Activity Report

1995/1996

Division of Optimization and Systems Theory
Department of Mathematics
Royal Institute of Technology
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S–100 44 Stockholm, Sweden

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 1995/1996 (July 1995 – June 1996).

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. During this academic year the division has joined the Center for Autonomous Systems together with the divisions of Computer Vision and Active Perception, Mechatronics, Machine Elements, Automatic Control and Signal Processing. This research consortium is 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)

Tomas Björk, FD, universitetslektor (on leave 1995/1996)
Anders Forsgren, TeknD, universitetslektor
Xiaoming Hu, PhD, forskare
P. O. Lindberg, TeknD, universitetslektor (on leave 1995/1996)
Krister Svanberg, TeknD, universitetslektor Director of undergraduate studies

Forskarassistent (Research associate)

Ulf Brännlund, TeknD

Forskare (Researchers)

Yishao Zhou, TeknD (on leave spring 1996)

Postdoktorstipendiat (Postdoctoral fellow)

Daniele G. Galardini, PhD

Gästforskare (Guest researchers)

Per-Olof Gutman, docent
Vladimir Yakubovich, professor

Intendent (Administrator)

Leena Druck

Doktorander (Graduate students)

Patrik Alfredsson, civing
Anders Dahlén, FK
Per Enqvist, civing
Stefan Feltenmark, civing
Camilla Landén, civing
Jorge Marí, MS, TeknL
Mattias Nordin, civing, TeknL
Sven Nõmm, M.S.
Andreas Nõu, civing

1.2 Biographies

[0,l,[width=30mm]was born in Södertälje, Sweden, in 1967. He received a civilingenjör degree in Engineering Physics from KTH in 1991. His main research interests are systems engineering and systems efficiency, concentrated on spare parts optimization problems. As part of his PhD program, Alfredsson has spent nine months at Virginia Polytechnic Institute and State University during the fall of 1992 and the spring of 1994.,] **Patrik Alfredsson**

Tomas Björk was born in Fagersta, Sweden, in 1947. He received his B.A. from the University of Stockholm in 1971, and his PhD in Optimization and Systems Theory from the Royal Institute of Technology in 1981. In 1994 he was appointed Docent. Between 1971 and 1974 he worked as a Researcher at the National Defense Research Establishment (FOA). In 1981 he became a Research Associate and in 1987 a Senior Lecturer of Optimization and Systems Theory at the Royal Institute of Technology. He has also given several courses in Mathematical Finance at the Stockholm School of Economics. His main research interests include martingale theory, nonlinear filtering and mathematical economics.

[0,l,[width=30mm]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. His main research interests are nondifferentiable optimization, semidefinite programming and production planning.,] **Ulf Brännlund**

[0,l,[width=30mm]was born in Karlskrona, Sweden, in 1969. He did his undergraduate work in Mathematics of Science in Växjö. He is presently a PhD student at the Division of Optimization and Systems Theory. His main interest is Mathematical Systems Theory, and especially Stochastic Realization theory and Identification.,] **Anders Dahlén**

[0,l,[width=30mm]is the administrator at the Division of Optimization and Systems Theory since 1992.,] **Leena Druck**

[0,l,[width=30mm]was born in Upplands Väsby, Sweden, in 1971. He received a civilingenjörs degree in Engineering Physics from KTH in 1994. He is presently a PhD student at the Division of Optimization and Systems Theory.,] **Per Enqvist**

[0,l,[width=30mm]was born in Boden in 1968. He received a civilingenjör degree in Engineering Physics from KTH in 1991. He is presently a PhD student at the Division of Optimization and Systems Theory. Main research interests are dual methods for large-scaled problems, particularly applied to short-term power production planning problems.,] **Stefan Feltenmark**

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. His main research interest is nonlinear programming.

Daniele G. Galardini was born in Colle di Val d'Elsa, a mediaeval town in the middle of Tuscany, Italy, in 1962. He received the "laurea" in electronic engineering (1989) from the University of Pisa, Italy, the MSc in Robotics (1990) and the PhD in Automatic Control (1993) both from the Université catholique de Louvain, Belgium. From 1989 to 1990 he served as researcher the Italian Research Council and from 1990 to 1995 he was university assistant at the Center for Systems Engineering and Applied Mathematics (Cesame), Universitè catholique the Louvain. During 1994 he has hold positions at the European Commission and at EUROCONTROL. From 1995 is post-doctoral fellow at KTH.

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. Since 1990 he holds the position of Senior Lecturer with the Faculty of Agricultural Engineering, Technion, Haifa. He has spent several periods as a guest researcher at the Division of Optimization an Systems Theory, Royal Institute of Technology, Stockholm, Sweden. He was a Visiting Professor at the Laboratoire d'Automatique de Grenoble 1995-96.

His research interest include robust and adaptive control, control of non-linear systems, computer aided design, control of agricultural systems, and process quality control by feedback.

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.

[0,l,[width=30mm]was born in Upplands Väsby, Sweden, in 1970. She received a civilingenjör degree in Engineering Physics from KTH in 1994. She is presently a PhD student at the Division of Optimization and Systems Theory.,] **Camilla Landén**

Per Olov Lindberg was born in Stockholm on February 20, 1942. He received a civilingenjörs examen in Engineering Physics at KTH in 1967 and a PhD in Optimization Theory at KTH in 1975.

He served as a Systems Analyst at Datema in 1967–68. From 1968 to 1974 he served as a Research Assistant at the Department of Mathematics at KTH, on Transportation Research Grants. From 1975 to 1979 he was Assistant Professor of Optimization and Systems Theory at KTH. From 1980 he has been Associate Professor at KTH. He also has served as

Acting Professor on several instances, including the three year period Fall 1980–Spring 1983.

Lindberg was a board member of the Swedish OR Association 1974–1980. He has served on the board of the School of Computer Science at KTH and is presently serving at the boards of the Schools of Vehicle Engineering and Industrial Engineering.

Lindberg was visiting professor at Sloan School of Management, MIT, during the Spring Semester 1988. He has also been Visiting Scholar at Stanford University and University of Washington. He has recently been appointed Adjunct Professor at University of Florida.

Lindberg is on the editorial board of Computational Optimization and Applications.

Lindberg's research interests include most areas of Mathematical Programming and its applications, including Linear, Nonlinear, Dynamic and Integer Programming, Convexity and Duality, Inventory Control and Random Utility Models. He has guided six students to a PhD and four for a Licentiate Degree. Furthermore he has guided well over 100 students for an Engineering Master's Thesis (examensarbete).

Anders Lindquist was born in Lund, Sweden, in 1942. He received the civiling., TeknL and TeknD degrees from the Royal Institute of Technology, Stockholm, Sweden, and in 1972 he was appointed a Docent of Optimization and Systems Theory there.

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 presently a Professor at the Royal Institute of Technology, where in 1982 he was appointed to the Chair of Optimization and Systems Theory, and an Affiliate Professor at Washington University, St Louis. He has also held visiting positions at University of Padova, Italy, University of Arizona, USSR Academy of Sciences, Moscow, East China Normal University, Shanghai, and Technion, Haifa, Israel. From 1975 to 1976 he was a SIAM Visiting Lecturer. He is the author of many papers in the area of systems and control, especially stochastic control, filtering, stochastic systems theory, realization theory, and applications of nonlinear dynamics in estimation and control, and he is an editor of four research volumes. Since 1989 he is a Fellow of the IEEE (Institute of Electrical and Electronics Engineers), and since 1994 an honorary member the Hungarian Operations Research Society.

Lindquist is a Communicating Editor of the *Journal of Mathematical Systems, Estimation, and Control* (published by Birkhäuser Boston) and, until 1993, he was an Associate Editor of *Systems and Control Letters* (North-Holland). He also serves on the editorial boards of *Adaptive Control and Signal Processing* (John Wiley & Sons) and of the book series *Systems and Control: Foundations and Applications* and *Applied and Computational Control, Signals, and Circuits* (Birkhäuser Boston). Until 1993, he also served on the editiorial board of the book series *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 biannual international symposia on the Mathematical Theory of Networks and Systems (MTNS).

Jorge Marí became Electrical Engineer in 1992, after a six-year programme at the Facultad de Ingeniería in Montevideo, Uruguay. He also studied optimization and dynamical systems at the Facultad de Ciencias, and worked as assistant at the Math department of the first mentioned place. Later he joined the telephone company ANTEL where he worked as advisor in power supply systems. Since early 1993 he was engaged in a KTH-industry project in Stockholm, concerning modelling and optimal control of fermentation processes. During this time he started as PhD student at Optimization and Systems Theory, KTH, and received in January 1995 the Teknisk Licenciat degree. He spent half year in 1995 at the Institute for Robotics and System Dynamics, German Aerospace Research Establishment in Oberpfaffenhofen, where he became involved in control applications to automobiles and aircraft. His main interests include engineering systems and control theory applications.

Mattias Nordin received his civilingenjör degree in Engineering Physics from KTH in 1992, where his Masters Thesis:*Robust Control of Rolling Mills* was awarded with the VOLVO Royal Institute Technologist of 1992 as one of two that year. Subsequently he started as a Graduate Student at the Division of Optimization and Systems Theory in the project Robust Control of Electrical Drives, where his main research interest is systems with backlash or gear play. He also works in the area of robust control, especially Quantitative Feedback Theory (QFT). In 1995 he received his Licentiate Thesis:*Uncertain Systems with Backlash, Modelling, Estimation and Synthesis*. He has also published several designs for Benchmark Problems, and is generally interested in applying theoretical results to practical problems. His research is in cooperation with ABB Industrial Systems AB, Västerås, where he currently spends most of the week.

[0,l,[width=30mm]was born in Stockholm in 1967. He recieved a civilingenjör degree in Engineering Physics from KTH in 1991. He is presently a PhD student at the Division of Optimization and Systems Theory. His main research interests are optimization methods for applications within the transportation sector.,] **Andreas Nõu**

Krister Svanberg was born in Stockholm in 1950. He received his civilingenjör degree in Engineering Physics in 1975, and his TeknD degree in Optimization Theory in 1982, both from KTH. 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 (Universitetslektor) of Optimization and Systems Theory. His main area of research is structural optimization, dealing with optimal design of load-carrying structures.

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.

Yishao Zhou was born in Shanghai, China on October 7, 1959. She received the B.S. and M.S. in mathematics from Fudan University, Shanghai, China, in 1982 and 1984, respectively. After working two years for the Department of Mathematics at the East China University of Science and Technology, in 1987, she moved to Stockholm, Sweden where she received TeknD from KTH (Royal Institute of Technology), in 1993. From 1993 to 1995 she was a postdoctoral fellow of Swedish Natural Science Research Council at the University of Gronongen, the Netherlands. Afterwards she returned to KTH (July 1995 – June 1996). She is a senior lecturer of the Department of Mathematics at Stockholm University since 1996. Her research interests include the theory of Riccati equations, mathematical modelling and control in *behavioral approach*, the applications of nonlinear dynamics in control and estimation, and most recently in optimal control design for infinite-dimensional systems.

1.3 Visiting and interacting scientists

- Professor Jürgen Ackermann, Institute for Robotics and System Dynamics, DLR, German Aerospace Research Establishment, Wessling, Germany
- Professor Christopher I. Byrnes, Department of Systems Science and Mathematics, Washington University, St. Louis, Missouri, USA
- Professor Ruth F. Curtain, Department of Mathematics, University of Groningen, Groningen, the Netherlands
- Professor Jacques Desrosiers, GERAD and HEC, Montréal, Québec, Canada
- Professor A. L. Fradkov, Department of Mathematics and Mechanics, St. Petersburg University, Russia
- Professor Ruggero Frezza, Dipartimento di Elettronica, Universita di Padova, Padova, Italy
- Johann Galić, Department HUB, Metals Division, ABB Industrial Systems AB, Västerås, Sweden
- Professor Philip E. Gill, Department of Mathematics, University of California, San Diego, La Jolla, California, USA
- Dr. S. V. Gusev, Department of Mathematics, St. Petersburg University, St. Petersburg, Russia
- Professor Krzystof C. Kiwiel, Systems Research Institute, Warsaw, Poland
- Professor Clyde F. Martin, Department of Mathematics, Texas Tech University, Lubbock, Texas, USA
- Professor A. S. Matveev, Department of Mathematics, St. Petersburg University, St. Petersburg, Russia
- Professor György Michaletzky, Department of Probability Theory and Statistics, Eötvös Lorand University, Budapest, Hungary
- Professor Walter Murray, Department of Engineering Economic Systems and Operations Research, Stanford University, Stanford, California, USA
- Professor Giorgio Picci, Department of Electronics and Informatics, University of Padova, Padova, Italy
- Professor Alfredo Piria, Department of Mathematics, Facultad Ingeneria, Montevideo, Uruguay
- Dr. Paolo Rapisarda, DEEI, University of Trieste, Trieste, Italy
- Professor Francois Soumis, GERAD and École Polytechnique de Montréal, Montréal, Québec, Canada
- Jos Verrijdt, Faculty of Technology Management, Eindhoven University of Technology, Eindhoven, The Netherlands
- Dr. Martin Weiss, Systems and Control Group, Faculty of Applied Physics, Technical University of Eindhoven, Eindhoven, the Netherlands.
- Professor Jan C. Willems, Department of Mathematics, University of Groningen, Groningen, the Netherlands.

1.4 Networks

- European Research Network for Systems Identification (ERNSI)
- INTAS Network on Robust Control
- European Research Consortium for Informatics and Mathematics (ERCIM): Working Group Control and System Theory
- Strategic Research Consortium of Atonomous Systems, KTH

2 Research

2.1 List of projects

- Advanced optimization methods for crew and vehicle scheduling
- Allocation of scarce track capacity
- Autonomous systems
- Control of land and air vehicles
- Dual methods for short term power planning problems
- Dual methods for the unit commitment problem
- Financial economics
- Infinite dimensional systems
- KTH Optimization Laboratory
- Large scale decomposition and nonsmooth optimization
- Linear stochastic systems theory
- Locomotive scheduling
- Optimal damping of forced oscillations in discrete-time systems
- Optimization of spare parts inventory systems
- Phase portraits of nonstandard Riccati equations and applications of Riccati theory
- Robust control of electrical drives
- Robust feedback control of nonlinear and uncertain systems
- Robust quality control for paper manufacturing
- Second-derivative methods for nonlinear programming
- Stochastic realization theory and identification
- Structural optimization
- The behavioral approach to systems and control
- The rational covariance extension problem
- The structure of linear discrete-time stochastic systems

2.2 Description of projects

Advanced optimization methods for crew and vehicle scheduling

Researchers: P. O. Lindberg and Andreas Nõu, in cooperation with Krzystof C. Kiwiel (Systems Research Institute, Warsaw, Poland).

Sponsor: Swedish Transport and Communications Board (KFB).

This project aims at using advanced dual methods on crew and vehicle scheduling problems.

Recently there has appeared optimizing methods for crew and vehicle scheduling problems. These methods solve resource (e.g. time and capacity) constrained shortest path problems as subproblems and combine the subproblem solutions through Dantzig-Wolfe decomposition. The master problem is solved to generate dual multipliers. We are looking at using advanced dual methods in this framework, since the solution of the master problem may be very time consuming.

The problems we have in mind are very large, sparse, set-covering problems that arise e.g. in airline crew scheduling. Our computational results are promising.

Allocation of scarce track capacity

Researchers: Ulf Brännlund, P. O. Lindberg and Andreas Nöu in cooperation with Jan-Eric Nilsson, CTS, Borlänge.

Sponsors: The Swedish Transport Research Board (TFB) and the Swedish National Rail Administration (Banverket).

Industrial contacts: The Swedish National Rail Administration.

This is a project concerning the optimal allocation of scarce track capacity between a number of different railway companies.

It is assumed that the companies can provide utility functions giving their monetary values of different time tables.

For the problem of allocating the capacity so that the total utility is maximized, we have set up an optimization model and devised an algorithm based on dual methods. The modelling has been done in close cooperation with Jan-Eric Nilsson at the Centre for Research in Transportation and Society at Borlänge. The resulting model is extremely large. A typical case with 25 trains, 17 stations and one-minute discretization gives on the order of 400 000 binary variables and constraints. Our method uses the structure of the model and does not have to treat these variables explicitly.

Preliminary computational testing shows that the method works and it gives close to optimal solutions.

Autonomous systems

Researchers: Anders Lindquist, Xiaoming Hu, P.-O. Gutman, and Daniele Galardini, within the framework of the Center for Autonomous Systems.

Sponsor: The Strategic Research Foundation (Stiftelsen för strategisk forskning).

This is a broad and long-term project in collaboration with the Division of Computer Vision and Active Perception, (Numerical Analysis and Computing Science), Department of Mechatronics and Machine Elements, and Department of Signals, Sensors and Systems, which together with the Divison of Optimization and Systems Theory form a research consortium supported by a grant from the Strategic

Research Foundation. By autonomous systems is meant technical systems (such as mobile robots) that are capable of performing advanced tasks in unpredictable environments. This multidisplinary project has just begun.

Control of land and air vehicles

Researchers: Jorge Marí in cooperation with J. Ackermann, German Aerospace Research Establishment in Oberpfaffenhofen (Anders Lindquist; advisor).

Sponsors: The Swedish Research Council for Engineering Sciences (TFR) and the Swedish Institute.

The dynamics of vehicles considered as rigid bodies and different control strategies for their “safe” movement are being studied. We have shown that under ideally satisfied assumptions the use of transversal accelerometers attached to a vehicle is the key to guaranteeing the generic rejection of disturbances. We have also derived computable criteria for a system to be robustly decoupable, and we have shown that aircraft with tailerons and canards can have their longitudinal movements decoupled against uncertainties in the load and in the position of the center of gravity, while insuring stability. We are participating in the High Incidence Research Model benchmark organized by GARTEUR, which deals with the design of controllers satisfying certain specifications for a military aircraft. We also plan to study the effect of lateral accelerometers to enhance yaw-rotations to lateral dynamics decoupling in cars. This could be an interesting extension to the present yaw-rate driven decoupling controllers.

Dual methods for short term power planning problems

Researchers: P. O. Lindberg and Stefan Feltenmark.

Sponsor: The Ernst Johnson Foundation.

Industrial contacts: ABB Network Control AB, Krångede Power Pool, Vattenfall AB.

This project comprises a host of related, but diverse, problems. The Economic Dispatch Problem (EDC) concerns the optimal distribution of an electric load among power generating units, while keeping reserves. For this problem, we have developed an efficient method based on the special structure of the constraints. This method has been extended to problems with losses, problems with area spinning reserve constraints, and dynamical problems with bounds on the rate of change in production for each unit, so called ramping.

When applying Lagrangian decomposition to short term planning of a system that includes thermal- and hydrounits, one get independent subproblems, the solutions of which must be coordinated. We have treated the variable-head hydroelectric planning problem, showing how to compute local optima to this non-convex, network flow problem by modifying algorithms for the linear case, [R5]. The thermal subproblem is described in another project.

Dual methods for the unit commitment problem

Researchers: Stefan Feltenmark and P. O. Lindberg, in cooperation with Krzysztof C. Kiwiel.

Sponsor: The Ernst Johnson Foundation.

Industrial contacts: ABB Network Control AB, Krångede Power Pool, Vattenfall AB.

This project aims at developing efficient dual methods for large scale unit commitment problems (i.e. short term production planning for thermal power stations). The work has evolved along the following lines:

- Using a cutting plane or bundle method for the dual of the Unit Commitment problem, one obtains not only a lower bound of the primal optimal value, but also relaxed schedules and weights associated with these schedules.This was established in [R6].
- The value of these relaxed solutions and multipliers in constructing good primal feasible solutions has been demonstrated through computations.
- The convexified solutions has additional use in a branch-and-bound algorithm for guiding in the branching decisions.

Financial economics

Researchers: Tomas Björk and Camilla Landén, in cooperation with Y. Kabanov (CEMI, Moscow), and W. Runggaldier (University of Padova).

The goal of this project is to study the mathematical theory of financial derivatives. In particular we have studied the term structure of interest rates, when the dynamics of the short rate (or the forward rate curve) is driven by a general marked point process as well as by a diffusion term. For hedging purposes this leads to a new theory of infinite-dimensional portfolios and in particular to the study of integral equations of the first kind.

Infinite dimensional systems

Researchers: Yishao Zhou in cooperation with Ruth F. Curtain (University of Groningen) and in part with Martin Weiss (Technical University of Eindhoven).

Sponsor: The Swedish Natural Science Research Council (NFR).

In many application areas, systems are more accurately described by partial differential equations or delay difference equations, for example, large scale flexible space structures, noise suppression in large cavities and process control, where there are considerable delays in control implementation. Control problems for such systems can be formulated in an analogous way to those for lumped parameter systems (those described by ordinary differential equations) if one introduces a suitable infinite-dimensional space and suitable operators A, B, C, D, instead of the usual matrices. Infinite-dimensional systems theory is concerned with the extension of more familiar theory to this more general setting, insofar this is possible. Control design in this context is a synthesis of this theory, taking into account numerical, physical and implementational aspects.

This project fits in the main areas modelling and system description and control systems, with contributions to the research themes distributed parameter systems and discrete event systems, design methods for control systems and robust control.

Subproject 1: Weighted mixed senstivity H_∞ control. This is a very useful formulation in applications of control design. It gives stability and robustness requirements in one formula, and therefore it is important in engineering applications. Work has been completed on various approximations for certain classes of irrational transfer matrices, published in [A8], [A9], [A6] and [A7] (Better approximations and wider classes of problems are still demanded.) This approach is made in frequency-domain in contrast to next part which is taken in time-domain.

Subproject 2: Numerical solutions of Riccati equations for delay systems. This includes positive definite and indefinite cost functionals. The aim is to develop an effective numerical algorithm for such an operator Riccati algebraic equation from LQ-control, then (if successful) to disturbance attenuation H_∞ control, and later to the two coupled operator AREs from the so-called standard H_∞ control. To the investigators' knowledge, there are no numerical schemes for solving the last mentioned equations up to now. The main idea here is to use a bilinear mapping to transform the continuous-time ARE whose parameter operators are normally unbounded to its discrete-time version with bounded parameter operators. In this way, one hopefully can avoid certain numerical problems potentially caused by the unboundedness of those operators.

KTH Optimization Laboratory

Researchers: Patrik Alfredsson, Ulf Brännlund, Stefan Feltenmark, Anders Forsgren, Andreas Nõu, Krister Svanberg.

Sponsors: The Swedish National Board for Industrial and Technical Development (NUTEK) and the Swedish Council for Planning and Coordination of Research (FRN).

Industrial contacts: ABB Network Control, AlfGam Optimering AB, Ericsson Telecom AB.

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, QPSOL, LSSOL, NPSOL	(Gill et al, Stanford)
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 Adademy 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 decomposition and nonsmooth optimization

Researchers: Ulf Brännlund and P. O. Lindberg.

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

Many important optimization problems are inherentely nonsmooth, i.e. the objective function does not have continuous derivatives. A typical source of nondifferentiability is when the objective function is the maximum of other functions. One such very important class of nonsmooth problems arise in decomposition in the framework of Lagrangian relaxation.

In this project we try to extend and improve a new bundle method for nonsmooth optimization. We believe this bundle method, is more stable than other bundle methods at least when a good estimate of the optimal value is known. This is the case in decomposition and many other nonsmooth optimization problems. We have proposed a new bundle method for, possibly, constrained convex optimization. It does not use linesearches and it is proven to be globally convergent. In [A4] we present some preliminary computational experience with this algorithm.

Linear stochastic systems theory

Researchers: Anders Lindquist, in cooperation with Giorgio Picci (University of Padova).

Sponsors: The Swedish Research Council for Engineering Sciences (TFR) and the Göran Gustafsson Foundation.

A comprehensive theory for state-space modelling of vector-valued (stationary and stationary-increment) stochastic processes has been developed within the framework of the geometric Hilbert space theory of Markovian splitting subspaces developed by Lindquist and Picci and others. It will be presented in detail in a forthcoming monograph, which is under preparation. This geometric theory should be regarded as a natural and logically consistent way of building up linear stochastic systems theory. Traditionally there has been little attention paid even to the most elementary structural concepts in linear stochastic systems, like, for example, minimality. This has led to derivations of filtering algorithms by formula manipulations without deeper understanding of why the estimates satisfy recursive equations and whether the algorithms obtained are of minimal complexity, etc. In fact, many structural properties important in dynamic estimation, such as, for example, the existence of recursive (i.e. differential-equation type) solutions, the minimality of filtering algorithms, and processing of specific observed signals, possibly with a noncausal information pattern, are best formulated and understood in a coordinate-free form, using the geometric language of Hilbert space theory, as the use of coordinates may sometimes only obscure the basic issues.

Locomotive scheduling

Researchers: Andreas Nõu (P. O. Lindberg; advisor), in cooperation with Jacques Desrosiers and Francois Soumis (Montréal, Canada).

Sponsor: Swedish Transport and Communications Board (KFB).

Industrial contacts: Swedish State Railways (SJ).

This is a project concerning the construction of periodic locomotive schedules, needed e.g. at a planning stage at the Swedish State Railways.

The objective is to find cyclic locomotive schedules, who minimize operational costs while respecting maintenance and availability constraints on each type of locomotive. The locomotive requests might have restrictions on the type of locomotive to be used. Maintenance constraints are expressed in terms of accumulated traveled distance by each locomotive. The modeling has been done in close cooperation with Anders Jönsson at the Swedish State Railways, SJ.

A realistic size problem has been supplied to us by SJ. The problem has, after preprocessing, more than 2400 locomotive requests. We consider two types of locomotives. Our preliminary computational results are encouraging.

Optimal damping of forced oscillations in discrete-time systems

Researchers: Anders Lindquist and Vladimir A. Yakubovich.

Sponsors: The Swedish Research Council for Engineering Sciences (TFR), the Royal Swedish Academy of Sciences, NUTEK 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. 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. In [R14][R15] we show 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 also show that any OUR for this (deterministic) problem is an optimal regulator for a class of stochastic control problems of similar structure. In [A18] we consider the case of complete state feedback, in which case an OUR always exists. The problem of optimal tracking is considered in [R15].

We stress that our solutions are optimal in the sense stated above only, and that other desirable design specifications may not be satisfied for an arbitrary universal optimal regulator. Therefore it is an important 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 spare parts inventory systems

Researchers: P. O. Lindberg and Patrik Alfredsson.

Sponsors: The Swedish National Board for Industrial and Technical Development (NUTEK) and the Swedish Defense Material Administration (FMV).

Industrial contact: Swedish Defense Material Administration (FMV).

The aim of this project to develop techniques to improve the behavior of logistics support systems. A natural problem of interest is the spare parts optimization problem, where the objective is to allocate spares within the support system so as to achieve optimum performance while satisfying a budget constraint. We are devoloping algorithms for solving this difficult, nonconvex, nonlinear integer problem.

We have also extended our models to include decisions regarding level of repair and test equipment necessary to perform repair of faulty items.

However, the number of spares at various stock points is not the only parameter that are influencing the overall support system performance. Therefore, we have developed techniques to efficiently compute the sensitivity of the performance with respect to other system parameters (variables), e.g. transportation and repair times. In connection, we have also studied robustness issues and are developing techniques to obtain more robust solutions (spare parts allocations).

Phase portraits of nonstandard Riccati equations and applications of Riccati theory

Researcher: Yishao Zhou.

Sponsor: The Swedish Natural Science Research Council (NFR).

As is well-known, Riccati differential/difference equations arise in many aspects of control, estimation and filtering problems. To understand their eventual behavior is a crucial problem from both mathematical and implementation viewpoints. This project fits in the main areas system description, control systems, estimation and filtering, with contributions to the research themes linear and nonlinear systems, methods for control systems and robust control, and dynamical system theory.

Subproject 1: Necessary and sufficient conditions for the Riccati equation to converge to its maximal solution. If the initial and parameter matrices are assumed to be positive (semi)definite, one pretty well knows necessary and sufficient conditions for Riccati equation to converge to its strong solution. The purpose of this project is to work out necessary and sufficient conditions for convergence to its maximal solution without *a priori* assumption on the signature of the initial and parameter matrices. This provides the important insights into the investigation of eventual behavior in more general context. Partial results were reported in [C21] and [R27]. Some applications were reported in [C12] and [R11].

Subproject 2: Phase portrait of nonstandard Riccati equation. A major goal of this research will be to systematically study the existence of finite escape time for nonstandard Riccati equations (say in H_∞-control), leading to the development of necessary and sufficient conditions in terms of the system parameters. Partial results are obtained [R25], [R24] and [R26].

Subproject 3: Description of equilibrium set. The equilibrium set of the Riccati equation is the solution of the algebraic Riccati equations. It is an interesting topic in its own right. To have a complete picture of this set is, without question, an important step in description of phase portraits of the Riccati equation. The research purpose is to describe the equilibrium set from geomtric, topological aspects as well as the so-called polynomial approach. Good understanding of the equilibrium structure from the last mentioned aspect may also interpret some unclear problems arising in control problems in the behavioral context.

Robust control of electrical drives

Researchers: P. O. Gutman, Xiaoming Hu, Daniele G. Galardini, Mattias Nordin and Anders Lindquist, in cooperation with Johann Galić (ABB Industrial Systems AB, Västerås.

Sponsors: The Swedish National Board for Industrial and Technical Development (NUTEK) and ABB Industrial Systems AB.

The aim of this project is to combine robust linear control with nonlinear and/or adaptive control elements, implemented in a microprocessor, that alleviate the effects of the process nonlinearities. In particular are electrical drives with friction, backlash and uncertain loads and disturbances studied.

The project has been running since January 1992, and has received continued funding until June 1997. The following has been achieved during the year:

Tuning rules for PI-control of resonant systems have been developed, [R8][C3][R9]. This result is very important in view of the fact that tuning rules hitherto found in the literature deal exclusively with non-resonant systems. The tuning rules have been successfully tested on a 60 kW electrical drive in the laboratory of ABB Industrial Systems.

A Variable Structure design of a two-mass sytem has been tested [R10].

The work on backlash compensation has continued. An algorithm for speed control has been suggested based on rapid gain sceduling between different linear control laws, depending on the estimated load torque. Presently the properties of this algorithm are being analyzed and proved. The algorithms will shortly be tested in the laboratory.

The new models for backlash or gear play, prevously develped will soon be published [A20].

New methods for idententification of the backlash gap, based on frequency response measurements has been developed [C16].

Mattias Nordin and Per-Olof Gutman won the design competition at the European Control Conference in Rome in September 1995 ([C15]). Stringent specifications for the regulation and step response of a resonant and uncertain three-mass benchmark system were postulated and their QFT design was the only entry that satisfied all specifications. The Benchmark, including all designs has been publised in European Journal of Control [A21].

An important issue for robust control is the identification of the set of frequency functions representing the uncertain system, in form of value sets, i.e. the set of complex frequency function values at a given frequency. We have found an method to identify value sets using a set of Lissajou figures, whereby a necessary and sufficient condition for a correct identification is that the value set is convex; otherwise the convex hull is identified. This work was reported in [C9]. The Lissajou figure sets have been shown to be efficient for eliminating outlier, other bad data, and measurement noise. Moreover, if a number of value sets are given, then the problem to fit them to an assumed transfer function model structure that is linear in the parameters (e.g. Laguerre or Kurtz models) was found to lead to a Linear Programming problem. Reports on the latter two topics are being prepared.

The project is now entering an experimental phase, where we are trying to test some of the different proposed method on the ABB laboratory system.

Robust feedback control of nonlinear and uncertain systems

Researchers: Xiaoming Hu.

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

In the past year we have continued to study the problems of feedback stabilization and output regulation for nonlinear control systems possibly with uncertainties and apply the results to some practical systems, such as servo systems affected by friction forces and robust car steering. Our main task for nonlinear feedback stabilization on compacta by using high gain feedback control is to obtain results for a system which does not satisfy the well known "nonpeaking" conditions. This case proves to be quite subtle. In fact, contrary to the belief of some researchers, in this case, being globally exponentially minimum phase is not necessarily a stronger hypothesis than being globally (maybe critically) minimum phase, as far as global stabilization is concerned.

Robust quality control for paper manufacturing

Researchers: P. O. Gutman, in cooperation with Bo Wahlberg, Torsten Bohlin, Alf Isaksson, and Jens Pettersson (Department of Automatic Control, KTH), and with Bengt Nilsson (Assi-Domän Frövifors Bruk AB, Frövi).

Sponsors: The Swedish National Board for Industrial and Technical Development (NUTEK) through its REGINA program, and Assi-Domän Frövifors Bruk AB.

Given a complicated multi-input multi-output, non-linear and time varying process, whose model is known only with very large uncertainty, affected by unknown and unmeasurable disturbances, and whose output variables are measured at a sampling interval that is much larger than the sampling intervals of the control variables and the measurable process variables, or some of the time constants of the system, and occasionally the process is brought to halt (either intentionally or due to a mishap), and started again, the aim of this research project is to

a) find a methodology to build prediction models of the process for various time horizons, including experiment design, using normal operating data and adaptation over time. The task may include the adaptive selection and deselection of significant input variables, overcoming the difficulty of non-uniform sampling and missing data, and solving the initialization after start-ups;

b) integrate suitable predictors into an existing computer control system as an operator aid. The task includes solving the theoretical problems of treating missing and invalid data, and computing an estimate of the goodness of the prediction;

c) design an automatic quality controller that minimizes a non-linear criterion including deviations from specified quality limits, and raw material and energy costs.

The industrial process on which this program is conducted, including experiments and test, is the paper board manufacturing machine at Assi-Domän Frövifors Bruk AB, Frövi, which suffers of all problems mentioned above.

The program has started by modelling the laboratory measured quality variable bending stiffness index, as reported in [C10], where the use of an ARMA model with input non-linearities resulted in an on line predictor with a prediction error less than half the laboratory measurement error. The predictor is currently tested on-line at Assi-Domän Frövifors Bruk AB, Frövi.

However, the grey box model developed by Prof. Bohlin seems to be even more promising, and work is continuing along this line.

In parallell, a benchmark problem of controlling a paper machine with uncertain dynamics was solved in [C18] where the QFT approach taken was seen to be more successful to meet specifications than the solutions contributed by others.

Second-derivative methods for nonlinear programming

Researchers: Anders Forsgren, in cooperation with Philip E. Gill (UCSD), Walter Murray (Stanford University) and Joseph R. Shinnerl (UCSD).

Sponsors: The Swedish Natural Science Research Council (NFR) and the Royal Swedish Academy of Sciences (Magnusons fond, KVA).

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 joint work with Walter Murray has been focused on the development of modified Newton methods of the linesearch type for linearly constrained optimization. The methods utilize both descent directions and directions of negative curvature. A paper, dealing with strategies suitable for large-scale problems has been written [A11].

Together with Philip E. Gill and Joseph R. Shinnerl, the stability of barrier equations has been investigated. In particular, the focus has been on the stability of the symmetric indefinite systems of equations that arise in barrier methods for constrained optimization [A10]. More recently, the joint work with Philip E. Gill has been directed towards penalty-barrier methods for general nonlinear programming methods. A method, solving a primal-dual system of equations at each iteration, utilizing an augmented penalty-barrier merit function, has been developed [R7].

One subproject has been directed to weighted linear least-squares problems. Such problems arise when using interior methods, and good understanding of these problems is of vital importance for extending the stability analysis further. A paper dealing with extensions of results for diagonal matrices to more general matrices such as diagonally dominant matrices has been written [A12].

Stochastic realization theory and identification

Researchers: Anders Lindquist, Anders Dahlén and Jorge Marí, in cooperation with Giorgio Picci (University of Padova).

Sponsors: The Swedish Research Council for Engineering Sciences (TFR) and the Göran Gustafsson Foundation.

In this project we analyze a class of identification algorithms based on canonical correlation analysis in the light of recent results on stochastic systems theory. In principle these so called “subspace methods” can be described as covariance estimation followed by stochastic realization. The method offers the major advantage of converting the nonlinear parameter estimation phase in traditional ARMA models identification into the solution of a Riccati equation but introduces at the same time some nontrivial mathematical problems related to positivity. The reason for this is that an essential part of the problem is equivalent to the well-known rational covariance extension problem. Therefore the usual deterministic arguments based on factorization of a Hankel matrix are not valid, something that is habitually overlooked in the literature.

In [A16] we demonstrate that there is no guarantee that several popular identification procedures based on the same principle will not fail to produce a positive extension, unless some rather stringent assumptions are made which, in general, are not explicitly reported. This brings in the issue of stochastic model reduction. The statistical problem of stochastic modeling from estimated covariances is phrased in the geometric language of stochastic realization theory. We discuss the concept of stochastic balancing and of stochastic model reduction by principal subsystem truncation. The model reduction method of Desai and Pal, based on truncated balanced stochastic realizations, is partially justified, showing that the reduced system structure is has a positive covariance sequence but is in general not balanced. As a byproduct of this analysis we obtain a theorem prescribing conditions under which the "subspace identification" methods produce *bona fide* stochastic systems. A mini-course on these results was given at the International Symposium on the mathematical Theory of Networks and Systems (MTNS96) in St. Louis, June 1996.

Work is now under way to construct alternative algorithms which insure positivity.

Structural optimization

Researchers: Krister Svanberg and Ulf Brännlund.

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

The aim of this project is to develop mathematical models and efficient numerical methods for optimizing both the topology and the element sizes of different load-carrying structures. During the year, we have been able to show that the so called truss topology design (TTD) problem can be formulated as a semidefinite programming (SDP) problem in which the structural stiffness matrix and the given load vectors appear in a surprisingly appealing way. Further, we have shown that the dual problem corresponding to this SDP problem has the property that, at the optimal solution, all the semidefinite matrices involved are of rank one. Finally, based on these theoretical results, we have developed a primal-dual interior point method which has been applied to some very large TTD problems (involving more than ten thousand potential bars).

The behavioral approach to systems and control

Researchers: Yishao Zhou in cooperation with Jan C. Willems (university of Groningen) and in part with Paolo Rapisarda (University of Trieste).

Sponsor: The Swedish Natural Science Research Council (NFR).

The principal aim of the project concerning the behavioral approach is the development of a conceptual mathematical framework for the description of dynamical systems. It gives a suitable mathematical language which covers open physical engineering systems, and can be used very effectively in synthesis questions, especially in those related to control.

The central concept which we have introduced and which we take as our starting point is that of a dynamical system. This is defined as a triple $\Sigma = (T, W, B)$, with $T \subseteq R$ the time-axis, W the signal space, and B a subset of W^T, called the behavior of Σ. The behavior consists of those trajectories $w : T \to W$ which satisfy the laws imposed by Σ. In first principles modelling one invariably needs to introduce auxiliary variables in order to express the laws of a system. This feature is incorporated by distinguishing between manifest variables (the variables which the model aims at) and latent variables (the auxiliary variables). The systems which we consider interact with their environment. In our set-up the input/output and state space structure enter as very useful, but special, types of system representations.

This starting point has proven a very flexible one and a wealth of concepts, problems, and algorithms have been cast and resolved in this framework.

This project fits in the main areas modelling and system description, system identification and control systems, with contributions to the research themes system theory and modelling, nonlinear systems, methods for system identification, design methods for control systems and robust control.

Subproject 1: Control in a behavioral context. The purpose of this research project is the formulation of control problems and algorithms in the context of behaviors. The starting point is a set of behavioral equations, for example a system of differential equations $R(d/dt)w = 0$ with R a polynomial matrix. We view control as interconnection, that is, adding a new system of differential equations $C(d/dt)w = 0$. The resulting closed loop system has been studied w.r.t. stabilization, pole assignment, invariant factor assignment, etc.

The research objectives are

- To generalize the solution of the LQ-problem as given by Willems to situations where stability is not imposed and where a larger class of trajectory variations is considered. This will yield in particular the behavioral analogue of what is usually called the *free-end point problem* in LQ-control. Our preliminary calculation shows very likely that the optimal trajectory exists iff the quadratic form is half-line positive.
- To investigate the LQ/H_∞-control problems for finite time horizon, very valuable control problems, in the behavioral context, since all work, up to now, is accumulated on the steady state control.
- To obtain a full generalization of the ARE in terms of storage functions and a parametrization for the set of storage functions in terms of the maximal and minimal ones.

Subproject 2: System representations. The purpose of this research is to study different representations of dynamical systems defined by integral equations or operator or convolution equations in the behavioral framework. These have potential to cause considerably mathematical difficulties due to the infinite dimensionality. There are several preliminary results in preparation [R21], [R22] and [R23]. In particular, this investigation will lead to the behavioral approach to control problem for such infinite-dimensional systems, i.e. view the feedback control as interconnection of two systems in the same spirit of that for finite-dimensional systems.

The rational covariance extension problem

Researchers: Anders Lindquist and Per Enqvist, in cooperation with C. I. Byrnes (Washington University, St Louis) and S. V. Gusev and A. S. Matveev (University of St. Petersburg).

Sponsors: The Swedish Research Council for Engineering Sciences (TFR) and the Göran Gustafsson Foundation.

The minimal rational covariance extension problem is a fundamental problem in systems theory, control theory, and signal processing, many aspects of which have remain unsolved for a long time.

In [A5] we formalize the observation that filtering and interpolation induce complementary, or “dual” decompositions of the space of positive real rational functions of degree less than or equal to n. From this basic result about the geometry of the space of positive real functions, we are able to deduce two complementary sets of conclusions about positive rational extensions of a given partial covariance sequence.

On the one hand, by viewing a certain fast filtering algorithm as a nonlinear dynamical system defined on this space, we are able to develop estimates on the asymptotic behavior of the Schur parameters of positive rational extensions. On the other hand we are also able to provide a characterization of all positive rational extensions of a given partial covariance sequence. Indeed, motivated by its application to signal processing, speech processing and stochastic realization theory, this characterization is in terms of a complete parameterization using familiar objects from systems theory and proves a conjecture made by Georgiou. However, our basic result also enables us to analyze the robustness of this parameterization with respect to variations in the problem data.

In [R1] we describe this parameterization in terms of a nonstandard matrix Riccati equation, which we call the Covariance Extension Equation. We also compute the dimension of partial stochastic realizations in terms of the rank of the unique positive semi-definite solution to the Covariance Extension Equation, yielding some insights into the structure of solutions to the minimal partial stochastic realization problem. By combining this parameterization with some of the classical approaches in partial realization theory, we are able to derive new existence and robustness results concerning the degrees of minimal stochastic partial realizations. As a corollary to these results, we note that, in sharp contrast with the deterministic case, there is no generic value of the degree of a minimal stochastic realization of partial covariance sequences of fixed length. In [R3] we present a convex optimization problem for solving the rational covariance extension problem. Given a partial covariance sequence and the desired zeros of the modeling filter, the poles are uniquely determined from the the minimum of the corresponding optimization problem. In this way we obtain a covariance extension problem, as well as an alternative proof of Georgiou's conjecture.

The structure of linear discrete-time stochastic systems

Researchers: Anders Lindquist in cooperation with Gy. Michaletzky (Eötvös Lorand University, Budapest).

Sponsors: The Swedish Research Council for Engineering Sciences (TFR) and the Göran Gustafsson Foundation.

In this project we establish for discrete-time systems a useful connection between the geometric theory of splitting subspaces and geometric control theory in the style of Wonham and Basile and Marro. This has been done previously in the continuous-time case in collaboration with Giorgio Picci. However, the discrete-time case is more complicated due to the possibility of the occurrence of invariant directions, and therefore, in addition to the the notion of *output-induced subspace*, we need to introduce the stronger concept of *strictly output-induced subspace*. In [A15] we discuss the role of invariant directions, zeros of spectral factors and output-induced subspaces in determining the systems-theoretical properties of stochastic systems. We demonstrate that the maximal output-induced subspace can be decomposed as a direct sum of the subspace of invariant direction over the future, the subspace of invariant direction over the past, and the maximal strictly output-induced subspace, corresponding to the zeros at zero, the zeros at infinity, and the remaining zeros respectively. The maximal strictly output-induced subspace can be determined by algorithms akin to that used in geometric control theory for determining the maximal output-nulling subspace. A basic tool in this analysis is a pair $(\sigma, \bar{\sigma})$ of shift operators on the family of minimal splitting subspaces, which produces a family of totally ordered splitting subspaces. We show that these splitting subspaces are tied together by Kalman filtering recursions in the sense that we can pass from one state process to the next by Kalman filtering, an intersting fact that enables us actually to compute these spaces.

As a by-product of this analysis we solve the following estimation problem: Consider a linear stochastic system where both the state process and the output process is observed, but there is a "black out" of state information during a finite interval of time. A problem considered in [A15] is to reconstruct the lost state information from the remaining observations. This gives a systems theoretical interpretation to *each* minimal stochastic realization akin to that of a minimum-phase solution in the classical theory. When the interval with the lost information grows, this pair of realizations converge to "the tightest internal bounds".

3 Education

3.1 Undergraduate courses

5B1712 Optimeringslära för F, Optimization, General Course for F

K. Svanberg 4 p

5B1722 Tillämpad optimeringslära, Applied Optimization

C. Trygger 4 p

5B1740 Mathematical Systems Theory, A. Lindquist
(*Matematisk systemteori)*

P. Enqvist 3.5 p

5B1750 Optimeringslära för E och D, Optimization, General Course for E and D

K. Svanberg 4 p

5B1780 Applications of Mathematics and Computer Science, A. Forsgren
(*Matematikens och datateknikens tillämpningar)*

M. Nordin 3 p

5B1810 Matematisk programmering, Mathematical Programming

A. Forsgren 5 p

5B1820 Advanced Course in Mathematical Systems Theory, A. Lindquist
(*Matematisk systemteori, fortsättningskurs)*

J. Marí 4 p

5B1830 Systems Engineering, A. Forsgren
(*Systemteknik)*

P. Alfredsson 7 p

5B1840 Systemtekniska metoder, Methods of Systems Engineering

A. Forsgren 3.5 p

5B1850 Matematisk ekonomi, Mathematical Economics

U. Brännlund 3 p

5B1862 Stokastisk kalkyl och kapitalmarknadsteori, Stochastic calculus and the theory of capital markets

T. Björk 5 p

5B1870 Optimal styrteori, Optimal Control Theory

C. Trygger 3.5 p

5B1880 Produktions- och lagerstyrning, Production and Inventory Control

U. Brännlund 3 p

3.2 Graduate courses

Course name	Instructor	Credit	Participants KTH	Participants industry
Introduction to Hybrid Control Systems	X. Hu	5 p	8	-
Probability Theory	T. Björk	5 p	7	2

3.3 Master theses (Examensarbeten)

4 Publications

4.1 Papers in journals and books (published and accepted)

[A1] P. Alfredsson, *Optimization of multi-echelon repairable item inventory systems with simultaneous location of repair facilities*, To appear in European Journal of Operational Research.

[A2] V. Blondel, M. Gevers, and A. Lindquist, *Survey on the state of systems and control*, European Journal of Control, 1(1995), 5–23.

[A3] U. Brännlund, *A generalized subgradient method with relaxation step*, Mathematical Programming 71 (1995), 207-219.

[A4] U. Brännlund, K. C. Kiwiel and P. O. Lindberg, *Preliminary computional experience with a descent level method for convex nondifferentiable optimization*, System Modelling and Optimization, Ed. J. Dolezal and J. Fidler, Chapman & Hall, pp. 387-394.

[A5] C. I. Byrnes, A. Lindquist, S. V. Gusev and A. S. Matveev, *A complete parameterization of all positive rational extensions of a covariance sequence*, IEEE Transactions on Automatic Control, AC-40 (1995), 1841–1857.

[A6] R. F. Curtain, M. Weiss and Y. Zhou, *Closed formulae for a parametric-mixed-sensitivity problem for Pritchard–Salamon systems*, Systems & Control Letters 27(1996), 157–167.

[A7] R. F. Curtain, M. Weiss and Y. Zhou, *Approximate solutions to a weighted mixed-sensitivity H^∞-control design for irrational transfer matrices*, International Journal of Robust and Nonlinear Control 6(1996), 399–411.

[A8] R. F. Curtain and Y. Zhou, *A weighted mixed-sensitivity H^∞-control design for irrational transfer matrices*, Computation and Control IV, Birkhäuser, Boston, 1995, 99–113.

[A9] R. F. Curtain and Y. Zhou, *Weighted mixed-sensitivity H_∞-control design for irrational transfer matrices*, IEEE Trans. Automatic Control, 41 (no. 9) to appear.

[A10] A. Forsgren, P. E. Gill and J. R. Shinnerl, *Stability of symmetric ill-conditioned systems arising in interior methods for constrained optimization*, SIAM Journal on Matrix Analysis and Applications 17(1996), 187–211.

[A11] A. Forsgren and W. Murray, *Newton methods for large-scale linear inequality-constrained minimization*, To appear in SIAM Journal on Optimization.

[A12] A. Forsgren, *On linear least-squares problems with diagonally dominant weight matrices*, To appear in SIAM Journal on Matrix Analysis and Applications.

[A13] X. Hu, *An invariant manifold approach to nonlinear feedback stabilization on compacta*, J. of Math. Systems, Estim., and Control, vol 6, No. 2, 1996.

[A14] K. C. Kiwiel, P. O. Lindberg and A. Nõu, *Dual Bregman proximal methods for large-scale 0-1 problems*, System Modelling and Optimization, Ed. J. Dolezal and J. Fidler. Chapman & Hall, pp. 459-465.

[A15] A. Lindquist and Gy. Michaletzky, *Output-induced subspaces, invariant directions and interpolation in linear discrete-time stochastic systems*, SIAM J. Control and Optimization, 35(1997), to be published.

[A16] A. Lindquist and G. Picci, *Canonical correlation analysis, approximate covariance extension, and identification of stationary time series*, Automatica, 32(1996), 709–733.

[A17] A. Lindquist and G. Picci, *Geometric methods for state space identification*, in Identification, Adaption and Learning (S. Bittanti and G. Picci, editors), NATO Advanced Science Institute Series, Vol. 153, Springer 1996, pp. 1–69.

[A18] A. Lindquist and V. A. Yakubovich, *Optimal damping of forced oscillations in discrete-time systems*, IEEE Transactions on Automatic Control, to be published.

[A19] J. Marí, *A counterexample in power signals space*, IEEE Transactions on Automatic Control, 1(1996), 115-116.

[A20] M. Nordin, J. Galić and P.-O. Gutman, *New models for backlash and gear play*, Int. J. of Adaptive Control and Signal Processing, 1997 (accepted).

[A21] M. Nordin and P.-O. Gutman, *Digital QFT design for the flexible transmission benchmark problem*, European Journal of Control 1 (1995), 97–103.

4.2 Papers in conference proceedings (published and accepted)

[C1] J. Ackermann and X. Hu, *Acceleration and braking effects on robustly decoupled car steering*, Proc. of the third European Control Conference.

[C2] S. Feltenmark and P. O. Lindberg, *Network methods for head-dependent hydro power scheduling*, To appear in proc. of Networks Conference, Gainesville, Fl., U.S.A., February, 1996.

[C3] D. G. Galardini and M. Nordin, *PI and model-based control of a two-mass systems with backlash*, Proceedings Reglermöte, Luleå, pp.201–206.

[C4] D. Galardini, A. Balestrino, A. Landi and M. D'Alessandro, *Finite observers applied to motion control*, Proceedings of the IFAC workshop on Motion Control, Munich, Germany, 1995, 213-229.

[C5] D. Galardini and R. Gorez, *Robust control with disturbance observers for robot manipulators*, Proceedings of the IFAC workshop on Motion Control, Munich, Germany, 1995, 617-624.

[C6] D. Galardini and R. Gorez, *A design procedure for control systems with disturbance observers*, Proceedings of the 3th European Control Conference, Rome, Italy, 1995, Vol.1, 538-542.

[C7] D. Galardini and R. Gorez, *About models of robot for decoupled joint control*, EUROSIM'95, F. Breitenecker and I. Husinsky (Editors), Elsevier Science, Amsterdam, Netherlands, 1995, 391-396.

[C8] D. Galardini, R. Gorez and H. Hsu, *On the use of disturbance observers for control of flexible robot arms*, Proceedigs of the 7th IEEE International Conference on Advanced Robotics, Barcelona, Spain, 1995, Vol. 2, 538-542.

[C9] N. Galperin, P.-O. Gutman, and H. Rotstein, *Value set identification using Lissajou figure sets*, 13th IFAC World Congress, San Francisco, June 30 - July 5, 1996.

[C10] P.-O. Gutman and B. Nilsson, *Modelling and prediction of bending stiffness for paper board manufacturing*, 13th IFAC World Congress, San Francisco, June 30 - July 5, 1996.

[C11] R. Gorez, D. Galardini and M. De Neyer, *A unifying approach to some model-based control structures*, Proceedings of the IFAC Symposium on Systems Structure and Control, Nantes, France, 1995, 237-242.

[C12] M. Hagström and Y. Zhou, *An algorithm for finding positive rational extensions of a finite covariance sequences*, Proceedings of 3rd European Control Conference, 1995.

[C13] J. Marí, *Controller structure design for the longitudinal motions of the HIRM*, Preprints Reglermöte 96, p. 128-133.

[C14] J. Marí and J. Ackermann, *Output shaping for robust decoupling*, Proc. 13th IFAC World Congress, 1996, Vol. G, 411-416.

[C15] M. Nordin and P.-O. Gutman, *Digital QFT design for the flexible transmission benchmark problem*, Invited paper to 1995 European Control Conference.

[C16] M. Nordin and P. Bodin, *A backlash gap estimation method*, Accepted to 1995 European Control Conference.

[C17] M. Nordin, *QFT-designs for two benchmark problems*, Proceedings Reglermöte '96, Luleå.

[C18] M. Nordin and P.-O. Gutman, *A robust QFT-design for a multivariable paper machine benchmark*, IEEE Conference on Decision and Control, december 1995, New Orleans.

[C19] B. Robyns, D. Galardini, R. Gorez, F. Labrique and H. Buyse, *High performance model-based control of induction motor*, Proceedings of the IFAC workshop on Motion Control, Munich, Germany, 1995, 477-484.

[C20] K. Svanberg, *A globally convergent version of MMA without linesearch*, In N. Olhoff and G. Rozvany: Proceedings of the First World Congress of Structural and Multidisciplinary Optimization, pp. 9-16, Elsevier Science (1995).

[C21] Y. Zhou, *Necessary and sufficient conditions for discrete-time Riccati equation to converge to its maximal solution*, Proceedings of IEEE Conference on Decision and Control, 1996, to appear.

4.3 Technical reports and preprints

[R1] C. I. Byrnes and A. Lindquist, *On the partial stochastic realization problem*, IEEE Transations on Automatic Control, submitted for publication.

[R2] C. I. Byrnes and A. Lindquist, *On a duality between filtering and interpolation*, collection of plenary lectures to be published by Birkhäuser Boston.

[R3] C. I. Byrnes, S. V. Gusev and A. Lindquist, *A convex optimization approach to the rational covariance extension problem*, preprint.

[R4] C. I. Byrnes, H. J. Landau and A. Lindquist, *On the well-posedness of the rational covariance extension problem*, in *Current and Future Directions in Applied Mathematics*, M. Alber, B. Hu and J Rosenthal (editors), to be published.

[R5] S. Feltenmark and P. O. Lindberg, *Network methods for head dependent hydro power scheduling*, Report TRITA/MAT-1996-OS2, Department of Mathematics, KTH, 1996, Submitted for publication.

[R6] S. Feltenmark and K. C. Kiwiel, *Lagrangian relaxation of nonconvex problems via bundle methods*, Report TRITA/MAT-1996-OS3, Department of Mathematics, KTH, 1996, Submitted for publication.

[R7] A. Forsgren and P. E. Gill, *Primal-dual interior methods for nonconvex nonlinear programming*, Report TRITA-MAT-1996-OS4, Department of Mathematics, Royal Institute of Technology, 1996.

[R8] D. G. Galardini, M. Nordin and J. Galić, *PI controllers for an elastic two-mass system*, Report TRITA-MAT-95-OS11, Department of Mathematics, 1995.

[R9] D. G. Galardini, M. Nordin and P.-O. Gutman, *Robust PI tuning for an elastic two-mass system*, Submitted for publication.

[R10] D. G. Galardini and X. Hu, *Variable structure control of two-mass systems based on output measurements*, Submitted for publication.

[R11] M. Hagström and Y. Zhou, *Approximate model of partial stochastic realization problems*, preprint.

[R12] X. Hu, *Global nonlinear feedback stabilization and nonpeaking conditions*, Preprint.

[R13] X. Hu and C. Martin, *Linear reachability versus global stabilization*, Preprint.

[R14] A. Lindquist and V. A. Yakubovich, *Optimal damping of forced oscillations by output feedback*, submitted for publication.

[R15] A. Lindquist and V. A. Yakubovich, *Universal regulators for optimal tracking in discrete-time systems affected by harmonic disturbances*, Submitted for publication in IEEE Transactions on Automatic Control.

[R16] A. Lindquist and V. A. Yakubovich, *Universal regulators for optimal damping of forced oscillations in linear discrete-time systems*, submitted for publication in Dokl. Akad. Nauk (Transactions of the Russian Academy of Sciences).

[R17] J. Marí and J. Ackermann, *Output shaping for robust decoupling*, IB.Nr.: 515-95-9, DLR Oberpfaffenhofen.

[R18] J. Marí, *Use of state-derivatives for disturbance rejections and its application to automatic control of vehicles*, IB.Nr.: 515-95-9, DLR Oberpfaffenhofen.

[R19] A. Matveev, A. Schiriaev, X. Hu and R. Frezza, *Deterministic Kalman Filtering for Systems with Implicit Output*, Submitted.

[R20] A. Matveev, A. Schiriaev, X. Hu and R. Frezza, *Observers and filters for systems with implicit output*, Preprint.

[R21] J. C. Willems and Y. Zhou, *Dynamical systems with integral structure in a behavioral setting*, preprint.

[R22] J. C. Willems and Y. Zhou, *A behavioral approach to systems of integrodifferential equations*, preprint.

[R23] J. C. Willems and Y. Zhou, *Characterization of systems defined by operator/convolution equations*, preprint.

[R24] Y. Zhou, *Phase portrait of the fast filtering algorithms*, Submitted to ECC97.

[R25] Y. Zhou, *Some convergence results of the discrete-time matrix Riccati equation with indefinite weighting matrix*, preprint.

[R26] Y. Zhou, *Phase portrait of the discrete-time Riccati equations: single input or single output case*, to be submitted for publication.

[R27] Y. Zhou, *Convergence of the discrete-time Riccati equation to its maximal solution*, preprint.

5 Seminars at the division

- Professor György Michaletzky, Eötvös Lorand University, Budapest, Hungary, *Output-induced subspaces, invariant directions and interpolation in linear discrete-time stochastic systems*, Oct. 13, 1995.
- Docent Anders Rantzer, Inst. f. Reglerteknik, Lunds Tekniska Högskola, *Error bounds for truncation of uncertain systems*, Oct. 20, 1995.
- Professor Krzysztof C. Kiwiel, Systems Research Institute, Polish Academy of Sciences, Warsaw, Poland, *Decomposition via alternating linearization*, Nov. 3, 1995.
- Professor G. A. Leonov, Dean at the University of St. Petersburg, Russia, *Stability and bifurcations of pendulum-like feedback systems*, Nov. 17, 1995.
- Dr. Rüdiger Schultz, Konrad Zuse Zentrum, Berlin, Germany, *On optimal dispatch of electric power*, Dec. 15, 1995.
- Professor Giorgio Picci, Depaartment of Electronics and Informatics, University of Padova, Italy, *A simple "subspace" identification method with exogenous inputs*, Mar. 6, 1996.
- Dr Andrea Gombani, LADSEB-CNR, Padova, Italy, *On external spectral factors and geometric control*, Mar. 12, 1996.
- Dr. Anton Shirjaev, St. Petersburg State University, Russia, *Dynamic output stabilization of a class of nonlinear systems*, Mar. 15, 1996.
- Professor Ruth Curtain, Department of Mathematics, University of Groningen, The Netherlands, *Positive-real, dissipative, passive, Nevanlinna class and the connection with controllers for large flexible space structures*, Mar. 22, 1996.
- Professor Clyde F. Martin, Department of Mathematics, Texas Tech. University, Lubbock, USA, *Visual dynamics as a hybrid control system*, Mar. 29, 1996.
- Professor Krzysztof C. Kiwiel, Systems Research Institute, Polish Academy of Sciences, Warsaw, Poland, *Proximal minimization methods with generalized Bregman functions*, Apr. 12, 1996.
- Professor Sanjoy Mitter, MIT, Cambridge, Mass., USA, *The LQG problem with communication constraints*, Jun. 14, 1996.

6 Awards and appointments

Anders Forsgren was awarded a Fulbright grant for spending three months as a visiting scholar at the University of California, San Diego, in the spring of 1996.

Mattias Nordin and **Per-Olof Gutman** were awarded first prize in the controller design contest of the 1995 European Control Conference [A21].

7 Presentations by staff

[P1] P. Alfredsson, *Quantitative methods for system optimization*, Advanced Course in Reliability and LCC arranged by FMV, Stockholm, Sweden, February 1, 1996.

[P2] P. Alfredsson, *Modelling emergency supply flexibility in a two-echelon inventory system*, Eindhoven University of Technology, Eindhoven, The Netherlands, February 29, 1996.

[P3] P. Alfredsson, *Modelling emergency supply flexibility in a two-echelon inventory system*, 7th Stockholm Optimization Days, KTH, Stockholm, Sweden, June 24, 1996.

[P4] U. Brännlund, *Preliminary computional experience with a descent level method for convex nondifferentiable optimization*, IFIP conference on System Modelling and Optimization, Prague July 10-14, 1995.

[P5] U. Brännlund, *An implementation of an interior point method for truss topology design*, 7th Stockholm Optimization Days, Stockholm, June 24-25, 1995.

[P6] S. Feltenmark, *Head-dependent hydro power scheduling*, NOAS'95 conference, Reykjavik, Iceland, August 18-19, 1995.

[P7] S. Feltenmark, *Head-dependent hydro power scheduling*, Linköping University, Linköping, Sweden, March 13, 1996.

[P8] S. Feltenmark, *A dual cutting surface algorithm for unit commitment*, Fifth SIAM conference on optimization, Victoria, Canada, May 20-22, 1996.

[P9] S. Feltenmark, *Solving unit commitment problems in power production planning*, 7th Stockholm Optimization Days, Stockholm, Sweden, June 24-25, 1996.

[P10] A. Forsgren, *Second-derivative methods for large-scale optimization*, Chalmers University of Technology, Göteborg, Sweden, January 31, 1996.

[P11] A. Forsgren, *On weighted linear least-squares problems and their relation to interior methods for optimization*, University of California, San Diego, La Jolla, California, April 9, 1996.

[P12] A. Forsgren, *On weighted linear least-squares problems and their relation to interior methods for optimization*, Stanford University, Stanford, California, May 10, 1996.

[P13] A. Forsgren, *Primal-dual interior methods for nonconvex nonlinear programming*, The 5th SIAM Conference on Optimization, Victoria, British Columbia, Canada, May 20–22, 1996.

[P14] A. Forsgren, *Newton methods for large-scale linear inequality constrained minimization*, The 7th Stockholm Optimization Days, Stockholm, Sweden, June 24–25, 1996.

[P15] D. G. Galardini, *Some issues in control of resonant systems*, CESAME, Université catholique de Louvain, February 13, 1996.

[P16] D. G. Galardini, *Robust control of electrical drives systems*, LEI, Université catholique de Louvain, February 15, 1996.

[P17] D. G. Galardini, *Variable structure control of a two-mass systems based on output measurements*, MTNS96, St Louis, Missouri, June 24, 1996.

[P18] X. Hu, *Acceleration and braking effects on robustly decoupled car steering*, The third European Control Conference, Rome, Italy, September, 1995.

[P19] X. Hu, *On global nonlinear feedback stabilization*, MTNS 96, St. Louis, USA, June, 1996.

[P20] X. Hu, *Deterministic Kalman filtering for systems with implicit output*, MTNS 96, St. Louis, USA, June, 1996.

[P21] Anders Lindquist, *Speech synthesis and optimization*, Royal Academy of Engineering Sciences, Stockholm, April 16, 1996.

[P22] A. Lindquist, *Subspace identification and positivity: What are the hidden assumptions?*, University of Padova, Italy, June 7, 1996.

[P23] A. Lindquist and Giorgio Picci, *Geometric methods in identification*, Four-hour mini-course at the 12th International Symposium on the Mathematical Theory of Networks and Systems, St Louis, June 1996.

[P24] A. Lindquist, *The geometry of positive real functions with applications to filtering and rational covariance extension*, Plenary lecture at the 12th International Symposium on the Mathematical Theory of Networks and Systems, St Louis, June 1996.

[P25] J. Marí, *Principles of flight dynamics*, Deutsche Forschungsanstallt für Luft und Raumfahrt, Oberpfaffenhofen, Germany, July 4 1995.

[P26] J. Marí, *Robust decoupling: Theory and applications*, Deutsche Forschungsanstallt für Luft und Raumfahrt, Oberpfaffenhofen, Germany, July 18, 1995.

[P27] J. Marí, *Robust decoupling issues*, Deutsche Forschungsanstallt für Luft und Raumfahrt, Oberpfaffenhofen, Germany, Dec. 19, 1995.

[P28] J. Marí, *Generalidades sobre la Programación Estocástica, optimización cuadrática determinística y el método LQG con información incompleta de estados*, Facultad de Ingeniería, Montevideo, Uruguay, March 12, 1996.

[P29] J. Marí, *HIRM design challenge: Parameter space approach with optimization of vector performance index*, SAAB, Military Aircraft, Linköping, Sweden, April 23, 1996.

[P30] J. Marí, *Controller structure design for the longitudinal motion of the HIRM*, Reglermöte, Luleå, Sweden, June 7, 1996.

[P31] M. Nordin, *Digital QFT design for the flexible transmission benchmark problem*, Invited paper to the 1995 European Control Conference, Rome, september 1995.

[P32] M. Nordin, *QFT-designs for two benchmark problems*, Reglermöte '96, Luleå.

[P33] M. Nordin, *A robust QFT-design for a multivariable paper machine benchmark*, IEEE Conference on Decision and Control, december 1995, New Orleans.

[P34] A. Nõu, *Locomotive scheduling with homogeneous consists*, 14th European Conference of Operations Research, Jerusalem, Israel, July 3-6, 1995.

[P35] A. Nõu, *Dual Bregman proximal methods for large-scale 0-1 problems*, 17th IFIP TC7 Conference on System Modelling and Optimization, Prague, Czech Republic, July 10-14, 1995.

[P36] A. Nõu, *Dual Bregman proximal methods for large-scale 0-1 problems*, Københavns Universitet, Copenhagen, Denmark, December 14, 1995.

[P37] A. Nõu, *Dual Bregman proximal methods for large-scale 0-1 problems*, Fifth SIAM Conference on Optimization, Victoria, Canada, May 20-22, 1996.

[P38] A. Nõu, *Dual Bregman proximal methods for large-scale 0-1 problems*, 7th Stockholm Optimization Days, Stockholm, Sweden, June 24-25, 1996.

[P39] K. Svanberg, *Optimal truss topology, semidefinite programming, and a method based on conservative approximations*, The 7th Stockholm Optimization Days, Stockholm, Sweden, June 24–25, 1996.

[P40] Y. Zhou, *An algorithm for finding positive rational extensions of a finite covariance sequences*, 3rd European Control Conference, Roma, Italy, September, 1995.

8 7th Stockholm Optimization Days

The 7th Stockholm Optimization Days were held at KTH in Stockholm, June 24–25, 1996. The format was similar to the previous years with approximately 50 participants, coming from many different countries. The conference was financially supported by the Göran Gustafsson Foundation and the Swedish National Board for Industrial and Technical Development (NUTEK). The organizing committee consisted of U. Brännlund, A. Forsgren, and K. Svanberg (head).

In total 37 talks were given, among them 15 invited presentations. The following is a list of presentations, where the speakers' names are given in boldface:

Patrik Alfredsson, Royal Institute of Technology, Stockholm, Sweden and Jos Verrijdt, Eindhoven University of Technology, Eindhoven, The Netherlands, *Modeling emergency supply flexibility in a two-echelon inventory system.*

Aharon Ben-Tal*, Technion—Israel Institute of Technology, Haifa, Israel, *Robust solutions of uncertain convex programming problems.*

Ulf Brännlund and Krister Svanberg, Royal Institute of Technology, Stockholm, Sweden, *An implementation of an interior point method for truss topology design.*

Andrew R. Conn*, IBM T. J. Watson Research Center, Yorktown Heights, New York, USA and Philippe Toint, Facultés Universitaires ND de la Paix, Namur, Belgium, *An approach to derivative free optimization.*

Vladimir F. Demyanov*, St.-Petersburg State University, Staryi Peterhof, Russia, *New faces of the old problems: NSA in the making.*

Jacques Desrosiers*, Brigitte Jaumard, Pierre Hansen and Francois Soumis, GERAD and HEC, Montreal, Quebec, Canada, *Dantzig-Wolfe decomposition and column generation for integer and non-convex programs.*

Stefan Engevall and Peter Värbrand, Linköping University, Linköping, Sweden, *Cost allocation for Norsk Hydro.*

Francisco Facchinei and Stefano Lucidi, Università di Roma "La Sapienza", Roma, Italy, *A Newton-type algorithm for the solution of constrained minimization problems.*

Leonid Faybusovich*, University of Notre Dame, Indiana, USA, *Jordan algebras, symmetric cones and interior point methods.*

Stefan Feltenmark, Royal Institute of Technology, Stockholm, Sweden, Krzysztof C. Kiwiel, Systems Research Institute, Warsaw, Poland, and P. O. Lindberg, Linköping University, Linköping, Sweden, *Solving unit commitment problems in power production planning.*

Francisco Facchinei, Università di Roma "La Sapienza", Roma, Italy, **Andreas Fischer**, Technical University of Dresden, Dresden, Germany, and Christian Kanzow, University of Hamburg, Hamburg, Germany, *On the accurate identification of active constraints.*

Sjur Didrik Flaam, Bergen University, Bergen, Norway and Jean-Noel Corvellec, Univ. de Perpignan, Perpignan, France, *Nonconvex feasibility problems and proximal point methods.*

Anders Forsgren, Royal Institute of Technology, Stockholm, Sweden and Walter Murray, Stanford University, Stanford, California, USA, *Newton methods for large-*

*Invited speaker.

scale linear inequality-constrained minimization.

Anders Forsgren, Royal Institute of Technology, Stockholm, Sweden and **Philip E. Gill***, University of California, San Diego, La Jolla, California, USA, *Primal-dual interior methods for nonconvex nonlinear programming.*

Clovis Gonzaga* and Romulo Castillo, Federal University of Santa Catarina, Brazil, *Asymptotic properties of some generalized penalty methods for nonlinear programming.*

Pia Bergendorff, Linköping University, Linköping, Sweden, **Donald W. Hearn*** and Motakuri V. Ramana, University of Florida, Gainesville, Florida, USA, *Congestion toll pricing of traffic networks.*

Georgi Christov and **Rumena Kaltinska**, Bulgarian Academy of Sciences, Sofia, Bulgaria, *Optimizing a product of two affine functions on linear constrained set.*

Peter Kirkegaard, Jan Skov Pedersen and Morten Eldrup, Risø National Laboratory, Roskilde, Denmark, *Tikhonov regularization and non-linear programming techniques for predicting cavity distributions in materials from 2D pictures.*

Krzysztof C. Kiwiel*, Systems Research Institute, Warsaw, Poland, *A subgradient method with entropic projections for convex nondifferentiable minimization.*

Eva K. Lee, Columbia University, New York, New York, USA, *An optimization model for machine learning and constrained discriminant analysis.*

Claude Lemaréchal*, INRIA, Le Chesnay, France and Arnaud Renaud, Electricité de France, Clamart, France, *Dual-equivalent convex and nonconvex problems.*

Riho Lepp, Institute of Cybernetics, Tallinn, Estonia, *Approximation of the subgradient of the* L^∞*-norm.*

Ron Levkovitz, Technion—Israel Institute of Technology, Haifa, Israel and Eithan Schweitzer, Center for Technological Education Holon, Holon, Israel, *A parallel interior random vector algorithm for multistage stochastic linear programs.*

Walter Murray*, Stanford University, Stanford, California, USA, *SQP algorithms with nonconvex subproblems.*

Anna Nagurney, University of Massachusetts, Amherst, Massachusetts, USA and Royal Institute of Technology, Stockholm, Sweden, *Dynamic multi-sector, multi-instrument financial networks with futures: Modeling and computation.*

Krzysztof C. Kiwiel, Systems Research Institute, Warsaw, Poland, P. O. Lindberg, Linköping University, Linköping, Sweden, and **Andreas Nõu**, Royal Institute of Technology, Stockholm, Sweden, *Dual Bregman proximal methods for large-scale* 0–1 *problems.*

François Oustry, INRIA, Le Chesnay, France, $\mathcal{U}$*-Newton algorithm to minimize the maximum eigenvalue function.*

Farid Alizadeh, Rutgers University, Piscataway, New Jersey, USA, Jean-Pierre A. Haeberly, Fordham University, Bronx, New York, USA, and **Michael L. Overton***, Courant Institute of Mathematical Sciences, New York, New York, USA, *Primal-dual interior-point methods for semidefinite programming: Convergence rates, stability and numerical results.*

Torbjörn Larsson, Michael Patriksson and **Clas Rydergren**, Linköping University, Linköping, Sweden, *Applications of nonlinear column generation in simplicial decomposition algorithms.*

*Invited speaker.

Jorge Nocedal, Northwestern University, Evanston, Illinois, USA, **Annick Sartenaer***, Facultés Universitaires ND de la Paix, Namur, Belgium, and Ciyou Zhu, Northwestern University, Evanston, Illinois, USA, *On the accuracy of the steepest-descent method in nonlinear optimization.*

Klaus Schittkowski*, University of Bayreuth, Bayreuth, Germany, *Parameter estimation in dynamic systems.*

Trond Steihaug and Yasemin Yalcinkaya, University of Bergen, Bergen, Norway, *Asynchronous methods and least squares: An example of deteriorating rate of convergence.*

Torbjörn Larsson, Michael Patriksson and **Ann-Brith Strömberg**, Linköping University, Linköping, Sweden, *A simplicial decomposition scheme for nonsmooth minimization.*

Ulf Brännlund and **Krister Svanberg**, Royal Institute of Technology, Stockholm, Sweden, *Optimal truss topology, semidefinite programming, and a method based on conservative approximations.*

Stephen J. Wright*, Argonne National Laboratory, Chicago, Illinois, USA, *Modified Cholesky factorizations in interior-point algorithms for linear programming.*

Laura Wynter, INRETS, Arceuil, France, *Solving the asymmetric traffic assignment problem with a non-monotonic cost operator.*

Leonid Mosheyev and **Michael Zibulevsky**, Technion—Israel Institute of Technology, Haifa, Israel, *New penalty/barrier and Lagrange multiplier approach for semidefinite programming.*

*Invited speaker.

9 Other activities

Patrik Alfredsson

- Visited the Faculty of Technology Management at Eindhoven University of Technology, Eindhoven, the Netherlands, February 4-March 3, 1996.

Ulf Brännlund

- Referee for Mathematical Programming and Computational Optimization and Applications.
- Visited the Courant Institute, NYU, New York, Feb. 1996.

Per Enqvist

- Participated in the conference "Reglermöte 96" in Luleå, Sweden, June 6-7, 1996.
- Participated in the conference MTNS 96 in St.Louis, Missouri, USA, June 24-28, 1996.
- Participated in the conference IFAC 96 in San Francisco, California, USA, June 30 - July 5, 1996.

Stefan Feltenmark

- Organized seminar course on stochastic programming.

Anders Forsgren

- Participated in the IMA Workshop on Large-Scale Optimization, Minneapolis, Minnesota, USA, July 10–14, 1995.
- Visited the Department of Mathematics at the University of California, San Diego, California, USA, December 4–11, 1995.
- Fulbright Visiting Scholar at the Department of Mathematics at the University of California, San Diego, California, USA, March 1–June 1, 1996.
- Opponent at a doctoral thesis defense, Department of Computing Science, Umeå University, Umeå, Sweden, June 7, 1996.
- Referee for International Journal of Technology Management and SIAM Journal on Optimization.

Daniele G. Galardini

- Participated in Reglermöte '96, Luleå, June 6-7, 1996.

Camilla Landén

- Participated in the XXII Annual Meeting of the European Finance Association, Milan, Italy, August 24-26, 1995.

Anders Lindquist

- Communicating Editor, *Mathematical Systems, Estimation and Control*, journal published by Birkhäuser Boston.
- Member Editorial Board, *Adaptive Control and Signal Processing*, journal published by John Wiley & Sons.
- Associate Editor, *Systems and Control: Foundations and Applications*, book series published by Birkhäuser, Boston.
- Editorial Board, *Applied and Computational Control, Signals, and Circuits*, book series published by Birkhäuser, Boston.
- Referee for six other journals, for NATO, and for Stichting Matematisch Centrum.
- Affiliate Professor, Washington University, St Louis, USA.
- Member of the Committee for IIASA, Systems Analysis and Risk Analysis, FRN (Swedish Council for Planning and Coordination of Research).

- Member of the Evaluation Committee for the Mathematical Sciences, NFR (Natural Science Foundation).
- Team leader, European Research Network for System Identification (ERNSI).
- Vice-Chairman, International IFAC Committee on Stochastic Systems.
- Steering Committee, International Symposium on the Mathematical Theory of Networks and Systems (MTNS).
- Member, International IFAC Committee for Mathematics in Control.
- Member, Steering Committee of the ERCIM Working Group Control and System Theory.
- International Advisory Board for the 27th ISCIE Symposium on Stochastic Systems Theory and its Applications in Oita, Japan, October 31 – November 2, 1995.
- Organizing committee of ERCIM Workshop on Systems and Control, Budapest, Hungary, November 6–8, 1995.
- Organizing committee of Conference on Stochastic Differential and Difference Equations, Györ, Hungary, August 21–24, 1996.
- Organizing committee of 2nd ERCIM Workshop on Systems and Control, Prague, Czech Republic, August 25–27, 1996.
- Program Committee for the 1996 IEEE Conference on Decision and Control, Kobe, Japan, December 11-13, 1996.
- International advisory committee of the 28th ISCIE International Symposium on Stochastic Systems Theory and its Applications, Kyoto, Japan, November 14–16, 1996.

Jorge Marí

- Corrected and compiled the notes for the course Matematisk systemteori, fortsättningskurs. New exercises for the course.
- Participated in Tag der Robusteregelung, Dec. 1995, at the Deutsche Forschungsanstallt für Luft und Raumfahrt, Oberpfaffenhofen, Germany.
- Wrote the notes "Elements of Automata Theory", for the course on Discrete Event Systems.
- Gave a four-weeks course on "Topics of Linear Programming" at the Facultad de Ingeniería, Montevideo, Uruguay, during March 1996. This activity is part of an international programme financed by BITS. The course included two hours daily teaching. Five sets of homework were distributed to be solved by the students. Eight students attended regularly the course.

Mattias Nordin

- Referee for IEEE Transactions on Automatic Control, European Journal of Control, and several Conferences.
- Visited LAG-ENSIEG, Grenoble, February 1996.

Andreas Nõu

- Visited Københavns Universitet, Copenhagen, Denmark, December 13-17, 1995.

Krister Svanberg

- Member of the evaluation committee at a dissertation in Linköping, December 1995.
- On the editorial board of Structural Optimization.
- Referee for Journal of Structural Engineering.

Yishao Zhou

- Research visit at Mathematics Institute, University of Groningen, November 18-25, 1995.