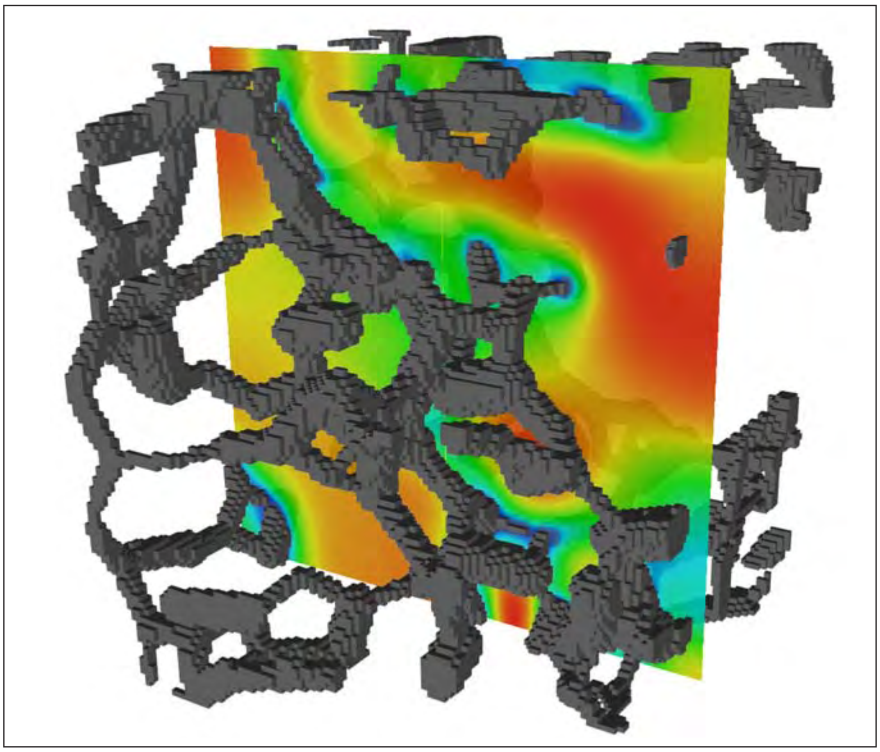
Fraunhofer

CHALMERS

Research Centre
Industrial Mathematics

Annual Report 2008



FCC

Fraunhofer-Chalmers Research Centre for Industrial Mathematics

This and other FCC reports are distributed by

FCC
Chalmers Science Park
SE-412 88 Göteborg
Sweden

Telephone: +46 (0)31 7724000
Telefax: +46 (0)31 7724260
info@fcc.chalmers.se
www.fcc.chalmers.se

Cover

Simulation of mass transport through a gel structure using the FCC solver IBOFlow. The figure shows the velocity field in a cutting plane, cf pages 16 and 43.

Illustrations

To illustrate our research on pages 12 - 43 we use pictures from Göteborg and Mölndal, see also the inner back cover.

Annual Report 2008

Fraunhofer-Chalmers Research Centre for Industrial Mathematics, FCC

Editors: Annika Eriksson, Uno Nävert
Layout: Annika Eriksson
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Contents

Preface

FCC operates in Chalmers Science Park.

For three years 2006-2008 the Centre has shown an annual income level slightly below thirty million Swedish crowns or three million euros, each year making a positive net.

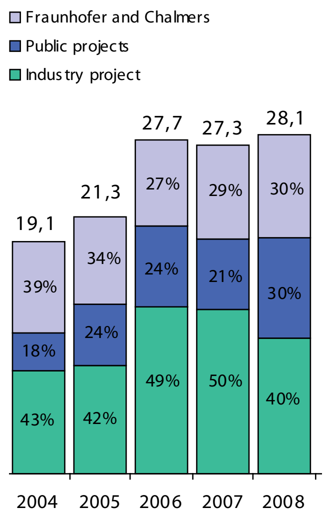
Together with our partners Chalmers and the Fraunhofer industrial mathematics institute ITWM we cover a wide range of applications. In 2008 the project exchange was about ten million Swedish crowns with each partner including basic project funding.

For 2008-2009 we have started an industrial partner group IPG. The research theme 2008 was "Inverse problems, parameter and structure identification, and optimization". The IPG met twice in Gothenburg and twice in Kaiserslautern to define a research programme from a research scenario, industrial scenarios, and making a synthesis.

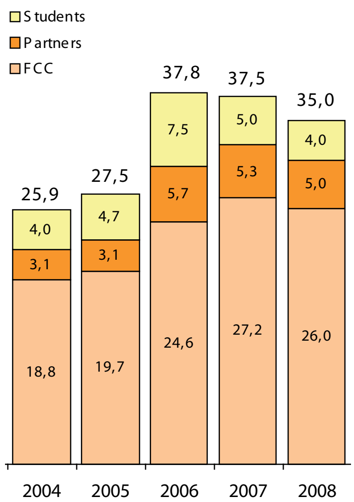
To offer an interesting option to Chalmers students and at the same time boost our base for future recruitments, the Centre made a student campaign by the end of the year. As a result we have hired twenty students for contracted work and master thesis projects.

The diagrams below show the development of the centre in terms of income and staff.

Income MSEK



Staff - full time equivalents



The profile of the Centre is controlled by its income structure. The result of 2008 is in line with the Fraunhofer financial model, i.e., the project volumes from industry (40%), public financiers (30%), and Fraunhofer and Chalmers (30%) are well in balance. We noted a decrease in number of staff in 2008, which we expect to reestablish the next year.

www.fcc.chalmers.se

The department Geometry and Motion Planning, working in close cooperation with the Chalmers Wingquist Laboratory, has established an income level well above ten million Swedish crowns. The activities 2008 included the start of two Vinnova MERA projects on electro coating and efficient inspection, growing interest in path-planning software, and substantial joint development with the ITWM department Mathematical Methods in Dynamics and Durability.

The department Computational Engineering and Design has expanded its work on multi-physics applications involving fluid-structure and fluid-electromagnetics interaction, in particular through projects with Swedish and other European industrial partners together with the ITWM departments Optimization, Transport Processes, and Flow and Material Simulation. The department runs a strategic cooperation with Chalmers on simulation-based optimization through the Gothenburg Mathematical Modelling Centre GMMC.

The department Reliability and Risk Management has its focus on fatigue life and load analysis of mechanical structures in, e.g., automation and automotive industry. In particular, the department runs a three-year joint project with the Chalmers Stochastic Centre, Fraunhofer ITWM Dynamics and Durability, and SP Technical Research Institute of Sweden. The industrial partners are six European truck manufacturers from Germany, Italy, the Netherlands, and Sweden.

The department Systems Biology and Bioimaging has continued to grow by adding substantial industrial (pharmaceuticals) and public (EU and GMMC) income to our long-term grant from the Swedish Foundation for Strategic Research SSF. Our cooperation with the ITWM department System Analysis, Prognosis and Control has intensified through a strategic project on particle filtering techniques.

I thank my co-workers at FCC for your excellent work and my colleagues at Chalmers and Fraunhofer ITWM for our fruitful collaboration. Since start 2001 the Centre has earned eight million euros from more than 70 industrial clients and completed more than 200 industrial and public projects. Together we are well positioned for the challenges to come!

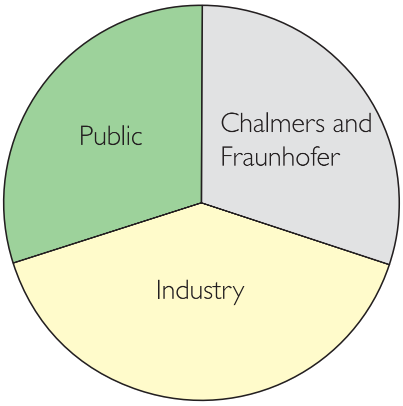
Uno Nävert, Director of FCC.

Göteborg in May 2009

Uno Nävert
Director

Profile

Mathematics has become a key technology for industrial innovation since mathematics is behind all work in the virtual world.



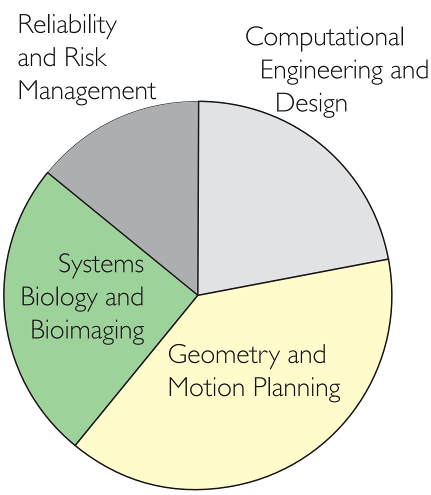
Project mix by income.

The Fraunhofer-Gesellschaft and Chalmers have founded FCC to undertake and promote scientific research in the field of applied mathematics to the benefits of Swedish and European industry, commerce, and public institutions. To do so the Centre undertakes scientific research and marketing financed by the founders and by public institutes, and works on projects defined by companies on a commercial basis.

FCC is an example of a bottom-up strategy to build the European research space. First we define a small network of closely (daily) co-operating research institutes. To solve concrete problems from companies from all over Europe, we then create optimal teams built out of this network. We do this in the field of mathematics, which is a key technology for industrial innovation, lying behind all work in the virtual world, e g, simulation for prediction, control, optimization, and risk assessment.

By the end of 2008 the staff was twentynine full-time equivalents, including five scientific advisers from Chalmers, each one working 10 percent to 20 percent of full time at FCC. Statements of income was given for fiftyeight persons including advisers, board, and nineteen students.

FCC undertakes scientific research financed by its founders and by public institutes.



Departments by income.

Scientific competence

The Centre undertakes scientific research projects and marketing of scientific results financed by its founders and by public institutes. Respecting the confidentiality of data from customers, the Centre encourages the publication of results. FCC supports efforts to use its research for educational purposes at all levels at Chalmers as well as at other educational institutions in Sweden and Europe. FCC sponsors PhD work, if the subjects are of basic interest for the research in the Centre. FCC keeps contact with the worldwide community of applied mathematicians by active participation in conferences and by inviting guest scientists.

In 2008 the Centre has received public grants from SSF (Swedish Foundation for Strategic Research), Vinnova (Swedish Agency for Innovation Systems), and EU (Network of Excellence Biosim, coordinated actions YSBN and Sysinbio, and collaborative projects Cancersys and Unicellsys).

Entrepreneurial competence

The Centre served twentyeight industrial clients in 2008. The clients represent many branches, e.g., automotive, pharmaceuticals, automation, radar and telecommunications, and pulp, paper, and packaging. A list of industrial and public clients is shown on page 7.

Experiences from Fraunhofer show that small and medium size companies constitute an important market for an industrial mathematics institute. The number of SME projects at FCC is however still only marginal.

In 2008 the Centre has served international industrial clients from Germany, Italy, the Netherlands, and Switzerland.

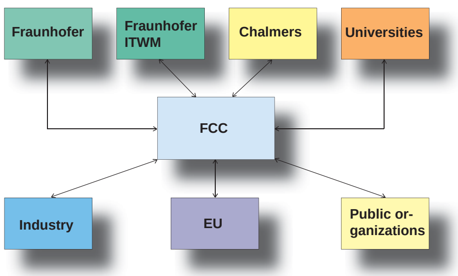
FCC works on projects defined by companies on a commercial basis.

Professional networking

The Centre has a very close relation to its founders Chalmers and Fraunhofer ITWM, cf pages 8 - 11, exchanging staff members, cooperating in projects, by joint participation in European projects, by connecting Swedish clients with ITWM and vice versa, and by stimulating the cooperation between Swedish industry and other Fraunhofer institutes.

In order to fulfil its tasks optimally, the Centre cooperates with competent scientific groups at universities and elsewhere, and promotes research and education in industrial mathematics at institutions outside the Centre, cf pages 12-13, 20-21, 26-27, and 34-35.

FCC in close cooperation with Chalmers and Fraunhofer shall be a leading international partner in industrial mathematics.



Financial mix

The financial model distinguishes between three income sources: project financing from the founders, industrial project income, and public project income. These three should be in reasonable balance.

Since start, the industrial and public project volume has increased more than expected in the original business plan. As a result of this, the relative project financing from the founders has decreased from 44 percent in 2001 to 30 percent in 2008.

FCC earns approximately 30% from its founders, 40% industrial income, and 30% public income.

Acknowledgements

The Centre is a Swedish foundation established by Chalmers and the Fraunhofer-Gesellschaft. The decision has been based on a business plan prepared by the Swedish Institute for Applied Mathematics (ITM) and Fraunhofer-Institut für Techno- und Wirtschaftsmathematik (ITWM).

The Swedish Society for Applied Mathematics (STM) and the former Swedish National Board for Technical and Industrial Development (NUTEK) have supported FCC taking over ITM operations.

The Swedish Foundation for Strategic Research (SSF) has played an essential role by giving support of one million euros for a public project whereby a research team in Systems Biology and Bioimaging has been established at the Centre.

In 2005 Fraunhofer and Chalmers decided to continue their commitments for the next five years 2006 - 2010.

Clients and Partners

Since its start in 2001, FCC has successfully cooperated with enterprises of different sizes and from many branches. Those clients and partners, who have accepted to be cited, are, among others:

- ABB
- ABB Corporate Research (CH)
- ABB Robotics
- ABB Power Technologies
- Adam Opel GmbH (DE)
- Aerotech Telub
- Albany International
- AP2 Second Swedish National Pension Fund
- AstraTech
- AstraZeneca R&D Alderley Park
- AstraZeneca R&D Mölndal
- AstraZeneca R&D Södertälje
- Atlas Copco Rock Drills
- Bergaskolan
- Bombardier Transportation
- BTG Pulp and Paper Sensors
- Chalmers
- Chalmers Industriteknik
- Cons Politechnico Innovazione (IT)
- DAF Trucks (NL)
- Daimler (DE)
- Delphi
- Efield
- EKA Chemicals
- Elforsk
- Elmo Leather
- Ericsson
- Faurecia Exhaust Systems
- FOI
- Fortum Power and Heat OY
- Fraunhofer ITWM (DE)
- Front Capital Systems
- General Motors (DE)
- IIR Sweden
- InNetics
- Innovativ Vision
- Iveco (IT)
- Jernkontoret
- KP Pension and Insurance
- MAN (DE)
- Micropos Medical
- NMCT
- Novo Nordisk (DK)
- Optimization Partner Stockholm
- PLANit Sweden
- Poseidon Diving Systems
- PSA Peugeot Citroën (FR)
- Saab
- Saab Automobile
- Saab Communication
- Saab Ericsson Space
- Saab Microwave Systems
- Safe Technology
- Saint-Gobain Sekurit Scandinavia
- Sandvik Steel
- SCA
- Scania
- SEM
- Simula Research Lab AS (NO)
- SKF (Sweden and NL)
- STM
- SP Technical Research Institute of Sweden
- Spotfire
- StoraEnso
- Svensk Verktygsteknik
- Swedish Insurance Federation
- Swerea IVF
- Sydkraft
- TetraPak
- Uddcomb
- Universitetssjukhuset MAS
- Volvo Aero Corporation
- Volvo Car Corporation
- Volvo Powertrain
- Volvo Truck Corporation
- Volvo 3P

- Chalmers
- Fraunhofer ITWM (DE)
- University of Copenhagen
- University of Gothenburg
- University of Kaiserslautern
- University of Linköping
- University of Lund
- University of Rostock
- University of Skövde
- Technical University of Denmark DTU
- The Royal Institute of Technology

- EU Biosim / DTU (DK)
- EU Cancersys, IFADO (DE)
- EU Sysinbio / Chalmers
- EU Unicellsys / GU
- EU Visicade / Fraunhofer IGD (DE)
- EU YSBN / Chalmers
- ITM
- Swedish Energy Agency, STEM
- Swedish Foundation for Strategic Research, SSF
- Swedish Governmental Agency for Innovation Systems, Vinnova

Year 2008

- ABB
- ABB Corporate Research (CH)
- Albany International
- AstraZeneca R&D Mölndal
- Chalmers
- Consorzio Politechnico Innovazione (IT)
- DAF Trucks (NL)
- Daimler (DE)
- Delphi
- Efield
- EKA Chemicals
- Fraunhofer ITWM (DE)
- General Motors (DE)
- InNetics
- Iveco (IT)
- MAN (DE)
- Saab Automobile
- Saab Communication
- Saab Microwave Systems
- Scania
- SKF
- SP Technical Research Institute of Sweden
- STM
- Stora Enso
- Svensk Verktygsteknik
- Swerea IVF
- TetraPak
- Volvo Car Corporation
- Volvo Truck Corporation

- Chalmers GMMC / SSF
- Chalmers Wingquist Laboratory VINN Excellence Centre / Vinnova
- Fraunhofer ITWM (DE)
- Universities of Gothenburg, Kaiserslautern, Linköping, DTU, Skövde

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- EU
- SSF
- Vinnova

Fraunhofer-Gesellschaft

Professor em Helmut Neunzert, ITWM, Vice Chairman of FCC.

The Fraunhofer-Gesellschaft is the largest organization for applied research in Europe.

The Fraunhofer-Gesellschaft undertakes applied research of direct utility to private and public enterprise and of wide benefit to society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration. The Fraunhofer-Gesellschaft maintains roughly 80 research units, including 57 Fraunhofer institutes, at over 40 different locations throughout Germany. A staff of some 15000, predominantly qualified scientists and engineers, works with an annual research budget of 1.4 billion euros. Roughly two thirds of this sum is generated through contract research on behalf of industry and publicly funded research projects. The remaining one third is contributed by the German federal and Länder governments in the form of institutional funding.

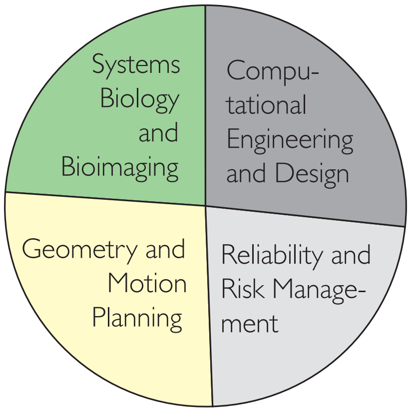
The Fraunhofer-Gesellschaft is also active on an international level: Affiliated research centers and representative offices in Europe, USA, Asia, and in the Middle East provide contact with the regions of greatest importance to present and future scientific progress and economic development.

The Institut für Techno- und Wirtschaftsmathematik, ITWM, in Kaiserslautern became a Fraunhofer institute on January 1, 2001. ITWM has continued its exceptional development and has now (2008) a budget of 14.0 million euros and a staff of 197 persons including 117 scientists, 61 PhD students, and 19 employees of the central services. The Institute further engages 151 research assistents, 48 interns, and 8 trainees. Its director is Professor Dieter Prätzel-Wolters.

The ITWM is organized into eight units, which reflect key competence fields: Departments in Transport Processes, Flow and Material Simulation, Image Processing, System Analysis Prognosis and Control, Optimization, Financial Mathematics, Mathematical Methods for Dynamics and Durability, and the Competence Centre High Performance Computing and Visualization.

Professor em Helmut Neunzert is responsible for international affairs at ITWM. FCC originates from his vision of a European institution operating in the Fraunhofer spirit.

www.fraunhofer.de
www.itwm.fraunhofer.de



ITWM income from FCC projects in 2008, in total 4.9 MSEK.

Cooperation

FCC and ITWM are, more and more, growing together. Many projects are transferred in both directions - the flow is, in 2008, quite in balance, as it is altogether almost a million euros, which passes the border. But, of course, projects are not only given to the partner, but quite some projects were dealt with together, cf below.

The advantage of operating as one unit is clear: with a total of more than one hundred scientists FCC and ITWM offer a real power in industrial mathematics; it certainly belongs to the largest and most competent institutions for industrial mathematics in Europe.

Computational Engineering and Design

FCC and ITWM run joint projects on simulation-based optimization and multi-physics applications. A large joint project on simulation of papermaking and paperboard package quality has been initiated with four Swedish companies in the forest sector, cf page 17. We also run a project on multi-criteria optimization and assessment of product variant families, cf page 19.

Geometry and Motion Planning

ITWM has developed improved methods for the simulation and visualization of robot cable motion and transient cable dynamics supporting FCC research in simulation and path planning of flexible parts, cf page 33.

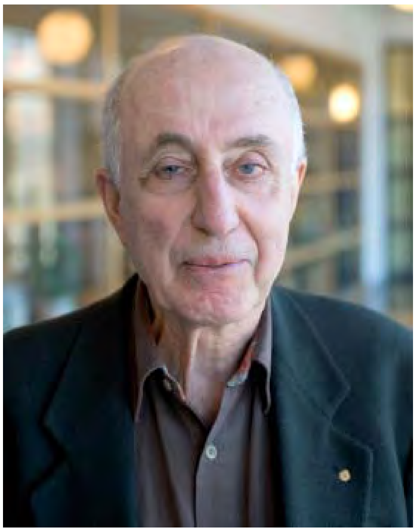
Reliability and Risk Management

FCC and ITWM run a joint project on load analysis for automotive applications with six European truck manufacturers, cf page 23. We also run a project on component packaging related to the project multi-criteria optimization and assessment of product variant families, cf page 19.

Systems Biology and Bioimaging

In a project carried out in collaboration with ITWM the aim has been to implement, compare, and benchmark approaches to parameter estimation based on so called particle filter methods. Another long term collaboration addresses the interplay between neurons and glial cells in the brain, cf page 37.

Chalmers



Professor em Peter Jagers, Chalmers, Chairman of FCC.

The Chalmers University of Technology (Chalmers tekniska högskola) was founded in 1829. It is a non-profit, non-governmental university. With its 8700 students for engineering and architecture degrees, and 975 PhD students it is one of Sweden's two leading technology universities.

Most of Chalmers' resources come from contracts with the state of Sweden (73%), but Chalmers also has strong support from non-governmental research organizations (15%) and industry (12%). The annual (2008) turnover is 230 million euros. Two thirds of the budget are alotted to research and to graduate studies. With its staff of 2137 full time equivalents, including 174 full professors, the University has strong and well-known departments in most fields of science and engineering.

Chalmers has made special efforts to integrate mathematics into a broader scientific and technological perspective. Strong activities in stochastics and numerical and modelling mathematics have emerged. Thus, besides activities in the various mathematical fields, Chalmers Applied Mathematics comprises three more specialized centres.

Professor em Peter Jagers was the President of the Chalmers Faculty Senate 1993 - 2002. He brought up the idea of engaging Chalmers in a joint venture, when the Fraunhofer-Gesellschaft started to look for Swedish partners. He also represented Chalmers in the subsequent negotiations.

Cooperation

A key element in the operation of FCC is its close cooperation with Chalmers.

This cooperation is mainly organized through scientific advisers and affiliated experts. Each adviser and expert typically spends between 10 and 20 percent of full time at the Centre. In 2008 there were four advisers and one affiliated expert representing optimization, stochastics (fatigue life), bio imaging, and mechanical engineering (product and production).

Here we describe three particularly successful areas within the cooperation:

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www.math.chalmers.se

Geometry and Motion Planning

Chalmers started the Wingquist Laboratory in October 2001 as part of Mechanical and Vehicular Engineering to increase the collaboration with Swedish industry and to concentrate research in strategic areas. The laboratory conducts interdisciplinary research within the field of virtual verification of product and production concepts.

FCC and Wingquist have a very close cooperation in geometry and motion planning focusing on product and production system modelling, robust design and variation simulation, and flexible production and automation systems, cf pages 26-33.

VINNOVA has decided on a ten year grant to Chalmers of 700 kEUR per year 2007 - 2016 for the Wingquist Laboratory VINN Excellence Centre for Virtual Product Realization. Its director is Professor Rikard Söderberg.

Statistical Fatigue of Materials

Chalmers and FCC have together built up a strong operation in fatigue life and load analysis, with industrial income 2001 - 2008 from Swedish (995 kEUR), Dutch (80 kEUR), French (165 kEUR), German (160 kEUR), and Italian (95 kEUR) companies. The total industrial income 2008 was 220 kEUR.

The strategy has been to consider the fatigue group as one unit jointly supported by Chalmers and FCC. In that way, problems from industry are imported into the academic work and research results are exported to industry. This two-way communication has proved fruitful for the students at Chalmers, including students from industry hosted at Chalmers and FCC, as well as for the industrial partners, cf pages 20-25.

"*The establishment of FCC has made it possible for the fatigue group to host competence for solving particular industrial problems as well as for doing purely academic work.*"

Professor Jacques de Maré
Chalmers Mathematical Sciences,
Scientific adviser FCC

Gothenburg Mathematical Modelling Centre GMMC

In December 2005 the Swedish Foundation for Strategic Research (SSF) decided to finance seventeen strategic centres including the Gothenburg Mathematical Modelling Centre (GMMC).

The research programme includes (1) Optimization and modelling, (2) Risk, reliability, quality, and (3) Biomathematics. In 2008 the focus of FCC has been on (1) antenna optimization, (2) reliability and quality through variation mode and effect analysis, and (3) parameter estimation, model reduction, particle tracking and gel structure modelling, cf page 18-19, 20-25, 34-43.

SSF has decided on a five year grant to Chalmers of 500 kEUR per year 2006 - 2010 for the Gothenburg Mathematical Modelling Centre GMMC. The director of GMMC is Professor Holger Rootzén.

Computational Engineering and Design

Modern product design and process operations are heavily based on computational mathematics through work in the virtual world. Traditional hands-on engineering is replaced by systematic approaches based on computer simulations, which provide insight in the design phase without the need for expensive measurements. The department of computational engineering and design does mathematical modelling of physical phenomena that can be described by partial differential equations (PDEs). Novel methods and engineering tools are developed which enable efficient solution of complex system of PDEs, making real industrial problems tractable to scientific analysis and simulation-based optimization.

The work is organized in three areas:

- Electromagnetics
- Fluid Dynamics
- Optimization

In electromagnetics we are an implementation partner of the company Efield that commercializes the software that was developed in the national research and code development project GEMS. The software constitutes an excellent platform for research as well as for performing consultancy projects. The research in fluid dynamics is focused on the development of methods and algorithms for multi-phase flows, free surface flows, and fluid-structure interaction. The focus is on multi-physics applications such as paint and surface treatment processes in the automotive paint shops, and paper-making and paperboard package quality.

In optimization the research is focused on simulation-based optimal design and multiple criteria optimization. This includes development of novel optimization algorithms, coupling of simulation and optimization software and development of decision support systems that integrate multiple criteria optimization and simulation.

Contact
Dr Fredrik Edelvik
Phone +46 31 7724246
fredrik.edelvik@fcc.chalmers.se

Kallebäcks källa *and the near-by water tower are among the oldest buildings in the district Kallebäck ("water with kettle", a name mentioned already in the fifteenth century) at the eastern entrance to Göteborg. The small well-house of stone was inaugurated by King Gustav III in 1787. The monument in front was erected in 1801 in memory of the first laying out of a water-conduit for Göteborg. Today Kallebäck also hosts several industries, e.g., Saab Microwave Systems.*

Cooperation

During 2008, the successful collaboration with the department of Geometry and Motion Planning at FCC has been strengthened through joint projects on virtual paint-shop.

Also the collaboration with the departments of Optimization, Transport Processes and Flow and Material Simulation at Fraunhofer-ITWM has grown by working on joint projects.

Acknowledgement

In 2008 the department received substantial funding from Vinnova and the Swedish Foundation for Strategic Research (SSF) through the Gothenburg Mathematical Modelling Centre (GMMC).

The Computational Engineering and Design Research Group

- Fredrik Edelvik, PhD, Associate Professor, Head of Department
- Björn Andersson, MSc Engineering
- Stefan Jakobsson, PhD
- Andreas Mark, PhD
- Robert Rundqvist, PhD
- Ann-Brith Strömberg, PhD
- David Wrangborg, MSc Engineering
- Anders Ålund, Lic
- Olivier Goury, contracted student
- Samuel Lorin, contracted student
- Linda Noreheim, contracted student
- Ruben Sharma, contracted student
- David Sjögren, MSc student
- Muhammad Saif-Ul-Hasnain, MSc student
- Peter Lindroth, Lic, Volvo 3P, PhD student
- Marco Günther, PhD, ITWM
- Michael Patriksson, Professor in Applied Mathematics at Chalmers, Scientific Adviser at FCC


Fredrik Edelvik


Björn Andersson


Stefan Jakobsson


Andreas Mark


Robert Rundqvist


Ann-Brith Strömberg


David Wrangborg


Anders Ålund


Olivier Goury


Samuel Lorin


Linda Noreheim


Ruben Sharma


David Sjögren


Muhammad Saif-Ul-Hasnain


Peter Lindroth


Marco Günther


Michael Patriksson

Electromagnetics

The rapid increases in computer power and the development of efficient numerical methods have facilitated computer simulation of complex electromagnetic propagation and interaction phenomena. This is an emerging technology in application areas such as wireless technology, antenna analysis, electromagnetic compatibility, micro electronics, radar signature and medical engineering.

The high frequency activities in electromagnetic simulations at FCC are based on the software suite developed in the national research and software development project GEMS (General ElectroMagnetic Solvers), PSCI project 24082-62591. FCC's participation as sub-contractor in GEMS has brought the Centre to the forefront in electromagnetic simulations.

FCC is an implementation partner of the recently founded company Efield AB that commercializes the GEMS software. FCC markets efield® to new customers as well as performing consultancy projects using the software.

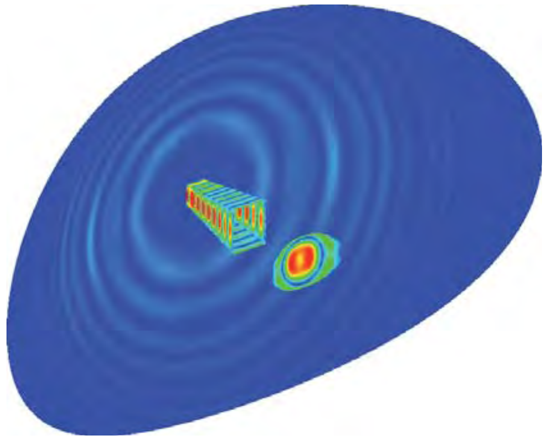
In 2008 the FCC group in computational electromagnetics was involved in the preparation of new releases of efield®. The final touches were also put on research on alternative integral formulations for dielectric and lossy materials. This novel work resulted in orders of magnitude faster convergence for the multilevel fast multipole method (MLFMM) compared to the original solver. Proof-of-concept projects have been performed with companies on the German market interested in acquiring the software. The German Aerospace Centre (DLR) has chosen efield® as its simulation tool for radar signature applications. Within GMMC we initiated efforts on EEG-based source localization in the human brain using finite element methods.

Gustav Adolfs Torg *got its name in 1854, when the statue by Bengt E Fogelberg was erected. The statue depicts King Gustavus Adolphus (Gustav II Adolf), who founded Göteborg in 1621.*

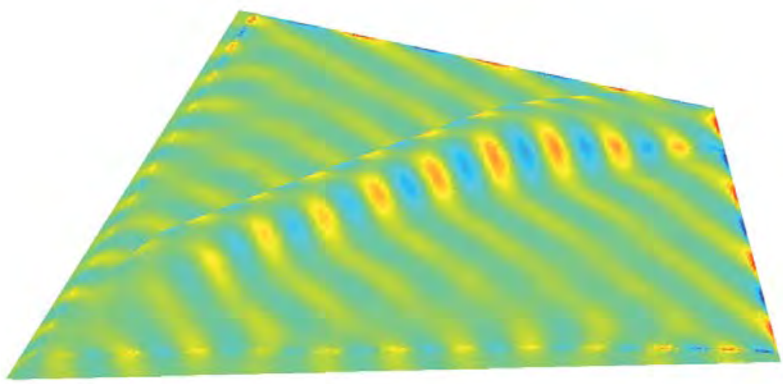
The efield® software

The efield® software is a result from a successful collaboration between Swedish academia and industry. FCC has played an important part in the development of the software and have performed further development contracted by Efield AB. The activities during 2008 have mainly been preparation work for new releases and improvement of the MLFMM solver for dielectric materials.

The software is used for antenna design, electromagnetic compatibility, radar signature and microwave applications. The solvers are based on formulations in both time domain and frequency domain. A key feature is the use of hybrid methods. In frequency domain a Method of Moments, MoM, boundary integral solver is coupled to a physical optics solver. In time domain an unstructured finite element method is coupled to a finite difference method. The underlying idea of the hybrid methods is to take advantage of the strengths of the individual methods without suffering from their weaknesses and thereby substantially increase the spectrum of solvable problems.



Surface currents on a horizontally polarized L-Band Cassegrain reflector antenna simulated with the efield® multilevel fast multipole method (illustration from Efield AB).

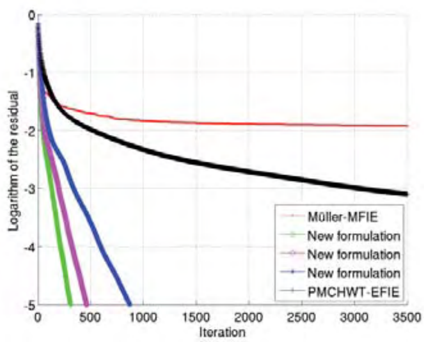


Surface currents on Eikon, modeled as a metallic object with radar absorbing material on the leading edges, after a radar pulse has hit the aircraft. A multilevel fast multipole method (MLFMM) has been used.

Improved integral formulations for dielectric bodies in MLFMM

In the frequency domain solver, the integral formulation for dielectrics is very ill-conditioned. This is a problem in particular when iterative methods are used since the iterative process converges slowly if it converges at all. This is of crucial importance since this fact limits the use of the fast multipole method to problems with only perfect electric conductors. In a project earlier funded by the industrial consortium STM alternative integral formulations have been investigated.

A particularly challenging problem is to combine dielectric material with metal. Below the bistatic radar cross section for the UAV Eikon with radar absorbing material on the leading edges is presented. Results for the old solver based on the Rumsey reaction formulation (PMCHWT) are compared to results for which the PMCHWT formulation is combined with the Müller formulation. The old implementation suffered from a non-optimal scaling of the equations. Furthermore, a careful analysis of eigenvectors and eigenvalues lead us to a novel combination of equations in the Müller formulation. As seen in the figure the effect on convergence is dramatic.



Comparison of bistatic radar cross section for the UAV Eikon with radar absorbing material on the leading edges computed by the two standard formulations and the new solver based on an improved integral formulation, respectively.

Fluid Dynamics

To be able to predict and optimize product development and manufacturing processes are major competitive advantages in industry. For industrial systems such as papermaking, energy production or paint shops understanding the physics of fluid dynamics holds one key to drastically improving the process with respect to production speed, environmental impact, production cost and product quality.

Although single phase fluid flow has many scientifically challenging questions that are still open, flows in industrial systems often include complications such as the presence of more than one phase, interactions between the fluid flow and its boundaries or some other direct link connecting the flow solution with the solution of a different problem. These aspects of CFD – multiphase flow, free surface flows, fluid structure interaction and flow with multiphysics coupling respectively, are the main interests and core competences of the CFD group at FCC.

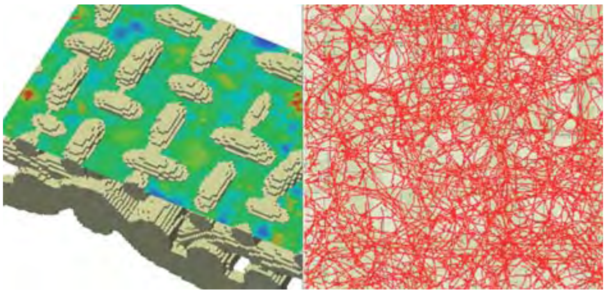
Our activities during 2008 within the CFD field have concerned paint and surface treatment processes in the automotive paint shop, papermaking and filters. Much of the work has been devoted to further development of the in-house flow solver IBOFlow (Immersed Boundary Octree Flow Solver). The solver is essentially mesh free in that surface descriptions of the flow boundaries are the only requirements to run a simulation. IBOFlow is designed for complex applications with feautures such as multiphase and free surface flows, and moving and interacting bodies.

In several projects we have a close collaboration with the departments of Transport Processes and Flow and Material Simulation at our partner Fraunhofer ITWM.

Poseidon, *a statue by Carl Milles erected in 1931, is in the centre of Götaplatsen, surrounded by the City Theatre, the Museum of Art (picture background), and the Concert Hall. The Avenue between Gustav Adolfs Torg (page 14) and Götaplatsen is the main esplanade of the city.*

Paper forming simulations

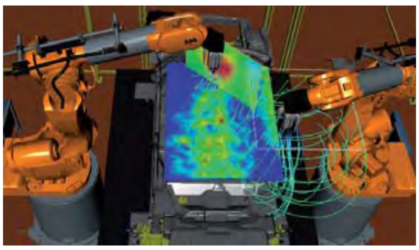
FCC has, together with Albany International and Fraunhofer-ITWM continued the investigations of the influence of the forming fabric on the initial stages of paper formation. Virtual representations of four different fabric types have been subjected to a flow of water with immersed cellulose fibres, where the fluid phase is modelled as laminar water flow and the fibres are modelled using a ball-and-spring approach; this allows for moderate fibre flexibility and a natural curl of the fibres. The results indicate differences between the surface characteristics of the formed paper depending on the geometrical properties of the fabric. In 2009, FCC deepens its engagement in papermaking simulations, initiating a larger development project for modelling and simulation of paperboard quality.



The cut plane shown in the left image represents velocity differences between undisturbed flow and flow with fibres around and onto a specific forming fabric. The laydown pattern on the same simulation case is shown to the right.

Virtual Painting

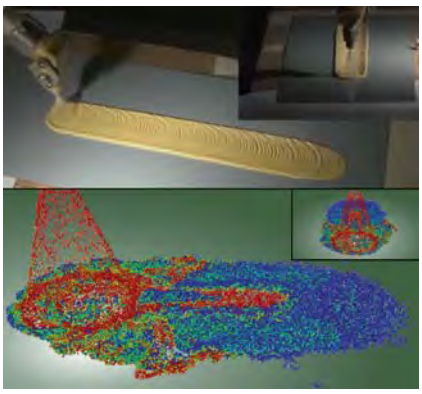
During 2008, FCC has continued to develop tools for predicting quality in the processes of the automotive paintshop. In a Vinnova project in collaboration with SAAB Automobile, Volvo Car Corporation, and the Industrial Research and Development Corporation (IVF), FCC has taken important steps towards a more complete virtual description of the paintshop. In recent years FCC has developed models and simulation tools for predicting paint thickness in robotized paint application, especially for the technically advanced and physically challenging paint process using rotary spray bell applicators. In 2008 development has continued with improved models, speed up of computations and integration of the flow solver into the path planning tool IPS. During 2009, spray painting and sealing software demonstrators are finalized and further process steps in the automotive paintshop are approached.



Snapshot from a transient simulation of a car roof in a spray box with two ESRB applicators. The thickness of the wet paint film is illustrated by the colouring of the target, where blue represents little or no paint and red represents a thick paint film. Electrostatic field is illustrated by the cutting plane at the leftmost paint robot and the electrostatic field lines surrounding the rightmost robot. Paint droplet paths are shown between both applicators and the target (courtesy of Volvo Car Corporation).

Sealing

Another important process in the automotive paintshop is the application of sealing material. This is done for instance in order to dampen noise or to cover cavities where moisture otherwise can create a corrosive environment. The sealing application is similar to painting in that moving robots apply a liquid material to the target (car body), but different in that the influence of air flow on the transfer of coating material is negligible. Instead the process is complicated by the flow of material on the target surface, as the applied material normally is thick compared to what is common in painting – thickness ranges are normally in the order of millimetres instead of micrometers – the sealing material is moving after impacting on the target surface and forming a liquid film. Physically this represents an extra challenge, especially since the rheology of the sealing material is complicated. Not only the viscosity of the material depend on the local shear stress; the sealing material form and break complicated structures on the molecular level over relatively long time-scales, which means that the viscosity will depend on the history of shear stress of that particular element of sealing liquid. FCC has solved this problem by implementing a Smoothed Particle Hydrodynamics (SPH) module in IBOFlow. In this approach to solving the Navier-Stokes equations for incompressible flow the grid points are allowed to flow freely with the fluid. This facilitates tracking free surfaces in the flow and also is a great advantage in that shear history for each fluid element (grid point) can be retained. The model for sealing rheology is based on a Bingham fluid equilibrium viscosity combined with a first order differential equation to account for the thixotropy of the material.



Early comparison between lab tests and simulation results of hollow cone nozzle sealing spray. The simulation nodes in the SPH model shown in the bottom image are coloured by viscosity; red signifies low and blue high viscosity (courtesy of Volvo Car Corporation).

Optimization

In the last decades the engineering sciences have seen a massive breakthrough of computer assisted methods. This enables the use of simulations for virtual testing of products and processes prior to expensive physical testing and validation which, in turn, opens the door for applying modern optimization techniques in the design process. Mathematical optimization methods, tailored for specific application areas and customer demands on precision and robustness, provide efficient search strategies, which improve this process. In many applications trade-offs between different criteria such as costs and quality indicators are necessary.

Together with our colleagues at the Optimization department at Fraunhofer ITWM the department focuses on:

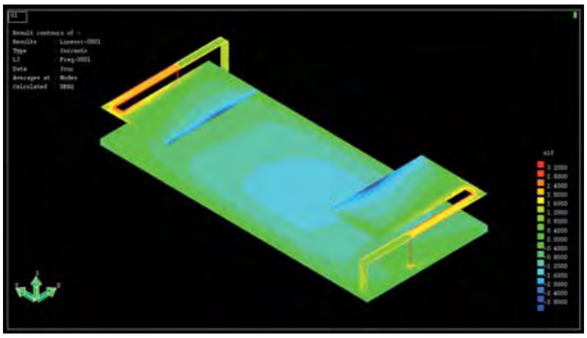
- Development and implementation of optimization algorithms for best possible solutions

- Integration of simulation and optimization software

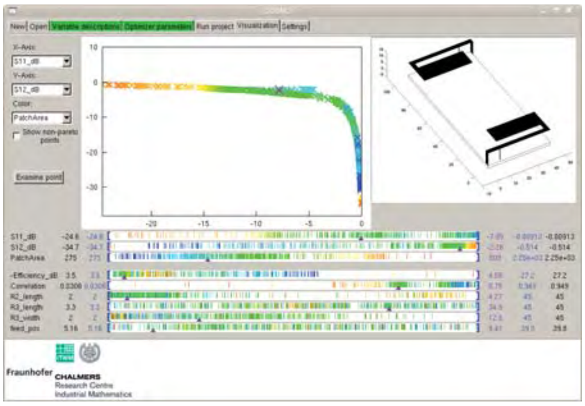
- Development and implementation of decision support systems that integrate multiple criteria optimization and simulation

A highlight during 2008 has been the development of novel efficient optimization algorithms and a decision support system for optimal antenna design in a project funded by GMMC. A licentiate thesis was successfully defended by our industrial PhD student Peter Lindroth and a project on multi-objective optimization of hot rolling was initiated with ABB Corporate Research.

The original East Indiaman "Götheborg" *ran aground at the entrance to Göteborg on the 12th September 1745 after her third voyage to China. After a fundraising campaign the Svenska Ostindiska Compagniet (SOIC) was established in 1993 to build a copy of the old ship. The launch took place in 2003 and the expedition to China started in October 2005 (photo). This time the Götheborg arrived safely home, in June 2007, after a voyage of 32,500 nautical miles.*



Surface currents at 775 MHz on the MIMO antenna system for the design with best efficiency. The efield® method of moments solver has been used.



Snapshot of COSMO - a decision support system for antenna optimization.

Multi-objective antenna optimization

The performance of antenna systems is highly dependent on the received signal levels and also on the correlation between different signals. Also, from a radio-engineering point of view, there are limitations on the scattering parameters of the design. Further, the antennas also need to share space with other devices on the platform, which adds requirements on the size of the antennas. All these aspects often lead to conflicting requirements, which traditionally are dealt with by weighting the different requirements into a single requirement. The trial-and-error approach of setting those weights has many disadvantages, and multi-objective optimization provides a better insight in possible trade-offs.

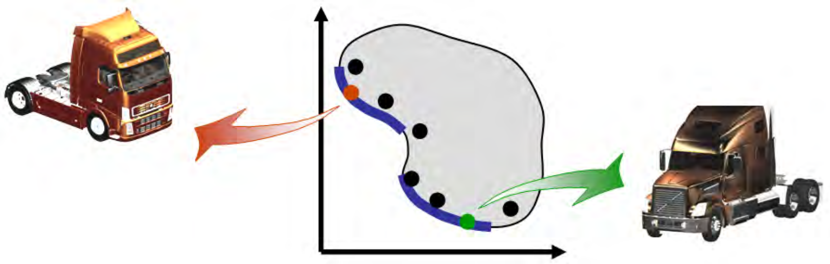
We have developed an optimization algorithm based on approximation with radial basis functions. A challenge in antenna optimization is that the objective functions based on scattering parameters often have sharp gradients close to optimas. Much effort has been spent to further develop RBF-based algorithms that can accurately interpolate such functions. The algorithms are coupled to CAD and mesh generation software, and the efield® electromagnetic solvers.

In the project which was performed in co-operation with GMMC and the Antenna Research Centre at Ericsson, we developed a prototype of a decision support system for optimization of MIMO (multiple input multiple output) antenna systems. The prototype offers visualization in a database of Pareto optimal antenna designs.

Product configuration with respect to multiple criteria

The industry is increasingly characterized by specialization and customization; specifications and equipment must be tailored to suit each particular service task. The main focus is on optimizing product features to give each customer the best product with respect to effectiveness, safety, quality and environmental impact – all with the intention of minimizing product lifetime costs. Therefore many products are available in an enormous number of variants in order to fulfill these demands on features and different missions, operating environments, and product utilizations. Beside these demands the product must fulfill internal company demands that secure an efficient development and manufacturing process.

In cooperation with Volvo 3P the PhD student Peter Lindroth is developing a framework for finding optimal sets of truck configurations. The problem of deciding "what is a good product configuration" (i.e., design solution) for a certain purpose has multiple criteria, and the goal for the production and sales is typically formulated as the maximization of safety, transport efficiency, quality, diving performance, and environmental friendliness. The project contains theoretical and applied studies on, amongst other things, optimization with a large number of objectives, on Pareto set approximation, on simulation-based optimization, and on robust multi-objective optimization. The areas are tackled both generally and with a specific focus on the truck configuration problem.



Different operating environments and transport missions imply different functional requirements. For each reasonable requirement Volvo wants to have a truck configuration available.

Reliability and Risk Management

Understanding the impact of uncertainty and quantifying and managing risk to secure and optimize reliable operations, products, and systems are important issues for most industrial and societal sectors.

The department develops mathematical models of products and processes, emphasizing a sound balance between model complexity, uncertainty, and optimality, providing key competences in mathematical statistics and stochastic processes.

Our focus is on fatigue life and load analysis of mechanical systems. We have primarily addressed automotive and related applications, as illustrated by some examples of industrial projects. Within the Gothenburg Mathematical Modelling Centre (GMMC) we have started a new line of research: marine safety and ocean climate

Fatigue Life and Load Analysis

Many failures of engineering structures are caused by the fatigue of metals. Numerical solvers of partial differential equations can calculate mechanical stresses and strains into great detail. However, the knowledge of the actual loads on the structure in service is usually very vague. In addition, fatigue damage must be predicted for the whole specified service life of the structure. Lacking detailed information about material imperfections and geometry, the engineer is forced to use simple empirical models for the fatigue damage evaluation, and compensate by large safety factors, which unfortunately often are based on experience and not rationalized in a robust way. Statistical methods are needed for a rational development of sound safety factors based on both measurements and on historical experience.

Marine Safety and Ocean Climate

This area is in its start-up phase within GMMC. There we plan to develop methods for ship routing which minimizes the risk of fatigue failures and fuel consumption. For this we model the variability of the loads that cause damaging during a trip, investigate damage mechanisms at different locations of the structure, and develop methods to predict the damage from indirect measurements. A further problem is to model uncertainties in sea weather predictions used for planning ship routes.

Contact
Dr Uno Nävert
Phone +46 31 7724285
uno.navert@fcc.chalmers.se

Gamlestadens fabriker *hosted textile industry when Sven Wingquist was employed as operating engineer in 1899. In 1906 he was granted a patent for the single-row self-aligning ball bearing, thus laying the ground for SKF, founded 1907, now a world-wide operating company. A few years later, in 1911, the name Volvo was registered, as a separate company within SKF.*

Cooperation

We collaborate closely with Chalmers Mathematical Sciences, Fraunhofer ITWM, and SP Technical Research Institute of Sweden.

Acknowledgement

In 2008 the department has received funding from the Swedish Foundation for Strategic Research, SSF, through the Gothenburg Mathematical Modelling Centre, GMMC.

The Reliability and Risk Management Research Group

- Pär Johannesson, PhD, Fatigue Life and Load Analysis
- Sara Lorén, PhD, Fatigue Life and Load Analysis
- Roland Jakobsson, MSc student
- Yun Niu, MSc student
- Mattias Ohlsson, MSc student
- José Sanchez, MSc student
- Ralf Korn, Professor, University of Kaiserslautern / Fraunhofer-ITWM, Scientific Adviser at FCC
- Jacques de Maré, Professor in Mathematical Statistics at Chalmers, Scientific Adviser at FCC
- Igor Rychlik, Professor in Mathematical Statistics at Chalmers, Affiliated expert at FCC


Pär Johannesson


Sara Lorén


Roland Jakobsson


Yun Niu


Mattias Ohlsson


José Sanchez


Ralf Korn


Jacques de Maré


Igor Rychlik

Fatigue Life

Fatigue from a Statistical Point of View

The strategy of the fatigue group is to develop new methods for reliability and fatigue assessment in industrial practise. Statistical methods can help to build a complete picture of the reliability of mechanical constructions with respect to fatigue resistance and load conditions, and hence show where it is most efficient to take steps to improve the quality of a product. Within this overall perspective, the FCC fatigue reliability group in particular focuses on the following areas:

- *Modelling of fatigue life.* We develop and make use of statistical methods for fatigue life prediction for spectrum loads, as well as methods for estimation of the fatigue limit, especially in connection to defects.

- *Analysis of service loads.* We use the theory of stochastic processes, rainflow count analysis, and work on questions concerning on-board logging, acceleration of fatigue tests, and the relation between laboratory tests and service loads.

- *Reliability and robust design.* The load and the strength variables may be combined in a statistical reliability approach, where the design targets can be evaluated.

- *Automotive and oceanographic applications.* The main focus of our interest has been on the automotive industry, and its suppliers. However, we are currently making efforts in off-shore and ocean applications, where Professor Igor Rychlik is an expert.

Scientific projects

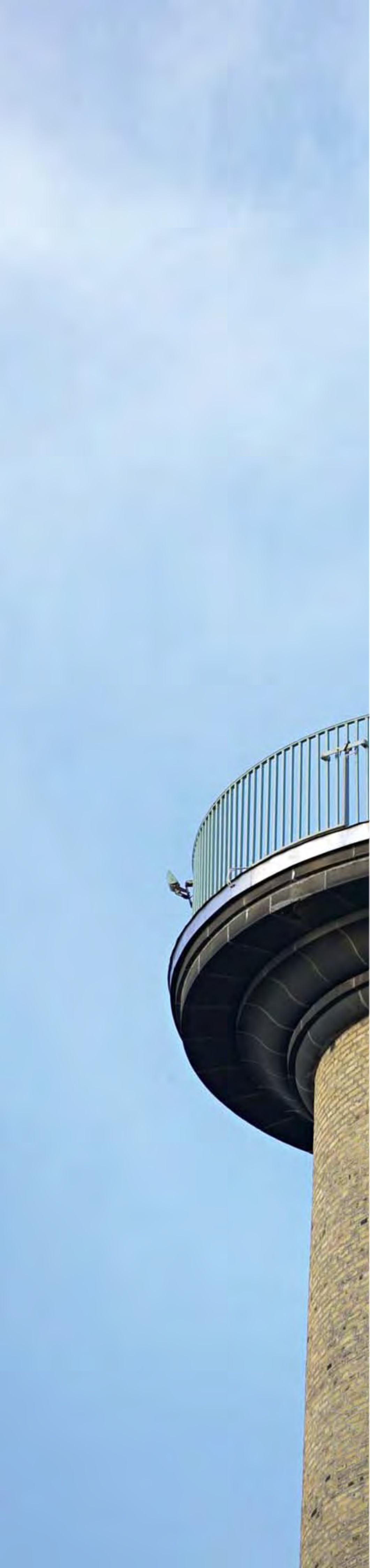
Since 2006 the group participates in one part of the Gothenburg Mathematical Modelling Centre (GMMC). The work aims at merging different reliability tools into a common framework, useful for industrial practice, which will be published as a Wiley book.

Industrial projects

Two projects have dominated our work during 2008, namely the three-year project to write a Guide to Load Analysis for the six European truck manufacturers, and a project for SKF regarding analysis of the fatigue strength of bearing steel.

Contact

Dr Pär Johannesson
Phone +46 31 7724295
par.johannesson@fcc.chalmers.se



Kvinna vid havet *by Ivar Johnsson was erected in 1933 in memory of the Swedish seamen who passed away during the First World War. With its height of sixty meters this statue is the tallest monumental sculpture in Sweden.*

Guide to Load Analysis for Automotive Applications

The goal of this three-year project that started in 2007 is to develop a Guide to load analysis, especially oriented towards truck applications. The guide will provide a toolbox of useful methods within different areas of load analysis. This project is run by FCC, with Dr P Johannesson as the project leader, in collaboration with SP Technical Research Institute of Sweden, Mathematical Sciences at Chalmers, and Fraunhofer ITWM. The project is financed by the six European truck manufacturers, namely DAF, Daimler, Iveco, MAN, Scania, and Volvo.

Development of the Guide

The task of the project is to write a Guide to Load Analysis for Automotive Applications, following the structure; Part I, Introduction; Part II, Methods for load analysis, focusing on describing useful methods and indicating how and when they should be used; Part III, Load analysis in view of the vehicle design process, focusing on the work process, starting by describing the customer load distribution, from which design load specifications are derived, and finally validation of systems and components.

The durability specifications of trucks depend on the transport mission. The timber truck in the picture needs to be designed to sustain very high loads.

The design specifications within the automotive industry are to a large extent based on testing and measuring loads on test tracks (courtesy of Volvo).

Results

Each year a report is written, which step by step builds up the full Guide. Further, every year a seminar will be given at each company with the aim to introduce the Guide. The result of this year is the completion of Part II, Methods for load analysis, with contents

- *Basics on load analysis,* which contains three sections; cycle counting methods, where only the configuration of the local extremes are of importance, and describing for example the rainflow cycle counting procedure; frequency based methods, where the spectral properties are considered; and methods for multi-input loads, where the problem of multiple dependent signals are treated.
- *Load editing and generation of time signals,* which treats methods for correction of measured data, acceleration of tests, editing of the loads information, and generation of loads signals with prescribed properties.
- *Models for random loads.* A measured load signal can be viewed as an outcome of random process, where Gaussian and Markov loads are appropriate models. The variability of random loads is central, and the uncertainty of the damage potential is studied, which is needed in order to know how long field measurements are appropriate.
- *Response of mechanical systems.* The external input loads to the truck is typically the road. The modelling of the mechanical system, by FEM (Finite Element Method) and MBS (Multi Body Simulation), is reviewed.
- *Load variation and reliability.* Methods for reliability assessments in the truck application are discussed, especially in connection to the overall load variability. It is recommended that the classical safety factor approach should be partly replaced be a load-strength model that is based on only mean and variance of the influential variables, which corresponds to the available information in a typical engineering application.

Fatigue Limit and Inclusions

Many fatigue properties of materials are governed by defect contents in the material, either at the surface, or in the interior. Especially for hard steels the fatigue limit is coupled to the size distribution and the intensity of non-metallic inclusion. According to the Murakami $\sqrt{area_{max}}$ -model, the fatigue limit depends on the square root of the maximum inclusion size perpendicular to the applied stress. One way of estimating the fatigue limit distribution, is to use the detrimental inclusion size distribution together with the $\sqrt{area_{max}}$ -model. If the stress distribution in the component is homogeneous, the largest inclusion is the detrimental one. However, if the stress distribution is inhomogeneous, the detrimental inclusion is not necessarily the largest one, but can be a smaller inclusion exposed to a higher stress.

The distribution of the maximum inclusion size in a material may be estimated in three different ways, namely

1) by polishing the surface and measuring the inclusion size, either the maximum size in a small control area or all inclusion sizes over a threshold, see figure 1.
2) by fatigue tests, where the detrimental inclusion is experimentally found, see figure 2 and
3) by ultrasonic tests, where the inclusions in a scanned volume may be observed, and their sizes measured.

During the last years the fatigue group has mostly worked with the first two methods above. During the last year we have started to work with analysing the result from ultrasonic test and thereby also incorporated image analysis.

In the polishing method two different ways of analysing the inclusions are possible as mentioned above. The first one divides the total inspection area into a number of control areas, where the maximum inclusion sizes in each control area are fitted to a Gumbel distribution, which is used for extrapolation to the reference area. The second method uses all inclusions in the total inspection area with sizes above a certain threshold. The overshoots of the inclusion sizes above the threshold are fitted to an exponential distribution, which is used for extrapolation to the reference area, see figure 3. For both of these methods the result is a Gumbel distribution for the maximum inclusion on a two-dimensional surface, and has to be transform to the maximum inclusion distribution in a three-dimensional volume.

For the ultrasonic test a volume is analysed instead of a two-dimensional surface. The transformation to the volume needed for the method in 1) is then not necessary. To be able to see the inclusions in a binary image from the ultrasonic scan, a suitable transformation of pixel values, spatial smoothing and thresholding has to be done. After the extraction of the observed inclusion size, either of the two ways of analysing the result can be applied.

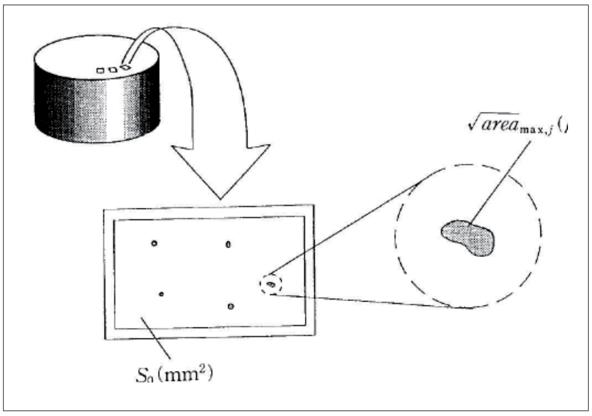


Figure 1. Detection of the maximum inclusion in a control area S0.

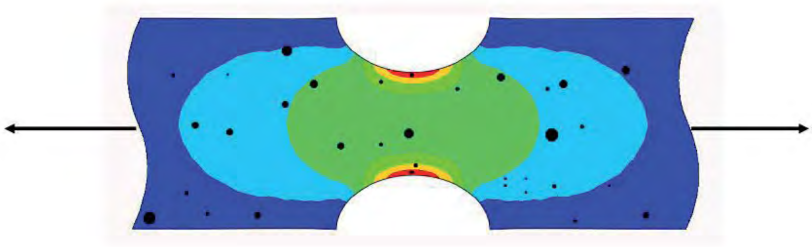


Figure 2. Fatigue test, where the detrimental inclusion is experimentally found. The largest inclusion need not be the most detrimental one, since the local stress may be small, in this example blue.

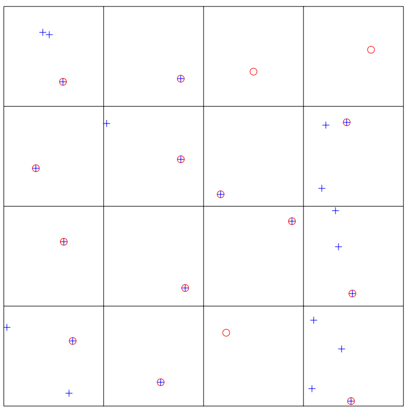


Figure 3. Total inspection area, which is divided into 16 equally sized inspection areas of 150 mm2. The largest inclusion in each control area is marked by 'o', and the inclusion which are larger than the threshold size of 15 µm are marked by '+'.

GMMC Reliability

Since 2006 the group has participated as one part of the Reliability group within the Gothenburg Mathematical Modelling Centre (GMMC). The work aims at merging different reliability tools into a common framework, useful for industrial practice. The main work during 2008 has been the book "Robust design methodology for reliability – exploring the effects of variation and uncertainty", which is scheduled for publication by Wiley in the second half of 2009.

Unreliability is caused by Variation

The Failure Mode and Effect Analysis, FMEA, is often used in industry for reliability assessments. Studies of FMEA have indicated that the failure modes are trigged by unwanted variation. As a complement, or possibly, as a replacement of FMEA we suggest an enhancement of that technique what we call Variation Mode and Effect Analysis, VMEA. The VMEA takes the quantitative measures of failure causes into account. The VMEA method is presented at three levels of complexity, basic, enhanced and probabilistic. The basic VMEA can be used when we only have vague knowledge of the variation. The sensitivity and variation size assessments are made by engineering judgement and are usually made on a 1-10 scale. When we can better judge the sources of variation the enhanced VMEA can be used. The probabilistic VMEA can be used in the later design stages where we have more detailed information in terms of for example material data, finite element models, and physical experiments.

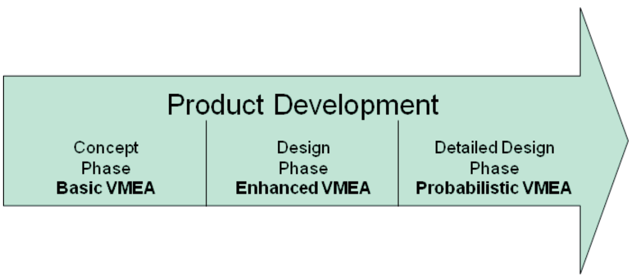
Participants at the Robust construction for improved reliability seminar on April 17, 2008.

Marine Applications

Within GMMC we are working on modelling of the fatigue damage accumulation at hot spots in ships. Such models are needed when designing routing programs. Here we are applying both statistical analysis of measured signals and the hydrodynamical computations of ship responses. Two PhD students are engaged in the project: one employed at Chalmers Mathematical Sciences and one at the Chalmers Department of Shipping and Marine Technology.

Robust Construction for improved Reliability

This seminar took place in Chalmers Science Park in April 2008. The program included eight talks from industry and academia. The seminar gathered seventy participants from fifteen companies. The seminar was jointly arranged by FCC, GMMC, and SP/UTMIS.



Master projects

Yun Niu is writing her master thesis on statistical description of whippings contribution to the extreme responses and fatigue damage accumulation of a container ship sailing the North Atlantic route. Whippings are high frequency oscillations superimposed on the wave induced stresses. Although the energy in the whippings frequency band is small, about 1%, the non-linear nature of this phenomenon can have an huge impact on the design stress related to the so called 100 years stress. We expect to get some answers to this question in the thesis. The work is done in cooperation with Det Norske Veritas.

In December a master thesis project within Engineering Mathematics with José Sanchez was initiated. The project aimes to investigate the possibility to use the standard on board logging system at Volvo Trucks to predict the residual fatigue life.

Also a master thesis project together with Volvo Bus started with Mattias Ohlsson and Roland Jacobsson, master students at Chalmers. In the project the fuel consumption of buses will be studied. The aim is to be able to predict how the future consumption of a bus depends on its equipment, e.g., engine, transmission, AC-system, and speed control.

Geometry and Motion Planning

Many products such as car and truck bodies, engines, medical prosthesis, mobile phones, and lumbering equipment depend visually and functionally on its geometry. Since variation is inherent in all production, consistent efforts in styling, design, verification and production aiming at less geometrical variation in assembled products is necessary to achieve easy-to-build high-quality products. Also, the demand on short ramp up time and throughput in the manufacturing industry increases the need of effectively generate and visualize collision-free and optimized motions in the assembly plant. During 2008 the department of Geometry and Motion Planning have successfully developed methods, algorithms and tools supporting these activities within two main subjects

- Geometry Assurance
- Path planning and Robotics

In particular, the FCC software tool Industrial Path Solutions for automatic path planning of collision-free motions has been successfully used by our partners in the automotive industry to solve geometrically complex manufacturing problems in mere minutes instead of hours or days. The strength of the mathematical algorithms in combination with the easy user interface has allowed the path planning technology to be spread outside the expert teams of simulation engineers. The IPS path planning technology is now also part of the master education in virtual production at Chalmers.

An industrial and scientific challenge of car body manufacturing is to guarantee geometrical quality and factory throughput during spot welding. To solve this problem FCC has started to develop algorithms integrating line balancing, sequencing and coordination of operations with our path planning technology, see Virtual Geometry, Path Planning and Station Logic.

Today, many assembly problems are detected too late in the product and production realization, involve cables, hoses and wiring harness. The reason for this is the lack of virtual manufacturing tools supporting real time simulation of flexible parts and motions. The FCC technology developed together with ITWM has been successfully implemented as a IPS Cable Solver module, see Simulation and Path Planning of Flexible Parts.

Contact
Dr Johan Carlson
Phone +46 31 7724289
johan.carlson@fcc.chalmers.se

The Älvsborg Bridge *is a 418 meters suspension bridge, 933 meters in total, across Göta Älv connecting central Göteborg with the island Hisingen hosting industries such as Volvo Cars and Volvo Trucks. The bridge was officially inaugurated in 1966 and the 107 meters tall pylons make it one of Göteborg's most prominent landmarks. The Bridge was the finish line for the 2005 – 2006 Volvo Ocean Race and is one of the two bridges that the more than 50.000 participants of the Göteborg Half Marathon have to cross during the race.*

Cooperation and acknowledgement

During 2008, the successful collaboration with Wingquist Laboratory Vinn Excellence Centre has continued with Geometry and Motion Planning as one of its major research groups. Also the collaboration with the Industrial Research and Development Corporation (IVF), and the ITWM departments Dynamics and Durability and Image Processing, has grown by working together on common projects.

In 2008, the Geometry and Motion Planning group has received substantial funding from Vinnova and the Swedish Foundation for Strategic Research.

The Geometry and Motion Planning Research Group

- Johan Carlson, PhD, Vice Director FCC, Head of Department
- Robert Bohlin, PhD
- Fredrik Ekstedt, Lic
- Thomas Hermansson, MSc Engineering
- Daniel Segerdahl, MSc Engineering
- Domenico Spensieri, MSc Engineering
- Sebastian Tafuri, MSc Engineering
- Johan Torstensson, MSc Engineering
- Fredrik Andersson, contracted student
- Ludwig Andersson, contracted student
- Christian Bengtsson, contracted student
- Kristoffer Hahn, contracted student
- Babak Saboori, contracted student
- Behzad Saboori, contracted student
- Gustav Eek, MSc student
- Christer Eriksson, MSc student
- Johan Segeborn, MSc Engng, Volvo Cars, PhD student
- Rikard Söderberg, Professor in Product and Production Development at Chalmers, Director Wingquist Laboratory, Scientific Adviser at FCC


Johan Carlson


Robert Bohlin


Fredrik Ekstedt


Tomas Hermansson

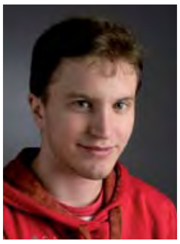

Daniel Segerdahl


Domenico Spensieri


Sebastian Tafuri


Johan Torstensson


Fredrik Andersson


Ludwig Andersson


Christian Bengtsson


Kristoffer Hahn


Babak Saboori


Behzad Saboori


Gustav Eek


Christer Eriksson


Johan Segeborn


Rikard Söderberg

Geometry Assurance

Geometry-related quality problems are often discovered during the assembly process when parts are about to be assembled and do not fit as expected. Often the reason is geometrically sensitive product and production concepts that have not been verified enough due to lack of powerful analysis tools. A design or production change at this stage is very costly and does almost always result in delays in market introductions with lost revenue as a consequence. Therefore, FCC in cooperation with the Wingquist Laboratory at Chalmers and the Swedish Institute of Production Engineering (IVF) operates to support a systematic reduction of variability in processes and products in the following key areas:

- Robust design and variation simulation
- Inspection planning preparation and optimization
- Statistical process control and root cause analysis

The Göteborg Opera, *designed by the architect Jan Izkowitz, was inaugurated in October 1994, with the Swedish opera Aniara. The 160 metres long, 85 metres wide, and 32 metres high building was erected with financial help from more than 6,000 contributors and 400 donators.*

Robust Design & Variation Simulation

The key idea behind Robust Design is to make the product as insensitive to variation or disturbance as possible, to make it withstand potential uncertainties in the manufacturing process or changes in the operating environment. We use statistical Monte Carlo simulation, sensitivity analysis and contribution analysis from our partner RD&T Technology to make the product insensitive to manufacturing and assembly tool variation. This reduces the need for costly physical prototypes and test series, see figure 1.

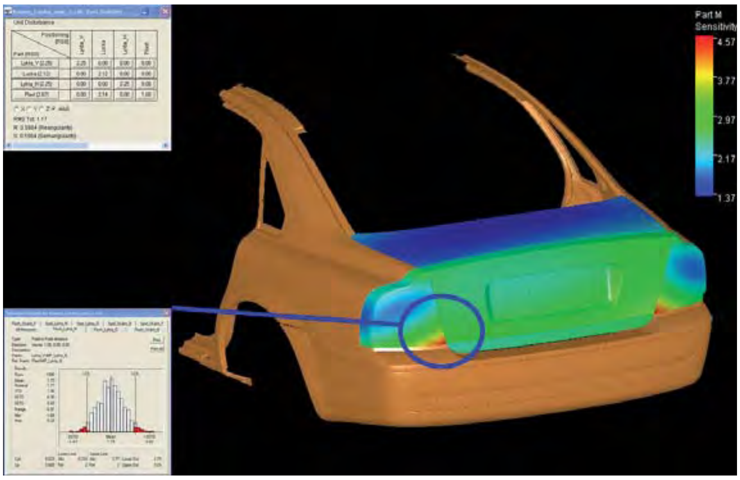


Figure 1. Colour Coding, based on sensitivity analysis, of the Volvo S80 Car Body. Areas sensitive to dimensional variation are indicated with red colour (courtesy of Volvo Car Corporation).

Inspection Planning and Analysis

Inspection planning refers to the activity to gather information about variation in individual parts, processes, assemblies and assembly equipment, in order to control the manufacturing process and to be able to give feed-back to a number of activities in the geometry assurance process. Today inspection planning is almost always solely based on experience and can be improved significantly by using mathematical and statistical analysis. We develop methods and support tools for intelligent inspection preparation. The motive is to gather as much information about the product and the process as possible with minimum number of inspection points, see figure 2.

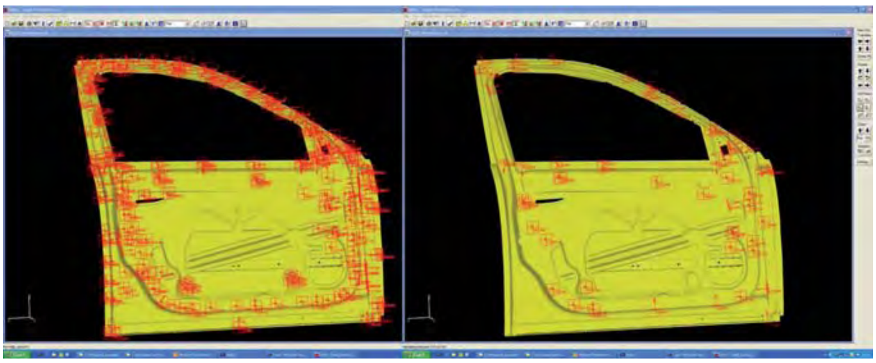


Figure 2. Inspection point reduction in action on car body door (courtesy of Saab Automobile).

Statistical Process Control and Root Cause Analysis

Today routine measurements in the industry are often made on-line during the production process. Statistical process control (SPC) is a set of quality tools aimed at reducing variability utilizing these measurements. For manufacturing processes of simple parts, patterns on a control chart may provide enough diagnostic information to an experienced operator to pin point the root cause. However, experience shows that many SPC attempts fail to produce meaningful results because the lack of diagnostic support for the effort. Therefore, we develop statistical methods to make root cause analyses on the product to find and correct problems in the manufacturing and assembly process. The motive is fast identification and correction of problems and increased knowledge about product/process correlation, see figure 3.

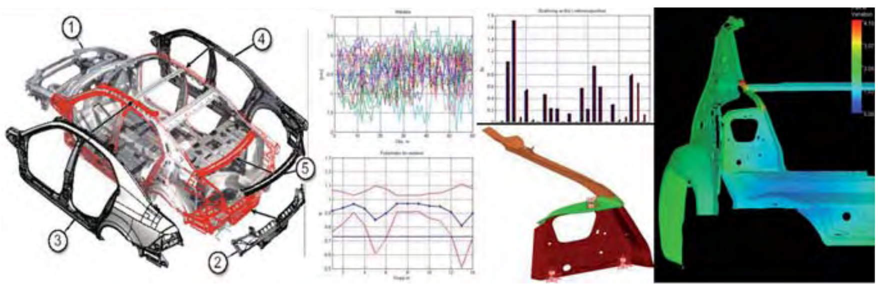


Figure 3. A multi-fixture assembly where a number of parts are assembled. From left to right: Assembly, production data, multivariate statistical process control, root cause analysis, assembly fixture fault, simulated effect of correction (courtesy of Saab Automobile).

Path Planning

Automatic Path Planning for Rigid Bodies and Industrial Robots

Despite that modern industries use virtual prototypes to replace physical prototypes, visualize assembly processes and program industrial robots off-line, the full potential of the virtual factory is not reached. Programming of motions and paths for robots and equipment is still done manually, since the existing support for automatic path planning is very limited. Another limitation is the geometrical accuracy between the virtual model and the physical reality. Therefore, geometrical tolerances need to be considered during path planning. This is a first step, going from nominal to production adapted virtual models and hence connecting the production loop including styling, design and manufacturability.

Virtual verification of that products can be assembled and later on disassembled for service purposes is an important part of geometry simulation in the manufacturing industry. Methods and software for automatically generating collision free assembly paths are therefore of great interest. Also, off-line programming of robots and coordinate measurement machines used in the factory lead to hard problems for the simulation engineer when trying to manually find collision free paths between points, with that of minimizing cycle time and joint wear. Therefore, FCC operates to support the following path planning applications:

- Assembly visualization / verification/design
- Assembling with robot
- Welding and sealing
- Coordinate measurement machine
- Load balancing, sequencing and coordination of robot operations

The Major canal. *When Göteborg was founded in 1621 the city was heavily influenced by the Dutch and Dutch city planners were contracted to build the city as they had the skills needed to build in the marshy areas around the city. The Major canal, inaugurated in 1622, and several other canals where built after Dutch blueprints; the blueprints for the canals of Göteborg are actually the same as those used for Jakarta. In the beginning of the 20th century many of the canals were filled up to become streets.*

Assembly Visualization/ Verification/Design

This project with our partner Volvo Car Corporation has resulted in simulation software for automatic path planning, viewed in figure 1. The software is based on a virtual 3D model describing the kinematics and the geometry in the assembly cell, interacting with a collision tester.

For small sub-assemblies as well as final assemblies, simulations give valuable support when evaluating new concepts and comparing alternative solutions. Also different assembly sequences can be compared and verified. As a result, product functionality and manufacturability can be improved.

Assembling with Robot

In addition to collision avoidance and kinematic constraints, automatic robot programming involves minimization of cycle time, robot wear and joint forces. Efficient path planning and reachability analysis is also beneficial when comparing station layouts choosing robots and designing tools, grippers, and fixtures, see figure 2.

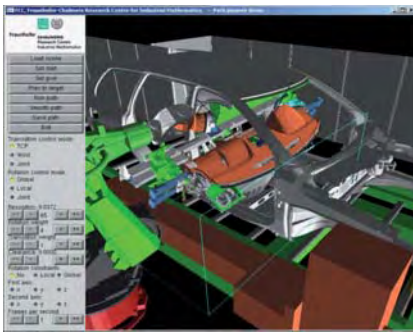


Figure 2. In this station, the driving unit is assembled into the car body. Due to the narrow door opening, the clearance is very small and programming without support from a path planner is difficult. This demo application developed by FCC finds a solution in 3 minutes (courtesy of Volvo Car Corporation).

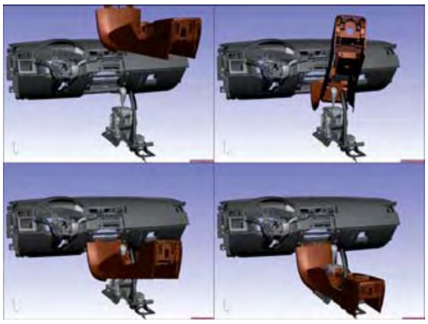


Figure 1. Is it possible to assembly the tunnel bracket? The FCC path planner finds a solution in less than 2 minutes. Even an experienced simulation engineer will struggle for days with this assembly verification (courtesy of Volvo Car Corporation).

Path Planning and Sealing of Car Body Seams

This project with our partner Volvo Car Corporation has resulted in simulation software for automatic path planning of Robotized sealing applications. In the sealing station, robots spray the sticky sealing mass along, for instance, spot welded seams. By covering the seams, dirt and water cannot come into the chinks and cause corrosion. The sealing also has a sound insulating effect. In the first step, the algorithm finds several different collision-free motions applying the sealing mass along each seam. In the second step, collision-free motions are generated in such way that an optimal sequence connecting one solution for each seam is obtained, see figure 3.

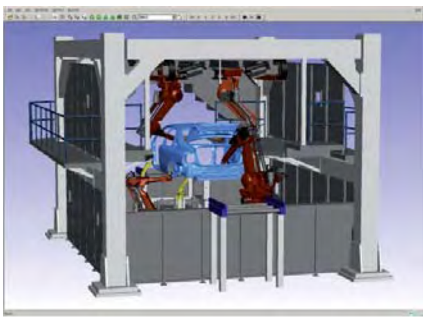


Figure 3. Automatic path planning and optimization of a sealing station (courtesy of Volvo Car Corporation).

Coordination/Interlocking of Multi-Robot Manufacturing Cells

In many manufacturing operations, e.g. spot welding of car bodies, several robots needs to share the same workspace. To coordinate and avoid collisions the robots are synchronized by defining interlocking points along the robot paths. At an interlocking point it is checked whether the program can continue without the risk of collision or not. If the risk of collision is present the program halts until this is no longer the case. Programming of interlocking points is today done on-line, as current simulation software lacks support for automatic generation and validation. This project with our partner Volvo Car Corporation has resulted in interactive software providing methods and algorithms for minimizing interlocking related time-loss through an efficient use of interference zones, see figure 4.

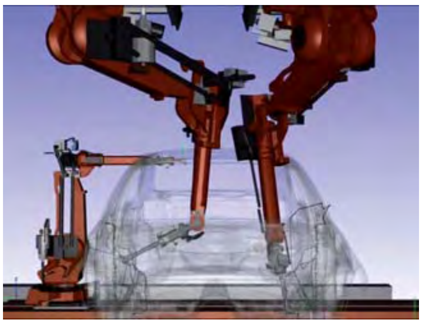


Figure 4. Where and when shall the robots wait for each other in order to avoid collisions and minimize cycle time (courtesy of Volvo Car Corporation)?

Virtual Geometry, Path Planning and Station Logic

This project is part of the Vinnova MERA program and is a collaboration project between Volvo Cars Corporation, AB Volvo, Saab Automobile AB, Scania AB, Semcon AB, Caran AB, Fraunhofer-Chalmers Centre, and Wingquist Laboratory at Chalmers.

The project goal is to create a cost-effective and quality-assured assembly process for complex products. Today, geometry assurance, robot path planning and line balancing are carried out partly manually and isolated with limited transparency.

Therefore, this project integrates variation simulation, path-planning, sequencing and line balancing with station logic to generate an integrated and cost-effective manufacturing process where product quality and cycle time can be evaluated and optimized for different product and production systems. A PhD student within Volvo Cars industrial PhD program is specially working with integration and interfaces between the three areas. The projects will in particular show how welding point locations and sequence affect auto-body quality and cycle time.

Results of the project are (i) An RD&T demonstrator with the capability to simulate the geometrical effect of welding order for non-rigid assemblies, (ii) An RD&T demonstrator for inspection point reduction with the capability of drastically reducing the number of inspection point with minimum loss of information, (iii) An IPS demonstrator with the capability to automatically load balance, sequence and find collision free motions of multi-robot welding stations, see figures 5-7, (iv) New strategies for how standard components should be developed and designed in order to facilitate automatic generation of PLC programs, (v) A physical demonstrator in our Robot and Automation lab at PPD, showing the integration of geometry assurance, path planning and station logic.

Figure 5. Task Planning. Find collision-free alternatives to perform each welding operation (courtesy of Volvo Car Corporation).

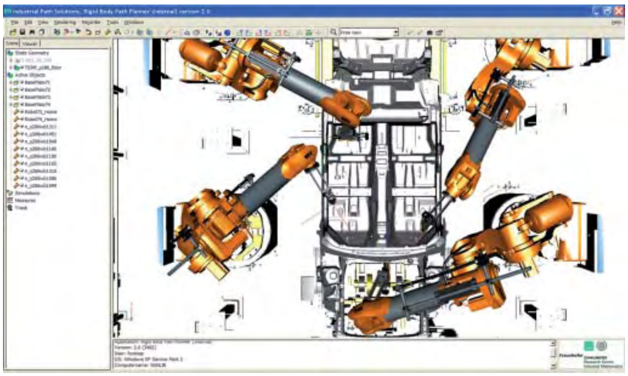


Figure 6. Station Load balancing. Distribute the welding operations between the robots to minimize the cycle time (courtesy of Volvo Car Corporation).

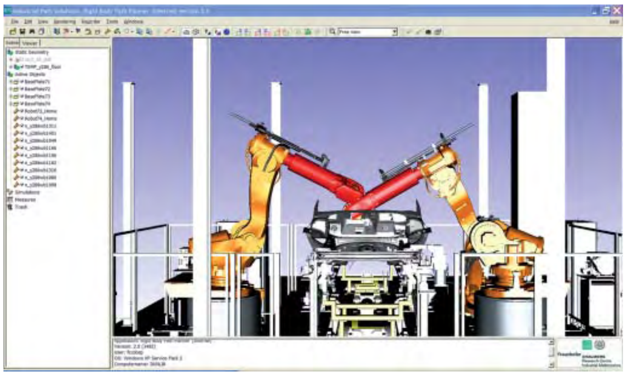


Figure 7. Sequencing and Path Planning. Decide in which order and with what alternative the robot should weld. Coordination. Decide where, when and how long a robot should wait on each other to avoid collision (courtesy of Volvo Car Corporation).

Fast and Memory Efficient Sweep Volume of Moving Parts

The swept volume is the space generated when a part is moved along a path. Such volumes have many applications in virtual prototyping, e.g. booking the volumes needed for different parts during an assembly operation or to find interference zones for multi-robot coordination. The sweep volume can be very complex since both the part geometry and motion can be complex.

Due to this complexity the computing time and the memory needed for generating and representing the volumes has been too large to be used in practice. In this project, FCC has developed and implemented a solution that meets the high demands of manufacturing engineering when it comes to computing time and complexity of geometry models, see figure 8.

Figure 8. An assembly path and corresponding swept volume (courtesy of Volvo Car Corporation).

Non-Nominal Path Planning

One important aspect in the assembly process design is to assure that there exists a collision-free assembly path for each part. To manually verify assembly feasibility in a digital mock-up tool can be hard and time consuming. Therefore, the recent development of efficient and effective automatic path planning algorithm and tools are highly motivated. However, in real production, all equipment, parts and subassemblies are inflicted by geometrical variation, often resulting in conflicts and on-line adjustments of off-line generated assembly paths. Therefore, we have developed a new algorithm and working procedure enabling and supporting a more cost effective non-nominal path planning process for assembly operations. The basic idea is to combine state-of-the-art technology within robust design and variation simulation with automatic path planning. By integrating variation and tolerance simulation results into the path planning algorithm we can allow the assembly path going closer to areas of low variation, while avoiding areas of high variation, see figure 9.

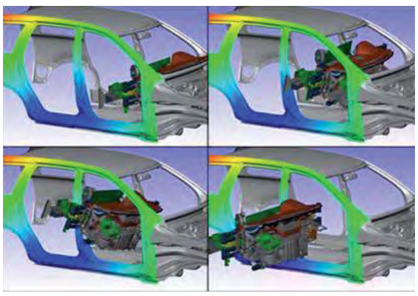


Figure 9. A driving unit assembly path taking results from variation simulation of the car body into account. Areas of high geometrical variation are avoided (courtesy of Volvo Car Corporation).

Simulation and Path Planning of Flexible Parts

The project Simulation and Path Planning of Flexible Parts is part of the Vinnova MERA program, and it is a collaboration project between Saab Automobile, Volvo Car Corporation, Delphi and FCC. The goal of the project has been to reduce the need for physical tests and hardware usage and instead use virtual tools for validation of compliant parts. Examples of compliant parts in the vehicle industry are air and fuel pipes, electrical cables/harnesses and robot hoses, see figures 10-12.

Figure10. Robot hoses (courtesy of Volvo Car Corporation).

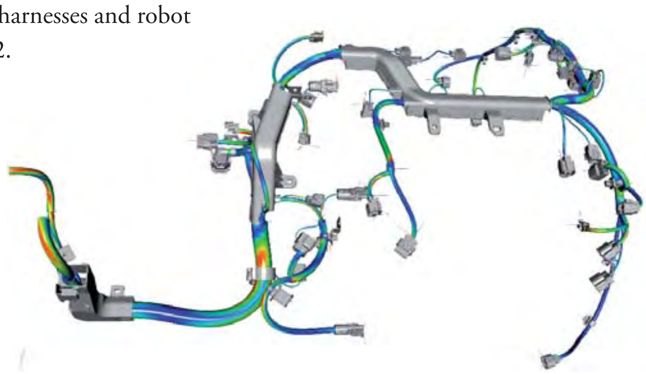


Figure11. Simulation of harnesses (courtesy of Delphi).

A mathematical model developed and adapted to real time simulation of flexible cables constitutes a basis for the realization of the project. The model is based on non-linear beam theory allowing for large bending, twisting and shearing. It has been implemented in a software demonstrator in which the industrial partners can test the results at an early stage. Experiments comparing measured data with simulated data have been conducted. A database for material properties has been developed, and a model for computing the material parameters for wiring harnesses has been calibrated through measured data.

The project has resulted in methods, techniques and knowledge for real time simulation of flexible materials adapted to vehicle industries requirements. Outcomes of the project are (i) A software-demonstrator IPS for real time simulation and visualization of flexible materials with different material properties. Forces and torque can be analyzed, hose and cable lengths can be optimized, clips be applied and movements can be analyzed, (ii) Geometric measurements and physical tests within GM and Delphi show that the simulation results are very close to the reality, only with some few percents discrepancies, and (iii) Over 80 engineers have been trained in the developed software, today frequently used by engineers in Sweden, USA, Germany and Japan for simulations in packaging, assembly and after sales departments.

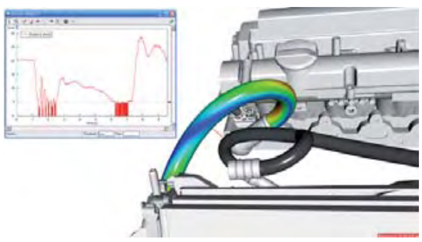


Figure 12. Clearance and stress analysis of engine hoses (courtesy of Saab Automobile).

Systems Biology and Bioimaging

The application of tools and techniques, borrowed from engineering disciplines such as systems and control theory, signal processing, and computer science, for studying biological and biochemical systems has received an increasing attention over the last couple of years. This is due to a number of factors such as recent advancements in measurement technology, a need for pharmaceutical companies to find alternative strategies to beat current shortcomings in early drug development and increase competitiveness, and the improved understanding of living systems due to the sequencing of genomes and characterization of the function and role of corresponding proteins. FCC provides an integrated approach to the study of biochemical and physiological processes, from the characterization of single parts to the analysis of dynamic phenomena on a systems level. The work at the department includes both biological/biomedical modeling applications as well as development of computational tools and algorithms. The department is organized in two areas:

- Systems Biology
- Bioimaging

We are currently involved in modeling projects where yeast *(Saccharomyces cerevisiae)* and frog oocytes *(Xenopus laevis)* are used as model organisms. Modeling of ion-channels and action potential propagation are other areas of interest. The computational tools and algorithms developed at the department can be divided in four main areas: system identification, model reduction, image analysis, and software tools.

This year was the fourth year of operation for the EU funded network of excellence – BIOSIM, which aims at increasing the use of biosimulation in drug development. The department has also received additional EU funding during the year with participation in three new projects: UNICELLSYS, CANCERSYS, and SYSINBIO. The department co-organized the 9th International Conference on Systems Biology 2008 (www.ICSB-2008.org), attended by over thousand participants, together with the Department of Cell and Molecular Biology at Gothenburg University and Chalmers Biocenter. This year was also the final year for the department's long term SSF project aiming at establishing an independent research group in systems biology, which has successfully been accomplished.

Contact
Dr Mats Jirstrand
Phone +46 31 7724250
mats.jirstrand@fcc.chalmers.se

Gunnebo House *was built at the end of the 18th century as a grand summer residence for the wealthy merchant John Hall. The house and its gardens have recently been restored in keeping with past tradition, following the original drawings and other documentation. In 1949 the estate was purchased by the City of Mölndal, a twin town to Göteborg hosting industries such as Astra Zeneca.*

Cooperation

We have a close collaboration with the Swedish company InNetics. Other collaborations include joint work with General Zoology at Kaiserslautern University; Bionanophotonics, Systems Biology, and Mathematical Sciences at Chalmers; Cell- and Molecular Biology at Gothenburg University; the Department of System Analysis, Prognosis and Control at ITWM; and partners in the BIOSIM, YSBN, UNICELLSYS, CANCERSYS, and SYSINBIO EU-projects.

Acknowledgement

In 2008, the Systems Biology and Bioimaging department has received substantial funding from the Swedish Foundation for Strategic Research both directly and via Gothenburg Mathematical Modelling Centre, GMMC. Furthermore, the group has received funding for the BIOSIM, YSBN, UNICELLSYS, CANCERSYS, and SYSINBIO projects from the European Commission.

The Systems Biology and Bioimaging Research Group

- Mats Jirstrand, PhD, Systems Biology, Associate Professor, Head of Department
- Joachim Almquist, MSc Engineering, Systems Biology
- Jonas Hagmar, MSc Engineering, Bioimaging
- Mats Kvarnström, PhD, Bioimaging
- Mikael Sunnåker, MSc Engineering, Systems Biology
- Mikel Wallman, MSc Engineering, Systems Biology
- Armin Böller, contracted student
- Erik Holmgren, contracted student
- Emilia Lundberg, contracted student
- John Johansson, MSc student
- Niklar Skaar, MSc student
- Jan Hauth, PhD, ITWM
- Mats Rudemo, Professor in Mathematical Statistics at Chalmers, Scientific Adviser at FCC

Mats Jirstrand

Joachim Almquist

Jonas Hagmar

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Mikael Wallman

Armin Böller

Erik Holmgren

Emilia Lundberg

John Johansson

Niklas Skaar

Jan Hauth

Mats Rudemo

Systems Biology

Combining model based signal processing, system identification, mechanistic models, and sensitivity analysis with novel measurement platforms provides a strong competitive edge for researchers in the pharmaceutical and biotech industry. Systems biology partly addresses these issues and is an emerging scientific field that aims at elucidating the properties and function of biochemical and biological systems on a systems level, e.g., how biomolecules interact and implement various functions which cannot be understood by studying the system components in isolation.

The activities in systems biology at FCC are focused around the application and development of computational methods and mathematical models of biological systems on different levels of abstraction utilizing time and spatially resolved measurement data. The research is carried out in close cooperation with both academic and industrial partners. The in-house competences are in the area of control and dynamic systems and the group has several years of experience of both software development and application of methods from systems and control theory to projects in both the engineering and pharmaceutical industry.

Our vision is to develop means to enable researchers to delineate and understand the underlying mechanisms of a disease or phenomenon at the mechanistic level, i.e., in terms of biochemical reaction or interaction networks. We focus on mechanistic models to map out and better understand a specific biological phenomenon or pathological condition.

The systems biology group at FCC also has very close collaboration with the Swedish company InNetics, the developers of the systems biology software PathwayLab.

Contact
Dr Mats Jirstrand
Phone +46 31 7724250
mats.jirstrand@fcc.chalmers.se

The Göteborg Botanical Garden *was conceived and planned by the municipality of Göteborg in the 1910's as a botanical garden with an extra emphasis on horticulture, and with a broad scope in the Swedish community life. The area in total is 175 hectares, of which most constitutes a nature reserve including an arboretum. The garden is about 40 hectars and is growing about 16,000 different species in, e g, the Rock Garden (with three stars in Guide Michelin), the Rhododendron valley, and the Japanese Glade. The Greenhouses hosts about 4,000 various plants, including some 1,500 orchids and the rare Eastern Island Tree. In 2007 the Linnaeus Garden was awarded a gold medal at the Chelsea Flower Show and was reinaugurated in Göteborg.*

Modeling the Ras/cAMP/PKA Signaling Pathway - Stress Response in Yeast

This pathway serves as an important regulator of the metabolic and transcriptional activity of yeast cells and is partially well characterized. However, the regulatory feedback loop, transferring information from PKA to RAS, remains unclear. In a first approach we perturb the signal flow using genetic and chemical methods, and observe resulting changes in GFP-tagged Msn2p localization, see figure 1, which indicates PKA activity. Following the localization dynamics of Msn2p over time under both different genetic modifications and under different stress conditions, such as light or heat, we detect different localization patterns. The project is also used to drive method development of a framework for system identification from spatiotemporal cell population data. The framework includes single cell modeling, image processing, and parameter estimation. The objective of image processing is to lump the spatiotemporal data content in images obtained by time lapse microscopy into time-series, where the resulting aggregated entities reflect properties described by the model. Estimation of model parameters is performed both on individual and population level using a maximum likelihood approach exploiting so called nonlinear mixed effects modeling. This is a joint project together with Prof Mikael Käll at the Division of Bionanophotonics at Applied Physic at Chalmers and Prof Anders Blomberg at the Department of Cell and Molecular Biology, Gothenburg University. The project is supported by the Swedish Research Council and GMMC.

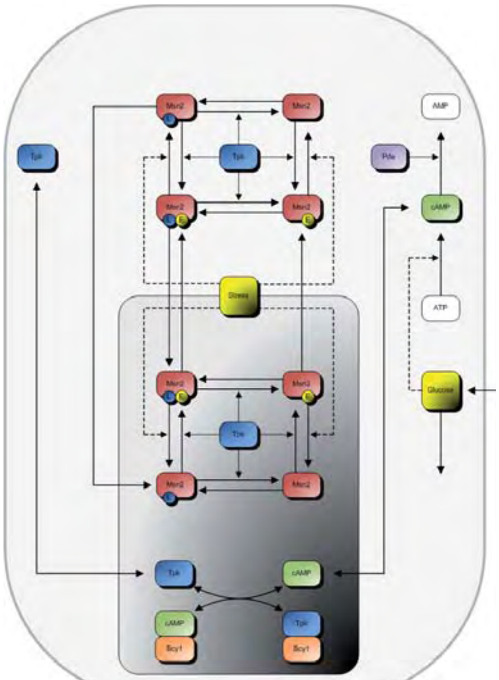

Figure 1. A model diagram for the Ras/CAMP/PKA signaling pathway implemented in PathwayLab.

Modeling Components of the Neuron-Glial Interplay

Glial cells serve a variety of functions in nervous systems. A special kind of glial cells, known as astrocytes, can be seen as mediators between neurons and blood vessels. Astrocytes respond to neurotransmitters, released by neurons, via receptors, but also take up some of the transmitters to help terminate the synaptic process. The main objective in this project has been to improve the understanding of the interplay between the neuron and glial cells with respect to the shuttling of sodium ions and acid/base equivalents done by the sodium-bicarbonate cotransporter (NBC) and the monocarboxylate transporter (MCT) and their relation to glutamate uptake, CO_2 cycling, and metabolite transport. In this work we have built a mathematical model of a biological model system of a subsystem of the neuron glial system – the NBC and MCT transporters, see figure 2. The model system consists of *Xenopus laevis oocytes,* which has been genetically engineered to express membrane transport proteins that can be found in astrocytes. In this way a part of the mechanisms proposed for the neuron astrocyte interplay can be investigated in isolation with experimental techniques such as patch clamping (fixing membrane potential and measuring ion-currents) which can be used to generate time-series data to be used for system identification and parameter estimation. A substantial part of the project has been on establishing an expression for the kinetics of the MCT transporter both with and without the influence of carbonic anhydrase enzyme using model reduction techniques. The project is carried out in close cooperation with Fraunhofer-ITWM and Professor Dr Joachim Deitmer and Dr Holger Becker at the Division of General Zoology at Kaiserslautern University.

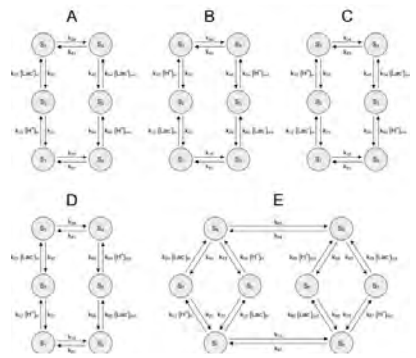

Figure 2. Kinetic models of MCT1 transport with differences in binding order of substrate and co-substrate.

Nonlinear Mixed Effects Modeling Tools

The statistical population modeling framework of nonlinear mixed effects (NLME) modeling is finding increased use by the pharmaceutical industry in the analysis of pharmacokinetic and pharmacodynamic (PKPD) data. Our focus in this project has been on the application and development of parameter estimation methods to NLME models. Typically, PKPD models take the form of state-space models based on ordinary differential equations (ODEs), but in this project we have considered stochastic differential equations (SDEs). This has been done to account for potential model errors and correlations in the data, which is usually referred to as system noise. Altogether, NLME models with SDEs contain three levels of uncertainty; system noise, measurement noise and interindividual random variation. A maximum likelihood framework has been used to estimate the model parameters and a mathematical filter, the extended Kalman filter, has been employed to handle the situation that only some states or combination of states can be directly measured.

To perform parameter estimation in a NLME setting special techniques needs to be employed based on statistical and stochastic theory. A prototype implementation of NLME modeling algorithms – NLMETools, developed during the course of this project, is based on the Systems Biology Toolbox for Matlab. It can be used for rapid model specification, simulation, and parameter estimation of NLME models with stochastic differential equations. A user-friendly graphical user interface is provided to support the system identification workflow from specification of the model structure to estimating parameters as well as generation of synthetic data and comparison with real estimation data, see figure 3.

The estimation techniques and developed computational tools have been applied to a multi-compartment model of the injection of the amino acid leucine in the blood plasma and subsequent transfer of leucine to the liver, see figure 4. The goal is that this model will be part of a larger stochastic population model for lipoprotein kinetics, in which the lipoprotein particles are synthesized in the liver and leucine functions as a tracer. First, artificially generated data was used to investigate the practical identifiability of the model, i.e., if for a given choice of measured variable(s) the parameters can be determined within some reasonable bounds, see figure 5. This was done both for the structural parameters and the stochastic parameters, i.e., parameters corresponding to the different types of noise and uncertainty in the model. Second, having established the identifiability of the model the parameters of the model was estimated using experimental data from a group of fifteen diabetes patients and sixteen healthy control individuals. In particular, the efforts were focused on establishing differences between the two groups. This applied part of the project is carried out within the framework of the Gothenburg Mathematical Modelling Centre (GMMC) in collaboration with Prof Bernt Wenneberg, Mathematical Sciences at Chalmers and the Sahlgrenska Centre for Cardiovascular and Metabolic Research. The project has also been supported by the Swedish Foundation for Strategic Research and the BIOSIM grant from the European Commission.

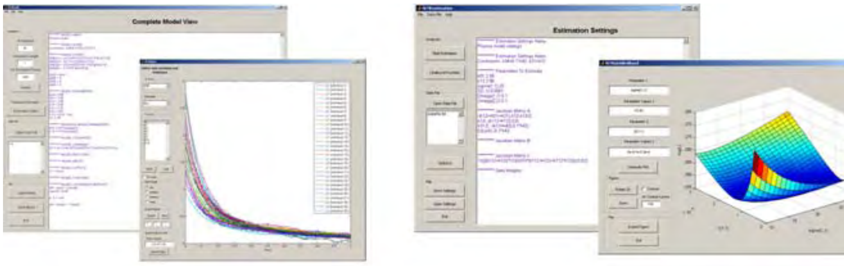

Figure 3. Model specification, simulation, estimation specification and a plot of the likelihood as a function of σ_{11} and S in NLMEtools, for the leucine kinetics model.

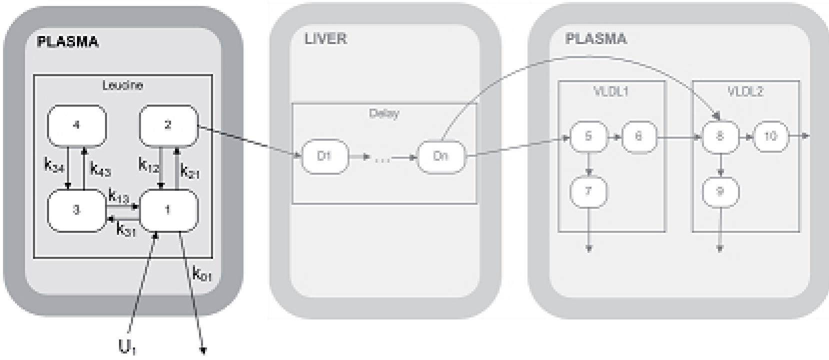

Figure 4. A compartment model for apoB lipoprotein kinetics.

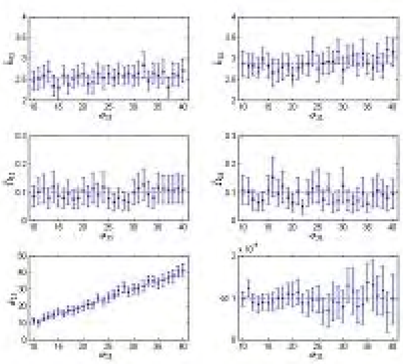

Figure 5. Monte Carlo based identifiability analysis: in silico generated data for repeated parameter estimation followed by visualization of estimation results.

In Silico Simulation of Fibrillation in Canine Atrial Tissue

Atrial fibrillation is the most common form of heart arrhythmia and is associated with a 5-6 fold increase in the incidence of stroke. Computer models describing the temporal evolution of the action potential over realistic atrial geometries are very useful to understand or predict the effect of drugs acting as inhibitors on single or multiple ion-channels. In particular, these models make it possible to relate the dynamics of the action potential propagation to drug effects on the single cell level. This in turn permits in silico reconstruction and investigation of phenomena like atrial flutter and fibrillation.

In this project together with AstraZeneca R&D Mölndal we have developed a framework for modeling and simulation of electro-chemical activity in large scale cell networks. The outline of the complete atrial tissue model, which consists of about 1.000.000 coupled nonlinear ordinary differential equations, is illustrated in figure 6. The simulation framework has been used to induce fibrillation and flutter like electrodynamic activity in cell networks, see figure 7, and the effect of ion-channel modulation on this behavior has subsequently been investigated. Qualitatively the results are in good accordance with in vivo observations, which indicates that the approach is viable for this application and motivates further extensions and studies. The type of simulations presented in this work has great potential to provide insights into the underlying mechanisms of atrial fibrillation and flutter, as well as a basis for prediction of drug effects.

Recently, the atrial geometry model has been improved by refining the spatial discretization. Furthermore, detailed low level mechanistic descriptions of a particular ion-channel including drug interaction effects has been investigated and integrated with the atrial model. The cell models used in previous projects implement ion-current mechanisms using the Hodgkin-Huxley paradigm. To

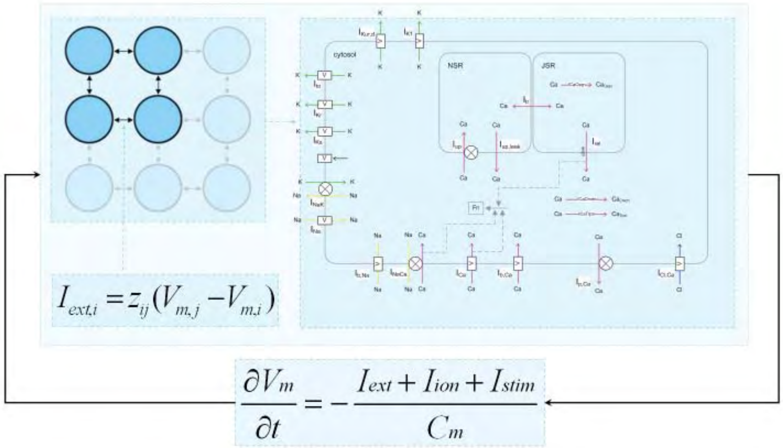

Figure 6. Outline of the developed modeling and simulation framework: network model, cell model, and connectivity model (membrane potential equations).

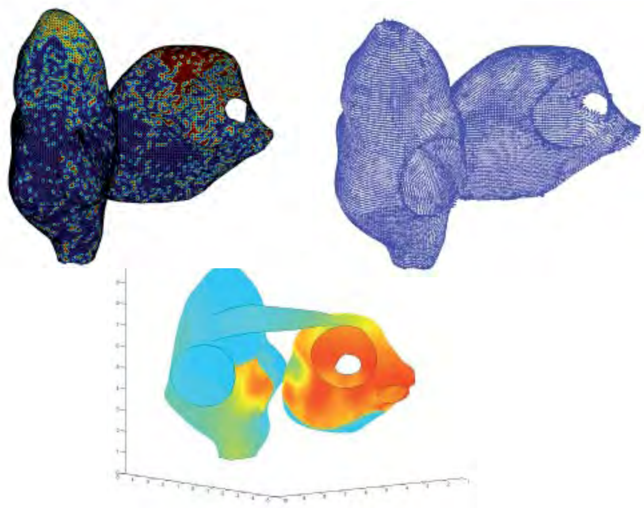

Figure 7. Sample distribution of different cell types on the surfaces of the atria (top left). Muscle fibre orientation (top right). Simulated fibrillation in a canine atrial model (bottom). Left and right atrium connected by a conducting structure known as Bachmann's bundle.

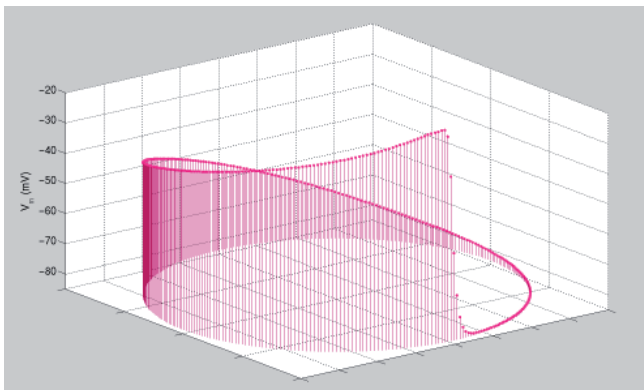

Figure 8. Simulated reentry in a ring of atrial myocytes. This construction can be used to investigate how increased action potential duration on the single cell level affects the ability to trigger self sustained oscillations in simple geometries.

gain insight of the quantitative effects of a drug inhibiting a particular ion-channel so called Markov models are believed to provide the necessary level of detail. We have implemented more detailed models of an ion-channel of particular interest using this formalism. The refined cell model has been used both for single cell simulations, in ring-like constructions, see figure 8, and in the full scale atrial model (reproducing self sustained behavior as shown in figure 7) providing a better approximation to the real drug-ion-channel interaction effects in terms of increased refractory period, i.e., the time until a cell can be restimulated, to prevent self sustained electro-chemical behaviors. Using the more detailed ion-channel model the arrhythmic behavior can be terminated by increasing the level of the extracellular concentration of the drug targeting the specific ion-channel.

The developed modeling and simulation framework has been translated into a high performance computing setting first tested and executed on FCCs internal computational servers and recently deployed onto Chalmers Centre for Computational Science and Engineering (C3SE) facilities.

Parameter Estimation

In this project we have considered system identification of biological and biochemical systems described by differential equations. Since measurement data often is sampled at discrete points in time we are faced with a mixed continuous-discrete parameter estimation problem. A common way of addressing this problem is to add Gaussian measurement noise to the measured variables and perform a maximum likelihood estimation of the unknown parameters. However, the underlying assumption that there is no uncertainty in the proposed differential equations for the system under study is often not that realistic. A formal way of introducing a measure of this uncertainty is to consider stochastic differential equations (SDEs), which also incorporates noise terms or disturbances to account for unknown or non mechanistically modeled effects. We have studied and implemented methods for system identification for a model class described by a system of stochastic differential equations and measurements taken at discrete time instants.

The methods have been based on a prediction error minimization framework, which means that the performance of a model is being judged based on its predictive power. We have used both directly parameterized Kalman filters (DKF) and an extended Kalman filters (KF) to compute the predicted output of the model. The prediction error is then formed and its size is measured in some norm, which becomes a function of the parameters to be determined as well as the available data. Parameter estimates are then computed by minimizing this measure and we have utilized gradient based methods which require the predictor structures to be differentiated. Equations for the differentiated version of the EKF equations have been derived, which has to be solved simultaneously with the original EKF equations to obtain the value of the objective function and its gradient in each step of the optimization algorithm. The method has been implemented in Mathematica, which makes it possible to both automate the process of setting up the EKF and differentiated EKF equations for a given problem as well as applying robust state-of-the art implementations of various gradient based optimization algorithms. The methods have been validated on some small test examples, which show promising results.

A more computationally demanding approach compared to the nonlinear filtering setting described above is to directly work with the involved probability distributions (instead of only their first and second moments as is the case for the EKFs). Particle methods, also called sequential Monte Carlo methods, have recently evolved as a tool for the task to make inference on unknown parts of nonlinear dynamical systems and can be used in such an approach. In an effort carried out in collaboration with ITWM the aim has been to investigate, implement, compare, and benchmark approaches for parameter estimation based on Maximum Likelihood, prediction error minimization, and Bayesian approaches. During the course of the project Mathematica implementations of the investigated particle methods have been developed.

Model Reduction

Model reduction is an important topic in systems biology, since models tend to become increasingly complex. In this project we have developed a step-by-step method to reduce the number of states in linear models to the largest possible extent, while preserving the interpretability of the states. The preservation of states interpretability is of particular importance in a systems biology context, since the states have typically a clear interpretation to biologists.

The method relies on a clear separation of model parameter time-scales and is based on lumping of the states. The main steps of the method are to identify which of the states that may be lumped and to calculate the fraction of each lumped variable that corresponds to the different states in the original model. These steps are then divided into a number of sub-steps to allow for easy implementation of the method in computer code. Our implementation of the method has been applied to two models involved in photosynthesis, see figure 9.

The same principles for model reduction as in the linear case can also be extended to nonlinear models. We have previously used a method based on separation of time-scales and lumping to reduce a nonlinear 102 state EGF-activated MAP kinase cascade model, to a model with 48 states, with well preserved identifiability of the original states. We are currently striving to develop a more automated method for reduction of nonlinear models, with promising results.

The approach to model reduction as described above can be useful to construct models consisting of zoomable sub-systems.

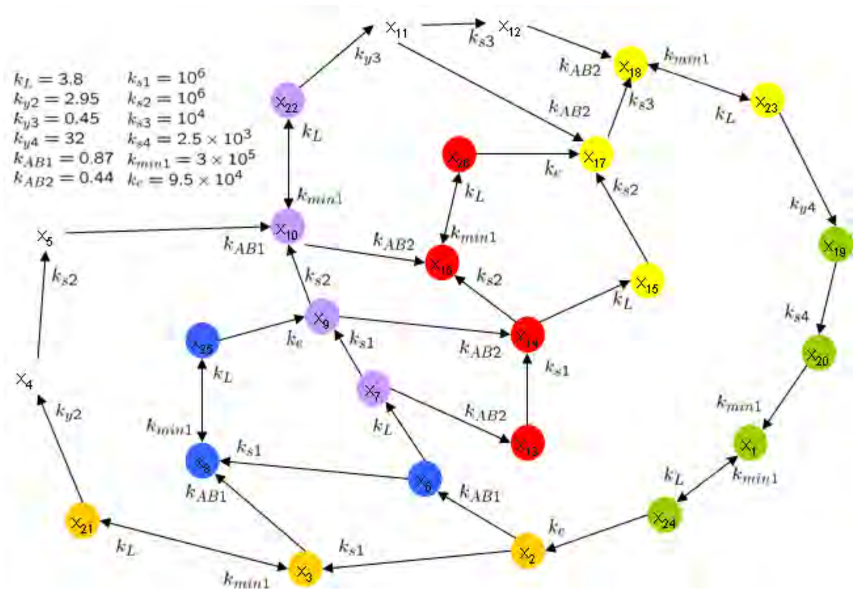

Figure 9. A 26-state linear system modeling transitions between different configuration states of a protein complex involved in photosynthesis. The coloring corresponds to the lumped states after model reduction.

If more details regarding any part of the model are required, one may simply switch to the 'zoomed-in' version of this model part. A great advantage is that changes in the values of parameters in the reduced model are automatically translated to the more detailed version of the model.

MAXSIM2 – Interactive Pharmacokinetic/Pharmacodynamic Simulations

This is an interactive software for computer based simulation of pharmacological, pharmacodynamical, and pharmacokinetic models developed in collaboration with Prof Johan Gabrielsson at AstraZeneca and Prof Gunnar Tobin at the Department of Pharmacolcogy at Gothenburg University. The current version of the software is a reengineered version of MAXSIM, a simulator developed by Prof Gabrielsson in the 1980ies, but based on modern software concepts and state of the art numerical solvers of ordinary differential equations. The original MAXSIM had a large user-base both in academia, industry, and governmental institutes (EPA, FDA, etc) and MAXSIM2, once released, is believed to be of great value to both old users of MAXSIM and new users.

Bioimaging

Quantitative bioimaging has in the last couple of years aroused substantial interest for life science applications. In eukaryotic cells, quantitative measurements of protein expression, protein localization and protein-protein interactions are key components for a proper understanding of cell functionality. Fluorescence microscopy and the use of fluorescent protein tags enables visualization of localization processes, levels of expression, protein kinetics, and protein-protein interactions in real time and in vivo, at the level of individual cells. The importance of fluorescence labelling techniques in quantitative microscopy was also acknowledged in October 2008, when the Nobel Prize in Chemistry was awarded to O Shimomura, M Chalfie, and RTsien for their contributions to the discovery and development of the green fluorescence protein (GFP).

Since human interpretation of images is qualitative and subjective, software for objective automatic image analysis are necessary for standardized measurements and high-throughput studies. Quantitative bioimaging and corresponding algorithms for image analysis is also an excellent setup for generating high quality data needed in systems biology modeling projects. At FCC we develop image analysis methods for automated quantitative analysis of images. The applications are for example automated tracking of cells or particles in time-lapse sequences of images and high-throughput screening of protein expressions in large populations. We also conduct research to understand diffusion mechanisms of solutes in polymer-based hydrogels.

Our goal is to provide mathematical and statistical tools to application fields that produce images where quantitative measurements can, or could be, conducted. The first step typically involves image analysis methods but in order to reach true quantitative understanding of the studied phenomenon, assorted methods from statistical learning and/or simulation studies are usually required. Our present collaborating partners come from various academic institutions, research institutes, and industry.

Contact

Dr Mats Kvarnström
Phone +46 31 7724264
mats.kvarnstrom@fcc.chalmers.se

The Garden Society of Göteborg *lies in the heart of Göteborg and is one of the best preserved 19th century parks in Europe. The Garden Society has plenty to offer for all the family such as concerts, traditional festivities and, of course, daily walks in the park. It's also famous for the Rose garden with over 1,900 different species as well as the Palm house built in 1878.*

Quantitative Cell Studies

During the last couple of years, we have developed algorithms and computer software for quantitative analysis of in vivo imaging of yeast cells in microscopy. The emphasis here lies on robust methodologies which enables long time-lapse studies of protein localization, migration, and inheritance over several cell cycles, as well as high throughput screening of protein functionality of a large number of gene-disrupted cells. We have developed a software demonstrator CellStat equipped with graphical user-interface (GUI) for automated recognition and tracking of yeast cells from transmission microscope images, combined with quantification and localization of GFP-labeled proteins using fluorescence microscopy, see figure 1. In this project we collaborate with the Division of Bionanophotonics at Chalmers.

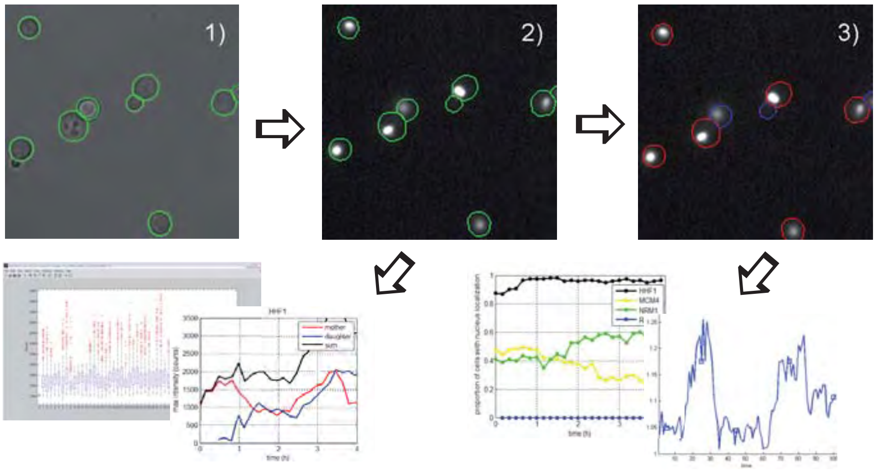

Figure1. General principle of quantification in bioimaging. Top row: Contours are identified in the original bright-field image (1) using our image analysis algorithms. These are transferred to the corresponding fluorescence image (2), where labelled protein content is quantified for each cell including spatial context (3). Here, cells which have large protein expression in the cell nucleus compared to the cytoplasm are colored red. The bottom row we illustrate ways of quantifying and display the labelled protein content, from left to right: boxplots of fluorescence in each cell; single cell expression of a daughter-mother pair over a couple of hours; proportion of cells with highly expressed protein in the cell nucleus of time for four different gene-disrupted cell types; ratio between expression level in the cell nucleus and the cytoplasm over 100 seconds after increasing the temperature.

Gel Structure Modeling

Understanding diffusion mechanisms of solutes in polymer-based hydrogels is important in many industrial applications. For example, in the pharmaceutical industry, in order to decrease the time it takes for new drugs to reach the market it is from a drug delivery point of view very important to understand the intrinsic coupling between the physical properties of the solute/drug and the structure of the surrounding matrix in which the solute/drug is incorporated. Another application is hygiene materials. Here the swelling rate depends to a large extent on the flow and diffusion rates of small solutes into a polymer based material. In future hygiene materials it may be foreseen that the material may also include other functions such as skin therapy and/or clinical testing providing a possibility of early decease warning. Thus, a basic understanding of the processes governing solvent, solute and polymer dynamics in these materials is of prime interest.

Previously a method for identifying the three-dimensional gel microstructure from statistical information in transmission electron micrographs has been developed by FCC in cooperation with SIK (the Swedish Institute for Food and Biotechnology), the Department of Mathematical Statistics and Department of Chemical and Biological Engineering at Chalmers. The micrographs, see the left part of figure 2 are projections of stained strands in gel slices. The gel strand network is modeled as a random graph with nodes and edges, and parameters in the model are estimated by a Markov chain Monte Carlo method. The three-dimensional network may be simulated from the model and the right part of figure 2 shows a 3D rendering from such a simulation.

In connection with the gel structure modeling project, we have also developed algorithms for simulation of diffusing particles and molecules in complex 3-D geometries such as a gel networks in figure 2. Here an adaptive time-stepping scheme is used for numerical solution of stochastic differential equations (SDE). The surrounding geometry acts as obstructing medium for the diffusing molecule and the solver can take care of more general kinds of particle-structure interactions using interaction potentials, as well as reflection and adsorption. By conducting simulation studies, the diffusive behavior (e.g. mobility, stability) of the molecule-structure pair can be predicted.

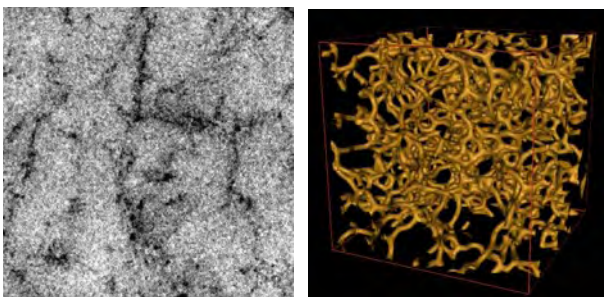

Figure 2. Left: part of a TEM micrograph from a stained Sepharose gel. Right: screen shot from a 3D rendering of the simulated gel network.

Årsredovisning

för tiden 1 januari 2008 - 31 december 2008

Resultaträkning (kSEK)	080101-081231
Intäkter	
Nettoomsättning	28 091
Övriga intäkter	-
Summa intäkter	**28 091**
Kostnader	
Externa kostnader	-10 062
Personalkostnader	-17 502
Avskrivningar av materiella anläggningstillgångar	-401
Summa kostnader	**-27 965**
Rörelseresultat	**126**
Resultat från finansiella investeringar	
Ränteintäkter och liknande	733
Räntekostnader och liknande	-64
Resultat efter finansiella poster	**795**
Bokslutsdispositioner	-228
Årets skatt	-201
ÅRETS RESULTAT	**366**

Balansräkning (kSEK)	081231
Anläggningstillgångar	
Maskiner och inventarier	800
Summa anläggningstillgångar	**800**
Omsättningstillgångar	
Kundfordringar	6 507
Förutbetalda kostnader och upplupna intäkter	1 203
Övriga kortfristiga fordringar	8
Skattefordringar	124
Kassa och bank	9 627
Summa omsättningstillgångar	**17 469**
SUMMA TILLGÅNGAR	**18 269**
Eget kapital	
Eget kapital vid årets ingång	2 627
Årets resultat	366
Summa eget kapital	**2 993**
Obeskattade reserver	1 047
Kortfristiga skulder	
Leverantörsskulder	4 155
Övriga kortfristiga skulder	896
Upplupna kostnader och förutbetalda intäkter	9 178
Summa kortfristiga skulder	**14 229**
SUMMA SKULDER OCH EGET KAPITAL	**18 269**

Styrelsen för Stiftelsen Fraunhofer-Chalmers centrum för industrimatematik, FCC, får härmed avge följande redovisning över verksamheten under tiden 1 januari 2008 – 31 december 2008, stiftelsens sjunde verksamhetsår.

Stiftelsen bildades av Chalmers och Fraunhofersällskapet i juni 2001 och registrerades av Länsstyrelsen i Västra Götalands län i oktober 2001 som en svensk näringsdrivande stiftelse. Stiftelsen skall enligt strategiplan från oktober 2005 bygga upp en verksamhet som år 2010 omsätter tre och en halv miljon euro och omfattar 35 anställda. Chalmers och Fraunhofersällskapet kommer under denna period att stegvis öka sin finansiering från 400 000 euro 2006 till 500 000 euro 2010.

Årets omsättning har varit drygt tjugoåtta miljoner kronor. Medelantalet anställda har varit trettio personer (varav fyra kvinnor) inklusive två industridoktorander som vistas på centret. Under senare delen av året har 15 studenter anställts till 10% för arbete inom projekt. Stiftelsen har ett femårigt hyresavtal till och med 31 mars 2011 omfattande 1 096 kvm i Chalmers Teknikpark med Fastighets KB Forskarbyn, Ny hyresvärd fr o m oktober 2008 är Chalmersfastigheter AB.

Styrelse och ledning den 4 november 2008. Från vänster till höger: Johan Carlson (biträdande föreståndare, FCC), Uno Nävert (föreståndare, FCC), Dieter Prätzel-Wolters (Fraunhofer ITWM), Bo Johansson (Chalmers), Peter Jagers (ordförande, Chalmers), Helmut Neunzert (vice ordförande, Fraunhofer ITWM).

FÖRVALTNINGSBERÄTTELSE

Stiftelsen Fraunhofer-Chalmers centrum för industrimatematik skall utveckla och anpassa matematiska metoder för industrin. Stiftelsen bedriver konkurrensneutral forskning och marknadsföring med finansiering från grundarna och offentliga finansiärer. Stiftelsen genomför projekt med företag på kommersiell grund.

Rörelsens intäkter har uppgått till 28 091 kSEK. Av detta utgör 40% industriprojekt, 30% offentliga projekt och 30% finansiering från grundarna. Årets resultat efter skatt är 366 kSEK. Eget kapital uppgick den 31 december 2008 till 2 993 kSEK.

Stiftelsens styrelse har under verksamhetsåret sammanträtt fyra gånger varav två gånger var per capsulam. Ersättning har utgått till ordföranden med 31.500 kronor och till övriga ledamöter med 16.750 kronor per person.

Stiftelsens ställning och resultatet av dess verksamhet framgår av efterföljande resultat- och balansräkningar, vilka utgör en integrerad del av årsredovisningen.

Göteborg den 17 mars 2009

Peter Jagers, ordförande
Helmut Neunzert, vice ordförande
Bo Johansson
Dieter Prätzel-Wolters

Räkenskaperna har granskats av Deloitte.

Appendix

Presentations / Conferences

J Almquist, H Schmidt, P Lang, D Prätzel-Wolters, J W Deitmer, M Jirstrand, and H M Becker:
A model reduction approach to the kinetics of the monocarboxylate transporter MCT1 and carbonic anhydrase II, The 9th International Conference on Systems Biology, Göteborg, August 2008.

K Bodvard, P Sliwa, K Logg, J Almquist, M Kvarnström, M Jirstrand, A Blomberg and M Käll:
Systematic analysis of the RAS/cAMP/PKA signalling pathway using in vivo fluorescence microscopy, The 9th International Conference on Systems Biology, Göteborg, August 2008.

J Almquist, M Sunnåker, J Hagmar, M Kvarnström, and M Jirstrand:
System identification from spatiotemporal cell population data, The 9th International Conference on Systems Biology, Göteborg, August 2008.

B Andersson:
Multiobjective Optimization Applied to Design of PIFA Antennas, SCEE, Helsinki, Finland, October 2008.

B Andersson:
Tekniska beräkningar på FCC, Matematik i yrkeslivet, Chalmers, Göteborg, October 2008.

J Carlson:
Virtual Paint, Svenska Mässan, Älvsjö, October 22, 2008.

J Carlson:
Simulation of cables, Svenska Mässan, Älvsjö, October 22, 2008.

J Carlson:
Virtual Geometry, Path Planing and Station Logic, Svenska Mässan, Älvsjö, October 22, 2008.

J Carlson:
Virtual Paint, Volvo MERA Internal Conference, Göteborg, June 2008.

J Carlson:
Wingquist Laboratory Annual Seminar on Virtual Product Realization, Chalmers, Göteborg, December 2008.

F Edelvik:
Multiobjective Optimization Based on Surrogate Models Applied to Antenna Design, invited speaker, 9th International Workshop on Finite Elements for Microwave Engineering, Bonn, Germany, May 2008.

F Edelvik:
Multi-objective Antenna Optimization, GMMC seminar Chalmers, Göteborg, September 2008.

M Jirstrand:
Software tools - a survey from a theoretical perspective, Invited talk at The 9th International Conference on Systems Biology, Göteborg, August 2008.

M Jirstrand:
Parameter Estimation in Biochemical Systems Using Prediction Error Minimization, invited lecture at a Systems Biology Workshop arranged by University of Skövde, Hjo, October 2008.

M Jirstrand:
Modeling and Simulation of Fibrillation in Canine Atrial Tissue, invited lecture at the NordForsk annual meeting on Atrial Fibrillation, Trolleholm, December 2008.

P Johannesson:
A load-strength model for fatigue applications, Random Modelling in Science, Engineering and Medicine - A Smögen Workshop, August 18-22, 2008.

M Kvarnström, K Logg, K Bodvard, J Hagmar, M Käll:
Automated Image Analysis for Quantification of Protein Localization in Budding Yeast. The 9th International Conference on Systems Biology, Göteborg, August 22-28, 2008.

S Lorén:
Fatigue limit and inclusions, Random Modelling in Science, Engineering and Medicine - A Smögen Workshop, August 18-22, 2008.

J de Maré:
On loads in the load-strength model, Random Modelling in Science, Engineering and Medicine - A Smögen Workshop, August 18-22, 2008.

R Rundqvist:
Virtual Paint - simulation of coating processes in car industry, SIAMUF seminar, Örenäs, October 2008.

I Rychlik:
Uncertainty in fatigue life prediction of structures subject to random loads, Random Modelling in Science, Engineering and Medicine - A Smögen Workshop, August 18-22, 2008.

D Spensieri, J Carlson,
R Bohlin and R Söderberg:
Integrating Assembly Design, Sequence Optimization, and Advanced Path Planning, the 34th ASME Design Automation Conference, New York City, USA, August 3-6, 2008.

M Sunnåker, M Berglund,
B Wennberg, M Adiels, and M Jirstrand:
A Matlab Toolbox for Nonlinear Mixed Effects Modeling - Illustrated with a Model for Lipoprotein Kinetics, The 9th International Conference on Systems Biology, Göteborg, August 2008.

M Wallman, M Jirstrand, and I Jacobson:
Simulation of Fibrillation in a Realistic Model of Canine Atrial Tissue, The 9th International Conference on Systems Biology, Göteborg, August 2008.

Publications

J Almquist, H Schmidt, P Lang,
J W Deitmer, M Jirstrand,
D Prätzel-Wolters, and HM Becker:
A kinetic model of the monocarboxylate transporter MCT1 and its interaction with carbonic anhydrase II, submitted to Biophysical Journal month, February 2008.

K Wärmefjord, J Carlson, R Söderberg:
A Measure of the Information Loss for Inspection Point Reduction. Proceedings of the ASME 2008 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, Brooklyn, New York, USA, August 3-6, 2008.

F Edelvik:
Antennensysteme im Weltall, Fraunhofer-Gesellschaft Mediendienst 1-2008-Thema 5, January, 2008.

J Hagmar, C Brackmann,
T Gustavsson, and A Enejder:
Image analysis in nonlinear microscopy, Journal of the Optical Society of America A, 25(9), 2195-2206, August 2008.

S Jakobsson, B Andersson, F Edelvik:
Multiobjective Optimization Applied to Design of PIFA Antennas, In SCEE 2008, pp 181-182, Helsinki, Finland, October 2008.

S Jakobsson, B Andersson, F Edelvik:
Multiobjective Optimization Applied to Design of PIFA Antennas, Scientific Computing in Electrical Engineering, accepted December 2008.

S Jakobsson, F Edelvik, B Andersson:
Multiobjective Optimization Based on Surrogate Models Applied to Antenna Design, Proceedings 9th International Workshop on Finite Elements for Microwave Engineering, Bonn, Germany, May 2008.

S Jakobsson, J Rudholm,
M Patriksson, A Wojciechowski:
A Method for Simulation Based Optimization Using Radial Basis Functions, submitted October 2008.

S Jakobsson, M Saif-Ul-Hasnain, R Rundqvist,
F Edelvik, B Andersson, M Patriksson,
M Ljungqvist, D Lortet and J Wallesten:
Combustion engine optimization: A multi-objective approach, submitted February 2008.

P Johannesson, T Svensson,
L Samuelsson, B Bergman, and J de Maré:
Variation mode and effect analysis: an application to fatigue life prediction, Quality and Reliability Engineering International, online http://dx.doi.org/doi:10.1002/qre.960, August 28, 2008.

M Kvarnström, K Logg,
A Diez, K Bodvard, and M Käll:
Image analysis algorithms for cell contour recognition in budding yeast. Optics Express. Vol 16, iss 17 pp 12943-12957, August 2008.

M Kvarnström, A Westergård,
N Lorén, and M Nydén:
Brownian dynamics simulations in hydrogels using an adaptive time stepping algorithm. Physical Review E (79), 016102, accepted December 2008.

P Lindroth:
Product configuration with respect to multiple criteria - a mathematical framework for finding optimal sets of truck configurations, Licentiate thesis Chalmers, May 2008.

B Bergman, J de Maré,
S Lorén, T Svensson(eds.):
Robust Design Methodology for Reliability, A collection of essays, Wiley, including, e g,

- P Johannesson, T Svensson, L Samuelsson, B Bergman, and J de Maré:
  Variation mode and effect analysis: an application to fatigue life prediction,
- S Lorén, P Johannesson, J de Maré:
  Monte Carlo Simulations versus sensitivity analysis,
- A Bengtsson, K Bogsjö, I Rychlik:
  Fatigue damage uncertainty. Accepted for publication in Robust,

accepted January 2008.

T Svensson and J de Maré:
On the choice of differential quotients for evaluating prediction intervals, Measurement, vol 41, no 7, pp. 755–762, August 2008.

A Mark:
The Mirroring Immersed Boundary Method. Modeling Fluids with Moving and Interacting Bodies, PhD thesis Chalmers, November 2008.

N Nedbal, J Cerveny, H Schmidt:
Scaling and Integration of Kinetic Models of C3 Photosynthesis: Towards Comprehensive E-Photosynthesis. In Eds. Laisk et al. Photosynthesis in silico - Understanding Complexity from Molecules to Ecosystems. Springer, accepted June 2008.

A Ericsson, D Mojzita,
H Schmidt, S Hohmann:
Case study in systematic modelling: Thiamine uptake in Yeast S. cerevisiae, In Eds. O Wolkenhauer et al. Essays in Biochemistry - Systems Biology, Portland Press, vol 45, pp 135-46, 2008.

D Dell'Orco, H Schmidt:
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H Schmidt, M Madsen, S Danø, G Cedersund:
Complexity Reduction of Biochemical Rate Expressions, Bioinformatics, 24(6), pp 848-854, February 2008.

J Segeborn, A Carlsson,
J Carlson, R Söderberg:
A Chronological Framework for Virtual Sheet Metal Assembly Design, accepted at the 11th CIRP International Conference on Computer Aided Tolerancing, Annecy, France, submitted September 2008.

J Segeborn, J Carlson,
A Carlsson, R Söderberg:
Parameters Influencing Geometrical Quality and Station Cycle Time in Sheet Metal Assemblies, In Proceeedings of The 2nd Nordic Conference on Product Lifecycle Management, submitted June 2008.

D Spensieri, J Carlson,
L Lindkvist, R Bohlin, R Söderberg:
A Method to Optimize Geometrical Quality and Motion Feasibility of Assembly Sequences. Accepted at the 11th CIRP International Conference on Computer Aided Tolerancing, Annecy, France, submitted September 2008.

Professor Jacques de Maré, scientific adviser Reliability and Risk Management, and Master theses students Yun Niu, Roland Jakobsson, José Sanchez, and Mattias Ohlsson.

A Isaksson, M Wallman,
H Göransson, and MG Gustafsson:
Cross-validation and bootstrapping are unreliable in a small sample classification, Pattern Recognition Letters, 29(14), pp 1960-1965, October 2008.

PhD students and theses

P Lindroth (Volvo 3P and Chalmers); advisors M Patriksson and A-B Strömberg. Product configuration with respect to multiple criteria in a heterogeneous and dynamic environment, in progress.

J Segeborn (Volvo Cars and Chalmers); advisors J Carlson, R Söderberg, A Carlsson. Cost Effective Manufacturing Engineering by Automatic Path Planning & Line Balancing, Integrated with Tolerance Analysis and Control Logic, in progress.

Master students and theses

G Eek och C Eriksson (Göteborgs Universitet); supervisor F Ekstedt, examiner Mattias Wahde, Balanserat och synkroniserat multipelt handelsresandeproblem (B&S-mTSP) med genetiska algoritmer (GA) in progress.

R Jakobsson and M Ohlsson (Volvo Buses and Chalmers); examiner J de Maré. Real World Fuel Consumption of Buses - Prediction for Auxiliary Units Using Multivariate Regression Methods, in progress.

J Johansson (Chalmers); supervisor M Jirstrand, examiner B Mehlig. Model Reduction in Biochemical Reaction Systems - A Method Based on Time Scale Separation and State Aggregation, Master Thesis, April 2008.

Y Niu (Det Norske Veritas and Chalmers); examiner I Rychlik. Influence of Whipings on Fatigue and Extreme Responses, in progress.

M Saif Ul Hasnain (Chalmers): supervisor S Jakobsson, examiner S Andersson, Simulation based multiobjective optimization of diesel combustion engines, February 2008.

J Sanchez (Volvo 3P and Chalmers); examiner J de Maré, Vehicle Damage Prediction from Advanced and Simple Systems Measurements, in progress.

D Sjögren (Chalmers); supervisor S Jakobsson, examiner T Norberg, Statistical methods for improving surrogate models in antenna optimization, in progress.

N Skaar (Chalmers); supervisor M Jirstrand, examiner B Mehlig, Parameter Estimation Methods for Continuous Time Dynamic Systems given Discrete Time Measurements, Master Thesis, January 2008.

K Viltersten and K Viltersten (Chalmers and Göteborgs Universitet); supervisor M Kvarnström, examiner M Rudemo. Simulating Diffusion With Brownian Dynamics Using an Adaptive Time-Stepping Algorithm, Master Thesis, April 2008.

Other assignments

J Carlson:
Supervisor for M Andersson (Chalmers), Effektiv simulering och analys av flexibla slangkomponenter, Master Thesis, August 2008.

J Carlson:
Member of the grading committee for A Kobetski (Chalmers), Optimal Coordination of Flexible Manufacturing Systems with automatic generation of collision- and deadlock-free working schedules, 2008.

F Edelvik:
Reviewer for IEEE Transactions on Advanced Packaging

F Edelvik:
Reviewer for Optimization and Engineering

S Jakobsson:
Reviewer for Zentralblatt

M Jirstrand:
Reviewer for BMC Systems Biology, EURASIP Journal on Bioinformatics and Systems Biology, and European Control Conference.

M Jirstrand:
Member of the PhD-thesis committee for O Eriksson, Simplicity within Complexity – Understanding dynamics of cellular networks by model reduction, Stockholm University, December 12, 2008.

M Kvarnström:
Co-advisor to PhD student V Olsbo together with A Särkkä and T Norberg, Spatial Analysis and Modelling Motivated by Nerve Fiber Patterns. Doctoral thesis. Department of Mathematical Sciences. Division of Mathematical Statistics, Chalmers University of Technology and Göteborg University, December 12, 2008.

A Mark:
Reviewer for Journal of Computational Physics.

R Rundqvist:
Reviewer for AIChE Journal

Courses

M Jirstrand:
Introduction to Computational Systems Biology and Tutorial on PathwayLab. Invited lecturer for The 3rd International Course in Yeast Systems Biology, Göteborg, June 2008.

M Jirstrand:
Tutorial: Component Based Modeling of Biochemical Networks using PathwayLab, The 9th International Conference on Systems Biology, Göteborg, August 2008.

M Jirstrand:
Systems Theory in the Toolbox for Systems Biology and Modeling Tools: PathwayLab, Systems Biology Toolbox, and Mathematica, co-lecturer in the course Mathematical Modelling and Computational Tools, Int. Master's Program for Bioinformatics and Systems Biology, Chalmers University of Technology, Göteborg, November 2008.

P Johannesson, T Svensson, E Johnson, and G Kjell:
Spectrum fatigue, three-day course on service load measurement, loads analysis, fatigue testing using spectrum loads, and derivation of design targets, Göteborg, Volvo CE, February - March 2008, Volvo Trucks, September - October 2008.

Guest seminars

M Werme (Kungliga Tekniska Högskolan), Sequential integer programming methods and their application in topology optimization, January 11, 2008.

E Shellshear (Bielefeld Universität), Game Theory – A Focus on Industry, January 18, 2008.

S Engblom (Uppsala Universitet), Simulation of stochastic reaction-diffusion processes on unstructured meshes, October 31, 2008.

A Hellander (Uppsala Universitet), Numerical simulation of well stirred biochemical reaction networks governed by the master equation, November 14, 2008.

D Anisi (Kungliga Tekniska Högskolan), Co-operative Multi-UGV Suverillance, November 28, 2008.

V Olsbo (Chalmers), Spatial analysis and modelling motivated by epidermal nerve fiber patterns, December 5, 2008.

H Härdin (Vrieje Universiteit), Simplified yet accurate enzyme kinetics for in vivo-like conditions, December 18.

FCC staff on December 19, 2008. From left to right: Johan Carlson, Babak Saboori, Peter Jagers, Robert Bohlin, Fredrik Edelvik, Rikard Söderberg, Christian Bengtsson, Johan Torstensson, Behzad Saboori, Joachim Almquist, Gustav Eek, Emilia Lundberg, Jenny Ekenberg, Tomas Hermansson, Samuel Lorin, Christer Eriksson, Johan Segeborn, Stefan Jakobsson, Anders Ålund, Sara Lorén, Fredrik Andersson, Domenico Spensieri, Daniel Segerdahl, Sebastian Tafuri, Mikael Wallman, Robert Rundqvist, Olivier Goury, Jonas Hagmar, Annika Eriksson, Mikael Sunnåker, David Wrangborg, Pär Johannesson, Helén Johansson, Armin Böller, Andreas Mark, Björn Andersson, Peter Lindroth, Erik Holmgren, Uno Nävert, Fredrik Ekstedt.

We have used twelve sights in Göteborg and Mölndal to illustrate our departments and research areas:

Fraunhofer-Chalmers Research Centre
for Industrial Mathematics, FCC

Chalmers Science Park
SE-412 88 Göteborg
Sweden

Phone +46 (0)31 7724000
Fax +46 (0)31 7724260
info@fcc.chalmers.se
www.fcc.chalmers.se

The Fraunhofer-Chalmers Research Centre for Industrial Mathematics, FCC, has been founded by Chalmers and the Fraunhofer-Gesellschaft as a business making, non-profit Swedish foundation.

The purpose of FCC is to promote the application of mathematical methods in industry. To do so the Centre will undertake pre-competitive scientific research in the field of applied mathematics and work on projects defined by companies or public institutes.

The Centre, in close cooperation with Chalmers in Göteborg and Fraunhofer ITWM in Kaiserslautern, shall be a leading partner for international industry and academia to mathematically model, analyse, simulate, optimize, and visualize phenomena and complex systems in industry and science, to make development of products and processes more efficient and secure their technological and financial quality.