Doctoral student positions in scientific computing

University of Eastern Finland
Department of Physics and Mathematics
Kuopio campus

Inverse problems group

Finnish Centre of Excellence
in Inverse Problems Research

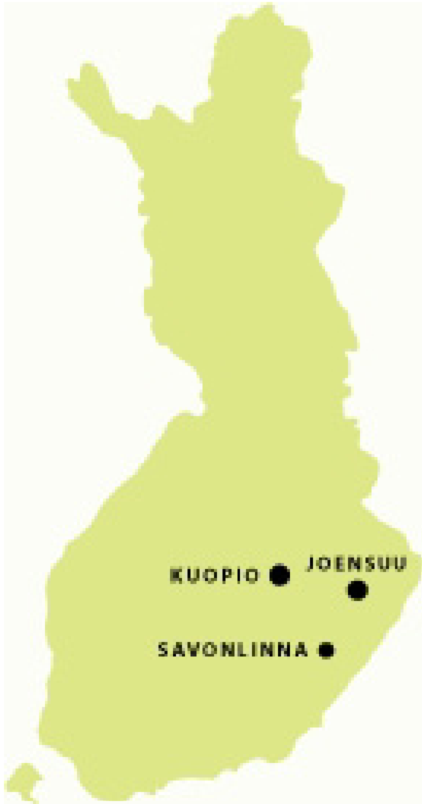
UNIVERSITY OF
EASTERN FINLAND

University of Eastern Finland

The University of Joensuu and the University of Kuopio will merge to constitute the University of Eastern Finland, which begins its operations on 1 January 2010. The University of Eastern Finland seeks to be an internationally recognised research and teaching university, which is among the top three most significant universities in Finland and among the leading 200 universities in the world. Due to its high standard teaching and competitive research, the University of Eastern Finland is a prominent player in the Finnish and international innovation system.

The merger of the two strong universities into the University of Eastern Finland is a response to the recent changes in the global research and innovation environment. The goal is to create a sufficiently large and operational unit, which is efficient in research, education and societal impact. The operational integration of the campuses will lay the foundations for a strong and competitive, research-based competence cluster in eastern Finland.

The University of Eastern Finland comprises four faculties: the Philosophical Faculty, the Faculty of Science and Forestry, the Faculty of Health Sciences, and the Faculty of Social Sciences and Business. The University of Eastern Finland has its main campuses in Joensuu and Kuopio, and there is also a satellite campus in Savonlinna. The new university has over 14 000 students and some 3 000 members of staff. The annual budget of the university amounts to approximately 200 million euros.



Department of Physics and Mathematics

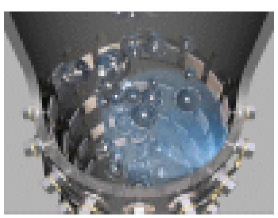
The Department of Physics and Mathematics resides both in the Kuopio and Joensuu campuses of the UEF, and research at the department covers a wide range of fields in science and technology. The main fields of research are industrial physics and mathematics, medical physics, aerosol physics and modern optics and photonics.

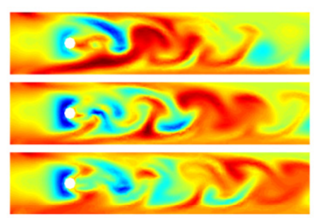
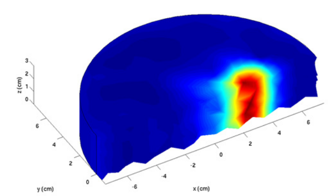
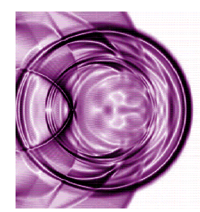
In the Kuopio campus there are 10 active research groups, two of which belong to national programmes for Centers of Excellence in Research. Total number of research and other personnel in the Kuopio campus is about 130.

Inverse problems group

The inverse problems group (IPG) at the Department of Physics and Mathematics (Kuopio campus) is affiliated with the Center of Excellence in Inverse Problems Research (Academy of Finland). The IPG is led by Prof. Jari P. Kaipio, and it consists currently of 10 senior and postdoc researchers and 8 PhD students.

The research of the inverse problems group covers various tomographic imaging approaches as well as general topics related to statistical inversion theory and computational issues. In addition, mathematical modeling of different physical systems is studied. Research areas include e.g. electrical impedance tomography in various applications, optical tomography, computational acoustics and approximation error modeling.



Doctoral student positions in scientific computing

The Inverse problems group will hire 3-5 new doctoral students in 2010. All PhD projects are related to scientific computing, either to the stable forward, or the unstable inverse problems. With all projects, part of the work is to be carried out while visiting one or several of the international collaborators. Furthermore, with most projects, the starting times are negotiable, and the style and contribution can be adjusted somewhat to match the students' strengths.

We invite prospective candidates (persons with a relevant MSc degree or students graduating in the near future) to apply for one or several of the following projects

1. **Stochastic boundary models for inverse problems induced by PDEs**
2. **Computational methods for thermal tomography**
3. **Development of advanced modelling for optical imaging of the brain**
4. **Electrical capacitance tomography imaging of concrete**
5. **Optimal control in geophysical tomographic problems**
6. **Computational methods for full-wave inversion**

The applicants should send the following documents as pdf attachments to Dr. Arto Voutilainen (Arto.Voutilainen@uef.fi) by January 15, 2010:

- Cover letter indicating which project(s) are addressed
- Short CV
- Scanned copies of relevant diplomas and transcripts of studies. The diplomas and transcripts should be in English or Finnish and the grading system should be described
- Names and contact information of two references.

Stochastic boundary models for inverse problems induced by PDEs

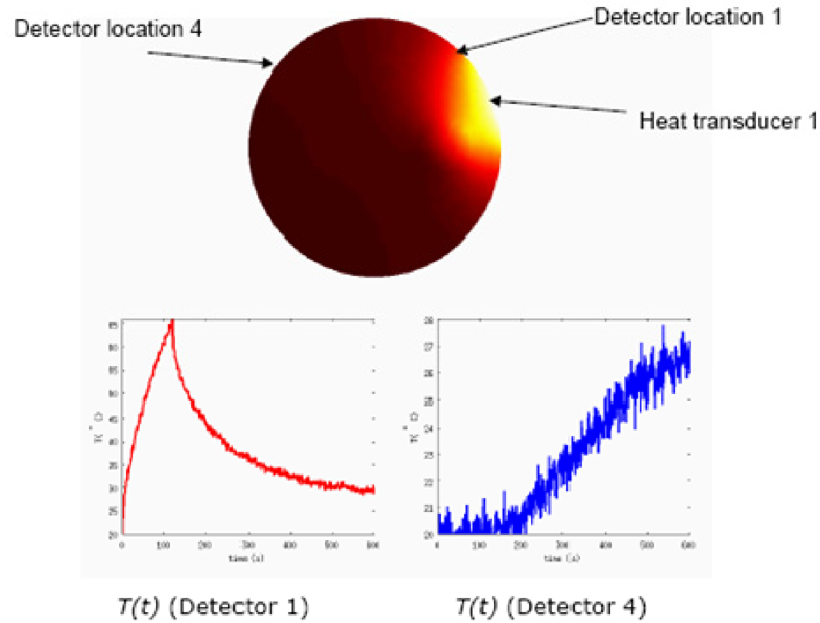
An important practical class of problems that induces inverse problems is parameter estimation in partial differential equations and the related boundary value problems. A primary source of model error is that required boundary values are almost always only partially known. In particular, in practically all real world problems, computational complexity demands that the computational domain is reduced to enclose the volume of interest only, and the boundary data on the resulting truncation boundaries is always unknown. Perhaps the most common cause of failure in computational modeling and data assimilation using real data is the use of infeasible and ad hoc boundary data or models on truncation boundaries.

Recently, our group has been involved in developing a general methodology for treating model errors and uncertainties in inverse problems [Kaipio, Somersalo, *Statistical and Computational Inverse Problems*, Applied Mathematical Sciences 160, Springer, 2005]. This approximation error approach is able to yield computational models that are efficient and stable, and has been shown to enable the reduction of computational complexity for inverse problems induced by partial differential equations. Furthermore, the general framework has been shown to handle a broad range of types of uncertainties and modeling errors, such as severe model reduction, mismodelled anisotropy, and incorrect domain geometry. The approach has also been extended to time-varying inverse problems, induced by parabolic and hyperbolic partial differential equations.

In this PhD project, the aim is to extend the approximation error approach to treat unknown boundary values, especially at truncation boundaries. The main focus is on the construction of the associated nonlocal stochastic boundary operators. As applications of the general methodology we will study cases in electrical impedance tomography, applied to process tomography and geophysical inverse problems in particular.

Supervisors: Prof. Jari Kaipio and Dr. Ville Kolehmainen
Collaborating institutions: Lawrence Berkeley National Laboratory (Berkeley, CA), University of Auckland (Auckland, NZ), Case Western Reserve University (Cleveland, OH), Numcore Ltd (Kuopio, FIN).

Computational methods for thermal tomography

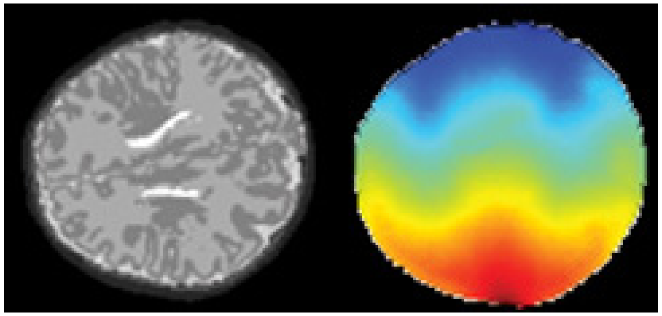


Thermal tomography is a novel imaging technique which derives information about thermal properties of a body using a set of non-invasive heat flux and temperature measurements on the surface of the body. The measurements may be based on either contact or non-contact sensors (e.g. thermal cameras). The applications of thermal tomography include, for example, thermal characterization of novel materials, non-destructive testing and identification of heat sources. Mathematically, the thermal tomography problem amounts to an inverse boundary value problem of estimating the coefficients of the heat equation based on noisy, incomplete boundary data. In a recent study [V. Kolehmainen et al. *International Journal of Heat and Mass Transfer, 50:5150–5160, 2007*], we developed numerical estimation methods for the solution of thermal tomography problem and conducted simulation based feasibility study of thermal tomography assuming a highly "controlled" laboratory setup. The present PhD project aims at developing the computational methods of thermal tomography up to the level that they are applicable to demonstration of thermal tomography in laboratory setting. The project involves both theoretical and experiment oriented tasks, including design of forward models and boundary conditions for relevant measurement configurations, extension of the methods for temperature dependence of the material properties, treatment of modeling errors (e.g. partially unknown boundary data, computational model reduction) by the approximation error theory and verification of the methods with experimental data.

Supervisors: Prof. Jari Kaipio and Dr. Ville Kolehmainen.
Collaborating institutions: Federal University of Rio de Janeiro, University of Auckland.

Development of advanced modelling for optical imaging of the brain

Optical tomography is a modern medical imaging method that can be used to image and monitor the concentrations of oxygenated and deoxygenated hemoglobin by measuring the absorption of near-infrared light transmitted through tissue. The method has important applications in neuroscience, for example in monitoring preborn infant brain oxygenation level and imaging stroke patients. Currently, the use of optical tomography in neuroscientific or clinical studies is not widespread because of limitations of existing implementations in quantitative accuracy, spatial and temporal resolution, and reproducibility. These limitations can be overcome by appropriate developments in instrumentation, modelling and computational methods.



The inverse problems group has developed sophisticated methods for modelling and reconstruction in optical tomography. The developments include efficient numerical methods to model light propagation in tissues and highly advanced inversion methods for image reconstruction. One of the most important recent advances is the development and utilization of the approximation error method in optical tomography [S.R. Arridge et al., *Inverse Problems,* 22:175-195, 2006].

In this PhD project the aim is to develop computational methods for modelling and image reconstruction in optical tomography. The main focus is on the modelling and analyzing of the geometric and other measurement systems related uncertainties and utilization of this information in image reconstruction using the approximation error approach.

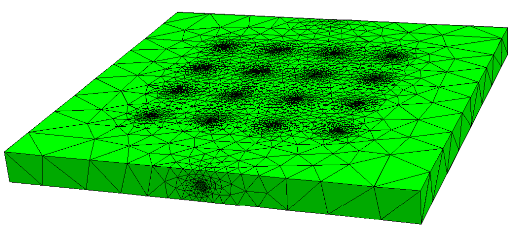
Supervisors: Dr. Ville Kolehmainen, Dr. Tanja Tarvainen, Prof. Jari Kaipio
Collaborating institutions: University College London (London, UK), University of Auckland (Auckland, NZ), Aalto University (Helsinki, FIN)

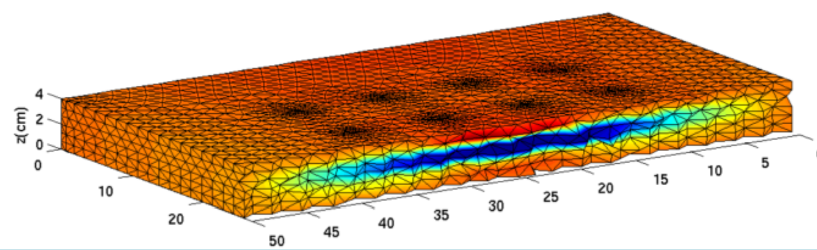
Electrical capacitance tomography imaging of concrete

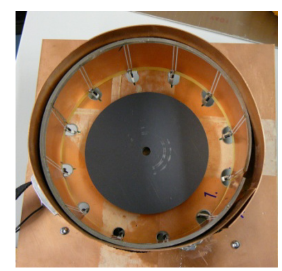
Concrete is distinctly the most extensively used construction material in the world. About 7.5 cubic kilometers of concrete are made every year. Concrete powers a US $35-billion industry which employs more than two million workers in the United States alone. During the life-cycle of concrete, there are several situations necessitating measurement and analysis of the structural integrity and other properties of concrete structures. The activities concerned with the evaluation, repair and restoration of structures are estimated to amount to 35% of the total volume of the work in the building sector and this continues to increase.

In this PhD project, the aim is to develop Electrical Capacitance Tomography (ECT) to non-destructive evaluation of concrete structures [Karhunen et al. Electrical resistance tomography imaging of concrete, *Cement and Concrete Research*, 40: 137-145, 2010]. ECT is an imaging modality in which the three-dimensional distribution of electrical permittivity is reconstructed on the basis of electrical surface measurements. Several properties of concrete possess contrast with respect to permittivity. In this project, the focus is on determining the distribution of relative humidity in concrete using ECT. In addition, the capability of the modality to localization of reinforcing bars, estimating distributions of fibers, cracks and air voids, and assessment of other properties of concrete is studied. The project consists of experimental work and development of image reconstruction methods in ECT (mathematical modeling, statistical and computational inverse problems).

Supervisors: Dr. Aku Seppänen, Prof. Marko Vauhkonen and Prof. Jari Kaipio
Collaborating institutions: University of California, Berkeley (Berkeley, CA), University of Auckland (Auckland, NZ), Aalto University (Helsinki, FIN), Numcore Ltd (Kuopio, FIN).







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Optimal control in geophysical tomographic problems

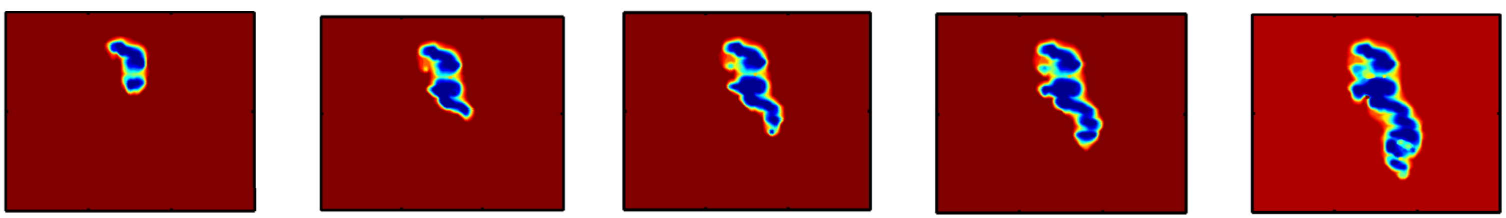
Geophysical tomography refers to the task of estimating the distribution of soil types, water content (saturation) and other parameters in ground. The measurements are usually carried only on the surface but borehole measurements are also sometimes available. The modeling of the measurement setting and the characteristics of the unknowns are riddled with uncertainties, such as including transfer losses of measurement information, exact measurement locations and distribution of uninteresting soil properties.

Of particular interest are the hydrogeophysical properties of soil, that is, how water is transported. This is a central topic in estimating the dynamics of pollutants and other substances. Recently, the bioremediation research has been an active field: how to plant microbes in soil to transform pollutants to less harmful substances. One of the central technical problems here is how to observe and control the remediation process. This task can be posed as an optimal stochastic control problem in which the evolution of a nonlinear dynamic process is observed via tomographic measurements.

We have recently made progress in constructing the related observation and evolution models as well as models for the uncertainties[Lehikoinen *et al*, Dynamic Inversion for Hydrological Process Monitoring Under Model Uncertainties, *Water Resources Res*, in press, 2009]. Some uncertainties, however, require further study.

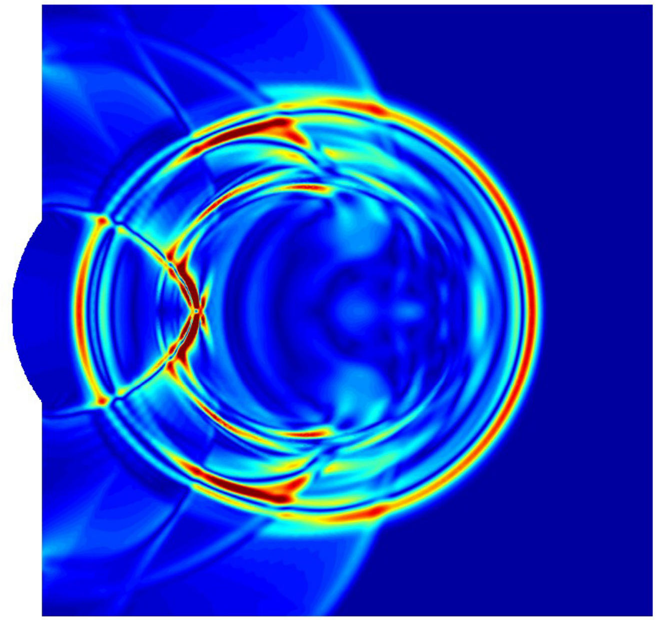
In this PhD project, the aim is to study some of the remaining uncertainties and study optimal stochastic controllers for bioremediation problems. Of particular interest are reduced order models that allow for efficient computational implementations.

Supervisors: Dr. Arto Voutilainen, Anssi Lehikoinen and Prof. Jari Kaipio
Collaborating institutions: Lawrence Berkeley National Laboratory (Berkeley, CA), University of Auckland (Auckland, NZ, Numcore Ltd (Kuopio, FIN).



Computational methods for full-wave inversion

The imaging applications of electromagnetic and mechanical waves range from medical ultrasonics to non-destructive testing and exploration seismology. While these imaging techniques have gained tremendous success, the most image reconstruction algorithms include severe approximations about wave propagation. There are currently a number of relatively efficient computational approaches to solve the forward wave propagation problems (see e.g. [Huttunen, Malinen, Monk, Solving Maxwell's equations using the ultra weak variational formulation, *Journal of Computational Physics*, 223(2), 731-758, 2007]). Unfortunately, these are still too heavy for many practical applications.



For the related inverse problems, however, the solvers don't necessarily need to be extremely accurate. In several cases, the errors may exhibit such statistical properties that the approximation error theory can handle these efficiently [Kaipio, Somersalo, *Statistical and Computational Inverse Problems*, Applied Mathematical Sciences 160, Springer, 2005].

In this PhD project, the aim is to combine efficient forward solvers and the approximation error approach and construct a computational scheme that is computationally feasible for many practical problems. The applications of the project include ultrasonic and microwave imaging methods for the process tomography.

Supervisors: Dr. Tomi Huttunen, Prof. Jari Kaipio
Collaborating institutions: University of Delaware (USA), University of Auckland (Auckland, NZ)

Further information:

All enquiries related to the PhD projects: Arto.Voutilainen@uef.fi

http://physics.uku.fi/research/IP	(Inverse problems group)
http:// wiki.helsinki.fi/display/inverse	(Finnish CoE in Inverse Problems research)
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