Ph.D Thesis offer

Multivariate Scale-Free Texture Analysis:

Texture segmentation, interface estimation, anomaly detection with applications to real-world images
From multifractal analysis to statistical and deep learning: stability and robustness

Starting Date :	01/10/2019	*Duration :*	3 years
Deadline :	**20/04/2019**	*Funding :*	DGA Ph.D fellowship (secured)
Requirements :	M2 research or equivalent EU nationality	*Place :*	Ecole Normale Supérieure de Lyon

Research team and supervision.

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The conduction of the PhD will be framed into a more general research program of the Signals, Systems and Physics team.

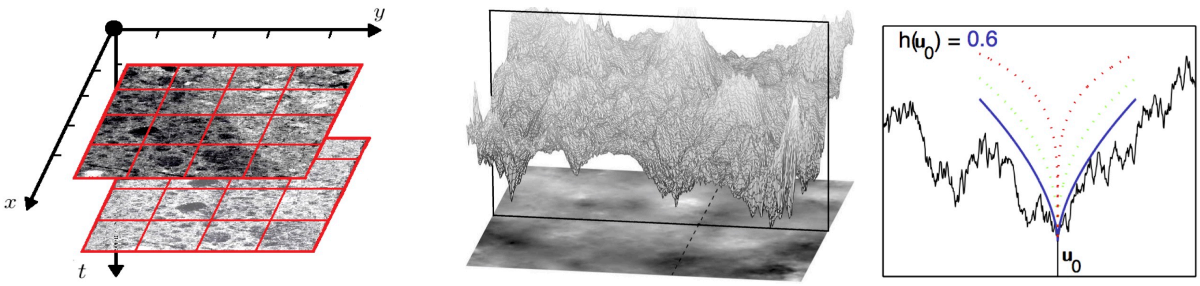
Scientific context.

Anomaly detection and texture segmentation are ubiquitous and challenging issues in image processing and have been envisaged through many different concepts. Over the decades following the seminal works of Benoît Mandelbrot, an overwhelming number of images have been shown to be well-characterized by scale-free textures. This implies a major change in paradigm: the characterization can no longer rely on one specific analysis scale since all scales play equivalent roles, and the classical signal/image processing tools must thus be replaced with tools that evidence and quantify the mechanisms relating scales one to the other.

Multifractal analysis has recently matured to become one of the most powerful tools for this purpose. It benefits from a well-grounded theoretical framework and a robust practical and has been extremely successful in a large panel of applications of very different natures. Yet, these successes assumed that

i) data are univariate (independent analysis of one image at a time)
ii) data are isotropic (all directions in an image are equivalent)
iii) data are homogeneous (multifractal properties are the same everywhere in the image)

while these requirements are no longer met in many modern real-world applications. Indeed, data are often naturally multivariate (dependent measurements, captured by different imaging sensors, jointly convey the information of interest), anisotropic (certain directions in the image have privileged roles) and often consist of zones, to be detected, whose properties differ from that of the rest of the data.



Left: a multivariate image consisting of a spatial (x,y) and temporal (t) collection of patches (in red).
Multifractal analysis characterizes scale invariance of the image intensities (schematized in the center) via the fluctuation if their pointwise regularity, measured by the Hölder exponent h(u) (right).

Missions and Activities. Research program and targeted contributions

The overarching goal of the proposed Ph.D is to devise and compare texture segmentation and anomaly detection for multivariate, non isotropic and heterogeneous images using tools and concept ranging from optimization formulation to statistical and deep learning. Emphasis will be on assessing stability and robustness. Real-world applications stemming from physics, geophysics or biomedical imaging will be targeted.

The research program is organized around two main directions:

(i) **Statistical and deep learning**. The PhD student will formally study the link between unsupervised and supervised strategies for scale-free and multifractal texture segmentations: The former,
already partially developed, relies on estimated multifractal attributes combined into variational segmentation frameworks, the latter will be based on deep neural networks. The PhD candidate will first propose variations on state-of-the-art of unsupervised multifractal segmentation strategies to explore the potential benefits in semi-supervision before turning to self-supervised or fully-supervised deep neural network strategies. A methodology to conduct relevant and meaningful comparisons (beyond the simple classificationperformance) between the different approaches will also constitute an important research track.

(ii) **Stability and robustness assessment**. Segmentation performance often strongly depend on hyperparameter tuning. For instance, in the unsupervised fractal current formulation, crucial choices need to be made by the users (decomposition level or range of scales, properties of the underlying multiscale quantities, level of redundance in the representation). While current formulations rely on standard 2D discrete wavelet transform, extension to other multiscale quantities (such as complex wavelets or shearlets) will be explored. The issue is even more critical in deep learning where the robustness of achieved results with respect to the network architecture is often debatable. An important research direction will thus be to devise a sound and robust methodology to assess the sensitivity of the output to hyperparameter tuning. Providing application experts not only with a segmentation or classification outcome, but also with confidence levels on both how much the classification of each pixel/subject should be trusted and on robust the overall classification is (in terms in number of classes for instance) are key conditions for relevant interpretations of the outcome with respect to the application.

The method developed during the PhD will be evaluated on both synthetic data and real-world data, benefiting from the expertise and collaboration network of the SiSyPh team, for a large panel of real-world applications ranging from geophysics to biomedical data and art investigation.

Application.

All applications must be sent electronically and as soon as possible to P. Abry (minimum: motivation letter, CV).
Only candidates with nationality from EU countries can be considered.
The deadline is 20 April 2019.

Selected references.

S.G. Roux, M. Clausel, B. Vedel, S. Jaffard, and P. Abry. “Self-similar anisotropic texture analysis: the hyperbolic wavelet transform contribution.” IEEE Transaction on Image Processing, 22(11):4353-4363, 2013

N. Pustelnik, H. Wendt, P. Abry, N. Dobigeon, “Combining Local Regularity Estimation and Total Variation Optimization for Scale-Free Texture Segmentation.” IEEE Transaction on Computational Imaging, 2(4): 468-479, Dec. 2016.