Inverse Problems: Methods, Applications and Synergies

January 15th -16th -17th 2019

PROGRAM

Registration and Welcome: Tuesday 15th, 09:00-09:30.

Schedule	Tuesday 15th	Wednesday 16th	Thursday 17th
	ASTRONOMY SESSION *Chair: Clémentine Béchet*	***MEDICAL SESSION 2*** *Chair: Matías Courdurier*	***GEOPHYSICS SESSION*** *Chair: Jorge Crempien*
09:30	Éric Thiébaut	Sergio Uribe	Chen Ji
10:20	Simón Casassus	Benjamin Palacios	Marcos Moreno
11:00	Coffee Break	Coffee Break	Coffee Break
11:30	Tapio Helin	Victor Castañeda	Francisco Ortega
12:10	Ferréol Soulez	Daniel Hurtado	Felipe Aron
12:50	Lunch	Moving to CMM by bus and Welcome brunch	Lunch
	MEDICAL SESSION 1 *Chair: Carlos Sing-Long*		***MINING SESSION*** *Chair: Jaime Ortega*
14:00	Cristobal Bertoglio	***INTERACTIVE SESSION*** *Chair: Axel Osses*	Sergio Gaete
14:50	Joaquín Mura	Hands-on session	Christian Ihle
15:30	Coffee Break		Coffee Break
16:00	Jean-Gabriel Minonzio		Joaquín Fontbona
16:40		Posters session & Coctel	
17:00			

Tuesday January 15th

Astronomy session

---------- 9:30

Éric Thiébaut * : **"Inverse Problems applied to astronomy and biomedical imaging"**

* Centre de Recherches Astrophysiques de Lyon (France)

I will present some results of the MiTiV project whose objectives were to develop reconstruction methods for astronomy and bio-medical imaging in a common framework. These results illustrate some of the benefits of using regularized iterative methods to solve inverse problems. Compared to direct methods, iterative algorithms can consistently cope with missing data and impose almost no restrictions on the direct model (like being invertible or shift-invariant). More realistic direct models can thus be implemented to improve the quality of restored images and/or to reduce the number of required measurements. This can be exploited to lower the dose of radiations in dynamical X-ray tomography. Myopic and blind deconvolution are examples that the direct model does not even need to be exactly known which is very convenient when calibrating the PSF is difficult or impossible as it is the case in microscopy or angiography.

---------- 10:20

Simón Cassasus * : **"Image synthesis in radio astronomy"**

* Universidad de Chile (Chile)

Radio interferometers such as the ALMA Observatory correlate the sky signal over a number of baselines joining antenna pairs and so yield discrete samples of the sky image in the Fourier domain (also called uv-plane). The challenge posed by image synthesis is to fill-in the gaps in the uv-plane in complex interpolation, and so recover the full sky image. I will give a brief overview of the techniques used in the field, with an emphasis on local efforts. Example applications range from single baseline and poor uv-plane coverage, to high-fidelity imaging and super-resolution. Although the success of radio image synthesis is spectacular, a frequent shortcoming is an incomplete understanding of the statistical properties of the resulting synthetized images.

---------- 11:00

Coffee break

---------- 11:30

Tapio Helin * : **"Inverse problems and correlation imaging in adaptive optics"**

* LUT University (Finland)

Adaptive optics is a technology in modern ground-based optical telescopes to compensate for the wavefront distortions caused by atmospheric turbulence. In the next-generation wide-field adaptive optics modalities it is beneficial to have good real-time statistics of the turbulence available. One method that allows to recover such information based on telescope data is so-called SLODAR, where the atmospheric turbulence profile is estimated based on correlation data of Shack–Hartmann wavefront measurements. This approach relies on a layered Kolmogorov turbulence model. In this talk, we discuss a novel extension

of the SLODAR concept by including a general non-Kolmogorov turbulence layer close to the ground with an unknown power spectral density.

---------- 12:10

Ferréol Soulez *: **“Proximity operators for phase retrieval”**

* Centre de Recherches Astrophysiques de Lyon (France)

The phase retrieval problem consists in estimating a complex valued signal of interest from the measurements of its magnitude only. Such issues arise in a wide number of applications such as optical long baseline interferometry, holography, lensless microscopy, crystallography… . As the seminal work of Gerchberg & Saxton, a large part of the abundant literature dedicated to this problem belongs to the class of constraint algorithms involving some projection steps. To rigorously take into account measurement noise statistics we have proposed proximity operators dedicated proximity operators that can be viewed as generalized projection.

In this talk, after a glimpse on proximal operator theory, I will present these proximity operators for phase retrieval and their use in three different application: polychromatic optical long baseline interferometry, space varying PSF estimation of space telescope and lensless phase microscopy.

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Medical Session I

---------- 14:00

Cristobal Bertoglio * : **“Inverse problems in hemodynamics from MRI”**

* University of Groningen

We will present recent advances and future challenges in the field of data-based mathematical modeling of blood flows with data coming from Magnetic Resonance Imaging. Specifically, we will explore different inverse problems when going from more to less measured data: (a) Pressure maps estimation from 3D+time velocity fields, (b) Parameter estimation from 2D velocity fields (c) dual velocity-encoding in PC-MRI and potential extension to parameter estimation from highly undersampled raw MRI data.

---------- 14:50

Joaquín Mura * :

* Pontificia Universidad Católica de Chile (Chile)

---------- 15:30

Coffee break

---------- 16:00

Jean-Gabriel Minonzio * : **“Multi modal guided waves inverse problem: Application to in vivo estimation of cortical bone thickness and porosity”**

* U de Valparaiso (Chile)

Guided waves can be found in a variety of domains such as musical instruments, optical fibers, underwater acoustics, or non destructive testing. In these cases, waves are propagating in a bounded medium and thus, the different reflections or paths interacts to create interference patterns leading to guided waves. Measurements of such waves together with appropriate waveguide modeling have therefore the potential for providing estimations of both geometric and elastic properties of the inspected waveguide. This point of view has been applied for in vivo cortical bone assessment, using axial transmission technique. In this configuration, multiple ultrasonic transmitters and receivers are aligned with the bone axis.
Identification of cortical parameters is achieved through an inverse approach that is an extension of the signal processing applied to extract the experimental guided mode wave numbers from the maxima of the so-called Norm function. Each pixel of the Norm function corresponds to the projection of a tested plane wave into the reception singular vector basis at each frequency; it values ranges reflects in 0-1 scale the presence rate of a tested wave in the measured signals. The Norm function can be thus interpreted as an enhanced spatio-temporal Fourier transform. In the case of waveguide parameter estimation, instead of spanning all measurable waves, the testing waves are limited to the possible guided mode values, given by a dedicated cortical bone waveguide model, being a 2D transverse isotropic free plate, parametrized in term of thickness and elasticity. The aim of this study is to present the inverse approach and its validation on simulated waveguides using Python and FEniCS framework. Ex vivo validation and clinical results will also be discussed.

Wednesday January 16th

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Medical Session II

---------- 09:30

Sergio Uribe * : **“MRI2: some inverse problems in magnetic resonance imaging”**

* Pontificia Universidad Católica de Chile (Chile)

In this talk, we will introduce how are obtained images by magnetic resonance and some of the inverse problems related to this technique. We will review for instance speed images and separation of images from water and fat.

---------- 10:20

Benjamin Palacios * : **“A microlocal method for artifact reduction in Quantitative Susceptibility Mapping”**

* University of Chicago (USA)

Quantitative Susceptibility Mapping (QSM) is an image method that employs MRI data to determine the magnetic susceptibility distribution of different structures inside the human body. It is common that images obtained through this technique are contaminated with streaking artifacts and is therefore of great interest for practical applications to understand the nature of the artifacts as well as finding methods to reduce their effect. In this talk I will explain, using tools from microlocal analysis, the principle behind the appearance of image artifacts in QSM and I will propose a new method for their reduction that involves the use pseudo-differential operators to pre-process and post-process the data. This is a joint work with G. Uhlmann and Y. Wang.

---------- 11:00

Coffee break

---------- 11:30

Victor Castañeda: **"Light Sheet Fluorescence Microscopy"**

* Universidad de Chile (Chile)

Light Sheet Fluorescence Microscopy (LSFM) is a cutting-edge microscopy which is being used in the most important laboratories worldwide in order to study relevant aspects in the modern biology. LSFM allows optical sectioning to do high-speed 3D acquisition of big size specimens with high space-time resolution, high contrast, low photo-toxicity and low photo-bleaching. These LSFM's characteristics are the best choice for the visualization and analysis of the whole dynamics inside of a specimen in vivo, even for 3D complex structures. This talk will show the physical principles of the LSFM and its variants. Also, relevant aspects, limitations and challenges of the implementation/maintenance of a multi-view LSFM and its high-throughput data processing will be reviewed.

---------- 12:10

Daniel Hurtado * : **“Análisis biomecánico del pulmón basado en imágenes médicas”**

* Pontificia Universidad Católica de Chile (Chile)

En esta charla presentaré una aproximación interdisciplinaria al desarrollo de una herramienta de diagnóstico temprano a este problema, donde los ingredientes fundamentales son la modelación matemática, los métodos numéricos, la biomecánica de tejidos, las imágenes médicas y la medicina de cuidados intensivos. Nuestros resultados demuestran que es posible determinar la deformación regional que sufre el parénquima pulmonar in-vivo en forma no invasiva a partir de imágenes médicas tradicionales. Más aún, nuestro equipo ha sido pionero en demostrar que la deformación regional está correlacionada espacialmente con la inflamación regional, primer síntoma de daño, confirmando así una de las hipótesis médicas más importantes de la última década en el área de cuidados intensivos. Finalmente mostraré como esta interacción ha motivado el desarrollo de modelos constitutivos basados en la teoría de homogeneización no-lineal para entender la relación entre deformaciones y tensiones en el tejido pulmonar.

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Hands-on session

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Posters Session

Thursday January 17th

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Geophysics Session

---------- 09:30

Chen Ji * : **“Subject-oriented finite fault inversion of global large earthquakes”**

* University of California Santa Barbara (USA)

Finite fault source studies are well-known ill-posed geophysical inverse problems. To reduce the error introduced during the source parameterizations, hundreds to thousands parameters are typically used. Because of limited independent constraints from geophysical surface observations, various constraints were introduced to stabilize the inversions. The solutions are then non-unique and the uncertainties are caused by both the data limitation and theimprintsof a prioriconstraints, which are difficult (if not impossible) to separate. When the inverted solutions are used to study another geophysical subject, the uncertainties in models inevitably lead to the uncertainties of the subject that we are interested in. Here we introduce a strategy to explore the uncertainty of the ultimate subject due to the misfit to the data by conducting a series of ***subject-oriented finite fault inversions.****Comparing with conventional finite fault approaches, this new approachdirectly includes the evaluation of the subject into its objective function that will be minimized. The uncertainty of the subject then can be directly accessed by inspecting the trade-off curve between its value and the misfit to the data. This is a computationally intensive strategy as hundreds of finite fault inversions need to be conducted, but the entire procedure can be embarrassingly parallelized to take advantage of fat-node or clusters with multiple core CPUs or GPUs. We demonstrate the power of this approach in understanding source physics by analyzing the energy based average stress drop () of two large earthquakes using seismic and geodetic data individually. We find only the low boundof the average stress drop() can be constrained with seismic and geodetic data, and advocate to use to stabilize the fault slip because of its clear physical meaning. leads to the lower bound of the apparent available energy () and the upper bound of the seismic radiation efficiency (. Our analysis reveals the of the 2015 Gorkhaearthquake is only 0.09-0.15 though it was reported to have fast rupture velocity. However, this discrepancy can be well reconciled by considering the aspect ratio of the dominant slip patch.*

---------- 10:20

Marcos Moreno:

title and abstract not yet available.

---------- 11:00

Coffee break

---------- 11:30

Francisco Ortega *: “**The Impact of Regularization on Slip Inversion:**

Proposing an EPIC Condition for Tikhonov regularization”

* Universidad de Chile (Chile)

Imaging subsurface slip behavior from surface observations is essential to increase our level of understanding of the kinematics and physical processes controlling earthquake and tsunami occurrence. As the estimation procedure is an inherently ill-posed problem, the adopted inverse methodology to obtain such estimates, in particular the form of the a priori information, plays a key role in this learning process. There are two general end member approaches to estimate the distribution of slip on a fault that deals with the inherent instability of the inverse problem: An unregularized, computationally expensive, fully Bayesian MCMC approach and a much more expedient but biased optimization approach, for instance, using some form of regularized least squares. We focus our efforts in the latter approach.

On the regularized inversion, the chosen form of a priori information will introduce a bias on fault slip estimates that needs to be well understood to be able to achieve rigorous interpretation of the obtained slip values. Here we discuss the effects that a priori information implied by commonly used regularization schemes has on slip estimates of fault behavior. Also, we propose a novel Equal a Posteriori Information Content (EPIC) condition to calculate a priori variances for Tikhonov regularization. The proposed scheme accounts for the spatial variability of the constraints provided by the observations (typically onland) and improves the stability and resolution of the inferred slip distributions of fault behavior. Also, with the proposed methodology, the regularization parameter is naturally defined as the target a posteriori variance of model parameters. We present study cases in the Japan Trench subduction megathrust.

---------- 14:30

Felipe Aron * : **“Probabilistic inversion of long-term slip rates on seismogenic crustal faults in the San Francisco Bay area using mechanics, geomorphology and plate motion”**

* Pontificia Universidad Católica de Chile (Chile)

In this contribution, we examine the long-term kinematic behavior of geologic crustal faults in response to tectonic loads by combining geomorphic modeling of channel incision with uplift predicted over a mountain range by a Boundary Element Model (BEM). In particular, we developed a method for using the elevation structure of channels in a landscape to infer the far-field plate motion rates that produce this topography. Specifically, we use a BEM to compute Greens functions that relate far field plate velocities to slips along active, 10-100 kilometer-scale geologic faults and surrounding rock uplift rates. That process of stress/strain accommodation and partitioning in the crust, acting over centennial to million-year scales, is responsible of building up mountain ranges and other kinds of structurally-generated reliefs along active tectonic regions such as plate boundaries. In a second step, computed rock uplift rates were used with the geomorphic power-law incision rule, which relates uplift rates and rock erodibility to channel elevations/incision at steady-state, to calculate the far-field plate rates and rock erodibilities that produce channel elevations that best match the observed topography. Because the geomorphic model contains non-linear components, we used a Markov-Chain Monte Carlo (MCMC) sampler to infer best-fitting erodibilities and plate-rates. Additionally, this sampler divulges the joint posterior probability density function of model parameters, allowing us to assess the uncertainty within and uniqueness of erodibilities and plate rates. This approach was applied to a restraining bend along the San Andreas Fault (SAF) within the Santa Cruz Mountains, which rises to more than a thousand meters above the southern San Francisco Bay, limiting most of the western side of Silicon Valley for about 100 kilometers. There, slowly over geologic time, rock uplift *produced by slip on crustal faults, capable of nucleating big, magnitude 6 to 7 earthquakes with surface rupture, has competed against the atmospheric erosive forces to construct the mountains relief. That region is ideal to test our model because comprehensive geologic mapping constrains the surface distribution of exposed lithologies, geologic and geophysics observations constrain long-term rates and the fault architecture, and geodetic observations constrain current surface motions. Interestingly, calculated posteriors fall well within the range of reported values, suggesting that the joint use of elastic boundary elements and geomorphic models may have utility in estimating long-term fault slip-rate distributions.*

These results might contribute to determining possible seismic scenarios for Silicon Valley but perhaps more importantly, our approach could be used in estimations of long-term slip rates and surface deformation due to other crustal geologic faults with unknown displacement history.

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Mining Session

---------- 14:50 CANCELLED TALK

Christian Ihle * : **"Two inverse problems on the handling of tailings"**

* Universidad de Chile (Chile)

The Chilean mining sector is challenged by the arid environments where it often takes place, making water supply either difficult or expensive. In flotation plants, water use is more intensive in comparison to other beneficiation routes and it is thus crucial to maximize its recovery. This mostly occurs in thickeners and is frequently continued in tailing storage facilities. Two aspects that are related to inverse problems in this context are the modeling and measurement of flocculation, existing at the heart of thickeners, and the tailing rheology, related to both thickeners and tailing hydraulic transport. The former process is critical to limit thickener capacity and performance, and the latter additionally conditions both the throughput and the final placement characteristics of tailings. In the present talk, these unit operations and their related problems will be discussed.

---------- 15:30

Coffee break

---------- 16:00

Joaquin Fontbona * : **"A scalable Bayesian approach for passive first arrival time seismic tomography"**

* Universidad de Chile (Chile)

Mining-induced seismicity records are commonly used in large underground mining operations in order to localize micro-earthquake hypocenters and identify regions of increased seismic hazard or potential geomechanical instabilities in the mine. Currently employed source localization procedures mainly rely on records of seismic waves' first arrival times and on pre-existing estimations of their propagation velocity in the mine, typically obtained using blasting as calibrations shots, and assuming the medium to be homogeneous over large portions of the mine. However, such method only allows for estimating the velocity field on reduced regions of the mine under controlled conditions, and can otherwise lead to significantly biased sources localization.

We introduce and develop a new seismic tomography method in order to simultaneously reconstruct the heterogeneous velocity field in the mine and the unknown seismic source locations during a given period or dynamically in time, which is able to deal with, and take advantage of millions of P-waves arrival times, passively recorded over the years by the micro-seismic sensor network of a mine. Our method is scalable in the sense that it can treat unbounded amounts of data with linear complexity, and provides increasing estimation accuracy from larger available data of the seismic activity in each given zone and time period.

The algorithm is based on Bayesian on-line learning methods and ideas, in particular on the use of the Stochastic Gradient Descent method, which has revealed remarkably successful to deal with large streamed datasets in Machine Learning applications, and is to our knowledge used here for the first time in the context seismic tomography, a central example of high dimensional nonlinear statistical inverse problems. Our method avoids linearized approximations by working directly with minimum ray paths, and should allow for more precise hypocenter locations and finer local estimates of physical properties of interest such as attenuation, stress or damage.

Based on current work in progress with Claire Delplancke, Daniel Neira and Jorge Prado, (CMM) in collaboration with El Teniente Division of Codelco.

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END OF THE WORKSHOP IPMAS 2019. *See you at the next IPMAS!*