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

Activity Report

1993/1994

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The division of Optimization and Systems Theory is part of the Department of Mathematics at the Royal Institute of Technology. This report summarizes the activities at this division during the academic year 1993/1994 (July 1993 – June 1994).

Optimization and Systems Theory is a discipline in Applied Mathematics primarily devoted to mathematical programming, optimal control theory, and systems theoretic aspects of control and signal processing. In addition, attention is also given to mathematical economics and more 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, matrix Riccati equations, and robust and nonlinear control; dual optimization methods, with applications to crew and vehicle scheduling, large scale optimization and power planning; structural optimization; and nonlinear programming. The division also has an Optimization Laboratory devoted to collecting state-of-the-art optimization routines, making them available to research institutions and industry. For ease of reference, in this activity report research projects as well as publications are reported either under the heading of *Systems and Control* or under the heading of *Mathematical Programming*.

The division of Optimization and Systems Theory offers undergraduate courses in mathematical programming, mathematical systems theory, optimal control and calculus of variations, mathematical economics, as well as various topics in operations research and modeling. There is an active graduate program. During the academic year of 1993/94 one doctoral degree and one licentiate degree in Optimization and Systems Theory were awarded. One person has been appointed to the position of Docent.

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.

For the third time, a researcher holding a *Gustafsson Postdoctoral Fellowship* has been stationed at the division of Optimization and Systems Theory.

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1 Personnel

1.1 List of personnel

Professor (Professor)

Anders Lindquist, TeknD

Docenter, högskolelektorer (Associate professors)

Tomas Björk, FD, docent Director of undergraduate studies
P. O. Lindberg, TeknD, docent
Krister Svanberg, TeknD, docent

Forskarassistent (Research associate)

Anders Forsgren, TeknD

Förste forskningsingenjörer (Researchers)

Ulf Brännlund, TeknD
Xiaoming Hu, PhD

Postdoktorstipendiat (Postdoctoral fellow)

Vincent Blondel, PhD

Gästforskare (Guest researchers)

Claudio Baril, PhD
Per-Olof Gutman, TeknD, docent

Intendent (Administrator)

Leena Druck

Doktorander (Graduate students)

Patrik Alfredsson, civing
Anders Dahlén, FK
Stefan Feltenmark, civing
Martin Hagström, civing (graduated (TeknL) September 1993)
Jorge Mari, MS
Mattias Nordin, civing
Andreas Nöu, civing
Jan-Åke Sand, civing, TeknL (graduated (TeknD) April 1994)
Omar Viera, civing
Andreas Wolf, MS

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**

[0,l,[width=30mm]was born in Bahia Blanca, Argentina, on July 5, 1960. He received the Diploma in electrical engineering from the National University of the South, Bahia Blanca, Argentina. He received the M.Sc. and D.Sc. degrees from the Technion, Israel Institute of Technology, Haifa, Israel. His main research interests are robust control and nonlinear control theory, and their application to the design of feedback systems.,] **Claudio Baril**

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. During the period 1987-1990 he has also given several courses in Mathematical Economics at the Stockholm School of Economics. His main research interests include martingale theory, nonlinear filtering and mathematical economics.

Vincent Blondel was born in Antwerp, Belgium in 1965. He graduated from the Université Catholique de Louvain in 1988 with highest honours and obtained a M.Sc. in Pure Mathematics from Imperial College, London in 1990 and a Ph.D. in Applied Mathematics from the Catholic University of Louvain in 1992. In 1993 he was awarded a Göran Gustafsson Postdoctoral Fellowship to enable him to spend the academic year 1993-1994 at the Division of Optimization and Systems Theory. His main research interests are robust control, analytic functions and computational complexity of control problem. For more than three years he has been obsessed by the "simultaneous stabilization problem" until he found that the problem admits no solution.

[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 and production planning problems.,] **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 Systems.,] **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 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**

[0,l,[width=30mm]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. Since 1991, he is a research associate at the Division of Optimization and Systems Theory. His main research interest is nonlinear programming.,] **Anders Forsgren**

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.

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

[0,l,[width=30mm]was born in Stockholm in 1963. He received a civilinjenjör degree in Aeronautical Science at KTH in 1988 and a TeknL degree in Optimization and Systems Theory from KTH in 1993. His main research interest is nonlinear dynamics of filtering algorithms and stochastic realization theory and its applications.,]
Martin Hagström

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.

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).

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 two book series *Systems and Control: Foundations and Applications* and *Progress in Systems and Control* (Birkhäuser Boston). 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 graduated as Electrical Engineer at the Faculty of Engineering in Montevideo, 1992, and has also studied Mathematics at the Faculty of Sciences. He worked for the Mathematics Department at the first mentioned place from 1988 to 1992 and as project designer in power supply systems for the telephone company ANTEL. He has been working since late 1992 at KTH in identification and optimal control of fermentation processes. He is presently a PhD student at Optimization and Systems Theory, KTH. His main interests include electrical systems, computer controlled systems, optimization, dynamical systems and control.

[0,l,[width=30mm]was born in Lund, Sweden, in 1967. He received a civilinjenjör degree in Engineering Physics from KTH in 1992. He is presently a PhD student at the Division of Optimization and Systems Theory. His main research interests are robust control and systems theory. At the moment he is studying the effect of backlash in control of electrical drives. Also new methods for value set computations are being developed.,] **Mattias Nordin**

[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 dual methods in connection to Crew and Vehicle Scheduling.,] **Andreas Nöu**

[0,l,[width=30mm]was born in 1964 in Stockholm. He received the civilingenjör degree in Engineering Physics from KTH in 1988, the TeknL degree in Optimization and Systems Theory from KTH in 1992, and the TeknD degree in Optimization and Systems Theory from KTH in 1994. Since April 1994 he has been an analyst at the department of fixed income investments at the insurance company SPP. His research interests include time series analysis, stochastic systems, and the pricing of derivative securities.,] **Jan-Åke Sand**

Krister Svanberg was born in Stockholm in 1950. He received his civilingenjör degree in Engineering Physics from KTH in 1975, and his TeknD degree in Optimization Theory from KTH in 1982. In 1993 he was appointed Docent. Between 1976 and 1985 he held a position as Research Associate with the Contract Research Group of Applied Mathematics at KTH, and since 1985 he is a Senior Lecturer of Optimization and Systems Theory. His main area of research is structural optimization, in which area he has kept scientific contacts with such industrial companies as SAAB and VOLVO.

[0,l,[width=30mm]was born in 1953 in Montevideo, Uruguay. He received his civilingenjör degree in Engineering Physics at KTH in 1992. His main research interest is nonlinear programming, in particular energy applications.,] **Omar Viera**

[0,l,[width=30mm]was born in Hamburg, Germany, in 1956. He received his MS in hydrology from Freiburg university (Germany) in 1985. Since 1986 he has been

working at Vattenfall Utveckling AB with hydromechanics related to hydropower. In spring 1994 he began PhD-studies financed by TFR and Vattenfall. His main research interest is nonlinear programming, in particular energy applications.,] **Andreas Wolf**

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
- Dr. E. Anders Eriksson, Swedish Defense Research Establishment, Stockholm, Sweden
- Professor Michel Gevers, Centre for System Engineering and Applied Mechanics, Catholic University of Louvain, Louvain-la-Neuve, Belgium
- Professor Philip E. Gill, Department of Mathematics, University of California at San Diego, La Jolla, California, USA
- Dr. S. V. Gusev, Department of Mathematics, St. Petersburg University, St. Petersburg, Russia
- Professor Donald W. Hearn, Department of Industrial and Systems Engineering, University of Florida, Gainesville, Florida, USA
- Dr. Björn Johansson, Department of Mathematical Statistics, University of Stockholm, Stockholm, Sweden
- Professor Krzystof C. Kiwiel, Systems Research Institure, Warsaw, Poland
- Docent Lars-Göran Mattsson, Department of Regional Planning, KTH, Stockholm, Sweden
- 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 Operations Research, Stanford University, Stanford, California, USA
- Jan-Eric Nilsson, Centre for Research in Transportation and Society, Borlänge, Sweden
- Professor Giorgio Picci, Department of Electronics and Informatics, University of Padova, Padova, Italy
- Docent Ulf Ringertz, Department of Lightweight Structures, KTH, Stockholm, Sweden
- Dr. Rudolf Rupp, Department of Mathematics, University of Karlsruhe, Karlsruhe, Germany
- Professor Harold Shapiro, Department of Mathematics, Royal Institute of Technology, Stockholm, Sweden
- Professor Tony Smith, Regional Science Department, University of Pennsylvania, Philadelphia, Pennsylvania, USA
- Professor John Tsitsiklis, Laboratory for information and decision systems, Massachusetts Institute of Technology, Boston, Massachusetts, USA
- Professor Vladimir A. Yakubovich, Department of Mathematics, St. Petersburg University, St. Petersburg, Russia

1.4 Networks

- European Research Network for Systems Identification (ERNSI)

2 Research

2.1 List of projects

2.1.1 List of projects in Systems and Control

- Acausal realization theory
- Adaptive prediction and parameter identification
- Analytic functions in control
- Computational complexity of control problem
- Estimation of lost state information in linear stochastic systems
- Experimental optimization with biotechnical applications
- Financial economics
- Linear stochastic systems theory
- Nonlinear feedback stabilization and its applications
- Optimal damping of forced oscillations in discrete-time systems
- Robust control of electrical drives
- Robust nonlinear control of car steering system
- Stochastic realizations and geometric control theory—a synthesis
- Stochastic realization theory and identification
- The minimal rational covariance extension problem

2.1.2 List of projects in Mathematical Programming

- Advanced optimization methods for crew and vehicle scheduling
- Allocation of scarce track capacity
- Dual methods for large scale optimization problems
- Dual methods for short term power planning problems
- Dual methods for the unit commitment problem
- KTH Optimization Laboratory
- Large scale decomposition and nonsmooth optimization
- Optimal expansion strategies for transport networks
- Optimal short term operation of a cascade of hydropower stations
- Optimal water flow through a hydro power station
- Optimization of spare parts inventory systems
- Random utility models
- Second-derivative methods for nonlinear programming
- Structural optimization

2.2 Description of projects

2.2.1 Description of projects in Systems and Control

Acausal realization theory

Researcher: Jan-Åke Sand (Anders Lindquist; advisor).

Stochastic models of random phenomena that are spatially distributed are useful in many areas of applications, such as image analysis and computer vision. We study stochastic processes defined on the two-dimensional integer lattice, and the problem of modeling such processes as outputs of Markov random fields. In particular, we analyze observability and minimality of such models, see e.g. [A29].

In cooperation with Bernard Levy at UC Davis we study a problem of optimal acausal interpolation and reconstruction of a stationary time series. The problem is believed to have great significance to the area of linear predictive data compression and transmission.

Adaptive prediction and parameter identification

Researchers: Tomas Björk, in cooperation with Björn Johansson (University of Stockholm).

The goal of this project is to build a theory of parameter identification for a fairly general class of semimartingales, but up to now we have confined ourselves to diffusions and point processes. We have studied the existence of unbiased parameter estimators (and their asymptotic properties), as well as the existence of asymptotically consistent parameter estimators. Based on earlier work on adaptive prediction [A4], we have shown that unbiased parameter estimation can be seen as a limiting case of adaptive prediction, a fact which leads to interesting connections between unbiased estimators and reverse martingales. We have also shown that the existence of an unbiased parameter estimate is equivalent to the existence of a solution to an inverse (ill posed) parabolic boundary value problem. We obtain non standard representation formulaes of Feynman-Kac type for the optimal estimators, and we can also give error bounds extending the standard Cramer-Rao results. Presently we are working on finite dimensional representations of asymptotically sufficient tail-σ-algebras and on the existence of so called sufficient generating martingales.

Analytic functions in control

Researchers: Vincent Blondel, in cooperation with Daniel Bertilsson, Harold Shapiro and Rudolf Rupp (Karlsruhe, Germany).

Sponsor: The Göran Gustafsson Foundation.

Linear control theory has often borrowed its tools from the theory of analytic or meromorphic functions (the argument principle, the small gain theorem, etc). Indeed, in many cases, linear controller specifications can be translated into specifications on the transfer function of the controller, which at the limit, lead to meremorphic functions specifications. It is therefore not surprising that simple and relevant linear control problems have formulations in terms of analytic functions properties. Among these one finds the simultaneous stabilization problem, the bistable stabilization problem and the robust control design problem for systems with structured uncertainty. All these problems have unsolved analytic function formulations.

The aim of this project is to investigate the links between control problems and analytic function properties. During this academic year we have made progresses on all the problems mentioned above. These progresses are reported in [A5], **??** and [R4] for simultaneous stabilization, in [R6] for bistable stabilization and in [A6] and [A7] for other related results.

Computational complexity of control problem

Researchers: Vincent Blondel, in cooperation with John Tsitsiklis (MIT, Boston).

Sponsor: The Göran Gustafsson Foundation.

What is and what is not tractable, what can and what cannot be done? The notions of decidability, tractability and computational complexity have become increasingly important for all control applications. Many of the computational complexity questions arising in control can be answered by using standard results from computer science. There exists however problems that are specific to control theory.

The goal of this project is to analyse the computational complexity of control problems. So far we have succeeded in showing that some elementary linear control design problems are NP-complete. That is, unless P=NP, the number of computational steps required for their solution increase exponentially with the size of their description. Our present list of NP-complete control problems includes problems related to simultaneous stabilization by output feedback, state or output feedback stabilization and decentralized control. These results all follow from the fact that checking the presence of a stable matrix in an interval family of matrices is a NP-complete problem. Our results are reported in [R7].

Estimation of lost state information in linear 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.

The geometric theory of stochastic realization described in the project *Linear stochastic systems* with its symmetry under reversal of time is a very natural tool for the analysis of noncausal estimation problems. A case in point is the smoothing problem, earlier studied by Badawi, Lindquist and Pavon, which is very naturally cast in this framework, and also the noncausal estimation problem used as mathematical devise by Lindquist and Picci.

Now, 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 [R13] is to reconstruct the lost state information from the remaining observations. This is precisely a problem of the type described above. It corresponds to the smoothing problem or the noncausal estimation problem with the important difference that the estimate becomes a linear combination of noninternal states rather than internal states. 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".

Experimental optimization with biotechnical applications

Researchers: P. O. Lindberg and Jorge Mari in cooperation with J. P. Axelsson (Kabi).

Sponsors: NUTEK and Kabi.

Industrial contact: Kabi.

This is a project which tries to optimize incompletely known biotechnical processes. Specifically we have been working with fermentation processes.

Due to the incomplete process knowledge we are trying to device methods that are independent of the process description. This has led us to descent methods in Banach spaces. To apply the methods one first has to estimate process parameters from experiments. Then one has to implement the computed optimal control. However, due to the instability and stiffness of the process, the control cannot be applied in open loop. Instead, we have used feedback tracking of one easily measured state.

So far we have only applied first order methods (i.e. gradient based). Despite the mentioned difficulties we have been able to compute controls that outperform controls used hitherto. These new control suggest new working lines for process improvement.

Our methodology can be viewed as a closed loop iterative scheme for the optimization of any given process (see [A1]). We are at the moment investigating the potential of using symbolic software for automatizing the steps in the outlined procedure, so as to minimize the user's effort. Also we would like to develop further refined algorithms in function space of Newton-type for the optimization part.

Financial economics

Researcher: Tomas Björk.

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 [P3] [P4]. Within this framework we have extended the theories of Hull-White and Heath-Jarrow-Morton.

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 non-causal 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.

Nonlinear feedback stabilization and its applications

Researchers: Xiaoming Hu.

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

In the project we continue to study the problems of feedback stabilization and output regulation for nonlinear control systems and apply the results to some practical systems, such as servo systems affected by friction forces. The main task for nonlinear feedback stabilization on compacta by using high gain feedback control is to find more general "nonpeaking" conditions. We are trying to use an invariant manifold approach to get some new results.

Most recent results from nonlinear control theory are only applicable to smooth nonlinear systems. However, there are many nonsmooth nonlinear systems of practical importance, such as the dry friction force. In the project we study possible ways to design a stabilizing controller (possibly discontinuous) for such a system. In fact, we have shown that for a servo system with dry friction forces modeled by the popular Karnopp's model, there are no continuous feedback controllers which would stabilize the system. It would be extremely interesting to find a way to utilize smooth results in the design. Naturally, any simple "smoothization" of such a system would possibly result in the loss of some important properties of the original system.

Optimal damping of forced oscillations in discrete-time systems

Researchers: Anders Lindquist, in cooperation with Vladimir A. Yakubovich (St. Petersburg University).

Sponsors: The Swedish Research Council for Engineering Sciences (TFR), the Royal Swedish Academy of Sciences, NUTEK and the Gustaf Sigurd Magnuson Foundation.

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. We show that the natural solution from the point of view of optimal control is neither robust with respect to errors in the frequencies, and thus not optimal in practice, nor independent of the unknown amplitudes and phases. A main result of this project [R15] concerns the existence and design of a realizable, robust optimal regulator which does not depend on the unknown amplitudes and phases. The regulator allows for a considerable degree of design freedom. This regulator is also optimal for a wide class of stochastic control problems.

Robust control of electrical drives

Researchers: Claudio G. Baril, P. O. Gutman, Xiaoming Hu, Mattias Nordin and Anders Lindquist, in cooperation with Johann Galić (ABB Drives AB, Västerås).

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

This project is a continuation of the project: Nonlinear control of uncertain systems with hard non-linearities. The current program has been running since January 1992, and has received continued funding until June 1996.

Electro-mechanical control systems in industry, such as motor drives or robots, can be modelled as uncertain linear dynamic systems, affected by nondifferentiable nonlinearities such as friction, backlash, limiters, etc. Current linear control design practice is unable to yield high precision for such systems without expensive high quality mechanical components. The aim of this project is to combine robust linear control with nonlinear control elements, implemented in a microprocessor, that alleviate the effects of the process nonlinearities. In particular will electrical drives with friction, back-lash and uncertain loads and disturbances be studied.

P. O. Gutman organized a session on control of systems with non-differentiable non-linearities at the International Conference on Control Theory and its Applications in Jerusalem, Israel, on 8-21 October 1993, with participation of researchers from England, France, Germany, Israel, Sweden, and U.S.A. Among the participants were J. Galić, X. Hu, and M. Nordin. The exchange of ideas was very fruitful.

The following results have been obtained:

1. A new and correct model for backlash with and without rubber lining was developed. It was shown that the currently used dead zone model for backlash gives erroneous results for certain conditions [A26].
2. The Karnopp friction model has been analyzed from a system theoretical point of view [P26].
3. A systematic design method for uncertain linear systems that include a class of uncertain hard nonlinearities has been developed. It is assumed that the nonlinearity can be described as an uncertain linear operator, and a bounded disturbance. Common friction and backlash models are included in this description. The method is based on the Horowitz robust design methodology, and the describing function method (or alternatively the circle criterion). The method is believed to be one of the first systematic, performance related design methods for this class of systems [A27].
4. A method to compensate for stick-slip motion due to static friction for the servo control of high precision electromechanical systems was developed, [A3]. The idea is to insert appropriate pulses to release the system from sticking in such a way that limit cycles are avoided. A paper is being prepared.
5. A method to compute value sets for uncertain transfer functions in factored real form was developed [A15].
6. A method to estimate parameter intervals, on-line, for uncertain dynamical models using recursive least squares was presented [A14].
7. The applicability of fuzzy control to the control of electrical drives was investigated, [R2]. It was found that usaully, fuzzy control is not applicable to systems with complex poles, but that it could be beneficial to compensate non-linearities. The best type of fuzzy control was the one that weighted the

control signals of different controllers, each designed for its operating or load condition. This form of fuzzy control can be seen as a type of gain scheduling.

8. A comprehensive investigation of linear control of elastic two-mass systems has been concluded, [R3]. It was found that PI-control works well for high load-to-motor moment-of-intertia ratios when the equivalent delay of the digital control system and the converter is small. For some, but not all other cases, higher order controllers are satisfactory.

Robust nonlinear control of car steering system

Researchers: Xiaoming Hu, in cooperation with Jürgen Ackermann (DLR, Wessling, Germany).

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

In this project, we study a very important problem in vehicular control: robust motion control. And it will be studied particularly under the context of four-wheel steering, which has been a rapidly developing technology for improving automatic steering.

Present results for robust/adaptive four-wheel steering are based on the linearized model of the vehicle and are under the hypothesis that the vehicle's speed is constant. In the project, by using robust control combined with nonlinear control theory, center manifold theory and singular perturbation methods, we extend the results in two steps. Firstly, we study four-wheel steering of a vehicle with changing speed based on a nonlinear two-point mass model. Initial research has shown that, at least in a simple situation, we are able to devise a stable, robust motion control law. Secondly, we study the problem by using a more realistic model of a vehicle which has uneven or even uncertain mass distribution (for example, due to motions of the driver or a robot arm mounted on the vehicle). Of course, in all cases, we assume that the tire characteristics is nonlinear and only partially known.

Stochastic realizations and geometric control theory—a synthesis

Researchers: Anders Lindquist and Jan-Åke Sand, in cooperation with Gy. Michaletzky (Eötvös Lorand University, Budapest) and G. Picci (University of Padova).

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

In this project we show that there is an important connection between the geometric theory of splitting subspaces and geometric control theory in the style of Wonham and Basile and Marro. We introduce the notion of *output-induced subspace* of a minimal Markovian splitting subspace, and show that it is the analogue of *supremal output nulling subspace* in geometric control theory. Then we show how the zero structure of the family of (not necessarily square) spectral factors relates to the family of minimal Markovian splitting subspaces in the sense that the relationship between the zeros of different spectral factors is reflected in the partial ordering of minimal splitting subspaces and the corresponding solutions of the algebraic Riccati inequality. In [A23] we considered the continuous-time systems with nonsingular noise. This is the simplest case in which the *supremal reachability space* becomes trivial under our correspondence. In general this is not the case, and consequently more structure is introduced, especially in the discrete-time case [R13],

[T1]. This corresponds to singular control.

What makes the discrete-time case more complicated is the possibility of the occurrence of invariant directions. Now we also need to introduce the stronger concept of *strictly output-induced subspace*. In [R13] we discuss the role of invariant directions, zeros of spectral factors and output-induced subspaces in determining the systems-theoretical properties of the 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 Y^* now plays the role of maximal output-induced subspace in the regular case. We also show that Y^* can be determined by algorithms akin to that used in geometric control theory for determining the maximal output-modeling subspace Y^*. 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, a remarkable fact that enables us actually to compute these spaces.

Stochastic realization theory and identification

Researchers: Anders Lindquist and Anders Dahlén, 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 [R14] 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.

(We warn the reader that a preliminary version of [A24], containing some erroneous statements, was accidentally published in place of the paper finally submitted for publication. The correct version can be obtained from the authors.)

The minimal rational covariance extension problem

Researchers: Anders Lindquist, 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. This problem of finding all positive real rational functions interpolating the given covariance sequence is a version the Carathéodory extension problem with the added requirement of rationality.

In [A11] we provide a complete smooth parameterization of all positive rational extensions of a given partial covariance sequence, thereby proving a stronger version of an important conjecture by T. Georgiou that there is a one-one correspondence between positive extensions and zero structures of modelling filters. In [A11] we prove not only this set-theoretical result but also, which is important in applications, that the correspondence is actually a diffeomorphism.

In [R9], [A10], [R8] we describe the complete parameterization mentioned above in terms of a nonstandard matrix Riccati equation, called the Covariance Extension Equation. We also analyze the concept of positive rank and compute the dimension of partial stochastic realizations in terms of the rank of the unique positive semidefinite solution to the Covariance Extension Equation, yielding insights into the structure of solutions to the minimal partial stochastic realization problem.

2.2.2 Description of projects in Mathematical Programming

Advanced optimization methods for crew and vehicle scheduling

Researchers: P. O. Lindberg and Andreas Nöu.

Sponsors: Swedish Transport and Communications Board (KFB).

Industrial contacts: SAS, Swedish State Railways, Stockholm Transport.

This project aims at using advanced dual methods on crew and vehicle scheduling problems. During the year we have received funding for a three year doctorate project.

Recently there has appeared optimizing methods for crew and vehicle scheduling problems. These methods solve resource (e.g. time and capacity) constrained path problems as subproblems and combine the subproblem solutions through Dantzig-Wolfe decomposition. This fits very nicely into our metaproject on dual methods. We are currently working on using more advanced dual methods in this framework.

Since the subproblems are the most time consuming we plan to collect several subgradients in each dual iteration, using a bundle type method. This work is done in collaboration with Ulf Brännlund, and Niklas Kohl, IMSOR.

We are also looking at a differentiable dual approach to large scale integer programming problems, using probabilistic techniques to generate primal feasible solutions. The problems we have in mind are very large, sparse set-covering problems that arise e.g. in crew scheduling. Our initial computational results are promising

[R25], and have been presented at a workshop on large-scale optimization [P29] and [P46].

Allocation of scarce track capacity

Researchers: Ulf Brännlund, P. O. Lindberg and Andreas Nöu in cooperation with J.-E. Nilsson (CTS).

Sponsors: Swedish Transport and Communications Board (KFB) and the Swedish National Rail Administration (Banverket).

Industrial contact: The Swedish National Rail Administration.

This is a project concerning the optimal allocation of scarce track capacity between a number of different railway companies or between different divisions within one company.

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 CTS (the Centre for Research in Transportation and Society, 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.

Our computational results are encouraging ([R25])and have been presented in [P14]. We are currently rewriting our implementation in C, to be able to undertake extensive computational testing. This will also enable us to look at larger cases, and to further extend our model.

Dual methods for large scale optimization problems

Researchers: P. O. Lindberg, Ulf Brännlund, Stefan Feltenmark, Andreas Nöu, in cooperation with Don Hearn (University of Florida) and Krzysztof Kiwiel (Polish Academy of Sciences).

Sponsors: The Swedish National Board for Industrial and Technical Development (NUTEK), Swedish Transport and Communications Research Board (KFB), SAS, Swedish Institute of Applied Mathematics (ITM), Swedish National Rail Administration (Banverket), Swedish State Railways.

Industrial contacts: ABB Network Control AB, Krångede Power Pool, SAS, Swedish National Rail Administration (Banverket), Vattenfall AB, Swedish State Railways.

This is a meta project aiming at obtaining efficient dual methods for large scale optimization problems.

Central subprojects are the projects on short term power planning and second order decomposition methods. These projects share a common structure. Therefore it has been possible to exchange program modules between the projects (as planned). A similar project lead by Don Hearn in Florida is part of this program exchange.

The project on scarce track capacity also shares the same methodology. So does the project on crew and vehicle scheduling. In the former we have managed to build and test a prototype very fast, using existing pieces of code.

The common philosophy gives a strong backbone to our projects.

Finally, this meta project benefits strongly from the Optimization Laboratory.

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. A generalization of EDC includes the transmission network, so called Optimal Power Flow (OPF). We have done preliminary studies on OPF, which is a non-convex, large-scale, sparse programming problem.

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 previously treated the variable-head hydroelectric planning problem, [P28], showing how to compute local optima to this non-convex, network flow problem by modifying algorithms for the linear case. The thermal subproblem is described in another project. We have also initiated work on the hydro-thermal coordination, which suffers from severe instability due to the extreme point solutions of the hydro subproblem.

Dual methods for the unit commitment problem

Researchers: Stefan Feltenmark and P. O. Lindberg.

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:

- We have developed algorithms for the static EDC problem, which is solved each time one constructs a primal feasible solution.
- We have experimentally shown that there are *few* commitment plans optimal to the subproblems in the neighbourhood of the dual optimum.
- Based on the previous observation, we have developed an algorithm for the exact solution of the dual problem,[P28],[P19].
- We have started to look at different ways of closing the duality gap, including branch-&-bound and Benders decomposition, which may benefit from the results above. (I.e. good lower bounds, and efficient subproblem solutions (EDC)).

The project is under application to Elforsk together with the short term power planning project.

KTH Optimization Laboratory

Researchers: P. O. Lindberg, Patrik Alfredsson, Ulf Brännlund, Stefan Feltenmark, Anders Forsgren, Jorge Mari, Andreas Nöu, Krister Svanberg, Andreas Wolf.

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, Aeronautical Research Inst of Sweden, AlfGam Optimering AB, Avesta AB, Ericsson Telecom, Forest Operations Institute, Krångede Power Pool, Swedish Defense Material Administration (FMV), Swedish National Rail Administration (Banverket), Vattenfall AB, Swedish Telecommunications Administration, Stockholm Transport (SL), Systecon 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	(Saunders et al, Stanford)
QPOPT, LSOPT, NPOPT	(Gill et al, Stanford)
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, DASA	(Hearn, U Florida)
NAG	(NAG)
GAMS	(GAMS)
ELSUNC, ENLSIP	(Lindström, Umeå University)
LANCELOT	(Toint, UNDP, et al)
CPLEX	(CPLEX Inc)

During the year we have continued working at collecting optimization routines and facilitating easy use of these routines. For several routines, we have written an interface to MATLAB, thereby making them easy to use. These interfaced routines have been used extensively, both in our own research and for educational purposes.

The lab has a SUN 670MP server with several work stations connected to it. During the year we have started upgrading our computer system, using funds supplied by FRN (Swedish Council for Planning and Coordination of Research).

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, which we have previously developed [A31]. We believe this bundle method, which is related to Newton's 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. In [R20] we present a new bundle method for, possibly, constrained convex optimization. It does not use linesearches and it is proven to be globally convergent. This work continues. In particular, we plan to perform extensive numerical testing on real problems, arising from large scale decomposition, and also difficult academic testproblems.

Optimal expansion strategies for transport networks

Researcher: P. O. Lindberg in cooperation with Per Lindberg (Telia Research) and Anders Rudberg (Ericsson Telecom).

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

Industrial contacts: Ericsson Telecom and Telia Research.

This project is concerned with optimal expansion strategies for transport networks in the face of large demand uncertainties. Typical networks could be telecom or electricity networks.

We aim to model the problem as a multistage stochastic programming problem. The underlying network structure implies that we could utilize the structure to devise efficient methods.

We have applied and received a preliminary grant for exploring the area under the "complex systems" program at NUTEK.

Optimal short term operation of a cascade of hydropower stations

Researchers: Andreas Wolf and P. O. Lindberg.

Sponsors: Swedish Research Council for Engineering Sciences (TFR) and Vattenfall AB.

Industrial contact: Vattenfall AB.

In a cascade of hydro power stations considerable head losses can occur between stations. This is typically the case in river-like reservoirs. Head losses are high when the flow is high relative to the depth and width of the river. Further on head losses are varying due to changes in flow and water levels.

Varying head losses cause varying travel times of the water between stations. Up to now models for a cascade of hydropower stations either use a constant travel time or neglect the travel time totally. In river-like reservoirs this approximation is poor.

A new type of model, the dynamic production model DYNPRO, has been developed at Vattenfall. The new feature is that a hydrodynamic model is used for the river to obtain the head as a function of time at each station. After having simulated the head the production and its value are calculated.

The aim of the ongoing project is to embed DYNPRO in a nonlinear optimization setting. To this end, one has to derive gradient information with respect to the control parameters from DYNPRO, in order to calculate descent steps. We have outlined how this can be done.

Optimal water flow through a hydro power station

Researchers: P. O. Lindberg and Omar Viera.

Sponsor: The Swedish National Board for Industrial and Technical Development (NUTEK).

Industrial contacts: ABB and Vattenfall AB.

This project addresses, and has developed methods for, the problem of finding the optimal water flow through the turbines and tunnels of a water power station. The problem is difficult due to the inherent nonconvexities of the problem. The problem is attacked through a form of dynamic programming over the tunnel tree of the station. In particular, we have for certain power stations established the existence of several local optima for most water flows, showing the inherent difficulties of the problem. Moreover, our method makes it possible to treat the combinatorial problem of choosing which turbines to run, without extra computations.

Presently, we are looking at discretization errors of the model.

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.

This project entails a broad study of spare parts inventory systems. We are working with models for general multi-item, multi-echelon, multi-indenture systems for repairable spare parts. We are, e.g., studying the optimization of spare parts inventories, the location of repair facilities, and sensitivities of the optimal value with respect to inventory system parameters.

Presently we are investigating the possible use of dual methods to solve the spare parts optimization problem, a difficult nonlinear, nonconvex, integer problem. For this problem, we are also studying the robustness of the optimal solution with respect to parameter uncertainties.

During the academic year results have been presented at international conferences in Stockholm[P1] and Phoenix[P2].

Random utility models

Researchers: P. O. Lindberg, in cooperation with E. Anders Eriksson (Swedish Defense Research Establishment), Lars-Göran Mattsson (KTH), and (lately) Tony Smith (Regional Science Department, U. Pennsylvania).

Industrial contact: Stockholm County Council.

This is a long running project aiming at developing the theoretical foundations of random-utility-models. During the year we have finalized the revisions of our paper on the Robertsson-Strauss model [A34]. It has now been accepted for publication in Environment and Planning. The review comments on this paper has led us to work on a note on a central result on homothetic functions (Lau's Lemma), that one reviewer wanted us to use. All published proofs of this lemma turned out to be incorrect and stated under insufficient conditions.

Our work on characterizations of invariance as well as general ARU models continues.

The reviewer comments on the Eriksson-Lindberg paper on Stochastic Equilibria has induced us to write two papers [A35] and [R22] together with T. Smith. This promises to be a fertile cooperation.

Second-derivative methods for nonlinear programming

Researchers: Anders Forsgren, in cooperation with Philip E. Gill (UCSD), Walter Murray (Stanford University), Ulf Ringertz (KTH) 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.

Together with Philip E. Gill and Joseph R. Shinnerl, a new subproject regarding stability of barrier equations has been initiated during the year. In particular, the focus has been on the stability of the symmetric indefinite systems of equations that arise in barrier methods for constrained optimization. It has been shown that, given a suitable symmetric indefinite factorization routine, an accurate solution of such a system can be computed, despite the inevitable ill-conditioning that arises as the solution is approached [R23].

Recent joint work with Walter Murray has been focused 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. During this year, we have been focusing on strategies suitable for large-scale problems [R24].

The application of a modified Newton method to an energy minimization problem within nonlinear finite-element analysis, which was carried out jointly with Ulf Ringertz, has resulted in a published paper during the year [A33]. Similary, a paper describing the work with Philip E. Gill and Walter Murray on the computation of modified Newton directions using a partial Cholesky factorization has been accepted for publication [A32].

Structural optimization

Researcher: Krister Svanberg.

Structural optimization deals with computer-aided optimal design of load-carrying structures. An illustrative example is the truss sizing problem (truss = *fackverk*), where the cross section areas of the different bars in a truss structure should be chosen such that the total weight is minimized subject to constraints on displacements and stresses under given load conditions.

The ultimate goal of this project is a reliable and fast method for solving structural optimization problems. To reach that goal, one must first try to capture the special properties of this kind of problems. Some results in that direction are reported in [A36]. Further, some new convergence results for a classical heuristic method is reported in [R26].

3 Education

3.1 Undergraduate courses

5B1710 Optimeringslära, allmän kurs för D och F, Optimization, General Course

T. Björk 3.5 p

5B1720 Optimeringslära, allmän kurs för T, Optimization, General Course

U. Brännlund 4 p

5B1730 Optimeringslära, grundkurs för M, Optimization

K. Svanberg 4 p

5B1740 Matematisk systemteori, Mathematical System Theory

T. Björk 3.5 p

5B1750 Optimeringslära, grundkurs för E, Optimization

K. Svanberg 4 p

5B1780 Matematikens och datateknikens tillämpningar, Applications of Mathematics and Computer Science

T. Björk 3 p

5B1810 Matematisk programmering, Mathematical Programming

K. Svanberg 5 p

5B1820 Matematisk systemteori, fortsättningskurs, Advanced Course in Mathematical Systems Theory

A. Lindquist 4 p

5B1830 Systemteknik, Systems Engineering

T. Björk 7 p

5B1840 Systemtekniska metoder, Methods of Systems Engineering

T. Björk 3.5 p

5B1850 Matematisk ekonomi, Mathematical Economics

T. Björk 3 p

5B1860 Stokastisk kalkyl och kapitalmarknadsteori, Stochastic calculus and the theory of capital markets

T. Björk 4 p

5B1870 Optimal styrteori, Optimal Control Theory

T. Björk 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 Robust Control	X. Hu	5 p	5	-
Numerical Linear Programming	A. Forsgren	5 p	4	1

3.3 Doctoral thesis

[T1] Jan-Åke Sand, *Four papers in stochastic realization theory*, TRITA-MAT R-94-0006, Division of Optimization and Systems Theory, Department of Mathematics, KTH, 1994. Advisor: A. Lindquist.

3.4 Licentiate thesis

[T2] M. Hagström, *The positive real region and the dynamics of fast Kalman filtering in some low dimensional cases*, TRITA-MAT-93-0020, Division of Optimization and Systems Theory, Department of Mathematics, KTH, 1994. Advisor: A. Lindquist.

3.5 Master theses (Examensarbeten)

4 Publications

4.1 Published (and accepted) papers

4.1.1 Published (and accepted) papers in Systems and Control

[A1] J. P. Axelsson, P. O. Lindberg and J. Mari, *Design of optimal feed profiles for fedbatch production of human growth factors using yeast*, To appear in Proceedings ASCC '94, Tokyo.

[A2] J. P. Axelsson, A. Hagman and J. Mari, *The role of simulation during development of a recombinant yeast process for production of human growth factors*, To appear in Proceeding SIMS '94, Stockholm.

[A3] C. G. Baril and P.-O. Gutman, *Adaptive friction compensation for uncertain systems: the servo case*, International Conference on Control Theory and its Applications. Jerusalem, Israel, 18-21 October 1993.

[A4] T. Björk and B. Johansson, *On theorems of de Finetti type for continuous time stochastic processes*, Scandinavian Journal of Statistics, Vol 20, No 4,(1993), 289–312.

[A5] V. Blondel, *Simultaneous stabilization of linear systems*, Lecture notes in control and information sciences, Springer-Verlag, London, ISBN 3-540-19862-8, 1994.

[A6] V. Blondel, *On interval polynomials with no zeros in the unit disc*, IEEE Trans. Automat. Control, to appear, 1994.

[A7] V. Blondel and D. Bertilsson, *An upper bound for the gain of stabilizing proportional controllers*, Systems and Control Letters, to appear, 1994.

[A8] V. Blondel and M. Gevers, *Simultaneous stabilization of three linear systems is rationally undecidable*, Math. of Control, Signals, and Systems, 6(1994), 135-145.

[A9] V. Blondel, M. Gevers, R. Mortini and R. Rupp, *Simultaneous stabilization of three or more systems: conditions on the real axis do not suffice*, SIAM J. of Control and Optimization, 32(1994), 572-590.

[A10] C. I. Byrnes and A. Lindquist, *Toward a solution of the minimal partial stochastic realization problem*, Comptes Rendus Acad. Sci. Paris, to be published.

[A11] 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, to be published.

[A12] C. I. Byrnes, A. Lindquist and Y. Zhou, *On the nonlinear dynamics of fast filtering algorithms*, SIAM J. Control and Optimization 32(1994), 744–789.

[A13] M. Fu, S. Dasgupta and V. Blondel, *Robust stability under a class of nonlinear parametric perturbations*, IEEE Trans. Automat. Control, to appear, 1994.

[A14] P.-O. Gutman, *On-line parameter interval estimation using recursive least squares*, International J. Adaptive Control and Signal Processing 8(1994), 61–72.

[A15] P.-O. Gutman, C. G. Baril, and L. Neumann, *An algorithm to compute value sets for uncertain transfer functions in factored real form*, IEEE Trans. Aut. Contr., 39(1994), 1268–73.

[A16] P.-O. Gutman, P. O. Lindberg, I. Ioslovich, and I. Seginer, *A nonlinear optimal greenhouse control problem solved by linear programming*, Journal of Agricultural Engineering Research 55(1993), 335–351.

[A17] P.-O. Gutman, K. Peleg, and U. Ben-Hanan, *Classification with an erroneous sensor*, Automatica, 1995.

[A18] X. Hu, *Some results in nonlinear output regulation and feedback stabilization*, Int. J. Control, vol. 59 (1994), 1085-1093.

[A19] X. Hu, *Stabilization of planar nonlinear systems by polynomial feedback control*, Systems and Control Letters, 22 (1994), 177-185.

[A20] X. Hu, *Nonlinear output regulation and feedback stabilization for a class of globally nonminimum phase systems*, Systems and Networks: Mathematical Theory and Applications, vol. 2, (eds. U. Helmke etal.), Akademie Verlag, 1994.

[A21] X. Hu, *Output tracking with stability on compacta of nonlinear control systems*, Proceedings of the first Chinese World Congress on Intelligent Control, August, 1993, Beijing.

[A22] I. Ioslovich, P.-O. Gutman and I. Seginer, *A non-linear optimal greenhouse control problem with heating and ventilation*, International Conference on Control Theory and its Applications, Jerusalem, Israel, 18-21 October 1993.

[A23] A. Lindquist, Gy. Michaletzky and G. Picci, *Zeros of spectral factors, the geometry of splitting subspaces, and the algebraic Riccati inequality*, SIAM J. Control and Optimization, to be published.

[A24] A. Lindquist and G. Picci, *On "subspace methods" identification*, in Systems and Networks: Mathematical Theory and Applications II, U. Hemke, R. Mennicken and J. Saurer, eds., Akademie Verlag, 1994, pp. 315–320.

[A25] A. Lindquist and G. Picci, *On "subspace methods" identification and stochastic model reduction*, Proc IFAC Workshop on Systems Identification, Copenhagen, 397–403.

[A26] M. Nordin and J. Galic, *A nonlinear low order model of a drive with shaft torsion and backlash*, Proc. Int. Conference on Control Theory and its Applications, October 1993, Jerusalem, Israel.

[A27] S. Oldak, C. Baril and P.-O. Gutman, *Quantitative design of a class of nonlinear systems with parameter uncertainty*, Int. J. Robust & Nonlinear Control 4(1994), 101-117.

[A28] J.-Å. Sand, *Zeros of discrete-time spectral factors, and the internal part of a Markovian splitting subspace*, Journal of Mathematical Systems, Estimation, and Control (to appear).

[A29] J.-Å. Sand, *Geometric concepts in acausal stochastic realization theory*, Proceedings of MTNS-93, Regensburg, Germany (to appear).

[A30] J.-Å. Sand, *Reciprocal realizations on the circle*, To appear in SIAM Journal on Control and Optimization.

4.1.2 Published (and accepted) papers in Mathematical Programming

[A31] U. Brännlund, *A descent method with relaxation type step*, Proceedings of 16th IFIP Conference on System Modelling and Optimization, Lecture Notes in Control and Information Sciences, Springer Verlag, Editors: J. Henry and J-P. Yvon. 1993.

[A32] A. Forsgren, P. E. Gill and W. Murray, *Computing modified Newton directions using a partial Cholesky factorization*, To appear in SIAM Journal on Scientific Computing.

[A33] A. Forsgren and U. Ringertz, *On the use of a modified Newton method for nonlinear finite element analysis*, Computer Methods in Applied Mechanics and Engineering 110(1993), 275-283.

[A34] P. O. Lindberg, L.-G. Mattsson and A. Eriksson, *Invariance of achieved utility in random utility models*, To appear in Environment and Planning.

[A35] T. E. Smith, E. A. Eriksson and P. O. Lindberg, *Existence of optimal tolls under conditions of stochastic user equilibria*, To appear in Road Pricing: Theory, Empirics, Assessment and Policy, Kluwer 1994.

[A36] K. Svanberg, *On the convexity and concavity of compliances*, Structural Optimization 7(1994), 42-46.

4.2 Technical reports and preprints

4.2.1 Technical reports and preprints in Systems and Control

[R1] J. Ackermann and X. Hu, *Acceleration and braking effects on robustly decoupled car steering*, Preprint.

[R2] C. G. Baril, *Fuzzy control*, Lecture notes, 1994.

[R3] C. G. Baril and J. Galić, *Speed control of an elastic two-mass system*, Preprint.

[R4] D. Bertilsson and V. Blondel, *Transcendence in simultaneous stabilization*, Report TRITA-MAT-93-31, Department of Mathematics, KTH, 1994, Submitted for publication.

[R5] T. Björk and B.Johansson, *Parameter estimation and reverse Martingales*, Preprint.

[R6] V. Blondel and H. S. Shapiro, *On zero and one points of analytic functions*, Report TRITA-MAT-94-28, Department of Mathematics, KTH, 1994, Submitted for publication.

[R7] V. Blondel and J. Tsitsiklis, *Computational complexity of robust control design problems*, Preprint.

[R8] C. I. Byrnes and A. Lindquist, *Some recent results on the rational covariance extension problem*, Submitted to Proceedings of the IEEE European Workshop on Computer Intensive Methods in Control and Signal Processing, Prague 1994.

[R9] C. I. Byrnes and A. Lindquist, *On the partial stochastic realization problem*, preprint.

[R10] X. Hu, *Nonlinear control of servo systems affected by friction forces*, Preprint.

[R11] X. Hu, *An invariant manifold approach to nonlinear feedback stabilization on compacta*, Preprint.

[R12] P. O. Lindberg and J. Mari, *A note on second order optimization methods for stiff nonlinear systems*, In preparation.

[R13] A. Lindquist and Gy. Michaletzky, *Output-induced subspaces, invariant directions and interpolation in linear discrete-time stochastic systems*, Submitted for publication in SIAM J. Control and Optimization.

[R14] A. Lindquist and G. Picci, *Canonical correlation analysis, approximate covariance extension, and identification of stationary time series*, Submitted for publication in Automatica.

[R15] A. Lindquist and V. A. Yakubovich, *Optimal damping of forced oscillations in discrete-time systems*, To be submitted for publication in IEEE Transactions on Automatic Control.

[R16] J. Mari, *A counterexample in power signals space*, Submitted for publication.

[R17] J.-Å. Sand, *On 2-D stochastic realization theory*, Report TRITA-MAT-1994-1, Department of Mathematics, KTH, 1994.

4.2.2 Technical reports and preprints in Mathematical Programming

[R18] P. Alfredsson and P. O. Lindberg, *Föreläsningsanteckningar i Systemteknik*, Lecture Notes.

[R19] U. Brännlund, *A generalized subgradient method with relaxation step*, Preprint, 1993, Submitted for publication.

[R20] U. Brännlund, K.C. Kiwiel and P.O. Lindberg, *A descent proximal level bundle method for convex nondifferential optimization*, Report TRITA-MAT-94-15, Department of Mathematics, KTH, 1994, Submitted for publication.

[R21] U. Brännlund, P. O. Lindberg, J.-E. Nilsson and A. Nöu, *Allocation of scarce track capacity using Lagrangian relaxation*, Report TRITA-MAT-93-32, Department of Mathematics, KTH, 1993, Submitted for publication.

[R22] A. Eriksson, T. Smith and P. O. Lindberg, *Stochastic equilibria in general additive random utility models*, Working Paper, Department of Regional Science, U. Pennsylvania, 1994.

[R23] A. Forsgren, P. E. Gill and J. R. Shinnerl, *Stability of symmetric ill-conditioned systems arising in interior methods for constrained optimization*, Report TRITA-MAT-1994-24, Department of Mathematics, Royal Institute of Technology, 1994.

[R24] A. Forsgren and W. Murray, *Newton methods for large-scale linear inequality-constrained minimization*, Preprint.

[R25] P. O. Lindberg and A. Nöu, *A differentiable dual approach to large scale 0-1 problems*, Working Paper, Department of Mathematics, KTH, 1994.

[R26] K. Svanberg, *Global convergence of the stress ratio method for truss sizing*, Submitted for publication.

5 Seminars at the division

5.1 Optimization and Systems Theory seminars

- Professor V.L. Makarov, Director, Central Economic and Mathematical Institute (CEMI) Moscow, *Dual economy in transition: The case of Russia*, Aug. 27, 1993.
- Professor Vadim Arkin, Central Economic and Mathematical Institute (CEMI) Moscow, *Stochastic and endogenous changes of technology in an economic dynamic model: A probabilistic approach to nonconvex models*, Aug. 30, 1993.
- Professor Walter Murray, Stanford University, *Applications of nonlinear optimization*, Sep. 7, 1993.
- Professor Andrzej Ruszczynski, International Institute for Applied Systems Analyses, Laxenburg, Austria, *Regularized decomposition methods for large structured optimization problems*, Sep. 10, 1993.
- Professor Andrzej Ruszczynski, International Institute for Applied Systems Analyses, Laxenburg, Austria, *An augmented Lagrangian decomposition method for sparse convex optimization*, Sep. 13, 1993.
- Professor Professor Thomas L. Magnanti, Sloan School of Management, Massachusetts Institute of Technology, *Modelling and solving network design problems*, Sep. 14, 1993.
- Professor Oli B. G. Madsen, The Institute of Mathematical Statistics and Operations Research, The Technical University of Denmark, *Vehicle routing with time windows - optimal solutions*, Sep. 17, 1993.
- Civ.ing. Martin Hagström, Optimization and Systems Theory, Royal Institute of Technology, *The positive real region and the dynamics of fast Kalman filtering in some low dimensional cases*, Sep. 24, 1993.
- Professor Laszlo Gerencser, Computer and Automation Research Institute of the Hungarian Academy of Sciences, *Identification, complexity and control*, Sep. 24, 1993.
- Dr. Vincent Blondel, Optimization and Systems Theory, Royal Institute of Technology, *Some mathematical questions in linear systems theory*, Oct. 1, 1993.
- Högskolelektor Kenneth Holmström, Mälardalens Högskola, *Optimization problems in chemical equilibrium*, Oct. 8, 1993.
- Dr. Anders Rantzer, Reglerteknik, Lunds Tekniska Högskola, *Robust control with structured uncertainty using linear matrix inequalities*, Oct. 15, 1993.
- Dr. Sergei V. Gusev, Dept. of Mathematics and Mechanics, St. Petersburg University, *Optimal control under restrictions on correlation coefficients of disturbances*, Oct. 18, 1993.
- Dr. Alexey S. Matveev, Dept. of Mathematics and Mechanics, St. Petersburg University, *Spectral approach to nonconvex global optimization with constraints*, Oct. 19, 1993.
- Professor Christopher I. Byrnes, Dept of Systems Science and Mathematics, Washington University, St Louis, USA, *An integral invariance principle for nonlinear systems*, Oct. 22, 1993.

- Professor Tony E. Smith, University of Pennsylvania, Philadelphia, PA, USA, *Equilibria for networks with lower semicontinuous costs with an application to congestion pricing*, Oct. 27, 1993.
- Professor Michael Taksar, State University of New York at Stony Brook, USA, *Singular control of diffusion processes*, Oct. 29, 1993.
- Dr. Yishao Zhou, Department of Mathematics, University of Groningen, The Netherlands, *Some problems in polynomial matrix factorization*, Nov. 12, 1993.
- Professor V.A. Troitskii, St. Petersburg Technical University, *Variation method for the problems of the theory of optimum processes*, Nov. 23, 1993.
- Professor Michel Gevers, Université Catholique de Louvain, Belgium, *Connecting identification and control design*, Nov. 24, 1993.
- Professor Michel Gevers, Université Catholique de Louvain, Belgium, *Parametrizations in control, estimation and filtering: Accuracy aspects*, Nov. 26, 1993.
- Teknolog Daniel Bertilsson, Royal Institute of Technology, *Transcendental methods in systems theory*, Dec. 7, 1993.
- Professor David J. Hill, Dept. of Electrical and Computer Engineering, The University of Newcastle (-1993) Dept. of Electrical Engineering, The University of Sidney (1994-), *Dissipative nonlinear systems: Basic properties, stability analysis and applications*, Dec. 10, 1993.
- Professor Alexander Ioffe, Technion, Haifa, Israel, *Maximum principle for general semilinear optimal control problem*, Dec. 10, 1993.
- Dr. Peter van Overschee, Department of Electrical Engineering, Katholieke Universiteit Leuven, Belgium, *Numerical algorithms for subspace state space system identification: An introduction*, Jan. 18, 1994.
- Civ.ing. Mattias Nordin, Royal Institute of Technology, *A low order model of an elastic shaft with backlash and inner damping: Modelling and simulations*, Jan. 28, 1994.
- Dr. Anders Rantzer, Reglerteknik, Lunds Tekniska Hoögskola, *Integral quadratic constraints as a unifying concept*, Mar. 11, 1994.
- Associate professor Jens Clausen, University of Copenhagen, *The use of parallel processing in solving large combinatorial optimization problems*, Apr. 7, 1994.
- Associate professor Jens Clausen, University of Copenhagen, *The constants that matter*, Apr. 8, 1994.
- Professor Michele Pavon, Dip de Elettronica e Informatica, Universita di Padova and LADSEB-CNR, Italy, *Lagrange functionals and optimal control problems*, Apr. 11, 1994.
- Professor Christopher I. Byrnes, Dept of Systems Science and Mathematics, Washington University, St Louis, USA, *A complete parametrization of all positive rational extensions of a covariance sequence*, May 27, 1994.
- Dr. Tomas Björk, Royal Institute of Technology, *Parameter estimation and reverse martingales* (Docent seminar), Jun. 1, 1994.
- Professor Ravi Ahuja, Indian Institute of Technology, Kanpur, *Use of scaling techniques in network optimization*, Jun. 1, 1994.

- Professor Ravi Ahuja, Indian Institute of Technology, Kanpur, *Applications of network optimization*, Jun. 3, 1994.
- Civ.ing. Niklas Kohl, The Institute of Mathematical Statistics and Operations Research, The Technical University of Denmark, *Lagrangean relaxation methods for the vehicle routing problem with time windows*, Jun. 10, 1994.

5.2 Informal seminars in Systems and Control

- Anders Lindquist, Division of Optimization and Systems Theory, *On the minimal covariance extension problem*, Nov. 25, 1993.
- Per-Olof Gutman, Division of Optimization and Systems Theory, *Robust control with an erroneous sensor*, Jan. 31, 1994.
- Olga Leonova, St. Petersburg University, *On optimization by S-procedure*, Apr. 7, 1994.
- Andrej Cygankov, Vilnius, Lithuania, *Singular linear quadratic problem with quadratic constraints*, Apr. 14, 1994.

5.3 Informal seminars in Mathematical Programming

- Jorge Mari, Division of Optimization and Systems Theory, *Optimal short-term hydro-thermal power generation*, Sep. 16, 1993.
- Krister Svanberg, Division of Optimization and Systems Theory, *Topological optimization of certain electrical networks*, Sep. 23, 1993.
- Andreas Nöu, Division of Optimization and Systems Theory, *Allocation of scarce track capacity*, Sep. 30, 1993.
- Anders Forsgren, Division of Optimization and Systems Theory, *On the computation of search directions in modified Newton methods for linearly constrained optimization*, Oct. 14, 1993.
- Ulf Brännlund, Division of Optimization and Systems Theory, *Presentation of a problem in LMI*, Feb. 23, 1994.
- Jorge Mari, Division of Optimization and Systems Theory, *Motivation for linear matrix inequality problems*, Mar. 9, 1994.
- P. O. Lindberg, Division of Optimization and Systems Theory, *Differentiable duals of 0-1 problems*, Mar. 16, 1994.
- P. O. Lindberg and Andreas Nöu, Division of Optimization and Systems Theory, *More on differentiable 0-1 problems and some practical results*, Mar. 23, 1994.
- Andreas Wolf, Division of Optimization and Systems Theory, *Theoretical background of DYNPRO*, Mar. 30, 1994.
- Andreas Wolf, Division of Optimization and Systems Theory, *Application and demonstration of DYNPRO*, May 6, 1994.
- Ravindra Ahuja, India Institute of Technology, *Scaling in network problems*, Jun. 2, 1994.

6 Awards and appointments

Daniel Bertilsson was nominated the KTH candidate to the Polhem Prize for his Master's thesis in Optimization and Systems Theory **??**.

Tomas Björk was appointed Docent of Optimization and Systems Theory.

Tomas Björk was elected *Teacher of the Year 1994* at KTH.

Anders Lindquist was elected Honorary Member of the Hungarian Operational Research Society.

7 Presentations by staff

[P1] P. Alfredsson, *On robust optimization of spare parts inventory systems*, 4th Stockholm Optimization Days, KTH, Stockholm, Sweden, August 16, 1993.

[P2] P. Alfredsson, *Sensitivity analysis of a repairable item inventory system*, ORSA/TIMS Joint National Meeting, Phoenix, Arizona, USA, November 1, 1993.

[P3] T. Björk, *On the term structure of interest rates*, Institute of International Economic Studies, Stockholm, January 25, 1994.

[P4] T. Björk, *On the term structure of discontinuous interest rates*, Nordic Symposium on Contingent Claims Analysis, Bergen, Norway, May 7, 1994.

[P5] V. Blondel, *Simultaneous stabilization*, Linköping Institute of Technology, Linköping, Sweden, October 1993.

[P6] V. Blondel, *Simultaneous stabilization*, University of Lund, Lund, Sweden, October 1993.

[P7] V. Blondel, *Simultaneous stabilization*, California Institute of Technology, Pasadena, USA, December 1993.

[P8] V. Blondel, *Simultaneous stabilization*, Massachusetts Institute of Technology, Cambridge, April 1994.

[P9] V. Blondel, *Simultaneous stabilization*, University of Massachusetts, Amherst, USA, April 1994.

[P10] V. Blondel, *Simultaneous stabilization*, Princeton University, Princeton, USA, April 1994.

[P11] V. Blondel, *Simultaneous stabilization*, Imperial College of Science and Technology, London, UK, May 1994.

[P12] U. Brännlund, *A descent method with relaxation type step*, 16th IFIP Conference on System Modelling and Optimization, July 5-9, 1993.

[P13] U. Brännlund, *Allocation of scarce track capacity*, Köpenhamns universitet, Oct 26, 1993.

[P14] U. Brännlund, P. O. Lindberg, J.-E. Nilsson and A. Nöu, *Allocation of scarce track capacity using Lagrangean relaxation*, Regional Planering, KTH, May 1994.

[P15] U. Brännlund, *Allocation of scarce track capacity using Lagrangian relaxation*, 5th Stockholm Optimization Days, June 27-28, 1994.

[P16] S. Feltenmark, *Using primal structure in dual optimization*, 4th Stockholm Optimization Days, Stockholm, August 1993.

[P17] S. Feltenmark and P. O. Lindberg, *Network flow solutions of hydro scheduling problems*, Netflow93, San Miniato, Italy, October 1993.

[P18] S. Feltenmark, *Subgradient techniques for structured duals with application to unit commitment problems*, ORSA/TIMS Joint National Meeting, Phoenix, November 1993.

[P19] S. Feltenmark, *Solving detailed structured duals of unit commitment problems*, 5th Stockholm Optimization Days, Stockholm, June 1994.

[P20] A. Forsgren, *Computing modified Newton directions using a partial Cholesky factorization*, The 4th Stockholm Optimization Days, Stockholm, Sweden, August 16–17, 1993.

[P21] A. Forsgren, *On the use of NAG routines for optimization linked to MATLAB*, NAG Swedish Technical Seminar, Stockholm, Sweden, September 22, 1993.

[P22] A. Forsgren, *On the conditioning of barrier methods for numerical optimization*, The 3rd Meeting of the Nordic Section of the Mathematical Programming Society, Linköping, Sweden, February 11–13, 1994.

[P23] A. Forsgren, *Stability of symmetric ill-conditioned systems arising in interior methods for constrained optimization*, The 5th Stockholm Optimization Days, Stockholm, Sweden, June 27–28, 1994.

[P24] X. Hu, *Nonlinear output regulation and feedback stabilization for a class of globally nonminimum phase systems*, MTNS 93, Regensburg, Germany, August, 1993.

[P25] X. Hu, *Output tracking with stability on compacta of nonlinear control systems*, The First Chinese World Congress on Intelligent Control, Beijing, China, August, 1993.

[P26] X. Hu, *Nonlinear control of servo systems affected by friction forces*, International Conference on Control Theory and Applications, Jerusalem, Israel, October, 1993.

[P27] P. O. Lindberg, *A simple geometric model for the simplex method*, Scandinavian Workshop on Linear Programming, August 11-13, 1993.

[P28] P. O. Lindberg and S. Feltenmark, *Network flow solutions of hydro scheduling problems*, Netflow93, San Miniato, Oct 1993.

[P29] P. O. Lindberg and S. Feltenmark, *Solving large structured optimization problems through Lagrangean relaxation and extensions, with applications to set covering and unit commitment problems*, Workshop on Decomposition and Parallel Computing Techniques for Large Systems, IIASA, Laxenburg, Austria, June 13-23 1994.

[P30] A. Lindquist, *On "subspace methods" identification and stochastic realization theory*, International Symposium on the Mathematical Theory of Networks and Systems, Regensburg, August 2–6, 1993.

[P31] A. Lindquist, *On the nonlinear dynamics of Kalman filtering*, International Symposium on the Mathematical Theory of Networks and Systems, Regensburg, August 2–6, 1993.

[P32] A. Lindquist, *On the approximate covariance extension problem by canonical correlation analysis*, Swedish-Italian Workshop on New Perspectives in Modelling and Identification with Applications, Stockholm, September 2–3, 1993.

[P33] A. Lindquist, *A complete parametrization of all positive rational extensions of a covariance sequence*, University of Lund, November 19, 1993.

[P34] A. Lindquist, *Toward a solution of the minimal stochastic realization problem*, Washington University, St. Louis, February 23, 1994.

[P35] A. Lindquist, *A complete parametrization of all positive rational extensions of a covariance sequence*, Technion, Haifa, May 17, 1994.

[P36] A. Lindquist, *Toward a solution of the minimal stochastic realization problem*, Ben Gurion University of the Negev, Beersheeva, Israel, June 13, 1994.

[P37] A. Lindquist, *On the nonlinear dynamics of Kalman filtering*, Technion, Haifa, Israel, June 14, 1994.

[P38] A. Lindquist, *A complete parametrization of all positive rational extensions of a covariance sequence*, Key note speaker, IFAC Symposium on Modeling and Identification, Herzelia, Israel, June 21, 1994.

[P39] A. Lindquist, *A complete parametrization of all positive rational extensions of a covariance sequence*, University of Tel-Aviv, Israel, June 22, 1994.

[P40] J. Mari, *Applied optimal control and identification schemes*, University of Lund, Department of Automatic Control, Dec. 8, 1993.

[P41] J. Mari, *Design of optimal feed profiles for fedbatch production of proteins using yeast*, Danmarks Tekniske Højskole, Institut for Kemiteknik, Dec. 9, 1993.

[P42] J. Mari, *Design of optimal feed profiles for fedbatch production of proteins using yeast*, Kabi Pharmacia, Stockholm, Dec. 14, 1993.

[P43] J. Mari, *Control and Identification of Nonlinear Systems: an Application Example*, University of Groningen, Holland, Mar. 1, 1994.

[P44] M. Nordin, *A nonlinear low order model of a drive with shaft torsion and backlash*, Conference on Control Theory and its Applications, October 1993, Jerusalem, Israel.

[P45] M. Nordin, *New models for backlash and gear play*, Technion, Haifa, Israel, April 1994.

[P46] A. Nöu, *A differentiable dual approach to large scale 0-1 problems*, 5th Stockholm Optimization Days, June 27-28, 1994.

[P47] J.-Å. Sand, *Geometric concepts in acausal stochastic realization theory*, MTNS-93, Regensburg, Germany, August 2–6, 1993.

[P48] K. Svanberg, *On the convexity and concavity of structural stiffness*, 4th Stockholm Optimization Days, August 16-17, 1993.

8 Conferences

8.1 4th Stockholm Optimization Days

The 4th Stockholm Optimization Days, a two-day workshop on optimization, was held at KTH in Stockholm, August 16-17, 1993. It attracted a small but qualified audience and an impressive list of speakers. The number of participants was close to 70, 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 P. O. Lindberg (head), U. Brännlund, A. Forsgren and K. Svanberg.

In total 39 talks were given, among them 12 invited presentations. The following is a list of presentations, where the speakers' names are given in boldface:

Martin Grötschel and **Atef Abdel-Hamid**, Konrad-Zuse-Zentrum für Informationstechnik Berlin, Berlin, Germany, *Generalized assignment problems encountered in the optimization of an automatic storage system.*

Patrik Alfredsson, Royal Institute of Technology, Stockholm, Sweden, *On robust optimization of spare parts inventory systems.*

Knud D. Andersen, Odense University, Odense, Denmark, *An efficient Newton barrier method for minimizing a sum of Euclidean norms.*

Abdessamad Barbara and J. P. Crouzeix, Université Blaise Pascal, Aubiere Cedex, France, *Penalty problems in linear programming derived from concave gauge functions.*

Martin P. Bendsøe*, Technical University of Denmark, Lyngby, Denmark, *Optimization methods for truss geometry and topology design.*

Ali Bouaricha, CERFACS, Toulouse, France and Robert B. Schnabel, University of Colorado at Boulder, Boulder, Colorado, USA, *Tensor methods for large sparse systems of nonlinear equations and nonlinear least squares.*

Torsten Bråmå, Saab Military Aircraft, Linköping, Sweden, *Application and development of optimization software in an industrial environment.*

Jerome Chifflet, CNET-Sophia-Antipolis, Sophia-Antipolis Cedex, France, P. Mahey and V. Reynier, Laboratoire ARTEMIS, Grenoble, France, *Proximal decomposition for multicommodity flow problems with convex costs.*

Ingrid Bongartz, IBM T. J. Watson Research Center, Yorktown Heights, New York, USA, Paul H. Calamai, University of Waterloo, Waterloo, Ontario, Canada and **Andrew R. Conn***, IBM T. J. Watson Research Center, Yorktown Heights, New York, USA, *A second-order algorithm for the continuous capacitated location-allocation problem.*

Per-Åke Wedin, University of Umeå, Umeå, Sweden and **Lennart Edsberg**, Royal Institute of Technology, Stockholm, Sweden, *An efficient and stringent discrete alternative to trust-region regularization for nonlinear optimization - with application to an almost singular nonlinear least squares problem.*

Samuel K. Eldersveld, Boeing Computer Services, Seattle, Washington, USA, *A performance comparison of nonlinear programming algorithms for large sparse problems.*

*Invited speaker.

Björn Esping, Östersund University, Östersund, Sweden and Dan Holm, Alfgam Optimering AB, Stockholm, Sweden, *Design optimization using OASIS-ALADDIN.*

Stefan Feltenmark, Royal Institute of Technology, Stockholm, Sweden, *Using primal structure in dual optimization.*

Lidia Filus, Northeastern Illinois University, Chicago, Illinois, USA, *Application of fixed point algorithms in optimization.*

Sjur Didrik Flåm, Bergen University, Bergen, Norway, *Approximate iterates of averaged and relaxed firmly nonexpansive mappings.*

Anders Forsgren, Royal Institute of Technology, Stockholm, Sweden, Philip E. Gill, University of California at San Diego, La Jolla, California, USA and Walter Murray, Stanford University, Stanford, California, USA, *Computing modified Newton directions using a partial Cholesky factorization.*

Jean Charles Gilbert, INRIA, Le Chesnay, France, *Superlinear convergence of a reduced BFGS method for equality constrained minimization.*

Philip E. Gill, University of California at San Diego, La Jolla, California, USA, Walter Murray and Michael A. Saunders, Stanford University, Stanford, California, USA, *Transformed Hessian methods for large-scale constrained optimization.*

Jean-Louis Goffin*, McGill University, Montréal, Quebec, Canada, *The primal-dual interior cutting plane method.*

Mario Arioli, University of Pavia, Pavia, Italy and CERFACS, Toulouse, France, Tony F. Chan, University of California at Los Angeles, Los Angeles, California, USA, Iain S. Duff and **Nicholas I. M. Gould***, CERFACS, Toulouse, France and Rutherford Appleton Laboratory, Chilton, England and John K. Reid, Rutherford Appleton Laboratory, Chilton, England, *Computing a search direction for large-scale unconstrained and linearly-constrained nonlinear optimization calculations.*

Mårten Gulliksson, University of Umeå, Umeå, Sweden, *Algorithms for weighted nonlinear least squares problems—especially surface fitting problems.*

Alexander L. Hipolito and **Donald W. Hearn***, University of Florida, Gainesville, Florida, USA, *Using affine scaling and centering to generate bundle-descent directions for nonsmooth functions.*

Kaj Holmberg, Linköping Institute of Technology, Linköping, Sweden, *Efficient decomposition and linearization methods for the stochastic transportation problem.*

Kristjan Jonasson, Technical University of Denmark, Lyngby, Denmark, *Tools for sparse matrices.*

Poul Erik Grohnheit and **Peter Kirkegaard**, Risø National Laboratory, Roskilde, Denmark, *Use of LP for the electricity market and large energy systems.*

Ulf Brännlund, Royal Institute of Technology, Stockholm, Sweden, **Krzysztof C. Kiwiel***, Polish Academy of Sciences, Warsaw, Poland and Per Olov Lindberg, Royal Institute of Technology, Stockholm, Sweden, *A descent proximal level bundle method for convex nondifferentiable optimization.*

Anders Klarbring, Joakim Petersson and Mikael Rönnqvist, Linköping Institute of Technology, Linköping, Sweden, *Truss topology optimization involving unilateral contact.*

Claude Lemaréchal*, INRIA-PROMATH, Le Chesnay, France, *An overview of bundle methods.*

*Invited speaker.

Kaj Madsen, Hans Bruun Nielsen and Mustafa Ç. Pınar, Technical University of Denmark, Lyngby, Denmark, *Linear programming by smoothing.*

Marko M. Mäkelä and Kaisa Miettinen, University of Jyväskylä, Jyväskylä, Finland, *A proximal bundle-based method for nonsmooth interactive multiobjective optimization.*

Jorge Nocedal* and Todd Plantenga, Northwestern University, Evanston, Illinois, USA, *A trust region method for large constrained optimization.*

Panos Pardalos*, University of Florida, Gainesville, Florida, USA, *The quadratic assignment problem.*

Ulf Ringertz, Royal Institute of Technology, Stockholm, Sweden, *On optimization of eigenvalues using barrier methods.*

Claudia Sagastizábal, INRIA, Le Chesnay, France, *Moreau-Yosida regularizations and quasi-Newton algorithms: recent developments in bundle methods.*

Andrew R. Conn, IBM T. J. Watson Research Center, Yorktown Heights, New York, USA, Nicholas I. M. Gould, CERFACS, Toulouse, France, **Annick Sartenaer** and Philippe Toint, Facultés Universitaires ND de la Paix, Namur, Belgium, *Convergence properties of an augmented Lagrangian/Lagrangian barrier algorithm for optimization with a combination of general and linear constraints.*

Krister Svanberg, Royal Institute of Technology, Stockholm, Sweden, *On the convexity and concavity of structural stiffness.*

Andrew R. Conn, IBM T. J. Watson Research Center, Yorktown Heights, New York, USA, Nicholas I. M. Gould, CERFACS, Toulouse, France and **Philippe Toint**, Facultés Universitaires ND de la Paix, Namur, Belgium, *Nonlinear optimization using barrier merit functions.*

Dag Wedelin, Chalmers University of Technology, Gothenburg, Sweden, *An algorithm for a class of 0-1 integer programming problems.*

Yu-Sheng Zheng*, University of Pennsylvania, Philadelphia, Pennsylvania, USA, *Optimal control of multi-echelon inventory systems with stochastic demand and setup costs.*

*Invited speaker.

8.2 Swedish-Italian Workshop on New Perspectives in Modelling and Identification with Applications

On September 2–3, 1993 a Swedish-Italian workshop on modelling and identification was held at the Royal Institute of Technology. It was organized by Sergio Dellonte, scientific attaché at the Italian Embassy in Stockholm, Anders Lindquist, Royal institute of Technology, and Giorgio Picci, University of Padova, Italy, and sponsored by Consiglio Nazionale delle Ricerche (CNR), Swedish Research Council for Engineering Sciences (TFR), Alitalia and Pirelli.

In total 18 invited presentations were given. The following is a list of presentations:

Sergio Bittanti, Politecnico di Milano, Milano, Italy, *GRC theorem revisited.*

Torsten Bohlin, Royal Institute of Technology, Stockholm, Sweden, *Experience from three applications of Grey-Box identification to industrial processes.*

Paolo Bolzern, Politecnico di Milano, Milano, Italy, *On the robustness of linear estimators in the face of parameter uncertainty.*

Torkel Glad, Linköping University, Linköping, Sweden, *Differential algebraic methods for deciding identifiability.*

Guido Guardabassi, Politecnico di Milano, Milano, Italy, *Identification of nicely nonlinear models.*

Roberto Guidorzi, Universitá di Bologna, Bologna, Italy, *Open problems in Frisch scheme identification.*

Anders Lindquist, Royal Institute of Technology, Stockholm, Sweden, *On the approximate covariance extension problem by canonical correlation analysis.*

Lennart Ljung, Linköping University, Linköping, Sweden, *On global identifiability for arbitrary model parameterizations.*

Mario Milanese, Politecnico di Torino, Torino, Italy, *Set membership identification of parametric and nonparametric models.*

Edoardo Mosca, Universitá di Firenze, Firenze, Italy, *Predictive adaptive control with self-excitation.*

Björn Ottersten, Royal Institute of Technology, Stockholm, Sweden, *A subspace based instrumental variable method for state-space system identification.*

Pietro Perona, Universitá di Padova, Padova, Italy, *Recursive motion and structure estimation from a sequence of images.*

Giorgio Picci, Universitá di Padova/LADSEB-CNR, Padova, Italy, *Stochastic realization theory and identification.*

Stefano Pinzoni, Universitá della Calabria, Callabria, Italy, *Identification of errors-in-variables models with white measurement errors.*

Torsten Söderström, Uppsala University, Uppsala, Sweden, *On "linear" methods for array processing.*

Bo Wahlberg, Royal Institute of Technology, Stockholm, Sweden, *Approximation of stable systems by Kautz filters.*

Björn Wittenmark, Lund Institute of Technology, Lund, Sweden, *Adaptive extremal control: an example.*

Karl-Johan Åström, Lund Institute of Technology, Lund, Sweden, *Matching criteria for control and identification.*

8.3 5th Stockholm Optimization Days

The 5th Stockholm Optimization Days were held at KTH in Stockholm, June 27–28, 1994. 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 (head), P. O. Lindberg and K. Svanberg.

In total 32 talks were given, among them 16 invited presentations. The following is a list of presentations, where the speakers' names are given in boldface:

Ulf Brännlund and Per Olov Lindberg, Royal Institute of Technology, Stockholm, Sweden, Jan-Eric Nilsson, Center for Research in Transportation and Society, Borlänge, Sweden and Andreas Nöu, Royal Institute of Technology, Stockholm, Sweden, *Allocation of scarce track capacity using Lagrangian relaxation.*

Thomas F. Coleman*, Cornell University, Ithaca, New York, USA, *On using conjugate gradients for nonlinear minimization subject to linear constraints.*

Luis Contesse-Becker, Universidad Catolica, Santiago, Chile, *A new asymptotically exact minimization stopping rule for the methods of multipliers.*

Jacques Desrosiers*, GERAD and HEC, Montreal, Quebec, Canada, *An algorithm for airline crew rostering.*

Zdenek Dostal, Technical University Ostrava, Ostrava, Czech Republic, *Active set strategy with inexact subproblem solver and projections.*

Stefan Feltenmark and Per Olov Lindberg, Royal Institute of Technology, Stockholm, Sweden, *Solving detailed structured duals of unit commitment problems.*

Edite M. G. P. Fernandes, University of Minho, Braga, Portugal, *An exact penalty approach with Newton based descent directions for nonlinear optimization with constraints.*

Anders Forsgren, Royal Institute of Technology, Stockholm, Sweden, Philip E. Gill and Joseph R. Shinnerl, University of California at San Diego, La Jolla, California, USA, *Stability of symmetric ill-conditioned systems arising in interior methods for constrained optimization.*

David M. Gay*, AT&T Bell Laboratories, Murray Hill, New Jersey, USA, *Automatic differentiation and detection of partially separable structure.*

Philip E. Gill, University of California at San Diego, La Jolla, California, USA, *On the implementation of quasi-Newton methods for large-scale constrained optimization.*

Jean-Louis Goffin*, McGill University, Montreal, Quebec, Canada, Zhi-Quan Luo, McMaster University, Hamilton, Ontario, Canada and Yinyu Ye, The University of Iowa, Iowa City, Iowa, USA, *Complexity analysis of an interior cutting plane method for convex feasibility problems.*

Jacek Gondzio*, Systems Research Institute, Warsaw, Poland, *Presolve analysis of linear programs prior to applying the interior point method.*

Nicholas I. M. Gould*, Rutherford Appleton Laboratory, Chilton, England, *More on algorithms for large-scale linearly-constrained nonlinear optimization.*

Luana Gibbons, Donald W. Hearn* and Panos Pardalos University of Florida, Gainesville, Florida, USA, *Continuous based heuristic for the maximum clique prob-*

*Invited speaker.

lem.

Kenneth Holmström, Mälardalen University, Västerås, Sweden, *Constrained parameter estimation problems in chemical equilibrium analysis.*

Krzysztof C. Kiwiel*, Systems Research Institute, Warsaw, Poland, *A bundle method for minimizing a sum of convex functions with smooth weights.*

Riho Lepp, University of Zurich, Zurich, Switzerland and Institute of Cybernetics, Tallinn, Estonia, *Discrete approximation in infinite dimensional optimization.*

Yuying Li, Cornell University, Ithaca, New York, USA, *An affine scaling and trust region method for nonlinearly constrained minimization.*

Jerry Eriksson, **Per Lindström** and Per-Åke Wedin, University of Umeå, Umeå, Sweden , *Solving ill-conditioned nonlinear least squares problems using regularization with application in artificial neural networks.*

Pontus Matstoms, Linköping University, Linköping, Sweden, *Multifrontal QR factorization and the solution of sparse linear least squares problems.*

Robert Mifflin*, Washington State University, Pullman, Washington, USA, *A quasi-second-order proximal bundle algorithm.*

Walter Murray*, Stanford University, Stanford, California, USA and Francisco Prieto, Universidad Carlos III de Madrid, Madrid, Spain, *Negative curvature for problems with nonlinear constraints.*

Per Olov Lindberg and **Andreas Nöu** Royal Institute of Technology, Stockholm, Sweden, *A differentiable dual approach to large scale 0-1 problems.*

Michael L. Overton*, Courant Institute of Mathematical Sciences, New York, New York, USA, *Primal-dual interior point methods for semidefinite programming.*

Michael J. D. Powell*, University of Cambridge, Cambridge, England, *A quadratic interpolation method for optimization calculations without derivatives.*

Ulf Ringertz, Royal Institute of Technology, Stockholm, Sweden, *Optimization of eigenvalues in structural design.*

Andrzej Ruszczyński*, IIASA, Laxenburg, Austria, *A partial regularization method for saddle point seeking and its applications.*

Carl-Louis Sandblom, Technical University of Nova Scotia, Halifax, Canada and H. A. Eiselt, University of New Brunswick, Fredericton, Canada, *Global optimization with the bounce method.*

Andrew R. Conn, IBM T. J. Watson Research Center, Yorktown Heights, New York, USA, Nicholas I. M. Gould, Rutherford Appleton Laboratory, Chilton, England, **Annick Sartenaer*** and Philippe Toint, Facultés Universitaires ND de la Paix, Namur, Belgium, *On iterated-subspace minimization methods for nonlinear optimization.*

Torbjörn Larsson, Michael Patriksson and **Ann-Brith Strömberg**, Linköping University, Linköping, Sweden, *Conditional subgradient optimization—theory and applications.*

Philippe Toint, Facultés Universitaires ND de la Paix, Namur, Belgium, *Exploring non-monotone linesearch and trust-region algorithms for nonlinear optimization.*

Shi-cai Zhu, Imperial College of Science Technology and Medicine, London, England, *A modification on the predictor-corrector interior-point algorithm for linear programming.*

*Invited speaker.

9 Other activities

Patrik Alfredsson

- Participated in the 4th Stockholm Optimization Days, Stockholm, Sweden, August 16–17, 1993.
- Participated in ORSA/TIMS Joint National Meeting, Phoenix, Arizona, USA, October 31–November 3, 1993
- Followed the Systems Engineering program at Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA, January 11– May 15, 1994.
- Participated in the 5th Stockholm Optimization Days, Stockholm, Sweden, June 27–28, 1994.

Tomas Björk

- Director of Undergraduate Studies (studierektor) in Optimization and Systems Theory.
- Visited the Institute of International Economic Studies, Stockholm, January 1994.
- Referee for Systems and Control Letters.

Ulf Brännlund

- Referee for Mathematical Programming.
- Visited the Promath group at INRIA, Rocquencourt, France, from November 15, 1993, to February 15, 1994.

Stefan Feltenmark

- Participated in the Nordic Research Course on "Stochastic Programming" in Lillehammer, Norway, January 11–18, 1994.
- Participated in the conference/workshop on "Decomposition and Parallell Computing Techniques for Large Scale Systems", Vienna, June 13–23, 1994.

Anders Forsgren

- Referee for Linear Algebra and its Applications and SIAM Journal on Matrix Analysis and its Applications.
- Visited the Department of Mathematics at the University of California at San Diego, La Jolla, California, USA, November 20–29, 1993 and February 25–March 4, 1994.
- Visited the Department of Operations Research at Stanford University, California, USA, November 29–December 2, 1993.

Xiaoming Hu

- Referee for System and Control Letters.
- Referee for J. of Math. Systems, Estimation and Control.
- Referee for the Int. J. of Adaptive Control and Signal Processing.
- Expert reviewer for International Science Foundation.
- Opponent at a Licentiate thesis defense.
- Visited German Aerospace Research Establishment, Wessling, Germany, January 17–February 6, 1994.

P. O. Lindberg

- Adjunct Professor in Industrial and Systems Engineering, University of Florida at Gainesville, USA.
- Head of organizing committee of the 4th Stockholm Optimization Days, August 16-17, 1993.
- On editorial board of Computational Optimization and Applications.

- Initiator and administrator of student exchange program with dept of Industrial and Systems Engineering at U Florida, Gainesville, whereby this year 9 4th-year students were sent to Florida to complete a Master's thesis.
- Devised a Simulation project for the course Introduction to Vehicle Engineering
- On the Doctoral Thesis Committee of Michael Patriksson, LiTH.

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, *Progress in Systems and Control Theory*, book series published by Birkhäuser, Boston.
- Associate Editor, *Systems and Control: Foundations and Applications*, book series published by Birkhäuser, Boston.
- Referee for several other journals.
- Referee for Airforce Office of Scientific Research, Washington D.C. and Soros Foundation, Washington D.C..
- Affiliate Professor, Washington University, St Louis, USA.
- Member of Swedish Committee for IIASA (International Institute for Applied System Analysis in Vienna, Austria).
- Steering Committee, International Symposium on the Mathematical Theory of Networks and Systems (MTNS).
- Vice-Chairman, International IFAC Committee on Stochastic Systems.
- Member, International IFAC Committee for Mathematics in Control.
- Program Committee of MTNS-93, Regensburg, Germany, August 2- 6, 1993.
- Co-chairman, organizing Committee of the Swedish-Italian Workshop on "New Perspectives in Modelling and Identification with Applications", Stockholm, September 2-3, 1993.
- Organizing Committee of the 25th ISCIE Symposium on Stochastic Systems Theory and its Applications, Osaka, Japan, November 10-12, 1993.
- Co-chairman, European Network for Systems Identification Workshop, Noordwijkerhout, September, 1994.
- Organizing committee of the 26th ISCIE Symposium on Stochastic Systems Theory and its Applications in Kyoto, Japan, October 26-28, 1994.

Jorge Mari

- Participated in the 17th IFIP Conference, Compiegne, France, July 1993.
- Participated in the 4th Stockholm Optimization Days, KTH Sweden, August 1993.
- Participated in the First Swedish-Italian Workshop on System Identification with Applications, KTH Sweden, September 1993.
- Lecture given: A Survery of Optimal Control Methods, for the course Optimalstyrteori, KTH, Sweden, January 1994.
- Participated in the 13th Benelux Meeting in Control and Systems Identification, Veldhoven, Holland, March 1994.

Mattias Nordin

- Studied at Technion, Haifa, Israel as a Visiting Graduate Student during the spring of 1994.

Andreas Nöu

- Participated in the conference NETFLOW93 in San Miniato, Italy, October 3–7, 1993.
- Participated in a NorFA Research Course on "Mathematical programming under uncertainty" in Lillehammer, Norway, January 12–17, 1994.

Krister Svanberg

- Opponent (informal) of a licentiate thesis in Linköping.
- Refereed two papers for Numerical Methods in Engineering.