Swedish Study Group: Mathematics in Industry

17-21 August 2015

INSTITUT MITTAG-LEFFLER
THE ROYAL SWEDISH ACADEMY OF SCIENCES

EU MATHS IN.se

KTH VETENSKAP OCH KONST
ROYAL INSTITUTE OF TECHNOLOGY

Contents

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- **Institut Mittag-Leffler**
- **Center of Industrial and Applied Mathematics (CIAM), KTH**
- **School of Computer Science and Communication, KTH**
- **Department of Mathematics, KTH.**

Program committee

Sandra Di Rocco (KTH), Catarina Dudas (FCC), Magnus Fontes (LTH), Johan Hoffman (KTH), Henrik Hult (KTH), Mats Larson (UMU), Jesper Oppelstrup (KTH), Sergei Silvestrov (MDH), and Ozan Öktem (KTH).

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Organizing committee

Johan Karlsson (KTH) (project leader), Sandra Di Rocco (KTH), Johan Hoffman (KTH),
Karl Jonsson (KTH), Maria Weiss (IML), and Ozan Öktem (KTH).

1 About SSGMI

Swedish Study Group Mathematics in Industry (SSGMI) is a workshop for interaction between companies and mathematicians in the academia. The format of the workshop is based on the Oxford study group, where industrial scientists work alongside academic mathematicians on problems of direct industrial relevance. This is the first workshop of its kind in Sweden and was hosted by Institut Mittag-Leffler August 17-21, 2015. It gathered 35 scientists from eight universities and six companies: Ericsson Research, Greenely, Lynx, Protracer, Scania, and Swedbank.

The workshop is organized and sponsored jointly by Institut Mittag-Leffler and KTH: Center for Industrial and Applied Mathematics, Department of Computer Science and Communication, and Department of Mathematics. The workshop is organized as an activity within the Swedish network eu-maths-in.se which is a newly established network created to promote the use of mathematics in industry and to serve as an interface between academia and industry.

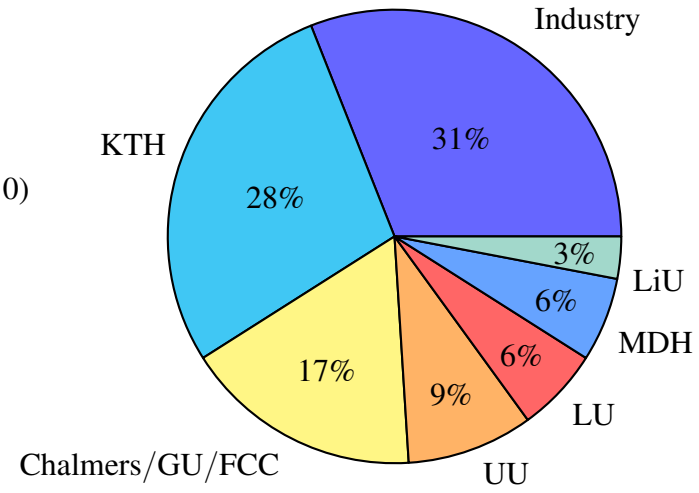
Participating companies:

Company	Company representative	Team leader	Affiliation
Ericsson Research	Ather Gattami	Magnus Fontes	LTH
Greenly	Mohammed Al Abassi	Thomas Schön	UU
Lynx	Tobias Rydén	Filip Lindskog	KTH
Protracer	Joakim Lindblad	Johan Hoffman	KTH
Scania	Frida Nellros	Catarina Dudas	FCC
Swedbank	Ola Hammarlid	Henrik Hult	KTH

Participants:

Total of 35 participants: 24 from academia, 11 from industry.

- Chalmers University (3)
- Fraunhofer-Chalmers Centre (2)
- Göteborg University (1)
- KTH Royal Institute of Technology (10)
- Linköping University (1)
- Lund University (2)
- Mälardalen University (2)
- Uppsala University (3)
- Industry participants (11)



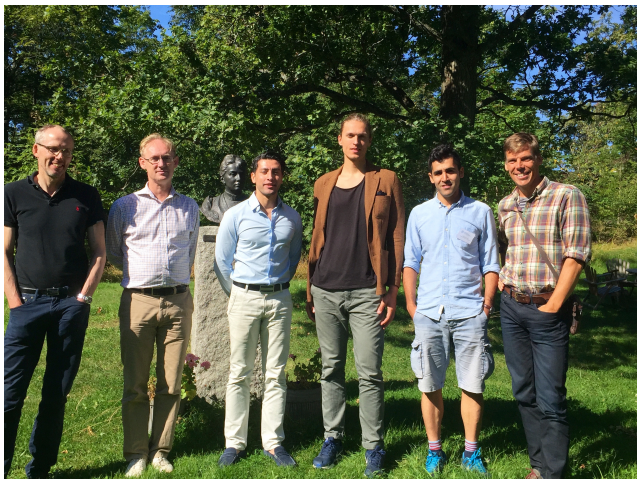
2 Ericsson Research: A waveform design problem with time and frequency constraints

In this project we consider a mathematical problem of waveform design with constraints on both time and frequency domain. The goal is to find a waveform of minimum time duration with respect to the given constraints. It is possible to set up a strategy to solve the mathematical problem. However, the solution to the problem, i.e., the waveform may be difficult to generate in practice. By making an ansatz, we rewrite the an infinite-dimensional version of the problem to a finite-dimensional non-convex optimization problem. We solve this problem by using the yalmip toolbox. The solutions obtained are compared with rectangle waves. We observe that our solutions have better properties and behavior with respect to the given constraints.

The report is available at: `http://eu-maths-in.se/wp-content/uploads/SSGMI_2015_report_Ericsson.pdf`

Team members

- Magnus Fontes (LTH)
- Dawan Mustafa (Chalmers University)
- Ather Gattami (Ericsson Research)
- Magnus Olsson (COMSOL)
- Karl Jonsson (KTH)
- Olof Runborg (KTH)



3 Greenely: Energy disaggregation with low resolution data

Energy disaggregation deals with the problem of separating a signal containing the total energy consumption into information about the energy consumption of individual appliances. Studies have shown that by providing this information households can reduce their energy consumption with up to 20%. The traditional approach has relied on costly hardware that residents have to buy and install on their electricity meters. The cost (150-200 EUR) together with complicated installation has led to very few people investing in such a solution. Accordingly, the major energy reduction which was envisioned has been absent. During recent years, more than 100 million smart meters have been installed in different parts of the world. These smart meters can communicate hourly to 15 minutes readings, but are unfortunately not being utilized to their maximum capacity.

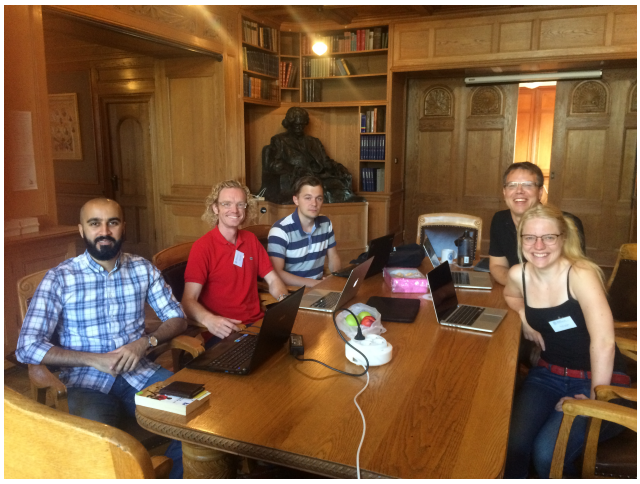
Greenely wants to approach the energy disaggregation problem using low-resolution data from these smart meters. This is a complex problem and most existing approaches rely on data with much higher frequency. However, if such disaggregation is successfully applied on smart meters, no additional hardware is required and Greenely can utilize information from already existing smart meters in order to facilitate in-depth analyzes of households' individual appliances.

The report present initial results from a few different solutions to the energy disaggregation problem using low frequency data. In particular, methods are considered that exploit theory from sparse estimation and Hidden Markov models, respectively. This initial study shows that the energy consumption from some of the devices in the household could be estimated with moderate accuracy also from low frequency data.

The report is available at: `http://eu-maths-in.se/wp-content/uploads/SSGMI_2015_report_Greenely.pdf`

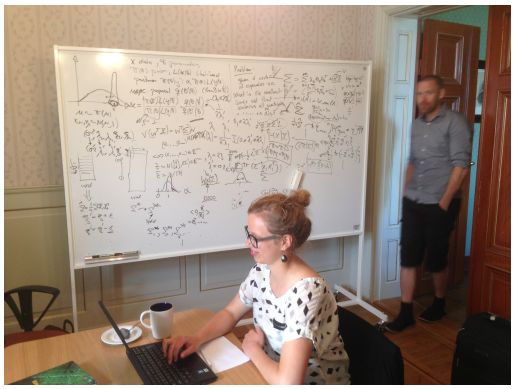
Team members

- Mohammed Al Abassi (Greenely)
- Kerstin Johnsson (LTH)
- Johan Karlsson (KTH)
- Thomas B. Schön (Uppsala University)
- Johan Wågberg (Uppsala University)



4 Lynx: Portfolio selection with many assets

During the workshop at the Mittag-Leffler Insititute we addressed the difficulties of Sharpe Ratio maximization when using the $p \times p$ sample covariance matrix based on an i.i.d. sample of size n, when p is large and of size similar to n, as a proxy for the unknown covariance matrix. The problem may be formulated in terms of the eigenvalues and eigenvectors of the sample covariance matrix. Given well-known results in Random Matrix Theory, such as the convergence, as $n \to \infty$ and $p/n \to$ some constant, of the empirical distribution of eigenvalues to the Marchenko-Pastur distribution, the difficulties are expected.

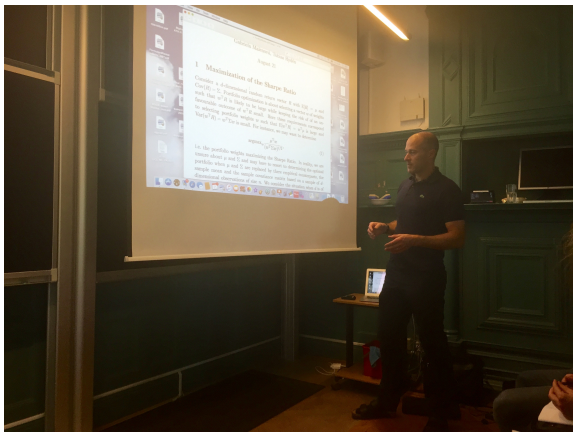


The Spiked covariance matrix model provides a parametric form that may be useful if the number M of spikes is not too large. For a fixed M we may analyze the inverse of the covariance matrix using a Bayesian approach with Metropolis-Hastings (MH) or simply by Maximum Likelihood (ML) estimation. For M small, ML performs very well and using the posterior mean of the inverse covariance matrix based on MH is not likely to improve things further. However, the MH output may be used to suggest appropriate uncertainty regions for robust optimization. A challenge is how to describe these regions in a way that both describe the parameter uncertainty and that leads to optimization problems that can be handled well. Finally, the number M of spikes must be selected. Using the Gaussian likelihood evaluated at the ML-estimates, we may look at likelihood ratios to come up with suitable values for M. Using MH we may use Bayes factors for model selection. Another alternative is to remove/subtract an estimate of the part of the sample covariance matrix due to the believed spikes and test whether the remaining empirical spectrum matches the corresponding Marchenko-Pastur limit well.

The report is available at: `http://eu-maths-in.se/wp-content/uploads/SSGMI_2015_report_Lynx.pdf`

Team members

- Marta Leniec (Uppsala University)
- Filip Lindskog (KTH)
- Johan Löfberg (Linköping University)
- Gabriela Malenová (KTH)
- Tobias Rydén (Lynx)



5 Protracer: Accurate ball flight aerodynamics through data driven inverse and forward modelling

Mathematical modelling of ball flight dynamics has a number of attractive applications within sports, for practitioners as well as spectators. Knowledge of ball flight paths can provide a practice aid for sportsmen, a means for enhancing the experience for spectators, and a tool for assisting referees in their judgements. Protracer has a unique material consisting of more than 10 million observed ball trajectories, sampled at 25 or 50 Hz.

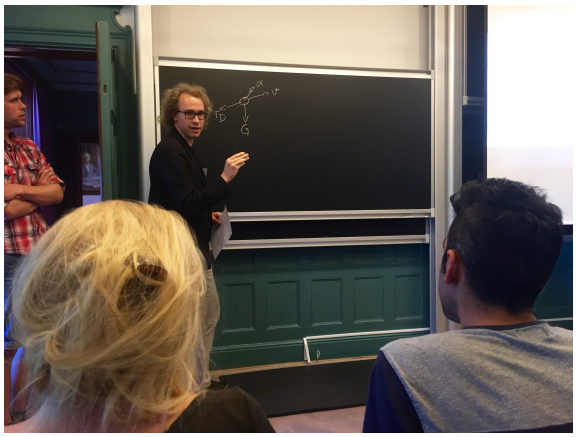
The problem presented by Protracer was to compute the entire trajectory of a flying golf ball based on observed position data from a part of the trajectory and in the process also estimate parameters such as initial velocity and spin of the flying golf ball. Based on $5 - 50$ observations of a ball flying through the air, we wish to estimate relevant flight parameters such as velocity, spin, and wind in order to accurately model the ball flight trajectory over time.

During the week at Institut Mittag Leffler a model for describing the physics of the motion of a flying golf ball was formulated based on the literature. The observed position data provided by Protracer was analysed in detail and two approaches for modelling the motion were considered: (i) finite difference reconstruction of acceleration data from the position data, to obtain the forces and hence the model parameters, and (ii) formulation of an optimization problem where the difference between the position data and the position from the physics model is minimised. The finite difference approach (i) turned out to be too sensitive to the noise in the data, whereas the optimisation approach (ii) showed promising results, both to predict the trajectory and to predict the model parameters.

The report is available at: `http://eu-maths-in.se/wp-content/uploads/SSGMI_2015_report_Protracer.pdf`

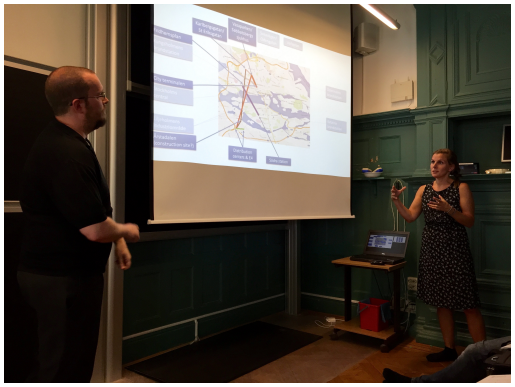
Team members

- Carl Lundholm (Chalmers University)
- John Malmberg (Gothenburg University)
- Johan Westerborn (KTH)
- Joakim Lindblad (Protracer)
- Joakim Hugmark (Protracer)
- Johan Hoffman (KTH)



6 Scania: Investigate graph and network algorithms in transport vehicle GPS data to detect and quantify hubs and flow

Scania offers products based on GPS-data provided from the vehicles. Services are e.g. driver coaching and maintenance planning and the current usage is mainly related to live tracking. This project focus on expanding the usage of the huge amount on available GPS-data. It is believed that the data can be used to identify hubs in the transport network, which extends the problem to detect bottlenecks, optimal routes and deviations from normal vehicle behavior.



The team were provided with several different data sets, different regions and time horizons, in order to be able to try different methods and algorithms. The stop-positions are clustered in order to identify the hubs and as clustering algorithm the density based DB-scan was used. The hubs were afterwards used for primarily two applications. The hubs possess certain characteristics, such as area and time length for the stop, which can be used to cluster the hubs. For this clustering the EM-algorithm was applied. The hubs were also used as nodes in a graphs and edges were created where there are traffic to identify main routes between nodes. These methods were successfully applied to the data sets and the results show that it is possible to identify reasonable hubs within the region under investigation. As an example, the bus terminal and the fire stations in the Stockholm data set were pinpointed as hubs. It could also be seen that it is possible to find different types of hubs and a rough identification of some of these types as well as main traffic flows between hubs.

The report is available at: `http://eu-maths-in.se/wp-content/uploads/SSGMI_2015_report_Scania.pdf`

Team members

- Catarina Dudas (Fraunhofer-Chalmers Centre)
- Christopher Engström (Mälardalen University)
- Johan Karlsson (Fraunhofer-Chalmers Centre)
- Frida Nellros (Scania)
- Luyuan Qi-Gautier (KTH)
- Sergei Silvestrov (Mälardalen University)
- Jesper Ulke (Scania)

7 Swedbank: Fast simulation for computing credit value adjustment of interest rate portfolios

Monte Carlo simulation is frequently used within the bank for the purpose of pricing and risk quantification. The proposed project is directed towards efficient Monte Carlo simulation for portfolios of interest rate products. The fixed-income portfolio of a typical bank consists of interest rate derivatives such as caps and floors, interest rate swaps, cross-currency swaps, swaptions and FX forwards. These instruments are being sold to customers and used for mitigating the bank's exposure on the fixed-income market. The portfolio consists of thousands of such derivatives. The valuation of such fixed income products is quite complicated in practice. In particular, the introduction of collateral agreements creates a significant computational overhead. The details of the collateral agreements as well as the counterparties respective credit worthiness must be taken into account and the theoretical risk neutral price must be corrected with the appropriate collateral value adjustment, default value adjustment, funding value adjustment, etc.

In addition, in the aftermath of the financial crisis the fixed-income markets have become more complicated. The liquidity crisis transformed markets into multi-curve families where, for each currency, there is a yield-curve for each tenor. The stochastic evolution of the collection of yield-curves and exchange rates can be described by a high-dimensional stochastic process that is calibrated to be consistent with current market prices.

For the purpose of pricing and risk management of the interest rate portfolio scenarios of the underlying stochastic process are generated and the value of the portfolio is computed under each scenario. As the number of contracts to value is high, as is the dimensionality of the underlying stochastic process, the computational cost is significant and even with a limited number of time steps the accuracy obtained by standard Monte Carlo is poor. The aim of this project is to develop a general framework for significantly reducing the computational time.

In a simplified setting, using a one-factor Hull-White model for the short rate and a single currency, an efficient method for computing credit value adjustments have been constructed. The limited numerical experiments indicate and excellent performance and significant variance reduction, greater than expected. The results achieved thus far will be written in a joint paper that will be submitted to the Journal of Computational Finance.

The report is available at: `http://eu-maths-in.se/wp-content/uploads/SSGMI_2015_report_Swedbank.pdf`

Team members

- Jonatan Eriksson (Swedbank)
- Jonas Hallgren (KTH)
- Ola Hammarlid (Swedbank)
- Henrik Hult (KTH)
- Björn Löfdahl (KTH)
- Carl-Johan Rehn (Swedbank)

8 Participant feedback

- The concept I think is the best initiative I have come across, in terms of industry-academia connections. Please keep it. /Ola Hammarlid, Swedbank
- Intense but productive. /Ola Hammarlid, Swedbank
- Jag tycker att formatet har varit bra, med en blandning av seniora forskare och doktorander. /Tobias Rydén, Lynx
- Det problem som Lynx hade var en smula löst formulerat, till skillnad från en del av de andra problemen som jag uppfattade som mer direkta, eller precisa. Arbetet i gruppen tog en litet annan riktning är vad som fanns beskrivet i den ursprungliga problemformuleringen, men för min egen del så lärde jag mig en hel del nytt (om robust optimering) som känns väldigt värdefullt. /Tobias Rydén, Lynx
- It has been an intense and very productive week here at the institute where most of the time was spent on actually solving the energy disaggregation problem that Greenely is facing. The team was handpicked based on their skills and most of us had not worked together before. It worked fantastic and we went straight into productive mode implementing and testing four different solutions to the problem. /Thomas Schön, Uppsala University.
- In my experience, academia and industry can both gain a lot from contact. The study group was a good opportunity for this. /PhD student
- A good environment for high tempo learning. Very rewarding to see how 'talented' and 'experienced' people solve problems together. /PhD student
- It was a great experience–don't change too much! /PhD student

What advice would you like to give to future workshop participants?

- Work together as a group. Don't split the work into one package each. /Faculty participant
- Since one week is fairly short time, focus on exploring general ideas and testing principles. Do not get too distracted by details. /PhD Student

What was the best aspects of the workshop?

- Meeting people and working on fun stuff for a week with nothing else to bother about. The environment. /Faculty participant
- The best aspect was the possibility to make contacts with professionals in academia as well as industry, and being introduced to new (and unexpected) (research) problems. /PhD student
- Meeting and working with interesting people on a truly applied problem in a very nice environment. /PhD Student
- The environment, the real world applications and interaction with industry. /PhD student

Detailed participant feedback (to improve future workshops)

What was the best aspect(s) of the workshop?

- Working in a group.
- Meeting people and working on fun stuff for a week with nothing else to bother about. The environment.
- The retreat style, that groups were more or less together round the clock in the Mittag-Leffler house.
- To meet people from different areas and with different expertise. Gives a good environment for high tempo learning. Very rewarding to see how 'talented' and 'experienced' people solve problems together.
- Working together with people from different areas of mathematics and industry.
- Meeting and working with interesting people on a truly applied problem in a very nice environment.
- All being closed out from the outside world for a week, meeting professionals.
- The environment, the real world applications and interaction with industry.
- The best aspect was the possibility to make contacts with professionals in academia as well as industry, and being introduced to new (and unexpected) (research) problems.

Was the workshop meaningful? (Grade 1-5).
Why/why not?
Would you participate again if given the opportunity?

- 4. Interesting way of working. Yes.
- 5. Meaningful? Depends on what we mean with that word. Meaningful for the development of the world, probably not, but extremely fun an inspiring. Yes.
- 4. [No answer]. Yes.
- 5. I have learnt a new area in just a week and hopefully done some novel things in that area. Yes.
- 3. It was a great way of getting started after the summer vacations. Meeting and working together with other mathematicians is usually very stimulating. Maybe.
- 5. Learning from others. Meeting new people. Working on fun problems. Yes, if the topic suited me.
- 4. I am not sure if we actually contributed with anything to the company's issue solving. Yes.
- 5. [No answer]. Definitely.
- 5. In my experience, academia and industry can both gain a lot from contact. The study group was a good opportunity for this. Yes, very likely.

What would you suggest to improve?

- More breaks.
- Perhaps some kind of more official coffee break (have a cake, and more will come)
- Maybe require (even) more preparations within the groups before the workshop, to make the work time allotted at ML more efficient.
- A bit less of time for the presentations, sometimes it gets too specialized when the concepts in the presentations are not familiar. It is however good to have presentations, since this is a good platform for learning from the other participants. For our group the mid-week presentation turned out very useful since we got a lot of good suggestions and help from there.
- Remove the half-time presentation session. It just felt unnecessary. We already had three long presentation sessions and there was only half a day of actual work between the mid- and final presentation. Which isn't that much time to develop the project further.
- Consider shortening the presentation times.
- Clearer instructions within the group
- Forced interaction between the groups. Perhaps a short joint fika everyday.
- The "half-way" presentation, which was good for getting input from the other groups, but took some time to prepare, time which might have been more profitably spent working on the project instead of summarizing half-ready ideas. Perhaps interaction and discussion between the groups could be encouraged in a more informal context, such as discussions during lunch or dinner.

What advice would you like to give to future workshop participants?

- "Work together as a group. Don't split the work into one package each."
- Do your best.
- Prepare a plan and structure for the problem. Since one week is fairly short time, focus on exploring general ideas and testing principles. Do not get too distracted by details.

Is there anything else you would like to add?

- Bra jobbat Johan!
- It was a great experience–don't change too much!
- Well done