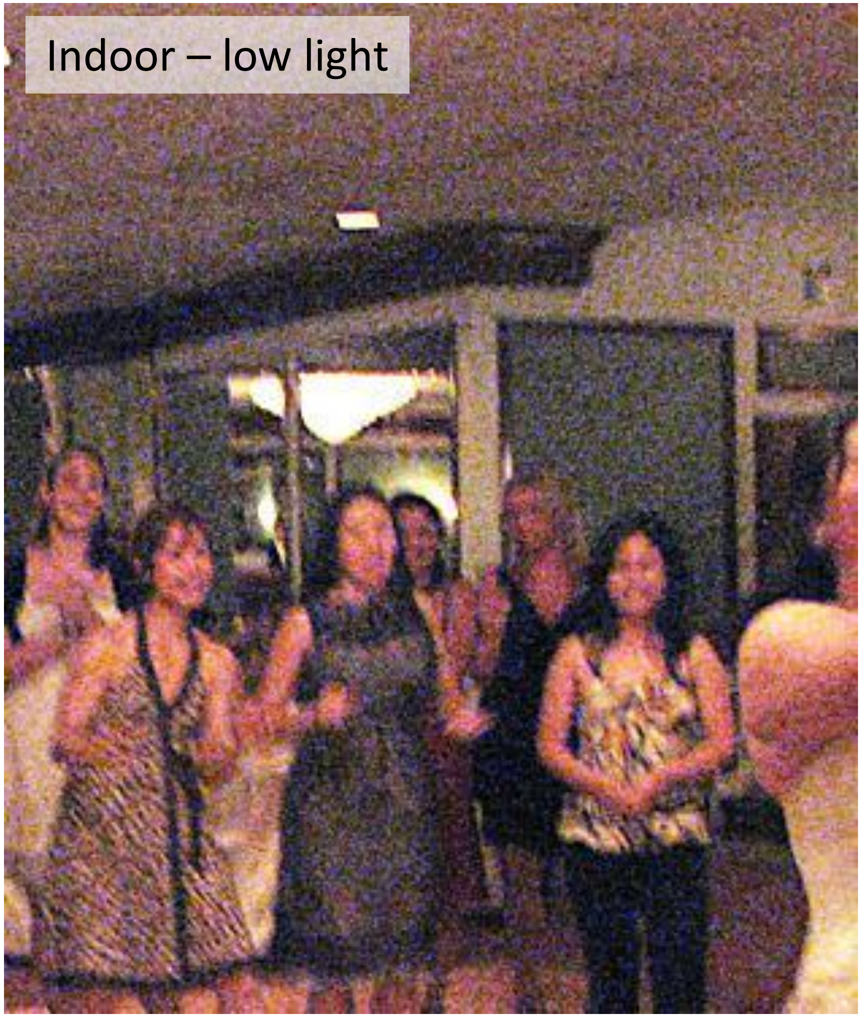
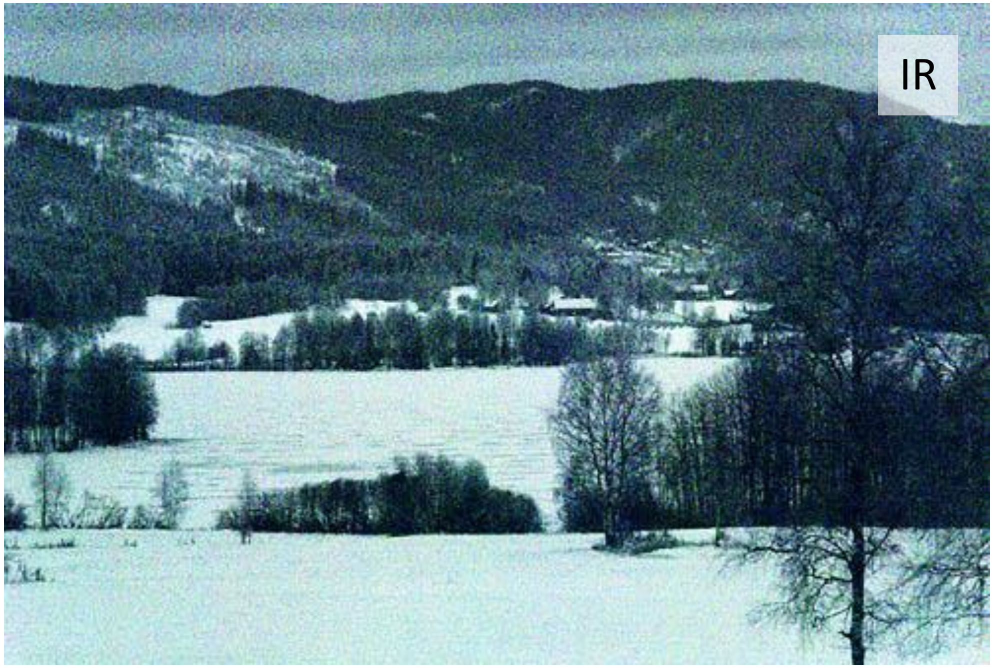
Estimation and removal of noise from Images

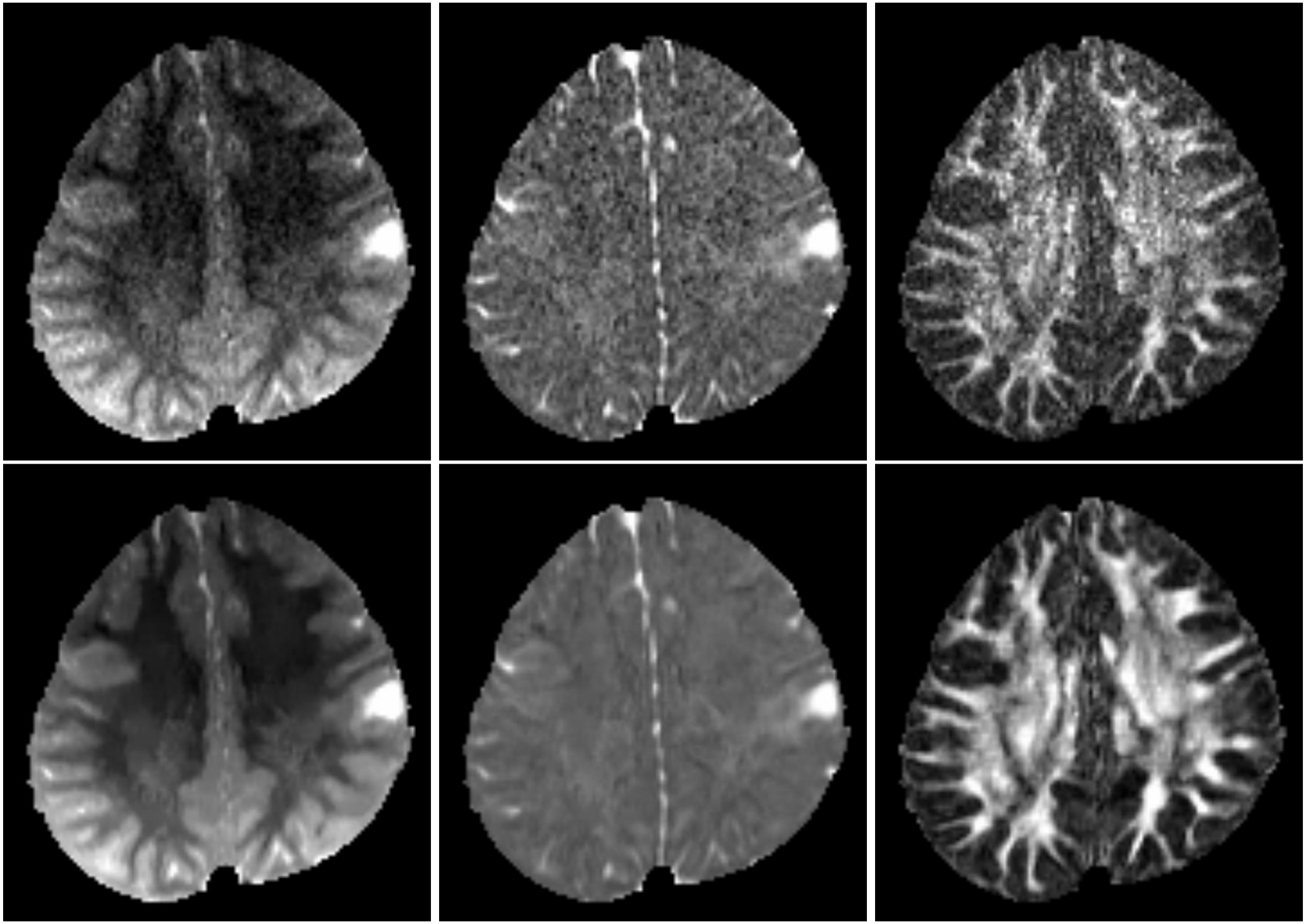
Noise

- Where does noise come from?
  - Sensor (e.g., thermal or electrical interference)
  - Environmental conditions (rain, snow etc.)
- Why do we want to denoise?
  - Visually unpleasant
  - Bad for compression
  - Bad for analysis


Indoor – low light


IR

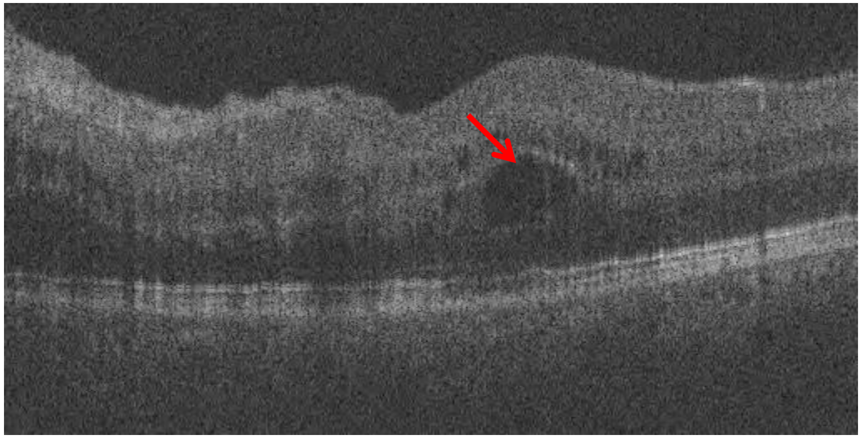

US



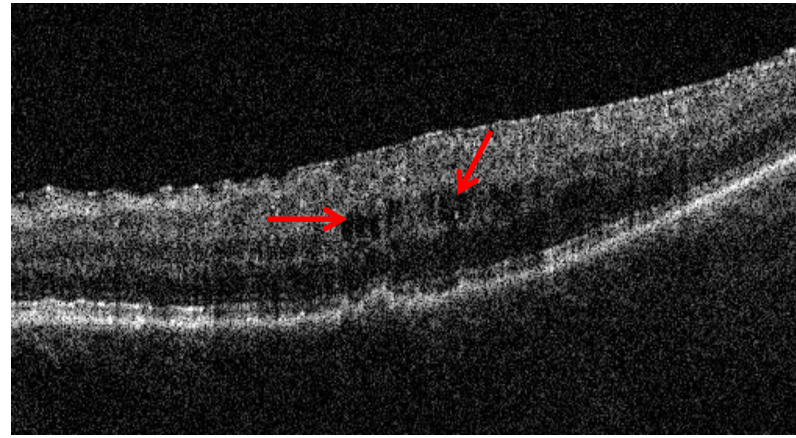
Diffusion weighted images : Before and after denoising

Brain Tractography

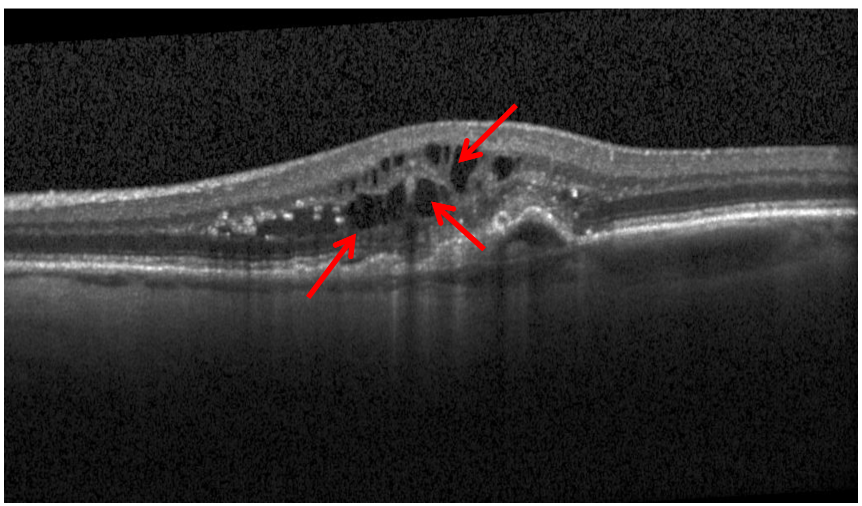
Challenges: Scan quality and Vendor differences



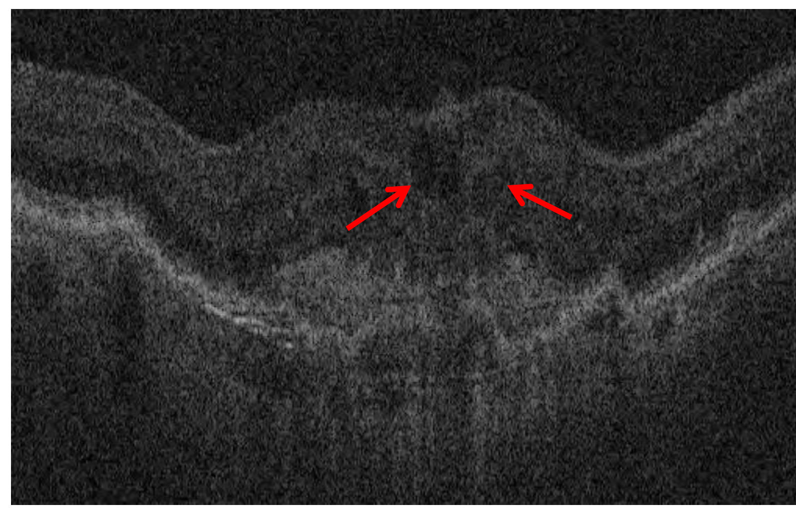
Cirrus



Nidek

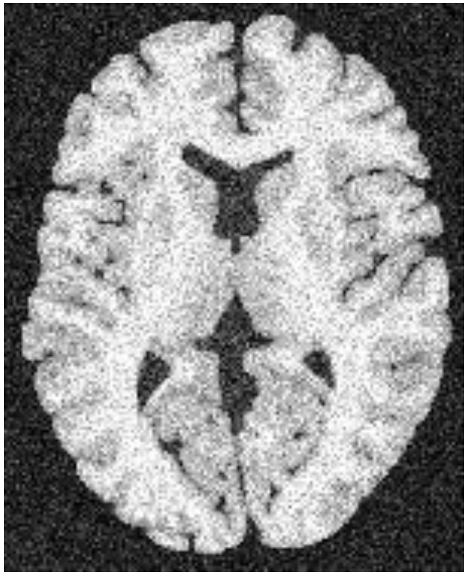


Spectralis



Topcon

Arrows indicates the retinal cysts

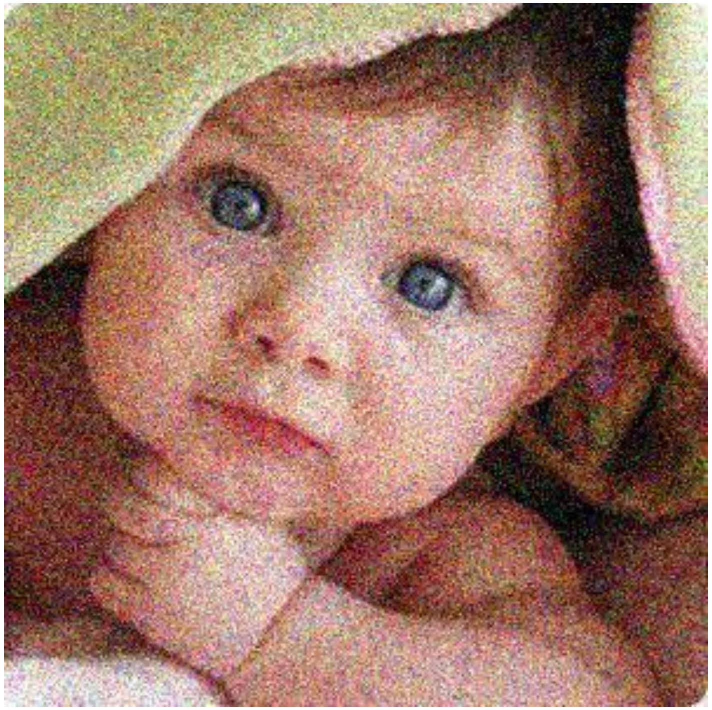


Rician

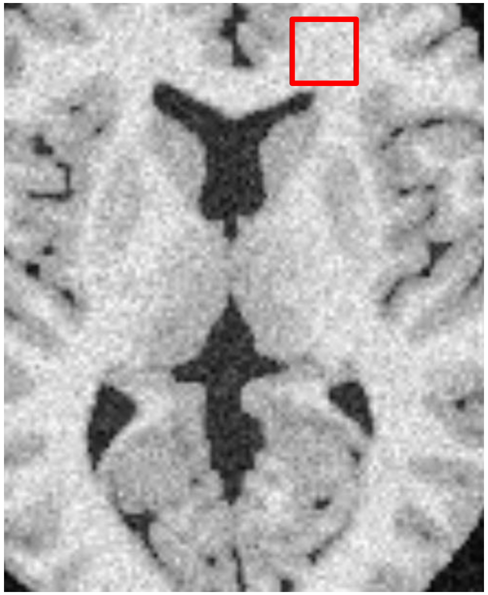
Salt & pepper

Periodic noise

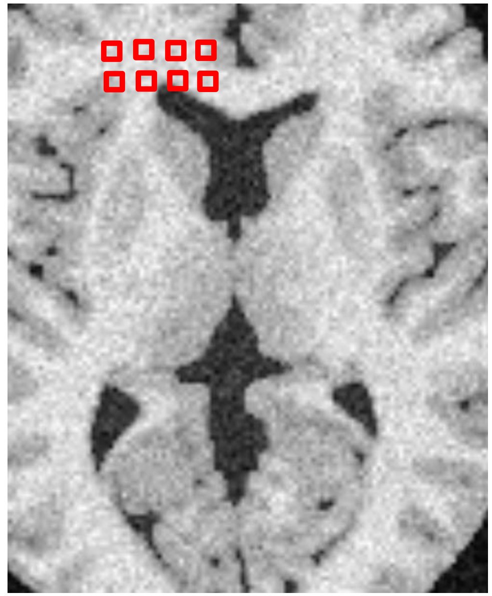
Which image do you prefer?



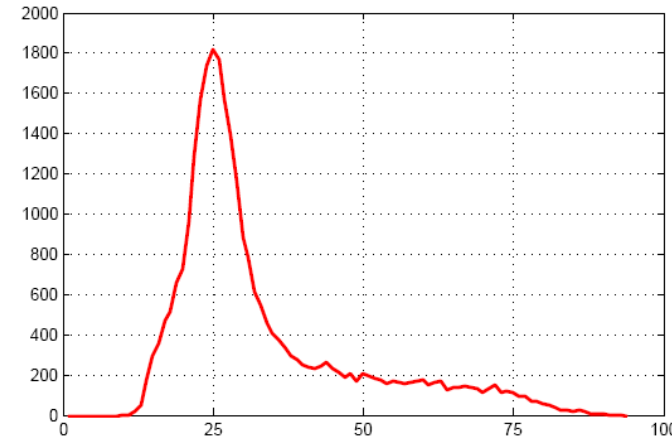
How to measure the level of noise in an image ?



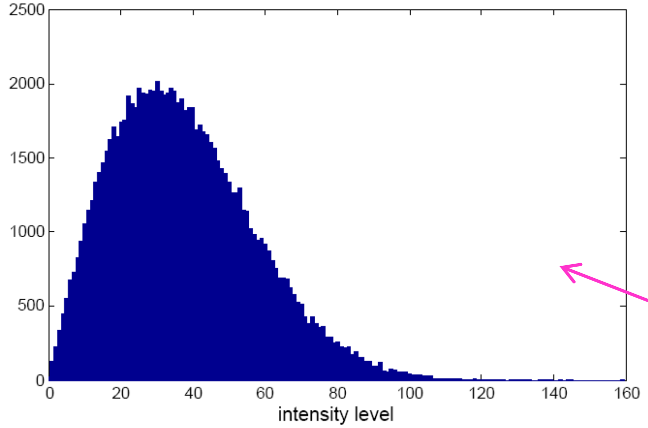
$$\sigma = \sigma_L$$



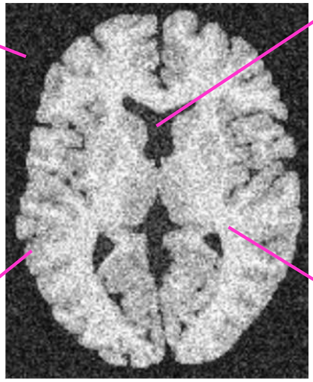
$$\sigma = \mathrm{mode}\{\sigma_L\}$$



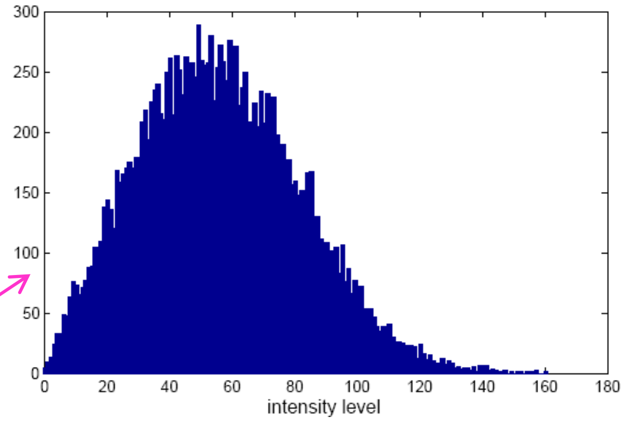
Noise Distribution in Magnitude MRI



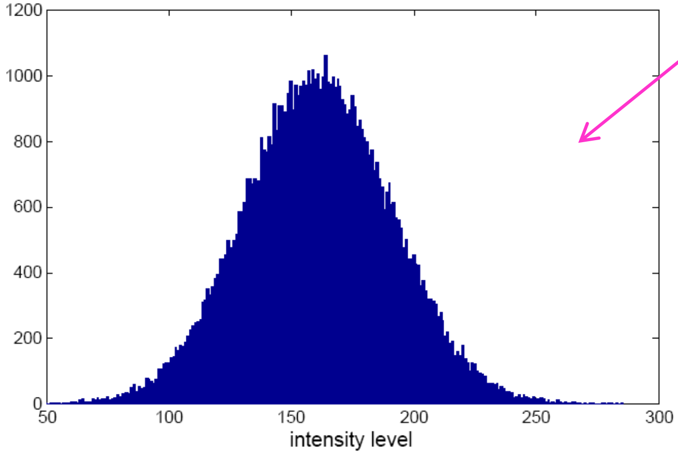
Distribution of pixels in the **background** region



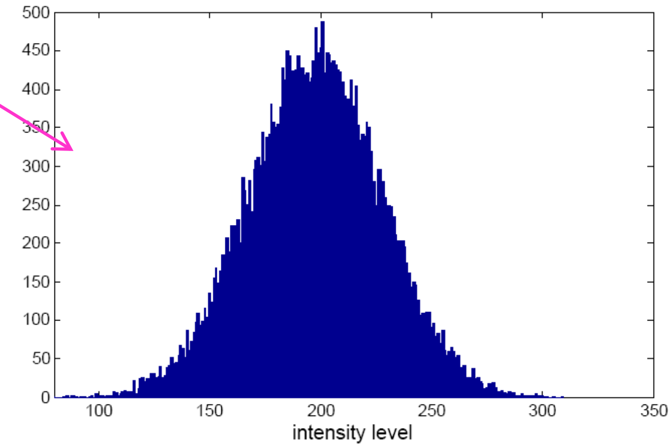
Noisy MR image



Distribution of pixels in the **CSF** region



Distribution of pixels in the **gray matter** region

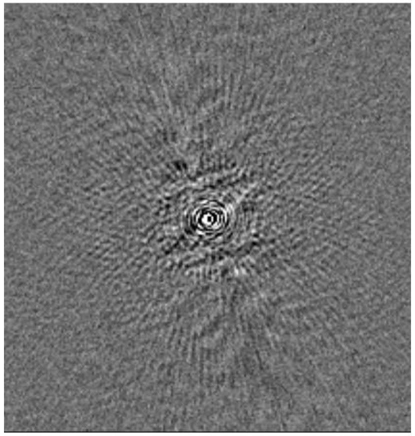


Distribution of pixels in the **white matter** region

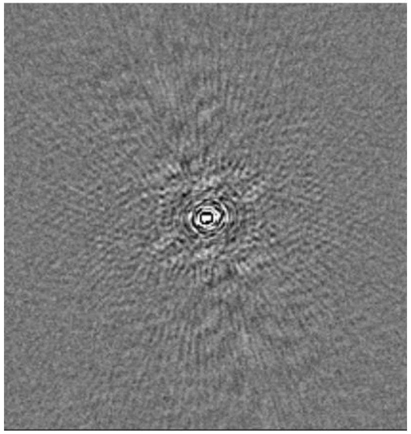
Noise in MRI – from *k*-space to Magnitude Images

Complex k - space

Real



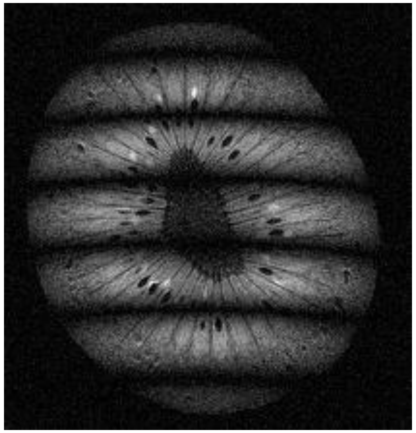
Imaginary



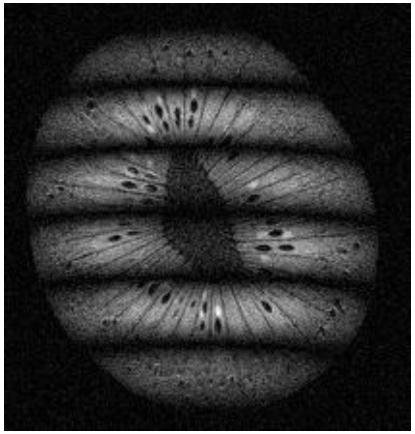
$\mathcal{F}^{-1}$

Complex Object Space

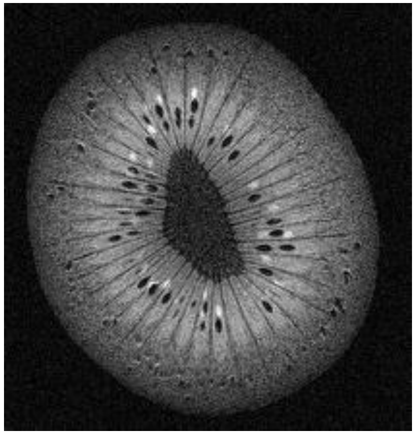
Real



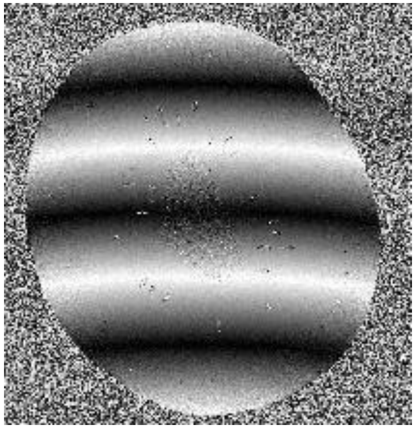
Imaginary



Magnitude



Phase



Noise Distribution in Magnitude MRI

Probability density function

$$p(m|a,\sigma_g) = \frac{m}{\sigma_g^2} e^{-\frac{m^2+a^2}{2\sigma_g^2}} I_0\left(\frac{ma}{\sigma_g^2}\right) \varepsilon(m) \quad (1)$$

Rice pdf

at low SNR when a=0

$$p(m,\sigma_g) = \frac{m}{\sigma_g^2} e^{-\frac{m^2}{2\sigma_g^2}} \varepsilon(m) \quad (2)$$

Rayleigh

at high SNR

$$p(m|a,\sigma_g) = \frac{1}{\sigma_g\sqrt{2\pi}} e^{-\frac{(m-a)^2}{2\sigma_g^2}} \quad (3)$$

Gaussian

Experiments and results

Image with Rayleigh distributed background region

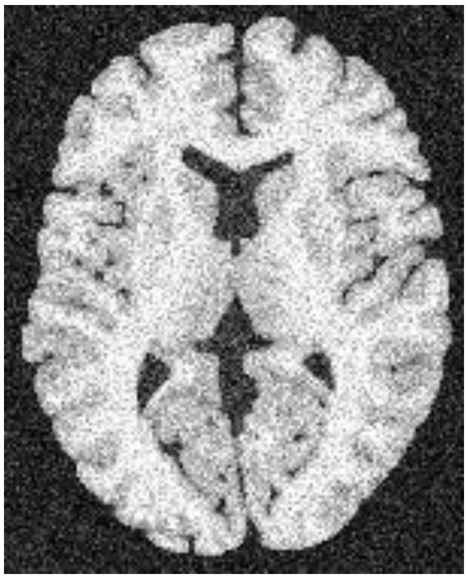
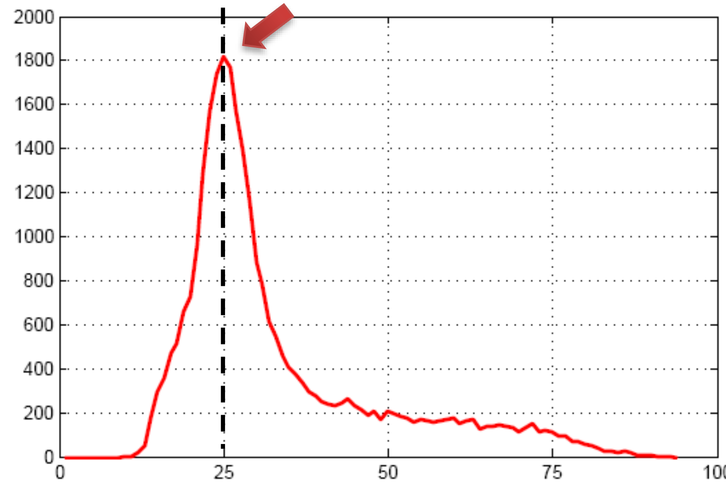
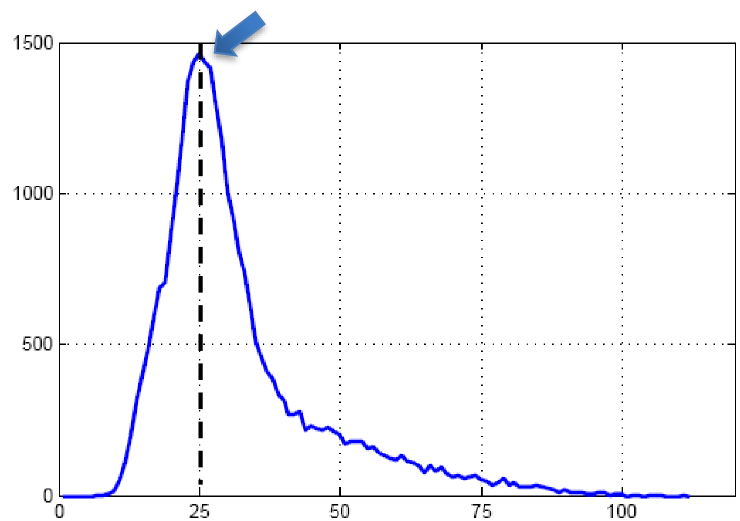


Image corrupted with noise with σ_g =25



Distribution of local estimates of σ_g estimated using local ML method.

Local window size 5 x 5



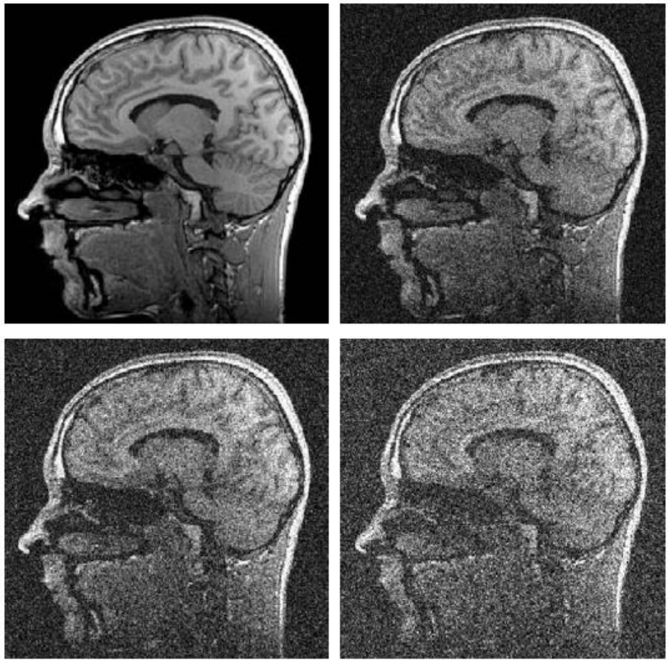
Distribution of local estimates of σ_g estimated based on the local skewness.

Local window size 5 x 5

Image Denoising

Why denoising?

- High noise levels reduce the visibility of small details and low-contrast changes.
- Generally improves the SNR



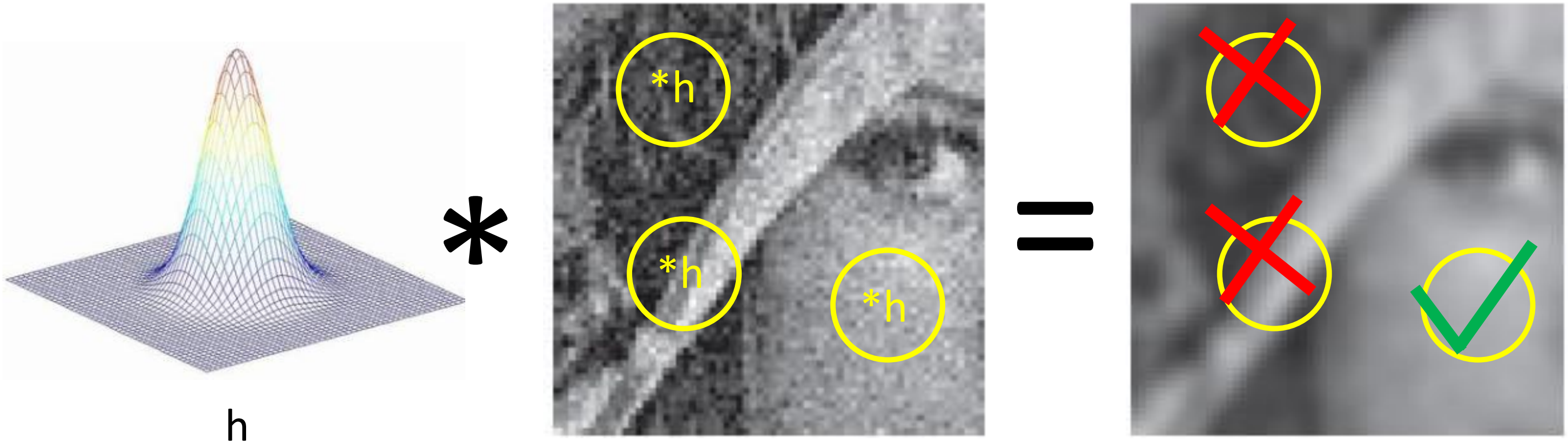
Denoising through local averaging

$$I_n(x, y) = I(x, y) + \eta$$

$$I(x, y) = \frac{1}{|N(x, y)|} \sum_{j \in N(x,y)} I(x_j, y_j)$$

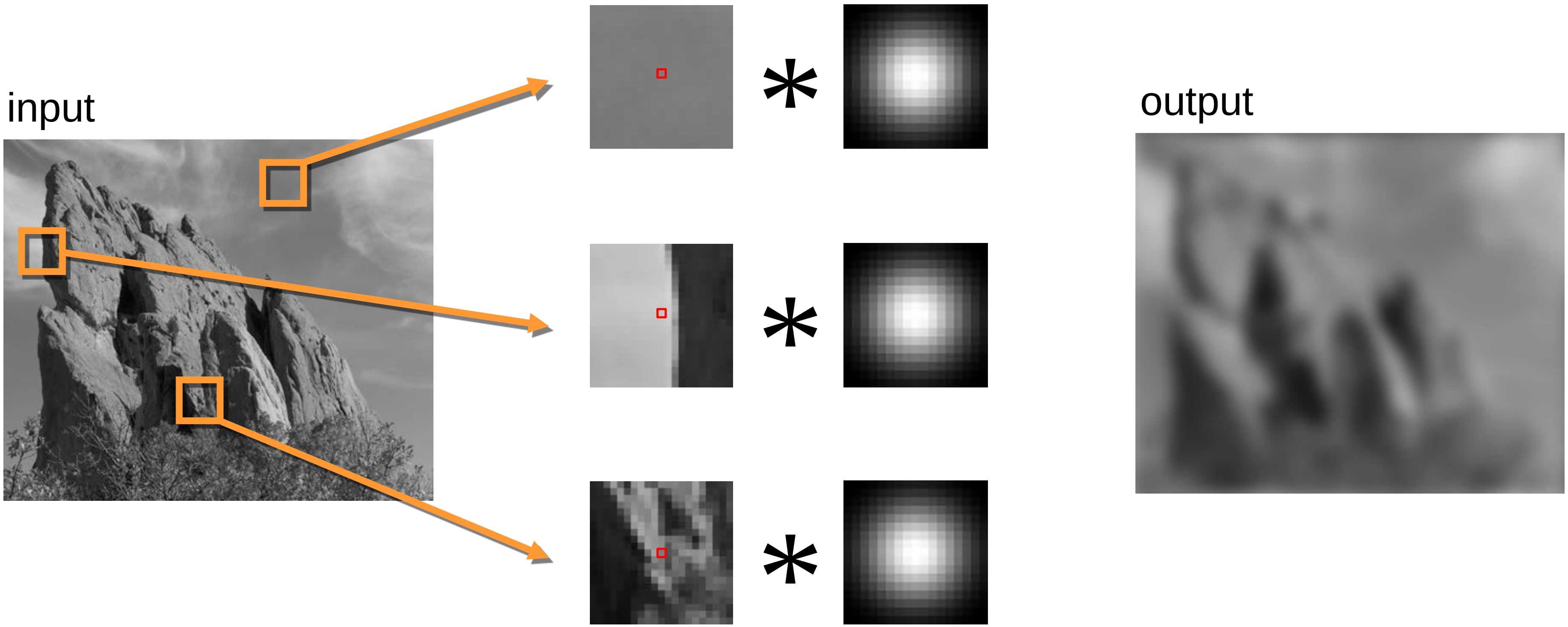
Simple averaging filter – will cause blurring of edges and textures in the image

Gaussian Smoothing



Slides taken from Sylvain Paris, Siggraph 2007

Gaussian Smoothing



Same Gaussian kernel everywhere

Averages across edges ⇒ blur

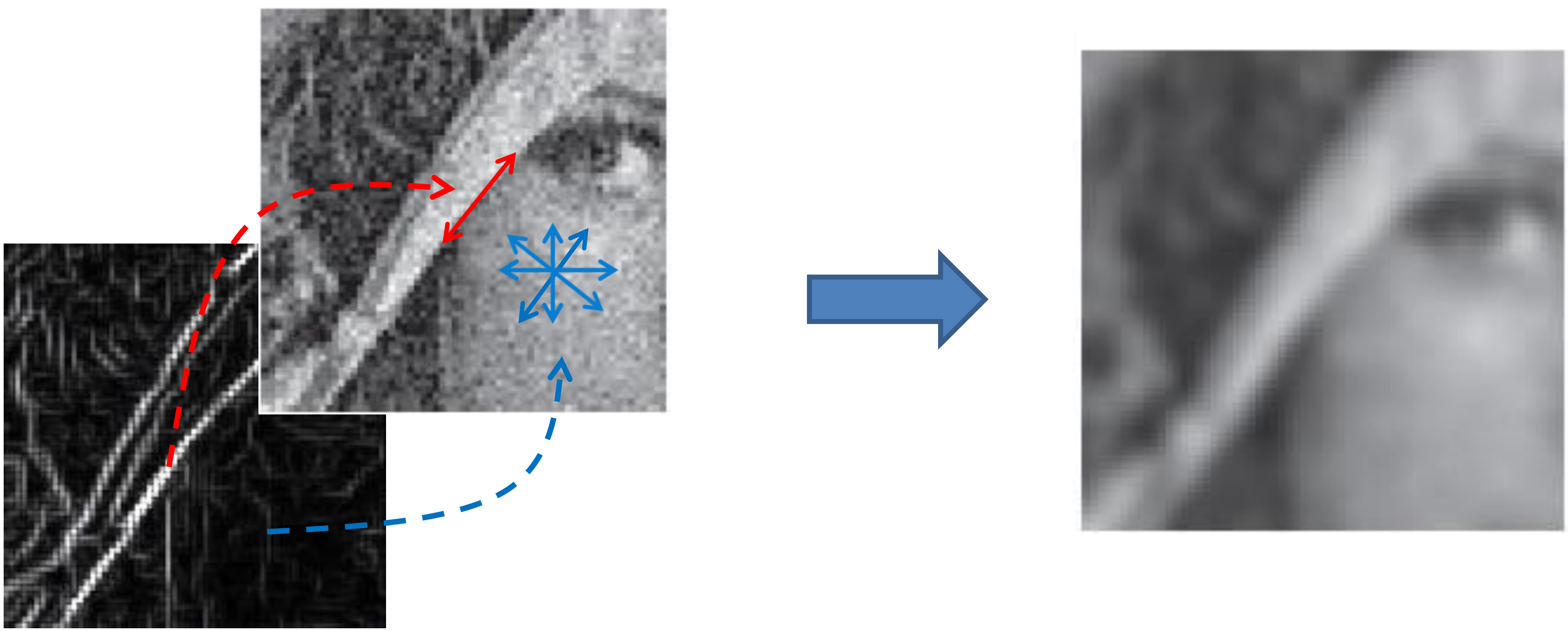
Local adaptive smoothing

- Non uniform smoothing
  Depending on image content:
  - Smooth where possible
  - Preserve fine details

How?

Anisotropic Filtering

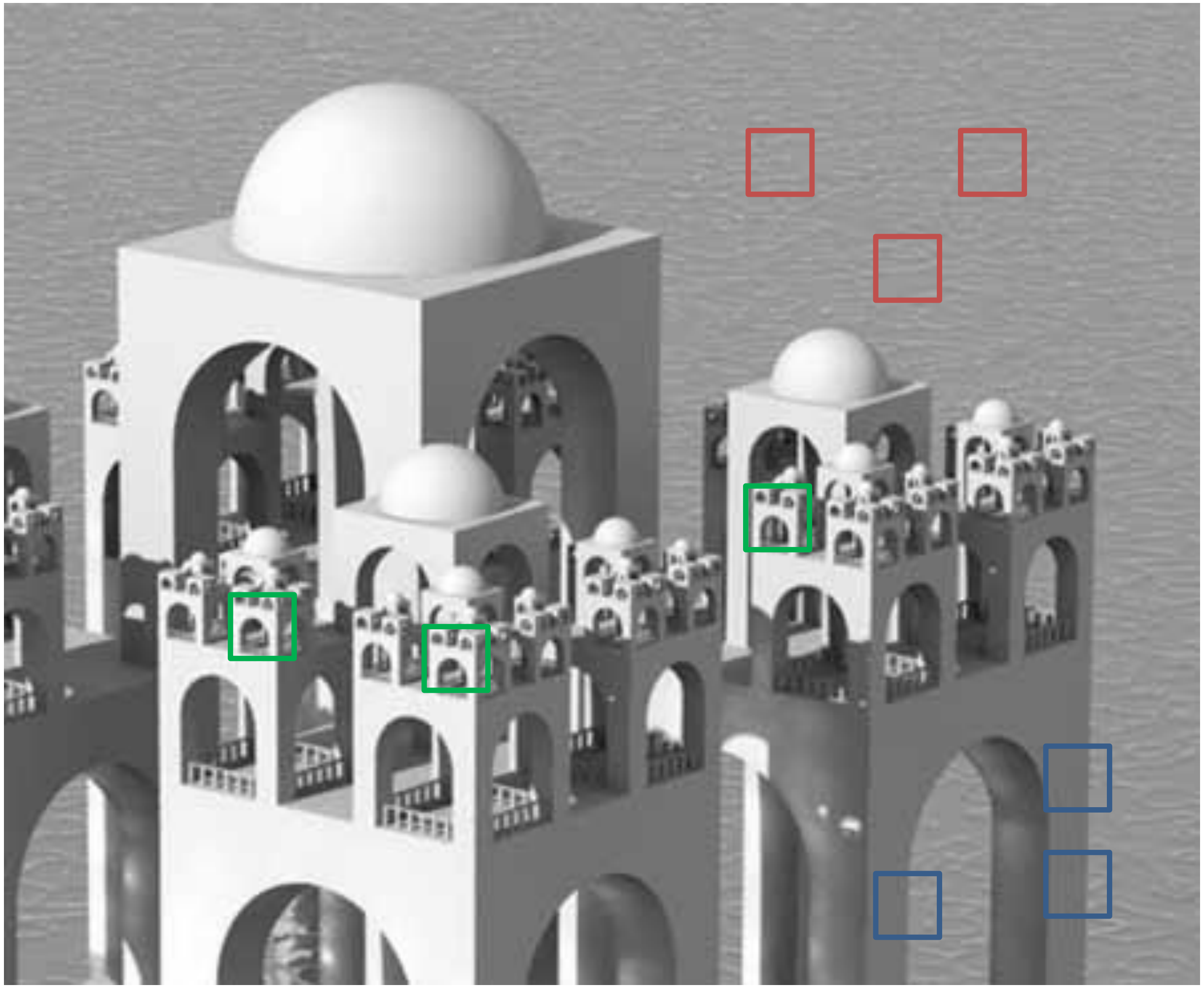
- Edges ⇒ smooth only along edges
- “Smooth” regions ⇒ smooth isotropically



gradient

Perona and Malik (1990)

Redundancy in natural images



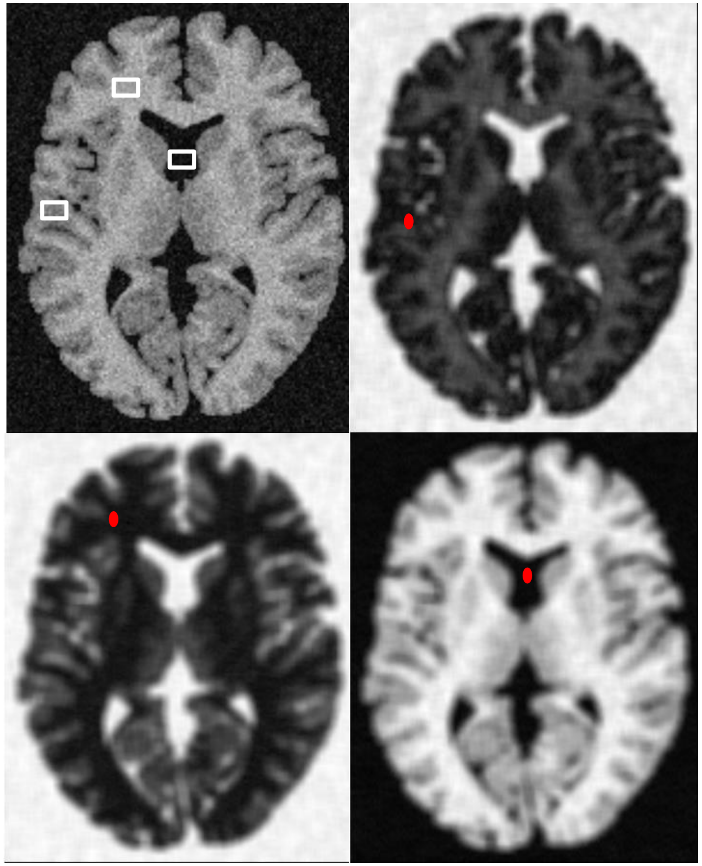
Glasner *et al*. (2009)

Patch Similarity – Euclidean Distance

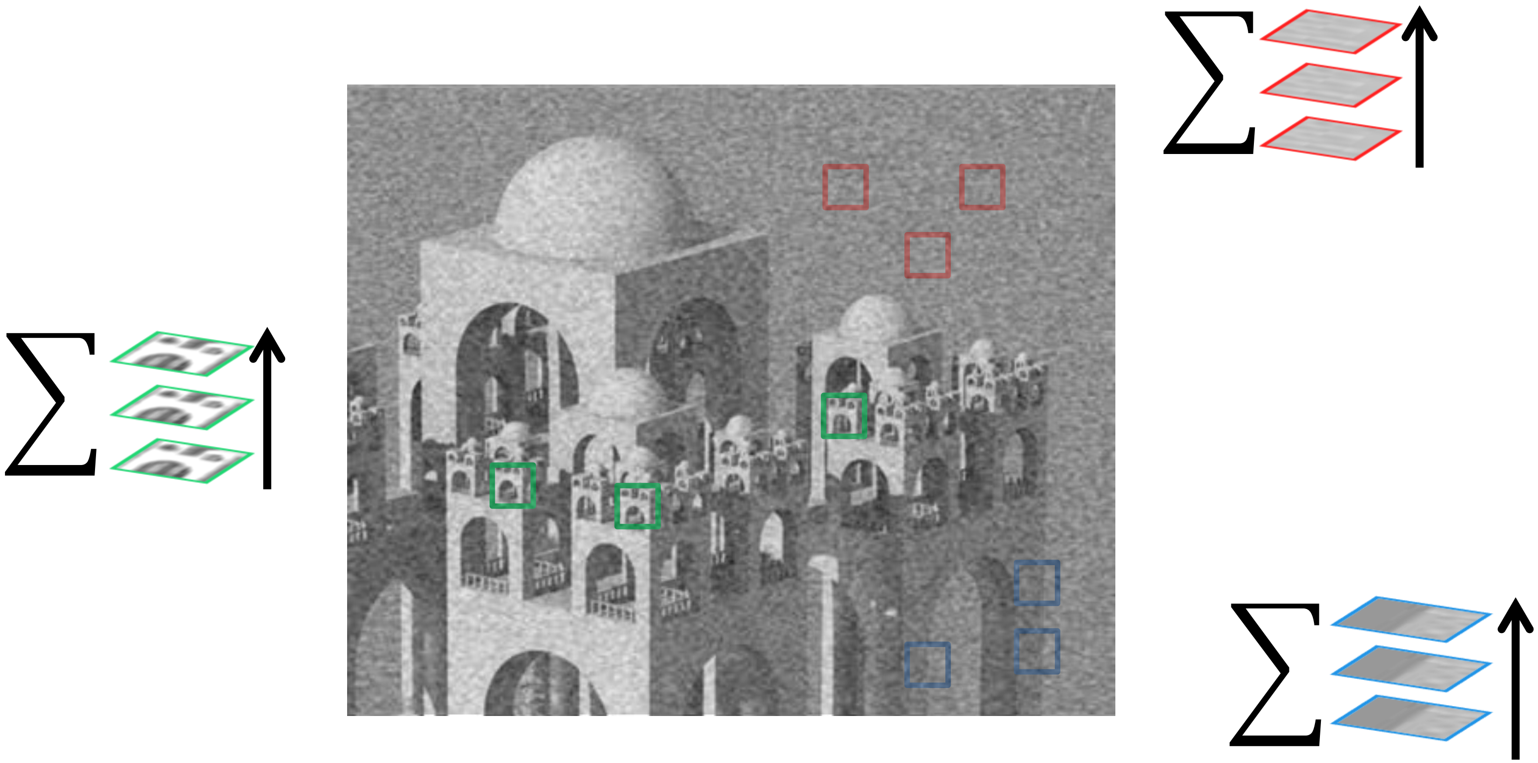
Selecting samples m_1, m_2 ,m_3 … m_n

$$d_{i,j} = \|N_i - N_j\|$$

- NL pixels – selected based on the intensity similarity of pixel neighborhoods.



Single Image "time-like" denoising



Unfortunately, patches are not exactly the same
⇒ simple averaging just won't work

Non Local Means – Basic Principle

- Non-local means compares entire patches (not individual pixel intensity values) to compute weights for denoising pixel intensities.
- Comparison of entire patches is more robust, i.e. if two patches are similar in a noisy image, they will be similar in the underlying clean image with very high probability.

Non Local Means (NLM)

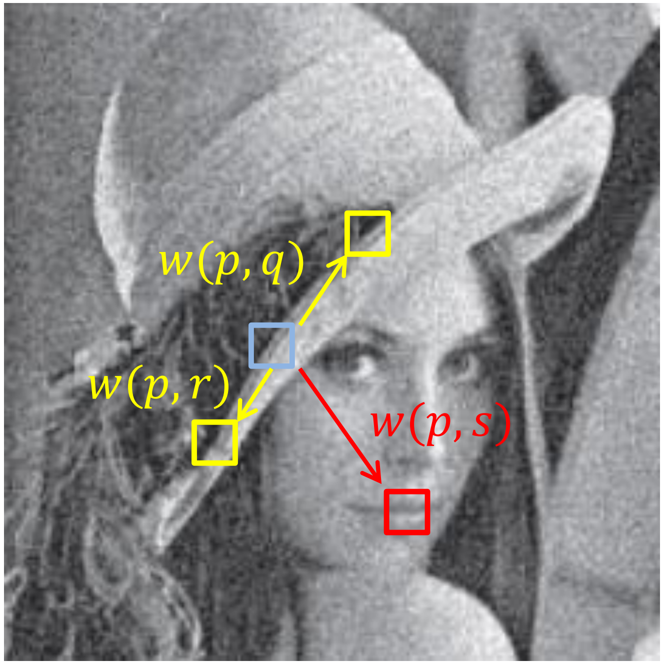
Baudes *et al*. (2005)

Use a weighted average based on similarity

$$NL(v)(i) = \sum_{j \in I} w(i,j) v(j),$$

$$w(i,j) = \frac{1}{Z(i)} e^{-\frac{\|v(\mathcal{N}_i) - v(\mathcal{N}_j)\|^2_{2,a}}{h^2}},$$

$$Z(i) = \sum_j e^{-\frac{\|v(\mathcal{N}_i) - v(\mathcal{N}_j)\|^2_{2,a}}{h^2}}$$

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