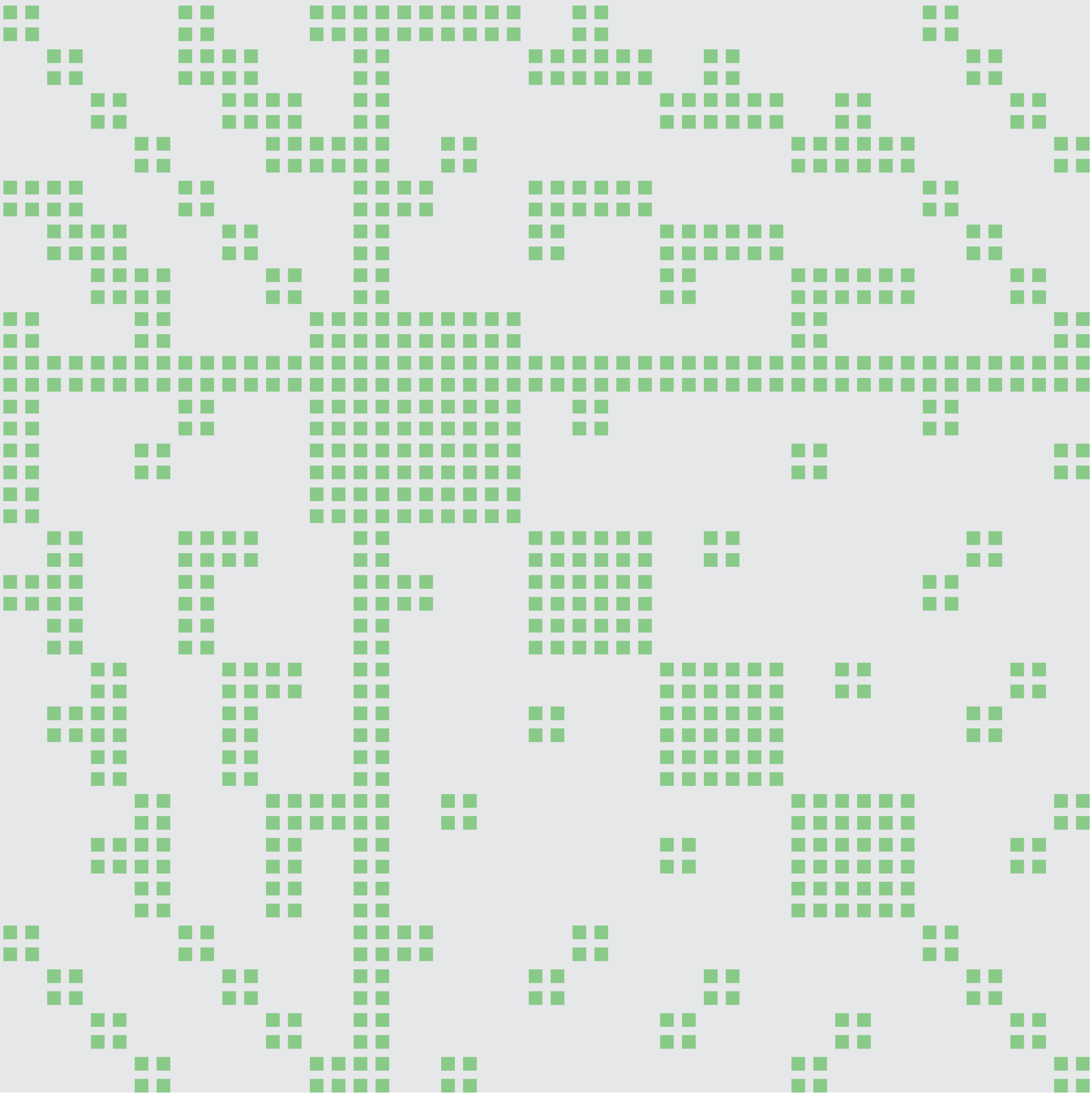
UMEÅ UNIVERSITET

ANNUAL REPORT | 2014

UMIT Research Lab



About UMIT

UMIT Research Lab is a strategic initiative in computational science and engineering with a focus on industrial applications and innovative software development. The lab is a dynamic, intellectual and physical environment enabling worldclass interdisciplinary research in scientific, high-performance, distributed, real-time and visual computing.

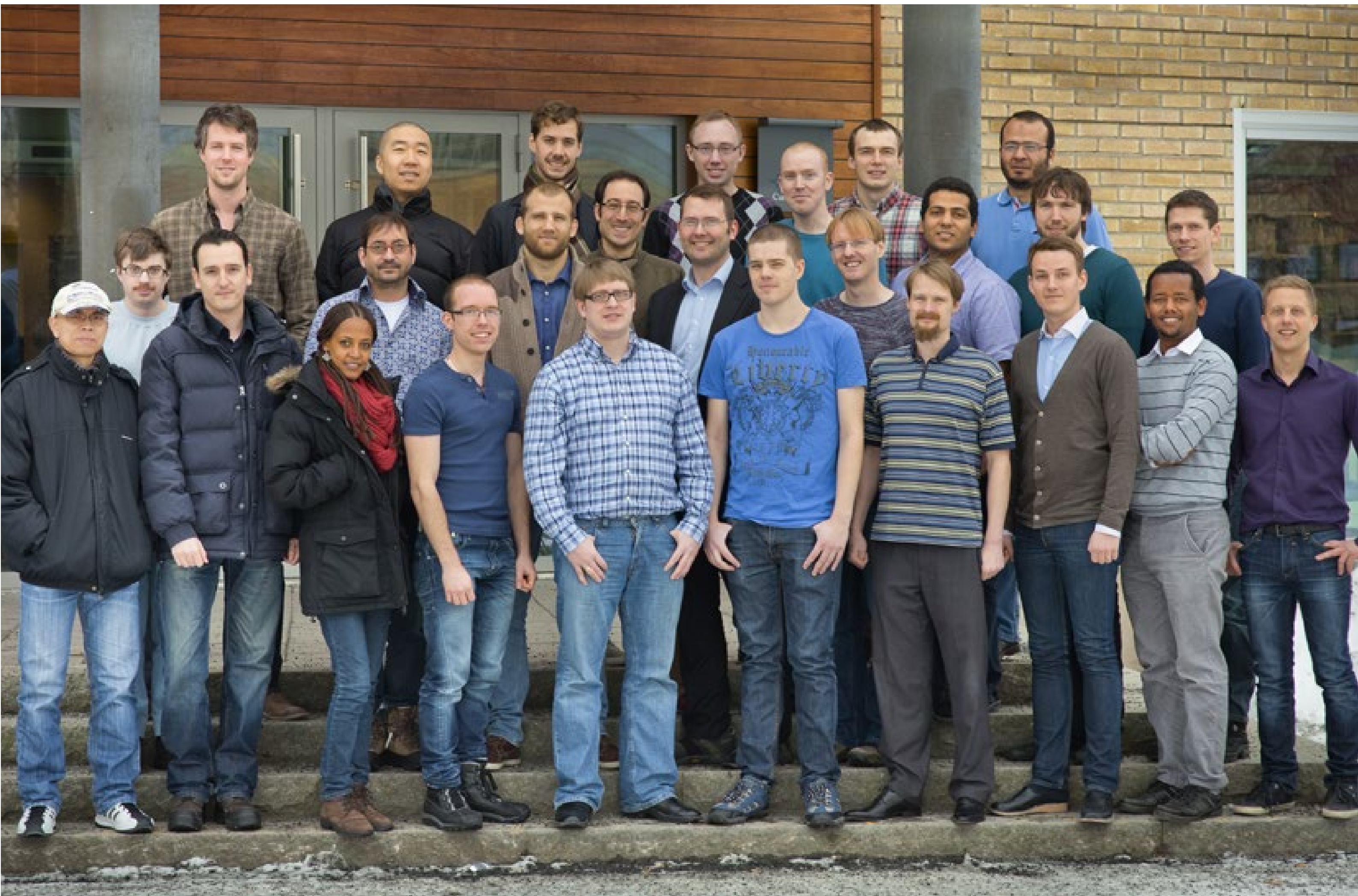
The research lab's activities result in new models, methods, algorithms for advanced simulations and analysis. This research also develops quality software solutions, which target new high-performance computing platforms and IT infrastructures. UMIT focuses on challenges and applications that have a high relevance to industry and society. A collaboration between research and development and industry and society is key to the research lab.

Research lab
The lab is a natural meeting place for interdisciplinary research and development, with affiliated staff from the departments of computing science, mathematics, mathematical statistics, physics and applied physics and electronics. Around 50 researchers and developers are involved in the UMIT environment, and about 30 of them work in the lab. The lab offers access to special equipment and software. Seminars and workshops are centered around recent research results and advances in numerical methods, software, and hardware architectures, as well as scientific and industrial applications and new work methods.

Applications
Since 2009, the UMIT Research Lab has featured many recruitments, projects, and spinoffs. This work has established the lab as a leading center in the field of computational science and technology. In addition to conducting fundamental research, UMIT is active in the development of new software technologies. The lab also frequently participates in various collaborations with partners from industry and society, in order to explore the science, engineering, media, and entertainment applications for its research. Many projects have led to new products, more energy efficient and environmentally conscious processes, and new job opportunities.

Top-class infrastructure
The High Performance Computing Center North (HPC2N), which is part of the national meta center SNIC, provides UMIT with expertise and e-infrastructure for grid and cloud computing, high-performance, and parallel computing, which includes effective mass-storage solutions.

Funding
The original funders are the EU Structural Fund Objective 2, Umeå municipality, Umeå University and the Baltic Donation Fund. Other sources of funding and agencies include EU FP7/Horizon 2020, Kempe Foundations, ProcessIT Innovations, Skogstekniska Klustret, Swedish Research Council Swedish Foundation for Strategic Research, VINNOVA and several other companies.



2014 – A brief review

2014 was an important transitional year for UMIT. Several PhD students earned their doctoral degrees and moved on. Several younger researchers became docent and are now ready to take on bigger roles in supervising new research students. Researchers also completed the large projects Simovate and eSSENCE and began planning for future research and development. Some of these new research projects and commercial ventures have already started, while others will launch in 2015.

People
Assistant professor Fredrik Bengzon, postdoc Olivier Verdier, and PhD student Mahmoud Eljammaly joined UMIT. Daniel Espling, Fotios Kasiolis, Petter Swärd, and Wubin Li earned their doctoral degrees. (See the article on page 6 for how their career has continued.) David Cohen, Christian Engström and Johan Tordsson earned the title of docent. Martin Servin was awarded the faculty prize for interaction with the external society. Mats Johansson earned a bigger, more active role as project coordinator at UMIT. Cristian Klein, Johan Tordsson, Francisco Hernandez-Rodriguez, and Luis Tomas were awarded Best Paper at the International Conference on Cloud and Autonomic Computing (CAC 2014) with their paper "The straw that broke the camel's back: safe cloud overbooking with application brownout". Additionally, Computational Mathematics, a larger research group with specializations in finite elements, geometric numerical integration, and special theory, joined the mathematicians at UMIT.

Projects and innovations
Mats G Larson and Martin Berggren at UMIT and Peter Hansbo at Jönköping University were awarded a grant of 21 MSEK by the Swedish Foundation of Strategic Research (SSF) for the project "Cut finite element, geometry and design optimization". The Swedish Research Council granted Bo Kågström 3.4 MSEK for the project "Stratification of matrix pencils with structure". In the SSF program Strategic Mobility Johan Tordsson was granted 1 MSEK for research in collaboration with Ericsson Research in Lund. The project addresses the convergence between cloud and telecom systems. Led by Martin Servin at UMIT, the project "Control of granular processes" will address the simulation-based development of new methods for processes handling granular materials. VINNOVA supports the project with MSEK. Project partners that include Algoryx Simulation, LKAB, and Optimation also support the project with 4 MSEK. Stage 2 of project SIMOVATE was concluded in 2014. The project aims to increase and improve the use of simulators in the development of complex products and processes. The eSSENCE strategic research program in e-science, in collaboration with Uppsala University and Lund University, concluded its first five year. In the self-evaluation, UMIT is highlighted as a successful example of a multidisciplinary research environment with strong industry engagement and spin-offs. The Cloud Control project arranged a series of workshops that attracted increasingly large audiences of leading academic and industrial groups.

Looking forward to 2015
UMIT Research Lab is currently working with regional companies to establish "Computational design" as a strong and expanding research, innovation and business speciality. We look forward to starting up this project in 2015 and to merging computational science with additive manufacturing, design, and art with new exciting tools and methods. Sliperiet and its FabLab, which was inaugurated in 2014, will serve as a platform for exploring these ideas. The MIT-building, where UMIT resides, will be renovated and a 'focus environment' for mathematics and information technology will be created and designed to facilitate strong interaction between education, research and industry and society. Stage 3 of Simovate is expected to start in 2015 and last for two years. The focus in stage 3 is to rigorously test the solutions in simulation-based product development at several leading vehicle manufacturers. Stage 3 will also focus on demonstrating a prototype solution for a simulation app store, as well as for a platform for open innovation based on distrubuted co-simulation over the web.

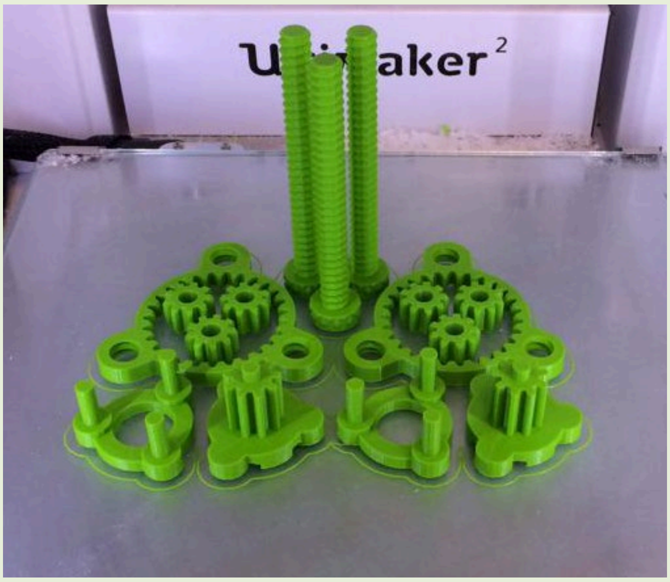
Some project highlights...

UMIT Researchers were awarded 21 MSEK from the Swedish Foundation for Strategic Research for working with “Cut finite elements, geometries and design optimization”

“I'm very happy about the award and it's perfect timing since we already started the project with some promising results”, says Mats G. Larson, the principal investigator of the project.

The project focuses on the development of computer-based methods for the simulation of physical phenomena, such as the strength of materials, wave propagation, and fluid flow in complex geometries. The new methods are well suited to simulate complex geometries or to gauge how the geometries evolve over time.

“We will in particular study optimization of geometries, for example making a mechanical component as light as possible and at the same time carry a certain load”, he says. The project will focus on the development of new methods, the analysis of the properties of the methods, and applications in collaboration with industrial partners. The project is a joint effort between Umeå University (Larson and Berggren), Jönköpings University (Hansbo), and Linköpings University (Klarbring).



National agenda for additive manufacturing and 3D-printing

The services and production of additive manufacturing grew 35 percent internationally in 2013 and are expected to quadruple by 2018.

“We see tremendous opportunities to provide both industry and consumers with new, creative, and easy-to-use solutions for design, modeling, simulation, and optimization adapted for additive manufacturing”, says Kenneth Bodin, CEO of Algoryx Simulation AB and member of the working group. This is a new ecosystem of software, services and products that Sweden can take a leading role in.

The agenda will be developed within the framework of the Strategic Innovation areas, a joint venture between VINNOVA, the Swedish Energy Agency, and Formas. The purpose of the initiative is to create conditions for Sweden to compete internationally and sustainable solutions to global societal challenges.

The 3rd eSSENCE Academy workshop in Umeå

eSSENCE
THE e-SCIENCE COLLABORATION

e-Science is one of 20 strategic research areas (SFOs) funded by the Swedish government. One of the two SFO programmes in e-Science is eSSENCE - a strategic collaboration between three Swedish universities with a strong tradition of excellence in e-Science research: Uppsala University, Lund University and Umeå University.

The vision of eSSENCE is to provide excellence and scientific solutions at all stages of the e-Science process and thereby advancing science through leading computation, information and communication technologies. There are four main research areas in eSSENCE: Material Science, Human Function and Environment, Life Science, and Generic e-Science Methods and Tools. The Umeå projects funded by eSSENCE are focused on Generic e-Science Methods and Tools and include topics like Distributed services and grids, Computational algorithms and implementation, and High performance and parallel computing. Some of these also carry a UMIT-hat. Notably, in the recent self-evaluation report of eSSENCE, UMIT was chosen as the one “best practice” project that includes collaboration as an example of conducting research of high international quality with relevance for society or the business sector.

The annual eSSENCE Academy Workshop was held , this time, at Umeå University. In October 2014, around 90 researchers from Lund, Uppsala and Umeå took the opportunity to meet and acquaint themselves with the exciting ongoing research within eSSENCE. Besides interesting talks and posters there was also an invited presentation by Anders Ynnerman followed by a panel discussion on “Swedish Science Cases for e-Infrastructure and the Future of e-Science in Sweden”. The local organizers of the workshop were Bo Kågström and Erik Elmroth, two of the ten national eSSENCE-PIs, with support from HPC2N and the Department of Computing Science.

UMIT and Ericsson Research exchange

In the SSF program Strategic Mobility Johan Tordsson was granted 1 MSEK for research in collaboration with Ericsson Research in Lund. The project addresses the convergence between cloud and telecom systems.

UMIT Alumni

Becoming a PhD is a big step in the world of academics, but then what? Will you continue to immerse yourself even more in academia, perhaps by taking a post-doctoral position? Or do you want to try your wings in industry? Petter Svärd and Daniel Espling, two PhDs within the research area of IT Infrastructure, graduated from UMIT in 2014. Svärd and Espling have chosen to continue their careers in the industrial sector. We were interested to hear what they are up to now and how they look back at their time at UMIT.

Daniel Espling currently works at Ericsson Research in Luleå as an Experienced Researcher. His work assignment consists of designing and implementing new components for cloud-focused research projects, in which he and his colleagues try to create intelligent automated procedures to make it easier to deploy and run complex applications. “This technology area is changing swiftly, so the hardest challenge is to be flexible enough to be able to quickly change direction according to the latest development,” Espling says.

Petter Svärd works as a project manager at 5 High Innovations (Hi5) in Umeå. He is responsible for development of the software controlling the company's cloud offering, Norrmoln. “We see a need for more self-management, self-service and self-configuration in the future, as well as a range of new opportunities to bring cloud technologies to a wider audience,” he says.

Svärd describes the biggest challenge as being able to keep the customers satisfied with the service and at the same time implement new features. “From a technical standpoint, it is a bit tricky to integrate the different systems that make up the cloud offering, as they all use different data formats and have different ways to get data in and out,” explains Svärd.

Daniel Espling

New challenges

Both Espling and Svärd find the big difference between industrial work and academic research to be the customer, and that someone actually is willing to pay for what you develop. Espling describes it as the “Why?” part of strategic work planning. “In academia, the ‘Why?’ is mostly theoretical contributions such as research articles, and you use practical projects to validate the results, while industry tends to prioritize the practical outcome of projects and use publications more as a strategic tool. But I have found that it affects the ‘How?’ part more than I expected, and also provides a base for very fruitful collaborations between industry and academia,” explains Espling.

Espling says that versatility is the most helpful attribute he learned during his PhD education. “As a consequence, I feel confident enough to work in any phase of a research project, from formulating the project plan and research questions to actually implementing software components and integrating them with full-blown production systems.”

The benefits of an interdisciplinary research lab

Both highlight the ease of being able to discuss a problem with researchers from other areas as the implicit benefit of being in an interdisciplinary research lab. “We often encounter the same basic problem that we attack in different ways,” says Svärd. Furthermore, Espling describes collaboration as the more explicit aspect: “You can run common projects; there have been successful collaborations between researchers doing cloud computing with people from the optimizations team, for example, where they contributed a lot to improve the knowledge and use of optimization models on problems like scheduling in cloud computing.”

Espling also tells us that they are starting a collaboration with the UMIT Cloud Computing Research Group to work on automation challenges from different perspectives.

“Some of the work directions that we see contain some very interesting theoretical problems that I personally think would provide great research topics for academia,” Espling comments. Also, Svärd sees potential collaboration in finding better software for managing data centers. “It would be interesting to run such research on our [company’s] data center,” says Svärd.

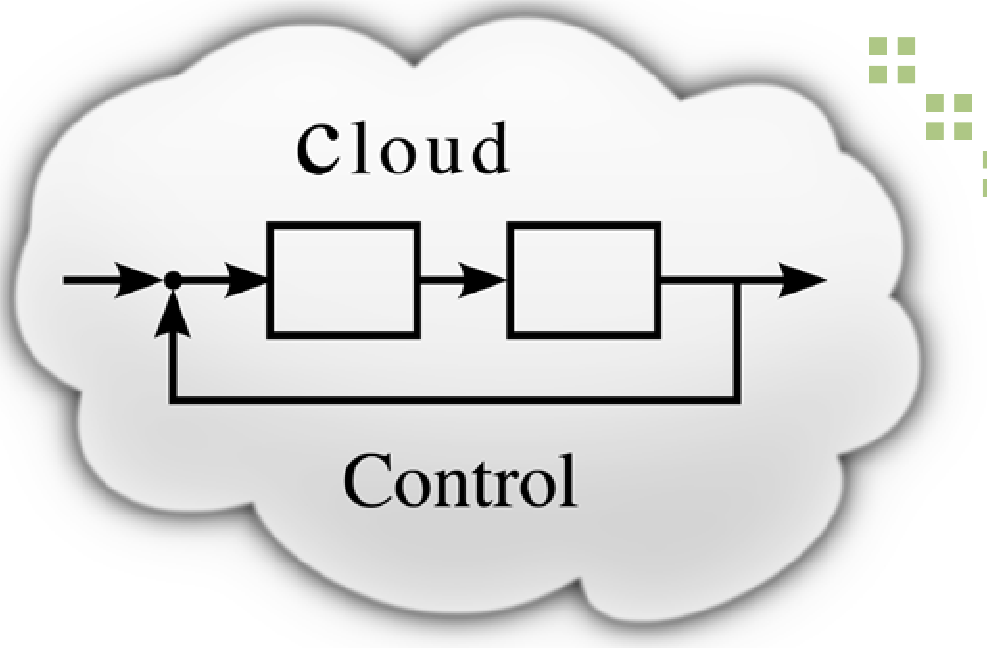
Petter Svärd

Facts About Cloud Computing

Cloud computing is the delivery of IT capabilities as a utility, just like water or electricity. Clouds on the Internet offer IT resources (servers, storage, networking, software, etc.) to which users can get instant access, instead of having to build and maintain their own computing infrastructures.

Thanks to the pay-per-use business model of clouds, users can dynamically change the amount of resources they use and pay accordingly. This elasticity is enabled by the way that cloud providers multiplex all user workloads in huge warehouse-scale data centers, comprising hundreds of thousands of servers.

With properties such as on-demand self service and seemingly infinite capacity, clouds are particularly suitable, for example, to solving computationally intense mathematical problems or to hosting large-scale web sites that need to be online and accessible at all times.



Simulation of granular materials

Computer simulation is indispensable to understanding the nature of granular materials. It is also an important tool for design and optimization in the industries of processing, manufacturing, storage, and transportation of granular materials, including grains, minerals, pharmaceutical pills, pellets, sand, and rocks.

A complex matter
Granular materials consist of many macroscopic particles, from microns to meters in size, which interact strongly with each other through contact forces. The systems composed of these materials are strongly dissipative and meta-stable with critical phenomena like jamming and avalanches, and they exhibit phenomena on several very different lengths and timescales. The materials can switch quickly between solid, liquid, and gaseous form. Especially characteristic of these systems is the presence of strong force chains; these chains extend through the material and cause arching phenomena that give structural strength to granular materials and are fundamental for the design of storage silos and, keeping grains in an hourglass flowing at a steady rate. For many phenomena, it is important to model all individual particles, which may amount to many millions, and their detailed interactions. Many challenges remain before the modeling and simulation of granular matter can be considered a mature science and technology.

Research at Umeå University
The research on granular materials at UMIT Lab is focused on models and methods for simulating large-scale granular flows and strong interaction with other types of dynamic systems, that may represent machines for transportation and processing. The different dynamical systems are modeled in a unified mathematical formalism. Particular focus is on particle-based modeling of granular materials, as well as numerical methods and algorithms for high-performance computing, allowing for interactive real-time simulation and systematic and time-efficient exploration of large design spaces with complex geometries.

Simulation for design and control
Computer simulation is an essential tool for developing design and control methods for industrial processes involving granular materials. Physical experiments are often practically or economically unfeasible and provide only limited information about the dynamic. Simulations make it possible to understand the relations between the macroscopic bulk behavior of a granular material, the shape of the surrounding geometry, and the material's microscopic properties, such as particle size, shape, friction, and elasticity. With virtual experiments -, a design can be scrutinized easily to find bottlenecks

in the flow and damaging effects on the material or the equipment during a process. Enough powerful simulations allow for systematic design optimization of systems for transportation and processing, to minimize energy consumption, maintenance costs, and improve product quality.

Industry collaboration

UMIT Research Lab is part of a joint venture since 2009, together with the spin-off company Algoryx Simulations AB, the mining company LKAB, and Optimation AB, which is specialized in process- and control optimization. The partners collaborate in developing the next generation software tools and work methods for simulation-based design, analysis, and optimization of bulk handling and processing of granular materials. Algoryx's software AgX Dynamics and its CAD-integrated version Dynamics for SpaceClaim have been expanded with a module for particle-based granular matter. Several solutions have been developed specifically to support simulation of iron ore green pellets. The software has been used in developing new designs for pelletization drums at LKAB's plants. In 2014, the partners started extending the framework to include control systems in a project named GranuReg (Control of granular processes). This work is co-financed by VINNOVA in the national strategic innovation program Process Industrial IT and Automation.

The research and software solutions for granular matter simulation have several other industrial applications, including training and engineering simulators by Oryx and Algoryx Simulation and machine manufacturers Atlas Copco and Volvo Construction Equipment. Particle-based methods for simulating terrain vehicles on soft soil is also are under development at UMIT and are being tested for analyzing the design of forestry machines for increased mobility and less ground damage.

Interviews

Tomas Berglund, developer at Algoryx Simulation AB, Umeå

What is your role in the collaboration?

- I develop solutions for the core simulation engine AgX Dynamics and the front-end user tool, Dynamics for SpaceClaim Granular.

What is your expectation of the GranuReg project?

- The simulation tool will support a wider range of processes involving bulk materials, in addition to the pelletizing process, and support co-simulation with other tools. This might also help to spread our solutions further.

What is the biggest value of UMIT Research Lab in the collaboration?

- UMIT has made essential contributions to the theoretical and numerical foundation for doing these types of large-scale granular simulations. It is essential that the user can be confident and trust in the results from your simulation.

Stefan Rönnbäck, PhD in control theory, senior consultant, and co-founder of Optimation AB, Luleå

What is your role in the collaboration on granular matter simulation?

- Until recently, granular matter simulation was a missing tool in our work on process- and control optimization. We have used Dynamics for SpaceClaim Granular for developing new design of balling drum outlets for LKAB. Many costly and time consuming full-scale experiments are now replaced by virtual experiments. In some cases, this has speeded up our work with several years, mainly due to reduced waiting time for getting access to the real plant. Furthermore, many experiments can now be performed that would never have been allowed in full scale due to the need for process modifications.

What is your expectation for the GranuReg project?

- The simulation tool will be further developed such that it can also be used for control optimization, which is expected to greatly increase its usability. This new functionality will be tested for designing control solutions for balling circuits.

What is the biggest value of UMIT Research Lab in the collaboration?

- Besides being very nice and talented people to collaborate with, we are very grateful to them for initiating and taking the lead in forming the GranuReg project. We also highly appreciate their academic work on modeling and numerical methods for high-performance simulation of granular matter.

Kjell-Ove Mickelsson, research engineer at LKAB R&D in Malmberget

What is your role in the collaboration on granular matter simulation?

- Using simulations, we have tried out numerous mechanical designs of different machinery and parts of the pelletizing process. Today several solutions are a reality in our plants. The biggest device yields a production of 260 tonnes per hour of our finest product, and the smallest is a piece of laboratory equipment meant to test new products, which potentially can increase our outcome in future product lines. As a very active participant, I have the privilege to also affect the features in the DFSC-Granular tool as it performs today.

What is your expectation of the GranuReg project?

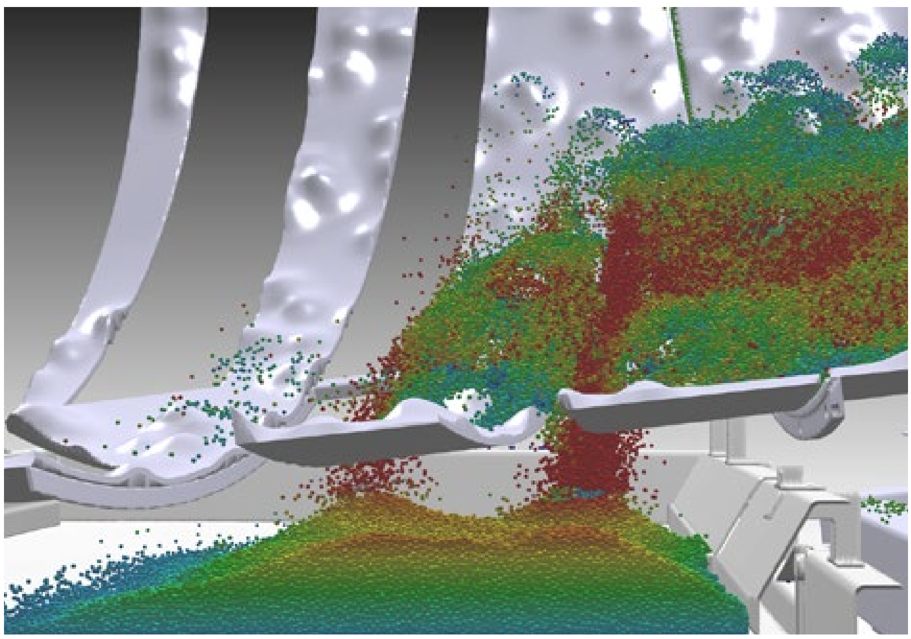
- Today we have the tools, the competence, and the work methods not only to create new optimal designs but also to improve existing designs. If our goals in the GranuReg project are met, we will also have the power to engender optimized strategies to control our processes. The value is enormous to be able to rule out errors, bench test, and have the possibility to be creative in a way that we can only dream of without the power of modeling and simulation.

What is the biggest value of UMIT Research Lab in the collaboration?

– We see UMIT as a great partner, a cluster of high competence, a social and professional counterpart really needed in these types of projects on the very front edge of technology.

How did you first come in contact with UMIT?

– I actively searched for relatively local partners for collaboration in the area of modeling and simulation of granular matter.



Simovate - a holistic view on simulation based development

Bild: Oryx Simulations och Skogforsk

Virtual simulation is increasingly being recognized as a vital tool in industries that conduct product and process development. Virtual models become indispensable as products becoming ever more complex, parallel to tougher demands from customers and society.

The Simovate project differentiates itself from other initiatives in simulation by addressing not only specific technical issues, but also the challenge of changing the development process to integrate simulation into all stages.

The goal of the Simovate project is to develop and implement a new methodology and technology platform. The platform should enable easy access and interoperability of data, models and tools for integrated full-system simulation through the various stages of the development process, such as idea and concept studies, systems development, testing, sales, and training.

The expected impacts of the project include reducing the time and resource to bring an idea to product or process. By doing more simulation the innovation capacity and organizational flexibility increase. This lead to better products.

The project has spawned several follow-up projects in which the methodology and technology developed is being implemented by some of Sweden's leading system-building companies, such as Atlas Copco, LKAB and Volvo. Through the project, UMIT has gained recognition as research environment and capability of operating and achieving success in major national initiatives in close collaboration with industry. The project has also cultivated a network of contacts in a part of Swedish industry that can lead to even more fruitful collaborations in the future.

“Simovate is different from most other initiatives within the simulation area, as the initiative takes on a broader problem that also includes organizational structures and business models. Through this holistic approach, besides new simulation technology, the participants also gain a deeper understanding of the concept of simulation-based development and its values as well as drawbacks,

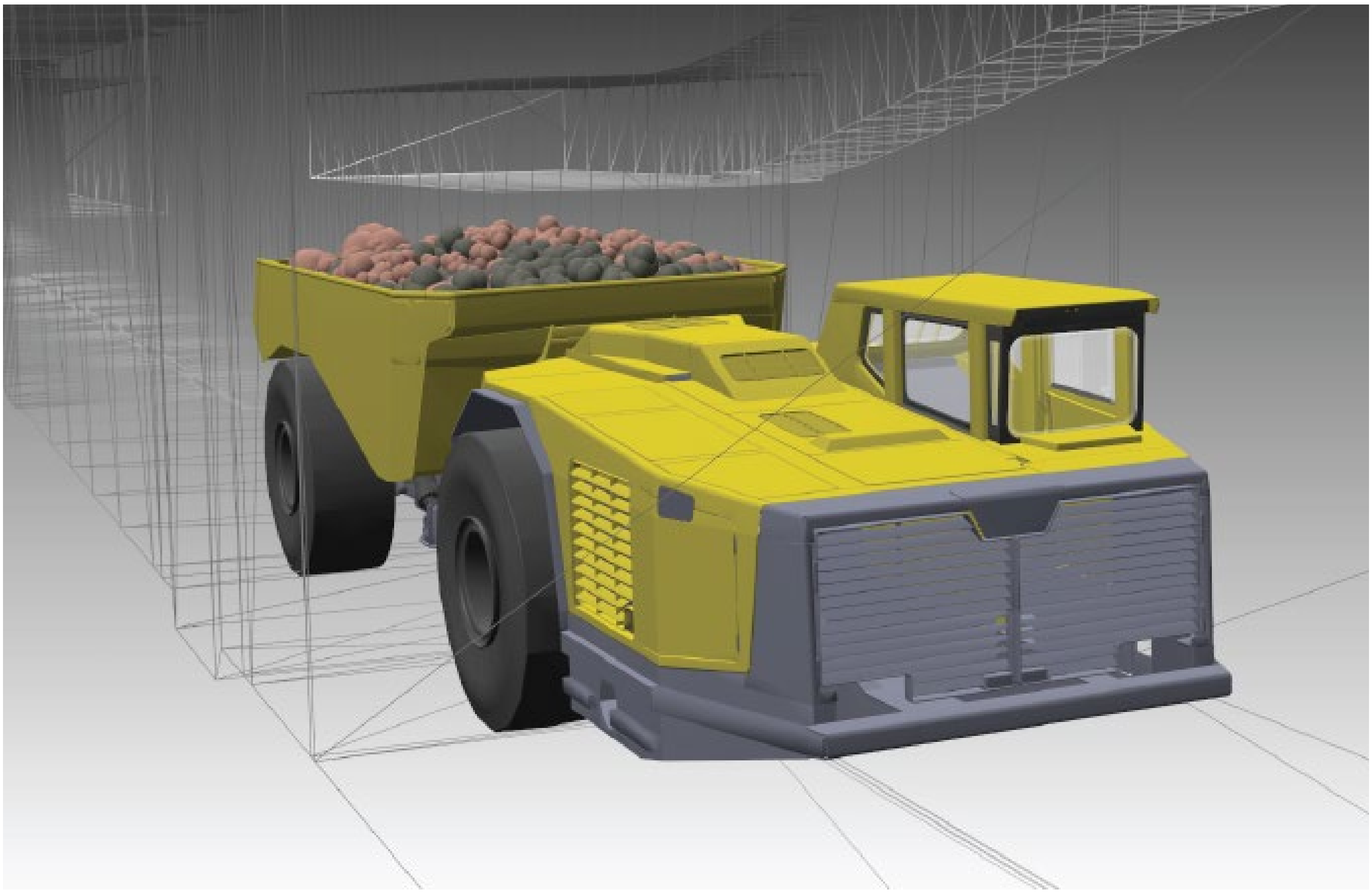


Bild: Algoryx Simulations och Atlas Copco

Recommended best practice:

- **Simulate early and often** — It is important to use simulation when the design room still is large and where one can test and compare many different solutions simultaneously.
- **Educate decision makers about the simulation process** — Managers need to be trained in the value of simulation and its process, and how it differs from traditional product development.
- **Build bridges for interoperability between software** — Interoperability allows users to use the simulation tool that they know best. This requires that the tools are modifiable and that models and data can be transmitted through the development chain over the walls of software.

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Project Info

Simovate
VINNOVA's "challenge-driven innovation" (UDI)

Project participants
SME: Algoryx, Oryx, Modelon, Optimation

Industry
Atlas Copco, SKF, Volvo CCT, Volvo CE, LKAB

Academia
Umeå University, Linköping University and Skogforsk.

2012–2014: UDI stage 2 — 23 MSEK
(13 MSEK from Industry + 10 MSEK VINNOVA)

Stage 3 is planned to start mid 2015.

and also knowledge of the organizational barriers that exist within the company and its local climate," says Mats Johansson, coordinator of the project.

The project's latest phase (2012–2014) resulted in a series of good results. One example is the simulation editor developed by Oryx, which enables clients to build and modify scenarios and machines of various types directly from CAD drawings and put them in an environment where humans can be included in the loop. This shortens development cycles, allowing specialists themselves to make parameter changes and re-run a simulation again without having to go through external consultants.

Another example is the simulation of a mining truck loaded with ore. Algoryx and Atlas Copco created models and dynamic simulations of the vehicle in a realistic driving scenario along a winding mine tunnel. Based on data gained from simulation results, new principles for the design of the truck's flatbed could be developed with these models.

The Simovate project has also advanced the fundamental technology of simulation-based development:

- Algorithms and software for distributed strong-coupled simulation, which enables simulations based on different software to be run strongly linked in different geographical locations across networks.
- An organizational best practice that addresses how companies should work with the simulation.

The project also highlights that major organizational challenges exist in implementing simulation-driven development, but that embracing those challenges is well worth it when it comes to the benefits of the approach.

The latest phase of the Simovate project has created legacies that in themselves are evidence of the project's success. Projects such as GranuReg (PiiA) and Virtual Truck and Bus (FFI) show that the ideas and technology developed in Simovate are of highest relevance to both industry and academia. Simovate will live on in many forms, and in the meantime, the application for the third phase has been submitted to the VINNOVA program Challenge-Driven Innovation.

Research areas

UMIT unites excellent fundamental research in computational science and engineering with innovative and application-oriented research and software development. Within UMIT are scientists from the areas of computing science, mathematics, physics, and engineering. The science produced is internationally competitive and has strong support from VR, the Swedish Foundation for Strategic Research, Vinnova and the EU's 7th Framework Program.

- **Computational design optimization**
- **Finite elements**
- **Flexible and scalable IT infrastructures**
- **Interactive multiphysics and complex mechanical systems**
- **Geometric numerical integration**
- **Parallel and scientific computing**
- **Spectral theory and Finite elements**

Three global technology trends that will radically change our use of simulations and computations:

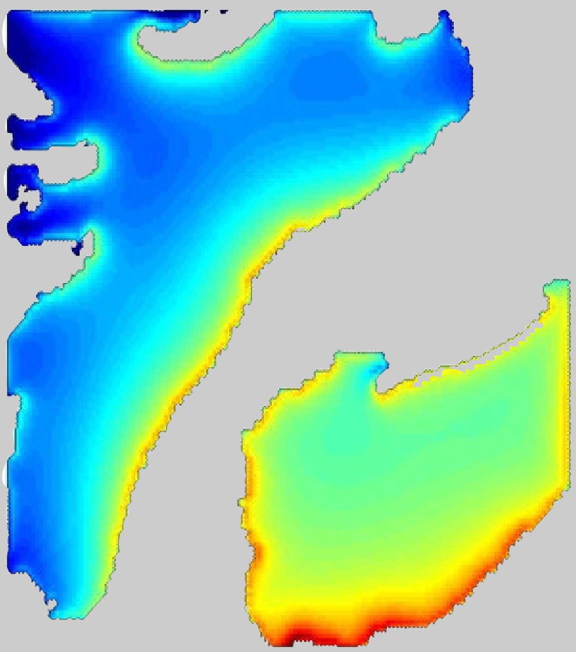
- Convergence in the technologies behind CAD/CAE, technical and scientific computing, and visualisation
- More powerful computers through parallelism and multicore architectures
- The embedding of everything in the web browser and connection through scalable and flexible IT infrastructures

Computational design optimization

Computational design optimization is based on the idea of exploiting the power of computer simulations and optimization in the engineering design process.

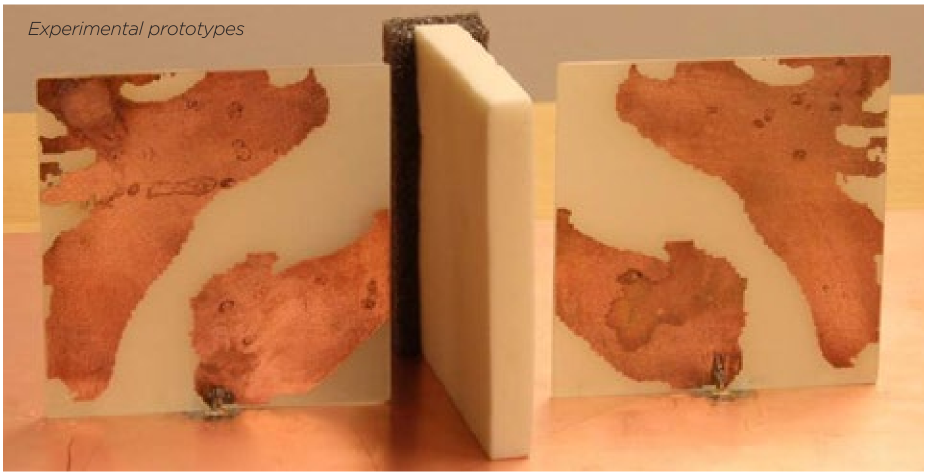
The research group in computational design optimization develops and analyzes methods that combine physics-based mathematical modeling, computer simulations, and optimization. The purpose is to find the particular shape or material arrangement of an object that yields the most favorable performance. Presently, we focus particularly on problems and situations where the measure of performance involves acoustic or electromagnetic wave propagation effects. We also consider problems that, from a methodological perspective, are closely related to design optimization, such as off-line optimal control problems and inverse problems, that is, the problem of determining the properties of a system from observations.

Simulated current distribution



A pair of microwave antennas on printed circuit boards optimized for nearfield sensing and communication. The device could be used, for instance, for noninvasive monitoring of bone regeneration and healing.

Experimental prototypes



Research focus
Using simulations and numerical optimization to determine material compositions or shapes of objects in order to maximize the technical performance.

Applications
- Design optimization of systems where the measure of performance involves mechanical or electromagnetic properties
- Inverse problems: determining system properties from data observations

Projects
- Metallic antenna design optimization
- Nano-optic device optimization
- Loudspeaker design optimization
- Determination of moisture content from scattered electro magnetic radiation

Results
- Accurate computational models of the systems under consideration
- Fast and robust methods for design optimization of systems with a large number of design variables
- Loudspeaker horns with optimal transmission properties

Collaborations
Valutec AB, SP Trätek, Trächentrum Norr, DAS Audio, and Limes Audio

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Finite elements

The objective of the research group in Computational mathematics at Umeå University is to conduct research on novel computational methods for the solution of partial differential equations and to promote its application in education, science and engineering.

Our research is interdisciplinary and located in the intersection between mathematics, computer science, engineering and applications. We focus in particular on developing adaptive finite element methods, efficient and robust methods for solving multiscale and multiphysics problems, and model reduction techniques for large-scale problems. Applications are found, for instance, in the simulation of complex mechanical systems involving fluids and solids. Recently we have focused on the development of so called cut finite element methods CutFEM that provides a new technique for simultaneous discretization of both the geometry of the computational domain and the solution to the governing equations on a common background mesh. CutFEM is particularly interesting in situations where the geometry evolves over time or through numerical iterations, for instance in shape optimization methods. Part of our research is done in collaboration with industry. In particular, together with SKF, we are developing new model-reduction methods with improved local accuracy for the simulation of, for example, rolling bearings and gear wheels.

Research focus
Our work is focused on development, analysis, implementation, and application of novel finite element methods for partial differential equations. We consider in particular engineering applications in computational mechanics involving multiphysics and multiscale phenomena.

Applications
Applications are found in simulations of complex mechanical systems and in biomechanics.

Projects
- Development of a two-phase fluid solver for design optimization
- CutFEM methods
- Methods and error estimates for polynomial and non-symmetric eigenvalue problems
- Methods for higher order partial differential equations on surfaces
- Model reduction for localized stresses in rolling bearings

Results
- New finite element methods for membranes with large deformations
- New model reduction methods for viscoelastic materials implemented in SKF software
- New techniques for error analysis of finite element methods for partial differential equations on surfaces
- New software for CutFEM discretization of complicated geometries including CAD import

Collaborations
Chalmers, Jönköping Universitet, KTH, Linköping Universitet, Simula Research Laboratory AS, SKF

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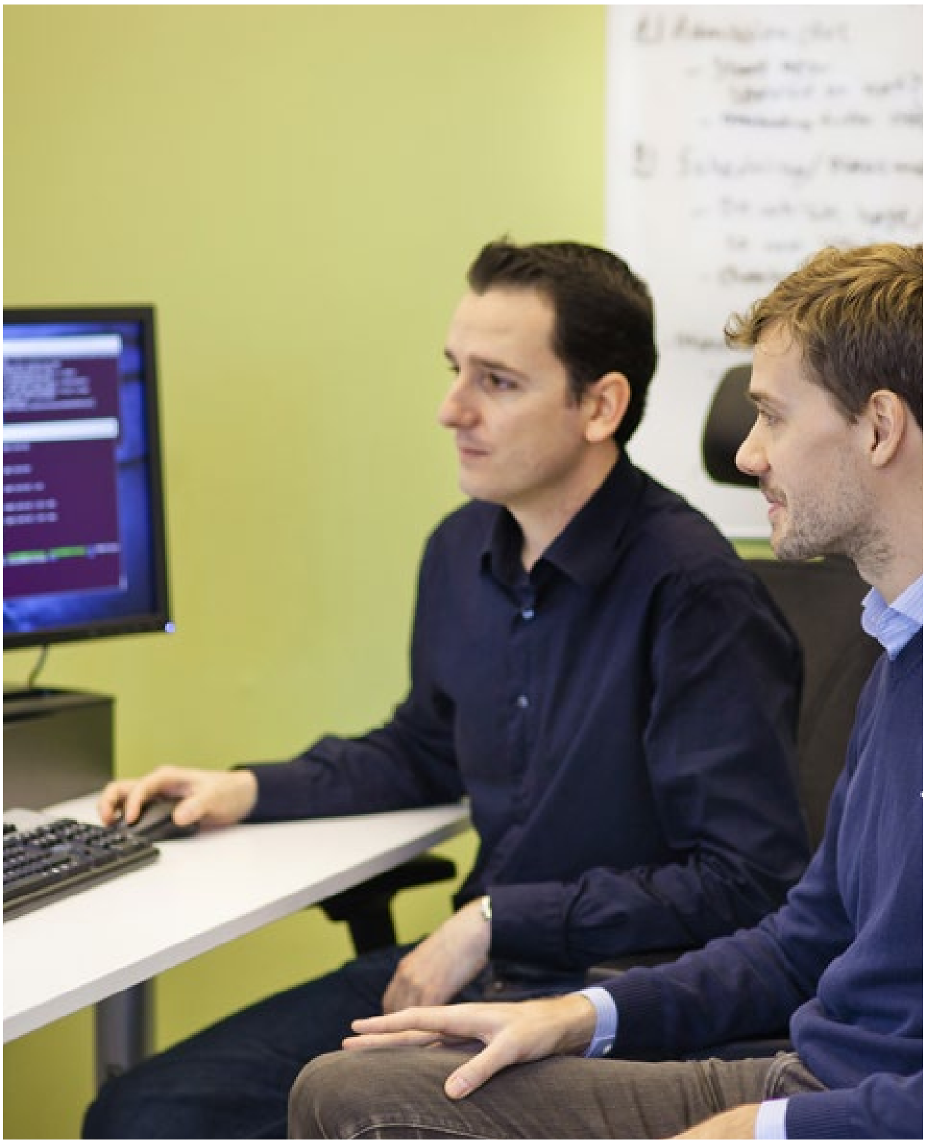
Flexible and scalable IT infrastructures

The research group focuses on flexible and scalable IT infrastructures, and covers a range of topics central to cloud and grid computing

Research drivers are computer and data intensive applications requiring elastic locality-aware infrastructures to meet the rapid capacity and locality variations of industrial services and large-scale distributed environments that enable coordinated use of federated resources for eScience. Research outcomes include autonomous infrastructure management systems and sophisticated tools for creating cloud-enabled applications. Examples of recent results include algorithms for Virtual Machine (VM) scheduling in clouds, methods for improved live migration of VMs, and algorithms for cloud elasticity control. Other results include tools and principles for (energy) montoring and accounting, as well as fair-share scheduling systems. Ongoing projects with immediate industrial benefits include collaboration with Hawc International AB with a focus on transforming Hawc's platform for feature film editing into a cloud service. Another result with industrial applications is the creation of the Elastisys spinoff company, with a focus on cloud auto-scaling and a product based on the elasticity research.



Research focus
Architectures, algorithms, and tools for the development and use of virtual computer and storage infrastructure: clouds (elastic on-demand resources) and grids (large-scale federated computing).

Applications
Suitable applications would have large and varying rapid capacity demands in terms of computational power and storage.

Projects
Feature film editing as a cloud service: collaboration with Hawc International AB to transform Hawc's product for film editing into a cloud service.

Creation of Elastisys AB, a spin-off company focusing on cloud management software. A first product, the elastisys: scale autoscaling engine is currently available in beta and is undergoing validation with selected partners.

Collaborations
IBM Haifa Research Labs, SAP Research, ATOS, Leeds University, Lund University, HLRS Stuttgart, Hawc International AB, and others

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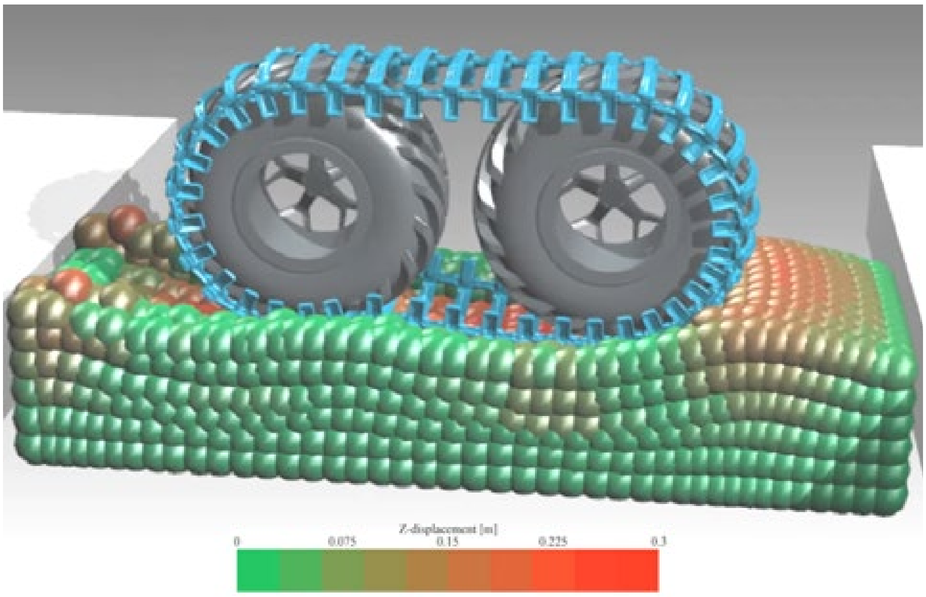
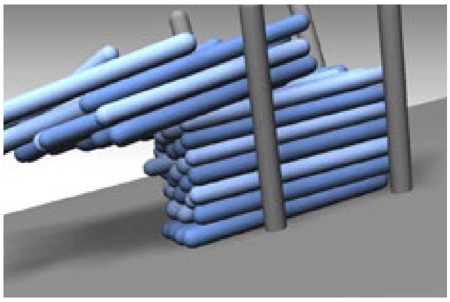
Interactive multiphysics and complex mechanical system

How can the real world, with all its complexity and dynamics on different time and length scales, fit in a computer program?





The question is, “What properties of the real world need to be captured in order to make a realistic virtual replica of complex mechanical systems?” And then there is the challenge of making the computations fast and scalable, for example, to make applications run at an interactive rate or to exploit the full potential of a supercomputer. The research addresses multi-domain modeling, numerical methods, and software for multibody system dynamics with nonsmooth phenomena. Discrete variational time-stepping of large-scale rigid multibody systems with frictional and impacting contacts, meshfree solids and fluids, and mechatronic systems are of particular interest. Methods are developed for sparse direct, iterative, and parallel solvers for the linear and nonlinear complementarity problems that describe the dynamics. The approach allows for fast and stable simulation of nonsmoth multidomain dynamics systems. Can you break up this sentence? It is very long and a bit confusing. The research has applications for various types of virtual environments, including visual interactive 3D simulation for making real-time simulators for training, education, design, research, and development. Other applications include industrial simulations for the purpose of understanding, redesigning, and optimizing industrial processes, robots, and vehicles.

The past year yielded many positive results. A partitioning method for the parallelization of large multibody systems in real-time was developed and demonstrated for training simulators for ship and oil rig anchor handling. A variational time-stepping scheme to integrate the Differential Algebraic Equations (DAE) of finite-dimensional, multi-domain systems was developed. The solution supports the coupling of multibody system dynamics to other components such as electronics, hydraulics, and drivelines. Solutions for strong co-simulation distributed over the Internet were implemented and demonstrated with a vehicle simulator in the Simovate project. The nonsmooth DEM approach to granular matter has been successfully validated by comparing simulations of large-scale granular flows with experimental data of material flows from the production iron ore balling drums at LKAB. The collaboration continues with modeling of the granulation process and the development of methodology and software for prototyping control methods. A meshfree elastoplastic model for forest terrain has been developed and shown compatible with nonsmooth dynamics.

Research focus
Models and algorithms for fast multi-domain dynamics simulation, for example vehicles, robots, biomechanics, granular matter, fluids, cables and cloth, electronics, and hydraulics.

Applications
- Visual real-time interactive simulation.
- Simulation-based design, control and optimization of complex mechanical systems.

Projects
- Modelling and simulation of large-scale granular matter and machines
- Applications of non-smooth mechanics to rough terrain vehicles
- Modelling and simulation of the complex forestry environment
- Control of granular processes
- Simovate

Collaborations
Algoryx Simulation, LKAB, Optimation, Oryx Simulations, Rensselaer Polytechnic Institute, Skogstekniska Klustret, and the Swedish University of Agriculture

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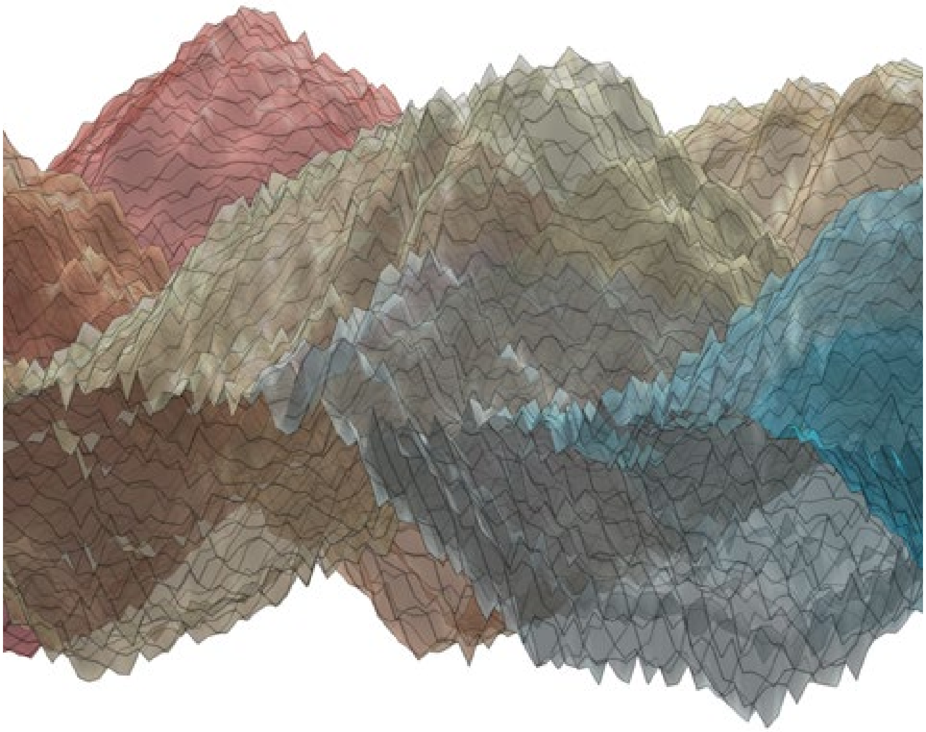
Geometric numerical integration

Differential equations appear everywhere in science and can rarely be solved analytically, so numerical methods have to be employed. Our group develops and analyzes novel numerical algorithms for these problems.



In particular, our research concentrates on developing and analyzing the so-called geometric numerical integrators. Differential equations often show important qualitative features such as long-term dynamical behavior or geometry (conserved quantities, symplecticity, volume preservation, symmetries, and so forth). This information is generally lost under standard discretization. On the other hand, the goal of geometric numerical integration is to design methods that preserve the particular underlying structure of such problems. This concept usually proves to offer more reliable time integrators.

Our research group's investigation focuses on the following topics: Highly oscillatory and multiscale problems. Such problems frequently arise in biology, geo-sciences, or molecular dynamics. We offer very competitive numerical methods for these problems.

Stochastic differential equations. With the increased presence of stochastic terms in mathematical models from biology, chemistry, finance, physics, and many other scientific fields, there is a strong demand for advanced numerical algorithms to handle these problems. We have answered this demand by developing more advanced numerical methods for stochastic differential equations, tailored to fit specific problems.

Research focus
Development, implementation and analysis of efficient and reliable structure-preserving numerical algorithms for the discretization in time of (stochastic) differential equations.

Applications
Applications can be found in physics, molecular dynamics, and finance.

Projects
- Numerical methods for the discretization in time of stochastic (partial) differential equations.
- High-order time integrators for Hamiltonian partial differential equations.

Results
Development and analysis of geometric numerical methods for highly oscillatory problems, Schrödinger equations, shallow water waves, stochastic differential equations, and stochastic partial differential equations. Analysis of the long-time behavior of numerical solutions to nonlinear wave equations.

Collaborations
University of Geneva, EPFL, NTNU Trondheim, Chalmers University of Technology, Inria Lille Nord-Europe, TU Berlin, Karlsruhe Institute of Technology, University of Tübingen, The University of Tokyo, Osaka University, Kyushu Institute of Technology, University of Oxford, University of Southampton, Autonomous University of Barcelona, and the Chinese Academy of Sciences.

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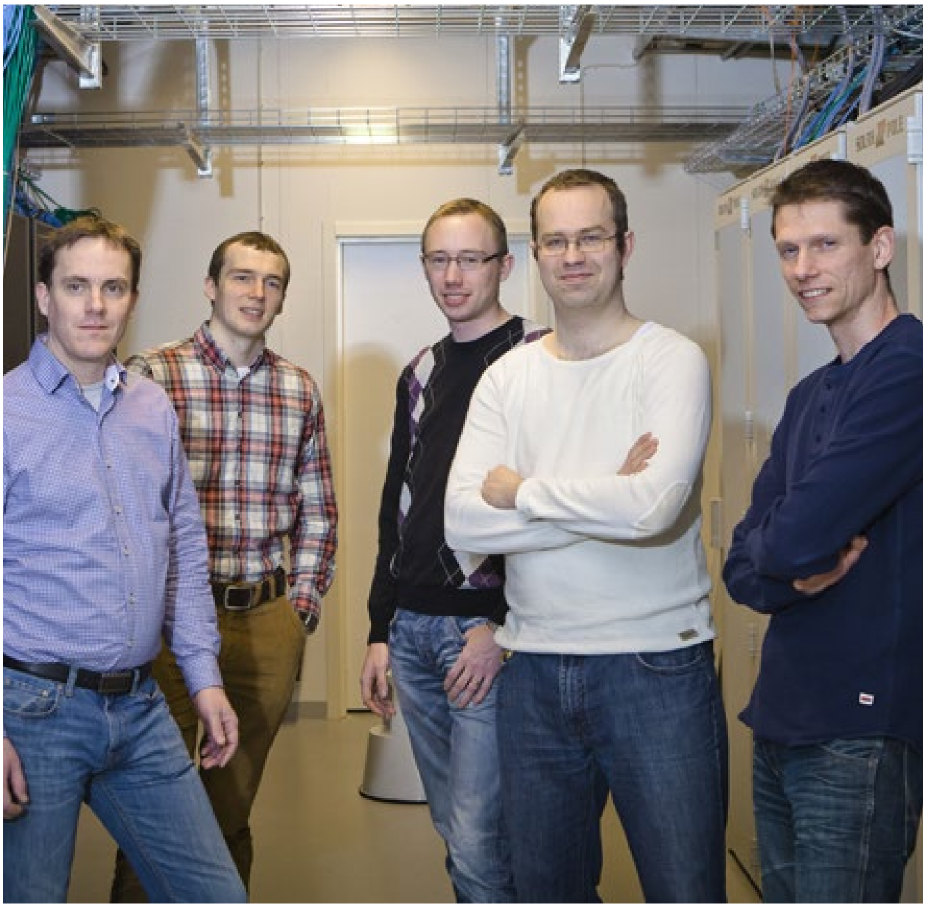
Parallel and scientific computing

Parallelism is here to stay! Today, most computers, from laptops to supercomputers, are based on the so-called multicore architectures. Connecting many hundreds of powerful, and possibly heterogeneous, GPU-equipped multicore nodes using a high-performance interconnect leads to truly massive parallel systems with a tremendous performance potential.

This evolution makes it possible to solve even more complex and large-scale computational problems in science and engineering. At the same time, there is an immense demand for new and improved scalable, efficient, and reliable numerical algorithms, library software, and tools. This is essential, so that computations are carried out in a reasonable time and with the accuracy and resolution required. Matrix computations are both fundamental and ubiquitous in the computational Sciences, for example in the modelling and simulation of problems ranging from galaxies to nanoscale, and in real-time airline scheduling and medical imaging. Computing the Google PageRank vector of all web pages on the Internet is called the world´s largest matrix computation of today, with a hyperlink matrix of n-by-n, where $n > 50$ billion.

Besides such large-scale problems, there are many challenging matrix computations in the design and analysis of linear control systems. Modeling interconnected systems (electrical circuits, for example) and mechanical systems (such as multibody contact problems) can lead to descriptor systems. Periodic models arise in several practical applications, e.g. the control of rotating machinery. We are investigating how to exploit the inherent structure of several of the associated matrix problems.



Research focus
Design of efficient and reliable algorithms for structured and dense matrix computations targeting many-core architectures, accelerators, and massive parallelism.

Applications
Applications can be found, for example, in control system design and analysis, real-time physics simulations, biochemistry, and molecular dynamics.

Projects
- Parallel and cache-efficient algorithms and data structures for multi-core and hybrid architectures.
- Design of parallel algorithms for eigenvalue problems, matrix factorizations, matrix equations, and matrix functions.
- Algorithms and tools for computing structural information of general and structured matrix pencils and polynomials.
- Design, evaluation, and analysis of numerical algorithms for the stabilization of linear systems with periodic coefficients.
- Direct sparse solvers for constrained simulations of poly-peptides submerged in water.

Results
Novel theory, algorithms, library software, and tools to be used as building blocks for various applications.

Collaborations
Algoryx, DLR, IBM, Niconet/SLICOT, ScaLAPACK; several universities, including KI, Berkeley, Cornell, EPFL, Inst. of Mathematics Kiev, Fudan Univ., HU Berlin, UC Louvain, Univ. of Manchester, Univ. of Denver, Cavasotto Lab Buenos Aires, Univ. of Tennessee, Knoxville, Univ. of Zagreb, and Uppsala Univ.

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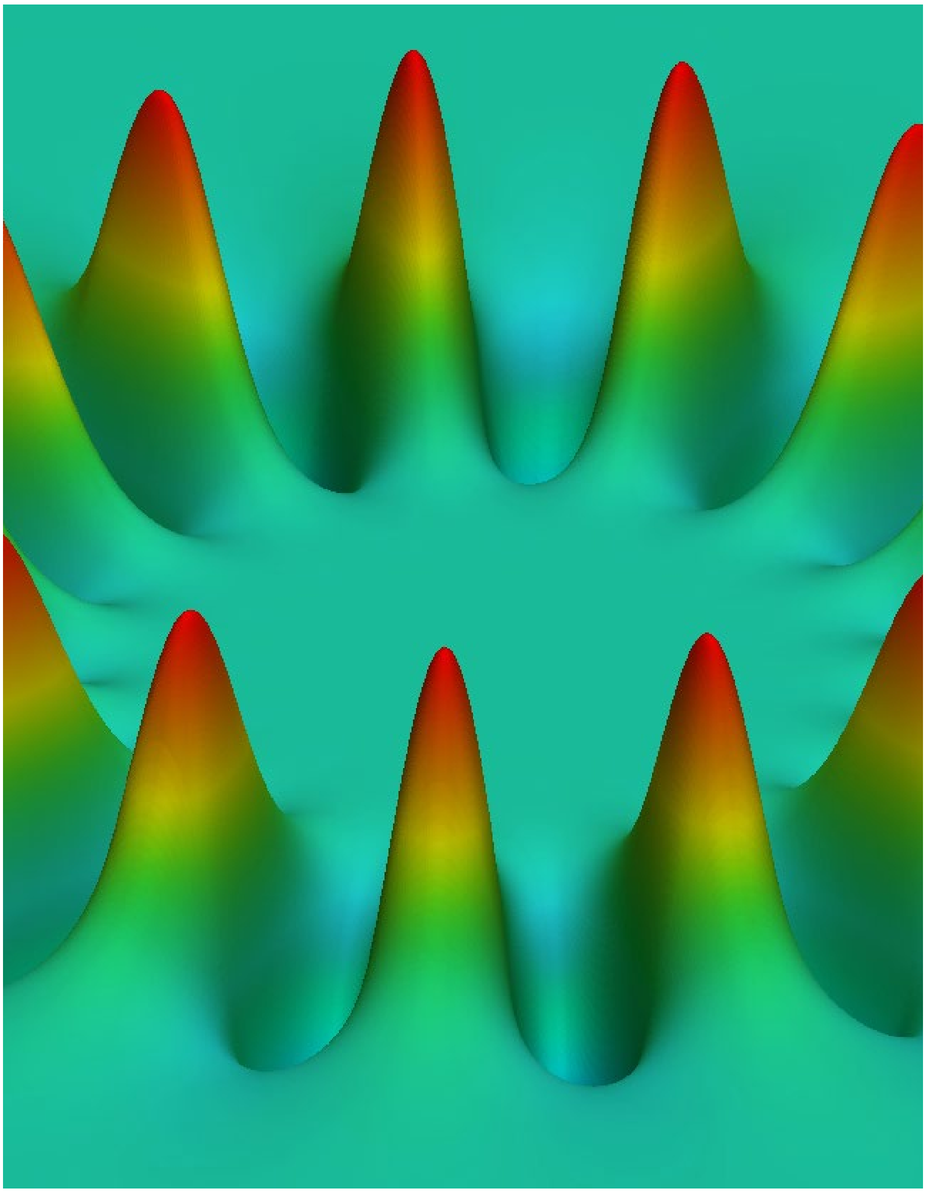
Spectral theory and Finite Elements

The objective of this research group is to study the whole chain, from physical modeling-, to mathematical analysis and approximation theory to software development.

In particular, this research is concerned with the analysis and numerical solution of non-linear spectral problems and simulation of wave phenomena. One of the group's research focuses is photonic crystals, which are periodic structures with promising optical properties. These structures have many applications in optical communication, spectroscopy, and photonic crystal nanocavity lasers. This project aims to achieve a greater understanding of how quantum mechanical effects and losses affect the performance of these structures. Another research focus is the analysis and computation of resonances in open structures. Possible applications include calculations of sound pressure levels in compressor blade rows, instabilities in aircraft engines, semiconductor lasers, single-atom detection using microdisk resonators, and plasmonic nano-antennas. Several of the proposed projects require an interplay between spectral theory, finite element discretization, and linear algebra. Physical understanding and optimization are also highly important to the success of the projects. Therefore, members of the group collaborate closely with the physics department and other groups within UMIT Research Lab.



Research focus
We are working on the spectral theory of operator-valued functions relevant for problems in science and engineering, as well as the discretization of partial differential equations with high-order finite element methods.

Applications
Simulations of wave phenomena, multiphysics, and design of structures in nano-optics.

Projects
- Spectral analysis and approximation theory for a class of operator functions.
- Finite element approximations of time-dependent problems in nano-optics.

Results
- New spectral theory for block operator matrices.
- New Galerkin spectral approximation theory for quadratic eigenvalue problems.
- New perturbation theory to study non-self-adjoint perturbations of self-adjoint rational eigenvalue problems.
- Development of a high-order interior penalty method code.

Collaborations
ETH Zurich, EPFL, TU Berlin, TU Wien, University of Bern, University of Zagreb.

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List of publications | 2014

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The importance of collaboration

One of the underlying reasons for the success of UMIT is its broad spectrum of activities, ranging from fundamental research projects in mathematics and computer science to real life applications, which are often developed in cooperation with industry.

Since it is necessary to focus on time and resources in order to be competitive in a specialized area, it's often hard for each researcher, or research group to realize the broad range of activities. The UMIT environment offers opportunities to participate in interdisciplinary projects and to share knowledge and experience in different areas. An excellent example of such a collaborative project is Simovate, which involved researchers from several research groups and ten industrial partners ranging from SMEs to large cooperations. This project was funded by Vinnova. Simovate featured the development of basic algorithms for co-simulation, implementation of software, and industrial applications with the goal of developing next generation simulation software for engineers and designers in industry. The interplay between application and fundamental research is also important to establish since relevant basic research problems can be identified through applications; often a new solution to these problems actually demands a new idea or breakthrough in fundamental research. In the future, UMIT will continue to strengthen its position as an interdisciplinary laboratory through further development of collaborative projects and increased collaborations with external partners, and particularly with regional industries.

Mats G. Larson
Professor at the Department of Mathematics and Mathematical Statistics. Board member at UMIT Research Lab.

Industry collaborations 2014

- **Algoryx Simulation**
- **Adopticum**
- **Atlas Copco**
- **ATOS**
- **DAS Audio**
- **DLR**
- **Enmesh**
- **Hawc International**
- **IBM**
- **IBM Haifa Research Labs**
- **Komatsu Forest**
- **Limes Audio**
- **LKAB**
- **Modelon**
- **Olofsfors**
- **Optimation**
- **Oryx Simulations**
- **SAP Research**
- **Simula Research Laboratory**
- **SKF**
- **Skogforsk**
- **Skogstekniska Klustret**
- **SP Trätek**
- **Träcentrum Norr**
- **Valutec**
- **Volvo Construction Equipment**

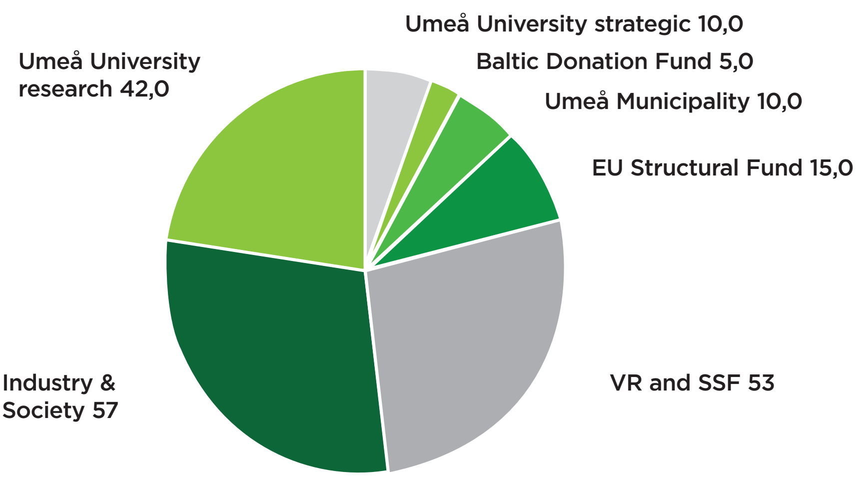
Financing

The UMIT project was initiated in 2009 with a total funding budget of 40 MSEK distributed over a five-year period.

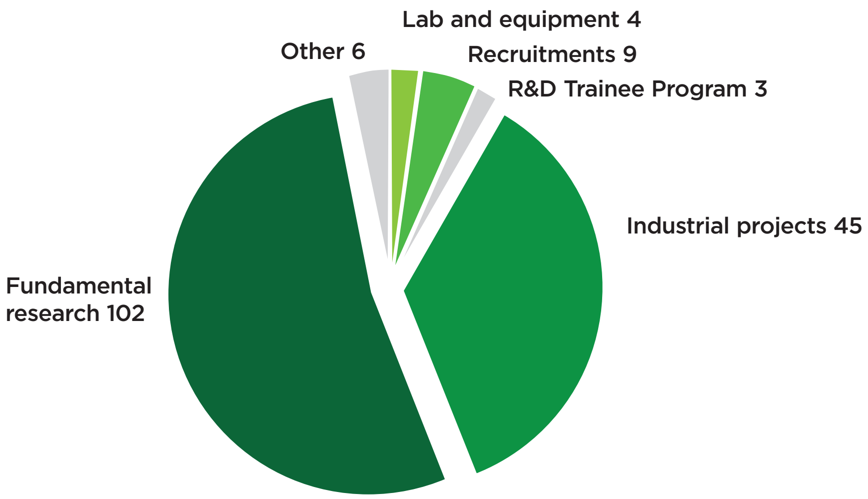
Founding financiers are the Baltic Donation Fund (5 MSEK), the EU Structural Fund -Objective 2 (15MSEK), Umeå municipality (10 MSEK) and Umeå University (10 MSEK). In addition to the initial funding of 40 MSEK, UMIT had, by the end of 2014, raised 110 MSEK from external sources for the co-financing of specific projects, e.g. EU FP7, EU Bottnic-Atlantica, FOI, Kempestiftelserna, LKAB, ProcessIT Innovations, SKF, Skogtekniska Klustret, Sorubin, SSF - SwedishFoundation for Strategic Research, Surgical Science, Valutec, VINNOVA and VR - The Swedish Research Council.

This is in line with UMIT ́s vision of an external funding of 15 MSEK annually and a strong support for both fundamental science and for applied research in industry collaboration. By the end of 2014, our affiliated scientists had in total been granted 42 MSEK from VR since 2009. The research financed by faculty and the industrial doctoral school during the same period amounts to 43 MSEK. UMIT's (expected) finances and distribution of expenses for the years 2009-2015 are displayed below.

Financing, total 193 MSK



Budget, total 193 MSK



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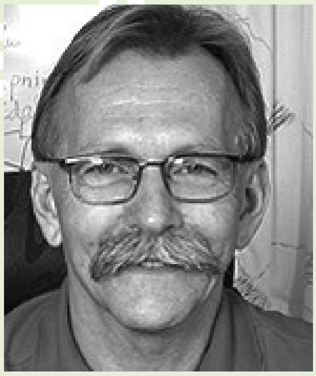
Dean of the faculty of Science and Technology, Professor, Umeå University

Mats G. Larson
Board member, Professor, Umeå University



Bo Kågström
Board member, Professor, Umeå University

UMIT staff during 2014

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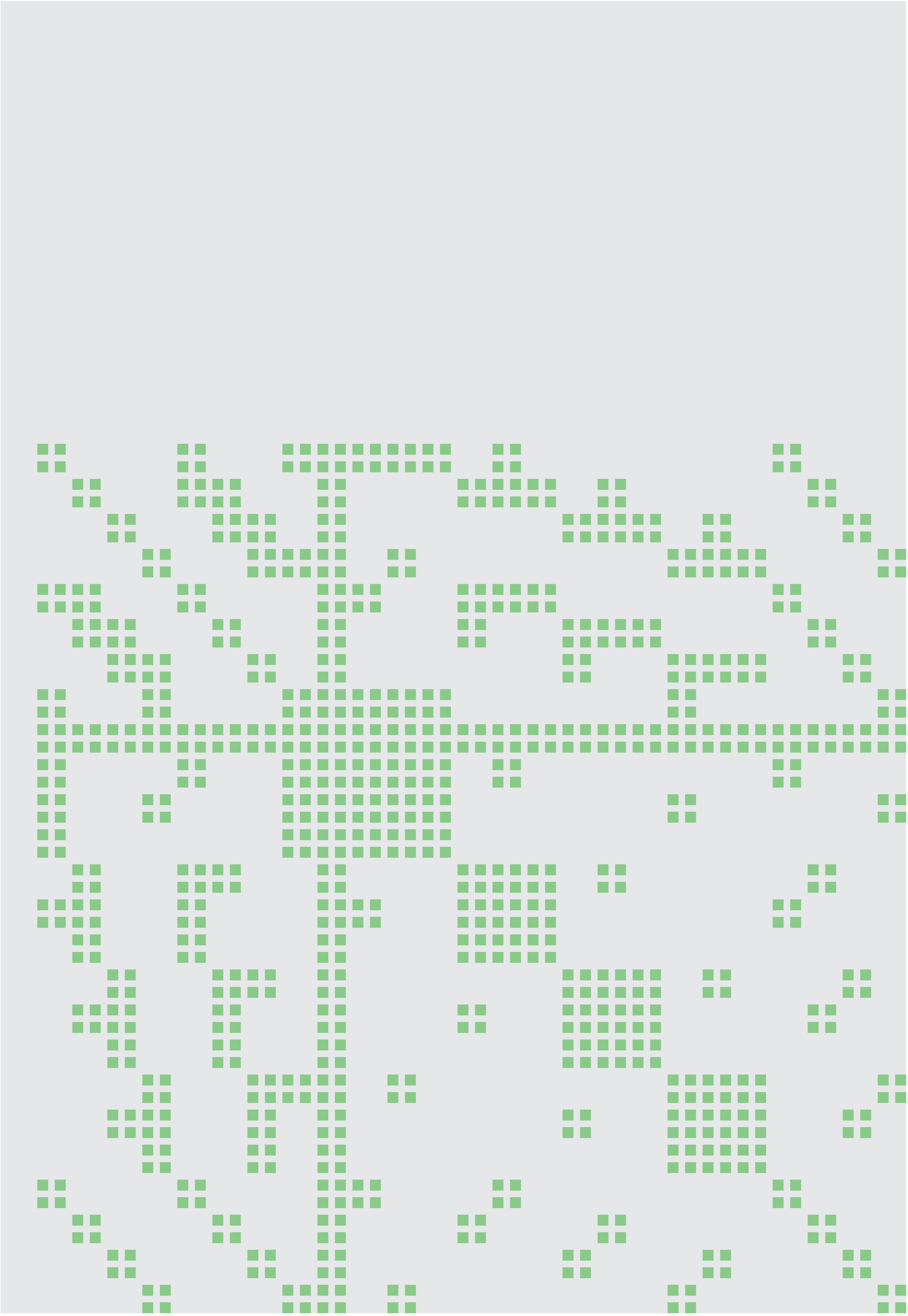

UMIT Research Lab is a strategic initiative in computational science and engineering with focus on industrial applications and innovative software development. The research lab, formed in 2009, is a dynamic, intellectual and physical research environment enabling worldclass interdisciplinary, research in scientific, high-performance, distributed, real-time and visual computing.

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UMIT Research Lab

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