KTH Mathematics

Activity Report 2002/2003

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

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 2002/2003 (July 2002 – June 2003).

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 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 (Guest researcher)

Per-Olof Gutman, associate professor

Administratör (Administrator)

Erika Appel

Doktorander (Graduate students)

Stefan Almér, civing (since February 2003)
Anders Blomqvist, civing
Gianantonio Bortolin
Fredrik Carlsson, civing (since March 2003)
Simon Cedervall, civing (since January 2003)
Vanna Fanizza
Christelle Gaillemard
Tove Gustavi, civing (since January 2003)
Ryozo Nagamune (graduated (PhD) September 2002)
Göran Sporre, civing (graduated (TeknD) February 2003)
Mathias Stolpe, civing (graduated (TeknD) March 2003)
Mats Werme, civing (since January 2003)
Petter Ögren, civing (graduated (TeknD) June 2003)

1.2 Biographies

Stefan Almér received the degree of civilingenjör in Engineering Physics from KTH in 2003. He spent the academic year 2000-2001 as an exchange student at ETH Zuerich, Switzerland. Since February 2003 he is a graduate student at the Division of Optimization and Systems Theory. He is currently doing research on stability of pulse-width modulated systems with applications in power electronics.

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 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.

Fredrik Carlsson was born in Halmstad, Sweden, in 1978. He received his MSc degree in Engineering Physics from Chalmers University of Technology in 2002. He spent the academic year 2001-2002 as an exchange student at Imperial College in London and did his master thesis at Hewlett-Packard Labs in Palo Alto, USA. Since the spring of 2003 he is a graduate student at the Division of Optimization and Systems Theory. His research project, performed in collaboration with RaySearch Medical AB, focus on studying and developing optimization algorithms for intensity modulated radiation therapy.

Vanna Fanizza was born in Conversano, South of Italy, in 1975. She received a degree in Mathematics from University of Bari. She gots a schoolarship 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 vi a orthonormal basis and Nevanlinna-Pick interpolation with complexity constraint for the MIMO case.

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 au tomatic control, in June 2001 at ESSTIN in Nancy, France. She did her master thesis in 2001 at AssiDomän Frö vi AB, Sweden. Currently she is a PhD student at the Division of Optimization and Systems Theory and her project i n collaboration with AssiDomän Frövi AB will consist of modelling the moisture content of a four layers pap ersheet using grey-box modelling and identification.

Tove Gustavi was born in Tumba, Sweden, in 1977. She received her M.Sc. in Engineering Physics from KTH, Stockholm, in 2001. 2001-2002 she worked as development engineer in optical communication. Since the spring 2003 she is a graduate student at the Division of Optimization and Systems Theory. Her main area of research is motion planning for mobile robots, including path-following, tracking and formation planning.

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.

Since 1990 he spends two—three months a year as a guest researcher at the Division of Optimization an Systems Theory, Royal Institute of Technology, Stockholm, Sweden, where he has served as an advisor for several students. He 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 and he is an associate editor for IEEE Transactions on Automatic Control since 2003.
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, the Russian Academy of Sciences, Moscow, East China Normal University, Shanghai, Technion, Haifa, Israel, and University of California at Berkeley.
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 of Engineering Sciences, a Foreign Member 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), an Advisory Board Member of the Institute for Mathematics of the Life Sciences, Texas Tech University, and a member of the Board of Governors of the Israel Institute of Technology (Technion) in Haifa. For the first half of 2003, he served as the scientific leader at Institut Mittag-Leffler.
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 a Master's degree in Engineering from Osaka University in 1997. He was then a PhD student at the Division of Optimization and Systems Theory, from where he received a PhD degree in September 2002. He was a post-doctoral research fellow at the Mittag-Leffler Institute from January to June 2003. From September 2003, he is currently a post-doctoral research fellow at Department of Mechanical Engineering, University of California, Berkeley. 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.

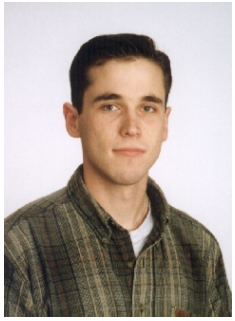
Göran Sporre was born in Järfälla, Sweden, in 1972. He received a civilingenjör degree in Engineering Physics from KTH in 1996. During 1997 he worked at Telia Engineering with issues related to network planning for telecommunication. After five years at the division, he successfully defended his thesis in early 2003. His main research interest is interior methods for optimization.

Mathias Stolpe was born in Skerike, Sweden, in 1972. He received a Master of Science degree in Vehicle Engineering from KTH in 1997 and a PhD degree in Optimization and Systems Theory from KTH in 2003. His main area of research is methods for global optimization and topology 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.

Mats Werme was born in Uppsala, Sweden, in 1976. In 2001 he received a M. Sc. in Mechanical Engineering from KTH. Since 2003 he is a PhD student at at the Division of Optimization and Systems Theory. The research deals with optimal design of load-carrying mechanical structures.



Petter Ögren was born in 1974 in Stockholm, Sweden. He recieved his Master of Science degree in Engineering Physics from KTH in 1998. In June 2003 he finished his PhD at the division with the thesis Formations and Obstacle Avoidance in Mobile Robot Control. He is currently a researcher at the Swedish Defence Research Institute (FOI). 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 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
- Docent Karl H. Johansson, Department of Signals, Systems and Sensors, KTH
- Dr. Chung-Yao Kao, Lund Institute of Technology and the Mittag Leffler Institute.
- Professor Naomi E. Leonard, Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, New Jersey, USA.
- Dr. Johan Löf, RaySearch Laboratories AB, Stockholm, Sweden
- 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.
- Dr. Henrik Rehbinder, RaySearch Laboratories AB, Stockholm, Sweden
- 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
- Professor Margaret H. Wright, Department of Computer Science, New York University, New York, New York, USA
- Professor Vladimir Yakubovich, St. Petersburg State University, St. Petersburg, Russia
- 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.
- Real-time Embedded Control of Mobile Systems with Distributed Sensing (RECSYS)
- Strategic Research Consortium of Autonomous Systems, KTH

2 Research

2.1 List of projects

- Generalized interpolation in H^∞ with a complexity constraint
- Generalized moment problems with complexity constraints
- Geometric theory of linear stochastic systems
- Hybrid control of autonomous system
- Integral quadratic constraints
- Interior point solutions of variational problems
- Large-scale nonlinear optimization
- Optimal damping of forced oscillations in discrete-time systems
- Optimization of radiation therapy
- 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
- Real-time embedded control of mobile systems with distributed sensing
- Robust control along trajectories
- Stability of a class of PWM systems
- Topology optimization of load-carrying structures

2.2 Description of projects

Generalized interpolation in H^∞ with a complexity constraint

Researchers: Anders Lindquist in cooperation with C. I. Byrnes (Washington University, St Louis), T. T. Georgiou (University of Minnesota) and A. Megretski (MIT).

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

In a well-known paper, Sarason generalized some classical interpolation problems for H^∞ functions on the unit disc to problems concerning operators on a coinvariant subspace $K = H^2 \ominus \phi H^2$ where ϕ is an inner function. These operators have norm not greater than one, and, among his results, he studied the structure of generalized interpolants for operators having norm one. In a variety of interesting cases, there is a unique such interpolant, which is given by the quotient of functions in K. In [R4] we study the case where the operator is a strict contraction. There turns out to be an infinite number of interpolants that are such quotients, and we give a complete parameterization of these.

Our methodology is inspired by the engineering applications of classical interpolation problems in circuits, systems and signal processing, cases which all deal with the situation where ϕ is a finite Blaschke product and in which the quotient representation is physically natural. These are the problems we study in the project *Rational Nevanlinna-Pick interpolation with degree constraints*. We generalize this to the case of arbitrary inner functions by first constructing on a certain set a differential form which is exact (in an appropriate sence) and which gives rise intrincically to a convex optimization problem. Indeed, or method of proof reposes on a rigorous treatment of nonlinear optimization on certain (nonreflexive) Banach spaces.

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 [R3][A2] 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 project *Rational Nevanlinna-Pick interpolation with degree constraints* 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 [R2]. This solves the long-standing

problem of how to incorporate positivity constraints in identification with orthonormal basis functions. Moreover, some connections to probability and statistics are being pursued.

In [A3] we study the generalized moment problem with complexity constraints in the case where the actual values of the moments are uncertain. For example, in spectral estimation the moments correspond to estimates of covariance lags computed from a finite observation record, which inevitably leads to statistical errors, a problem studied earlier by Shankwitz and Georgiou. Our approach is a combination of methods drawn from optimization and the differentiable approach to geometry and topology. In particular, we give an intrinsic geometric derivation of the Legendre transform and use it to describe convexity properties of the solution to the generalized moment problems as the moments vary over an arbitrary compact convex set of possible values. This is also interpreted in terms of minimizing the Kullback-Leibler divergence for the generalized moment problem.

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, Petter Ögren and Simon Cedervall.

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, active sensing and nonlinear observers.

3. Feedback Control under sensor and communication constraints.
4. Path following, mobile manipulation and multi-agent control.

Integral quadratic constraints

Researchers: U. Jönsson, in cooperation with A. Megretski (M.I.T), A. Rantzer (Lund Institute of Technology, C-Y Kao (LTH and the Mittag Leffler Institute).

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 IQCbeta [O1]. One important aspect is the development of efficient algorithms for IQC optimization. Recent work shows that cutting plane techniques gives efficient algorithms for IQC optimization of LTI systems [A16].

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.

Large-scale nonlinear optimization

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

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 research has been directed towards interior methods for nonlinear optimization [A6], in particular linear algebra issues related to such methods [A7]. Sporre has defended his thesis during the academic year [T2].

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 of radiation therapy

Researchers: Fredrik Carlsson and Anders Forsgren, in cooperation with Johan Löf (RaySearch Laboratories AB) and Henrik Rehbinder (RaySearch Laboratories AB).

Sponsors: The Swedish Research Council (VR) and RaySearch Laboratories AB.

This is an industrial graduate student project, carried out jointly between RaySearch Laboratories AB and the Division of Optimization and Systems Theory, Department of Mathematics, KTH. The specific goal of the project is to develop tailored optimization tools that are suitable for optimization problems that arise within radiation therapy. In addition, we intend to look at the biological models used and the formulations of the optimization problems that arise.

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 and S. Almér, in cooperation with A. Megretski (M.I.T), C-Y Kao (LTH and the Mittag Leffler Institute), K.H. Johansson S3, KTH, L. Iannelli, Università degli Studi di Napoli "Federico II", F. Vasca, Università del Sannio in Benevento, J. Mari, Bombardier Transportation.

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 three 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 [A15]. 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 averaging theory for discontinuous systems. 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 is difficult even in simple discontinuous systems such as relay feedback systems. We have recently developed new methods for analysis and design of dithered relay system that are based on LMI optimization [A13],[C4] and [C5]. Generalizations to more general systems and dither signals have been obtained in [R6].

In the third and most recent topic we consider stability analysis of a class of pulse-width modulated systems. The work is motivated from the practical problem of deciding global stability or large regions of attractions for switched DC-DC converters. This problem is often addressed using either averaging techniques or by linearization. We suggest a quasi-linearization approach that allow us to verify stability by checking the feasibility of a set of coupled linear matrix inequalities. We have considered analog as well as digital PWM techniques and our results can be used for single phase as well as multi phase converters.

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).

Sponsors: AssiDomän Cartonboard 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. In November 2002 Gianantonio Bortolin completed his licentiate thesis on modelling and estimation of curl and twist in multi-ply paperboard (Bortolin, 2002) and is now continuing his doctoral research. Christelle Gaillemard models the drying section, and the moisture content of a four layers papersheet using grey-box modelling and identification, using Modelica for simulation.

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 [T1] 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 [T1] these results are generalized to the the case of multiple interpolation points, and in [A1] they are extended to the multvariable case.
- In [T1] 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 [T1] and [C1] 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 avoids spectral factorization. The ill-conditoning intrinsic in the previous solvers is therefore avoided. In [R1] a homotopy continuation method is instead used to solve the system of nonlinear equations obtained from the the stationarity condition of the convex optimization problem.
- In [A8] 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.
- Studies have begun to apply our methods Nevanlinna-Pick interpolation with degree constraint to the clasical Youla's problem of optimal power transfer.

Real-time embedded control of mobile systems with distributed sensing

Researchers: Anders Lindquist, Xiaoming Hu, Ulf Jönsson and Tove Gustavi.

This is a joint EU project with several partners. The goal of the project is to develop methodologies and unifying principles for the rational design of embedded systems with distributed and heterogeneous sensors operating in an uncertain and changing environment. This implies that fundamental issues in the design of such embedded systems include modeling, verification, data processing from distributed and heterogeneous sensors, as well as design of concurrent controllers under sensory and communication constraints should be addressed. These research problems present the core of this project and four workpackages are accordingly organized.

Robust control along trajectories

Researchers: U. Jönsson in cooperation with C. Martin (Texas Tech), A. Megretski (M.I.T) C.-Y. Kao (LTH and the Mittag Leffler Institute).

Sponsor: The Swedish Research Council (VR).

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. Our contribution to this field is to develop methods for estimation of ellipsoidal sets around the nominal

solution of a system where uncertainty and disturbances are described by IQCs. This year we presented the results in [C7] at [P4], [P5], and [P6].

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 [A14] we solve such a robustness problem for periodic solutions of non-autonomous systems. A much more difficult task is to consider the same problem for autonomous syst ems. This is done in [R7].

The third topic is planning of trajectories and synthesis of robust control laws for these trajectories. A first step in this was taken in [R8] 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.

Topology optimization of load-carrying structures

Researchers: Krister Svanberg, Mathias Stolpe, Mats Werme.

Sponsor: The Swedish Research Council (VR).

The purpose of this project is to develop mathematical models and efficient numerical methods for optimizing the topology and shape of load-carrying structures. During the year, Mathis Stolpe has successfully defended his PhD thesis, and the new doctorate student Mats Werme has started to work within the project.

3 Education

3.1 Undergraduate courses

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

Instructor: Krister Svanberg.

Assistants: Camilla Landén 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: Göran Sporre and 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.

5B1760 Linear and Quadratic Optimization, 4 p
(*Linjär och kvadratisk optimering)*

Instructor: Krister Svanberg.

Assistant: Camilla Landén and Petter Ögren.

The course should deepen the knowledge in linear algebra and give basic knowledge about optimization. In particular, the course deals with linear programming (LP) and quadratic programming (QP), where linear algebra is the main mathematical tool.

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

Instructor: Anders Forsgren.

Assistant: Ulf Jönsson.

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.

5B1822 Advanced Course in Mathematical Systems Theory, 4 p
(*Matematisk systemteori, fortsättningskurs)*

Instructor: Xiaoming Hu.

Assistant: Ryozo Nagamune.

The course should deepen and broaden the theoretical and methodological knowledge in mathematical systems theory. Some subjects dealt with in the course are: Geometric control theory, modeling of linear stochastic systems, stochastic realization theory.

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: Camilla Landén.

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 Camilla Landén.

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.

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 courses

5B5760 Introduction to Nonlinear Control Systems, 5 p
(*Introduktion till icke-linjär styrteori)*

Instructor: Xiaoming Hu.

The purpose of this course is to present the fundamentals of the theory and application of nonlinear control systems, with emphasis on the geometric approach. In particular, this course provides methods for analysis and synthesis of nonlinear feedback control systems.

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] R. Nagamune, *Robust Control with Complexity Constraint: A Nevanlinna-Pick Interpolation Approach*, TRITA-MAT-02-OS-10, Division of Optimization and Systems Theory, Department of Mathematics, KTH, 2002. Advisor: A. Lindquist.

[T2] G. Sporre, *On Some Properties of Interior Methods for Optimization*, TRITA-MAT-03-OS-02, Division of Optimization and Systems Theory, Department of Mathematics, KTH, 2003. Advisor: A. Forsgren.

[T3] M. Stolpe, *On Models and Methods for Global Optimization of Structural Topology*, TRITA-MAT-03-OS-03, Division of Optimization and Systems Theory, Department of Mathematics, KTH, 2003. Advisor: K. Svanberg.

[T4] P. Ögren, *Formations and Obstacle Avoidance in Mobile Robot Control*, TRITA-MAT-03-OS-06, Division of Optimization and Systems Theory, Department of Mathematics, KTH, 2003. Advisor: X. Hu.

3.4 Licentitate thesis

[T5] G. Bortolin, *On Modelling and Estimation of Curl and Twist in Multi-ply Paperboard*, Division of Optimization and Systems Theory, Department of Mathematics, KTH, 2002. Advisor: P.-O. Gutman.

3.5 Master theses (*Examensarbeten)*

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

[T6] S. Almér (F), *Control and analysis of a PWM DC-DC converter*. Performed at Bombardier. Advisor: U. Jönsson. (E261)

[T7] L. Colldén (F), *Adaptive radiation therapy for handling position uncertainties*. Performed at RaySearch Laboratories AB. Advisor: A. Forsgren. (E259)

[T8] L. Ekelin (F), *Planering av turer med hög kvalitet för lokförare*. Performed at Green Cargo AB. Advisor: A. Forsgren. (E262)

[T9] T. Ekroth (F), *Optimal node placement in resilient packet ring*. Performed at Cisco Systems. Advisor: A. Forsgren. (E257)

[T10] A. Eriksson (F), *Planering för robustare turplaner*. Performed at Green Cargo AB. Advisor: A. Forsgren. (E260)

[T11] M. Fredriksson (F), *Biological fractionation effects in radiation therapy optimization*. Performed at Karolinska Institutet. Advisor: A. Brahme and B. Lind/A. Forsgren. (E254)

[T12] D. Fuentes Alarcon, *Path following and obstacle avoidance for mobile robots*. Performed at Centre for Autonomous systems. Advisor: X. Hu. (E258)

[T13] J. Karlsson (F), *Spectral estimation and distortion measures in speech processing*. Performed at University of Minnesota. Advisor: T. Georgiou/A. Lindquist. (E263)

[T14] A. Kobetski (F), *Optimization of Electrical Devices using FLUX*. Performed at CEDRAT, Grenoble. Advisor: U. Jönsson. (E255)

[T15] J. Svärling (F), *Optimal long-horizon portfolio allocation using a binomial tree asset return model*. Performed at Stanford University. Advisor: W. Murray/A. Forsgren. (E256)

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

[T16] T. Afram, *A simulation model for logistic processes in inter-company process chains*. Performed at DaimlerChrysler AG, Tyskland. Advisor: C. Trygger. (S155)

[T17] H. Albertsson, *Improved free day assignments for cabin crew at Scandinavian Airlines System*. Performed at SAS. Advisor: U. Brännlund. (S157)

[T18] A. Alm, *Autopilot för autonomous ground vehicle - modelling, design and implemention*. Performed at FOI. Advisor: X. Hu. (S149)

[T19] A. Altunisik, *Identifiering av serviceparametrar samt matematisk modellering av kundadministrativa processer*. Performed at SkandiaLink. Advisor: C. Trygger. (S156)

[T20] F. Boström (T), *Dimensionering av förnödenhetsresurser för snabbinsatsbataljon 90 för internationell tjänstgöring.* Performed at FMV. Advisor: U. Brännlund. (S152)

[T21] P. Fastén, *Alternative and complementary risk models for energy companies.* Performed at Vattenfall AB. Advisor: U. Brännlund. (S159)

[T22] C. Frössberg (M), *Ökad tillförlitlighet med avseende på igensättning vid varvtalsreglerad avlopps- pumpning med hjälp av parameterstyrning.* Performed at ITT Flygt. Advisor: C. Trygger. (S154)

[T23] M. Kyhlstedt (M), *Conditional value-at-risk i ett system för risk management.* Performed at Harald Lundén kapitalförvaltning. Advisor: U. Brännlund. (S146)

[T24] M. Olsson (T), *Generell modell för system innehållande livslängdsbegränsade komponenter.* Performed at FMV. Advisor: C. Trygger. (S153)

[T25] P. Sundbergh (T), *Optimal tillskärning av aluminiumprofiler.* Performed at Sapa, Vetlanda. Advisor: A. Forsgren. (S150)

[T26] J. Wallgren, *Optimization of IMRT treatment plans — Implementation and testing of a CVaR approach.* Performed at University of Florida. Advisor: E. Romeijn/U. Brännlund. (S158)

[T27] V. Zetterquist (T), *Dantzig-Wolfe decomposition with subproblem truncation.* Performed at Univ of Florida. Advisor: S. Lawphongpanich/U. Brännlund. (S151)

4 Seminars at the division

- Ryozo Nagamune, KTH, *Robust control with complexity constraint: A Nevanlinna-Pick interpolation approach*, September 13, 2002.
- Bjørn Nygreen, NTNU, *Optimal routing of oil and gas from wells to separators*, October 4, 2002.
- Gianantonio Bortolin, KTH, *On modelling and estimation of curl and twist in multi-ply paperboard*, Licentiate seminar, November 14, 2002.
- Maurice Heemels, Eindhoven University of Technology, *Complementarity systems and other hybrid model classes - Well-posedness issues*, November 22, 2002.
- Oleg Kirillov, Moscow State Lomonosov University, *Overlapping of the characteristic curves and optimization of nonconservative systems*, November 29, 2002.
- Manfred Morari, ETH, *Optimal control of hybrid systems*, December 6, 2002.
- Göran Sporre, KTH, *On some properties of interior methods for optimization*, January 31, 2003.
- Mathias Stolpe, KTH, *Topology optimization of truss structures*, February 21, 2003.
- Mathias Stolpe, KTH, *Topology optimization of continuum structures*, February 28, 2003.
- Henrik Sandberg, Lund Institute of Technology, *Balanced truncation of linear time-varying systems*, March 21, 2003.
- Amol Sasane, Institut Mittag-Leffler, *Time-autonomy and time-controllability with respect to Ws*, March 28, 2003.
- Chung-Yao Kao, Institut Mittag-Leffler, *Efficient computational algorithms for IQC analysis*, April 4, 2003.
- Petter Ögren, KTH, *Formation and obstacle avoidance in mobile robot control*, May 23, 2003.
- Antonio Bicchi, Università di Pisa, *Quantized control systems and hybrid nonholonomy*, June 4, 2003.
- Magnus Egerstedt, Georgia Institute of Technology, *Autonomous formation switching for multiple mobile robots*, June 13, 2003.
- Michael Friedlander, Argonne National Laboratory, *An LCL algorithm for constrained optimization*, June 16, 2003.

5 Publications

5.1 Papers in journals and books (published and accepted)

[A1] A. Blomqvist, A. Lindquist and R. Nagamune, *Matrix-valued Nevanlinna-Pick interpolation with complexity constraint: An optimization approach*, IEEE Transactions on Automatic Control 48, to be published.

[A2] C. I. Byrnes and A. Lindquist, *A convex optimization approach to generalized moment problems*, Control and Modeling of Complex Systems: Cybernetics in the 21st Century: Festschrift in Honor of Hidenori Kimura on the Occasion of his 60th Birthday, Koichi Hashimoto, Yasuaki Oishi, and Yutaka Yamamoto, Editors, Birkhäuser, 2003, 3–21.

[A3] C. I. Byrnes and A. Lindquist, *The uncertain generalized moment problem with complexity constraint*, New Trends in Nonlinear Dynamics and Control, W. Kang, M. Xiao and C. Borges (Eds.), Springer Verlag, 2003, to be published.

[A4] D. Cheng, X. Hu and Y. Wang, *Non-regular feedback linearization of nonlinear systems via a normal form algorithm*, to appear in Automatica.

[A5] J.-L. Coulomb, A. Kobetski, M. C. Costa, Y. Maréchal, and U. Jönsson, *Comparison of radial basis function approximation techniques*, The International Journal of Computation and Methematics in Electrical and Electronic Engineering, 22(3):616–629, 2003.

[A6] A. Forsgren, P. E. Gill and M. H. Wright, *Interior methods for nonlinear optimization*, SIAM Review 44 (2002), 525-597.

[A7] A. Forsgren, *Inertia-controlling factorizations for optimization algorithms*, Applied Numerical Mathematics 43 (2002), 91-107.

[A8] T. T. Georgiou and A. Lindquist, *Kullback-Leibler approximation of spectral density functions*, IEEE Transactions on Information Theory 49, to be published.

[A9] P.-O. Gutman, *Robust and adaptive control — Fidelity or a free relationship?*, Systems and Control Letters, vol. 49, no. 1, 9-19, May 2003.

[A10] P.-O. Gutman, E. Horesh, R. Guetta and M. Borshchevsky, *Control of the aero-electric power station - an exciting QFT application for the 21st century*, International Journal of Robust and Nonlinear Control, vol. 13, pp. 619-636, June 2003.

[A11] P.-O. Gutman and B. M. Mirkin, *Output-feedback model reference adaptive control for continuous state delay systems*, ASME Journal of Dynamic Systems, Measurement, and Control, vol 125, 257-261, June 2003.

[A12] X. Hu, U. Jönsson, and C. Martin, *Input tracking and output fusion for linear systems*, In C. I. Byrnes and A. Rantzer, editors, *New Directions in Mathematical Systems Theory and Optimization*, Lecture Notes in Control and Information Sciences, pages 159–172. Springer, 2002.

[A13] L. Iannelli, K. H. Johansson, U. Jönsson, and F. Vasca, *Dither for smoothing relay feedback systems*, IEEE Transactions on Circuits and Systems-I: Fundamental Theory and Applications, 50(8):1025–1035, August 2003.

[A14] U. Jönsson, C. Kao and A. Megretski, *Robustness analysis of periodic trajectories*, IEEE Transactions on Automatic Control, 47(11):1842 -1856, November 2002.

[A15] U. Jönsson, C. Kao and A. Megretski., *Analysis of periodically forced uncertain feedback systems*, IEEE Transactions on Circuits and Systems-I: Fundamental Theory and Applications, 50(2):244 -258, 2003.

[A16] C.-Y. Kao, A. Megretski, and U. Jönsson, *Specialized fast algorithms for IQC feasibility and optimization problems*, Accepted for publication in *Automatica*.

[A17] R. Nagamune, *A robust solver using a continuation method for Nevanlinna-Pick interpolation with degree constraint*, IEEE Transactions on Automatic Control, vol.48, no.1, pp.113-117.

[A18] R. Nagamune, *Closed-loop shaping based on Nevanlinna-Pick interpolation with a degree bound*, IEEE Transactions on Automatic Control, accepted for publication.

[A19] R. Nagamune, *A shaping limitation of rational sensitivity functions with a degree constraint*, IEEE Transactions on Automatic Control, accepted for publication.

[A20] M. Nordin and P.-O. Gutman, *Controlling mechanical systems with backlash – a survey*, Automatica, vol. 38, no. 10, 1633-1649, October 2002.

[A21] H. Rehbinder and X. Hu, *Drift-free attitude estimation for accelerated rigid bodies*, to appear in Automatica.

[A22] M. Stolpe and K. Svanberg, *A note on stress-constrained truss topology optimization*, Structural and Multidisciplinary Optimization 25:1(2003), 62-64.

[A23] M. Stolpe and K. Svanberg, *Modelling topology optimization problems as linear mixed 0-1 programs*, International Journal for Numerical Methods in Engineering, 57:5(2003), 723-739.

[A24] M. Stolpe and K. Svanberg, *Stress-constrained truss topology optimization problems which can be solved by linear programming*, Accepted for publication in Structural and Multidisciplinary Optimization, 2003.

[A25] O. Yaniv and P.-O. Gutman, *Cross-over frequency limitations in MIMO non-minimum phase feedback systems*, IEEE Transactions on Automatic Control, vol. 47, no. 9, 1560-1564, 2002.

[A26] P. Ögren, M. Egerstedt and X. Hu, *A control Lyapunov function approach to multi-agent coordination*, IEEE Transactions on Robotics and Automation, October 2002, 847-852.

5.2 Papers in conference proceedings (published and accepted)

[C1] A. Blomqvist and R. Nagamune, *An extension of a Nevanlinna-Pick interpolation solver to cases including derivative constraints*, Proc. 41st IEEE Conf. on Decision and Control, Vol. 3, Dec. 2002, 2552–2557.

[C2] C.-F. Fransson, B. Lennartson, T. Wik, K. Holmström, M. Saunders and P.-O. Gutman, *global controller optimization using Horowitz bounds*, Proc. IFAC World Congress, Session T-Tu-A15, paper 2420, Barcelona, Spain, July 21-26, 2002.

[C3] X. Hu, D. Fuentes and T. Gustavi, *Sensor-Based Navigation Coordination for Mobile Robots*, to appear in the proc. of CDC 2003.

[C4] L. Iannelli, K. H. Johansson, U. Jönsson, and F. Vasca, *Practical stability and limit cycles of dithered relay feedback systems*, In *Proceedings of the European Control Conference*, Cambridge, UK, 2003.

[C5] L. Iannelli, K. H. Johansson, U. Jönsson, and F. Vasca, *Analysis of dither in relay feedback systems*, In *Proceedings of the IEEE Conference on Decision and Control 2002*, page 4425 – 4430, Las Vegas, Nevada, USA, 2002.

[C6] I. Ioslovich and P.-O. Gutman, *Large-scale linear model for optimal industrial investments: robust presolving analysis*, Proc. 4th International IMACS Symposium on Mathematical Modelling (4th MATHMOD), pp. 276-284, Vienna, Austria, 5-7 February, 2003.

[C7] U. Jönsson, *On reachability analysis of uncertain hybrid systems*, In *Proceedings of the IEEE Conference on Decision and Control 2002*, page 2397 – 2402, Las Vegas, Nevada, USA, 2002.

[C8] B. M. Mirkin and P.-O. Gutman, *Decentralized Adaptive Control With Improved Steady State Performance*, Proc. IFAC World Congress, Barcelona, Spain, Session T-Mo-A03, paper no 1457, July 21-26, 2002.

[C9] B. M. Mirkin and P.-O. Gutman, *Output adaptive model reference control of linear continuous state-delay plant*, Proc. 15th International symposium on the mathematical theory of networks and systems, Notre Dame, USA, August 12-16, 2002.

[C10] B. M. Mirkin and P.-O. Gutman, *Control decomposition for output-feedback adaptive tracking of state delayed systems*, International Symposium on Control Sciences, Moscow, Russia, June 17-19 , 2003.

[C11] B. M. Mirkin and P.-O. Gutman, *Coordinated adaptive robust decentralized output feedback tracking*, 4th IFAC Symposium on Robust Control Design, Milan, Italy, June 25-27, 2003.

[C12] R. Nagamune, *Simultaneous robust regulation and robust stabilization with degree constraint*, Fifteenth International Symposium on Mathematical Theory of Networks and Systems (MTNS02) (CD-ROM).

[C13] M. Stolpe, *A branch-and-cut method for global optimization of minimum weight truss topology problems with stress, displacement, and local buckling constraints*, Proceedings of The Fifth World Congress on Structural and Multidisciplinary Optimization, Lido di Jesolo-Venice, Italy, May 19-23, 2003.

[C14] K. Svanberg, *Stress-constrained truss-type topology optimization problems that can be solved as convex optimization problems*, Proceedings of The Fifth World Congress on Structural and Multidisciplinary Optimization, Lido di Jesolo-Venice, Italy, May 19-23, 2003.

[C15] P. Ögren and N. Leonard, *A provable convergent dynamic window approach to obstacle avoidance*, IFAC World Congress, Barcelona, Spain, July 2002.

[C16] 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.

[C17] P. Ögren and N. Leonard, *A tractable convergent dynamic window approach to obstacle avoidance*, IEEE/RSJ International Conference on Intelligent Robots and System, Sept. 2002. 595- 600.

[C18] P. Ögren and N. Leonard, *Obstacle Avoidance in Formation*, IEEE International Conference on Robotics and Automation, Taipei, Taiwan, May 2003.

5.3 Other publications

[O1] A. Megretski, C. Kao, U. Jönsson and A. Rantzer, *A Guide To IQC-beta: Software for Robustness Analysis*, http://www.math.kth.se/ cykao/.

5.4 Technical reports and preprints

[R1] A. Blomqvist, G. Fanizza and R. Nagamune, *Computation of bounded degree Nevanlinna-Pick interpolation by solving nonlinear equations*, Institut Mittag-Leffler Report No. 17 2002/2003 spring.

[R2] A. Blomqvist and G. Fanizza, *Identification of rational spectral densities using orthonormal basis functions*, to appear in Proc. of Symposium on System Identification, 2003.

[R3] C. I. Byrnes and A Lindquist, *Interior point solutions of variational problems and global inverse function theorems*, submitted for publication.

[R4] C. I. Byrnes, T. T. Georgiou, A. Lindquist and A. Megretski, *Generalized interpolation in H-infinity with a complexity constraint*, Institut Mittag-Leffler Report No. 28 2002/2003 spring.

[R5] A. Forsgren and M. Prytz, *Telecommunications network design*, Manuscript in preparation for the forthcoming *Handbook of Optimization in Telecommunications*, P. M. Pardalos and M. G. C. Resende, eds.,Kluwer Academic Publishers.

[R6] L. Iannelli, K.-H. Johansson, U. Jönsson, and F. Vasca, *Conditions on the dither shape in the averaging of switched systems*, Technical Report TRITA/MAT-03-OS08, Department of Mathematics, Royal Institute of Technology, 2003.

[R7] U. Jönsson and A. Megretski, *A small gain theory for limit cycles*, Technical Report TRITA/MAT-03-OS07, Department of Mathematics, Royal Institute of Technology, 2003.

[R8] U. Jönsson, C. F. Martin, and Y. Zhou, *Trajectory planning for systems with a multiplicative stochastic uncertainty*, Submitted 2003.

[R9] J. Malinen and R. Nagamune, *On the geometry of the Hermite-Fejer interpolation problem through conservative realisations*, Preprint, Institut Mittag-Leffler, The Royal Swedish Academy of Sciences.

[R10] G. Sporre, *A note on iterative techniques in interior methods for linear programming*, Report TRITA-MAT-2003-OS1, Department of Mathematics, Royal Institute of Technology, 2003.

6 Awards and appointments

Ulf Jönsson was nominated as an outstanding reviewer for Automatica in 2003.

Chung-Yao Kao was awarded one of two *Göran Gustafsson Postdoctoral Fellowships* to enable him to spend academic year 2003/04 at the Division of Optimization and Systems Theory.

7 Presentations

[P1] A. Blomqvist, *Spectral Estimation via Generalized Orthonormal Basis Functions*, The 11th ERNSI workshop, Port-aux-Rocs, France, September 22-25, 2002.

[P2] A. Blomqvist, *From Robust Control via Analytic Interpolation to ARMA Estimation*, Technische Universität Wien, December 16, 2002.

[P3] A. Forsgren, *Interior methods for optimization*, Linköping University, Linköping, Sweden, June 12, 2003.

[P4] U. Jönsson, *On reachability analysis of uncertain hybrid systems*, The IEEE Conference on Decision and Control 2002, Las Vegas, Nevada, USA.

[P5] U. Jönsson, *On Verification of Uncertain Systems*, The Recsys meeting in Lausanne, January 7, 2003.

[P6] U. Jönsson, *On Verification of Uncertain Systems*, ETH, Zurich, 2003-01-08.

[P7] U. Jönsson, *Dynamisk programmering*, KTHs Matematiska Cirkel 2003-02-06.

[P8] A. Lindquist, *A convex optimization approach to generalized moment problems*, Invited talk at International Symposium on the Mathematical Theory of Networks and Systems, University of Notre Dame, August 12–16, 2002.

[P9] A. Lindquist, *Analytic interpolation with degree constraint with applications to systems and control and signal processing*, Institute of Control Sciences, Chinese Academy of Sciences, August 28, 2002.

[P10] A. Lindquist, *A convex optimization approach to generalized moment problems*, Invited speaker at the the Satellite Conference of ICM 2002 on Optimization and Control, Xian, China, August 30 - September 1, 2002.

[P11] A. Lindquist, *Kullback-Leibler Approximation of Spectral Density Functions*, ERNSI Workshop System Identification, 23-25 September 2002, Le Croisic, France.

[P12] A. Lindquist, *A convex optimization approach to generalized moment problems with applications to systems and control*, Gordon McKay Lecture at University of California, Berkeley, October 11 - 17, 2002.

[P13] A. Lindquist, *Analytic interpolation with degree constraint with applications to systems and control and signal processing*, Invited Distinguished Lecturer in EECS Joint Colloquium, UC Berkeley, October 16, 2002.

[P14] A. Lindquist, *Analytic interpolation with degree constraint with applications to systems and control and signal processing*, Invited Distinguished Lecturer inÊ EECS Joint Colloquium, UC Berkeley, October 16, 2002.

[P15] A. Lindquist, *A convex optimization approach to generalized moment problems*, Invited speaker at the Symposium on New Trends in Nonlinear Dynamics and Control, and their Applications, Naval Postgraduate School, Monterey, California, October 18–19, 2002.

[P16] A. Lindquist, *An optimization approach to generalized moment problems with complexity constraints*, Department of Mathematics, Uppsala University, Sweden, November 5, 2002.

[P17] A. Lindquist, *An optimization approach to generalized moment problems with complexity constraints*, Institut Mittag-Leffler, Djursholm, Sweden, March 6, 2003.

[P18] A. Lindquist, *A global analysis approach to robust control*, Institut Mittag-Leffler, Djursholm, Sweden, April 24, 2003.

[P19] A. Lindquist, *A global analysis approach to robust control*, Invited speaker at the Workshop on the Geometry in Nonlinear Control,Ê Stephan Banach International Mathematical Center, June 16 - 21, 2003.

[P20] R. Nagamune, *Simultaneous robust regulation and robust stabilization with degree constraint*, MTNS2002 in University of Notre Dame, USA (August 13, 2002).

[P21] A. Blomqvist and R. Nagamune, *An extension of a Nevanlinna-Pick interpolation solver to cases including derivative constraints*, the 41st Conference on Decision and Control (CDC02) in Las Vegas, Nevada (December 12th, 2002).

[P22] R. Nagamune, *Robust control with complexity constraint: A Nevanlinna-Pick interpolation approach*, Seminar at the University of Padova, Italy (October 18, 2002).

[P23] R. Nagamune, *Robust control design based on Nevanlinna-Pick interpolation with degree constraint*, Seminar at the Mittag-Leffler Institute (April 24, 2003).

[P24] G. Sporre, *Semidefinite programming (and the asymptotic behavior of the barrier trajectory)*, Universidad Rey Juan Carlos, Madrid, Spain, October 17, 2002.

[P25] M. Stolpe, *A branch-and-cut method for global optimization of minimum weight truss topology problems with stress, displacement, and local buckling constraints*, The Fifth World Congress on Structural and Multidisciplinary Optimization, Lido di Jesolo-Venice, Italy, May 19-23, 2003.

[P26] M. Stolpe, *A branch-and-cut method for topology optimization of truss structures*, Institute of Mathematics, Linköping University, Sweden, March, 2003.

[P27] K. Svanberg, *Stress-constrained truss-type topology optimization problems that can be solved as convex optimization problems*, The Fifth World Congress on Structural and Multidisciplinary Optimization, Lido di Jesolo-Venice, Italy, May 19-23, 2003.

[P28] Petter Ögren, *A convergent dynamic window approach*, Princeton University, December, 2002.

8 New Directions in Mathematical Systems Theory and Optimization

The international symposium *New Directions in Mathematical Systems Theory and Optimization* was held at KTH in November 15-16, 2002, in honor of Anders Lindquist on the occasion of his 60th birthday.

The organizing committee consisted of Anders Forsgren, KTH (chair), Xiaoming Hu, KTH, Krister Svanberg, KTH, Chris Byrnes, Washington University St. Louis, Clyde Martin, Texas Tech University, Anders Rantzer, Lund Institute of Technology, and Yishao Zhou, Stockholm University.

In total 25 invited presentations were given, as listed below:

- Tom Banks, North Carolina State University, North Carolina, USA
- Vincent Blondel, Université Catholique de Louvain, Belgium
- Chris Byrnes, Washington University St. Louis, St. Louis, Missouri, USA
- Peter Caines, Montréal, Québec, Canada
- Harry Dym, Weizmann Institute of Science, Rehovot, Israel
- Paul Fuhrmann, Ben-Gurion University of the Negev, Beer-Sheva, Israel
- Tryphon Georgiou, Minneapolis, Minnesota, USA
- László Gerencsér, Hungarian Academy of Sciences, Budapest, Hungary
- Michel Gevers, Université Catholique de Louvain, Belgium
- Andreas Gombani, LADSEB-CWR, Padova, Italy
- Sergei Gusev, St Petersburg, Russia
- Michiel Hazewinkel, CWI, Amsterdam, The Netherlands
- Arthur Krener, University of California, Davis, California, USA
- Lennart Ljung, Linköping University, Linköping, Sweden
- Clyde Martin, Texas Tech University
- Alexandre Megretski, Massachusetts Institute of Technology, USA
- György Michaletzky, Eötvös Lorand University, Budapest, Hungary
- Sanjoy Mitter, Massachusetts Institute of Technology, USA
- Stephen Morse, Yale University, New Haven, Connecticut, USA
- Giorgio Picci, University of Padova, Padova, Italy
- Boris Polyak, Moscow, Russia,
- Anders Rantzer, Lund Institute of Technology
- Olof Staffans, Åbo Akademi University, Åbo, Finland
- Héctor Sussmann, Rutgers University, Piscataway, New Jersey, USA
- Jan Willems, University of Groningen, Groningen, The Netherlands

The symposium was financially support by the Göran Gustafsson Foundation, the Swedish Research Council, the Wenner-Gren Foundations, ABB Industries AB, AssiDomän Cartonboard AB and RaySearch Laboratories AB.

A selection of papers presented at the symposium and other papers dedicated to Anders Lindquist have been published in the book *Directions in Mathematical Systems Theory and Optimization*, Lecture Notes in Control and Information Sciences, Vol. 286, A. Rantzer and C. I. Byrnes (Eds.), Springer, 2003.

9 Other activities

Anders Blomqvist

- Visited Department for Econometrics, Operations Research and Systems Theory, Technische Universität Wien, Austria, November 18 - December 20, 2002.
- Participated in the Mittag-Leffler Institute Program "Mathematical Control and Systems Theory" during the spring 2003.
- Review assignments for IEEE Control Systems Magazine and IEEE Conference on Decision and Control 2003.

Ulf Brännlund

- Responsible for the line of competence (kompetensinriktning), Systems engineering, for the schools of mechan ical and vehicle engineering.
- Part time employed by Optimization Partner Stockholm AB.

Anders Forsgren

- Program Director, SIAM Aactivity Group on Optimization, 2001–2003.
- Associate editor for Mathematical Programming, Series A.
- Member of editorial board for Computational Optimization and Applications.
- Visited the University of California, San Diego, California, USA, June 24–July 5, 2002.
- Co-chair of the *8th SIAM Conference on Optimization*, to be held in Stockholm, May 15-18, 2005.
- Chair of organizing committee for the internatinal symposium *New Directions in Mathematical Systems Theory and Optimization*, KTH, November 15-16, 2002.
- Referee for Mathematical Programming, SIAM Journal on Matrix Analysis and Applications, and BIT.

Christelle Gaillemard

- Participation in ERNSI Workshop in Le Croisic, France, September 22-25, 2002.
- Participation in 41st IEEE Conference on Decision and Control in Las Vegas, Nevada December 10-13 2002.

Ulf Jönsson

- Associate editor for IEEE Transactions on Automatic Control.
- In the evaluation committee at the PhD dissertation of Sven Hedlund, Department of Automatic Control, Lund Institute of Technology, May 2003.
- Referee for IEEE Transactions on Automatic Control, European Journal of Control, American Control Conference, Automatica, European Control Conference 2003, IEEE Conference on Decision and Control 2003 (3)

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).
- Scientific leader, Mittag-Leffler Institut, Spring 2003.
- Affiliate Professor, Washington University, St Louis, USA.
- Advisory Board of the Institute for Mathematics of the Life Sciences, Texas Tech University, Texas, USA.

- Member, Board of Governors of the Israel Institute of Technology (Technion) in Haifa.
- 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 National Research Foundation.
- Examiner (Revisore), University of Padova, Italy.
- Member, Steering Committee of the ERCIM Working Group on Control and System Theory.
- Member, Organizing Committee of Fourth European Mathematical Congress, Stockholm, June 27–July 2, 2004.
- Member, Steering Committee of MTNS2002, University of Notre Dame, August 12-16, 2002.
- 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–September 1, 2002.

Ryozo Nagamune

- Research visit at University of Padova, Italy (October 18, 2002).
- Referee for IEEE Transactions on Automatic Control, Automatica, IEEE Conference on Decision and Control 2003.

Göran Sporre

- Visited Universidad Carlos III de Madrid, Madrid, Spain and Universidad Rey Juan Carlos, September 2–November 28, 2002.

Krister Svanberg

- Referee for Structural and Multidisciplinary Optimization.
- Responsible for the development of the new undergraduate course 5B1760 Linear and Quadratic Optimization, which is now mandatory for students on the Vehicle Engineering program.

Mats Werme

- Participation in the DCAMM/HMS2000 Ph.D.-course "Topology Optimization - Theory, Methods and Applications", Technical University of Denmark (June 19-25, 2003).

Petter Ögren

- Visited the Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, New Jersey, USA, November 26-December 8, 2002.