TOPICS OFFERED BY PROFESSORS OF THE UNIVERSITY

TOPICS OFFERED BY INDUSTRY

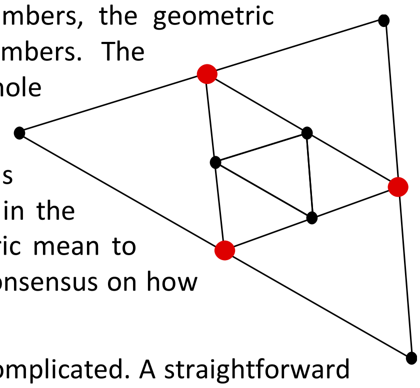
MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
Computing the tensor geometric mean	
GUIDANCE	
• For more information, please contact:	Raf Vandebril & Mario Berljafa
• Promotor:	Raf Vandebril
• Supervisor:	Mario Berljafa

CONTEXT

In many applications the data contain noise or arise from various sources and need to be averaged in some way or another, e.g., in bio-informatics connections between proteins, or in radar technology many sources need to be averaged. If the data are matrices or tensors, translating existing means of scalar numbers to a higher dimension is not necessarily trivial.

The geometric mean of some positive numbers is defined as the n-th root of the product of these numbers. Whereas the arithmetic mean averages some numbers, the geometric mean is more a measure to average ratios between numbers. The geometric mean is therefore a more natural mean for a whole variety of applications.



Unfortunately, due to the noncommutativity of matrices, it is not straightforward to generalize this to matrices. However, in the domains mentioned in the beginning extending the geometric mean to matrices seems the natural thing to do. Nowadays there is consensus on how the matrix geometric mean should be defined.

When going to tensors, however, things become even more complicated. A straightforward way to tackle the problem is to go to the flattening of the tensor, which is putting all data of the tensor in one big matrix. One possible solution in the matrix case is based on computing the centroid of a triangle as shown below. This is likely not optimal for all tensors, but by using the correct approximation of the tensor one can develop some algorithms which should approximate the ``tensor geometric mean''.

GOAL

The aim is to study manifold optimization techniques and/or basic linear algebra routines for tensors by considering the appropriate flattening. Depending on the student's interest the topic can become more theoretical (e.g., matrix structures, tensors), more tailored towards high performance computing, more application oriented (radar technology, averaging biomedical data),…

RESULT

The student has to study the problem of computing the matrix geometric mean. Next we will see what sort of algorithm we want to implement for tensors and test on a specific application.

PROFILE

The student should have a basic knowledge of numerical linear algebra, be aware of the important aspects in scientific computing, such as accuracy, memory, and computing time. The student should also be able to implement the algorithms in, e.g., Matlab.

1 or 2 students	**1 student**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
From CMV to CMR and beyond	
GUIDANCE	
• For more information, please contact:	Marc Van Barel, Raf Vandebril
• Promotor:	Marc Van Barel, Raf Vandebril
• Supervisor:	Marc Van Barel, Raf Vandebril

CONTEXT

Around the turn of the century, the *orthogonal function community* was confronted with, as named by some, a new paradigm: Cantera, Moral, and Velazquez published their new found connection between zeros on the unit circle and pentadiagonal matrices. The impact even resulted in the class of pentadiagonal matrices now bearing their initials: CMV-matrices.

On the other side, the *linear algebraists* were uncomforted by this CMV-hype. These pentadiagonal matrices, and their factorization into essentially 2×2 unitary matrices was introduced twenty years earlier by Ammar, Gragg, and Reichel. Since then this factorization was studied by numerous others, Elsner, Bunse- Gerstner, Watkins, and others. History repeats itself, and again a lack of communication between various disciplines resulted in re-inventions.

In this thesis we will generalize the CMV to CMR: Compressed Matrix Representations. The CMR matrices generalize the CMV case on two fronts. First we will loosen the unitarity constraint, that means a CMR admits a factorization in essentially 2×2 nonsingular matrices named *core transformations*. Second, we will add a diagonal. So CMR matrices can be written as the sum of a diagonal and a product of core transformations.

Specific instances of these matrices have been popping up recently, e.g., in the study of orthogonal rational functions linked to zeros on the unit circle, rational Krylov for unitary matrices, or Krylov for biorthogonal extended Krylov spaces.

GOAL

The aim of this thesis is the study of compressed matrix representations from a linear algebra as well as an orthogonal function viewpoint. We will unravel the intimate connections between CMR's, moment matrices, Krylov subspaces, and orthogonal rational functions thereby fitting many of the existing results in the literature in this new more general framework.

RESULT

The research includes a study of the literature, the development of the theory and the corresponding numerical methods, the implementation and testing of these methods in Matlab, and applying those to nontrivial examples.

PROFILE

Depending on the interest of the student, the focus can be more on theoretical aspects or more on developing and implementation of algorithms.

1 or 2 students	**1 student**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
Positive polynomials and low rank matrices	
GUIDANCE	
• For more information, please contact:	Marc Van Barel
• Promotor:	Marc Van Barel
• Supervisor:	Marc Van Barel
CONTEXT	
Many scientific and engineering problems can be formulated in terms of positive univariate and multivariate polynomials. The set of univariate positive polynomials is equivalent to the set of sum of squares (SOS) polynomials. For the multivariate positive polynomials this is not true anymore but on the other hand, the SOS polynomials are much more easy to work with. They can be represented by low rank matrices where the rank is the so-called Pythagoras number of the SOS polynomial. In this thesis, we will study this link between SOS polynomials and low rank matrices and develop the corresponding algorithms to solve related problems. We will compare these algorithms to semidefinite programming algorithms that are often used to solve the corresponding optimization problems.	
GOAL	
The aim of this thesis is the study of the interplay between SOS polynomials and low rank matrices and their corresponding algorithms.	
RESULT	
The research includes a study of the literature, the development of the theory and the corresponding numerical methods, the implementation and testing of these methods in Matlab, and applying those to nontrivial examples.	
PROFILE	
Depending on the interest of the student, the focus can be more on theoretical aspects or more on developing and implementation of algorithms.	
1 or 2 students	**1 student**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
In search for a globally componentwise backward stable algorithm for solving polynomial equations	
GUIDANCE	
• For more information, please contact:	Marc Van Barel
• Promotor:	Marc Van Barel
• Supervisor:	Marc Van Barel
CONTEXT	
The existing methods to solve polynomial equations that are based on solving a corresponding eigenvalue problem, can be shown to be globally backward stable in a normwise sense on the vector of the coefficients of the polynomial. In a recent paper [1], Matronardi and Paul Van Dooren give a counterexample of a degree 2 polynomial for which no globally componentwise backward stable algorithm can be developed. However, their definition of this type of stability does not take into account the specific properties of the problem of looking for all roots of a univariate polynomial. In this thesis, we will investigate adapted definitions of backward stability that are more strict than the normwise stability but less strict than the componentwise stability. Based on this new definition, corresponding algorithms will be designed with this type of globally componentwise backward stability. [1] N. Mastronardi, P. Van Dooren, Revisiting the stability of computing the roots of a quadratic polynomial, Electronic Transactions on Numerical Analysis. Volume 44, pp. 73–82, 2015.	
GOAL	
The aim of this thesis is the study of the concept of globally componentwise backward stability in the context of solving univariate polynomial equations. Based on a new definition of globally componentwise backward stability, algorithms will be developed that exhibit this type of stability.	
RESULT	
The research includes a study of the literature, the development of the theory and the corresponding numerical methods, the implementation and testing of these methods in Matlab, and applying those to nontrivial examples.	
PROFILE	
Depending on the interest of the student, the focus can be more on theoretical aspects or more on developing and implementation of algorithms.	
1 or 2 students	**1 student**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
Model order reduction and optimization of wind farms	
GUIDANCE	
• For more information, please contact:	Karl Meerbergen
• Promoters:	Karl Meerbergen & Johan Meyers
• Supervisor:	Pieter Lietaert

CONTEXT

The optimization of the controls of a wind farm is a challenging problem. This requires repeated solves of the Navier-Stokes equation within an optimization loop. The solution of the Navier Stokes equation may last days, therefore, any reduction in the number of such large solves is beneficial. This master thesis continues the work on three previous theses.

GOAL

In a follow-up thesis we want to continue the work of the last thesis on the optimization of the driven cavity flow. The method developed in the thesis is not optimal, since it only matches the function values. We wish to go for the next step: a reduced model that matches the function value *and the gradient*, so that optimization can happen even faster.

METHODOLOGY

The student starts reading papers and two master theses that were carried out this year and two years ago. The Matlab software developed in the last thesis can be used to generate the differential equations and POD reduced models for a 2D driven cavity model. Those are a good starting point. The main part of the thesis will develop Matlab code for the adjoint equation and plug this in the reduced model and then the optimization method. If the student is interested in developing a 'real' code, we will be able to solve more realistic 3D problems. Weekly meetings with supervisor and promoters will be held to guide the research.

PROFILE

The work involves some theory and some practical implementations to test the different ideas. Knowledge of computational fluid dynamics (CFD) is not required but may be helpful for understanding the Navier-Stokes equation. Matlab is used by preference, but if the student is interested in solving truly large scale problems, a compilable language may be used in a later stage.

1 or 2 students	**1 student**

MASTER’s THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE

Wavelet-based data analysis for biomedical signals

GUIDANCE

• For more information, please contact:	Daan Huybrechs
• Promotor:	Daan Huybrechs
• Supervisor:	Vincent Coppé, Daan Huybrechs

CONTEXT

Wavelets are a popular tool for image compression and denoising. Compared to Fourier transforms, wavelets offer localization simultaneously in both the time and frequency domain. This also makes wavelets highly suited to analyze non-stationary signals: signals with a frequency content that changes over time. In that context, Fourier analysis can predict which two (or more) frequencies are present in a signal, but wavelets can also inform the researcher where the transition takes place.

In practice, measured signals are noisy and may contain artifacts. For this reason data is usually pre-processed in an application-specific way, often using filters. Furthermore, measured signals are finite and boundary conditions are used to simplify the wavelet transform. Yet, both of these measures potentially influence the subsequent wavelet analysis. The standard boundary conditions correspond to signal extensions which are non-physical. Furthermore, in principle there is no need to filter data a priori since the wavelet transform itself includes low-pass filters.

Data is available from a recent study within KU Leuven involving elderly people with equilibrium difficulties. It is expected that medical imaging data might become available in the course of 2017 from functional MRI and EEG in a study of children with epilepsy, in collaboration with the Maastricht University Medical Center.

GOAL

The goal of this master thesis is two-fold:

- to implement and analyze the effect of more physical boundary conditions for a wavelet transform with finite data, compared to standard signal extensions in available wavelet software

- to design and assess a wavelet-based metric to quantify the extent to which a signal is non-stationary

METHODOLOGY

- Commonly used boundary conditions correspond to different signal extensions in different steps of the wavelet transform. We intend to examine a single extension of the original signal, prior to the transform. This complicates the transform and its inverse slightly, yet can still be described with elementary linear algebra.

- A crude metric for the non-stationarity of a signal is the Shannon entropy of the wavelet coefficients. Improvements may be possible based on wavelet packets, in particular when the latter are adapted to the signal at hand.

- Analysis of actual data can be performed depending on availability, but at least noisy pressure plate data is available. Of interest are the low frequencies in the spectrum, which correspond to different equilibrium mechanisms of the human sensomotorical system.

PROFILE

The thesis is both theoretical and practical. No prior knowledge of wavelets is required, but it is advised to study wavelets very early on in the academic year. The implementation can be in Matlab or in Julia.

1 or 2 students	**1 or 2 students**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE

Coping with geometric complexity in several dimensions via lattice sets

GUIDANCE

• For more information, please contact:	Daan Huybrechs, Ronald Cools
• Promotor:	Daan Huybrechs, Ronald Cools
• Supervisor:	Daan Huybrechs, Ronald Cools

CONTEXT

Computational problems posed on domains with moderate or high geometric complexity, such as a CAD model of a car, require an expensive and time-consuming meshing phase. This leads to low-order piecewise approximations of the solution to the problem. In contrast, a comparatively simpler approach is to embed the domain into a larger bounding box, on which a regular tensor-product basis can be defined. This leads to two new problems: (i) the number of degrees of freedom in a full tensor-product set is large, and (ii) it is not clear how the basis can be used to efficiently approximate a function on the subdomain.

Recent research results in the department offer solutions to both of these problems, independently. The number of degrees of freedom in a multivariate Fourier series approximation can be heavily reduced by the use of so-called lattice sets. Here, the frequencies of the discrete Fourier transform correspond to points on a lattice, rather than on a regular grid. The function approximation problem is best solved with a discrete least squares approximation. An efficient solver is available in case Fourier series are used, and this solver is tested with tensor-product grids. It is written in Julia, a modern dynamic programming language with Matlab-like syntax, but with execution speed comparable to C and C++. It is hoped that the combination of these solutions will make problems tractable up to dimension 5 or 6.

GOAL

The goal is to investigate the use of lattice point sets for function approximation on arbitrary domains in multiple dimensions. The starting point is a Matlab implementation of lattice-based approximations (ChebInt), and a Julia package for computing with Fourier series on complicated domains (FrameFun). The implementation goal is to combine the two. The theoretical goal is to extend a fast approximation algorithm for Fourier series from tensor-products to lattice sets.

METHODOLOGY

The main result of the thesis is a fast implementation of lattice-based Fourier series for the approximation of functions on arbitrary domains. This may enable fast PDE solvers on complicated CAD geometries in the future without the need for meshing.

PROFILE

No prior knowledge of Julia or lattice sets is required. You have an interest in programming, but you don't want to be limited by the speed of Matlab and you don't appreciate the daunting error messages of C++ template programming.

1 or 2 students	**1 or 2 students**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
Teaching the computer how to pronounce words	
GUIDANCE	
• For more information, please contact:	
• Promotor:	patrick.wambacq@esat.kuleuven.be
• Supervisor:	lyan.verwimp@esat.kuleuven.be
CONTEXT	
In speech recognition (and text-to-speech), one of the main challenges is to link sounds to their written variant. A traditional speech recognizer consists of an acoustic model, which determines to what sound ('phoneme') an acoustic signal corresponds, a language model, which determines which word sequences are more likely than others, and a lexicon. The lexicon is an important link between the acoustic model and the language model, because it links phonemes to written words ('graphemes'). The grapheme-to-phoneme ('G2P') system that we are currently using consists of a list of phonetic transciptions for difficult words/exceptions and uses a decision tree based system to generate the pronunciations for the words not occurring in the list [1]. However, recently, neural network-based approaches for G2P are becoming more popular (see for example [2] and [3]). Typically a bidirectional long short-term memory network (a powerful type of neural network with a memory) is used to convert graphemes to phonemes.	
GOAL	
In this master thesis, we will build and try to improve this model for Dutch. We will not only focus on converting graphemes to phonemes, but also on doing the opposite: converting phonemes to graphemes. Thanks to the existence of modular and easily adaptable libraries such as Tensorflow, Keras, Caffe, Torch ..., the neural network will not have to be built from scratch. [1] Demuynck, K., Laureys, T. and S. Gillis. 2002. "Automatic generation of phonetic transcriptions for large speech corpora". In Proc. ICSLP, Vol. 1. [2] Mousa, A. E. and B. Schuller. 2016. "Deep Bidirectional Long Short-Term Memory Recurrent Neural Networks for Grapheme-to-Phoneme Conversion utilizing Complex Many-to-Many Alignments". In Interspeech 2016. [3] Toshniwal, S. and K. Livescu. 2016. "Read, Attend and Pronounce: An Attention-Based Approach for Grapheme-To-Phoneme Conversion". In Workshop on Machine Learning in Speech and Language Processing (MLSLP), Interspeech 2016.	
RESULT	
Improving the G2P will improve the quality of the speech recognition, so this will be the most important application. If there is time and if the student(s) is (are) interested, the G2P can also be tested in a speech interface for KU Leuven's "who-is-who", which will be especially interesting since names are notoriously difficult for a G2P, or for the word list of the Dutch language (also known as "Het groene boekje"), which will enable the user to query for a name (who-is-who) or a word (Groene boekje) by voice.	
PROFILE	
Literature and study - 20%, Implementation - 40%, Experiments - 40%	
1 or 2 students	**1 or 2 students**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
Deep neural speech recognizer for Dutch: from signal to phonemes	
GUIDANCE	
• For more information, please contact:	
• Promotor:	dirk.vancompernolle@esat.kuleuven.be
• Supervisor:	reza.sharaeian@esat.kuleuven.be
CONTEXT	
Speech recognition performance has dramatically increased in recent years. There are two reasons for this. First of all, products have evolved from niche applications to user interfaces for the general public (Siri, Google Now, Cortana, a.o.) providing developers with a wealth of real-life data and user experience. Secondly, the core performance has dramatically increased thanks to the application of deep neural nets (DNNs), especially to build the acoustic models that attribute phoneme probabilities to short segments of signals. Recently even 'super-human' performance has been claimed by Microsoft and IBM on the 'Switchboard' benchmark. While impressive by all means, such claims also have to be read with the necessary scepticism as the research systems were highly overtrained and the error rate of commercial grade technology on the same benchmark is at least 5 times as high. Finally we should stress that the top rated deep neural net systems require thousands of hours of data, tens of thousands of parameters and should be trained on computer farms with thousands of GPUs; this is only feasible for a limited number of languages and applications.	
GOAL	
The goal of this thesis is to approach the DNN training in a stacked approach with generic acoustic feature extractors, universal linguistic feature extractors and finally a language specific layer that maps to the phonemes of a particular language. This should drastically reduce the requirements on data and compute infrastructure, opening up the technology to languages with few speakers, dialects, limited applications, etc. The underlying idea is that the acoustic layer can be pretrained on general acoustic data, that the linguistic feature layer can be pretrained a multitude of languages and that only the last layer needs to be trained with language specific data. Current state-of-the-art multilingual training typically requires further training of ALL layers in the network in order to obtain optimal performance which is contradictory to our goals. It is believed that we can make the initial layers significantly more generic by using a well thought 'multi-task learning' strategy. So instead of optimising the first layer as part of a typical though more compact speech recogniser, we should include other classification tasks as well such as well speech/no-speech discrimination, gender discrimination, and possibly other paralinguistic features. The same multi-task approach will be used to train the generic linguistic layer including multiple languages and diverse materials including formal and spontaneous speech in diverse acoustic backgrounds. The ultimate goal of this thesis is to incorporate it in an existing Dutch transcription system, geared at the transcription of free speech, such as lectures, meetings, etc.	
RESULT	
The ultimate goal of this thesis is to incorporate it in an existing Dutch transcription system, geared at the transcription of free speech, such as lectures, meetings, etc.	
PROFILE	
Literature and study - 20%, Implementation - 40%, Experiments - 40%	
1 or 2 students	**1 or 2 students**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
Deep neural speech recognizer for Dutch: from phonemes to words	
GUIDANCE	
• For more information, please contact:	
• Promotor:	patrick.wambacq@esat.kuleuven.be
• Supervisor:	lyan.verwimp@esat.kuleuven.be
CONTEXT	
Recently, artificial neural networks haven taken over the field of machine learning, achieving excellent performance on a multitude of different tasks. In speech recognition too, they have replaced the traditional models i.e. the acoustic model and the language model. Whereas the acoustic model estimates the probability of sound units (phones) given a waveform, the language model estimates how likely a sequence of words is observed in a given target language. Although neural networks are currently the state of the art for both models, they do come with one practical disadvantage: training these models requires a lot of memory and computing power. In language modelling, where a target word is predicted based on the already observed history of words, the current state of the art consists of recurrent neural networks (RNNs) which are very popular when it comes to sequence modelling. Instead of explicitly defining the length of the history, an RNN keeps track of a state which is updated based on the current word and the previous hidden state. This recurrent connection essentially gives the model a memory that in theory could remember the entire history. However, keeping track of this memory, learning the parameters of the model and estimating a probability estimation over the possible target words often requires days if not weeks of processing on Graphical Processing Units (GPUs) which are optimized for this type of computations. This is especially true when the set of possible target words - the vocabulary - and the training data are large. How this computational burden should be solved is still very much under investigation in the research community.	
GOAL	
This thesis is an attempt to contribute to this ongoing investigation and an opportunity to improve the current state of the art. The goal of this thesis is to develop a state-of-the-art neural network language model for Dutch and, more importantly, to investigate whether and how we can scale this model to large vocabularies and training data.	
RESULT	
The student is expected to: 1. find an upper bound on the vocabulary size such that an RNN language model can still be trained in a reasonable amount of time; 2. investigate different techniques such as sampling or approximation techniques in an attempt to surpass this upper bound; 3. investigate how these models can further be optimized to handle very large datasets; 4. apply this language model to a Dutch speech recognizer to achieve state-of-the-art performance.	
PROFILE	
Literature and study - 20%, Implementation - 40%, Experiments - 40%	
1 or 2 students	**1 or 2 students**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
Solving the cocktail party problem using deep neural networks	
GUIDANCE	
• Promotor:	hugo.vanhamme@esat.kuleuven.be
• Supervisor:	jeroen.zegers@esat.kuleuven.be

CONTEXT

For many years the cocktail party problem has been considered the holy grail of speech processing. To solve the cocktail party problem, the speech signals of all speakers that are being recorded by a single microphone have to be retrieved. However, people can speak simultaneously, which makes the source (or speaker) separation problem very hard. Furthermore, most applications require the separation algorithm to be speaker independent, which means that no prior information on the speaker is known. If we would be able to determine speech tracks for every speaker present, this would be a great help in applications such as hearing aids, automatic transcriptions of meetings and natural language interfaces such as Siri, Google Now, Corona and so on.

Recently (2016), major steps have been made in solving the cocktail party problem using Deep Neural Networks (DNNs). In general, DNNs try to retrieve high level features from low level (or input) features, using multiple layers of hidden units. For this task we want to know which parts (time-frequency bins) of the recorded audio spectrogram belong to which speaker. This can be done by training a network that maps each bin of the audio spectrogram to a so called embedding space where afterwards a clustering mechanism is used to assign bins to the corresponding speaker. Impressive results are achieved. However, the generalizability and robustness of this technique can be questioned. The multi-speaker mixture is artificially created by mixing together two or more independent utterances. These utterances come from the Wall Street Journal (WSJ) database, where studio recordings are made of sentences from the Wall Street Journal being read out loud. It is unclear how the DNN would perform in other scenarios where one or more of the following changes are made:

- Microphone: Different microphones have different transfer functions in the frequency domain. For example, there will be differences in the spectrogram of a mixture recorded with high quality microphone compared to a (cell)phone.
- Reverberation: How well does the DNN cope with reverberation? Is there a difference between outdoors and indoors? How much reverberation can be allowed?
- Read versus spontaneous speech: The WSJ database consists of read sentences. The way we talk in spontaneous manner is different from the way we read out loud.
- (Non-) stationary noise: In the original experiments of [1], there are no added noise sources but only speech. Does speech source separation still work in the presence of stationary noise (e.g. a fan) and non-stationary noise (refrigerator, construction site, music, …)?

GOAL

In the first phase you will try to analyse whether the DNN struggles towards robustness. Since this technique is new, little research has already been done. Afterwards you will research how to adapt the network to increase performance in these more realistic scenarios. Experiments will be done using TensorFlow, a toolkit for research using DNNs. Baseline code will be provided.

RESULT

A robust system which takes a mixture signal as input and outputs two separated source estimates for a broad scale of applications.

PROFILE

Literature - 20%, Analysis and problem statement - 40%, Implementation and experimenting - 40%

1 or 2 students	**1 student**

MASTER’s THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE

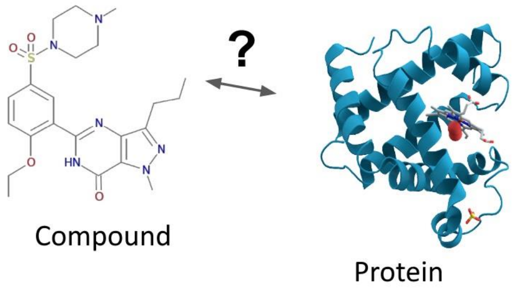
Collaborative filtering with Graph information for Chemogenomics

GUIDANCE

• For more information, please contact:	Joris.Tavernier@cs.kuleuven.be
• Promotor:	Karl Meerbergen, Dirk Roose
• Supervisor:	Joris Tavernier

CONTEXT

Recommender systems play an important role in consumer applications and are used by e.g., Amazon, Netflix, YouTube, ... The data in these applications consists of incompletely filled matrices, for example item-user rating or movie-user rating. The goal is to predict the unknown values to complete the matrix.



Similar recommender systems are used in the pharmaceutical industry. Here, a large-scale incomplete filled matrix contains information on the activity of chemical compounds on targets. Knowledge of these activities (“chemogenomics”) is important for the development of new drugs. For a limited set of compound-target pairs, the activities are known from biological assays. Since performing such biological assays is expensive, the completion of the matrix by experiments in vivo is unfeasible. Recommender systems can help to predict compound-target activity pairs and to guide additional biological assays.

GOAL

Side information can be added to the recommender system in the form of a graph of the variables and improve the predictive performance. For chemogenomics data a graph can be efficiently constructed for the chemical compounds using the substructures of the compounds. The student will investigate collaborative filtering with graph information for chemogenomics. The project involves large-scale data and optimization methods.

METHODOLOGY

Starting from recent literature, the student can further investigate how to incorporate the side information by investigating different graphs and similarity measures. The student will learn about techniques from optimization, high performance computing and machine learning.

PROFILE

The main part is practical implementation within the High Performance Computing framework. In the beginning MATLAB can be used for small tests, but the developed techniques should be implemented in a compilable language and tested on an actual industry-scaled data set. Courses that may be selected in the framework of the thesis: parallel computing, bio-informatics, machine learning …

1 or 2 students	**1 student**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

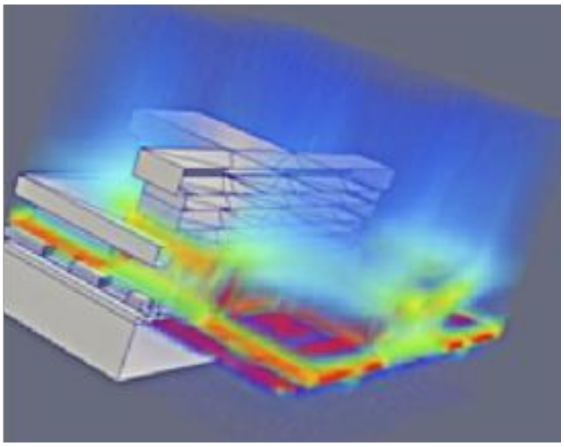
TITLE

Can we solve ill-conditioned linear systems arising from semi-conductor simulations?

GUIDANCE

• For more information, please contact:	Karl Meerbergen & Raf Vandebril
• Promoters:	Karl Meerbergen & Raf Vandebril
• Supervisor:	Daan Camps & Mario Berljafa

CONTEXT



Large scale linear systems arising from real life computations in industry are often ill conditioned. Amazingly, methods based on LU-factorization with partial pivoting compute relatively accurate solutions of systems with condition numbers of the order of 10^{16}. Iterative methods such as the conjugate gradient method often fail although the residual norm is relatively small. This behaviour is observed in many different applications: semiconductor devices, acoustics, structural analysis … We have access to such linear systems by the company Magwel N.V. in Leuven.

GOAL

The goal of the thesis is to understand why a very ill-conditioned large scale linear system can be solved by LU-factorization where iterative methods fail. As a side result, the thesis may give suggestions on how to improve iterative methods so that they do not fail.

METHODOLOGY

The work will start by comparing various linear system solvers for a variety of linear systems in Matlab, including well-conditioned and ill-conditioned systems, for different choices of the right-hand side. From these experiments, we will look for a pattern, and from there on try and understand why we see what we see. The next step is to strip the matrix and look at its structure, look at the right-hand side, the structure of the errors in the solution and try and understand the behaviour. The student will work in close collaboration with the supervisors and promoters and will meet with them on a weekly basis to discuss progress and exchange ideas.

PROFILE

This master thesis will require a mix of skills:

- Some practical work: solving the linear systems in Matlab or other language of choice
- Interest in analysing matrices and their properties

1 or 2 students	**1 student**

MASTER’s THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
Fourier series and Fourier frames on a triangle	
GUIDANCE	
• For more information, contact:	Marcus Webb, Daan Huybrechs
• Promotor:	Daan Huybrechs
• Supervisor:	Marcus Webb
CONTEXT	
To numerically approximate a periodic function on an interval, Fourier series can be employed with great speed and accuracy, but when the function is not periodic, the convergence is too slow. The method of Fourier frames, where the nonperiodic function is approximated by a Fourier series which is periodic on a larger interval, has been developed in the department, and provides a fast and accurate approximation. Although this solves the issue, great care must be taken because we work with a redundant set of functions — a frame, not a basis. For functions defined on a 2D domain, there is much current research on fast and accurate approximation algorithms, but it remains a challenge except when the domain is simple, like a rectangle or a circle. In this thesis we use generalisations of Fourier series to a triangle, which can provide algorithms for domains approximated by a polygon (by triangulating the polygon). The generalised Fourier series are simply explicit expressions for the eigenfunctions of Laplace’s equation with boundary conditions on the triangle (just like sin(kx) and cos(kx) are eigenfunctions of the second derivative with periodic boundary conditions). When the function does not satisfy the boundary conditions, the convergence of the approximation is too slow, and a new approach will be to generalise Fourier frames to triangle domains.	
GOAL	
The goal of this thesis is to develop algorithms for approximating functions defined on a a triangle, which lead naturally to algorithms for functions on polygons and more general domains. The approach is by a generalisation of Fourier series to the equilateral triangle, and then Fourier frames on an equilateral triangle.	
METHODOLOGY	
The thesis starts with a literature study of approximation of functions by Fourier series and Fourier frames in 1D, and how Fourier series generalise to triangles. Simple software to approximate a given function by a Fourier series on an interval and a triangle is implemented and the drawbacks of these approaches are shown by experiment. The essential goal of the thesis is to write software for Fourier frames on an equilateral triangle, and perform numerical experiments exploring the convergence of approximation errors and timings for different functions.	
PROFILE	
Some knowledge of Fourier series or signal processing is essential. Good programming skills are necessary. Basic numerical linear algebra is desired but not necessary. The supervisor Marcus Webb can only advise the project in English.	
1 or 2 students	**1 student**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE

Multidimensional system theory and its challenges

GUIDANCE

• For more information, contact:	bob.vergauwen@esat.kuleuven.be
• Promotor:	bart.demoor@esat.kuleuven.be
• Supervisor:	bob.vergauwen@esat.kuleuven.be

CONTEXT

In recent year the next big revolution in system theory has been initiated, the step to a **multidimensional system description**, or nD systems. Multidimensional systems are systems characterised by signals who depend on **several independent variables**. These variables could be for example time and space. In recent years a number of results have been developed around this idea. A handful of **nD state space models** can be found in the literature such as those proposed by Roesser, Attasi, Fornasini and Marchesini. A summary and generalisation of these models is presented by Kurek. All of the previous models differ in **the way that the inputs are introduced.**

GOAL

At the moment a new input-output model for linear nD systems is developed at STADIUS. To derive this model we started from the **Dreesen model**, this is an **nD autonomous** system. To include the inputs we notice that every discrete impulse generates a corresponding **Green's function.**

For a full description of an nD state space model there are still a lot of challenges to overcome. The model proposed by me can only handle **homogeneous boundary conditions**. The next step is to include a general set of boundary conditions into the equations. After this extension, **corresponding realisation algorithms** have to be developed to estimate the model from a given dataset. At the moment the **model estimation** is only possible in the autonomous case. Research for **subspace methods** to estimate the full model are being developed.

METHODOLOGY

In modelling nD dynamical systems from data, there are two extreme approaches: modelling from **first principles** and **black box modelling**. First principles modelling starts from physical laws (e.g. conservation of energy) and leads to Partial Differential Equation (PDEs) (such as heat and diffusion equations, evolution equations, etc.), which can be simulated once boundary and initial conditions are known. Black box modelling, such as **deep learning** or **Support Vector Machines** proceeds from nonlinearly parameterised models (such as neural networks or kernels), that 'fit' the data, but that do not provide any further physical insight.

The approach followed in this research proposal is to use **nD-state space models based on the structure of linear partial differential equations.**

PROFILE

There are still **a lot of open question** related to the research on nD systems theory and identification. Some general prerequisites are,

- **System theory/system identification**
- Knowledge of **Partial differential equations**/Greens functions
- Matlab/python or a similar programming language

1 or 2 students	**1 student**

MASTER’s THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
Clustering time series: A novel algorithm revisited	
GUIDANCE	
• For more information, please contact:	oliver.lauwers@esat.kuleuven.be
• Promotor:	Prof. Bart De Moor
• Supervisor:	Oliver Lauwers
CONTEXT	
An important topic in many different disciplines and fields is the clustering of time series. Whether you have to process biomedical, financial or demographics, this type of data is ubiquitous. Very often, we need a notion of how similar or close two time series are. Many distance and similarity measures are already available, mainly divisible in three classes, based on the data domain they are defined on. First of all, we can act directly on the raw data, and use more traditional metrics like the Euclidean distance. A second class of time series is based on features of the data, mainly correlation-like properties. Lastly, we can look at a set of distances based on models of time-series. In this last category, we do not really define a distance on time series as such, but rather model the time series (for example as an ARMA process, or a dynamical system), and look at distances between these processes. These measures, more so than the other two classes, are very good at capturing the dynamics and structure of the time series, which is often our most important interest in time series clustering. It is an example of the last class of measures that interests us in this thesis. Following some work done by Dr. Katrien De Cock, Professor Bart De Møor and one of your predecessors as master thesis student, we will look at the cepstral distance between ARMA processes and a novel algorithm that provides an on-line equivalent of this metric.	
GOAL	
Prototypes of the algorithm mentioned above for certain model classes were implemented in a previous thesis project. Now, we will go deeper into improving the algorithm (both by including more model classes and by scaling the algorithm), and into the applications part of the research.	
METHODOLOGY	
This algorithm, in short, works as follows. Given a list of time series, we model the first one as an ARMA process with a white noise input. We then find the inverse model of this process, and proceed to apply this inverse model to all other time series in the set. If a time series, when run through the inverse model of another, gives a result that resembles white noise “close enough”, we will consider these time series similar, and belonging to the same cluster. When the time series does not produce a “white enough” result, we iterate the algorithm, with the ARMA process built from this new time series, until all-time series are clustered.	
PROFILE	
We are looking for a student who does not mind getting his hands dirty on implementing different clustering algorithms (in any scientific programming language, like Matlab, Python, …), and has a healthy intellectual interest in time series and their properties. An interest in an application domain with many time series data (like economics and finance) is an added bonus.	
1 or 2 students	**1 or 2 students**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

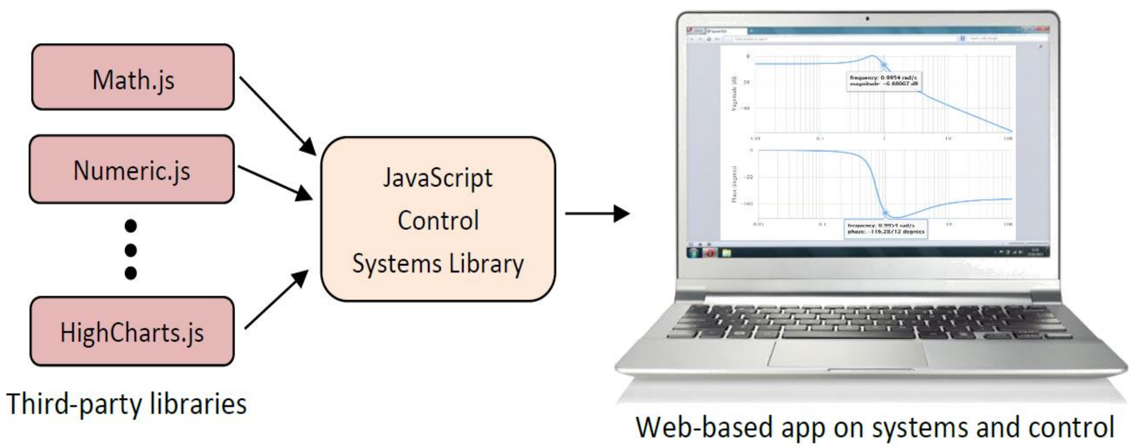
TITLE	
Development of a Javascript library for the analysis and design of feedback control systems	
GUIDANCE	
• For more information, contact:	mauricio.agudelo@esat.kuleuven.be
• Promotor:	Prof. Dr. Bart De Moor
• Supervisor:	Dr. Oscar Mauricio Agudelo Msc. Supinya Piampongsant

CONTEXT

Massive Open Online Courses (MOOCs) have become the most recent development in distance education. A MOOC is a model for delivering learning content online to any person who wants to take a course, with no limit on attendance. Typically MOOCs use traditional course materials such as videos, readings, and problem sets as well as interactive user forums aimed to build a community for students, professors and teaching assistants. For the specific case of a MOOC on systems and control, it is vital to count with web-based tools that facilitate the analysis, design and simulation of feedback control systems. Alongside HTML and CSS, JavaScript, a high-level interpreted programming language, is one of the three essential technologies of World Wide Web content production; the majority of websites employ it and it is supported by all modern web browsers without plug-ins. Although there are thousands of JavaScript libraries that make easier the development of web-based applications, there is not a single library that implements basic operations for the analysis and design of feedback control systems. Therefore the development of demos, and in general of web-based applications on systems and control is quite time-consuming and cumbersome.

GOAL

The aim of this project is to develop a Javascript library for the analysis, design and simulation of feedback control systems.



The library should provide a basic functionality to work with SISO (Single-Input Single-Output) LTI (Linear Time Invariant) systems in both the continuous and discrete-time domains. Among other things, the library should allow the user to:

- Create transfer function, zero-pole-gain and state-space models in both continuous and discrete-time.

- Connect Linear models in different ways (Series, Parallel, feedback, …).
- Generate the pole-zero map and compute the poles and zeros of a given transfer function.
- Calculate and visualize the step response, the impulse response, the initial conditions response (state-space models), and the response to an input defined by the user of a given linear system.
- Compute and visualize the frequency response of a system via Bode and Nyquist plots
- Determine the phase and gain margins
- Generate the root locus plot of a given system
- Display the transfer function or state-space representation using MathJax
- Convert the continuous-time models into their discrete-time equivalents and vice versa using several methods (zero-order-hold, Tustin rule, Backward rectangular rule, etc.)
- Create PID controllers
- …

The functions should be in line as much as possible with the ones available in the MATLAB Control system toolbox. The library should be constructed in such a way that future expansions can be easily made; For example, it is desirable that MIMO systems and state-space control system design techniques can be added in the future. The candidate is permitted to use any free (for non-commercial use) third-party library that he/she considers necessary such as Math.js (an extensive math library for JavaScript), Numeric.js (for sophisticated numerical computations), HighCharts.js (for plotting and visualization), MathJax, etc. At the end of the project, the candidate should create a website (it will be hosted in the STADIUS/SMC servers) where the library as well as the user manual and other supporting material such as demos should be available.

KIND OF WORK

Literature 30% / Programming 70%

PROFILE

Good knowledge on web application development (Javascript, HTML, etc.), control theory and dynamical systems, MATLAB, and some basic knowledge on numerical analysis, and linear algebra.

1 or 2 students	**1 student**

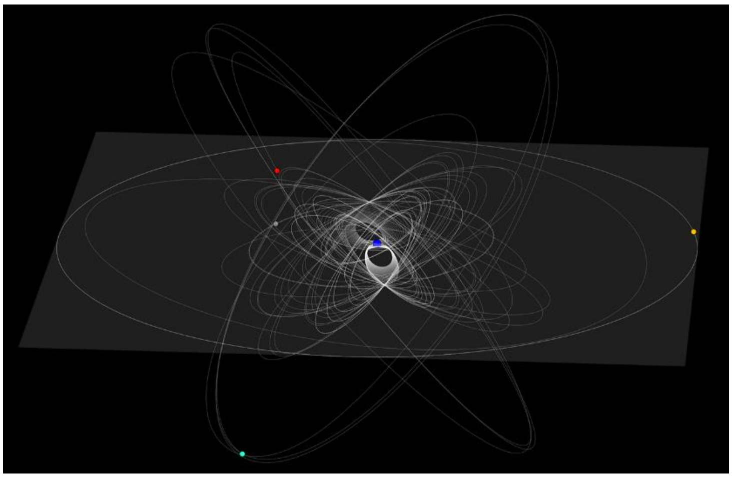
MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
Robust optimization by means of Powel-Sabin splines	
GUIDANCE	
• For more information, please contact:	Goele Pipeleers
• Promotor:	Stefan Vandewalle and Goele Pipeleers
• Supervisor:	Erik Lambrechts
CONTEXT	
While many engineering problems are nowadays translated into a mathematical optimization problem, the associated numerical data are often inaccurate or uncertain. As this uncertainty of data may turn the numerical optimum into a poor or even unacceptable solution for the true problem, there is a great push for robust optimization techniques suited for engineering applications. Robust optimization seeks a solution that is feasible for all possible values of the numerical data and gives the best worst-case performance. As the data is generally considered to vary in infinite sets, robust optimization problems are numerically intractable in general. Therefore most problems are currently relaxed —that is: replaced by a tractable, yet conservative approximation— by means of Pólya's theorem or sum-of-squares certificates of positivity. As these approaches suffer from limited applicability or high computational load, we have recently developed a novel relaxation scheme based on tensor-product B-splines and their properties. This approach has already been show very powerful in solving robust control and optimal control problems. To facilitate the usage of the novel relaxations a software toolbox for efficient spline manipulations and optimization is being developed (C++ with Python and Matlab interfaces through SWIG).	
GOAL	
In this master thesis you will extend the spline based robust optimization approach with relaxations based on Powel-Sabin splines. These splines are naturally defined on polyhedral sets and hence, for such uncertainty sets relaxations based on Powel-Sabin splines are expected to outperform the current ones based on tensor-product splines. The thesis involves practical as well as theoretical parts: – extension of the current toolbox with an efficient implementation for Powel-Sabin splines, – analysis of the conservatism of the relaxation as a function of its complexity (number of constraints), – derivation of appropriate refinement strategies to reduce conservatism, – comparison with existing relaxation approaches on various robust optimization problems.	
RESULT	
A new methodology for deriving relaxations of robust optimization problems based on the properties of Powel-Sabin splines that is (i) complemented with an efficient toolbox to supports its use in practice; (ii) thoroughly analysed and compared to existing approaches; and (iii) evaluated on various robust optimization problems.	
PROFILE	
The thesis focusses on practical software implementation, but also includes theoretical parts.	
1 or 2 students	**1 student**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
ESA Global Trajectory Optimization Competition	
GUIDANCE	
• For more information, please contact:	Goele Pipeleers
• Promotor:	Goele Pipeleers and Panos Patrinos
• Supervisor:	Joris Gillis

CONTEXT



The ESA Global Trajectory Optimization Competition (GTOC) is an event taking place every one-two years over roughly one month during which the best aerospace engineers and mathematicians worldwide challenge themselves to solve a "nearly-impossible" problem of interplanetary trajectory design. Space may be infinite, but certain trajectories are much more efficient in terms of energy and time expended to perform particular tasks. To give an idea of the type of challenge involved, GTOC-8 – as seen in the image – asked participants to line up different spacecraft as efficiently as possible to perform 'very-long baseline interferometry': precisely combine their individual observations through long-distance formation flying, in order to acquire an imaging resolution equivalent to a single, giant radio telescope. More information on ESA's GTOC can be found: https://sophia.estec.esa.int/gtoc_portal.

GOAL

In this master thesis you will take up the challenge of this year's competition (GTOC-9, April 2017) and try to beat the winning solution.

METHODOLOGY

You will both model, analyse and solve the problem, and compare your solution to the winner of the competition. On the modelling you will be supported by the expertise of the aerospace research team of the Dept. of Mechanical Engineering, who are mainly active in the field of attitude determination and control of earth-orbiting satellites. They will guide you with questions on the overall space environment and on orbit propagation models. The trajectory optimization part of the assignment will be supported by the numerical optimization an optimal control expertise of prof. Panos Patrinos (Dept. of Electrical Engineering) and prof. Goele Pipeleers (Dept. of Mechanical Engineering) and their teams.

PROFILE

The focus is on software implementation (Python / C++) in order to model, analyse and solve the problem. Knowledge on numerical optimization is essential.

1 or 2 students	**1 or 2 students**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

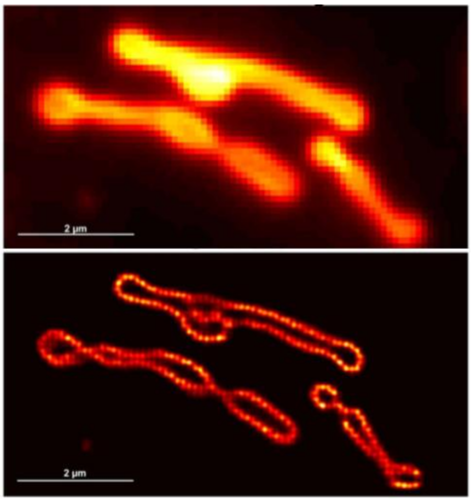
TITLE

Optimization based image processing for fluorescence microscopy

GUIDANCE

• For more information, please contact:	Panos Patrinos
• Promotor:	Panos Patrinos, Goele Pipeleers, Peter Dedecker
• Supervisor:	Andreas Themelis

CONTEXT



Fluorescence microscopy is the method of choice for the highly sensitive and non-invasive imaging of live cells (human or otherwise). Using this approach, individual molecules tagged with fluorophores can be followed with a spatial resolution down to a few hundreds of nano-meters and a temporal resolution down to milliseconds or better. However, life is structured at much smaller length scales, down to ten nanometers or less. This structuring is highly essential because it allows the cell to limit and/or guide the interactions and chemical reactions that occur. In fact, this spatial regulation is thought to be one of the essential aspects of life. However, this level of spatial information is difficult due to the inherently limited spatial resolution of fluorescence imaging that arises due to diffraction of light. In technical terms, the diffraction of light causes the molecules to be imaged as much larger shapes on the detector. More mathematically, the spatial distribution of the fluoro-phores is convolved with the point spread function, which is the impulse response of the imaging system. However, the past few years have seen the development of 'smart' fluorophores, that deliver controllable fluorescence. Using these labels, we can rapidly acquire many images from the same sample, where only a low but dynamic number of emitters is active at any given time. This allows direct numerical analysis of the acquired data via deconvolution. However, because the acquired data is always noisy, this deconvolution is non-trivial.

GOAL

Develop novel optimization based deconvolution methods for fluorescence imaging.

METHODOLOGY

Within the group of prof. Panos Patrinos new algorithms for optimization problems related to structured approximations (e.g. L1/L0 norm, total variation, nuclear norm, rank constraints,…) have been developed. Preliminary tests have revealed large potential of these algorithms to enable enhanced images with a much higher spatial resolution. However, this calculation is highly challenging to carry out and remains a clear obstacle to widespread use. You will continue upon these initial results and implement efficiently novel, matrix-free algorithms tailored to the image deconvolution problem.

PROFILE

The thesis comprises theoretical analyses of the optimization algorithms, as well as their numerical implementation and their application to the fluorescence image processing. In collaboration with prof. Peter Dedecker actual fluorescence microscopy experiments may be performed.

1 or 2 students	**1 or 2 students**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE

Fast methods for solving matrix distance problems

GUIDANCE

• For more information:	Wim Michiels
• Promotor:	Wim Michiels, Karl Meerbergen
• Supervisor:	t.b.a.

CONTEXT

Distance problems receive an increasing interest in several fields of science and engineering, driven by the importance from both a theoretical and application point of view. Mathematical models for dynamical systems are namely characterized by uncertainty on parameters. An important question is then how large the uncertainty on the mathematical model can be without losing a desired property such as stability (called distance to instability), a level of performance or robustness.

In this thesis we focus on eigenvalue problems with uncertainty, which arise in the frequency domain description of linear systems. Existing methods for the associated distance problems are computationally demanding, limiting the applicability to small-scale model problems.

The thesis fits within a collaboration with Prof. Emre Mengi (Koc University, Istanbul).

GOAL

Recently, a fast iterative method has been proposed for computing the distance to instability, which relies on solving a so-called optimization problem. In the set-up, it is assumed that the uncertain parameters are complex valued. This simplifies the analysis significantly, but is not realistic from an application point of view. Combining recent advances in linear algebra and control theory indicates that it is possible to relax this stringent assumption.

The goal of the thesis is two-fold:

- to analyse this method, to implement it and compare with existing methods;
- to extend this method from complex valued to real valued uncertain parameters.

Nonlinear eigenvalue problems are important in mechanical and civil engineering applications (noise and vibrations), systems and control (handling feedback delays) and quantum-physics (computing bound states), just to mention a few.

METHODOLOGY

1. Study of the literature, analysing the method, implementation and benchmarking
2. Extension from complex to real valued uncertainty
3. Validation on an application from mechanical engineering.

PROFILE

Both a theoretical and implementation component, the theoretical component is the most challenging. Software in MATLAB

Prerequisite: basic matrix computations. It can be useful to take the course "Numerical linear algebra" in the 2nd master.

1 or 2 students	**1 student**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

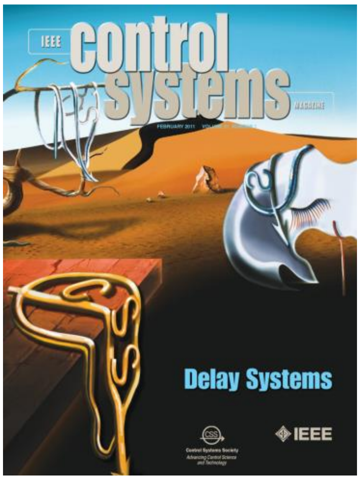
TITLE

Numerical methods and software for analysis and control of time-delay systems

GUIDANCE

• For more information:	Wim Michiels
• Promotor:	Wim Michiels
• Supervisor:	Wim Michiels

CONTEXT



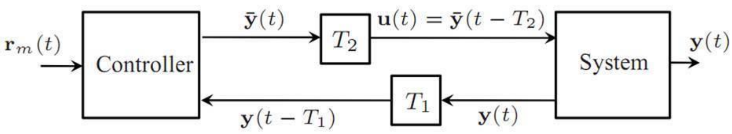
Time-delays are important components of many systems from engineering, economics and the life sciences, due to the fact that the transfer of material, energy and information is mostly not instantaneous. They appear, for instance, as computation and communication lags, they model transport phenomena and heredity, and they arise as feedback delays in control loops. Applications range from traffic flow control and lasers with phase-conjugate feedback, over (bio)chemical reactors and cancer modelling, to tele-operation, control of communication networks such as the internet and networked control. In the last decade an increased research activity on methods and algorithms for analysis and control of delay systems can be observed.

[1] Michiels, W., Niculescu, S.-I. Stability, control, and comptation of time-delay system, 2nd edition, SIAM Publications, 2014.
[2] Gumussoy, S. Webinar on Time-Delay Systems: Analysis and Design with MATLAB and Simulink, http://nl.mathworks.com/videos/time-delay-systems-analysis-and-design-with-matlab-and-simulink-81948.html

GOAL

The aim of the thesis is to develop a software package for analysis, control and optimization of a broad class of dynamical systems with delays.

This thesis concerns research with a high potential impact. In various application areas there is namely a large need for fast and reliable software. Mathematical models with delays are omnipresent, and in many areas significant advances can be obtained by complementing analytical, qualitative studies with accurate simulation and optimization. Existing numerical algorithms for systems with delays are scattered over different research fields, and they mostly restrict to a small class of systems, while existing software is still in a stage of "research codes".



METHODOLOGY

In a first stage a thorough study of dynamical systems with delays and existing algorithms and software for analysis and control is made, with a lot of attention paid to the applicability and limitations. Subsequently all steps in a software design are taken: conceptual design, architecture, representation of systems, functionality … to the implementation and validation on model problems. The implementation is in MATLAB.

PROFILE

A strong interest in computational mathematics, in particular numerical linear algebra (=matrix computations) and optimization, is needed. The implementation component is important.

1 or 2 students	**1 student**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE

Tensor-based algorithms for learning latent variable models

GUIDANCE

• For more information, please contact:	Nick Vannieuwenhoven, Karl Meerbergen
• Promotor:	Nick Vannieuwenhoven, Karl Meerbergen
• Supervisor:	Nick Vannieuwenhoven, Karl Meerbergen

CONTEXT

Tensor decompositions are a novel approach for learning the parameters of a wide array of latent variable models, such as exchangeable topic models, independent component analysis (ICA), naïve Bayes, Gaussian mixtures, and hidden Markov models (HMMs). Even neural networks can be trained under suitable assumptions. The approach consists of estimating the kth order moment tensor of these models from the input data and then computing a tensor rank decomposition.

A kth order moment tensor is an array with k indices. It turns out that several latent variable models admit a very specific structure in their 3rd or 4th order moment tensor, namely they correspond with a tensor rank decomposition. Such a decomposition is comparable with a singular value decomposition of a matrix, but one that applies to higher orders as well. Computing the tensor rank decomposition then yields the hidden parameter values of the model.

Having obtained the parameters of the model via the tensor method, it can be employed for a variety of machine learning tasks. For instance, even the simplest exchangeable topic models may be employed for document clustering.

GOAL

Design and implement a clustering algorithm by computing a tensor decomposition of the fourth-order moment tensor of the data.

METHODOLOGY

Depending on the interests of the student(s), the research could focus on several issues ranging from investigating several latent variable models and their tensor structures, optimization of the tensor decomposition algorithm, or investigation of the tensor-based method versus classic expectation-maximization for learning parameters. This could lead to questions such as:

- For which problems are the assumptions of the tensor-based clustering algorithm accurate?
- How do the algorithms for computing the tensor decomposition perform? Which algorithm is best?
- How does the algorithm scale in terms of memory and time? What optimizations should we use in practice? Can we exploit parallelism?
- How well are the parameters of the model learned with respect to expectation-maximization?
- How does the algorithm compare with, e.g., k-means clustering on a particular clustering problem?

To answer these questions, the student will:

- Study the relevant literature
- Design and implement a basic tensor-based algorithm for learning latent variable models
- Optimize memory and time complexity
- Evaluate the algorithm on model problems (e.g. document clustering)
- Compare with another general-purpose clustering algorithm such as k-means clustering

PROFILE

Both theoretical and implementation-oriented approaches are possible.

1 or 2 students	**1 or 2 students**

MASTER’s THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
Spectral clustering of sparse graphs	
GUIDANCE	
• For more information, please contact:	
• Promotor:	Prof. Johan A.K. Suykens
• Supervisor:	Dr. Michael Fanuel
CONTEXT	
Clustering sparse graphs is currently an active domain of research. Spectral methods based on Laplacian-type matrices have been very successful in the context of dense graphs. However, the eigenvectors of these matrices are often too localized in the case of sparse graphs. Many methods have been proposed in the literature to circumvent this problem by applying for instance regularization techniques. See, for instance, the following references: Tai Qin and Karl Rohe, Regularized Spectral Clustering under the Degree-Corrected Stochastic Blockmodel, NIPS 2013 Pan Zhang, Robust spectral detection of global structures in the data by learning a regularization, NIPS 2016	
GOAL	
Often, the graphs studied are built with the so-called stochastic block model which is convenient for a statistical analysis. In reality, graphs can differ from this model. The first goal of this thesis would first be to empirically compare several existing methods and identify in which case each of them would be more efficient or instructive. The benchmarks could be both artificial and real datasets. Thanks to the understanding gained in this first phase, the second goal would consist in the development of an algorithm to deal with realistic clustering problems involving sparse graphs in order to combine the advantages of the known methods. This novel method could also be based on a “non-spectral” algorithm. Since clustering is an unsupervised problem, the issues related to the tuning of parameters will be also investigated in the context of machine learning.	
METHODOLOGY	
The approach will certainly include a computational part in view of applications in a realistic context. A theoretical investigation will be carried in parallel in order to fully understand the different hypotheses formulated and the approximations that are necessary in order to obtain numerically tractable methods. To sum up, we expect a constant interplay of theory and numerical implementations.	
PROFILE	
The ideal master student will have a keen interest for theoretical aspects and good coding skills (Matlab or python). We look for a candidate with a very good motivation. This topic is ambitious and therefore we expect very regular research meetings with the daily advisor.	
1 or 2 students	**1 student**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE

Using Multi-task Learning in Black-box Weather Forecasting

GUIDANCE

• For more information, please contact:	{zahra.karevan,lynn.houthuys}@esat.kuleuven.be
• Promotor:	Johan A.K. Suykens
• Supervisor:	Zahra Karevan, Lynn Houthuys

CONTEXT

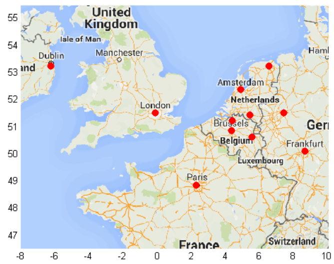
Accurate weather forecasting is an important challenging problem which can influence our daily lives in different ways. In order to have a reliable weather forecasting, state-of-the-art methods utilized Numerical Weather Prediction (NWP) which is computationally intense method and uses thousands of CPUs to model the data. Recently, there has been an increasing interest in data-driven weather forecasting.

Multi-task Learning is a major area of interest within the field of machine learning. It has been shown that for learning multiple related task, it is better to learn them simultaneously rather than learning each task independently. Multi-task Learning aims to improve generalization performance by pooling the information of related tasks and learning them simultaneously. The structure of tasks relationships need to be estimated based on the data.

GOAL

Accurate weather forecasting includes prediction of different variables using multiple sources of information including different variables from different stations. Thus, Multi-task Learning seems a promising method for this application. As an example the data from multiple cities can be used to predict the weather condition in multiple cities.

The aim of this thesis is to focus on Multi-task Learning approach and leverage how it can help with improving the performance of weather prediction.



METHODOLOGY

Collecting and cleaning the data is part of the work.

The methodology depends on student's interest. Also, it is nice to investigate different methodologies to see which one is more promising.

Some options can be predicting multiple variables at the same place or predicting the weather condition in multiple cities.

PROFILE

40% literature, 60% implementation

The student should have some knowledge about Machine Learning.

Programming skills are required (Preferably MATLAB).

1 or 2 students	**1 student**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

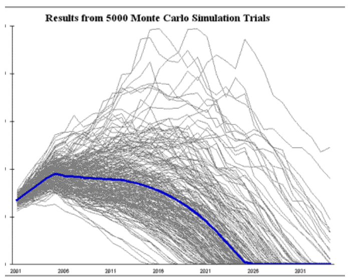
TITLE

Multilevel Monte-Carlo methods for uncertainty quantification in engineering applications

GUIDANCE

• For more information, please contact:	Stefan Vandewalle
• Promotor:	Stefan Vandewalle
• Supervisor:	Pieterjan Robbe

CONTEXT



Many problems in science and engineering can be described by using a mathematical model in the form of one or more partial differential equations (PDE). These equations are then discretized, leading to a huge linear system that is solved on a computer. With the increase of computing power, and availability of efficient algorithms, engineers have been able to solve increasingly complex problems. The challenge nowadays is the solution of PDEs where some (or many) of the involved parameters are not precisely know. Such uncertain parameters may appear in the material characteristics, in the boundary conditions, in the shape of the domain, or in the source and other input terms. Because of those uncertainties, also the output to the PDE is uncertain. Hence, one would like to quantify that uncertainty, and compute the expectation, the variance, and possibly also some other stochastic characteristics of the output.

GOAL

Sampling based methods, such as the Monte Carlo method, are the methods of choice for the uncertainty quantification of problems with many uncertainties. These methods are "non-intrusive". In principle, they can be "wrapped around" any existing simulation code.

Recent extensions of the Monte Carlo method include Multilevel Monte Carlo and Multi-Index Monte Carlo. These methods start from a hierarchy of coarse to fine discretizations, and apply a Monte Carlo method on each grid of the hierarchy. One of the challenges that needs to be solved for every new application, is the choice of these grids, as well as finding enough "coupling" between the different levels or indices. These novel multilevel methods have up to now only been tested on simple model equations. In this thesis, we will investigate how the methods can be used for complex real-life models from civil engineering and fluid dynamics.

METHODOLOGY

First, a literature survey will be conducted in order to identify the current state-of-the-art on Multilevel Monte Carlo. Next, two (or more) engineering applications will be selected: a problem from structural engineering, and a fluid flow problem. This will be done in collaboration with the departments of Civil and Mechanical Engineering, who will also advise about the (industrial) simulation codes to be used. Those codes will then be coupled with a library for the Multilevel Monte-Carlo method, that was developed at the Department of Computer Science.

PROFILE

After the initial literature survey, the thesis will be mainly implementation oriented. Existing engineering simulation codes (in C++ , Python, MATLAB), will have to be interfaced with the Multilevel Monte Carlo software (Python/Julia). The student will also have to write pieces of code to make the code coupling possible, to process the numerical data, to visualize the results, and to evaluate the quality of the multilevel Monte Carlo output.

1 or 2 students	**1 student**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

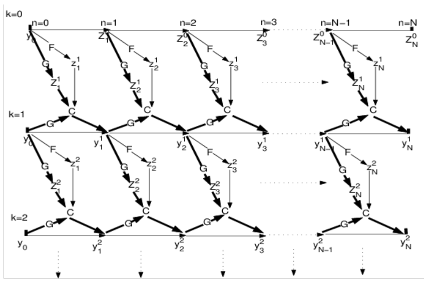
TITLE

Time-parallel time-integration for simulation and control of parabolic partial differential equations

GUIDANCE

• For more information, please contact:	Stefan Vandewalle
• Promotor:	Stefan Vandewalle
• Supervisor:	Andreas Van Barel

CONTEXT



Time evolution problems are mathematically described by ordinary or partial differential equations. Their numerical solution is usually done via a time-stepping procedure. Starting from the initial condition, the solution is advanced time step per time step until the end point of the time integration interval is reached. Obviously, such time-integration methods are inherently sequential. This is nowadays considered to be a major drawback. Indeed, it seems impossible to use the massively parallel computers that will become available soon, in order to speed up such a time-integration procedure. The parallel efficiency of the time integration appears to be limited to the parallel efficiency of the stationary solver that is used at each time level.

GOAL

Since many years, researchers have been searching for new numerical techniques that would also allow parallelism across time. Already in the early 90's several breakthroughs were realized, also at the Computer Science Department in Leuven [1]. The idea of those alternative algorithms is to apply iterative methods on space-time meshes. That is, one computes on multiple time levels simultaneously; computations on future time levels are already started, when the computation on earlier time levels has not yet converged. In this way, different processors can operate concurrently on different parts of the space-time mesh. In this master thesis, we want to catch up with the many recent developments in this research area. We will analyse some of the newly developed methods, implement them, and compare their performance with the methods that were developed earlier. Once the most promising algorithms are identified, we will study their applicability towards solving optimal control problems. In such problems, a system of two parabolic PDEs has to be solved.

METHODOLOGY

Recently, a large number of new algorithms has become available, with names as PARAREAL [2], PFASST [3], RIDC [4], MGRIT [5], SST-MGM [6]. Hence, the thesis will start with a literature survey with focus on identifying the similarities and differences of those methods. In the implementation phase, some of the algorithms will be implemented in MATLAB, and their performance will be compared. Next, a model parabolic control problem will be selected and the applicability of the methods to such problems will be investigated. If time permits, also an implementation on a parallel machine can be considered.

[1] G. Horton and S. Vandewalle, A space-time multigrid method for parabolic PDEs, SIAM J. Sci. Comp, 1996.
[2] M. Gander and S. Vandewalle, The Parareal time-parallel time-integration method, SIAM J Sci Comp, 2007.
[3] M. Emmett et.al., Toward an efficient parallel in time method for PDEs, Comm. Appl. Math, 2012
[4] A. Chrislieb, et.al., A parallel space-time algorithm, SIAM J. Sci Comp., Vol 34 (5), 2012
[5] R. Falgout, et.al., Parallel time integration with multigrid, SIAM J Sci. Comp. Vol 36 (6), 2014
[6] M. Gander, et. al, Analysis of a new space-time parallel multigrid algorithm for parabolic problems, 2015

PROFILE

Literature study and implementation.

1 or 2 students	**1 student**

MASTER’s THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE

Semi-supervised image segmentation

GUIDANCE

• For more information, please contact:	eugene.belilovsky@kuleuven.be
• Promotor:	Matthew Blaschko
• Supervisors:	Eugene Belilovsky, Maxim Berman

CONTEXT

Semantic image segmentation is the task of assigning an object class to each of the pixels of a digital image, for instance distinguishing between persons, birds, houses, streets. This task is crucial to the future of autonomous driving, drone navigation, robotics and many others...

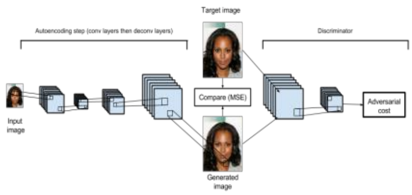
Thanks to neural networks, this challenging task has seen considerable improvements in recent years. However, the best methods require considerable amount of very precisely labelled data, which can be quite difficult to acquire. On the other hand getting lots of images with weak annotations (e.g. just a list of objects in the image) is relatively easy. Much like in human learning we don't expect that one needs to specify every single pixel in an image to learn to distinguish objects at the pixel level.

We will aim to make the process of learning image segmentation by machines a little smarter, by developing and implementing approaches that allow using the large available "weak" annotations.

Example of semantic segmentation (fig. from C. Hazirbas)

GOAL

Our main focus will be on the use of probabilistic generative modelling techniques, for example the Generative Adversarial Networks, to enhance the learning process. Probabilistic generative models have had a variety of recent success in the realm of semi-supervised learning, with many recent demonstrations of marrying neural network concepts with generative models to create scalable and efficient solutions.



Adversarial Network

METHODOLOGY

First, you will have to get up and running a state-of-the-art segmentation pipeline. Though experimentation on different approaches, we will then attempt to incorporate weak supervision in the training pipeline. Finally, we will aim to deploy the final application demo running either on a portable camera or possibly a quadcopter drone.

PROFILE

Student with interest in applying mathematical methods to real-world machine learning problems, who enjoys programming; with some experience in Python, Matlab, or C++.

1 or 2 students	**1 student**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE

Real-time semantic segmentation with superpixels

GUIDANCE

• For more information, please contact:	maxim.berman@kuleuven.be
• Promotor:	Matthew Blaschko
• Supervisor:	Maxim Berman

CONTEXT

Semantic image segmentation is the task of assigning an object class to each of the pixels of a digital image, for instance distinguishing between persons, birds, houses, streets...

an example of semantic segmentation on the cityscapes dataset

Thanks to neural networks, this challenging task has seen considerable improvements in previous years. However, the best methods require considerable computation and processing time for each image.

We are interested in reducing the processing time and computation needed for image segmentation, and make it able to perform in real time. This is relevant to many fields, such as mobile processing, video segmentation, robot, drones and autonomous cars vision...

The work will take place in the Processing Speech and Images department of ESAT.

GOAL

Our main idea is to use superpixels segmentation as a pre-treatment step before doing a segmentation. As shown in the right figure, superpixel segmentation is a way to divide the images into "big pixels" which should belong to a unique object. It is a way to reduce the number of pixels of the input image without losing segmentation accuracy.

METHODOLOGY

First, you will have to integrate superpixels in a neural network segmentation pipeline. This will require a thorough understanding of the underlying mathematical methods. Though experimentation on different datasets, we will search for the best compromise between precision and speed. For real-time segmentation, we might consider adding temporal continuity constraints. We will also consider superpixel refinement techniques to improve the visual appearance of the results.

With this project, the student can expect to gain the following knowledge

- Experience in state-of-the-art computer vision and machine learning algorithms
- Understanding of the algorithms involved and experience in mathematical modelling
- Programming experience

PROFILE

Student with interest in applying mathematical methods to real-world machine learning problems, who enjoys programming; with some experience in Python, Matlab, or C++.

1 or 2 students	**1 student**

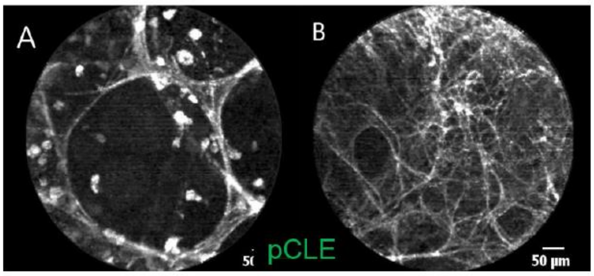
MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

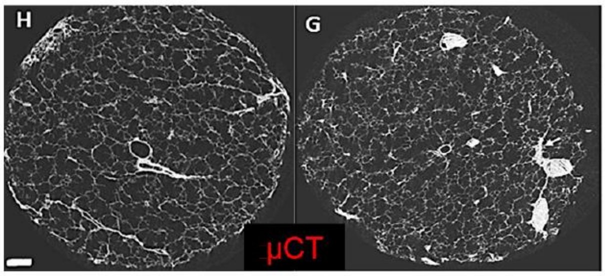
TITLE	
Generative models for lung post-transplantation dysfunction detection	
GUIDANCE	
• For more information:	amal.rannen@esat.kuleuven.be
• Promotor:	Matthew Blaschko
• Supervisor:	Amal Rannen Triki, Jonas Yserbyt (UZ Gasthuisberg)

CONTEXT

After lung transplantation (LTx), patients can experience some dysfunctions. One of the most significant burdens for such a surgery is called Bronchiolitis obliterans syndrome (BOS). BOS is "is an inflammatory condition that affects the lung's tiniest airways, the bronchioles". Nowadays, there is no effective in-vivo diagnostic procedure for this syndrome.

However, early detection of BOS may result in a faster treatment and thus prevent from further functional decline in the early phase after LTx. A pilot study based on a sample of 24 patient who received LTx and for a 2- year surveillance highlighted some morphometric changes in the bronchioles of patients who are developing BOS. This structure can be seen in images obtained from ex-vivo micro-CT (H = BOS-free; G = BOS). The same kind of structural difference can be found in robe-based confocal laser endomicroscopy (pCLE). pCLE is a preclinical endoscopic technique enabling real-time and in vivo visualization of the pulmonary acinus. In the figure, A is BOS-free and B shows characteristics of BOS.





Challenges: Although a pilot study suggests that pCLE is able to detect morphologic changes in BOS, this needs to be confirmed in **a lager trial**. Manual, frame-by-frame analysis of pCLE images is hampered by **a low signal-to- noise ratio** (SNR), it is **time consuming** and **operator-dependent**.

GOAL

Diagnostic tools for the direct clinical diagnosis of BOS are lacking. pCLE is well tolerated, easy to use during flexible bronchoscopy and provides microscopic images in real-time. **This project aims to produce a real-time analysis tool for BOS diagnostic based pCLE images.**

METHODOLOGY

Current dataset: For a larger study, a database consisting of pCLE imaging in 189 LTx recipients of which 34 procedures were performed in patients with BOS (155 are BOS-free) has been collected. Each procedure consists of 1500-2000 video frames of which the SNR can be estimated at 0.9.

Image denoising: The first stage of the project will be to pre-process the images to increase the SNR. You will investigate and test denoising methods based on generative models (models that randomly generate observable data values).

Image classification: Based on the pCLE images (denoised or original), you will design a real-time classifier in order to detect the changes in the patient bronchioles. Most of the state-of-the-art tools for such applications are based on deep neural networks. As these models use a large number of parameters, a good regularization is required. You will study how generative models can be used for

regularization in a context of supervised (all data is labelled) or semi-supervised learning (a part of the data is labelled).	
PROFILE	
The project is rather practical, but a good mathematical background is helpful. The student would test state-of- the-art machine learning methods, and should be able to implement them using MATLAB or Python. You will have the opportunity to acquire or perfect skills that are useful for many domains and are in high demand in industry, including Google, Microsoft, Apple, Facebook, Amazon, etc.	
1 or 2 students	**1 student**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
Domain Adaptation in a Lifelong Learning setup	
GUIDANCE	
• For more information, please contact:	Rahaf.aljundi@esat.kuleuven.be
• Promotor:	Tinne Tuytelaars
• Supervisor:	Rahaf Aljundi

CONTEXT

Lifelong Learning (LL) is an emerging field of Machine Learning. It considers an agent that learns multiple tasks $t_1, t_2, \dots, t_n$ over a lifetime, from one or more domains. The agent has to efficiently and effectively retain the previously learned knowledge and use it when learning a new task. A *domain* D is a distribution over $X \times Y$, where X represents the data (e.g. images) and Y represents the labels. For each task, the agent receives: $\{(x_i, y_i)\}_{i=1}^{n}$ samples drawn i.i.d. from D. Learning a task t means learning a function $g(x) = y$, called a *model*. Lifelong learning considers a sequence of tasks and the agent needs to be functional on all the tasks. Yet after learning a task t, the agent can only store the learned function g (the model) and not the data.

Domain Adaptation (DA), on the other hand, deals with situations where an agent has learned a task t_s from a source domain D_s and now needs to adapt the model to a new target domain D_t. D_t is different from but related to D_s (e.g. real images vs. simulations, or images of European vs. American street scenes). This is the so-called *domain shift*. For the target domain, we have no or few labels $Y$and thus the agent needs to transfer the knowledge (data, labels and model) from the source domain to improve the learning of the target task. In contrast to the lifelong learning setting, there is normally no need to preserve the performance of the source task, and the source data is typically still accessible.

GOAL

The goal of this master thesis is to study the domain adaptation problem from a lifelong learning perspective, in the context of convolutional neural networks: 1) Consider more than two tasks in the adaptation process. 2) Adapt to the new task without assuming that data from the previous tasks is stored. 3) Preserve the performance on the old tasks.

METHODOLOGY

In order to preserve the performance on the previous task without needing access to the previous task data, methods like Learning Without Forgetting or Encoder based lifelong learning can be used. In such methods, the performance of the previous task is estimated by the output of the previous model given the new task data.

In order to correct the domain shift between the two tasks without having access to the old task data, autoencoders learned on the old tasks can be used to estimate the data generating distribution. Alternatively, the subspace learned by the autoencoders can be used to adapt to the target domain as in Unsupervised visual domain adaptation using subspace alignment. Also a Domain Adversarial Loss or Maximum Mean Discrepancy loss can be used to obtain a domain-invariant representation. The student has to understand the problem and develop a method to efficiently incorporate the two approaches.

PROFILE

Machine Learning, Optimization, Deep Learning.

Any programming language can be used.

Students should have a strong mathematical background.

1 or 2 students	**1 student**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
Privacy-friendly machine learning algorithms for intrusion detection systems	
GUIDANCE	
• For more information, please contact:	Abdelrahaman Aly, Aysajan Abidin
• Promotor:	Abdelrahaman Aly, Aysajan Abidin
• Supervisor:	Prof. dr. ir. Bart Preneel
CONTEXT	
In today's information age, the risks and security threats to data are commonplace. Vital enterprise and user information should be protected from uninvited intruders lurking in our systems. Imagine the case where intruders are accessing to sensitive medical, industrial or governmental records using stolen or hacked but valid credentials. Machine learning techniques and algorithms have been used as a tool for intrusion detection in such scenarios. They typically monitor the behavior of the users, detecting anomalies that indicate possible infiltrations.	
GOAL	
Given that these systems, typically monitor the behavior of the users, detecting anomalies that can be used to identify possible infiltrations. Our goal is to ensure the privacy of honest users' daily behavior without sacrificing detection efficiency. Many of the machine learning techniques that are used by such applications are deployed in the cloud, which is a characteristic that should be preserved by this work. Furthermore, the thesis would pursue the development of machine learning and artificial intelligence algorithms that can be used for such applications in a privacy friendly manner, using, for instance, multi-party computation, homomorphic encryption and differential privacy.	
METHODOLOGY	
First, the student must start by gathering and building a relevant literature review. It will then proceed to define the scope of the problem that he desires to solve. Then it will proceed to select, analyze, discuss and benchmark the mechanisms for machine learning that he would like to use and implement. Finally, she/he should propose setting and/or protocol improvements to improve their use in practice. The thesis could be accompanied by some prototyping.	
PROFILE	
Ideally, the student should have some background/interest on the following: • Cryptography, • Artificial Intelligence, • Privacy-preserving, • Number Theory, • Domain of a programming language	
1 or 2 students	**1 student**

MASTER’s THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE

Quantum Attacks on Public Key Cryptosystems

GUIDANCE

• For more information, please contact:	alan.szepieniec@esat.kuleuven.be (ESAT-B01.18)
• Promotor:	Bart Preneel
• Supervisor:	Alan Szepieniec

CONTEXT

The security of today’s internet, financial sector, and everyday life relies in large part on the cryptographic hardness of computational problems such as the integer factorization problem or the discrete logarithm problem over elliptic curves. However, these foundational pillars of public-key cryptography are being threatened by the advent of large-scale quantum computers; in particular by Shor’s polynomial-time quantum algorithm for their solution. As a result, cryptographers are racing against time to design, develop and deploy post-quantum cryptography — cryptographic primitives that promise to resist attacks on quantum computers.

But how does one prove that a cryptosystem is immune to quantum attack? There is only one strategy, which falls short of any kind of proof: to develop cryptography relying on hard computational problems for which no fast quantum algorithm is known, such as solving large systems of multivariate quadratic equations; decoding noisy codewords; finding short lattice points; inverting hash functions; or computing isogenies between elliptic curves. Indeed, recent years have seen a plethora of proposals relying on precisely these problems.

Nevertheless, with very few exceptions, the security analyses of these cryptosystems take into account only classical algorithms. While it may be safe to assume that Shor’s algorithm does not apply, nearly all classical algorithms can be sped up to some degree by using clever quantum techniques such as Grover’s search, amplitude amplification, or quantum walks. Therefore, while these post-quantum cryptosystems do offer some security against quantum attackers, the exact security guarantee is unknown.

GOAL

In this thesis, you will analyze existing classical attacks on post-quantum cryptosystems (as well as new ones, if you can find them) from the perspective of a quantum attacker. The objective is to get a better idea of the security offered by the cryptosystem in terms of the number of qubits required to run the attack, the number of quantum gates required, and the expected success probability. In some cases, trapdoor simulation — running the quantum algorithm when you know the solution already — can provide experimental evidence for these figures.

METHODOLOGY

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PROFILE

If you have no background on quantum computation then you will have to learn about this at the start of the project. Fortunately, quantum computation boils down to little more than linear algebra with fancy notation and basic probability theory. Knowledge of cryptography and computational complexity theory is an advantage but not required as you can learn about this as you go.

1 or 2 students	**1 or 2 students**

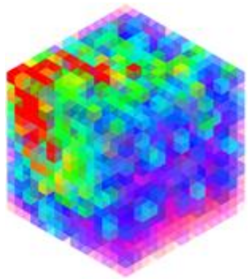
MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
Automatic Cryptanalysis of Stream Ciphers	
GUIDANCE	
• For more information, please contact:	chaoyun.li@esat.kuleuven.be (B01.18)
• Promotor:	Bart Preneel
• Supervisor:	Chaoyun Li
CONTEXT	
We are today surrounded by many communicating electronic devices. The security of such devices is often critical to their functionality. Stream ciphers are widely exploited to provide confidentiality of the electronically transmitted data. Compared to other primitives, stream ciphers are competitive in software applications with exceptionally high speed, and in hardware applications with exceptionally small footprint. Notable examples of stream ciphers include the A5/1 in GSM standard and RC4 in WPA and TLS protocols. Cryptanalysis is the study of how to crack encryption algorithms or their implementations. Typically, a cryptanalyst proposes attacks on a particular cipher by hand or *ad hoc* computer search algorithm. It appears that a lot of time and effort in programming is required to attack any particular cipher. In order to avoid extensive manual work, cryptographic researchers tend to develop automatic tools, with which many cryptographic primitives can be analyzed in a general framework. Automatic ``black box'' techniques, such as SAT or MILP solvers, have become increasingly sophisticated and powerful. Indeed, they have been employed to attack many block ciphers. It turns out automatic tools can outperform human cryptanalysts in some occasions. On the other hand, the tools can be used to prove security bounds against various cryptanalysis. Hence, the cipher designers also benefit from the tools.	
GOAL	
This thesis project aims to develop automatic tool for the analysis of stream ciphers. We are expected to model the cryptanalysis problem by programming language and then solve the problem by existing software.	
METHODOLOGY	
/	
PROFILE	
Knowledge of programming languages (e.g. C) is required while knowledge of cryptography is not necessary. Any background on mathematical optimization and/or dynamic programming would be advantageous. By doing this project, the student will have a better understanding of symmetric cryptanalysis and algorithm design techniques, which is beneficial for career development.	
1 or 2 students	**1 student**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
Fast matrix multiplications	
GUIDANCE	
• For more information, please contact:	Lieven De Lathauwer
• Promotor:	Lieven De Lathauwer
• Copromotor:	Marc Van Barel, P.-A. Absil (UCL)
• Supervisor:	Ignat Domanov

CONTEXT



The straightforward way to multiply two (2×2) matrices requires 8 scalar multiplications. The arithmetic operations can however be grouped to reduce the work to 7 multiplications. By working recursively, we can reduce the multiplication cost for (N×N) matrices from the straightforward $O(N^3)$ to $O(N^{2.8074})$ operations. More substantial computational savings may be obtained by starting from the reduction that can be achieved for (3×3) or (4×4) matrices, for instance. The reduction of the complexity may actually become so significant that a new architecture for large matrix multiplication emerges. Essential is first that we find inexpensive schemes for the multiplication of relatively small matrices. The latter problem amounts to finding decompositions of associated "multiplication tensors".

GOAL

The multiplication of two matrices A and B can be viewed as the bilinear map (A,B) → A*B. By duality, we can also view the multiplication as the trilinear form M: (A,B,C) → trace(A*B*C). The trilinear form is naturally associated with a third-order tensor. The decomposition of this tensor in rank-1 terms is the key to a reduction of the complexity of matrix multiplication. The purpose of this project is to investigate decompositions of the multiplication tensor in order to speed up matrix multiplication. A suggested approach relies on exploiting the invariance

$\mathrm{trace}(A*B*C) = \mathrm{trace}((X *A* Y^{-1})(Y *B* Z^{-1})(Z *C* X^{-1}))$. If the student does not progress sufficiently well in this topic, an alternative topic would be to investigate tensor block term decompositions from a Grassmann manifold perspective, as in Ishteva's http://dx.doi.org/10.1137/090764827.

RESULT

The required know-how w.r.t. tensor methods is acquired through discussions, attending a few lectures and a limited, guided study of the literature. A concise course text is available. For optimization on manifolds, we use the book P.-A. Absil, R. Mahony, R. Sepulchre, *Optimization Algorithms on Matrix Manifolds*, Princeton Univ. Press, 2008.

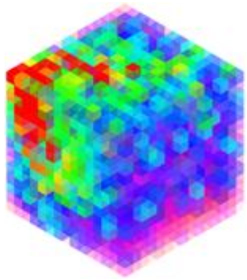
PROFILE

An interest in numerical optimization is required. Algorithms are implemented in Matlab.

1 or 2 students	**1 or 2 students are allowed**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
Generalized cost functions in tensor optimization	
GUIDANCE	
• For more information, please contact:	Lieven De Lathauwer
• Promotor:	Lieven De Lathauwer
• Supervisor:	Martijn Boussé
CONTEXT	



An important research trend is the transition from vector and matrix based mathematical engineering to generalizations that make use of higher-order tensors. Higher-order tensors are "matrices in more than two dimensions". This trend manifests itself across many disciplines, such as signal processing, data mining, machine learning, scientific computing, … Tensorlab is an in-house developed Matlab toolbox that comprises numerically reliable and efficient algorithms for the computation of tensor decompositions (www.tensorlab.net). The high performance is the result of a careful handling of multilinear (rank-1) structure that is inherent in tensor decompositions.

GOAL

Tensorlab assumes that the tensors that need to be decomposed, are given. However, the tensor itself could only be implicitly available, for instance as the solution of a linear system. This leads to solving sets of linear equations under low-rank (tensor) constraints on the solution. Such problems are fundamental and open up significant new applications. For instance, recognition tasks (image, video) are naturally formulated in this way. There are also intimate links with (large-scale) system identification, compressed sensing, array processing and wireless communication, to give just a few examples. The aim of the thesis is the extension of the algorithms in Tensorlab to cost functions that encompass such constrained set of linear equations. A second possible aim is the extension from least-squares optimization to the minimization of non-quadratic cost functions that are a better match for pixel intensities, audio, spectra, concentrations, …

RESULT

The required know-how w.r.t. tensor methods is acquired through discussions, attending a few lectures and a limited, guided study of the literature. A concise course text is available. New algorithms are developed with attention for numerical aspects. The algorithms are validated on synthetic examples and real-life data.

PROFILE

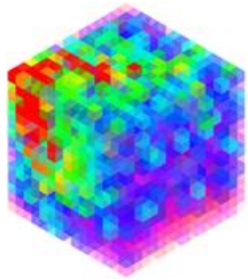
Depending on the interest, the emphasis can be put less or more on numerical aspects, implementation, development of a software tool or applications. The algorithms are implemented in Matlab.

1 or 2 students	**1 or 2 students are allowed**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
Tensor-based pattern recognition and deep learning	
GUIDANCE	
• For more information, please contact:	Lieven De Lathauwer
• Promotor:	Lieven De Lathauwer
• Copromotor:	Johan Suykens
• Supervisor:	Martijn Boussé, Nico Vervliet

CONTEXT



Recently, deep learning has significantly improved the state of the art in speech recognition, visual object recognition, object detection, genomic data analysis, and many other fields. Deep artificial neural networks (ANN) may involve the learning of hundreds of millions of weights. On the other hand, an important research trend is the transition from vector and matrix based mathematical engineering to generalizations that make use of higher-order tensors. Higher-order tensors are "matrices in more than two dimensions". This trend manifests itself across many disciplines, such as signal processing, data mining, machine learning, … Tensor methods have recently revolutionized scientific computing in high dimensions, enabling the reliable computation, in minutes or hours, of functions of which the number of unknown values "exceeds the number of atoms in the observable universe". In machine learning and big data analysis, the potential still largely has to be unleashed.

GOAL

The aim of this thesis is to contribute significantly to the transfer of know-how from tensor-based scientific computing to large-scale data analysis and pattern recognition. We will develop a new class of tensor-based learning algorithms that are advantageous over current techniques in the sense that they are matrix SVD-like, i.e. (i) different degrees of accuracy can be obtained by varying the number of singular values that is taken into account, (ii) for the computation one can resort to the powerful methods that have been developed in numerical linear algebra, and (iii) models are easily interpretable in comparison with for instance ANNs.

RESULT

The required know-how w.r.t. tensor methods is acquired through discussions, attending a few lectures and a limited, guided study of the literature. A concise course text is available. New algorithms are developed with attention for numerical aspects. The algorithms are validated on synthetic examples and real-life data.

PROFILE

Depending on the interest, the emphasis can be put less or more on tensor concepts, numerical aspects, implementation or machine learning applications. The algorithms are implemented in Matlab and may eventually become part of Tensorlab. Tensorlab is an in-house developed Matlab toolbox that comprises numerically reliable and efficient algorithms for the computation of tensor decompositions (www.tensorlab.net).

1 or 2 students	**1 or 2 students are allowed**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
Accurate computations on GPUs using varying precision corrections by a multilevel method	
GUIDANCE	
• For more information, please contact:	Dirk Nuyens
• Promotor:	Dirk Nuyens
• Supervisor:	Dirk Nuyens
CONTEXT	
On CPUs, single precision can be made double as fast than double precision by using vectorized SIMD instructions. On GPUs one can gain a factor of 5 to 10 by switching from double to single precision, and another factor of 2 by switching to even lower precision. At the same time, these lower precision calculations need less hardware and therefor even consume less power. Double win! But at the expense of precision. Mostly the precision is specified in advance and often we cannot use these fast low precision calculations directly. The question then is: could one devise an algorithm that combines such faster low-power calculations to construct an accurate approximation in less time and power? One such algorithm is the multilevel Monte Carlo algorithm to approximate an expectation (where the precision of the resulting corrections is normally influenced by the number of samples taken at that level).	
GOAL	
Devise a multilevel algorithm that takes varying levels of floating point precision into account.	
METHODOLOGY	
Study the general concept of recursively calculating cheap rough estimates and correcting those by higher precision calculations. This is a telescoping sum of corrections as in the multilevel Monte Carlo method. Extend the analysis to also make use of varying precision floating point arithmetic. Define the cost in terms of power consumption and speed. Find the optimal balance in terms of those two costs, taking into account low precision arithmetic where advantageous. As a practical example one could look at calculating the expected value of a functional applied to a Brownian motion path (sampling the normal distribution by only using the first moments and preferably deterministic low-discrepancy point sets).	
PROFILE	
The student must feel comfortable to read through some light mathematical literature, implement the numerical example in C/C++, do lots of numerical tests, probably look at assembly, and (re)code for GPU.	
1 or 2 students	**1 student**

TITLE	
Convolutional Neural Network for face recognition	
GUIDANCE	
• For more information, please contact:	dzemila.sero@kuleuven.be
• Promotor:	dirk.vandermeulen@kuleuven.be
• Supervisor:	peter.claes@kuleuven.be
CONTEXT	
Face biometrics studies the facial shape in order to build a recognition system able to identify an unknown individual (for example, on a crime scene) or verify whether a user should be given access, for instance, to a specific building. The standard characteristics used as identifiers are the face, fingerprints, iris and voice. At the Medical Imaging Research Center, we build recognition systems such that information like sex, age, height, weight, ancestry is predicted from the face and then compared to a target unknown face, for which the correspondent string information is extrapolated (in real case scenarios, these could be from a blood or saliva sample, for example). The combination of multiple matching scores gives the likeliness of the target face to match each of the faces present in the database. Given the central role of the face in determining a successful classification task, its representation needs specific care. Multiple facial characteristics have been investigated: principal components, radial and stream lines, linear distances between specific points on the face, and so on.	
GOAL	
The goal of the current thesis is to implement a convolutional neural network able to construct invariant descriptors of the face, and use its coefficients as predictors. The second goal, is to use these facial descriptors in a biometric system.	
METHODOLOGY	
The student will be asked to: 1. implement a convolutional neural network from the 3D facial meshes; 2. implement a biometric recognition system; 3. evaluate the results with the standard approaches such as the Identification (Cumulative Rank Curves) and Verification curves (Equal Error Rate value).	
PROFILE	
The topic is of value for anyone who is willing to contribute with his/her skills and motivation to improve the knowledge of some aspects of facial recognition. There aren't specific requirements, besides some basic skills and passion in programming. The work will be done at Medical Image Computing research group (K.U. Leuven, ESAT/PSI, MIC), located at the Medical Imaging Research Center (MIRC) (UZ Gasthuisberg, Herestraat 49 bus 7003, B-3000 Leuven; http://www.medicalimagingcenter.be).	
1 or 2 students	**1 or 2 students**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
Multi Resolution Decomposition for Face Recognition	
GUIDANCE	
• For more information, please contact:	dzemila.sero@kuleuven.be
• Promotor:	dirk.vandermeulen@kuleuven.be
• Supervisor:	peter.claes@kuleuven.be

CONTEXT

Face biometrics studies the facial shape in order to build a recognition system able to identify an unknown individual (for example, on a crime scene) or verify whether a user should be given access, for instance, to a specific building. The standard characteristics used as identifiers are the face, fingerprints, iris and voice. At the Medical Imaging Research Center, we build recognition systems such that information like sex, age, height, weight, ancestry is predicted from the face and then compared to a target unknown face, for which the correspondent string information is extrapolated (in real case scenarios, these could be from a blood or saliva sample, for example). The combination of multiple matching scores gives the likeliness of the target face to match each of the faces present in the database. Given the central role of the face in determining a successful classification task, its representation needs specific care. Multiple facial characteristics have been investigated: principal components, radial and stream lines, linear distances between specific points on the face, and so on.

GOAL

The goal of the current thesis is to implement a wavelet decomposition of the face, and use its coefficients as predictors. Another key topic is the combination of scores. Literature on combination of multiple scores proposes three methods: the sum rule, the classification based fusion, and density based score fusion. The second main goal of the thesis is implementing a density based score fusion.

METHODOLOGY

The student will be asked to:

1. implement a wavelet decomposition on the 3D facial meshes;
2. implement a classifier able to predict soft traits from facial wavelets;
3. implement a biometric recognition system wherein a good matching score fusion technique should be included;
4. evaluate the results with the standard approaches such as the Identification (Cumulative Matching Curves) and Verification curves (Equal Error Rate value).
5. (optional): combine the wavelet decomposition with the in-house facial representation methodology.

PROFILE

The topic is of value for anyone who is willing to contribute with his/her skills and motivation to improve the knowledge of some aspects of facial recognition. There aren't specific requirements, besides some basic skills and passion in programming.

The work will be done at Medical Image Computing research group (K.U. Leuven, ESAT/PSI, MIC), located at the Medical Imaging Research Center (MIRC) (UZ Gasthuisberg, Herestraat 49 bus 7003, B-3000 Leuven; http://www.medicalimagingcenter.be).

1 or 2 students	**1 or 2 students**

MASTER’s THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

<table>
<tr><td colspan="2">TITLE</td></tr>
<tr><td colspan="2">Benchmarking Google Tensorflow and Python Scikit Flow</td></tr>
<tr><td colspan="2">GUIDANCE</td></tr>
<tr><td>• For more information, please contact:</td><td>Dirk Roose</td></tr>
<tr><td>• Promotor:</td><td>Dirk Roose</td></tr>
<tr><td>• Supervisor:</td><td>Dirk Roose; Bart Verleye (Zensor)</td></tr>
<tr><td colspan="2">CONTEXT</td></tr>
<tr><td colspan="2">Renewable energy can only be environmental friendly if the producing infrastructure is sustainable. Predictive maintenance helps to extend the lifetime of, e.g., turbines in a sustainable way. Anomaly detection plays a key role in this. As an example, an anomaly in the movement pattern of a turbine, will reveal that something is broken, or will break soon.

To compute possible anomalies, first a dimensionality reduction is performed on the data-set. As the number of parameters and the available data is ‘big’, the dimensionality reduction is now a computational bottleneck in the anomaly analysis.

This thesis will be performed in collaboration with Zensor NV.</td></tr>
<tr><td colspan="2">GOAL</td></tr>
<tr><td colspan="2">Two of the most used frameworks in data-science are Google’s Tensorflow and Python Scikit. The goal is to implement a basic anomaly detection method, including dimensionality reduction, into these two frameworks. These implementations will be benchmarked, however, not only on computation speed, but also usability, total cost and applicability in a commercial setting.</td></tr>
<tr><td colspan="2">RESULT</td></tr>
<tr><td colspan="2">We expect two working implementations of an anomaly detector. Based on large scale computations on the VSC cluster, an extensive benchmark must be presented. Depending on the progress or and the student profile:
» one of the implementations can be used in a non-academic setting,
» a more theoretical improvement of the dimensionality reduction can be suggested.</td></tr>
<tr><td colspan="2">PROFILE</td></tr>
<tr><td colspan="2">- 40% analysis and 60% implementation and validation

or

- 60% analysis and 40% implementation and validation

AI background is clearly an advantage.</td></tr>
<tr><td>1 or 2 students</td><td>1 student</td></tr>
</table>

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE

Simulation of boundary layers in automated optimal design strategies

GUIDANCE

• For more information, please contact:	joris.codde@diabatix.com
• Promotor:	t.b.a.
• Supervisor:	joris.codde@diabatix.com

CONTEXT

Automated optimal design is revolutionizing engineering practice. Topology optimization in particular, results in very performant designs that often have a 'natural' look. Topology optimization originally started with structures, enhancing the possibilities of 3D-printing. Recently, it has been applied to the domains of fluid dynamics and heat transfer. Characteristic for both flow and convective heat transfer is the presence of the boundary layer: this is the area where the flow is significantly influenced by the wall. In CFD simulations, which are a part of the topology optimization procedure, the treatise of the boundary layer requires extra care: it has to be resolved by the mesh. Therefore adaptive mesh refinement, exemplified on the figure below, is applied in standard CFD simulations. However, currently, it is difficult to incorporate the treatise of the boundary layer in the topology optimization procedure effectively (Sigmund & Maute, 2013).

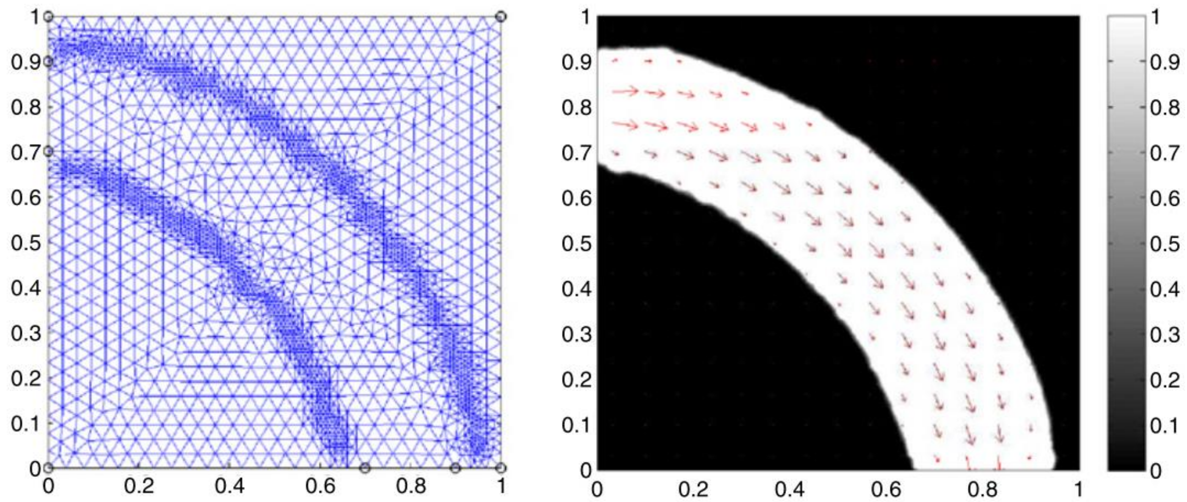


Fig. 1: Adaptive mesh refinement applied to a pipe bend. The left figure displays the mesh, the right figure the design: the flow enters at the left and flows through the white part to the bottom (Duan, Li, & Qin, 2015).

As in topology optimization the flow path is 'carved out' by the optimization step, the location of the boundary layer is also amenable to change. In the example of the pipe bend above, one would start from a uniform mesh and a uniform design space (e.g. white everywhere), whereas the resulting design will be the bend. Thus, the location of the boundary layer is not known a priori, which complicates the application of adaptive mesh refinement.

This thesis is in cooperation with Diabatix, a young company that designs heat sinks through topology optimization. This thesis frames into the companies' future ventures.

GOAL

The goal of this work is to apply adaptive mesh refinement in the context of topology optimization. In this context, the change of the number of cells/variables should be taken into account in the optimization algorithm.

METHODOLOGY

An adaptive mesh method, which refines the mesh close to the fluid-solid interface, is very suitable

to correctly simulate boundary layers. This method is widely applied in CFD simulations and has recently been applied in the context of topology optimization (Duan, Li, & Qin, 2015). However, this method has to be tested and improved in order to generalize it for e.g. 3D problems. Furthermore, the combination of adaptive mesh refinement and the MMA-algorithm - which is typically used in topology optimization - is incompatible: MMA needs to be restarted when the number of variables/elements changes. Therefore, a method to project the simulation results of the refined mesh onto the original coarse mesh needs to be elaborated (Park & Sutradhar, 2015).
PROFILE
Requires an interest in theoretical concepts, such as markers that can drive mesh refinement, but ultimately the focus is on realizing the method.

1 or 2 students	**1 student**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE
Block coupled solvers for fluid flow and heat transfer

GUIDANCE

• For more information, please contact:	joris.codde@diabatix.com
• Promotor:	t.b.a.
• Supervisor:	joris.codde@diabatix.com

CONTEXT

Diabatix designs heat sinks based on virtual prototyping and optimal design. The procedure is based on large-scale CFD simulations (see figure below). These simulations can take multiple days to complete. Typically, these calculations are executed on dedicated systems with 100 processors or more (HPC). Any improvement in solution method yielding a performance improvement saves both time and money.

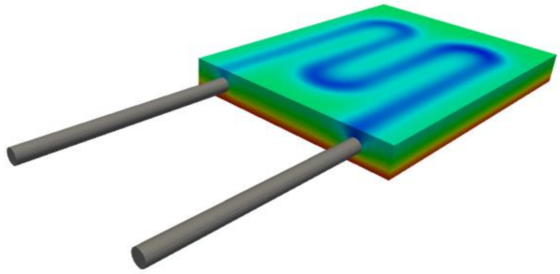


Fig.: liquid cold plate, whereby water runs through the tubes in the metal heat sink, cooling the heat source at the bottom of the plate.

In order to solve the underlying Navier-Stokes and energy equations, two fundamentally different strategies are available: coupled or segregated solution methods. This feature is apparent when looking at the matrix system that has to be solved: in case of coupled solution, discretized equations are fit together in a matrix system, while a segregated approach takes only one equation. More specifically, if solving the Navier-Stokes equations, a segregated approach means solving for each velocity component separately. In case of solving the energy equation for multiple domains (e.g. fluid and solid domains), a segregated approach means solving the energy equation for each domain separately and iterating over the domains until the heat flux from one domain to the other is equal. Such an approach is easy, but requires more iterations, because of diminished accuracy. Therefore, coupled solution methods are an interesting alternative.

GOAL

Develop a block coupled solver in OpenFOAM for the solution of flow and heat transfer problems.

RESULT

While the problem is easy to understand on a matrix level, it is harder to implement in OpenFOAM. From its base version, the software is only fitted with segregated solvers. Nevertheless, an implementation is available in a fork of OpenFOAM, OpenFOAM-ext or OpenFOAM extend. Together with a detailed analysis of the available C++ code (Jareteg, 2012), this facilitates programming of the coupled solver.

The next step is tailoring the coupled solver to several algorithms:

- A coupled solver for the Navier-Stokes equations as a whole
- A coupled solver for pressure-based methods such as SIMPLE
- A coupled solver for the heat transfer equation when applied to multiple regions

The coupled solver will be applied to the most promising algorithm, selected based on a literature review. Then, the performance can be tested against the standard solver. Performance includes at least CPU time, memory footprint and robustness of the solution process. If performance is case-specific, the last step is to provide metrics for selecting the best solver a priori.

PROFILE

Requires a decent background in C++ and object-oriented programming, in order to be able to implement the coupled solver.

1 or 2 students	**1 student**

MASTER’s THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

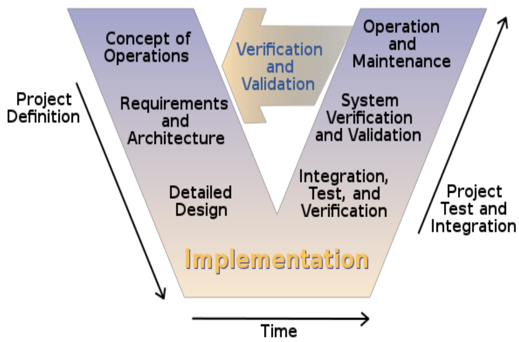
TITLE	
Simulation-Based Verification of Embedded Control Systems in ADAS Development	
GUIDANCE	
• For more information, please contact:	Dr. Son Tong (son.tong@siemens.com)
• Promotor:	t.b.a.
• Supervisor:	Dr. Son Tong (son.tong@siemens.com)

CONTEXT

Automotive industry innovation has been strongly driven by developing vehicles capable of driving (semi) autonomously, leading to a fast growth of Advanced Driver Assistance Systems (ADAS) technologies. Some examples of ADAS systems are autopilot, autonomous parking, and lane change assist. Vehicles have evolved from a mainly mechanical system into a truly mechatronic system, combining mechanical, electronic, software, and controls systems. Embedded control software system in vehicles has been thus increasing in both scale (of more driving functionalities) and complexity (of more advanced algorithms) remarkably. A car nowadays may contain one hundred million lines of code distributed a number of microprocessors. In order to save time and money, while gaining confidence that requirements and safety standards are met, simulation-based verification and testing techniques are usually employed in automotive industry to debug and verify software for embedded control systems, especially in the early development stages.

GOAL

The goal of this Master thesis is to develop and apply a simulation-based verification approach for an ADAS control application (adaptive cruise control or autonomous parking). The methodology is based on the model-based development approach (see picture). The left side of V-cycle focuses on high level requirements, control algorithms, where the simulation-based analysis are mainly considered. This approach helps to provide a unified framework for requirements, testing, and deploying reliable embedded systems.



METHODOLOGY

The task is to first review the state-of-the-art literature related simulation-based verification within the context of ADAS development. In the second step, as the main target, different

verification techniques of embedded control code will be implemented, for example, open-loop, closed-loop, and formal verifications. The student will use mainly the Siemens PLM software: LMS Imagine.Lab Embedded Software Designer as the verification platform. During the thesis project, you will collaborate closely with researchers from Siemens Industry Software NV, Leuven.

PROFILE

Background in embedded control system, knowledge in verification and validation (V&V) of software system, and Matlab/Simulink are considered important assets.

Self-motivated, well organized, and good communication skills in technical English.

1 or 2 students	**1 student**

MASTER’s THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
Failsafe design of electrical power systems for more-electric aircraft	
GUIDANCE	
• For more information, please contact:	Jonathan Menu (jonathan.menu@siemens.com)
• Promotor:	t.b.a.
• Supervisor:	Jonathan Menu
CONTEXT	
More stringent regulations on emission and fuel consumption make aircraft manufacturers move into more-electric aircraft (MEA) designs. In these aircraft, we see traditional hydraulic and/or pneumatic subsystems being replaced with more economic and lighter electrical systems. Examples are the recent Airbus A380 and Boeing 787 Dreamliner. More-electric aircraft design means more electrical power consumers, both non-essential (e.g., in-flight entertainment, galleys) and essential (e.g., avionics, landing gear). From a system point of view, these complex electrical power systems need a redundant and failsafe design that allows reconfiguration in case of failure.	
GOAL	
The goal of this project is working out and testing a new methodology for the design of electrical power systems for aircraft. Multiple aspects are involved: automatic generation of system concepts, fault tree analysis for failure rate estimation, controller creation for network reconfiguration (in case of failure), and system simulation for (formal) verification. The focus of the project will be on the latter two aspects. By the end of the project, a proof-of-concept implementation for the design workflow should be ready.	
METHODOLOGY	
Different mathematical formalisms and methodologies will need to be aligned. The controller creation will use Temporal Logic formalisms, which is a form of logic to formalize the requirements of a given system. Contracts will be used as a framework to specify the task of (part of a) system, under the form of assume-guarantee relations. For the verification of the created controller, an automatic export towards state charts will be created. Finally, behavioral simulations with the simulation software LMS Imagine. Lab Amesim will be used to investigate the performance under transient (switching) effects, during a given mission with a virtual aircraft prototype.	
PROFILE	
The topic combines both theoretical and practical aspects. The theoretical side of the project focuses on understanding the mathematical concept of temporal logics and formalize the interactions between components within a system by means of contracts. This requires abstract and formal thinking from the student. From a practical point of view, the importance of this project will be to provide a practical solution for electrical power system design, and support at least a proof-of-concept implementation of the workflow. The student should be willing to independently investigate existing and new solutions. Good object-oriented programming skills (e.g., in Python) will facilitate the practical implementation needed for the project. Some affiliation with, or at least interest in, aerospace and general aviation is an asset.	
1 or 2 students	**1 student**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE	
Mathematical optimization and machine learning techniques for efficient car engine calibration	
GUIDANCE	
• For more information, please contact:	bram.cornelis@siemens.com
• Promoters:	t.b.a.
• Supervisor:	Bram Cornelis, Fabio Bianciardi
CONTEXT	
Modern car engines are fitted with Engine Control Units (ECUs), which can regulate various combustion-related parameters (e.g. spark advance, ignition duration, …). A proper calibration of these parameters allows for an optimal engine performance in terms of noise/vibration generation, fuel economy, emissions (NOx, CO) and/or a desirable trade-off between these different attributes. In the current practice, engine calibration is a long and expensive process, typically requiring manual tuning by engine experts. Moreover, as internal combustion engine behave as extremely nonlinear systems, changing a single parameter can drastically affect the performance. There is a need for advanced mathematical tools which allow for a more efficient and accurate calibration process.	
GOAL	
The aim of the thesis is to explore various approaches to expedite the calibration of ECU parameters, in order to achieve a desired engine performance. It will be investigated how the ECU calibration problem can be formulated as a (multi-objective) mathematical optimization problem, where trade-offs between (quantifiable) attributes such as noise/vibration generation, fuel economy and emissions can be taken into account. Moreover, practical constraints (e.g. parameter intervals which endanger the engine) should be incorporated. The calculation of the optimization cost function entails evaluating the engine performance for a given set of ECU parameters. Different approaches will be compared in terms of accuracy and efficiency: either through a numerical simulation using (available) lumped-parameter engine CAE models (i.e. LMS Imagine. Lab Amesim), or through a data-driven predictive model which is obtained through a machine learning approach (e.g. neural networks).	
METHODOLOGY	
1. It is expected that the student will program the algorithms in Matlab, Python or similar mathematical programming languages. 2. The student will acquire hands-on expertise with an industrial simulation software suite (LMS Imagine.Lab Amesim), for which training support can be given by Siemens specialists. The student will not have to build an engine model, but rather make use of an already available model. 3. The student will investigate how to build (or rather learn) a data-driven predictive model using machine learning methods. These methods can be implemented in Matlab, or alternatively open source machine learning tools (e.g. "Weka") can be utilized. 4. An experimental dataset, obtained on an engine test rig, will be available for validating the methods on a real-life example.	
PROFILE	
- The topic is related to the courses "Optimization" (Prof. Patrinos) and "Data Mining and Neural Networks" (Prof. Suykens). - The student should have experience with mathematical software packages like Matlab, Octave, Python, R or similar. - Previous experience with LMS Imagine. Lab Amesim is useful but not mandatory.	
1 or 2 students	**1 or 2 students**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE

Optimized integration of the Frenet-Serret equations for the pipe-bending industry

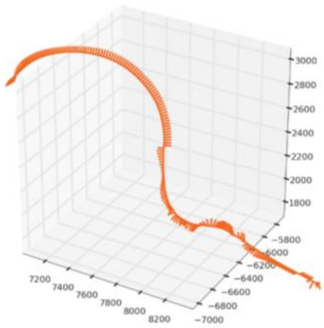
GUIDANCE

• For more information, please contact:	Lense Swaenen (lswaenen@siouxlime.nl)
• Promotor:	t.b.a.
• Supervisor:	Lense Swaenen (lswaenen@siouxlime.nl)

CONTEXT

Sioux LIME is a mathematics group that supports industry with its mathematical knowledge and techniques. Originally being an initiative of the Department Mathematics and Computer Science of the Eindhoven University of Technology, Sioux LIME evolved into a consultancy company for the industry. Since 2011, LIME is a subsidiary of the Sioux group, a service provider with expertise in embedded systems, automation technology and electronics.

For one of its clients, Sioux LIME has developed tools for metrology and control of metal pipes bent into 3D freeform shapes. A common low-level operation in these tools is the integration of a curve's curvature and torsion profile into a 3D coordinate representation. The equations governing this system are the Frenet-Serret equations. Currently a standard integration method is used. This is not optimized for the specific structure of the equations in terms computation time, nor in terms of conservation of orthonormality of the Frenet-Serret frame.



GOAL

The goal of this master's thesis is to develop a Frenet-Serret integrator which is optimized for the structure of these equations and for the real-world pipe bending test cases. Both reduction of the computation time and conservation of the orthonormality are in focus.

As a side goal, it may also be interesting to develop an optimized integrator for a competitor to the Frenet-Serret framework, namely the parallel transport framework, which avoid some common torsion problems.

METHODOLOGY

A few ideas exist to build a dedicated integrator. The Frenet-Serret system has a certain level o sparsity which could be exploited. The stiffness of the ODE following from common test cases should be studied, in order to select proper step sizes. For conservation of the orthonormality, ideas from symplectic integration and/or DAE solvers can be considered.

The developed integrator(s) are benchmarked on customer test cases and compared with existing methodologies.

PROFILE

This thesis is rather practical. The current tooling is written in Python. For performance reasons, the core of the assignment is best performed in C/C++, using bindings to Python. A background in ODE solving is welcome.

A final requirement is regular contact with Sioux LIME, requiring occasional visits to Eindhoven (to be discussed).

1 or 2 students	**1 student**

MASTER’s THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

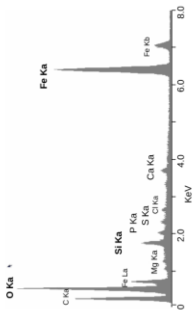
TITLE

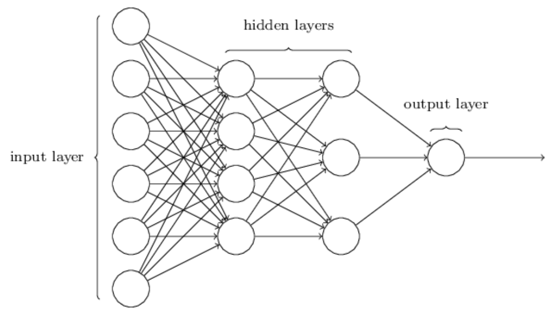
Energy dispersive X-ray spectrometry with Deep Learning

GUIDANCE

• For more information, please contact:	Lense Swaenen (lswaenen@siouxlime.nl)
• Promotor:	t.b.a.
• Supervisor:	Lense Swaenen (lswaenen@siouxlime.nl)

CONTEXT





Sioux LIME is a mathematics group that supports industry with its mathematical knowledge and techniques. Originally being an initiative of the Department Mathematics and Computer Science of the Eindhoven University of Technology, Sioux LIME evolved into a consultancy company for the industry. Since 2011, LIME is a subsidiary of the Sioux group, a service provider with expertise in embedded systems, automation technology and electronics.

Sioux LIME has developed for one of its clients a methodology to extract elemental compositions from x-ray spectra. The technical term for the used technique is ‘Energy dispersive x-ray spectroscopy (EDX)’. The developed approach uses a physics-based forward model and an inverse solver. The forward model predicts spectra when given an elemental composition. The inverse solvers solves a corresponding optimization problem. As the forward model is made progressively more complex (including higher order physical effects and constraints), the requirements for the inverse solvers become more difficult to satisfy.

GOAL

In this master’s thesis, we investigate and tune the performance of a solution in which the inverse solver is replaced with a trained neural network. The neural network will be trained using artificially generated ground truths using the forward model. The final performance will be tested on a real-world dataset (which is too small to be sufficient for training) as well.

To the EDX problem there is qualitative (which elements?) and quantitative (how much of each?) sub problem, which can be mapped to a classification and a regression-type problem. Both problems are possible to investigate.

METHODOLOGY

The specific type of neural networks which is most promising for this application is a (deep) 1D convolutional network. Moreover, we look to reuse pre-trained networks, of which we only need to re-train the last few layers. In order to generate training samples quickly, some effort to speed up the existing routine may also be beneficial. The EDX results will be compared to existing white-box methodologies.

PROFILE

The thesis is rather practical. Use of the Tensorflow toolkit is recommended, for which Python is the natural programming language. A background in artificial intelligence or system identification is welcome. A final requirement is regular contact with Sioux LIME, requiring occasional visits to Eindhoven (to be discussed).

1 or 2 students	**1 student**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE

Evolution model for simultaneous MRI segmentation of white matter lesions in multiple sclerosis patients

GUIDANCE

• For more information, please contact:	Dr. Diana Sima, Dr. Dirk Smeets (Ico**metrix**)
• Promotor:	t.b.a.
• Supervisor:	Dr. Diana Sima, Dr. Dirk Smeets (Ico**metrix**)

CONTEXT

Multiple sclerosis is characterised by the presence of white matter lesions, which can be visualised and quantified on Magnetic Resonance images (MRI). Typically, these MS brain lesions follow an evolution trajectory according to the inflammatory or destructive processes that occur at cellular level (demyelination, remyelination, or chronic axonal loss). Such processes can be inferred from (various types of) MR images as they correspond to different image intensities: inflammation is represented by hyperintensities on FLAIR MR images, chronic damage as hypointense regions on T1 weighted MR images[1], etc. icometrix has developed a clinical software, MSmetrix[2], a general segmentation method for multiple sclerosis lesions on MR images, but lesion evolution is not taken into account.

[1] https://radiopaedia.org/cases/multiple-sclerosis-black-holes-1

[2] Jain S., Sima D. M., Ribbens A., Cambron M., Maertens A., Van Hecke W., et al. . (2015). Automatic segmentation and volumetry of multiple sclerosis brain lesions from MR images. Neuroimage Clin. 8, 367–375. 10.1016/j.nicl.2015.05.003.

The thesis project will be conducted in close collaboration and at the premises of ico**metrix**, a spin-off company of KU Leuven (Kolonel Begaultlaan 1b/12, 3012 Leuven, www.icometrix.com). ico**metrix** specializes in providing services for quantification of brain MRI scans, in particular for diagnosis of MS.

GOAL

During the master thesis the students will develop a mathematical model for characterising the evolution in time of MR image intensities in multiple sclerosis lesions. The model will be designed based on a combination of prior knowledge and data-driven modelling applied at pixel level.

RESULT

The work will involve first an in-depth familiarisation with MR imaging and brain segmentation in multiple sclerosis, including mastering concepts of image registration by normalised mutual information optimisation and image segmentation through expectation maximisation framework. The main work will then focus on including a time-constrained intensity model for simultaneous segmentation and labelling of white matter lesions according to evolution state. Actual longitudinal follow-up MR images from patients with multiple sclerosis will be available for model validation.

PROFILE

Student(s) must have a good theoretical background and a strong practical mind-set; enthusiasm to perform the Master thesis research project in industry; knowledge of Python.

1 or 2 students	**2 students**

MASTER's THESIS MASTER of SCIENCE in MATHEMATICAL ENGINEERING

TITLE

1D Loudspeaker non-linear modelisation

GUIDANCE

• For more information, please contact:	Gregory Lielens (Free Field Technologies – gl@fft.be)
• Promotor:	t.b.d.
• Supervisor:	Gregory Lielens

CONTEXT

A loudspeaker is a complex device whose goal is to transform a variable electric input (potential difference or current) into a variable acoustic pressure output. This transformation has to be as accurate as possible, i.e. linear with a constant gain for a wide frequency range. Gain can usually be adjusted by the control circuit, but linearity is the primary design goal regarding audio quality, so understanding and controlling non-linear effects is crucial.

Investigating numerically the non-linear behaviour of the loudspeaker will be done in collaboration with Free Field Technologies, the Belgian software editor behind the ACTRAN vibro-acoustic simulation package.

GOAL

The goal of this work is to design and implement a 1D loudspeaker numerical model. Complex deformation of the loudspeaker cone and acoustic propagation pattern will be simplified, but the model must incorporate in a realistic way the main non-linear effects (mechanical nonlinearities, coil-magnet nonlinearities and nonlinear modulation by Doppler effects). Model results will be analysed in time-domain and frequency domain. The implemented model will be used and calibrated against linear Finite element models.

RESULT

The student will do a small literature review on loudspeaker modelling, getting familiar with simple numerical modelling of the device. Then a mathematical 1D model of a loudspeaker will be formulated, incorporating N-L electromagnetic forces, cone vibration and acoustic radiation. This model will be implemented numerically, first in time domain then using non-linear harmonics technique.

PROFILE

The work involves some theory and some numerical implementations, without much focus on performance or large-scale simulations. Knowledge of vibro-acoustics is not required but may be helpful. Python is used by preference, but Matlab may be used.

1 or 2 students	**1 student**