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Abstracts

Nocturnal Heart Rate Variability Estimation from 3D Seismocardiography Using Deep Learning

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Abstract

Heart rate variability (HRV) is an important physiological biomarker associated with autonomic nervous system activity. Nocturnal HRV is widely used in sleep analysis, stress management, and monitoring recovery from physical training. Seismocardiography (SCG) is a noninvasive sensing modality that captures subtle chest wall vibrations produced by the mechanical activity of the heart. While SCG has shown promise for HRV estimation, existing methods largely rely on conventional signal processing, which may limit robustness in noisy, long-duration recordings. In contrast, deep learning approaches, capable of automatically handling noisy segments with high precision, remain underexplored in nocturnal HRV monitoring. This study evaluates the applicability of a previously developed deep neural network (DNN)-based method for HRV estimation from nocturnal SCG recordings.

HRV was estimated from 3D SCG signals using a U-Net-based model, trained on short resting SCG recording from 4620 subjects. The model was evaluated on the publicly available NightbeatDB dataset, which consists of 38 overnight sleep recordings collected in real-world environments, totaling approximately 290.7 hours of data. Heart rate (HR) and HRV parameters were calculated from 10-minute segments and compared against time-aligned ECG-derived reference values. For HR estimation, the model achieved a strong correlation with ECG-derived HR, with a correlation coefficient of 0.982. The mean bias was -0.3 bpm and the 95% limits of agreement (LoA; mean$\pm$ 1.96$\times$SD) ranged from -1.7 to 1.0 bpm. HRV was further assessed using the root mean square of successive differences (RMSSD), a commonly used indicator of parasympathetic activity. The estimated RMSSD showed a high correlation coefficient of 0.929, with a mean bias of 0.6 ms and LoA ranging from -10.0 to 11.1 ms.

These results demonstrate the feasibility of using nocturnal SCG signals combined with deep learning techniques for reliable HRV estimation in real-world sleep monitoring scenarios.

Instance Segmentation of Dendrites from 3D-Electron Microscopy Images

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Abstract

Segmenting cellular structures in electron microscopy (EM) images is essential for studying the morphology of neurons and glial cells in both healthy and diseased brain tissue, but manual annotation remains labor-intensive and time-consuming. Although convolutional neural networks have improved EM image segmentation, their reliance on local feature extraction can limit the use of broader image context. Transformer-based models offer a promising alternative, and the Segment Anything Model (SAM) has recently shown strong segmentation performance in natural images. In this study, we investigated whether SAM can be adapted to microscopy data to improve segmentation accuracy and annotation efficiency in neuroanatomical research.

We fine-tuned models from micro-SAM on in-house serial block-face scanning EM datasets with a cutting interval of 40 nm. Dataset A, obtained from the CA1 region of the hippocampus of a healthy rat, contained 1044 slices and was used for training and internal evaluation. External evaluation was performed on Dataset B, consisting of 698 slices from the same region after pilocarpine-induced status epilepticus in a rat, and Dataset C, consisting of 697 slices from a cortical layer II biopsy of a patient with idiopathic normal pressure hydrocephalus. Model performance was assessed using the object-level error metric [1].

Using prompts derived from ground-truth masks and taking the mask quality of bounding-box prompts as a benchmark, the fine-tuned ViT-B and ViT-L models improved performance by approximately 19.1% and 20.8% over the original SAM, and by 150.1% and 181.9% over micro-SAM, respectively. A user study further showed that the fine-tuned model allowed annotators to produce segmentations more consistent with ground truth while reducing annotation

time. To improve automatic inference, we also integrated YOLO to generate bounding-box prompts, addressing the limitations of grid-point-based auto-prompting. This framework may also support pseudo-mask generation in future work and contribute to 3D dendrite connectome reconstruction.

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Photoacoustic contrast for virus-like nanoparticles

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Abstract

Photoacoustic tomography (PAT) is an imaging technique based on the photoacoustic effect [1]. In the photoacoustic effect, a short light pulse is absorbed by light-absorbing molecules (chromophores), resulting in the generation of ultrasound waves in the target being imaged. By measuring the ultrasound waves around the target using an ultrasound detector, and applying mathematical image reconstruction method, an image of the initial pressure distribution – reflecting the distribution of chromophores – can be reconstructed. Due to its high optical contrast, i.e. sensitivity to chromophores, PAT has various medical applications including vascular, skin, cancer, and small-animal imaging. In addition to endogenous tissue chromophores such as hemoglobin in blood, exogenous contrast agents that enhance image contrast and provide a platform for therapy are being developed for PAT [2].

In this thesis project, the goal is to develop new tools and applications for biomedical photoacoustic imaging. In the first part of this thesis, a new virus-like nanoparticle (VLNP) contrast agent for PAT is developed and characterized. The performance of these VLNPs is evaluated using controlled spectral photoacoustic signal measurements and photoacoustic tomography experiments in animal tissue. Tomographic images are obtained using Bayesian reconstruction methods developed in the group [3].

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Utilising a learned forward operator in the inverse problem of photoacoustic tomography

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Abstract

Photoacoustic tomography (PAT) is a hybrid medical and biomedical imaging modality that combines unique optical contrast with the high resolution of ultrasound [1]. Applications of PAT include, for example, imaging of skin and breast tumours, microvasculature, and small animals. In PAT, a short nanosecond scale light pulse, is directed to the target. Absorption of this light generates increases in pressure, which relax as ultrasound waves that can be measured on the boundary of the target. In the inverse problem of PAT, the initial pressure is estimated from the measured ultrasound signals by solving an inverse problem. Numerical solving of the problem can be computationally expensive due to the need for repeated evaluations of a forward operator describing ultrasound propagation.

In this work, we study a deep learning-based method for approximating ultrasound propagation in PAT [2]. The solution of the inverse problem is estimated using a gradient-based method using a learned forward operator based on the Fourier neural operator (FNO) [3]. The approach is studied using numerical simulations in full and limited-view sensor geometries. The results are compared to a conventional method, where solution of the forward model is numerically is approximated using the pseudospectral k-space method. Simulations show that the FNO can be used as a computationally efficient forward operator in the inverse problem of PAT.

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Image reconstruction methods for single photon emission computed tomography

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Abstract

The recent advances within solid-state radiation detection technology have the potential to enable quantitative dynamic imaging with single photon emission computed tomography (SPECT). Modern devices have transformed towards having more, but physically smaller, detector panels. This in turn allows for more spatial coverage of the field-of-view (FOV) in a unit time. Dynamic image reconstruction requires inherently different regularization and modelling strategies than conventional static image reconstruction. For example, the dimensionality of the problem grows quickly with the amount of time steps used.

For easy testing and validation of reconstruction methods, part of this work includes implementing SPECT reconstruction capabilities to OMEGA reconstruction software. This allows for implementing a grid of voxels with irregular resolution, centered around the region of interest. These multi-resolution models have previously been used in local computed tomography (CT) with promising results. Future work includes subspace projection in temporal regularization. In practice, enough time-activity curves are to be simulated to allow for projecting the image estimates during reconstruction onto this subspace.

Simulation of SPECT Myocardial Perfusion Imaging using numerical cardiac phantoms

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Abstract

Heart disease remains one of the leading causes of mortality worldwide. Myocardial perfusion imaging (MPI) using single photon emission computed tomography (SPECT) is widely employed to assess myocardial perfusion and cardiac function. To study image quality, accuracy, and imaging parameters, experimental phantom acquisitions are typically performed. In addition, SPECT MPI acquisitions can be simulated numerically using computational models that incorporate realistic anatomical structure, left ventricular (LV) wall motion and tissue properties. This study aims to simulate SPECT MPI acquisition using realistic cardiac phantom models and clinical imaging parameters. The cardiac phantoms are constructed from the MR-based segmentations of the myocardium wall across one cardiac cycle, combined with CT-based segmentations of the thorax and surrounding organs. Monte Carlo simulations using GATE software are performed using these phantoms in conjunction with a digital 3D Cadmium Zinc Telluride (CZT) SPECT scanner model, incorporating relevant clinical imaging parameters such as activity, number of projections, and imaging time. The projections are reconstructed using both the vendor-provided software and the inhouse OMEGA reconstruction framework. Preliminary results demonstrate the feasibility of realistic SPECT myocardial imaging simulations. This approach has potential applications in the optimization of imaging parameters, image denoising, and generation of high-quality training data for deep learning applications, among others.

Collaboration: This research is a collaborative effort between the Department of Technical Physics, University of Eastern Finland and Kuopio University Hospital. The research group has ongoing technical collaboration with Spectrum Dynamics Medical, which provides system-specific information about the SPECT scanner. The development of the numerical model for the digital 3D CZT SPECT system is conducted as a separate project led by A. Etxebeste and D. Sarrut from CREATIS, INSA-Lyon. The development of the OMEGA reconstruction algorithm for the digital SPECT is a separate project by N. Saarlemo et al.

Multi-Resolution Reconstruction for Extended Field-of-View in Cone-Beam CT

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Abstract

Cone-beam computed tomography (CBCT) is a three-dimensional medical imaging technique that uses a cone-shaped X-ray beam to acquire an image in a single rotation. CBCT often suffers from truncation artifacts, commonly referred to as out-of-FOV artifacts, when the object is larger than the field of view (FOV). These artifacts appear near the boundaries of the truncated region and occur because portions of the projection data are missing. To address this issue, we propose a separated multi-resolution extended FOV (MR-EFOV) reconstruction approach. The method extends the FOV in each direction where truncation occurs, ensuring that the entire object is sufficiently covered. To reduce computational cost, the extended regions are reconstructed using larger voxel sizes, while the main FOV is preserved at high resolution. In addition, projection extrapolation is incorporated to eliminate residual boundary artifacts. The reconstruction is performed within a least-squares optimization framework and solved using the primal–dual hybrid gradient (PDHG) algorithm. The proposed MR-EFOV method successfully removes out-of-FOV artifacts, suppresses bright boundary streaks, and accurately estimates missing information in the truncated regions, resulting in improved image quality and more reliable HU values.

Bayesian state estimation of dynamic greenhouse gas emissions in facility scale from multi-open-path measurements

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Abstract

Quantification of greenhouse gas (GHG) emissions at facility scale is essential for the implementation of effective transparent GHG reporting, part of emission mitigation strategies. Continuous monitoring systems based on multi-open-path laser spectroscopy enable long-term measurement of path-averaged GHG concentrations across industrial sites. However, translating these measurements into reliable source localization and emission rate estimates remains challenging, particularly under variable meteorological conditions and complex facility geometries.

This work utilizes a three-dimensional Bayesian State Estimation (BSE) framework for dynamic GHG emission reconstruction from continuous multi-open-path concentration measurements. The method combines a physics based convection-diffusion model, discretized using the finite element method, with BES, particularly fixed-lag Kalman smoothing, to estimate the evolving GHG concentration field and emission source distribution over a facility. Unlike steady-state inversion approaches, the proposed framework explicitly accounts for temporal variability, model uncertainty, and measurement noise within a probabilistic state-space formulation.

The overall aim of this PhD thesis work is to apply BSE-based GHG emission mapping experimentally in multiple test sites, such as biogas production facilities. At the first stage of this project, we study the sensitivity of the technique to various factors, such as wind variability, source dynamics and constraints applied computationally in BSE. For this purpose, the BSE is first tested with

numerical simulation studies and subsequently, with experimental data from a controlled methane release test.

Motion Correction in k-space for ZTE fMRI

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Abstract

Functional magnetic resonance imaging (fMRI) relies on the continuous acquisition of brain volumes to map neural activation. These measurements are highly susceptible to subject motion, such as respiratory fluctuations and muscle movements, which severely degrade data quality. Zero Echo Time (ZTE) fMRI presents an attractive, acoustically quiet, and geometrically distortion-free alternative to conventional fMRI sequences [1]. However, the inherently low tissue contrast in ZTE limits the efficacy of traditional volume-to-volume image registration. Furthermore, these conventional image-based methods inherently fail to resolve continuous intra-volume motion.

To address these limitations, we propose a novel motion correction framework applied directly in the frequency domain (k-space). Our method leverages the fundamental rotation and translation properties of the Fourier transform. For rotation correction, we use 3D cross-correlation between the moving and target k-space volume. We evaluated this method using numerical simulations, where we first artificially displaced baseline k-space volumes by known rotations. We then assessed the algorithm's accuracy by recovering these ground-truth parameters, demonstrating robust performance even when utilizing downsampled k-space data.

Because translation is a continuous process, we correct it by estimating temporally smoothed phase differences across volumes and subtracting them from original phases. We evaluate this directly on in-vivo fMRI data acquired from the brain and spinal cord of rats. To quantify the extent of motion and validate our correction, we track the shifts in the center of mass and compute volume-to-volume cross-correlation relative to the first volume. Furthermore, the overall efficacy of our framework will be benchmarked against both uncorrected data and conventional image registration, with the aim of demonstrating improvements in the resulting functional activation maps.

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Bridging Scales: Adapting RAPSODI for High-Precision Rat Brain MRI-Histology Co-Registration

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Abstract

Multimodal co-registration of magnetic resonance imaging (MRI) and histology is essential for linking macrostructural and microstructural information in brain research, but remains challenging due to large differences in image contrast, scale, and tissue deformation. In this work, we adapted the RAPSODI image registration framework [1], originally developed for prostate MRI–histopathology alignment, to the co-registration of rat brain histology and *ex vivo* MRI.

The dataset was acquired from a lateral fluid percussion traumatic brain injury model and included naïve, sham, and moderate traumatic brain injury subjects. *Ex vivo* T1-weighted MRI was acquired at 11.7 T with 100 µm isotropic resolution, and corresponding histological sections were imaged at 0.1369 µm × 0.1369 µm in-plane resolution with 30 µm section thickness.

Preprocessing included identification of missing sections, binary mask generation for both modalities, and histology downsampling to make slice-to-volume reconstruction computationally feasible. Affine registration was then performed within the RAPSODI pipeline to align reconstructed histology slices to the MRI volume. Registration accuracy was evaluated using manually selected anatomical landmark pairs distributed across multiple brain regions, including cortex, ventricles, corpus callosum, and gray–white matter boundaries.

Qualitative assessment showed good anatomical correspondence after alignment, and quantitative evaluation using Euclidean centroid distance demonstrated encouraging accuracy, with 73 % of landmark pairs falling within a sub-voxel to low multiple-voxel error range relative to MRI resolution. These findings indicate that adapting RAPSODI for rat brain MRI–histology co-registration is feasible for multimodal analysis in preclinical neuroimaging. Future work will extend the evaluation to more subjects, deformable registration methods, and additional histology stains and MRI contrasts.

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Forecasting Future Anatomies: Longitudinal Brain MRI-to-MRI Prediction

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Abstract

Predicting future brain state from a baseline magnetic resonance image (MRI) is a central challenge in neuroimaging, with important implications for studying neurodegenerative diseases such as Alzheimer's disease (AD). Most existing approaches predict future cognitive scores or clinical outcomes, such as conversion from mild cognitive impairment to dementia. Instead, we investigate longitudinal MRI image-to-image prediction that forecasts a participant's entire brain MRI several years into the future, intrinsically modeling complex, spatially distributed neurodegenerative patterns.

We implement and evaluate five deep learning architectures (UNet, U^2-Net, UNETR, Time-Embedding UNet, and ODE-UNet) on two longitudinal cohorts (ADNI and AIBL). Predicted follow-up MRIs are directly compared with actual follow-up scans using metrics that capture global similarity and local differences. The best performing models achieve high-fidelity predictions, with U^2-Net obtaining the highest structural similarity (SSIM=0.990, PSNR=31.32 dB) and ODE-UNet excelling at longitudinal change prediction (Δ-Pearson=0.253). All models generalize well to an independent external dataset, demonstrating robust cross-cohort performance.

Our results indicate that deep learning can reliably predict participant-specific brain MRI at the voxel level, offering new opportunities for individualized prognosis and understanding of brain aging trajectories in neurodegenerative disease.

Simulator for low-field MRI

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Abstract

Magnetic Resonance Imaging (MRI) is a widely used medical imaging technique in hospitals and in veterinary medicine. However, most clinical MRI machines require expensive superconducting magnets. Low-field MRI (LF-MRI) offers low-cost alternative but it suffers from worse image quality due to the reduced signal-to-noise ratio and main field inhomogeneities. The goal of this work is to develop a simulation program suitable for LF-MRI which we can use as an accurate forward model for the development of model-based image reconstruction methods.

The simulator is designed to be as physically accurate as possible accounting for both main field inhomogeneities and anisotropies in the spin dynamics. Gradient and RF coils are also modelled to account for all non-idealities. Other components of the simulator include the models of the MRI system, including electronics and signal processing. All components of the simulator have modular design, allowing for easy model switching. The simulator has been implemented in Matlab and it has parallelization support to speed up the simulation.

We tested the simulator with a digital brain phantom and using standard MRI sequences, such as TSE and EPI sequences. Results were mostly similar to what is expected to be seen in real MRI images but more sophisticated validation is still required. However, some sequences, such as UTE, had poor image quality due to the too sparse voxel discretization compared to the amplitude of spoiler and crusher gradients. Later, we will test compare the simulator results with an actual LF-MRI machine to validate the simulator.

Advanced Data Analysis of Non-proton Metabolic Magnetic Resonance Imaging

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Abstract

Medical imaging plays a key role in modern patient management. Metabolic imaging can reveal metabolic alterations underlying many diseases. Magnetic resonance-based metabolic imaging could make this approach more widely available. The aim of the PhD thesis project is to develop more efficient 5D (3*spatial, spectral and temporal) modeling and denoising methods to maximise the information content in a reasonable imaging time. The methods studied in the project will be tested not only with synthetic data but also with pre-clinical in vivo experiments. The developed methods can be also translated to clinical use.

Sub-study 1: Comparison of Existing Techniques (subspace, tensor, low-rank...) for Denoising of Deuterium Metabolic Imaging (DMI) and Hyperpolarised 13C-images on Simulated and Experimental Data.

Sub-study 2: Deep learning-based metabolic imaging analysis method for Deuterium Metabolic Imaging (DMI).

Sub-study 3: Enhancing Dynamic Nuclear Polarization (DNP) Imaging with Anatomical Priors and Deep Learning: Development and Validation Using In Vivo Data.

A Dirichlet-to-Neumann map-based model reduction framework for three-dimensional electrical impedance tomography

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Abstract

Electrical Impedance Tomography (EIT) is a non-invasive imaging technique with significant potential in industrial and medical applications; however, full three-dimensional models utilized in this study are often computationally expensive. As an example in a cylindrical pipeline geometry, the computational domain can be divided into multiple regions to improve efficiency. The outer sections of the domain are replaced by Dirichlet-to-Neumann (DtN) operators, resulting in a reduced model that preserves the boundary effects while concentrating the computations on the central region. The reduced model is then employed within an inverse problem framework to estimate the unknown conductivity parameters from boundary measurements.

The results show that the DtN map-based model provides a close approximation to the full solution while significantly reducing computational cost. This approach offers a promising pathway toward faster and more efficient three-dimensional EIT for applications in both medicine and industry, such as flow monitoring, process control, and medical imaging tasks including human chest imaging. This work is carried out in collaboration with Rocsole company.

End-to-end electrical impedance tomography: custom sub-second hardware and lightweight neural networks

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Abstract

Current clinical protocols for brain hemorrhages rely on initial MRI or CT scans to determine anomaly size and position. However, there is a critical lack of continuous, real-time monitoring to alert physicians if a patient's condition worsens. Electrical Impedance Tomography (EIT) offers a promising pathway toward a non-invasive, 24/7 wearable monitor. Small neural networks have shown the ability to process EIT measurements in real time with minimal errors while remaining feasible to run on energy-efficient embedded hardware. To train these networks, one must collect massive amounts of training data, thereby raising the need for a high-speed EIT data collection system.

To address this, an end-to-end EIT measurement system optimized for high-throughput data collection is being developed. Unlike traditional systems that rely on resource-heavy AC sampling, this custom hardware is largely frequency-agnostic. It utilizes analog temperature-compensated rectification to DC, significantly reducing ADC processing requirements. The current 8-electrode prototype cycles through all injection pairs, achieving a frame rate of 40 fps with a 14-bit equivalent resolution.

This sub-second speed enables the rapid collection of large datasets (e.g., 50k–100k measurements) to train NNs for the EIT inverse problem. Preliminary synthetic data tests show that lightweight architectures—ranging from MLPs to Transformers—can isolate critical variables like hemorrhage size while ignoring unimportant spatial variations.

Following feasibility studies on synthetic data, a fully functional first prototype of the measurement system has been built, and experimental validation on a 2D physical phantom is currently underway. While the primary target is a scalable 3D head phantom for medical monitoring, the underlying lightweight, multi-frequency (25–250 kHz) architecture is highly adaptable and can be scaled to high-channel counts (e.g., 64–256) for industrial applications, such as underground sensing or aerosol concentration research.

Patient-Specific Biomechanics in Late-Stage Knee Osteoarthritis: Gait, Load Distribution, and Pain

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Abstract

Late-stage knee osteoarthritis (KOA) is a whole-joint disease associated with structural and biomechanical changes that can alter internal tibiofemoral load distribution. In collaboration with Kuopio University Hospital, we characterized internal tibiofemoral load distribution in 8 individuals with late-stage KOA and 8 healthy controls using magnetic resonance image-based participant-specific musculoskeletal modeling [1] together with motion capture and gait analysis. The KOA group showed a more pronounced anterior-to-posterior redistribution of tibiofemoral loading impulse compared to healthy controls. Our findings suggest that late-stage KOA is associated with altered internal knee joint loading distribution. Such patient-specific loading measures may provide clinically relevant information for pre-operative total knee arthroplasty planning and post-operative rehabilitation.

[1] Esrafilian A et al., IEEE TBME, 2025.

Measurement Modalities: Towards Measuring Human Movement Outside the Laboratory

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Abstract

The modern health and wellness environment presents many unique challenges. The increase in the global elderly population is causing a rise in age-related illnesses and injuries which can decrease overall health and well-being. This research project utilizes musculoskeletal modeling and human motion measurement to understand and analyze a wide range of movements to improve overall health. Through these methods, tailor-made solutions are being developed for estimating and predicting human kinematics and kinetics for personalized medicine and customized prosthetic design and control.

Achieving these goals requires the development of methods for simple and accurate human motion measurement in any environment. For example, estimating ground reaction forces using only wearable sensor data enables dynamics analysis in a wide variety of new environments. Augmenting existing measurement technologies enables decreasing the overall amount of sensors required for motion measurement. These advances will improve the accessibility of biomechanics analysis for everyone by decreasing measurement expense, complexity, and location dependence.

Translating recent laboratory breakthroughs to real, outdoor environments allows us to simply and effectively develop methods to analyze and utilize sensor data in real life. In this project, we are building mathematical, machine learning, and physics-informed methods to create next generation health and biomechanics innovations. These methods will help restore and improve patients' well-being and locomotion abilities which improves their overall quality of life.

University of Jyväskylä

Abstracts

TRUDINGER'S PARABOLIC EQUATION

RIKU ANTTILA

Abstract

Trudinger's equation is a non-linear parabolic PDE that generalizes the classical heat equation. In this talk, I present some of our recent development related to this equation and discuss a few open problems related to our ongoing work.

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Discrete exterior calculus for phonon propagation in layered periodic structures

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Abstract

Discrete exterior calculus (DEC) is a modern method for discretizing differential equations, drawing inspiration from differential geometry. In this presentation, I briefly introduce the most important ideas of DEC and showcase an application in the simulation of elastic waves. Specifically, linear elastic waves are propagated in layered structures with piecewise constant isotropic material parameters and horizontal translational symmetry. The structure is illuminated with plane waves at varying frequencies, angles of incidence, and polarizations, measuring outgoing energy to obtain transmission coefficients for the corresponding phonon modes. Results can be applied e.g. to the estimation of heat conductivity in low-temperature nanostructures.

Tensor tomography in gas giant geometry

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Abstract

Gas giant geometry is a special type of Riemannian manifold with boundary that describes acoustic wave propagation in gas giant planets. In this talk I will present recent and ongoing progress on solving the tensor tomography problem in the setting of gas giant geometry.

In practice the data of interest for the tensor tomography problem is given by travel times of seismic waves that travel through a planet from boundary to boundary. The goal is then to recover a physical property, e.g. the sound speed within the planet, from the data. In a geometric setting the data corresponds to integrals of a symmetric tensor field over maximal geodesics. The tensor tomography problem asks if one can uniquely recover a symmetric tensor field from its integrals over maximal geodesics. In certain seismological models the sound speed within a planet is given by a Riemannian metric which connects the geometry with physics.

On gas giants the sound speed goes to zero up to the boundary according to previous equation of state type of models of gas giants. The Riemannian metric that physically corresponds to the propagation of acoustic waves has the inverse of this property: The Riemannian metric in gas giant geometry is singular up to the boundary of the manifold. The singularity in the metric is tame enough so that for example all maximal geodesics have finite length. All results regarding the tensor tomography problem on gas giants so far can be found in the two pre-prints Arxiv:2602.10322 and Arxiv:2403.05475.

Abstract title

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Quantitative discrete time hedging under initial insider information

The problem of quantitative discrete time hedging within the Black-Scholes model has been intensively studied for many years. In this presentation we study this problem under initial insider information. To include non-smooth terminal conditions, which induce a blow-up of trading strategies, we use adapted, i.e. not equidistant, deterministic time-nets. It is well known that the best possible rate of the L_2-hedging error in the setting without insider information is $n^{-1/2}$, when the number n of trading dates tends to infinity.

We investigate the question to what extent this convergence improves in the presence of insider information. Moreover, we compute the limit of the re-scaled L_2-hedging error. Because of the insider information, the underlying stochastic analysis in order to treat this models changes, for example Skorohod integration has to be used.

This is joint work with Hannah Geiss and Stefan Geiss

Bio-optical Inversion of Satellite Imagery of Inland Waters

Pritish Naik[1], Pauliina Salmi[2], Anna-Maria Raita-Hakola[1], Ilkka Pölönen[1]

[1] University of Jyväskylä, [2] Norwegian University of Science and Technology, Norway,

The inverse problem of resolving bio-optical variables from satellite data of inland waters is an ill-posed and active area of research[1] . The atmospherically corrected and processed reflectance spectra from ENMAP[2] and PRISMA[3] has low signal-to-noise ratio and additionally, the background components such as bottom surface reflectance in shallow water, anthropogenic effect, Colored Dissolved Organic Matter (CDOM) and suspended sediments make it difficult to account for their individual contributions. This project addresses the inverse problem in optically complex inland waters. Specifically, given reflectance spectra from hyperspectral satellites, can we infer the inherent optical properties and bio-optical parameters, and can we distinguish phytoplankton groups such as cyanobacteria from other phytoplankton?

The key questions that this project seeks to answer are as follows.

- How can we extract representative lake spectrum from hyperspectral satellite images from inland water bodies under varying cloud cover that contain sufficient features to resolve the bio-optical variables?
- How can the inversion model account for the different optical signals from different types of background spectra such as suspended solids and CDOM ?
- How can the inversion model account for natural variation introduced by different bottom types in shallow waters and the corresponding variations in their optical properties?

In 2024, we acquired 24 EnMAP[2] and 13 PRISMA[3] hyperspectral satellite images from Scottish and Finnish inland waters of anthropogenic significance and collected the ground truth measurements using multiparameter buoy sensors. This project includes building a data pipeline to filter and identify representative inland water spectra under varying cloud cover, identifying the appropriate priors for the inversion model and training the inversion model to resolve bio-optical variables from the satellite data.

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Computational Methods for Analyzing Layered Paintings in Hyperspectral Images

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Abstract

Hyperspectral (HS) imaging combines imaging with spectroscopy, capturing tens or hundreds of wavelength channels. Each pixel is a spectrum, often a complex mixture of the materials present in the scene. Because materials have unique spectral signatures, it is possible to extract the pure materials' spectra and their fractional proportions from the mixed spectra using methods such as spectral unmixing. Since many pigments behave transparently at certain wavelengths (especially within the infrared range), HS imaging can "see beneath" the surface layer of paint and reveal subsurface features, such as underdrawings or earlier compositions. However, traditional spectral unmixing algorithms do not take into account the presence of multiple paint layers. In this work, we develop a neural-network–based model that not only performs unmixing but also disentangles the hyperspectral image into two separate reconstructions: one of the visible paint layer and one of the hidden layer. This supports tasks such as art authentication and conservation, but is also applicable to other domains.

HORIZONTAL AND VERTICAL REGULARITY OF ELASTIC WAVE GEOMETRY

JOONAS ILMAVIRTA, PIETI KIRKKOPELTO AND ANTTI KYKKÄNEN

Abstract. The elastic properties of a material are encoded in a stiffness tensor field and the propagation of elastic waves is modeled by the elastic wave equation. We characterize analytic and algebraic properties a general anisotropic stiffness tensor field has to satisfy in order for Finsler-geometric methods to be applicable in studying inverse problems related to imaging with elastic waves.

Regularity for the geodesic X-ray transform in non-smooth geometry

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Abstract

In this talk we study the geodesic X-ray transform If, which encodes the integrals of f over all maximal geodesics, on Riemannian manifolds with low regularity metrics. When metric is smooth, it is known that normal operator $N = I^*I$, where I^* is a formal adjoint of I, is an elliptic pseudodifferential operator. Hence there exists an approximative inverse operator Q such that

$$QNf(x) = f(x) + Rf(x),$$

where R is smoothing operator. Now $If = 0$ implies $f = -Rf$ i.e functions f in the kernel of I are smoother than assumed a priori. In order to prove injectivity of the geodesic X-ray transform, one needs to prove injectivity only for smooth functions.

In non-smooth case we use similar approach. We decompose normal operator

$$N = P + R,$$

where P is pseudodifferential operator in suitable non-smooth calculus and R is smoothing operator. Moreover, we use symbol smoothing arguments to reduce matters to an elliptic operator in the smooth calculus.

University of Helsinki

Abstracts

Inverse Obstacle Problems

Ziyao Zhao[1]

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Abstract

In this talk, we will give an introduction to some inverse obstacle problems and present the results that have been obtained. In particular, we study an inverse problem of determining an obstacle with Signorini contact boundary condition from boundary measurements for the isotropic elasticity system. We prove that the obstacle can be uniquely determined by a single measurement of displacement and normal stress for the Signorini problem on an open subset of the boundary up to a natural obstruction. In addition to considering the Signorini problem, we develop techniques that can be used to study inverse problems for general differential inequalities and obstacle problems.

Wave Speed Recovery from Spectral Data in a (1+1)-Dimensional Wave Equation

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Abstract

An inverse boundary spectral problem for a (1+1)-dimensional wave equation with wave speed $c(x)$ is considered. We propose a two-step recovery procedure. In the first step, the Neumann-to-Dirichlet map Λ is reconstructed from spectral data of the impedance spectral problem—a Sturm–Liouville eigenvalue problem for the spatial operator $-c^2(x)\partial_x^2$ on $[0,1]$. Namely, we show that the result of Kurylev, Lassas, and Weder (2005) on the generic behaviour of eigenvalues under Robin impedance perturbations yields a spectral representation of Λ. In the second step, the reconstructed map Λ is used within the regularization strategy for the boundary control method presented by Korpela, Lassas, and Oksanen (2016). The strategy recovers $c(x)$ by solving a sequence of optimal control problems driven by the Blagoveščenskiĭ identities.

As an improvement, the regularization of the control problems employs a weighted combination of L^2 and H^1 penalty terms. Furthermore, we prove a uniform convergence result for the sequence of optimal controls, thereby allowing the regularization parameters to be tuned simultaneously.

The method is implemented numerically and validated on both smooth and piecewise smooth wave speed profiles. The impedance spectral problem is discretized using the finite element method, yielding a forward simulation of Λ. Subsequently, the travel time volumes obtained via the regularization strategy are differentiated in order to compute the wave speed function. To reduce sensitivity to noise in the differentiation step, total variation and H^1 regularization are employed.

Numerical experiments demonstrate that the recovery of the wave speed exhibits high accuracy and robustness.

Calderón's forward problem with singularities using darned processes

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Abstract

Calderón's inverse problem is the mathematical model for electrical impedance tomography (EIT), where the forward problem is given by the conductivity equation on a domain with Neumann boundary values. The conductivity equation is well-understood when the conductivity parameter is assumed to be uniformly elliptic and bounded. In this case, the solutions of the conductivity equation can be represented probabilistically by a Feynman-Kac formula for corresponding diffusion processes using the theory of Dirichlet forms.

We investigate a forward conductivity problem with singular inclusions in the domain, where the conductivity parameter is allowed to be unbounded. We connect the problem to a probabilistic interpretation using Markov processes with darning formulated in the language of Dirichlet forms. This is joint ongoing work with Petteri Piiroinen in the Department of Mathematics and Statistics in University of Helsinki.

Dual-Grid Parameter Selection for Tomographic Inverse Problems

Chuyang Wu

April 15, 2026

Abstract

We study ill-posed inverse problems in imaging and tomography, where stable reconstruction requires balancing data fidelity with prior regularization. In variational formulations, this balance is governed by a regularization parameter $\alpha > 0$, whose optimal choice remains an open challenge. We introduce a dual-grid parameter selection method that determines α by enforcing consistency between reconstructions computed from two slightly perturbed forward models. The method selects the smallest α for which the structural similarity $\mathrm{SSIM}(f_\alpha, g_\alpha)$ stabilizes, yielding a fully data-driven criterion that does not require noise estimates or ground truth. Experiments in image deblurring demonstrate that the approach works across different regularizers, including Tikhonov and total variation, and performs robustly on both simulated and real data. The results highlight regularization as a mechanism for stabilizing inference under uncertainty.

Improving reconstruction quality of Passive Gamma Emission Tomography

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Abstract

Passive Gamma Emission Tomography (PGET) is an imaging method for gamma radiation sources. In the current implementation of PGET for spent nuclear fuel assemblies, the method of image reconstruction features a regularized reconstruction with optimization methods, incorporating knowledge about the fuel assembly's geometry and physical constraints of radiation activity and attenuation. To extend the method to a wider range of spent fuel assemblies and to reduce measurement time, improvements on quality of reconstructed images are required. The research includes several different methods to improve the image's quality and the usefulness in fuel rod classification. On the preprocessing side, improvements can be made via incorporating simulated detector sensitivity corrections. Further for the regularization, a Joint Total Variation approach used to combine gamma emission from Cs-137 and from Eu-154, benefiting from characteristics of both gamma ray energies, is tested for a further improvement in images reconstructed from VVER-440 fuel.

Artificial Intelligence Gamma Ray Imaging Detectors

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Abstract

This study presents the development of an experimental and computational framework for gamma-ray imaging using semiconductor detectors enhanced by artificial intelligence techniques. The growing demand for high-performance radiation detectors in nuclear security, medical imaging, and astrophysics has driven the adoption of semiconductor-based systems, particularly Cadmium Zinc Telluride (CZT), due to its high atomic number, wide bandgap, and ability to operate at room temperature with excellent energy resolution. Compared to conventional detectors such as high-purity germanium (HPGe), CZT offers improved portability and efficiency, making it well-suited for modern gamma-ray detection applications.

To generate training and evaluation data, a narrow gamma-ray beam was systematically scanned across the surface of a GDS-100 CZT detector with position-sensitive readout. The beam was produced using a collimation system consisting of a 1 mm diameter, 50 mm long aperture drilled into a $10 \times 10 \times 5$ cm^3 lead block, resulting in a geometric efficiency of approximately 2.5×10^{-5}. Due to this low efficiency, radioactive sources with activities of several MBq were required to achieve sufficient counting statistics. A full-area grid scan over a 30 mm × 30 mm region with 0.5 mm step size was performed using a Cs-137 source with activity 3.91 MBq, yielding a total of 3721 measurement files.

The acquired dataset was used to train a convolutional neural network based on a compact residual network (ResNet) architecture with an upsampling component. The model learns to reconstruct higher-resolution spatial information from low-resolution detector data, mapping an 11 × 11 input representation to a 22 × 22 output. To further enhance spatial resolution, a multi-stage upscaling approach was employed (11 × 11 → 22 × 22 → 66 × 66).

The integration of machine learning techniques with CZT detector data enables improved spatial reconstruction and has the potential to enhance gamma-ray imaging beyond traditional methods. This approach demonstrates how data-driven models can complement advances in detector physics, offering a pathway toward more accurate, efficient, and scalable radiation imaging systems.

Detecting Emissions from Space - A New Unsupervised Method for Finding Emission Hotspots from Satellite Data

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Abstract

A crucial part of tackling the problem of climate change is the monitoring of human-caused greenhouse gas emissions. To reach a global scale, greenhouse gas measuring satellites appear to be the best solution. Emissions from point sources, such as power plants, can produce distinct plumes that are visible from satellite data. Automated plume detection is key to identify and monitor the largest sources of human-caused greenhouse gas emissions.

We present a new unsupervised clustering-based algorithm, SCEA (**S**patial **C**lustering of **E**levated-valued **A**reas), for detecting and outlining hotspots in spatial datasets with continuous attributes. The method extends the principles of density-based clustering by introducing a value-dependent radius function that adapts locally to the density of the data and the magnitude of the attributes. Unlike many conventional hotspot detection approaches, SCEA does not require the data to be on a regular grid or to have well-defined neighbors, and it remains robust in the presence of missing values, all of which are common characteristics of satellite remote sensing data.

We evaluate SCEA's performance with various synthetic datasets, exploring the two main parameters of the algorithm and their relationship to different noise levels. Furthermore, we demonstrate its potential to capture meaningful information with Sentinel-5P TROPOMI satellite observations of tropospheric NO_2. The generality of the algorithm and its lack of dependence on training data make SCEA a promising tool for automatic hotspot detection in large-scale remote sensing and other spatial datasets with continuous attributes.

Methodological Advances in Satellite-Based Point-Source Greenhouse Gas Emission Estimation

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Abstract

With ongoing climate change and rising global temperatures, quantifying anthropogenic greenhouse gas (GHG) emissions has become increasingly important. Recent satellite missions, such as TROPOMI, along with the forthcoming CO2M constellation, provide high-resolution observations capable of capturing atmospheric signatures of emissions from individual point sources, including large power plants and industrial facilities, while offering global coverage.

Converting these observations into quantitative emission estimates is a complex inverse problem. Typical processing steps include automated plume detection, estimation of the atmospheric background, characterization of wind speed and direction, and inversion of column-average GHG enhancements into source-specific emission rates. Each step introduces uncertainties that must be carefully managed to ensure reliable results.

In this talk, we present two methodological developments relevant to this retrieval chain: a scattering graph method for 3D radiative transfer by Mikkonen, A. et al. [1], and a Gaussian process (GP) approach to the divergence method for emission quantification and uncertainty estimation by Anssi Koskinen, Janne Nurmela, Teemu Härkönen, & Johanna Tamminen.

References

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Rayleigh wave focal spot imaging of the Kylylahti mine area

Valtteri Hopiavuori[1], Christina Tsarsitalidou[1], Kauri Kolehmainen[1], Gregor Hillers[1], Bruno Giammarinaro[2], Pierre Boué[3], Laurent Stehly[3], Yang Lyu[1], Michal Malinowski[4], Suvi Heinonen[1], Kari Komminaho[1]

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Abstract

The importance of non-destructive imaging methods in mineral exploration has grown in recent years as the demand for critical raw materials has increased. Methods that utilize seismic ambient noise to estimate the Green's function of the medium offer an efficient and economical approach for non-destructively imaging the subsurface, making them well suited for sustainable mineral exploration. Among these, the Rayleigh wave focal spot imaging method is particularly promising due to its potential depth resolution and inversion-free approach. It is based on the analysis of focal spots, a high-amplitude features formed from the spatial distribution of zero-lag amplitudes of Green's functions obtained by cross-correlating a reference station with all other stations in the seismic array. From their shapes, local Rayleigh wave velocities can be determined, serving as proxies for subsurface properties. We investigate, for the first time, the Rayleigh wave focal spot imaging method in near surface structural mapping in the context of mineral exploration. Our study area is the Kylylahti mining area in eastern Finland, which has an extensive research history and provides a valuable benchmark for validating our results. We compute Rayleigh wave velocity distributions from the focal spots across the array, creating velocity maps that characterize subsurface structures. From these velocity distributions, we perform a dispersion curve clustering analysis to characterize spatially coherent regions. Our results demonstrate that the focal spot method provides a robust imaging tool for shallow subsurface characterization, even under non-ideal wavefield conditions. From the velocity maps and dispersion curve clustering analysis, we identify a low-velocity zone corresponding to the Kylylahti formation, surrounded by higher-velocity areas. The existing geological model validates our findings, showing that the velocity distributions are consistent with the known geology of the study area.

Deblurring seismic focal spot images

Kauri Kolehmainen[1], Gregor Hillers[1], Hjørdis Schlüter[2], Bruno Giammarinaro[3], Markus Juvonen[2], Alexander Meaney[2], Samuli Siltanen[2]

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Abstract

Conventional seismic tomography methods invert quantities such as wave traveltime measured between seismic instruments. The focal spot imaging technique provides an inversion-free method for imaging the subsurface using surface wave spatial autocorrelation fields computed from seismic ambient noise cross-correlations. Seismic wave velocities are estimated from focal spot data in the one-wavelength distance range through regression using a Bessel function model. Performing focal spot imaging on dense seismic arrays provides high-resolution images of seismic wave velocity estimates comparable to direct light intensity measurements in optical images. Focal spot images are inherently blurred because distant data are used to constrain local velocities in the regression step. In optical images, blurring is undone by deconvolving the blurred image with the corresponding point spread function that describes the blur caused by the imaging device. The direct focal spot imaging approach provides a unique opportunity to perform similar deblurring on seismic velocity images. We estimate the focal spot imaging point spread function by imaging a point-like high-velocity inclusion in two-dimensional acoustic simulations. We apply the estimated point spread functions to reconstruct improved focal spot images using deconvolution solved with Tikhonov and mollified total variation regularization. The image reconstructions show significant improvements compared to blurred focal spot images, as confirmed both visually and quantitatively.

Perception–based inversion methods

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Abstract

Despite the important role of visual evaluation in the field of imaging, the relationship between perception and image contents or quality is generally disregarded in research. We propose a new avenue of research to develop methods of determining image quality in such a way that it is the best fit for the end user's needs. Such a project requires a combination of ideas and methods used in mathematical and psychological research. Despite the complexity of merging concepts from these two very different fields, this approach is necessary in understanding the effect of the human element in producing and analyzing visual data.

We begin the research into this complicated issue by studying a simpler situation from which we can then expand to a wider area. We select a noisy base image, and construct a parameter grid corresponding to total variation denoised solutions of different strengths. We perform psychometric scaling on these parameters, resulting in a set of images that displays all the different levels of quality (noisiness) detectable to the human eye, but that does not contain any redundant data. Simultaneously, the set is optimized for further use in the second part of the research campaign.

In the second part, we conduct a comparison test on the previously constructed set to find out which denoising parameter(s) result in the best perceived image quality. A Metropolis-Hastings algorithm is used to create a model of the pairwise data obtained from the test.

Reconstructing the metric from relative distance comparisons

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Abstract

Humans have a hard time estimating the similarity of pictures in terms of raw numbers, but they can fairly consitently pick out the two most similar pictures out of a set of three. What can we infer from data consisting of such relative comparisons?

In this talk, I will present an overview of a theoretical method for constructing a metric that is consistent with the given relative comparison data.

Expanding our understanding of street-level greenness: evaluation of mapping perceived greenery.

Jussi Torkko[1]
Tuuli Toivonen[1,2,3], Elias Willberg[1,2,3]

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Abstract

The presence of greenery, the natural green vegetation, is of great importance to our wellbeing, providing various physical, psychological and social benefits. While it has been traditionally observed with a top-down approach, through the lenses of aerial vehicles, there is an increased interest in mapping the greenery that people perceive on the street level. By incorporating novel visual indices into planning procedures and metrics, cities and stakeholders are also keen to understand how people experience their daily commutes and activities. The recent approaches commonly use computer vision and massive street view imagery datasets to quantify what is visible on street level, but also more experimental techniques such as point cloud analysis, viewshed mapping and AI are being tested. However, most of the current methods still simplify the whole experience of perceiving greenery into limited and largely unexplored indices, where the broader dimensions and dynamism of greenery are forgotten or blatantly ignored.

My work challenges the surprisingly stagnant state of the methodology behind our street-level greenery calculations. I empirically show how methodological choices made on the various mapping methods can have a wide range of impacts on the results gained. I also try to understand how the dynamic, preferential, and temporal nature of greenery should be quantified, to show that the perception of greenery is more complex and nuanced than a single number might indicate. To do this, I use a mix of computer vision techniques, big data, surveys, AI, virtual reality, modelling and rigid empirical testing. With my results, I hope to improve our current methodologies on street-level greenery, so that its benefits can better be brought to people's daily lives.

Geo-computational modeling for understanding urban cycling behavior

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Abstract

This doctoral dissertation aims to understand the dynamics (i.e., demographic, spatial, and temporal disparities) of urban cycling behavior using both empirical and simulation-based approaches. Specifically, it investigates the mechanism underlying cycling demands and route choices and, therefore, generates synthetic data of cycling flows in the city. At the demographic level, it explores the differences in cycling behavior between gender groups (i.e., men and women) and among age groups (i.e., children, teenagers, young adults, middle-aged adults, and seniors). At the spatial level, it analyzes where people cycle and how their perceptions of built environments along the route vary across various European cities (i.e., Copenhagen, London, Helsinki, Munich, and Las Palmas). At the temporal level, it evaluates how cycling behavior differs on a hourly, daily, and seasonal basis. The findings of this doctoral dissertation can provide relevant stakeholders (e.g., planners and policy makers) with significant implications to establish a more sustainable, inclusive, and equitable urban environment.

Complementing respiratory infection hospitalization data through Bayesian modelling

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Abstract

Respiratory infections (such as influenza, COVID-19 and RSV) cause a significant burden on the healthcare system every year. Around 30 000 people are hospitalized in Finland yearly due to respiratory infections. Information about the numbers and causes of hospitalizations is stored in a register maintained by the Finnish Institute for Health and Welfare.

Since respiratory infections are symptomatically very similar, it is usually impossible to diagnose the infectious agent without microbiological testing. Thus, a notable portion of the hospitalization data lacks specific diagnoses. Accurate diagnosis information would be important for planning interventions such as vaccinations as well as monitoring their effectiveness.

To address this problem of underreporting, we develop a method to classify the undiagnosed hospitalization data between known pathogens of interest and background infections. The proposed method uses Bayesian inference and Markov chain Monte Carlo sampling to estimate the unobserved numbers of hospitalizations caused by the target pathogens. The performance of the method is assessed by applying it to a variety of simulated data sets.

Aalto University

Abstracts

Total variation regularization with reduced basis in electrical impedance tomography

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Abstract

Electrical impedance tomography (EIT) is a noninvasive imaging technique in which information about the internal conductivity of a body is reconstructed based on voltage measurements on electrodes placed on its surface. Due to the ill-posedness of the problem, dense meshes are typically needed to obtain a sufficiently accurate finite element approximation of the forward model. This can lead to impractically long computation times, which motivates the consideration of model-reduction techniques.

In this talk, we consider using reduced basis methods combined with total variation regularization in EIT. We explain how a reduced basis can be built and applied to the forward model. We then present the Bayesian framework used to derive the reconstruction algorithm. Finally, we show results of numerical experiments demonstrating that using a reduced basis can speed up the algorithm without significantly compromising the reconstruction quality or ability of the algorithm to reconstruct jumps in the conductivity.

Computing Measurement Sensitivities in Time- and Frequency-Domain Optical Tomography

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Abstract

Optical tomography (OT) comprises non-invasive imaging techniques that use visible or near-infrared light to recover three-dimensional maps of absorption and scattering coefficients, or their changes relative to a baseline, inside highly scattering media such as biological tissue. Applications include, for example, functional brain imaging and early diagnosis of breast cancer.

In OT, the forward problem of light transport is commonly modelled using the radiative transfer equation (RTE), for which the Monte Carlo (MC) method is widely regarded as the gold-standard numerical solver due to its flexibility in handling complex optical systems. The associated inverse problem of recovering optical parameters from boundary measurements is non-linear and severely ill-posed. Reconstruction techniques typically rely on linearising the relationship between the measurements and changes in the optical parameters. The linearisation is obtained via the Fréchet derivative of the forward model, also referred to as the sensitivity profile, and its finite-dimensional representation as the Jacobian matrix.

In this talk, I present recent work on computing absorption and scattering sensitivities for time- and frequency-domain measurements using the MC method. I compare the resulting sensitivity profiles with those obtained from the diffusion approximation of the RTE using the finite element method.

A bilinear inverse problem with forward operator inaccuracy applied to diffuse optical tomography

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Abstract

Linear inverse problems are common in real-world applications from industry to medical imaging, but handling inaccuracies in the associated forward operators is a relatively unstudied problem. In this work, we assume that we have a set of candidate forward operator matrices and suggest principal component analysis for modeling their variation from the mean. We combine the original linear problem with the included forward operator inaccuracy into a bilinear tensor inverse problem and present two optimization algorithms and Gibbs sampling for approximately solving the problem. As a real-world test case, we apply the algorithms to account for the inaccuracy that is present in the sensitivity profiles or Jacobian matrices in diffuse optical tomography when an atlas-based model of the head anatomy is used instead of the subject's own anatomical model. We report visual and numerical improvements in the spatial localization and contrast-to-noise-ratio in reconstructions of simulated brain activity.

Source localization of somatosensory evoked potentials recorded using stereotactic electroencephalography

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Abstract

Stereotactic electroencephalography (SEEG) is a modality where brain activity is measured with surgically implanted depth electrodes. In addition to being a valuable clinical tool for the presurgical evaluation of focal refractory epilepsy, SEEG provides neuroscientists with a unique opportunity to study neural electrophysiology at a much finer spatial resolution than is possible with conventional noninvasive methods. However, SEEG is limited by its sparse cortical coverage and the sampling bias associated with conventional interpretation based on bipolar derivations. Furthermore, heterogeneous implantation schemes and the lack of robust methods for integrating data between patients restrict its broader application in neuroscience research. Biophysically informed source estimation could address these challenges by enabling localization of neuronal activity beyond the implanted sites and providing a direct anatomical representation of SEEG data.

As an initial step in evaluating SEEG source estimation techniques, we analyzed median-nerve somatosensory evoked potentials (SEPs) recorded from 15 epilepsy patients at Helsinki University Hospital (HUS). Using structural imaging data, we constructed individualized volume-conduction models with realistic geometry and assessed dipole-source-localization performance using both numerical simulations and the recorded SEPs. Our results indicate that source estimation, even when using relatively simple forward models, can localize focal neuronal sources with sub-centimeter accuracy. This holds even in cases where conventional interpretation is uninformative, such as when the signal originates further from the recording electrodes.

Advancing Neuroscience for Clinical Need and Impact

Physiological Markers and Neuroimaging for Translational Applications

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Abstract

This doctoral thesis focuses on improving the clinical usability of neuroscience methods by (i) advancing objective, feasible, and reproducible approaches for measuring human participants' cognitive and affective state via pupillometry, and (ii) for improving neuroimaging accuracy in functional near-infrared spectroscopy/diffuse optical tomography (fNIRS/DOT). The common aim is to develop methods that are both scientifically robust and practical for translational use.

A central theme in the first part of the thesis is the identification of pupillometry-based markers that can support clinical assessment and intervention development. Our preliminary results show that pupillometry can be used as a sensitive and accessible measure of task-related cognitive effort during magnetoencephalography recordings, supporting its potential as an objective marker of cognitive load. In Alcohol Use Disorder (AUD), we used pupillary responses to evaluate whether C-tactile (CT)-optimal tactile stimulation can modulate alcohol cue reactivity. The findings suggest reduced cue-evoked arousal in AUD patients after CT stimulation and support further development of non-pharmacological intervention strategies for AUD.

In the second part of the thesis, we address methodological limitations in fNIRS/DOT and develop approaches to improve anatomical localization, reproducibility, and ease of use. Together, these studies aim to strengthen the methodological foundations of clinically oriented neuroscience and support the development of tools that are more accurate, practical, and impactful in real-world settings.

Non-invasive functional brain network characterization in ANT DBS for epilepsy

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Abstract

Deep brain stimulation (DBS) of the anterior nucleus of the thalamus (ANT) is a promising treatment option for drug-resistant epilepsy (DRE) patients ineligible for resective surgery. ANT DBS has been shown to reduce seizure frequency (SF) by 50-70% after five stimulation years. However, the clinical outcome of ANT DBS is highly variable between individuals and depends on DBS programming parameters such as the location of the active contact, but we continue to lack markers to guide individualized DBS programming.

The Percept™ PC (Medtronic Inc.) is the first commercially available neurostimulator able to both stimulate and record local field potentials (LFPs) from the chronically implanted DBS electrodes. LFP recordings combined with non-invasive functional brain imaging techniques such as magnetoencephalography (MEG) could provide information about the cortical brain networks modulated by ANT DBS, which could be useful for elucidating mechanisms underlying DBS effects and optimizing stimulation settings.

This study measured simultaneous resting-state MEG and thalamic LFP signals in DRE patients to characterize the spatial and spectral properties of the coherence between the ANT and various cortical regions. The thalamocortical coherence peaked in the theta (4-8 Hz) frequency band, and depended on the subjects' vigilance state. Different ANT depths connected to distinct but still highly overlapping cortical networks that mainly included ipsilateral prefrontal and temporal regions, which matches the anatomical connections of the ANT. Further research is needed to understand the relationship between thalamocortical coherence, anatomical lead location and clinical outcomes.

Sensing and imaging of ultrasonically actuated surgical devices

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Abstract

Ultrasonically actuated surgical devices are medical devices consisting of an invasive surgical instrument *e.g.*, a needle or a blade, connected to an ultrasonic actuator. This study is focused on flexurally oscillating medical needles. These devices employ a longitudinally oscillating Langevin transducer, which is connected to the medical needle *via* a waveguide. This translation of the oscillations also facilitates the transition of the oscillatory motion to a flexural mode. Currently, the flexurally oscillating medical needles are considered for biopsy and histotripsy treatments.

The sensing and imaging of these instruments in operation, along their effects, is crucial for efficiency and safety. The focus of the study is in the detection, quantification, and tracking of the tissue effects of the actuated needles. Exemplary targets of analysis are the accurate position of the instrument *in vivo* and the location and magnitude of a histotripsy lesion generated by the instrument. Considering this aim, novel US imaging radio frequency data analysis methods are developed and experimentally validated, supported by conventional methodologies. Experimentation in *ex vivo* tissue models allows for histological analysis of the ground truth.

Current efforts focus on temporally evolving horizontally normalized Shannon entropy imaging of radio frequency US signals for lesion quantification and US echo frequency cross correlation methods for instrument tracking.

Computation of cardiac timing intervals using continuous-wave resonant ultrasound sensing

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Abstract

Non-invasive assessment of cardiac electromechanical timing is useful for characterizing systolic function, monitoring therapy and detecting hemodynamic decompensation. Continuous-wave resonant ultrasound sensing by driving a piezoelectric element at mechanical resonance and tracking changes in its complex electrical admittance can be used for tissue motion and loading without time-of-flight imaging. We investigated whether this architecture can be used at the chest wall to derive cardiac timing intervals from a single, low-frequency transducer.

A custom device integrating a 40 kHz piezo-MEMS resonator, a simple EKG setup and a microphone was placed over the aortic auscultation area of a healthy volunteer at rest. Simultaneous in-phase and quadrature signals from the resonator, ECG and PCG were recorded. From the complex resonant response, a propagation-velocity-like waveform at the sensor–tissue interface was computed, a high-contrast derivative signal and a displacement-like waveform were obtained by numerical differentiation and integration, respectively. Beat-by-beat fiducial points were identified on the ECG, PCG envelope and propagation-velocity derivative.

From these landmarks, standard systolic time intervals, including electromechanical activation time, pre-ejection period, isovolumetric contraction time and left-ventricular ejection time, were calculated. The propagation-velocity derivative exhibited a stable, pulsatile morphology that was tightly phase-locked to ECG and PCG, with its dominant complex consistently initiating during ventricular systole, just after the first heart sound and coincident with the putative aortic valve opening. Peak times derived from the resonant signal closely matched ECG-based timings on a beat-by-beat basis, and the relationships among the derived intervals were physiologically coherent. These findings suggest that continuous-wave resonant ultrasound can provide chest-wall propagation-velocity and displacement waveforms from which clinically relevant cardiac timing intervals can be obtained using a single, compact sensor.

Data Requirements for Stable and Reproducible EEG Features in Mild Cognitive Impairment

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Abstract

Mild Cognitive Impairment (MCI) refers to a stage between normal aging and clinical dementia, of which Alzheimer Disease (AD) is the most common endpoint. Symptoms of AD appear years after the first pathological changes in the nervous system begin: early neurophysiologicalbiomarkers could enable diagnosis already at the MCI stage. With electroencephalography (EEG), the brain's electrical activity can be measured noninvasively with high temporal resolution. EEG reflects structural and functional changes in the brain and thus has considerable potential for clinical biomarkers. However, the reproducibility of EEG features suggested as AD biomarkers has not been established in MCI participants, mainly due to lack of data from large homogeneous studies with well-defined subjects. Here data from 100 participants in the recent AI-Mind study (Haraldsen et al., 2024) were analyzed. Resting-state EEG was recorded at the BioMag Laboratory in Helsinki using a 128-channel EEG system. We evaluated the within-session stability of power spectral features across varying data durations, preprocessing approaches, vigilance levels, and eyes open versus eyes closed conditions. Our preliminary results indicate minimal differences between manual and automated preprocessing, suggesting that for clinical diagnostic purposes automatized EEG preprocessing provides good data quality for biomarker identification in MCI subjects. We also propose minimum EEG data requirements and preprocessing standards to achieve stable and reproducible features in MCI populations, enhancing early-stage biomarker research for Alzheimer's disease.

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Origami modeling and folding simulation via energy minimization

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Abstract

Origami modeling and simulation of expected folding behavior is a problem that has been approached in many ways ranging for example from kinematics to finite element method and multiphysics simulations in the multidisciplinary field of origami science. Inspired by the online tool Origami Simulator, we interpret the problem of solving a folded configuration of an origami piece from its crease pattern as an energy minimization problem and implement our own solver for it on MATLAB. This is a difficult optimization problem since the pattern undergoes large nonlinear deformations and has a large number of constraints. In our implementation, we model the origami as a bar and hinge model without any material parameters, leading to an ideal material mathematical abstraction of the pattern. As a test subject, we use the Miura-ori pattern which is known for its many applications and predictable single degree of freedom movement. With the pattern, we study the convergence of the simulation under different criteria.

Accelerating Bio-Based Foam Development via Bayesian Optimization

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Abstract

The increasing demand for sustainable materials has positioned bio-based foams as promising alternatives to petroleum-derived counterparts. However, limited functional performance and the resource-intensive nature of experimental optimization remain significant barriers to industrial adoption. Since diverse applications require specific mechanical or chemical profiles, a universal formulation is impractical. This study addresses these challenges by developing a **Bayesian multi-objective optimization framework** to identify tailored compositions for cellulosic-based foams with minimal experimental overhead.

The framework utilizes **Gaussian Process** surrogate models and an **Expected Hypervolume Improvement (EHVI)** acquisition function to guide an active learning loop. Starting with a sparse initial dataset of only 17 samples, the model evaluated three key additives—lignin, graphite, and precipitated calcium carbonate—to optimize for mechanical stability and hydrophobicity.

Key results from this study include:

- **Mechanical Reinforcement:** The optimized formulation achieved a 90–157% increase in Young's modulus, compared to the initial samples.
- **Enhanced Hydrophobicity:** The foam maintained stable hydrophobic behavior for over 20 minutes, a critical factor for functional packaging stability.
- **Efficiency:** The iterative active learning scheme significantly reduced the required number of experiments compared to traditional trial-and-error methods.

By integrating experimental data with an intelligent planning strategy, this approach demonstrates a systematic, data-efficient pathway for material R&D. The results highlight the potential for Bayesian optimization to accelerate the development of high-performance, sustainable materials in alignment with evolving global material regulations.

Data-Driven Prediction of Thin-Film Metallic Glass Forming Ability via Bayesian Classification and Experimental Verification in the Cu-Zr-Al System

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Abstract

Metallic glasses (MGs) are a class of non-crystalline alloys characterized by the absence of long-range order while often exhibiting pronounced short-range ordering. This atomic arrangement yields materials with unique combination of physical properties.

The formation of an amorphous structure in metal alloys is a non-equilibrium process, in which the liquid is rapidly cooled to bypass crystallization. A key metric in this context is the glass forming ability (GFA), which describes the ease with which a metallic alloy can form a glass.

At present, there is no universal rule to design MGs, and conventional experimental screening is costly. Identifying alloy compositions suitable for metallic glass formation from the vast and multi-dimensional space of elemental combinations remains a significant challenge.

In the present study, we develop - using literature data - a Bayesian machine learning model based on Gaussian processes for predicting the GFA of metal-alloy compositions, the model achieves a prediction accuracy of 87%. The prediction is experimentally verified in Cu-Zr-Al thin film alloy by magnetron sputtering, the results confirm the compositional dependence of GFA and demonstrate the effectiveness of our combined computational–experimental approach for guiding thin-film metallic glasses and amorphous alloy discovery.

LUT University

Abstracts

Relating geometric inverse problems for different families of generalized geodesics

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Abstract

Geometric inverse problems are a subset of inverse problems in which the goal is to recover geometric information through indirect measurements of a mathematical object. A classical example of an inverse problem is X-ray computed tomography (CT), where attenuation data of X-rays is measured passing through an object and the goal is to reconstruct an image of the inside of the object. This problem can be generalized to the geometric setting by replacing the straight lines of the X-ray with geodesics on a Riemannian manifold (M, g).

The motivation for this project comes from studying the magnetic potential ($\mathcal{MP}$) system given by a Lorentzian force and a potential. One can show that a geodesic of the $\mathcal{MP}$ system can be understood as reparameterization of a geodesic for a different simpler system, where the metric is obtained from g by a conformal change. Using this fact, one can solve a geometric inverse problem for the $\mathcal{MP}$ system using existing results of the simpler system.

In this talk, we discuss building a framework under which we can move from one dynamical system to another and understand how geometric inverse problems of one system are related to the other.

Bayesian Inverse Eigenvalue Problems via Surrogate Modeling with Sparse Stochastic Collocation

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Abstract

Inverse problems are a class of optimization problems where the objective is to recover unmeasurable quantities, for example, of a physical phenomenon, through accessible information related to the quantity of interest. Mathematically, this can be expressed as a function $G : x \mapsto y$, where x is the input and y is a measurable output, leading to the objective of recovering x given a noisy measurement of the output y.

The Bayesian framework is one of the standard approaches to solving inverse problems and estimating uncertainty, but the methods require substantial computational effort to produce the desired quantities. Our research aims to demonstrate the use of an approximative (surrogate) model $\tilde{G} \approx G$ in the setting of Bayesian inverse eigenvalue problems, to greatly reduce the computational cost while maintaining accuracy.

Our method of choice is to utilize stochastic finite elements to construct a polynomial approximation of the forward map via sparse stochastic collocation. Prior research on the topic has established the approximation capabilities of the approach, providing a solid foundation for its application to inverse problems.

We aim to demonstrate the capabilities of the methodology, both in theory and in practice, using the 1D inverse Sturm–Liouville problem as an example. The result of our research provides an overview for application in Bayesian inverse eigenvalue problems, with spatially continuous underlying parameters.

Scalable Bayesian Deep Learning via Amortized Inference and Partial Stochasticity

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Abstract

Bayesian deep learning aims to provide neural networks with uncertainty quantification, moving from estimates toward full posterior distributions over model parameters. Despite considerable progress, challenges of scalability, computational efficiency, and expressive posterior approximation still remains. In this work, we present two approaches to this problem from different angles, each targeting a distinct bottleneck in the deployment of Bayesian methods for deep learning.

In the first part, we employ BayesFlow, a simulation-based inference framework based on normalizing flows, to perform amortized posterior estimation over the parameters of simulator models. By training a conditional normalizing flow on simulated parameter-data pairs, the framework learns a reusable posterior approximator that does not require additional simulation at inference time. This amortization property makes the approach particularly beneficial to settings where the same model structure is repeatedly fitted to new observations, such as in computational neuroscience or epidemiological modelling.

In the second part, we investigate partially stochastic neural networks, in which a carefully chosen subset of network parameters are treated as random variables while the remainder are kept deterministic. This selective stochasticity offers a practical middle ground between computationally expensive fully Bayesian networks and overconfident deterministic models, preserving meaningful uncertainty estimates at a significantly reduced computational cost.

Hyperparameter Estimation in Gaussian Process Modelling

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Abstract

As a data-driven approach, the Gaussian Process (GP) modelling is a powerful Bayesian framework for nonlinear regression that requires minimal prior functional knowledge. The model's flexibility and predictive power are primarily encoded in its covariance function (kernel), which defines the probability distribution over sample functions. The geometric properties of these functions—such as mean-square differentiability (smoothness), periodicity, and characteristic length-scales—are governed by a set of latent parameters known as hyperparameters. Consequently, hyperparameter estimation is the fundamental process that aligns the GP with the observed data. By aligning the kernel with underlying data patterns, accurate estimation ensures reliable uncertainty quantification in GP modeling for risk-aware decision-making.

Deep Learning for Air Quality Forecasting

$PM_{2.5}$ are fine particles suspended in the air, emitted by traffic, industry, and wildfires. Because of their tiny size, they penetrate deep into the lungs and bloodstream, and long-term exposure is strongly linked to cardiovascular and respiratory disease. Forecasting their concentration one to several days ahead helps public health authorities issue warnings and supports policy decisions on emission controls. However, existing operational models operate at coarse spatial resolution, making it impossible to identify pollution hotspots at the neighbourhood level.

My doctoral research develops **physics-guided deep learning** architectures that embed physical knowledge about how wind transports pollution and how terrain blocks or accumulates particles directly into neural network structure, enabling high-resolution $PM_{2.5}$ forecasting over large domains.

The work follows a progressive trajectory. An initial contribution, **AQ-Net** [1], introduced a deep spatio-temporal architecture for air quality reanalysis over Finland, establishing the foundations of the approach (published, SCIA 2025). Building on this, **TopoFlow** [2] encodes terrain and wind direction into the attention mechanism of a Vision Transformer to predict $PM_{2.5}$ over China, significantly improving the capture of pollution accumulation in complex topography (last stage of review, *npj Climate and Atmospheric Science*). **CRAN-PM** [3] then scales this approach to continental Europe via a dual-branch architecture that bridges coarse meteorological data with fine-scale local observations through physically-informed cross-attention (under review, ECCV 2026).

The next step of this research is to extend the framework to a global scale, moving towards a worldwide high-resolution air quality forecasting system.

Keywords: $PM_{2.5}$, air quality forecasting, physics-guided deep learning, Vision Transformer

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Mineral segmentation for scanning electron microscopy

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Abstract

Segmentation of mineral images, i.e., classifying pixels into specific mineral types, is a fundamental task in the geological sciences. In this work, we focus on data from Scanning Electron Microscopes (SEMs) and utilize two distinct data sources to segment the image: Backscattered Electrons (BSE) image and sparse Energy-Dispersive X-Ray Spectroscopy (EDS) data. While the BSE image is fast to acquire, it lacks sufficient discriminatory power for accurate mineral classification. In contrast, the EDS measurements provide comprehensive information about the chemical composition but are time-consuming to acquire. These complementary characteristics motivate the fusion of sparse EDS data with dense BSE images to achieve both fast data acquisition and processing, as well as compositional EDS information on critical locations. This introduces two challenges: (1) how to select the most informative sampling locations for EDS while minimizing the number of measurements, and (2) how to fuse the BSE image data with pointwise EDS measurements for segmentation. This work proposes a new way to select the most informative sampling points and leverages graph neural networks for data fusion and segmentation. The method is capable of effectively working with sparse EDS data and is faster than previous state-of-the-art methods. The approach accelerates the mineral segmentation process in two ways: by enabling the use of sparser data to achieve the same accuracy and by reducing data-processing time.

Mathematical Phase Retrieval

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Abstract

In many imaging problems, measurements record only the intensity of a wave, while the phase information is lost. This missing phase is often essential for reconstructing the original signal, which leads to the mathematical problem known as phase retrieval. The problem appears in areas such as X-ray crystallography, diffraction imaging, and microscopy.

This talk offers an accessible introduction to mathematical phase retrieval. It explains what the phase retrieval problem is, why the loss of phase makes reconstruction difficult, and which questions mathematics seeks to answer. In particular, the focus is on the uniqueness and stability of the signal reconstruction when the measurements are affected by Gaussian white noise.

Remote sensing applications on lake quality monitoring

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Abstract

Remote sensing is a widely utilized methodology in environmental monitoring due to its extensive coverage from a single image. This approach enables monitoring in hard-to-reach areas, primarily through satellite data acquisition. Satellites are equipped with sensors capturing data across multiple wavelengths, resulting in multi- or hyperspectral datasets. Such spectral data provide comprehensive information, facilitating effective modelling when combined with ground truth measurements. This study employs imagery from the Landsat 8-9 satellite system as it is widely applied in environmental monitoring applications.

Finland employs automatic measurement stations in select lakes to collect hourly data, which can be correlated with satellite imagery to calibrate retrieval models for specific water quality traits. These models enable estimation of trait concentrations at various sites of interest. This study utilizes data from two Finnish lakes, with measurements focusing on Chlorophyll-a and turbidity to assess lake quality.

This study evaluates the impact of pansharpening on Chlorophyll-a concentration mapping for Lake Saimaa, Finland, by using original and pansharpened Landsat 8-9 images. Pansharpening is a data fusion technique used to enhance spatial resolution in multi- or hyperspectral satellite imagery. Additionally, correlations between Chlorophyll-a levels, turbidity concentrations, and satellite band-based indices are examined to elucidate the spatial variability across different regions of Lake Vesijärvi, located in Lahti, Finland.

Smart Mobility and Sports Performance Analytics

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Abstract

Quantitative assessment of propulsion and pole-use mechanics in real-world sport environments remains challenging because many performance-related variables cannot be directly observed during training or competition. This work proposes smart wheelchair and ski-pole prototypes as instrumented sensing platforms for mobility and sports performance analytics, with particular focus on para wheelchair racing and cross-country skiing. The main objective is to transform these sports interfaces into practical measurement systems that capture force, motion, and temporal patterns during natural use, enabling more informative analysis than conventional video-only or laboratory-based assessments.

From a **sensing** perspective, the proposed systems integrate embedded sensors such as inertial measurement units, force-sensitive elements, and timing-related measurements to capture propulsion cycles, pole-ground interaction, asymmetries, and movement variability. Raw signals are pre-processed through filtering and synchronization, and relevant features are extracted in both time and frequency domains. For example, Fourier-based spectral analysis can be used to identify dominant propulsion or pole-plant frequencies, while transient features can reveal technique changes, fatigue, or instability.

From a **modelling** perspective, the sensor data are linked to meaningful performance descriptors through calibration models, sensor fusion, and data-driven estimation. The general modelling problem can be expressed as

$$y = f(x, \theta) + \epsilon,$$

where x represents multimodal sensor measurements, θ denotes unknown system or athlete-specific parameters, y represents target performance quantities, and ϵ accounts for noise and uncertainty. The framework supports regression and classification tasks for estimating quantities such as stroke rhythm, propulsion symmetry, contact timing, cycle consistency, and technique phase. The emphasis is on robust models that remain reliable under outdoor disturbances and athlete-to-athlete variability.

The **industry relevance** of the work lies in its potential to support next-generation sports equipment, athlete monitoring systems, and intelligent training feedback tools. Instrumented wheelchairs and ski poles could provide manufacturers, coaches, and sports technology companies with practical pathways toward performance-oriented product development, personalized training analytics, and field-deployable sensing solutions. Overall, the work positions smart sports equipment as a bridge between mechatronic sensing, applied modelling, and real-world athletic performance analysis.

Lagrangian Modeling of Aerosol Transport and Chemistry in the Arctic

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Abstract

Aerosols play a key role in the Arctic climate system by affecting radiative balance, cloud properties, and Arctic-specific feedback loops.They originate from sea salt emitted by the ocean and blowing snow, long-range transport of sulfate and black carbon from mid-latitudes, and secondary formation from natural and anthropogenic precursors. Their effects depend strongly on composition: black carbon and mineral dust absorb sunlight and reduce snow and ice albedo, enhancing warming, while sulfate aerosols scatter sunlight and cool the surface. Still, Arctic aerosol sources and formation pathways remain uncertain.

To address this, we investigate the sources and chemical evolution of Arctic aerosols using two Lagrangian 1D chemistry models, ADCHEM and SOSAA-FP, which differ in emission handling and particle-phase chemistry. Comparing the models allows us to quantify key uncertainties, and we do this by analyzing two Greenland case studies. At Disko Island, west coast of Greenland (August–September 2023), aerosols are dominated by secondary organic aerosol, DMS-derived particles, and black carbon, including contributions from Canadian wildfires. At Villum Research Station, northeastern Greenland (March–August 2024), particle formation and growth are largely driven by DMS from phytoplankton blooms in the Norwegian, Greenland, and Barents Seas.

Finally, we aim to extend this work using machine learning. While particulate matter with diameter less than 2.5 μm (PM2.5) is a major contributor to premature mortality, its mass concentration alone does not capture toxicity. Instead, particle size distribution (PSD) is critical, as smaller particles penetrate deeper into tissues. Our goal is to train a machine learning model that predicts the PSD from PM2.5 measurements.

Uncertainty and Computation in Acoustic Imaging of Pipes.

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Abstract

We compare two inverse algorithms for reconstructing the cross-sectional area of a pipe from boundary measurements: the SG approach, adapted from vocal-tract imaging, and the KLO boundary control method, adapted from the wave speed recovery.

Using randomly generated area profiles and two complementary forward models, we evaluate reconstruction accuracy under varying noise levels. Our statistical analysis based on relative errors and paired comparisons examines how the relative performance of the two methods varies with the data-generation scenario and noise level.

We conclude with a summary of the key numerical findings and visual examples that illustrate the behavior of both algorithms.

Bayesian Optimization with Inhomogeneous Smoothness

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Abstract

Bayesian optimization (BO) is a popular global optimization technique that uses a Gaussian Process (GP) as a surrogate model for the objective function. Traditional BO methods often assume a stationary GP kernel, meaning that the function is assumed to have the same level of smoothness everywhere in the input space. However, many real-world objective functions exhibit varying smoothness across the input space. To address this limitation, we propose a BO framework that employs locally adaptive estimation of GP kernel hyper-parameters, allowing the model to adapt to local variations in smoothness and improve optimization performance. Preliminary benchmark results show that our proposed framework successfully adapts to varying smoothness, consistently outperforming standard stationary baselines.

Resource-Efficient Machine Learning for Particle Jet Tagging

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Abstract

Due to the increase in data volume caused by the high-luminosity upgrade of the CERN Large Hadron Collider (LHC), there is a need for methods for real-time data reduction with strict latency constraints. High-interest particles such as the Higgs boson and W and Z bosons create boosted jets, which creates a motivation to identify these jets at the Compact Muon Solenoid (CMS) detector's Level-1 trigger (L1T). Jet tagging is traditionally performed by large offline models, but methods such as distributed arithmetic optimization with `da4ml` and quantization-aware training enable the efficient use of machine learning models on field-programmable gate arrays (FPGAs). Leveraging these methods, we present a model for tagging boosted Higgs jets that meets the latency and resource constraints of the FPGAs in CMS L1T.

University of Oulu

Abstracts

Quantitative MRI reconstructions under inhomogeneous B_0 field

Emile Vaysse

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Abstract

We study the effect of the inhomogeneities of B_0 field in Quantitative MRI reconstructions. We show how important it is to takes these inhomogeneities into account, more specifically in the Low - Field MRI case, where the inhomogeneities of the field can not be neglected.

Chemical Exhance Saturation Transfer MRI in Brain Tumor Imaging

Kalle Inget
University of Oulu

Abstract

Goal of the study is to distinguish glioma grade with amide proton transfer (APT) chemical exchange saturation transfer MRI (APT-CEST). A total of 20 patients is imaged with CEST (10 low grade and 10 high grade gliomas). We except the CEST effect to significantly differ inside the tumor among the two groups. The results could significantly advance brain tumor diagnostics by enabling earlier detection and earlier initiation of treatment, ultimately leading to improved patient outcomes.

Normative T1 and T2 Relaxation Time Values of Healthy Knee Cartilage in a Single-Age, Population-Based Cohort

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Abstract

Osteoarthritis (OA) is one of the most common joint diseases worldwide and involves the progressive degeneration of articular cartilage, often starting in early adulthood before clinical symptoms appear. Although conventional clinical MRI methods are useful for diagnosing OA, they often lack the sensitivity required to detect early microstructural changes in cartilage. Quantitative MRI (qMRI), in contrast, can reveal subtle compositional alterations at early stages of the disease, potentially enabling earlier interventions to slow OA progression.

Despite its promise, qMRI has not yet been widely adopted in clinical practice. This is partly due to relatively long acquisition times, variability in acquisition and analysis methods, and a limited availability of well-validated reference data in healthy populations. Although qMRI has been widely used to study knee cartilage, comprehensive normative values for healthy cartilage remain scarce.

In this study, we utilize data from the Northern Finland Birth Cohort (NFBC1986) to examine the influence of genetic and lifestyle factors on knee cartilage health. In addition, we will report detailed compartment-specific normative T1 and T2 values for healthy knee cartilage in young adults using multiple qMRI sequences. These reference values provide a benchmark for future studies investigating early cartilage degeneration and OA progression.

Space weather influence on ionospheric dynamics

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Abstract

Disturbances in the Earth's magnetic field observed on the ground can be used to estimate the horizontal electric currents flowing in the ionosphere. These estimates are referred to as ionospheric equivalent currents. During geomagnetic storms, the enhanced ionospheric currents can lead to induced currents in power grids, increased satellite drag, and navigation errors, highlighting the need for accurate modeling. We have developed two approaches to predict equivalent currents based on solar wind conditions: a statistical model and a deep-learning model. Solar Wind driven SuperMAG statistical equivalent current model (SW-SMEC) is based on data from 1997-2008 and obtained by averaging the equivalent currents over varying solar wind conditions [1]. It reproduces typical equivalent current behavior, but tends to underestimate the strongest currents and cannot capture smaller-scale features. For the deep-learning model we used the ResNet architecture which was trained on storm-time data from 1997-2008. Two different versions were trained with and without the ground-based magnetic indices as input. Case studies of geomagnetic storms show that the ResNet model captures small-scale features of the equivalent currents during storm conditions. The relative prediction error averaged over storms from 2009-2019 is 25% for ResNet with magnetic indices and 38% for SW-SMEC. The ResNet model without magnetic indices underestimates the current amplitude, resulting in lower accuracy (53% error), but still captures more small-scale variation than the statistical model.

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Advanced methods for 3D observations of the ionosphere using the EISCAT3D radar

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Abstract

The ionosphere is an ionized region of the upper atmosphere that extends approximately from 60 to 1000 km above the Earth's surface, formed primarily through the ionization of neutral atmospheric constituents mainly by solar radiation. Incoherent scatter (IS) radars are ground-based instruments that transmit radio waves and detect those scattered from thermal density fluctuations of ionospheric plasma. Because the spectrum received by an IS radar is a known function of ionospheric plasma parameters, including electron density (N_e), electron temperature (T_e), ion temperature (T_i), bulk plasma velocity (V_i), and ion composition, the plasma parameters can be inverted from the measured spectra. The standard inversion provides four parameters, N_e, T_e, T_i, and V_i, while including the ion composition requires additional information.

EISCAT3D will be an advanced multistatic multibeam IS radar system in northern Fennoscandia. The radar is currently under construction, and first observations are expected in 2027. The rapid beam scanning capability of EISCAT3D with electronically steerable phased array antennas will allow volumetric observations of the ionosphere. However, new and advanced data analysis techniques need to be developed for the unprecedented observations. Ion composition inversion has been previously enabled for measurements along a geomagnetic field line by means of sequential filtering, smoothness priors, and chemistry modeling. We extend the technique by making optimal use of data from all beams from all receive sites of a multistatic radar system and bin the data to form field-aligned profiles to enable the ion composition fits. Because EISCAT3D is not yet available, we apply the technique to make 2D plasma parameter inversion using the EISCAT Svalbard Radar (ESR) meridional scan measurements during a geomagnetic storm period. Our results reveal the 2D structure of the ionospheric heating caused by the geomagnetic storm and the associated ion composition variations. These observations are potentially valuable for many applications, including understanding upper atmospheric density variations caused by the ionospheric heating, which affect atmospheric drag on low Earth orbit satellites, and plasma density fluctuations, which affect satellite navigation and communication systems.

Novel NMR methods for investigating chemical and physical properties of rubber compounds

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Abstract

Rubbers are an important materials for modern life, industry and science, presenting attributes not found on other materials. These attributes include an ability to undergo and recover from large deformations without breaking or permanent damage. Rubbers are elastomer chains that have been cross-linked into a three dimensional network. With fillers and various additives rubbers make a compound. Cross-links are the element giving rubber the unique characteristics. Thus one of the most important and desirable information on rubber compounds is the cross-link density. [1]

Nuclear magnetic resonance (NMR) spectroscopy is considered a powerful method for acquiring cross-link density and other information. In NMR a samples nuclei are excited with radio-frequency electromagnetic radiation and their response measured in high external magnetic field. Time-dimension NMR (TD-NMR) measures the time dependence of this response since it is dependent on the chemical and physical environment of the nuclei, thus giving information on these aspects.

Currently multiple different methods have been developed for investigating rubber materials with TD-NMR. Most commonly used method is called Double quantum measurement (DQ-measurement) [2], giving accurate information on cross-link density. It has disadvantages in industry applications, long measurement times and multi-step person-dependent data preparation. Therefore in this doctoral research project we develop and refine new TD-NMR methods which address these points.

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Computational methods for nonlinear inversion

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Abstract

We develop computational methods for inverse problems arising in nonlinear models. The first project addresses a semilinear Calderón-type problem in two dimensions: given boundary data for

$$-\Delta u + q(x)\, u^p = 0 \quad \text{in } \Omega, \qquad u\big|_{\partial\Omega} = f,$$

with $p \in \mathbb{N}_{\geq 2}$, on a bounded domain $\Omega \subset \mathbb{R}^2$ and Dirichlet data f. Our numerical approach is based on higher-order linearization of the nonlinear Dirichlet-to-Neumann map, by differentiating the DN map, we obtain auxiliary linear elliptic problems that gives Fourier transform of q. We then reconstruct q from these data using Tikhonov and total variation (TV) regularization, which remains effective in regimes where the corresponding linear inverse problem is challenging.

The second project considers inverse scattering for a Kerr-type nonlinear Helmholtz equation

$$\Delta u + k^2 u + k^2 q(x)\, |u|^2 u = 0 \qquad \text{in } \mathbb{R}^n,$$

where $k > 0$ is the wavenumber and q describes the unknown potential. We propose a reconstruction strategy that extracts information on q from the third Fréchet derivative of the scattering amplitude, leading to a formula of Fourier data of the potential, which allow the reconstruction of the unknown by regularization methods.

The third project extends these ideas to nonlinear inverse problems for time-harmonic Maxwell equations, with the goal of recovering material parameters from boundary or far-field measurements by combining suitable linearization procedures with stable numerical inversion.

This is joint work with Teemu Tyni and Matti Lassas.

A goal-oriented Bayesian algorithm to optimally select view angles in X-ray computed tomography

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Abstract

X-ray computed tomography (CT) is an imaging technique that reconstructs the interior of an object from exterior measurements. Each measurement corresponds to a set of view angles from which the object is hit by the X-ray beam. The ill-posedness of the CT inverse problem becomes more severe when the view angles are limited or not chosen carefully. A naive selection of these angles can lead to inefficient use of experimental resources, because missing informative directions lead to larger uncertainty in the reconstructed image.

In our goal-oriented Bayesian framework, view angles are treated as experimental design parameters. The method proposes new angles that provide the most informative directional measurements for the boundary, such that uncertainty reduction is optimal.

Additionally, we combine posterior uncertainty with ideas from microlocal analysis. We estimate the expected wavefront directions of the object, which reveal singularities that remain invisible under the available set of angles. The algorithm then selects the next projection angle orthogonal to these directions at locations where the posterior variance is highest. Numerical experiments support the optimality of this strategy.

Our results turn wavefront analysis from a diagnostic tool into an active part of the design process. It links the direction of singularities with the reduction of posterior uncertainty.

Future Spectral CT

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Abstract

The research focuses on advancing medical imaging techniques, specifically addressing limitations in computed tomography (CT) and cone-beam computed tomography (CBCT), which are widely used for diagnosing conditions in the head, neck, and dentomaxillofacial regions, yet these modalities suffer from challenges such as beam hardening and metal artifacts due to dense bone structures and metal implants, as well as poor soft tissue visibility and exposure to ionizing radiation. This study aims to develop and optimize novel image reconstruction algorithms and spectral imaging methods using PCD technology for CT/CBCT imaging. It hypothesizes that combining spectral CBCT and CT with material decomposition (MD) and virtual monochromatic imaging (VMI) techniques can significantly reduce beam hardening and metal artifacts, and that IR and DLR can enhance image quality while minimizing radiation doses. Furthermore, spectral PCD-CT is expected to improve diagnostic capabilities, particularly in the assessment of stenoses, tissue classification, and artifact reduction in stroke imaging. The research employs a three-pronged approach: 1) Utilizing MD and VMI techniques for artifact reduction in CBCT and CT imaging, 2) MD and VMI techniques for delayed phase tumor enhancement, and 3) Implementing spectral PCD-CT for enhanced diagnostic accuracy. The project holds significant potential to revolutionize CT/CBCT imaging by improving image quality, reducing radiation exposure, and enhancing diagnostic precision.

On unsupervised iterative reconstructions and range characterization of 2D fan beam

Antti Sällinen

We study how to apply unsupervised training setting, Noise2Inverse, to previously supervised iterative reconstruction algorithm Learned Primal Dual. We show that this particular implementation succeeds to yield better reconstructions than U-Net post-processing with the same training setting. The algorithm in this implementation is novel and requires changes to the original Learned Primal Dual.

Another topic is about ongoing research on how to characterize the range of 2D fan beam geometry. First we study the John's equation, a partial differential equation that characterizes the range of X-ray transform in three or higher dimensions. We derive a approximation to 2D fan beam for this John's equation from a cone beam CT geometry, and show numerically that these results tend to satisfy the equation in question. We also discuss possible future directions about this project.

Evaluation of iodine-based contrast agents in the micro computed tomography visualization and histology examination of swine hearts

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Abstract

This study compares two iodine-based contrast agents, iodine in ethanol (I2E) and an aqueous solution of potassium triiodide (I2KI) in optimizing high-resolution, contrast-enhanced micro computed tomography imaging (micro-CT) of the cardiac conduction system (CCS) in porcine hearts. The work evaluates their relative efficacy in enhancing tissue contrast and anatomical delineation. To our knowledge, it is the first time I2E is introduced as a contrast agent in cardiac micro-CT imaging.

Dissected porcine hearts were stained with I2E and I2KI and scanned with micro-CT. Signal-to-noise ratio (SNR), contrast-to noise ratio (CNR), and volumetric shrinkage were evaluated. Additionally, qualitative visualization of CCS-related anatomical landmarks, such as the sinoatrial node (SAN), atrioventricular node (AVN), and Purkinje fibres, was performed, along with assessment of artifact occurrence and sample integrity. The efficacy of the contrast agents was also determined by segmenting the regions of interest corresponding to the CCS from micro-CT images. These were then further validated against histology.

I2E allowed for seamless post-processing and histological sectioning by offering better segmentation, CNR, fewer artifacts, and sample integrity. Compared to I2E (day 3), I2KI staining generated a greater soft-tissue signal intensity and a quicker stain saturation (day 2). However, I2KI exhibited leaching and introduced substantial staining artifacts. I2KI also exhibited structural disintegration, which, in turn, compromised downstream processing. These results suggest that I2E is a viable alternative to I2KI for CCS micro-CT imaging when sample preservation and downstream analyses are essential, whereas I2KI may be preferred for rapid, high-intensity staining where tissue integrity is less critical.

Underuse and Misapplication of Automatic Exposure Control Compromise Image Quality and Radiation Safety in Diagnostic Imaging

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Abstract

I study automatic exposure control (AEC) mechanisms in medical imaging. I develop an angular tube current modulation (ATCM) for cone beam computed tomography (CBCT). I study a situation where air kerma rate increases in angiography with tight collimation when automatic dose control region is obscured. Furthermore, I develop patient specific radiation detriment estimation framework where I can estimate the impact of the studied methods on lost life years due to X-ray caused harm.

ATCM in CBCT can reduce effective dose by almost 20% in thoracic vertebrae imaging. Tight collimation can increase paediatric patient air kerma rate by 850% and decrease image contrast. Medical imaging causes about 1.5 fatal cancers every year in Oulu university hospital.

Raman spectroscopy for serum-based diagnosis and disease management in rheumatic diseases

Minna Mannerkorpi

March 2026

1 Abstract

Rheumatic diseases, particularly Rheumatoid Arthritis (RA) and Juvenile Idiopathic Arthritis (JIA), significantly affect the musculoskeletal system and quality of life across age groups. Despite advances in understanding, challenges remain in the diagnosis and management of these conditions. In the initial stages, RA is often asymptomatic, and the sensitivities of current biomarkers in RA diagnosis often lead to false negatives. However, JIA is rarely asymptomatic; among young children, the expression of symptoms is not always clear. Furthermore, given the several subtypes of JIA, understanding the disease course is crucial for personalized treatment options. The absence of a single defining biomarker complicates the timely and robust diagnosis of both RA and JIA. In this doctoral research, machine learning and deep learning models will be trained to classify the Raman spectra of RA patients and healthy controls, providing a new method for diagnosing RA. Additionally, the potential of Raman spectroscopy to predict the disease course in JIA will be investigated. This research underscores the importance of early detection, timely treatment, and improved diagnostic tools to enhance patient outcomes in rheumatic diseases.

Tampere University

Abstracts

How Neuron Type, Morphology, and Myelination Shape Temporal Interference Responses: A Computational Study

Ivan Perez-Torres[1], Jarno Tanskanen[1], Annika Ahtiainen[1], Jari Hyttinen[1]

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Abstract

Temporal interference stimulation (TIS) has emerged as a promising non-invasive neuromodulation technique capable of targeting deep brain regions using interfering high frequency electric fields. However, its underlying single cell mechanisms remain insufficiently understood, limiting its accurate interpretation and in vitro translation. In this study, we investigate how detailed biophysical properties of cortical neurons shape their sensitivity to TIS at the single cell level. Using morphologically and physiologically realistic multicompartment neuron models implemented in NEURON, we simulated a diverse set of cortical cell types, incorporating optional axonal myelination to evaluate structural contributions to TIS responsiveness. Our preliminary results show that TIS sensitivity varies across neuron types, with activation thresholds influenced by morphology, ion channel dynamics, and myelination status. Myelinated neurons exhibited lower stimulation thresholds. To approximate more realistic physiological conditions, we incorporated synaptic noise via Poisson distributed excitatory and inhibitory inputs. Under ongoing activity, TIS produced frequency specific modulations of subthreshold membrane dynamics, with effects dependent on both cell type and ongoing oscillatory state. Band power and phase locking analyses further demonstrated that inhibitory and excitatory interneuron classes exhibit distinct susceptibility profiles, suggesting that TIS interacts differentially with local microcircuit elements. Overall, our findings identify key cellular determinants, myelination, and intrinsic excitability—that drives TIS effectiveness at the single cell level. These mechanistic results provide the basis for developing circuit level models that preserve essential nonlinearities and guide future in vitro experimental designs.

Functional connectivity methods in brain connectivity estimation

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Abstract

Exploring how different brain regions are functionally connected provides valuable insight into cognitive processes and the underlying mechanisms of various brain disorders. Functional connectivity methods are based on the idea of studying the statistical interdependencies between signals and thus estimating the underlying functional connectivity structure of the network producing the signals. Network-based conditions such as epilepsy could be studied more effectively using approaches that provide information on how connections between brain regions transfer information and how such connections change.

Traditionally, research has relied on bivariate functional connectivity methods, but more recently, multivariate techniques have been developed and applied to brain signals to obtain improved estimation accuracy. However, the question about how different network properties affect the accuracy of multivariate methods remains unaddressed. Thus, the first objective of my PhD work is to evaluate the performance of three multivariate directed functional connectivity methods under different network properties.

If these analysis methods were able to identify brain regions with a high susceptibility to start a seizure, it would be crucial information for physicians and surgeons treating an epilepsy patient. Thus, the second objective of my PhD is to study how functional connectivity methods can be used to predict the outcome of surgical removal of epileptic tissue from drug-resistant epilepsy patients.

Finally, these multivariate methods are computationally expensive, and even though several attempts have been made to address the estimation accuracy of these methods, the problem of detecting spurious connections persists. Therefore, the third and final objective of my work is to determine how to improve multivariate methods to make them computationally more feasible and even more accurate.

Acute scalp EEG signatures of anterior nucleus of the thalamus DBS in epilepsy

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Abstract

Deep brain stimulation (DBS) of the anterior nucleus of the thalamus (ANT) is an established treatment for drug-resistant epilepsy, but it is still not well understood which scalp EEG changes reliably reflect the stimulation state. In this work, I studied whether scalp EEG shows reproducible spectral changes during ANT-DBS and how these changes evolve immediately after stimulation is turned off. Scalp EEG was recorded from five implanted patients at two time points approximately one year apart (10 patient-years) during cyclic stimulation with 1 s ON and about 5 s OFF periods. I compared stimulation ON with the mean OFF state using power spectral analysis, channel-by-frequency-by-time cluster-based analysis, and spectral parameterization to separate broadband aperiodic changes from oscillatory activity. The results showed a consistent increase in gamma-band activity during stimulation ON across all patient-years, with the most reproducible effects seen in central and frontal low-gamma regions. In contrast, lower-frequency changes in the theta, alpha, and beta ranges were more variable and were strongest immediately after stimulation offset, then gradually weakened across the OFF period, suggesting post-offset relaxation dynamics. The analyses also showed that DBS was associated with broadband aperiodic changes, including a flatter spectrum and reduced offset during stimulation, which explained a substantial part of the overall ON–OFF spectral difference. After correcting for these broadband effects, a smaller but still meaningful low-gamma enhancement remained. Overall, these findings suggest that ANT-DBS produces a reproducible scalp-EEG signature combining high-frequency enhancement, broadband aperiodic modulation, and transient post-stimulation low-frequency dynamics, which may serve as candidate indicators of DBS state.

Imaging engineered heart tissues with inverted selective plane illumination microscopy

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Abstract

Cardiovascular diseases (CVDs) have remained the highest in global mortality rate for decades. Advanced *in vitro* models that recapitulate the structure and function of the human heart could be used for better disease modeling and discovery of therapeutics. Engineered heart tissues are 3D human-based *in vitro* models that can be derived from patients, enabling the study of genetic CVDs in a personalized level. However, studying EHT tissue architecture has remained limited without technological advancements, which has hindered the usability of the *in vitro* model in clinical research. In this project, we take advantage of advanced imaging technology with the development and optimization of an inverted selective plane illumination microscopy (iSPIM) for EHT imaging. We show novel insights into the structural composition of the fixed EHT, and provide quantification tools for 3D structural analysis. With the current iSPIM platform, we aim to implement the method to studying tissue maturation through culture time. With ongoing and further development, the iSPIM will allow live imaging of dynamic events in beating EHTs, where we aim to combine the structural and functional information of EHTs on tissue section level. Finally, we aim to use the developed system for studying structural and functional changes in the most common inherited cardiac disease, hypertrophic cardiomyopathy (HCM).

A Bayesian Framework for Ill-posed Geometric Primitive Reconstruction from Point Clouds using Prior Information

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Abstract

Point clouds have become a standard representation for capturing the geometry of real-world objects and are typically obtained via range sensors such as LiDAR, depth cameras, or structured light scanners. In many practical applications, the point clouds are incomplete, and both sampling density and measurement uncertainty can vary significantly across the object. In such ill-posed conditions, even reconstructing simple geometric primitives (e.g., ellipses, spheres or cylinders) becomes a challenging task. Traditional distance-based fitting methods often yield biased or unstable results.

To address these issues, we propose incorporating prior information about the data acquisition process — such as the scanner position, sensor noise properties or visibility constraints — directly into the primitive-reconstruction. To enable this, we introduce a Bayesian reconstruction framework that explicitly models both the spatial distribution of observed points and their measurement uncertainty. This formulation naturally allows integration of prior knowledge about measurement-locations and noise-characteristics.

We demonstrate for two widely used geometric primitives, ellipses and cylinders, that under ill-posed conditions, integrating such prior information — especially about the measurement-origins — can significantly improve robustness and reconstruction quality compared to established methods.

Topology-Aware Deep Learning for Structural Analysis of Tree Point Clouds from Terrestrial Laser Scanning

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Abstract

Terrestrial Laser Scanning provides detailed three-dimensional measurements of forest environments and produces large point cloud datasets representing individual trees. These data offer valuable opportunities to study tree architecture and estimate structural properties important for forest monitoring and ecological research. However, extracting meaningful structural information from TLS point clouds remains challenging due to occlusions, irregular sampling, measurement noise, and the complex topology of stems and branches.

In this research, we develop topology-aware deep learning methods for analyzing TLS point cloud data. The proposed approach combines geometric features with graph-based neural networks to learn relationships between neighboring points. By modeling local structural organization, the method improves the identification of stems and branches in complex and high-density 3D measurements.

The framework is evaluated using high-density TLS datasets of individual trees. Experimental results show that incorporating topological information improves the robustness of stem and branch detection, particularly in regions affected by occlusion or sparse sampling.

These methods contribute to scalable artificial intelligence approaches for analyzing complex 3D natural structures. Potential applications include stem and branch detection, segmentation, tree reconstruction, biomass estimation, and large-scale forest monitoring from terrestrial laser scanning data.

AI-Driven Context-Aware AAC System: Framework Design, Prototype Development, and Personalization

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Abstract

Augmentative and Alternative Communication (AAC) systems support individuals with complex communication needs. However, many current AAC systems rely on static vocabulary structures and limited contextual adaptation, which can make communication slow, effortful, and less responsive to users' everyday situations. This project addresses these limitations through three main objectives: to develop a flexible framework for context-aware AAC, to implement the framework through prototype design, and to enhance the system through personalization. The project investigates how multimodal contextual inputs, including location, time, audio, images, and user-specific information, can be integrated to provide more adaptive communication support. Prototype development is used to examine the practical implementation of the framework, while personalization enables the system to better respond to individual preferences, habits, and communication needs. The project ultimately aims to advance the design of more responsive, context-sensitive, and user-centered AAC systems.

Multiplicities of eigenvalues of resultant matrices

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Abstract

In the talk, I will go through our recent work regarding the Smith form of the Sylvester and Bézout resultant matrices. The partial multiplicities associated to the eigenvalue of a polynomial matrix tell us about the conditioning of computing the eigenvalue, and hence gives us hints about the expected stability of solving the polynomial system via resultant methods.

For bivariate polynomials $f, g \in \mathbb{K}[x, y]$, we make a connection between the partial multiplicities of the eigenvalues of the resultant matrices and the structure of the dual space of the zero-dimensional ideal $\langle f, g \rangle$. We show this by explicitly constructing the root polynomials for the matrix $S(y)$ using a *Gauss basis* of the dual space, introduced in [**3M96**].

Our main contribution is to deal with the case where f and g have a common factor leading coefficients. Using a Möbius transformation that takes the "infinte roots" in the x-coordinate to finite roots, we prove that the Smith normal form stays intact through the transformation, allowing us to lift the earlier assumption. In the talk, I aim to go through the associated definitions and structures as intuitively as possible using an example.

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Improving EEG Source Localization Through Practical Head Modeling Choices

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Abstract

Electroencephalography (EEG) source localization depends strongly on how the head is modeled, but it is still not fully clear when adding more anatomical detail actually improves the results. In our work so far, we examined how different aspects of head modeling influence both forward and inverse EEG solutions. We compared several subject-specific multi-compartment head models that differed in anatomical detail, skull representation, mesh quality, and modeling choices. We then evaluated their performance using common inverse methods under different levels of noise to better reflect realistic recording conditions.

Our results showed that noise level and the choice of inverse method had the largest impact on localization accuracy. In general, performance improved as the signal quality increased, especially for Dipole Scan inverse solver, while sLORETA solver was less sensitive to these changes. We also found that adding more anatomical subdivisions did not necessarily lead to better results. In many cases, simpler models performed better than more detailed ones. By contrast, improving skull modeling and mesh quality led to more consistent gains, although these improvements were moderate.

Overall, our findings suggest that making head models more detailed is not always the most effective way to improve EEG source localization. Greater benefit may come from careful solver selection, better skull representation, and good mesh construction. These results highlight the importance of balancing anatomical realism with practical modeling choices when building multi-compartment head models for EEG analysis.

Exploratory Study for Radar Tomography of Dimorphos - the Asteroid Moon of 65803 Didymos

Topi Pajala[1], Sampsa Pursiainen [1], Alexandra Koulouri [1], Christelle Eyraud [2], Jean-Michel Geffrin [2], Alain Hérique [3].

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Abstract

Understanding the interior structure of small solar system bodies is essential for both understanding the formation of our galaxy and for planetary defence purposes. Dimorphos is a rubble-pile asteroid moonlet that is the target of the European Space Agency's (ESA) HERA mission, which is planned to rendezvous in December 2026 and perform thorough measurements of its electromagnetic, dynamical, and structural properties.

Current data inversion methods often rely on synthetic forward simulations, which are computationally too heavy for accurate results. Our aim in this study is to fabricate a 3D-printed asteroid model of Dimorphos using a stochastic process that follows prior knowledge about the composition of the asteroid, resulting in a realistic rubble-pile model. This analogue is later measured using a microwave tomography setup that scales with respect to the asteroid size to produce similar wave propagation effects as in the mission, allowing us to obtain a realistic set of tomographic data. This data can then be used to develop inversion methods that are robust enough for this type of structure.

Additionally, after obtaining the measurement data, we plan to implement our own inversion method to localize possible voids inside the structure and characterize the size of the scatterers present within the model using time–frequency analysis. If the proposed method works, the same workflow can then be used for the actual mission pipeline, providing similar statistics from the asteroid after the measurement data arrives.

As for now, we have been able to fabricate a total of 4 analogue models for Dimorphos that has all undergone a microwave radar measurement. The measurement data has already shown to have some minor deviations from the synthetic data, indicating that this type of measurement data is essential for the use of radar data inversion applications.

Hierarchical Bayesian modelling for predicting component failure

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Abstract

Probabilistic Risk / Safety Assessment (PRA / PSA) of components is an important field in structural, systems, risk engineering and related disciplines. This is a integral part of safety analyses conducted in nuclear power plants (NPPs), where robust techniques are required to estimate failure rates of their components such as diesel generators, pumps, etc. Several specialized modelling strategies such as Bayes-Empirical Bayes (BEB)[1], Parametric-Robust-Empirical-Bayes (PREB) and Parametric-Empirical-Bayes (PEB) currently exist. Most of these models are dated, and they also present notable deficiencies[2] – particularly in their ability to manage uncertainty in failure rate estimation, and zero-inflated data. There exist several promising avenues for addressing these limitation - using Markov Chain Monte Carlo (MCMC) to estimate the hyperpriors of the Bayesian model, using zero-inflated likelihood, and alternate Bayesian models which may also be implemented in STAN. In our work, we start from the BEB model and focus on reducing identified model limitations, utilising techniques which can leverage more computing power, and also aim to improve prediction of the failure rate. The primary motivation is to improve PRA in NPPs, however the Bayesian modelling framework and inference methods can be applied and transferred across other structural, and mechanical engineering domains.

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Control of incompressible fluid flows

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Abstract

The control of fluid flows is essential in numerous applications from cooling systems to blood circulation and aerodynamics. Over the years different questions have been investigated from the stability of systems to numerical feasibility. Motivated by blood flows we focus our attention on the incompressible Navier–Stokes equations in tubular domains and the problem of output regulation.

In output regulation the goal is to control a system in such a way that a given output of the system tracks a desired reference signal in spite of disturbances. While the theory is well developed for linear systems, both in finite and infinite dimensions, significantly fewer results exist for nonlinear PDEs like the Navier–Stokes equations. We extend the mathematical theory to boundary acting controllers and mixed boundary condition setups, which correspond to more realistic physical configurations.

For the simplest settings we have been able to solve the problem with an integral controller and we continue to extend to more general assumptions. As we increase difficulty by allowing for complex disturbances, an unstable system and multidimensional output measurements, the controller design necessarily becomes more sophisticated. We also use numerical simulations to illustrate our theoretical results.

Methodological Advancements in Standardized Kalman Filtering for EEG Source Localization

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Abstract

Electroencephalography (EEG) source localization aims to reconstruct brain activity from scalp measurements, but it is a severely ill-posed inverse problem affected by depth bias and measurement noise. Dynamic approaches based on Kalman filtering provide a natural framework for incorporating temporal information, yet conventional formulations tend to favor superficial sources. The Standardized Kalman Filter (SKF) addresses this limitation through a normalization step that balances source contributions across different depths, enabling improved reconstruction of deep brain activity.

In this work, we focus on methodological advancements of the SKF framework. First, we investigated the role of prior parameters, showing how the choice of evolution and measurement noise, together with the standardization exponent and RTS smoothing, governs the balance between reconstruction accuracy and noise robustness. This highlights the importance of principled prior modeling in dynamic EEG source localization.

To improve computational efficiency, we proposed a discrepancy-based rescaling of the lead-field matrix that replaces the iterative, time-dependent standardization of SKF with a static approximation. This significantly reduced computational cost while maintaining comparable reconstruction accuracy at low noise levels, while highlighting a trade-off between efficiency and noise robustness.

Ongoing work extends this framework by incorporating structural connectivity information derived from diffusion tensor imaging (DTI) into the process noise covariance. This aims to introduce biologically informed priors that better reflect network-level brain organization and improve reconstruction performance.

Computer modelling and simulations of phenotypic plasticity in electro-chemo-mechanical function of the heart

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Abstract

Computational modelling and simulation of electro-chemo-mechanical function of heart muscle cells, cardiomyocytes, play an increasingly significant role in cardiovascular research, clinical decision support, and emerging heart digital twin applications. Despite considerable advances, current models lack a critical biological property: phenotypic plasticity. This limits the models' ability to capture how cardiac cells adapt to short- and long-term changes in their electrical, biochemical, and mechanical environment.

Our research enhances existing cardiomyocyte models by integrating feedback mechanisms that link changes in stimuli and environmental conditions to cellular electro-chemo-mechanical function and phenotype adaptation. Regarding the foundational characteristics of the models, the objective is to improve the physiological accuracy of long-term stability of extra- and intracellular ion dynamics and their interdependencies. Building on that, the focus shifts to developing a mitochondrial module for energy utilisation in excitation-contraction coupling, and to protein-expression changes arising from transcriptional and translational regulation. Model implementation utilises Python and MATLAB for numerical simulation, data processing, and visualisation. Code will be openly available to support reproducibility and community adoption.

The research is structured into three sub-studies that examine ionic imbalance as an arrhythmogenic mechanism alongside integration of an energy-usage module, investigate RNA expression differences as a manifestation of phenotypic plasticity from healthy heart towards atrial fibrillation, and demonstrate the capabilities of the novel modelling framework by applying it to multicausal disease mechanisms using atrial fibrillation as an example disease case.

By bringing phenotypic plasticity and other adaptive mechanisms into computational cardiomyocyte models, my thesis enhances their explanatory and predictive capacity, and advances foundation for digital twin technologies in precision cardiology, where personalised medicine and patient-specific simulation approaches are becoming the standard.

Beyond Geometric Error: Learning Radiomic Consistency for Histology-µCT Registration Validation

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Abstract

Histology provides high-resolution microscopic detail, whereas micro–computed tomography (µCT) preserves intact 3D morphology. Accurate alignment of these complementary modalities is essential for true 3D histology and cancer diagnoses, as misregistration can result in incorrect spatial interpretation of diagnostically relevant tissue. However, validating multimodal registration remains challenging due to the absence of geometric ground truth under tissue deformation and the low intrinsic contrast of µCT, limiting clinical adoption. Existing approaches rely on subjective slice matching or geometric overlap metrics without objective biologically meaningful validation criteria. We propose a learning-based framework that evaluates alignment through cross-modal radiomic consistency, reframing registration assessment as a feature-level biological agreement problem rather than a purely geometric transformation task. The method learns a modality-agnostic quality score based on preservation of radiomic phenotypes, enabling objective and reproducible validation. Corresponding histology-µCT slices were identified using tissue mask overlap followed by expert-defined anatomical patch selection to ensure biologically consistent cross-modality sampling. Rigid and non-rigid registration were applied to compensate for histological deformation. Radiomic features were extracted and registration quality was classified using cross-modal feature differences, with reference labels derived solely from overlap metrics. The framework was evaluated on 18 paired rat skin specimens comprising 1,186 aligned patches using specimen-level cross-validation to prevent data leakage. A support vector machine (SVM) achieved 90.5of 85.1This work introduces a biologically meaningful, modality-invariant quality metric for multimodal registration validation, supporting reliable multimodal pathology and true 3D histopathology

Enhanced Source Localization Using Bidirectional Deep Brain Stimulation Electrodes: A Comparative Study with Scalp EEG

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Abstract

Accurate neural source localization remains a fundamental challenge in electroencephalography (EEG), particularly for deep brain structures that are difficult to reconstruct using conventional scalp-based methods. Bidirectional deep brain stimulation (DBS) electrodes offer a promising complementary approach to enhance source localization by enabling simultaneous recording and stimulation through the same electrode.

We investigate the impact of integrating bidirectional DBS electrodes with scalp EEG on source localization accuracy across varying noise conditions. A computational framework based on the Finite Element Method (FEM) and an extended Complete Electrode Model (CEM) jointly models scalp and intracranial electrodes with realistic electrode–tissue interactions. Three DBS configurations (4-, 8-, and 40-contact arrays) were evaluated alongside a 72-channel scalp EEG system, with source reconstruction performed using sLORETA and dipole scan under three SNR levels (30 dB, 17.5 dB, and 5 dB).

Multimodal integration significantly improves source localization accuracy, particularly for deep structures such as the thalamus. The 40-contact configuration achieves error reductions of up to 97.4% under low-SNR conditions, with near-perfect localization (0.0 mm error) at high SNR using dipole scan. While scalp EEG provides strong orientational coverage at high SNR, its performance degrades with noise, whereas bidirectional DBS electrodes maintain robustness due to source proximity. These findings underscore the complementary advantages of scalp and intracranial recordings, with implications for epilepsy research, post-implantation monitoring, and adaptive neuromodulation.