MSc projects Computational Imaging at CWI

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Iterative image reconstruction with inexact adjoints

Many linear inverse problems can be formulated as convex optimization problems. These can be solved using iterative schemes that involve gradients and proximal operators of the functionals. Computation of the gradient requires the evaluation of the adjoint of the forward operator. In many large-scale applications, however, the adjoint cannot be evaluated exactly. This leads to a biased approximation of the gradient which can lead to failure of convergence of the iterative algorithm. In this project, you will develop iterative methods that are robust to such errors.

We are looking for a student with a strong background in (computational) mathematics, convex analysis, and numerical optimization.

Supervisor : Tristan van Leeuwen
keywords : numerical linear algebra, inverse problems, convex analysis

Improved optical imaging with compressed sensing

Optical imaging is traditionally limited to the wavelength of the emitted light. Mathematical super-resolution techniques can go beyond this limit, but require special preparation of the sample and long acquisition times. To allow for rapid in-vivo imaging, a novel approach based on glass fibers has recently been developed at ARCNL. First result using randomized illumination and advanced mathematical image reconstruction have shown great promise. However, there is room for further improvement on both computational and theoretical aspects of this approach. In this project, you will further investigate the use of techniques from compressed sensing and experimental design to develop new practical image reconstruction approaches and theoretical reconstruction guarantees.

We are looking for a student with a strong background in (computational) mathematics, harmonic analysis, and inverse problems.

Supervisor : Tristan van Leeuwen (CWI), Lyuba Amitonova (ARCNL)
keywords : imaging, compressed sensing, inverse problems, harmonic analysis.

Non-linear waveform inverse for biomedical ultrasound imaging

Wave-based imaging modalities such as biomedical ultrasound (US) are based on sending waves into a medium of interest through its boundary. The wave fields interact with the medium's internal structures through different wave-matter interactions, e.g., reflection, scattering, or absorption. Measurements of the wave fields leaving the medium thus carry information about its internal properties, and waveform inversion methods try to reconstruct those using a numerical wave propagation model. Typically, wave propagation in these methods is assumed to be governed by linear PDEs. However, in many relevant applications in biomedical ultrasound, nonlinear wave propagation effects play an important role and cannot be neglected. The project aims to develop a nonlinear wave inversion approach for ultrasonic fields. The method can be used for, e.g., reconstructing material properties of interest, nonlinearities in the model, convolution kernels for nonlocal dissipation, or the boundary excitation/shape.

We are looking for a student with a strong background in (applied) mathematics, PDEs, and numerical analysis.

Supervisor : Felix Lucka (CWI), Vanja Nikolic (Radboud University)
keywords : numerical methods for PDEs, inverse problems, ultrasound imaging

Large-scale uncertainty quantification for imaging

Many real-world applications require the estimation of images from limited and noisy data. The Bayesian framework provides a way to systematically model the effects of such limitations, as well as incorporate prior information about the images. The result of this modeling step is a *posterior distribution* that characterizes the resulting uncertainties and can be used to provide images with its corresponding error bars. In most practical applications only the mode or the mean of this distribution is computed, and uncertainties are ignored. This project consists of 2 parts:

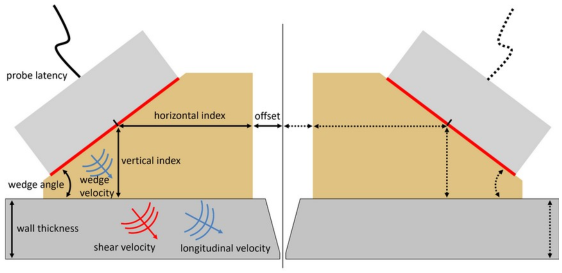
1. Adapt existing methods for uncertainty quantification (UQ) and asses their usability in large-scale imaging applications.
2. Develop a practical method for UQ in X-ray CT and validate it on real data from our in-house CT scanner.

We are looking for a candidate with a strong background in (computational) mathematics, basic knowledge of Bayesian statistics and an affinity with applications.

Supervisor : Tristan van Leeuwen
keywords : Bayesian statistics, inverse problems, tomographic imaging

Ultrasound Non-Destructive Testing

Non-destructive testing (NDT) refers to techniques to analyze objects and materials without damaging them. It is for example used in testing evaluating welds of pipelines. A particular setup that employs ultrasonic (US) waves is shown in figure. In this setup, a large volume of data is collected, from which a number of images (modes) can be produced. The various modes highlight different aspects of the structure, as shown in the figure below, and are used by inspectors to evaluate the weld.



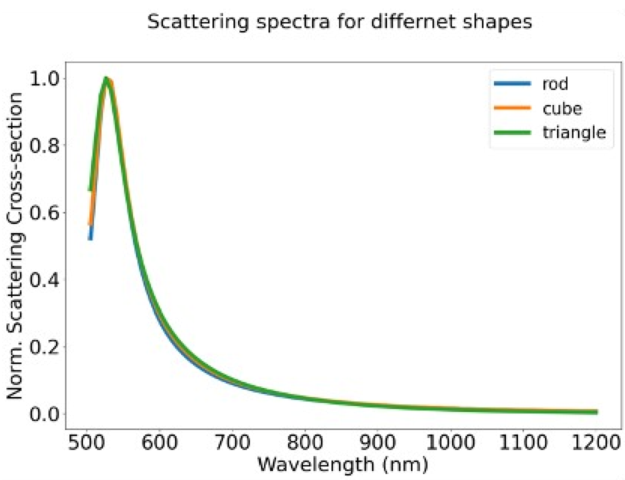
Mathematically, the imaging procedure is an *inverse problem*; given (noisy) data we want to compute an image such that it fits the data through the *non-linear* forward operator. Through a series of approximations, the image is computed from the data by a *linear* imaging step. The project aims to improve the accuracy and robustness of this imaging step. The projects are a collaboration between CWI, the Imaging Physics Department at TU Delft, and Applus RTD in Rotterdam.

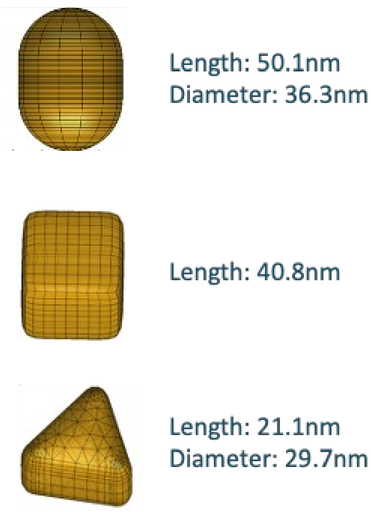
We are looking for students who have a strong background in computational mathematics and/or (computational) physics, and an affinity with imaging and machine learning.

Supervisor : Tristan van Leeuwen (CWI), Koen van Dongen (TU Delft)
keywords : Ultrasound Imaging, Inverse Problems

‘Hearing’ the shape of a nano-particle

Metal nano-particles are used in a variety of applications ranging from biomedical to single molecule sensing and catalytic processes owing to their unique optical and catalytic properties. In order to better understand and optimise the usage of nano-particles in these applications, it is important to quantify their shapes. One of the main barriers hereby is the diffraction limit, the fundamental limit restricting the ability to resolve details smaller than half the wavelength of light you are using for observation. With a new experimental setup, it is possible to optically excite the nano-particles and detect optical resonance frequencies. This principle is similar to hitting a drum; the shape of it will determine its resonant frequencies. Mathematically, the spectrum of a drum consists of the eigenvalues of the Laplace operator defined on the domain. This links the question of detecting the shape of a nano-particle with the classical question “can one hear the shape of a drum”, which is well-studied in the mathematical literature. In this project, the aim is to apply (and possible extend) these results to imaging nano-particles, which involves a more complicated differential operator.





We are looking for a student with a strong background in (applied mathematics), PDEs, and possible differential geometry.

Supervisor : Tristan van Leeuwen (CWI), Wiebke Albrecht (Amolf)
keywords : Imaging, eigenvalue problems, nano-particles,