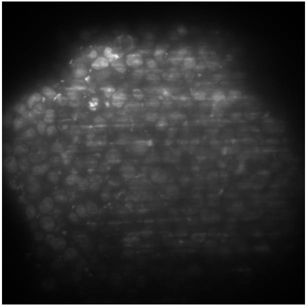
—— VSNR ——
Variational Stationary Noise Remover

Pierre Weiss, Jérôme Fehrenbach & IP3D team

Third light sheet microscopy workshop

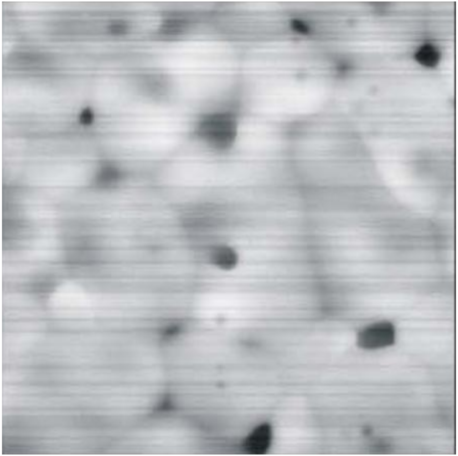
Starting observation

In many applications, structured noise degrades the images.

SPIM - Stripes due to light absorption and scattering.
Left: Xenopus leavis's late taibud (40X NA 0.8).
Right: Multicellular Tumor Spheroid (20X NA 0.5).

Examples of images with stripes



Scanning electron microscope: Stripes in a sintered specimen of Cerium Oxyde.

[Chen et al] *DeStripe: frequency-based algorithm for removing stripe noises from AFM images.* BMC Structural Biology 2011.

Examples of images with stripes

Ion beam nanotomography: Stripes in particles of cement paste.

[Münch et al] *Stripe and ring artifact removal with combined wavelet - Fourier filtering.* Optical express 2009.

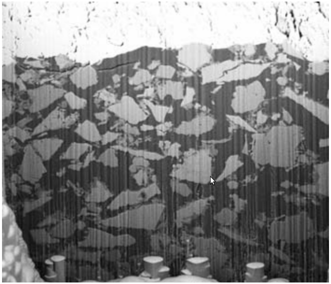
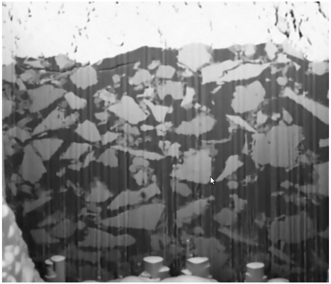
Other applications where correlated noise occurs.

- SPIM.
- Atomic force microscopy.
- Electron tomography.
- Synchrotron X-ray microscope.
- Ion beam nanotomography (waterfall effect).
- MODIS images (atmosphere imaging).
- Digital elevation models (satellite imaging).
- Imaging under turbulence.
- ...

Motivation - Standard denoising methods fail

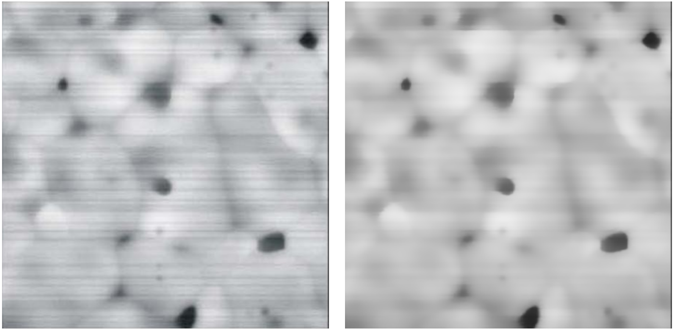
Left: original image. Right: denoised image using Gaussian smoothing.

Motivation - Standard denoising methods fail

Left: original image. Right: denoised image using anisotropic diffusion.

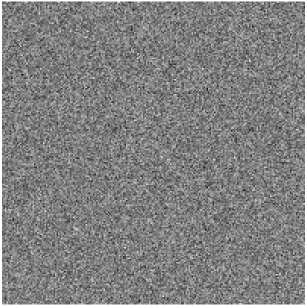
Motivation - Standard denoising methods fail

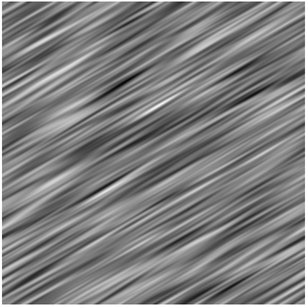


Left: original image. Right: denoised image using bilateral filtering.

Why do standard methods fail ?

- **Main reason:** standard methods rely on a white noise assumption. White means uncorrelated pixelwise.
- **Our objective:** design methods for correlated/stationary noise.

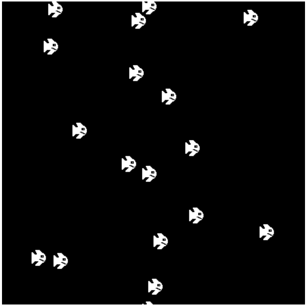
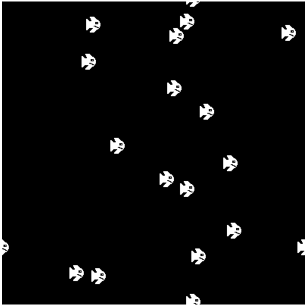




White noise (left) VS stationary noise (right) .

What is a stationary noise ?

Translating the sample in space does not change its probability.

Left: A sample of stationary noise.
Right: the same sample translated.

A natural assumption: we have no *a priori* knowledge on the location of features. They appear randomly.

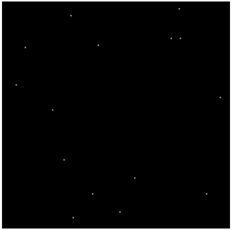
How can we generate stationary noises ?

- The class of stationary noises is too wide for numerical processing.
- We restrict to the class of noises obtained by

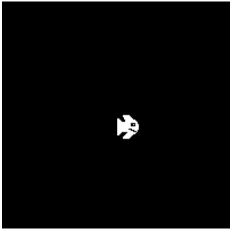
Replicating and translating an elementary pattern ψ.

This can be achieved by convolving white noise with a pattern:

$$\lambda * \psi(\mathbf{x}) = \sum_{\mathbf{y}} \lambda(\mathbf{y})\psi(\mathbf{x}-\mathbf{y}).$$



$*$



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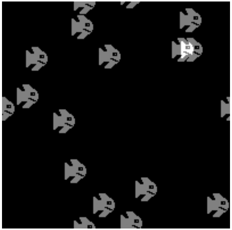
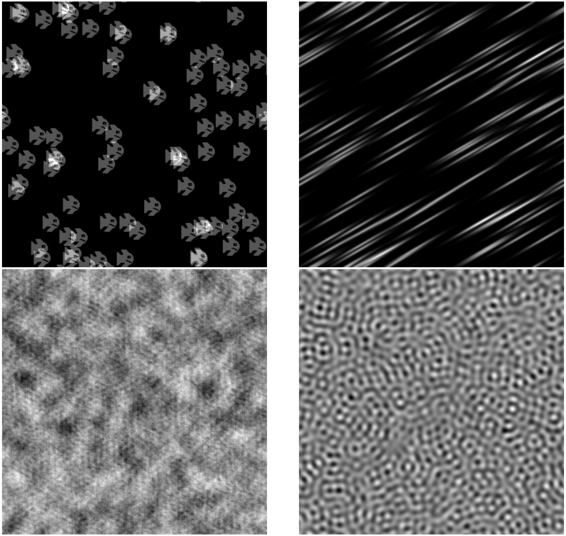


Examples of stationary noises



Model of image formation

A noisy image u_0 is the sum of:

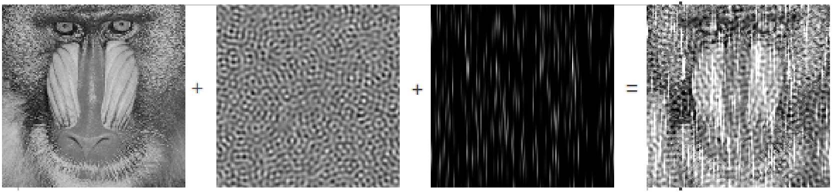
- the original image u.
- a stationary noise b.

$$u_0 = u + b$$

where

$$b = \sum_{i=1}^{m} \lambda_i * \psi_i$$

b is a sum of stationary processes.

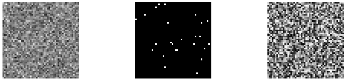


The VSNR algorithm

INPUT:

➢ *A pattern:*

➢ *A white noise statistics:*



➢ *A regularization parameter:* tunes the algorithm.

OUTPUT:

➢ *A “nice” image.*

The VSNR algorithm

The algorithm finds the most likely image.

Turns out to be a convex optimization problem.

$$\underset{\lambda \in \mathcal{R}^{m \times n}}{argmin} \left(\left\| \nabla \left(u_0 - \sum_{i=1}^{m} \lambda_i * \Psi_i \right) \right\|_1 + \sum_{i=1}^{m} \phi_i(\lambda_i) \right)$$

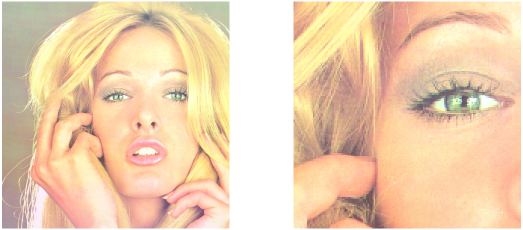
More details in :

[Fehrenbach et al] *Variational algorithms to remove stationary noise. Application to SPIM imaging.* Preprint 2011.

[Fehrenbach et al] *Variational algorithms to remove stripes: a generalization of the negative norm models.* 2011.

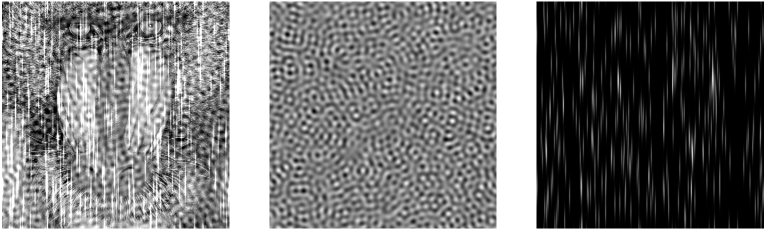
Examples of application - simulated data (1)

Left: noisy image. Right: detail.

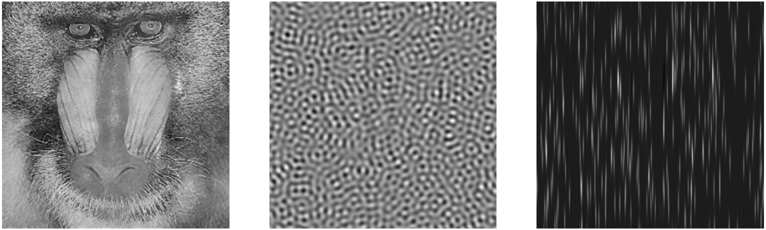


Denoised images.

Examples of application - simulated data (2)

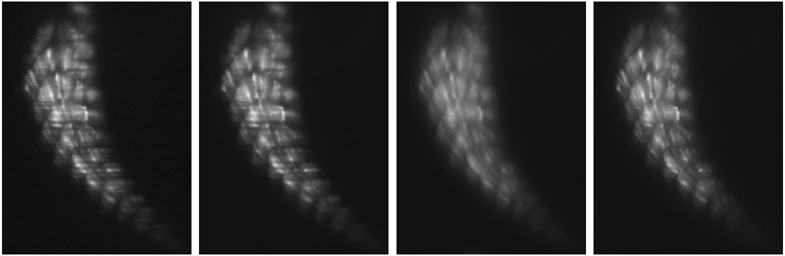


Left: noisy image. Mid: 1st component. Right: 2nd component.



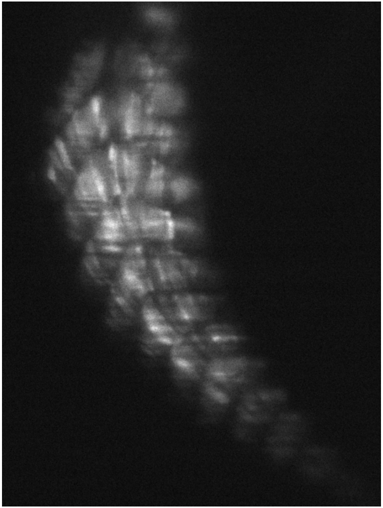
Recovered components.

Examples of application - SPIM image of a zebrafish



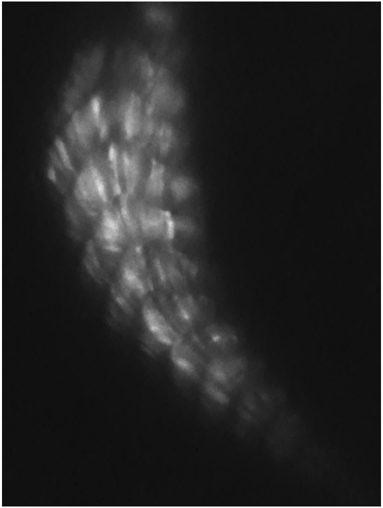
Original - TV-L2 (standard) - H^1-norm (fast) - VSNR

Examples of application - SPIM image of a zebrasfish



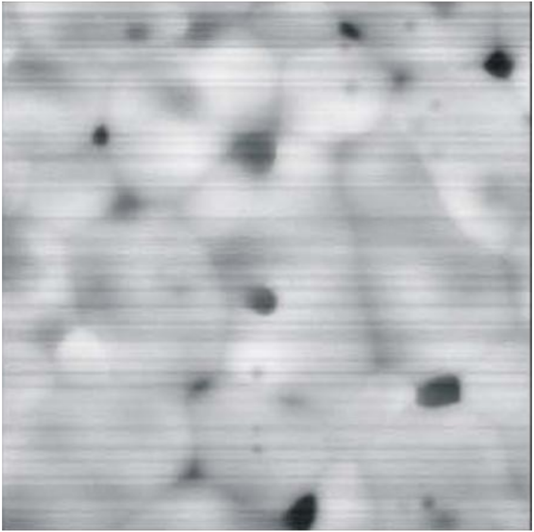
Original

Examples of application - SPIM image of a zebrasfish



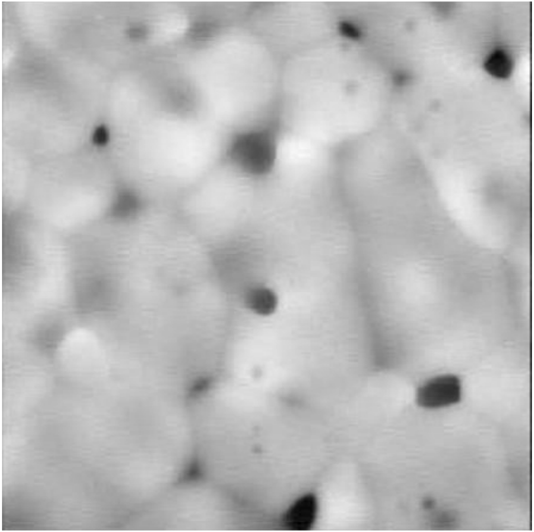
Denoised

Examples of application - Ion bean nanotomography



Original

Examples of application - Ion bean nanotomography

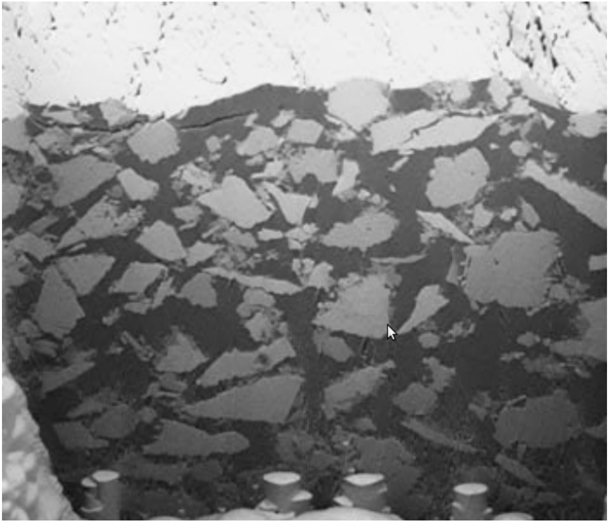


Denoised

Examples of application - SEM

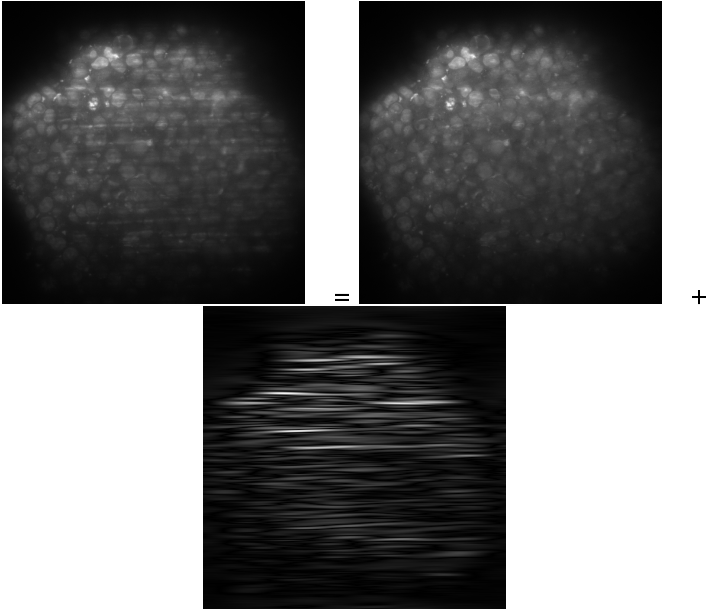
Original

Examples of application - SEM

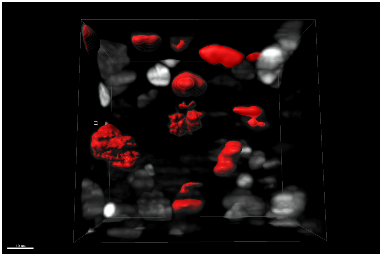
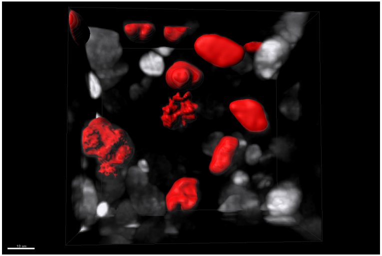


Denoised

Examples of application - SPIM image of a spheroid



Examples of application - SPIM image

3D rendering using Imaris.
Left: original. Right: denoised.

Conclusion

Main messages:

- Standard methods unadapted to the removal of correlated noise.
- Development of a versatile method for stationary noise.
- New theoretical bases (see preprints).
- Matlab implementation available on :
  `www.math.univ-toulouse.fr/~weiss/index.html`

Perspectives:

- Real 3D implementation.
- Acceleration using GPU programming.
- FIJI implementation.

[Fehrenbach et al] *Variational algorithms to remove stationary noise. Application to SPIM imaging.* Preprint 2011.

[Fehrenbach et al] *Variational algorithms to remove stripes: a generalization of the negative norm models.* 2011.

Ending words

- ♣ Thanks you for your attention ♣ -

– ♡ Thanks again to the organizers ♡ –

— ♠ Please welcome warmly the next magical speaker! ♠ —