Activity Report

2001/2002

Division of Optimization and Systems Theory
Department of Mathematics
Royal Institute of Technology
SE–100 44 Stockholm, Sweden
http://www.math.kth.se/optsyst/

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The Division of Optimization and Systems Theory is part of the Department of Mathematics at the Royal Institute of Technology. This report summarizes the activities at this division during the academic year 2001/2002 (July 2001 – June 2002).

Optimization and Systems Theory is a discipline in applied mathematics primarily devoted to methods of optimization, including mathematical programming and optimal control, and systems theoretic aspects of control and signal processing. In addition, attention is given to mathematical economics and applied problems in operations research, systems engineering and control engineering.

Research performed at the Division of Optimization and Systems Theory includes various topics in *mathematical systems theory*, with particular emphasis on stochastic systems, filtering, identification and robust and nonlinear control; *mathematical programming*, with emphasis on nondifferentiable optimization, large-scale nonlinear programming, dual optimization methods, structural optimization, and a wide range of applications; *systems engineering*; and *mathematical economics*. The division also has an Optimization Laboratory devoted to collecting state-of-the-art optimization routines, making them available to research institutions and industry. The division is also one of four core groups in the Center for Autonomous Systems, a research consortium supported by a grant from the Strategic Research Foundation.

The Division of Optimization and Systems Theory offers undergraduate courses in mathematical programming, mathematical systems theory, optimal control and mathematical economics, as well as various topics in operations research and modeling. There is an extensive graduate program.

A regular *Optimization and Systems Theory Seminar* has been running weekly. In addition, more tutorial and informal seminars in mathematical programming and systems and control have been running in parallel.

Contents

1 Personnel

1.1 List of personnel

Professor (Professor)

Anders Lindquist, TeknD

Docenter (Associate professors)

Anders Forsgren TeknD, universitetslektor
Xiaoming Hu, PhD, universitetslektor
Krister Svanberg, TeknD, universitetslektor Director of undergraduate studies

Universitetslektorer (Senior lecturers)

Ulf Brännlund, TeknD
Claes Trygger, TeknD

Forskarassistent (Research associate)

Ulf Jönsson, TeknD, docent

Gästforskare (Visiting professors)

Per-Olof Gutman, associate professor
Vladimir Yakubovich, professor

Administratör (Administrator)

Erika Appel

Doktorander (Graduate students)

Anders Blomqvist, civing
Gianantonio Bortolin
Torvald Ersson, civing (graduated (TeknL) December 2001)
Vanna Fanizza
Christelle Gaillemard
Ryozo Nagamune
Mikael Prytz, civing (graduated (TeknD) May 2002)
Henrik Rehbinder, civing (graduated (TeknD) November 2001)
Göran Sporre, civing
Mathias Stolpe, civing
Petter Ögren, civing

1.2 Biographies

Erika Appel has been administrator at the Division of Optimization and Systems Theory since 2000.

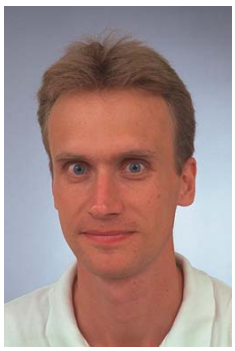
Anders Blomqvist was born in Täby, Sweden, in 1976. He received a civilingenjör degree in Engineering Physics from KTH in 2001. He spent the academic year 1999-2000 as an exchange student at Washington University in St. Louis. Since the spring of 2001 he is a graduate student at the Division of Optimization and Systems Theory. His research involves analytic interpolation theory with a complexity constraint and its applications in control and system identification.

Gianantonio Bortolin was born in Pordenone, Italy, in 1973. He received his degree in Electrical Engineering in 1999 from University of Padova. He did his undergraduate thesis in 1999 at Scania with KTH. Presently he is a PhD student at the Division of Optimization and Systems Theory and cooperates in a project on "Process modelling, operator training simulation, and optimization applied to a paper board manufactoring" at AssiDomän Cartonboard AB.

Ulf Brännlund was born in 1961. He received a civilingenjör degree in Aeronautical Engineering from KTH in 1986 and an MS degree in Engineering-Economic Systems from Stanford University in 1988 and his doctorate degree from KTH in 1993. He is the chairman of the board and cofounder of the company Optimization Partner Stockholm AB (www.optimizationpartner.com). His main research interests are nondifferentiable optimization, semidefinite programming and structural optimization.

Torvald Ersson was born in Västmanland, Sweden, in 1973. He received a Master of Science degree from the School of Engineering Physics, KTH, in 1998. In 2001 he received a Licentiate degree in Optimization and Systems Theory. His research deals with robotics and autonomous systems and has partly been done in cooperation with the Centre for Autonomous Systems (CAS).

Vanna Fanizza was born in Conversano, South of Italy, in 1975. She received a degree in Mathematics from University of Bari. She got a scholarship in Math Dept, University of Milano Bicocca from 1999 to 2000. She was employed in Ericsson Telecomunicazioni S.p.A, Italy from 2000 to 2001. Since the fall of 2001 she is a graduate student at the Division of Optimization and Systems Theory. Her research interest is the identification of positive real linear system via orthonormal basis.



Anders Forsgren was born in Danderyd, Sweden, in 1961. He received a civilingenjör degree in Engineering Physics from KTH in 1985, an MS degree in Operations Research from Stanford University in 1987 and a TeknD degree in Optimization and Systems Theory from KTH in 1990. Between 1991 and 1995 he held a position as research associate at the Division of Optimization and Systems Theory, where in 1995 he was appointed Docent. Since 1995 he is an associate professor at this division. Forsgren was a Visiting Fulbright Scholar at the University of California, San Diego, during three months in 1996. His main research interest is nonlinear programming, numerical optimization in particular.

Christelle Gaillemard was born in Cholet, France, in 1978. She received her degree in Mechanical Engineering with a specialisation in automatic control, in June 2001 at ESSTIN in Nancy, France. She did her master thesis in 2001 at AssiDomän Cartonboard AB, Frövi, Sweden. Currently she is a PhD student at the Division of Optimization and Systems Theory and her project in collaboration with AssiDomän Cartonboard AB will consist of modelling the moisture content of a four layers papersheet using grey-box modelling and identification.

Per-Olof Gutman was born in Höganäs, Sweden on May 21, 1949. He received the Civ.-Ing. degree in engineering physics in 1973, the Ph.D. degree in automatic control, and the title of docent in automatic control in 1988, all from the Lund Institute of Technology, Lund, Sweden. As a Fulbright grant recipient, he received the M.S.E. degree in 1977 from the University of California, Los Angeles.
He taught mathematics in Tanzania 1973-1975. 1983-1984 he held a post-doctoral position with the Faculty of Electrical Engineering, Technion - Israel Institute of Technology, Haifa, Israel. 1984-1990 he was a scientist with the Control Systems Section, El-Op Electro-Optics Industries, Rehovot, Israel, where he designed high precision electro-optical and electro-mechanical control systems. In 1990 he joined Technion — Israel Institute of Technology, Haifa, where he is currently an Associate Professor at the Faculty of Civil and Environmental Engineering.
He has spent several periods as a guest researcher at the Division of Optimization an Systems Theory, Royal Institute of Technology, Stockholm, Sweden, and was a Visiting Professor at the Laboratoire d'Automatique de Grenoble, France, 1995-96. Gutman served on the editorial board of Automatica 1997 - 2002.

Xiaoming Hu was born in Chengdu, China, in 1961. He received the B.S. degree from University of Science and Technology of China in 1983. He received the M.S. and Ph.D degrees from Arizona State University in 1986 and 1989 respectively. He served as a research assistant at the Institute of Automation, Academia Sinica, from 1983 to 1984. He was Gustafsson Postdoctoral Fellow at the Royal Institute of Technology, Stockholm, from 1989 to 1990. His main research interests are nonlinear control theory, the analysis and design of nonlinear feedback systems and the applications of nonlinear dynamics in control and state estimation.

Ulf Jönsson was born in Barsebäck Sweden. He received the M.Sc. degree in Electrical Engineering in 1989 and the Ph.D. degree in Automatic Control in 1996, both from Lund Institute of Technology, Lund, Sweden.
He spent the academic year 1989-1990 at the Department of Electrical Engineering at University of California, Santa Barbara. In the first half of 1997 he was a postdoctoral fellow at California Institute of Technology and thereafter he had a two year appointment as a postdoctoral fellow at the Laboratory for Information and Decision Systems, Massachusetts Institute of Technology. He has been with the Division of Optimization and Systems Theory at the Royal Institute of Technology since 1999. He was appointed Docent in the spring 2002.
His current research interests include design and analysis of nonlinear and uncertain control systems, periodic system theory, robust control along trajectories, and convex optimization applications in systems theory.

Anders Lindquist received his PhD degree from the Royal Institute of Technology, Stockholm, Sweden, where in 1972 he was appointed a Docent of Optimization and Systems Theory. From 1972 to 1974 he held visiting positions at the University of Florida, Brown University, and State University of New York at Albany. In 1974 he became an Associate Professor, and in 1980 a (full) Professor of Mathematics at the University of Kentucky, where he remained until 1983. He is now a Professor at the Royal Institute of Technology, where in 1982 he was appointed to the Chair of Optimization and Systems Theory. Since then he has also held visiting positions at the University of Padova, Italy, University of Arizona, USSR Academy of Sciences, Moscow, East China Normal University, Shanghai, Technion, Haifa, Israel, and University of California at Berkeley, USA.
Presently, Anders Lindquist is the Chairman of the Mathematics Department at the Royal Institute of Technology. He is a Member of the Royal Swedish Academy Sciences, a Foreign Mamber of the Russian Academy of Natural Sciences, a Fellow of the Institute of Electrical and Electronics Engineers (IEEE), and an Honorary Member the Hungarian Operations Research Society. He is an Affiliate Professor at Washington University, St Louis (since 1989) and an Advisory Board Member of the Institute for Mathematics of the Life Sciences, Texas Tech University.

Lindquist has served on many editorial boards of journals, among them the *Journal of Mathematical Systems, Estimation, and Control* (Communicating Editor), *Systems and Control Letters*, *Adaptive Control and Signal Processing*, and book series, namely *Systems and Control: Foundations and Applications*, *Applied and Computational Control, Signals, and Circuits*, and *Progress in Systems and Control*. Since 1983 he has been a member, and between 1985 and 1987 the chairman, of the steering committee for the biennial international symposia on the Mathematical Theory of Networks and Systems (MTNS).

Ryozo Nagamune was born in Yamaguchi, Japan, in 1972. He received Master's degree in Engineering from Osaka University in 1997. He is presently a PhD student at the Division of Optimization and Systems Theory. His research interests are the application of the Nevanlinna-Pick interpolation theory with degree constraint to robust control, development of an efficient solver for Nevanlinna-Pick interpolation with degree constraint, and the extension of the analytic interpolation theory to the multivariable cases.

Mikael Prytz was born in 1969 in Stockholm, Sweden. He received a Master of Science-degree in Engineering Physics from KTH in 1993 and a Masters-degree in Engineering Economic Systems and Operations Research from Stanford University in 1998. Between 1993 and 1996 he worked at Ericsson Telecom with network consulting and developing models and solution methods for telecommunications network design problems. He was an industry PhD-student at the division, supported by Ericsson and the Swedish Research Council, from 1997 until graduation May, 2002. His research interests are in network optimization, network design, multicasting, and network architecture and infrastructure. He is currently a researcher at the Radio Interface Architecture group within Wireless Access Networks at Ericsson Research.

Henrik Rehbinder was born in 1972 in Värmdö, Stockholm, Sweden. He recieved his Master of Science degree in Engineering Physics from KTH in 1996. He was a PhD-student at the division, affiliated with the WARP at the Centre for Autonomous Systems until graduation November 22, 2001. His research interests are in sensor fusion for state estimation focused on nonlinear attitude estimation for walking machines using inertial sensors and vision. He is also interested in control and filtering with limited communication. He is currently Director of Research at RaySearch Laboratories AB, Stockholm

Göran Sporre was born in Järfälla, Sweden, in 1972. He received a civilingenjör degree in Engineering Physics from KTH in 1996. In 1997 he was employed at Telia Engineering, working with issues related to network planning for telecommunication. Since the beginning of 1998 he is a PhD student at the Division of Optimization and Systems Theory. His main research interest is interior methods for nonlinear programming.

Mathias Stolpe was born in Skerike, Sweden, in 1972. He received a Master of Science degree in Vehicle Engineering from KTH in 1997. He is presently a PhD student at the Division of Optimization and Systems Theory. His main area of research is structural optimization.

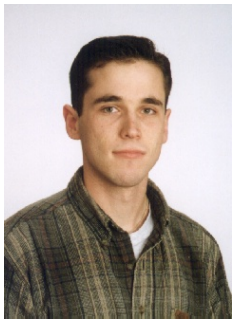
Krister Svanberg was born in Stockholm in 1950. In 1975 he got his Civilingenjör degree in Engineering Physics, in 1982 he got his TeknD degree in Optimization Theory, and in 1993 he was appointed Docent. Between 1976 and 1985 he worked for the Contract Research Group of Applied Mathematics, and since 1985 he is a Senior Lecturer. His main area of research is structural optimization, dealing with theory and methods for optimal design of load-carrying structures.

Claes Trygger was born in Stockholm, Sweden, in 1945. He received his civilingenjör degree in Engineering Physics in 1969 and his TeknL and TeknD degrees in Optimization and Systems Theory in 1974 and 1980, respectively; all from KTH. Since 1966 he has been employed in various positions at the Department of Mathematics at KTH, mainly in the Division of Optimization. At present he is a Senior Lecturer of Optimization and Systems Theory. Apart from teaching, his main professional interests are control theory and mathematical biology.

Vladimir Yakubovich was born in Novosibirsk, Russia, in 1926. He was a student of Mechanics and Mathematics at Moscow University from 1946 to 1949. In 1949 he received the first prize for student scientific work and was recommended by two chairs (those of I. M. Gelfand and V. V. Nemyzki) for postgraduate education but was refused at the request of Comsomol and the Communist Party (after he had protested against discrimination of Jewish students in admittance to postgraduate studies). In 1953, after having worked for some time in industry as an engineer, he received the Candidate of Science degree (PhD), and then he served as an Assistant and an Associate Professor at Leningrad Mining Institute. From 1956 to present time he has been associated with St. Petersburg University (formerly Leningrad University), where in 1959 he received the Doctor of Science Degree. He became a (full) Professor of Mathematics in 1963 and head of the Theoretical Cybernetics Chair in 1971.

He is the author of more than 250 papers and coauthor of seven books in different areas of mathematics, especially applied mathematics and control theory. He has worked in parametric resonance theory (extending and improving some Lyapunov results), in the theory of stability of nonlinear systems, and in optimization theory. He introduced a method of "recursive aim inequalities" in the theory of adaptive systems, and an abstract theory of optimal control, extending the Pontrjagin maximum principle to many new cases. The "Kalman-Yakubovich-Popov Lemma" connects two areas of control theory, frequency methods and Lyaponov methods, and it is also of importance in stochastic realization theory. His main results in recent years concern new aspects of linear-quadratic optimization problems.

Yakubovich has served on the editorial boards of Siberian Mathematical Journal (1973-1980), Systems and Control Letters (1981-1988) and Dynamics and Control (since 1990). He has served on many scientific committees and is a member of several scientific societies in Russia. In 1991 he was awarded the Norbert Wiener Prize by the Russian Academy of Natural Sciences. Since 1991 he is a corresponding member of the Russian Academy of Sciences and since 1992 a member of the Russian Academy of Natural Science.



Petter Ögren was born in 1974 in Stockholm, Sweden. He recieved his Master of Science degree in Engineering Physics from KTH in 1998. He is currently a PhD-student at the division, affiliated with the Centre for Autonomous Systems. Research interests are the systems theory of mobile robotics, including multi-agent coordination, navigation and obstacle avoidance.

1.3 Visiting and interacting scientists

- Professor Christopher I. Byrnes, Department of Systems Science and Mathematics, Washington University, St. Louis, Missouri, USA
- Professor Daizhan Cheng, Institute of Systems Science, Chinese Academy of Sciences, Beijing, China
- Professor Mario di Bernardo, Dipartimento di Ingegneria, Università del Sannio in Benevento, Benevento, Italy
- Fernando D'Amato, School of Aeronautics and Astronautics, Purdue University, West Lafayette, IN, USA
- Professor Tryphon T. Georgiou, Department of Electrical and Computer Engineering, University of Minnesota, Minneapolis, Minnesota, USA
- Professor Bijoy K. Ghosh, Department of Systems Science and Mathematics, Washington University, St. Louis, Missouri, USA
- Professor Philip E. Gill, Department of Mathematics, University of California, San Diego, La Jolla, California, USA
- Luigi Iannelli, Dipartimento di Informatica e Sistemistica, Università degli Studi di Napoli "Federico II", Napoli, Italy
- Dr. Karl H. Johansson, Department of Signals, Systems and Sensors, KTH
- Dr. S. V. Gusev, Department of Mathematics, St. Petersburg University, St. Petersburg, Russia
- Chung-Yao Kao, Laboratory for Information and Decision Systems, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA.
- Professor Naomi E. Leonard, Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, New Jersey, USA.
- Dr. Jorge Marí, Bombardier Transportation, Västerås, Sweden
- Professor Clyde F. Martin, Department of Mathematics, Texas Tech University, Lubbock, Texas, USA
- Professor Alexandre Megretski, Laboratory for Information and Decision Systems, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA.
- Professor György Michaletzky, Department of Probability Theory and Statistics, Eötvös Lorand University, Budapest, Hungary
- Professor Giorgio Picci, Department of Electronics and Informatics, University of Padova, Padova, Italy
- Professor Anders Rantzer, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden.
- Professor Mario Rotea, School of Aeronautics and Astronautics, Purdue University, West Lafayette, IN, USA
- Professor Shankar Sastry, Department of Electrical Engineering and Computer Sciences, University of California, Berkeley, USA
- Professor Francesco Vasca, Dipartimento di Ingegneria, Università del Sannio in Benevento, Benevento, Italy
- Docent Yishao Zhou, Department of Mathematics at Stockholm University, Stockholm, Sweden

1.4 Networks

- European Research Consortium for Informatics and Mathematics (ERCIM): Working Group on Control and System Theory
- European Research Network for Systems Identification (ERNSI)
- NorFa Network on Structural Optimization.
- Strategic Research Consortium of Autonomous Systems, KTH

2 Research

2.1 List of projects

- Generalized moment problems with complexity constraints
- Geometric theory of linear stochastic systems
- Hybrid control of autonomous system
- Identification of positive real linear systems via orthonormal basis expansion
- Integral quadratic constraints
- Interior point solutions of variational problems
- KTH optimization laboratory
- Large-scale nonlinear programming
- Models and methods for structural optimization
- Optimal damping of forced oscillations in discrete-time systems
- Optimization in telecommunications network design
- Path planning and control of nonlinear systems using sensor-data feedback
- Periodic systems
- Process modelling, operator training simulation and optimization applied to paper board manufacturing
- Rational Nevanlinna-Pick interpolation with degree constraints
- Robust control along trajectories
- The rational covariance extension problem, cepstral geometry, and global analysis of shaping filters

2.2 Description of projects

Generalized moment problems with complexity constraints

Researchers: Anders Lindquist, Anders Blomqvist and Vanna Fanizza in cooperation with C. I. Byrnes (Washington University, St Louis).

Sponsors: The Swedish Research Council (VR) and the Göran Gustafsson Foundation.

In [R2][A3] we derived a universal solution to the generalized moment problem, with a nonclassical complexity constraint, obtained by minimizing a strictly convex nonlinear functional. This optimization problem has been derived in two different ways. We have answered the question of why, intrinsically, there should always be an equivalent convex optimization problem. We have settled this question in a geometric way by path integration of a one-form which defines the generalized moment problem. We have shown that this one-form is closed and defined on a convex set, and thus exact. Since its integral is therefore path-independent, it is intrinsic and a strictly convex functional. We have also given a new derivation of this convex functional as the dual problem of a problem to maximize a a cross entropy functional. In particular, these approaches give a constructive parameterization of all solutions to the Nevanlinna-Pick interpolation problem, with possible higher-order interpolation at certain points in the complex plane, with a degree constraint.

This generalizes some the results in the projects *Rational Nevanlinna-Pick interpolation with degree constraints* and *The rational covariance extension problem, cepstral geometry, and global analysis of shaping filters* to the more general setting of generalized moment problems. In another direction, these results are being applied to systems identification using orthogonal basis function expansions, and some connections to probability and statistics are being pursued.

Geometric theory of linear stochastic systems

Researchers: Anders Lindquist, in cooperation with Giorgio Picci (University of Padova) and Gy. Michaletzky (Eötvös Lorand University, Budapest).

Sponsors: The Swedish Research Council (VR) and the Göran Gustafsson Foundation.

The objective of this project is to develop a comprehensive geometric theory for state-space modeling of stochastic processes within the coordinate-free framework of Markovian splitting subspaces and with emphasis on systems theoretical concepts, and to apply these results to problems in identification and model reduction. A theory for linear stochastic systems has been developed which describes structural systems-theoretic properties in the geometric language of Hilbert space theory. A monograph, jointly authored by Lindquist and Picci, is under preparation. Recent results include:

- We have developed a synthesis of stochastic realization theory and geometric control theory in the style of Wonham and Basile and Marro.
- We have generalized the well-known characterization of the solutions of the algebraic Riccati equation in terms of Lagrangian subspaces invariant under the corresponding Hamiltonian to the larger solution set of the algebraic Riccati inequality. The discrete-time Riccati equation has been studied in detail.

- Connections have been established between stochastic realization theory and identification algorithms based on canonical correlation analysis. Some geometric alternatives to subspace identification methods are considered.

Hybrid control of autonomous system

Researchers: Anders Lindquist, Xiaoming Hu, Henrik Rehbinder, Torvald Ersson and Petter Ögren.

Sponsor: The Swedish Foundation for Strategic Researches (SSF).

This project is part of an ongoing research effort of the Center for Autonomous Systems. In this project we use a hybrid system approach to study some issues concerning the integration of control and sensor systems for complex systems such as autonomous systems. In particular, the following issues are studied.

1. Hierarchical control architechtures for autonmous systems.
2. Sensor fusion and active sensing under real-time constraints.
3. Feedback Control under sensor and communication constraints.
4. Path following, mobile manipulation and multi-agent control.

Identification of positive real linear systems via orthonormal basis expansion

Researchers: Anders Lindquist, Anders Blomqvist and Vanna Fanizza.

Sponsor: ERNSI.

A very popular method in system identification amont to estimating the first n coefficients in an orthogonal basis function expansion of a transfer function. Given these estimated coefficients, the usual problem considered has been to find a rational function of smallest degree which match these coefficients. In this project we consider the corresponding class of problems when the transfer function is required to be positive real i.e. a Caratheodory function. This is important both for stochastic system and in robust control. To achive this we shall use a recent theory on the generalized moment problem with complexity constraint developed by Byrnes and Lindquist.

Integral quadratic constraints

Researchers: U. Jönsson, in cooperation with A. Megretski (M.I.T), A. Rantzer (Lund Institute of Technology, C. Kao (M.I.T), M. Rotea (Purdue University), and F. D'Amato (Purdue University).

We are involved in an effort to develop the framework of Integral Quadratic Constraints (IQCs). In 1994 it was shown by Megretski and Rantzer how Integral Quadratic Constraints (IQCs), a term originally coined by Yakubovich, can be used to unify the scaling techniques from robust control with the multiplier techniques from the input-output theory. There have been a rapid development in this research area during the last few years. One important direction is the development efficient and user friendly software for IQC analysis. We have made several contributions in this area and we participated in the development of the software package IQC-beta [O4]. One important aspect is the development of efficient algorithms for IQC optimization. Recent work by Kao shows that cutting plane techniques gives efficient algorithms for IQC optimization of LTI systems [R7]. We gave two tutorial talks on IQCs this year, [P3] and [P7].

Interior point solutions of variational problems

Researchers: Anders Lindquist in cooperation with C. I. Byrnes (Washington University, St Louis).

Sponsors: The Swedish Research Council (VR) and the Göran Gustafsson Foundation.

Variational problems and the solvability of certain nonlinear equations have a long and rich history beginning with calculus and extending through the calculus of variations. We have studied "well-connected" pairs of such problems which are not necessarily related by critical point considerations. We have also studied constrained problems of the kind which arise in mathematical programming as well as constraints of a geometric nature where a solution is sought on a leaf of a foliation. In these cases we are interested in interior minimizing points for the variational problem and in the well-posedness (in the sense of Hadamard) of solvability of the related systems of equations. We have proved a general result which implies the existence of interior points and which also leads to the development of certain generalization of the Hadamard-type global inverse function theorem, along the theme that uniqueness quite often implies existence. This result has been illustrated by proving the nonexistence of shock waves for certain initial data for the vector Burgers' equation, by a geometric analysis of the existence of interior points for linear programming problems, and by a derivation of the existence of positive definite solutions of matrix Riccati equations without first analyzing the nonlinear matrix Riccati differential equation.

KTH optimization laboratory

Researchers: Ulf Brännlund, Anders Forsgren, Mikael Prytz, Göran Sporre, Mathias Stolpe, Krister Svanberg.

This project aims at creating a productive research environment for development of optimization methods and at spreading modern optimization practice in Swedish industry. This is done by collecting state-of-the-art portable optimization routines as well as optimization problems and keeping them available in a network of work stations. This obviously will facilitate research, but through our projects and through making the routines available for testing, we also fulfill the other goal.

A partial list of routines include:

MINOS, SNOPT, QPOPT, LSSOL, NPOPT	(Gill et al, Stanford and UCSD)
CPLEX	(Cplex Corporation)
MMA	(Svanberg, KTH)
GRG2	(Lasdon, U Texas)
RELAX	(Bertsekas, MIT)
NETFLO, NETSIDE	(Kennington, S Methodist U)
NLPQL	(Schittkowski, U Bayreuth)
NOA3	(Kiwiel, Polish Academy of Sciences)
RSDNET, RSDTA	(Hearn, U Florida)
GAMS	(GAMS)
ELSUNC, ENLSIP	(Umeå University)

The routines reside in a Unix workstation environment, in which we have written an interfaces to Matlab for several routines, thereby making them easy to use. These interfaced routines have been used extensively, both in our own research and for educational purposes.

Large-scale nonlinear programming

Researchers: Anders Forsgren and Göran Sporre, in cooperation with Philip E. Gill (UCSD).

Sponsor: The Swedish Research Council (VR).

The goal of this project is the development of computationally efficient methods for solving large sparse nonlinear optimization problems. We focus on methods that utilize second-derivatives, since we expect such methods to prove more robust and efficient than methods that only use first-derivative information.

Recent algorithmic work has been directed towards penalty-barrier methods for general nonlinear programming methods, in particular linear algebra issues related to such methods [A7]. The current focus of Sporre's research is on primal-dual interior methods, convergence properties in particular. Two reports have been completed during the academic year [R11][R12].

Models and methods for structural optimization

Researchers: Krister Svanberg and Mathias Stolpe.

Sponsor: The Swedish Research Council (VR).

Structural optimization deals with optimal design of load-carrying structures. The purpose of this project is to develop mathematical models and efficient numerical methods for different types of structural optimization problems. The main result obtained during the year is that a large class of topology optimization problems can in fact be modelled as *linear* mixed integer programming problems, see [R13]. This unexpected result may constitute the basis for a new approach to global optimization of structural topology.

Optimal damping of forced oscillations in discrete-time systems

Researchers: Anders Lindquist and Vladimir A. Yakubovich.

Sponsors: The Swedish Research Council (VR), the Royal Swedish Academy of Sciences (KVA), the Göran Gustafsson Foundation and INTAS.

In this project we consider a linear discrete-time control system affected by additive harmonic disturbances with known frequencies but unknown amplitudes and phases. The problem is to damp this forced oscillation in an optimal fashion by output feedback and to track a given signal. To this end we design a robust optimal regulator which is universal in the sense that it does not depend on the unknown amplitudes and phases and is optimal for all choices of these values. We have shown that, under certain natural technical conditions, an optimal universal regulator (OUR) exists in some suitable class of linear or nonlinear stabilizing and realizable regulators, provided the dimension of the output is no smaller than the dimension of the quasi-harmonic disturbance. When this dimensionality condition is not satisfied, the existence of an OUR is not a generic property. We have also shown that any OUR for this (deterministic) problem is an optimal regulator for a class of stochastic control problems of similar structure. Nonrationals solutions are also being studied.

We stress that our solutions are optimal in the sense stated above only, arbitrary universal optimal regulator. Therefore it is an important for an property of our procedure that it allows for a considerable degree of design freedom, and optimality should be regarded as one of several design specifications.

Optimization in telecommunications network design

Researchers: Mikael Prytz and Anders Forsgren (advisor).

Sponsor: Ericsson Radio Systems AB and the Swedish Research Council (VR).

This project considers models and optimization methods for telecommunications network design problems. The focus is on practical solution methods for real problems that are relevant for network designers in the tele- and datacommunications industry. The specific problems concern mainly link topology design and capacity dimensioning/provisioning in a communications backbone network with multicast traffic requirements. Network capacity is here selected from a discrete set of non-uniform levels such that total provisioning cost is minimized. Certain multicast routing constraints are also studied, in particular the case when the multicast distribution trees (source based/shortest path or core based/shared) have to be realizable by a common shortest path routing metric (e.g. when the multicast routing protocol PIM uses the unicast routing protocol OSPF to find shortest path trees). A certain shared tree multicast RP (Rendezvous Point) location problem is also studied in the project. A paper has been published [A15], three reports have been written [R8][R9][R10], a presentation has been held [P14], and Prytz has obtained his PhD degree [T1].

Path planning and control of nonlinear systems using sensor-data feedback

Researchers: Xiaoming Hu, B. Ghosh (Washington University) and C.F. Martin (Texas Tech. Univ.).

Sponsor: The Swedish Research Council (VR).

An integral part in the design and operation of autonomous systems is path planning and following. Both are difficult problems in a realistic environment and for a realistic mobile system. Equally if not even more difficult , is the problem of observing the structure of a dynamic environment using state variables. In brief, in this project we will study how to use sensor data for sensing, modeling and control. Several relevant theoretical issues will be studied. They include: using splines and other methods for environment reconstruction and path planning, fusing data from different types of sensors for more robust environment reconstruction and state observation, robust path following control and global feedback stabilization. Our methods will be strongly motivated from approaches in systems and control theory.

Periodic systems

Researchers: U. Jönsson, in cooperation with A. Megretski (M.I.T), C. Kao (M.I.T), K.H. Johansson S3, KTH, M. di Bernardo, University of Bristol, L. Iannelli, Università degli Studi di Napoli "Federico II", F. Vasca, Università del Sannio in Benevento.

Periodic phenomena can appear due to limit-cycle oscillation, forced vibration, or parametric excitation of the system. There is a rich theory for periodic systems, which addresses questions such as existence and uniqueness of solution, stability of solutions, robustness to period changing bifurcations, and many other properties.

Our work has been along two different directions. In the first branch of research we have considered extensions of systems analysis based on integral quadratic constraints to systems consisting of a nominal linear time periodic operator in feedback

interconnection with a structured operator, which represents uncertainties and nonlinearities in the system. Such feedback structures appear either directly or after linearization of the nominal system dynamics around a periodic solution. We have developed theoretical as well as computational tools for robust stability in previous years. In our most recent work we show that IQCs play an important role as a tool for proving existence of periodic solutions, for studying harmonic distortion in a nonlinear system, and for estimation of the magnitude of a periodic oscillation in an uncertain and/or nonlinear system [A11]. The key for success of this analysis is to consider IQCs defined on the space of square integrable periodic functions, which leads to an elegant and computationally attractive framework.

The second branch of research focus on relay systems. This is an important class of systems that may or may not give rise to a stable limit cycle oscillation. The existence of a limit cycle oscillation is desirable in some applications such as in autotuning of PID controllers while it is highly undesirable in pulse width modulated systems or systems with friction.

It is well known that small relay perturbations may change the appearance of closed orbits dramatically. In a recent work we showed that certain stable periodic solutions in relay feedback systems are robust to relay perturbations [C2]. In this way we have identified a class of limit cycle solutions, which is insensitive to small parametric perturbations in the system dynamics and the relay characteristic.

Undesired oscillations in a nonlinear system can sometimes be quenched by injecting appropriately designed dither signals on the input of the nonlinearity. Rigorous design and analysis of dither signals in relay feedback systems is complicated since the dynamics in nonsmooth. We are developing new methods for analysis and design of dithered relay system that are based on LMI optimization [C8].

Process modelling, operator training simulation and optimization applied to paper board manufacturing

Researchers: Per-Olof Gutman, Anders Linquist, Xiaoming Hu, Gianantonio Bortolin, Christelle Gaillemard in cooperation with Bengt Nilsson (AssiDomän Cartonboard AB), Hilding Elmqvist (Dynasim AB, Lund), and Pontus Ryd (Solvina AB, Göteborg).

Sponsors: The Swedish National Board for Industrial and Technical Development (Vinnova) through its KTS (Complex Technical Systems) program, and AssiDomän Cartonboard AB, Dynasim AB, and Solvina AB.

The project was funded by Vinnova from April 1999 until December 2001, and has continued thereafter with external support from AssiDomän Cartonboard AB, only. During 2002 Gianantonio Bortolin completed the research towards his licentiate thesis on modelling and estimation of curl and twist in multi-ply paperboard. Christelle Gaillemard joined the project as a graduate student, and will model the moisture content of a four layers papersheet using grey-box modelling and identification. She will also further develop the Modelica model of the drying section.

Rational Nevanlinna-Pick interpolation with degree constraints

Researchers: Anders Lindquist, Ryozo Nagamune, Anders Blomqvist and Vanna Fanizza in cooperation with C. I. Byrnes (Washington University, St Louis) and T. T. Georgiou (University of Minesota).

Sponsors: The Swedish Research Council (VR) and the Göran Gustafsson Foundation.

Several important problems in circuit theory, robust stabilization and control, signal processing, and stochastic systems theory lead to a Nevanlinna-Pick interpolation problem, in which the interpolant must be a rational function of at most a prescribed degree. We have obtained a complete parameterization of all such solutions in terms of the zero structure of a certain function appearing naturally in several applications, and this parameterization can be used as a design instrument. We have developed an algorithm to determine any such solution by solving a convex optimization problem, which is the dual of the problem to maximize a certain generalized entropy critierion. Software based on state space concepts is being developed, and the computational methods are applied to several problems in systems and control.

Recent results include:

- In [C12] a method for shaping the frequency response of a closed-loop system, based on the theory of Nevanlinna-Pick interpolation with a degree bound, is presented. It turns out that the spectral zeros of a certain function related to the closed-loop transfer function serve as design parameters. If necessary, some additional interpolation constraints can also be employed to increase the design flexibility. The main difference between this method and the existing H^∞ controller design methods is that we do not use the weighting functions to shape the frequency response of the sensitivity function. Instead, we will tune the spectral zeros of a positive real function related to the sensitivity function to obtain a desirable frequency response. In [C1] these results are generalized to the the case of multiple interpolation points, and in [R1] they are extended to the multvariable case.
- In [C14] the theory of Nevanlinna-Pick interpolation with degree constraint has been applied to the problem of robust regulation with robust stability. The controller set satisfying robust regulation with robust stability as well as a degree restriction forms a set with infinitely many elements. Other performance specifications can be satisfied by choosing the appropriate solution without increasing the controller degree.
- In [A14][C1][C13] a robust algoritm is developed for solving the convex optimization problem in our theory of Nevanlina-Pick interpolation with degree constraint. This algorithm, which is based on homotopy continuation with predictor-corrector steps, turns out to be quite efficient and numerically robust and avoid spectral factorization. The ill-conditoning intrinsic in the previous solvers is therefore avoided.
- In [R4] we introduce a Kullback-Leibler type distance between spectral density functions of stationary stochastic processes and solve the problem of optimal approximation of a given spectral density Ψ by one that is consistent with prescribed second-order statistics obtained from data produced by a bank of filters. In particular, we show (i) that there is a unique spectral density Φ which minimizes this Kullback-Leibler distance, (ii) that this optimal approximate is of the form Ψ/Q where the "correction term" Q is a rational spectral density function, and (iii) that the coefficients of Q can be obtained numerically by solving a suitable convex optimization problem. In the special case where $\Psi = 1$, the convex functional becomes quadratic and the solution is then specified by linear equations.

- Solutions of bounded complexity for generalized interpolation in H^∞ are also being studied together with the connections to the commutant lifting theorem of Sarason.
- Studies have begun to apply our methods Nevanlinna-Pick interpolation with degree constraint to the clasical Youla's problem of optimal power transfer.

Robust control along trajectories

Researchers: U. Jönsson in cooperation with C. Martin (Texas Tech), A. Megretski (M.I.T) C.-Y. Kao (LTH), Y. Zhou (Stockholm University).

Sponsor: The Swedish Research Council for Engineering Sciences (TFR).

This project considers a wide range of topics related to the design and analysis of trajectories for uncertain systems. So far our work has focused on three topics. The first is reach set computation for uncertain systems. This is the problem of computing the set of states that can be reached by an uncertain system and it is a crucial tool when verifying a hybrid system. Most of the reachability tools available today only consider coarse uncertainty descriptions such as differential inclusions, set valued disturbances, and ellipsoidal approximations. In our first contribution to this field we considered estimation of ellipsoidal sets around the nominal solution of a system, where uncertainty and disturbances are described by IQCs defined over a finite time horizon [A9]. More recently we developed similar ideas for estimating the transition map from one switching surface to another, which is useful when verifying hybrid systems [C10],[R6], and [C11].

The second topic is robustness analysis of periodic trajectories. We are here interested in deciding whether a periodic solution remains and if it stays stable in a neighborhood of the nominal solution when the dynamics of the system changes. This problem is hard since the nominal trajectory is perturbed when we introduce uncertainty, which is in stark contrast to the traditional problems in robust control where stability is considered for equilibrium points that remain fixed for all values of the uncertainty. In [A10] we solve such a robustness problem for periodic solutions of non-autonomous systems.

The third topic is planning of trajectories and synthesis of robust control laws for these trajectories. A first step in this was taken in [C9] where we showed how dynamic programming can be used to plan a trajectory for a linear stochastic differential equation such that the expected value of the output interpolates given points at given times while the variance and an integral cost of the control effort are minimized.

The rational covariance extension problem, cepstral geometry, and global analysis of shaping filters

Researchers: Anders Lindquist in cooperation with C. I. Byrnes (Washington University, St Louis) and Per Enqvist, LADSEB-CNR, Padova, Italy.

Sponsors: The Swedish Research Council (VR) and the Göran Gustafsson Foundation.

In [A2], we present a systematic description of all autoregressive moving-average (ARMA) models of processes that (i) match a finite window of $n+1$ covariance lags, (ii) are rational of degree at most n, and (iii) have stable zeros and poles. Indeed, we show each such ARMA model determines and is completely determined by its finite

windows of cepstral coefficients and covariance lags. This characterization has an intuitively appealing interpretation of a characterization by using measures of the transient and the steady-state behaviors of the signal, respectively. More precisely, we show that these nth order windows form local coordinates for all ARMA models of degree n and that the pole-zero model can be determined from the windows as the unique minimum of a convex objective function.

We also study the well-posedness of the problems of determining shaping filters from combinations of finite windows of cepstral coefficients, covariance lags, or Markov parameters. For example, we determine whether there exists a shaping filter with prescribed window of Markov parameters and a prescribed window of covariance lags. We show that several such problems are well-posed in the sense of Hadamard; that is, one can prove existence, uniqueness (identifiability) and continuous dependence of the model on the measuremnts. Our starting point is the global analysis of linear systems, where one studies an entire class of systems or models as a whole, and where one views measurements, such as covariance lags and cepstral coefficients or Markov parameters, from data as functions on the entire class. This enables one to pose such problems in a way that tools from calculus, optimization, geometry and modern nonlinear analysis can be used to give a rigorous answer to such problems in an algorithm-independent fashion. In this language, we prove that a window of cepstral coeficients and a window of covariance coefficients yields a bona fide coordinate system on the space of shaping filters thereby establishing existence, uniqueness and smooth dependence of the model parameters on the measurements from data.

3 Education

3.1 Undergraduate courses

5B1712 Optimization for F, 4 p (*Optimeringslära för F)*

Instructor: Krister Svanberg.

Assistants: Anders Blomqvist and Mathias Stolpe.

The course gives knowledge about basic concepts and theory for optimization, useful models, and numerical solution methods. Some subjects dealt with in the course are: Linear programming, network flows, nonlinear programming, convexity, Lagrangean relaxation, and duality.

5B1722 Applied Optimization for T and M, 4 p (*Tillämpad optimeringslära för T och M)*

Instructor: Claes Trygger.

Assistant: Mathias Stolpe.

The course gives knowledge about basic concepts and theory for optimization, useful models, and numerical solution methods. It also gives training in formulating and solving optimization problems. Some subjects dealt with in the course are: Linear programming, network flows, integer programming, deterministic dynamic programming, and nonlinear programming.

5B1742 Mathematical Systems Theory, 4 p (*Matematisk systemteori)*

Instructor: Claes Trygger.

Assistant: Anders Blomqvist.

The course gives knowledge about basic concepts in mathematical systems theory. Some subjects dealt with in the course are: Linear control systems, realization theory, feedback, stability, linear-quadratic optimal control, and Kalman filtering.

5B1750 Optimization for E and D, 4 p (*Optimeringslära för E och D)*

Instructor: Claes Trygger.

Assistant: Mathias Stolpe.

The course gives knowledge about basic concepts and theory for optimization, useful models, and numerical solution methods. It also gives training in formulating and solving optimization problems. Some subjects dealt with in the course are: Linear programming, network flows, integer programming, deterministic dynamic programming, and nonlinear programming.

5B1814 Applied Mathematical Programming—Linear Problems, 4 p
(*Tillämpad matematisk programmering—linjära problem)*

Instructor: Anders Forsgren.

Assistant: Göran Sporre.

The course should deepen and broaden the theoretical, methodological and modeling knowledge in linear and integer programming. Some subjects dealt with in the course are: Interior point methods for linear programming, stochastic programming, Lagrangian relaxation for integer programming, subgradient optimization. The modeling part of the course is carried out on a project basis in small groups. An important aspect of the course is cooperation within the group as well as presentation in talking and writing.

5B1816 Applied Mathematical Programming—Nonlinear Problems, 4 p
(*Tillämpad matematisk programmering—ickelinjära problem)*

Instructor: Anders Forsgren.

Assistant: Göran Sporre.

The course should deepen and broaden the theoretical, methodological and modeling knowledge in nonlinear programming. Some subjects dealt with in the course are: Interior point methods for nonlinear programming, quadratic programming, SQP methods for nonlinear programming and semidefinite programming. The modeling part of the course is carried out on a project basis in small groups. An important aspect of the course is cooperation within the group as well as presentation in talking and writing.

5B1832 Systems Engineering, 8 p
(*Systemteknik)*

This course is equivalent to the course 5B1842 Methods of Systems Engineering together with the course 5B1846 Applied Systems Engineering.

5B1842 Methods of Systems Engineering, 4 p
(*Systemtekniska metoder)*

Instructor: Claes Trygger.

Assistant: Mathias Stolpe.

The course gives knowledge about quantitative methods in operations research. Some subjects dealt with in the course are: Queueing theory, inventory theory, stochastic dynamic programming, and Markov decision processes.

5B1846 Applied Systems Engineering, 4 p
(*Tillämpad systemteknik)*

Instructors: Ulf Brännlund and Krister Svanberg.

Assistant: Mathias Stolpe.

The course gives deeper knowledge about some quantitative methods for analysis and design of technical systems. Some subjects dealt with in the course are: LCC analysis, multi-echelon spare parts optimization, and inventory control.

5B1852 Mathematical Economics, 4 p
(*Matematisk ekonomi)*

Instructor: Claes Trygger.

The course gives basic knowledge in modern mathematical microeconomics. Some subjects dealt with in the course are: Behavior of the firm, individual preferences, consumer demand, economic efficiency, competetive equilibrium, game theory, oligopoly and monopoly.

5B1872 Optimal Control Theory, 4 p
(*Optimal styrteori)*

Instructor: Ulf Jönsson.

Assistant: Ryozo Nagamune and Petter Ögren.

The course gives knowledge in the theory of optimal control. Some subjects dealt with in the course are: The Pontryagin maximum principle, dynamic programming in discrete and continuous time, the Hamilton-Jacobi-Bellman equation and numerical methods for solving optimal control problems.

3.2 Graduate course

5B5782 Robust control with classical methods — QFT, 4 p
(*Robust reglering med klassiska metoder)*

Instructor: Per-Olof Gutman.

Assistant: Gianantonio Bortolin.

The course covers robust linear control for uncertain linear and non-linear dynamical systems, using the Quantitative Feedback Theory (QFT) or the Horowitz method which is based on classical Bode-Nyquist-Nichols design in the frequency domain. The aim of the course is that the participant will be able to design controllers for a large class of industrial control systems, and will have a fundamental understanding of control design robustness issues. See the web page www.math.kth.se/optsyst/research/5B5782.pdf.

3.3 Doctoral theses

[T1] M. Prytz, *On Optimization in Design of Telecommunications Networks with Multicast and Unicast Traffic*, TRITA-MAT-02-OS-05, Division of Optimization and Systems Theory, Department of Mathematics, KTH, 2002. Advisor: A. Forsgren.

[T2] H. Rehbinder, *State Estimation and Limited Communication Control for Nonlinear Robotic Systems*, TRITA-MAT-01-OS-09, Division of Optimization and Systems Theory, Department of Mathematics, KTH, 2001. Advisors: X. Hu and A. Lindquist.

3.4 Licentitate thesis

[T3] T. Ersson, *Active Sensing, Navigation and On-line Path Planning*, TRITA-MAT-01-OS-12, Division of Optimization and Systems Theory, Department of Mathematics, KTH, 2001. Advisor: X. Hu.

3.5 Master theses (*Examensarbeten)*

5B1022 Master Thesis in Optimization and Systems Theory, 20 p (*Examensarbete i optimeringslära och systemteori)*

[T4] K. Bröms (F), *Punctuality analysis at Arlanda airport.* Performed at SAS. Advisor: A. Forsgren. (E253)

[T5] T. Bäckmark (F), *Neuronnätsbaserad agent.* Performed at OM Technology. Advisor: U. Jönsson. (E245)

[T6] T. Carbin (F), *Random early detection.* Performed at Ericsson Telecom. Advisor: A. Forsgren. (E247)

[T7] L. Häggroth (F), *Passiv lägesbestämning av markfast emitter med hjälp av långbasinterferometri.* Performed at FOI, Linköping. Advisor: A. Forsgren. (E246)

[T8] M. Lindkvist (F), *Modeling of purkinje cell death.* Performed at Texas Tech University. Advisor: X. Hu. (E252)

[T9] M. Philip (F), *Mathematical modelling of cardiac arrhythmias.* Performed at Texas Tech University. Advisor: X. Hu. (E248)

[T10] J. Pütz (F), *A case study of two stochastic programming methods for portfolio management with conditional value-at-risk constraints.* Performed at University of Florida. Advisor: U. Brännlund. (E249)

[T11] C. Weiler (F), *En modell för optimalt val av felutfallsnivå på utmattningsbelastade detaljer.* Performed at Volvo Wheel Loaders. Advisor: K. Svanberg. (E250)

[T12] K. Winter (F), *Mathematical modeling of propagating waves in the visual cortex.* Performed at Texas Tech University. Advisor: X. Hu. (E251)

5B1023 Master Thesis in Systems Engineering, 20 p (*Examensarbete i systemteknik)*

[T13] H. Björk (T), *Portföljvalsoptimering för småsparare.* Performed at Ekedahl & Co. Advisor: U. Brännlund. (S142)

[T14] D. Ehrenstråhle (M), *Route planning for sales representatives using utility functions and simulated annealing.* Performed at ZC Associates, Paris. Advisor: K. Svanberg. (S143)

[T15] C. Forsgren (M), *Finding globally optimal beam angles in intensity modulated radiotherapy.* Performed at RaySearch Laboratories. Advisor: A. Forsgren. (S146)

[T16] S. Hermansson (T), *Customized asset allocation models.* Performed at CrossCap AB. Advisor: U. Brännlund. (S140)

[T17] A. Kassem Chireh (T), *An algorithm for torque measurement by wrench.* Performed at Atlas Copco Tools AB. Advisor: X. Hu. (S139)

[T18] J. Lindberg (T), *Optimering av räntebindningsstrategi för låneportfölj.* Performed at AGL Structured Finance. Advisor: U. Brännlund. (S141)

[T19] H. Pott (M), *The Market Selection Problem.* Performed at University of Florida. Advisor: C. Trygger. (S144)

[T20] H. Stark (T), *The duty assignment problem for pilots at SAS*. Performed at SAS. Advisor: U. Brännlund. (S147)

[T21] M.-D. Tram (T), *LCC-modell för robotcell*. Performed at ABB Body in White. Advisor: U. Brännlund. (S138)

[T22] C. Viberg (M), *Analysis of various one and two period models for asset liability management of pension funds*. Performed at University of Florida. Advisor: U. Brännlund. (S145)

4 Seminars at the division

- Mikael Johansson, Stanford University, *Joint optimization of wireless networks and linear systems*, August 31, 2001.
- Sven Leyffer, University of Dundee, *How the Grinch solved MPECs, mathematical programs with equilibrium constraints*, September 25, 2001.
- Sven Leyffer, University of Dundee, *A review of mixed integer nonlinear programming*, September 27, 2001.
- Yulia Gel, St. Petersburg State University and Mälardalen University, *The convergence analysis of the least-squares estimates for AR models of infinite order*, October 5, 2001.
- Vladimir A. Yakubovich, St. Petersburg State University, *Design of stabilizing controllers with system output independent of external disturbance*, October 11, 2001.
- Natalia Balashevich, National Academy of Sciences of Belarus, *Real-time optimization of control systems*, October 16, 2001.
- Henrik Rehbinder, KTH, *State estimation for nonlinear robotic systems*, November 16, 2001.
- Torvald Ersson, KTH, *Active sensing, navigation and on-line path planning for mobile robots*, Licentiate seminar, December 14, 2001.
- György Michaletzky, Eötvös Loránd University, Budapest, Hungary, *Risk sensitive identification of ARMA processes*, February 8, 2002.
- Mikael Prytz, KTH, *On optimization in design of telecommunications networks with multicast and unicast traffic*, March 15, 2002.
- Ulf Jönsson, KTH, *On reachability analysis of uncertain systems*, Docent seminar, April 12, 2002.
- Jorge Marí, Bombardier Transportation, Västerås, *Analyses of propulsion system configurations for dynamic performance at design stage*, May 17, 2002.
- Luigi Iannelli, Università degli Studi di Napoli Federico II, Napoli, Italy, *Pricing techniques for network congestion control*, May 24, 2002.
- Magnus Egerstedt, Georgia Institute of Technology, Atlanta, Georgia, USA, *Linguistic control of mobile robots*, May 31, 2002.

5 Publications

5.1 Papers in journals and books (published and accepted)

[A1] C. I. Byrnes, S. V. Gusev and A. Lindquist, *From finite covariance windows to modeling filters: A convex optimization approach*, SIAM Review 43 (Dec. 2001), 645–675, SIGEST paper.

[A2] C. I. Byrnes, P. Enqvist and A. Lindquist, *Identifiability and well-posedness of shaping-filter parameterizations: A global analysis approach*, SIAM J. Control and Optimization 41 (Jan. 2002), 23–59.

[A3] C. I. Byrnes and A. Lindquist, *A convex optimization approach to generalized moment problems*, to appear in festschrift for Hidenori Kimura to be published by John Wiley.

[A4] M. Egerstedt and X. Hu, *A hybrid control approach to action coordination for mobile robots*, Automatica, vol. 38 , no. 1, 2002.

[A5] M. Egerstedt, X. Hu and A. Stotsky, *Control of mobile platforms using a virtual vehicle approach*, IEEE. Trans. Aut. Control, vol. 46, November, 2001.

[A6] M. Egerstedt and X. Hu, *Formation constrained multi-agent control*, IEEE trans. Robotics and Automation, December, 2001.

[A7] A. Forsgren, *Inertia-controlling factorizations for optimization algorithms*, To appear in Applied Numerical Mathematics.

[A8] I. Ioslovich and P.-O. Gutman, *A model for the global optimization of water prices and usage for the case of spatially distributed sources and consumers*, Mathematics and Computers in Simulation, vol. 56, 347-356, 2001.

[A9] U. Jönsson, *Robustness of trajectories with finite time extent*, Automatica, 38(9)(2002), 1485-1497.

[A10] U. Jönsson, C. Kao and A. Megretski, *Robustness analysis of periodic trajectories*, To appear in IEEE Transactions on Automatic Control.

[A11] U. Jönsson and C. Kao and A. Megretski, *Analysis of periodically forced uncertain feedback systems*, To appear in IEEE Transactions on Circuits and Systems-I: Fundamental Theory and Applications.

[A12] A. Liberzon, D. Rubinstein and P.-O. Gutman, *Active suspension for single wheel station of off-road track vehicle*, Int. J. of Robust and Non-linear Control, vol. 11, issue 10, 977-999, 2001.

[A13] R. Linker, P.-O. Gutman and I. Seginer, *Observer-based robust failure detection and isolation in greenhouses*, Control Engineering Practice, vol. 10, no. 5, 519-531, 2002.

[A14] R. Nagamune, *A robust solver using a continuation method for Nevanlinna-Pick interpolation with degree constraint*, IEEE Transactions on Automatic Control (accepted for publication).

[A15] M. Prytz and A. Forsgren, *Dimensioning multicast-enabled communications networks*, Networks 39(2002), 216-231.

[A16] H. Rehbinder and B. K. Ghosh, *Pose estimation using line based dynamic vision and inertial sensors*, To appear in the Transactions on Automatic Control.

[A17] M. Stolpe and K. Svanberg, *An alternative interpolation scheme for minimum compliance topology optimization*, Structural and Multidisciplinary Optimization 22(2001), 116-124.

[A18] M. Stolpe and K. Svanberg, *A note on stress-constrained truss topology optimization*, To appear in Structural and Multidisciplinary Optimization.

[A19] K. Svanberg, *A class of globally convergent optimization methods based on conservative convex approximations*, SIAM Journal on Optimization 12(2002), 555–573.

[A20] P. Ögren and C. F. Martin, *Vaccination strategies for epidemics in highly mobile populations*, Journal of Applied Mathematics and Computation, 127 (2002) 261-276.

[A21] P. Ögren, M. Egerstedt and X. Hu, *A control Lyapunov function approach to multi-agent coordination*, To appear in IEEE Transactions on Robotics and Automation, October 2002 issue.

5.2 Papers in conference proceedings (published and accepted)

[C1] A. Blomqvist and R. Nagamune, *A new solver for degree constrained Nevanlinna-Pick interpolation including derivative constraints*, Reglermöte 2002, Linköping, Sweden, 25-30.

[C2] M. di Bernardo, K. H. Johansson, U. Jönsson and F. Vasca, *On the robustness of periodic solutions in relay feedback systems*, In *IFAC World Congress, Preprints*, Barcelona, Spain, 2002.

[C3] T. Ersson and X. Hu, *Path planning and navigation of mobile robots in unknown environments*, in the proc. of IROS 2001.

[C4] T. Ersson and X. Hu, *Implicit observers and active perception*, in the proc. of IROS 2001.

[C5] T. Ersson and X. Hu, *State observer of system with nonlinear outputs*, in the proc. of CDC 2001.

[C6] P.-O. Gutman, E. Horesh, R. Guetta, M. Borshchevsky, *Control of the aeroelectric power station - an exciting QFT application for the 21st century*, International Symposium on Quantitative Feedback Theory and Robust Frequency Domain Methods, Plenary Lecture, Public University of Navarre, Pamplona, Spain, 23 - 24 August, 2001.

[C7] X. Hu, U. Jönsson and C. Martin, *Input tracking for stable linear systems*, In *IFAC World Congress*, Barcelona, Spain, 2002.

[C8] L. Iannelli, K. H. Johansson, U. Jönsson and F. Vasca, *Analysis of dither in relay feedback systems*, In *Reglermöte 2002, preprints*, pages 36–41, Linköping, Sweden, 2002.

[C9] U. Jönsson, C. F. Martin and Y. Zhou, *Trajectory planning under a stochastic uncertainty*, In *Fifteenth International Symposium on Mathematical Theory of Networks and Systems*, 2002.

[C10] U. Jönsson, *Robustness of transitions in switched hybrid system*, In *Proceedings of the IEEE Conference on Decision and Control 2001*, pages 2484–2489, Orlando, FLA, 2001.

[C11] U. Jönsson, *On reachability of uncertain systems*, In *Reglermöte 2002, Preprints*, pages 340–345, Linköping, Sweden, 2002.

[C12] R. Nagamune, *Closed-loop shaping by analytic functions with a bounded degree*, European Control Conference 2001 (ECC01) in Porto, Portugal, 722-726.

[C13] R. Nagamune, *A robust solver using a continuation method for Nevanlinna-Pick interpolation with degree constraint*, the 40th Conference on Decision and Control (CDC01) in Orlando, Florida, 1119-1124.

[C14] R. Nagamune, *Simultaneous robust regulation and robust stabilization with degree constraint*, Fifteenth International Symposium on Mathematical Theory of Networks and Systems, 2002.

[C15] J. Norberg, T. Ersson, J. Vinter, M. Thörngren, P. Folkesson and J. Karlsson, *A co-design approach for error handling in computer control systems*, International Conference on Dependable Systems and Networks, 2002.

[C16] H. Rehbinder and B. K. Ghosh, *Rigid body state estimation using line based dynamic vision and inertial sensors*, IEEE Conference on Deciscion and Control, Orlando, Florida, USA, Dec. 2001.

[C17] H. Rehbinder and B. K. Ghosh, *Multi-rate fusion of visual and inertial data*, IEEE Conference on Multisensor Fusion and Integration for Intelligent Systems, Baden-Baden, Germany, Aug. 2001.

[C18] K. Svanberg and M. Stolpe, *On the modeling of topology optimization problems*, Proceedings of the 2nd Max Planck Workshop on Engineering Design Optimization, Nyborg, October 12-14, 2001.

[C19] P. Ögren, M. Egerstedt and X. Hu, *A control Lyapunov function approach to multi agent coordination*, IEEE Conference on Decision and Control, Orlando, Florida, USA, Dec. 2001, 1150-1155 vol.2.

[C20] P. Ögren and N. Leonard, *A provable convergent dynamic window approach to obstacle avoidance*, IFAC World Congress, Barcelona, Spain, July 2002.

[C21] P. Ögren, E. Fiorelli and N. Leonard, *Formations with a mission: Stable coordination of vehicle group maneuvers*, 15th Int. Symposium on Mathematical Theory of Networks and Systems, Indiana, Aug. 2002.

[C22] P. Ögren and N. Leonard, *A tractable convergent dynamic window approach to obstacle avoidance*, IEEE/RSJ International Conference on Intelligent Robots and System, 2002. 595- 600.

5.3 Other publications

[O1] P.-O. Gutman, *Robust and adaptive control fidelity or a free relationship?*, Chapter 7 in: S. O. Reza Moheimani (ed.), Perspectives in Robust Control. Lecture Notes in Control and Information Sciences 268, Springer-Verlag, London, 374 pages, 2001.

[O2] P.-O. Gutman, R. Linker, *QFT - Méthode classique pour la synthèse de commande robuste*, chapter 1 in J. Bernussou , A. Oustaloup (eds), Commande robuste, Hermès, Paris, 2002.

[O3] U. Jönsson, *Review of "A Course in Robust Control Theory: A Convex Approach", G. E. Dullerud and F. Paganini, Springer-Verlag, New York, NY*, International Journal of Robust and Nonlinear Control 12(7), 2002, page 623–625.

[O4] A. Megretski and C. Kao and U. Jönsson and A. Rantzer, *A Guide To IQC-beta: Software for Robustness Analysis*, http://www.mit.edu/people/cykao/home.html.

[O5] M. Nordin, P. Bodin and P.-O. Gutman, *New models and identification methods for backlash and gear play*, in G. Tao and F.L. Lewis (eds.), Adaptive Control of Nonsmooth Dynamic Systems, Springer, London, 407 pages, 2001.

5.4 Technical reports and preprints

[R1] A. Blomqvist, A. Lindquist and R. Nagamune, *Matrix-valued Nevanlinna-Pick interpolation with complexity constraint: An optimization approach*, submitted for publication (available as Report TRITA/MAT-02-OS13, 2002).

[R2] C. I. Byrnes and A Lindquist, *Interior point solutions of variational problems and global inverse function theorems*, submitted for publication (available as Report TRITA/MAT-01-OS13, 2001).

[R3] M. di Bernardo, K. H. Johansson, U. Jönsson, and F. Vasca, *On the robustness of periodic solutions in relay feedback systems*, Technical Report TRITA/MAT-02-OS06, Department of Mathematics, Royal Institute of Technology, 2002.

[R4] T. T. Georgiou and A. Lindquist, *Kullback-Leibler approximation of spectral density functions*, submitted for publication (available as Report TRITA/MAT-02-OS11, 2002).

[R5] L. Iannelli and K.-H. Johansson and U. Jönsson and F. Vasca, *Analysis of dither in relay feedback systems*, Department of Signals, Sensors and Systems, Royal Institute of Technology.

[R6] U. Jönsson, *Robustness of transitions in switched linear systems*, Technical Report TRITA/MAT-02-OS08, Department of Mathematics, Royal Institute of Technology, 2002.

[R7] C.-Y. Kao, A. Megretski, and U. Jönsson, *Oracle-based cutting plane algorithms for iqc feasibility and optimization problems*, Technical Report LIDS-P-2539, Laboratory for Information and Decision Systems, Massachusetts Institute of Technology, March 2002.

[R8] M. Prytz and A. Forsgren, *Dimensioning of a multicast network that uses shortest path routing distribution trees*, Report TRITA-MAT-2002-OS1, Department of Mathematics, Royal Institute of Technology, 2002.

[R9] M. Prytz, *RP placement for shared multicast distribution trees in a shortest path routing network*, Report TRITA-MAT-2002-OS2, Department of Mathematics, Royal Institute of Technology, 2002.

[R10] M. Prytz, *Lagrangian decomposition for general step cost single path network design*, Report TRITA-MAT-2002-OS3, Department of Mathematics, Royal Institute of Technology, 2002.

[R11] G. Sporre and A. Forsgren, *Relations between divergence of multipliers and convergence to infeasible points in primal-dual interior methods for nonconvex nonlinear programming*, Report TRITA-MAT-2002-OS7, Department of Mathematics, Royal Institute of Technology, 2002.

[R12] G. Sporre and A. Forsgren, *Characterization of the limit point of the central path in semidefinite programming*, Report TRITA-MAT-2002-OS12, Department of Mathematics, Royal Institute of Technology, 2002.

[R13] M. Stolpe and K. Svanberg, *Modeling topology optimization problems as linear mixed 0–1 programs*, Report TRITA-MAT-01-OS10, Department of Mathematics, KTH, 2001. Submitted for publication.

6 Awards and appointments

Ulf Jönsson was appointed Docent of Optimization and Systems Theory, April 2002.

Ryozo Nagamune was awarded *CDC Best Student-Paper Award* from IEEE Control Systems Society. The award ceremony was held on December 6th, 2001, Control (CDC01) at Orlando, Florida.

7 Presentations

[P1] A. Forsgren, *On the convergence to second-order points in nonconvex optimization*, The 7th SIAM Conference on Optimization, Toronto, Canada, May 20–22, 2002.

[P2] U. Jönsson, *Robustness analysis of periodic systems*, Department of Mathematics and Statistics, Texas Tech University, October 10, 2001.

[P3] U. Jönsson, *Introduction to integral quadratic constraints*, Department of Mathematics and Statistics, Texas Tech University, October 17, 2001.

[P4] U. Jönsson, *Reachability analysis of uncertain systems*, Laboratory for Information and Decision Systems, M.I.T, October 25, 2001.

[P5] U. Jönsson, *Robustness of transitions in switched hybrid system*, Conference on Decision and Control, Orlando, Florida.

[P6] U. Jönsson, *On reachability analysis of uncertain systems*, Department of Automatic Control, LTH, May 15, 2002.

[P7] U. Jönsson, *Introduction to integral quadratic constraints*, Department of Automatic Control, LiTH, June 12, 2002.

[P8] A. Lindquist, *A global analysis approach to robust control*, Plenary speaker at 5th IFAC Symposium "Nonlinear Control Systems" (NOLCOS 2001), Saint Petersburg, Russia, July 4 - 6, 2001.

[P9] A. Lindquist, *Partial realization theory: A basic paradigm in signals, systems and control*, Plenary speaker at Fourth SIAM Conference on Linear Algebra in Signals, Systems and Control, Boston, USA, August 13-16, 2001.

[P10] A. Lindquist, *A global analysis approach to robust control*, In vited speaker at Cybernetics in the 21st Century: Information and Complexity in Control Theory, University of Tokyo, Japan, November 1–2, 2001.

[P11] A. Lindquist, *A short course on Nevanlinna-Pick interpolation theory*, Eight hours of lecturesat Åbo Academi University, November 26 - 29, 2001.

[P12] A. Lindquist, *On the duality between filtering and Nevanlinna-Pick interpolation*, 40th IEEE Conference on Decision and Control (CDC01), Orlando, Florida, December, 2001.

[P13] A. Lindquist, *A convex optimization approach to generalized moment problems*, Invited colloquium lecture at the Stieltjes Analysis Colloquium, Thomas Stieltjes Institute for Mathematics, Amsterdam, the Netherlands, April 8, 2002.

[P14] M. Prytz, *Network dimensioning for multicast traffic*, Networking Laboratory, Department of Electrical and Communications Engineering,Helsinki University of Technology, October 23, 2001.

[P15] K. Svanberg, *Topology optimization of load-carrying structures*, NTNU, Trondheim, December 3, 2001.

[P16] K. Svanberg, *On the modeling of topology optimization problems*, 2nd Max Planck Workshop on Engineering Design Optimization, Nyborg, October 12-14, 2001.

[P17] P. Ögren, *A control Lyapunov function approach to multi-agent coordination*, Princeton University, October 12, 2001.

8 Other activities

Gianantonio Bortolin

- ERNSI meeting, September 16-19, 2001 Cambridge, England.
- SPCI2002 Control System Conference, June 3-5 Stockholm, Sweden.
- Referee for Automatica.

Ulf Brännlund

- Responsible for the line of competence (kompetensinriktning), Systems engineering, for the schools of mechanical and vehicle engineering.
- Opponent on Licentiate Thesis (Tuomo Takkula) at Chalmers University.
- Referee for Power Systems Computations Conference in Sevilla 2002.

Vanna Fanizza

- Participated in the minicourse entitled *A short course in Nevanlinna-Pick interpolation theory* in Åbo Akademi University, Finland, November 26-29, 2001.

Anders Forsgren

- Associate editor for Mathematical Programming, Series A.
- Member of editorial board for Computational Optimization and Applications.
- Expert evaluation (sakkunningutlåtande) for two academic positions.
- Visited the University of California, San Diego, California, USA, June 24–July 5, 2002.
- Referee for Mathematical Programming, SIAM Journal on Matrix Analysis and Applications, and BIT.

Christelle Gaillemard

- Participation to the minicourse entitled *A short course in Nevanlinna-Pick interpolation theory* in Åbo Akademi University, Finland, November 26-29 2001.
- Participation to Reglermöte in Linköping, May 29-30 2002.

Ulf Jönsson

- Appointed Docent on April 12, 2002.
- Referee for Automatica, IEEE Transactions on Automatic Control, SIAM Journal of control and optimization, ASME journal of dynamical systems, measurement and control, American Control Conference, IEEE Conference on Decision and Control, IFAC.

Anders Lindquist

- Chairman, Department of Mathematics, Royal Institute of Technology.
- Member Central Faculty Board ("Centrala fakultetsnämnden"), KTH.
- Board Member, Strategic Center for Autonomous Systems, KTH.
- Vice-President, Division VII (Basic and Interdisciplinary Engineering Sciences) of the Royal Swedish Academy of Engineering Sciences (IVA).
- Affiliate Professor, Washington University, St Louis, USA.
- Advisory Board of the Institute for Mathematics of the Life Sciences, Texas Tech University, Texas, USA.
- Team Leader, European Research Network for System Identification (ERNSI), TMR network.
- Member, Editorial Board, *Applied and Computational Control, Signals, and Circuits*, book series published by Birkhäuser, Boston.
- Referee for several other journals, for NATO, STINT, KVA and Italian Na-

tional Research Foundation.
- Examiner (Revisore), University of Padova, Italy.
- Member, Steering Committee of the ERCIM Working Group on Control and System Theory.
- Member, Scientific Steering Committee of Mittag-Leffler Institute program on Mathematical Control and Systems Theory, Spring 2003.
- Member, Organizing Committee of Fourth European Mathematical Congress, Stockholm, June 27 – July 2, 2004.
- Member, International Scientific Committee of 2001 WSES International Conference on Speech, Signal and Image Processing, Malta, September 1 - 6, 2001.
- Member, Steering Committee of MTNS2002, University of Notre Dame, August 12-16, 2002.
- Member, International Advisory Committee of the 33th ISCIE International Symposium on Stochastic Systems Theory and its Applications, Tochigi, Japan, October 29 - 30, 2001.
- International Advisory Committee of the 34th ISCIE International Symposium on Stochastic Systems Theory and its Applications, Fukuoka, Japan, October 31 - November 1, 2002
- International Advisory Committee of the Satellite Conference of ICM 2002 on Optimization and Control, Xian, China, August 30 - September1, 2002

Ryozo Nagamune
- Participation in 10th ERNSI Workshop in Cambridge, United Kingdom (September 16-19, 2001).
- Research visit at Helsinki University of Technology, Institute of Mathematics (May 17-23, 2002).

Mikael Prytz
- Member of steering committee for research project Expansion of Infrastructure within Telecommunications at Division of Optimization, Department of Mathematics, Linköping Institute of Technology, Linköping University.
- Opponent at Patrik Björklunds licentiate thesis defense, April 2002, Linköping University in Norrköping, Sweden. Title of thesis: Two Resource Optimization Applications in Wireless Networks.

Krister Svanberg
- In the evaluation committee at the PhD dissertation of Clas Rydergren, Division of Optimization, Linköping University, Nov 29, 2001.
- In the evaluation committee at the PhD dissertation of Sigurd Trier, NTNU, Trondheim, Dec 4, 2001.
- In the evaluation committee at the PhD dissertation of Thomas Borrvall, Department of Mechanical Engineering, Linköping University, June 7, 2002.
- Referee for Structural and Multidisciplinary Optimization.
- Referee for International Journal for Numerical Methods in Engineering.

Petter Ögren
- Visited the Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, New Jersey, USA, August 15-December 20, 2001.