Deconvolution of astronomical images with shape constraints

Keywords – Deconvolution, sparsity, weak lensing, Euclid mission

Context

Weak gravitational lensing is a very promising probe of modern cosmology (Schneider et al. 2006). Under General Relativity, light is known to follow the curvature of space-time, which is affected by massive objects. This causes distortions in the observed shapes of distant galaxies. The Euclid spacecraft plans to observe billions of galaxies with the goal of measuring their shape and extract the weak lensing signal. However, the observed galaxy images have themselves been blurred by the instrument's Point Spread Function (PSF), which can be thought of as a convolution kernel applied to the galaxy images. They are also afflicted by noise.

Sparsity has been shown to be a powerful tool to solve a large number of inverse problems, including deconvolution of noisy images. In the particular case of galaxy images affected by a PSF, Farrens et al. (2017) recently proposed one such method. Some use cases, in particular for the Euclid mission, require some improvements of this approach: this internship's goal is to study and implement one such improvement.

Image moments

To perform weak lensing studies, the observable of interest is the galaxies' ellipticity. These can be computed directly from the galaxy images using the second order moments of its brightness distribution:

$$Q_{ij} = \int I(\hat{x}, \hat{y}) \hat{x}^i \hat{y}^j d(x, y), \tag{1}$$

Where $i + j = 2$ are positive integers, $\hat{x} = x - x_c, \hat{y} = y - y_c$ are the coordinates centered on the image centroid (x_c, y_c), and I is the function mapping any position to the intensity.

While the work of Farrens et al. (2017) yields catalogs of denoised galaxies corrected for the PSF, there is no guarantee regarding the effect of the approach on the moments of these 'clean' images. For several applications of interest to weak lensing studies, such guarantees could prove highly beneficial. In the discrete case, Equation 1 can be expressed as a linear operator (Ngolè & Starck 2017, Appdx.) and the moments of the observed image, the PSF, and the reconstructed images are known to verify an analytical expression. This enables us to add a constraint related to the images' moments to the optimization problem solved by Farrens et al. (2017)'s deconvolution approach, and attain such a guarantee.

Outline of project objectives

The internship will be broadly divided into the following main blocks and objectives:

1. Reach an understanding of the required methods and previous works; in particular, the intern will need to be very comfortable with the Farrens et al. (2017) paper, with using the associated software[1], and with the concept of moments and their use in typical, weak lensing-like situations.

2. Establish how to properly add in the moments' contraint to the optimization problem to be solved.

3. Begin by implementing and thoroughly testing it in a simpler case (denoising, no deconvolution).

4. Move on to joint deconvolution and denoising with shape constraints by adding it to the existing code.

[1] `https://github.com/sfarrens/sf_deconvolve`

5. Apply the upgraded deconvolution method on Euclid-like data.

Depending on the intern's knowledge of topics of interest at the beginning of the internship and their efficiency in solving the above tasks, more could be added at their discretion – for instance combining their approach with other generalizations of the method.

Candidate

The candidate should be a Master 2 (or equivalent) student in applied maths/signal processing/data science. Knowledge in optimization and sparsity-based methods would be a plus. Experience coding in Python is not required, but would be advantageous.

Internship

The internship will take place in the CosmoStat laboratory, under the supervision of Jean-Luc Starck and in close collaboration with Morgan Schmitz.

- *Deadline for applications:* February 28th, 2018.
- *Contact:* Morgan Schmitz (morgan.schmitz@cea.fr).
- *Duration:* At least 4 months.
- *Possibility to continue on for a PhD:* Yes.

References

Farrens, S., Mboula, F. N., & Starck, J.-L. 2017, Astronomy & Astrophysics, 601, A66

Ngolè, F. & Starck, J.-L. 2017, arXiv preprint arXiv:1703.06066

Schneider, P., Kochanek, C., & Wambsganss, J. 2006, Gravitational Lensing: Strong, Weak and Micro: Saas-Fee Advanced Course 33, Vol. 33 (Springer Science & Business Media)