

## Higher-order Total Variation Reconstruction for Structured Illumination Microscopy (SIM)

Laurène Donati<sup>1\*</sup>, Denis Fortun<sup>1,2</sup>, Daniel Sage<sup>1</sup> and Michael Unser<sup>1</sup>

<sup>1</sup> *Biomedical Imaging Group, Ecole Polytechnique Fédérale de Lausanne, Switzerland*

<sup>2</sup> *CIBM-SP, Ecole Polytechnique Fédérale de Lausanne, Switzerland*

\* *Corresponding author: [laurene.donati@epfl.ch](mailto:laurene.donati@epfl.ch)*

### Abstract Submission for Topical Workshop:

- X Computational Imaging
- Computer Vision and Machine Learning
- Large Data in Optics
- Virtual/ Augmented Reality

**Keywords:** Structured Illumination Microscopy (SIM), Image Reconstruction, Sparsity, Regularization, Hessian-Schatten.

### Abstract

Structured illumination microscopy (SIM) is an effective and widely used method for producing high-resolution fluorescence micrographs. This imaging technique successively overcomes the diffraction limit and reaches up to twice the lateral resolution of conventional wide-field microscopy [1]. In SIM, the sample is imaged with varying configurations of an illumination pattern and a high-resolution image is reconstructed from the collected data (i.e. multiple low-resolution images). The quality of the reconstructed image depends strongly on the type of reconstruction method used. The classical Gustafsson-Heitzmann reconstruction method relies on a sequence of demodulation and recombination of the measurements, followed by some Wiener filtering [1]. This direct method typically does not include prior information about the image. Other recent approaches based on an variational formulation of the reconstruction have shown promising results for SIM [2,3].

By taking advantages of recent advances in mathematical imaging and sparse signal recovery [4,5], we have designed a fast iterative algorithm that imposes sparsity constraints on the Hessian of the image. By penalizing higher-order derivatives, Hessian-Schatten (HS) regularization favors piece-wise linear solutions which do not harbor block artifacts [5]. The non-linear optimization is performed iteratively via the alternative direction of multipliers method (ADMM), which decomposes the initial task into two basic optimization sub-problems.

By applying the proposed framework, we are able to outperform the current linear reconstruction methods (multichannel Wiener filter) (Figure 1), while avoiding the staircase artifacts of total variation regularization (Figure 2). As a result, thin filament-like cell structures can be distinguished more easily.

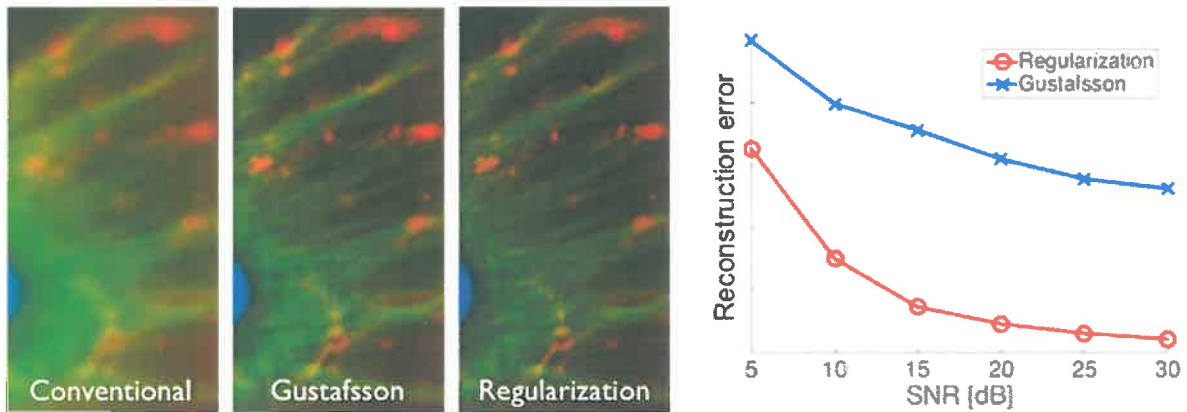


Figure 1: Comparison of SIM reconstruction with Wiener-based method and our regularized approach

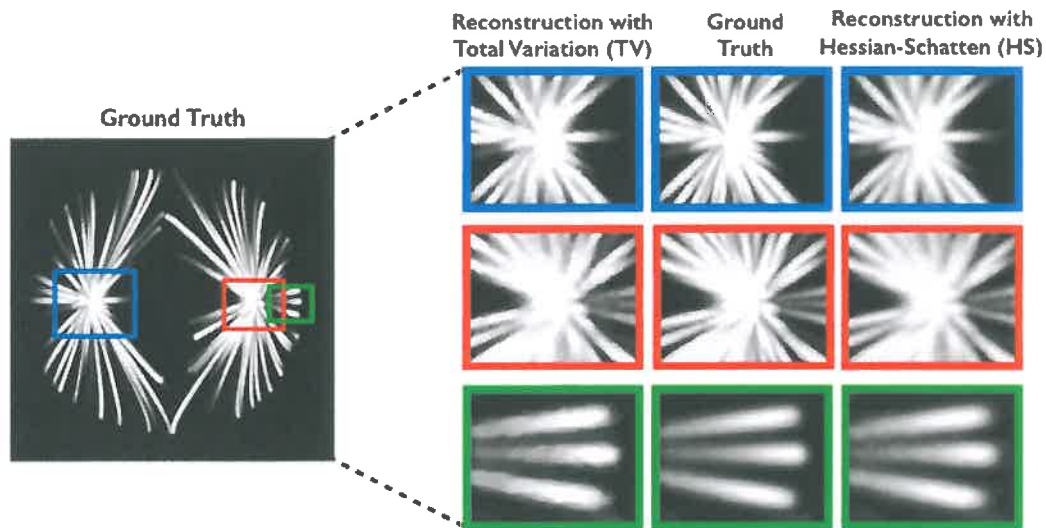


Figure 2: Comparison of SIM reconstruction with TV regularization and HS regularization

- [1] M. G. L. Gustafsson, "Surpassing the Lateral Resolution Limit by a Factor of Two using Structured Illumination Microscopy", *Journal of Microscopy*, 198 (2000), pp. 82-87.
- [2] F. Orioux, E. Sepulveda, V. Lorient, B. Dubertret, J.-C. Olivo-Marin, "Bayesian Estimation for Optimized Structured Illumination Microscopy", *IEEE Trans. Image Processing* (2012), no.2, pp.601-614
- [3] J. Boulanger, N. Pustelnik, L. Condat, "Non-smooth Convex Optimization for an Efficient Reconstruction in Structured Illumination Microscopy", ISBI 2014
- [4] E. Bostan, U. S. Kamilov, M. Nilchian, M. Unser, "Sparse Stochastic Processes and Discretization of Linear Inverse Problems", *IEEE Trans. Image Processing*, 22 (2013), pp. 2699-2710.
- [5] S. Lefkimmiatis, J.P. Ward, M. Unser, "Hessian Schatten-Norm Regularization for Linear Inverse Problems", *IEEE Trans. Image Processing*, 22 (2013), no. 5, pp. 1873-1888.