Activity Report 2016

Project-Team GEOSTAT

Geometry and Statistics in acquisition data

RESEARCH CENTER
Bordeaux - Sud-Ouest

THEME
Optimization, machine learning and statistical methods

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Project-Team GEOSTAT

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Keywords:

Computer Science and Digital Science:

3.4.2. - Unsupervised learning
3.4.7. - Kernel methods
3.4.8. - Deep learning
5.3. - Image processing and analysis
5.3.2. - Sparse modeling and image representation
5.3.3. - Pattern recognition
5.3.5. - Computational photography
5.7. - Audio modeling and processing
5.7.3. - Speech
5.7.4. - Analysis
5.9. - Signal processing
5.9.2. - Estimation, modeling
5.9.3. - Reconstruction, enhancement
5.9.5. - Sparsity-aware processing

Other Research Topics and Application Domains:

2. - Health
2.2. - Physiology and diseases
2.2.1. - Cardiovascular and respiratory diseases
2.2.6. - Neurodegenerative diseases
3. - Environment and planet
3.3. - Geosciences
3.3.2. - Water: sea & ocean, lake & river
3.3.4. - Atmosphere

1. Members

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2. Overall Objectives

2.1. Overall Objectives

Singularity exponent A measure of the unpredictability around a point in a complex signal. Based on local reconstruction around a point, singularity exponents can be evaluated in different ways and in different contexts (e.g. non-localized, through the consideration of moments and structure fonctions, trough the computation of singularity spectra). In GEOSTAT we study approaches corresponding to *far from equilibrium* hypothesis (e.g. microcanonical) leading to geometrically localized singularity exponents.

Singularity spectrum The mapping from scaling exponents to Hausdorff dimensions. The singularity spectrum quantifies the degree of nonlinearity in a signal or process, and is used to characterize globally the complexity of a signal.

Most Singular Manifold The set of most unpredictable points in a signal, identified to the set of strongest transitions as defined by the singularity exponents. From that set the whole signal can be reconstructed.

Fully Developed Turbulence (FDT) Turbulence at very high Reynolds numbers; systems in FDT are beyond deterministic chaos, and symmetries are restored in a statistical sense only.

Compact Representation Reduced representation of a complex signal (dimensionality reduction) from which the whole signal can be reconstructed. The reduced representation can correspond to points randomly chosen, such as in Compressive Sensing, or to geometric localization related to statistical information content (framework of reconstructible systems).

Sparse representation The representation of a signal as a linear combination of elements taken in a dictionary (frame or basis), with the aim of finding as less as possible non-zerio coefficients for a large class of signals.

Universality class In theoretical physics, the observation of the coincidence of the critical exponents (behaviour near a second order phase transition) in different phenomena and systems is called universality. Universality is explained by the theory of the renormalization group, allowing for determination of the changes a physical system undergoes under different distance scales. As a consequence, different macroscopic phenomena displaying a multiscale structure (and their acquisition in the form of complex signals) can be grouped into different sets of universality classes.

Every signal conveys, as a measure experiment, information on the physical system whose signal is an acquisition. As a consequence, it seems therefore natural that signal analysis or compression makes use of physical modelling of phenomena: the goal is to find new methodologies in signal processing that goes beyond the simple problem of interpretation. Physics of disordonned systems, and specifically physics of spin glasses is putting forward new algorithmic resolution methods in various domains such as optimization, compressive sensing etc. with significant success notably for NP hard problems.

Physics of turbulence also introduces phenomelogical approaches based on singularity exponents. Energy cascades are indeed closely related to singular geometrical sets defined randomly. At these structures' scales, information of the process is lost by dissipation. However, all the cascade is encoded in the singular sets. How do these structures organize in space and time, in other words, how do the entropy cascade itself ? To unify these two notions, a description in term of free energy of a generic physical model is possible, such as an elastic interface model in a random nonlinear energy landscape: this is for instance the correspondance between compressible stochastic Burgers equation and directed polymers in a disordonned medium. Typical of such systems, dekrieging transition indicates that each singularity can be understood as a transition between two metastable states. Each of these transitions marks large fluctuations of the system which visits randomly the minima of the free energy. A signal which is an acquisition of such systems displays statistical properties characteristic of different classes, and the nature of noise is determinant. In particular, the dynamics enters a so-called Griffiths phase if for example noise gets structured like a hierarchical network, connected on long range distances, locally recursive, and randomly sparse. In such a context, phenomenologies related to cascades and multi-affine intermittence are present. As a typical example, in the study of cardiac dynamics (a subject that gets interest among statistical physicists) an effective model belonging to a similar category can be contemplated. In such model, an explicitely broken symetry is restaured spontaneously. This is a consequence from the existence of an abelian symetry of topological solutions, where these topological solutions are fronts excited by limiting conditions. A statistical jauge is the signature of a nonlinear intrinsic disorder which emerges for certain regions of parameter space. Such areas have a *vitrous* nature (Griffiths). The jauge is responsible for jumps between different metastable states and allows to recover singularity exponents of acquired signals. Conversely, the exploration of the phase space in such models can lead to a possible "testing" of the measured system through the computation of singularity exponents and the determination of the nature of intrinsic noise. From these considerations and in a heuristical framework, one sees that the recovering of a *semantics* in a measured signal can be contemplated.

GEOSTAT is a research project in **nonlinear signal processing** which develops on these considerations: it considers the signals as the realizations of complex dynamic systems. The driving approach is to understand the relations between complexity (or information content) and the geometric organization of information in a signal. For instance, for signals which are acquisitions of turbulent fluids, the organization of information is related to the effective presence of a multiscale hierarchy, of multifractal nature, which is strongly related to intermittency and multiplicative cascade phenomena; the determination of this geometric organization unlocks key nonlinear parameters and features associated to these signals; it helps understanding their dynamical properties and, as a consequence, their analysis. We use this approach to derive novel solution methods for **super-resolution** and data fusion in Universe Sciences acquisitions [10]. Another example can be found heartbeat signal analysis, where singularity exponents help understand the distribution of activation points in a signal during episodes of atrial fibrilation. Specific advances are obtained in GEOSTAT in using this type of statistical/geometric approach to get validated dynamical information of signals acquired in Universe Sciences, e.g. Oceanography or Astronomy. The research in GEOSTAT encompasses nonlinear signal processing and the study of emergence in complex systems, with a strong emphasis on geometric approaches to complexity. Consequently, research in GEOSTAT is oriented towards the determination, in real signals, of quantities or phenomena, usually unattainable through linear methods, that are known to play an important role both in the evolution of dynamical systems whose acquisitions are the signals under study, and in the compact representations of the signals themselves. Research in GEOSTAT is structured in two parts:

- Theoretical and methodological aspects.
- Applicative aspects which encompass biomedical data (heartbeat signal analysis, biomedical applications in speech signal analysis) and the study of universe science datasets.

The theoretical objectives are:

- multiscale description in terms of multiplicative cascade (essential in the characterization of turbulent systems).
- Excitable systems (cardiac electrophysiology): study of intermittency phenomena.

The methodological tools used in reaching these objectives place GEOSTAT at the forefront of nonlinear signal processing and complex systems. We cite: singularity exponents [48], [7] [11], how these exponents can be related to *sparse representations* with reconstruction formulae [13] [49], [5] and super-resolution in Oceanography and Earth Observation [10], [2], comparison with embedding techniques, such as the one provided by the classical theorem of Takens [46], [38], the use of Lyapunov exponents [34], how they are related to intermittency, large deviations and singularity exponents, various forms of entropies, persistence along the scales, *optimal wavelets* [6], comparison with other approaches such as sparse representations and compressive sensing [https://hal.inria.fr/tel-01239958], and, above all, **the ways that lead to effective numerical and high precision determination of nonlinear characteristics in real signals**. Presently GEOSTAT explores new methods for analyzing and understanding complex signals in different applicative domains [47]. Derived from ideas in Statistical Physics, the methods developed in GEOSTAT provide new ways to relate and evaluate quantitatively the *local irregularity* in complex signals and systems, the statistical concepts of *information content* and *most informative subset*. As a result, GEOSTAT is aimed at providing *radically new approaches* to the study of signals acquired from different complex systems (their analysis, their classification, the study of their dynamical properties etc.). A common characteristic of these signals, which is related to *universality classes* [41] [42] [39], being the existence of a *multiscale organization* of the systems. For instance, the classical notion of *edge* or *border*, which is of multiscale nature, and whose importance is well known in Computer Vision and Image Processing, receives profound and rigorous new definitions, in relation with the more physical notion of *transition* and fits adequately to the case of chaotic data. The description is analogous to the modeling of states far from equilibrium, that is to say, there is no stationarity assumption. From this formalism we derive methods able to determine geometrically the most informative part in a signal, which also defines its global properties and allows for *compact representation* in the wake of known problematics addressed, for instance, in *time-frequency analysis*. It appears that the notion of *transition front* in a signal is much more complex than previously expected and, most importantly, related to multiscale notions encountered in the study of nonlinearity [44]. For instance, we give new insights to the computation of dynamical properties in complex signals, in particular in signals for which the classical tools for analyzing dynamics give poor results (such as, for example, correlation methods or optical flow for determining motion in turbulent datasets).

3. Research Program

3.1. Multiscale description in terms of multiplicative cascade

GEOSTAT is studying complex signals under the point of view of methods developed in *statistical physics* to study complex systems, with a strong emphasis on multiresolution analysis. Linear methods in signal processing refer to the standard point of view under which operators are expressed by simple convolutions with impulse responses. Linear methods in signal processing are widely used, from least-square deconvolution methods in adaptive optics to source-filter models in speech processing. Because of the absence of localization of the Fourier transform, linear methods are not successful to unlock the multiscale structures and cascading properties of variables which are of primary importance as stated by the physics of the phenomena. This is the reason why new approaches, such as DFA (Detrented Fluctuation Analysis), Time-frequency analysis, variations on curvelets [45] etc. have appeared during the last decades. Recent advances in dimensionality reduction, and notably in Compressive Sensing, go beyond the Nyquist rate in sampling theory using nonlinear reconstruction, but data reduction occur at random places, independently of geometric localization of information content, which can be very useful for acquisition purposes, but of lower impact in signal analysis. One important result obtained in GEOSTAT is the effective use of multiresolution analysis associated to optimal inference along the scales of a complex system. The multiresolution analysis is performed on dimensionless quantities given by the *singularity exponents* which encode properly the geometrical structures associated to multiscale organization. This is applied successfully in the derivation of high resolution ocean dynamics, or the high resolution mapping of gaseous exchanges between the ocean and the atmosphere; the latter is of primary importance for a quantitative evaluation of global warming. Understanding the dynamics of complex systems is recognized as a new discipline, which makes use of theoretical and methodological foundations coming from nonlinear physics, the study of dynamical systems and many aspects of computer science. One of the challenges is related to the question of *emergence* in complex systems: large-scale effects measurable macroscopically from a system made of huge numbers of interactive agents [36], [33], [50], [40]. Some quantities related to nonlinearity, such as Lyapunov exponents, Kolmogorov-Sinai entropy etc. can be computed at least in the phase space [34]. Consequently, knowledge from acquisitions of complex systems (which include *complex signals*) could be obtained from information about the phase space. A result from F. Takens [46] about strange attractors in turbulence has motivated the determination of discrete dynamical systems associated to time series [38], and consequently the theoretical determination of nonlinear characteristics associated to complex acquisitions. Emergence phenomena can also be traced inside complex signals themselves, by trying to localize information content geometrically. Fundamentally, in the nonlinear analysis of complex signals there are broadly two approaches: characterization by attractors (embedding and bifurcation) and time-frequency, multiscale/multiresolution approaches. Time-frequency analysis [35] and multiscale/multiresolution are the subjects of intense research and are profoundly reshaping the analysis of complex signals by nonlinear approaches [32], [37]. In real situations, the phase space associated to the acquisition of a complex phenomenon is unknown. It is however possible to relate, inside the signal's domain, local predictability to local reconstruction and deduce from that singularity exponents [11] [7]. We are working on:

- the determination of quantities related to universality classses,
- the geometric localization of multiscale properties in complex signals,
- cascading characteristics of physical variables.

The alternative approach taken in GEOSTAT is microscopical, or geometrical: the multiscale structures which have their "fingerprint" in complex signals are being isolated in a single realization of the complex system, i.e. using the data of the signal itself, as opposed to the consideration of grand ensembles or a wide set of realizations. This is much harder than the ergodic approaches, but it is possible because a reconstruction formula such as the one derived in [47] is local and reconstruction in the signal's domain is related to predictability. This approach is analogous to the consideration of "microcanonical ensembles" in statistical mechanics.

A multiscale organization is a fundamental feature of a complex system, it can be for example related to the cascading properties in turbulent systems. We make use of this kind of description when analyzing turbulent signals: intermittency is observed within the inertial range and is related to the fact that, in the case of FDT, symmetry is restored only in a statistical sense, a fact that has consequences on the quality of any nonlinear signal representation by frames or dictionaries.

The example of FDT as a standard "template" for developing general methods that apply to a vast class of complex systems and signals is of fundamental interest because, in FDT, the existence of a multiscale hierarchy $\mathcal{F}_h$ which is of multifractal nature and geometrically localized can be derived from physical considerations. This geometric hierarchy of sets is responsible for the shape of the computed singularity spectra, which in turn is related to the statistical organization of information content in a signal. It explains scale invariance, a characteristic feature of complex signals. The analogy from statistical physics comes from the fact that singularity exponents are direct generalizations of *critical exponents* which explain the macroscopic properties of a system around critical points, and the quantitative characterization of *universality classes*, which allow the definition of methods and algorithms that apply to general complex signals and systems, and not only turbulent signals: signals which belong to a same universality class share common statistical organization. In GEOSTAT, the approach to singularity exponents is done within a microcanonical setting, which can interestingly be compared with other approaches such that wavelet leaders, WTMM or DFA. During the past decades, classical approaches (here called "canonical" because they use the analogy taken from the consideration of "canonical ensembles" in statistical mechanics) permitted the development of a well-established analogy taken from thermodynamics in the analysis of complex signals: if $\mathcal{F}$ is the free energy, $\mathcal{T}$ the temperature measured in energy units, $\mathcal{U}$ the internal energy per volume unit $\mathcal{S}$ the entropy and $\widehat{\beta} = 1/\mathcal{T}$, then the scaling exponents associated to moments of intensive variables $p \to \tau_p$ corresponds to $\widehat{\beta}\mathcal{F}$, $\mathcal{U}(\widehat{\beta})$ corresponds to the singularity exponents values, and $\mathcal{S}(\mathcal{U})$ to the singularity spectrum.

The singularity exponents belong to a universality class, independently of microscopic properties in the phase space of various complex systems, and beyond the particular case of turbulent data (where the existence of a multiscale hierarchy, of multifractal nature, can be inferred directly from physical considerations). They describe common multiscale statistical organizations in different complex systems [44], and this is why GEOSTAT is working on nonlinear signal processing tools that are applied to very different types of signals.

For example we give some insight about the collaboration with LEGOS Dynbio team [1] about high-resolution ocean dynamics from microcanonical formulations in nonlinear complex signal analysis. Indeed, synoptic determination of ocean circulation using data acquired from space, with a coherent depiction of its turbulent characteristics remains a fundamental challenge in oceanography. This determination has the potential of revealing all aspects of the ocean dynamic variability on a wide range of spatio-temporal scales and will enhance our understanding of ocean-atmosphere exchanges at super resolution, as required in the present context of climate change. We show that the determination of a multiresolution analysis associated to the multiplicative cascade of a typical physical variable like the Sea Surface Temperature permits an *optimal inference* of oceanic motion field across the scales, resulting in a new method for deriving super resolution oceanic motion from lower resolution altimetry data; the resulting oceanic motion field is validated at super resolution with the use of Lagrangian buoy data available from the Global Drifter Program [2]. In FDT, singularity exponents range in a bounded interval: $]h_\infty, h_{\max}[$ with $h_\infty < 0$ being the most singular exponent. Points $\mathbf{r}$ for which $h(\mathbf{r}) < 0$ localize the stongest transitions in the turbulent fluid, where an intensive physical variable like sea surface temperature behaves like $1/\mathbf{r}^{|h(\mathbf{r})|}$. The links between the geometricaly localized singularity exponents, the scaling exponents of structure functions, the multiplicative cascade and the multiscale hierarchy $\mathcal{F}_h$ is the following:

$$\begin{cases} \mathcal{F}_h = \{\mathbf{r} \mid h(\mathbf{r}) = h\} \\ D(h) = \dim \mathcal{F}_h \\ \tau_p = \inf_h \{ph + 3 - D(h)\} \\ D(h) = \inf_p \{ph + 3 - \tau_p\} \end{cases} \tag{1}$$

Let $\mathfrak{S}(\mathbf{x})$ be the bidimensionnal signal recording, for each sample point $\mathbf{x}$ representing a pixel on the surface of the ocean of given resolution, the sea surface temperature (sst). To this signal we associate a measure μ whose density w.r.t Lebesgue measure is the signal's gradient norm, and from which the singularity exponents are computed [6]. It is fundamental to notice here that, contrary to other types of exponents computed in Oceanography, such as Finite Size Lyapunov exponents, singularity exponents are computed at instantaneous time, and do not need time series.

Having computed the singularity exponents at each point of a SST signal, a microcanonical version of the multiplicative cascade associated to the scaling properties of the sst become available. The idea of the existence of a geometrically localized multiplicative cascade goes back to [43]. The multiplicative cascade, written pointwise, introduces random variables $\eta_{l'/l}(\mathbf{x})$ for $0 < l' < l$ such that

$$\mathcal{T}_\psi \mu(\mathbf{x}, l') \;=\; \eta_{l'/l}(\mathbf{x}) \mathcal{T}_\psi \mu(\mathbf{x}, l) \tag{2}$$

in which the equality is valid pointwise and not only in distribution. Any mother wavelet ψ such that the process $\eta_{l'/l}(\mathbf{x})$ is independant of $\mathcal{T}_\psi \mu(\mathbf{x}, l')$ is called an optimal wavelet: it optimizes inference of physical variables across the scales and consequently describes the multiplicative cascade at each point $\mathbf{x}$ in the signal domain. The injection variables $\eta_{l'/l}(\mathbf{x})$ are indefinitely divisible: $\eta_k(\mathbf{x})\eta_{k'}(\mathbf{x}) \doteq \eta_{kk'}(\mathbf{x})$. It is possible to optimize cross-scale inference of physical variables by considering a *multiresolution analysis*

[1] http://www.legos.obs-mip.fr/recherches/equipes/dynbio.
[2] http://www.aoml.noaa.gov/phod/dac/index.php.

associated to a discrete covering of the "space-frequency" domain. Denoting as usual $(V_j)_{j\in\mathbb{Z}}$ and $(W_j)_{j\in\mathbb{Z}}$ the discrete sequence of approximation and detail spaces associated to a given scaling function, and denoting by $\psi \in L^2(\mathbb{R}^2)$ a wavelet which generates an Hilbertian basis on each detail space W_j, it is known that the detail spaces encode borders and transition information, which is ideally described in the case of turbulent signals by the singularity exponents $\mathbf{h}(\mathbf{x})$. Consequently, a novel idea for super-resolution consists in computing a multiresolution analysis on the signal of singularity exponents $\mathbf{h}(\mathbf{x})$, and to consider that the detail information coming from spaces W_j is given the signal $\mathbf{h}(\mathbf{x})$. The associated orthogonal projection $\pi_j : L^2(\mathbb{R}^2) \to W_j$ defined by $\pi_j(\mathbf{h}) = \sum_{n\in\mathbb{Z}} \langle\ \mathbf{h} \mid \psi_{j,n}\ \rangle \psi_{j,n}$ is then used in the reconstruction formula for retrieving a physical variable at higher resolution from its low resolution counterpart. If $\mathfrak{S}(\mathbf{x})$ is such a variable, we use a reconstruction formula: $A_{j-1}\mathfrak{S} = A_j\mathfrak{S} + \pi_j(\mathbf{h})$ with $A_j : L^2(\mathbb{R}^2) \to V_j$ is the orthogonal projection on the space V_j (approximation operator) and π_j is the orthogonal projection on the detail spaces W_j associated to the signal of singularity exponents $\mathbf{h}(\mathbf{x})$. Validation is performed using Lagrangian buoy data with very good results [10]. We have realized a demonstration movie showing the turbulent ocean dynamics at an SST resolution of 4 km computed from the SST microcanonical cascade and the low-resolution GEKCO product for the year 2006 over the southwestern part of the Indian Ocean. We replace the missing data in the SST MODIS product (clouds and satellite swath) by the corresponding data available from the Operational SST and Sea Ice Analysis (OSTIA) provided by the Group for High-Resolution SST Project [11], which, however, is of lower quality. Two images per day are generated for the whole year of 2006. The resulting images show the norm of the vector field in the background rendered using the line integral convolution algorithm. In the foreground, we show the resulting vector field in a linear gray-scale color map. See link to movie (size: 800 Mo).

3.2. Excitable systems and heartbeat signal analysis

We are developing novel approaches to heartbeat signal analysis for understanding chronic atrial fibrillation. The noisy aspect of data recorded by electrodes, on the inner surface of human atria during episodes of atrial fibrillation, exhibit intriguing features for excitable media. Instead of phase chaos as typically expected, it shares many common traits of non-equilibrium fluctuations in disordered systems or strong turbulence. To assess those peculiar observations we investigate a *synaptic plasticity* that affects conduction properties. Electrical synapses comprise many different kinds of connexins, which may be affected by diverse factors, so we use a generic approach. Slight detuning of their linear response leads to an instability of the modulating agents, here an excess charge. Acting on slow time scales of repolarisation, it is understood as *collective modes* propagating through and retroacting on each synapse: the medium is *desynchronised*. It is not a syncytium. We propose to associate transient states with a phenomenon called *electrical remodelling*, which has not received any accepted description thus far. Moreover, from the properties of the model it is possible to start exploring phase space. Transitions between different regimes could help decipher stages in the evolution of the disease from acute to chronic, one main goal of cardiovascular research.

Theoretically, a myocardium is an excitable tissue acting under normal circumstances as a functional syncytium of myocardial cells. Models of excitability for the heart are reaction-diffusion systems describing the propagation of electric pulses called action potentials similarly to models for axons. Reaction results from ionic exchange cycles between the cytoplasm of excitable cells and their extra-cellular medium, when initiated by a stimulus above some threshold. Pulses are robust topological structures.

Considering the stable fixed point as a phase resetting state, chaos may arise in spatio-temporal sequences. This is the paradigm for cardiac fibrillation. But, it is incompatible with the following observations: the distributions of amplitudes all collapse on a scaling function G. We map exponents on data patients provided by IHU LIRYC showing non-universal properties. Singular exponents are observed with consistent Hausdorff dimension of sets $D(h)$. Negative contribution is high, suggesting an underlying multiplicative process.

Excess charge in cells like of *Ca* may perturb the dynamics of synapses. We consider a physiologically plausible linear response of synapses to the electro-chemical potential. This response is unknown as of today. The new dynamics may interact with excitability. It has the specific form of a Rayleigh instability.

Cycles become retarded or advanced. Hopf bifurcation and chaos are allowed creating EADs (Early After Depolarization). Regarding propagation, pulses are pinned and released on a chaotic background. Cycle modulations create defects via facilitation through the third dimension. Defects proliferate creating a glassy phase, which back-scatter fronts in 1D and roughens them in 2D. Further effective inhibitor diffusion splits them. Electrical remodelling is here the abnormal modification of the cell dynamics without any membrane alteration.

There are features of Self Organized Criticality (SOC) in large regions of phase space. Pulses have a phase and propagate on a random medium. For instance one paradigm we investigate would be:

$$\partial_t \theta + \sin(\theta + \widetilde{\phi}) = \Omega + \partial_{xx}\theta \tag{3}$$

(θ: phase of activation front, Ω: tachycardia frequency, $\widetilde{\phi}$: phase perturbation). Randomness reactualises non-linearly, which tells that the noise is quenched and reset. For instance in 1 + 1D, spatio-temporal maps look very much like optimal directed paths along diagonals. In 1 + 2D, we are guessing that pulses do propagate in the (q)KPZ universality class, just as the remodelling front does. This class is only fractal, but together with large deviations of the fluctuations, it may be consistent with a multi-affine process. Physiologically, one interesting bonus is the interpretation of non-reentrant Tachycardia as dislocation patterns slowly evolving.

3.3. Speech analysis

Our research in speech processing focus on the development of novel nonlinear analysis methods for the characterization and classification of pathological and affective speech. For the latter, classical linear methods do not generally capture the nonlinearity, aperiodicity, turbulence and noise that can be present in pathological voices. We thus aim to design and extract new features that allow better characterization/classification of such voices, while being easy to interpret by clinicians. For the former, recent research have shown that the voice source signal information allow significant improvement of speech emotion detection systems. Our goal is to develop novel nonlinear techniques to extract relevant voice source features and to design efficient machine learning algorithms for robust emotion classification.

4. Highlights of the Year

4.1. Highlights of the Year

- N. Brodu is joining GEOSTAT as a research associate (2016).
- K. Daoudi has been invited to the Senate on June 20th 2016 to accompany BatVoice which was finalist of the 2016 edition of "Tremplin Entreprises".

4.1.1. Award

Hicham Badri is winning the AFRIF PhD price 2015 for his PhD *Sparse and Scale-Invariant Methods in Image Processing* [https://hal.inria.fr/tel-01239958].

5. New Software and Platforms

5.1. Fluex

KEYWORDS: Signal - Signal processing

SCIENTIFIC DESCRIPTION

Fluex is a package consisting of the Microcanonical Multiscale Formalism for 1D, 2D 3D and 3D+t general signals.

FUNCTIONAL DESCRIPTION Fluex is a C++ library developed under Gforge. Fluex is a library in nonlinear signal processing. Fluex is able to analyze turbulent and natural complex signals, Fluex is able to determine low level features in these signals that cannot be determined using standard linear techniques.

- Participants: Rémi Paties and Hussein Yahia
- Contact: Hussein Yahia
- URL: https://geostat.bordeaux.inria.fr/index.php/downloads.html
- URL: https://bil.inria.fr/fr/software/view/2113/tab

5.2. FluidExponents

- Participants: Hussein Yahia and Antonio Turiel
- Contact: Hussein Yahia
- URL: https://bil.inria.fr/fr/software/view/336/tab

6. New Results

6.1. Automatic segmentation of activation periods in an electrogram during atrial fibrillation

Participants: G. Attuel, H. Yahia.

Experiments show that the multiscale properties displayed in signals recording the electrical activity of the heart during (atrial) fibrillation are of the type *out of equilibrium dynamics*. These dynamics have common features, possibily shared by "subclasses": "$1/f$ power spectrum", large proability laws for the distributions of the amplitude increments, multifractal spectra. Theoretically these dynamics are at least the result of a competition between elastic energies and disorder, which leads to the emergence of collective behaviours. Mathematically, the universality classes involved are not those corresponding to the central limit theorem, but generalize it in its more elaborated forms (Levy & Gnedenko). A class has recently been described completely: directed polymers on a random medium. Scaling exponents are known, together with the fluctuations' statistics. Large deviation theory plays a central role. The fixed point of the associated dynamics is that of KPZ (Kardar-Parisi-Zhang). We have indications that heartbeat dynamics in episodes of atrial fibrillation belongs to that class. In such a context, the questions raised relate to finite size effects when asymptotic convergence is slow. From an experimental point of view, the problem of determining universality classes is very hard. However, it is possible to formulate hypothesis on the universality class so as to extract important information from acquisition signals. A good modus operandi consists in using key properties of a model stated *a priori*, to combine them with experimental signal analysis in order to produce *a posteriori* characteristics of interest. Last year, we developed the first model of cardiac dynamics compatible with observed data. The model allows us to test the efficiency of a combined methodology using singularity exponents and Bayesian analysis. This has led us to a first automatic method able to identify periods of cardiac activity and make the distinction with measure noise. From this, the fine automatic determination of activity periods become tractable. This will lead to an automatic quantitative determination of fragmentation, hence opening the way for a determination of universality classes. We illustrate some steps in the figures below.

Publications: [24], [23], [25]

6.2. Pathological voice classification

Participants: K. Daoudi, N. Brodu.

We propose a fully reproducible speech-based technique for objective differential diagnosis between progressive supranuclear palsy (PSP) and multiple system atrophy (MSA). Our technique yields a classification mean accuracy of 86.1% which is a significant improvement as compared to a recent pioneer study on this task. We also show that information extracted through a variety of speech tasks can be used to estimate the degree of Parkinson's disease severity.

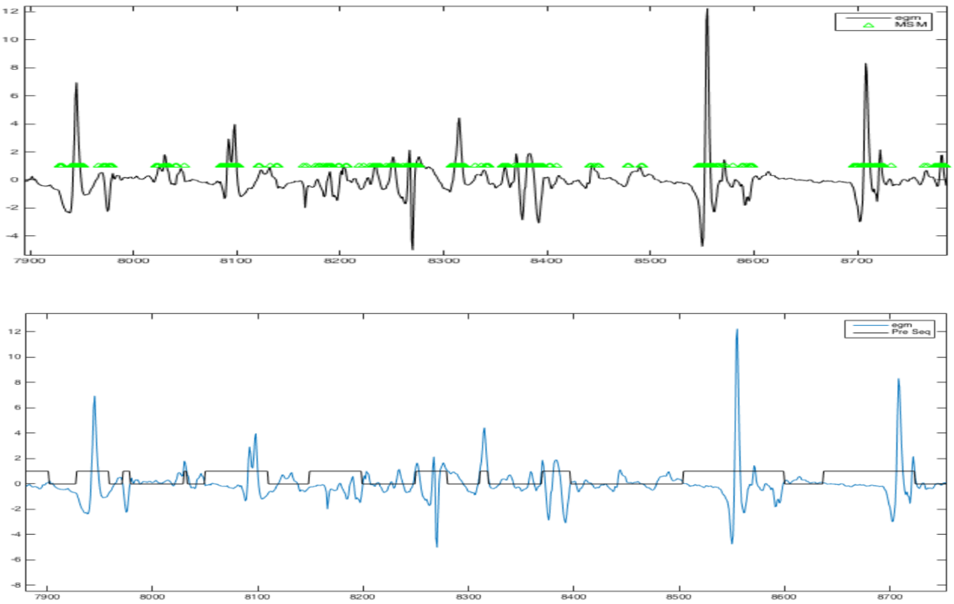

Figure 1. Egm during fibrilllation (in black). Density of the most singular manifold (in green). Result of a 2-state HMM (in blue).

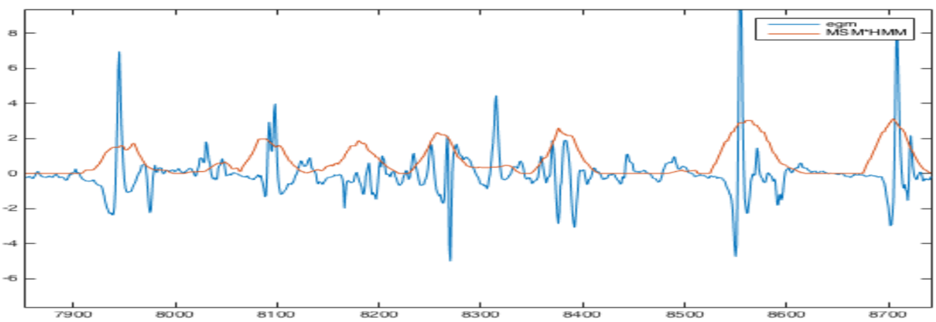

Figure 2. Egm during fibrillation (in blue). Signal of activation probability computed with the result of an HMM and the singularity density (in red).

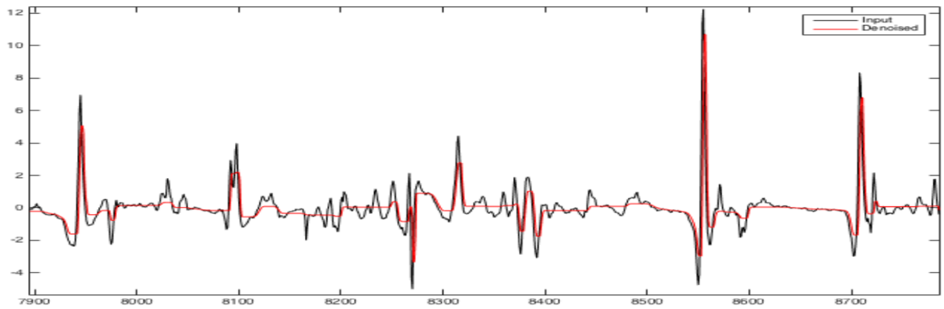

Figure 3. Egm during fibrillation (in black). Signal denosised (norm L^p) (in red).

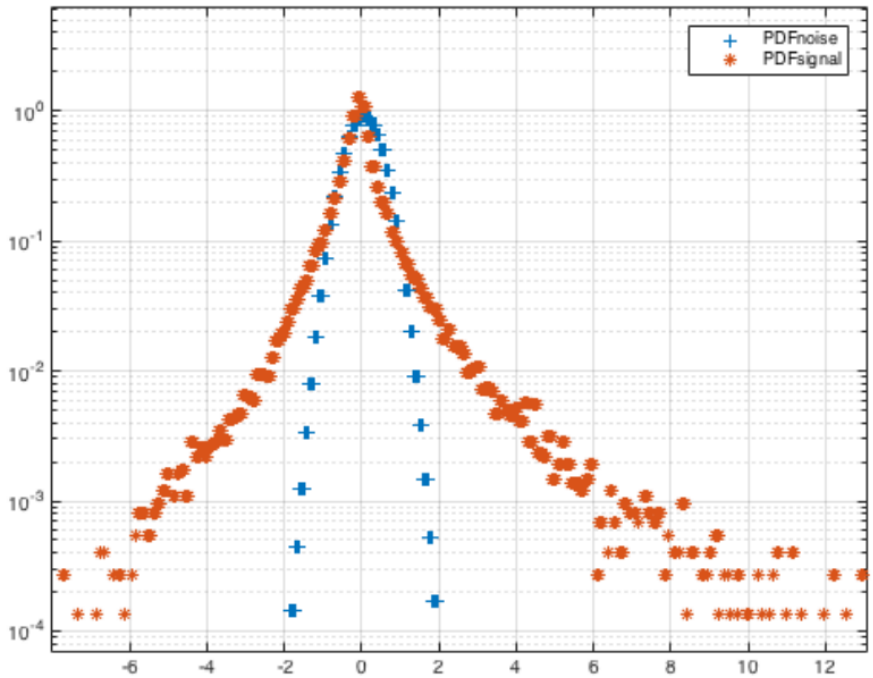

Figure 4. Probability distribution of estimated noise (in blue). Distribution of estimated active dynamics (in red).

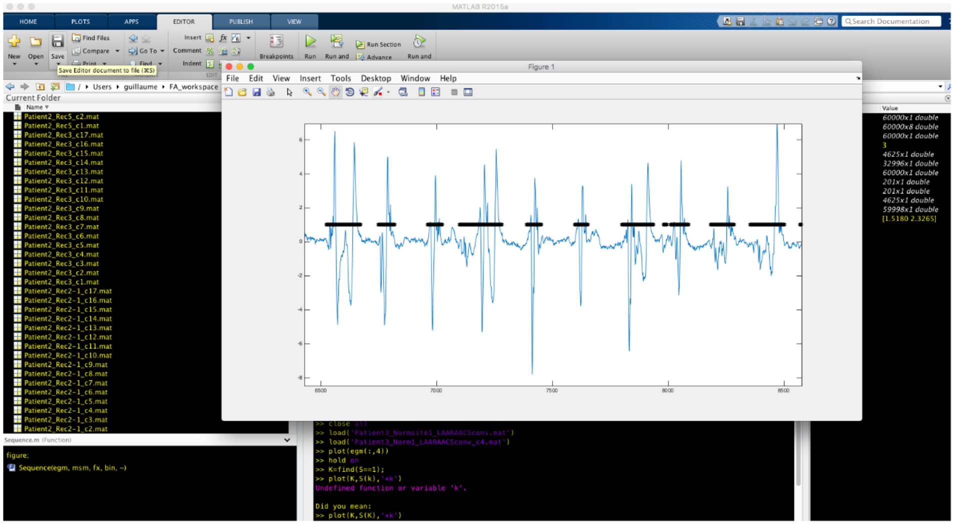

Figure 5. Snapshot of the software (written partially in Matlab and which makes use of FluidExponents). The image shows the result of sequencing, with average confidence level, of a real egm

Publications: [18], [20], [https://hal.inria.fr/hal-01360038].

6.3. Temporal evolution of coastal upwelling

Participants: A. El Aouni, K. Minaoui, A. Tamim, K. Daoudi, H. Yahia, A. Atillah, D. Aboutajdine.
We present a new methodology to derive rigorous SST-based coastal upwelling index for the purpose of conducting a saisonal variablity of upwelling area along the Moroccan Atlantic coast. The method is based on the scientific knowledge of upwelling area and its spatial dis- tribution provided by expert oceanographers.The latter consists in automatically identify and extract the region covered by the upwelling waters in the costal ocean of Morocco using the Fuzzy c-means algorithm and finding regions of homogeneous pixels. Then Region Growing process is used to filter out the remaining noisy structures in the offshort waters. The methodology is used to provide a satistical view of the spatial and temporal variability of the Moroccan upwelling activity. The relevance of the proposed Coastal Upwelling Index (CUI) is evaluated by an oceanographer using 86 8-days sea surface temperature images and it is shown to be superior to that of the standard upwelling index.
Publication: [https://hal.inria.fr/hal-01424036].

6.4. Non-local and low rank approach for integrability

Participants: H. Badri, H. Yahia.
A formulation is proposed which consists in a sparse gradient data-fitting term to handle outliers together with a gradient-domain non-local low-rank prior.
Publication: [15].

6.5. Low-Rankness transfer for realistic denoising

Participants: H. Badri, H. Yahia, D. Aboutajdine.

Current state-of-the-art denoising methods such as non-local low-rank approaches are mainly tuned to work with uniform Gaussian noise corruption and known variance, which is far from the real noise scenario. Noise level estimation is already a challenging problem and denoising methods are quite sensitive to this parameter. Moreover, these methods are based on shrinkage models that are too simple to reflect reality, which results in over-smoothing of important structures such as small-scale text and textures. We propose a new approach for more realistic image restoration based on the concept of low-rankness transfer (LRT).
Publication: [14].

6.6. Multiscale methods for Earth Observation data

Participants: H. Yahia, N. Brodu, V. Garçon, J. Sudre, S. Kumar Maji, D. Singh, K. Daoudi, D. Aboutajdine.
Earth observation data of different kinds are tested for super-resolution or analysis using the multiscale approaches developped in the team. This paragraph is mainly concerned with the publications of last year results.
Publications: [https://hal.inria.fr/hal-01254482], [https://hal.archives-ouvertes.fr/hal-01425021], [https://hal.inria.fr/hal-01287182], [https://hal.inria.fr/hal-01287181], [https://hal.inria.fr/hal-01426666], [16], [27], [30], [28], [31], [21].

6.7. Signal analysis of ultrasonic dental response

Participants: H. Yahia, G. Rosi, S. Jaffard, S. Seuret.
The long-term success of a dental implant is related to the properties of the bone-implant interface. It is important to follow the evolution of bone remodeling phenomena around the implant. Methods based on ultrasound wave propagation were already successfully used by collaborators, in the qualitative and quantitative evaluation of primary and secondary stability of dental implants. Results, numerical and experimental, are analysed with signal processing tools based on multifractal methods. Analysis of the first results shows that these methods are potentially efficient in this case because they can explore and exploit the multi-scale structure of the signal.
Publication: [22].

6.8. Complexity in Electrophysiological Dynamics

Participants: O. Pont, H. Yahia, B. Xu.
Action potentials play an important role in the dynamics of cell-cell communication and they are thus of key relevance in neural tissues. We show that typical real-world electrophysiological signals, with smooth deviations from harmonicity, are typically well described with just the first few terms and result in a rather compact, sparse representation. In particular, we have done an analysis of FitzHugh-Nagumo impulse trains; we have found that 3 anharmonic terms reconstruct better than an equivalent 8-term Fourier representation, with less than half the PSNR and no artifacts from Gibbs phenomenon.
Publication: [17].

6.9. Nonlinear trend removal and heart rate variability analysis

Participants: B. Xu, R. Dubois, O. Pont, H. Yahia.
Publication: [29].

7. Bilateral Contracts and Grants with Industry

7.1. Carnot-Inria

GeoStat has been granted in 2015 a Carnot-Inria project to fund a 1 year engineer to develop a prototype of a speech emotion detection system. This contact, led by K. Daoudi, is in collaboration with the start-up BatVoice which targets the commercialization of affect-interactive digital systems. The prototype was developed and transferred to BatVoice for 48000 euros. The phase 2 of the collaboration is under discussion. Engineer: N. Brodu.

7.2. Bilateral Grants with Industry

- With Batvoice company: *Détection des émotions à partir de la voix*. Startup Batvoice: M. Sendorek & G. Maluréanu.
- With CARDIOLOGS company, headed by Y. Fleureau. Contacts and first collaborations started in 2016.

Patent in the process of being first deposited in January 2017 *Dispositif analyseur de rythme cardiaque*, Inria-185.

8. Partnerships and Cooperations

8.1. Regional Initiatives

GEOSTAT is working with the following regional partners:

- GEOSTAT has a decade-long close scientific collaboration with team SYSCO2 (LEGOS LAboratory UMR 5566): V. Garçon, B. Dewitte, J. Sudre.
- Laboratoire d'Astrophysique de Bordeaux (S. Bontemps, N. Schneider).
- Flood monitoring in Equator : Luc Bourrel (GET Toulouse / IRD) and Frédéric Frappart (GET / UMR EPOC). Co-supervision of Christophe Fatras (post-doc).
- With Bruno Castelle (EPOC).
- With LOMA (Laboratoire Ondes & Matière d'Aquitaine): A. Arneodo & F. Argoul.
- With Dominique Gibert (OSUR) on signal and image processing.
- CHU Bordeaux : Prof. Wassilios Meissner (IMN), Dr. Solange Milhé de Saint Victor (service ORL).
- CHU Toulouse : Dr. Anne Pavy Le traon (service Neurologie), Prof. Virginie Woisard (service ORL)
- IRIT : Prof. Régine André-Obrecht, Dr. Julie Mauclair
- IMT (Institut de Mathématique de Toulouse) : Dr. Sébastien Déjean, Dr. Laurent Risser.
- Mercator Océan: Dr. Abdelali El Moussaoui.

8.2. National Initiatives

- ANR project *Voice4PD-MSA*, led by K. Daoudi, which targets the differential diagnosis between Parkinson's disease and Multiple System Atrophy, has been accepted. The total amount of the grant is 468555 euros, from which GeoStat has 203078 euros. The duration of the project is 42 months. Partners: CHU Bordeaux (Bordeaux), CHU Toulouse, IRIT, IMT (Toulouse).
- ICARODE [2013-2016]. Participants : Hussein Yahia, Oriol Pont, Véronique Garçon, Joel Sudre, Antonio Turiel, Christine Provost [LOCEAN]. 4-year contract, CNES-NASA funding, started 2013. Title: *ICARODE: Integration and cascading for high resolution ocean dynamics*. Project leader: H. Yahia.
- PhD grant for C. Artnana from UPMC University, under co-supervision with H. Yahia and C. Provost (LOCEAN, Paris).
- PhD grant for G. Singh from IIT Roorkee, under co-supervision with D. Singh (IIT Roorkee).
- PhD grant for A. El Aouni from PHC Toubkal and Morrocan governement, under co-supervision with K. Minaoui and D. Aboutajdine (LRIT).

8.3. International Initiatives

8.3.1. OPTIC

Title: Optimal inference in Complex and Turbulent data

International Partner (Institution - Laboratory - Researcher):

IITR (India) - Dept. Of Electrical Engineering - Dharmendra Singh

Start year: 2014

See also: https://optic.bordeaux.inria.fr/

The OptIC associated team targets the extension and development of a strong collaboration between Inria GEOSTAT team and INDIAN INSTITUTE OF TECHNOLOGY ROORKEE Dept of Electronics and Computer Engineering (Prof. D. Singh's group) on non-linear Signal Processing for Universe Sciences, with a strong emphasis on data fusion in Earth Observation and monitoring. Non-linear Physics puts strong evidence of the fundamental role played by multiscale hierarchies in complex and turbulent data: in these data, the information content is statistically localized in geometrical arrangements in the signal's domain, while such geometrical organization is not attainable by classical methods in linear signal processing. This is one of the major drawbacks in the classical analysis of complex and turbulent signals. The goal of this associated team is to show that inference of physical variables along the scales of complex and turbulent signals can be performed through optimal multiresolution analysis performed on non-linear features and data extracted from the signals, resulting in novel and powerful approaches for data fusion between different acquisitions (in temporal/spatial/spectral resolutions). This program needs both strong expertise in the physical processes beyond the acquisitions and the application of non-linear physics ideas on the behavior of the acquired physical phenomena. The proposal will focus on specific applications in Earth Observation and monitoring for which the Indian partner has developed a very strong expertise, notably in its knowledge and use of the physical processes in remote sensing acquisitions. This partnership is an extremely interesting and high potential collaboration between two teams which focus separately either on the acquisition of the physical processes or their analysis by Complex Systems and non-linear physics methodologies. The recent results obtained in super-resolution by GEOSTAT promises strong applications to a much wider range of Universe Sciences problems, notably with a strong emphasis on data fusion between the physical variables acquired on related but different acquisitions. OptiC builds on a collaboration between Inria and IIT ROORKEE teams, added with partners in Universe Sciences and earth observation (ONERA, CNRS) already involved in research actions with GEOSTAT.

8.3.2. Inria International Partners

8.3.2.1. Informal International Partners

- Laboratory LRIT from Rabat University (K. Minaoui, D. Aboutajdine).
- Czech Technical University in Prague (Jan Rusz).
- Brno University of Technology (Jiri Mekyska).
- University of Heidelberg (C. Garbe).

8.3.3. Participation in Other International Programs

8.3.3.1. Indo-French Center of Applied Mathematics

OPTIC

Title: Optimal Inference in complex and turbulent data

International Partner (Institution - Laboratory - Researcher):

Institutions: Inria and IIT Roorkee

Duration: 2013 - 2016

Start year: 2013

See above.

8.3.3.2. PHC-Toubkal

PHC-Toubkal

Title: Caractérisation multi-capteurs et suivi spatio-temporel de l'Upwelling sur la côte atlantique marocaine par imagerie satellitaire

International Partner (Institution - Laboratory - Researcher):

- GEOSTAT.
- CRTS (Centre Royal de Télédetection Spatiale), Rabat.
- Faculté des sciences de Rabat.
- Mercator-Océan.

Duration: from January 1st 2016 to 31 December 2018.

Start year: 2016.

8.4. International Research Visitors

8.4.1. Visits of International Scientists

- Prof. D. Singh (IIT roorkee, OPTIC Associated Team). Duration: 1 month.
- G. Singh (phd student in co-supervision, IIT roorkee, OPTIC Associated Team).
- A. El Aouni (PhD student in co-supervision, PHC Toubkal).
- Dr. Nicola Schneider (Koln University): nonlinear signal processing for astronomical data.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events Organisation

9.1.1.1. General Chair, Scientific Chair

H. Yahia: organization of the conference *Signals & Physics* in October 2016, Inria Paris.

9.1.1.2. *Member of the Organizing Committees*

H. Yahia: organization of the conference *Signals & Physics* in October 2016, Inria Paris.

9.1.2. Scientific Events Selection

9.1.2.1. *Chair of Conference Program Committees*

H. Yahia, N. Brodu and K. Daoudi are members of the advisory board committee of the IEEE *11th International Conference on Industrial and Information Systems* (ICIIS 2016), 3-4 December 2016, IIT Roorkee, India, http://www.iciis2016.org/commitee.html.

9.1.2.2. *Member of the Conference Program Committees*

N. Brodu is co-organizing an EGU session (European Geophysical Union) and has presented 2 papers in the session.

9.1.2.3. *Reviewer*

H. Yahia and N. Brodu have reviewed papers for the ICIIS 2016 conference.

9.1.3. Journal

9.1.3.1. *Member of the Editorial Boards*

- G. Attuel is a member of the editorial board of CMSIM journal (from CHAOS Conference), sections plama and biophysics.
- H. Yahia: Frontiers in Fractal Physiology.

9.1.3.2. *Reviewer - Reviewing Activities*

- N. Brodu: PRL (physical review letters), PRE, Remote Sensing.
- K. Doudi: reviewer for IEEE Transactions on Audio, Speech and Language Processing.
- H. Badri: ICIP Conference.

9.1.4. Invited Talks

- H. Badri is invited to give on oral presentation at the conference RFIA 2016 for the reception of his AFRIF 2015 Best PhD award. Title of the presentation: *Sparse and Scale-invariant methods in image processing*.
- H. Yahia was an invited keynote speaker at the 11th International Conference on Industrial and Information Systems (ICIIS 2016), 3-4 December 2016, IIT Roorkee, India. Title: *Non-convex sparsity. Applications in Image processing*.
- N. Brodu was an invited keynote speaker on the subject of super-resolution at the 11th International Conference on Industrial and Information Systems (ICIIS 2016), 3-4 December 2016, IIT Roorkee, India. Title: *Super-resolving multiresolution images with band-independent geometry of multispectral pixels* .

9.1.5. Leadership within the Scientific Community

- N. Brodu has given a presentation at the RISC-E school held at Rennes in October 2016. The presentation corresponds to 2 master UE.
- N. Brodu has given a presentation in february 2016 at the LaBRI/IMS/IMB lab: *Super-resolution of multispectral images* (part 1) and *Stochastic image analysis* (part 2).

9.1.6. Scientific Expertise

- H. Yahia and K. Daoudi have proposed scientific expertise for the I2S company, with an industrial collaboration prepared and submitted for 2017.
- H. Yahia and N. Brodu have proposed scientific expertise for the LECTRA company.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Doctorat: H. Yahia, *Advancement in Signal Processing, Application to Earth Observation*, 30 hours, IIT Roorkee, GIAN courses, India.

Master : K. Daoudi, *financial mathematics*, 20 hours, Master2 MIAGE, University of Lorraine.

Master: N. Brodu, *Analyse de données massives par apprentissage automatique*, 2 days, EDMI Bordeaux.

Licence : A. El Aouni, *Programmation web (PHP, javascript, CSS)*, 24 hours, L3, Rabat University, Morroco.

9.2.2. Juries

- H. Yahia: member of the HDR jury of S. Jacquir (Bourgogne University, Laboratoire LE2I UMR CNRS 6306).
- N. Brodu: 1st year PhD jury.

9.3. Popularization

N. Brodu has given a presentation at Inria's *Unithé ou café* : (April 1st): Title: « Des images satellites aux messages sur les sites »

10. Bibliography

Major publications by the team in recent years

[1] H. BADRI, H. YAHIA, K. DAOUDI. *Fast and Accurate Texture Recognition with Multilayer Convolution and Multifractal Analysis*, in "European Conference on Computer Vision", Zürich, Switzerland, ECCV 2014, September 2014, https://hal.inria.fr/hal-01064793

[2] I. HERNÁNDEZ-CARRASCO, J. SUDRE, V. GARÇON, H. YAHIA, C. GARBE, A. PAULMIER, B. DEWITTE, S. ILLIG, I. DADOU, M. GONZÁLEZ-DÁVILA, J. SANTANA CASIANO. *Reconstruction of super-resolution ocean pCO 2 and air-sea fluxes of CO 2 from satellite imagery in the Southeastern Atlantic*, in "Biogeosciences", September 2015, 20 p. , This work is a contribution to ESA Support To Science Element Grant N 400014715/11/I-NB OceanFlux- Upwelling Theme. The Surface Ocean CO2 Atlas (SOCAT) is an international effort, supported by the International Ocean Carbon Coordination Project (IOCCP), the Surface Ocean Lower Atmo- sphere Study (SOLAS), and the Integrated Marine Biogeochem- istry and Ecosystem Research program (IMBER), to deliver a uni- formly quality-controlled surface ocean CO2 database. The many researchers and funding agencies responsible for the collection of data and quality control are thanked for their contributions to SO- CAT, https://hal.inria.fr/hal-01193339

[3] V. KHANAGHA, K. DAOUDI, H. YAHIA. *Detection of Glottal Closure Instants based on the Microcanonical Multiscale Formalism*, in "IEEE Transactions on Audio, Speech and Language Processing", December 2014, https://hal.inria.fr/hal-01059345

[4] V. KHANAGHA, K. DAOUDI, H. YAHIA. *Efficient and robust detection of Glottal Closure Instants using Most Singular Manifold of speech signals*, in "IEEE Transactions on Acoustics Speech and Signal Processing", 2014, forthcoming, https://hal.inria.fr/hal-00802014

[5] S. K. MAJI, H. YAHIA. *Edges, Transitions and Criticality*, in "Pattern Recognition", January 2014, http://hal.inria.fr/hal-00924137

[6] O. PONT, A. TURIEL, C. PEREZ-VICENTE. *On optimal wavelet bases for the realization of microcanonical cascade processes*, in "International Journal of Wavelets Multiresolution and Information Processing", 2011, vol. 9, pp. 35-61

[7] O. PONT, A. TURIEL, H. YAHIA. *Singularity analysis in digital signals through the evaluation of their Unpredictable Point Manifold*, in "International Journal of Computer Mathematics", 2012, http://hal.inria.fr/hal-00688715

[8] O. PONT, H. YAHIA, R. DUBOIS, M. HAÏSSAGUERRE. *A Singularity-analysis Approach to characterize Epicardial Electric Potential*, in "Computing in Cardiology ", 2012, http://hal.inria.fr/hal-00750003

[9] O. PONT, H. YAHIA, B. XU. *Arrhythmic dynamics from singularity analysis of electrocardiographic maps*, in "EBMC'13-The 35th Annual International Conference of the IEEE Engineering in Medicine and Biology Society", Osaka, Japan, IEEE, July 2013 [*DOI :* 10.1109/EMBC.2013.6610955], http://hal.inria.fr/hal-00823856

[10] J. SUDRE, H. YAHIA, O. PONT, V. GARÇON. *Ocean Turbulent Dynamics at Superresolution From Optimal Multiresolution Analysis and Multiplicative Cascade*, in "IEEE Transactions on Geoscience and Remote Sensing", June 2015, vol. 53, n^{o} 11, 12 p. [*DOI :* 10.1109/TGRS.2015.2436431], https://hal.inria.fr/hal-01166170

[11] A. TURIEL, H. YAHIA, C. PEREZ-VICENTE. *Microcanonical multifractal formalism: a geometrical approach to multifractal systems. Part I: singularity analysis*, in "Journal of Physics A: Math. Theor", 2008, vol. 41, http://dx.doi.org/10.1088/1751-8113/41/1/015501

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[13] H. YAHIA, J. SUDRE, C. POTTIER, V. GARÇON. *Motion analysis in oceanographic satellite images using multiscale methods and the energy cascade*, in "Pattern Recognition", 2010, vol. 43, pp. 3591-3604, http://dx.doi.org/10.1016/j.patcog.2010.04.011

Publications of the year

Articles in International Peer-Reviewed Journals

[14] H. BADRI, H. YAHIA, D. ABOUTAJDINE. *Low-Rankness Transfer for Realistic Denoising*, in "IEEE Transactions on Image Processing", November 2016, https://hal.inria.fr/hal-01361246

[15] H. BADRI, H. YAHIA. *A Non-Local Low-Rank Approach to Enforce Integrability*, in "IEEE Transactions on Image Processing", June 2016, https://hal.inria.fr/hal-01317151

Invited Conferences

[16] N. BRODU, D. SINGH, A. GARG. *A sub-pixel resolution enhancement model for multiple-resolution multispectral images*, in "European Geophysical Union General Assembly 2016", Vienne, Austria, April 2016,

Présentation orale ayant pour titre "Super-Resolution of Sentinel-2 multispectral images", https://hal.inria.fr/hal-01287184

[17] O. PONT, H. YAHIA, B. XU. *Complexity in Electrophysiological Dynamics. Emergence and measures of organization*, in "2nd BCAM Workshop on Nonlinear Dynamics in Biological System", Bilbao, Spain, Basque Center for Applied Mathematics Bilbao, Spain, September 2016, https://hal.inria.fr/hal-01392644

International Conferences with Proceedings

[18] K. DAOUDI, N. BRODU, J. RUSZ, J. KLEMPIR. *Objective discrimination between Progressive Supranuclear Palsy and Multiple System Atrophy using speech analysis*, in "38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (IEEE-EMBC'16)", Orlando, United States, August 2016, https://hal.inria.fr/hal-01328206

[19] A. EL AOUNI, K. MINAOUI, A. TAMIM, K. DAOUDI, H. YAHIA, D. ABOUTAJDINE. *An improved method for accurate computation of coastal upwelling index using Sea Surface Temperature Images*, in "13th ACS/IEEE International Conference on Computer Systems and Applications", Agadir, Morocco, 13th ACS/IEEE International Conference on Computer Systems and Applications, ACS/IEEE, November 2016, https://hal.inria.fr/hal-01424036

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[21] A. GARG, S. VARDHAN NAIDU, S. GUPTA, D. SINGH, N. BRODU, H. YAHIA. *A novel approach for optimal weight factor of DT-CWT coefficients for land cover classification using MODIS data*, in "Geoscience and Remote Sensing Symposium (IGARSS), 2016 IEEE International", Beijing , China, IEEE, July 2016 [*DOI :* 10.1109/IGARSS.2016.7730181], https://hal.inria.fr/hal-01400795

[22] G. ROSI, I. SCALA, V. NGUYEN, S. NAILI, R. VAYRON, G. HAIAT, H. YAHIA, S. SEURET, S. JAFFARD. *Caractérisation de la Réponse Ultrasonore d'Implant Dentaire : Simulation Numérique et Analyse des Signaux*, in "Congrès Français d'Acoustique 2016", Le Mans, France, Actes en ligne du Congrès Français d'Acoustique, April 2016, https://hal.inria.fr/hal-01356146

Conferences without Proceedings

[23] G. ATTUEL. *Surprising "quantum statistical" treatment of Landau damping: discussion on simple models*, in "The 9th Chaotic Modeling and Simulation International Conference, CHAOS 2016", London, United Kingdom, CMSIM Journal, May 2016, https://hal.inria.fr/hal-01322853

Scientific Books (or Scientific Book chapters)

[24] G. ATTUEL, O. PONT, B. XU, H. YAHIA. *Sudden cardiac death and turbulence*, in "The Foundations of Chaos Revisited: From Poincaré to Recent Advancements", C. SKIADAS (editor), Understanding Complex Systems, Springer Verlag, May 2016, X, 224 p. [*DOI :* 10.1007/978-3-319-29701-9], https://hal.inria.fr/hal-01279000

Other Publications

[25] G. ATTUEL, H. YAHIA. *The role of abnormal inhibitory transmission at the gap junctions of cardiac cells in fibrillation*, January 2016, Physical Principles of Biological and Active Systems - IOP Topical Meeting, Poster, https://hal.inria.fr/hal-01253790

[26] N. BRODU. *Super-resolving multiresolution images with band-independent geometry of multispectral pixels*, December 2016, Invited speaker session, https://hal.inria.fr/hal-01426666

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