Analysis of 19F MRI images (WP2, Task 2.3)

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for the Rome group
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Goals

- **Evaluate bio-distribution of fluorinated tracers in patients**

- Proposal: **MRI with 19F**

- Absence of intrinsic signal in living tissues allows in vivo visualization of exogenous fluorinated tracers

  - Suffers from low Signal to Noise Ratio (SNR)

- Our strategy:

  - SNR optimization (new RF antenna, SDR technology, digital signal processing)

  - optimization of the image analysis: Task 2.3

Analysis Tasks

- Currently 19F images are extremely coarse because of low SNR

- **Noise reduction**
  - Recent developments in deep learning neural network (DNN) based denoisers show promising results in noise reduction tasks

- **Registration with 1H images**
  - Together with 19F images 1H high resolution images can be taken
    => Better estimate of the 19F noise from the correspondence with 1H image
  - Need automatic registration methods => DNN methods

- **Automated Segmentation of anatomical structure in 1H MRI**
  - Can help to study tissue-specific noise correlation
  - Can also be done with DNN

Image Denoising

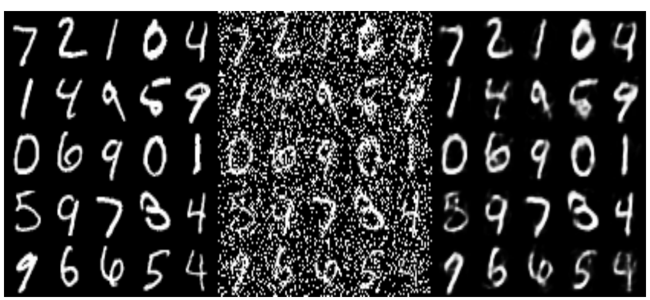
- Recent DeepNN architectures have been shown to outperform conventional denoiser algorithms (BM3D, NCSR, GMM)

- Two different approaches under study

Denoising-AutoEncoders (DAE)

- extension of the basic autoencoder (more hidden nodes than input/output nodes)
- In order to avoid the risk that the algorithm learns the identity function in this configuration: randomly corrupt the input (i.e. introducing noise)

Convolutional-NN (CNN):



original | original + noise | CNN denoised

Image+Noise

DAE
PNSR = 25 dB

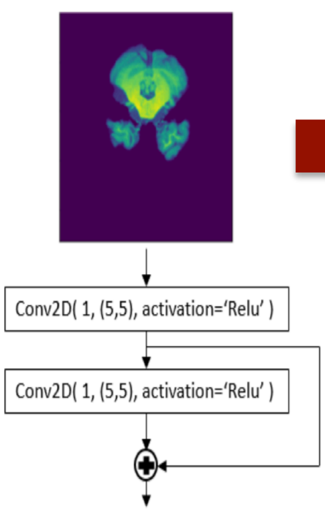
CBM3D
PNSR = 24 dB

1H/19F Co-registration and Segmentation

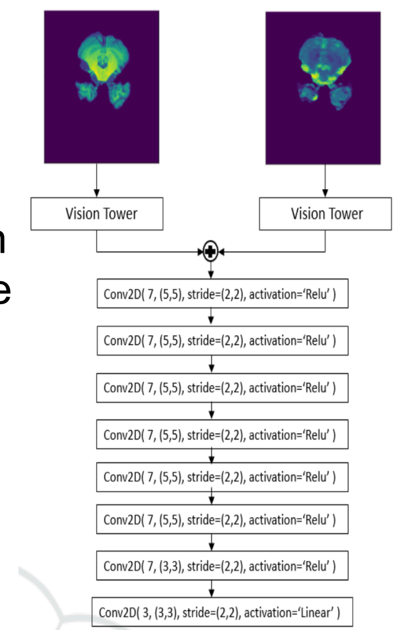
- Several studies have leveraged deep learning techniques to improve medical image registration

- DL algorithms typically adopt **convolutional neural networks** (CNNs) to learn informative image features and a mapping between the learned image features and spatial transformations that register images in a training dataset
  - predict spatial relationship between image pixel/voxels from a pair of images based on their image patches. The learned prediction model can then be applied to images pixel/voxel-wisely to achieve an overall image registration

vision tower: extract features from the input images



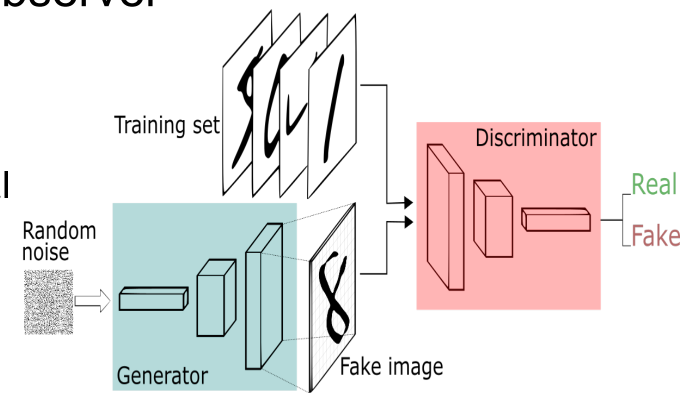
regress the transformation between a given reference and template image features extracted by the two vision towers



1H/19F Images Data-Augmentation

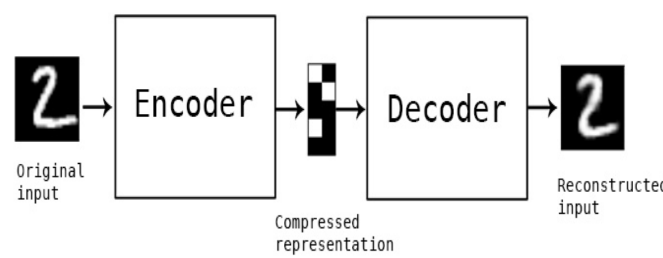
- **Could be necessary to artificially increase the number of images**
- **Generative Adversarial Network** (GANs)
  - class of artificial intelligence algorithms used in unsupervised machine learning, implemented by a system of two neural networks contesting with each other in a zero-sum game framework. They are able to generate images that look at least authentic to human observer

Generator: generate fake images and mix it with real images



Discriminator: try to recognise real from fake images

- **Variational Auto Encoder** (VAEs)
  - are DNN algorithms that learn a compressed representation of the image in a vector space called latent space of the image. Once this is achieved we can sample the latent space representation to produce realistic synthetic images



Preliminary Study: 19-F MRI

- **1H and 19F MR in-vivo images from S. Capuani (2007)**
- Rats with implanted brain tumor
- 19F-BPA fructose complex administrated (300 mg(Kg^{-1} b.w.))
- Imaging with a 7T scanner at different times after injection (t=0):

  - 1H T2-w images: t = 30min, 5h10min

  - 19F T2-w images: t = 2.5h, 4h, 5h

- **Analysis performed (as a function of time):**

  - Study of the noise distribution

  - Resolution in 19F images

  - Signal to Noise Ratio

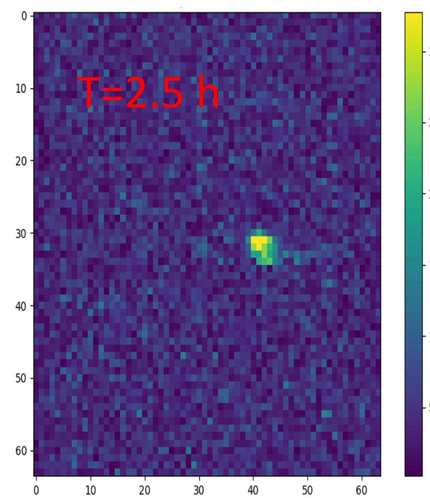
  - Correlation of noise in 19F-1H images

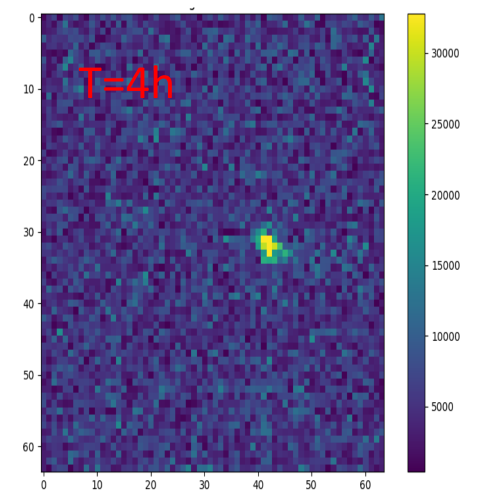
MRI Images Characteristic

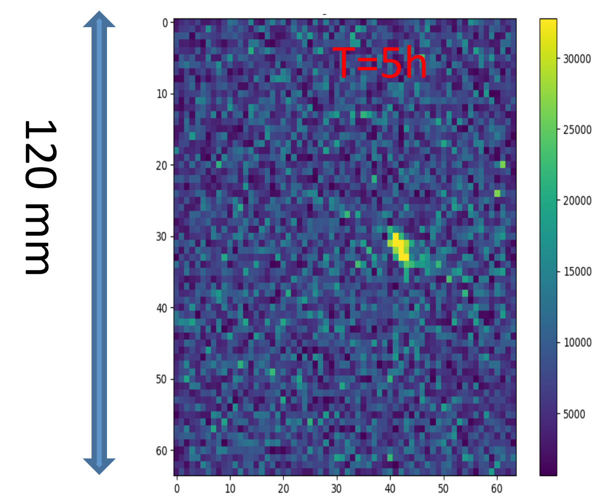
19F
FOV= 120 mm
Resolution: 64x64 Pixels
Pixel dim.= 1.875 mm
Slice thickness = 40 mm

1H
FOV= 40 mm
Resolution : 128x128Pixels
Pixel dim. = 0.3125 mm
Slice thickness = 40 mm

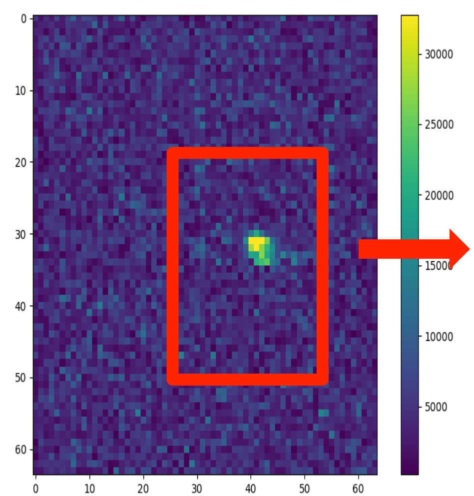
19F MRI



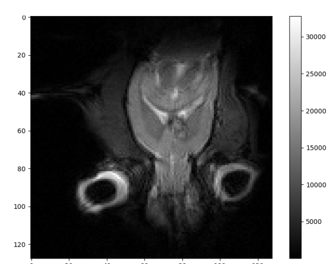




Relative position 19F/1H images



1H MRI

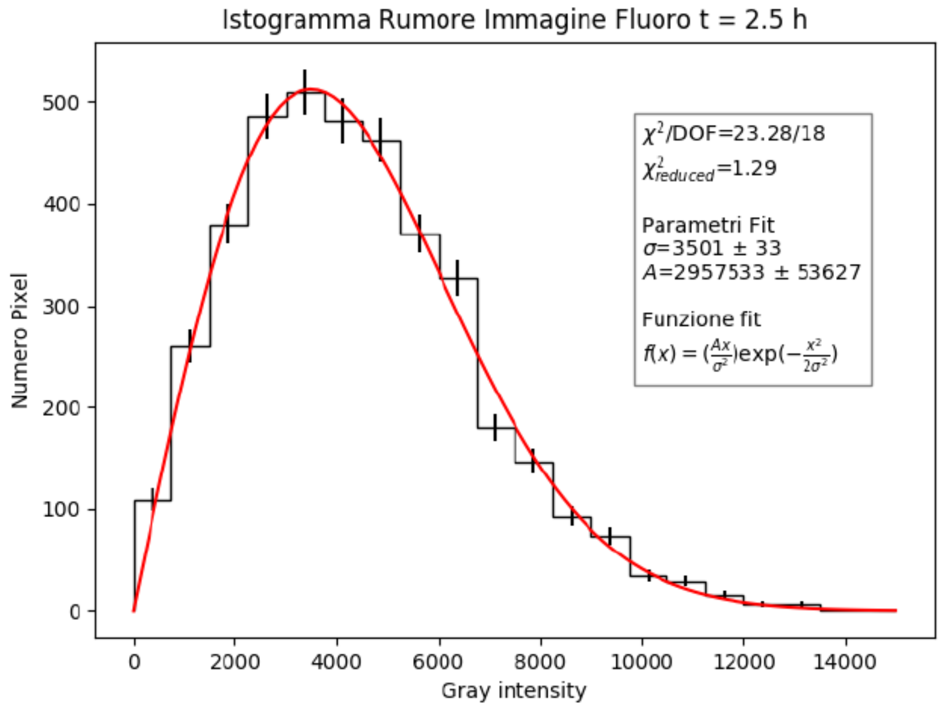


Study of the Noise Distribution

- Expected distribution: **Raleigh function**

$$P_M(M) = \frac{M}{\sigma^2} e^{-\frac{M^2}{\sigma^2}}$$

- Measured removing area of the image where signal is present

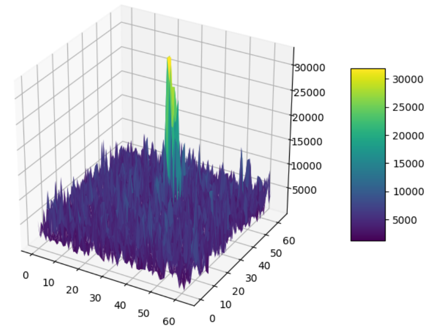


	Tempo [h]	Dev. Standard
19F	2.5	2294 ± 22
19F	4.0	2939 ± 21
19F	5.0	3983 ± 38
1H	0.5	126 ± 2
1H	5.2	230 ± 5

Increase of noise vs. time

Study of the 19F Spatial Resolution

- Fit to the whole 19F image with a bivariate gaussian



$$f(x,y) = p + \frac{A}{2\pi\sigma_x\sigma_y\sqrt{\rho^2}} e^{-\frac{Q^2}{2}}$$

$$Q^2 = \frac{1}{1-\rho^2}\left[\frac{(x-m_x)^2}{\sigma_x^2} + \frac{(y-m_y)^2}{\sigma_y^2} - 2\rho\frac{(x-m_x)^2(y-m_y)^2}{\sigma_x\sigma_y}\right]$$

- Increase in the flat component (noise) and in correlation term (19F diffusion?)

Tempo [h]	ρ
2.5	0.32±0.05
4.0	0.42±0.06
5.0	0.62±0.06

Tempo [h]	σx [mm]
2.5	3.3±0.1
4.0	3.2±0.2
5.0	2.8±0.2

Tempo [h]	σy [mm]
2.5	2.8±0.1
4.0	2.8±0.2
5.0	3.4±0.2

Tempo [h]	P
2.5	4390±37
4.0	5647±46
5.0	7681±64

Signal to Noise Ratio

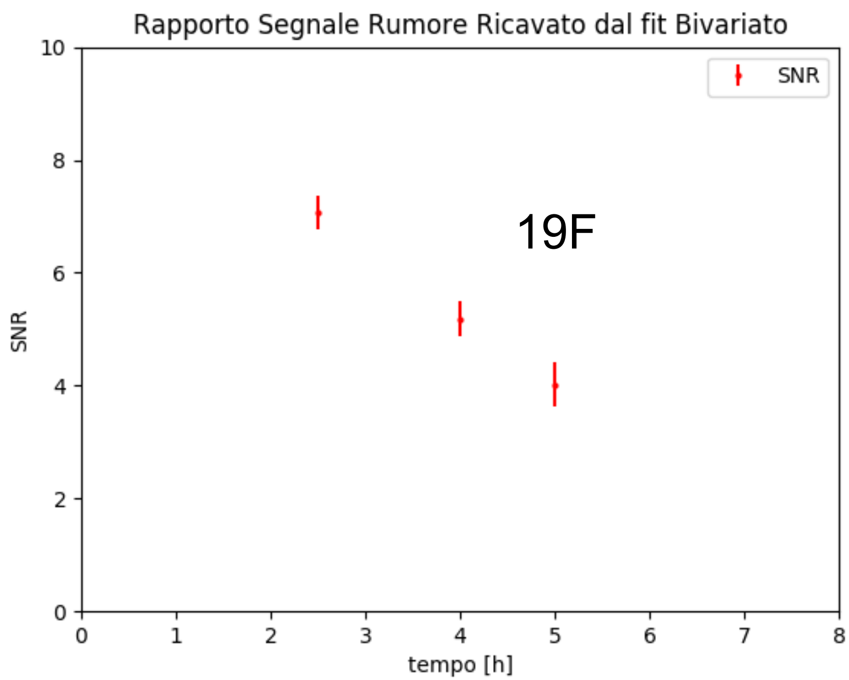
- Definition of **Signal to Noise Ratio**

$$SNR = \frac{\bar{M}}{\sigma_N}$$

Average signal ($\bar{M}$); Standard deviation of noise (σ_N)

- M is the average NMR signal: usually noise is not substracted:

  - Negligible in 1H images (12 pixel area in tumor region)
  - Relevant in the 19F images => subtracted using the bigaussian-fit



- **Better SNR in 1H images**
- **Decrease of SNR vs time**

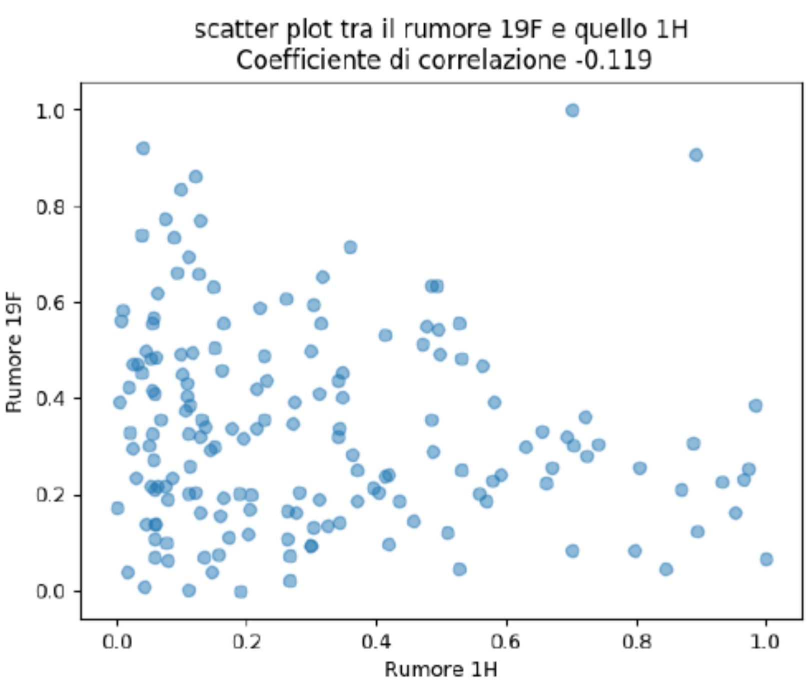
1H

Tempo [h]	SNR
0.5	109 ± 3
5.2	70 ± 2

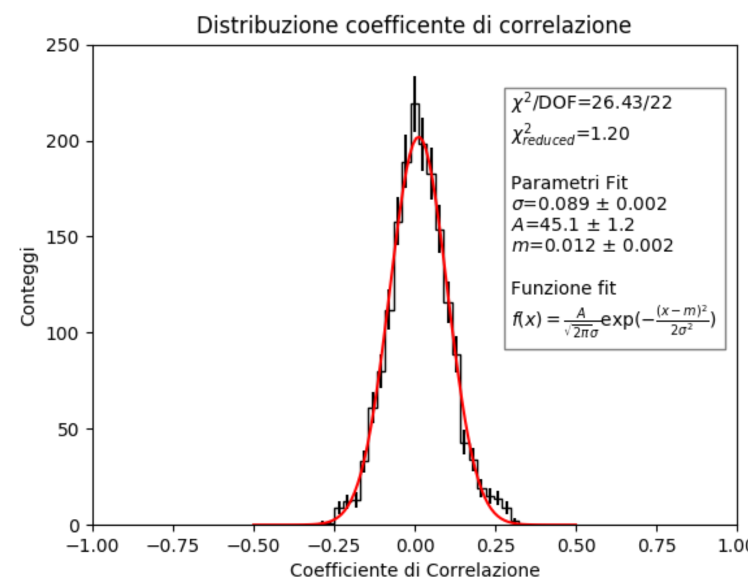
Study of Noise Correlation

- Downscaling of the 1H images (36 contiguous pixels put together)
- Co-Registration between the two images done "by hand" to a reference pixel in the tumor area-> Several reference pixel tested
- Mask that contains only the proton background applied to both images

1H-19F noise correlation for one specific registration



1H-19F noise correlation distribution for the different registrations=> **no significant correlation observed**



Summary and Plans

- Plans to apply **deep learning methods to 19F images** to improve SNR in image analysis

  - Denoising
  - Registration and segmentation (1H)
  - Data augmentation

- **Preliminary study performed with old in-vivo 19F-1H images**:
  - Resolution
  - SNR ratio
  - Noise correlation between images

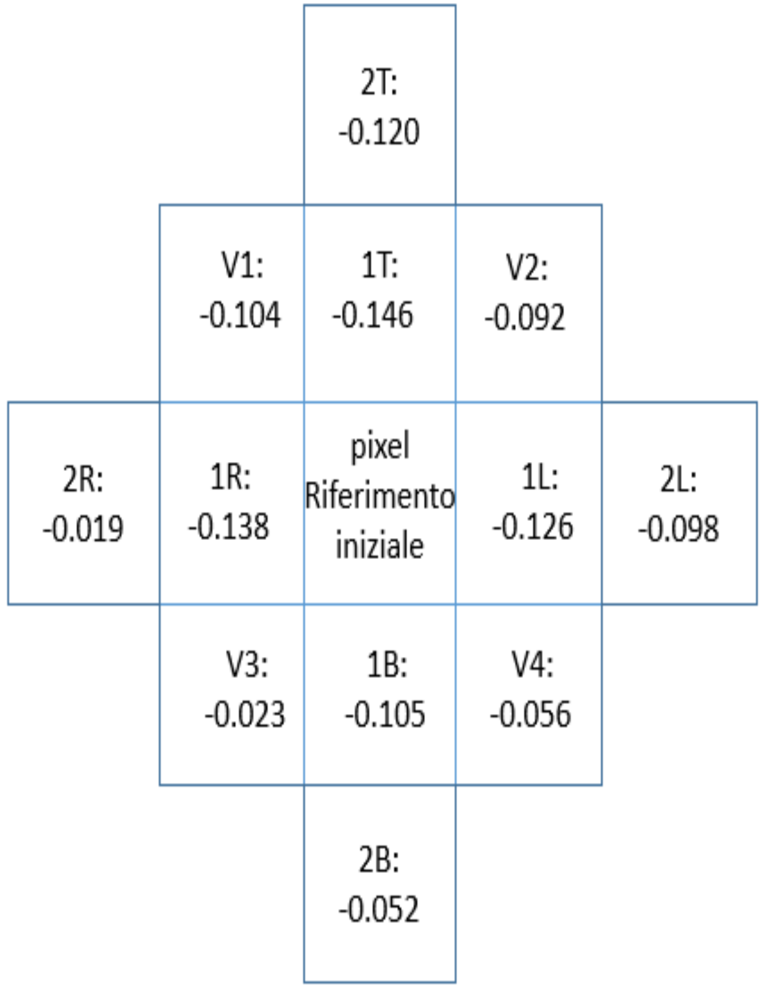
- **Next: Develop algorithms with new images to be taken with 7T Rome scanner**

  - Take 1H and 19F images with phantoms of different shape/19Fconcentrations to start to play with DNN algorithms

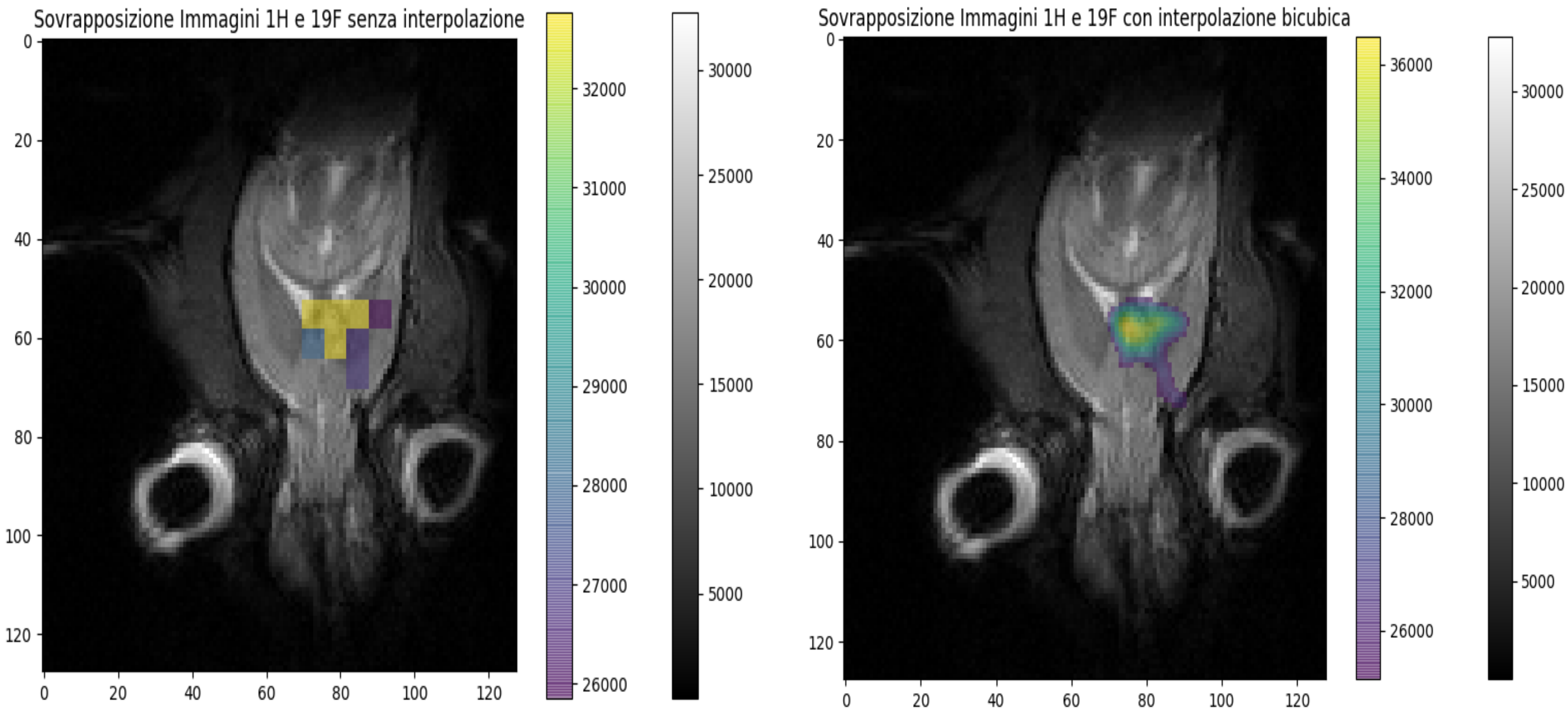
  - Study correlation of noise in 1H-19F images using the same voxel size on both

Backup

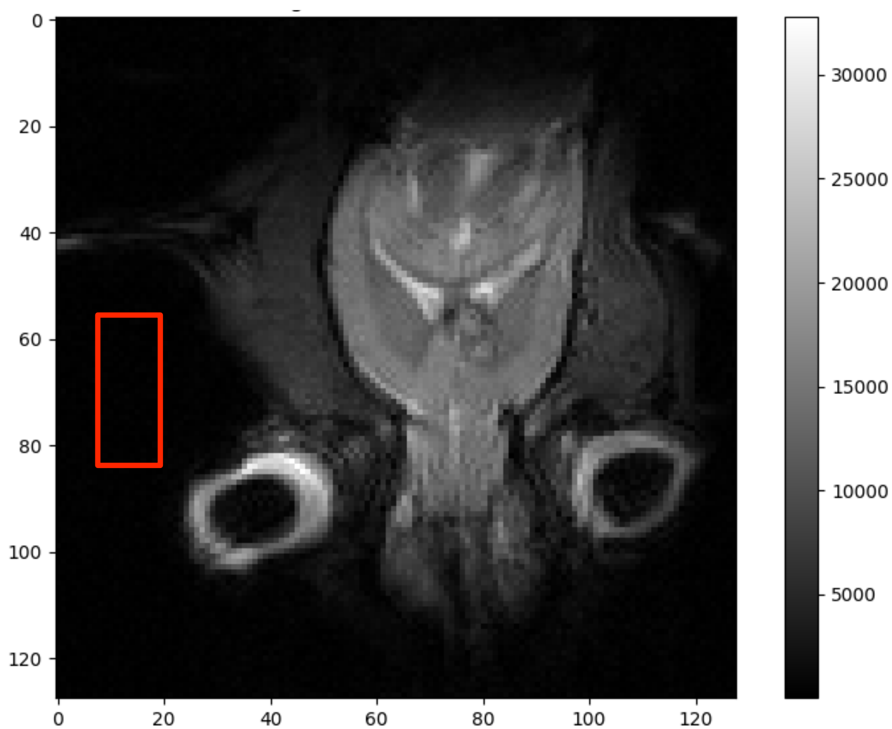
Reference Pixel Variation

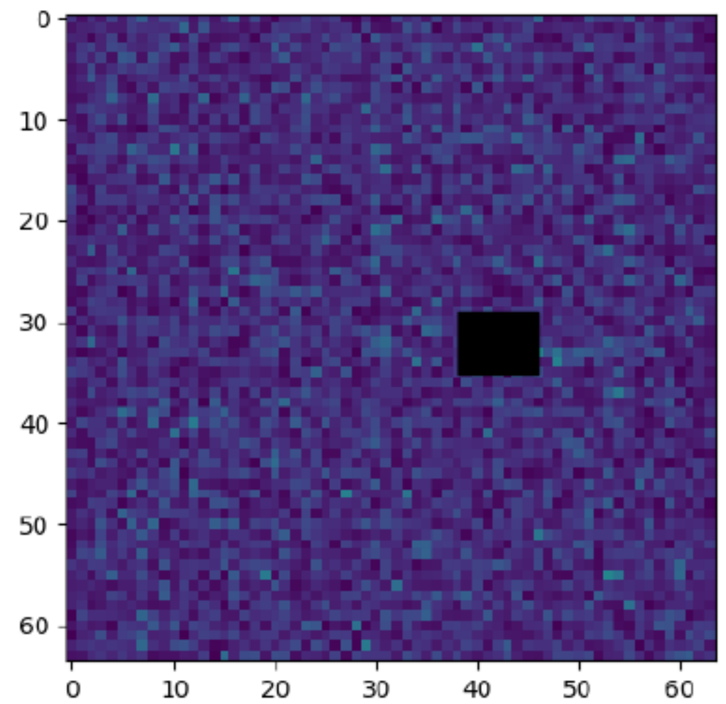


19F-1H Registration



Regions for Noise Study





Downscaling of 1H Images