30 years of mathematical imaging in optics

Dates :

Monday 25/09/2023 to Wednesday 27/09/2023

Place:

Villages club du soleil, Marseille

23 Rue François Simon

13003 – Marseille

Organizing committee :

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Financial support :

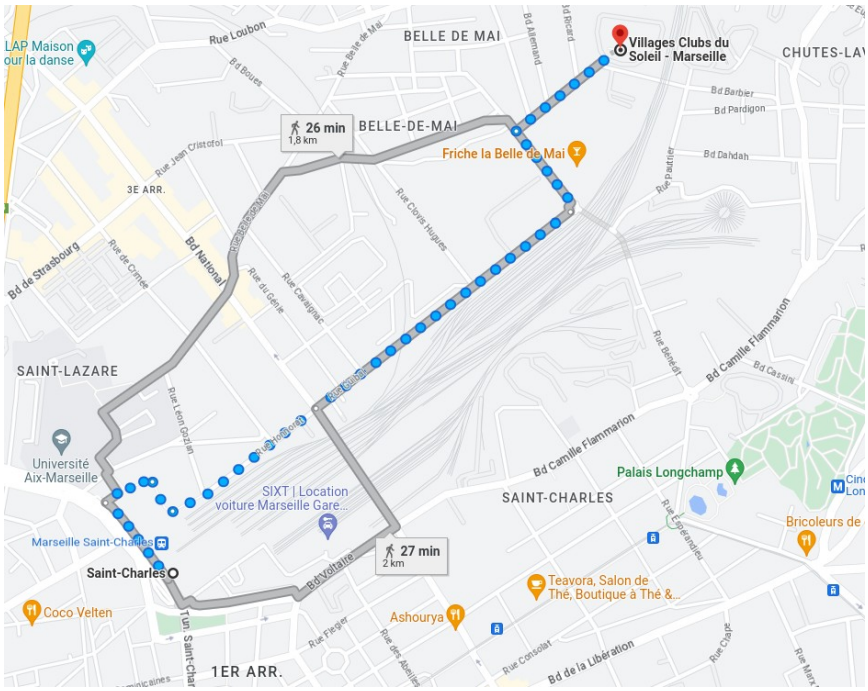
ANR Micro-Blind

GDR MIA

Getting there :

Gare TGV Marseille Saint-Charles à 1,7 km.
A pied : 20 minutes
Correspondance par taxi en 5 minutes
Correspondance en bus ligne n°49

Transports en commun :
Métro : arrêt Gare Saint Charles (puis 20mn).
Tram : Arrêt Longchamp (puis 10mn)
Bus : lignes n°49 et n°56, arrêt « Belle de Mai »



The program in a glance :

	Monday 25 September	Tuesday 26 September	Wednesday 27 September
9:00 - 9:30		Jean-François Aujol	Christine Fernandez-Maloigne
9:30 - 10:00	**Welcoming/opening**	Walid Hachem	Vanna Lisa Coli
10:00 - 10:30	Jalal Fadili	Marco Prato	Françoise Peyrin
10:30 - 11:00	**Coffee break**		
11:00 - 11:30	Julian Tachella	Jerôme Idier	Lola Bautista
11:30 - 12:00	N. Munier / M.H. Nguyen	Vasiliki Stergiopoulou	**Closing remarks**
12:00 - 14:00	**Lunch**		
14:00 - 14:30	Nelly Pustelnik	Laure Blanc-Féraud	
14:30 - 15:00	Jean-François Giovannelli	Sebastien Schaub	
15:00 - 15:30	Sébastien Bourguignon	Ellen Van Obberghen	
15:30 - 16:00	**Coffee break**		
16:00 - 16:30	Cédric Herzet	Jérôme Boulanger	
16:30 - 17:00	Vincent Duval	Gabriel Peyré	
17:00-17:30	Bastien Laville	Julie Delon	
17:30-19:00	**Posters**	**Posters + Apéritif**	
19:30 - 21:00	**Dinner**	**Cocktail dinner**	
	Learning	**Optimisation**	**Biomedical imaging**
	Sparsity	**Microscopy**	
		Optimal transport	

Titles and abstracts :

Monday

9:30-10:00 -- Welcoming words by the organizers

10:00-10:30 -- Jalal Fadili

Title : *Convergence and Recovery Guarantees of Generative Neural Networks for Inverse Problems*

Abstract : Neural networks have become a prominent approach to solve inverse problems in recent years. While a plethora of data-driven methods was developed to solve inverse problems empirically, we are still lacking clear theoretical guarantees of these methods. On the other hand, many works have outlined the role of overparametrization to show convergence to optimal solutions of neural networks training. In this work we investigate how to bridge these two worlds and we provide deterministic convergence and recovery guarantees for a class of neural networks optimized to solve inverse problems. In the random setting, we also derive overparametrization bounds under which a two-layer Deep Inverse Prior network with smooth activation function will benefit from our guarantees. It is thus a first step towards the theoretical understanding of neural networks in the inverse problem setting.

11:00-11:30 – Julian Tachella

Title: *Deep Inverse: A PyTorch library for solving imaging problems with deep learning*

Abstract: Despite the ever-increasing research effort in the field of imaging inverse problems, most deep learning-based algorithms are built from scratch, are hard to generalize beyond the specific problem they were designed to solve, and the results reported in papers are often hard to reproduce. In order to tackle these pitfalls, I will present Deep Inverse (https://deepinv.github.io/), an open-source PyTorch library for solving imaging inverse problems with deep learning. The library covers most of the steps in modern imaging pipelines, from the definition of the forward sensing operator to the training of unfolded reconstruction networks in a supervised or self-supervised way.

11:30-11:45 -- Minh Hai Nguyen :

Title: *Correcting micro-vibrations in satellite imaging with pushbroom camera*

Abstract: Images obtained from onboard satellite using pushbroom camera suffer from geometric distortion, in the presence of vibrations. We proposed a mathematical modeling of the acquisition of pushbroom camera under vibrations and a pipeline for detecting micro-vibrations and correcting its effects.

11:45-12:00 -- Nathanaël Munier :

Title: *Non-identifiability visualisation algorithms*

Abstract: The identification of a set of parameters x from observed data y is often reduced to the resolution of a problem of the type $\Phi(x) = y$, where Φ is a continuous application. This equation appears in domains such as (blind) inverse problems, data assimilation, or optimal control. When the solution is not unique, it may be important to inform the user about the set of plausible solutions. We propose here an algorithm to locally describe a set of solutions of this equation. It is essentially based on automatic differentiation and on a local parameterization of the solution manifold. We illustrate the interest of this approach on two examples.

14:00-14:30 -- Nelly Pustelnik :

Title: *PNN: From proximal algorithms to robust unfolded image denoising networks and Plug-and-Play methods*

Abstract: A common approach to solve inverse imaging problems relies on finding a maximum a posteriori (MAP) estimate of the original unknown image, by solving a minimization problem. In thiscontext, iterative proximal algorithms are widely used, enabling to handle non-smooth functions and linear operators. Recently, these algorithms have been paired with deep learning strategies, to further improve the estimate quality. In particular, proximal neural networks (PNNs) have been introduced, obtained by unrolling a proximal algorithm as for finding a MAP estimate, but over a fixed number of iterations, with learned linear operators and parameters. As PNNs are based on optimization theory, they are very flexible, and can be adapted to any image restoration task, as soon as a proximal algorithm can solve it. They further

have much lighter architectures than traditional networks. In this article we propose a unified framework to build PNNs for the Gaussian denoising task, based on both the dual-FB and the primal-dual Chambolle-Pock algorithms. We further show that accelerated inertial versions of these algorithms enable skip connections in the associated NN layers. We propose different learning strategies for our PNN framework, and investigate their robustness (Lipschitz property) and denoising efficiency. Finally, we assess the robustness of our PNNs when plugged in a forward-backward algorithm for an image deblurring problem.

14:30-15:00 -- Jean-François Giovannelli (joint work with Cornelia Vacar)

Title: *Unsupervised image deconvolution-segmentation for oriented textures*

Abstract: The talk tackles the problem of joint deconvolution and segmentation of textured images. The images are composed of a patch of textures from a set of K possible classes. Each class is described by a Gaussian random field with parametric power spectral density whose parameters are unknown. The labels are modelled by a Potts field driven by a granularity coefficient that is also unknown. The method relies on a hierarchical model and a Bayesian strategy to jointly estimate the labels, the K textured images in addition to hyperparameters: signal and noise levels as well as texture parameters and granularity coefficient. The estimates are designed in an optimal manner as a risk minimizer that yields the posterior maximizer for the labels and the posterior mean for the rest of the unknowns. They are computed based on a convergent procedure from samples of the posterior obtained through an advanced MCMC algorithm: Perturbation-Optimization step and Fisher-Langevin Metropolis-Hastings step within a Gibbs loop. The paper is available here: http://giovannelli.free.fr/Papers/TextSegDCV.pdf

15:00-15:30 -- Sébastien Bourguignon

Title: *Branch-and-bound algorithms for exact resolution of l0-norm sparsity-enhancing problems*

Abstract: In the past ten years, exact optimization of sparse approximation criteria has raised a certain interest, thanks to mixed integer programming solvers and, more recently, more efficient dedicated branch-and-bound-based methods. Such methods are now able to solve non-trivial problems involving several hundreds of unknowns and sparsity levels up to several tens, with optimality guarantee and numerical complexity much lower than brute-force search. In this talk, we review the main components conditioning the efficiency of such methods, and we propose our own implementation. Tree-search exploration strategies are discussed to schedule the nodes of the search tree. Mathematical properties of subproblems involved at each node are exploited, convex duality is invoked to early prune suboptimal nodes, and screening methods are implemented for reducing the subproblem sizes. Such a methodology is then generalized for solving structured sparsity problems. Numerical performance of the different building blocks is discussed as a function of the problem complexity. An open-source C++ software and a precompiled linux package are made available. The related paper is available at https://hal.science/hal-03661177v2, and source code at https://gitlab.univ-nantes.fr/samain-g/mimosa-solver.

This is a joint work with Jordan Ninin, Ramzi Ben Mhenni and Gwenaël Samain.

16:00-16:30 -- Cédric Herzet

Title: *From ``screening'' to ``peeling'' : new pruning strategies for branch-and-bound methods involving ``l0 norm''*

Abstract: In this talk, I will present two new strategies to accelerate branch-and-bound (BnB) procedures.

Our work takes place in a ``sparse representation'' framework where the cost function to optimize involves a counting function, also commonly dubbed ``l0 norm''.

Our first strategy aims to identify (via low-computational tests) when some nullity/non-nullity decisions cannot lead to an optimal solution in some branches of the BnB decision tree. This procedure generalizes the well-known ``safe screening rules'' derived during the last decade for convex sparsity-inducing problems to a non-convex setup.

Our second strategy goes one step further and investigate how to safely (that is without changing the optimal solution of the problem) modify the ``Big-M'' constraints commonly added to the optimization problem to ensure the properness of the convex relaxations performed at the nodes of the decision tree. In a nutshell, our proposed method allows to tighten the convex relaxations considered by the BnB procedure and thus allows for more agressive pruning of the decision tree. Interestingly, our peeling strategy reduces to the screening method described above in some limit cases.

The two proposed strategies will be shown numerically to improve the running time of BnB procedures by order of magnitude in some cases.

This is a joint work with Théo Guyard, Clément Elvira and Ayse Nur Arlsan.

16:30-17:00 -- Vincent Duval

Title: *Stabilty of piecewise constant images using total (gradient) variation regularization*

Abstract: Total variation regularization has been widely used in inverse problems arising in image processing, since the work of Rudin, Osher and Fatemi. The conventional wisdom is that this regularization is well suited to the recovery of piecewise constant images. In this talk, I will describe how the recovery of such images is related to geometric variational problems. By studying their stability properties, it is possible to derive a condition which ensures that, at low noise, the reconstructed solutions have exactly the same number of constant components, which converge both in shape and amplitudes towards those of the unknown. It is a joint work with Romain Petit and Yohann De Castro.

17:00-17:30 -- Bastien Laville

Title: Off-the-grid curve reconstruction: theory and applications to fluorescence microscopy'

Abstract: Recent years have seen the development of super-resolution variational optimisation in measure spaces. These so-called off-the-grid approaches offer both theoretical and numerical results, with very convincing results in biomedical imaging. However, the gridless variational optimisation is formulated for reconstruction of point sources, which is not always suitable for biomedical imaging applications: more realistic biological structures such as curves should also be reconstructed. We propose a new strategy for the reconstruction of curves in an image through an off-the-grid variational framework, thanks to the sharp characterisation of the extreme points of the unit ball of a new regulariser thus enabling new theoretical and numerical results.

This is a joint work with Laure Blanc-Féraud and Gilles Aubert.

17:30-19:00 – Posters

Mohamed Mimoun : *Guaranteed sparse support recovery using the Straight-Through-Estimator*

Pascal Nguyen : *Nouvelles approches algorithmiques pour la Tomographie optique diffuse de fluorescence dans la seconde fenêtre biologique (SWIR) pour l'imagerie in vivo de modèles murins avec des agents de contrastes*

Olivier Leblanc : *CoLSI: Continuous Lippmann-Schwinger Intensity diffraction tomography.*

An efficient implementation of the discrete Lippmann-Schwinger equation is combined with a continuous representation of a 3D refractive index volume using a NeRF. This contribution integrates previous works in both the fields of optical and intensity diffraction tomography and aims at improving the reconstruction capabilities for strong scattering media.

Cristobal Villalobos : *The Magnetization Inverse Problem on 2-dimensional sources*

Sixin Zhang: *Generalized rectifier wavelet covariance model for texture synthesis*

Tuesday

9:00-9:30 -- Jean-François Aujol

Title: *FISTA is an automatic geometrically optimized algorithm for strongly convex functions*

Abstract: This work is related with large scale optimization. We are interested in the famous FISTA algorithm. We show that FISTA is an automatic geometrically optimized algorithm for functions satisfying a quadratic growth assumption. This explains why FISTA works better than the standard Forward-Backward algorithm (FB) in such a case, although FISTA is known to have a polynomial asymptotical convergence rate while FB is exponential. We provide a simple rule to tune the α parameter within the FISTA algorithm to reach an ε-solution with an optimal number of iterations. These new results highlight the efficiency of FISTA algorithms, and they rely on new non asymptotic bounds for FISTA.

This is a joint work with Charles Dossal and Aude Rondepierre (INSA Toulouse).

9:30-10:00 -- Walid Hachem

Title: *Trap avoidance by the stochastic algorithms: some recent results in the smooth and non-smooth cases*

10:00-11:00 -- Marco Prato

Title: *From ISRA and EM to variable metric inexact linesearch algorithms: application to optical imaging*

Abstract: Many problems in optical imaging can be reformulated as the minimization of a smooth – possibly nonconvex – functional given by a data fidelity term plus a convex – possibly nonsmooth – regularization terms, including the indicator function of a convex set when constraints are available on the set of the desired images. Starting from the iterative space reconstruction algorithm and the expectation maximization method, we show the successive generalizations to the split gradient, scaled gradient projection and variable metric inexact linesearch algorithms, the last one being a recent approach able to address very general formulation of imaging problems in a mathematically sound and practically efficient way.

11:00-11:30 -- Jérôme Idier

Title: *3D Variance Based Random Illumination Microscopy*

Abstract: Structured illumination or scanning microscopes are commonly used to visualize the dynamics of macromolecules in biological tissues beyond the diffraction limit. However, the superresolution capacity of such intruments is often deteriorated because of sample induced aberrations. Random Illumination microscopy (RIM) has been proposed at Institut Fresnel to tackle this fundamental issue, the principle being to illuminate the sample with random speckles, which are insensitive by nature to aberrations and scattering. This presentation will make an overview of some recent advances about RIM, with a particular focus at a three-dimensional version. The available superresolution guaranties will be presented and discussed, as well as the computational imaging problem that we must solve. Some biological examples will be taken to illustrate the presentation.

11:30-12:00 -- Vasiliki Stergiopoulou

Title: *Learning and optimization for 3D super-resolution in fluorescence microscopy*

Abstract: Spatial resolution in fluorescence microscopy is limited by light diffraction, restricting the study of sub-200 nm lateral and sub-500 nm axial structures. Our work introduces novel algorithmic techniques for enhancing super-resolution without the need for special fluorophores or complex setups. In this presentation, I will speak about COL0RME, a method reconstructing high-resolution images from short temporal stacks using covariance-based sparsity regularization. Moreover, I present two extensions of COL0RME: a 2D approach where the proximity operator used in the method is now replace with a pretrained image denoiser (Plug-and-Play approach), and a 3D super-resolution approach for Total Internal Reflection Fluorescence (TIRF) microscopy. Finally, I will discuss an unsupervised hybrid approach using generative networks for fluorescent image deconvolution. All the methods that will be described enable live cell imaging with improved resolution and minimal sample damage using standard equipment.

This is a joint work with my PhD advisors: Laure Blanc-Feraud, Luca Calatroni and Sebastian Schaub.

14:00-14:30 -- Laure Blanc-Féraud

Title: *Quelques résultats en traitement des images.*

Abstract: La présentation sera l'occasion de rappeler des éléments clés de la régularisation des problèmes inverses à travers quelques résultats obtenus depuis 1990, avec un petit focus sur les singularités (points, courbes).

14:30-15:00 -- Sébastien Schaub

Title: *Dirty mathematics with a physicist*

Abstract: When the algorithm development is not preceded by the data acquisition, there are useful interactions with instrument expert making unorthodox mathematical approach.

Here some illustrations where inelegant development led to fruitful collaborations.

15:00-15:30 -- Ellen Van Obberghen

Title: *Surprise surprise !*

16:00-16:30 -- Jérôme Boulanger

Title: *A model for the reconstruction of light sheet microscopy images with a mixed noised model*

Abstract: We will present the problem of deconvolution for light-sheet microscopy, where the data is corrupted by spatially varying blur and a combination of Poisson and Gaussian noise. The spatial variation of the point spread function of a light-sheet microscope is determined by the interaction between the excitation sheet and the detection objective PSF. We introduce a model of the image formation process that incorporates this interaction and we formulate a variational model that accounts for the combination of Poisson and Gaussian noise through a data fidelity term consisting of the infimal convolution of the single noise fidelities, discussed by L. Calatroni et al. This is a joint work with Bogdan Toader, Yury Korolev, Martin Lenz, James Manton, Carola Bibiane Schönlieb and Leila Mureşan.

16:30-17:00 -- Gabriel Peyré

Title : *Abide by the Law and Follow the Flow: Conservation Laws for Gradient Flows*

Abstract: Understanding the geometric properties of gradient descent dynamics is a key ingredient in deciphering the recent success of very large machine learning models. A striking observation is that trained over-parameterized models retain some properties of the optimization initialization. This "implicit bias" is believed to be responsible for some favorable properties of the trained models and could explain their good generalization properties. The purpose of this article is threefold. First, we rigorously expose the definition and basic properties of "conservation laws", which are maximal sets of independent quantities conserved during gradient flows of a given model (e.g. of a ReLU network with a given architecture) with any training data and any loss. Then we explain how to find the exact number of these quantities by performing finite-dimensional algebraic manipulations on the Lie algebra generated by the Jacobian of the model. Finally, we provide algorithms (implemented in SageMath) to: a) compute a family of polynomial laws; b) compute the number of (not necessarily polynomial) conservation laws. We provide showcase examples that we fully work out theoretically. In particular, for linear and ReLu networks, we recover the conservation laws known in the literature, and prove that there are no other laws. The associated paper can be found here https://arxiv.org/abs/2307.00144 and the open source code is here https://github.com/sibyllema/Conservation_laws.This is a joint work with Sibylle Marcotte and Rémi Gribonval.

17:00-17:30 -- Julie Delon

Title: *Optimal transport with invariances between Gaussian mixture models*

Abstract: Gaussian Mixture Models (GMMs) are ubiquitous in statistics and machine learning and are especially useful in applied fields to represent probability distributions of real datasets. Optimal transport can be used to compute distances or geodesics between such mixture models, but the corresponding Wasserstein geodesics do not preserve the property of being a GMM. It has been shown in https://arxiv.org/abs/1907.05254 that restricting the set of possible coupling measures to GMMs transforms the original infinitely dimensional optimal transport problem into a finite dimensional problem with a simple discrete formulation, well suited to applications where a clustering structure is present in the data. In this talk, we will present two possible extensions of this Wasserstein-type distance between GMMs that remain invariant to isometries. Inspired by the Gromov-Wasserstein distance, these extensions can also be used to compare GMMs of different dimensions.

17:30-19:00 – Poster + cocktail session !

Wednesday

9:00-9:30 -- Christine Maloigne-Fernandez

Title: *AI and brain imaging: latest advances and future challenges/ IA et imagerie cérébrale : dernières avancées et enjeux futur*

Abstract: For many years, medical imaging has been widely used for the early detection and monitoring of pathologies. Machine learning approaches have recently gained in popularity as an aid to diagnosis, choice and therapeutic follow-up, and many current studies use convolutional neural networks (CNNs). Some very interesting results have been produced since 2015 concerning retinal, pulmonary, cardiac, abdominal, musculoskeletal and even cerebral pathologies. This article will describe the latest generation of imagers, ultra-high-field MRI, the most suitable for brain diseases, and give a brief overview of the latest AI methods for medical imaging, to show what they bring to specialists and patients alike. We will conclude with some of the difficulties and new challenges for healthcare introduced by machine learning in medical imaging.

9:30-10:00 -- Vanna Lisa-Coli

Title: *Tomographic imaging for a medical and an archaeological applications*

Abstract: Tomographic imaging allows to access the internal structures of objects and tissues by means of measurements on different types of penetrating waves.

In the first part of the talk, I will present an application of microwave tomography in the context of medical imaging, concerning the detection and monitoring of brain strokes.

In the second part of the talk, I will present the analysis of scans of archaeological pottery as an application of micro-CT imaging. The 3D reconstruction of the internal structure of pottery allows the visualization and study of the signatures of manufacturing technique, with the aim of investigating the technical traditions of the early stages of the north western Mediterranean Neolithic.

These are joint works with Laure Blanc-Féraud, Juliette Leblond and Claire Migliaccio.

10:00-10:30 -- Françoise Peyrin

Title: *X-Ray CT bone imaging: form micro to nano*

Abstract: Osteoarticular diseases like osteoporosis or osteoarthritis are increasing with the aging of the population. However progresses in diagnosis and treatment are still necessary motivating research to have a better understanding of the biological mechanisms involved in these diseases. We will review progresses in X-ray CT to have a multiscale assessment of bone. In particular we will present 3D synchrotron micro and nano CT providing attenuation or phase contrast maps, at a given energy with a high signal-to-noise ratio at very high spatial resolution. The combination of synchrotron CT image acquisition with the development of dedicated image processing algorithms allows to go beyond imaging and extract quantitative parameters on bone tissue at different scales. We will review examples of applications to assess bone microarchitecture, bone microcracks and the bone cell network, and open perspectives with the promise of artificial intelligence, and particularly deep learning methods to improve bone imaging.

11:00-11:30 -- Lola Bautista

Title: *Glaucoma detection using fundus images of the eye*

Abstract: Glaucoma is one of the worldwide leading causes of blindness. In developing countries, there is a small number of opththalmologists able to detect suspect patients from the reading of fundus images of the eye. In this work we present different approaches that had been used to provide automatic tools to detect accurately those patients and refer them to further exams to confirm the existance of the disease.

11:30-12:00 – Closing remarks