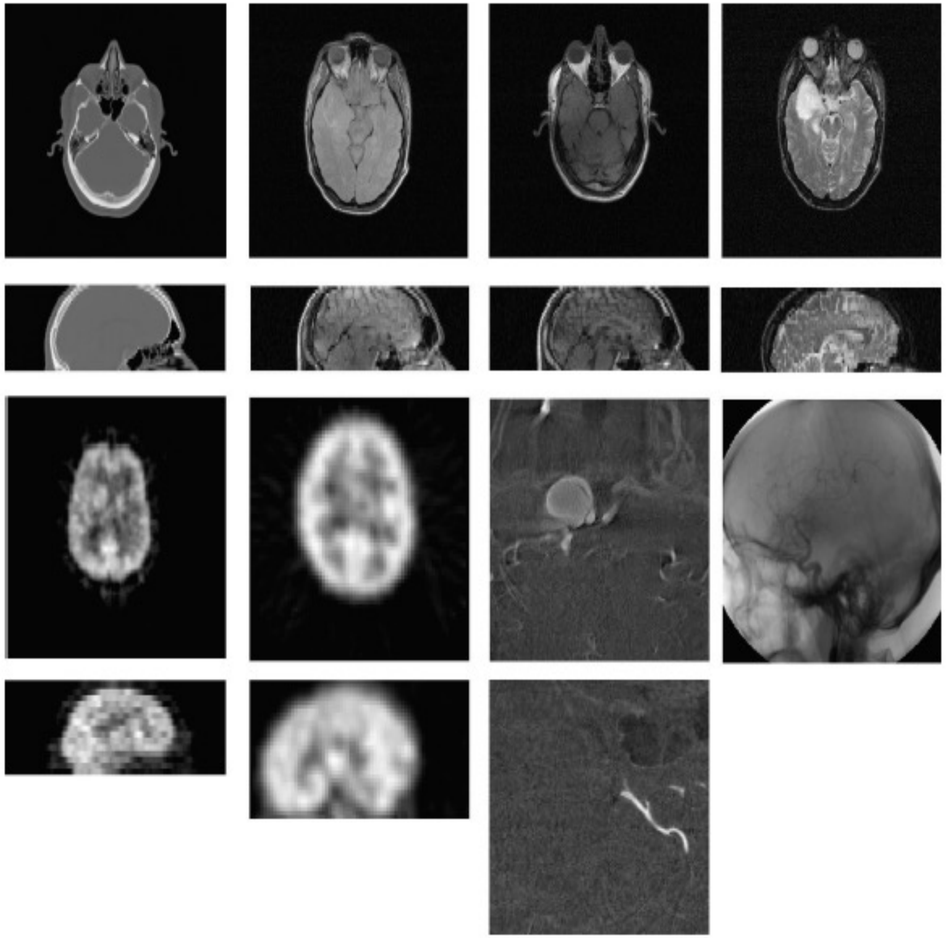


TABLE I

Summary of the Image Dimensions and Voxel Sizes for the Four Data Set Types. Five Images of Each Type Were Used

Data set type	In-plane grid sizes	In-plane dimensions (mm^2)	No. slices	slice spacing[1] (mm)
CT head	256×256–320×320	0.94×0.94–0.65×0.65	15–145	1.5–4.7
MR head[2]	256×256	0.98×0.98–0.90×0.90	50–90	2.0–3.0
CT abdomen	320×320–512×512	1.19×1.19–0.62×0.62	28–50	3.0–7.0
MR foot	256×256	0.74×0.74–0.70×0.70	18–20	3.0

[1] Center-to-center distance between slices.

[2] The original slice thickness for the MR head data was 1–1.5 mm, this was increased to 2–3 mm by slice averaging to make the slice thickness consistent with data used by Grevera and Udupa [1].

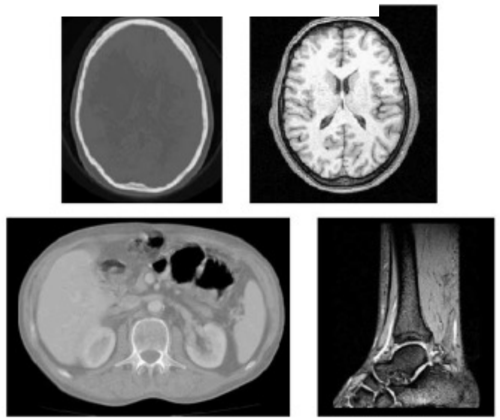


Fig. 3. Sample slices from each type of data set: from top left to bottom right, CT head, MR head, CT abdomen, and MR foot.

Image Digitization

- **Sampling** ⇨ number of pixels
- Quantification ⇨ number of bits per pixel

256x256

128x128

64x64

32x32

Image Digitization: Sampling

- **Image coordinates :**
  - Origin:
    - Generally the upper left corner.
  - Directions:
    - *x* axis is across
    - *y* axis is down
  - Units are pixels.
  - Differs from **Cartesian coordinates (mm)**.

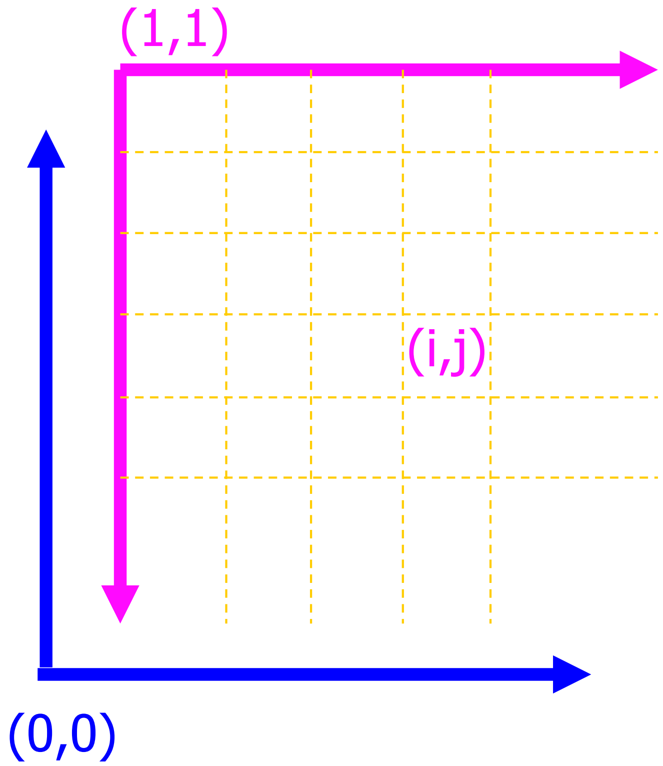


Image Digitization

- **Physical** coordinates to **Image** coordinates:

$$\begin{pmatrix} u \\ v \end{pmatrix} = \begin{pmatrix} \boxed{s_x} & 0 \\ 0 & \boxed{-s_y} \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} + \boxed{\begin{pmatrix} t_u \\ t_v \end{pmatrix}}$$

Scaling from physical to pixel units: parameters are pixels per mm

Translation of origin in pixel units

Image Digitization

- Sampling ⇨ number of pixels
- **Quantification** ⇨ number of bits per pixel

6 bits *4 bits* *3 bits* *2 bits* *1 bit*

Overview

- What is an image ?
- Spatial resolution & sampling
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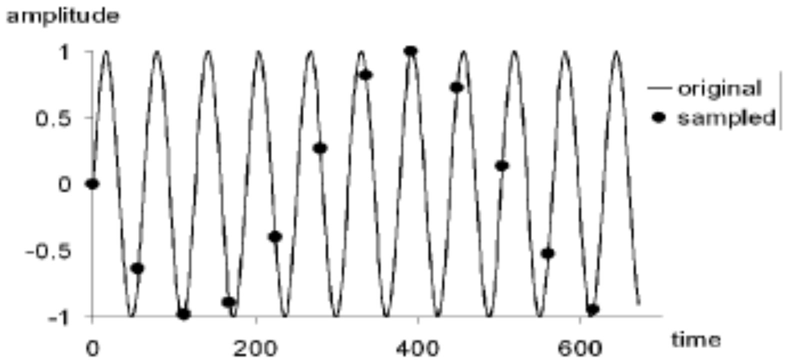
Image Resolution

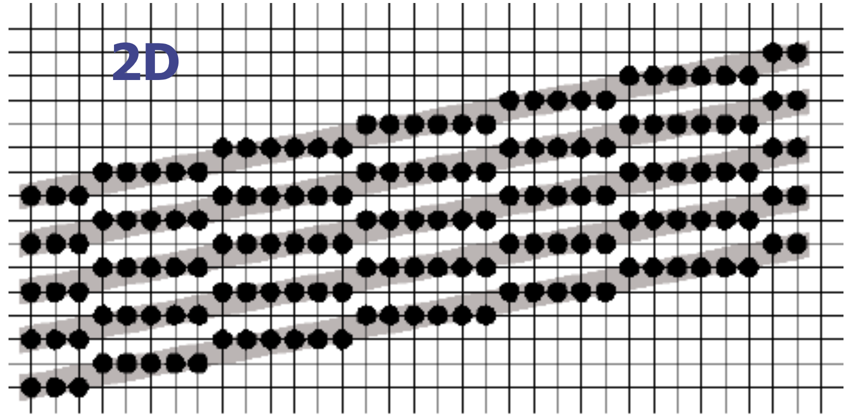
- **Resolution:**
  - Human vision is able to look at very small objects and large ones.
  - Digital images have a fixed resolution determined by the # of pixels in the image.
- **Sampling constraints:**
  - Preserve the image frequency content (Shannon theory, 2D Fourier transform).
  - Preserve the image spatial content: application-dependent (psycho-visual tests, size of the smallest element to detect, …)

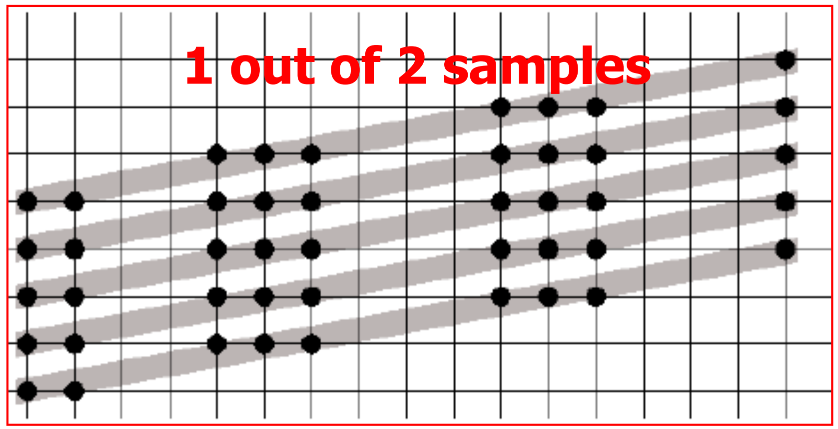
Sampling

- Preserve the image <u>frequency</u> content:

1D



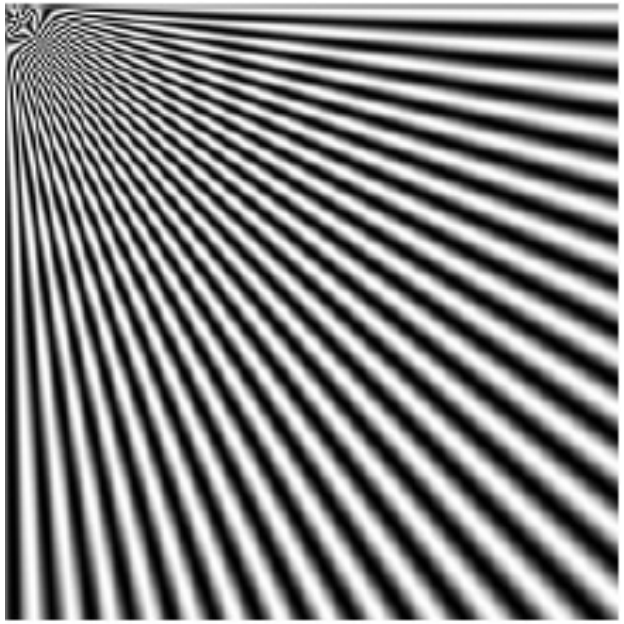




⇨ Aliasing : false frequencies

Sampling

- Preserve the image frequency content:



Overview

- What is an image ?
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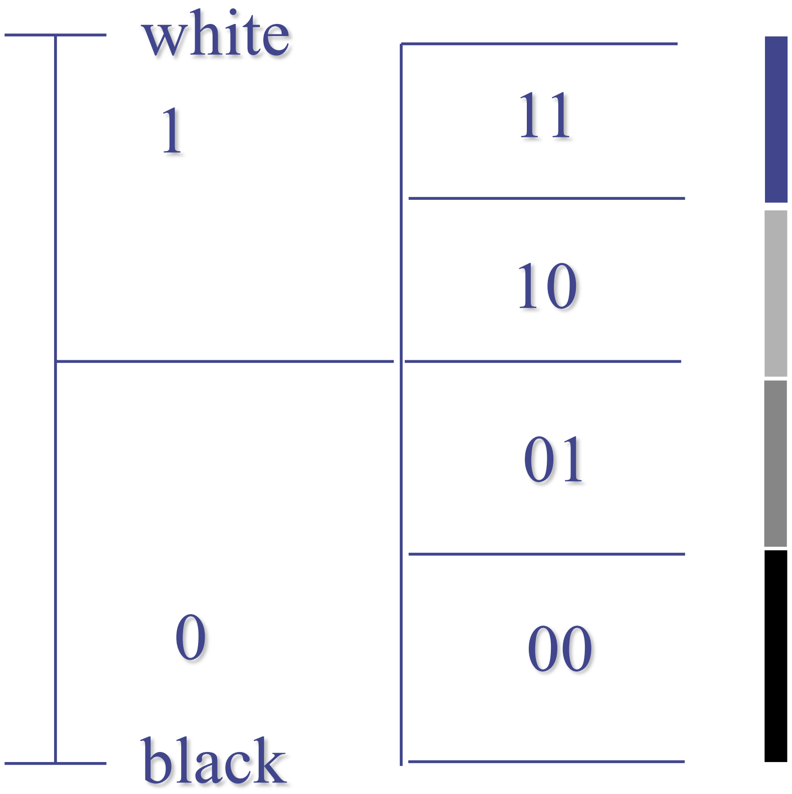
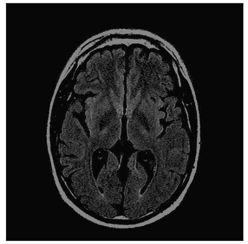
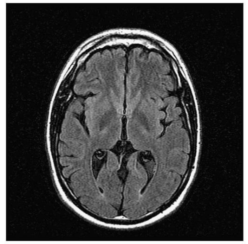
Image Depth

- Binary representation: b bits, 2^b levels

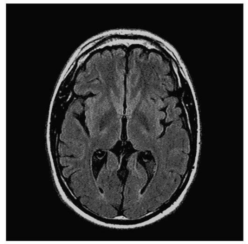




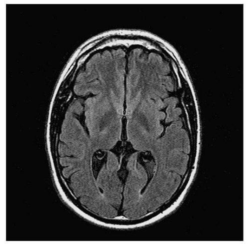
1 bit



2 bits



3 bits



4 bits

Image Depth

- Vision sensitivity
  - limited to 6 - 8 bits per color component ⇨ max 24 bits

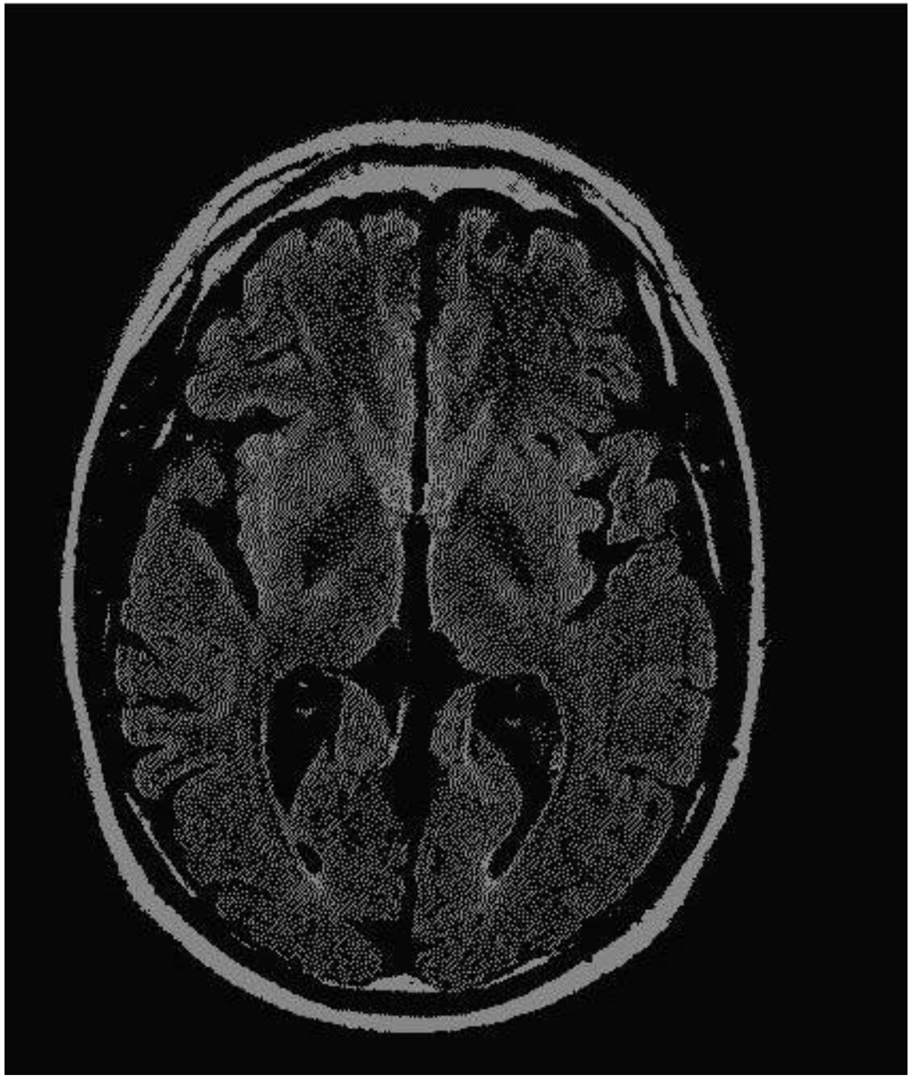
- Digital images
  - Much larger depth (e.g. medical imaging, remote sensing)
  - Image visualization: 8 bits = 256 grey-levels

  (0 for black and 255 for white)

  => Need to use specific windowing for some modalities such as CT images.

Image Depth

1 bit



2 bits

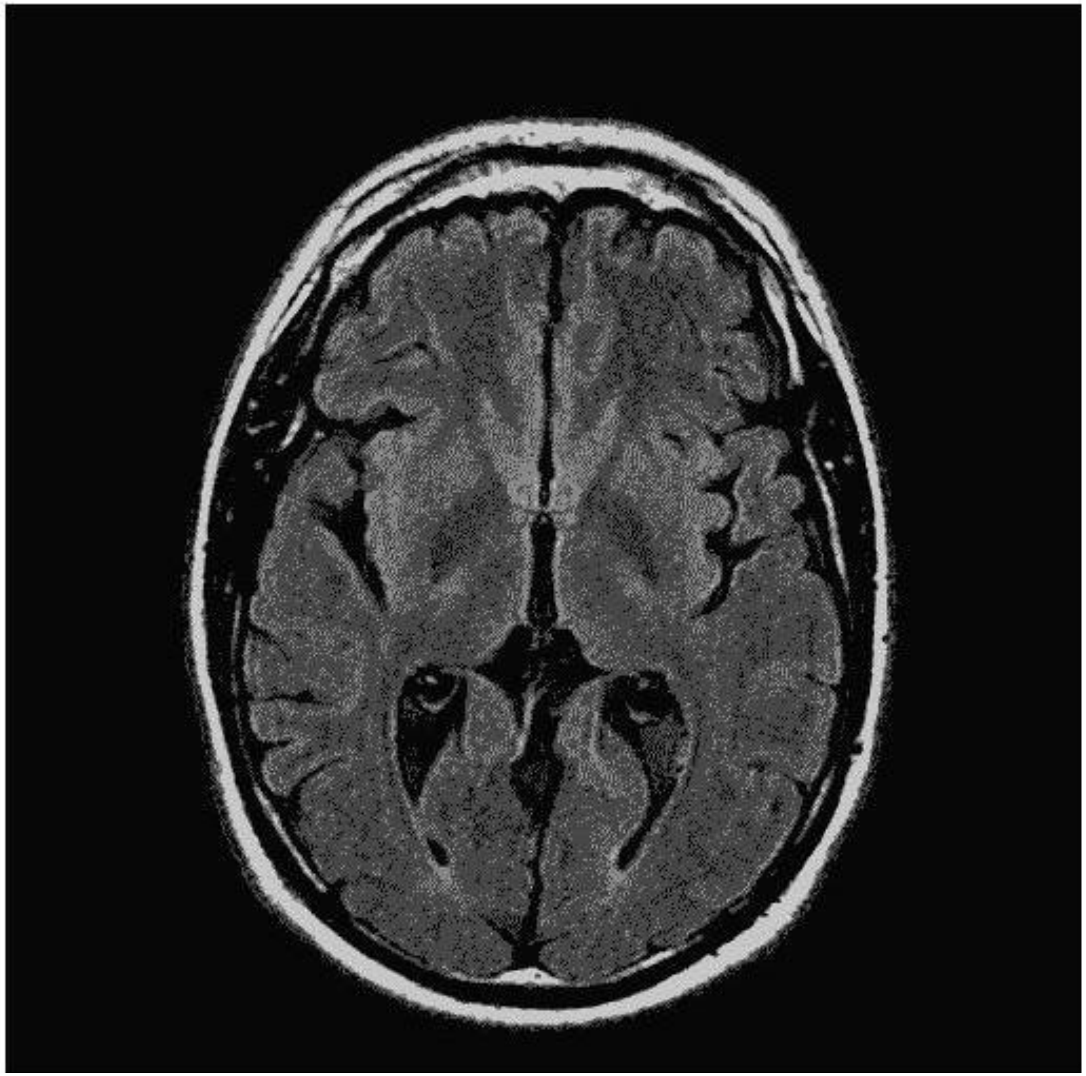
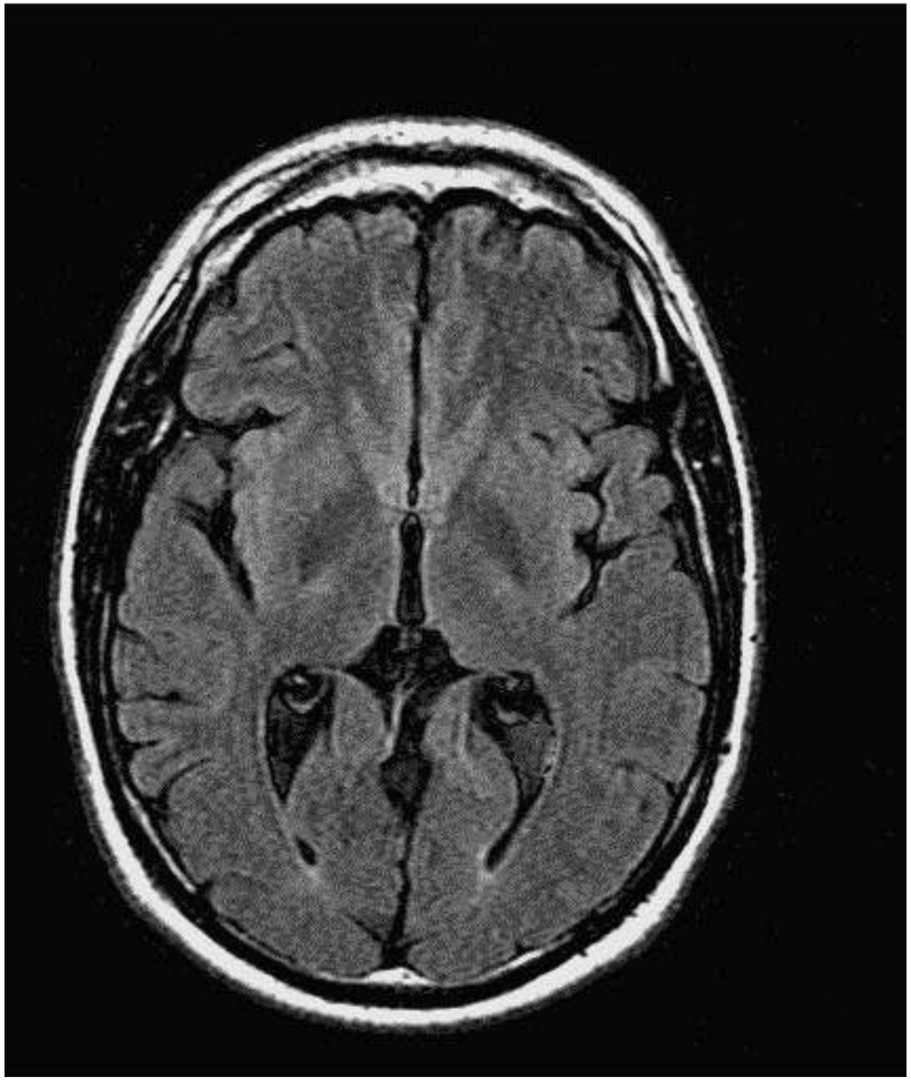


Image Depth

3 bits



4 bits

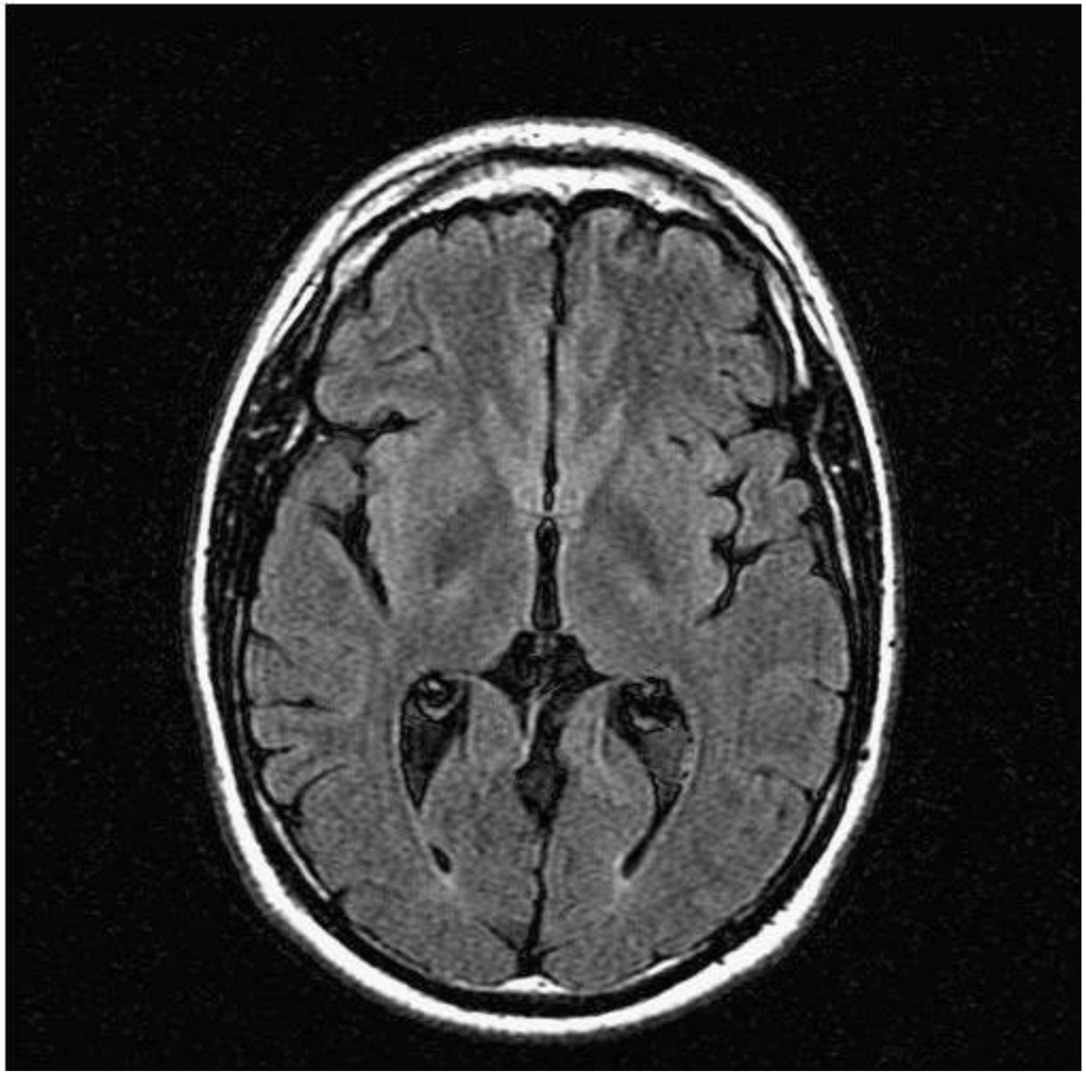
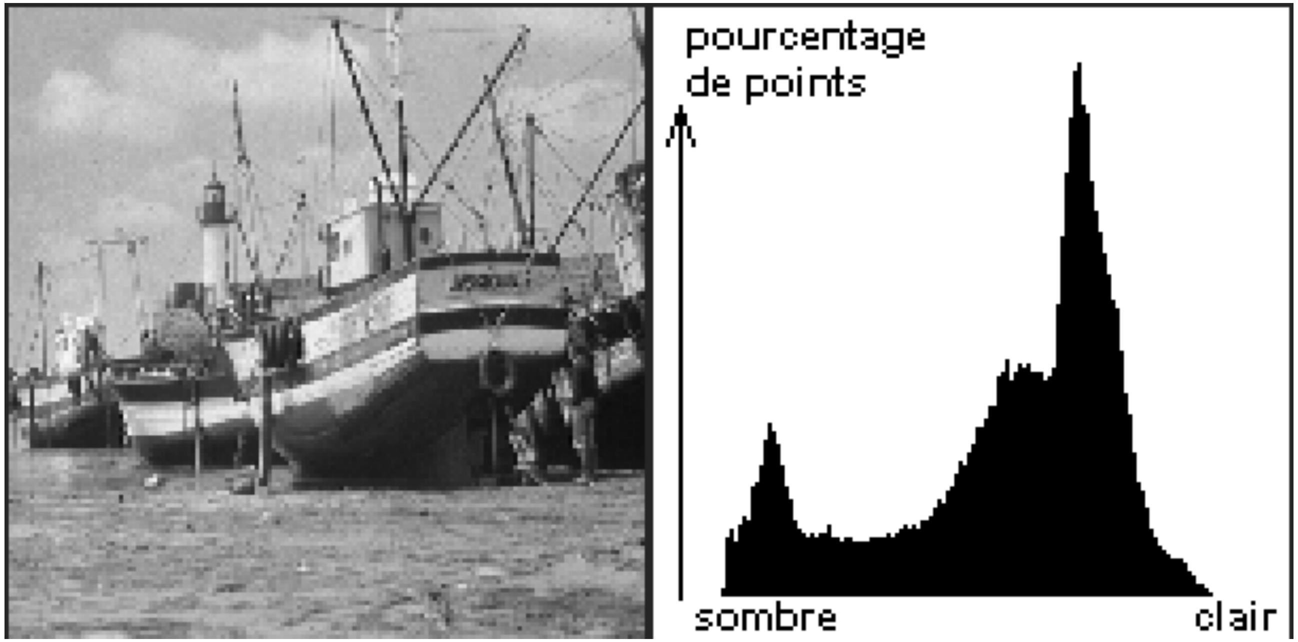


Image Histogram

- Histogram: grey level distribution
  - F(x) = number of pixels having x as grey-level
  - If normalized = probability of the grey-level
- Used for
  - Contrast enhancement
  - Classification

Image Histogram



Histogram modes correspond to regions of interests (clouds, parts of the boats, etc.)

Image Histogram

Image Histogram

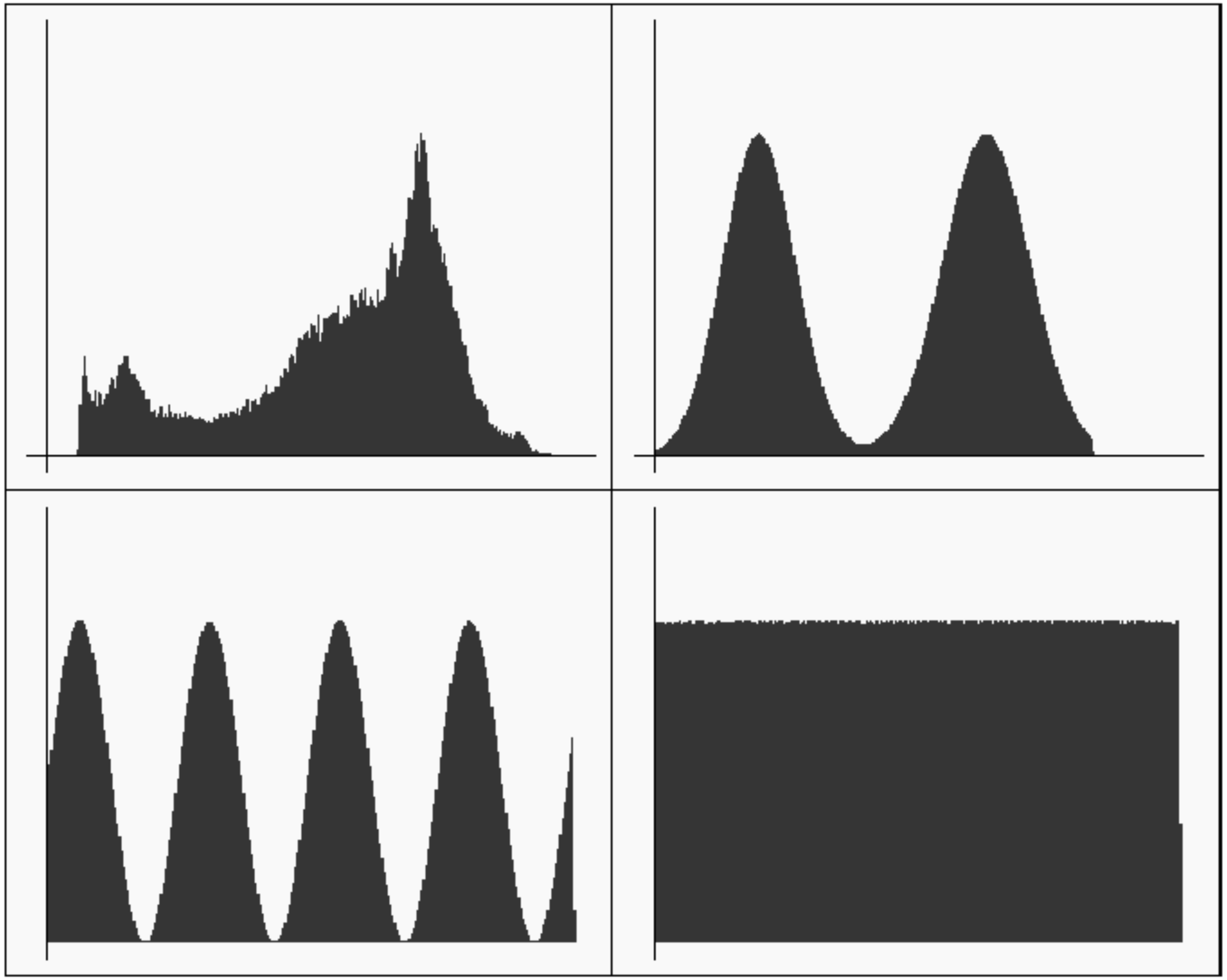
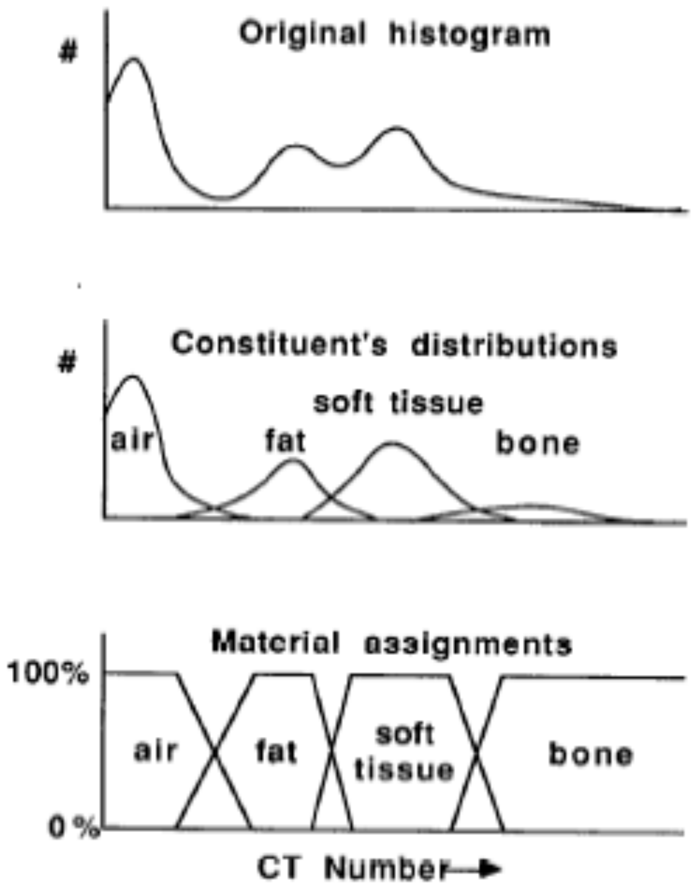


Image Histogram



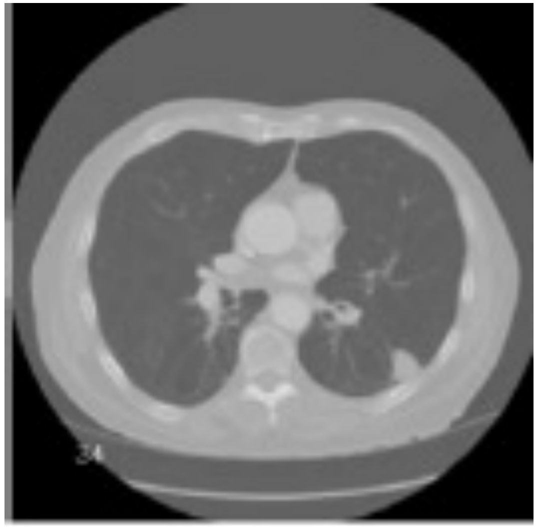
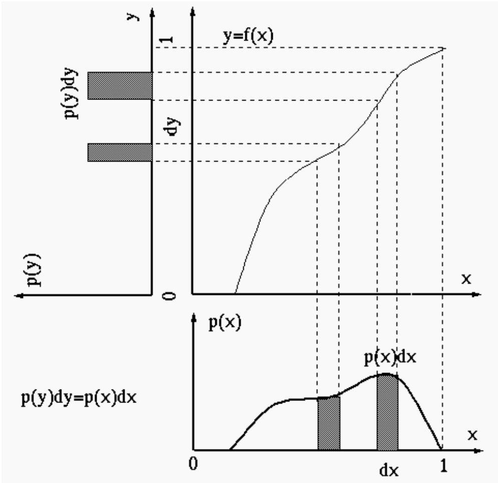


Image Histogram

- Histogram Equalization



Histogram transformation for Equalization

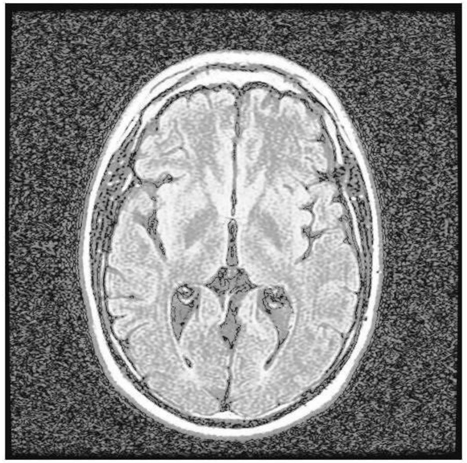


Image equalized

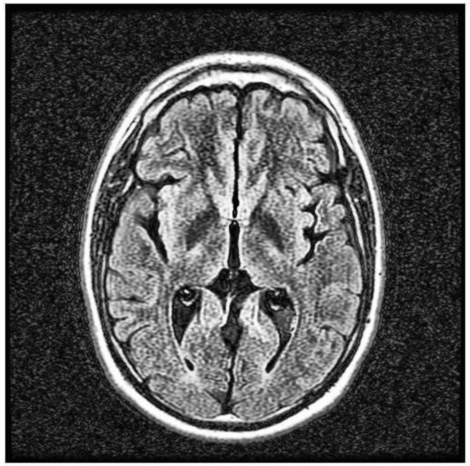


Image adaptively equalized (CLAHE method)

Overview

- What is an image ?
- Spatial resolution & sampling
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Linear Filtering

- Property :

  $F(I+aJ)=F(I)+aF(J)$

  F = operator of the spatial filter h(i,j)

- In the Image domain: F is a convolution

  $$y(i,j) = x(i,j)*h(i,j)$$

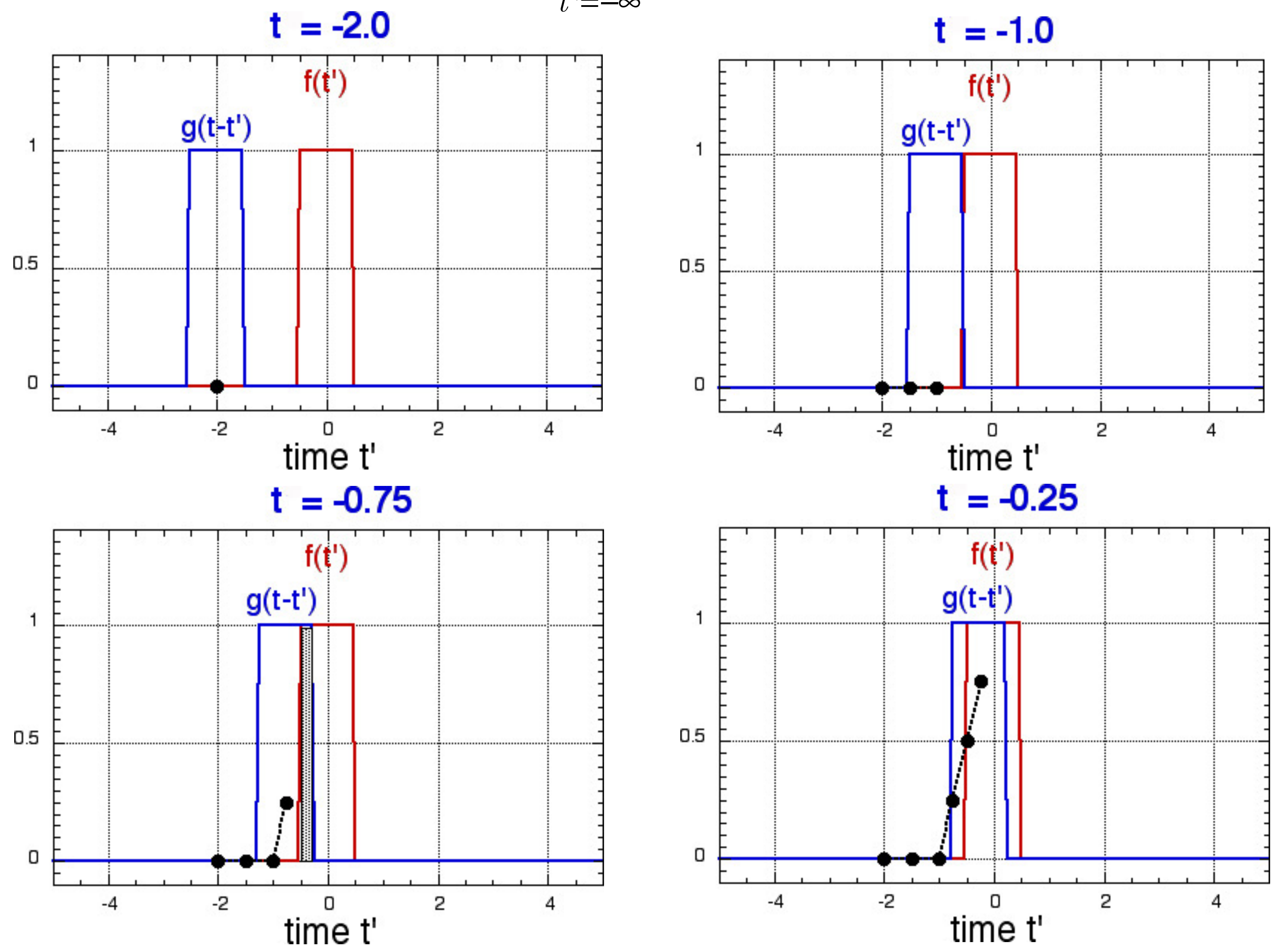
  $$y(i,j) = \sum_{k=-\infty}^{\infty} \sum_{l=-\infty}^{\infty} h(k,l)x(i-k,j-l)$$

- In the Fourier domain : F is a multiplication

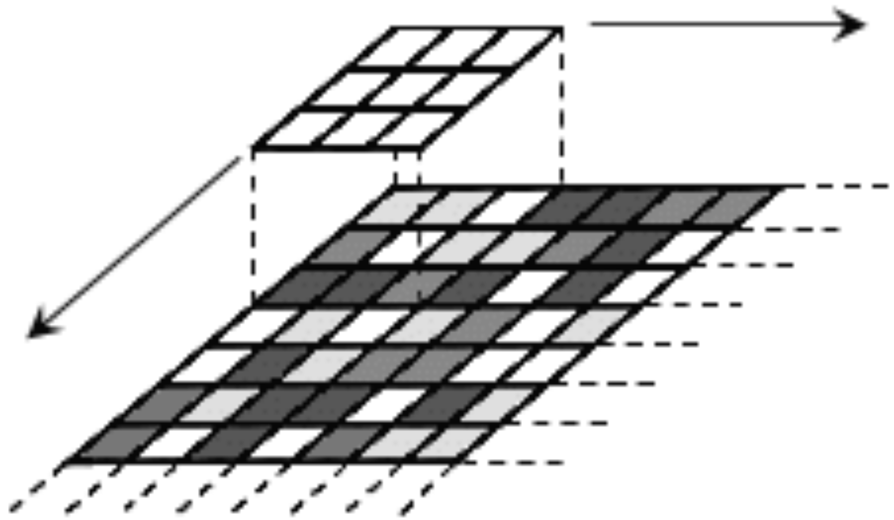
  $$Y(u,v)=X(u,v) \times H(u,v)$$

Linear Filtering

$$y(t) = \sum_{t'=-\infty}^{\infty} h\left(t - t'\right) f(t')$$



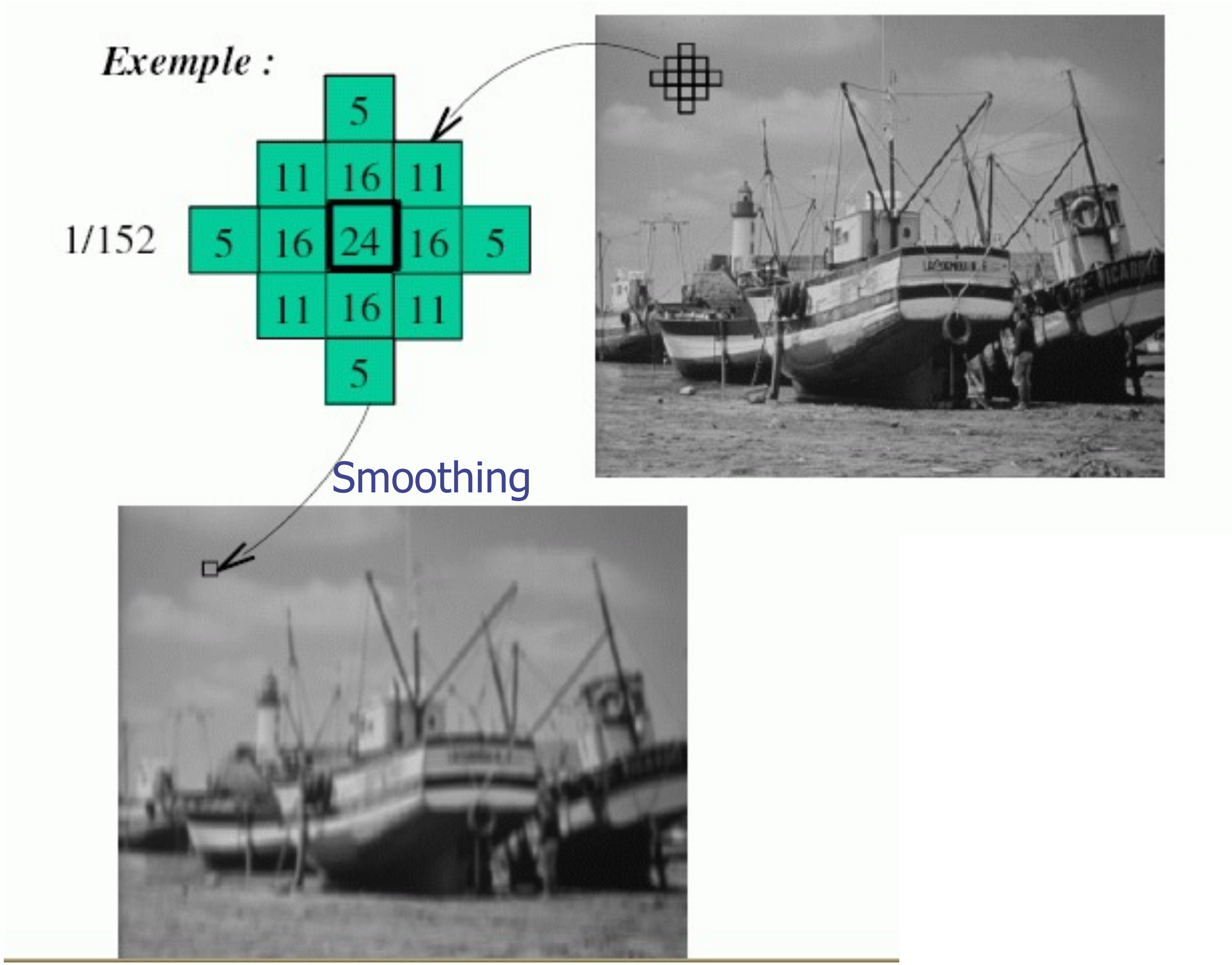
Linear Filtering



Convolution: for each pixel in the image…

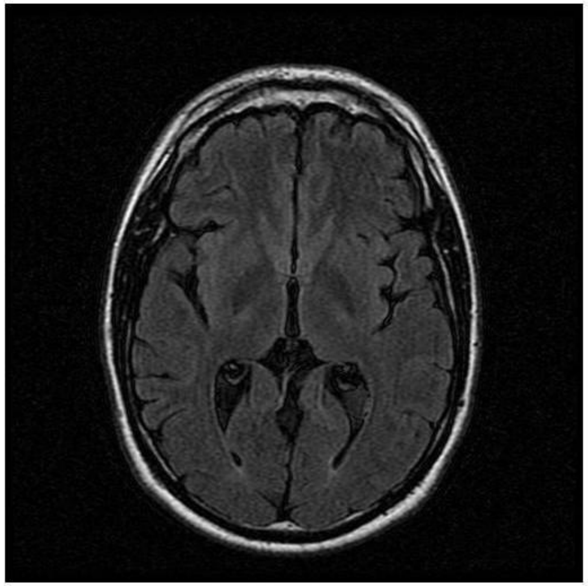
1. move a 'window' of a N pixels in each dimension (e.g. 3x3, 5x5, etc.),
2. mathematical computation using pixel values covered by that window
3. replace the central pixel of the window with the new value.

Linear Filtering

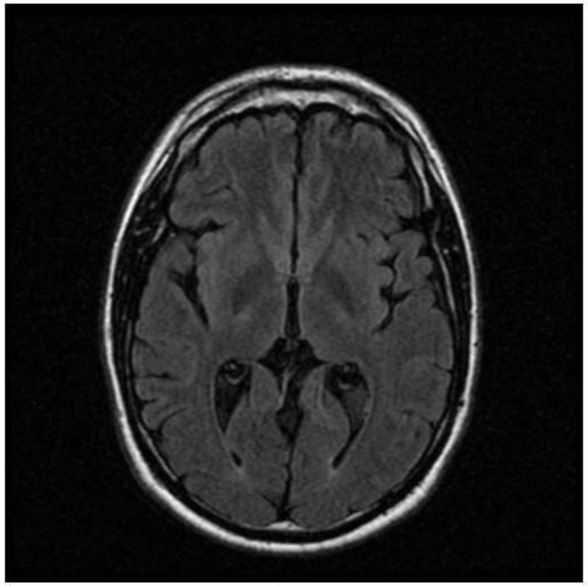


Linear Filtering

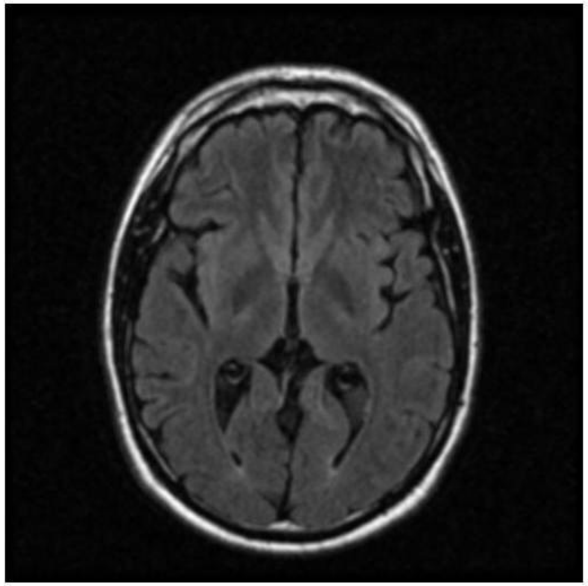
- **Low pass filters:**
  - noise suppression (= high frequencies).
  - blurring



Original MRI
(FLAIR)



Mean filter
(3×3)

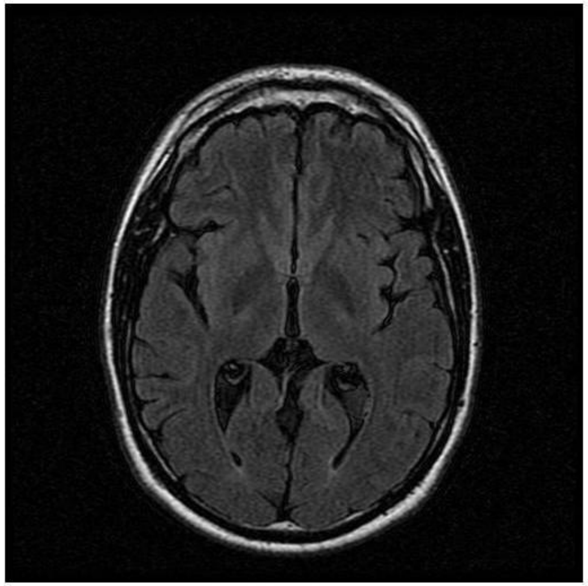


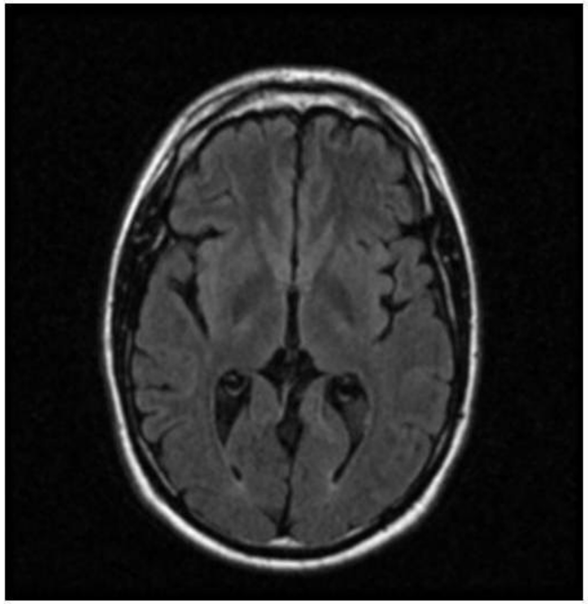
Mean filter
(5×5)

Linear Filtering

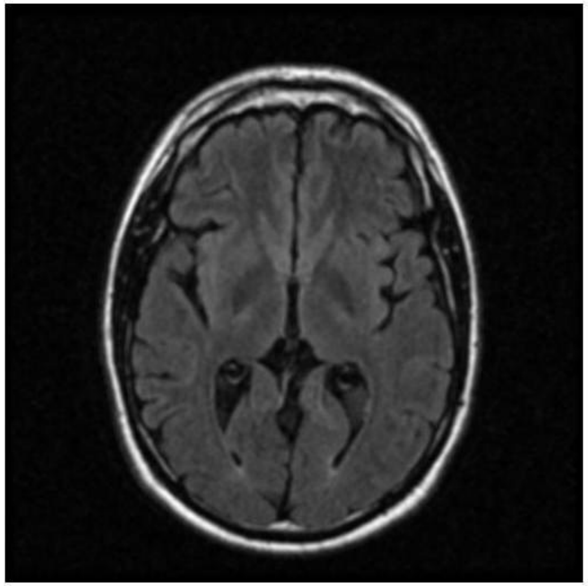
- **Low pass filters:**
  - noise suppression (= high frequencies).
  - blurring

Original MRI
(FLAIR)

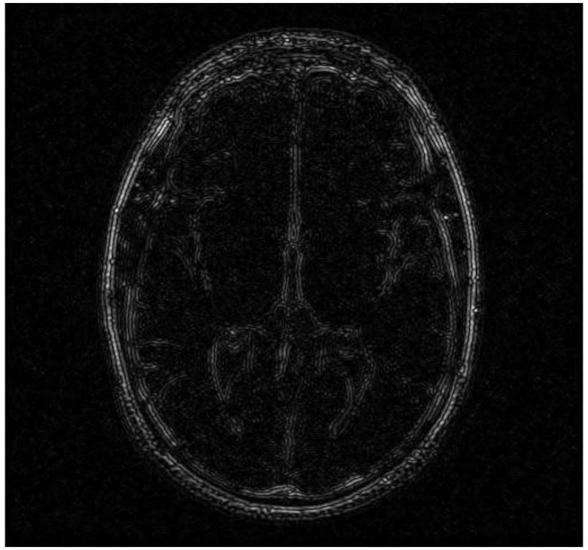




Gaussian filter
(5×5)



Mean filter
(5×5)

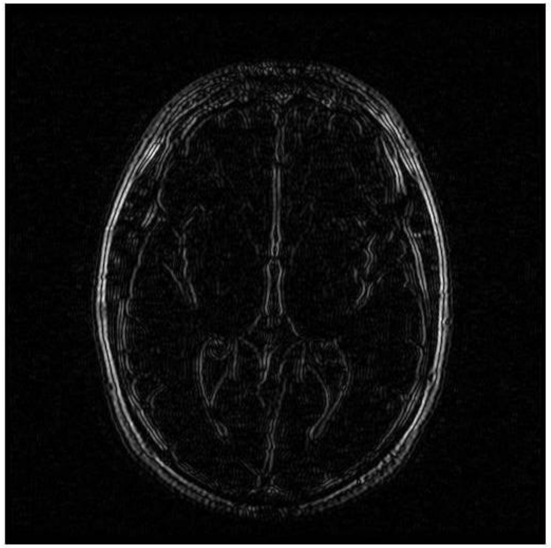


Difference of smoothed images

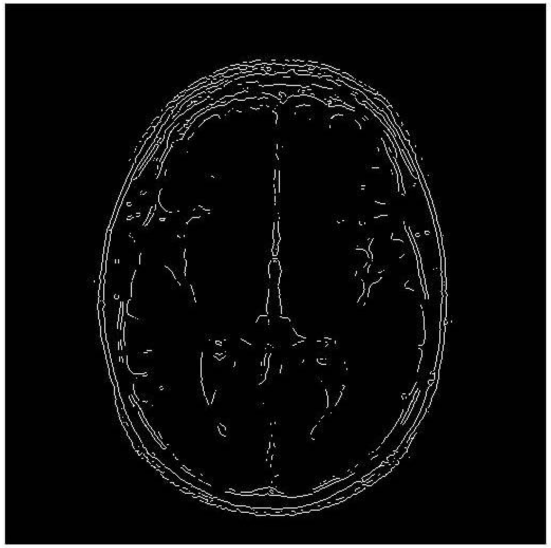
Linear Filtering

- **High pass filters:**
  - Selection of frequencies of interest
    - High frequencies (edges)

$$\begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix}$$



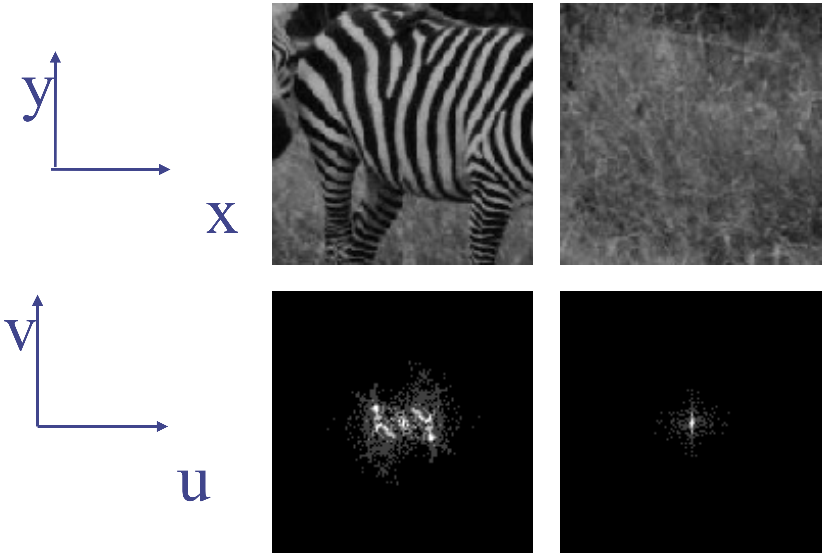
Prewitt filter



Thresholded image

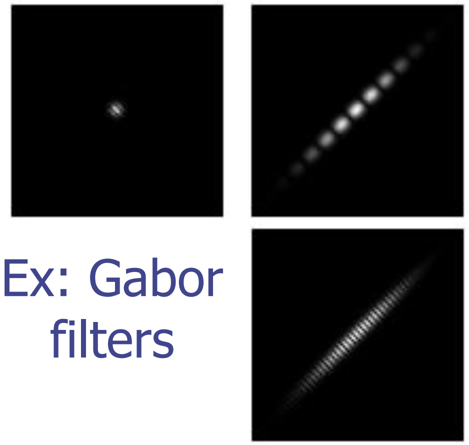
Linear Filtering

- **Band-pass filters**:
  - Selection of frequencies of interest
    - Specific frequencies (texture analysis)

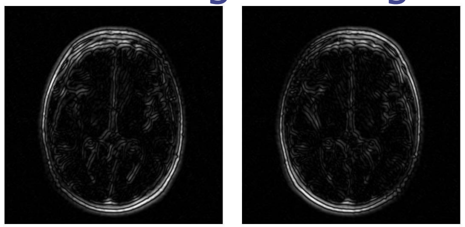


Stripes of the zebra create high energy waves generally along the u-axis; grass pattern is fairly random causing scattered low frequency energy

Ex: Gabor filters



±30 deg. filtering



Linear Filtering

◆ Band-pass filters:

- Gabor filters

Automated Tag Tracking Using Gabor Filter Bank, Robust Point Matching, and Deformable Models

Ting Chen, Sohae Chung, and Leon Axel

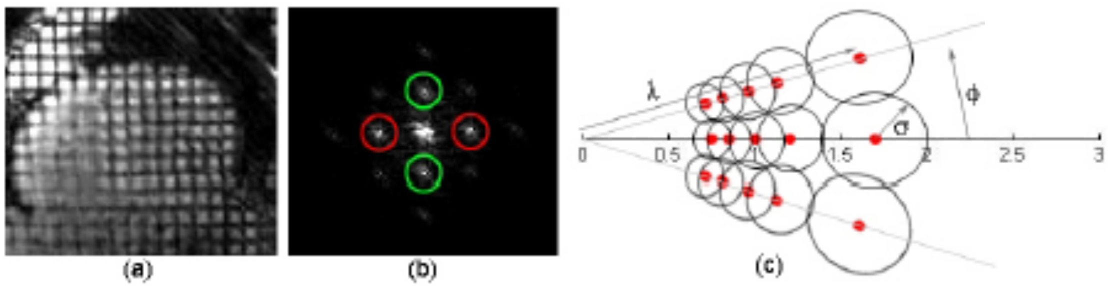
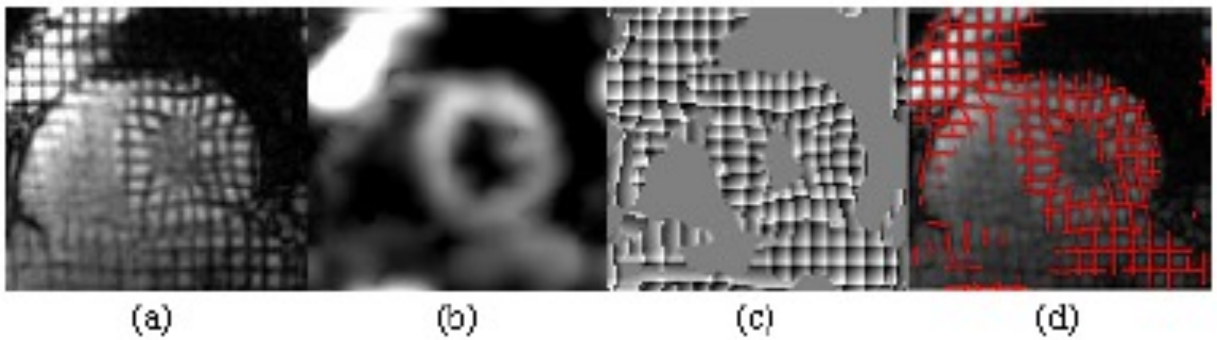
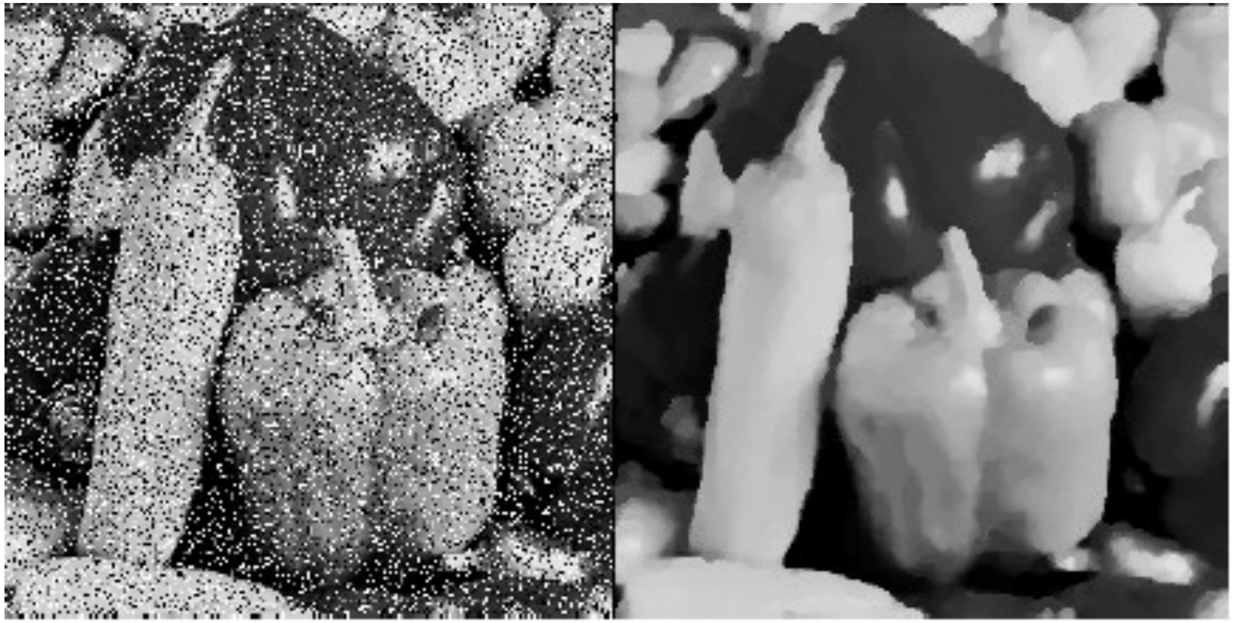


Fig. 2. (a) A cardiac MRI image with grid tags. (b) The magnitude of the Fourier transform of the tagged MR image. Peaks inside red circles correspond to vertical tags and green circles to horizontal tags. (c) A bank of Gabor filters in the Fourier domain with parameters ν, θ and σ. The red dots represent centers of Gabor filters in the Gabor filter bank. The value of the horizontal axis is $\frac{\nu}{\nu_{ini}}$ in the Fourier domain.

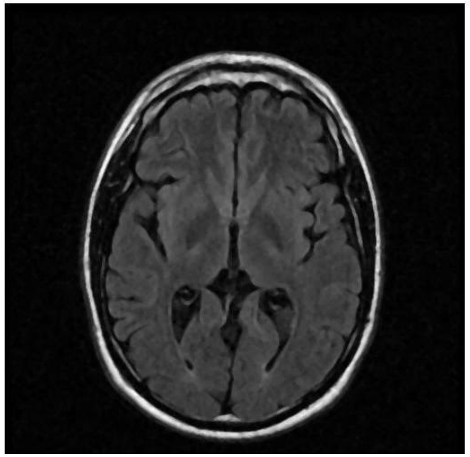


Non-linear Filtering

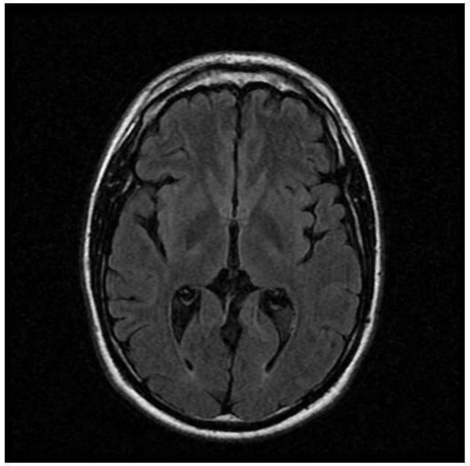
- Simple non-linear filters:
  - **median filters**: the output of the filter is the median value in a given window



Images with impulse noise



Median (5×5)

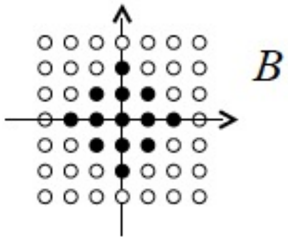


Median (3×3)

Non-linear Filtering

- Simple non-linear filters:
  - **Local Min / Max** : mathematical morphology with erosion, dilation, opening, closing….

Structural element



$\varepsilon_B(X)$

$\delta_B(X)$

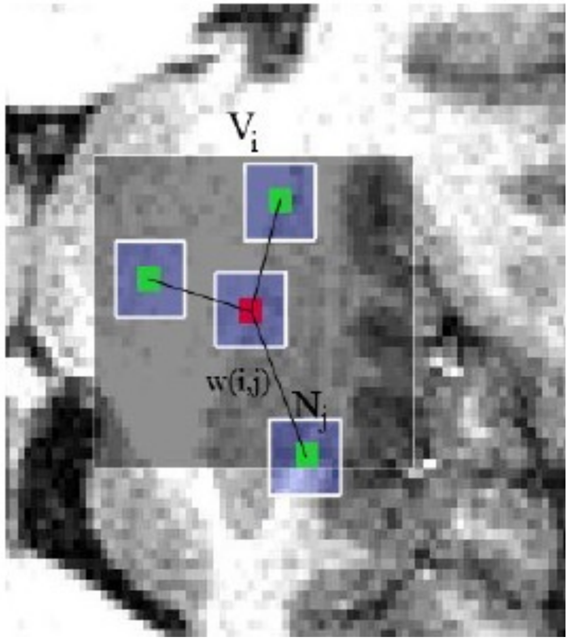
X

$\gamma_B(X)$

$\varphi_B(X)$

Non-linear Filtering

Non-Local Means



Fast Non Local Means Denoising for 3D MR Images

Pierrick Coupé[1], Pierre Yger[1,2], Christian Barillot[1]

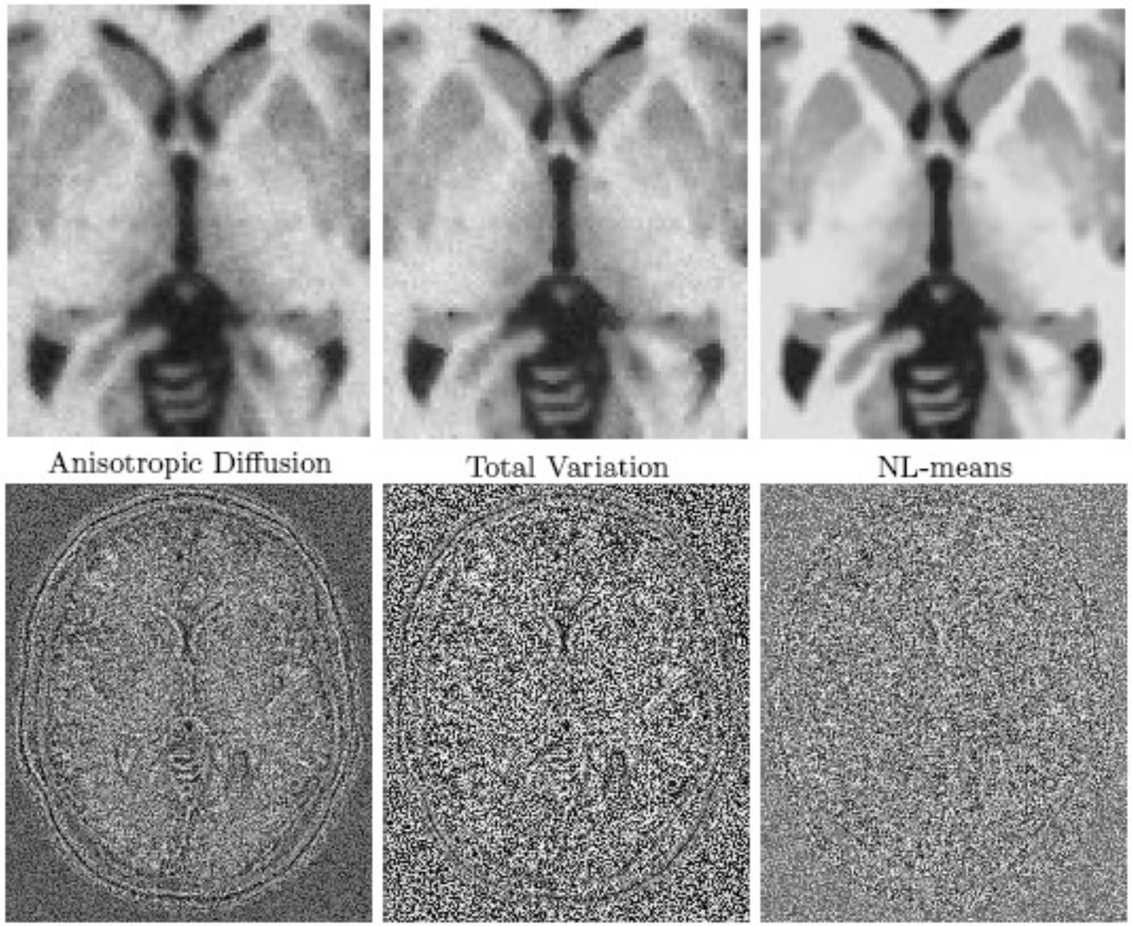


Fig. 4. Top: details of the Brainweb denoised images obtained via the three compared methods for a noise level of 9%. Bottom: images of the removed noise, i.e. the difference between noisy images and denoised images, centered on 128. From left to right: Anisotropic Diffusion, Total Variation and NL-means.

Image Filtering

IEEE TRANSACTIONS ON IMAGE PROCESSING, VOL. 13, NO. 4, APRIL 2004 1

Image Quality Assessment: From Error Visibility to Structural Similarity

Zhou Wang, *Member, IEEE,* Alan C. Bovik, *Fellow, IEEE*
Hamid R. Sheikh, *Student Member, IEEE,* and Eero P. Simoncelli, *Senior Member, IEEE*

- Measures of image quality:
  - Mean Square Error (MSE)
  - Peak Signal to noise ratio (PSNR)
  - Structural Similarity (SSIM) index

$$MSE = \frac{1}{m\,n}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - K(i,j)]^2$$

$$\mathrm{SSIM}(\mathbf{x},\mathbf{y}) = \frac{(2\,\mu_x\,\mu_y + C_1)\,(2\,\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)\,(\sigma_x^2 + \sigma_y^2 + C_2)}\ .$$

$$\begin{aligned} PSNR &= 10 \cdot \log_{10}\left(\frac{MAX_I^2}{MSE}\right) \\ &= 20 \cdot \log_{10}\left(\frac{MAX_I}{\sqrt{MSE}}\right) \\ &= 20 \cdot \log_{10}(MAX_I) - 10 \cdot \log_{10}(MSE) \end{aligned}$$

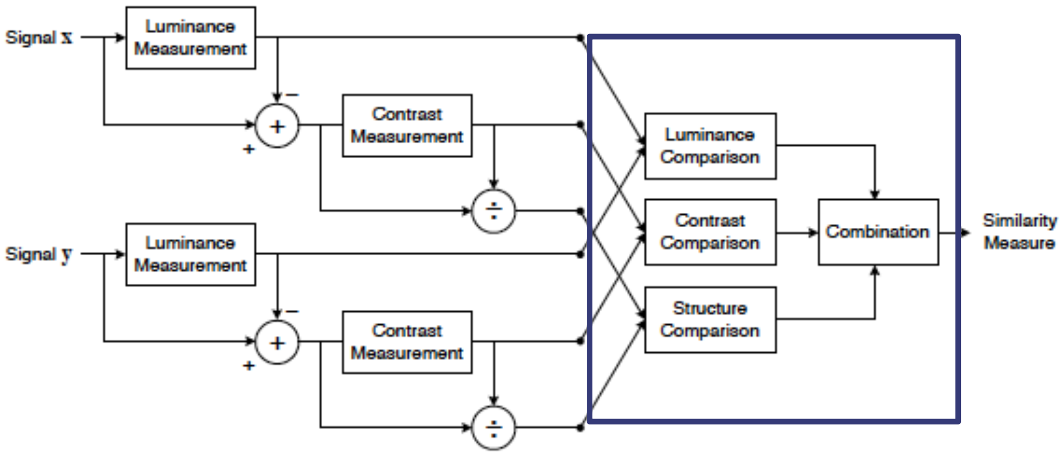


Fig. 3. Diagram of the structural similarity (SSIM) measurement system.

Fig. 2. Comparison of "Boat" images with different types of distortions, all with MSE = 210. (a) Original image (8bits/pixel; cropped from 512×512 to 256×256 for visibility); (b) Contrast stretched image, MSSIM = 0.9168; (c) Mean-shifted image, MSSIM = 0.9900; (d) JPEG compressed image, MSSIM = 0.6949; (e) Blurred image, MSSIM = 0.7052; (f) Salt-pepper impulsive noise contaminated image, MSSIM = 0.7748.

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