CoMFoS23

MATHEMATICAL ASPECTS OF CONTINUUM MECHANICS 2023

DECEMBER 11 - 12, 2023

via ZOOM

This is the program for the
CoMFoS23: Mathematical Aspects of Continuum Mechanics 2023
for print use.
The website for the meeting can be found at:
`https://sites.google.com/view/comfos23/home`

Contents

About

The Conference

This is a two-day conference on mathematical aspects of continuum mechanics for solids.

The intended audience consists of experts from fields ranging from mathematics and physics to engineering and industry. We focus on mathematical theory and numerical simulations related to, but not limited to, topics such as fracture mechanics, elasticity, plasticity, scattering, inverse problems, optimal shape design, and continuum limits. These topics have become increasingly important in engineering and industry, and a deeper understanding of their mathematical properties is required for future applications.

CoMFoS was initiated in 1995 under the auspices of the activity group "Continuum Mechanics Focusing on Singularities (CoMFoS)" of the Japan Society for Industrial and Applied Mathematics (JSIAM). From April 2010, the activity group CoMFoS was renamed "Mathematical Aspects of Continuum Mechanics (MACM)".

The Organizers

Thomas de Jong	Kanazawa University, Japan
Masato Kimura	Kanazawa University, Japan
Manabu Machida	Kindai University, Japan
Hirofumi Notsu	Kanazawa University, Japan
Julius Fergy Rabago	Kanazawa University, Japan

Registration

Please register through the link: `https://us06web.zoom.us/meeting/register/`.

Timetable

Japan Standard Time

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17:30 - 18:00	**Oussama Ounissi** Japan	A new proof of symmetry and positive definiteness of the spring constant derived from P1-FEM
18:00 - 18:30	**Tim Suchan** Germany	Shape optimization for fluid-mechanical design under uncertainties and fracture propagation
18:30 - 19:00	**Mariia Dvoriashyna** United Kingdom	Oscillatory and steady streaming flow of cranial cerebrospinal fluid
19:00 - 19:30	**Hiroshi Ishii** Japan	Effect of integral kernel shape on interface dynamics in a nonlocal bistable equation
19:30 - 20:00	**Ayumi Ozawa** Japan	Analyses of interacting oscillators in the limit of the infinite number of oscillators: synchronization and stochastic oscillation quenching
DAY 2	**December 12, 2023**	
17:00 - 17:30	**Andreas Hauptmann** Finland	Learned reconstructions for photoacoustic tomography
17:30 - 18:00	**Manabu Machida** Japan	Reconstruction of the absorption property in biological tissue with the inverse Rytov series
18:00 - 18:30	**Koondanibha Mitra** The Netherlands	Analysis of coupled degenerate and singular systems: Well-posedness and travelling waves
18:30 - 19:00	**Jyrki H. Jauhiainen** Finland	Online optimization for dynamic electrical impedance tomography
19:00 - 19:30	**Renier G. Mendoza** The Philippines	Reconstructing images in electrical impedance tomography using multi-operator differential evolution algorithm
19:30 - 20:00	**Rhudaina Z. Mohammad** The Philippines	A thresholding scheme for cellular patterning in sensory epithelial morphogenesis
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Greenwich Mean Time

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09:00 - 09:30	**Tim Suchan** Germany	Shape optimization for fluid-mechanical design under uncertainties and fracture propagation
09:30 - 10:00	**Mariia Dvoriashyna** United Kingdom	Oscillatory and steady streaming flow of cranial cerebrospinal fluid
10:00 - 10:30	**Hiroshi Ishii** Japan	Effect of integral kernel shape on interface dynamics in a nonlocal bistable equation
10:30 - 11:00	**Ayumi Ozawa** Japan	Analyses of interacting oscillators in the limit of the infinite number of oscillators: synchronization and stochastic oscillation quenching
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Central European Time

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10:00 - 10:30	**Tim Suchan** Germany	Shape optimization for fluid-mechanical design under uncertainties and fracture propagation
10:30 - 11:00	**Mariia Dvoriashyna** United Kingdom	Oscillatory and steady streaming flow of cranial cerebrospinal fluid
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Eastern European Time

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Philippine Standard Time

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List of Abstracts – Talks

Day 1, Monday, December 11th

Compressed sensing for the sparse Radon transform

G. S. Alberti[a]**, *A. Felisi***[a]**, *M. Santacesaria***[a]**, *S. I. Trapasso***[b]

[a]MaLGa Center, Department of Mathematics, University of Genoa
[b]Department of Mathematical Sciences, Polytechnic University of Turin

Compressed sensing allows for the recovery of sparse signals from few measurements, whose number is proportional, up to logarithmic factors, to the sparsity of the unknown signal. The classical theory mostly considers either random linear measurements or subsampled isometries. In particular, the case with the subsampled Fourier transform finds applications to undersampled magnetic resonance imaging. In this talk, I will show how the theory of compressed sensing can also be rigorously applied to the sparse Radon transform, in which only a finite number of angles are considered. One of the main novelties consists in the fact that the Radon transform is associated to an ill-posed inverse problem, and the result follows from a new theory of compressed sensing for abstract inverse problems.

A new proof of symmetry and positive definiteness of the spring constant derived from P1-FEM

O. Ounissi[a]**, *M. Kimura***[b]**, *H. Notsu***[b]

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We study the solvability of the tensor-valued spring block system derived from P1-FEM for the equations of linear elasticity. The model is solvable if the spring constants are symmetric and positive definite. We seek to extend the results obtained in [2] to 3 dimensions. Under the homogeneity assumption, we offer a unified proof of the symmetry of the spring constants in 2 and 3 dimensions. Additionally, in the case of isotropic materials, we propose a sufficient condition on the FEM mesh, under which we prove the positive-definiteness of the derived spring constants.

References

[1] M. Kimura and H. Notsu. A mathematical model of fracture phenomena on a spring-block system. Kyoto University RIMS Kokyuroku, 1848:171 – 186, 2013.

[2] H. Notsu and M. Kimura. Symmetry and positive definiteness of the tensor-valued spring constant derived from p1-fem for the equations of linear elasticity. Networks and Heterogeneous Media, 9(4):617 – 634, 2014. doi: doi:10.3934/nhm.2014.9.617.

Shape optimization for fluid-mechanical design under uncertainties and fracture propagation

T. Suchan[a], ***C. Geiersbach***[b], ***W. Wollner***[c], ***K. Welker***[d]

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[c]Universität Hamburg, Germany
[d]TU Bergakademie Freiberg, Germany

The formulation of shape optimization problems as an optimization on shape spaces – specifically, infinite-dimensional Riemannian manifolds – provides the possibility to use known convergence properties of established algorithms like gradient-based optimization algorithms on Riemannian manifolds. Furthermore, it enables the generation of mesh-independent results due to the continuous formulation of the optimization problem. As the shape optimization problems are often motivated by physical models, the optimization problems are constrained by partial differential equations (PDE), which have to be solved numerically.

In this talk, we first consider the minimization of viscous energy dissipation under uncertainties with additional geometrical constraints to avoid trivial solutions. The uncertainties enter this optimization problem as a boundary condition of the PDE constraint. A stochastic gradient descent algorithm, where the geometrical constraints are enforced by an Augmented Lagrange approach, is proposed and then used to solve this type of problem. As a second application, we use the deterministic shape optimization algorithm to simulate fracture propagation in brittle materials.

Oscillatory and steady streaming flow of cranial cerebrospinal fluid

M. Dvoriashyna[a]***, A. Goriely***[b]

[a]School of Mathematics and Maxwell Institute, University of Edinburgh
[b]Mathematical Institute, University of Oxford

Cerebrospinal fluid (CSF) is a clear, transparent fluid that bathes the brain and spinal cord. It fills the subarachnoid space (SAS), which surrounds the spinal canal and the brain and is externally lined by the dura membrane. During the cardiac cycle, this fluid pulsates in response to the time-varying changes in brain volume: during systole, CSF is displaced from cranial to the spinal compartment, and during diastole, the flow reverses. This flow plays a key role in mixing of solutes in the SAS.

In this study, we investigate the oscillatory CSF flow in the cranial SAS to comprehend its role in solute transport within the SAS and waste clearance. We develop a theoretical model of the flow using lubrication theory, as the SAS has a small aspect ratio. We impose realistic displacements of the brain surface obtained from MRI data [1]. The model reveals complex three-dimensional flow profiles within the SAS. We use this model to predict pressure gradients in SAS, which are challenging to measure experimentally.

The model also predicts the presence of a steady streaming driven by oscillations. This flow has a magnitude of approximately 100 m/s, comparable to another steady flow in SAS: the flow generated by the production and drainage of CSF. This suggests that steady streaming contributes to the mixing processes and transport of solutes within the SAS.

References

[1] Adams AL, Viergever MA, Luijten PR, Zwanenburg JJM. Validating faster DENSE measurements of cardiac-induced brain tissue expansion as a potential tool for investigating cerebral microvascular pulsations. Neuroimage. 2020 Mar; 208:116466

Effect of integral kernel shape on interface dynamics in a nonlocal bistable equation

Hiroshi Ishii

Research Center of Mathematics for Social Creativity, Research Institute for Electronic Science, Hokkaido University

This talk deals with a bistable equation with a convolution term of an appropriate integral kernel and the unknown function in the spatial direction. The linear part of our problem is derived from a reduction method of linear reaction-diffusion systems proposed by [1]. In particular, the integral kernel shape represents the network structure of the reaction-diffusion system and varies with it. The motivation of this study is to analyze how the spatio-temporal dynamics of the solution changes with the integral kernel shape. In this talk, the behavior of phase-separated solutions will be discussed as an example of the effect of integral kernel shape. First, we introduce a nonlocal reaction equation with a sufficiently small parameter . Then, we derive the interface equation by taking the limit . The derived interface equation is explicitly included in the integral kernel information. Finally, to investigate the effect of the integral kernel shape, we focus on the band solution as the characteristic solution in this talk and discuss its behavior.

References

[1] S.-I. Ei, H. Ishii, S. Kondo, T. Miura, Y. Tanaka "Effective nonlocal kernels on reaction-diffusion networks" Journal of Theoretical Biology, 509, (2021), 110496, 17pages.

[2] H. Ishii, "Interface dynamics in a nonlocal bistable equation" preprint.

Analyses of interacting oscillators in the limit of the infinite number of oscillators: synchronization and stochastic oscillation quenching

A. Ozawa[a], ***H. Kori***[a]

[a]Graduate School of Frontier Sciences, The University of Tokyo

Oscillation is abundant in nature, and mathematical analysis of systems composed of interacting oscillators is essential for understanding various systems, such as mechanical and biological systems, to name a few [1]. Among various mathematical models of interacting oscillators, phase oscillator models describe the state of each oscillator by using a single variable, the phase, and are relatively simple and analytically tractable. Nevertheless, the models become difficult to deal with as the number of oscillators increases. In such a case, it is often advantageous to take a limit where the number of oscillators goes to infinity. In this limit, the dynamics of the system is described by a partial differential equation (PDE) that has the same or similar form as the continuity equation [2]. In this talk, I illustrate how the analyses of PDEs can provide insights into the dynamics of corresponding interacting oscillator systems. First, the studies of oscillators in the continuous limit will be briefly reviewed. We then focus on a large assemblage of interacting phase oscillators, where the random removal and addition of the constituent oscillators cause the turnover of the assemblage of the oscillators [3]. Typically, the stable solutions of the PDE describing the evolution of this system fall into three types: (1) periodic solutions reflecting the collective oscillation produced by synchronized oscillators, (2) steady solutions corresponding to the loss of coherence in the state of the oscillators, and (3) steady solutions that imply the cessation of the individual oscillators. While the transition between the first and second types of solution owing to changes in parameter values has been observed in various oscillator systems, the third type of solution is novel and owing to the synergetic effect of interaction and turnover. In addition to illustrating these solutions, the transitions between different types of solutions are discussed by employing formal stability analysis and a self-consistent argument. These results are expected to be utilized for efficiently controlling oscillators with turnover, including protein molecules that change their state periodically.

References

[1] Pikovsky, A., Rosenblum, M. & Kurths, J. Cambridge University Press (2001).
[2] Crawford, J. D. & Davies, K. T. R. Physica D (1999).
[3] Ozawa, A. & Kori, H. Preprint at https://doi.org/10.48550/arXiv.2307.00630 (2023).

Day 2, Tuesday, December 12th

Learned reconstructions for photoacoustic tomography

A. Hauptmann

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Department of Computer Science, University College London, United Kingdom

In photoacoustic tomography biological tissue is illuminated with a short pulse of near infrared light. The absorbed energy creates a local pressure increase that propagates through the tissue, governed by the acoustic wave equation, and we can measure the pressure wave on the boundary. From this measured time-series we aim to reconstruct the initial pressure in the tissue, providing valuable information on local structures, such as microvasculature.

In limited-view photoacoustic tomography, the measurement geometry is restricted, resulting in a severely ill-posed linear inverse problem. Iterative model-based reconstruction approaches provide good reconstruction quality but can be highly time consuming for high-dimensional problems, especially with non-trivial forward operators. Thus, it is desirable to employ model reduction techniques to speed-up reconstructions in variational approaches as well as to enable training of learned model-based iterative reconstruction techniques [1]. Nevertheless, reduced or approximate models can lead to a degradation of reconstruction quality and need to be accounted for.

In this talk we discuss the possibility of learning data-driven model corrections for inverse problems [2]. We make a distinction between implicit [3] and explicit corrections [2]. In the former [3], correction and regularisation are trained simultaneously with a data-driven iterative updating network. This way a substantial speed-up, compared to classical variational approaches, can be achieved with improved reconstruction quality. Unfortunately, such implicit corrections offer limited insights into how approximate models are corrected for and hence we additionally discuss the latter case of learning an explicit correction that can be subsequently used in a variational framework [2]. We will discuss the conceptual difficulty of learning such an explicit forward model correction and present conditions under which solutions to the variational problem with a learned correction converge to solutions obtained with the accurate model.

References

[1] Hauptmann, Andreas, Felix Lucka, Marta Betcke, Nam Huynh, Jonas Adler, Ben Cox, Paul Beard, Sebastien Ourselin, and Simon Arridge. ”Model-based learning for accelerated, limited-view 3-D photoacoustic tomography.” IEEE transactions on medical imaging 37, no. 6 (2018): 1382-1393.

[2] Lunz, Sebastian, Andreas Hauptmann, Tanja Tarvainen, Carola-Bibiane Schonlieb, and Simon Arridge. ”On learned operator correction in inverse problems.” SIAM Journal on Imaging Sciences 14, no. 1 (2021): 92-127.

[3] Hauptmann, Andreas, and Jenni Poimala. ”Model-corrected learned primal-dual models for fast limited-view photoacoustic tomography.” arXiv preprint arXiv:2304.01963 (2023).

Reconstruction of the absorption property in biological tissue with the inverse Rytov series

M. Machida

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We consider the absorption of diffuse light in biological tissue. The light is governed by the diffusion equation. We wish to reconstruct the absorption coefficient in the diffusion equation from boundary measurements. This inverse problem is known to be nonlinear and severely ill-posed. Among different inversion algorithms, the (first) Rytov approximation is a commonly used technique. However, the nonlinear inverse problem has to be linearized to use this algorithm. In this talk, we extend the conventional Rytov approximation by the inverse Rytov series and reconstruct the absorption coefficient with nonlinear Rytov approximations.

References

[1] M. Machida, The inverse Rytov series for diffuse optical tomography, Inverse Problems 39, 105012, 2023.

Analysis of coupled degenerate and singular systems: Well-posedness and travelling waves

***K. Mitra*[a], *S. Sonner*[b], *J.M. Hughes*[c], *H.J. Eberl*[d], *J.D. Dockery*[e], *R.K.H. Smeets*[f], *I.S. Pop*[g]**

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Coupled nonlinear degenerate systems arise in various applications of societal relevance, such as biofilm growth, wildfires, and reactive transport in porous media. One of the equations in the system, describing the evolution of a biomass density/saturation, exhibits degenerate and singular diffusion behaviour. The other equations are either of advection-reaction-diffusion type or ordinary differential equations. In our analysis, we first propose a backward Euler time-discretization of the problem where the reactive terms coupling the equations are estimated semi-implicitly, and thus, the equations can be solved sequentially. Properties such as well-posedness, boundedness, and positivity of the time-discrete solutions are proven, and the existence of the time-continuous solutions is shown by passing the time-step size to zero. Global-in-time well-posedness is established for Dirichlet and mixed boundary conditions, whereas only local well-posedness can be shown for homogeneous Neumann boundary conditions. Using a suitable barrier function and comparison theorems we formulate sufficient conditions for finite-time blow-up or uniform boundedness of solutions. Assuming additional structural assumptions we also prove the uniqueness of solutions. The time-discretization method serves as an efficient way to solve such problems and numerical experiments are provided that support this.

Then, we show the existence of traveling wave (TW) solutions for a special case of PDE-ODE coupled models arising in the growth of cellulolytic biofilms. TW solutions for such systems have previously been observed numerically as well as in experiments. Using the TW ansatz and a first integral, the system is reduced to an autonomous dynamical system with two unknowns. Analysing the system in the corresponding phase-plane, the existence of a unique TW is shown, which possesses a sharp front and a diffusive tail, and is moving with a constant speed. The linear stability of the TW in two space dimensions is proven under suitable assumptions on the initial data. We present numerical results that exhibit the existence and stability of the TWs, along with corroborating predictions on parametric dependence.

Online optimization for dynamic electrical impedance tomography

***J. H. Jauhiainen*[a,b], N. Dizon[a], T. Valkonen[b,c]**

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Online optimization studies the convergence of optimization methods as more data is introduced into the problem; think of deep learning as more training samples become available. We adapt this approach to achieve real-time reconstructions in nonlinear dynamic inverse problems. We introduce a primal-dual online method specifically suited to these problems, study its properties through regret theory, and demonstrate its performance in dynamic monitoring of electrical impedance tomography.

Reconstructing images in electrical impedance tomography using multi-operator differential evolution algorithm

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Based on electrical measurements from electrodes placed around the boundary of a body, electrical impedance tomography (EIT) is an imaging procedure that recovers the spatial distribution of the conductivities in the interior of a body. Recent studies have shown promising results in reconstructing EIT images using heuristic algorithms. This work presents a solution to the inverse EIT problem using a differential evolution algorithm, whose hyperparameters are adaptive based on the success history of the previous iterations. Moreover, this method employs a linear population size reduction to improve the computational cost. Multiple operators are incorporated in the algorithm to balance the exploration and exploitation capabilities of the method. A series of numerical tests were carried out to assess the effectiveness of the algorithm.

References

[1] Velasco, A. C., Darbas, M., Mendoza, R., Bacon, M., & de Leon, J. C. (2020). Comparative study of heuristic algorithms for electrical impedance tomography. Philippine Journal of Science, 149(3), 747-772.

[2] Mohamed, A. W., Hadi, A. A., Fattouh, A. M., & Jambi, K. M. (2017, June). LSHADE with semi-parameter adaptation hybrid with CMA-ES for solving CEC 2017 benchmark problems. In 2017 IEEE Congress on evolutionary computation (CEC) (pp. 145-152). IEEE.

[3] Sallam, K. M., Elsayed, S. M., Chakrabortty, R. K., & Ryan, M. J. (2020, July). Improved multi-operator differential evolution algorithm for solving unconstrained problems. In 2020 IEEE congress on evolutionary computation (CEC) (pp. 1-8). IEEE.

A thresholding scheme for cellular patterning in sensory epithelial morphogenesis

R. Z. Mohammad

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In this talk, we discuss a thresholding scheme based on a level set-based computational framework for investigating cellular pattern formations observed in developing sensory ep- ithelia, an aggregate of two cell types: sensory and supporting cells, expressing different types of cell adhesion molecules, say of, nectins and/or cadherins. We illustrate that a compelling feature of the proposed method is its ability to correctly handle complex topology changes, including frequent cell intercalations. Moreover, we show that the proposed framework fea- tures minimum possible number of parameters and is capable of reproducing a wide range of tissue morphological phenomena, such as cell sorting, engulfment or internalization.