UMEÅ UNIVERSITET

ANNUAL REPORT | 2015

UMIT Research Lab

The UMIT Staff. Full list of employees on page 28

About UMIT

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

UMIT research results in new models, methods, algorithms for advanced simulations and analysis of complex systems and phenomena using the latest high-performance computing platforms and IT infrastructures. UMIT is engaged in many projects and collaborations that target key challenges in industry and society, including solutions for more sustainable use of energy and materials in manufacturing and transportation and flexible yet powerful tools for understanding, exploring and collaborating on the design and control of complex systems.

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 new hires, projects, and spinoffs. This work has established the lab as a leading center in the field of computational science and engineering. In addition to conducting fundamental research, UMIT is active in the development of new software technologies. The lab 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 or better products, more energy efficient and environmental solutions, and have created new job opportunities.

Top-class infrastructure
The High Performance Computing Center North (HPC2N), which is part of the Swedish National Infrastructure for Computing, SNIC, provides UMIT with expertise and e-infrastructure for grid and cloud computing, high-performance computing, 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 include The Swedish Research Council (VR), Swedish Foundation for Strategic Research, Formas, EU FP7 Horizon 2020, Vinnova, Kempestiftelserna, ProcessIT Innovations, Skogstekniska Klustret and several other companies.

2015 – A brief review

Every year, Gartner Inc releases its Hype Cycle, which is a graphical representation of the maturity, adoption and social application of emerging technologies. The predictive power and objectiveness of the diagram may be questioned, but it certainly reflects the current beliefs of what are the most important technology trends. In 2015, "digitalization" and "autonomous systems" are recurring themes. This agrees well with our experience from this year.

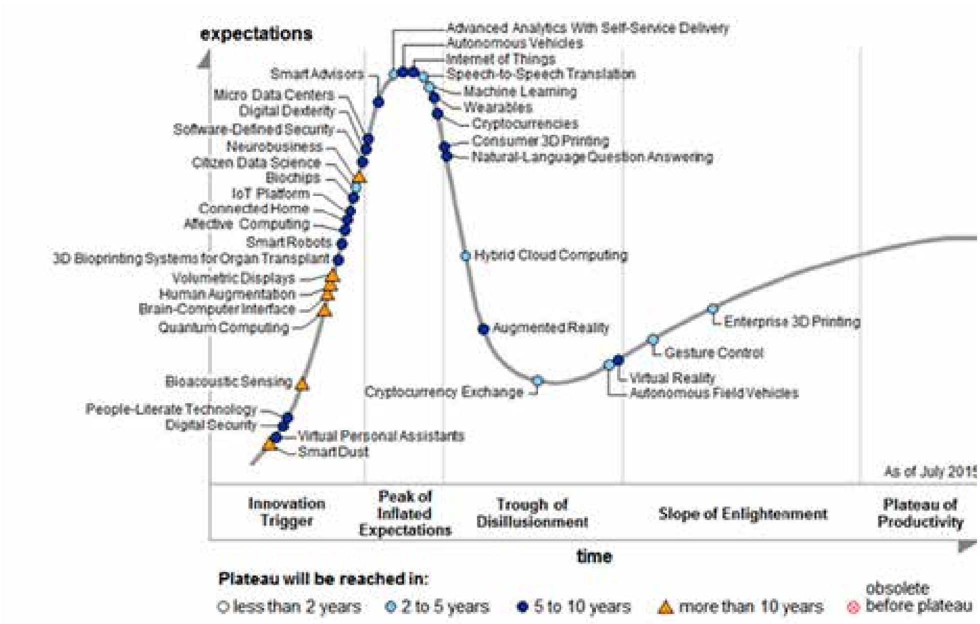


Figure 1. Hype Cycle for Emerging Technologies, 2015

Neither producing and analyzing digital data nor the design and control of autonomous systems are new to the field of computational science. However - the interest and number of initiatives to apply these to transform business and society was remarkable in 2015. Autonomous vehicles, advanced cloud services, 3D digital fabrication, and virtual and augmented reality have quickly become commonplace.

Numerous research programmes and projects have been launched nationwide and internationally to put current solutions to use and address the challenges and opportunities at the next stage – when all these systems become interconnected (Internet of Things, IoT). Betsy Burton, vice president at Gartner, says: "As enterprises continue the journey to becoming digital businesses, identifying and employing the right technologies at the right time will be critical." Computational science and engineering are more crucial than ever.

Projects and grants

The research group Distributed Systems has taken an important role in the ten-year Wallenberg Autonomous Systems Program (WASP). In the 2015-2017 project Virtual Truck & Bus, UMIT researchers collaborate with Scania and Volvo Cars to develop a new system simulation environment for the development of the next-generation powertrains, designed and controlled to significantly reduce fuel consumption. Another big UMIT project started in 2015 to address the challenges of interconnecting different systems: a method for handling boundaries between different complex and evolving geometries when solving Partial Differential Equations of physical systems. Bo Kågström and Lars Karlsson were granted 36 million SEK from the EU FP7 Horizon 2020 program for Future and Emerging Technologies (FET) for the project "Parallel Numerical Linear Algebra for Future Extreme-Scale Systems" (NLAFET) together with partners in France and Great Britain. The project targets algorithms and advanced scheduling for exascale supercomputers. Eddie Wadbro of UMIT is teaming up with Ola Lindroos at Swedish University of Agricultural Sciences (SLU) and researchers from Luleå University of Technology (LTU) and Oregon State University (OSU) to minimize the damage made by forestry vehicles using 3D-laser scanning and optimal route planning. The project is granted 4.5 Million SEK from Formas. Locally, Volvo Trucks and Umeå University signed a partnership agreement for developing a strategic collaboration with the manufacturing plant in Umeå, which was appointed as the Volvo Group's center of competence in core processes such as pressing, cab assembly and finishing – and invest in a pilot plant for experimental testing and verification of new product and process solutions. A first important result is the project "Finish Inspection and Quality Analysis," which addresses automated quality control in Volvo's painting processes based on statistical analysis of large heterogeneous data sets. With participation from Patrik Ryden, Jun Ya and Shafiq Ur Rehman of Umeå University, the project has a total budget of 14.5 million SEK with the support of 7.2 million SEK from Vinnova through the Strategic Vehicle Research and Innovation Initiative (FFI). One of the two e-science programmes, eSSENCE, funded by the Swedish government, has during the year funded many of the high-profile UMIT associates, such as Erik Elmroth, Bo Kågström, Mats G. Larson and Martin Berggren.

People

During 2015 UMIT welcomed Anders Bernland and André Massing as postdocs, Rikard Anton and Tobias Jonsson as PhD students, Tomas Härdin as research assistant and Ida Bodén as scientific consultant. Ahmed Ali-Eldin Hassan, Andrii Dmytryshyn, Emadeldeen Hassan, Ewnetu Bayuh Lakew and Da Wang defended their theses and earned doctoral degrees. Andrii Dmytryshyn was awarded the SIAM Student Paper Prize 2015 for the paper titled "Coupled Sylvester-Type Matrix Equations and Block Diagonalization," coauthored with Prof. Bo Kågström.

Highlights from the year

Partnership agreement and competence center strengthens cooperation with Volvo GTO

Volvo has inaugurated the its competence center at the factory in Umeå and a partnership agreement has been signed for closer cooperation in the future.

Volvo Trucks' plant in Umeå has been appointed as the Group's center of competence in core processes such as pressing, cab assembly and finishing. Being a center of competence means that Volvo's foremost expertise in methods and techniques in these areas will be in Umeå and the strategic research and development initiatives in the area concentrated in the competence center.

A cooperation agreement focusing on research, education and innovation has been signed with Umeå University. Researchers from UMIT have been deeply involved in the process to match the company's long-term challenges against strong research and education areas at Umeå University and are part of the joint steering committee to develop further cooperation.

Parallel to the new center, a pilot plant for experimental testing and verification of new product and process solutions is also stationed at Volvo in Umeå. This highly digitized infrastructure provides a unique platform for cooperation on computational methods and IT solutions for the future of manufacturing processes.

Formas grant for planning and optimizing route planning for forestry machines

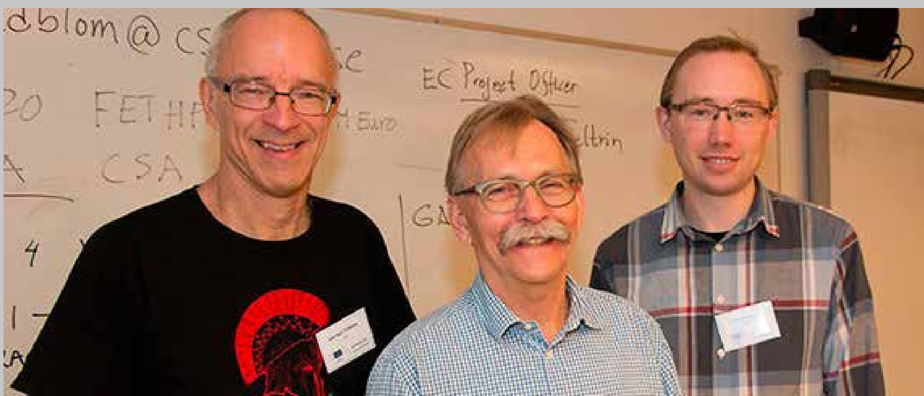
Eddie Wadbro from UMIT Research Lab is teaming up with Ola Lindroos at Sveriges Lantbruksuniversitet (SLU) and researchers from Luleå tekniska universitet (LTU) and Oregon State University (OSU) to minimize the damage made by forestry vehicles using 3D-laser scanning and optimal route planning

To make forestry more efficient, it is necessary to consider more objectives than maximizing the profit of forestry operations. It is important to preserve the recreational areas and the resource supplies, such as clean water, while at the same time getting the most out of the forest.

One of the challenges of today's forestry operations is how to plan the routes of the machinery. It is vital that this is done when the first machine enters the forest, since that dictates the tracks to all the machines used in subsequent operations.

Together with Umeå University, LTU, SLU and OSU has made this a common cause and has been granted 4.5 million SEK from Formas for the project "Reduced forest soil damage by advanced machine routing and motion planning."

Eddie Wadbro, UMIT Research Lab



NLAFET Management at Umeå University. From left to right: Assoc. Prof. Lennart Edblom (Administrative Manager), Prof. Bo Kågström (Coordinator and Scientific Director), Asst. Prof. Lars Karlsson (Deputy Research Group Leader).

NLAFET – a high-profile extreme-scale computing Horizon 2020 project coordinated by Umeå University

Future extreme-scale supercomputers will be heterogeneous and lead to new and challenging demands for efficient numerical algorithms and parallel software libraries. The aim of NLAFET is to tackle these challenges and ultimately deliver new scalable numerical libraries for fundamental problems in numerical linear algebra, including the solution of dense and sparse systems of equations and eigenvalue problems. Achieving this requires a co-design effort including developing novel algorithms, exploration of advanced scheduling strategies and runtime systems and offline and online autotuning, as well as avoiding communication and synchronization bottlenecks.

NLAFET is an acronym for "Parallel Numerical Linear Algebra for Future Extreme-Scale Systems." Bo Kågström, professor in the department of Computing Science and UMIT, is coordinator of NLAFET. The other partners are the University of Manchester, UK; Institut National de Recherche en Informatique et en Automatique, France (INRIA); and Science and Technology Facilities Council, UK (STFC). The Horizon 2020 budget for NLAFET is 3.9 Million Euro for three years. See http://www.nlafet.eu/ for more information.

Andrii Dmytryshyn

Andrii Dmytryshyn awarded SIAM Student Paper Prize 2015

Andrii Dmytryshyn, PhD student in the Department of Computing Science and UMIT, has been awarded the prestigious SIAM Student Paper Prize 2015. The winning paper is titled "Coupled Sylvester-type Matrix Equations and Block Diagonalization,"published in SIAM Journal on Matrix Analysis and Applications, and is co-authored with Prof. Bo Kågström.

"The SIAM Student Paper Prizes are awarded every year to the student author(s) of the most outstanding paper(s) submitted to the SIAM Student Paper Competition. This award is based solely on the merit and content of the student's contribution to the submitted paper. The purpose of the Student Paper Prizes is to recognize outstanding scholarship by students in applied mathematics or computing," according to SIAM's website.

Andrii defended his PhD thesis, "Tools for Structured Matrix Computations: Stratifications and Coupled Sylvester Equations," in December 2015.

Dissertation 2015

Ahmed Ali-Eldin Hassan

Thesis title
Workload Characterization, Controller Design and Performance Evaluation for Cloud Capacity Autoscaling

Description
This thesis studies cloud capacity autoscaling, or how to provision and release resources to a service running in the cloud based on its actual demand using an automatic controller. As the performance of server systems depends on the system design, the system implementation, and the workloads the system is subjected to, Hassan and his colleagues focus on these aspects with respect to designing autoscaling algorithms.

Does today
Postdoctoral researcher at the Department of Computing Science at Umeå University.

Andrii Dmytryshyn

Thesis title
Tools for Structured Matrix Computations: Stratifications and Coupled Sylvester Equations

Description
In his dissertation, Dmytryshyn has constructed stratification graphs, which in turn provide information for a deeper understanding of how the characteristics of the underlying physical system can change under small perturbations. Of particular interest is to identify more degenerate and more generic nearby systems of a given system. This knowledge can, for example, lead to a better understanding of how different types of control systems can be made more robust.

Does today
Postdoctoral researcher at the Department of Computing Science at Umeå University.

Da Wang

Thesis title
Accelerated Granular Matter Simulation

Description
A number of solutions to radically improve the computational efficiency of discrete element method simulations are developed and analysed. These include treating the material as a nonsmooth dynamical system and methods for reducing the computational effort for solving the complementarity problem that arise from implicit treatment of the contact laws. This allows for large time-step integration and ultimately more and faster simulation studies or analysis of more complex systems.

Does today
Freelance consultant and globetrotter.

Ewnetu Bayuh Lakew

Thesis title
Autonomous Cloud Resource Provisioning: Accounting, Allocation, and Performance Control

Description
The rapidly growing interest in cloud computing from both the public and industry, together with the rapid expansion in scale and complexity of cloud computing resources and the services hosted on them, have made monitoring, controlling, and provisioning cloud computing resources at runtime into a very challenging and complex task. This thesis investigates algorithms, models and techniques for autonomously monitoring, controlling, and provisioning the various resources required to meet services' performance requirements and account for their resource usage.

Does today
Postdoctoral researcher at Department of Computing Science at Umeå University.

Emadeldeen Hassan

Thesis title
Topology Optimization of Antennas and Waveguide Transitions

Description
This thesis introduces a topology optimization approach to design from scratch, efficient microwave devices, such as antennas and waveguide transitions. The design of these devices is formulated as a general optimization problem that aims to build the whole layout of the device in order to extremize a chosen objective function. By the proposed approach, various design problems, including tens of thousands of design variables, are formulated and solved in a few hundred iterations. Examples of solved design problems are the design of wideband antennas, dual-band microstrip antennas, wideband directive antennas, and wideband coaxial-to-waveguide transitions.

Does today
Postdoctoral researcher at Department of Computing Science at Umeå University.

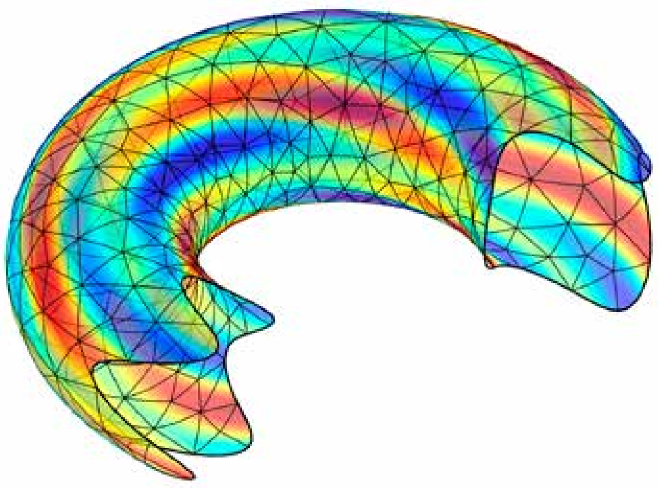
CutFEM: seeing the whole with the sum of the parts

Geometry can describe very complex shapes, such as fluted curves or metallic mesh. Chemistry and physics can describe properties such as temperatures, velocities, and concentrations or flexibility and elasticity. How do you combine these seemingly separate ways of seeing objects? And what if those objects change over time? A successful method would allow researchers to predict material failures, simulate fluids in changing domains, and design products with optimized properties.

It's often said that to solve a problem (mathematical or otherwise), it's easiest to break it down into smaller pieces. Then it's possible to address each piece, one at a time.

That's part of the strategy for the project CutFEM: A team of researchers based at Umeå University intends to use numerical methods to "cut" apart large and complex geometric models into smaller pieces with simple geometry. Models of physical phenomena can be formulated using these smaller pieces, which then can be folded together again to see the whole picture.

The Umeå team is working to use this modeling method to look at a variety of materials and objects, while improving the formulations in CutFEM to make it more accurate and useable.



The figure shows a computed, high-order accurate solution for a diffusion problem on a half-torus surface with curved boundary.

Puzzle pieces

When modeling new materials and shapes, researchers want to see not only how an object's outer surface changes, say, with regard to its shape, but how that might affect its other characteristics – mass or stiffness, thickness or stretchiness – and vice versa. That whole picture might be very complex. Examples include calculating the interactions between two objects that contain fluid within thin membranes, or the internal structure of a metal antenna with branching arms.

The Umeå team would like to be able to look at an elastic structure and find its optimal stiffness, given a certain amount of material. While commercial software can solve this problem, it typically generates unrealistic preliminary designs – the result could be unseen weak spots or fatigue at inward corners or stress points. A more precise mathematical formulation together with a more detailed description of the geometry of the object could lead to the accurate description of these boundaries.

Using this piecemeal method, CutFEM could also provide better representations of objects where the best design is very thin; these are difficult to represent using typical methods, draping the thin material on a background mesh using a density function.

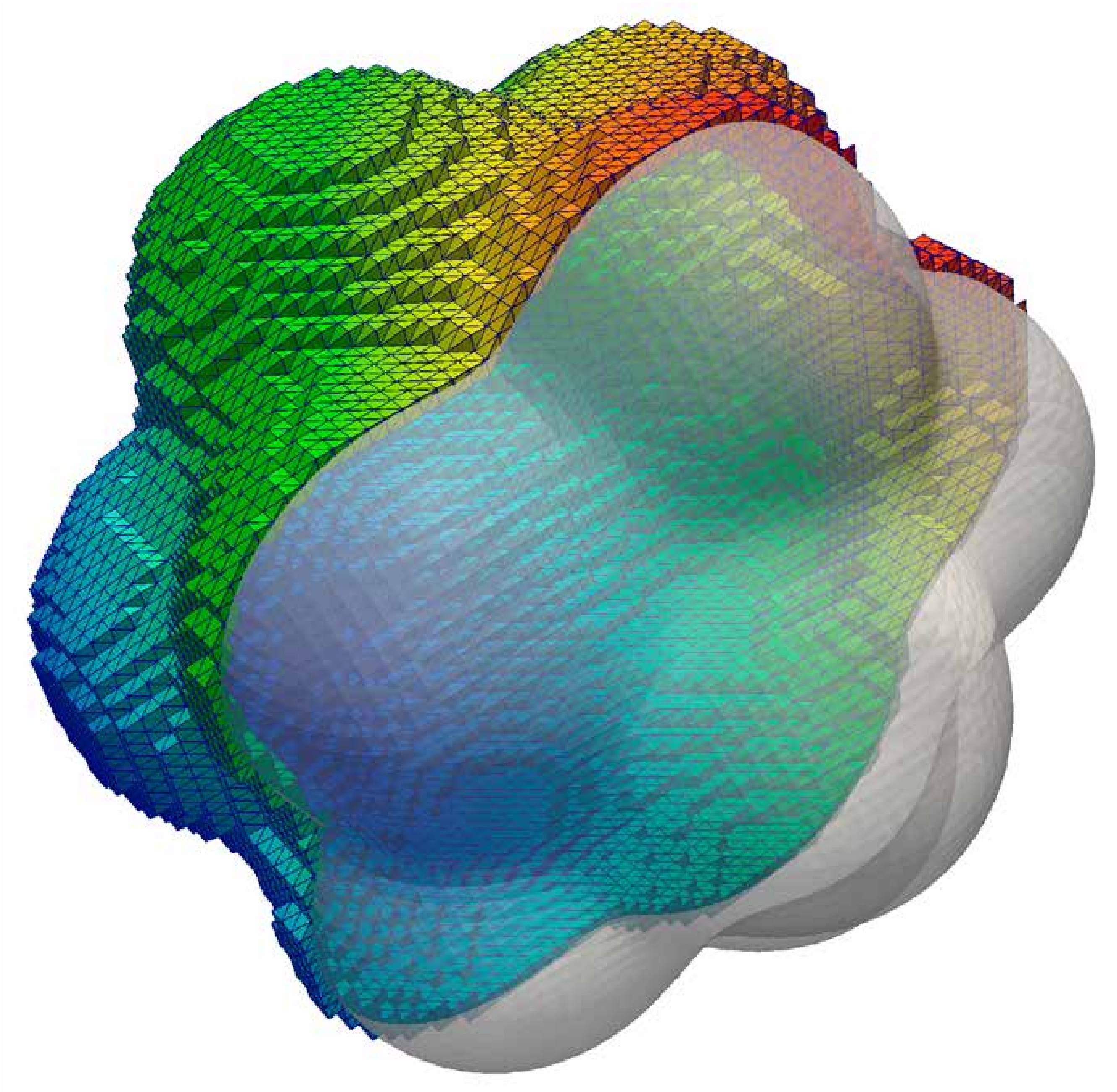
"We have developed a new CutFEM formulation for thin materials exposed to acoustic fields. As opposed to the standard formulation, this method can seamlessly handle the situation when the material distribution concentrates on a surface, a property that will be essential for shape optimization, in particular, in acoustic applications," says Martin Berggren, professor of computing science at Umeå University.

Researchers could use these modeling results to create acoustic devices, for example, a speaker that takes up as little room as possible in a car. Anything that receives waves – sound, for example, or radio signals to antenna – could be designed to use as little material as efficiently as possible, using complex geometrical patterns that can be accurately described with partial differential equations, cut apart into digestible chunks.

"CutFEM provides a solution to effective and robust discretization of complex geometries, which is the major bottleneck in industrial simulation, accounting for more than 80% of the time spent on finite element simulation in industry. Thus all applications where the geometry of the computational domain is complicated are suitable for CutFEM. An important example is stress analysis of complicated mechanical components and design optimization of the geometry. Another area of interest is fluid structure interaction with large deformations," such as the valves in the human heart, says Mats G. Larson, principal investigator for CutFEM and professor of mathematics at Umeå University.

Partners in the design optimization process

CutFEM reaches across computer science, mathematics and mechanical engineering, and across four partner universities: Jönköping,



The figure shows the computed solution to a stationary heat distribution problem on a popcorn kernel's surface. The transparent front shows parts of the actual smooth surface of the popcorn, which is embedded into a structured 3D mesh to compute an approximated solution (shown in the back).

Linköping and Chalmers, in addition to Umeå. "In order for new computational methods, such as the CutFEM methodology, to really gain impact in practice, there are many conceptually different physical, mathematical, and computational challenges that have to be addressed. The multidisciplinary environment at UMIT is essential," says Berggren.

These groups have also partnered with industrial companies that could use the researchers' results. "For instance, Linköping [University] has a longtime collaboration concerning topology optimization with Saab," the Swedish aerospace and defense company, in order to optimize mechanical components in aircraft, says Larson, "where guaranteed strength and reliability as well as low weight is very important. Also a large amount of different force situations must be taken into account," considering that aircraft take off, land and fly under varying atmospheric pressures so that they experience a wide range of forces.

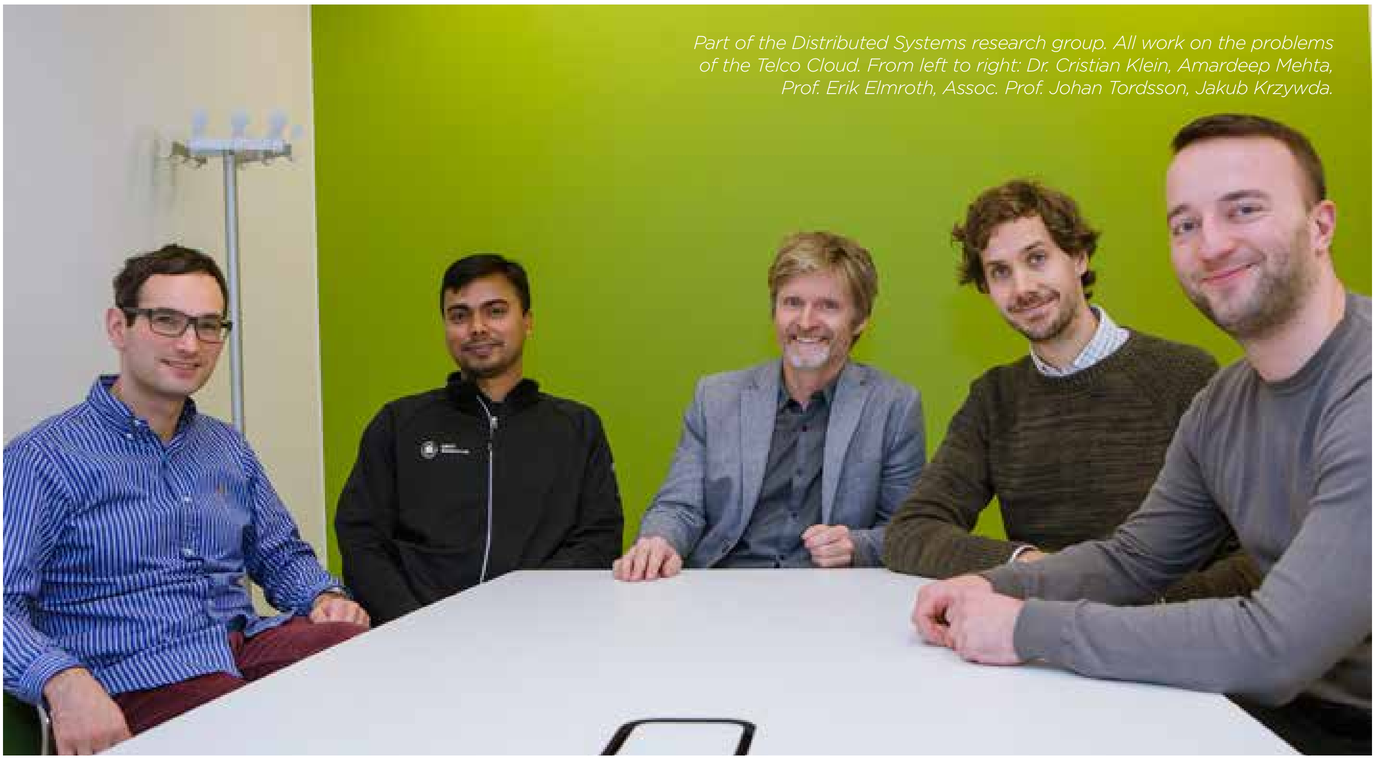
The Umeå team works with Svenska Kullagerfabriken AB, the world's leading manufacturer of ball bearings, in order to develop CutFEM into an advanced automated "tool for generating finite element models of mechanical components with applications in the simulation of bearings," Larson says. Such models are then used to study properties of a bearing, such as fatigue and wear, which may be used to improve designs and plan maintenance.

The biggest challenges CutFEM faces before it can be used for practical purposes, according to Larson, include computational geometry problems related to cut elements – in other words, the methods used to partition a large complex geometric object into small simple pieces. The team also needs to figure out more efficient computation of the stiffness matrix on cut elements; stabilization and preconditioning of the stiffness matrix; and to develop robust error estimates that take into account approximations of the geometry, which can be used for adaptive mesh refinement.

If successful, Larson says, the team hopes that CutFEM eventually "will be used on a wider range of applications including flow, wave and transport problems," which are very important for industrial applications.

Telco Cloud: cloudy with a chance

Mobile devices are ubiquitous in our lives. That means the cloud must be too. How will telecommunications companies adapt in order to support our networked society?



Part of the Distributed Systems research group. All work on the problems of the Telco Cloud. From left to right: Dr. Cristian Klein, Amardeep Mehta, Prof. Erik Elmroth, Assoc. Prof. Johan Tordsson, Jakub Krzywda.

We live in an interconnected, data-rich world. In a society with a mobile phone in every pocket, and tablets in the hands of everyone from engineers and commuters to school kids and cashiers, we all want data, and we all want it now.

But our current data delivery system is not sufficient for this new networked world. Telecommunications companies have to find ways to rethink the current system, in which our data are delivered by large data centers that send packets of digital information to our mobile devices from centralized locations. These concentrated clearinghouses cannot manage the ever-growing demands for data efficiently, without affecting the performance of mobile devices.

And hence, the Telco Cloud: data needs to be stored and delivered in a decentralized system, pulled down readily from the cloud, but also from smaller regional data centers or even hub sites or base stations inside the mobile network, i.e., closer to end-users, in order to make its delivery and the use of devices on the telecommunications network smooth and seamless. Even calculations made by applications that use that data must be distributed. But getting all those dispersed elements to interact well will require a lot of work – exactly how can large data centers interact with mobile phones, their base stations, and everything in between?

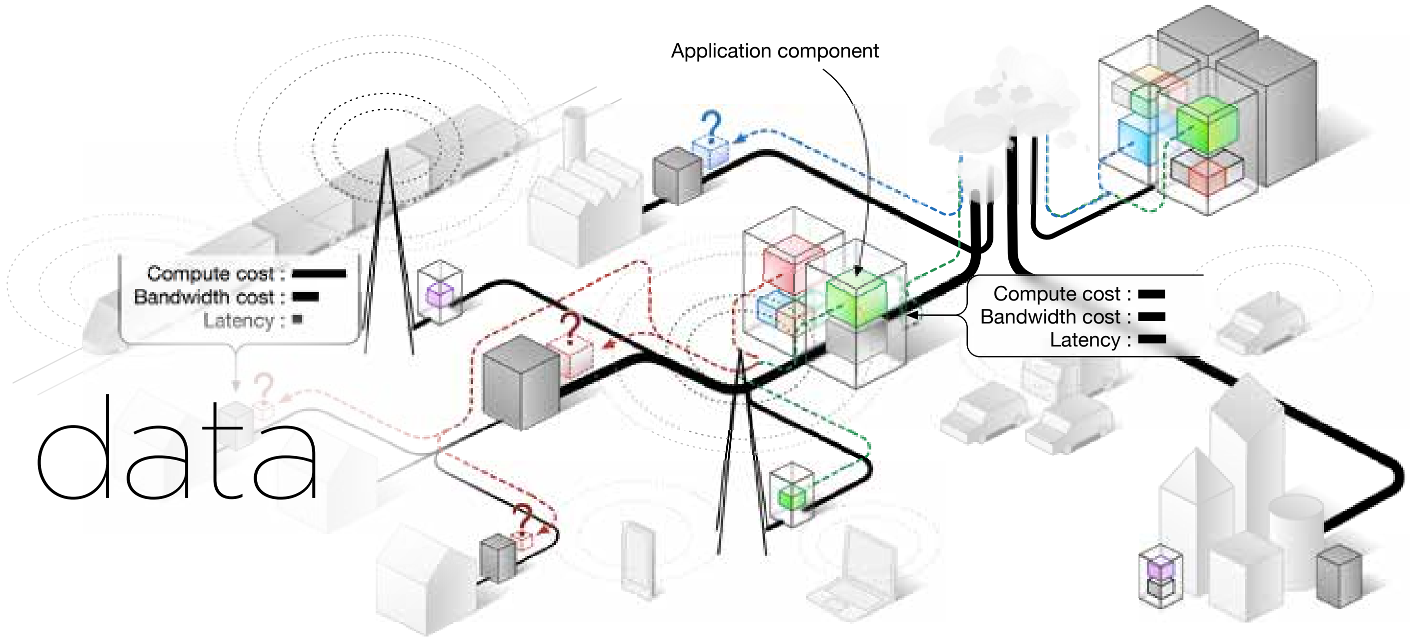
Johan Tordsson, associate professor of the distributed systems research group of Umeå University, and his colleagues in academia and industry want to find answers. They are working on the problems of the Telco Cloud starting out with statistical models that they can then test in reallife, to get insights into the most efficient configurations and resource management applications.

Big cloud, big problems?

Today, academic and industry researchers are tackling the scientific problems of how, when and where to allocate which resources to applications. The aim is to build an autonomous system that can monitor the infrastructure – data centers, mobile devices – as well as the applications, say for digital real-time maps or messaging services, augmented reality, personal virtual offices, and even remote surgery and personal video streaming.

This autonomous system should be able to predict future capacity and conditions on the network as mobile users come online and offline, for example. "Users move around during their daily activities, and they also tend to group together at university campuses, large live concerts, fairs," and other public and private spaces, says Tordsson. "For a given application, the problem is to know for each point in time, how many users are there, and where are these users located? An answer to these questions is

# of data



needed in order to perform dynamic capacity allocation." Based on this information, the system would be able to adjust the allocation of resources to achieve specific goals in terms of performance, resource utilization, and so forth.

The challenges for designing such autonomous systems are immense. Modeling the dynamic properties of users (usage patterns and mobility) as well as the existing infrastructure (variations in performance, errors, and more) is very difficult, Tordsson says. The approach to meeting these challenges requires decentralized nodes that give feedback and data analysis in real time.

In addition to looking at how, when, and where applications need resources, researchers want to develop methods for real-time aggregating and analyzing measurements from millions of devices (mobile, network, base stations, data centers, etc.) in the Telco Cloud infrastructures, and create a knowledge base for resource management from these methods. That would include building software that can figure all these things out on its own, through online learning.

The research group's main results are algorithms, and software prototypes. Because the ultimate goal is to build resource management methods, Tordsson says, his team's products "tend to be generic with respect to applications." To evaluate their products, they might test their applications on something typical or representative of the telecommunications network and its services, such as web server benchmarks that represent interactive, user-facing applications, or batch applications with background computations.

The researchers need to test mobile cognitive assistance, virtual or augmented reality, and other digital tools based on massive calculations in cloud computing on the telecommunications network, in order to see what they need to do so that these services are delivered with guaranteed response times. Would a real-world system need extra storage "reservoirs"? How would a certain algorithm work to speed up how an application works on a mobile, for example, when a million-plus customers are using the same network?

But testing must be done offline, and that's difficult: At the moment, Tordsson says, no good applications or real-world testing exist for what they want to accomplish. In some recent projects within the Telco Cloud area, his research team had to simulate "envisioned infrastructures as well as what we believe are suitable applications, with low-latency requirements, strong locality in usage patterns, roaming users," and so forth.

Collaborating on the cloud

Tordsson and his colleagues are not alone in their efforts: "This work is commonly carried out in larger collaborations with other universities and industrial partners, for example, within the scope of the European Framework programs," he says.

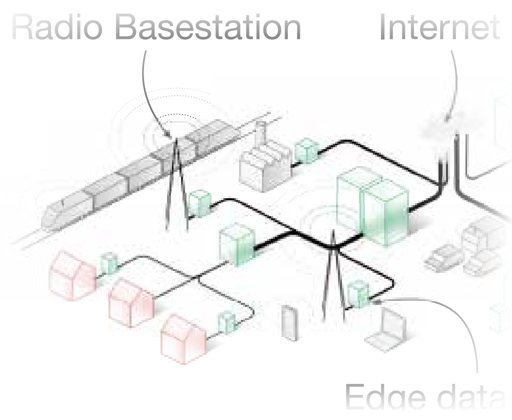
Collaboration with industry also means that the methods he and his colleagues develop, after first being evaluated in simulated environments, can be introduced to real infrastructures in testbeds built by industry. Access to these larger-scale systems and more realistic experiments are "a key benefit of collaborating with industry," Tordsson says.

Such collaborations often mean that research projects are applicable to real-world problems: Industry provides a reality check for academia. "Are the questions we are asking in our research really relevant, are they already solved to some extent by industry, or will industry – the research end-users – never bother with this problem? Conversely, industry can benefit from the somewhat more free research agenda of academia, [which] hopefully is able to look longer into the future and focus on problems with high long-term impact, but lower short-term benefit," Tordsson says.

"In any area where research topics are reasonably close to industrial interests, collaboration is very useful for both stakeholders," he adds. Academic-industry partnerships can lead to actual adoption of a software application or its parts that may have started out as a demonstration in an academic setting. "Another path to adoption is direct commercialization by creation of spin-off companies, as was the case with the Elastisys company created based on our research results in autoscaling," says Tordsson, who was a co-founder of the company after receiving his PhD at Umeå. That also means that results from the Telco Cloud research at Umeå could have an influence on the Swedish telecom industry and growing data center sector.

And while the Internet of Things and the Smart Grid are very different from the Telco Cloud, the concepts are generally similar, Tordsson says. Even though the actual managed resources may be power plants and grids versus data centers and computer networks, with very different characteristics, the concept of managing Smart Grids or the Internet of Things – to tie together objects in everyday life, from cars and public transport to home thermostats and lighting – has analogies to resource management and comparable fundamental techniques for studying and manipulating the system as in the Telco Cloud.

"The Internet of Things is a complementary paradigm to the Telco Cloud that we study," says Tordsson, "with work so far focused mostly on client aspects such as energy-efficient devices, lean communication protocols, etc. Our Telco Cloud research targets challenges for the backbone infrastructure, [in other words,] a combined telco operator network and distributed data center topology. However, advances in both these areas are needed to make the Internet-of-Things vision a reality."



Vehicle testing, without the vehicle

Modeling how a car or truck works could allow researchers to find cheaper, more efficient machines, before even building prototypes.

Modern vehicles include dozens of electronic devices that communicate over specialized networks. Each component of a car, truck, bus, or even a airplane includes a tiny built-in computer designed to help control the device. To make things more complex, these many components require tuning – that's tens of thousands of parameters – and they interact and interfere with each other.

Predicting what will happen when all of these components are integrated into a vehicle is incredibly difficult. In the real world, tracking down systemic errors is very hard and can stall production of a vehicle by months. A prime example is the Airbus A380, which has 98,000 wires and 40,000 connectors: figuring out the electrical wiring led to expensive production delays – and probably massive headaches.

"You might think configuring your smart phone is hard. The engineers linking together all of these components have a real challenge," says Claude Lacoursière, a principle investigator at Umeå working on the Virtual Truck & Bus project. But they have one advantage: virtual models of their machines.

In simulations, everything can be tested, Lacoursière says: "Contrary to reality, *everything* can be measured in a simulation, every variable can be analyzed." The Virtual Truck & Bus project basically is a computer model meant to unify all these different elements, in a way that is realistic enough to solve some problems before vehicle makers even make prototypes for testing. They want to approximate how, for example, an engine will work with a drive train, when a virtual driver hits the gas with a heavy foot – and help engineers and manufacturers solve problems before the real vehicles are made.

Purposeful programming

"As vehicles are getting more complex with dozens of interacting software and hardware components, understanding interactions and identifying systemic problem is of paramount importance. Being able to do this without having to experiment in the prototyping workshop can save much time and expense, but more relevantly, help bring more reliable, more sophisticated and safer products to the market," says Claude Lacoursière, Chief Scientist at Algoryx Simulation and a researcher at the High Performance Computing Centre North (HPC2N) at Umeå University.

This project makes use of emerging standards to directly address the communications and compatibility problems inherent in the multitude of modules available. Researchers at Umeå are working with Volvo Cars and Scania to create a kind of "co-simulation," in which different tools model different components. "There is no known reliable and efficient method for doing this at present. This is what we are focusing upon and have already made some headway," Lacoursière says.

Available tools

Today more than 20 software products are available that can create interfaces to binary objects or codes known as Functional Mock-up Units (FMUs). They may be built of several languages, say, MatLab, Simulink, C or Fortran, to represent clutches, engines, brakes and more. Connecting hundreds of these many tiny modules "is no small puzzle," Lacoursière says.

The Virtual Truck & Bus project is using a Functional Mockup Interface (FMI) to "help couple all the parts based on input and output relationships, and building tools to help doing this on very large systems," Lacoursière says. "It will soon be relatively easy to integrate everything together and construct the spider web of signal routing and 'stitching' everything together, as I like to say." Defining the FMIs for the components is fairly simple and straightforward, but no one has standardized this before, he says. Having a standard "opens [up] incredible opportunities and has far-reaching consequences, ranging from optimization, data analysis, validation, comparison, full system simulation and much more."

The UMIT team also focuses on developing techniques that allow for executing FMUs in parallel, to reach high performance and real-time capabilities, he says. This allows humans to test-drive these virtual machines. "I call that monkey-in-the-loop," Lacoursière adds. He is also working to develop numerical methods that deliver reliable results in the simulation, which may be a larger challenge than building the FMI.

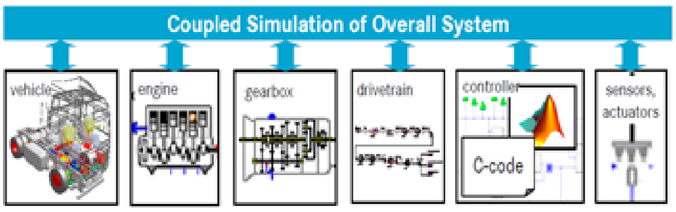
The new application will be usable on internal networks, clusters or multicore configurations. That flexibility allows researchers in academia and industry to work together or alone, and share across platforms and physical sites, for example, in Wide Area Networks or Local Area Networks.

The unifying software also will be open source and nonproprietary, which means that anyone can use it to test their simulation together. That interoperability and accessibility

The Research team from UMIT constiting of: Tomas Härdin(Research Engineer) on the left, Dr. Claude Lacoursière (Principal Investigator) in the middle and Mats Johansson (Project Coordinator) on the right.

may also contribute to the tool's adoption by industry users, who prefer not to be "locked in" to proprietary software. "This model allows people to choose what they want to use without restriction," Lacoursière adds.

The Virtual Truck & Bus project is building on previous successes with Simovate, another Umeå-based research project that examined processes and hierarchical modeling. The research team coupled simple 2D finite elements with rigid multibody systems, as a proof of



concept in how simulations might be coupled stably. The team must tackle how to model changes that happen quickly, in "discrete elements" that are physical pieces governed by simple laws of force. Because vehicles involve shifting clutches, changing gears, friction and stick-slip behaviors on road surfaces and at the wheels, these elements do not interact together smoothly.

Starting in 2D with Simovate, "we achieved high stability and large step size, making for fast simulations, and yet maintained high fidelity of coupling" between modules, Lacoursière says. "We are now extending these numerical models to more complicated systems."

Avoided costs, future benefits

Having a virtual vehicle on which to experiment stretches the lab space available to designers. They can run a lot of "experiments" with different designs at very little cost. Virtual methods also allow researchers to dig deep into the data, to see every variable and every message, in order to find "exactly what is inefficient, and why. New design ideas need not be so conservative and this brings the possibility of real gain in energy efficiency since the entire system is now considered, not just one component," says Lacoursière.

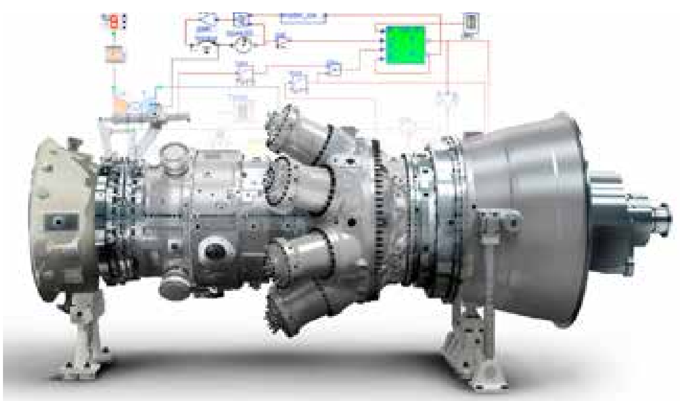
The hope is to reduce the time required to develop a new vehicle by 20%, and to explore new ideas for improving fuel efficiency at little cost. Gains can be made using basic laws of physics to figure out where problems might occur to begin with, or in finding fuel-consumption efficiencies, and eventually in avoiding corrections in the prototype stage, for example. Other benefits come with having more efficient collaboration and communication between different engineering teams working on different vehicle parts that eventually must fit together like so many puzzle pieces.

In light of recent scandals with Volkswagen, which manipulated the emission rates on their passenger cars, "our work on making powerlines on trucks more efficient becomes even more important. This is because a lot of the powertrain developments of the cars are inherited from the trucks, usually with a few years delay," says Mats Johansson of Umeå, academic coordinator of the Virtual Truck & Bus project.

"Constructing future vehicles is a complicated process, as both customer demands and laws are becoming stricter. This demands a change in development that is rapid and efficient and in this we believe that the project will deliver definite impacts," Johansson says. Having "a versatile simulation environment in which the departments can use their own specific tools, and in which you can mix fidelity and software/hardware components freely, the industry can enter the next era of development and also be more responsive to future changes."

With virtual simulations, engineers can try out more radical designs without having to test them in the workshop. "In the end, people want to deliver functionality but the practicalities of testing requires incremental development. Simulation can help [industry] take giant leaps," says Lacoursière.

The technology incorporated into trucks and busses also gets passed on to other complex machines, not just cars or other vehicles. Anything dynamic – with moving parts and multiple components – can be modeled in the same way, Johansson says. Their research "has applications in a broad spectrum of areas ranging from smart cities to future cars," he says. Plus, it holds useful answers to interesting scientific questions.



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, Vetenskapsrådet, Vinnova and the EU’s 7th Framework Program.

- **Computational design optimization**
- **Computational mathematics**
  - Finite elements
  - Geometric numerical integration
  - Spectral theory
- **Distributed systems**
- **Interactive multiphysics and complex mechanical systems**
- **Parallel and scientific computing**

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

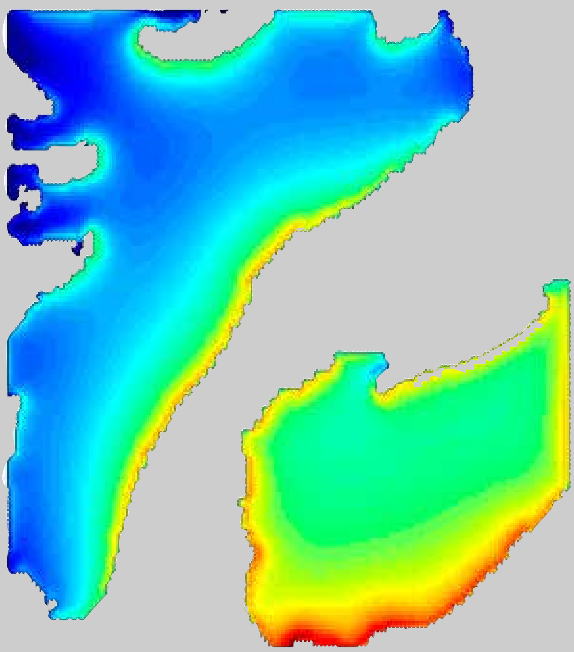
- Convergence in the technologies behind Computer Assisted Design (CAD) & Computer Assisted Engineering (CAE) technical and scientific computing, and visualization
- More powerful computers through parallelism and multicore architectures
- The embedding of everything in the web browser and connection 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.

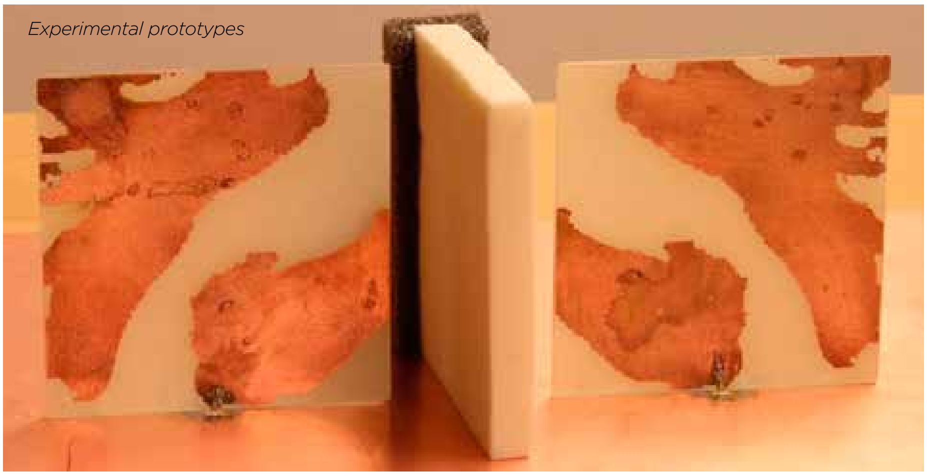
The computational design optimization research group develops and analyzes methods that combine physics-based mathematical modeling, computer simulations, and optimization. The purpose is to find the particular shape or material arrangement of an object that yields the most favorable performance. Presently, the group focuses 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 electromagnetic 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 Sveriges tekniska forskningsinstitut, Träcentrum 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 their application in education, science and engineering.

Our research is interdisciplinary and located at the intersection between mathematics, computer science, engineering and their 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 provide 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.

From left: Dr. André Massing, Prof. Mats G. Larson.

Research focus
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 nonsymmetric 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 University of Technology, Jönköping University, Royal Swedish Institute of Technology (KTH), Linköping University, Simula Research Laboratory AS, SKF

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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. The group develops and analyzes novel numerical algorithms for these problems.

In particular, our research concentrates on developing and analyzing 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, etc.). 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 offers more reliable time integrators.

The investigation done in our research group mainly focuses on the following two topics: highly oscillatory and multiscale problems. Such problems frequently arise in biology, geosciences, or molecular dynamics. We offer very competitive numerical methods for these problems.

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 stochastic differential equations. Our research group answers this demand by developing more advanced numerical methods for stochastic differential equations, tailored to fit specific properties of such 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, for example.

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 longtime behavior of numerical solutions to nonlinear wave equations.

Collaborations
University of Geneva, École polytechnique fédérale de Lausanne (EPFL), Norwegian University of Science and Technology (NTNU) Trondheim, Chalmers University of Technology, Inria Lille Nord-Europe, Technical University of Berlin (TU), Karlsruhe Institute of Technology, Chinese Academy of Sciences and others.

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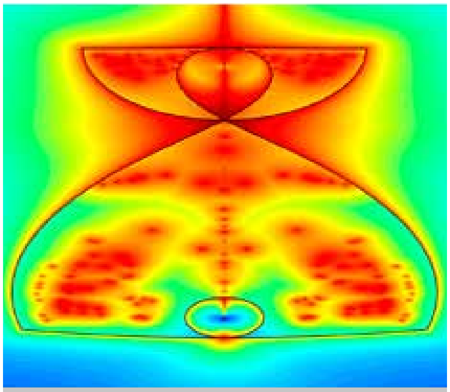
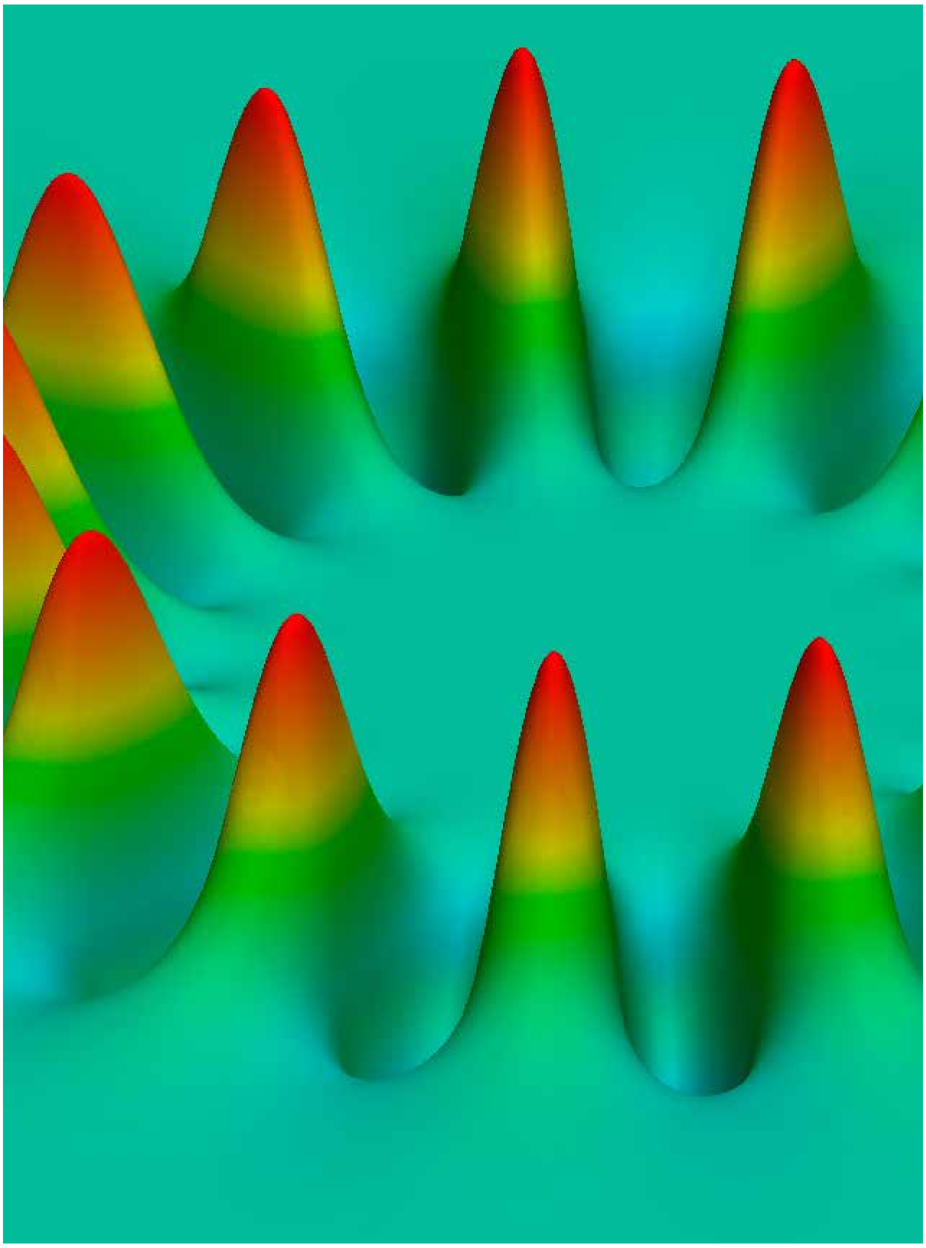
Spectral theory

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
Swiss Federal Institute of Technology in Zurich (ETH), École polytechnique fédérale de Lausanne (EPFL), Technical University of Berlin, Technical University of Wien, University of Bern, University of Zagreb

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Distributed systems

The research group focuses on autonomous management of cloud infrastructures, spanning from individual cloud infrastructures to large-scale distributed clouds, including so called telco clouds.

Research drivers are compute and data intensive applications requiring elastic locality-aware infrastructures to meet the rapid capacity and locality variations of, including all of industrial services, end-user applications, Internet-of-Things applications, and large-scale eScience applications. Research outcomes include autonomous infrastructure and application 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, algorithms for autonomous capacity scaling, as well as methods for service differentiation and for enhancing energy efficiency, fault tolerance, and disaster recovery. Ongoing projects with immediate industrial benefits include collaborations with Intel Ireland, Ericsson Research, IBM Haifa, Red Hat, and Google in Mountain View, CA. Another result with industrial applications is the creation of the Elastisys spinoff company, with a focus on cloud auto-scaling and multi-cloud management.

From left to right: Dr. P-O Östberg, Peter Gardfjäll, Prof. Erik Elmroth, Dr. Mina Sedaghat.

Research focus
Autonomous resource and application management systems for individual cloud datacenters and highly distributed clouds, including telco clouds and internet of things infrastructures.

Applications
Applications that benefit most from this research are those that have large and or varying capacity needs, and for which performance and cost efficiency is important.

Projects
Cloud Control (VR framework project), eSSENCE (Government / VR), Context-aware cloud topology optimization and simulation (CACTOS, EU FP7), Business continuity as a service (ORBIT, EU FP7), Cloudberry Datacenters (Vinnova), and the creation of Elastisys AB, a spin-off company focusing on providing a cloud management system.

Collaborations
IBM Haifa Research, SAP Software Solutions, Lund University, Intel Ireland, Ericsson Research, Red Hat, Google, and others

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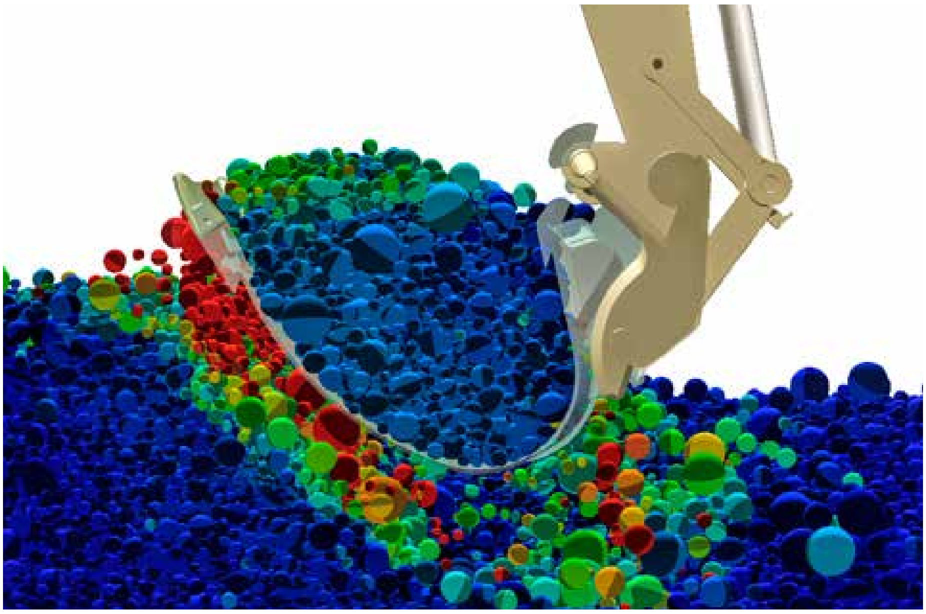
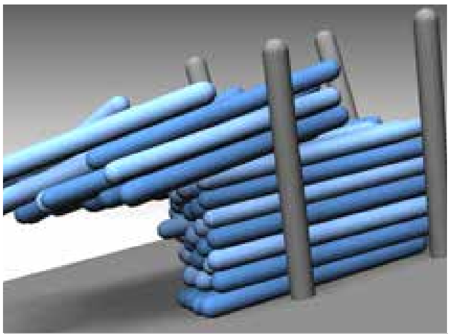
Interactive multiphysics and complex mechanical systems

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





A computer program cannot encompass the entire world. Something has to go. The question is what properties of the real world need to be captured in order to make a sufficiently realistic virtual replica of complex mechanical systems? And then there is the challenge of making the simulation code fast and scalable, for example, to make applications run at an interactive rate or to exploit the full potential of a supercomputer. The group's research addresses multidomain 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 nonsmooth multidomain dynamic systems. The research has applications for various types of virtual environments, including visual interactive 3D simulation for making real-time simulators for the purpose of understanding, redesigning, controlling and optimizing industrial processes, robots, and vehicles, as well as for training, education or entertainment.

The past year yielded many good results. The nonsmooth discrete element method for simulating granular matter was accelerated by orders of magnitude using model order reduction and warm-starting. Da Wang defended his doctoral thesis on this topic successfully. The applications of this research to simulation-based design and control of large-scale granular flows in iron ore pelletizing plants was presented at ECCOMAS IV International Conference on Particle-Based Methods in Barcelona. The last five years of collaborative development with LKAB, Algoryx and Optimation was summarized in a seminar at LKAB with more than 30 participants. Algorithms and interoperability solutions for distributed co-simulation were developed and tested in collaboration with Scania and Volvo Cars in the project Virtual Truck & Bus that started up in 2015. A framework for data exchange and benchmarking of frictional contact solvers in multibody dynamics was developed and presented at ECCOMAS Thematic Conference on Multibody Dynamics in Barcelona. A reduced-order meshfree elastoplastic terrain model was developed and show promising results for realtime simulation of vehicles on deformable terrain.

Research focus
Models and algorithms for fast multibody systems with nonsmooth and multidomain dynamics, for example vehicles, robots, biomechanics, granular matter, fluids, cables and cloth, electronics, and hydraulics.

Applications
- Simulation-based design, control and optimization of complex mechanical systems
- Visual real-time interactive simulation for physically faithful virtual environments

Projects
- Applications of nonsmooth mechanics to rough terrain vehicles
- Modeling and simulation of the complex forestry environment
- Modeling and simulation of large-scale granular matter and machinery
- Control of granular processes
- Virtual Truck & Bus

Collaborations
Algoryx Simulation, LKAB, Optimation, Oryx Simulations, Rensselaer Polytechnic Institute, Scania, Skogstekniska Klustret, Sveriges lantbruksuniversitet (SLU), Volvo Cars

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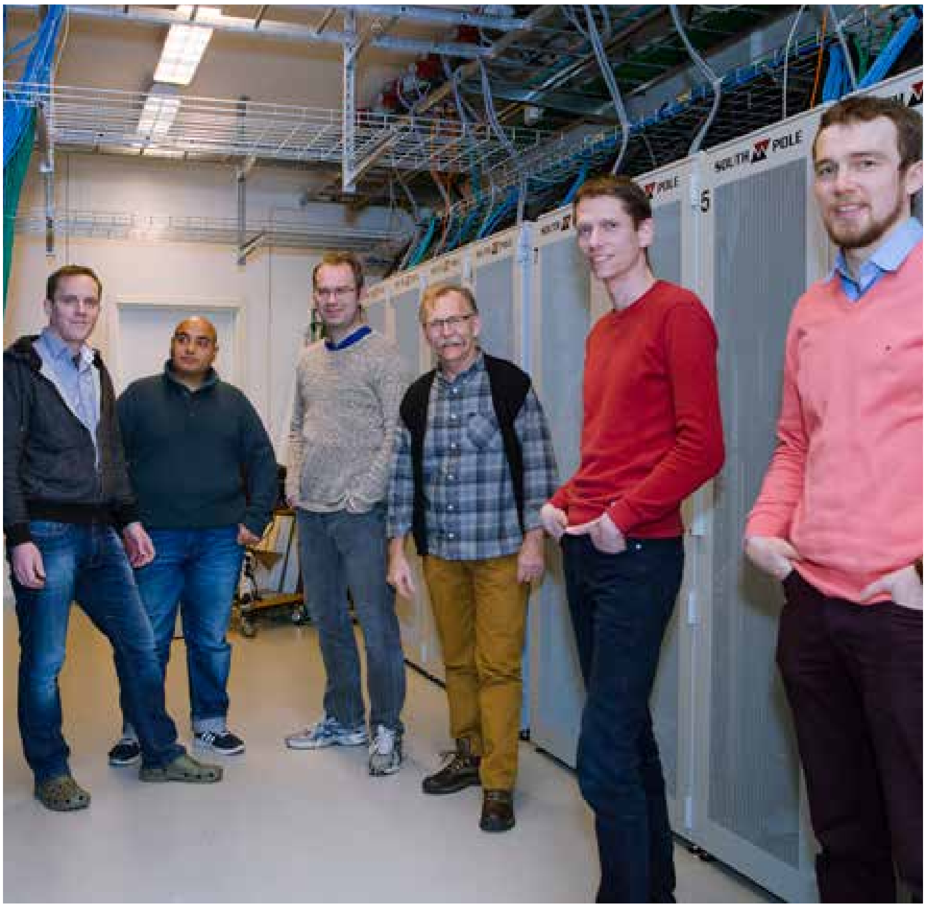
Parallel and scientific computing

Parallelism is here to stay! Today, most computers, from laptops to supercomputers, are based on so-called multicore architectures. Connecting many hundreds of powerful, and possibly heterogeneous, GPU-equipped multicore nodes using a high-performance interconnection leads to truly massive parallel systems with 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. See also the Horizon 2020 project NLAFET.

Matrix computations are both fundamental and ubiquitous in the computational sciences, for example, in the modeling and simulation of problems ranging from galaxy-sized to nanoscale, and in real-time airline scheduling and medical imaging. Computing the Google PageRank vector of all web pages on the Internet is considered to be 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 associated matrix problems.



Research focus
Design of efficient and reliable algorithms for structured and dense matrix computations targeting multicore 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 polypeptides submerged in water

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

Collaborations
Algoryx Simulation, DLR, IBM, Niconet/SLICOT, ScaLAPACK; Karolinska Institute, the University of California at Berkeley, and others.

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List of publications | 2015

Journal papers

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Dr. Ewnetu Bayuh Lakew

Industry collaborations 2015

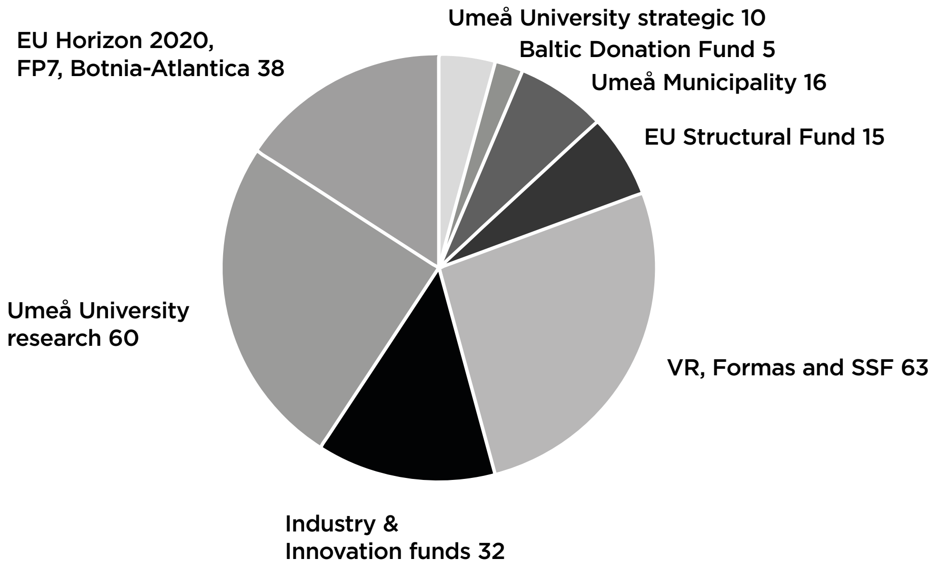
- Algoryx Simulation
- Adopticum
- DAS Audio
- DLR
- Elastisys
- Ericsson Research
- Enmesh
- Google
- IBM
- IBM Haifa Research Labs
- Intel Ireland
- Komatsu Forest
- Limes Audio
- LKAB
- Modelon
- Olofsfors
- Optimation
- Oryx Simulations
- Red Hat
- SAP Research
- Simula Research Laboratory
- SKF
- Scania
- Skogstekniska Klustret
- SP Sveriges tekniska forskningsinstitut
- Träcentrum Norr
- Valutec AB
- Volvo

Financing

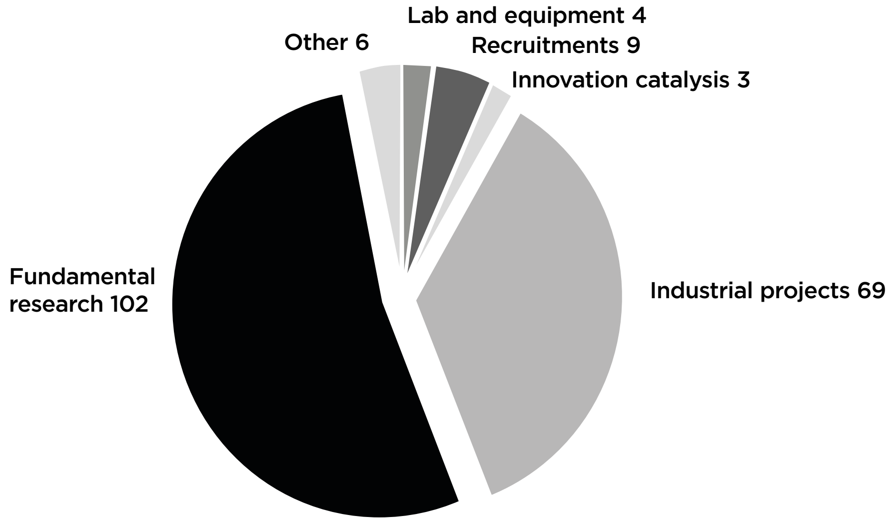
The UMIT project was initiated in 2009 with a total funding budget of 40 MSEK distributed over a five-year period.

Founding financiers are the Baltic Donation Fund (5 MSEK), the EU Structural Fund–Objective 2 (15 MSEK), Umeå Municipality (10 MSEK) and Umeå University (10 MSEK). In addition to the initial funding of 40 MSEK, by the end of 2015 UMIT had raised 133 MSEK from external sources for the co-financing of specific projects, e.g. EU FP7, EU Botnia-Atlantica, Totalförsvarets forskningsinstitut (FOI), Kempestiftelserna, LKAB, ProcessIT Innovations, SKF, Skogtekniska Klustret, Sorubin, SSF - Stiftelsen för strategisk forskning, Surgical Science, Valutec, VINNOVA and Vetenskapsrådet (VR). This corresponds to external funding of 20 MSEK annually and a strong support for both fundamental science and for applied research in industry collaboration. By the end of 2015, our affiliated scientists had in total been granted 48 MSEK from VR since 2009. The research financed by faculty and the industrial doctoral school during the same period amounts to 60 MSEK. UMIT's expected finances and distribution of expenses for the years 2009–2015 are displayed below.

Financing, total 193 MSEK



Budget, total 193 MSEK



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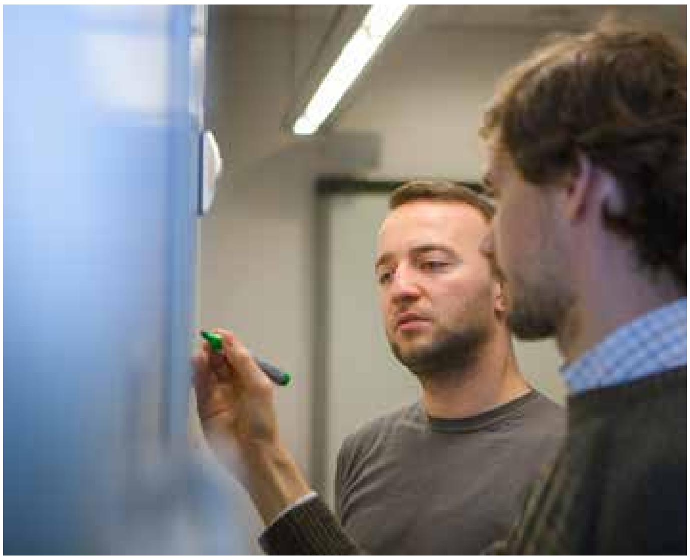

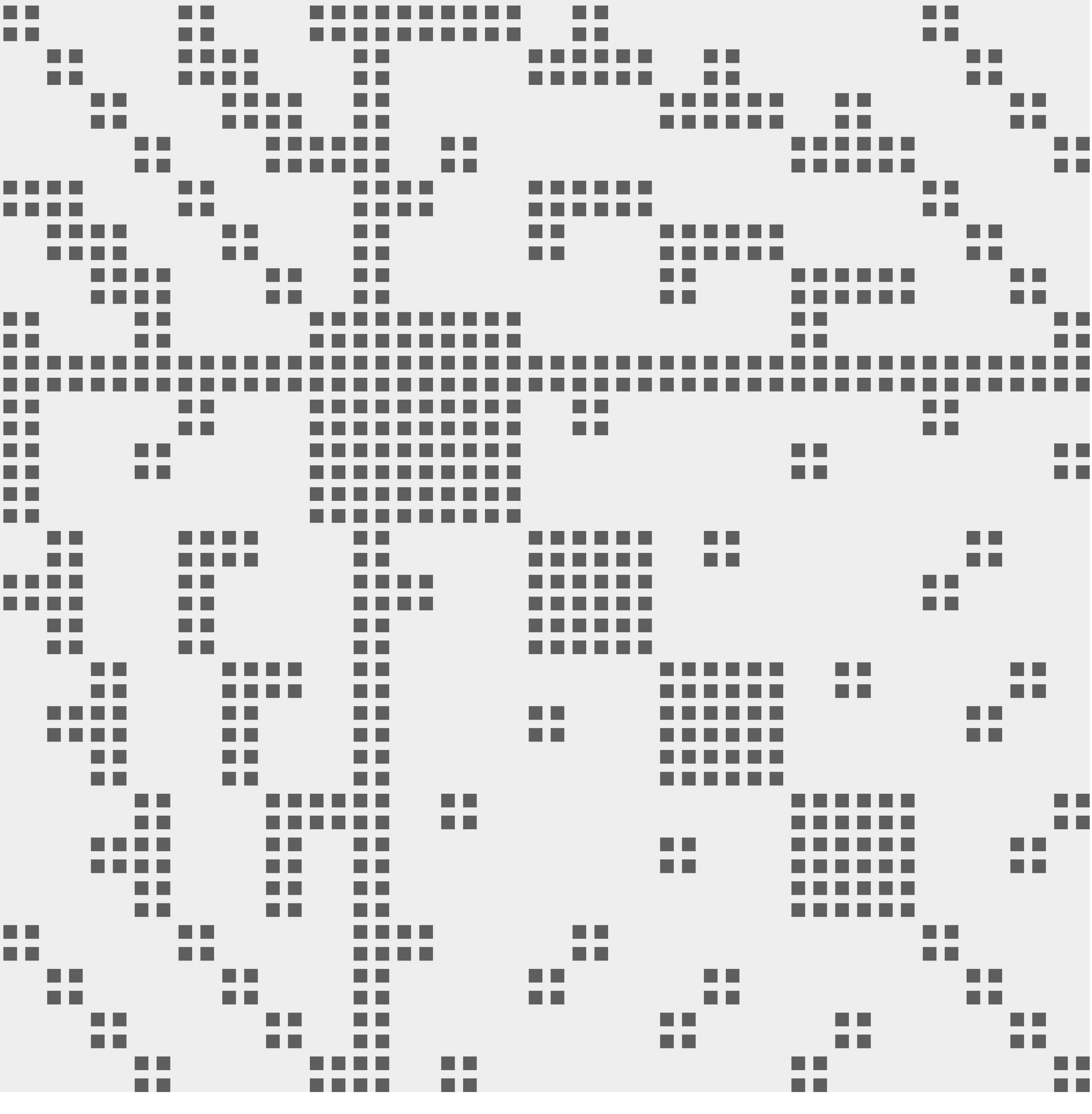

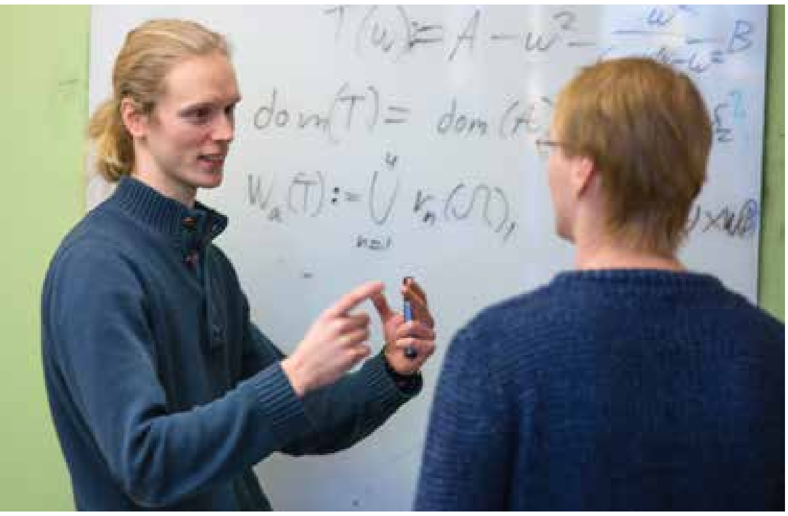

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UMIT Research Lab is a strategic initiative in computational science and engineering with a focus on industrial applications and innovative software development. The research lab, formed in 2009, is a dynamic, intellectual and physical research environment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

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En investering för framtiden

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